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

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Executive Summary

The Gulf of Alaska (GOA) dusky rockfish (*Sebastes variabilis*) is classified as a Tier 3 stock and is assessed using a bespoke statistical age-structured model based on a generic rockfish model (Courtney *et al.* 2007). 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. The data used in this assessment include total catch biomass, fishery age and size compositions, trawl survey abundance estimates, and trawl survey age compositions. For GOA dusky rockfish in 2024, we present a full assessment with updated assessment and projection model results to recommend harvest levels for the next two years.

Summary of Changes in Assessment Inputs

Changes in the input data: Relative to the last full assessment the following substantive changes have been made to assessment inputs:

- Include survey biomass estimates for 2023 from the Groundfish Assessment Program's (GAP) Vector Autoregressive Spatio-temporal (VAST) model with a lognormal error distribution,
- Update survey age compositions with 2023 data,
- Update fishery age compositions with 2022 data,
- Update fishery size compositions with 2023 data, and
- Final catch values for 2022 and 2023, and use preliminary catch for 2024.

Changes in the assessment methodology: Relative to the last full assessment the following are the assessment methodology changes:

- The trawl survey biomass likelihood is changed from a normal error structure to the lognormal error structure.
- The average recruitment estimate was adjusted to align with the modeled recruitment age. This is used for estimating the abundance at the start of the projection year, and estimation of B_{100} and B_{40}.
- An alternative apportionment methodology is applied to determine proportion of biomass within each management area (Western, Central, and Eastern), which uses an area-specific model-based (VAST) index of abundance with similar model setup as the VAST model used in the assessment (see section Appendix 12.B for further details).

Summary of Results

The author's recommended model is m22.5a, which is the 2022 model with updated data through 2024 and model updates to the survey biomass likelihood and starting year for recruitment. This model generally produces good visual fits to the data, estimates biologically reasonable patterns of abundance, recruitment, and selectivity, and has acceptable retrospective Mohn's rho values.

The recommended ABC for 2025 is 6,338 t, the maximum allowable ABC under Tier 3a. This ABC is a 17% decrease compared to the 2024 ABC of 7,624 and a 12% decrease from the projected 2025 ABC from last year's assessment. The recommended 2025 GOA-wide OFL for dusky rockfish is 7,705 t, which is a 17% decrease from the 2024 GOA-wide OFL of 9,281 t. The m22.5a projected age 4+ total biomass for 2025 is 85,912 t. Decreases in biomass estimates (e.g., spawning and total) and subsequent ABC and OFL derived quantities appear to be mainly attributed to the model updates with slight effects from the new input data. The stock is not being subject to overfishing, is not currently overfished, nor is it approaching a condition of being overfished.

Reference values for dusky rockfish are summarized in the following table:

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity/Status	2024	2025	2025*	2026*
M (natural mortality)	0.07	0.07	0.07	0.07
Tier	3a	3a	3a	3a
Projected total (age 4+) biomass (t)	103,997	100,827	85,912	83,297
Projected female spawning biomass (t)	43,197	41,200	35,982	34,478
$B_{100\%}$	65,565	65,565	59,467	59,467
$B_{40\%}$	26,226	26,226	23,787	23,787
$B_{35\%}$	22,948	22,948	20,813	20,813
F_{OFL}	0.112	0.112	0.111	0.111
$maxF_{ABC}$	0.091	0.091	0.09	0.09
F_{ABC}	0.091	0.091	0.09	0.09
OFL (t)	9,281	8,796	**7,705**	7,319
*max*ABC (t)	7,624	7,225	6,338	6,021
ABC (t)	7,624	7,225	**6,338**	6,021
	As determined *last* year for:		As determined *this* year for:	
Status	2023	2024	2024	2025
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 2,199 t for 2024 and estimates of 3,096 t and 2,812 t used in place of maximum permissible ABC for 2025 and 2026.

Area Apportionment

The following table shows the recommended ABC apportionment for 2025 and 2026. Presented is the alternative, recommended ABC apportionment for the Western, Central, and Eastern area. Please refer to the *Area Allocation of Harvests* section of this assessment for information regarding the apportionment rationale for GOA dusky rockfish and for results using *status quo* methodology.

		Western	Central	Eastern	Total
Year	Area Apportionment	13.7%	65.1%	21.2%	100%
2025	ABC (t)	868	4,128	1,342	6,338
2025	OFL (t)				7,705
2026	ABC (t)	824	3,922	1,275	6,021
2026	OFL (t)				7,319

Amendment 41 prohibited trawling in the Eastern area east of 140° W longitude. For the Eastern GOA, the upper 95% confidence interval of the weighted average produces the West Yakutat area proportion of 0.69. This results in the following apportionment to the West Yakutat and Southeast Outside area:

		W. Yakutat	Southeast Outside
2025	ABC (t)	926	416
2026	ABC (t)	880	395

Responses to SSC and Plan Team Comments on Assessments in General

"The SSC also appreciates the responsiveness of NOAA staff for updating the language for the Risk Tables. The revised three levels of concern will be important for assessment authors, GPTs and the SSC when considering specifications." (SSC, October 2024)

The risk table has been revised to align with the new three levels of concern categories.

Responses to SSC and Plan Team Comments Specific to this Assessment

"The Team recommended evaluating the use of VAST estimates of survey biomass for apportionments." (Plan Team, December 2022)

"The SSC recommends the authors investigate alternative apportionment methods that provide stability while also satisfying subarea-level biological concerns." (SSC, December 2022)

"The SSC supports the GOA GPT's recommendation for the authors to further evaluate and recommend an allocation method to further subdivide the EGOA allocated ABC into West Yakutat and Southeast subareas when using VAST since the current allocation method for the design-based estimator is not easily replicated in the model-based framework." (SSC, October 2024)

In September 2024, we presented an alternative apportionment method using an area-specific VAST model to determine the proportion of biomass in each of the three main management areas, Western, Central, and Eastern, based on previous Plan Team and SSC recommendations. Following additional SSC recommendations from October 2024, other preliminary VAST models were explored using different error structures for the temporal component (i.e., applying an AR-1 or random-walk process to the temporal and/or spatiotemporal component in the first and second linear predictor). However, further exploration and testing needs to be done before presenting these time-varying, area-specific VAST models as a viable apportionment option due to possible convergence issues and more thorough model comparisons. Therefore, at this time we recommend using the area-specific VAST model that is configured the same as the VAST model used in the assessment model for the trawl survey biomass index (as presented in September 2024).

We agree that the allocation method to further subdivide the EGOA allocated ABC (i.e., the West Yakutat – Southeast Outside split proportions) requires further exploration. Upon further discussion with other GOA rockfish authors, we decided to postpone bringing forward a new, alternative EGOA allocation method for this year and are presenting the status quo method for the West Yakutat split using the weighted survey average method from the design-based estimator. The decision was based on two reasons: 1) There are several rockfish stocks that apply the complex weighted survey average from the design-based estimator to estimate the EGOA proportions. We would like to present a unified methodology for all of these GOA rockfish stocks moving forward. 2) Changing to using VAST to determine the EGOA split will likely change the proportions between the two management subareas compared to the weighted survey average method from the design-based approach. The confidence intervals (and CVs) from the VAST model for dusky rockfish are smaller than those from the design-based estimator and require further exploration for dusky and other rockfish stocks. As such, we plan to present a unified method for all GOA rockfish stocks that apply a West Yakutat and Southeast Outside apportionment split to be presented in September 2025.

"The SSC requests bubble plots of Pearson residuals for all age and length data including the sign and scale of residuals to help in evaluating fit." (December 2022)

Pearson residual plots for age and length data are included in this assessment. One-step-ahead (OSA) residuals will be explored in future assessments.

"SSC supports the author and GOA GPT recommendation to investigate proper variance attribution of VAST indices within the assessment model, and to explore model sensitivity to data weighting." (December 2022)

"The SSC continues to recommend research investigating skip spawning." (December 2022)

We intend to explore the following for the next (2026) operational full stock assessment: 1) investigate proper variance attribution of VAST indices, 2) examine model sensitivity to data-weighting, and 3) explore uncertainty in recruitment due to skip spawning.

Introduction

Dusky rockfish (*Sebastes variabilis*) in the Gulf of Alaska (GOA) is managed as a Tier 3a stock on a biennial cycle using a bespoke age-structured assessment model. The stock is managed using a GOA wide overfishing limit (OFL) and acceptable biological catch (ABC) with the ABC apportioned to three management areas within the GOA (Western, Central, and Eastern) with the Eastern GOA further divided into West Yakutat and Southeast Outside. Dusky rockfish was originally managed as part of the 'pelagic shelf rockfish' assemblage designated by the North Pacific Fisheries Management Council (NPFMC), but was managed as a single stock in the GOA Federal Management Plan beginning in 2012. 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). *S. 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*.

Distribution

Dusky rockfish 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 GOA. 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 field biologists suggests that dusky rockfish are often caught in association with hard, rocky bottom on these banks or gullies. Several studies support that evidence noting that dusky rockfish are often found in both trawlable and untrawlable habitats (e.g., Rooper and Martin 2012). Research focusing on untrawlable habitats found rockfish species often associate with *Primnoa* spp. corals and other biogenic structure (Krieger and Wing 2002; Du Preez and Tunnicliffe 2011; Laman *et al.* 2015). 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 and Martin 2012).

Biology and Life History

Similar to all other species of *Sebastes*, dusky rockfish are ovoviviparous with fertilization, embryonic development, and larval hatching occurring inside the females. 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. There are minimal data on larvae and post-larval stages for dusky rockfish due to identification challenges. However, after extrusion, larvae are pelagic and their post-larval stage is hypothesized to be pelagic similar to other *Sebastes* species. The habitat of young juveniles is poorly understood. 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 and Heifetz 2002) or with other sampling gear. Older juveniles have been taken infrequently in trawl surveys, but when caught are often found at more inshore and shallower locations than 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 (*Ammodytes hexapterus*) along with euphausiids were the most common prey items of dusky rockfish, comprising 82% and 17%, respectively, of total stomach contents by weight.

The evolutionary strategy of spreading reproductive output over many years is a way of ensuring 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). Studies on other rockfish species have shown that reproductive success and larval survival are higher in older female spawners (e.g., black rockfish [*S. melanops*; Berkeley *et al.* (2004); Bobko and Berkeley (2004)], Pacific ocean perch and rougheye rockfish [*S. aleutianus*; Bruin *et al.* (2004); Leaman (1991)]). Such relationships have not yet been determined to exist for dusky rockfish 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). Abortive maturation has been observed in dusky rockfish in Alaska (Conrath 2019), though the frequency and duration are unknown. Stock assessments for dusky rockfish in the GOA have assumed that the reproductive success of mature fish is independent of age and that all mature females will spawn annually.

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 in the 2012 assessment document. A recent study examining otolith morphology and shape supported a single dusky rockfish stock in the GOA (TenBrink *et al.* 2025). New ongoing genetic research corroborates that finding suggesting that there is no genetic structure documented for dusky rockfish, which indicates high gene flow in this species across the GOA (pers. comm. Wes Larson and Diana Baetscher, AFSC). It is hypothesized that this gene flow is due to long distance larval dispersal. For rockfish with no structure, it is likely that areas that are locally depleted will be replenished by larval transport over longer timescales (decades, 100s of years), but short-term local depletion could cause reduced abundance because adult movement is likely low. In summary, available data suggest 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.

Fishery and Management History

Management Units

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

Description of the 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, with the highest catch-per-unit-effort (CPUE) in depths of 100-149 m in the commercial fisheries (Reuter 1999). During the period 1988-1995, the vast majority of the dusky rockfish catch (>95%) was taken by large factory trawlers that processed the fish at sea. However, in 1996, smaller shore-based trawlers begin taking sizable portions of the catch in the Central GOA and processing at 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. Increased observer coverage and sampled catch for trips that target dusky rockfish are benefits that arose from the Rockfish Program (Lunsford *et al.* 2009). Due to the majority of dusky rockfish catch coming from the Central GOA, the effects of the Rockfish Program have implications on the spatial distribution of dusky rockfish catch. In a study on localized depletion of Alaska 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 CPUE 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). Interpretation of these data is confounded, however, as it is 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 and with the addition of moving towards electronic monitoring, 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 was 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 1977–2024 (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. As total allowable catch (TACs) for slope rockfish became more restrictive in the early 1990's and markets changed, there was a greater economic incentive for catching 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 with recent years harvesting ~ 50% (or less) of the TAC. 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, to prevent excess bycatch of Pacific halibut (*Hippoglossus stenolepis*), or market conditions for dusky rockfish are low.

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 2023 not associated with a directed fishery including research catches are available and are presented in Appendix 12.A. In summary, research and recreational removals in aggregate have typically been less than 20 t. These levels likely do not pose a significant risk to the dusky rockfish stock in the GOA.

Bycatch and Discards

Bycatch of other species in dusky rockfish targeted hauls has historically been dominated by Pacific ocean perch and northern rockfish (Ackley and Heifetz 2001). These observations are supported by catch data from the observer program that showed dusky rockfish were most commonly associated with northern rockfish, Pacific ocean perch, and harlequin rockfish (*S. variegatus*; Reuter 1999).

Total FMP groundfish catch estimates in the GOA rockfish fishery from 2018–2024 are shown in Table 12-3. As an average for the GOA rockfish fishery during 2020-2024, the largest non-rockfish bycatch groups are arrowtooth flounder (*Atheresthes stomias*), sablefish (*Anoplopoma fimbria*), atka mackerel (*Pleurogrammus monopterygius*) and walleye pollock (*Gadus chalcogrammus*). Non-FMP species catch in the rockfish target fisheries is dominated by giant grenadier (*Albatrossia pectoralis*) and miscellaneous fish (Table 12-4), followed by sculpin and squid. However, the amounts from dusky rockfish 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 prohibited and non-target species generally decreased with implementation of the Central GOA Rockfish Program (Lunsford *et al.* 2013). Since the 2022 assessment the prohibited species catch observed in 2023 and 2024 increased for golden king crab (*Lithodes aequispinus*) and non-Chinook salmon (*Oncorhynchus* spp.), and remained at similar levels for Chinook salmon (*O. tshawytscha*) (Table 12-5).

Gulf-wide discard rates (percent of the total catch discarded within management categories; Table 12-6) of dusky rockfish for 2000–2024 have ranged from less than 1% to 7.6%. These rates are considered to be low and are consistent with other GOA rockfish species. These discard rates are generally similar to those in the GOA for Pacific ocean perch and northern rockfish. The discard rate for trawl gear is low (<6%), while the discard rate for the fixed gear (i.e., hook-and-line, pot, and jig) range from 0-62% (Table 12-6). However, the vast majority of dusky rockfish catch comes from trawl fisheries. Discard mortality is assumed to be 100% for GOA dusky rockfish.

Management Measures

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 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 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 presented as a stand-alone species in this document; widow and yellowtail rockfish have been included in the Other Rockfish stock assessment. Beginning in 2012, ABCs, TACs, and OFLs specific to dusky rockfish have been assigned.

In 1998, trawling in the Eastern GOA east of 140° W. longitude was prohibited through FMP Amendment 41 (officially recognized in 2000). This had important management implications 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° W. longitude) and Southeast Outside (area east of 140° W. longitude). ABC and TAC recommendations for dusky rockfish are generated for both West Yakutat and 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 established 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 Program 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 (composed of West Yakutat, and 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 used in the stock assessment model for dusky rockfish (* denotes new data for this assessment):

Source	Data	Years
NMFS Groundfish survey	Survey biomass	1990-1999 (triennial), 2001-2021 (biennial), 2023*
	Age composition	1990-1999 (triennial), 2003-2021 (biennial), 2023*
U.S. trawl fishery	Catch	1977-2022, 2023-2024*
	Age composition	1998-2002, 2004-2006, 2008-2020 (biennial), 2022*
	Length composition	1991-1997, 2003, 2007-2021 (biennial), 2023*

Fishery

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 2024 (Table 12-2; Figure 12-1) and range from 17 t in 1986 to 4,658 t in 1999. Catch data are from the Alaska Regional Office Catch Accounting System queried through AKFIN on October 08, 2024. Reported catches prior to 1988 are likely underestimated as 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

Observers aboard fishing vessels and at onshore processing facilities have collected samples for evaluating size and age compositions of the commercial catch of dusky rockfish. Ages were determined using the break-and-burn method (Chilton and Beamish 1982). Aging has been completed for the 2000–2022 samples and Table 12-7 depicts the raw age distribution of the samples without further analysis to estimate a more comprehensive age composition. Since the samples were randomly collected from fish in over 100 hauls that had large catches of dusky rockfish, the raw distribution is likely 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 11-13 years old in 2018-2022. Several large and relatively steady year classes are evident through the time series including 1986, 1992, 1995, and 1999 with a few years displaying bimodal distributions (e.g., 2002-2006, 2010; Figure 12-2).

Length frequency data for dusky rockfish in the commercial fishery are available for the years 1991-2023 but are only used in the model when age compositions are not expected to be available for that year (Table 12-8). In years when there were no fishery age compositions, the fishery lengths are fit directly in the model by converting the model predicted fishery age compositions to predicted length compositions using the externally derived age-length transition matrix. The fishery length 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. The relatively small sample sizes in 1995 and 1996 should be treated with caution, though they are included in these analyses. Size of fish taken by the fishery appears to relatively be consistent with a mode centered on 45 cm for the past 15 years (Figure 12-3). Fish smaller than 40 cm are seen in moderate numbers in certain years (1991-1992, 1997, and 2017-2023), 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.

Survey

Biomass Estimates from Trawl Surveys

Comprehensive trawl surveys were conducted on a triennial basis in the GOA from 1984-1999, and biennially since 2001 (Table 12-9). Dusky rockfish were separated into "light" and "dark" varieties in surveys since 1996 and starting in 2004 separated into two different species: 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 small quantities. Presumably, the dusky rockfish biomass in surveys previous to 1996 was predominately light dusky rockfish. The 1984 and 1987 surveys were completed using different vessels, net design, and sampling protocols so have been excluded from this assessment.

The spatial distribution of the catches of dusky rockfish in the 2019, 2021, and 2023 surveys are shown in Figure 12-4. 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. Catches of dusky rockfish are typically higher in the central GOA compared to the western and eastern GOA.

Two trawl survey biomass time-series datasets are presented for comparison. The first uses geostatistical model-based estimates (VAST model) with a lognormal error distribution (Table 12-9; Figure 12-5). The second is a design-based estimate of survey biomass (Figure 12-5A). The assessment model uses the VAST model as the 'observed' survey biomass index.

Age and Size Composition

Age

Gulf-wide age composition data for dusky rockfish are available for the 1990 through 2023 trawl surveys (Table 12-10; Figure 12-6). The mode of the age data has recently decreased from age-15 in 2015 to age-10/11 in 2017-2021, and increased to age-13 in 2023. There are weak signals of bimodal distributions of ages in some years (e.g., 1993-1999, 2021, and 2023). These age data 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 1986 year class appeared strong in the 1993, 1996, and perhaps the 1999 surveys (Figure 12-6). 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 and 2023, there appears to be some evidence for a potentially stronger year class in approximately 2010, though the signal is less clear in the 2021 survey data.

Size

Gulf-wide survey size compositions are available for 1990-2023 (Table 12-11; Figure 12-7). 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 1,000 to 3,000 lengths collected per year. Survey length compositions are used in estimating the length-age transition matrix, but not directly in the assessment model.

Maturity Data

Maturity-at-age data for female dusky rockfish maturity are obtained by combining data collected on female dusky rockfish from Lunsford (pers. comm. July 1997) and Chilton (2010). More recently Conrath (2019) has reported skip spawning in dusky rockfish, the impacts of which are not currently incorporated into the assessment.

Analytical 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 is similar to the GOA Pacific ocean perch and northern rockfish models (Courtney *et al.* 1999; Hanselman *et al.* 2007a). 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 12-8). The parameters, population dynamics, and equations of the model are the following:

Parameter definitions

Parameter	Definition
y	Year
a	Age class
l	Length bin
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	Recruitment variability
ε_y^r	Annual recruitment deviation
ε_a^r	Initial recruitment deviation by age
ϕ_y	Annual fishing mortality deviation
fSa	Vector of fishery selectivity at age, $a_0 \rightarrow a_+$
sSa	Vector of survey selectivity at age, $a_0 \rightarrow a_+$
δ	Logistic slope parameter
a_{50}	Logistic age at 50% selectivity
M	Natural mortality
$F_{a,y}$	Fishing mortality by age class and year, $fS_a \mu_f e^{\epsilon}$
$Z_{a,y}$	Total mortality by age class and year, $F_{a,y} + M$
$T_{a,a'}$	Aging error matrix
$T_{a,l}$	Size at age transition matrix
q	Survey catchability coefficient
SB_y	Annual female spawning biomass

Equations describing population dynamics.

First year

$$N_{a,1} = \begin{cases} e^{\mu_r + \epsilon_y^r} & a = a_0 \\ e^{(\mu_r + \epsilon_a^r)} e^{-M(a-1)} & a_0 < a < a_+ \\ \dfrac{e^{\mu_r - M(a-1)}}{(1 - e^{-M})} & a = a_+ \end{cases}$$

Subsequent years

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

Annual spawning biomass

$$SB_y = 0.5 \sum_{a_0}^{a_+} N_{a,y}\, w_a m_a$$

Equations describing observation data.

Equation	Description
$S_a = \frac{1}{1+e^{-\delta(a-a_{50})}}$	Logistic selectivity
$\hat{C}y = \sum a_0{}^{a_+} \frac{N_{a,y}F_{a,y}(1-e^{-Z_{a,y}})}{Z_{a,y}} w_a$	Catch
$F_{a,y} = fS_aF_y = fS_a e^{\mu_f+\phi_y}$	Fishing mortality
$\hat{I}y = q\sum a_0{}^{a_+} N_{a,y} sS_a w_a$	Bottom trawl survey biomass index
$\hat{P}a,y = \frac{Na,ysS_a}{\sum_a^{a+} N_{a,y}\, sS_a} T_{a,a\prime}$	Bottom trawl survey age composition
$\hat{P}a,y = \frac{\hat{C}a,y}{\sum_a^{a+} \hat{C}\, a,y} Ta,a'$	Fishery age composition
$\hat{P}l,y = \frac{\hat{C}l,y}{\sum_l^{l+} \hat{C}\, l,y} Ta,l$	Fishery length composition

Likelihood components

Likelihood Equation	Component
$\mathcal{L} = \lambda \sum_y \ln\left(\frac{C_y + 1e^{-5}}{\hat{C}_y + 1e^{-5}}\right)^2$	Catch
$\mathcal{L} = \lambda \sum_y \left[\ln(\sigma_y) + 0.5\left(\frac{\ln(I_y/\hat{I}y)}{\sigma y}\right)^2\right]$	Trawl survey biomass
where $\sigma_y = \sqrt{\ln\left(1+\frac{SE(I_y)^2}{I_y^2}\right)}$	
$\mathcal{L} = \lambda \sum_y -n^*y\sum a_0{}^{a_+}(P_{a,y}+1^{-5})\ln(\hat{P}_{a,y}+1^{-5})$	Age compositions
$\mathcal{L} = \lambda \sum_y -n^*y\sum l^{l_+}(P_{l,y}+1^{-5})\ln(\hat{P}_{l,y}+1^{-5})$	Length compositions
$\mathcal{L} = \lambda \left[\frac{\sum_y \left(\epsilon_y^r + \frac{\sigma_R^2}{2}\right)^2}{2\cdot\sigma_R^2}\right]$	Recruitment deviation penalty
$\mathcal{L} = \lambda \sum_y \phi_y$	Fishing mortality deviation penalty
$\frac{1}{2\sigma_\theta^2}\ln\left(\frac{\theta}{\theta_{prior}}\right)^2$	Prior penalties for $M, q, \sigma_r, a_{50}, \delta$ θ parameter estimate, σ_θ^r prior uncertainty θ_{prior} prior mean

Description of Alternative Models

Three models are presented here for comparison: 1) the accepted m22.3a 'base' model from 2022 (base), 2) the base model with updated 2024 data (m22.3a_base), and the final recommended, alternative model, m22.5a.

Model m22.5a: Two model changes include: 1) fitting the trawl survey biomass likelihood with a lognormal error structure, and 2) correcting the start year for the average recruitment calculation used for determining the abundance at the start of the first projection year and for use in the B_{100} and B_{40} calculations. These two minor changes are proposed this year to improve the model to follow best practices and to rectify a coding oversight. See Appendix 12B for further details.

Model comparisons were examined to ensure there were no major impacts on the model performance and population dynamics resulting from the two model changes.

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. Length-weight information for dusky rockfish is derived from data collected from GOA trawl surveys from 1990-2023. 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 = 0.020 and b = 2.272.

A von Bertalanffy growth curve was fitted to survey size at age data from 1990-2023 using length-stratified methods (Quinn and Deriso 1999; Bettoli and Miranda 2001) for both sexes combined. An age to size transition matrix was then constructed by adding normal error with a standard deviation equal to the survey data for the probability of different sizes for each age class. The estimated parameters for the growth curve from length-stratified methods were:

L_∞= 48.260, κ = 0.182, t_0 = 0.040

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

W_∞= 1928 g, κ = 0.190, t_0 = 0.607, b = 3.0

Ageing error matrices 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.

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 GOA 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. However, a recent study published found a maximum observed age of 79 years in the Aleutians (TenBrink *et al.* 2023). 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

In years when there was no fishery age composition, the fishery lengths are fit directly in the model by converting the model predicted fishery age compositions to predicted length compositions using survey the externally derived the age-length transition matrix.

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

The fit to the combined observations of maturity-at-age obtained in the recommended assessment model is shown in Figure 12-9. 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).

The age at 50% maturity is estimated to be 10.1. The size at 50% maturity is 40.8 cm using the von Bertalanffy growth parameters. Other parameters estimated conditionally in the model include, but are not limited to: logistic parameters for the survey and fishery selectivity, fishing mortality, spawner-per-recruit levels, mean recruitment, and logistic parameters for maturity. The numbers of estimated parameters are shown below. Other derived variables are described in the *General Model Structure* section.

Parameter	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	76
Average fishing mortality	μ_f	1
Fishing mortality deviations	ϕ_y	48
Logistic fishery selectivity	$a_{f50\%}, \gamma_f$	2
Logistic survey selectivity	$a_{s50\%}, \gamma_s$	2
Logistic maturity at age	$a_{m50\%}, \gamma_m$	2
Total		137

Model Uncertainty

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 5,000. 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).

Retrospective analysis is applied to examine the consistency of key parameter estimates when data from successive years are removed from the model. A 10-year retrospective analysis is completed removing data from 2015-2024 sequentially to examine whether any significant trends appear in the spawning biomass or total biomass. Mohn's rho is calculated as a measure of overall retrospective bias.

Results

The author's recommended model is model m22.5a. Results discussed below refer to the recommended model and are compared with the accepted model from 2022 (base) and accepted model with updated data (m22.3a_base). The author's recommended model (m22.5a) generally produced good visual fits to the data, provided biologically reasonable patterns of recruitment, abundance, and selectivity, and estimated a low retrospective Mohn's rho value.

General Model Evaluation

The model achieved convergence based on an invertible Hessian matrix and a low maximum gradient component of less than 1e-4 (value for m22.5a = 9.3 e-5). The maximum gradients for all the estimated parameters were <1e-4 and all parameters were estimated within their pre-specified bounds. Generally, the time series of biomass estimates and recruitment did not suggest any questionable patterns, and model result patterns from m22.5a were similar to the base model from 2022 (Table 12-12; Figure 12-10). The estimated survey biomass in the recommended model (m22.5a) appears to fit the observed VAST survey biomass better than the base and m22.3a_base, and the estimated survey catchability (*q*) is higher in the m22.5a compared to the base and m22.3a_base models. However, biomass estimates (e.g., spawning and total biomass) were lower compared to the base model due to the model changes (i.e., transition to lognormal error structure in the trawl survey likelihood) and added data, specifically the 2023 trawl survey data. Likewise, parameters, such as B_{100}, B_{40}, and ABC, changed due to adjustments in the new time series used for calculating average recruitment and updates to the maturity and growth estimates (Table 12-12). Other estimated parameters from the maturity, model (m22.5a) are similar compared to the base model (2022) and model m22.3a with updated data.

The model fits to the age compositional data (i.e., survey ages and fishery ages) were adequate and were also similar to the base model from 2022 (Figures 12-2, 12-6, 12-11). The model tended to fit the survey and fishery ages reasonably well in the second half of the time series compared to the earlier years. In particular, large modes in the survey and fishery age data are occasionally misrepresented (estimated mode is shifted or is underestimated; Figures 12-2, 12-6). However, the model did not fit the fishery length composition as well in the earlier part of the time series (Figures 12-3, 12-11). There was a lack of fit to the fishery length composition from 1991-1999; the estimated mode in the fishery length composition is shifted to larger sizes in first three years of data (1991-1993), but shifted to smaller sizes from 1995-1999 (Figure 12-3). 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. Additionally, there is inherent variability and bias in length composition fit due to growth variability and using ages with uncertainty (i.e., high aging error) in the age-length transition matrix.

Similarly, other model predictions fit to the data decently (e.g., survey and catch estimates (Figures 12-1, 12-5). Key results are summarized in Tables 12-13, 12-14, and 12-16.

Model Results and Evaluation

Definitions
Spawning biomass is the biomass estimate of mature females in tons. Total biomass is the biomass estimate of all dusky rockfish age four and greater in tons. 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.

Parameter Estimates and Uncertainty

Maximum likelihood estimates (MLE) of the key parameters are shown in Table 12-16 with the associated standard error along with the MCMC results with 95% credible intervals. The posterior densities of key parameters for the recommended model using histograms from the MCMC chains are summarized in Figure 12-12. These posterior distributions are used to show uncertainty around time series estimates such as total biomass, recruitment, and spawning biomass (Figures 12-13, 12-14). In general, the standard deviations from the Hessian estimates (i.e., MLE) were similar to the standard deviations from the MCMC. The mean MLE for most of the key parameters were similar to the mean and median MCMC estimates and were within bounds of the MCMC (Table 12-16; Figure 12-12). The MCMC distributions for the estimated ABC and $F_{40\%}$ are slightly skewed right, whereas the remaining parameter distributions from the MCMC were fairly symmetrical. The log mean recruitment parameter from the MLE differs from the MCMC results, but are still within the Bayesian credible intervals.

Time Series Results

Biomass and Exploitation Trends

The estimated total of dusky rockfish gradually increase throughout the time series with estimated historic lows in the early 1980's and highs in the late 2010's, which align with recent high estimates for the total biomass (Table 12-14; Figures 12-10, 12-13). The estimated spawning biomass follows a similar trend as the total estimated biomass with a few years lag due to the late maturity of dusky rockfish. While the MCMC credible intervals indicated that the historic lows are estimated with reasonable certainty, the highs at the end of the time series are more uncertain. The larger year classes from 1993, 2002, and 2014 are contributing to the larger biomass estimates in the second half of the time series, in which the estimated biomass has tripled since the beginning of the time series.

These population trends align with the observed (VAST geospatial model) and model predicted survey biomass; however, the survey biomass trends start in 1990 and only capture the latter half of the estimated biomass trends. While the estimated survey biomass from the assessment model matches the observed VAST survey index almost perfectly in 2023, the predicted survey biomass does not coincide as well in other years because the interannual variability from the observed VAST survey biomass is dampened in the model (Figure 12-5). For example, in 2007 and 2009, there was a decrease in observed survey catch, but the estimated survey biomass did not capture that signal.

The estimated selectivities for the fishery and survey data suggest a pattern similar to previous assessments (Table 12-15; Figure 12-9). The commercial fishery targets larger and subsequently older fish and the survey samples a larger range of ages. The age at 50% selection is 8.7 for the survey and 10.4 for the fishery, while fish are fully selected by the survey by age 18 and by 15 for the fishery. Estimated survey catchability (q) is slightly higher in model m22.5a (0.76) compared to the 2022 estimate (0.64).

Fully-selected fishing mortality time series indicates a rise in fishing mortality from the late 1980's through the late 1990's and has been relatively stable from 2004-2024 (Figure 12-10). Since 2004, fully-selected fishing mortality has ranged between 0.03 and 0.06 (Tables 12-12, 12-14). The exploitation rate was more variable and higher until 2000, then has been generally around the long-term average (Figure 12-15). 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. In the management path, the ratio of fishing mortality to F_{OFL} ($F_{35\%}$) is plotted and the estimated spawning biomass relative to $B_{35\%}$. Harvest control rules based on $F_{35\%}$ and $F_{40\%}$ and the Tier 3a adjustment are provided for reference. The historical management path for dusky rockfish has been above the F_{OFL} adjusted limit in the early 1980s and early 1990s. Since 2000, dusky rockfish in the GOA have been above $B_{40\%}$ and below $F_{40\%}$ (Figure 12-16).

Recruitment

In general, recruitment (age-4) is highly variable throughout the time series, particularly in 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 12-8). The model estimates that recruitment was mostly above average from 1980 until recently (Figure 12-14). Since 2019, recruitment has been below average with high uncertainty. There appear to be several high recruitment events in 1999, 2002, 2011, and 2014 (Figure 12-14). However, the MCMC credible intervals for recruitment are fairly large in many years, indicating uncertain recruitment estimates.

The survey and fishery age composition are able to demonstrate some of the large recruitment classes. Strong year classes from 1992 and 1995 (recruit class 1996 and 1999) have largely moved into the plus age group (Tables 12-12, 12-14; Figure 12-2). The survey age compositions also track the 1992 year class well and try to fit the 1995 year class, which appeared consistently strong in surveys through 2013 (Figure 12-6). In 2015 the model predicted a smaller proportion of fish to be in the plus age group than what was observed in the survey. Later strong recruit classes from 2002, 2011, 2012, and 2014 can be observed in the age compositions and recruitment numbers. In particular, the 2018 fishery age data suggest there is a large pulse of age 11 fish (with ages 10 and 12 also high) observed in the compositional data and the mode continues to be observed in the 2020 and 2022 fishery age data (Figure 12-2). That same 2011 recruit class can also be observed in the survey age compositions from the 2017 – 2023 data, which show increased proportions of fish aged 10 in 2017 and shifting to older ages with additional years of data (Figure 12-6).

Retrospective analysis

A within-model retrospective analysis of the recommended model is 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 is 0.047, an improvement from -0.123 in the previous model). When the last five or more years are removed, the model estimates a higher spawning biomass compared to when more years of data are included (Figure 12-17). A similar trend can be seen in the total biomass retrospective analysis results. The 95% credible intervals from the MCMC indicate that the end resulting estimates of total and spawning biomass mostly encapsulate each prior retrospective run; however, some end years appear to be fairly uncertain (e.g., estimated total biomass in 2019; Figure 12-17). The bimodal pattern in total and spawning biomass, where the earlier peels are characterized by consistent overestimation and the later peels (~5 years) show little pattern, is likely due to how the VAST index is treated in the AFSC retrospective analyses (i.e., for each peel the survey index value is removed, but the VAST index is not rerun). Overall, the recommended model (m22.5a) is more consistent compared to the base (2022) model as more years of data are added based on the retrospective analysis.

Harvest recommendations and Projections

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: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. Estimation of the $B_{40\%}$ reference point requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the average of age-4 recruitments between 1981 and 2020 (year classes between 1977 and 2016). Because of uncertainty in recent recruitment estimates, the last 4 recruitment events estimated in the model are not used in the average recruitment values used for reference points or projections. Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. The 2024 estimates of these reference points are:

$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	$F_{40\%}$	$F_{35\%}$
59,467	23,787	20,813	0.09	0.111

Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2025 is estimated at 35,982 t. This is above the $B_{40\%}$ value of 23,787 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 2025, yields the following ABC and OFL:

ABC	OFL
6,338	7,705

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 2024 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2025 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2024. 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 2024 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 2025, are as follows ("$maxF_{ABC}$" refers to the maximum permissible value of F_{ABC} under Amendment 56):

- *Scenario 1*: In all future years, F is set equal to $maxF_{ABC}$. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

- *Scenario 2*: In 2024 and 2025, F is set equal to a constant fraction of $maxF_{ABC}$, where this fraction is equal to the ratio of the realized catches in 2021-2023 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 $maxF_{ABC}$. (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 2019-2023 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
- *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

- *Scenario 6*: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be 1) above its MSY level in 2024 or 2) above ½ of its MSY level in 2024 and above its MSY level in 2034 under this scenario, then the stock is not overfished.)
- *Scenario 7*: In 2025 and 2026, F is set equal to max F_{ABC}, and in all subsequent years F is set equal to FOFL. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2026 or 2) above 1/2 of its MSY level in 2026 and expected to be above its MSY level in 2036 under this scenario, then the stock is not approaching an overfished condition.)

Projections in Scenario 2 (Author's F): Pre-specified catches are used to increase accuracy of short-term projections in fisheries where the catch is usually less than the ABC to help management with setting preliminary ABCs and OFLs for two-year ahead specifications.

The method to calculate catches for this scenario is as follows:

1. In-year catches are defined as the catch through the beginning or middle of October (specific date is when the data are pulled for the assessment) expanded by the expected amount of catch to be taken for the remainder of the year. This expected catch is determined by taking the average of the total catch divided by the catch taken through the 'data pulled' date of the previous three complete years (2021 to 2023). The expansion factor for the observed catch through 2024 is 1.01; the estimated in-year catch for 2024 is 2,199 t.

2. For 2025 and 2026, predicted catch is given by the ratio of the last three years of catches to their respective TACs, multiplied by the TACs in future year y^* given above (which are generally the same as the ABCs): $\langle\sum_{y-3}^{y-1}\frac{C_y}{TAC_y}\rangle TAC_{y^*}$. The resultant average ratio from catch to TAC in the previous three years is 0.49; predicted catches for 2025 and 2026 are 3,096 t and 2,812 t, respectively.

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 10 million. The projection shows wide credibility intervals on future spawning biomass (Figure 12-18). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1981-2020 age-4 recruitments, and this projection predicts that the median spawning biomass will decrease quickly until average recruitment is attained.

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios over a 13-year period (Table 12-17).

Risk Table and ABC Recommendation

The following reference table is used for the risk table with three levels to determine whether to recommend an ABC lower than the maximum permissible.

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

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. The types of considerations with examples of concerns that might be relevant include the following:

1. "Assessment-related: 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: decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. "Environmental/ecosystem: 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-informed: 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 2023 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 2024 stock assessment. The assessment model produces reasonable fits to the survey abundance index and age compositional data and the model outputs were similar to the previous full assessment. However, the model does not fit the length composition as well as age composition data, which is to be expected given uncertainty in estimating growth, using time-invariant growth curve, and ageing error. The MLE and MCMC results were similar to one another, but there was some model instability when estimating sigma-r and the credible intervals for the recruitment estimates (log mean recruitment and deviations) were very large. The high uncertainty in recruitment could be exacerbated due to the large lag from birth until when the fish show up in the fishery and survey. As noted in the previous assessment, the assessment model was sensitive to the scale of the VAST model biomass estimates (and low uncertainty from the VAST model). The bimodal pattern in total and spawning biomass in the retrospective analysis is likely due to how the VAST index is treated in the AFSC retrospective analyses (i.e., for each peel the survey index value is removed, but the VAST index is not rerun). We recommend a level 2 concern for assessment considerations.

Population dynamics considerations

Level 1. The population appears to be increasing in recent years; there is a continued increase in estimated survey biomass for dusky rockfish when using VAST inputs of abundance in the assessment (and the design-based survey index also showed higher catches than average). There are less notable large year classes than previously, but the most recent fishery data from 2022 has an increased proportion of age-12 fish, while the survey age compositions remain relatively uniformly distributed. We note that rockfish aging is challenging, and some 'smearing' across ages is expected. Skip spawning has been observed for this species (Conrath 2019), though the spatial and temporal extent is unknown. However, preliminary investigations that incorporate skip spawning in maturity estimates lead to a reduction is spawning biomass and associated ABC. However, population trends (i.e., relative scale) appear to be increasing in recent years and catch rates have remained unchanged. For these reasons we have given this risk table factor a level 1 for population dynamics considerations.

Environmental/Ecosystem considerations

Level 1. There is a lack of a mechanistic understanding for the direct and indirect effects of environmental change on the survival and productivity of dusky rockfish. However, changes in water temperatures and currents could have effects on prey abundance and success of transition of rockfish from pelagic to demersal stage. Benthic thermal conditions for adults in 2024 were average, while larval rockfish growth may have benefited from warm spring/summer eastern GOA surface waters. Prey availability in 2024 was average to above average for adults. Predator effects would likely be more important on larval, post-larval, and small juvenile slope rockfish, but there is insufficient information on these life stages and their predators to inform a conclusion. Additionally, changes in bottom habitat due to natural or anthropogenic causes could alter survival rates by altering available shelter, prey, or other functions. Estimates of structural epifauna habitat (with non-targeted data) have recently been in decline. There are no major environmental or ecosystem changes that cause concern; we scored this category as Level 1.

<u>Fishery-informed stock considerations</u>

Level 1. Catches are well below ABC for 2024, 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 2024). Thus, the quota is not fully caught due to socioeconomic reasons, not due to population size estimates. For these reasons, we have given this risk table factor a Level 1 rank and do not suggest there is reason to suggest a reduction in ABC based on fishery performance considerations.

<u>Summary and ABC recommendation</u>

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery-informed stock considerations*
Level 2: Increased concern	Level 1: Normal	Level 1: Normal	Level 1: Normal

The GOA dusky rockfish assessment model appears to fit available data reasonably well, the 2023 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 recruitment estimates with large uncertainty and the increased biomass (and resulting ABC and OFL), which may be influenced by the low uncertainty from the model-based VAST abundance index. Additionally, there are unknown levels of skip spawning within this population, the implications of which are not fully understood, though any increase in skip spawning reduces the spawning population. There are no major environmental or ecosystem changes that cause concern. Because GOA dusky rockfish ABC is not historically fully utilized, catch rates are relatively stable, and because there is some evidence of recruitment from age compositions, we are not recommending a reduction in ABC at this time.

Area Allocation of Harvests

Based on the geographic distribution of the exploitable biomass of dusky rockfish, the NPFMC has allocated the Gulf-wide ABC and corresponding TAC into three geographic management areas: Western, Central, and Eastern. The previously accepted apportionment method is the area-specific proportions from the design-based trawl survey abundance estimates smoothed by the random effects model. However, the resultant proportions are prone to large fluctuations due to the patchy distribution of dusky rockfish and survey inefficiencies when sampling available habitat (i.e., 'trawlable'/'untrawlable' habitat).

An alternative apportionment methodology was presented in September 2024 (Appendix 12B) using an area-specific model-based (VAST) approach. The apportionment VAST model applies the same model structure as the VAST model used for the assessment survey biomass index (i.e., years are modeled independently and uses a lognormal error distribution). The VAST model produces less variable interannual proportions and appears to more evenly distribute the biomass across the GOA compared to the design-based random effects model. As a result, the VAST output proportions of biomass in each management area are less contrasting to one another compared to the design-based model proportions, particularly in recent years. Based on the last year's trawl survey, larger proportions are given to the Western and Central GOA when using the VAST approach, which would result in higher ABC allocation to the Western and Central GOA compared to the previously accepted method. Dusky catch GOA-wide and in each management area are well below the allocated ABC in recent years (Figure 12-19).

The authors recommend the alternative apportionment methodology using an area-specific VAST model for consistency and less variability. Presented below are the proportions and associated allocated ABC to each of the three management areas using the alternative apportionment method. For further details on the methodology and comparison with the design-based random effects model see Appendix 12B.

Additionally, the Eastern GOA is subdivided into two management areas for dusky rockfish: West Yakutat (area between 147° W and 140° W) and Southeast Outside (area east of 140° W. longitude). The allocated ABC for the Eastern GOA is 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 design-based estimates of the Eastern GOA biomass proportion that is in the West Yakutat area using the split fraction based on the trawl survey biomass.

The GOA Plan Team and SSC requested further investigation into the Eastern GOA apportionment methodology in September and October of this year. Due to author concerns with the magnitude of change if the VAST confidence intervals (and CVs) were adopted compared to the design-based confidence intervals and because the current methodology is used by several GOA rockfish stocks, no changes are recommended at this time. The authors decided to support the previously accepted method for this year and explore other apportionment options for the Eastern GOA with the other GOA rockfish stock assessment authors for consistency. Additional discussion can be found in the 'Responses to SSC and Plan Team Comments' section. Dusky catch in the two Eastern GOA management areas, West Yakutat and Southeast Outside, have been below the TAC and ABC allocation, and the proposed allocated ABC using the VAST proportions and status quo Eastern GOA split results in a higher recommended ABC allocation compared to the previous years (Figure 12-19).

The proportions of ABC allocated to the Western, Central, and Eastern GOA are: 13.7%, 65.1%, and 21.2%, respectively. Below is the area apportionment for each of the management areas:

		Western	Central	Eastern	Total
Year	Area Apportionment	13.7%	65.1%	21.2%	100%
2025	ABC (t)	868	4,128	1,342	6,338
2025	OFL (t)				7,705
2026	ABC (t)	824	3,922	1,275	6,021
2026	OFL (t)				7,319

In the Eastern GOA, the upper 95% confidence interval of the weighted average results in the West Yakutat area proportion of 0.69. This results in the following apportionment to the West Yakutat and Southeast Outside area:

		W. Yakutat	Southeast Outside
2025	ABC (t)	926	416
2026	ABC (t)	880	395

Based on *status quo* methods (design-based random effects model), the proportions of ABC allocated to the Western, Central, and Eastern GOA are: 3.3%, 91.8%, and 4.9%, respectively. Below is the area apportionment for each of the management areas:

		Western	Central	Eastern	Total
Year	Area Apportionment	3.3%	91.8%	4.9%	100%
2025	ABC (t)	209	5,818	311	6,338
2025	OFL (t)				7,705
2026	ABC (t)	199	5,527	295	6,021
2026	OFL (t)				7,319

In the Eastern GOA, the upper 95% confidence interval of the weighted average results in the West Yakutat area proportion of 0.69 (*same as above*). The apportionments for West Yakutat and Southeast Outside are:

		W. Yakutat	Southeast Outside
2025	ABC (t)	215	96
2026	ABC (t)	204	91

Based on the definitions for overfishing in Amendment 44 in Tier 3a (i.e., $F_{OFL} = F_{35\%} = 0.11$), the 2025 overfishing (OFL) is set equal to 7,705 t for dusky rockfish in the GOA.

Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing.

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2023) is 3,489 t. This is less than the 2023 OFL of 9,638 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? Based on Harvest Scenario #6, the minimum stock size threshold (MSST) for dusky rockfish is given by the $B_{35\%}$, which is 20,813 t in 2024. The estimated stock spawning biomass in 2024 (37,407 t) is greater than the MSST. Therefore, the stock is not overfished.

Is the stock approaching an overfished condition? This is determined by referring to Harvest Scenario #7. The mean estimated stock spawning biomass in 2026 is 34,478, which is greater than the MSST. Therefore, the stock is not approaching an overfished state.

Projections can be found in Table 12-17. The fishing mortality that would have produced a catch for last year equal to last year’s OFL is 0.137.

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 (2024) GOA Ecosystem Status Report did not reveal strong evidence of declining trends in indicators which results in strong concern for dusky rockfish. Updated text on each section is included based on the 2024 GOA Ecosystem Status Report (Ferris

2024). 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, 12-5).

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. Yang (1993) reported that adult dusky rockfish consume mostly euphausiids. Yang *et al.* (2006) reports Pacific sandlance 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, which could lead to prey competition depending on abundance of these species. Current prey availability and nutritional quality appears to have been limiting in 2023, with improvement in 2024 (limited data). Limited information on biomass of euphausiids (primary prey for adults) and calanoid copepods in 2024 indicate average to above average availability in 2024, and a potential increase from 2023 (Seward Line, Hopcroft (2024), zooplanktivorous seabird reproductive success, Drummond and Renner (2024) and Whelan (2024)). Body condition of dusky rockfish in 2021 and 2023 was below average based on the NOAA bottom trawl surveys (O'Leary *et al.* 2021). The decreased condition in 2023 occurred across western GOA, in contrast to an increase in Southeast Alaska.

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. However, survival of larvae are thought to be more related to the abundance and timing of prey availability than predation, due to the lack of rockfish as a prey item commonly found in diets. There is no indication of increased predation on dusky rockfish, but there is potential for decreased competition from low returns of pink salmon in 2024 (Whitehouse 2024).

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. Changes in structural habitat may present a concern for dusky rockfish. Vertical structure, including sponges, corals, and rocky habitat, is important habitat for dusky rockfish and has experienced multi-year decline (with high uncertainty) across the GOA. Observations in 2023 from AFSC's bottom trawl and observer data of non-target catches (both not designed to sample structural epifauna and associated with high uncertainty) can be used to monitor trends in structural epifauna (NOAA bottom trawl, Laman and Dowlin (2023); Observer data, Whitehouse (2024)). The declines in sponges appear to be driven by trends in western GOA (Shumagin and to a lesser extent Kodiak regions).

Benthic thermal conditions for adults (100 - 200m) in 2024 were approximately average, while larval rockfish growth may have benefited from warm spring/summer surface waters (primarily in the eastern GOA) (satellite-derived data, Lemagie and Callahan (2024); Seward Line, Danielson and Hopcroft (2024)). The 2023/2024 El Niño event brought warmer surface temperatures to the GOA in the winter, but it was moderate and short-lived, resulting in approximately average surface temperatures by spring in the western GOA and continued warm surface waters through the spring in the eastern GOA. Larval surveys in Shelikof Strait in 2023 observed a decline to below average (from 2019 and 2021) of larval rockfish (not identified to species; Rogers and Axler (2023)), which may or may not be in response to a cooler 2023 spring and/or reduced zooplankton availability in that year. Surface waters in 2025 are predicted to cool with the development of a weak La Niña (Lemagie and Callahan 2024).

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; Service (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 (V.M. O'Connell, pers. comm. July 1997). 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 (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 dperusky rockfish 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 parturition is mostly in the spring. Hence, reproductive activities are probably not directly affected by the commercial fishery, but 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 12-3 (length frequency in the commercial fishery) and Table 12-7 (length frequencies in the trawl surveys) suggests that although the fishery does not catch many small fish <40 cm length, the fishery also does not catch a significantly greater percentage of very large fish, relative to trawl survey catches.

Fishery contribution to discards and offal production: fishery discard rates of dusky rockfish have been quite low in recent years, especially after formation of the Rockfish Program. The discard rate in the dusky rockfish fishery is unknown as discards are grouped as rockfish fishery target and are not available specifically for the dusky rockfish 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 12-3 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 heavy-duty rockhopper trawl gear commonly used in the fishery can move 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

Life history and habitat utilization

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 labor. 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. Likewise, dusky rockfish are known to occupy both trawlable and 'untrawlable' habitat, but rockfish in the 'untrawlable' habitat are difficult to quantify. Recent ongoing research with cameras on survey trawl gear (by the Groundfish Assessment Program) and the Science-Industry Rockfish Research Collaboration (SIRRCA) is currently examining this issue.

Little is known about the reproductive biology of dusky rockfish. Though they have been observed to skip spawn (Conrath 2019). The spatial and temporal extent of skip spawning is unknown and should be a priority research topic.

Assessment Data

Several techniques are used by stock assessors to determine 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 model weightings within this assessment. Recruitment parameters in the model are unstable; model exploration with the recruitment parameters should be examined (e.g., fixing sigma-r) as a priority research topic. Last, an examination of incorporating an error inflation parameter to increase the variance in VAST models and explore the effect low survey model variance has on resulting assessment outputs.

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Tables

Table 12-1. Commercial catch (t) of dusky rockfish in the Gulf of Alaska, with Gulf-wide values of acceptable biological catch (ABC), total allowable catch (TAC), overfishing level (OFL), the percent of TAC harvested (% TAC) and a summary of key management measures for pelagic shelf rockfish and dusky rockfish in the Gulf of Alaska. Units in metric tons.

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 NPFMC. 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 Southeast Outside and separate ABCs and TACs assigned
2000	3,728	5,980	5,980	9,040[3]	Amendment 41 became effective, prohibiting 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	2,453	5,436	5,436	6,662[3]	
2007	3,385	5,542	5,542	6,458[3]	Amendment 68 created the Central Gulf Rockfish Pilot Project
2008	3,644	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	3,142	5,059	5,509	6,142[3]	
2011	2,540[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	2,780[2]	5,109	5,109	6,246	
2016	3,322[2]	4,686	4,686	5,733	
2017	2,621[2]	4,278	4,278	5,233	
2018	2,909[2]	3,957	3,957	4,841	
2019	2,489[2]	3,700	3,700	4,521	
2020	2,198[2]	3,676	3,676	4,492	
2021	2,928[2]	5,389	5,389	8,655	

Year	Catch[1]	ABC	TAC	OFL	Management Measures
2022	2,586[2]	5,372	5,372	8,614	
2023	3,489[2]	7,917	7,917	9,638	
2024	2,176[2]	7,624	7,624	9,281	

[1] Catch is for entire pelagic shelf rockfish assemblage,
[2] Catch is for dusky rockfish only, updated through October 8, 2024. 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 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 (CAS) data.

Year	Catch	ABC[1]	TAC[1]	% TAC
1977	388			
1978	162			
1979	224			
1980	597			
1981	845			
1982	853			
1983	1,017			
1984	510			
1985	34			
1986	17			
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	2,187	4,800	4,800	46
1992	3,532	6,886	6,886	51
1993	3,182	6,740	6,740	47
1994	2,980	6,890	6,890	43
1995	2,882	5,190	5,190	56
1996	2,290	5,190	5,190	44
1997	2,467	5,140	5,140	48
1998	3,109	4,880	4,880	64
1999	4,658	4,880	4,880	95
2000	3,728	5,980	5,980	62
2001	3,006	5,980	5,980	50
2002	3,321	5,490	5,490	60
2003	3,056	5,490	5,490	56
2004	2,688	4,470	4,470	60
2005	2,236	4,553	4,553	49
2006	2,453	5,436	5,436	45
2007	3,385	5,542	5,542	61
2008	3,644	5,227	5,227	70
2009	3,075	4,781	4,781	64
2010	3,142	5,059	5,059	62
2011	2,540	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	2,780	5,109	5,109	54
2016	3,322	4,686	4,686	71
2017	2,621	4,278	4,278	61
2018	2,909	3,957	3,957	74
2019	2,489	3,700	3,700	67
2020	2,198	3,676	3,676	60
2021	2,928	5,389	5,389	54
2022	2,586	5,372	5,372	48
2023	3,489	7,917	7,917	44
2024	2,176	7,624	7,624	29

[1]ABC and TAC are for the pelagic shelf rockfish assemblage until 2011. ABC and TAC are dusky rockfish-specific starting in 2012. Catch values (1991-present) are from the Alaska Regional Office CAS queried through AKFIN on October 08, 2024.

Table 12-3. FMP species incidental catch estimates in tons for Gulf of Alaska rockfish targeted fisheries. Conf. = Confidential because of less than three vessels. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/26/2024.

Species Group	2020	2021	2022	2023	2024
Arrowtooth Flounder	890	2,523	2,823	860	1,278
Atka Mackerel	602	674	867	459	380
BSAI Skate and GOA Skate, Other	10	19	14	22	11
Flathead Sole	95	135	74	32	62
GOA Deep Water Flatfish	19	19	35	16	12
GOA Demersal Shelf Rockfish	11	5	5	7	7
GOA Dusky Rockfish	2,061	2,669	2,483	3,101	2,079
GOA Rex Sole	189	99	132	73	83
GOA Shallow Water Flatfish	22	33	30	32	22
GOA Skate, Big	6	4	6	8	4
GOA Skate, Longnose	24	31	31	30	21
GOA Thornyhead Rockfish	138	113	215	123	88
Halibut	2	0	1	3	3
Northern Rockfish	2,317	2,303	1,813	1,279	1,048
Octopus	1	1	1	1	2
Other Rockfish	522	975	869	751	268
Pacific Cod	170	660	670	447	350
Pacific Ocean Perch	22,881	27,399	26,358	26,665	21,998
Pollock	647	1,559	1,588	2,074	2,407
Rougheye Rockfish	89	162	221	210	156
Sablefish	647	893	995	809	649
Sculpin	30				
Shark	33	32	17	6	31
Shortraker Rockfish	225	240	181	237	212

Table 12-4. Non-FMP species bycatch estimates in tons for Gulf of Alaska rockfish targeted fisheries. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 10/26/2024.

Species Group	2020	2021	2022	2023	2024
Benthic urochordata	0.12	0.01	3.69	0.01	0.01
Birds - Black-footed Albatross					1.5
Birds - Northern Fulmar		59			
Birds - Shearwaters				49	
Bivalves	0	0.04	0	0.02	0
Bristlemouths	0				
Brittle star unidentified	0.01	0.05	0.02	0.01	0
Capelin	0.04				
Corals Bryozoans - Corals Bryozoans Unidentified	0.17	1.73	0.32	0.84	0.3
Eelpouts	0.01	0.13	0		
Eulachon	0.1				
Giant Grenadier	302.08	252.11	197.39	148.21	72.21
Greenlings	3.5	3.43	3.8	2.41	0.94
Grenadier - Rattail Grenadier Unidentified	1.73	0.19	1.87	5.52	15.74
Gunnels		0			
Hermit crab unidentified	0	0.01	0.01	0	0
Invertebrate unidentified	0.02	0.06	0.01	0	0.02
Lanternfishes (myctophidae)	0.02	0.05		0.05	0.39
Misc crabs	0.1	0.1	0.09	0.04	0.05
Misc crustaceans	0.07	0.06	0.05	0.16	0
Misc deep fish			0		
Misc fish	87.16	164.01	87.2	98.37	33.63
Misc inverts (worms etc)	0	0	0	0.01	0
Other osmerids	0.98	0.08	0.08	0	0.02
Pacific Hake	0.03				
Pacific Sand lance		0			
Pacific Sandfish				0	
Pandalid shrimp	0.17	0.29	0.09	0.02	0.03
Polychaete unidentified			0	0	
Sculpin		23.52	39.54	26.21	16.27
Scypho jellies	3.52	3.19	0.94	1.79	8.26
Sea anemone unidentified	1.24	1.78	0.93	0.31	0.96
Sea pens whips	0	0	0.02	0.01	0.01
Sea star	1.14	1.5	1.3	1.08	0.77
Smelt (Family Osmeridae)		0.23	0.27	0.03	0.08
Snails	0.08	1.18	0.11	0.05	1.88
Sponge unidentified	0.52	1.22	5.97	25.3	3.7
Squid	31.8	27.77	43.36	32.09	25.06
State-managed Rockfish	53.11	12.35	33.26	2.98	7.74
Stichaeidae	0		0	0.01	
urchins dollars cucumbers	0.91	0.23	0.22	0.09	0.11

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 last 5 years in the GOA rockfish fishery. Source: NMFS AKRO Blend/Catch Accounting System PSCNQ via AKFIN 10/26/2024.

Species Group	2020	2021	2022	2023	2024
Bairdi Tanner Crab	1,146	2,279	191	681	30
Blue King Crab	0	0	0	0	0
Chinook Salmon	655	1,042	1,137	1,199	1,086
Golden (Brown) King Crab	60	114	136	596	4,213
Halibut	111	179	129	55	61
Herring	0	0	1	0	0
Non-Chinook Salmon	723	1,628	4,002	2,745	6,422
Opilio Tanner (Snow) Crab	0	0	0	0	0
Red King Crab	0	0	0	0	0

Table 12-6. Estimated percentage of catch by main gear types, trawl and fixed gear (hook-and-line, jog, and pot), percent discarded by main gear types, and total discard rates for dusky rockfish in the Gulf of Alaska.

	Trawl Gear		Fixed Gear		Total %
Year	% of Catch	% Discarded	% of Catch	% Discarded	Discarded
2000	99.2	0.9	0.8	0.2	0.9
2001	99.0	1.8	1.0	0.0	1.7
2002	99.0	4.3	1.0	0.5	4.3
2003	99.2	1.5	0.8	18.0	1.7
2004	96.9	1.2	3.1	19.8	1.8
2005	97.9	0.6	2.1	15.7	0.9
2006	98.9	4.7	1.1	31.0	5.0
2007	98.9	0.6	1.1	7.3	0.7
2008	99.2	0.5	0.8	34.8	0.7
2009	99.3	1.1	0.7	51.2	1.5
2010	99.5	0.8	0.5	36.3	1.0
2011	99.2	1.5	0.8	30.0	1.8
2012	99.5	3.8	0.5	39.0	4.0
2013	98.6	4.7	1.4	42.4	5.2
2014	98.8	2.6	1.2	48.7	3.1
2015	98.4	4.7	1.6	39.0	5.3
2016	97.5	3.2	2.5	39.4	4.1
2017	96.6	5.7	3.4	61.6	7.6
2018	98.9	1.9	1.1	51.7	2.4
2019	98.9	6.1	1.1	24.5	6.3
2020	99.5	2.5	0.5	24.0	2.6
2021	99.7	3.5	0.3	34.2	3.6
2022	99.5	1.4	0.5	58.8	1.7
2023	99.8	1.1	0.2	36.6	1.1
2024	99.7	4.0	0.3	29.8	4.1

Table 12-7. Fishery age compositions for dusky rockfish in the Gulf of Alaska, where n_iss is the input sample size, n_h is the number of hauls, and n_ess is the effective sample size.

Ages	2000	2001	2002	2003	2004	2005	2006	2008	2010	2012	2014	2016	2018	2020	2022
4	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	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	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	0.003	0.006	0.000	0.002	0.003
7	0.000	0.004	0.007	0.000	0.007	0.002	0.006	0.007	0.000	0.002	0.000	0.002	0.010	0.007	0.007
8	0.012	0.004	0.009	0.019	0.002	0.005	0.026	0.007	0.006	0.003	0.019	0.013	0.059	0.018	0.021
9	0.007	0.043	0.011	0.030	0.055	0.014	0.036	0.038	0.033	0.003	0.008	0.034	0.048	0.018	0.048
10	0.034	0.035	0.104	0.046	0.069	0.092	0.078	0.086	0.054	0.025	0.036	0.058	0.071	0.091	0.069
11	0.049	0.068	0.109	0.177	0.066	0.104	0.146	0.109	0.069	0.090	0.022	0.056	0.117	0.078	0.076
12	0.141	0.077	0.095	0.102	0.182	0.079	0.097	0.065	0.151	0.095	0.031	0.054	0.091	0.102	0.138
13	0.207	0.132	0.063	0.091	0.114	0.191	0.074	0.164	0.105	0.116	0.099	0.064	0.077	0.098	0.079
14	0.212	0.170	0.154	0.038	0.083	0.099	0.113	0.076	0.048	0.139	0.065	0.054	0.045	0.067	0.071
15	0.100	0.161	0.134	0.073	0.040	0.061	0.071	0.060	0.133	0.085	0.076	0.089	0.027	0.060	0.069
16	0.051	0.089	0.120	0.127	0.076	0.038	0.052	0.058	0.066	0.062	0.110	0.062	0.051	0.044	0.053
17	0.027	0.060	0.052	0.097	0.104	0.061	0.039	0.045	0.027	0.075	0.088	0.056	0.045	0.042	0.031
18	0.015	0.031	0.025	0.062	0.055	0.061	0.071	0.041	0.045	0.033	0.060	0.077	0.049	0.038	0.013
19	0.015	0.012	0.011	0.018	0.019	0.063	0.036	0.043	0.042	0.021	0.071	0.056	0.058	0.042	0.020
20	0.012	0.017	0.007	0.014	0.021	0.038	0.049	0.050	0.018	0.029	0.048	0.043	0.037	0.038	0.028
21	0.029	0.012	0.016	0.008	0.017	0.023	0.023	0.036	0.009	0.034	0.028	0.048	0.033	0.040	0.034
22	0.022	0.010	0.005	0.008	0.012	0.023	0.019	0.030	0.051	0.036	0.031	0.034	0.034	0.035	0.028
23	0.019	0.010	0.007	0.010	0.007	0.002	0.010	0.013	0.051	0.021	0.032	0.021	0.021	0.024	0.015
24	0.015	0.019	0.014	0.002	0.000	0.000	0.006	0.010	0.021	0.031	0.020	0.037	0.021	0.022	0.023
25	0.007	0.014	0.016	0.019	0.000	0.007	0.003	0.005	0.012	0.021	0.015	0.022	0.019	0.033	0.036
26	0.007	0.010	0.011	0.014	0.002	0.005	0.000	0.003	0.009	0.013	0.022	0.021	0.016	0.018	0.018
27	0.005	0.004	0.007	0.014	0.019	0.000	0.006	0.002	0.003	0.015	0.032	0.013	0.018	0.018	0.033
28	0.005	0.008	0.000	0.008	0.019	0.009	0.006	0.005	0.000	0.007	0.015	0.011	0.009	0.009	0.008
29	0.002	0.002	0.002	0.003	0.002	0.002	0.003	0.005	0.003	0.003	0.023	0.014	0.004	0.009	0.010
30+	0.005	0.010	0.020	0.018	0.021	0.023	0.029	0.043	0.042	0.041	0.046	0.056	0.040	0.049	0.071
n_iss	411	517	441	628	422	444	309	604	332	612	647	626	673	451	609
n_h	131	166	147	270	184	186	143	302	223	400	357	437	423	370	459
n_ess	121	212	175	362	214	174	316	368	296	228	306	923	206	733	289

Table 12-8. Fishery length compositions for dusky rockfish in the Gulf of Alaska. Lengths below 22 are pooled and lengths greater than 52 are pooled, where n_iss is the input sample size, n_h is the number of hauls, and n_ess is the effective sample size.

Length (cm)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2007	2009	2011	2013	2015	2017	2019	2021	2023
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	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	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	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	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	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	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	0.000	0.000	0.000	0.000	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	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
29	0.000	0.003	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	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	0.000	0.000	0.000	0.000	0.001	0.002	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	0.001	0.000	0.000	0.001	0.001	0.002	0.001	0.000
32	0.003	0.012	0.000	0.000	0.000	0.004	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.001	0.001	0.001
33	0.004	0.015	0.000	0.002	0.000	0.014	0.004	0.001	0.000	0.002	0.002	0.001	0.001	0.002	0.003	0.003	0.004	0.001
34	0.007	0.019	0.000	0.001	0.001	0.008	0.008	0.001	0.000	0.003	0.004	0.001	0.004	0.006	0.006	0.003	0.006	0.002
35	0.025	0.019	0.000	0.004	0.002	0.004	0.019	0.000	0.002	0.003	0.006	0.001	0.004	0.007	0.008	0.009	0.011	0.005
36	0.029	0.015	0.000	0.004	0.005	0.010	0.026	0.001	0.002	0.005	0.010	0.001	0.004	0.007	0.011	0.019	0.013	0.006
37	0.019	0.017	0.001	0.003	0.004	0.008	0.042	0.003	0.001	0.010	0.013	0.002	0.005	0.014	0.023	0.031	0.019	0.013
38	0.024	0.027	0.001	0.009	0.007	0.002	0.041	0.006	0.004	0.014	0.021	0.007	0.009	0.017	0.031	0.043	0.026	0.019
39	0.069	0.036	0.006	0.004	0.020	0.010	0.034	0.012	0.006	0.019	0.027	0.014	0.012	0.023	0.044	0.052	0.039	0.026
40	0.084	0.108	0.020	0.019	0.028	0.033	0.041	0.027	0.011	0.035	0.043	0.026	0.018	0.035	0.059	0.070	0.055	0.036
41	0.134	0.117	0.046	0.041	0.045	0.052	0.060	0.059	0.028	0.057	0.049	0.044	0.031	0.038	0.069	0.078	0.081	0.057
42	0.145	0.125	0.103	0.074	0.059	0.082	0.088	0.099	0.079	0.075	0.070	0.077	0.053	0.049	0.070	0.090	0.083	0.074
43	0.140	0.114	0.145	0.076	0.084	0.093	0.106	0.147	0.116	0.103	0.086	0.107	0.081	0.078	0.089	0.091	0.089	0.100
44	0.136	0.117	0.200	0.146	0.098	0.120	0.112	0.170	0.164	0.115	0.104	0.121	0.120	0.108	0.097	0.097	0.096	0.120
45	0.085	0.100	0.197	0.171	0.124	0.128	0.119	0.163	0.182	0.131	0.121	0.137	0.132	0.128	0.113	0.092	0.095	0.123
46	0.057	0.073	0.151	0.176	0.126	0.126	0.097	0.126	0.148	0.132	0.123	0.128	0.120	0.122	0.119	0.083	0.089	0.108
47	0.023	0.033	0.078	0.123	0.138	0.097	0.069	0.080	0.109	0.109	0.110	0.103	0.123	0.115	0.100	0.081	0.077	0.099
48	0.007	0.014	0.031	0.078	0.089	0.103	0.049	0.053	0.064	0.091	0.081	0.085	0.100	0.089	0.072	0.057	0.078	0.077
49	0.002	0.006	0.015	0.040	0.075	0.047	0.028	0.030	0.045	0.051	0.056	0.061	0.069	0.067	0.039	0.042	0.056	0.051
50	0.000	0.003	0.004	0.015	0.054	0.019	0.020	0.011	0.021	0.024	0.032	0.038	0.052	0.038	0.021	0.022	0.039	0.040
51	0.000	0.002	0.002	0.005	0.026	0.012	0.014	0.006	0.011	0.011	0.021	0.024	0.031	0.026	0.008	0.011	0.023	0.023
52+	0.001	0.002	0.001	0.006	0.015	0.000	0.019	0.004	0.007	0.009	0.019	0.021	0.029	0.028	0.011	0.017	0.020	0.020
n_iss	2,012	5,495	3,659	2,117	1,794	515	3,090	2,565	1,684	4,599	4,843	3,550	4,792	4,784	4,575	4,920	4,534	6,584
n_h	42	127	64	38	26	12	53	34	83	405	415	331	404	507	474	676	609	760
n_ess	32	40	29	44	60	50	137	49	44	246	505	398	438	1,214	230	192	637	872

Table 12-9. GOA dusky rockfish biomass estimates, standard errors, and confidence intervals, based on results of NMFS bottom trawl surveys using a geostatistical general linear mixed model estimator (VAST with lognormal error) used in model 22.5a.

Year	Biomass (t)	SE	Lower CI	Upper CI
1990	12,987	2,213	8,650	17,324
1993	35,393	5,653	24,312	46,473
1996	35,191	5,987	23,457	46,925
1999	33,912	6,270	21,622	46,202
2001	40,393	8,356	24,015	56,770
2003	48,716	7,989	33,057	64,375
2005	73,180	10,893	51,830	94,531
2007	50,734	7,990	35,073	66,396
2009	40,091	6,541	27,271	52,910
2011	41,442	7,643	26,462	56,422
2013	59,986	10,730	38,956	81,017
2015	59,471	9,681	40,497	78,446
2017	61,716	10,741	40,663	82,768
2019	87,688	13,576	61,079	114,296
2021	69,870	12,121	46,113	93,627
2023	58,538	10,558	37,845	79,231

Table 12-10. NMFS trawl survey age compositions for dusky rockfish in the Gulf of Alaska, where n_iss is the input sample size, n_h is the number of hauls, and n_ess is the effective sample size.

Ages	1990	1993	1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017	2019	2021	2023
4	0.007	0.004	0.013	0.001	0.014	0.002	0.006	0.000	0.004	0.000	0.001	0.000	0.000	0.001	0.000	0.000
5	0.005	0.058	0.007	0.001	0.006	0.072	0.008	0.003	0.022	0.000	0.003	0.006	0.002	0.003	0.004	0.000
6	0.003	0.094	0.013	0.001	0.081	0.114	0.029	0.005	0.009	0.005	0.006	0.005	0.002	0.006	0.003	0.001
7	0.001	0.194	0.004	0.056	0.074	0.011	0.060	0.021	0.026	0.004	0.007	0.004	0.068	0.008	0.021	0.000
8	0.001	0.089	0.025	0.013	0.052	0.288	0.063	0.023	0.013	0.023	0.014	0.025	0.032	0.025	0.011	0.004
9	0.007	0.119	0.049	0.047	0.188	0.073	0.038	0.116	0.022	0.018	0.022	0.041	0.079	0.085	0.029	0.031
10	0.115	0.031	0.188	0.033	0.095	0.019	0.100	0.092	0.036	0.095	0.011	0.047	0.139	0.078	0.027	0.053
11	0.134	0.032	0.111	0.113	0.093	0.064	0.089	0.046	0.067	0.092	0.023	0.039	0.064	0.125	0.075	0.046
12	0.086	0.020	0.148	0.270	0.037	0.037	0.058	0.165	0.058	0.072	0.062	0.039	0.084	0.121	0.058	0.086
13	0.113	0.048	0.045	0.121	0.066	0.035	0.150	0.126	0.051	0.119	0.108	0.047	0.074	0.059	0.038	0.085
14	0.171	0.022	0.029	0.064	0.099	0.019	0.064	0.066	0.134	0.112	0.090	0.061	0.049	0.055	0.061	0.084
15	0.139	0.039	0.033	0.025	0.061	0.044	0.034	0.061	0.059	0.066	0.134	0.096	0.036	0.041	0.051	0.059
16	0.042	0.045	0.015	0.015	0.034	0.066	0.037	0.041	0.069	0.080	0.087	0.065	0.047	0.056	0.055	0.052
17	0.015	0.042	0.018	0.001	0.013	0.033	0.034	0.009	0.074	0.040	0.058	0.071	0.057	0.054	0.019	0.030
18	0.055	0.016	0.052	0.020	0.009	0.016	0.035	0.035	0.024	0.037	0.080	0.075	0.036	0.038	0.066	0.018
19	0.035	0.015	0.041	0.025	0.007	0.020	0.055	0.036	0.024	0.039	0.066	0.044	0.036	0.046	0.053	0.018
20	0.009	0.010	0.045	0.048	0.008	0.004	0.038	0.022	0.055	0.016	0.024	0.039	0.023	0.023	0.036	0.026
21	0.020	0.011	0.019	0.040	0.005	0.015	0.019	0.021	0.032	0.022	0.029	0.037	0.030	0.040	0.075	0.029
22	0.007	0.009	0.016	0.023	0.005	0.000	0.008	0.020	0.039	0.024	0.025	0.021	0.023	0.023	0.044	0.046
23	0.000	0.009	0.023	0.020	0.015	0.008	0.003	0.010	0.074	0.031	0.016	0.019	0.011	0.005	0.035	0.058
24	0.001	0.015	0.011	0.005	0.003	0.004	0.006	0.007	0.017	0.023	0.021	0.037	0.011	0.021	0.011	0.069
25	0.000	0.009	0.015	0.007	0.000	0.009	0.009	0.011	0.015	0.021	0.029	0.014	0.005	0.017	0.036	0.020
26	0.000	0.007	0.024	0.000	0.003	0.006	0.016	0.009	0.003	0.010	0.015	0.019	0.018	0.008	0.019	0.025
27	0.000	0.003	0.011	0.011	0.004	0.012	0.005	0.002	0.007	0.015	0.020	0.016	0.013	0.008	0.019	0.040
28	0.000	0.005	0.006	0.000	0.006	0.011	0.008	0.003	0.000	0.001	0.014	0.033	0.004	0.013	0.011	0.016
29	0.001	0.003	0.017	0.000	0.002	0.009	0.007	0.004	0.000	0.007	0.008	0.024	0.007	0.001	0.011	0.009
30+	0.032	0.051	0.026	0.039	0.019	0.010	0.023	0.046	0.065	0.029	0.028	0.076	0.049	0.040	0.132	0.094
n_iss	94	445	554	174	676	195	461	489	495	427	434	471	429	403	440	326
n_h	7	42	46	24	63	23	82	88	59	64	74	68	44	93	92	84
n_ess	26	46	62	41	57	15	219	121	74	262	140	171	122	155	61	126

Table 12-11. NMFS trawl survey length compositions for dusky rockfish in the Gulf of Alaska. Lengths below 22 are pooled and lengths greater than 52 are pooled. Survey size compositions are not used in model.

Length (cm)	1990	1993	1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017	2019	2021	2023
21	0.000	0.001	0.003	0.001	0.003	0.000	0.001	0.000	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000
22	0.008	0.002	0.001	0.001	0.002	0.004	0.001	0.000	0.006	0.000	0.001	0.000	0.000	0.000	0.000	0.000
23	0.004	0.004	0.004	0.001	0.003	0.000	0.001	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.002	0.007	0.003	0.000	0.005	0.001	0.002	0.000	0.012	0.000	0.000	0.001	0.001	0.000	0.000	0.000
25	0.006	0.002	0.003	0.002	0.003	0.000	0.002	0.001	0.005	0.000	0.001	0.002	0.000	0.000	0.001	0.000
26	0.000	0.015	0.001	0.000	0.004	0.004	0.001	0.001	0.009	0.000	0.002	0.003	0.001	0.000	0.000	0.000
27	0.006	0.018	0.001	0.001	0.006	0.017	0.001	0.001	0.005	0.000	0.001	0.001	0.001	0.000	0.000	0.000
28	0.006	0.023	0.001	0.000	0.002	0.024	0.001	0.001	0.006	0.000	0.001	0.002	0.001	0.003	0.001	0.001
29	0.007	0.021	0.005	0.001	0.022	0.027	0.004	0.001	0.007	0.000	0.002	0.001	0.002	0.003	0.002	0.001
30	0.000	0.030	0.002	0.002	0.024	0.044	0.005	0.003	0.010	0.002	0.003	0.003	0.005	0.002	0.003	0.001
31	0.001	0.039	0.002	0.006	0.029	0.027	0.010	0.001	0.008	0.002	0.004	0.007	0.019	0.004	0.001	0.000
32	0.007	0.051	0.002	0.008	0.033	0.031	0.014	0.004	0.010	0.002	0.003	0.005	0.018	0.003	0.003	0.000
33	0.001	0.043	0.007	0.008	0.026	0.053	0.016	0.003	0.005	0.003	0.005	0.006	0.017	0.006	0.004	0.001
34	0.003	0.040	0.003	0.013	0.030	0.008	0.019	0.011	0.007	0.005	0.003	0.010	0.013	0.007	0.003	0.002
35	0.001	0.047	0.006	0.015	0.026	0.011	0.021	0.015	0.007	0.006	0.005	0.010	0.022	0.010	0.004	0.005
36	0.002	0.053	0.001	0.015	0.042	0.013	0.046	0.013	0.008	0.015	0.007	0.014	0.032	0.019	0.012	0.007
37	0.004	0.038	0.009	0.016	0.039	0.043	0.027	0.019	0.006	0.019	0.011	0.017	0.042	0.025	0.010	0.006
38	0.006	0.049	0.009	0.019	0.040	0.077	0.053	0.025	0.011	0.017	0.012	0.024	0.037	0.050	0.014	0.015
39	0.019	0.052	0.016	0.016	0.059	0.072	0.031	0.051	0.011	0.036	0.011	0.027	0.040	0.064	0.016	0.029
40	0.017	0.052	0.036	0.031	0.061	0.066	0.042	0.071	0.020	0.042	0.009	0.029	0.074	0.066	0.027	0.030
41	0.077	0.035	0.080	0.035	0.071	0.050	0.046	0.077	0.031	0.058	0.021	0.039	0.078	0.083	0.042	0.036
42	0.125	0.044	0.065	0.072	0.061	0.050	0.072	0.108	0.036	0.091	0.043	0.050	0.066	0.097	0.051	0.057
43	0.115	0.061	0.127	0.104	0.064	0.065	0.092	0.104	0.073	0.135	0.101	0.051	0.082	0.096	0.056	0.090
44	0.153	0.063	0.133	0.115	0.058	0.070	0.101	0.113	0.069	0.114	0.112	0.083	0.077	0.086	0.074	0.105
45	0.175	0.072	0.111	0.150	0.083	0.065	0.100	0.097	0.105	0.109	0.179	0.106	0.055	0.082	0.098	0.115
46	0.151	0.065	0.113	0.141	0.076	0.062	0.101	0.097	0.154	0.103	0.153	0.114	0.071	0.077	0.120	0.114
47	0.069	0.036	0.130	0.093	0.059	0.050	0.075	0.070	0.126	0.073	0.134	0.112	0.072	0.068	0.122	0.110
48	0.023	0.025	0.065	0.057	0.041	0.028	0.060	0.049	0.082	0.062	0.075	0.108	0.069	0.058	0.096	0.118
49	0.009	0.006	0.030	0.041	0.017	0.017	0.027	0.037	0.063	0.042	0.050	0.071	0.053	0.036	0.090	0.067
50	0.001	0.004	0.017	0.021	0.007	0.007	0.016	0.016	0.046	0.025	0.030	0.052	0.022	0.029	0.064	0.043
51	0.001	0.001	0.004	0.015	0.001	0.004	0.007	0.007	0.035	0.023	0.009	0.029	0.014	0.014	0.046	0.022
52+	0.001	0.002	0.010	0.004	0.002	0.007	0.004	0.004	0.011	0.012	0.009	0.023	0.016	0.010	0.040	0.024
n_s	843	2,299	1,478	1,253	1,255	1,780	3,383	1,816	2,024	1,410	1,888	1,820	1,857	2,503	1,503	1,199
n_h	26	95	105	84	70	114	140	126	113	87	87	113	101	120	95	91

Table 12-12. Comparison of 2024 (m22.5a) estimated time series of female spawning biomass, total biomass, fully selected fishing mortality (*F*), and the number of age-4 recruits (millions) for dusky rockfish in the Gulf of Alaska from the maximum likelihood estimation compared with 2022 estimates.

	Spawning biomass		Total biomass		Fully Selected F		Age-4+ recruits	
Year	2022	m22.5a	2022	m22.5a	2022	m22.5a	2022	m22.5a
1977	11,752	12,797	28,141	30,718	0.030	0.029	1.61	1.72
1978	11,238	12,250	27,375	29,881	0.019	0.018	1.71	1.82
1979	10,919	11,908	27,078	29,545	0.022	0.022	2.19	2.33
1980	10,634	11,598	27,493	29,882	0.039	0.039	5.31	5.22
1981	10,265	11,192	28,231	30,526	0.049	0.048	6.04	6.05
1982	9,907	10,790	29,519	31,632	0.051	0.050	6.74	6.39
1983	9,667	10,507	30,822	32,763	0.058	0.057	3.87	3.80
1984	9,547	10,338	32,508	34,164	0.039	0.038	5.38	4.86
1985	9,816	10,565	34,404	35,813	0.009	0.009	3.46	3.30
1986	10,593	11,305	36,715	37,899	0.006	0.006	3.24	3.09
1987	11,645	12,302	38,704	39,685	0.006	0.006	2.24	2.27
1988	12,876	13,455	41,876	42,551	0.042	0.042	9.63	8.98
1989	13,762	14,216	43,958	44,291	0.052	0.051	6.17	5.84
1990	14,474	14,785	48,494	48,350	0.040	0.042	18.97	17.85
1991	15,249	15,393	53,734	53,093	0.044	0.047	13.17	12.48
1992	15,965	15,934	59,310	58,133	0.111	0.111	11.43	10.77
1993	15,946	15,768	61,696	60,118	0.103	0.104	3.10	3.02
1994	16,438	16,105	64,808	62,768	0.096	0.097	8.28	7.69
1995	17,533	17,027	67,469	64,991	0.088	0.088	6.15	5.74
1996	19,193	18,489	72,214	69,114	0.063	0.064	18.31	16.75
1997	21,379	20,460	75,360	71,800	0.059	0.060	3.36	3.16
1998	23,491	22,348	78,928	74,786	0.066	0.068	10.26	9.19
1999	25,093	23,728	83,971	79,077	0.094	0.097	20.84	18.98
2000	25,734	24,164	85,012	79,637	0.075	0.078	2.61	2.69
2001	26,642	24,859	88,141	82,211	0.059	0.061	12.85	12.00
2002	27,941	25,932	92,863	86,293	0.062	0.065	16.18	14.77
2003	29,228	26,977	95,982	88,955	0.054	0.057	7.12	6.90
2004	30,750	28,241	99,556	92,000	0.046	0.049	10.73	9.73
2005	32,528	29,756	103,187	95,104	0.036	0.039	10.20	9.25
2006	34,535	31,501	105,824	97,343	0.037	0.040	4.54	4.34
2007	36,394	33,116	107,499	98,595	0.048	0.052	5.46	4.74
2008	37,714	34,218	107,609	98,256	0.050	0.054	6.18	5.18
2009	38,715	35,017	107,142	97,300	0.041	0.044	7.51	6.32
2010	39,675	35,785	107,384	96,782	0.041	0.044	9.69	7.26
2011	40,242	36,173	108,569	97,051	0.032	0.035	14.44	11.97
2012	40,714	36,466	110,558	97,987	0.050	0.055	12.20	9.81
2013	40,230	35,799	111,072	97,432	0.041	0.045	9.87	7.96
2014	40,022	35,359	115,149	99,738	0.040	0.045	22.78	17.54
2015	39,969	35,002	116,783	100,666	0.037	0.041	2.80	4.84
2016	40,349	34,985	118,698	101,961	0.044	0.049	7.19	7.38
2017	40,872	35,036	118,701	102,333	0.034	0.039	2.92	6.54
2018	42,051	35,692	119,057	102,978	0.036	0.042	6.31	6.30
2019	43,268	36,408	117,746	102,112	0.030	0.035	2.39	2.19
2020	44,583	37,324	115,927	100,834	0.025	0.030	2.54	2.40
2021	45,657	38,205	113,545	99,009	0.033	0.039	2.37	2.06
2022	45,790	38,412	109,820	95,842	0.029	0.034	2.70	2.39
2023		38,339		92,559		0.046		2.53
2024		37,407		88,136		0.030		2.84

Table 12-13. Likelihood values and estimates of key parameters for a select few models for GOA dusky rockfish. Note: in m22.5a the trawl survey likelihood changed from a normal to lognormal distribution.

Likelihood	base	m22.3a	m22.5a
Catch	25.72	26.41	27.65
Trawl survey	30.03	32.12	-13.32
Fishery ages	41.52	48.32	48.14
Survey ages	138.14	139.26	139
Fishery lengths	60.03	49.68	49.72
Recruitment devs	36.21	33.43	28.6
Maturity	65	65	65
Data LL	295.43	295.79	251.19
Total LL	431.54	429.82	380.46
Penalties/Priors	**base**	**m22.3a**	**m22.5a**
priors sigr	0.41	0.51	0.66
priors q TWL	0.5	0.53	0.19
Fishing_Mortality_Regularity_Penalty	33.98	34.56	34.82
obj_fun	431.54	429.82	380.46
Parameter Estimates	**base**	**m22.3a**	**m22.5a**
# parameters	133	137	137
sigmaR	1.00	0.96	0.90
q	0.64	0.63	0.76
avg rec	2.70	2.82	2.84
a50	10.23	10.04	10.06
F40	0.09	0.09	0.09
Total Biomass	107186	97325	85862
SSB	44468	41170	35972
B100	65565	62394	59467
B40	26226	24958	23787
ABC	7921	7247	6338

Table 12-14. Estimated time series of number of age-4 recruits (thousands), total biomass (t), and female spawning biomass (t) with 95% confidence bounds for dusky rockfish in the Gulf of Alaska, from this year's model MCMC results (mean values differ slightly from the maximum likelihood estimation results).

	Full selected F			Age 4+ recruits			Total biomass			Spawning biomass		
Year	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
1977	0.032	0.014	0.062	1,793	402	4,192	31,425	25,772	38,419	13,022	10,421	16,040
1978	0.020	0.008	0.040	1,872	380	4,499	30,571	25,035	37,164	12,466	9,912	15,431
1979	0.024	0.010	0.048	2,497	486	6,039	30,274	24,780	36,742	12,132	9,633	14,991
1980	0.042	0.018	0.084	5,012	934	10,364	30,567	25,192	37,148	11,823	9,412	14,620
1981	0.053	0.023	0.109	6,537	1,070	14,252	31,229	25,709	37,823	11,398	9,124	14,044
1982	0.054	0.022	0.110	6,276	1,211	13,433	32,267	26,689	38,636	10,972	8,620	13,560
1983	0.063	0.026	0.139	4,069	678	9,435	33,403	27,690	39,918	10,674	8,357	13,213
1984	0.042	0.019	0.086	4,865	1,178	9,590	34,751	29,032	41,318	10,478	8,239	13,053
1985	0.009	0.004	0.019	3,405	612	7,096	36,402	30,818	42,842	10,701	8,429	13,201
1986	0.006	0.003	0.012	3,081	688	6,362	38,528	32,678	44,942	11,468	9,144	13,993
1987	0.006	0.003	0.012	2,329	505	5,428	40,358	34,280	46,870	12,495	10,063	15,179
1988	0.045	0.021	0.087	9,158	5,462	13,440	43,281	37,039	49,905	13,678	11,148	16,505
1989	0.056	0.026	0.107	5,583	2,086	9,880	44,926	38,791	51,647	14,433	11,960	17,293
1990	0.044	0.021	0.077	18,158	13,116	23,539	48,923	42,640	55,839	14,972	12,524	17,802
1991	0.049	0.024	0.093	12,458	7,672	17,904	53,614	47,079	60,857	15,567	13,104	18,300
1992	0.111	0.087	0.139	11,032	7,061	15,373	58,635	51,731	66,541	16,083	13,621	18,748
1993	0.104	0.082	0.132	2,811	667	5,743	60,615	53,342	69,144	15,932	13,420	18,676
1994	0.097	0.075	0.122	7,966	5,041	11,298	63,326	55,575	72,765	16,286	13,689	19,248
1995	0.088	0.067	0.114	5,502	2,650	8,858	65,529	57,303	75,399	17,227	14,455	20,402
1996	0.064	0.050	0.082	17,194	12,870	21,753	69,748	61,148	80,366	18,713	15,646	22,224
1997	0.060	0.045	0.077	2,969	922	5,808	72,431	63,323	83,355	20,700	17,326	24,487
1998	0.069	0.052	0.089	9,245	6,037	13,003	75,437	65,781	87,434	22,599	18,915	26,774
1999	0.098	0.075	0.125	19,371	14,745	24,511	79,802	69,548	92,446	23,979	20,141	28,469
2000	0.079	0.061	0.101	2,520	572	5,336	80,335	69,701	93,493	24,407	20,540	29,033
2001	0.062	0.047	0.079	12,245	8,743	16,127	82,947	71,485	96,569	25,102	21,079	29,997
2002	0.065	0.050	0.083	15,025	10,644	20,089	87,102	74,846	101,848	26,183	21,987	31,280
2003	0.058	0.044	0.074	6,749	3,411	10,674	89,777	76,701	105,599	27,241	22,780	32,608
2004	0.049	0.037	0.063	9,898	6,174	14,280	92,883	79,172	109,544	28,525	23,769	34,238
2005	0.039	0.029	0.050	9,365	5,797	13,592	96,029	81,836	113,671	30,059	24,951	36,189
2006	0.041	0.030	0.052	4,313	1,724	7,459	98,286	83,722	116,123	31,825	26,470	38,315
2007	0.053	0.040	0.067	4,821	2,244	7,782	99,547	84,597	117,921	33,454	27,869	40,314
2008	0.055	0.041	0.072	5,217	2,622	8,314	99,222	83,848	118,156	34,578	28,827	41,671
2009	0.045	0.034	0.058	6,377	3,544	9,755	98,250	82,720	117,555	35,381	29,360	42,941
2010	0.044	0.034	0.058	7,275	3,806	11,166	97,728	81,716	117,645	36,159	29,795	43,922
2011	0.036	0.026	0.046	12,157	7,693	17,607	98,024	81,413	118,378	36,554	29,932	44,566
2012	0.055	0.041	0.072	9,986	5,704	15,164	98,997	81,705	120,003	36,849	30,116	45,067
2013	0.046	0.034	0.059	7,841	3,918	12,462	98,419	80,660	119,875	36,179	29,354	44,375
2014	0.045	0.034	0.060	18,173	11,961	25,827	100,826	82,275	123,363	35,731	28,896	44,096
2015	0.042	0.031	0.053	4,609	1,261	9,630	101,737	82,550	124,998	35,369	28,375	43,895
2016	0.050	0.037	0.067	7,671	3,112	13,480	103,120	83,340	126,962	35,369	28,255	44,056
2017	0.039	0.029	0.052	6,628	2,064	13,139	103,552	83,292	128,705	35,438	28,036	44,324
2018	0.042	0.031	0.056	6,290	1,806	12,975	104,226	83,536	129,710	36,114	28,368	45,216
2019	0.036	0.026	0.047	2,361	419	6,280	103,413	82,644	129,036	36,855	28,735	46,331
2020	0.031	0.022	0.041	2,462	455	6,653	102,165	80,882	127,851	37,798	29,401	47,705
2021	0.040	0.028	0.054	2,352	413	7,361	100,408	78,797	126,336	38,702	29,957	48,895
2022	0.035	0.025	0.048	2,902	355	9,710	97,358	75,997	123,596	38,919	29,945	49,399
2023	0.046	0.033	0.064	3,174	440	11,424	94,280	73,186	120,247	38,863	29,800	49,504
2024	0.030	0.022	0.041	3,800	429	14,871	89,197	67,338	114,901	37,960	28,866	48,871
2025				7,894	1,247	26,879				36,500	27,490	47,150
2026				7,697	1,223	27,781				34,716	26,148	44,656

Table 12-15. Estimated numbers, fishery selectivity, and survey selectivity of dusky rockfish in the Gulf of Alaska based on the preferred model. Also shown are schedules of age-specific weight (in grams) and female maturity.

		Percent		Selectivity	
Age	Abundance	Mature	Weight	Fishery	Survey
4	2,838	2	208	0.00	0.04
5	2,359	3	351	0.00	0.07
6	2,081	5	509	0.01	0.12
7	1,670	10	672	0.03	0.20
8	1,815	18	830	0.08	0.32
9	1,535	29	978	0.22	0.47
10	4,082	44	1,113	0.48	0.62
11	3,872	61	1,233	0.75	0.75
12	3,954	75	1,339	0.91	0.85
13	2,338	85	1,431	0.97	0.91
14	7,630	92	1,510	0.99	0.95
15	3,115	96	1,578	1.00	0.97
16	3,449	98	1,635	1.00	0.99
17	3,768	99	1,684	1.00	0.99
18	2,043	99	1,724	1.00	1.00
19	1,586	100	1,759	1.00	1.00
20	1,160	100	1,787	1.00	1.00
21	946	100	1,811	1.00	1.00
22	770	100	1,831	1.00	1.00
23	1,463	100	1,848	1.00	1.00
24	1,373	100	1,862	1.00	1.00
25	868	100	1,873	1.00	1.00
26	1,652	100	1,882	1.00	1.00
27	1,192	100	1,890	1.00	1.00
28	238	100	1,897	1.00	1.00
29	1,495	100	1,902	1.00	1.00
30+	4,220	100	1,907	1.00	1.00

Table 12-16. Estimates of key parameters with Hessian estimates of mean μ, standard deviation σ, and μ, σ, median, and 95% Bayesian credible intervals (BCI) derived from MCMC.

Parameter	MLE μ	MLE σ	MCMC μ	MCMC Median	MCMC σ	BCI Lower	BCI Upper
log_mean_rec	1.043	0.129	0.956	0.954	0.118	0.734	1.190
q_srv1	0.757	0.086	0.762	0.758	0.085	0.604	0.941
F40	0.090	0.026	0.107	0.101	0.035	0.058	0.186
ABC	6,338	1,945	7,520	7,098	2,602	3,789	13,527
SSB_proj	35,972	5,176	36,500	36,242	5,065	27,490	47,150
tot_biom_proj	85,862	11,843	88,189	87,365	12,191	66,473	114,154

Table 12-17. 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. Note: The spawning biomass is discounted for the mortality up until the time of spawning (March). For a description of scenarios see section *Harvest Recommendations*.

Year	Maximum permissible F	Author's F (Estimated catches)	Half half_maxF	5-year average F	No fishing	Overfished	Approaching overfished
			Spawning biomass (mt)				
2024	36,798	36,798	36,798	36,798	36,798	36,798	36,798
2025	35,709	35,982	35,970	36,024	36,233	35,591	35,709
2026	32,706	34,478	34,390	34,748	36,163	31,968	32,706
2027	29,785	32,608	32,662	33,291	35,828	28,565	29,687
2028	27,122	29,609	30,960	31,820	35,371	25,545	26,514
2029	24,864	27,037	29,448	30,503	34,951	23,054	23,871
2030	23,145	25,021	28,283	29,497	34,732	21,258	21,894
2031	22,067	23,627	27,560	28,905	34,832	20,229	20,720
2032	21,587	22,843	27,285	28,742	35,294	19,809	20,190
2033	21,527	22,535	27,373	28,932	36,074	19,800	20,095
2034	21,707	22,514	27,696	29,352	37,073	20,013	20,240
2035	21,994	22,640	28,143	29,895	38,193	20,312	20,485
2036	22,312	22,829	28,643	30,489	39,362	20,624	20,756
2037	22,624	23,036	29,155	31,092	40,537	20,915	21,014
			Fishing mortality				
2024	0.030	0.030	0.030	0.030	0.03	0.030	0.030
2025	0.090	0.043	0.045	0.036		0.111	0.090
2026	0.090	0.041	0.045	0.036		0.111	0.090
2027	0.090	0.090	0.045	0.036		0.111	0.111
2028	0.090	0.090	0.045	0.036		0.111	0.111
2029	0.090	0.090	0.045	0.036		0.107	0.111
2030	0.087	0.090	0.045	0.036		0.098	0.101
2031	0.083	0.089	0.045	0.036		0.093	0.095
2032	0.080	0.085	0.045	0.036		0.090	0.092
2033	0.080	0.084	0.045	0.036		0.090	0.091
2034	0.081	0.084	0.045	0.036		0.091	0.092
2035	0.082	0.084	0.045	0.036		0.092	0.093
2036	0.083	0.085	0.045	0.036		0.094	0.095
2037	0.084	0.086	0.045	0.036		0.096	0.096
			Yield (mt)				
2024	2,199	2,199	2,199	2,199	2,199	2,199	2,199
2025	6,338	3,096	3,238	2,581		7,705	6,338
2026	5,757	2,812	3,070	2,470		6,862	5,757
2027	5,193	5,687	2,889	2,344		6,072	6,312
2028	4,682	5,115	2,714	2,221		5,376	5,581
2029	4,248	4,624	2,558	2,110		4,636	4,969
2030	3,794	4,241	2,437	2,025		3,891	4,128
2031	3,432	3,947	2,371	1,981		3,507	3,680
2032	3,286	3,682	2,363	1,982		3,369	3,501
2033	3,290	3,601	2,383	2,005		3,388	3,491
2034	3,377	3,624	2,429	2,051		3,507	3,586
2035	3,486	3,679	2,479	2,095		3,627	3,690
2036	3,589	3,744	2,524	2,138		3,746	3,791
2037	3,710	3,835	2,575	2,183		3,875	3,909

Figures

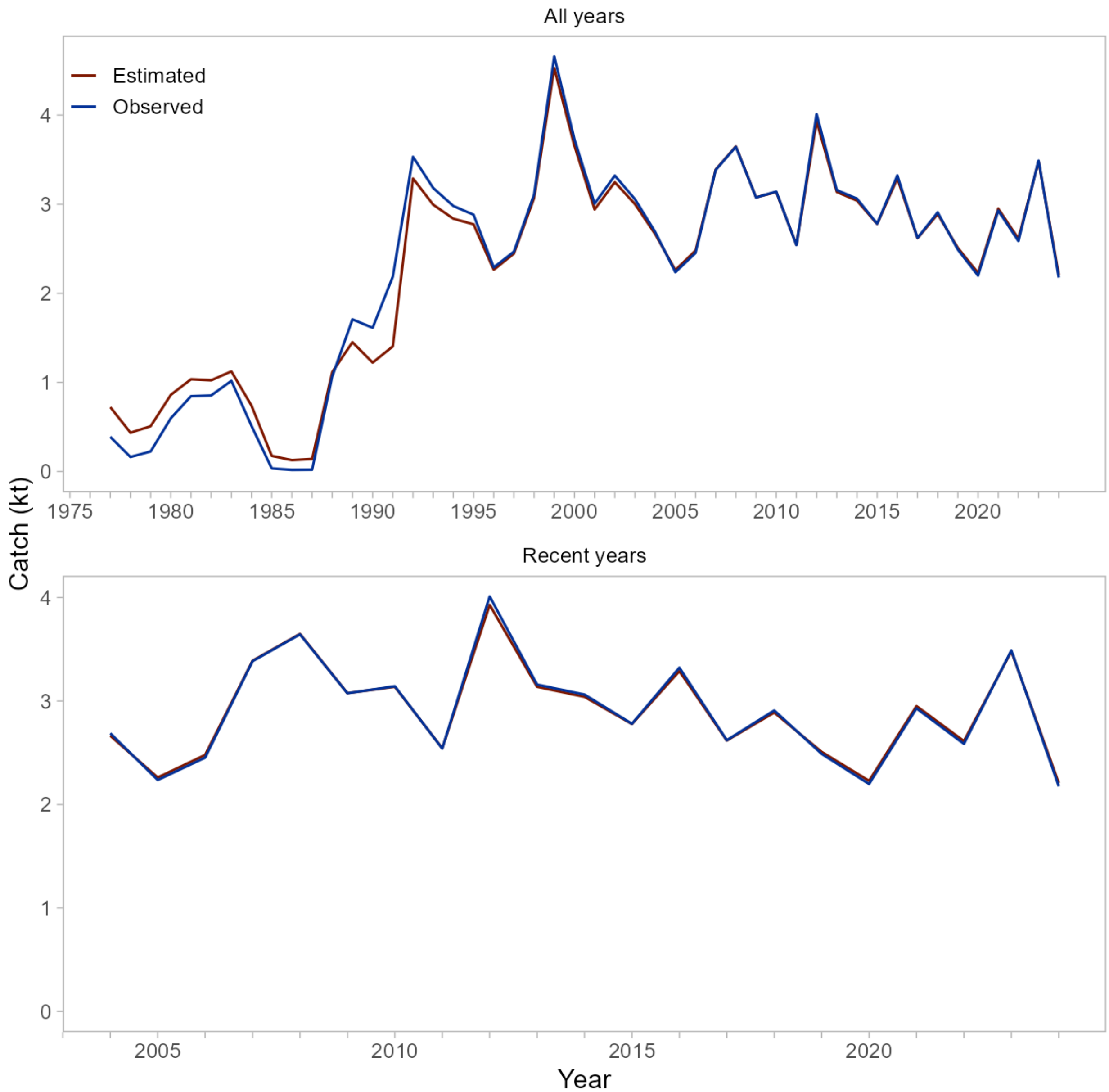

Figure 12-1. Estimated and observed long-term and recent commercial catch of GOA dusky rockfish in the Gulf of Alaska.

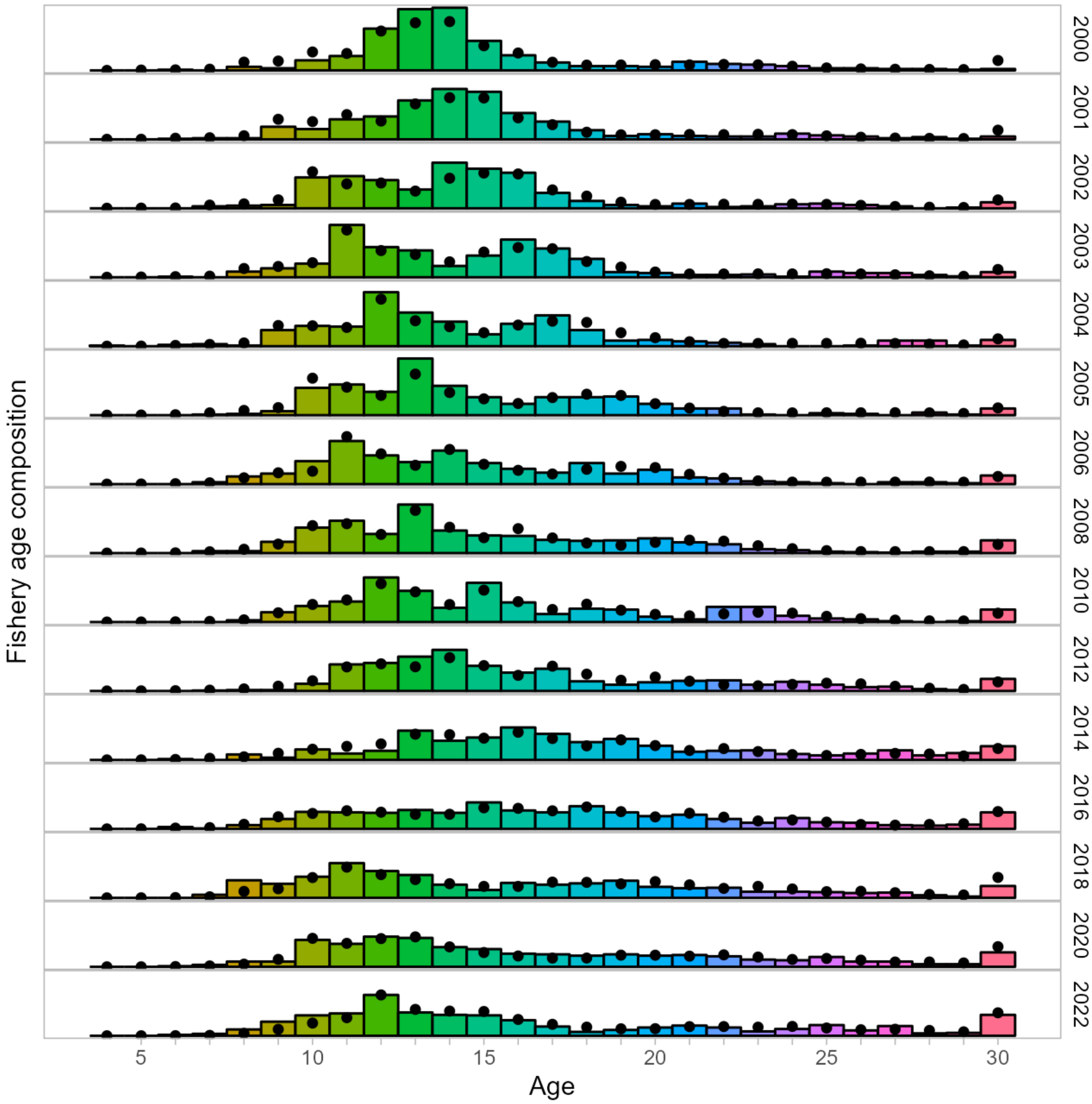

Figure 12-2. Fishery age compositions for GOA dusky rockfish. Observed values are bars, black circles are the predicted lengths from author's recommended model.

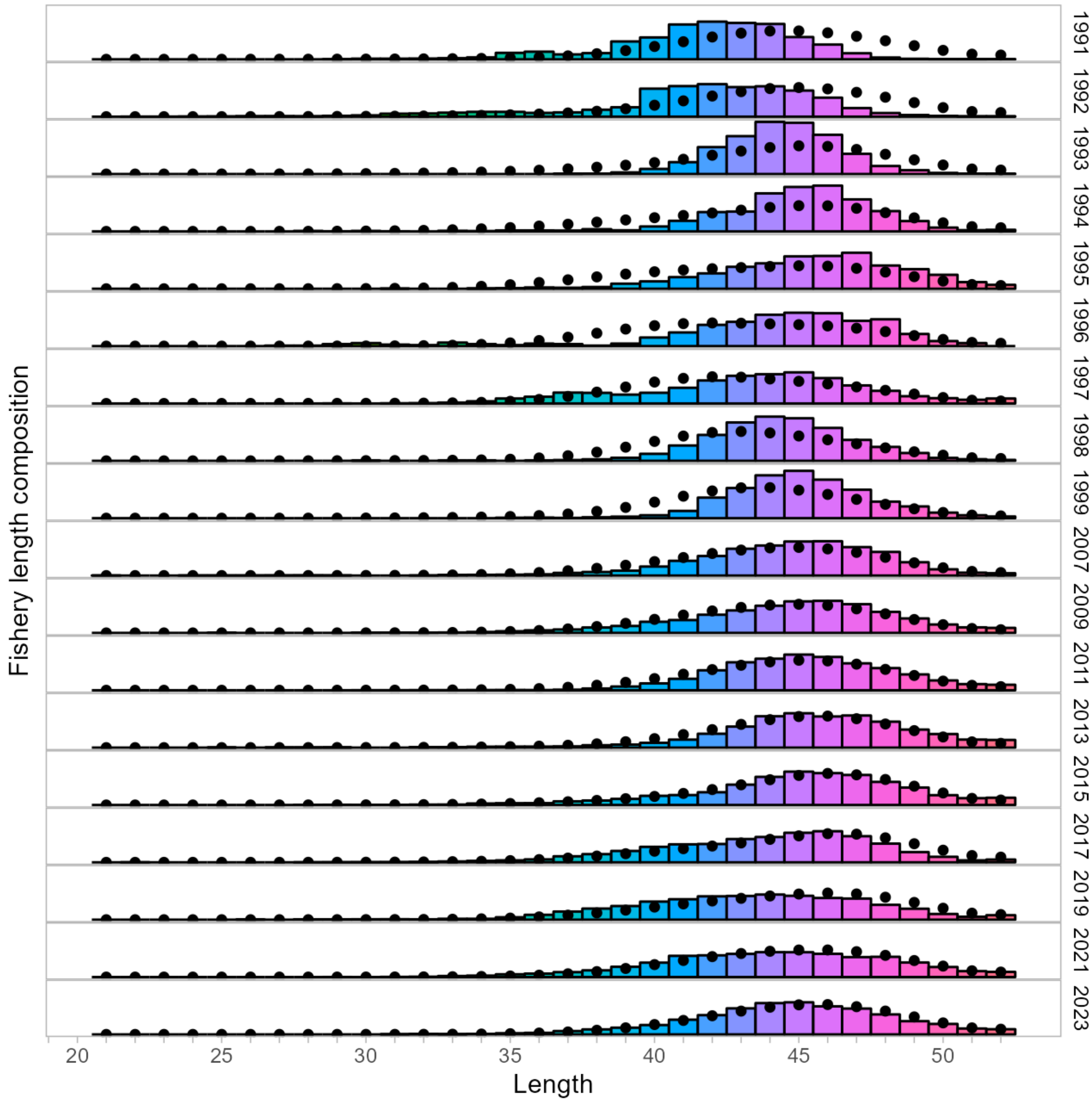

Figure 12-3. Fishery length compositions for GOA dusky rockfish. Observed values are bars, black circles are the predicted lengths from author's recommended model.

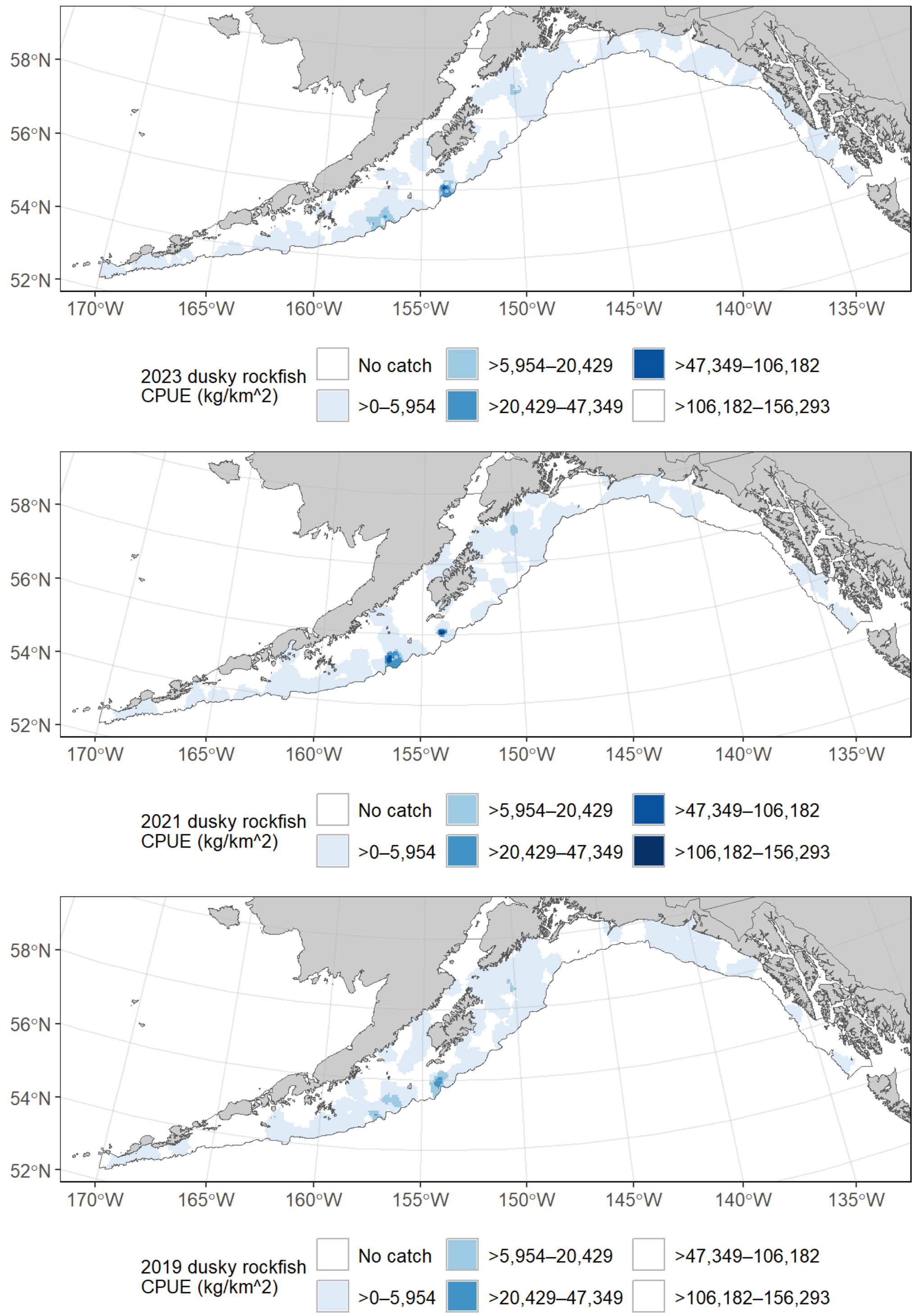

Figure 12-4. Spatial distribution of dusky rockfish in the Gulf of Alaska during the 2019, 2021, and 2023 NMFS trawl surveys.

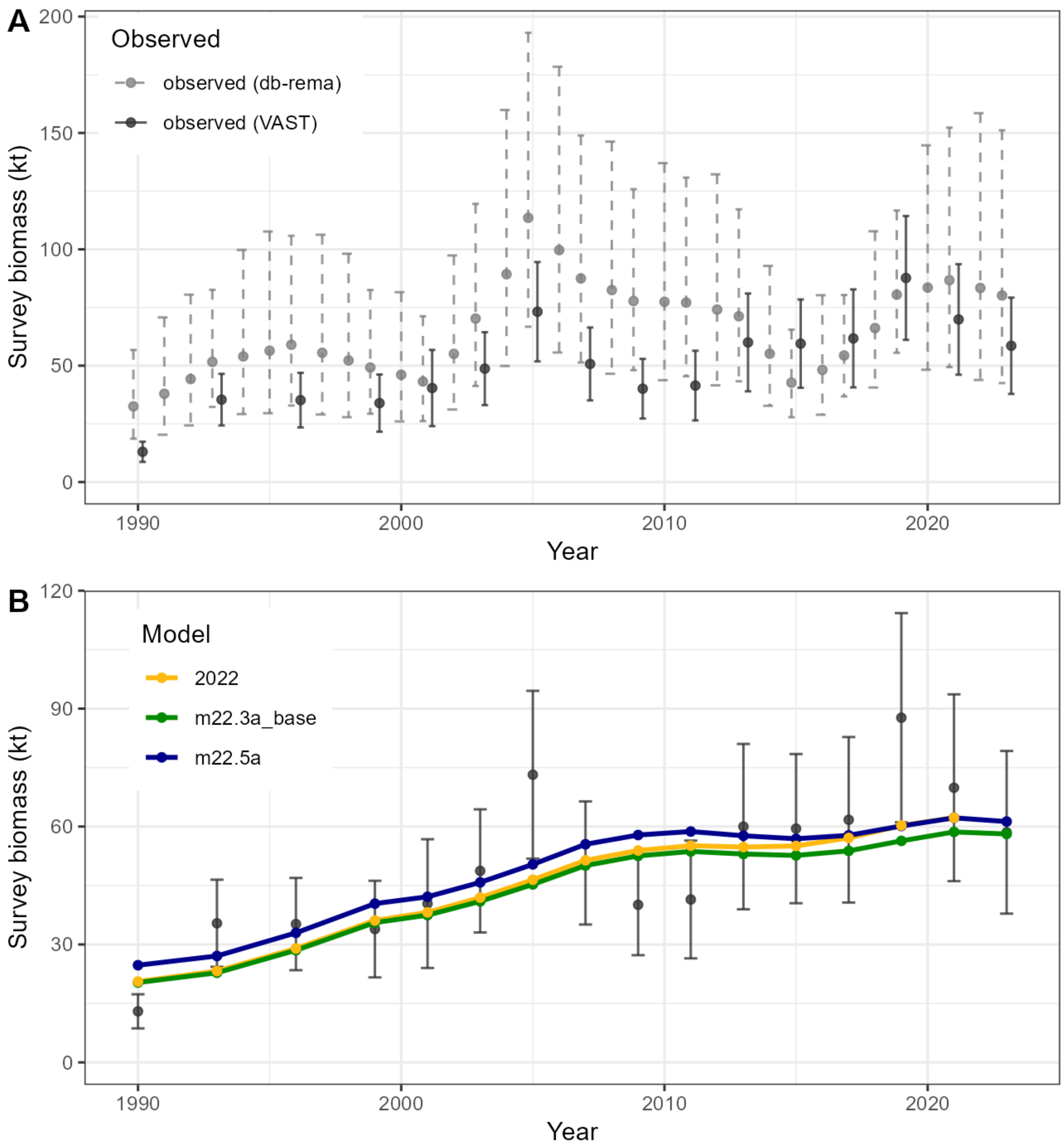

Figure 12-5. A) Observed GOA dusky rockfish trawl survey biomass calculated with VAST model-based estimates (black circles and solid lines) and design-based estimates smoothed by REMA (gray circles and dashed lines) for comparison, and B) observed GOA dusky rockfish trawl survey biomass calculated with VAST (black circles and lines) with predicted trawl survey biomass based on three separate models. Error bars are approximate asymptotic 95% confidence intervals of model error from the VAST model.

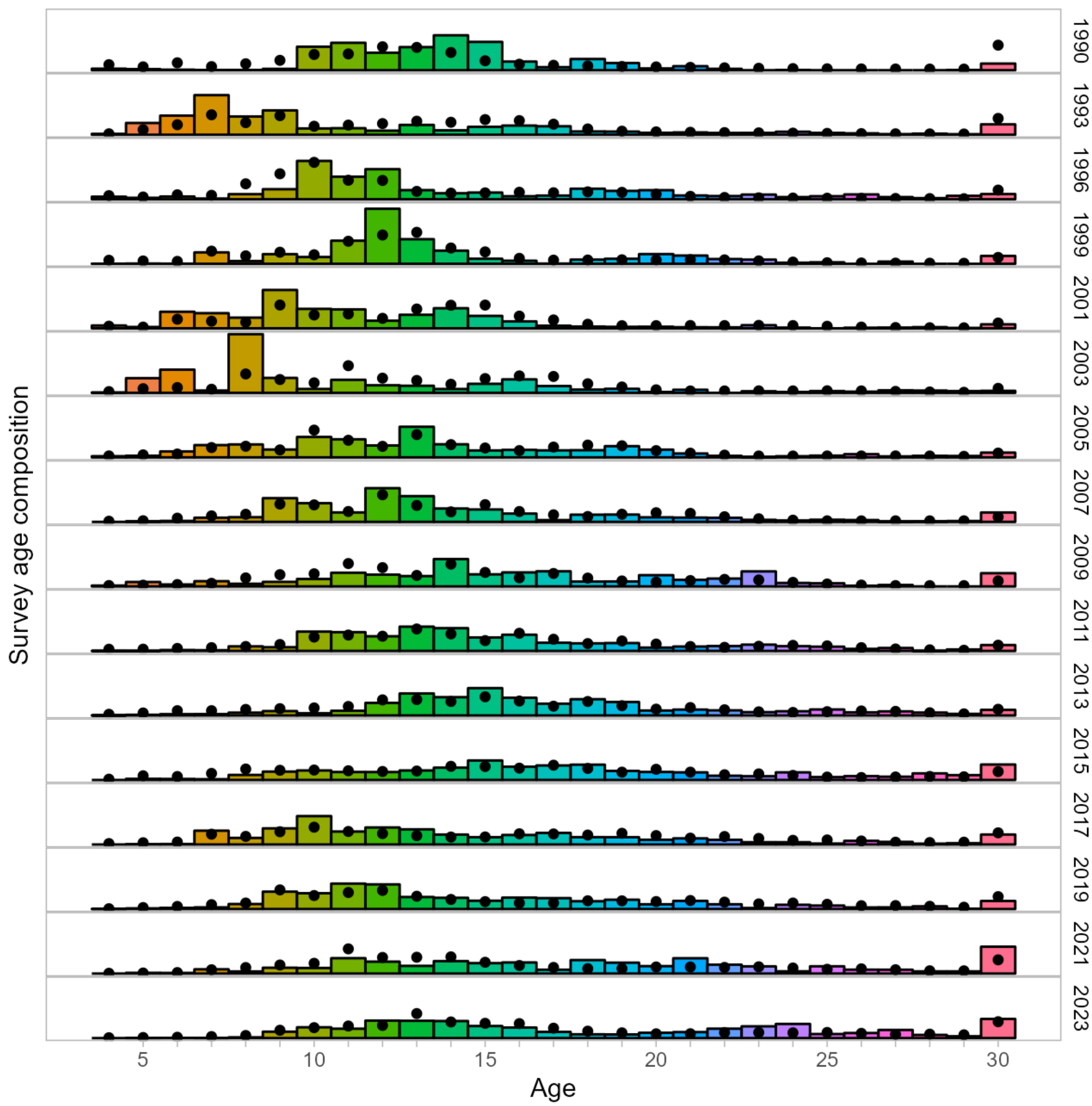

Figure 12-6. Survey age compositions for GOA dusky rockfish. Observed values are bars, black circles are the predicted lengths from author's recommended model.

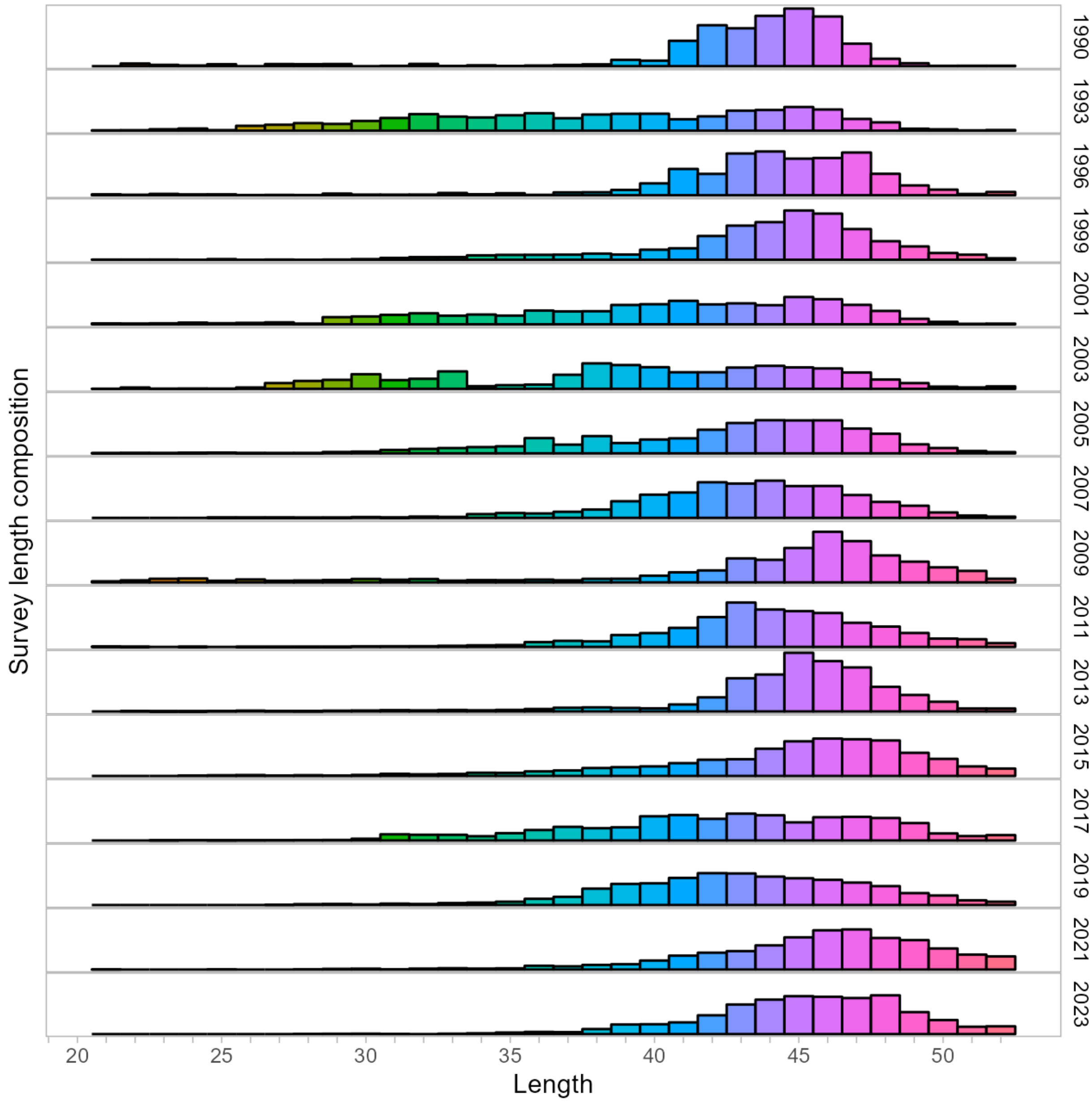

Figure 12-7. Survey length compositions (not used in model) for GOA dusky rockfish.

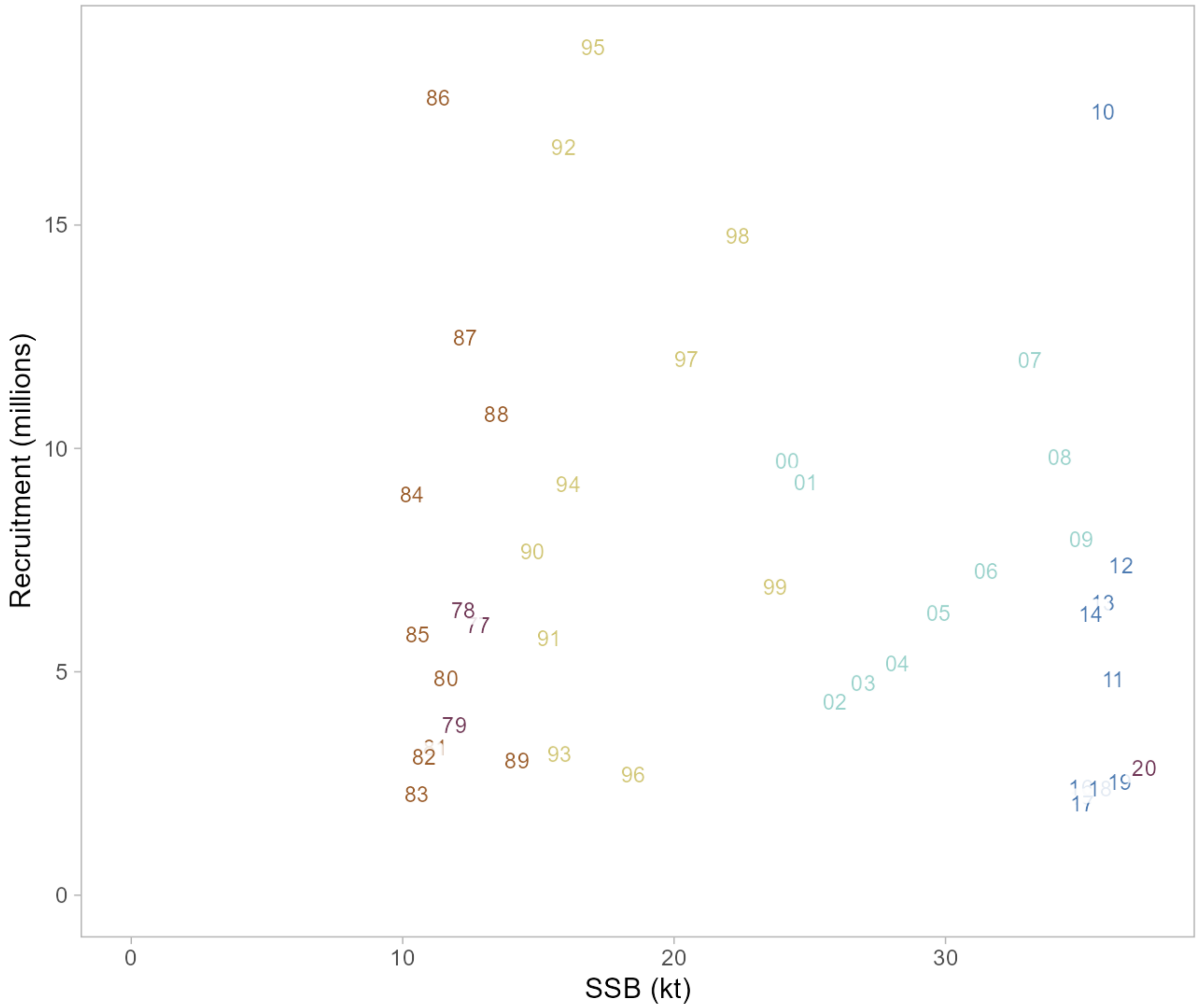

Figure 12-8. Scatterplot of spawner-recruit estimates for the GOA dusky rockfish author's recommended model.

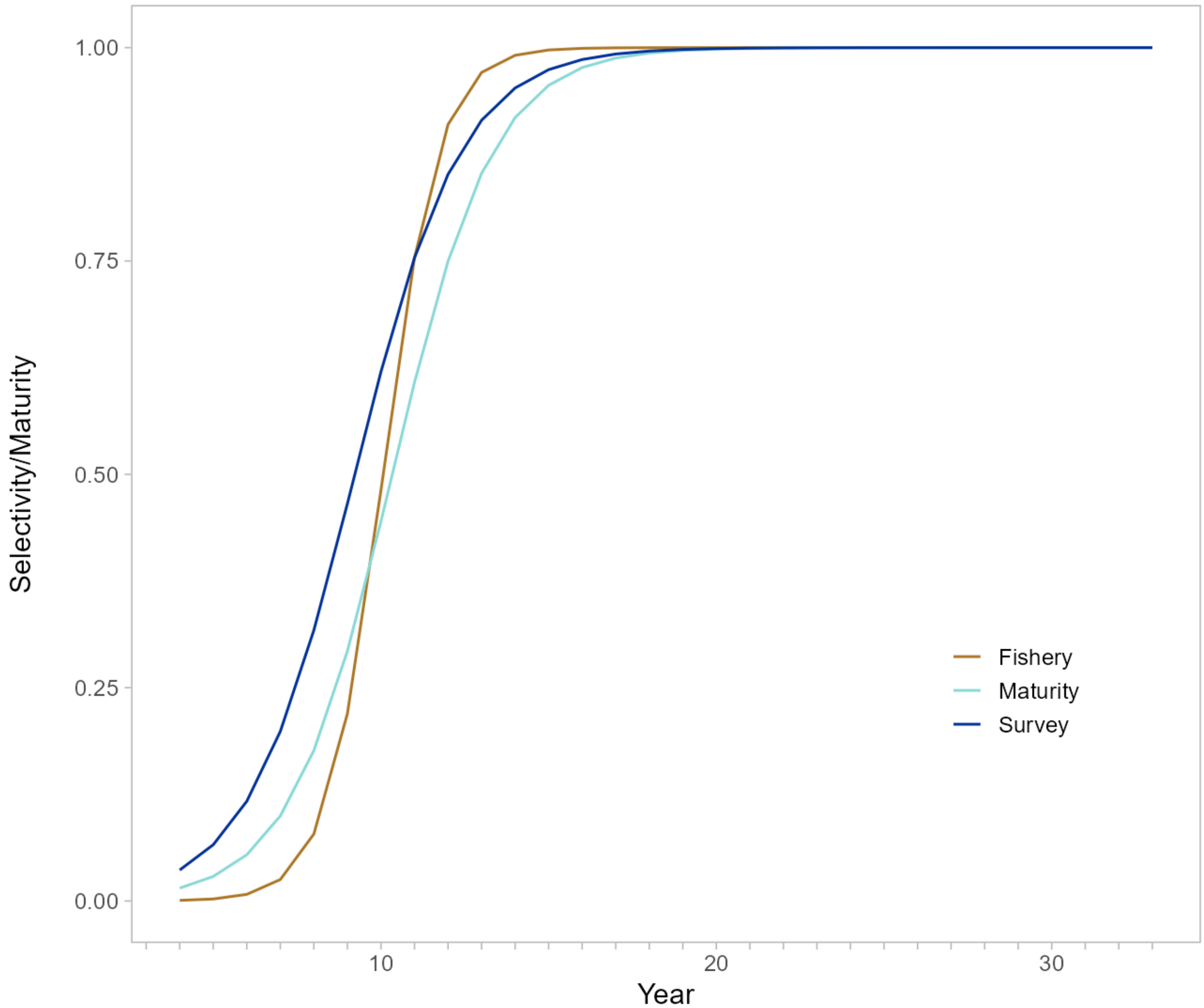

Figure 12-9. Estimated maturity, fishery and survey selectivities for GOA dusky rockfish from the 2024 model.

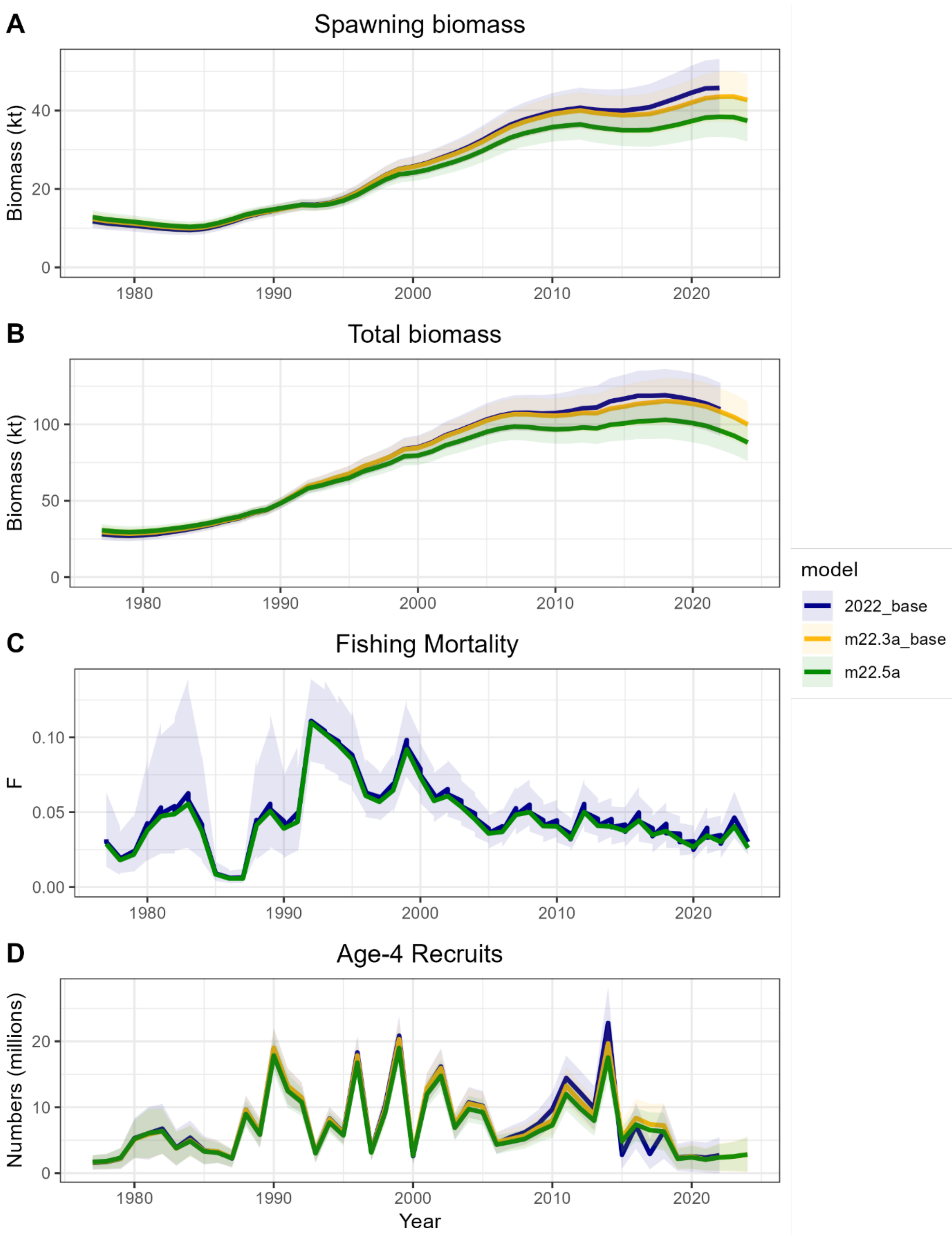

Figure 12-10. Time series of estimated female spawning biomass, total biomass, fully selected fishing mortality (*F*), and the number of age-4 recruits (millions) for dusky rockfish in the Gulf of Alaska as estimated by the recommended and accepted models.

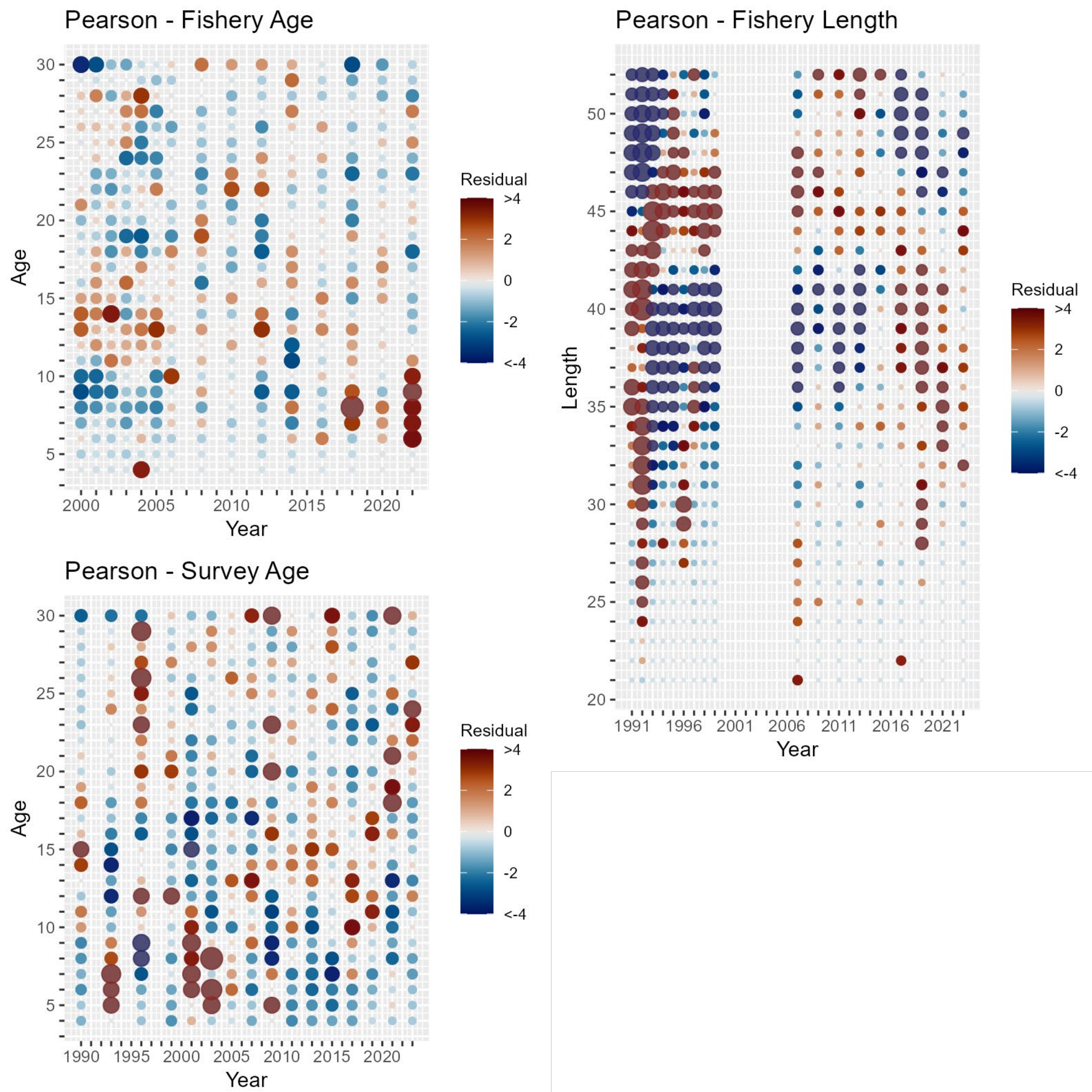

Figure 12-11. Pearson residuals for fishery and survey age and length compositions for GOA dusky rockfish.

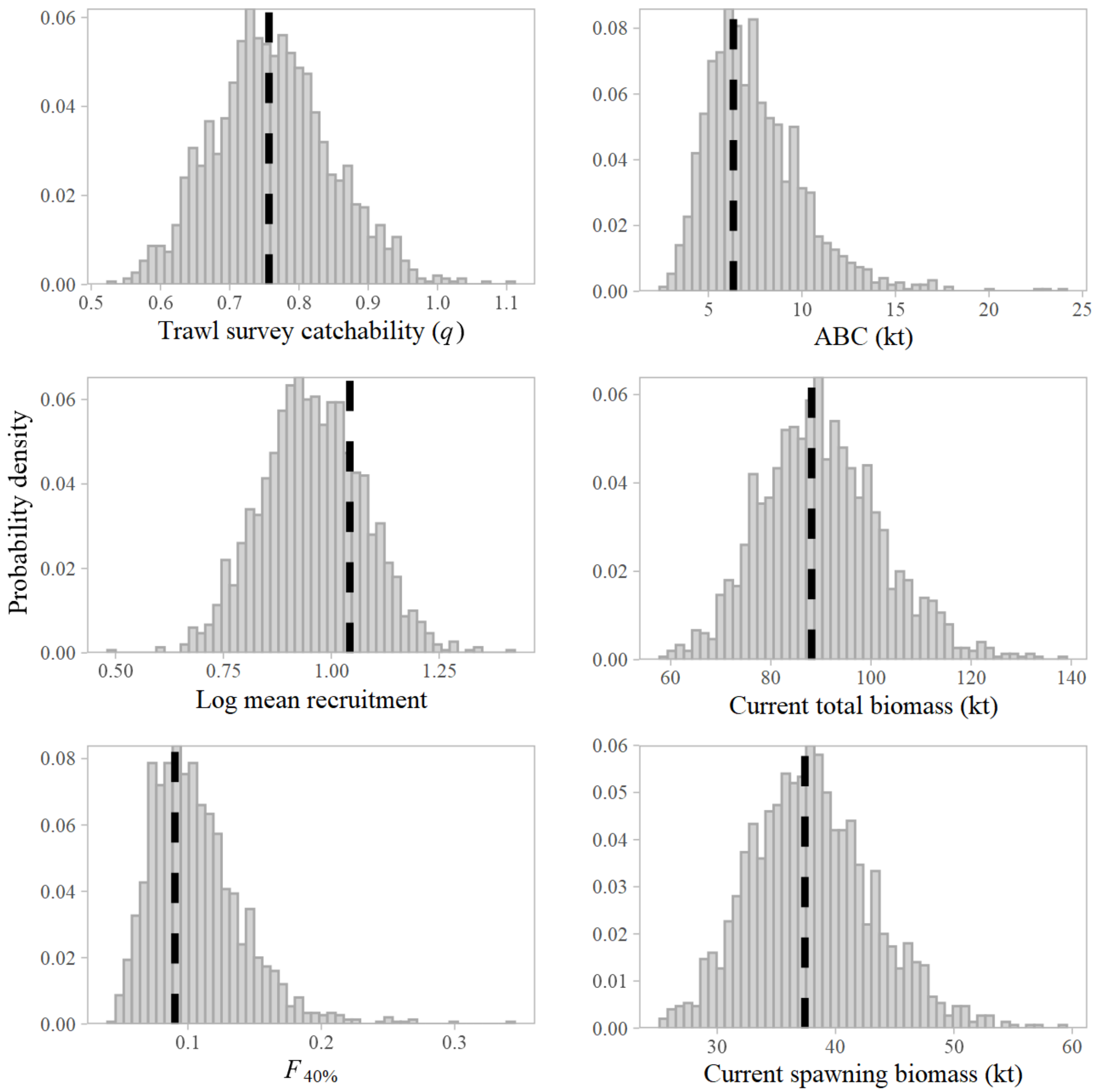

Figure 12-12. Histograms of estimated posterior distributions for key parameters derived (or estimated, in the case of *q*) from the MCMC for GOA dusky rockfish. Vertical black, dashed lines represent the maximum likelihood estimate for comparison with the MCMC results.

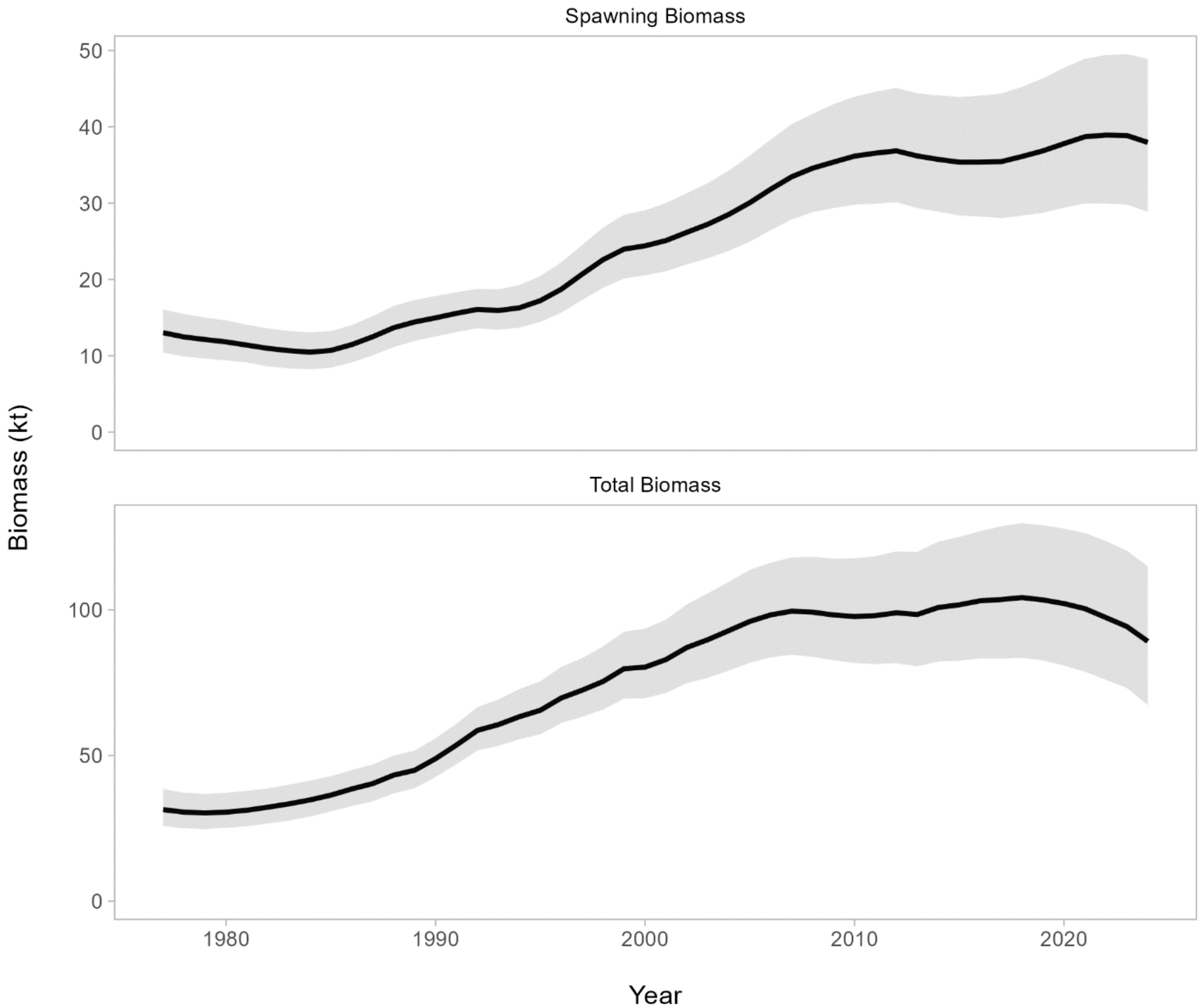

Figure 12-13. Model estimated total biomass and spawning biomass with 95% credible intervals determined by MCMC (shaded) for Gulf of Alaska dusky rockfish.

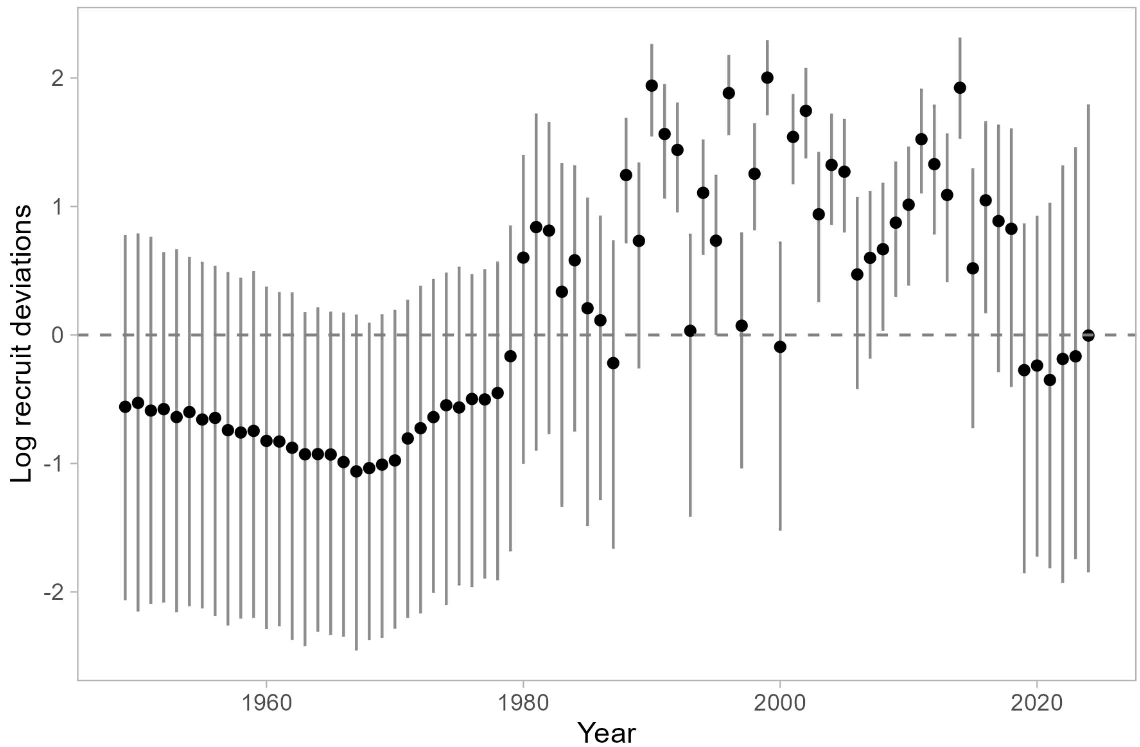

Figure 12-14. Time series of recruitment deviations with 95% credible intervals for GOA dusky rockfish.

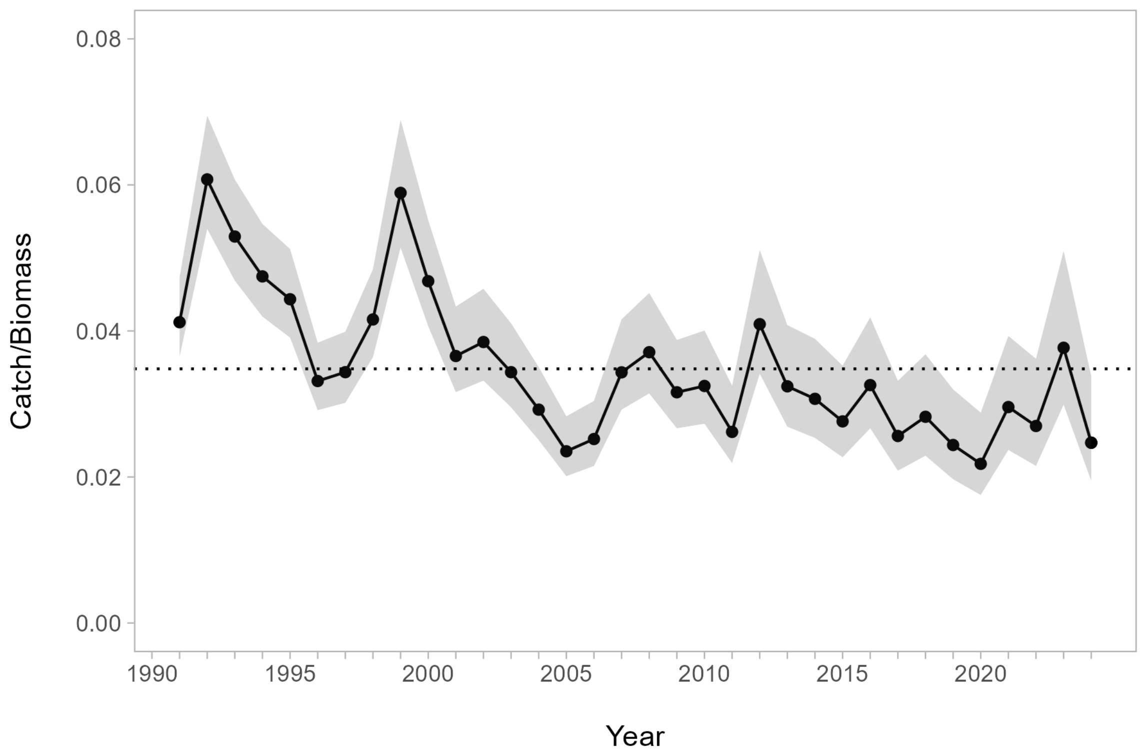

Figure 12-15. Gulf of Alaska dusky rockfish catch/age 4+ exploitation ratio with approximate 95% confidence intervals. Observed catch values were used for 1990-2024, the 2024 catch values were estimated using an expansion factor. The horizontal dashed line is the mean value for the entire dataset.

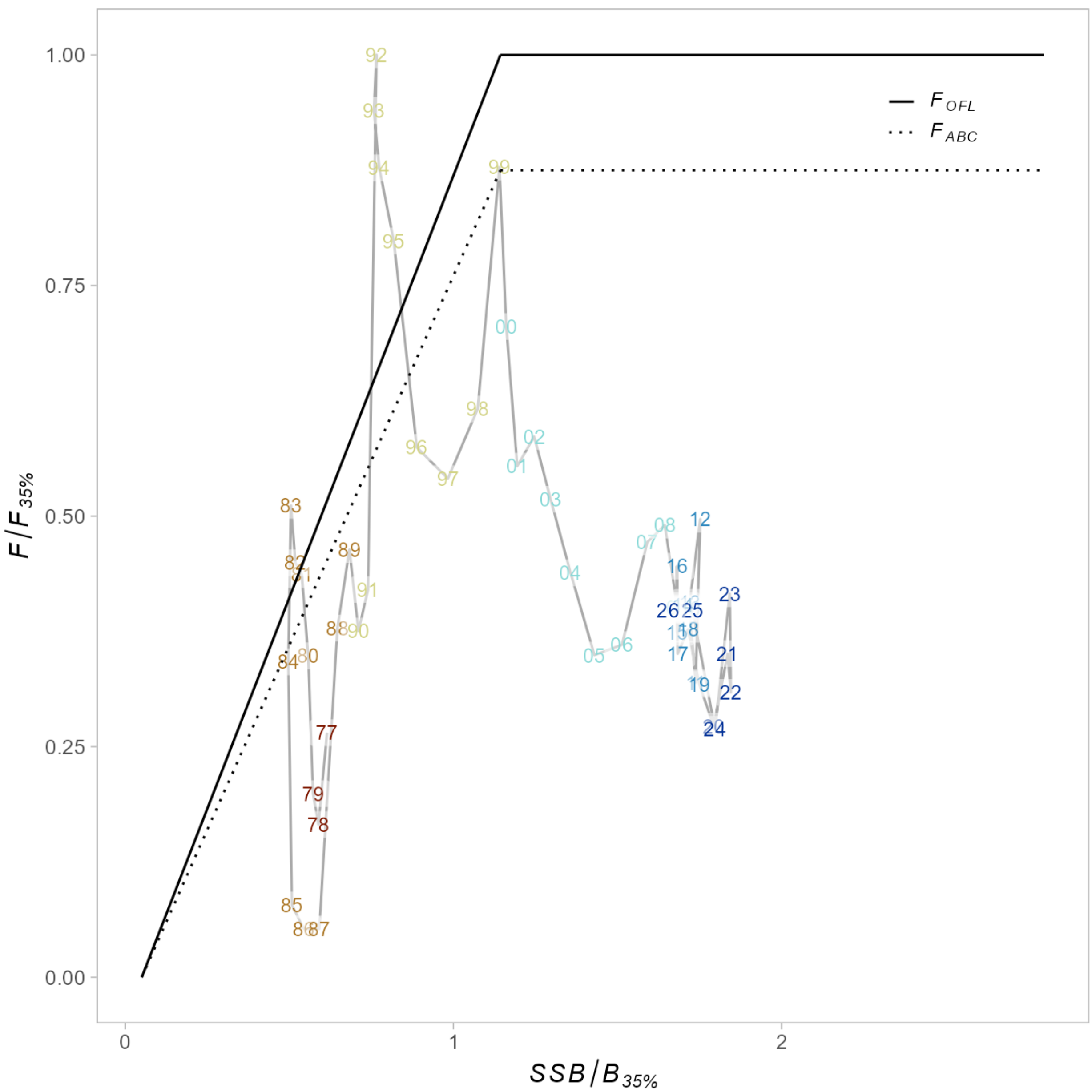

Figure 12-16. Time series of dusky rockfish estimated spawning biomass (SSB) relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ for author recommended model.

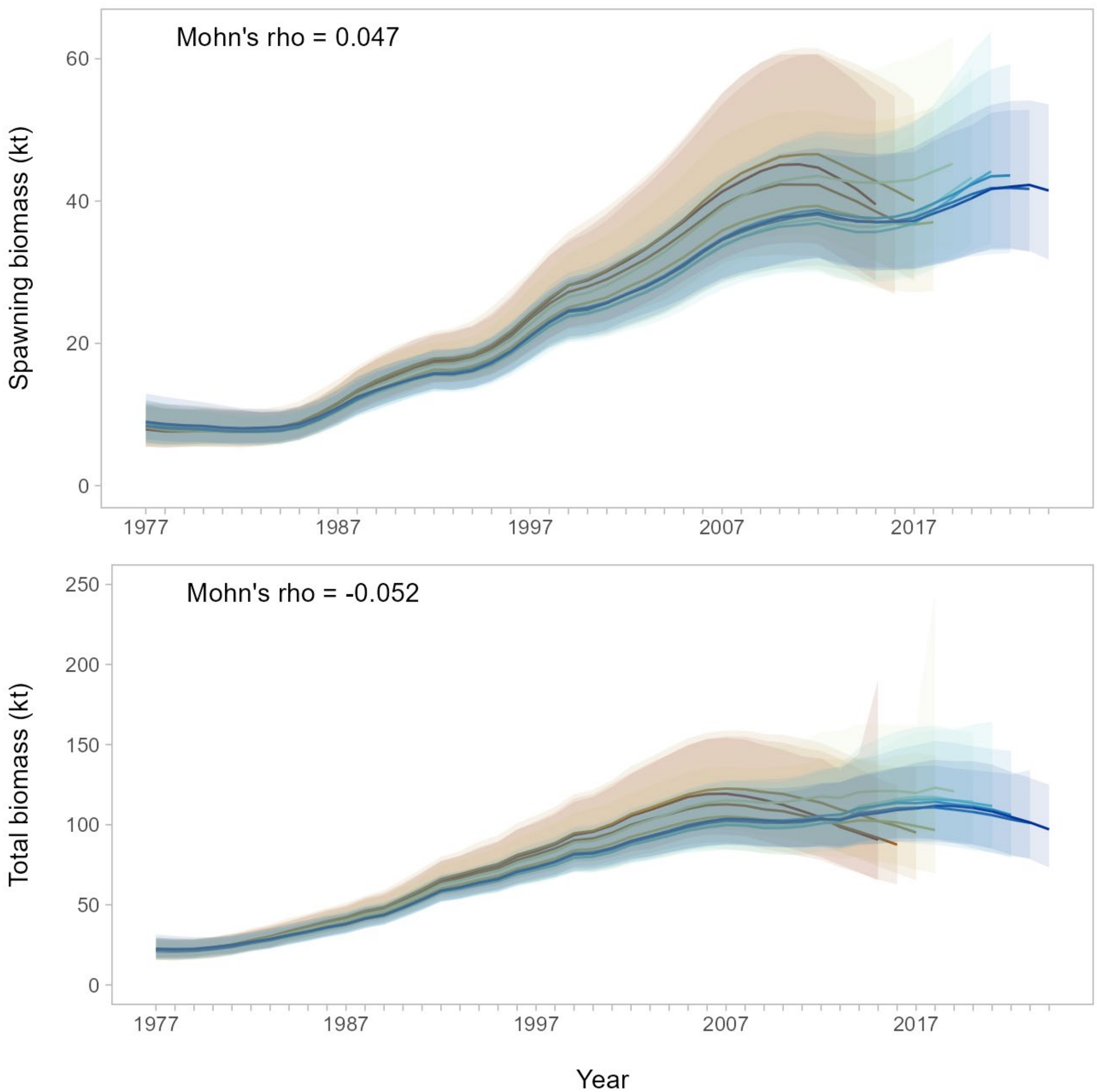

Figure 12-17. Retrospective peels of estimated female spawning biomass and total biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC. Mohn's rho value for spawning biomass is 0.047 and -0.052 for total biomass.

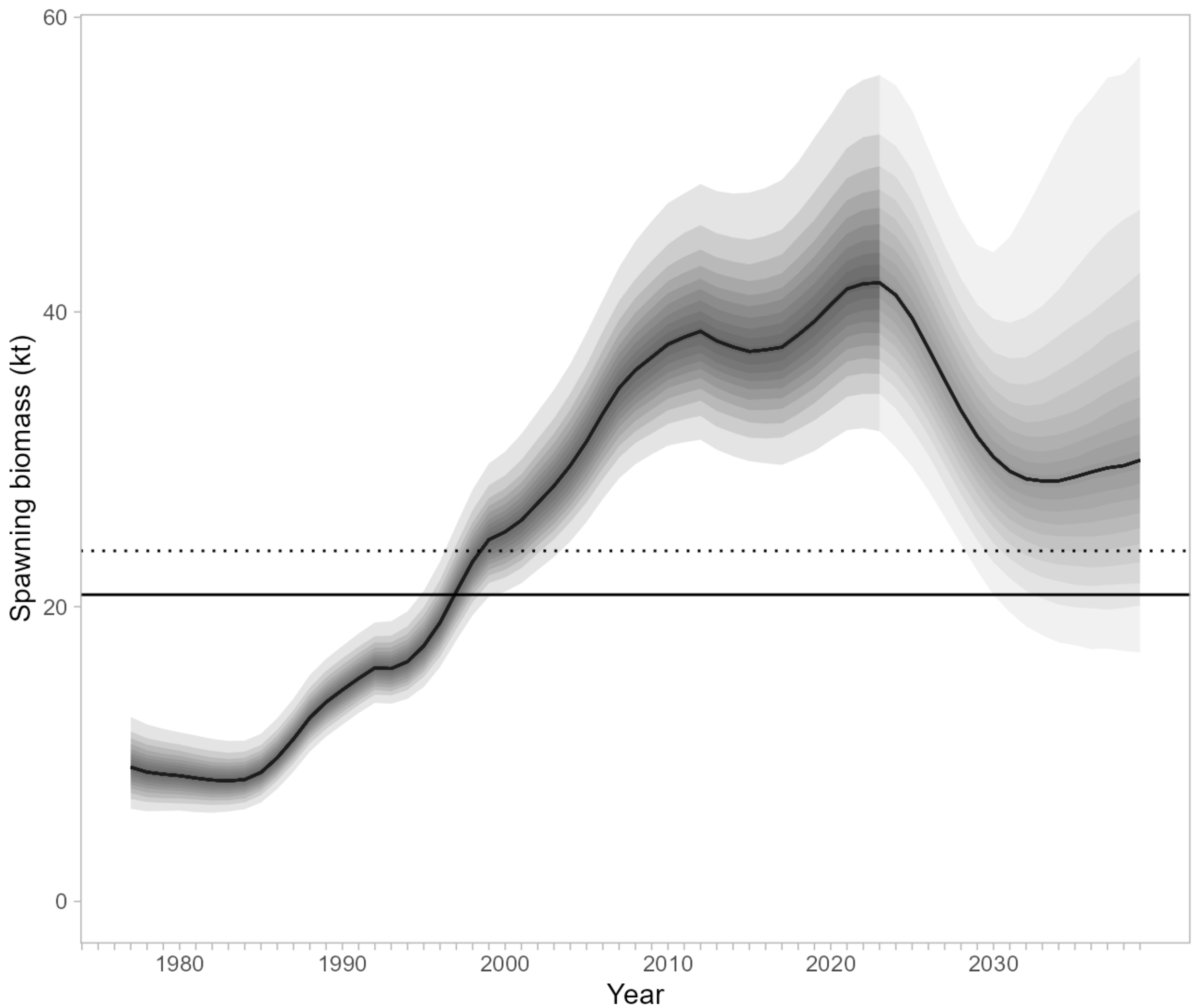

Figure 12-18. Median dusky rockfish spawning stock biomass from MCMC simulations with Bayesian credible intervals including projections for 2025-2037 (right of the vertical change in shading), when managing under Scenario 2. Assumes the same average yield ratio forward in time. Dotted horizontal line is $B_{40\%}$ and solid horizontal line is $B_{35\%}$ based on recruitments from 1977-2020. Each shade is 5% of the posterior distribution.

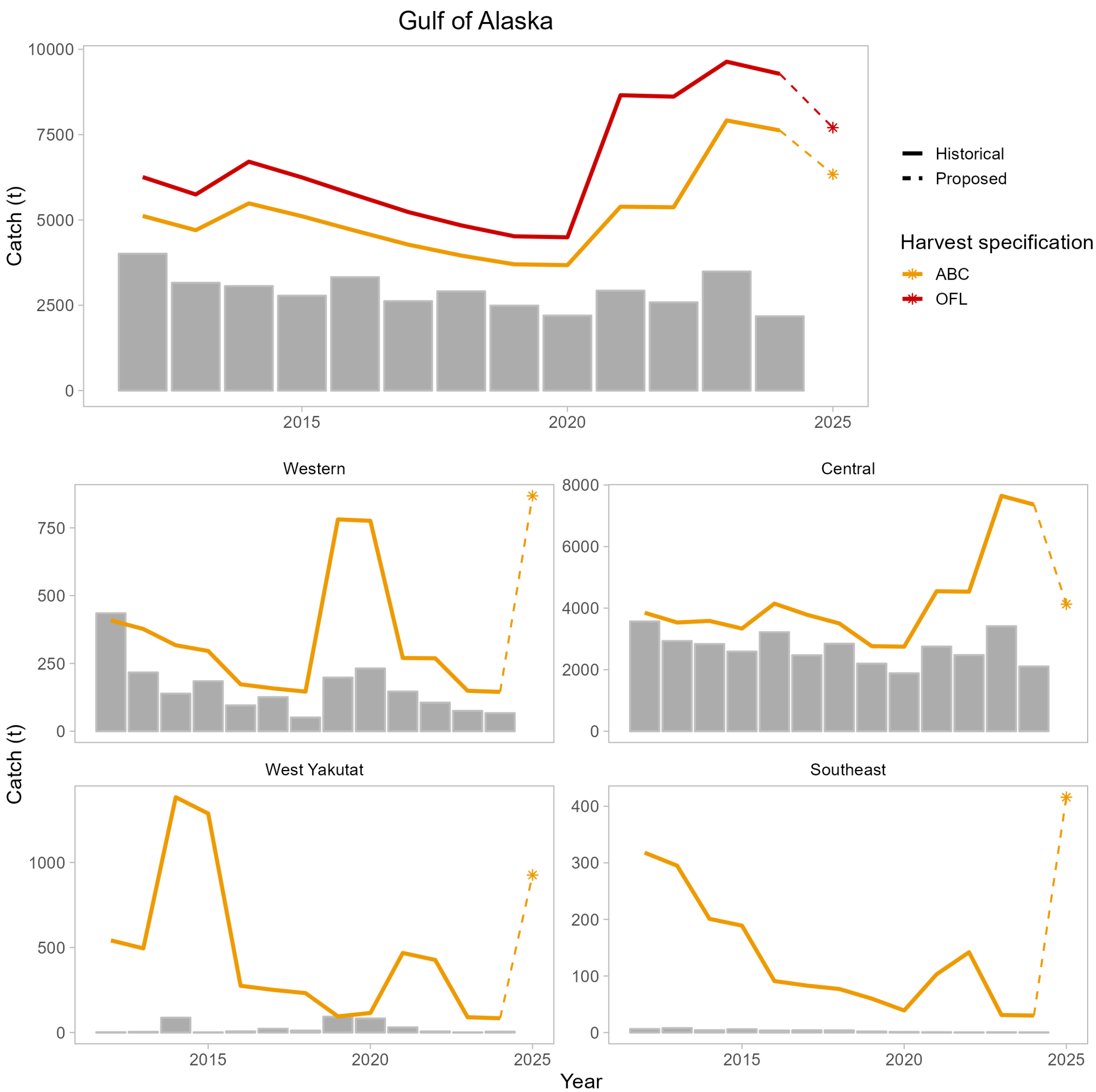

Figure 12-19. Total dusky rockfish catch in the Gulf of Alaska and management areas with associated historical and proposed harvest specifications.

Appendix 12A. Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, a data set has been generated to help estimate total catch and removals from NMFS stocks in Alaska. This data set 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 (Heifetz et al. 2009; Table 10 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 trawl surveys. Recreational harvest of dusky rockfish is variable, though typically below 20 t. Total removals from activities other than a directed fishery have been near 10-20 t for 2010–2023. Research harvests from trawl in recent years are higher in odd years due to the biennial cycle of the AFSC bottom trawl survey in the GOA. These removals do not pose a significant risk to the dusky rockfish stock in the GOA.

Reference

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

Table 12-18. Total removals of Gulf of Alaska dusky rockfish (t) from activities not related to directed fishing, since 2010. 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	Trawl Surveys	Recreational	Other
2010	1	9	<1
2011	5	5	<1
2012	<1	8	<1
2013	7	11	<1
2014	<1	16	<1
2015	5	17	<1
2016	<1	18	<1
2017	4	15	<1
2018	<1	11	<1
2019	6	17	1
2020	<1	8	<1
2021	9	13	<1
2022	<1	10	<1
2023	5	10	<1

Appendix 12B. September Plan Team document for Gulf of Alaska dusky rockfish updates

Kristen Omori, Ben Williams, and Pete Hulson
September, 2024

Executive Summary

Gulf of Alaska (GOA) dusky rockfish is assessed as a Tier 3 stock. The currently accepted assessment model, 22.3a, uses a bespoke statistical age-structured assessment model in AD Model Builder (ADMB; Fournier *et al.* 2012) based on a generic rockfish model (Courtney *et al.* 2007). Model 22.3a incorporates the Groundfish Assessment Program's Vector Autoregressive Spatio-Temporal (VAST) model as the survey biomass estimate with a lognormal error distribution. This assessment year, the authors propose to make several corrective updates to the assessment model and propose an alternative apportionment method.

Assessment model changes

There are two minor changes in the model code that either were incorrectly specified or diverges with common practice. The changes that are being proposed are to rectify those oversights.

1. Model m22.4a: The current model estimates the trawl survey biomass likelihood with a normal error structure:

$$L = \lambda \sum_y \frac{\left(I_y - \widehat{I_y}\right)^2}{2SE\left(I_y\right)^2}$$

However, the trawl survey biomass likelihood will be updated to incorporate a lognormal error structure:

$$L = \lambda \sum_y \left[\log\left(\sigma_y\right) + 0.5\left(\frac{\log\left(I_y/\widehat{I_y}\right)}{\sigma_y}\right)^2\right],$$

where

$$\sigma_y = \sqrt{\log\left(1 + \frac{SE\left(I_y\right)^2}{I_y^2}\right)}$$

Here, y is year, I_y is the annual survey biomass observation, $\widehat{I_y}$ is the estimated annual survey biomass, σ_y is annual survey biomass log standard error, λ is the likelihood weight, and $SE\left(I_y\right)$ is the annual survey biomass standard error.

This change aligns this assessment with the common assumption used in stock assessment models that population index data follow a log-normal distribution, because the population index uncertainty is often skewed rather than symmetric. For the purposes of this document, the model correction for updating to the lognormal error in the survey biomass likelihood is shown as 'm22.4a_srv' and compared to the base (accepted m22.3a) model.

2. Model m22.5a: The model code mis-specifies the starting number at age values when estimating the abundance at the start of the first projection year and in the B_{100} and B_{40} calculations. Currently, the start year is listed as 1979, but should be corrected to 1977 (established regime shift year) plus the recruitment age in order to start the predicted recruitment at the correct year. The recruitment age for dusky rockfish is age 4; thus, the start year should be listed as 1981 (1977+recruitment-age). The model correction for updating the start year with the recruitment age in the population projection model, B_{100}, and B_{40} will be built on the 'm22.4a_srv' model and shown as 'm22.5a_srvproj'.

Model comparisons are made between the currently accepted 'base' model, m22.3a, and the two updated models, m22.4a and m22.5a, with model likelihoods and key parameter estimates shown in Table 1 and 2, respectively. Model m22.5a with the lognormal error structure imperceptibly improves the fishery and survey age and lengths based on the negative log-likelihoods and visually appears to fit the observed survey data better than the base model (Table 1; Figure 1). Modifying the survey error structure to lognormal in model m22.4a did produce differences in the model results. The estimated survey catchability and biomass are higher in the model using the lognormal error structure (m22.4a) than the base model (m22.3a) by 6-23% (Figure 1), but yield lower female spawning biomass by up to 13% in the second half of the time series when the survey index starts (Figure 2A). The estimated fishing mortality rate is slightly higher in the updated model compared to the base in the latter half of the time series (Figure 2B). Consequently, the estimated biomass values and parameters (e.g., B_{100}, B_{40}, final year total biomass, and spawning biomass) are lower in the updated model with lognormal error than the base model (Table 2).

Adding the correction of the starting year for the predicted recruitment did not change most of the results and outputs from the model m22.4a (Figure 2). The likelihood values and majority of the key parameter estimates remained the same (Table 1 and 2). The parameters that are minimally affected by the projection model correction are the B_{100}, B_{40}, and associated biomass quantities, which changed by < 3% compared to the model m22.4a (Table 2).

The authors recommend using model 22.5a with both model changes.

Apportionment method update

Currently the ABC for GOA dusky rockfish is allocated to each of the three management areas, Western, Central, and Eastern (further partitioned), based on the proportion of biomass in each area. More specifically, the accepted apportionment method uses the area-specific proportions from the design-based bottom trawl survey abundance estimates that are smoothed by the random effects model (REMA model). Because dusky rockfish are patchily distributed and are often found in both survey 'trawlable' and 'untrawlable' habitat (Jones et al. 2012; Rooper and Martin 2012), the bottom survey catch and resulting area-specific estimated biomass can be variable (Figure 3). Thus, the allocated ABC for each management area can be prone to large fluctuations from year to year. Additionally, a model-based index of abundance (i.e., VAST index) was accepted in 2022 as the survey index in the assessment model, which uses a lognormal error structure and estimates each year independently.

For consistency with the stock assessment model, the authors propose to change the apportionment method to be based on the area-specific model-based (VAST) index of abundance using the same model structure as the assessment model. Apportionment method using the alternative model-based approach (VAST) is compared to the accepted design-based model smoothed by REMA (design-based, REMA model). For purposes of this comparison, apportionment methods use survey data from 1990 to 2023.

Both the current (REMA applied to design-based biomass) and alternative model (VAST) used for region-specific biomass estimates reduce the variability in trends compared to the "observed" design-based biomass (Figure 4). However, the results in apportionment using VAST reduce uncertainty both within any given year and across time as compared to the current apportionment method (Figure 5). For example, the proportion of biomass in the Central GOA ranges from 0.56 to 0.94 based on the currently accepted design-based, REMA model, whereas the proportion of biomass from the VAST model ranges from 0.62 to 0.70.

In addition to the differences in variability and fluctuations between the models, there are a few differences in the annual estimated biomass for each management area between the two models, thus affecting the proportion of biomass in each area (Figure 5). The proportions from 2021-2023 from each model are substantially different (Table 3). The proportion of biomass in the Western and Eastern GOA for the design-based, REMA model falls under 0.05 (i.e., < 5%), whereas the proportion of biomass from the VAST model ranges roughly around 0.10 to 0.20 (i.e., 10-20%). In contrast, the proportion of biomass in the Central GOA is notably smaller when using the VAST model (~0.65-0.67 or 65-67%) compared to the design-based model, REMA model (~0.93-0.94 or 93-94%).

Thus, the proportions based on the VAST model will lead to notable changes in the allocation of ABC. Backwards projecting the proportions from each allocation model using the historical ABC to each management area, the VAST model would have allocated a smaller proportion of ABC to the Central GOA, but higher proportion of ABC to the Western and Eastern GOA compared to the accepted methodology (Figure 6). While the historical catch does surpass the projected allocated ABC in one or two years for both the design-based, REMA model and VAST model, the total GOA-wide catch remains significantly under the ABC.

The authors recommend using the model-based, VAST model approach for apportionment in place of the design-based, REMA model. Switching to the VAST model would be consistent with the assessment model. Likewise, the VAST model produces less variable (i.e., smoother) estimated biomass and subsequent proportions compared to the design-based, REMA model. For management purposes, using the VAST model for the apportionment methodology can substantially change the proportions of ABC allocated to each management area, but, with the exception of one year, the catch for GOA dusky rockfish does not appear to surpass the historical projected allocation of ABC.

References

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

Fournier, D.A., Skaug, H.J., Acheta, J., et al. (2012) AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimization Methods and Software* 27, 233-249.

Jones, D., Wilson, C.D., De Robertis, A., Rooper, C., Weber, T.C. and Butler, J.L. (2012) Evaluation of rockfish abundance un untrawlable habitat: Combining acoustic and complementary sampling tools. *Fishery Bulletin* 110, 332-343

Rooper, C. and Martin, M. (2012) Comparison of habitat-based indices of abundance with fishery-independent biomass estimates from bottom trawl surveys. *Fishery Bulletin* 110, 21-35.

Tables

Table 1. Likelihood values from currently accepted 'base' model, m22.3a_base, and alternative models, m22.4a_srv and m22.5a_srvproj.

Likelihood	m22.3a_base	m22.4a_srv	m22.5a_srvproj
Catch	25.72	26.95	26.95
Trawl survey	30.03	31.43	31.43
Fishery ages	41.52	41.19	41.19
Survey ages	138.14	138.01	138.01
Fishery lengths	60.03	59.87	59.87
Recruitment devs	36.21	31.49	31.49
sigmaR	0.41	0.54	0.54
q prior	0.50	0.16	0.16
Data LL	295.43	297.44	297.44
Total LL	431.54	428.83	428.83

Table 2. Key parameter estimates from the currently accepted 'base' model, m22.3a_base, and alternative models, m22.4a_srv and m22.5a_srvproj.

Parameter	m22.3a_base	m22.4a_srv	m22.5a_srvproj
sigmaR	1.003	0.943	0.943
q	0.638	0.776	0.776
avg rec	2.702	2.705	2.705
F_{40}	0.091	0.092	0.092
Total Biomass	107,186	93,488	93,531
SSB	44,468	38,464	38,465
B_{100}	65,565	60,343	61,962
B_{40}	26,226	24,137	24,785
ABC	7,921	6,863	6,863

Table 3. Apportionment proportions each management area for each model (accepted design-based, REMA model [db+rema] and VAST model) from 2021-2023.

Year	Area	db+rema (base)	vast
2021	Western	0.029	0.138
2021	Central	0.939	0.674
2021	Eastern	0.033	0.187
2022	Western	0.031	-
2022	Central	0.929	-
2022	Eastern	0.040	-
2023	Western	0.033	0.137
2023	Central	0.918	0.651
2023	Eastern	0.049	0.212

Figures

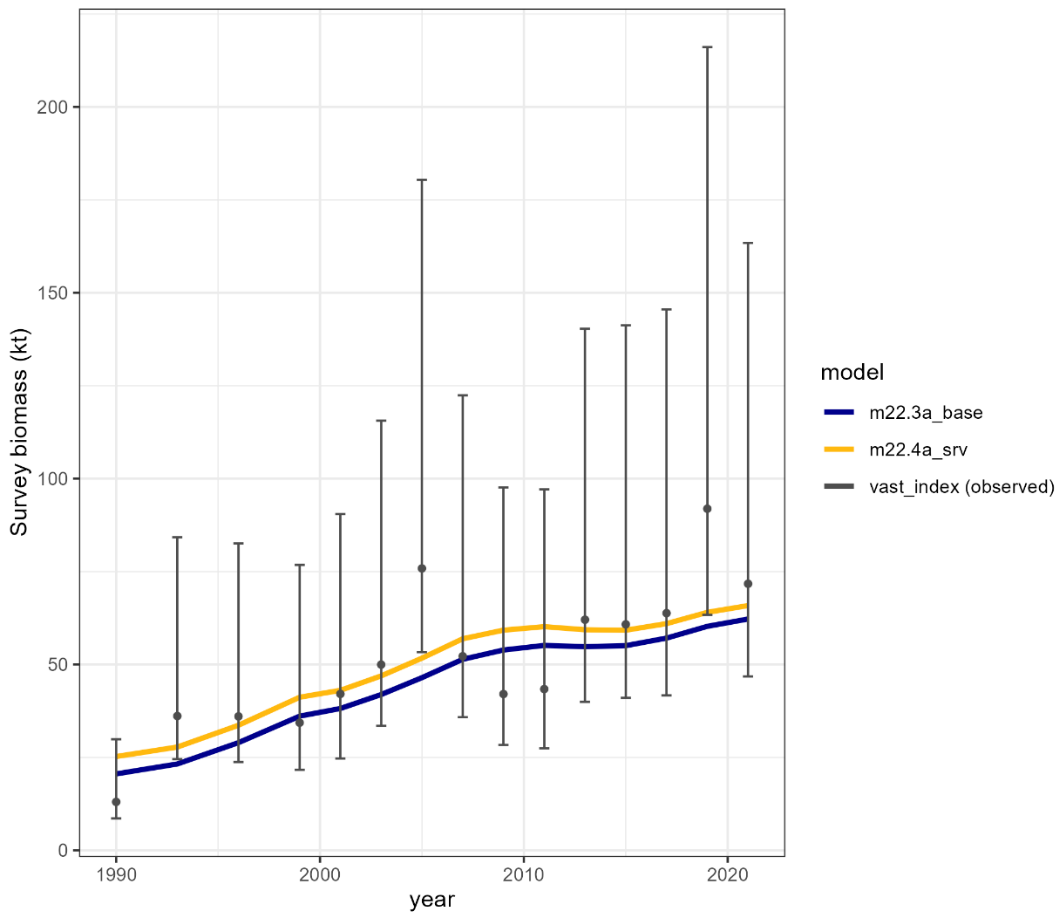

Figure 1. Estimated survey biomass (smooth lines) from the currently accepted 'base' model, m22.3a_base, and the alternative model, m22.4a_srv, with the VAST survey index (observed) values with confidence intervals.

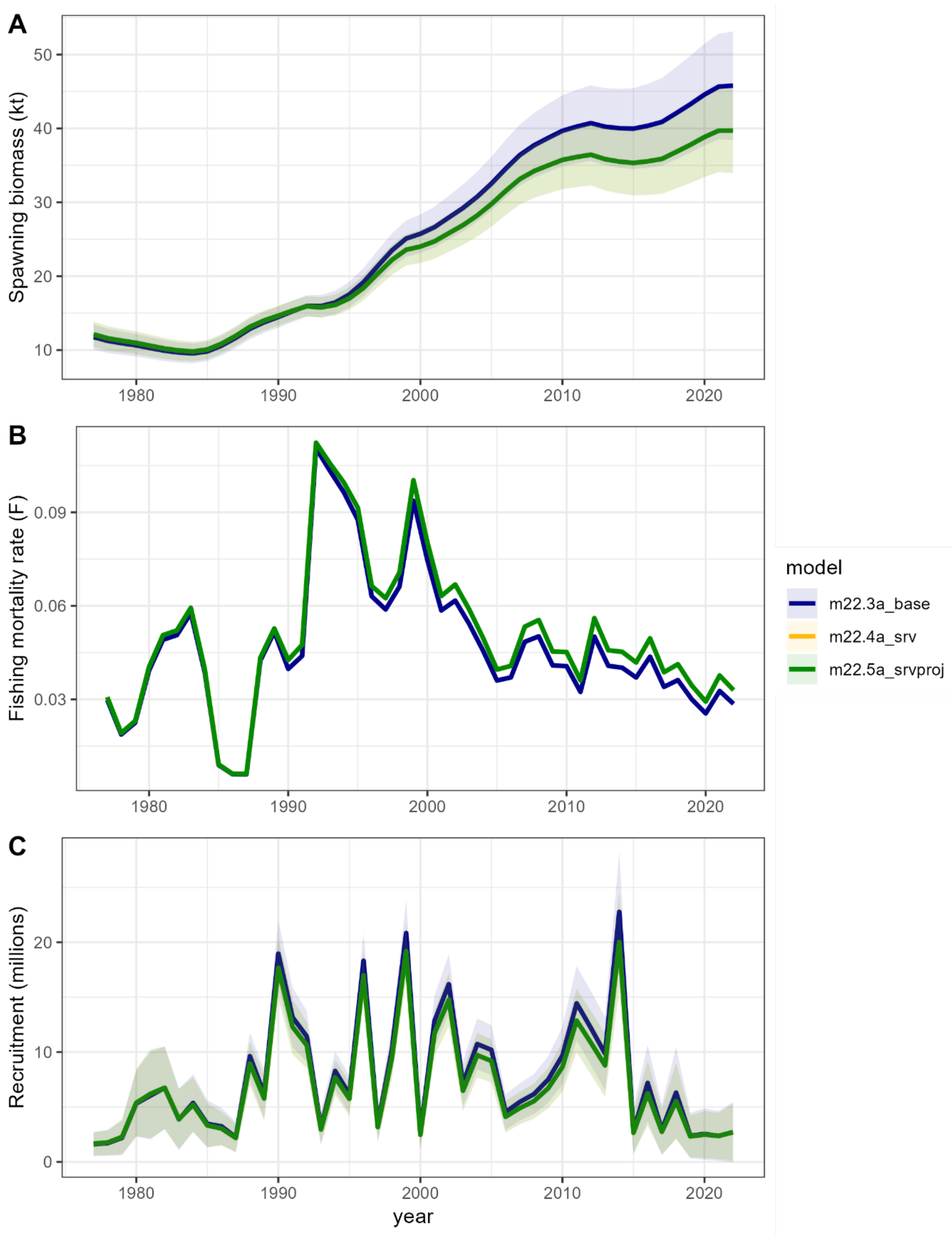

Figure 2. Time series estimates of A) female spawning biomass, B) fishing mortality rate, *F*, and C) recruitment for the accepted 'base' model (m22.3a_base) and alternative models with lognormal error in the survey biomass likelihood (m22.4a_srv) and correction of starting year in the projection module (m22.5a_srvproj). Note: there is no discernable difference between the updated models (m22.4a_srv and m22.5a_srvproj) in the time series of estimates.

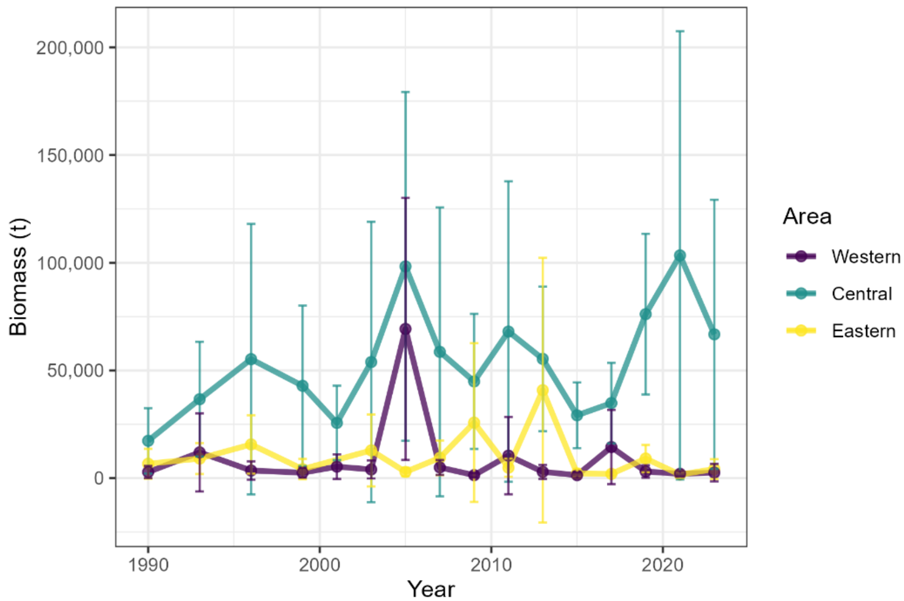

Figure 3. Design-based estimated biomass from the AFSC Groundfish Assessment Program bottom trawl survey for GOA dusky rockfish by management area.

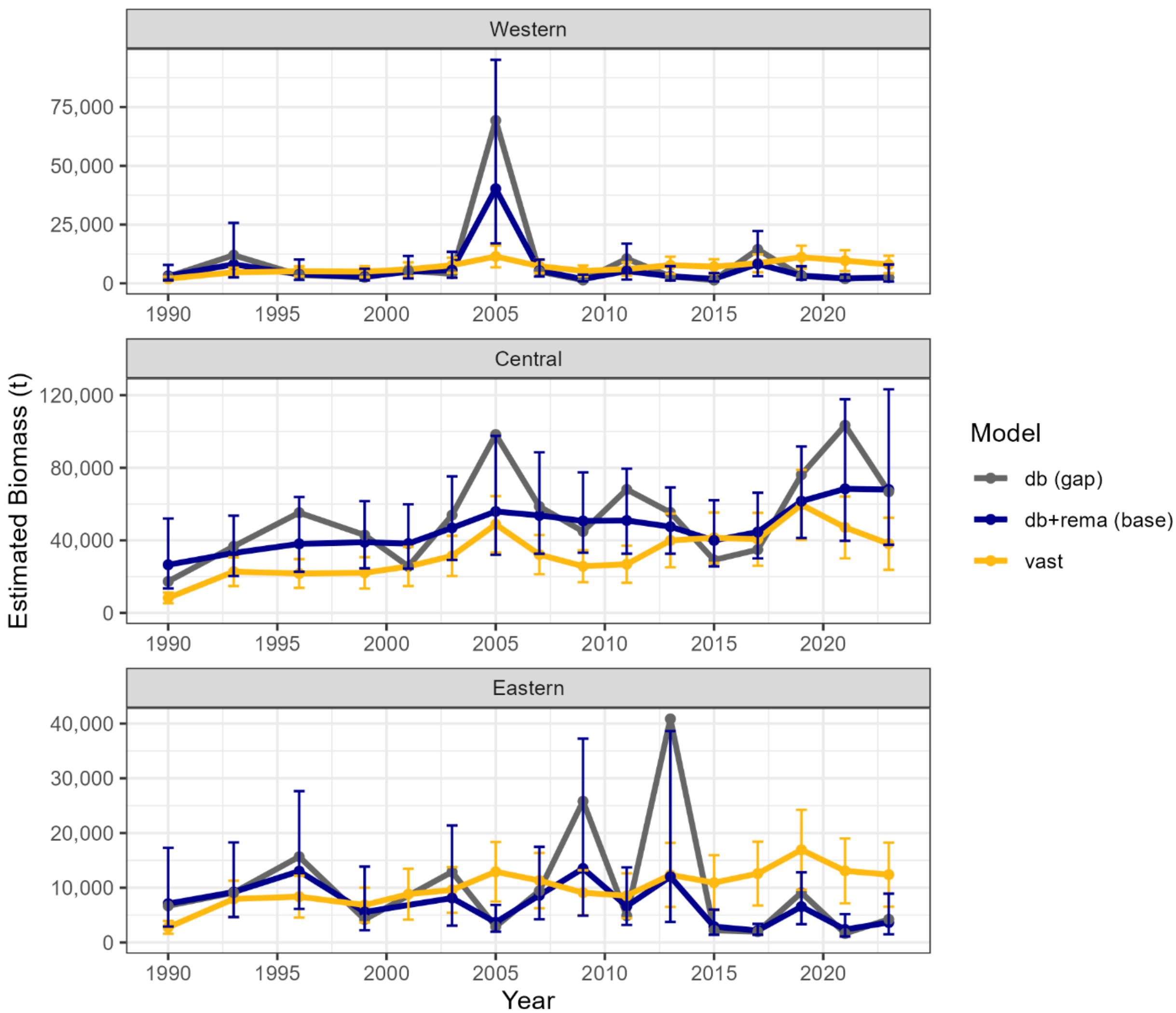

Figure 4. GOA dusky indices of abundance for each management area from the two model types, design-based model smoothed by REMA (db+rema) and VAST, with the associated uncertainty. Biomass point estimates from the Groundfish Assessment Program design-based model (df (gap)) are overlaid on each panel for comparison.

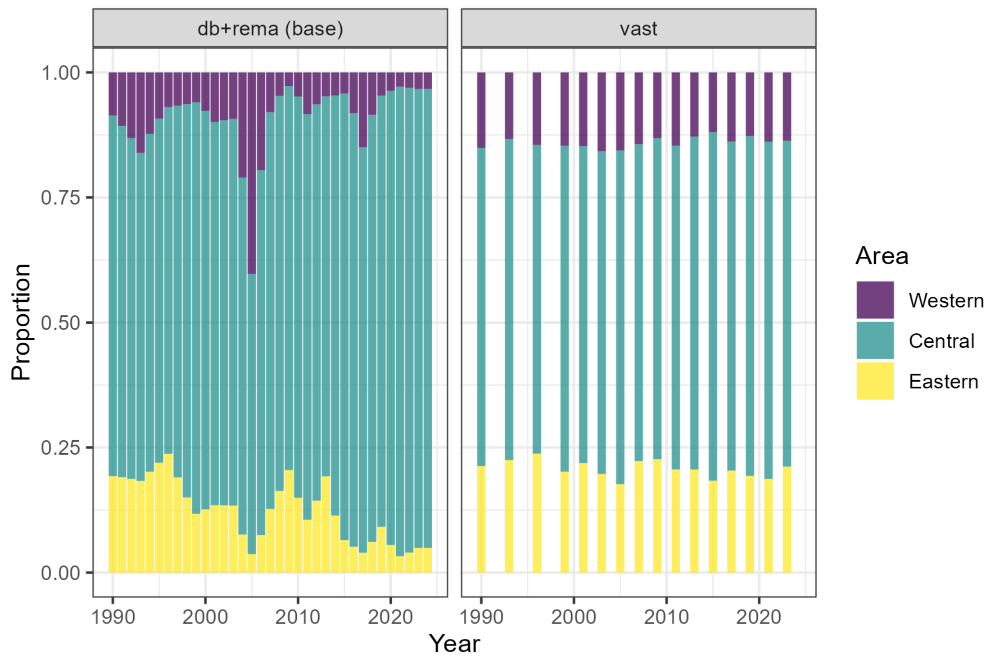

Figure 5. Proportion of biomass in each Gulf of Alaska (GOA) management area, Western, Central, and Eastern, based on the two model types, currently accepted design-based model smoothed by REMA (db+rema) and the alternative design-based VAST model.

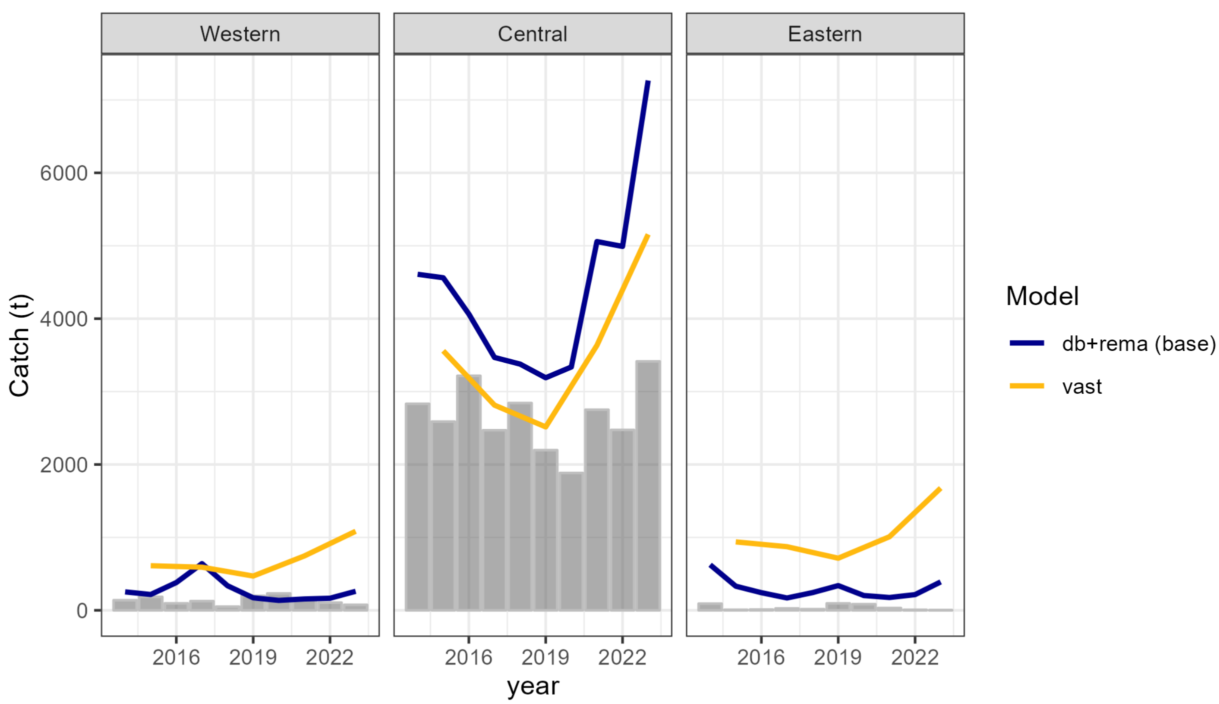

Figure 6. Historical projection of ABC allocated to each management area based on the proportions from each model types (accepted design-based, REMA model and alternative VAST model) with total fisheries catch for GOA dusky rockfish. Note: the allocation of ABC to the Eastern GOA is further divided into West Yakutat and Southeast and does not represent current management spatial areas. This panel is for visual purposes only.