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

Benjamin C. Williams, Peter-John F. Hulson, Chris R Lunsford, and and Bridget Ferriss

November 2022

## Executive Summary

The GOA dusky rockfish is classified as a Tier 3 stock and is assessed using a statistical age-structure model. 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 includes total catch biomass, fishery age and size compositions, trawl survey abundance estimates, and trawl survey age compositions. For Gulf of Alaska dusky rockfish in 2022 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

Relative to the last full assessment the following substantive changes have been made to assessment inputs:

- include survey biomass estimates for 2021,
- update survey age compositions with 2021 data,
- update fishery age compositions with 2020 data,
- update fishery size compositions with 2021 data, and
- final catch values for 2020 and 2021, and use preliminary catch for 2022.

The survey biomass estimate is based upon the Groundfish Assessment Program's (GAP) Vector Autoregressive Spatio-temporal (VAST) model for the GOA. The VAST model input deviates slightly from the GAP default settings in that a lognormal error distribution was implemented instead of the gamma distribution (described in more detail in the *Description of Alternative Models* section below). In the last few assessments survey biomass from 1984 and 1987 have been included in the survey biomass estimate (though not in the compositional data), however those surveys used different vessels and gear and are not directly comparable to survey data from 1990+. Therefore they have been excluded from this assessment going forward.

### Summary of Changes in Assessment Methodology

The following model changes are recommended in the current assessment: extend the age plus group from age-25 to age-30, and extend the length plus group from 47 cm to 52 cm.

### Summary of Results

A suite of incremental models were run to investigate the effects of removing 1980s survey data from the assessment, and increasing both the length and age plus groups.

| Model | Description |
|---|---|
| base | 2020 model (m15.5a) and results (includes 1980s survey data) |
| m15.5a | base model w/data updated through 2022, using GAP default VAST |
| m22 | m15.5a using GAP default VAST (survey data 1990+) |
| m22.1 | m22 w/increased length plus group |
| m22.2 | m22 w/increased age plus group |
| m22.3 | m22 w/increased age & length plus groups |
| m22a | m22 using lognormal error VAST (survey data 1990+) |
| m22.1a | m22a w/increased length plus group |
| m22.2a | m22a w/increased age plus group |
| m22.3a | m22a w/increased age & length plus groups |
| m22b | m22 using design-based survey abundance (1990+) |
| m22.1b | m22b w/increased length plus group |
| m22.2b | m22b w/increased age plus group |
| m22.3b | m22b w/increased age & length plus groups |

The author's preferred model is m22.3a, which is the 2020 model with updated data through 2022 and increased age and length plus groups, using a VAST model-based index of survey abundance with lognormal error. This model generally produces good visual fits to the data and biologically reasonable patterns of recruitment, abundance, and selectivity, and substantially decreases the retrospective Mohn's rho value.

The m22.3a projected age 4+ total biomass for 2023 is 107,160 t. The recommended ABC for 2023 is 7,917 t, the maximum allowable ABC under Tier 3a. This ABC is a 47% increase compared to the 2022 ABC of 5,372 t and a 53% increase from the projected 2023 ABC from last year. However, the past two years the ABC has been on a "stairstep" incremental increase to adjust for the substantially increased abundance when changing to the VAST model for trawl survey biomass in 2020. Comparisons of *max*ABC also increase from 2021 to 2022 though to a lesser extent than the "stairstep" ABC.

The 2023 GOA-wide OFL for dusky rockfish is 9,638 t. Comparisons based upon using *max*ABC would be a 12% increase compared to the 2022 *max*ABC and a 18% increase from the projected *max*ABC. The 2023 GOA-wide OFL for dusky rockfish is 9,638 t. 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** | 2022 | 2023 | 2023* | 2024* |
| M (natural mortality) | 0.07 | 0.07 | 0.07 | 0.07 |
| Tier | 3a | 3a | 3a | 3a |
| Projected total (age 4+) biomass (t) | 95,682 | 92,310 | 107,160 | 104,627 |
| Projected female spawning biomas (t) | 38,371 | 36,853 | 44,651 | 44,651 |
| $B_{100\%}$ | 60,855 | 60,855 | 65,565 | 65,565 |
| $B_{40\%}$ | 24,342 | 24,342 | 26,226 | 26,226 |
| $B_{35\%}$ | 21,299 | 21,299 | 22,948 | 22,948 |
| $F_{OFL}$ | 0.114 | 0.114 | 0.11 | 0.11 |
| *max*$F_{ABC}$ | 0.093 | 0.093 | 0.09 | 0.09 |
| $F_{ABC}$ | 0.093 | 0.093 | 0.09 | 0.09 |
| OFL (t) | 8,614 | 8,146 | **9,638** | 9,154 |
| *max*ABC (t) | 7,069 | 6,686 | 7,917 | 7,520 |
| ABC (t) | 5,372 | 5,181 | **7,917** | 7,520 |
| | As determined *last* year for: | | As determined *this* year for: | |
| **Status** | 2021 | 2022 | 2022 | 2023 |
| 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 2,644 t for 2022 and estimates of 4,787 t and 4,391 t used in place of maximum permissible ABC for 2023 and 2024.

## Area Apportionment

The following table shows the recommended ABC apportionment for 2023 and 2024. Apportionments have continued to increase in the Central GOA with reduced apportionment in the Eastern and Western GOA. Please refer to the *Area Allocation of Harvests* section of this assessment for information regarding the apportionment rationale for GOA dusky rockfish. The overall allocation has been compressed into the Central GOA due to survey catches in 2021.

| | | Western | Central | Eastern | Total |
|---|---|---|---|---|---|
| Year | Area Apportionment | 1.9% | 96.6% | 1.5% | 100% |
| 2023 | ABC (t) | 149 | 7,647 | 121 | 7,917 |
| 2023 | OFL (t) | | | | 9,638 |
| 2024 | ABC (t) | 141 | 7,264 | 115 | 7,520 |
| 2024 | OFL (t) | | | | 9,154 |

Amendment 41 prohibited trawling in the Eastern area east of 140° W longitude. The ratio of biomass still obtainable in the W. Yakutat area (between 147° W and 140° W) is 0.74. This results in the following apportionment to the W. Yakutat area:

| | | W. Yakutat | E. Yakutat/Southeast |
|---|---|---|---|
| 2023 | ABC (t) | 90 | 31 |
| 2024 | ABC (t) | 85 | 30 |

## Responses to SSC and Plan Team Comments on Assessments in General

*"The SSC revised and clarified the recommendation to maintain the status quo and only produce risk tables for full assessments (rather than all assessments, as indicated in the subgroup recommendation)." (SSC, June 2021)*

A risk table has been included in this full assessment.

*"The Team recommends all GOA authors evaluate any bottom trawl survey information used in their assessment prior to 1990 including the 1984 and 1987 surveys and conduct sensitivity analyses to evaluate their usefulness to the assessment. This may apply for Aleutian Islands surveys but this was only raised during GOA assessment considerations." (PT, November 2021)*

In recent assessments survey biomass estimates from 1984 and 1987 (note that age and size compistion data were not included) have been included in the survey biomass estimate, however those surveys used different vessels and gear and are not directly comparable to survey data from 1990+. A suite of incremental models were run to investigate the effects of removing 1980s survey data from the assessment. Therefore they have been excluded from this assessment going forward.

## Responses to SSC and Plan Team Comments Specific to this Assessment

*"The SSC has also requested diagnostics to evaluate VAST model fit and suggests the author frame the discussion of these diagnostics in a species-specific manner, including consideration of the life history of the species. For example, the use of the delta-gamma observation model would seem to be appropriate for a species with patchy survey distribution. However, the implementation of this VAST-GAP recommendation resulted in a large increase in the interannual variability of the VAST survey estimates, which the SSC notes may be biologically implausible for a long-lived species such as dusky rockfish. The SSC also supports the GOA GPT recommendation to further explore the number of knots that are optimal for this species. Finally, the SSC requests that design-based estimates of survey biomass be included in comparisons with VAST model estimates.*

*The SSC requests the assessment author justify the use of the new parameterization of VAST specifically as it relates to dusky rockfish. Past SSC discussions regarding the general implementation of VAST in assessments precluded a highly prescriptive approach and specifically recommended allowing for some species-specific adaptations of the VAST framework (October 2020)*

A suite of VAST parameterizations, associated diagnostics and design-based survey estimates have been explored and are provided as an appendix. The author's recommended model uses a lognormal error model instead of the GAP default model.

*The SSC registers concern with the large positive retrospective pattern in the recommended model and suggests that further investigation of this be a very high priority. (January 2020)*

Issues with the retrospective pattern are addressed with the author's recommended model, changing the Mohn's rho value from 0.51 to -0.123.

# Introduction

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

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

## Biology and Distribution

Parturition is believed to occur in the spring, based on observation of ripe females sampled on a research cruise in April 2001 in the Central GOA. Similar to all other species of Sebastes, dusky rockfish are ovoviviparous with fertilization, embryonic development, and larval hatching occurring inside the mother. After extrusion, larvae are pelagic, but larval studies are hindered because they can only be positively identified by genetic analysis. Post-larval dusky rockfish have not been identified; however, the post-larval stage for other Sebastes is pelagic, so it is also likely to be pelagic for dusky rockfish. The habitat of young juveniles is completely unknown. At some point they are assumed to migrate to the bottom and take up a demersal existence; juveniles less than 25 cm fork length are infrequently caught in bottom trawl surveys (Clausen and Heifetz 2002) or with other sampling gear. Older juveniles have been taken

---

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

only infrequently in trawl surveys, but when caught are often found at more inshore and shallower locations that adults. Laman *et al.* (2015) found juvenile Pacific ocean perch (*S. alutus*) utilize the vertical habitat that biogenic structures provide in otherwise low-relief, trawlable habitats, indicating these biogenic structures may represent refugia to juvenile rockfish. The major prey of adult dusky rockfish appears to be euphausiids, based on the limited food information available for this species (Yang 1993). In a more recent study, Yang *et al.* (2006) found that Pacific sand lance along with euphausiids were the most common prey item of dusky rockfish, comprising 82% and 17% , respectively, of total stomach contents by weight.

The evolutionary strategy of spreading reproductive output over many years is a way of ensuring some reproductive success through long periods of poor larval survival (Leaman and Beamish 1984). Fishing generally selectively removes the older and faster-growing portion of the population. If there is a distinct evolutionary advantage of retaining the oldest fish in the population, either because of higher fecundity or because of different spawning times, age-truncation could be deleterious to a population with highly episodic recruitment like rockfish (Longhurst 2002). Work on black rockfish (*S. melanops*) has shown that larval survival may be dramatically higher from older female spawners (Berkeley *et al.* 2004; Bobko and Berkeley 2004). Bruin *et al.* (2004) examined Pacific ocean perch and rougheye rockfish (*S. aleutianus*) for senescence in reproductive activity of older fish and found that oogenesis continues at advanced ages. Leaman (1991) showed that older individuals have slightly higher egg dry weight than their middle-aged counterparts. Such relationships have not yet been determined to exist for dusky rockfish in Alaska but maternal age effects on reproduction are an important consideration for assessing population status. Some literature suggests that environmental factors may affect the condition of female rockfish that contribute to reproductive success (Hannah and Parker 2007; Rodgveller *et al.* 2012; Beyer *et al.* 2015). Abortive maturation has been observed for 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 to the 2012 assessment document. In summary, available data suggests lack of significant stock structure, therefore the current resolution of spatial management is likely adequate and consistent with management goals (Lunsford *et al.* 2012). It is evident from this evaluation that life history focused research is warranted and will help in evaluating dusky rockfish stock structure in the GOA.

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

# Fishery

## 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, especially the “W” grounds west of Yakutat, Portlock Bank northeast of Kodiak

Island, and around Albatross Bank south of Kodiak Island. Highest catch-per-unit-effort in the commercial fishery is generally at depths of 100-149 m (Reuter 1999). During the period 1988-95, almost all the catch of dusky rockfish (>95%) was taken by large factory trawlers that processed the fish at sea. This changed starting in 1996, when smaller shore-based trawlers also began taking a sizeable portion of the catch in the Central GOA area for delivery to processing plants in Kodiak.

The Rockfish Program in the Central GOA initiated in 2007 allocated the rockfish quota by sector so the percentage of 2007-present catches by shore-based catcher vessels differs in comparison to previous years. One benefit realized from the Rockfish Program is increased observer coverage and sampled catch for trips that target dusky rockfish (Lunsford *et al.* 2009). Since the majority of dusky rockfish catch comes from the Central GOA, the effects of the Rockfish Program has implications on the spatial distribution of dusky rockfish catch. In a study on localized depletion of Alaskan rockfish, Hanselman *et al.* (2007b) found that dusky rockfish were rarely depleted in areas 5,000-10,000 $km^2$, except during 1994 in one area known as the "Snakehead" outside Kodiak Island in the GOA. This area was heavily fished for northern (*S. polyspinis*) and dusky rockfish in the 1990s and both fishery and survey catch-per-unit-effort have consistently declined in this area since 1994. Comparison of spatial distribution of the dusky rockfish catch before and after the Rockfish Program began did not show major changes in catch distribution (Lunsford *et al.* 2013). Interpreting this data is confounded, however, as it's unclear if results are attributable to changes in effort or observer coverage. To further complicate data interpretation, in 2013 the North Pacific Groundfish and Halibut Observer Program was restructured with the objective to create a more rigorous scientific method for deploying observers onto more vessels in Federal fisheries. Because many of the vessels targeting rockfish fall in the partial coverage category, we expect this restructuring effort will change the extent of data collected from the rockfish fishery and data should be monitored.

### Catch Patterns

Catch reconstruction for dusky rockfish is difficult because in past years dusky rockfish were managed as part of the pelagic shelf rockfish assemblage (Table 12-1). Fishery catch statistics specific to dusky rockfish in the Gulf of Alaska are available for the years 1977–2022 (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 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. This is largely due to in-season management regulations which close the rockfish fishery to ensure other species such as Pacific ocean perch do not exceed TAC, or to prevent excess bycatch of Pacific halibut (*Hippoglossus stenolepis*).

In response to Annual Catch Limit (ACL) requirements, assessments now document all removals including catch that is not associated with a directed fishery and reported in the Catch Accounting System. These types of removals may include sport fishery harvest, research catches, or subsistence catch. Research catches of pelagic shelf rockfish have been reported in previous stock assessments (Lunsford *et al.* 2009). For this year, estimates of all removals through 2021 not associated with a directed fishery including research catches are available and are presented in Appendix 12.A. In summary, research removals have typically been less than 20 t and some harvest occurs in the recreational fishery. These levels likely do not pose a significant risk to the dusky rockfish stock in the GOA.

**Bycatch and Discards**

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

Total FMP groundfish catch estimates in the GOA rockfish fishery from 2018–2022 are shown in Table 12-3. As an average for the GOA rockfish fishery during 2018-2022, the largest non-rockfish bycatch groups are arrowtooth flounder, sablefish, atka mackerel and walleye pollock. Non-FMP species catch in the rockfish target fisheries is dominated by giant grenadier (*Albatrossia pectoralis*) and miscellaneous fish (Table 12-4). However, the amounts from dusky 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 2020 assessment the prohibited species catch observed in 2021 and 2022 increased for Chinook salmon and non-chinook salmon increased, and remained at similar levels for halibut (Table 12-5).

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

Gulf-wide discard rates (percent of the total catch discarded within management categories; Table-6) of dusky rockfish are show for 2000–2022. Rates have ranged from less than 1% to 7.6% the total dusky rockfish catch over time. 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. 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 (see Appendix 12B, Lunsford *et al.* 2011). Beginning in 2012, ABCs, TACs, and OFLs specific to dusky rockfish have been assigned.

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

In 2007 the Central GOA Rockfish Program was implemented to enhance resource conservation and improve economic efficiency for harvesters and processors who participate in the Central GOA rockfish fishery. This rationalization program establishes cooperatives among trawl vessels and processors which receive exclusive harvest privileges for rockfish species. The primary rockfish management groups are northern, Pacific ocean perch, and pelagic shelf rockfish (changed to dusky rockfish only in 2012). Potential effects of this program on the dusky rockfish fishery include: 1) Extended fishing season lasting from May 1 – November 15, 2) changes in spatial distribution of fishing effort within the Central GOA, 3) improved at-sea and plant observer coverage for vessels participating in the rockfish fishery, and 4) a higher potential to harvest 100% of the TAC in the Central GOA region. We continue to monitor available fishery data to help understand effects the Rockfish Project may have on the dusky rockfish stock in the Central GOA. Within the GOA, separate ABCs and TACs for dusky rockfish are assigned to smaller geographical areas that correspond to NMFS management areas. These include the Western GOA, Central GOA, and Eastern GOA (comprised of West Yakutat, and East Yakutat/Southeast Outside sub-areas). OFLs for dusky rockfish are defined on a GOA-wide basis. A summary of key management measures, a time series of catch, ABC, and TAC are provided in Table 12-1.

# Data

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

| Source | Data | Years |
|---|---|---|
| NMFS Groundfish survey | Survey biomass | 1990-1999 (triennial), 2001-2019 (biennial), **2021** |
| | Age composition | 1990-1999 (triennial), 2003-2019 (biennial), **2021** |
| U.S. trawl fishery | Catch | 1961-2020, **2021-2022** |
| | Age composition | 1998-2002, 2004-2006, 2008-2018 (biennial), **2020** |
| | Length composition | 1991-1997, 2003, 2007-2019 (biennial), **2021** |

# 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 2022 (Table 12-2, Figure 12-1) and range from 17 t in 1986 to 4,535 t in 1999. 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 2000–2020 samples (Table 12-7). Table 12-7 depicts the raw age distribution of the samples without further analysis to estimate a more comprehensive age composition. However, the samples were randomly collected from fish in over 100 hauls that had large catches of dusky rockfish, therefore 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 and 2020. Several large and relatively steady year classes are evident through the time series including 1986, 1992, 1995, and 1999 (Figure 12-6).

Length frequency data for dusky rockfish in the commercial fishery are available for the years 1991-2021 but are only used in the model when age compositions are not expected to be available for that year (Table 12-8). These data are the raw length frequencies for all dusky rockfish measured by observers in a given year. Generally, these lengths were taken from hauls in which dusky rockfish were either the target or a dominant species, and they provide an indication of the trend in size composition for the fishery. The relatively small sample sizes in 1995 and 1996 should be treated with caution as all years, though they are included in these analyses. Size of fish taken by the fishery generally appears to generally be consistent with a mode centered on 45 cm. Fish smaller than 40 cm are seen in moderate numbers in certain years (1991-92, 1997, and 2017-2021, Figure 12-3), 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 labeled as dusky and dark rockfish. Each of these surveys has shown that dusky rockfish (light dusky) overwhelmingly predominate and that dark rockfish (dark dusky) are caught in 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 2017, 2019, and 2021 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. In the 2021 survey, catches of dusky rockfish were highest in the central GOA, with substantially lower catches observed in the western and eastern GOA.

Trawl survey abundance presented here uses geostatistical model-based estimates (VAST model) with a lognormal error distribution (Table 12-9; Figure 12-5), though trawl survey biomass from a design-based estimator is also presented per SSC request (Table 12-10).

**Age and Size Composition**

Age

Gulf-wide age composition data for dusky rockfish are available for the 1990 through 2021 trawl surveys (Table 12-11). The mode of the age data has recently decreased age-15 in 2015 and to age-10/11 in 2017-2021. 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 12-2). Because rockfish are difficult to age, especially as the fish grow older, one possibility is that some of the fish aged-12 in 1999 were actually age 13 (members of the 1986 year class), which would agree more with the 1993 and 1996 age results. Little recruitment occurred in the years following until the 1992 and 1995 year classes appeared. The only prominent year class until the most recent survey was the 1998 year class, which had the highest proportion of ages sampled in the 2013 survey. In 2019, there appears to be some evidence for a potentially stronger year classes in approximately 2010, though this is less clear in the 2021 survey data.

Size

Gulf-wide survey size compositions are available for 1990-2021 (Table 12-12; 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 conversion matrix and in estimating the population age composition, but are not used as an additional compositional time series because survey ages are available from those same years.

**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 in Box 1.

**BOX 1. AD Model Builder Model Description**

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

**BOX 1 (Continued)**

Equations describing the observed data

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

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

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

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

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

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

Equations describing population dynamics

Start year

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

Number at age of recruitment
Number at ages between recruitment and pooled age class
Number in pooled age class

Subsequent years

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

Number at age of recruitment
Number at ages between recruitment and pooled age class
Number in pooled age class

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

$$L_1 = \lambda_1 \sum_y \left( \ln \left[ \frac{C_y + 0.01}{\hat{C}_y + 0.01} \right] \right)^2$$
Catch likelihood

$$L_2 = \lambda_2 \sum_y \frac{\left( I_y - \hat{I}_y \right)^2}{2 * \hat{\sigma}^2 \left( I_y \right)}$$
Survey biomass index likelihood

$$L_3 = \lambda_3 \sum_{styr}^{endyr} -n^*{}_y \sum_a^{a+} \left( P_{y,a} + 0.001 \right) * \ln \left( \hat{P}_{y,a} + 0.001 \right)$$
Fishery age composition likelihood

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

$$L_5 = \lambda_5 \sum_{styr}^{endyr} -n^*{}_y \sum_a^{a+} \left( P_{y,a} + 0.001 \right) * \ln \left( \hat{P}_{y,a} + 0.001 \right)$$
Survey age composition likelihood

$$L_6 = \lambda_6 \sum_{styr}^{endyr} -n^*{}_y \sum_l^{l+} \left( P_{y,l} + 0.001 \right) * \ln \left( \hat{P}_{y,l} + 0.001 \right)$$
Survey size composition likelihood

$$L_7 = \frac{1}{2\sigma_q^2} \left( \ln \frac{q}{q_{prior}} \right)^2$$
Penalty on deviation from prior distribution of catchability coefficient

$$L_8 = \frac{1}{2\sigma_{\sigma_r}^2} \left( \ln \frac{\sigma_r}{\sigma_{r(prior)}} \right)^2$$
Penalty on deviation from prior distribution of recruitment deviations

$$L_9 = \lambda_9 \left[ \frac{1}{2 * \sigma_r^2} \sum_y \tau_y^2 + n_y * \ln \left( \sigma_r \right) \right]$$
Penalty on recruitment deviations

$$L_{10} = \lambda_{10} \sum_y \phi_y^2$$
Fishing mortality regularity penalty

$$L_{11} = \lambda_{11} \bar{s}^2$$
Average selectivity penalty (attempts to keep average selectivity near 1)

$$L_{12} = \lambda_{12} \sum_{a_0}^{a_+} \left( s_i - s_{i+1} \right)^2$$
Selectivity dome-shaped penalty – only penalizes when the next age's selectivity is lower than the previous (penalizes a downward selectivity curve at older ages)

$$L_{13} = \lambda_{13} \sum_{a_0}^{a_+} \left( FD(FD(s_i - s_{i+1})) \right)^2$$
Selectivity regularity penalty (penalizes large deviations from adjacent selectivity by adding the square of second differences)

$$L_{total} = \sum_{i=1}^{13} L_i$$
Total objective function value

## Description of Alternative Models

A suite of incremental models were run to investigate the effects of removing 1980s survey data from the assessment, and increasing both the length and age plus groups, the results of which can be found in Appendic 12c. For clarity the author's preferred model (m22.3a) and the base model (updated with 2022 data) are presented here. The author's preferred model is the base model with the 1980s survey data removed, with increased age and length plus groups and using a VAST model-based index of survey abundance with lognormal error. This model generally produces good visual fits to the data and biologically reasonable patterns of recruitment, abundance, and selectivity, and substantially decreases the retrospective Mohn's rho value.

## 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 1990-2021. The length-weight relationship for combined sexes, using the formula $W = aL^b$, where $W$ is weight in grams and $L$ is fork length in mm, $a$ = 8.12 x 10-6 and $b$ = 3.12.

A von Bertalanffy growth curve was fitted to survey size at age data from 1990-2021 using length-stratified methods (Quinn and Deriso 1999; Bettoli and Miranda 2001) for both sexes combined. An age to size conversion matrix was then constructed by adding normal error with a standard deviation equal to the survey data for the probability of different sizes for each age class. The estimated parameters for the growth curve from length-stratified methods were:

$L_\infty$= 55.004, $\kappa$ = 0.124, $t_0$ = -0.072

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:

$W_\infty$= 1962 g, $\kappa$ = 0.185, $t_0$ = 0.556, $b$ = 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 trawl survey of 59 this estimate is 0.08. The highest recorded age in the fishery ages was 76, which equates to a Hoenig estimate of 0.06. The current natural mortality estimate used in this assessment (0.07) is comparable to other similarly aged rockfish in the GOA.

## Parameters Estimated Inside the Assessment Model

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

The fit to the combined observations of maturity-at-age obtained in the preferred assessment model is shown in Figure 12-9. 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 10.3. Using the parameters from the von Bertalanffy growth model the size at 50% maturity is 40.6 cm. Other parameters estimated conditionally in the current model include, but are not limited to: logistic parameters for selectivity for both the survey and fishery, mean recruitment, fishing mortality, spawner-per-recruit levels, and logistic parameters for maturity. The numbers of estimated parameters are shown below. Other derived variables are described in the *General Model Structure* section.

| Parameter | Symbol | Number |
|---|---|---|
| Catchability | $q$ | 1 |
| Log mean recruitment | $\mu_r$ | 1 |
| Recruitment variability | $\sigma_r$ | 1 |
| Spawners per recruit levels | $F_{35\%}, F_{40\%}, F_{50\%}$ | 3 |
| Recruitment deviations | $\tau_y$ | 74 |
| Average fishing mortality | $\mu_f$ | 1 |
| Fishing mortality deviations | $\phi_y$ | 46 |
| 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 | | 133 |

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

# Results

## Model Evaluation

The author’s preferred model is model m22.3a. A subset of examined models are described here, a description of all intermediate model outputs is available in Appendix 12c. The models described here are:

| Model | Description |
|---|---|
| base | 2020 model (m15.5a) and results (includes 1980s survey data) |
| m15.5a | base model w/data updated through 2022, using GAP default VAST |
| m22 | m15.5a using GAP default VAST (survey data 1990+) |
| m22.3a | m22 w/increased age & length plus groups |
| m22b | m22 using design-based survey abundance (1990+) |

When we present alternative model configurations, our usual criteria for choosing a superior model are: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, catchabilities, and selectivities, (3) a good visual fit to length and age compositions, and (4) parsimony. We've presented results for multiple models because the 2020 and 2022 models differ in either the VAST parameterization for index production or the age and length plus group. The design-based model (m22b) is presented per SSC request. Note that there was little to no difference in biomass estimates from iterative model changes using a design-based trawl survey biomass (Appendix 12c). Model m22.3a produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. Therefore, the recommended 2022 model is utilizing the new information effectively, and we use it to recommend the 2023 ABC and OFL.

## Time Series Results

Key results have been summarized in Tables 12-13 – 12-16. In general, model predictions continue to fit the data well (Figures 12-1, 12-5, 12-6, 12-2, 12-3).

*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.

*Biomass and Exploitation Trends*
The estimates of current population abundance indicate that it is dominated by fish from the 1993 and 1998 year-classes (Table 12-14). The predicted survey biomass generally captures the trend in observed (VAST geospatial model) survey biomass similarly for the preferred and bridge models (Figure12-10 and Figure 12-5), but without matching the interannual variability that is present in observed values. The 2021 observed survey values are greater than the predicted model estimates for all models presented, indicating that the assessment model is tempering the observed increase in variability based on age compositional data. However, the model predicted survey biomass estimates for VAST models are quite similar with only the design-based survey estimator producing different results. Spawning biomass estimates are at a timeseries high (11). Total age-4+ biomass estimates for all model using VAST survey inputs indicate a steadily increasing trend with a peak around 2016.

The estimated selectivity curve for the fishery and survey data suggested a pattern similar to previous assessments for dusky rockfish (Figure 12-9). The commercial fishery targets larger and subsequently older fish and the survey should sample a larger range of ages. Ninety-five percent of dusky rockfish are selected survey by age 10. The age at 50% selection is 8.7 for the survey and 10.3 for the fishery.

The fully-selected fishing mortality time series indicates a rise in fishing mortality from late 1980's through the late 1990's and has been relatively stable from 2003-2022. Since 2003 fully-selected fishing mortality has ranged between 0.03 and 0.06 (Figure 12-12), and the exploitation rate has been generally around the long-term average (Figure 12-13). 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 we plot the ratio of fishing mortality to $F_{OFL}$ ($F_{35\%}$) and the estimated spawning biomass relative to $B_{35\%}$. Harvest control rules based on $F_{35\%}$ and $F_{40\%}$ and the Tier 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. In recent years, dusky rockfish have been above $B_{40\%}$ and below $F_{40\%}$ (Figure 12-14).

*Recruitment*
There is some lack of fit to the fishery size compositions for 1991-1999 (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. The fishery size composition fits from 2007+ are generally good. In general, the model fits the fishery age compositions well (Figure 12-6). Increasing the plus age group to age-30 provides more resolution in the age composition data, while mainatianing similar overall fits to the composition data. The strong year classes from 1992 and 1995 have largely moved into the plus age group (Tables 12-15 and 12-16). The 2018 age data suggest that there is a large pulse of age 11 fish (with ages 10 and 12 also high) observed in the compositional data and continues to be observed in the 2020 data.

The survey age compositions also track the 1992 year class well and try to fit the 1995 year class, which appeared consistently strong in surveys through 2013 (Figure 12-2); in 2015 the model predicted a smaller proportion of fish to be in the plus age group than what was observed in the survey. Similar to the fishery age compositions, the survey age compositions show an increase in proportions of fish aged 11 and 12 in the 2019 and 2021 data.

Recruitment estimates show several above average events in the 1990s through early 2000s, and a large recruitment in 2014 (Figure 12-15). This high recruitment value has relatively high uncertainty, which is likely due to age composition data indicating higher proportions of ages 10-12 fish, instead of a single age class. In general, recruitment (age-4) is highly variable throughout the time series, particularly the most recent years, where typically very little information is known about the strength of incoming year classes. There also does not seem to be a clear spawner-recruit relationship for dusky rockfish as recruitment appears unrelated to spawning stock biomass (Figure 12-8). MCMC credible intervals for recruitment are fairly narrow in some years; however, the credible intervals nearly contain zero for many years which indicates considerable uncertainty, particularly for the most recent years (Figure 12-15).

*Retrospective analysis*
From the MCMC chains described in the *Uncertainty approach* section, we summarize the posterior densities of key parameters for the recommended model using histograms (Figure 12-16) and credible intervals (Table 12-17). We also use these posterior distributions to show uncertainty around time series estimates such as total biomass, recruitment, and spawning biomass (Figures 12-17, 12-15, 12-18).

Table 12-17 shows the maximum likelihood estimate (MLE) of key parameters with their corresponding standard deviations derived from the Hessian matrix compared to the standard deviations derived from MCMC methods. The Hessian and MCMC standard deviations are larger for the estimates of $q$, $F_{40\%}$, ABC, and female spawning biomass. These larger standard deviations indicate that these parameters are more uncertain than indicated by the standard estimates. However, all estimates fall within the Bayesian credible intervals.

A within-model retrospective analysis of the recommended model was conducted for the last 10 years of the time-series by dropping data one year at a time. The revised Mohn's "rho" statistic (Hanselman *et al.* 2013) in female spawning biomass was -0.123, an improvement from 0.51 in the previous model) indicating that the model increases the estimate of female spawning biomass in recent years as data is added to the assessment. The retrospective female spawning biomass and the relative difference in female spawning biomass from the model in the terminal year are shown in Figures 12-20 and 12-21 (with 95% credible intervals from MCMC).

# Harvest recommendations

### Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL ($F_{OFL}$), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC ($F_{ABC}$) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, dusky rockfish in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$,,equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. Estimation of the $B_{40\%}$ reference point requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the average of age-2 recruitments between 1979 and 2020. Because of uncertainty in very recent recruitment estimates, we lag 2 years behind model estimates in our projection. Other useful biomass reference points which can be calculated using this assumption are $B_{100\%}$ and $B_{35\%}$, defined analogously to $B_{40\%}$. The 2022 estimates of these reference points are:

| $B_{100\%}$ | $B_{40\%}$ | $B_{35\%}$ | $F_{40\%}$ | $F_{35\%}$ |
|---|---|---|---|---|
| 65,565 | 26,226 | 22,948 | 0.11 | 0.09 |

### Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2022 is estimated at 44,651 t. This is above the $B_{40\%}$ value of 26,226 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 2022, yields the following ABC and OFL:

| ABC | OFL |
|---|---|
| 7,917 | 9,638 |

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 2022 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2023 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2022. 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 drawnfrom 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 2022 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 2023, are as follow ("$maxF_{ABC}$" 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 2022 and 2023, *F* is set equal to a constant fraction of $maxF_{ABC}$, where this fraction is equal to the ratio of the realized catches in 2019-2021 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 2017-2021 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 2022 or 2) above ½ of its MSY level in 2022 and above its MSY level in 2032 under this scenario, then the stock is not overfished.)
- Scenario 7: In 2023 and 2024, *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 2024 or 2) above 1/2 of its MSY level in 2024 and expected to be above its MSY level in 2034 under this scenario, then the stock is not approaching an overfished condition.)

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios (Table 12-18). For projections in Scenario 2 (Author's *F*); we use pre-specified catches to increase accuracy of short-term projections in fisheries where the catch is usually less than the ABC. This was suggested to help management with setting preliminary ABCs and OFLs for two-year ahead specifications.

During the 2006 CIE review, it was suggested that projections should account for uncertainty in the entire assessment, not just recruitment from the endpoint of the assessment. We continue to present an alternative projection scenario using the uncertainty of the full assessment model harvesting at the same estimated yield ratio (0.67) as Scenario 2, except for all years instead of the next two. This projection propagates uncertainty throughout the entire assessment procedure and is based on an MCMC chain of 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 1981-2018 age-4 recruitments, and this projection predicts that the median spawning biomass will decrease quickly until average recruitment is attained.

## Risk Table and ABC recommendation

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The following template is used to complete the risk table:

| | ***Assessment-related considerations*** | ***Population dynamics considerations*** | ***Environmental/ecosystem considerations*** | ***Fishery Performance*** |
|---|---|---|---|---|
| Level 1: Normal | Typical to moderately increased uncertainty/minor unresolved issues in assessment. | Stock trends are typical for the stock; recent recruitment is within normal range. | No apparent environmental/ ecosystem concerns | No apparent fishery/resource-use performance and/or behavior concerns |
| Level 2: Substantially increased concerns | Substantially increased assessment uncertainty/ unresolved issues. | Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical. | Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators. | Some indicators showing adverse signals but the pattern is not consistent across all indicators |
| Level 3: Major Concern | Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias. | Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns. | Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock) | Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types |
| Level 4: Extreme concern | Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable. | Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns. | Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components | Extreme anomalies in multiple performance indicators that are highly likely to impact the stock |

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

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

<u>Assessment considerations</u>

Level 2. The GOA trawl survey was conducted in 2021 as expected, and fishery and survey age and length composition data have been incorporated with the expected range of data made available on time for incorporation into the 2020 stock assessment. The assessment model produces reasonable fits to the survey abundance index and compositional data, but the model results are sensitive to the VAST biomass index and the additional year of survey data. The low variance of the VAST model configuration compared to uncertainty from the design-based methods, coupled with high 2021 survey biomass estimate has resulted in continued high levels of total and spawning biomass. In addition, all VAST configurations examined result in increased biomass and ABC estimates relative to design-based abundance inputs. It is worth noting that catch has not similarly increased. Because of the sensitivity of the assessment model to the scale of the VAST model biomass estimates, as well as the low uncertainty from this method, we recommend a level 2 concern for assessment considerations.

<u>Population dynamics considerations</u>

Level 2. There is a continued increase in estimated survey biomass for dusky rockfish when using VAST inputs of abundance in the assessment. Fishery and survey age compositions for the most recent year are both relatively uniformly distributed across ages with some increased proportions of 8-11 year old fish over the previous compositions. The assessment model estimates a high age-4 recruitment for 2010 and these recruits would be 13 years old in 2019. This lines up somewhat imperfectly with both the observed age compositions for the fishery and survey which show a higher proportion age 11 fish in 2018 (fishery) and age 11 and 12 fish in 2019 (survey). Rockfish aging is challenging, and some smearing across ages is expected. 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.
For these reasons we have given this risk table factor a level 2 concern for population dynamics considerations though make no recommendation for a reduction in ABC.

<u>Environmental/Ecosystem considerations</u>

Level 1. Environmental mechanisms for changes in survival and productivity of dusky rockfish remain unknown, though changes in water temperature and currents could have effects on prey abundance and success of transition of rockfish from pelagic to demersal stage. 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. However, given the continued lack of biological and habitat information for dusky rockfish, we scored this category as Level 1, as the level of concern has not changed.

Fishery performance

Level 1. Catches are well below ABC for 2022, which matches the historical trend of the fishery catch rarely approaching ABC (Table 12-2). Dusky rockfish are caught with a number of other rockfish species, so TAC levels for Pacific Ocean perch and northern rockfish, as well as prohibited species catch restrictions (i.e. salmon) can also affect fishery realization of the full TAC. In addition, dusky catches can be influenced by the price, and current prices are relatively low (J. Bonney, pers. Comm. Oct 2020). For these reasons we have given this risk table factor a ‘level 1, normal’ rank and do not suggest there is reason to suggest a reduction in ABC based on fishery performance considerations.

Summary and ABC recommendation

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

The GOA dusky rockfish assessment appears to fit available data well, the 2021 GOA trawl survey was undertaken as planned and data are included in this year’s assessment, and the fishery and environmental considerations appear to be within normal bounds. We have some concerns about the estimated increase in biomass and resulting increase in ABC. The VAST-based abundance index has low uncertainty which may be driving the estimated increase in biomass and ABC. Additionally, there are unknown levels of skip spawning withing this population, the implications of which are not fully understood, though any increase in skip spawning reduces the spawning population, and therefore ABC estimate. Because GOA dusky rockfish ABC is not historically fully utilized and because there is some evidence of recruitment from age compositions, we are not recommending a reduction in ABC at this time. We anticipate that we will monitor the survey abundance estimates, catch rates, and explore skip spawning more fully in the next assessment.

**Area Allocation of Harvests**

The random effects model was fit to the survey design-based biomass estimates (with associated variance) for the Western, Central, and Eastern GOA. The random effects model estimates a process error parameter (constraining the variability of the modeled estimates among years) and random effects parameters in each year modeled. The fit of the random effects model to survey biomass in each area is shown in (Figure 12-19). In general the random effects model fits the area-specific survey biomass reasonably well. Using the random effects model estimates of survey biomass, the apportionment results in 1.9% for the Western area, 96.6% for the Central area, and 1.5% for the Eastern area. The changes in apportionment in 2022 compared to 2020 can be attributed to a concentration in biomass from the bottom trawl survey biomass to the Central area. This results in recommended ABC’s of 149 t for the Western area, 7,647 t for the Central area, and 121 t for the Eastern area.

Because the Eastern area is divided into two management areas for dusky rockfish, i.e., the West Yakutat area (area between 147 degrees W. longitude and 140 degrees W. longitude) and the East Yakutat/Southeast Outside area (area east of 140 degrees W. longitude), the ABC for this management group in the Eastern area must be further apportioned between these two smaller areas. In an effort to balance uncertainty with associated costs to the fishing industry, the GOA Plan Team has recommended that apportionment to the two smaller areas in the Eastern GOA be based on the upper 95% confidence limit of the weighted average of the estimates of the Eastern GOA biomass proportion that is in the West Yakutat area. The upper 95% confidence interval of this proportion is 0.55, so that the dusky rockfish ABC for West Yakutat is 149 t, and the ABC for East Yakutat/Southeast Outside is 121 t. Based on the definitions for overfishing in Amendment 44 in Tier 3a (i.e., $F_{OFL} = F_{35\%} = 0.11$), the 2023 overfishing (OFL) is set equal to 9,638 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. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

*Is the stock being subjected to overfishing?* The official catch estimate for the most recent complete year (2021) is 2,928 t. This is less than the 2021 OFL of 3,676 t. Therefore, the stock is not being subjected to overfishing.

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

*Is the stock currently overfished?* This depends on the stock's estimated spawning biomass in 2022:

a. If spawning biomass for 2022 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2022 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2022 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 12-18). If the mean spawning biomass for 2034 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

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

a. If the mean spawning biomass for 2024 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2024 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2024 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2034 If the mean spawning biomass for 2034 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and projections in Table 12-18, the stock is not overfished and is not approaching an overfished condition. The fishing mortality that would have produced a catch for last year equal to last year's OFL is 0.0985.

# 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 (2021) GOA Ecosystem Status Report did not reveal strong evidence of declining trends in indicators which results in strong concern for dusky rockfish. 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; moreover, field-collected larval dusky rockfish at present cannot even be visually identified to species. Yang (1993) reported that adult dusky rockfish consume mostly euphausiids. Yang *et al.* (2006) reports Pacific sandlance *Ammodytes hexapterus* and euphausiids as the most common prey item of dusky rockfish with Pacific sandlance comprising 82% of stomach content weight. Euphausiids are also a major item in the diet of walleye pollock, Pacific ocean perch, and northern rockfish. Changes in the abundance of these three species could lead to a corollary change in the availability of euphausiids, which would then have an impact on dusky rockfish.

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

*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.

Body condition of dusky rockfish in 2021 improved from 2019 but continues a below average trend since 2015 (O’Leary *et al.* 2021). Zooplankton data are limited this year but appear average to above average, including large calanoid copepod biomass along the Seward Line in CGOA, and in Icy Strait, southeast Alaska (AFSC SECM survey, Fergusson 2022), and planktivorous seabird reproductive success. Euphausiids, a primary prey of adults, are above average in Icy Strait. Pacific sand lance, another key adult prey, was present in moderate amounts in seabird diets in CGOA, indicating availability.

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

2021 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, although with uncertainty as these surveys/fisheries are not designed to target these species Whitehouse and Gaichas (2021). By combining this fishery independent (AFSC survey) and fishery dependent (observer data) datasets, however, we can see a consistent trend rise above potential variability due to potential gear and effort changes (observer data) and the non-targeted sampling of both methods. A VAST model was run for gorgonian corals, pennatulaceans (e.g., sea pens), and sponges integrating and modeling trawls station densities across the Gulf of Alaska (Palsson 2021a). The coral abundance index is variable over time but the trend suggests low abundances resulting from the two most recent surveys (2019 and 2021) compared to most index values observed before 2017. The gulf-wide abundance of pennatulaceans shows an increasing trend from 1990 to 2005 and then a variable trend thereafter and a peak in 2017 followed by a decline in 2019. However, the 2021 index value increased from the 2019 value. The trend of sponges shows relative stability until 2015 followed by a continual 7 year decline in the GOA wide index through 2021 to a historic low value. The declines in sponges are driven by trends in western GOA. Sea anemones (not modeled in VAST) declined in Shumangins in 2019 and 2021, and Kodiak experienced a slight decline in 2021.

Thermal conditions for dusky rockfish are considered moderate in 2022, within the optimal range for growth and survival. Summer bottom thermal conditions in adult benthic habitat (100-200m) along the shelf edge was slightly above average in the western GOA (5.17°C at 250m Longline survey, Siwicke 2022). Temperatures at depth on the shelf were below average in the spring (5.4°C Seward Line Survey, Danielson and Hopcroft 2022), and above average in the summer (5.52°C Seward Line Survey, Danielson 2022). Younger pelagic stages of the rockfish experienced surface temperatures that were below average in the winter, transitioned from below average to above average in the spring Fergusson (2022), and above average in the summer across the GOA (Seward Line: 12.3°C).

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.[2] Also, dusky rockfish often co-occur and are caught with northern rockfish in the commercial fishery and in trawl surveys (Reuter 1999) and catches of northern rockfish have been associated with a rocky or rough bottom habitat (Clausen and Heifetz 2002). Based on this indirect evidence, it can be surmised that dusky rockfish are likely also associated with rocky substrates. An analysis of bycatch of HAPC biota in commercial fisheries in the Gulf of Alaska in 1997-99 indicated that the dusky rockfish trawl fishery ranked fourth among all

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

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 dusky rockfish trawl fishery in the GOA previously started in July and usually lasted only a few weeks. As mentioned previously in the fishery section, the fishery is concentrated at a number of offshore banks on the outer continental shelf. Beginning in 2007 the Rockfish Program began which allowed fishing in the Central GOA from May 1 – November 15. There is no published information on time of year of insemination or parturition (larval release), but insemination is likely in the fall or winter, and anecdotal observations indicate parturition is mostly in the spring. Hence, reproductive activities are probably not directly affected by the commercial fishery. However, there may be some interaction in the Central GOA if parturition is delayed until May 1. Fishery-specific effects on amount of large size target fish: a comparison between Table 12-3 (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 123 suggest that the fishery may catch some immature fish.

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

# Data Gaps and Research Priorities

## 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 manpower. Analysis of stock structure through the stock structure template illustrates the need for a large scale genetic study to investigate stock structure of dusky rockfish in the GOA. Habitat requirements for larval, post-larval, and early stage juvenile dusky rockfish are unknown. Habitat requirements for later stage juvenile and adult fish are anecdotal or conjectural. Research needs to be done to identify the HAPC biota on the bottom habitat of the major fishing grounds and what impact bottom trawling has on these biota.

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. 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.

# References

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

Berkeley, S.A., Hixon, M.A., Larson, R.J. and Love, M.S. (2004) Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries* 29, 23–32.

Bettoli, P.W. and Miranda, L.E. (2001) Cautionary note about estimating mean length at age with subsampled data. *North American Journal of Fisheries Management* 21, 425–428.

Beyer, S.G., Sogard, S.M., Harvey, C.J. and Field, J.C. (2015) Variability in rockfish (*sebastes* spp.) Fecundity: Species contrasts, maternal size effects, and spatial differences. *Environmental Biology of Fishes* 98, 81–100.

Bobko, S.J. and Berkeley, S.A. (2004) Maturity, ovarian cycle, fecundity, and age-specific parturition of black rockfish (*Sebastes melanops*). *Fishery Bulletin* 102, 418–419.

Bruin, J.-P. de, Gosden, R.G., Finch, C.E. and Leaman, B.M. (2004) Ovarian aging in two species of long-lived rockfish, *Sebastes aleutianus* and *S. alutus*. *Biology of Reproduction* 71, 1036–1042.

Carlson, H.R. and Straty, R.R. (1981) Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky, coastal areas of southeastern Alaska. *Marine Fisheries Review* 43.

Chilton, D.E. and Beamish, R.J. (1982) *Age determination methods for fishes studied by the groundfish program at the Pacific Biological Station*. Department of Fisheries and Oceans Ottawa, Canada.

Chilton, E.A. (2010) Maturity and growth of female dusky rockfish (*sebastes variabilis*) in the central Gulf of Alaska. *Fishery Bulletin* 108.

Clausen, D.M. and Heifetz, J. (2002) The northern rockfish, *Sebastes polyspinis*, in Alaska: commercial fishery, distribution, and biology. *Marine Fisheries Review* 64, 1–28.

Conrath, C.L. (2019) Reproductive potential of light dusky rockfish (*Sebastes variabilis*) and northern rockfish (*S. polyspinis*) in the Gulf of Alaska. *Fishery Bulletin* 117, 140–151.

Courtney, D.L., Heifetz, J., Sigler, M.F. and Clausen, D.M. (1999) An age structured model of northern rockfish, *Sebastes polyspinis*, recruitment and biomass in the Gulf of Alaska. *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 2000*, 361–404.

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, O'Connell V.M and R.D. Stanley). Alaska sea Grant, University of Alaska Fairbanks, pp 429–449.

Danielson, S and Hopcroft, R. (2022) Ocean temperature synthesis: Seward line May survey. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Du Preez, C. and Tunnicliffe, V. (2011) Shortspine thornyhead and rockfish (*Scorpaenidae*) distribution in response to substratum, biogenic structures and trawling. *Marine Ecology Progress Series* 425, 217–231.

Fergusson, E. (2022) Long-term trends in zooplankton densities in Icy Strait, Southeast Alaska. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Fournier, D.A., Skaug, H.J., Ancheta, 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.

Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (1995) *Bayesian data analysis*. Chapman; Hall/CRC.

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

Hannah, R.W. and Parker, S.J. (2007) Age-modulated variation in reproductive development of female Pacific Ocean Perch (*Sebastes alutus*) in waters off Oregon. In: *Biology, assessment, and management of North Pacific rockfishes.* (eds J. Heifetz, J. DiCosimo, A.J. Gharrett, M.S. Love, O'Connell V.M and R.D. Stanley). Alaska sea Grant, University of Alaska Fairbanks, pp 1–20.

Hanselman, D., Clark, B. and Sigler, M. (2013) Maturity estimates for Pacific ocean perch (*Sebastes alutus*), dusky (*S. ciliatus), northern (S. polyspinus*), rougheye (*S. aleutianus*), and blackspotted (*S. melanostictus*) rockfish. In: *Report submitted to the Gulf of Alaska Groundfish Plan Team*.

Hanselman, D., Heifetz, J., Fujioka, J., Shotwell, SK and J, I. (2007a) Pacific ocean perch. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Hanselman, D., Spencer, P., Shotwell, K. and Reuter, R. (2007b) Localized depletion of three Alaska rockfish species. In: *Biology, assessment, and management of North Pacific rockfishes.* (eds J. Heifetz, J. DiCosimo, A.J. Gharrett, M.S. Love, O'Connell V.M and R.D. Stanley). Alaska sea Grant, University of Alaska Fairbanks, pp 493–511.

Hoenig, J.M. (1983) Empirical use of longevity data to estimate mortality rates. *Fish. Bull.(Wash. DC)* 82, 898–903.

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

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

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

Leaman, B. and Beamish, R. (1984) Ecological and management implications of longevity in some northeast Pacific groundfishes. *International North Pacific Fisheries Commission Bulletin* 42, 85–97.

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

Lemagie, E. and Callahan, M. (2022) Ocean temperature synthesis: Satellite Data and Marine Heat Waves. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Longhurst, A. (2002) Murphy's law revisited: Longevity as a factor in recruitment to fish populations. *Fisheries Research* 56, 125–131.

Love, M.S., Carr, M.H. and Haldorson, L.J. (1991) The ecology of substrate-associated juveniles of the genus Sebastes. *Environmental Biology of Fishes* 30, 225–243.

Lunsford, C., Shotwell, S. and Hanselman, D. (2011) Assessment of the dusky rockfish stock in the Gulf of Alaska. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Lunsford, C., Shotwell, S. and Hanselman, D. (2009) Gulf of Alaska pelagic shelf 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, Anchorage, AK.

Lunsford, C., Shotwell, S., Hanselman, D. and DM, C. (2007) Gulf of Alaska pelagic shelf rockfish. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Lunsford, C., Shotwell, S., Hulson, P.-J. and Hanselman, D. (2012) Assessment of the dusky rockfish stock in the Gulf of Alaska. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Lunsford, C., Shotwell, S., Hulson, P.-J. and Hanselman, D. (2013) Assessment of the dusky rockfish stock in the Gulf of Alaska. In: *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska*. North Pacific Fishery Management Council, Anchorage, AK.

Malecha, P., Hanselman, D. and Heifetz, J. (2007) Growth and mortality of rockfishes (*Scorpaenidae*) from Alaska waters.

O'Leary, C., Laman, N. and Rohan, S. (2021) Gulf of Alaska groundfish condition. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Orr, J.W. and Blackburn, J.E. (2004) The dusky rockfishes (Teleostei: Socrpaeniformes) of the North Pacific Ocean: resurrection of *Sebastes variabilis* (Pallas, 1814) and a redescription of *Sebastes ciliatus* (Tilesius, 1813). *Fishery Bulletin* 102, 328–348.

Palsson, W. (2021a) Distribution of rockfish species along environmental gradients in the Gulf of Alaska bottom trawl survey. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Palsson, W. (2021b) Structural Epifauna – Gulf of Alaska. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Pearcy, W., Stein, D., Hixon, M., Pikitch, E., Barss, W. and Starr, R. (1989) Submersible observations of deep-reef fishes of Heceta Bank, Oregon. *Fishery Bulletin* 87, 955–965.

Quinn, T.J. and Deriso, R.B. (1999) *Quantitative fish dynamics*. Oxford University Press.

Reuter, R.F. (1999) Describing dusky rockfish (*Sebastes ciliatus*) habitat in the Gulf of Alaska using historical data.

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

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.

Service, N.M.F. (2001) Alaska groundfish fisheries draft programmatic supplemental environmental impact statement.Available from Alaska Region, National Marine Fisheries Service, Box 21668, Juneau, AK 99802.

Siwicke, K. (2022) Ocean temperature synthesis: Longline survey. In: *Ecosystem Status Report 2022: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

Whitehouse, A. and Gaichas, S. (2021) Time trends in non-target species catch. In: *Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report*. North Pacific Fishery Management Council, Anchorage, AK 99501.

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

Yang, M.-S., Dodd, K., Hibpshman, R. and Whitehouse, A. (2006) Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001. 199 pp. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-164.

# 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 North Pacific Management Council. Previously, *Sebastes* in Alaska were managed as "Pacific ocean perch complex" or "other rockfish" which included PSR species. Apportionment and biomass determined from average percent biomass of most recent trawl surveys |
| 1989 | 1,738 | 6,600 | 3,300 | n/a | No reported foreign or joint venture catches of PSR |
| 1990 | 1,647 | 8,200 | 8,200 | n/a | |
| 1991 | 2,187 | 4,800 | 4,800 | n/a | |
| 1992 | 3,532 | 6,886 | 6,886 | 11,360[3] | |
| 1993 | 3,182 | 6,740 | 6,740 | 11,300[3] | |
| 1994 | 2,980 | 6,890 | 6,890 | 11,550[3] | |
| 1995 | 2,882 | 5,190 | 5,190 | 8,704[3] | |
| 1996 | 2,290 | 5,190 | 5,190 | 8,704[3] | Area apportionment based on 4:6:9 weighting scheme of 3 most recent survey biomass estimates rather than average percent biomass |
| 1997 | 2,467 | 5,140 | 5,140 | 8,400[3] | |
| 1998 | 3,109 | 4,880 | 4,880 | 8,040[3] | Black and blue rockfish removed from PSR assemblage and federal management plan<br>Trawling prohibited in Eastern Gulf east of 140 degrees W. |
| 1999 | 4,658 | 4,880 | 4,880 | 8,190[3] | Eastern Gulf divided into West Yakutat and East Yakutat/Southeast Outside and separate ABCs and TACs assigned |
| 2000 | 3,728 | 5,980 | 5,980 | 9,040[3] | Amendment 41 became effective which prohibited trawling in the Eastern Gulf east of 140 degrees W. |
| 2001 | 3,006 | 5,980 | 5,980 | 9,040[3] | Dusky rockfish treated as Tier 4 species whereas dark, widow, and yellowtail broken out as Tier 5 species |
| 2002 | 3,321 | 5,490 | 5,490 | 8,220[3] | |
| 2003 | 3,056 | 5,490 | 5,490 | 8,220[3] | Age structured model for dusky rockfish accepted to determine ABC and moved to Tier 3 status |
| 2004 | 2,688 | 4,470 | 4,470 | 5,570[3] | |
| 2005 | 2,236 | 4,553 | 4,553 | 5,680[3] | |
| 2006 | 2,452 | 5,436 | 5,436 | 6,662[3] | |
| 2007 | 3,383 | 5,542 | 5,542 | 6,458[3] | Amendment 68 created the Central Gulf Rockfish Pilot Project |
| 2008 | 3,657 | 5,227 | 5,227 | 6,400[3] | |
| 2009 | 3,075 | 4,781 | 4,781 | 5,803[3] | Dark rockfish removed from PSR assemblage and federal management plan |
| 2010 | 3,119 | 5,059 | 5,509 | 6,142[3] | |
| 2011 | 2,538[2] | 4,754 | 4,754 | 5,570[3] | Dusky rockfish broken out as stand-alone species for 2012. Widow and yellowtail rockfish included in other rockfish assemblage. |
| 2012 | 4,010[2] | 5,118 | 5,118 | 6,257 | |
| 2013 | 3,158[2] | 4,700 | 4,700 | 5,746 | |
| 2014 | 3,062[2] | 5,486 | 5,486 | 6,708 | |
| 2015 | 2,781[2] | 5,109 | 5,109 | 6,246 | |
| 2016 | 3,327[2] | 4,686 | 4,686 | 5,733 | |
| 2017 | 2,622[2] | 4,278 | 4,278 | 5,233 | |
| 2018 | 2,913[2] | 3,957 | 3,957 | 4,841 | |

| Year | Catch[1] | ABC | TAC | OFL | Management Measures |
|---|---|---|---|---|---|
| 2019 | 2,491[2] | 3,700 | 3,700 | 4,521 | |
| 2020 | 2,172[2] | 3,676 | 3,676 | 4,492 | |
| 2021 | 2,928 | 5,389 | 5,389 | 8,655 | |
| 2022 | 2,553 | 5,372 | 5,372 | 8,614 | |

[1] Catch is for entire pelagic shelf rockfish assemblage,
[2] Catch is for dusky rockfish only, updated through October 5, 2022. Source: AKFIN.
[3] OFL is for entire pelagic shelf rockfish assemblage.

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

| Year | Catch | ABC[1] | TAC[1] | % TAC |
|---|---|---|---|---|
| 1977 | 388 | | | |
| 1978 | 162 | | | |
| 1979 | 224 | | | |
| 1980 | 597 | | | |
| 1981 | 845 | | | |
| 1982 | 853 | | | |
| 1983 | 1,017 | | | |
| 1984 | 510 | | | |
| 1985 | 34 | | | |
| 1986 | 17 | | | |
| 1987 | 19 | | | |
| 1988 | 1,067 | 3,300 | 3,300 | 32 |
| 1989 | 1,707 | 6,600 | 3,300 | 52 |
| 1990 | 1,612 | 8,200 | 8,200 | 20 |
| 1991 | 2,187 | 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 | 2,553 | 5,372 | 5,372 | 48 |

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

Table 12-3. 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 10/28/2022.

| Species Group | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Arrowtooth Flounder | 761 | 733 | 890 | 2,523 | 2,673 |
| Atka Mackerel | 1,140 | 824 | 602 | 674 | 867 |
| BSAI Skate and GOA Skate, Other | 28 | 26 | 10 | 19 | 13 |
| Flathead Sole | 48 | 40 | 95 | 135 | 74 |
| GOA Deep Water Flatfish | 66 | 39 | 19 | 19 | 34 |
| GOA Demersal Shelf Rockfish | 57 | 56 | 11 | 5 | 5 |
| GOA Dusky Rockfish | 2691 | 2,151 | 2,061 | 2,669 | 2,458 |
| GOA Rex Sole | 136 | 117 | 189 | 99 | 130 |
| GOA Shallow Water Flatfish | 57 | 34 | 22 | 33 | 26 |
| GOA Skate, Big | 6 | 5 | 6 | 4 | 4 |
| GOA Skate, Longnose | 46 | 28 | 24 | 31 | 28 |
| GOA Thornyhead Rockfish | 362 | 177 | 138 | 113 | 215 |
| Halibut | Conf | 0 | 2 | 0 | Conf |
| Northern Rockfish | 2,152 | 2,313 | 2,317 | 2,303 | 1,794 |
| Octopus | 3 | 9 | 1 | 1 | 0 |
| Other Rockfish | 992 | 669 | 522 | 975 | 900 |
| Pacific Cod | 401 | 322 | 170 | 660 | 626 |
| Pacific Ocean Perch | 22,172 | 22,258 | 22,881 | 27,399 | 24,916 |
| Pollock | 917 | 686 | 647 | 1,559 | 1,779 |
| Rougheye Rockfish | 317 | 320 | 89 | 162 | 219 |
| Sablefish | 708 | 801 | 647 | 893 | 912 |
| Sculpin | 65 | 53 | 30 | - | - |
| Shark | 48 | 62 | 33 | 32 | 12 |
| Shortraker Rockfish | 269 | 269 | 225 | 240 | 179 |
| Squid | 29 | - | - | - | - |

Table 12-4. Non-FMP species bycatch 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 10/28/2022.

| Species Group | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Benthic urochordata | 0.067 | 0.397 | 0.119 | 0.01 | 3.692 |
| Birds - Northern Fulmar | Conf | Conf | - | Conf | - |
| Bivalves | Conf | Conf | 0.002 | 0.036 | Conf |
| Brittle star unidentified | 0.008 | 0.024 | 0.011 | 0.052 | 0.022 |
| Corals Bryozoans - Corals Bryozoans Unidentified | 1.356 | 0.878 | 0.172 | 1.734 | 0.324 |
| Eelpouts | 0.217 | 0.005 | Conf | Conf | Conf |
| Eulachon | 0.127 | 0.272 | 0.1 | - | - |
| Giant Grenadier | 1,690.6 | 754.0 | 302. 1 | 252.1 | 196.3 |
| Greenlings | 4.51 | 9.566 | 3.496 | 3.428 | 3.624 |
| Grenadier - Rattail Grenadier Unidentified | 5.327 | 4.006 | 1.731 | 0.193 | 2.792 |
| Hermit crab unidentified | 0.008 | Conf | 0.002 | 0.011 | 0.015 |
| Invertebrate unidentified | 0.111 | 0.071 | Conf | 0.057 | 0.012 |
| Lanternfishes (myctophidae) | Conf | 0.06 | 0.017 | 0.047 | - |
| Misc crabs | 0.451 | 0.331 | 0.097 | 0.104 | 0.088 |
| Misc crustaceans | 0.127 | 0.197 | 0.069 | 0.059 | 0.049 |
| Misc fish | 137.4 | 359.0 | 87.2 | 164.0 | 77.5 |
| Pacific Hake | 0.071 | Conf | 0.034 | - | - |
| Pandalid shrimp | 0.072 | 0.113 | 0.175 | 0.293 | 0.092 |
| Scypho jellies | 0.925 | 8.431 | 3.524 | 3.191 | 0.934 |
| Sea anemone unidentified | 0.465 | 1.518 | 1.24 | 1.778 | 0.934 |
| Sea pens whips | 0.002 | 0.03 | 0.003 | Conf | 0.019 |
| Sea star | 4.329 | 1.362 | 1.138 | 1.499 | 1.286 |
| Snails | 5.669 | 1.786 | 0.084 | 1.177 | 0.114 |
| Sponge unidentified | 13.658 | 5.881 | 0.521 | 1.218 | 5.97 |
| State-managed Rockfish | 52.882 | 46.427 | 53.108 | 12.348 | 33.26 |
| Stichaeidae | 0.511 | - | Conf | - | Conf |
| urchins dollars cucumbers | 0.309 | 0.205 | 0.906 | 0.233 | 0.22 |
| Birds - Shearwaters | - | Conf | - | - | - |
| Capelin | - | Conf | Conf | - | - |
| Misc deep fish | - | Conf | - | - | Conf |
| Other osmerids | - | Conf | 0.977 | 0.084 | 0.083 |
| Polychaete unidentified | - | Conf | - | - | Conf |
| Squid | - | 10.869 | 31.804 | 27.769 | 43.117 |
| Bristlemouths | - | - | Conf | - | - |
| Misc inverts (worms etc) | - | - | 0.002 | 0.001 | Conf |
| Gunnels | - | - | - | Conf | - |
| Pacific Sand lance | - | - | - | Conf | - |
| Sculpin | - | - | - | 23.515 | 39.299 |
| Smelt (Family Osmeridae) | - | - | - | 0.229 | 0.263 |

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 10/28/2022.

| Species Group | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Bairdi Tanner Crab | 321 | 64 | 1,146 | 2,279 | 180 |
| Blue King Crab | 0 | 0 | 0 | 0 | 0 |
| Chinook Salmon | 336 | 410 | 655 | 1,042 | 1,116 |
| Golden (Brown) King Crab | 324 | 223 | 60 | 114 | 136 |
| Halibut | 100 | 115 | 111 | 179 | 128 |
| Herring | 0 | 2 | 0 | 0 | 1 |
| Non-Chinook Salmon | 325 | 380 | 723 | 1,628 | 4,002 |
| Opilio Tanner (Snow) Crab | 0 | 0 | 0 | 0 | 0 |
| Red King Crab | 0 | 0 | 0 | 0 | 0 |

Table 12-6. Gulf of Alaska discard rates rates (percent of the total catch discarded within management categories) of dusky rockfish.

| Year | % discard | Year | % discard |
|---|---|---|---|
| 2000 | 0.9 | 2012 | 3.9 |
| 2001 | 1.7 | 2013 | 5.2 |
| 2002 | 4.3 | 2014 | 3.1 |
| 2003 | 1.7 | 2015 | 5.3 |
| 2004 | 1.8 | 2016 | 4.1 |
| 2005 | 0.9 | 2017 | 7.6 |
| 2006 | 5.0 | 2018 | 2.4 |
| 2007 | 0.7 | 2019 | 6.3 |
| 2008 | 0.7 | 2020 | 2.6 |
| 2009 | 1.5 | 2021 | 3.6 |
| 2010 | 1.0 | 2022 | 1.6 |
| 2011 | 1.8 | | |

Table 12-7. Fishery age compositions for dusky rockfish in the Gulf of Alaska.

| Length (cm) | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |
| 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 |
| 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 |
| 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 | 0.016 |
| 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 |
| 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 | 0.090 |
| 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 | 0.076 |
| 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 | 0.103 |
| 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 | 0.097 |
| 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 |
| 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 | 0.061 |
| 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 | 0.045 |
| 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 | 0.043 |
| 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 |
| 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 | 0.043 |
| 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 | 0.036 |
| 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 | 0.038 |
| 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 | 0.036 |
| 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 | 0.025 |
| 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 |
| 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 | 0.034 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| Sample size | 411 | 517 | 441 | 628 | 422 | 444 | 309 | 604 | 332 | 612 | 647 | 626 | 673 | 445 |
| # hauls | 131 | 166 | 147 | 270 | 184 | 186 | 143 | 302 | 223 | 400 | 357 | 437 | 423 | 364 |

Table 12-8. Fishery length compositions for dusky rockfish in the Gulf of Alaska. Lengths below 22 are pooled and lengths greater than 47 are pooled. Survey size compositions are not used in model.

| Length (cm) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2019 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| Sample size | 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 |
| # hauls | 42 | 127 | 64 | 38 | 26 | 12 | 53 | 34 | 83 | 405 | 415 | 331 | 404 | 507 | 474 | 676 | 609 |

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 w/lognormal error) used in model 22.3a.

| Year | Biomass (t) | SE | Lower CI | Upper CI |
|---|---|---|---|---|
| 1990 | 13,032 | 2,262 | 8,598 | 29,885 |
| 1993 | 36,132 | 5,914 | 24,541 | 84,231 |
| 1996 | 36,044 | 6,269 | 23,757 | 82,607 |
| 1999 | 34,346 | 6,475 | 21,655 | 76,790 |
| 2001 | 42,086 | 8,875 | 24,691 | 90,480 |
| 2003 | 49,970 | 8,413 | 33,481 | 115,592 |
| 2005 | 75,852 | 11,492 | 53,328 | 180,374 |
| 2007 | 52,225 | 8,373 | 35,814 | 122,420 |
| 2009 | 42,053 | 6,991 | 28,351 | 97,620 |
| 2011 | 43,388 | 8,143 | 27,428 | 97,146 |
| 2013 | 62,049 | 11,280 | 39,940 | 140,332 |
| 2015 | 60,796 | 10,080 | 41,039 | 141,233 |
| 2017 | 63,808 | 11,281 | 41,697 | 145,535 |
| 2019 | 91,897 | 14,553 | 63,373 | 216,108 |
| 2021 | 71,717 | 12,718 | 46,790 | 163,425 |

Table 12-10. GOA dusky rockfish biomass estimates, standard errors, and confidence intervals, based on results of NMFS bottom trawl surveys using a design-based estimator used in model 22.3a.

| Year | Biomass (t) | SE | Lower CI | Upper CI |
|---|---|---|---|---|
| 1990 | 26,895 | 8,635 | 9,971 | 43,819 |
| 1993 | 57,746 | 16,835 | 24,749 | 90,743 |
| 1996 | 74,480 | 32,851 | 10,091 | 138,869 |
| 1999 | 49,628 | 19,194 | 12,008 | 87,248 |
| 2001 | 31,004 | 9,279 | 12,817 | 49,190 |
| 2003 | 70,856 | 34,352 | 3,526 | 138,186 |
| 2005 | 170,513 | 51,658 | 69,264 | 271,762 |
| 2007 | 73,074 | 34,498 | 5,457 | 140,690 |
| 2009 | 72,123 | 24,687 | 23,735 | 120,510 |
| 2011 | 83,407 | 36,806 | 11,267 | 155,546 |
| 2013 | 99,170 | 35,767 | 29,067 | 169,272 |
| 2015 | 32,790 | 7,870 | 17,364 | 48,216 |
| 2017 | 51,270 | 12,979 | 25,832 | 76,708 |
| 2019 | 88,365 | 19,363 | 50,414 | 126,316 |
| 2021 | 107,069 | 53,084 | 3,025 | 211,113 |

Table 12-11. NMFS trawl survey age compositions for dusky rockfish in the Gulf of Alaska.

| Length (cm) | 1990 | 1993 | 1996 | 1999 | 2001 | 2003 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2019 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 | 0.002 |
| 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 | 0.004 |
| 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 | 0.022 |
| 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 | 0.005 |
| 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 | 0.035 |
| 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 | 0.020 |
| 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 | 0.078 |
| 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 | 0.068 |
| 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 | 0.035 |
| 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 | 0.051 |
| 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 | 0.087 |
| 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 | 0.054 |
| 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 | 0.013 |
| 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 | 0.074 |
| 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 | 0.045 |
| 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 | 0.044 |
| 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 | 0.104 |
| 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 | 0.011 |
| 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 | 0.024 |
| 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 | 0.000 |
| 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 | 0.007 |
| 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 | 0.038 |
| 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 |
| 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 | 0.015 |
| 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 | 0.020 |
| 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 | 0.127 |
| Sample size | 94 | 445 | 554 | 174 | 676 | 195 | 461 | 490 | 495 | 427 | 434 | 471 | 429 | 403 | 440 |
| # hauls | 7 | 42 | 46 | 24 | 63 | 23 | 82 | 89 | 59 | 64 | 74 | 68 | 44 | 93 | 92 |

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

| Length (cm) | 1990 | 1993 | 1996 | 1999 | 2001 | 2003 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2019 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| 47 | 0.069 | 0.036 | 0.130 | 0.094 | 0.059 | 0.050 | 0.075 | 0.070 | 0.126 | 0.073 | 0.134 | 0.112 | 0.072 | 0.068 | 0.122 |
| 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 |
| 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 |
| 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 |
| 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 |
| 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 |
| Sample size | 1,113 | 2,299 | 1,478 | 1,340 | 1,255 | 1,780 | 3,383 | 1,818 | 2,024 | 1,410 | 1,889 | 1,820 | 1,857 | 2,503 | 1,503 |
| # hauls | 30 | 95 | 105 | 91 | 70 | 114 | 140 | 127 | 113 | 87 | 88 | 113 | 101 | 120 | 95 |

Table 12-13. Likelihood values and estimates of key parameters for a select few models for GOA dusky rockfish.

| Likelihoods | base | m22 | m22.3a |
|---|---|---|---|
| Catch | 26.96 | 25.06 | 25.72 |
| Survey biomass | 98.95 | 74.21 | 30.03 |
| Fishery ages | 32.84 | 36.60 | 41.52 |
| Survey ages | 124.75 | 130.01 | 138.14 |
| Fishery lengths | 49.29 | 53.82 | 60.03 |
| Maturity | 65.00 | 65.00 | 65.00 |
| Data | 332.80 | 319.70 | 295.43 |
| **Penalties/Priors** | | | |
| Recruitment devs | 38.83 | 41.34 | 36.21 |
| *F* regularity | 31.62 | 32.60 | 33.98 |
| $\sigma_r$ prior | 0.25 | 0.22 | 0.41 |
| *q* prior | 0.32 | 0.64 | 0.50 |
| Objective function | 468.81 | 459.28 | 431.13 |
| **Parameter estimates** | | | |
| # parameters | 124 | 128 | 133 |
| *q* | 0.70 | 0.60 | 0.64 |
| $\sigma_r$ | 1.10 | 1.12 | 1.00 |
| rec | 2.22 | 0.90 | 0.99 |
| $F_{40\%}$ | 0.93 | 0.09 | 0.09 |
| Projected total biomass | 97,702 | 110,493 | 107,160 |
| Projected spawning biomass | 38,362 | 46,083 | 44,495 |
| $B_{100\%}$ | 60,855 | 67,517 | 65,565 |
| $B_{40\%}$ | 24,342 | 27,007 | 26,226 |
| ABC | 7,101 | 8,187 | 7,917 |

Table 12-14. Estimated numbers (thousands), 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 and female maturity.

| | | Percent | | Selectivity | |
|---|---|---|---|---|---|
| Age | Abundance | Mature | Weight | Fishery | Survey |
| 4 | 2,703 | 2 | 204.2 | 0.00 | 0.04 |
| 5 | 2,210 | 3 | 343.9 | 0.00 | 0.07 |
| 6 | 2,209 | 5 | 499.6 | 0.01 | 0.12 |
| 7 | 1,938 | 10 | 660.1 | 0.02 | 0.20 |
| 8 | 4,767 | 18 | 817.1 | 0.07 | 0.32 |
| 9 | 2,051 | 29 | 965.1 | 0.19 | 0.47 |
| 10 | 4,685 | 44 | 1,101.0 | 0.43 | 0.62 |
| 11 | 1,680 | 61 | 1,223.2 | 0.71 | 0.75 |
| 12 | 12,456 | 75 | 1,331.4 | 0.89 | 0.85 |
| 13 | 4,898 | 85 | 1,426.1 | 0.96 | 0.91 |
| 14 | 5,473 | 92 | 1,508.2 | 0.99 | 0.95 |
| 15 | 5,836 | 96 | 1,578.7 | 1.00 | 0.97 |
| 16 | 3,517 | 98 | 1,639.0 | 1.00 | 0.99 |
| 17 | 2,445 | 99 | 1,690.3 | 1.00 | 0.99 |
| 18 | 1,803 | 99 | 1,733.7 | 1.00 | 1.00 |
| 19 | 1,426 | 100 | 1,770.3 | 1.00 | 1.00 |
| 20 | 1,061 | 100 | 1,801.2 | 1.00 | 1.00 |
| 21 | 2,132 | 100 | 1,827.1 | 1.00 | 1.00 |
| 22 | 2,009 | 100 | 1,848.9 | 1.00 | 1.00 |
| 23 | 1,193 | 100 | 1,867.1 | 1.00 | 1.00 |
| 24 | 2,419 | 100 | 1,882.3 | 1.00 | 1.00 |
| 25 | 1,712 | 100 | 1,895.0 | 1.00 | 1.00 |
| 26 | 310 | 100 | 1,905.6 | 1.00 | 1.00 |
| 27 | 2,216 | 100 | 1,914.5 | 1.00 | 1.00 |
| 28 | 973 | 100 | 1,921.9 | 1.00 | 1.00 |
| 29 | 283 | 100 | 1,928.0 | 1.00 | 1.00 |
| 30+ | 1,362 | 100 | 1,933.2 | 1.00 | 1.00 |

Table 12-15. Comparison of 2022 estimated time series of female spawning biomass, 6+ biomass (age 6 and greater), catch/(6+ biomass), and the number of age-4 recruits for dusky rockfish in the Gulf of Alaska compared with 2020 estimates.

| | Spawning biomass | | 6+ biomass | | Catch/6+ biomass | | Age-4+ recruits | |
|---|---|---|---|---|---|---|---|---|
| Year | Previous | Current | Previous | Current | Previous | Current | Previous | Current |
| 1,977 | 10,267 | 11,743 | 23,540 | 27,313 | 0.02 | 0.02 | 1,693 | 1,606 |
| 1,978 | 9,725 | 11,228 | 22,901 | 26,510 | 0.01 | 0.02 | 1,851 | 1,710 |
| 1,979 | 9,381 | 10,908 | 22,614 | 26,082 | 0.01 | 0.02 | 2,139 | 2,194 |
| 1,980 | 9,085 | 10,616 | 22,437 | 25,705 | 0.03 | 0.03 | 6,613 | 5,312 |
| 1,981 | 8,727 | 10,231 | 22,180 | 25,293 | 0.04 | 0.04 | 4,802 | 6,042 |
| 1,982 | 8,411 | 9,869 | 23,894 | 26,205 | 0.04 | 0.04 | 3,912 | 6,742 |
| 1,983 | 8,240 | 9,630 | 25,381 | 27,869 | 0.04 | 0.04 | 1,687 | 3,871 |
| 1,984 | 8,208 | 9,521 | 26,649 | 30,169 | 0.02 | 0.02 | 8,858 | 5,375 |
| 1,985 | 8,512 | 9,786 | 27,295 | 31,973 | 0.00 | 0.01 | 1,866 | 3,463 |
| 1,986 | 9,306 | 10,572 | 31,522 | 34,943 | 0.00 | 0.00 | 3,439 | 3,239 |
| 1,987 | 10,300 | 11,626 | 33,205 | 37,207 | 0.00 | 0.00 | 2,131 | 2,245 |
| 1,988 | 11,397 | 12,851 | 35,258 | 39,191 | 0.03 | 0.03 | 10,148 | 9,628 |
| 1,989 | 12,062 | 13,708 | 35,530 | 39,612 | 0.05 | 0.03 | 5,987 | 6,167 |
| 1,990 | 12,559 | 14,417 | 38,724 | 42,644 | 0.04 | 0.03 | 18,929 | 18,966 |
| 1,991 | 13,352 | 15,141 | 41,301 | 44,963 | 0.05 | 0.03 | 12,841 | 13,173 |
| 1,992 | 14,181 | 15,887 | 49,607 | 52,751 | 0.07 | 0.06 | 11,107 | 11,435 |
| 1,993 | 14,312 | 15,889 | 54,577 | 57,396 | 0.06 | 0.05 | 2,921 | 3,103 |
| 1,994 | 14,941 | 16,411 | 59,493 | 62,122 | 0.05 | 0.05 | 7,924 | 8,284 |
| 1,995 | 16,173 | 17,485 | 61,026 | 63,556 | 0.05 | 0.04 | 5,699 | 6,154 |
| 1,996 | 17,939 | 19,137 | 63,963 | 66,501 | 0.04 | 0.03 | 17,341 | 18,314 |
| 1,997 | 20,165 | 21,289 | 66,086 | 68,802 | 0.04 | 0.04 | 3,082 | 3,358 |
| 1,998 | 22,267 | 23,459 | 72,709 | 75,757 | 0.04 | 0.04 | 9,539 | 10,257 |
| 1,999 | 23,817 | 25,013 | 73,133 | 76,426 | 0.06 | 0.06 | 19,122 | 20,842 |
| 2,000 | 24,438 | 25,634 | 74,280 | 77,797 | 0.05 | 0.05 | 2,328 | 2,606 |
| 2,001 | 25,248 | 26,610 | 80,485 | 84,683 | 0.04 | 0.03 | 12,008 | 12,845 |
| 2,002 | 26,399 | 27,857 | 80,860 | 85,440 | 0.04 | 0.04 | 14,696 | 16,181 |
| 2,003 | 27,512 | 29,143 | 84,276 | 89,339 | 0.04 | 0.03 | 6,412 | 7,125 |
| 2,004 | 28,828 | 30,700 | 89,284 | 95,080 | 0.03 | 0.03 | 8,665 | 10,733 |
| 2,005 | 30,412 | 32,463 | 91,415 | 97,663 | 0.02 | 0.02 | 8,623 | 10,198 |
| 2,006 | 32,151 | 34,481 | 94,269 | 101,627 | 0.03 | 0.02 | 3,665 | 4,538 |
| 2,007 | 33,709 | 36,364 | 96,551 | 104,929 | 0.04 | 0.03 | 3,801 | 5,459 |
| 2,008 | 34,688 | 37,679 | 95,389 | 104,597 | 0.04 | 0.03 | 5,458 | 6,178 |
| 2,009 | 35,314 | 38,675 | 93,305 | 103,628 | 0.03 | 0.03 | 6,187 | 7,508 |
| 2,010 | 35,869 | 39,626 | 91,975 | 102,999 | 0.03 | 0.03 | 7,417 | 9,686 |
| 2,011 | 36,014 | 40,175 | 90,643 | 102,515 | 0.03 | 0.02 | 13,312 | 14,442 |
| 2,012 | 36,081 | 40,628 | 90,384 | 103,436 | 0.04 | 0.04 | 12,342 | 12,203 |
| 2,013 | 35,205 | 40,158 | 91,407 | 105,144 | 0.04 | 0.03 | 8,534 | 9,871 |
| 2,014 | 34,642 | 39,942 | 93,544 | 107,332 | 0.03 | 0.03 | 24,358 | 22,778 |
| 2,015 | 34,271 | 39,860 | 94,581 | 108,907 | 0.03 | 0.03 | 2,522 | 2,804 |
| 2,016 | 34,375 | 40,324 | 102,922 | 116,330 | 0.03 | 0.03 | 2,688 | 7,194 |
| 2,017 | 34,680 | 40,834 | 102,566 | 115,798 | 0.03 | 0.02 | 2,757 | 2,920 |
| 2,018 | 35,741 | 42,028 | 102,009 | 116,832 | 0.03 | 0.02 | 2,593 | 6,313 |
| 2,019 | 36,910 | 43,235 | 100,277 | 115,233 | 0.03 | 0.02 | 2,088 | 2,391 |
| 2,020 | 38,202 | 44,568 | 98,099 | 114,641 | 0.02 | 0.02 | 2,223 | 2,541 |
| 2,021 | | 45,641 | | 112,246 | | 0.03 | | 2,370 |
| 2,022 | | 45,775 | | 108,509 | | 0.02 | | 2,703 |

Table 12-16. Estimated time series of number at age-4 recruits (thousands), total biomass, and female spawning biomass with 95% confidence bounds for dusky rockfish in the Gulf of Alaska, from this year's model MCMC results.

| | Age 4+ recruits | | | Total biomass | | | Spawning biomass | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Mean | 2.5% | 97.5% | Mean | 2.5% | 97.5% | Mean | 2.5% | 97.5% |
| 1977 | 1,606 | 142 | 1,880 | 28,141 | 23,353 | 35,833 | 11,752 | 9,484 | 14,962 |
| 1978 | 1,710 | 127 | 1,916 | 27,374 | 22,750 | 34,504 | 11,238 | 9,089 | 14,354 |
| 1979 | 2,194 | 187 | 2,652 | 27,078 | 22,433 | 33,899 | 10,919 | 8,878 | 13,941 |
| 1980 | 5,312 | 166 | 4,894 | 27,493 | 22,753 | 34,007 | 10,634 | 8,660 | 13,535 |
| 1981 | 6,042 | 283 | 6,926 | 28,231 | 23,599 | 34,805 | 10,265 | 8,348 | 13,099 |
| 1982 | 6,742 | 291 | 6,225 | 29,519 | 24,724 | 35,865 | 9,907 | 8,041 | 12,504 |
| 1983 | 3,871 | 203 | 4,313 | 30,822 | 25,868 | 37,547 | 9,667 | 7,825 | 12,424 |
| 1984 | 5,375 | 527 | 4,682 | 32,508 | 27,254 | 39,174 | 9,547 | 7,693 | 12,194 |
| 1985 | 3,463 | 262 | 3,718 | 34,404 | 28,699 | 41,064 | 9,816 | 7,900 | 12,379 |
| 1986 | 3,239 | 235 | 2,989 | 36,715 | 31,033 | 43,447 | 10,593 | 8,631 | 13,248 |
| 1987 | 2,245 | 201 | 2,436 | 38,704 | 32,908 | 45,750 | 11,645 | 9,574 | 14,399 |
| 1988 | 9,628 | 2,263 | 6,346 | 41,876 | 35,945 | 49,376 | 12,876 | 10,804 | 15,767 |
| 1989 | 6,167 | 994 | 4,321 | 43,958 | 37,831 | 51,887 | 13,762 | 11,494 | 16,781 |
| 1990 | 18,966 | 5,508 | 11,586 | 48,494 | 41,819 | 57,062 | 14,474 | 12,131 | 17,537 |
| 1991 | 13,173 | 3,250 | 8,357 | 53,734 | 46,396 | 63,223 | 15,249 | 12,775 | 18,333 |
| 1992 | 11,435 | 3,081 | 7,585 | 59,310 | 51,657 | 69,119 | 15,965 | 13,408 | 19,315 |
| 1993 | 3,103 | 321 | 2,437 | 61,696 | 53,497 | 71,942 | 15,946 | 13,447 | 19,506 |
| 1994 | 8,284 | 2,321 | 5,268 | 64,808 | 56,090 | 75,916 | 16,438 | 13,844 | 20,121 |
| 1995 | 6,154 | 1,258 | 4,198 | 67,469 | 57,916 | 79,148 | 17,533 | 14,699 | 22,006 |
| 1996 | 18,314 | 5,676 | 10,546 | 72,214 | 61,879 | 85,311 | 19,193 | 16,136 | 24,155 |
| 1997 | 3,358 | 283 | 2,653 | 75,360 | 64,213 | 89,185 | 21,379 | 17,947 | 26,772 |
| 1998 | 10,257 | 2,768 | 6,327 | 78,928 | 67,399 | 93,766 | 23,491 | 19,763 | 29,345 |
| 1999 | 20,842 | 6,207 | 11,800 | 83,971 | 71,725 | 100,731 | 25,093 | 21,058 | 30,991 |
| 2000 | 2,606 | 218 | 2,365 | 85,012 | 71,872 | 102,780 | 25,734 | 21,294 | 31,963 |
| 2001 | 12,845 | 3,733 | 7,987 | 88,141 | 74,084 | 107,177 | 26,642 | 22,136 | 33,109 |
| 2002 | 16,181 | 4,739 | 9,536 | 92,863 | 77,763 | 112,993 | 27,941 | 23,162 | 34,908 |
| 2003 | 7,125 | 1,450 | 4,802 | 95,982 | 79,618 | 117,137 | 29,228 | 23,990 | 36,731 |
| 2004 | 10,732 | 2,742 | 7,134 | 99,556 | 82,277 | 121,882 | 30,750 | 25,167 | 38,797 |
| 2005 | 10,198 | 2,744 | 6,362 | 103,187 | 84,698 | 126,591 | 32,528 | 26,722 | 41,206 |
| 2006 | 4,538 | 860 | 3,487 | 105,824 | 86,647 | 130,485 | 34,534 | 28,412 | 43,893 |
| 2007 | 5,459 | 1,242 | 4,203 | 107,499 | 87,307 | 133,539 | 36,394 | 29,854 | 46,251 |
| 2008 | 6,178 | 1,104 | 4,246 | 107,609 | 86,788 | 134,468 | 37,714 | 30,591 | 47,945 |
| 2009 | 7,508 | 1,597 | 5,387 | 107,142 | 85,819 | 134,564 | 38,715 | 31,167 | 49,257 |
| 2010 | 9,686 | 2,266 | 6,621 | 107,384 | 85,643 | 135,803 | 39,675 | 31,608 | 50,626 |
| 2011 | 14,442 | 3,418 | 9,329 | 108,569 | 86,385 | 138,146 | 40,242 | 31,743 | 51,516 |
| 2012 | 12,203 | 2,838 | 8,910 | 110,558 | 87,435 | 141,670 | 40,714 | 31,744 | 52,174 |
| 2013 | 9,871 | 2,000 | 7,488 | 111,072 | 86,997 | 143,626 | 40,230 | 30,985 | 52,516 |
| 2014 | 22,778 | 6,154 | 14,456 | 115,149 | 90,457 | 149,609 | 40,022 | 30,590 | 52,819 |
| 2015 | 2,804 | 108 | 3,325 | 116,783 | 91,874 | 152,966 | 39,969 | 30,473 | 53,222 |
| 2016 | 7,194 | 822 | 6,658 | 118,698 | 93,607 | 156,228 | 40,348 | 30,727 | 53,988 |
| 2017 | 2,920 | 237 | 4,520 | 118,701 | 93,192 | 157,466 | 40,872 | 31,142 | 55,074 |
| 2018 | 6,313 | 499 | 6,894 | 119,057 | 92,720 | 158,843 | 42,051 | 32,118 | 57,114 |
| 2019 | 2,391 | 136 | 4,200 | 117,746 | 90,778 | 158,117 | 43,268 | 33,299 | 58,926 |
| 2020 | 2,541 | 158 | 5,365 | 115,927 | 89,892 | 157,116 | 44,582 | 34,368 | 60,959 |
| 2021 | 2,370 | 132 | 4,280 | 113,545 | 87,808 | 154,852 | 45,657 | 34,967 | 62,645 |
| 2022 | 2,703 | 136 | 6,251 | 109,820 | 83,364 | 150,302 | 45,790 | 35,195 | 63,129 |

Table 12-17. Estimates of key parameters with Hessian estimates of standard deviation σ, MCMC standard deviations σ_MCMC, and 95% Bayesian credible intervals (BCI) derived from MCMC.

| Parameter | $\mu$ | $\mu$ MCMC | Median MCMC | σ | σ MCMC | BCI Lower | BCI Upper |
|---|---|---|---|---|---|---|---|
| *q* | 0.638 | 0.639 | 0.636 | 0.079 | 0.085 | 0.496 | 0.838 |
| $F_{40}$ | 0.091 | 0.100 | 0.096 | 0.026 | 0.027 | 0.053 | 0.160 |
| SSB | 44,468 | 46,236 | 46,015 | 7,265 | 7,338 | 33,993 | 61,623 |
| ABC | 7,921 | 8,926 | 8,439 | 2,521 | 2,927 | 4,268 | 16,131 |

Table 12-18. Set of projections of spawning biomass (SB) and yield for dusky rockfish in the Gulf of Alaska. Six harvest scenarios designed to satisfy the requirements of Amendment 56, NEPA, and MSFCMA. For a description of scenarios see section *Harvest Recommendations*.

| Year | Maximum permissible F | Author's F (Estimated catches) | Half max.1 | 5-year average F | No Fishing | Overfished | Approaching overfished |
|---|---|---|---|---|---|---|---|
| | | | Spawning biomass (mt) | | | | |
| 2022 | 45,051 | 45,051 | 45,051 | 45,051 | 45,051 | 45,051 | 45,051 |
| 2023 | 44,233 | 44,495 | 44,554 | 44,664 | 44,883 | 44,085 | 44,233 |
| 2024 | 40,869 | 42,581 | 42,967 | 43,693 | 45,190 | 39,939 | 40,869 |
| 2025 | 37,468 | 40,210 | 41,068 | 42,360 | 45,070 | 35,920 | 37,342 |
| 2026 | 34,217 | 36,639 | 39,037 | 40,836 | 44,664 | 32,205 | 33,436 |
| 2027 | 31,311 | 33,432 | 37,077 | 39,321 | 44,156 | 28,971 | 30,026 |
| 2028 | 28,933 | 30,777 | 35,362 | 38,024 | 43,749 | 26,383 | 27,278 |
| 2029 | 27,199 | 28,794 | 34,079 | 37,109 | 43,613 | 24,567 | 25,301 |
| 2030 | 26,123 | 27,485 | 33,234 | 36,651 | 43,847 | 23,572 | 24,140 |
| 2031 | 25,601 | 26,728 | 32,900 | 36,590 | 44,423 | 23,158 | 23,597 |
| 2032 | 25,433 | 26,355 | 32,830 | 36,803 | 45,244 | 23,080 | 23,419 |
| 2033 | 25,456 | 26,208 | 33,061 | 37,175 | 46,208 | 23,168 | 23,429 |
| 2034 | 25,570 | 26,181 | 33,327 | 37,624 | 47,235 | 23,323 | 23,523 |
| 2035 | 25,724 | 26,220 | 33,718 | 38,103 | 48,279 | 23,499 | 23,652 |
| | | | Fishing mortality | | | | |
| 2022 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 |
| 2023 | 0.091 | 0.054 | 0.046 | 0.031 | | 0.112 | 0.112 |
| 2024 | 0.091 | 0.052 | 0.046 | 0.031 | | 0.112 | 0.112 |
| 2025 | 0.091 | 0.091 | 0.046 | 0.031 | | 0.112 | 0.112 |
| 2026 | 0.091 | 0.091 | 0.046 | 0.031 | | 0.112 | 0.112 |
| 2027 | 0.091 | 0.091 | 0.046 | 0.031 | | 0.112 | 0.112 |
| 2028 | 0.091 | 0.091 | 0.046 | 0.031 | | 0.111 | 0.111 |
| 2029 | 0.091 | 0.091 | 0.046 | 0.031 | | 0.104 | 0.104 |
| 2030 | 0.089 | 0.091 | 0.046 | 0.031 | | 0.100 | 0.100 |
| 2031 | 0.087 | 0.089 | 0.046 | 0.031 | | 0.098 | 0.098 |
| 2032 | 0.086 | 0.088 | 0.046 | 0.031 | | 0.097 | 0.097 |
| 2033 | 0.085 | 0.087 | 0.046 | 0.031 | | 0.097 | 0.097 |
| 2034 | 0.085 | 0.087 | 0.046 | 0.031 | | 0.098 | 0.098 |
| 2035 | 0.086 | 0.086 | 0.046 | 0.031 | | 0.098 | 0.098 |
| | | | Yield (mt) | | | | |
| 2022 | 2,644 | 2,644 | 2,644 | 2,644 | 2,644 | 2,644 | 2,644 |
| 2023 | 7,917 | 7,917 | 4,044 | 2,728 | | 9,638 | 7,917 |
| 2024 | 7,262 | 7,520 | 3,873 | 2,650 | | 8,668 | 7,262 |
| 2025 | 6,617 | 7,103 | 3,681 | 2,554 | | 7,748 | 8,055 |
| 2026 | 5,992 | 6,418 | 3,474 | 2,443 | | 6,885 | 7,150 |
| 2027 | 5,419 | 5,790 | 3,268 | 2,330 | | 6,117 | 6,343 |
| 2028 | 4,950 | 5,272 | 3,094 | 2,232 | | 5,463 | 5,693 |
| 2029 | 4,626 | 4,914 | 2,981 | 2,172 | | 4,763 | 5,038 |
| 2030 | 4,365 | 4,698 | 2,938 | 2,157 | | 4,425 | 4,633 |
| 2031 | 4,242 | 4,537 | 2,941 | 2,171 | | 4,325 | 4,482 |
| 2032 | 4,211 | 4,452 | 2,963 | 2,198 | | 4,335 | 4,453 |
| 2033 | 4,221 | 4,415 | 2,991 | 2,228 | | 4,383 | 4,473 |
| 2034 | 4,249 | 4,404 | 3,020 | 2,258 | | 4,441 | 4,509 |
| 2035 | 4,286 | 4,409 | 3,049 | 2,288 | | 4,504 | 4,555 |

# Figures

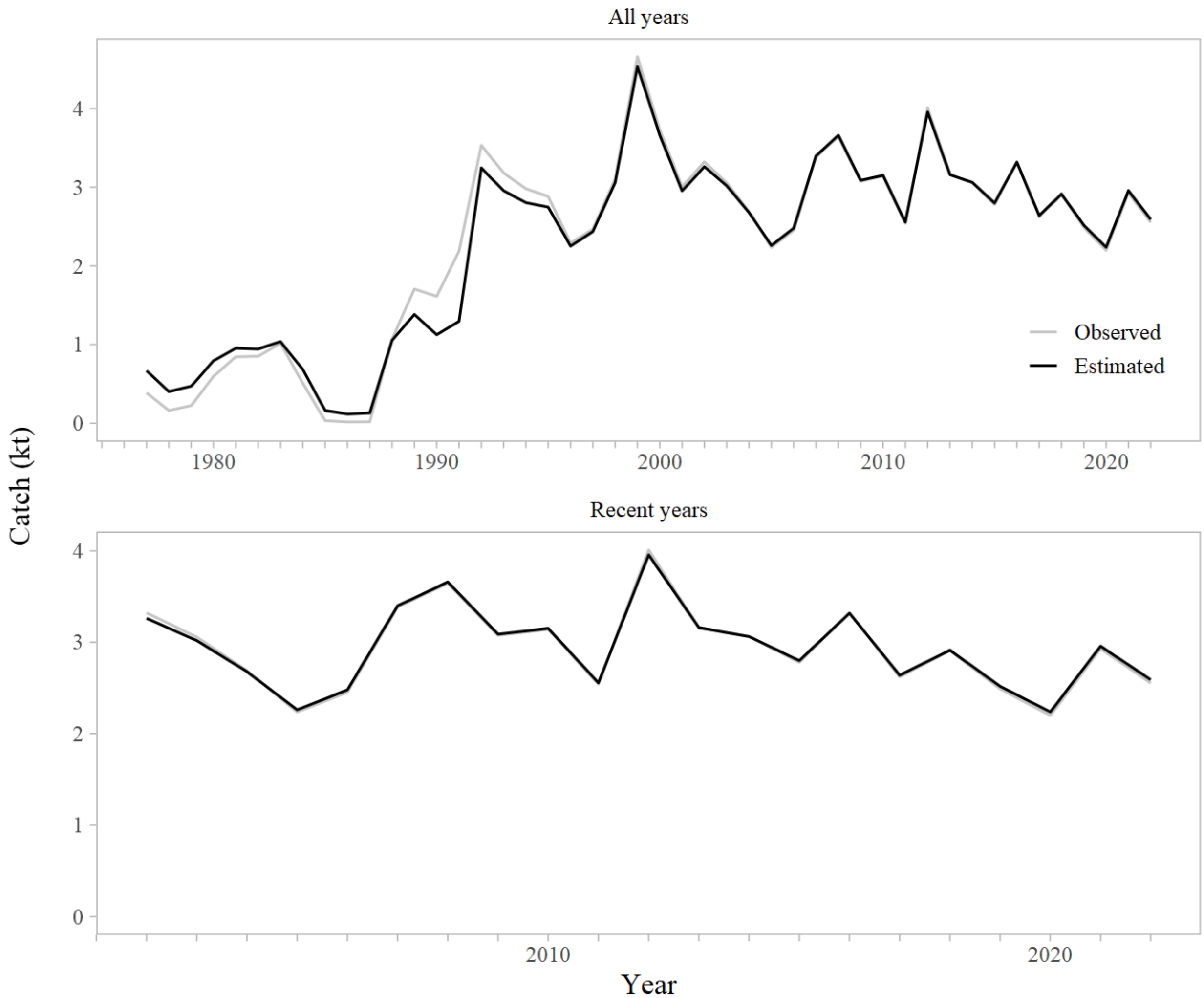


Figure 12-1. Estimated and observed long-term and recent commercial catch of GOA dusky rockfish in the Gulf of Alaska.

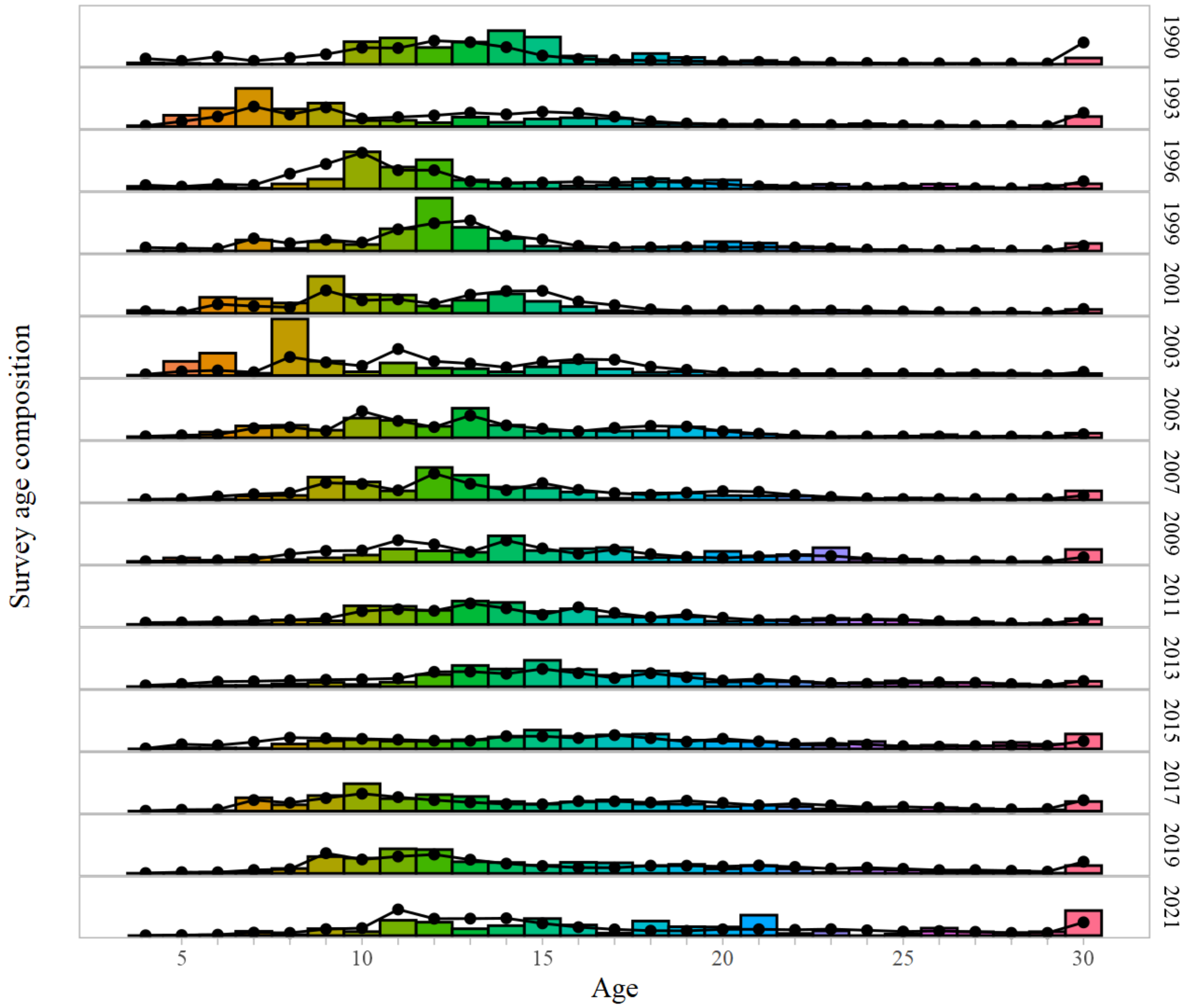


Figure 12-2. Survey age compositions for GOA dusky rockfish. Observed values are bars, lines are the predicted lengths from author's recommended model.

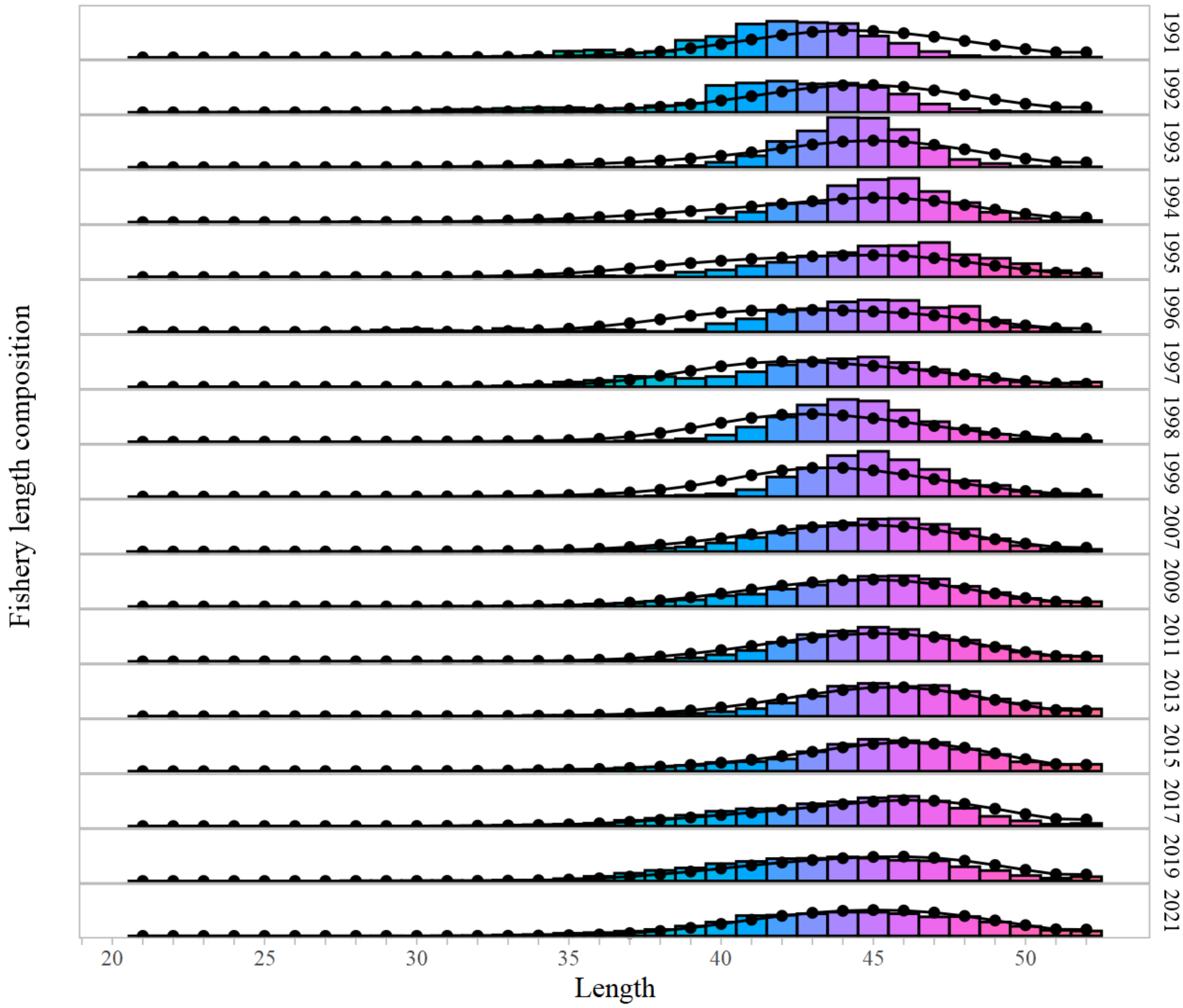


Figure 12-3. Fishery length compositions for GOA dusky rockfish. Observed values are bars, lines are the predicted lengths from author's recommended model.

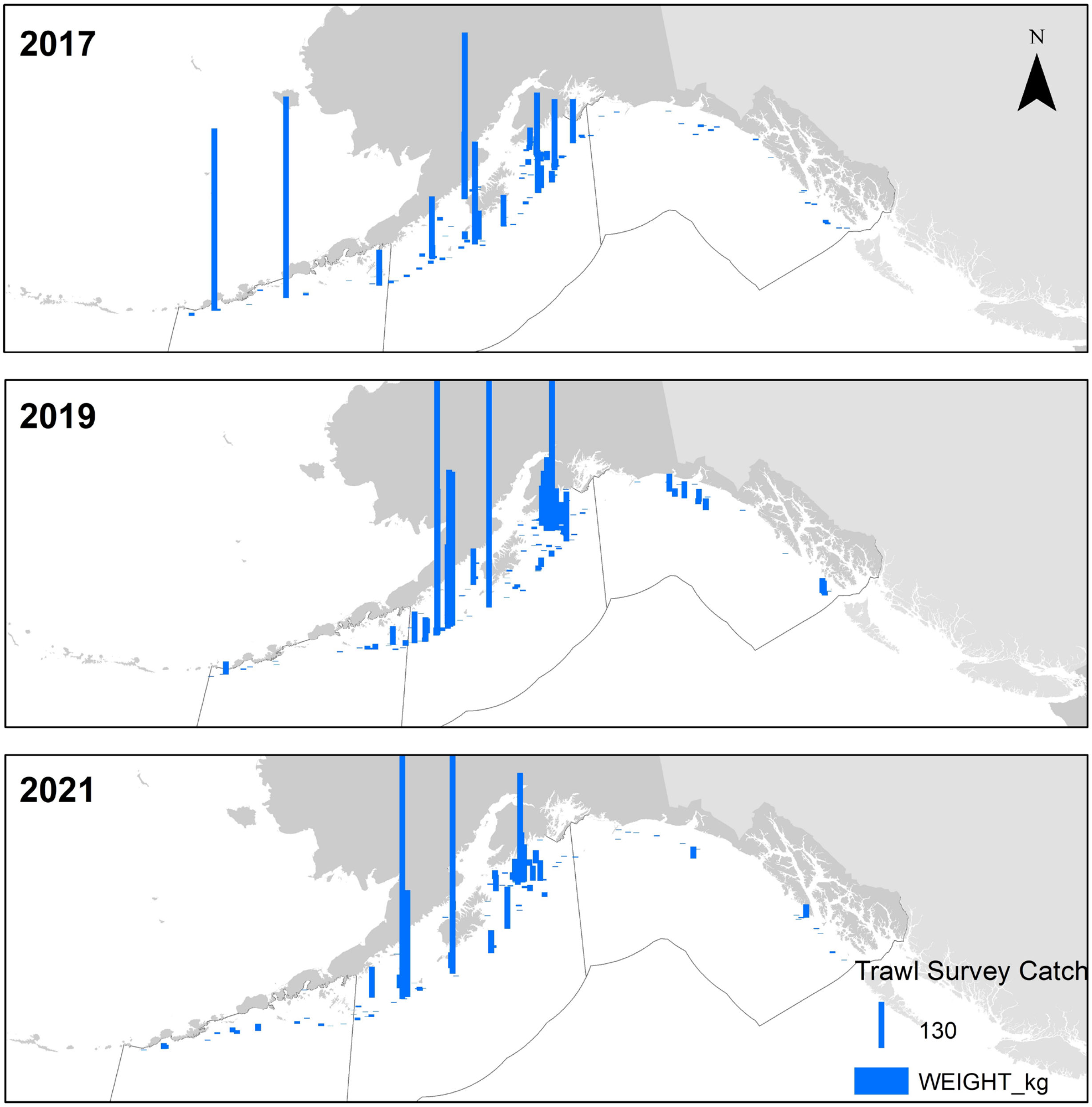


Figure 12-4. Spatial distribution of dusky rockfish in the Gulf of Alaska during the 2017, 2019, and 2021 NMFS trawl surveys.

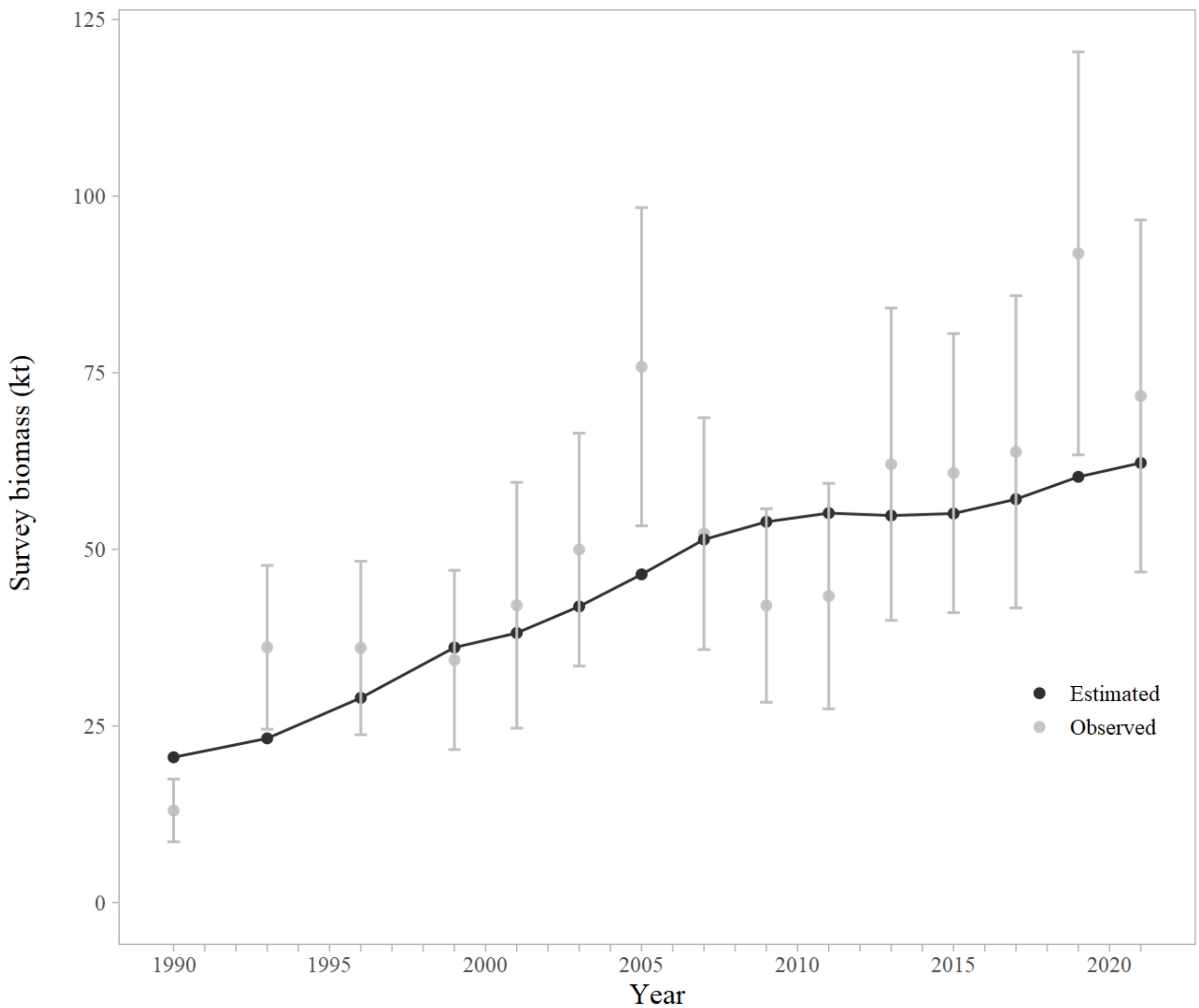


Figure 12-5. Observed VAST model-based estimates and predicted GOA dusky rockfish trawl survey biomass based on the 2022 recommended model. Error bars are approximate asymptotic 95% confidence intervals of model error.

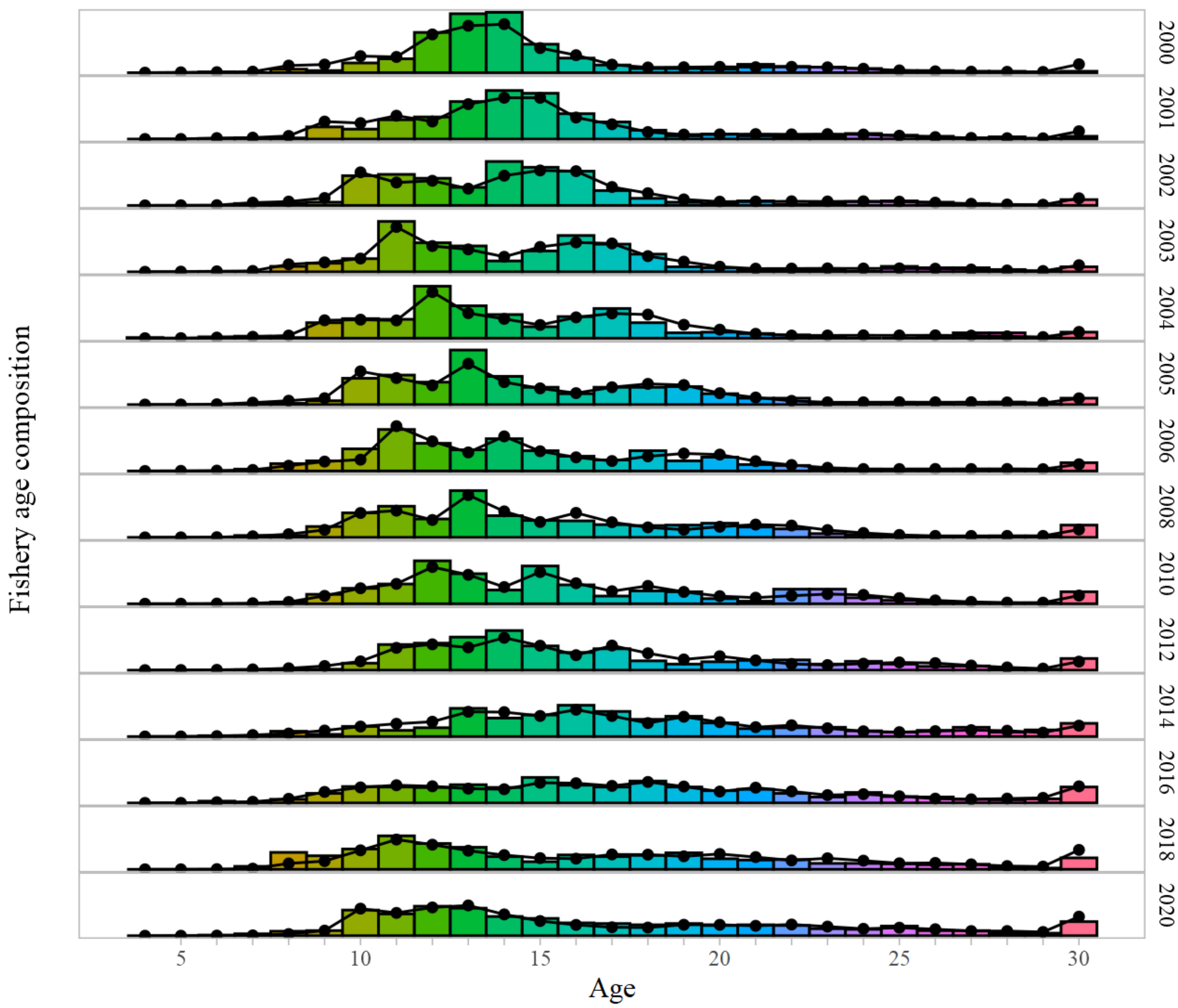


Figure 12-6. Fishery age compositions for GOA dusky rockfish. Observed values are bars, lines are the predicted lengths from author's recommended model.

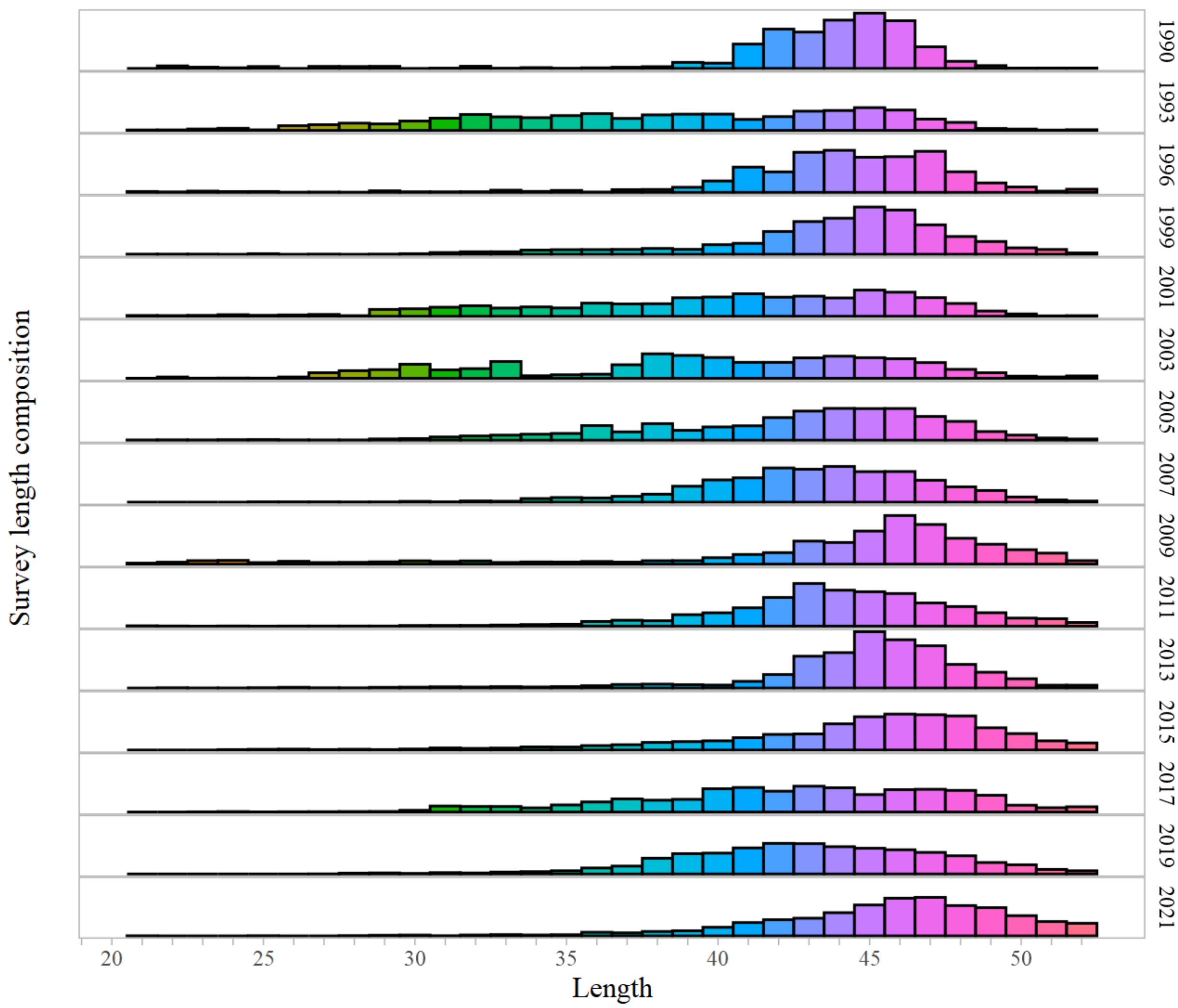


Figure 12-7. Survey length compositions (not used in model) for GOA dusky rockfish.

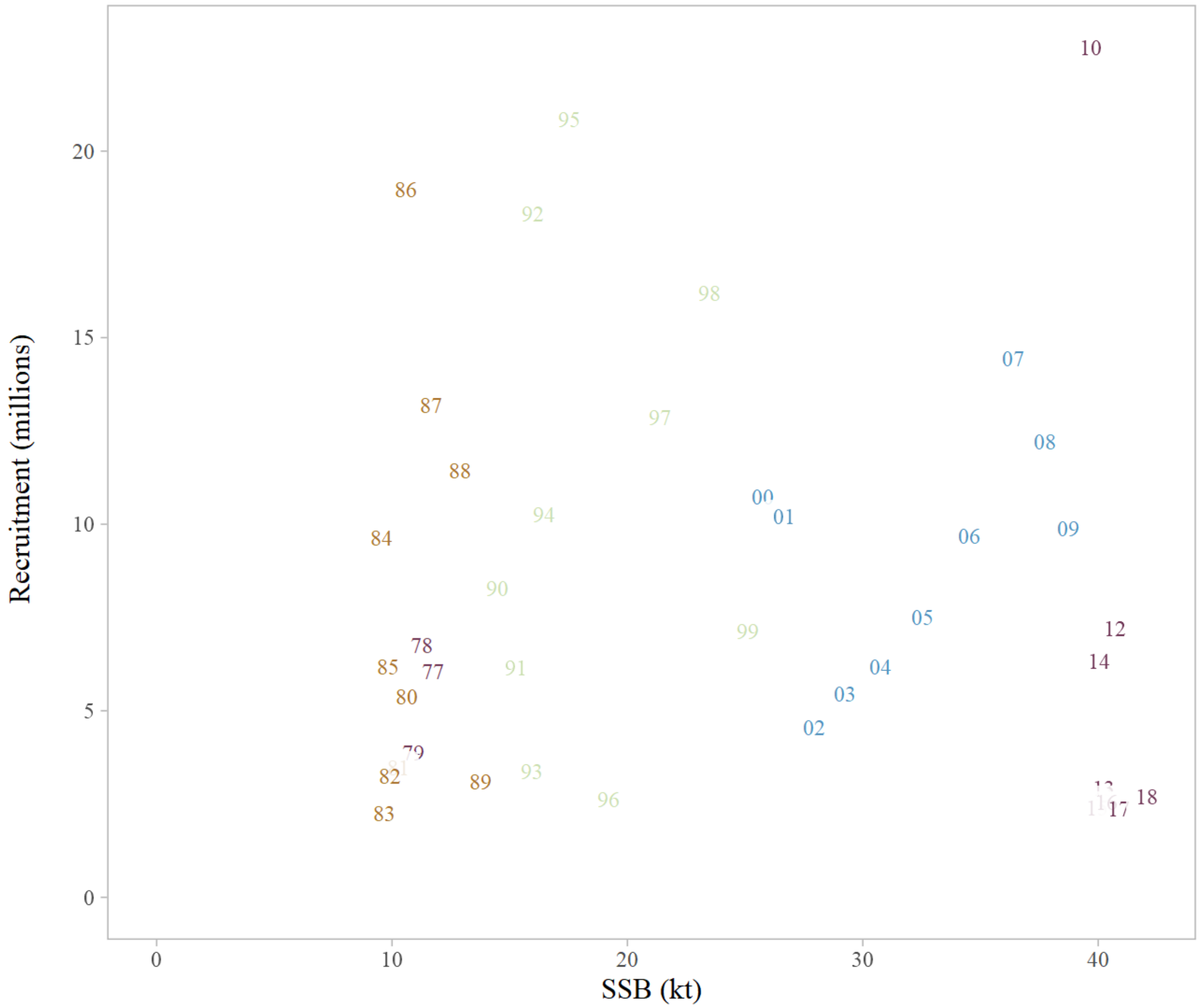


Figure 12-8. Scatterplot of spawner-recruit estimates for the GOA dusky rockfish author's recommended model.

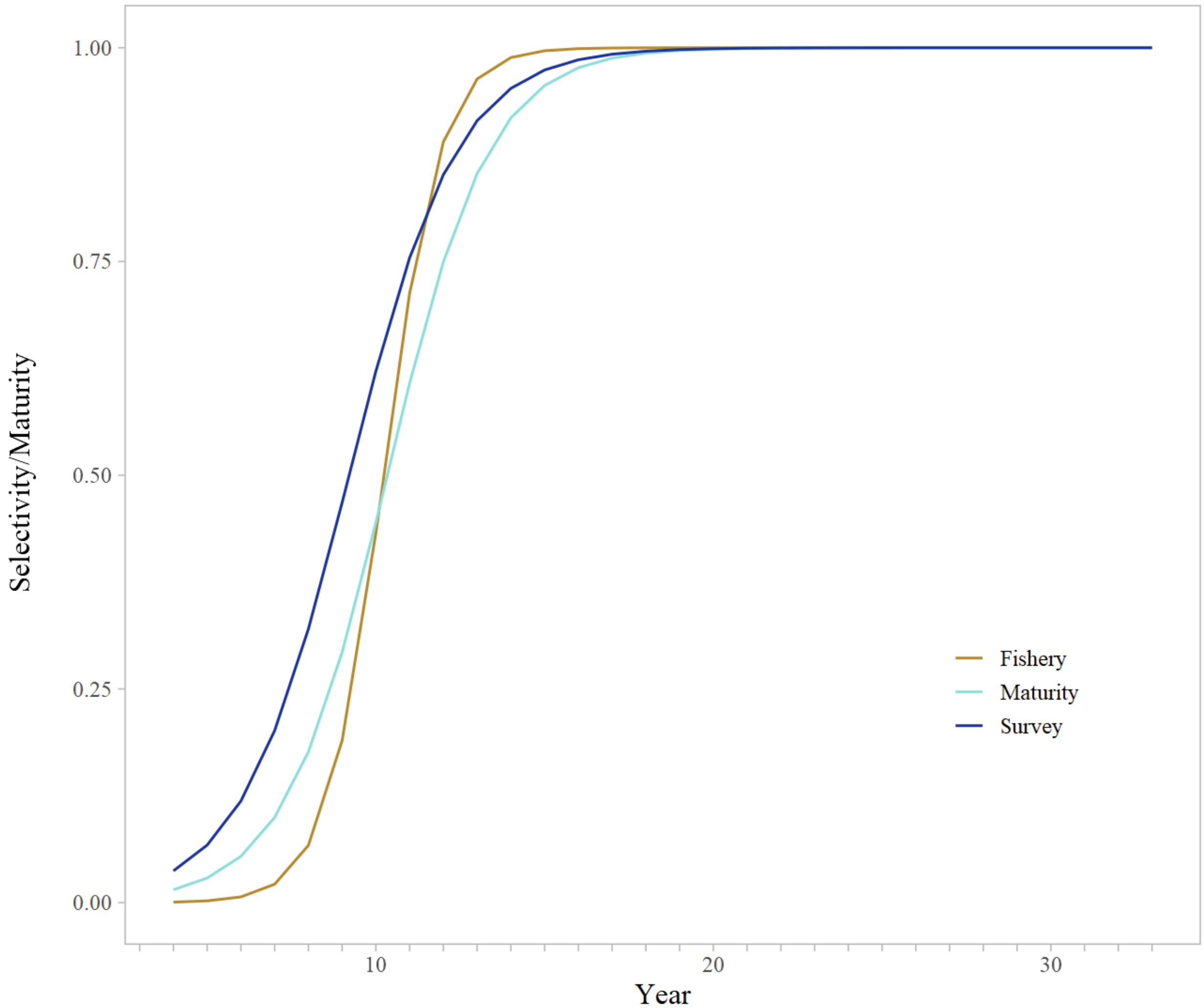


Figure 12-9. Estimated maturity, fishery and survey selectivities for GOA dusky rockfish from the 2022 model.

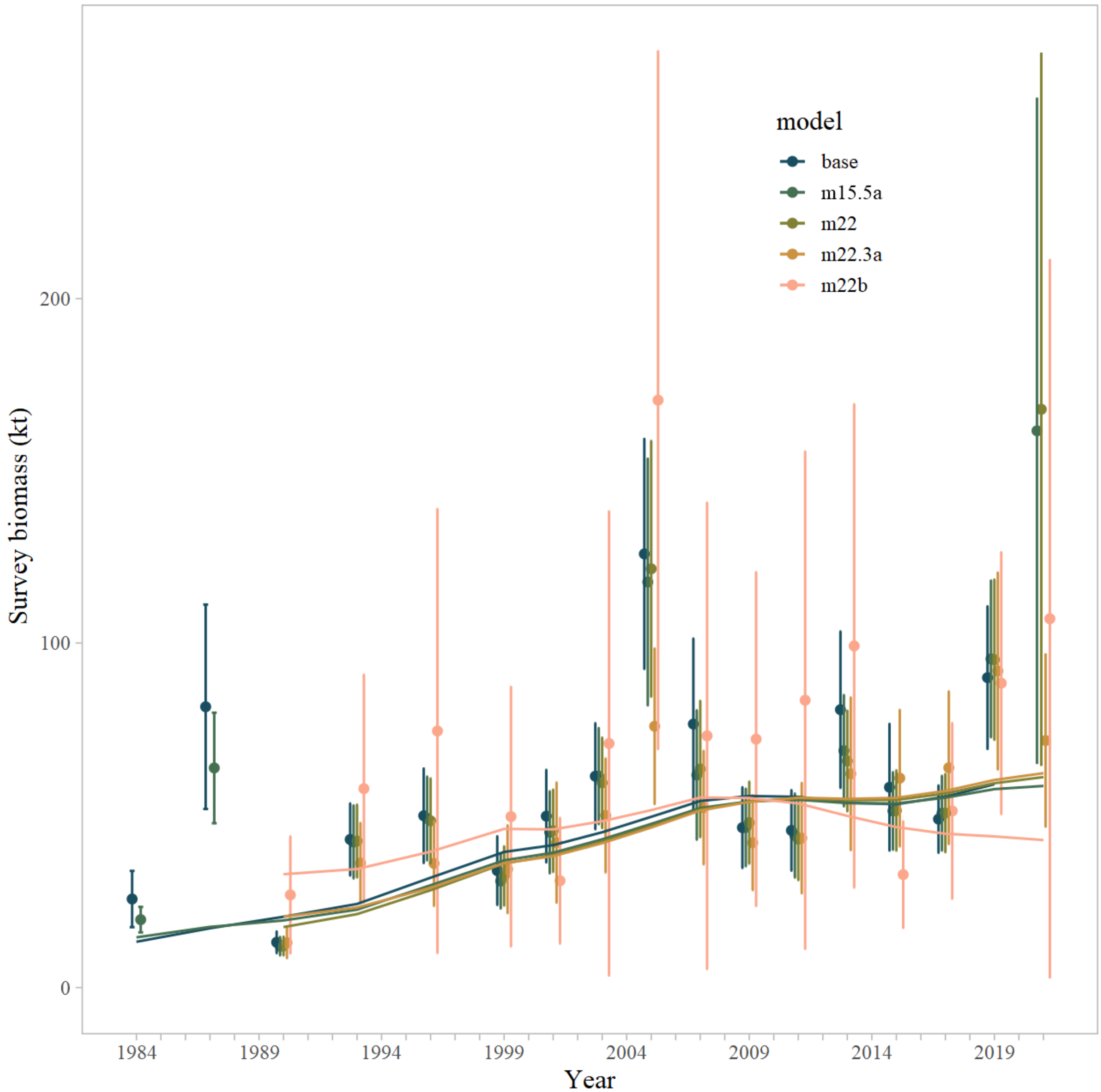


Figure 12-10. Comparisons of observed and predicted GOA dusky rockfish trawl survey biomass for different model variants. Error bars are approximate asymptotic 95% confidence intervals of model error. for different model variants.

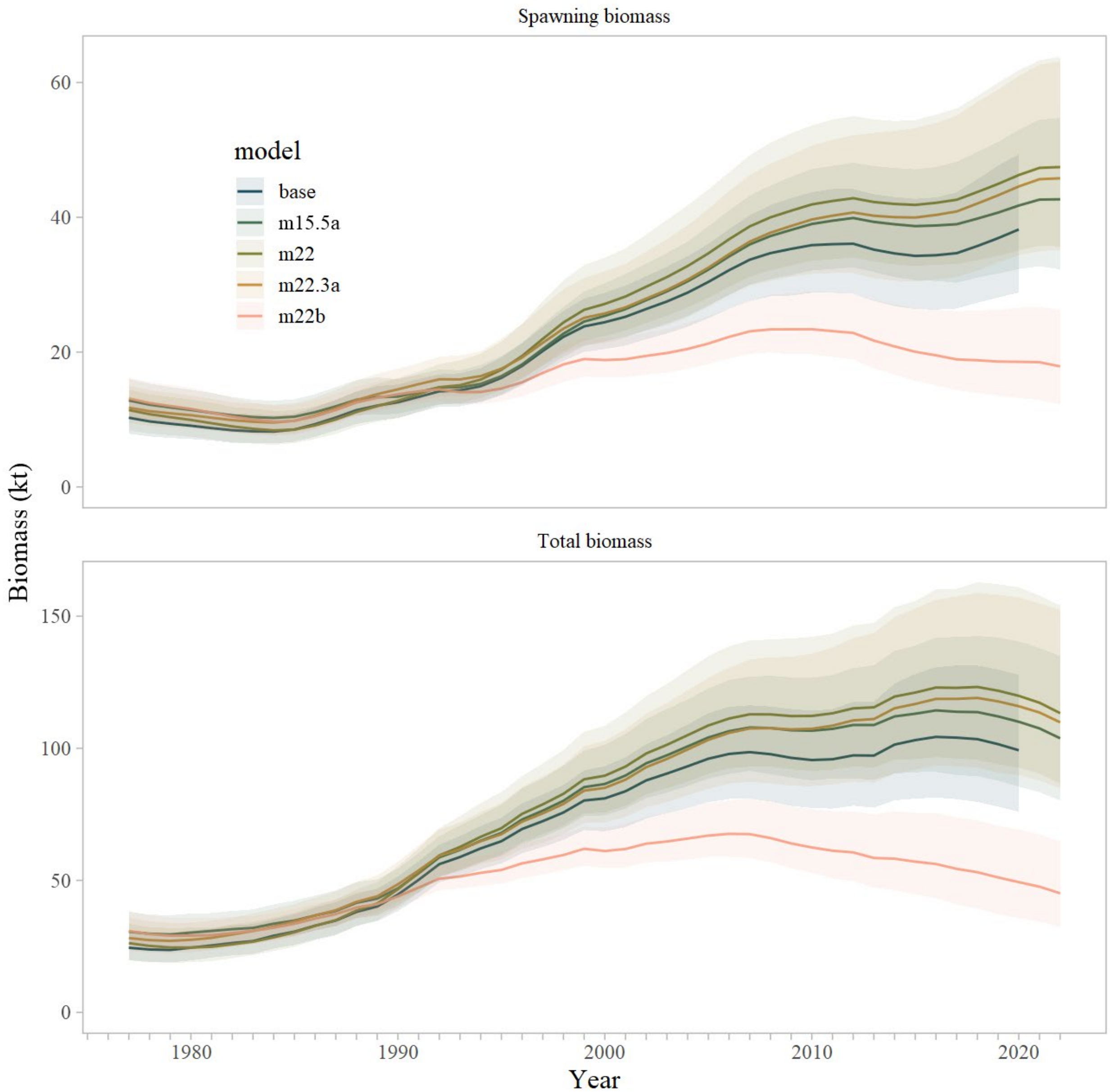


Figure 12-11. Comparisons of spawning and total biomass for different model variants.

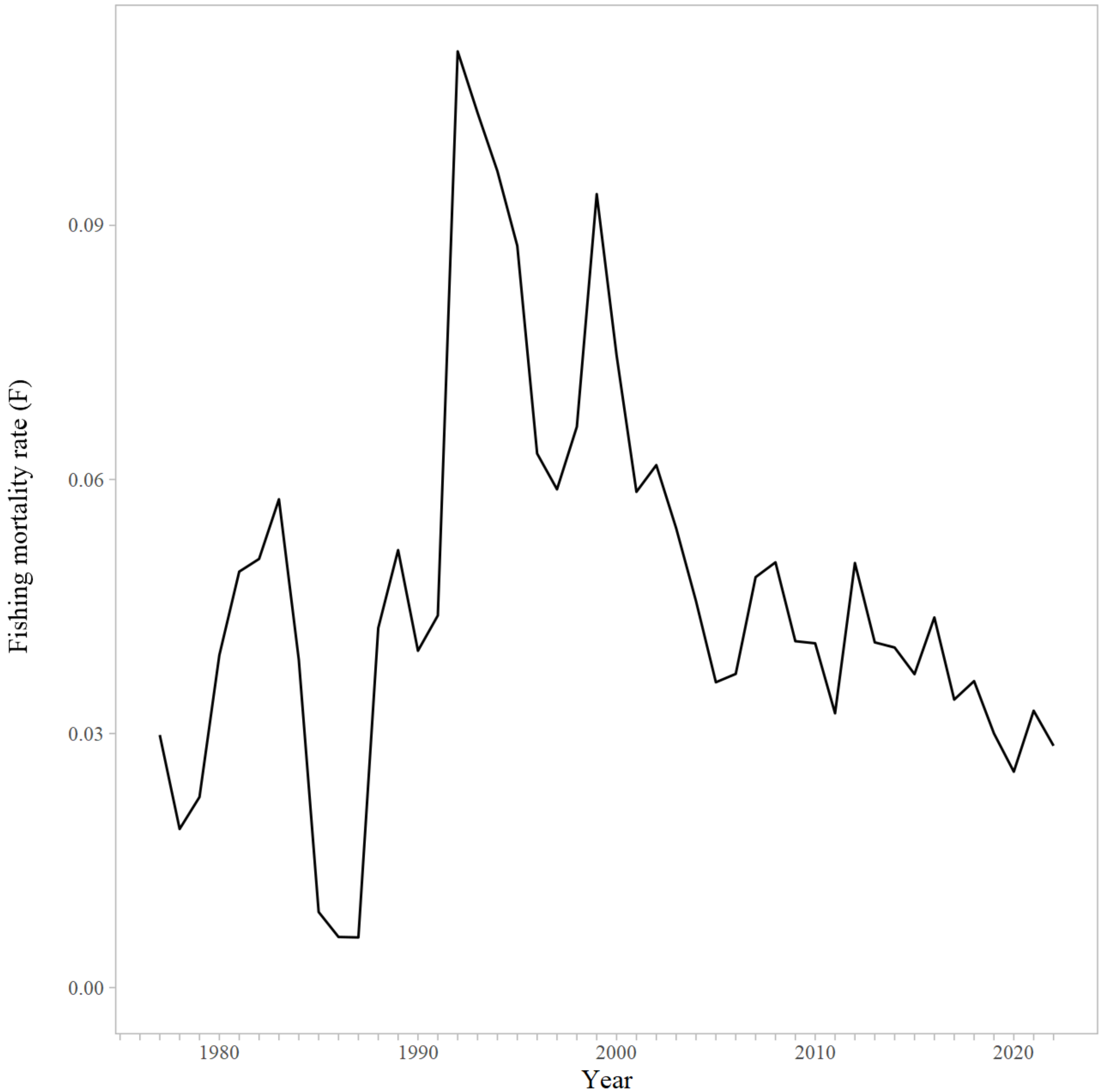


Figure 12-12. Time series of estimated fully selected fishing mortality for GOA dusky rockfish from the 2022 model.

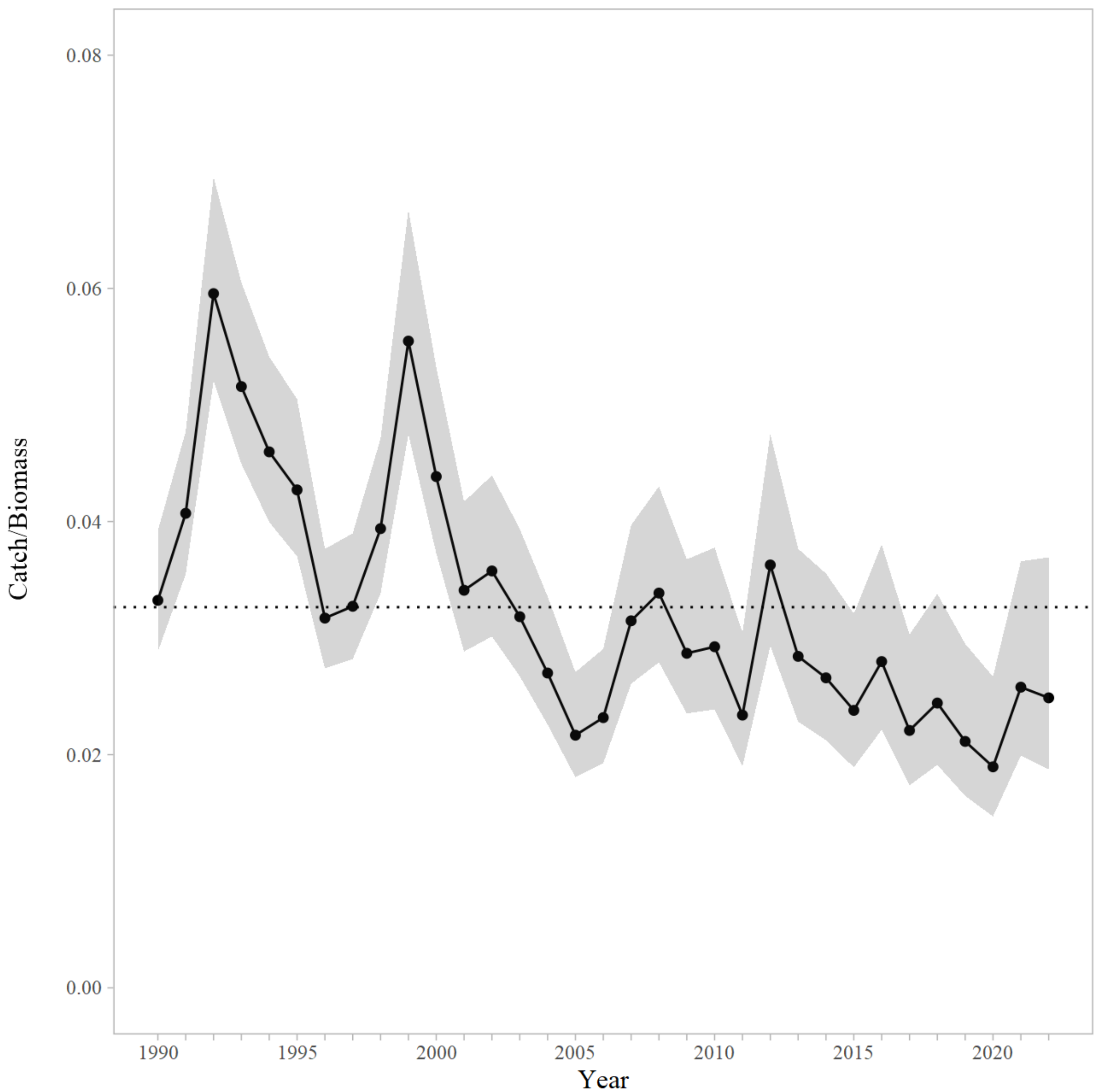


Figure 12-13. Gulf of Alaska dusky rockfish catch/age 4+ biomass ratio with approximate 95% confidence intervals. Observed catch values were used for 1990-2022, the 2022 catch values were estimated using an expansion factor. The horizontal dashed line is the mean value for the entire dataset.

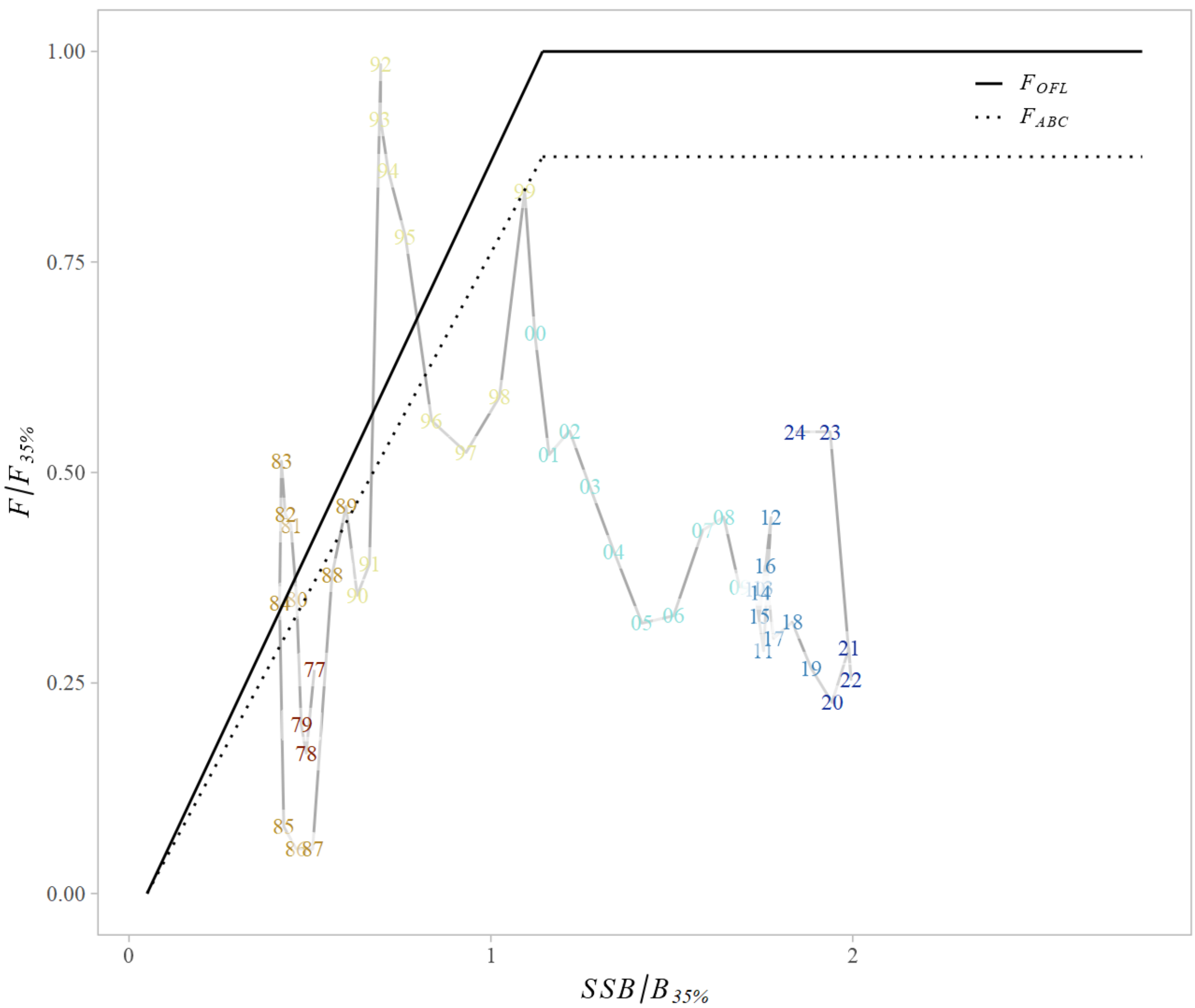


Figure 12-14. Time series of dusky rockfish estimated spawning biomass (SSB) relative to B_(35%) and fishing mortality (F) relative to F_(35%) for author recommended model.

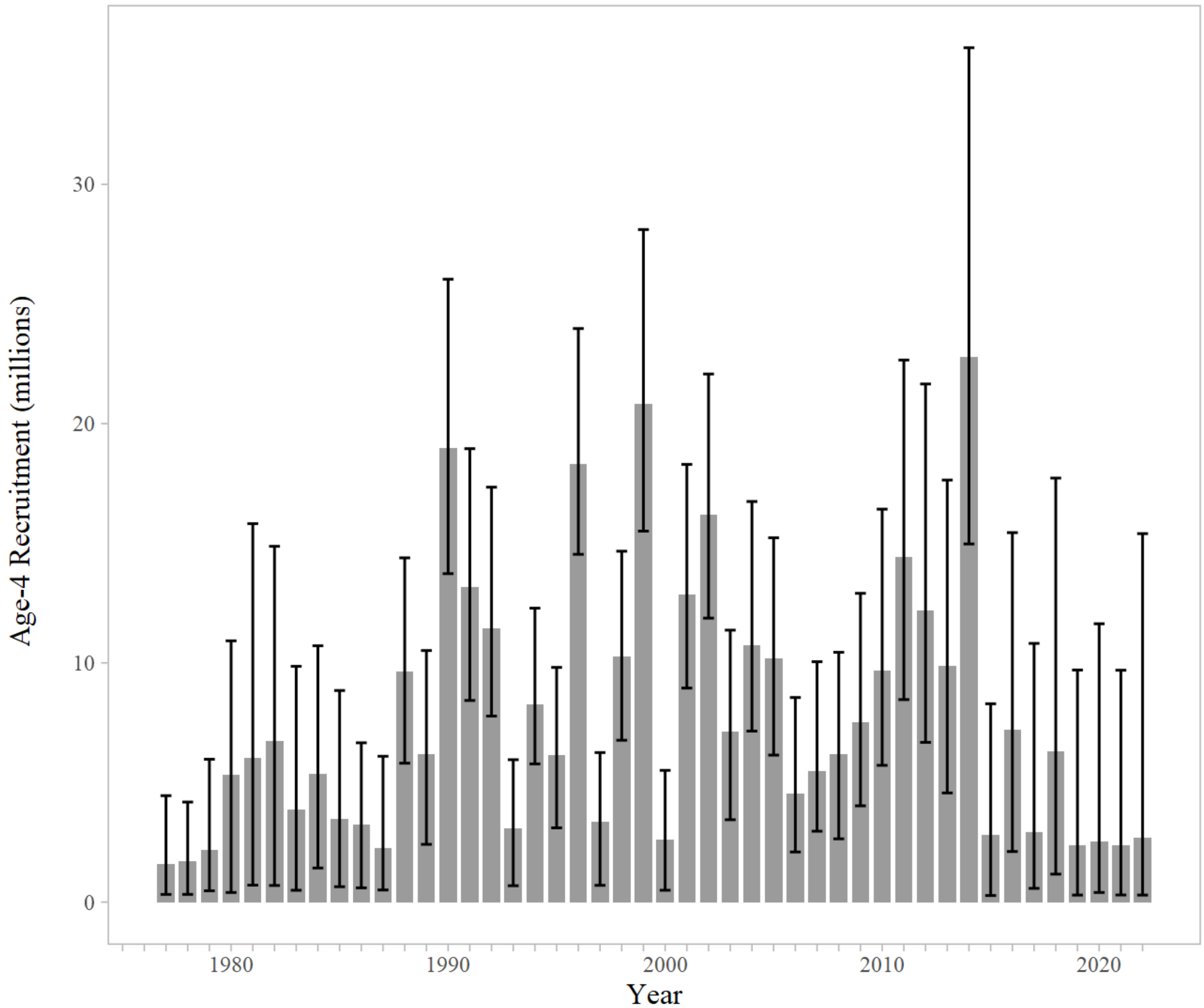


Figure 12-15. Estimates of age-4 recruitment with 95% credible intervals for GOA dusky rockfish.

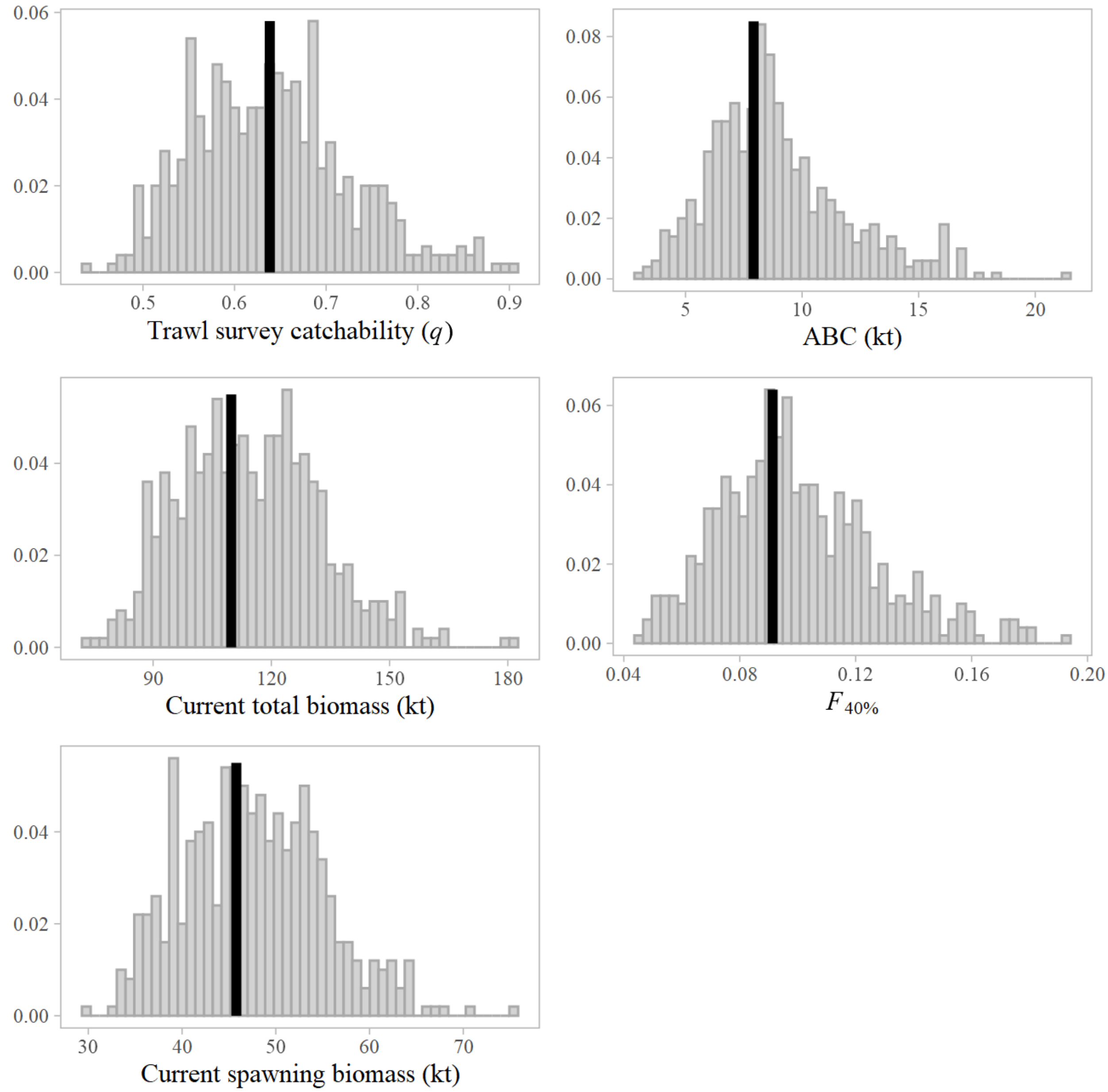


Figure 12-16. Histograms of estimated posterior distributions for key parameters derived (or estimated, in the case of *q*) from the MCMC for GOA dusky rockfish. Vertical black lines represent the maximum likelihood estimate for comparison with the MCMC results.

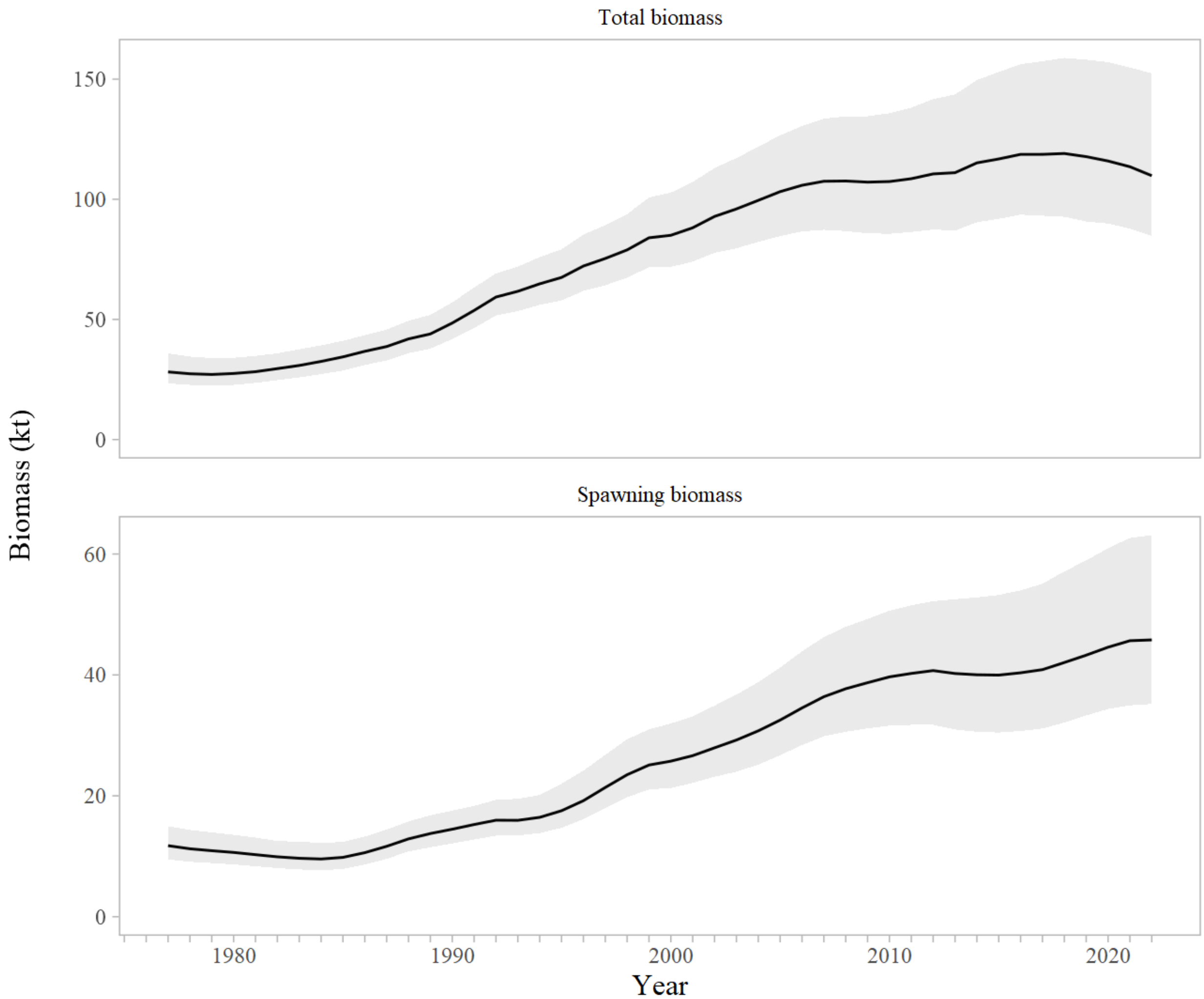


Figure 12-17. Model estimated total biomass and spawning biomass with 95% credible intervals determined by MCMC (shaded) for Gulf of Alaska dusky rockfish.

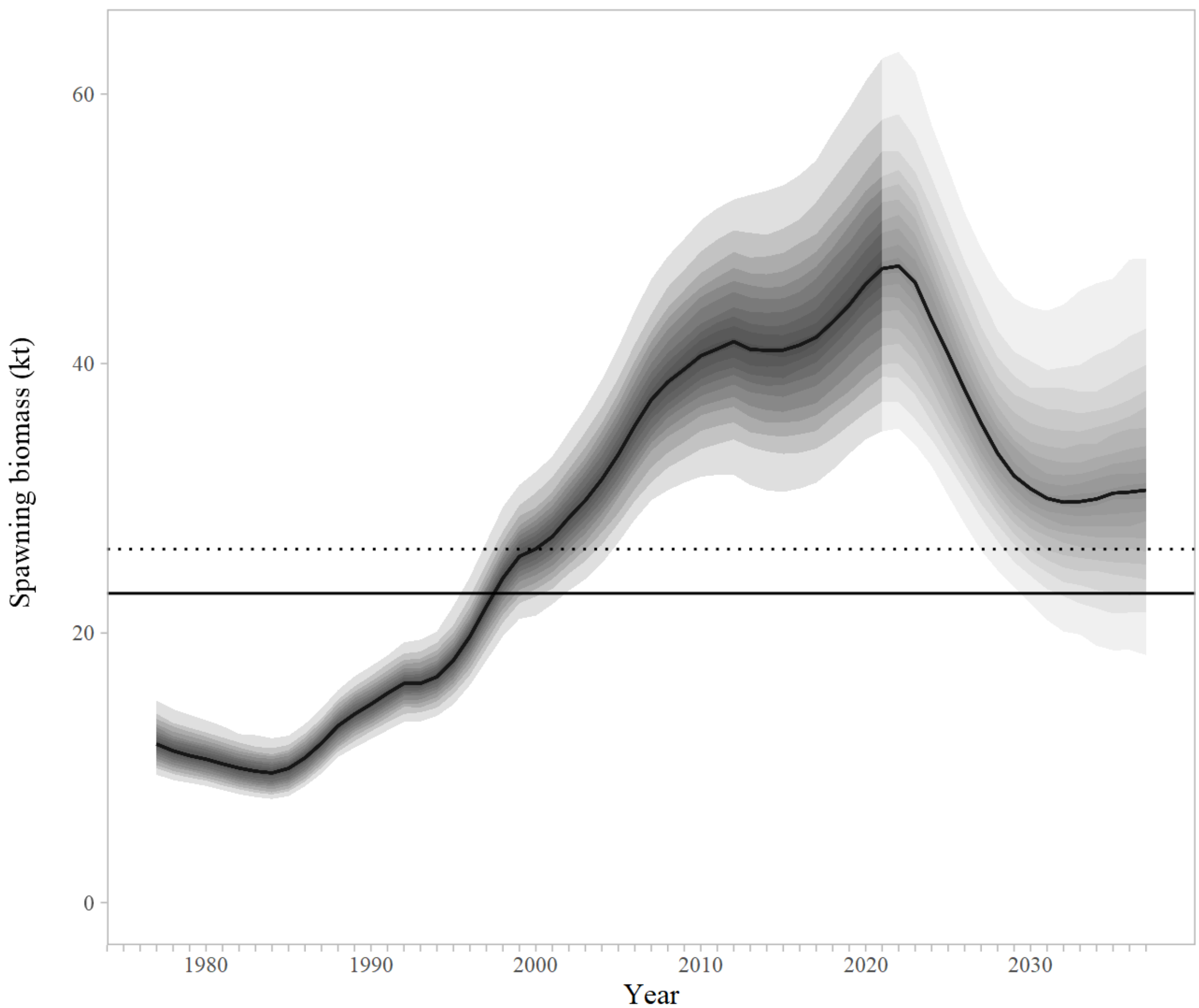


Figure 12-18. Median dusky rockfish spawning stock biomass from MCMC simulations with Bayesian credible intervals including projections for 2023-2037 (right of the vertical change in shading), when managing under Scenario 2. Assumes the same average yield ratio forward in time. Dotted horizontal line is $B_{40\%}$ and solid horizontal line is $B_{35\%}$ based on recruitments from 1977-2018. Each shade is 5% of the posterior distribution.

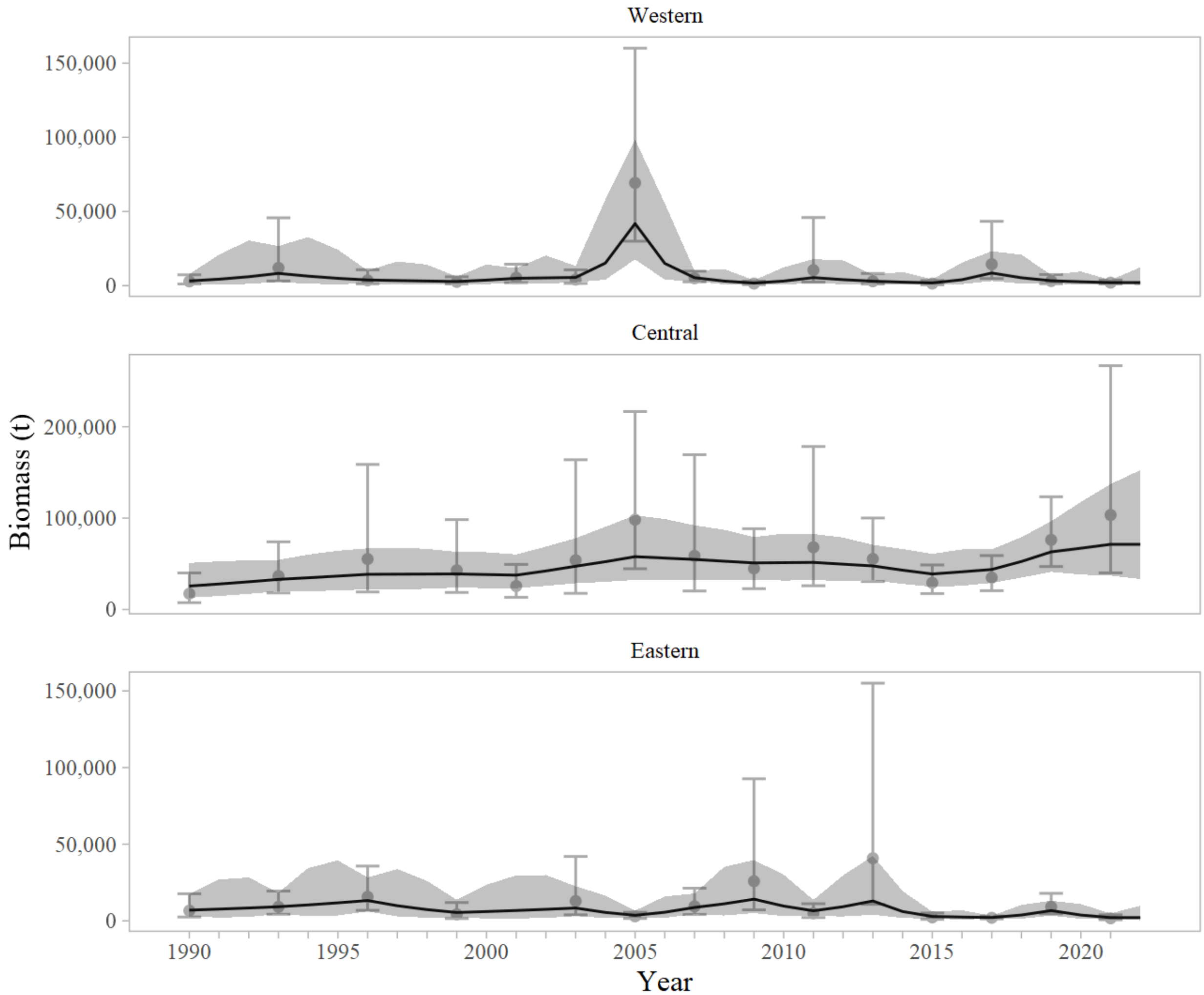


Figure 12-19. Random effects model fit (black line with 95% confidence intervals in light grey) to regional bottom trawl survey biomass (gray points and bar showing 95% sampling error confidence intervals).

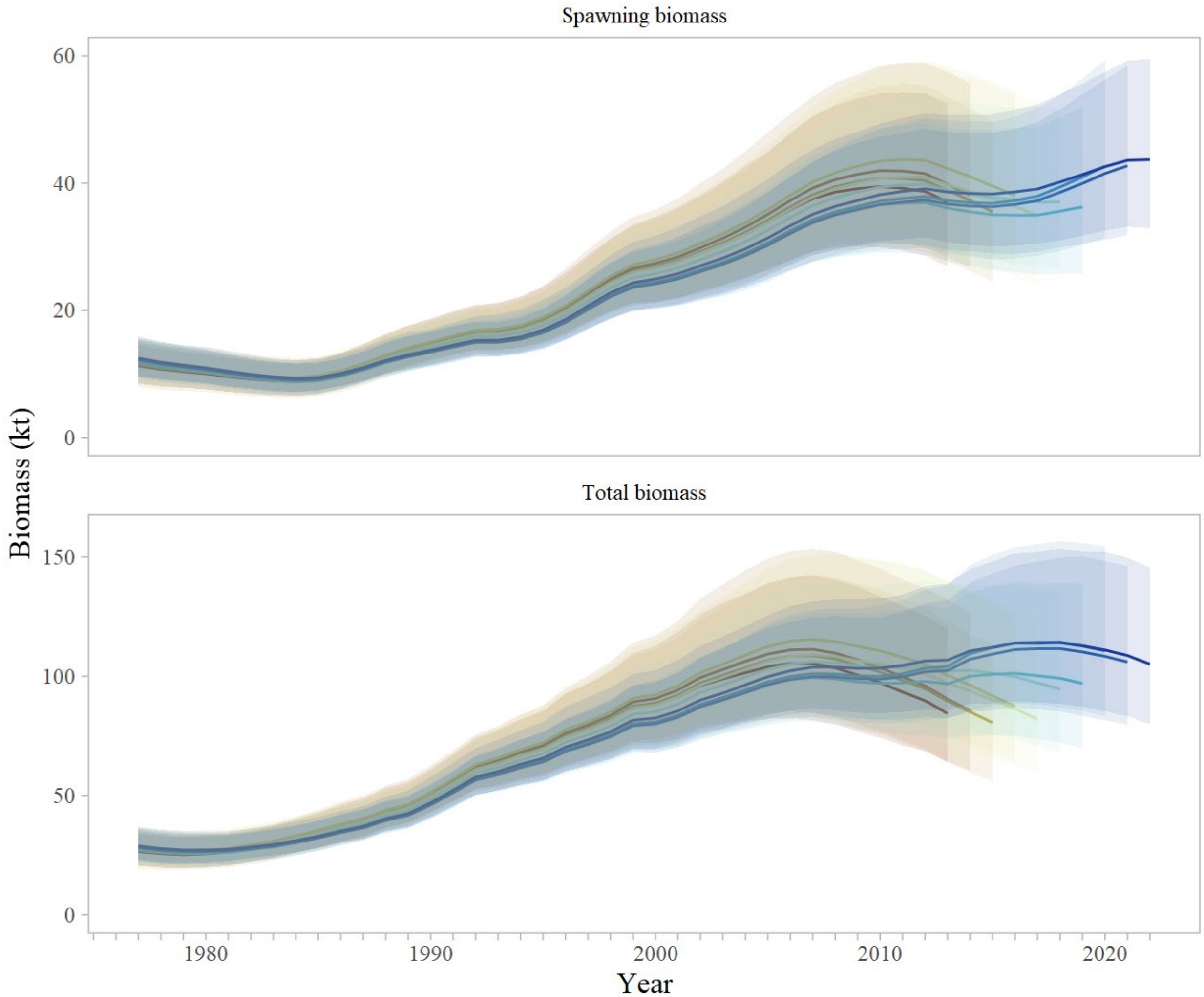


Figure 12-20. Retrospective peels of estimated female spawning biomass and total biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC. Mohn's rho value for spawning biomass is -0.123 and -0.115 for total biomass.

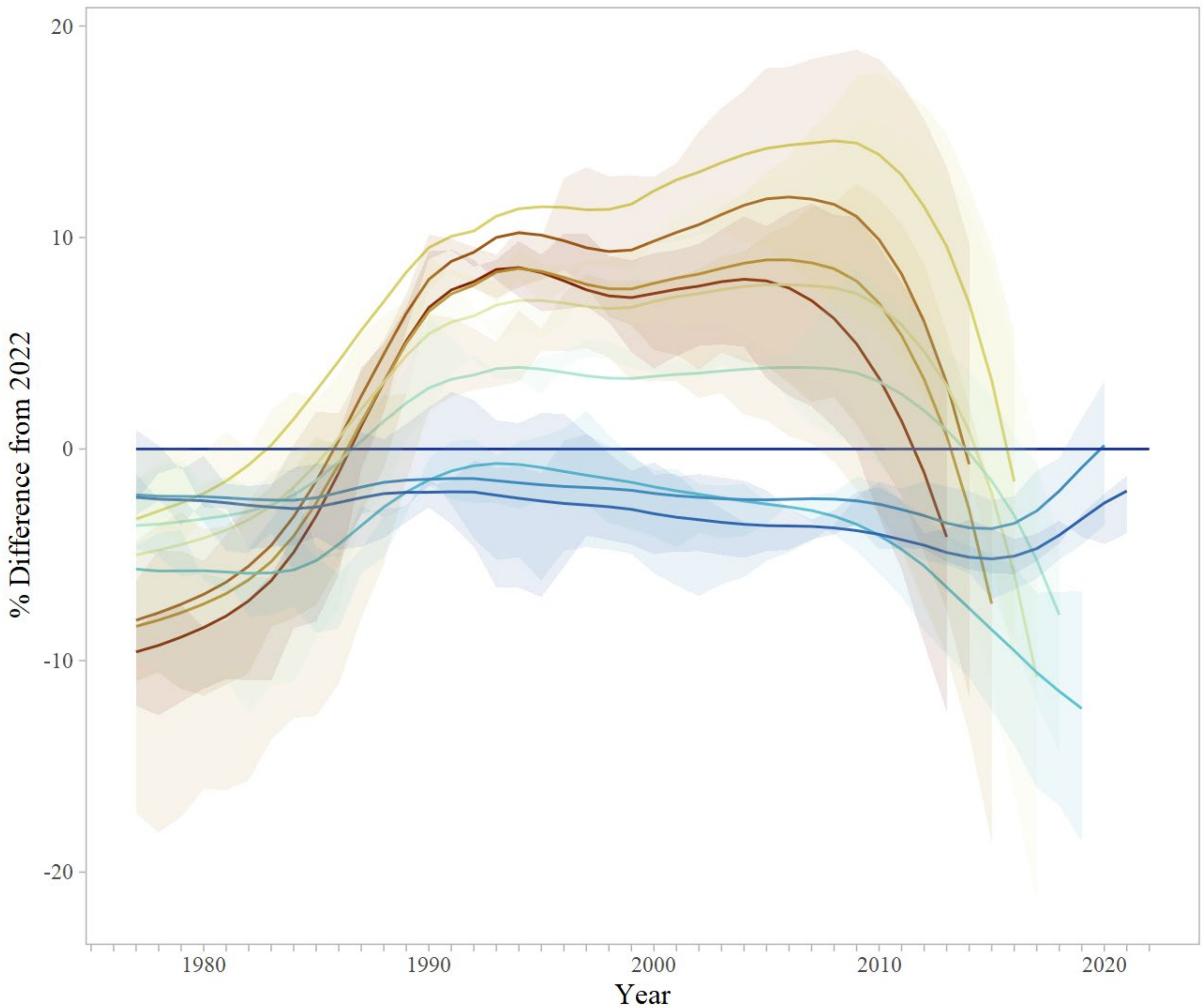


Figure 12-21. The percent difference in retrospective peels of female spawning biomass from the recommended model in the terminal year with 95% credible intervals from MCMC.

# Appendix 12a. Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, a dataset has been generated to help estimate total catch and removals from NMFS stocks in Alaska. This dataset estimates total removals that occur during non-directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For Gulf of Alaska (GOA) dusky rockfish, these estimates can be compared to the research removals reported in previous assessments (Heifetz et al. 2009; Table 10 A-1). Northern rockfish research removals are minimal relative to the fishery catch and compared to the research removals of other species. The majority of research removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of 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 2010–2021. 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.

## References

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 12a-1. 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 | Other | Recreational | Trawl | Total |
|---|---|---|---|---|
| 2010 | <1 | 9 | 1 | 10 |
| 2011 | <1 | 5 | 5 | 10 |
| 2012 | <1 | 8 | <1 | 8 |
| 2013 | <1 | 11 | 7 | 18 |
| 2014 | <1 | 16 | <1 | 16 |
| 2015 | <1 | 17 | 5 | 22 |
| 2016 | <1 | 18 | <1 | 18 |
| 2017 | <1 | 15 | 4 | 19 |
| 2018 | <1 | 11 | <1 | 11 |
| 2019 | 1 | 17 | 6 | 24 |
| 2020 | <1 | 8 | <1 | 8 |
| 2021 | <1 | 13 | 8 | 21 |

# Appendix 12b: VAST model-based abundance

## Background

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

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

## Settings used in 2021

The software versions of dependent programs used to generate VAST estimates were:

```
R (>=4.1.0), INLA (21.02.23), TMB (1.7.18), TMBhelper (1.3.0), VAST (3.6.1),
FishStatsUtils (2.8.0)
```

We used a Poisson-link delta-model (Thorson 2018) involving two linear predictors, and a gamma or lognormal distribution to model positive catch rates. We extrapolated catch density using 3705 m (2 nmi) X 3705 m (2 nmi) extrapolation-grid cells; this results in 36,690 extrapolation-grid cells for the eastern Bering Sea, 15,079 in the northern Bering Sea and 26,510 for the Gulf of Alaska (some Gulf of Alaska analyses eliminated the deepest stratum with depths >700 m because of sparse observations, resulting in a 22,604-cell extrapolation grid). We used bilinear interpolation to interpolate densities from 750 "knots" to these extrapolation-grid cells (i.e, using `fine_scale=TRUE` feature); knots were approximately evenly distributed over space, in proportion to the dimensions of the extrapolation grid. We estimated geometric anisotropy (how spatial autocorrelation declines with differing rates over distance in some cardinal directions than others), and included a spatial and spatio-temporal term for both linear predictors. To facilitate interpolation of density between unsampled years, we specified that the spatio-temporal fields were structured over time as an AR(1) process (where the magnitude of autocorrelation was estimated as a fixed effect for each linear predictor). However, we did not include any temporal correlation for intercepts, which we treated as fixed effects for each linear predictor and year. Finally, we used epsilon bias-correction to correct for retransformation bias (Thorson and Kristensen 2016).

**Diagnostics**

We checked model fits for evidence of non-convergence by confirming that (1) the derivative of the marginal likelihood with respect to each fixed effect was sufficiently small and (2) that the Hessian matrix was positive definite.
We then checked for evidence of model fit by computing Dunn-Smyth randomized quantile residuals (Dunn and Smyth 1996) and visualizing these using a quantile-quantile plot within the DHARMa R package.
We also evaluated the distribution of these residuals over space in each year, and inspected them for evidence of residual spatio-temporal patterns.

## References

Brodie, S.J., Thorson, J.T., Carroll, G., et al. (2020) Trade-offs in covariate selection for species distribution models: A methodological comparison. Ecography 43, 11–24.

Cao, J., Thorson, J., Richards, A. and Chen, Y. (2017) Geostatistical index standardization improves the performance of stock assessment model: An application to northern shrimp in the Gulf of Maine. Canadian Journal of Fisheries and Aquatic Sciences.

Dunn, K.P., and Smyth, G.K. 1996. Randomized quantile residuals. Journal of Computational and Graphical Statistics 5, 1-10.

Grüss, A. and Thorson, J.T. (2019) Developing spatio-temporal models using multiple data types for evaluating population trends and habitat usage. ICES Journal of Marine Science 76, 1748–1761.

Helser, T.E., Punt, A.E. and Methot, R.D. (2004) A generalized linear mixed model analysis of a multi-vessel fishery resource survey. Fisheries Research 70, 251–264.

Johnson, K.F., Thorson, J.T. and Punt, A.E. (2019) Investigating the value of including depth during spatiotemporal index standardization. Fisheries Research 216, 126–137.

Lo, N.C.-h., Jacobson, L.D. and Squire, J.L. (1992) Indices of relative abundance from fish spotter data based on delta-lognornial models. Canadian Journal of Fisheries and Aquatic Sciences 49, 2515–2526.

Maunder, M.N. and Punt, A.E. (2004) Standardizing catch and effort data: A review of recent approaches. Fisheries research 70, 141–159.

O'Leary, C.A., Thorson, J.T., Ianelli, J.N. and Kotwicki, S. Adapting to climate-driven distribution shifts using model-based indices and age composition from multiple surveys in the walleye pollock (gadus chalcogrammus) stock assessment. Fisheries Oceanography.

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

Stefánsson, G. (1996) Analysis of groundfish survey abundance data: Combining the GLM and delta approaches. ICES journal of Marine Science 53, 577–588.

Thorson, J.T. (2018) Three problems with the conventional delta-model for biomass sampling data, and a computationally efficient alternative. Canadian Journal of Fisheries and Aquatic Sciences 75, 1369–1382.

Thorson, J.T. and Barnett, L.A. (2017) Comparing estimates of abundance trends and distribution shifts using single-and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science 74, 1311–1321.

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

Thorson, J.T., Shelton, A.O., Ward, E.J. and Skaug, H.J. (2015) Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES Journal of Marine Science 72, 1297–1310.

Thorson, J.T. and Ward, E.J. (2013) Accounting for space–time interactions in index standardization models. Fisheries Research 147, 426–433.

# Appendix 12c: Model comparisons

## Trawl survey biomass examinations

A suite of VAST model alternative parameterizations were explored using the base model (2020 accepted model using 2020 data), the variants examined were:

- A = poisson-delta, gamma, 500 knots - 2020 accepted
- B = poisson-delta, gamma, 750 knots - 2020 accepted w/more knots (current default)
- C = delta, lognormal, 1000 knots
- D = delta, lognormal, 750 knots
- E = poisson-delta, lognormal, 750 knots
- F = delta, gamma, 750 knots

While survey survey biomass estimates inputs vary between VAST models the assessment model produces similar outputs for all of them (Figure 12c-1).

However, there are VAST variants that produce substantial annual variability between years (Figure 12c-2) and model that are less variable (Figure 12c-3). Given the relative longevity of the species it is unlikely that the large swings in estimated biomass are correct. They are likely due to the trawl survey sample design and inability to trawl in the preferred habitat of dusky rockfish. Though it is unclear whether addressing this sampling issue via modeling is appropriate it would be more in line with our understanding of the stock dynamics to choose a model that has less annual variability.

The spawning and total biomass estimates from the base model do vary depending upon the VAST survey model inputs (Figure 12c-4). The higher variability VAST model inputs differ from the base model (A), w/the current VAST default parameterization (B) increases both spawning and total biomass estimates (Figure 12c-5). The lower variability VAST model inputs all estimate less total and spawning biomass than the base model. Model E which only differs from the current default model (B) by using a lognormal error structure is just slightly under the estimates from the default VAST parameterization (Figure 12c-6), and is also below VAST input B.

Further examination of the current GAP recommended default model (B) and model E is warranted so model residuals were examined. VAST model B (current default) model residuals show more deviation from observed values (Figure 12c-7) than VAST model E (Figure 12c-8). Therefore our recommendation is to use VAST model E as it maintains the use of the delta model (reduced bias), has same number of knots as default GAP settings, has improved residual diagnostics and is precautionary relative to default GAP settings.

## Age and length plus group examinations

The SSC and Plan Team have requested an examination of changing the age and length plus groups for GOA dusky rockfish. Presented here are model results using the 2020 base model with an increase in the age plus group from age-25+ to age-30+ and increase in the length plus group from 47 cm to 52 cm. Increasing the length plus group, provides greater resolution of lengths (Figures 12c-9 and 12c-10), though the increase in modeled composition data does not have an effect on total or spawning biomass (Figure 12c-11).

Increasing the age plus group provides greater resolution and the model fits are slightly better for the plus age (Figures 12c-12 and 12c-13). There is a slight increase in total and spawning biomass associated with the increase in the age plus group (Figure 12c-14).
Introducing both an increase in the age and length composition data produced the same results as the

increase in age compositions so they are not shown. Associated likelihood values did increase (due to more age compositions for the model to estimate; Table 12c-1). Given the improved resolution and limited impact on model outcomes it is recommended to increase both the age and length compositions.

## 2022 model comparisons

Using the design-based survey biomass inputs produces both similar results for both modeled survey biomass predictions (Figure 12c-15) and estimates of spawning and total biomass (Figure 12c-16). These similarities occure regardless of increases in length or age plus groups, therefore to reduce the overall number of models being compared only m22b will be presented hereon and since the assessment has switched to using VAST estimates for survey abundance inputs, the design-based model (m22b) is presented for reference though not discussed.

The base model, m15.5a and m22 all have similar survey biomass input values and produce similar survey biomass estimates (Figure 12c-17), however the spawning and total biomass estimates increase for each iterative model (Figure 12c-18).
Since the most appropriate survey inputs exclude the 1980s data, m15.5a is dropped from review in favor of m22, these are the same models with m22 using survey data from 1990+. Increasing the length composition data by 5 cm (m22.1) produces the same survey biomass estimates as m22 (Figure 12c-19) and slightly decreases the overall spawning and total biomass estimates from m22 (Figure 12c-20).

Similar results are observed when the age-plus group in increased by 5 ages to age-30. The estimates of survey biomass are the same between m22.1 and m22.2 (Figure 12c-21) though the spawning and total biomass increase (Figure 12c-22). The same results are observed when both the age and length plus groups are increased (Figures 12c-23 and 12c-24).

Changing to a VAST lognormal error structure produces a different survey estimate, with the most noticeable differences being the decreased annual variability in VAST model inputs and a decreases from the 2019 etsimate to the 2021 estimate (Figure 12c-25). The spawning and total biomass are decreased from m22 (Figure 12c-26).

Similar results are observed when the length plus group is increased (Figures 12c-27 and 12c-28), the age plus group is increased (Figures 12c-29 and 12c-30) and when the length and age plus groups are increased (Figures 12c-31 and 12c-32).

Examinations or likelihoods and parameter estimates (Tables 12c-2 and 12c-3) show that overall model likelihoods are similar or follow expected trends (e.g., increase with increased parameterizations) though the introduction of the lognormal error structure in VAST (models with “a”) improves the data likelihoods from the base model. The design-based model estimates similar, or lower, data likelihoods. However, the design-based estimates of *q* are substantially higher, an unlikely scenario given understanding that this stock tends to inhabit areas on “untrawlable” habitat.

# Tables

Table 12c-1. Model likelihoods for increased age and length composition data.

| | Base | Length | Age | Age/Length |
|---|---|---|---|---|
| Parameters | 124 | 124 | 130 | 130 |
| | | | | |
| Likelihoods | | | | |
| Data | 332.8 | 340.1 | 350.7 | 3,256.6 |
| Survey-age | 124.8 | 124.4 | 131.9 | 132.1 |
| Fishery-age | 32.8 | 32.8 | 38.9 | 38.7 |
| Fishery-length | 49.2 | 55.9 | 52.2 | 57.6 |

Table 12c-2. Likelihood values and estimates of key parameters for a select few models for GOA dusky rockfish.

| Likelihoods | base | m15.5a | m22 | m22.1 | m22.2 | m22.3 | m22a | m22.1a | m22.2a | m22.3a |
|---|---|---|---|---|---|---|---|---|---|---|
| Catch | 26.96 | 29.70 | 25.06 | 24.94 | 25.24 | 25.16 | 25.57 | 25.40 | 25.85 | 25.72 |
| Survey biomass | 98.95 | 118.58 | 74.21 | 74.19 | 75.70 | 75.70 | 29.23 | 29.21 | 30.05 | 30.03 |
| Fishery ages | 32.84 | 36.73 | 36.60 | 36.41 | 43.76 | 43.52 | 35.06 | 34.90 | 41.74 | 41.52 |
| Survey ages | 124.75 | 145.09 | 130.01 | 130.40 | 140.01 | 140.32 | 127.16 | 127.49 | 137.85 | 138.14 |
| Fishery lengths | 49.29 | 57.92 | 53.82 | 58.57 | 55.15 | 60.12 | 53.86 | 58.66 | 55.04 | 60.03 |
| Data | 332.80 | 388.03 | 319.70 | 324.51 | 339.86 | 344.82 | 270.89 | 275.66 | 290.54 | 295.43 |
| | | | | | | | | | | |
| Penalties/Priors | | | | | | | | | | |
| Recruitment devs | 38.83 | 33.91 | 41.34 | 42.09 | 40.88 | 41.58 | 36.30 | 37.13 | 35.43 | 36.21 |
| *F* regularity | 31.62 | 35.51 | 32.60 | 32.34 | 32.91 | 32.71 | 34.16 | 33.87 | 34.21 | 33.98 |
| $\sigma_r$ prior | 0.25 | 0.40 | 0.22 | 0.20 | 0.29 | 0.28 | 0.34 | 0.31 | 0.43 | 0.41 |
| $q$ prior | 0.32 | 0.60 | 0.64 | 0.59 | 0.83 | 0.77 | 0.45 | 0.41 | 0.54 | 0.50 |
| Objective function | 468.81 | 523.65 | 459.28 | 464.53 | 479.47 | 484.87 | 406.80 | 412.08 | 425.72 | 431.13 |
| | | | | | | | | | | |
| Parameter estimates | | | | | | | | | | |
| # parameters | 124 | 126 | 128 | 128 | 133 | 133 | 128 | 128 | 133 | 133 |
| $q$ | 0.70 | 0.61 | 0.60 | 0.62 | 0.56 | 0.57 | 0.65 | 0.67 | 0.63 | 0.64 |
| $\sigma_r$ | 1.10 | 1.01 | 1.12 | 1.13 | 1.07 | 1.08 | 1.04 | 1.05 | 0.99 | 1.00 |
| Mean recruitment | 2.22 | 0.99 | 0.90 | 0.87 | 0.97 | 0.95 | 0.96 | 0.94 | 1.02 | 0.99 |
| $F_{40\%}$ | 0.93 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Projected total biomass | 97,702 | 101,171 | 110,493 | 108,291 | 117,133 | 115,044 | 105,736 | 103,929 | 108,833 | 107,160 |
| Projected spawning biomass | 38,362 | 41,453 | 46,083 | 45,142 | 48,951 | 48,056 | 43,847 | 43,083 | 45,164 | 44,495 |
| $B_{100\%}$ | 60,855 | 63,038 | 67,517 | 66,669 | 70,174 | 69,358 | 64,914 | 64,249 | 66,181 | 65,565 |
| $B_{40\%}$ | 24,342 | 25,215 | 27,007 | 26,667 | 28,070 | 27,743 | 25,966 | 25,699 | 26,473 | 26,226 |
| ABC | 7,101 | 7,279 | 8,187 | 8,030 | 8,660 | 8,511 | 7,829 | 7,702 | 8,037 | 7,917 |

Table 12c-3. Likelihood values and estimates of key parameters for design-based survey inputs for GOA dusky rockfish.

| Likelihoods | m22b | m22.1b | m22.2b | m22.3b |
|---|---|---|---|---|
| Catch | 33.04 | 32.76 | 33.99 | 33.76 |
| Survey biomass | 20.99 | 21.00 | 21.10 | 21.11 |
| Fishery ages | 34.75 | 34.59 | 41.02 | 40.79 |
| Survey ages | 125.73 | 125.94 | 137.18 | 137.36 |
| Fishery lengths | 53.86 | 58.68 | 54.91 | 59.92 |
| Data | 268.37 | 272.97 | 288.20 | 292.93 |
| Penalties/Priors | | | | |
| Recruitment devs | 15.31 | 16.50 | 12.04 | 13.14 |
| *F* regularity | 6.36 | 35.94 | 36.54 | 36.19 |
| $\sigma_r$ prior | 1.09 | 1.03 | 1.29 | 1.24 |
| *q* prior | 0.01 | 0.02 | 0.01 | 0.01 |
| Objective function | 386.15 | 391.45 | 403.08 | 408.51 |
| Parameter estimates | | | | |
| # parameters | 128 | 128 | 133 | 133 |
| *q* | 1.08 | 1.09 | 1.06 | 1.07 |
| $\sigma_r$ | 0.78 | 0.79 | 0.73 | 0.74 |
| Mean recruitment | 0.89 | 0.87 | 0.93 | 0.91 |
| $F_{40\%}$ | 0.09 | 0.09 | 0.09 | 0.09 |
| Projected total biomass | 43,553 | 42,883 | 43,576 | 42,990 |
| Projected spawning biomass | 16,839 | 16,583 | 16,780 | 16,556 |
| $B_{100\%}$ | 42,320 | 42,140 | 42,316 | 42,153 |
| $B_{40\%}$ | 16,928 | 16,856 | 16,926 | 16,861 |
| ABC | 2,984 | 2,909 | 2,955 | 2,890 |

# Figures

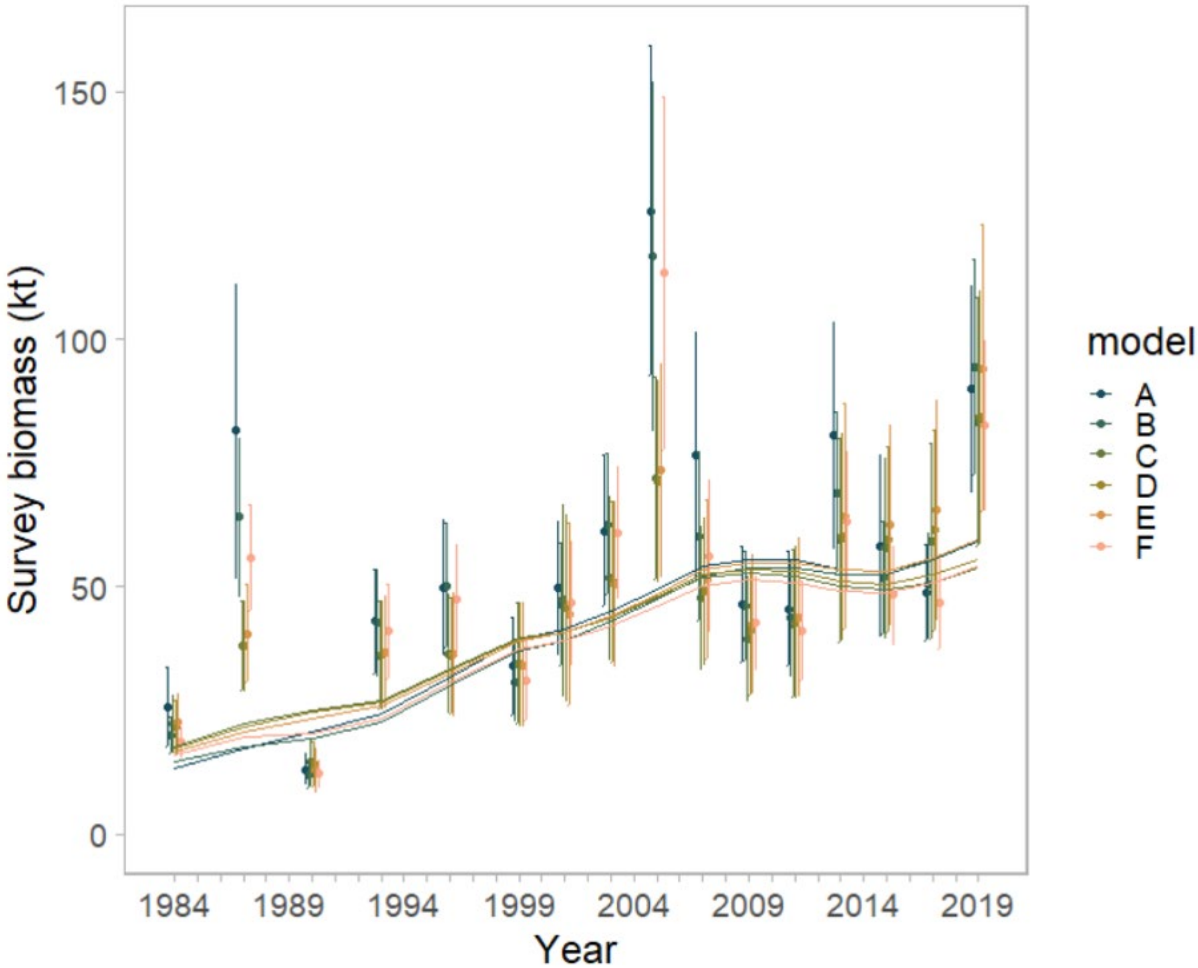


Figure 12c-1. Observed VAST (points) and predicted (lines) GOA dusky rockfish trawl survey biomass based on the 2020 recommended model. Error bars are approximate asymptotic 95% confidence intervals of model error.

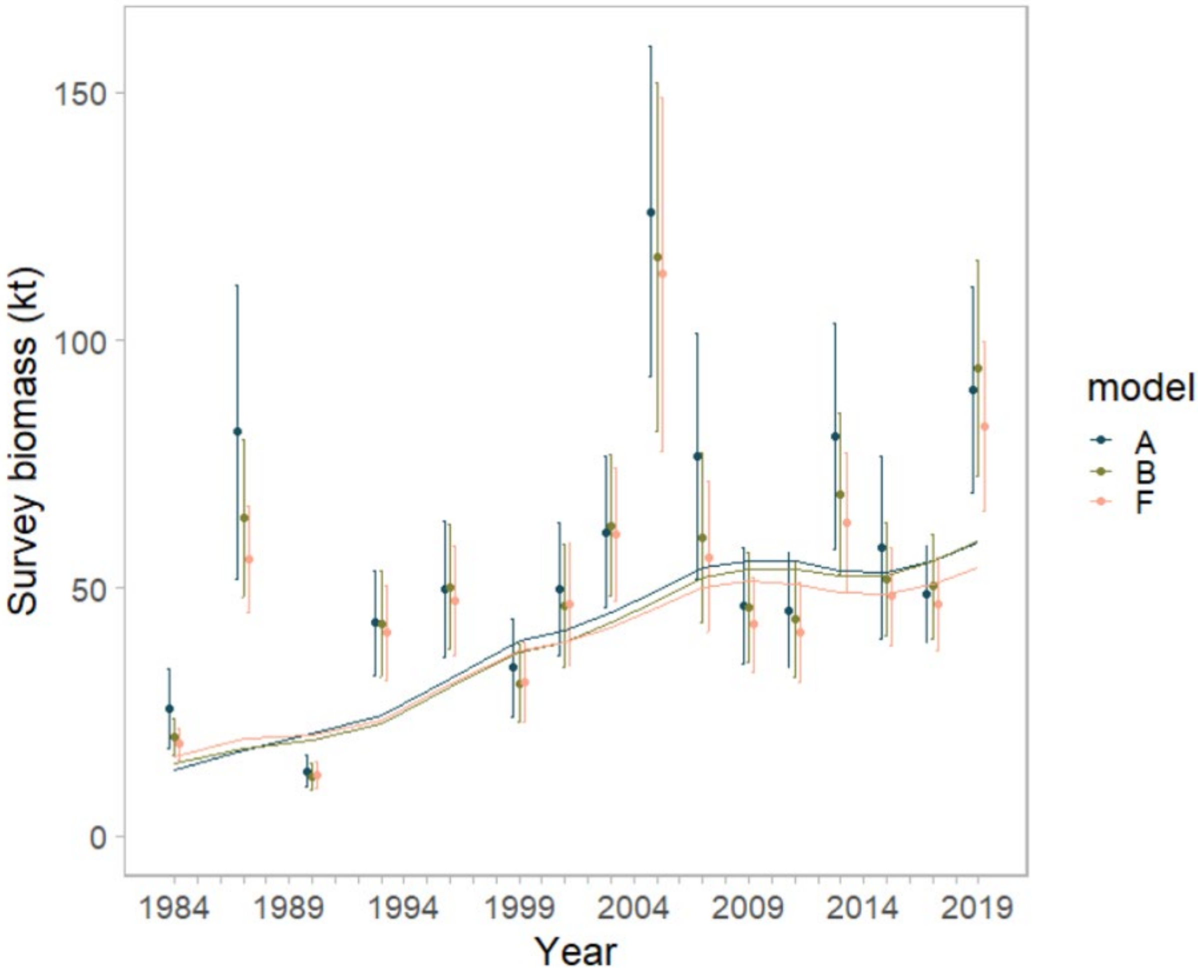


Figure 12c-2. High variability observed VAST inputs (points) and assessment estimates (lines) GOA dusky rockfish trawl survey biomass based on the 2020 recommended model. Error bars are approximate asymptotic 95% confidence intervals of model error.

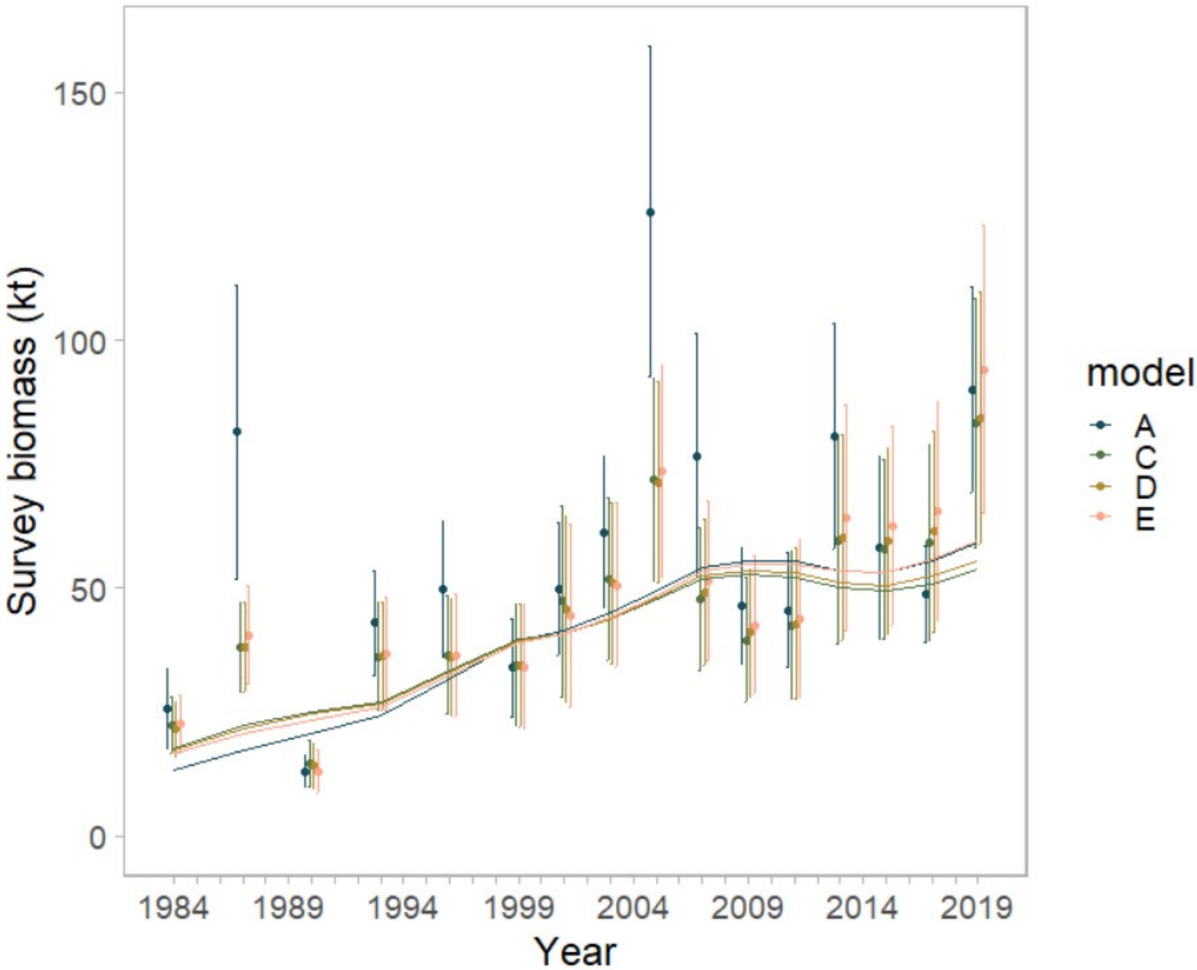


Figure 12c-3. Lower variability observed VAST inputs (points) and assessment estimates (lines) GOA dusky rockfish trawl survey biomass based on the 2020 recommended model. Error bars are approximate asymptotic 95% confidence intervals of model error. Note: the VAST model A would included as a comparison to the default.

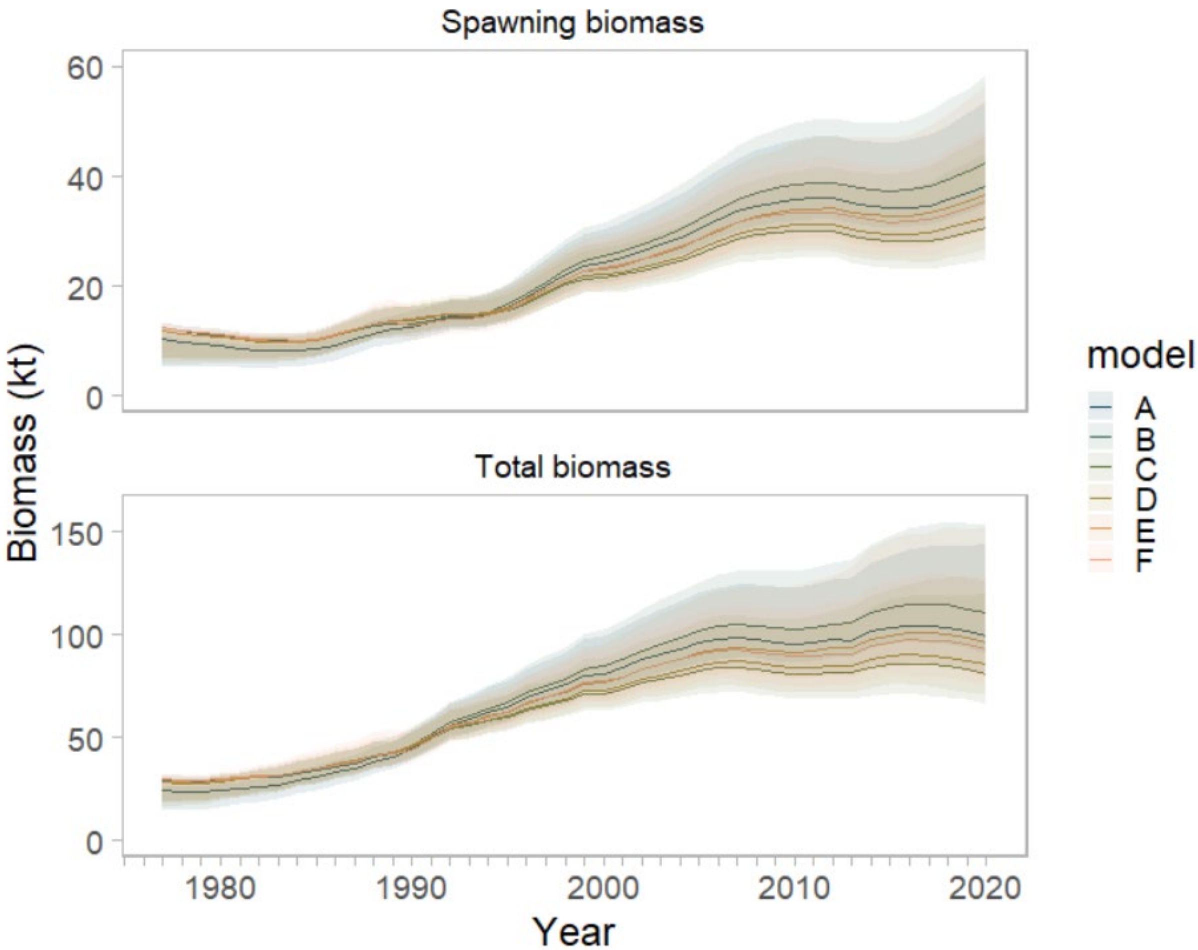


Figure 12c-4. Spawning and total biomass estimates using different VAST inputs for GOA dusky rockfish trawl survey biomass based on the 2022 recommended model.

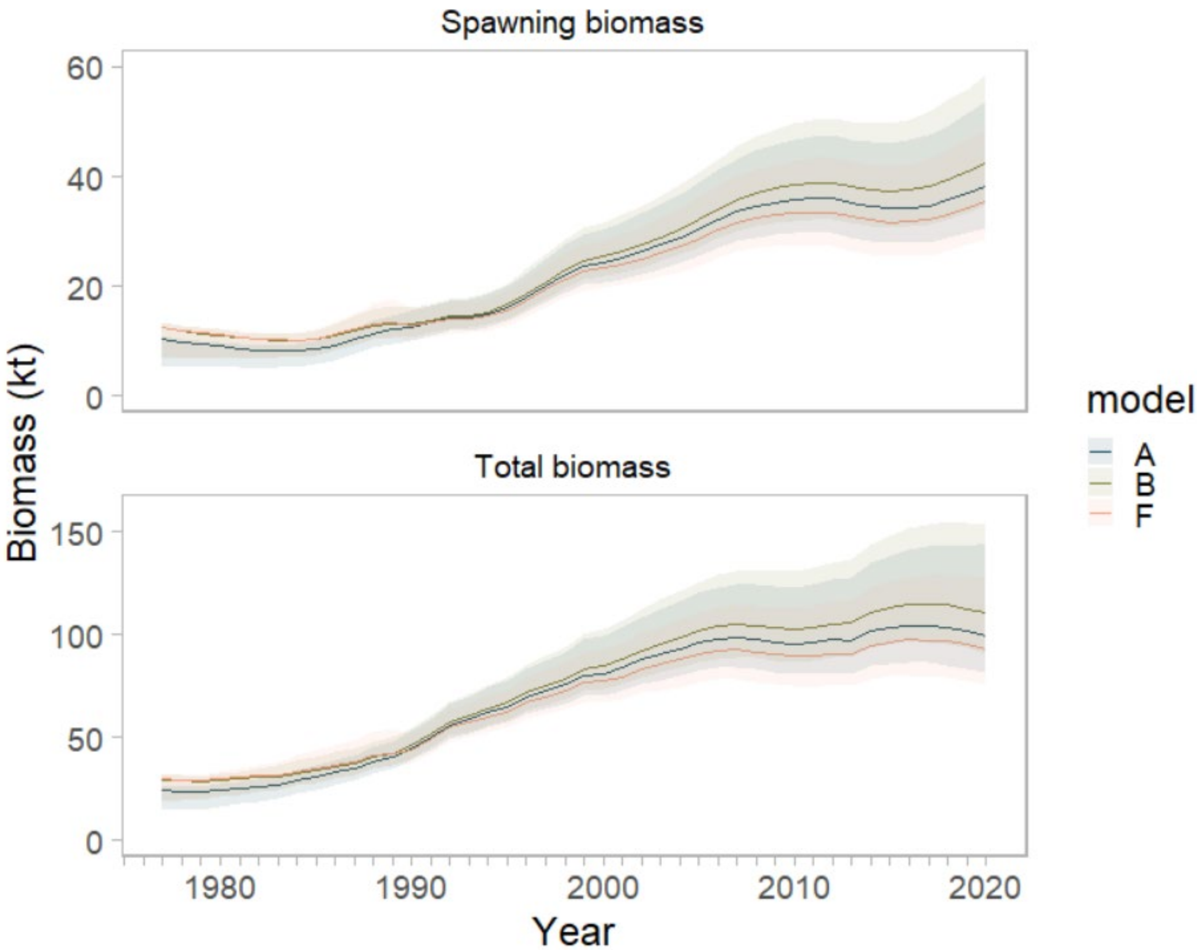


Figure 12c-5. Spawning and total biomass estimates using high variability VAST inputs for GOA dusky rockfish trawl survey biomass based on the 2022 recommended model.

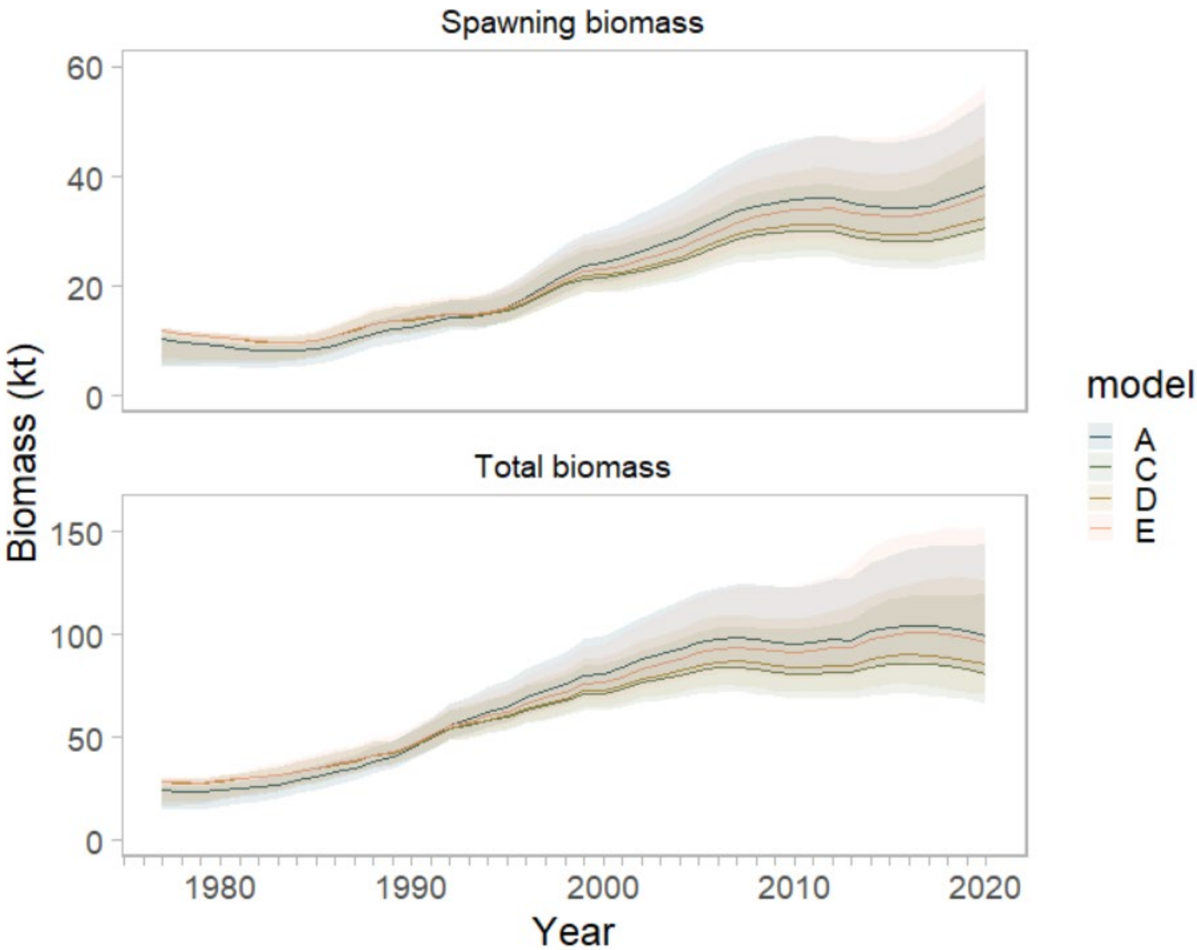


Figure 12c-6. Spawning and total biomass estimates using lower variability VAST inputs for GOA dusky rockfish trawl survey biomass based on the 2022 recommended model. Note: the VAST model A (default) is included as a comparison.

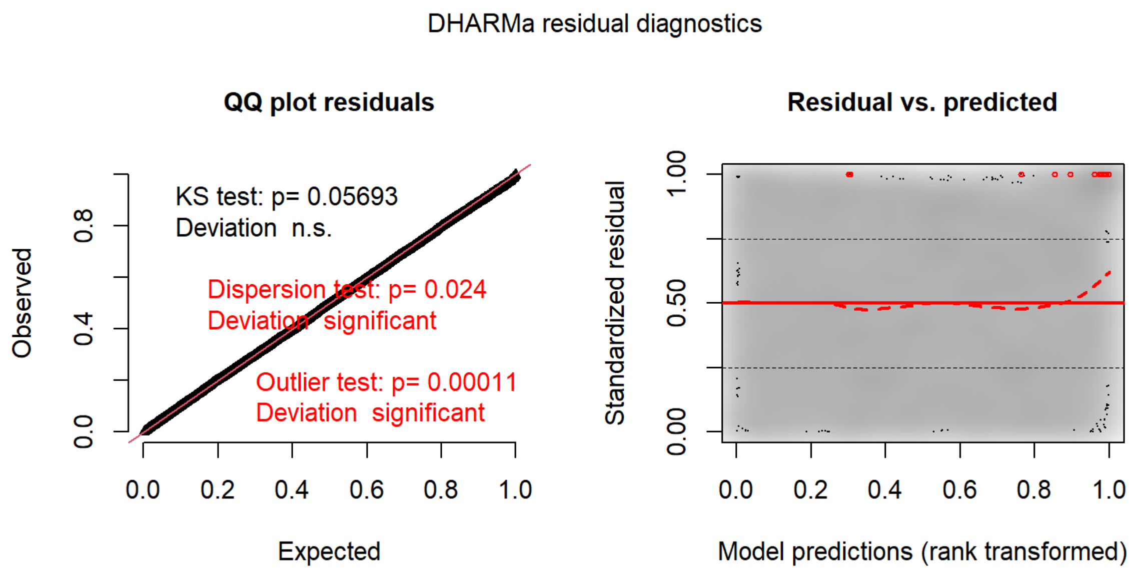


Figure 12c-7. Lognormal error VAST model (B) residual diagnostics plot.

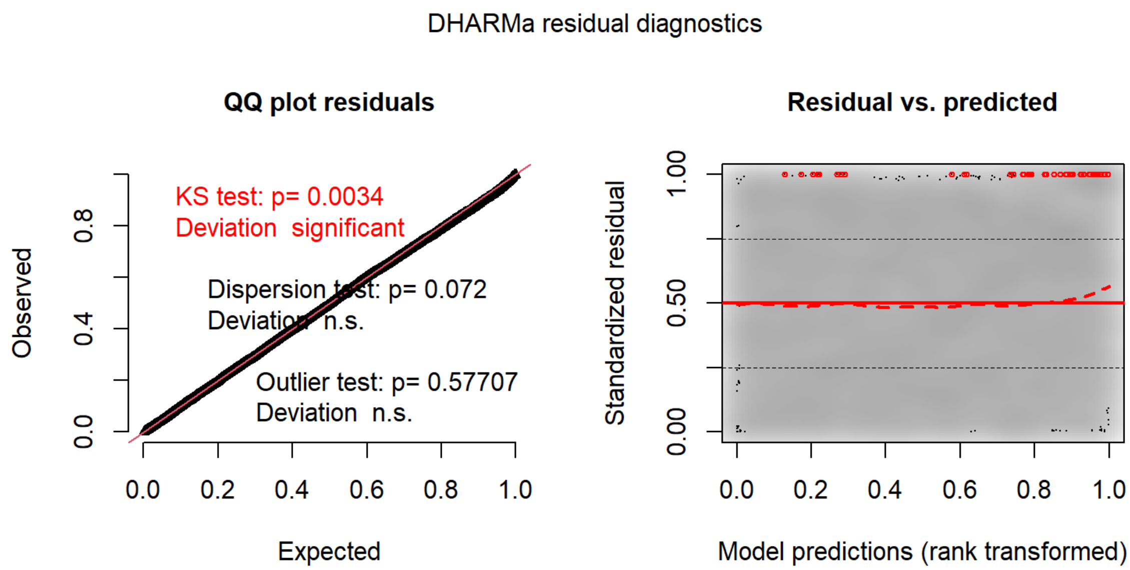


Figure 12c-8. Lognormal error VAST model (E) residual diagnostics plot.

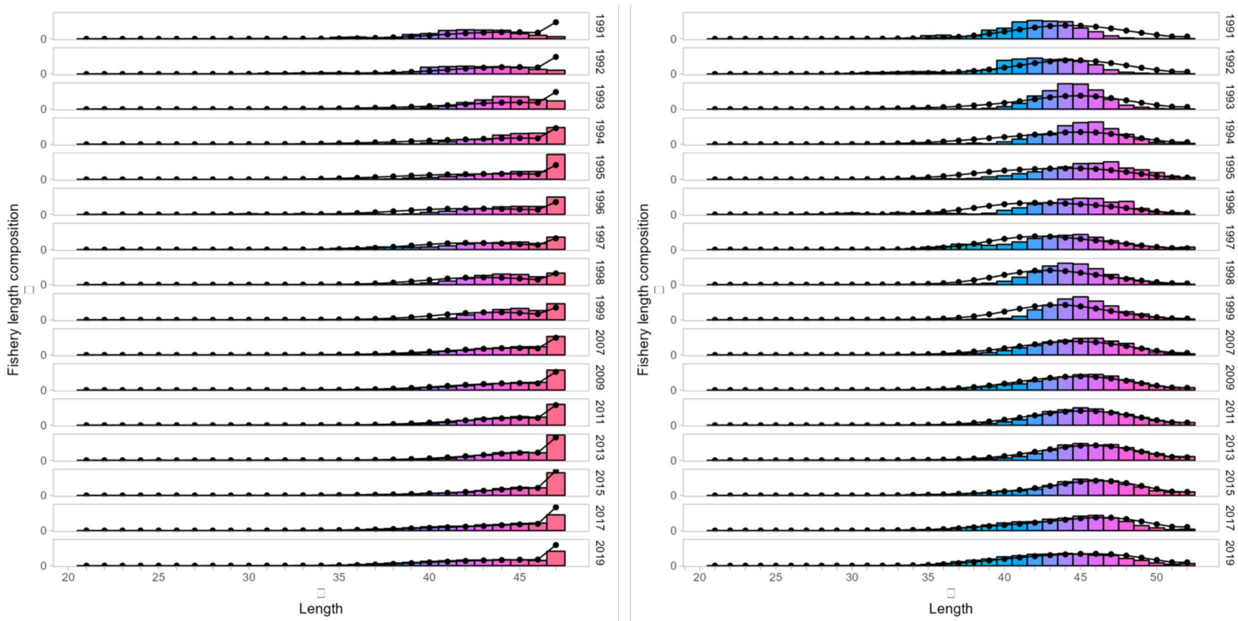


Figure 12c-9. Fishery length composition plus group and model fittings for the default (47 cm) and increased (52 cm) plus groupings.

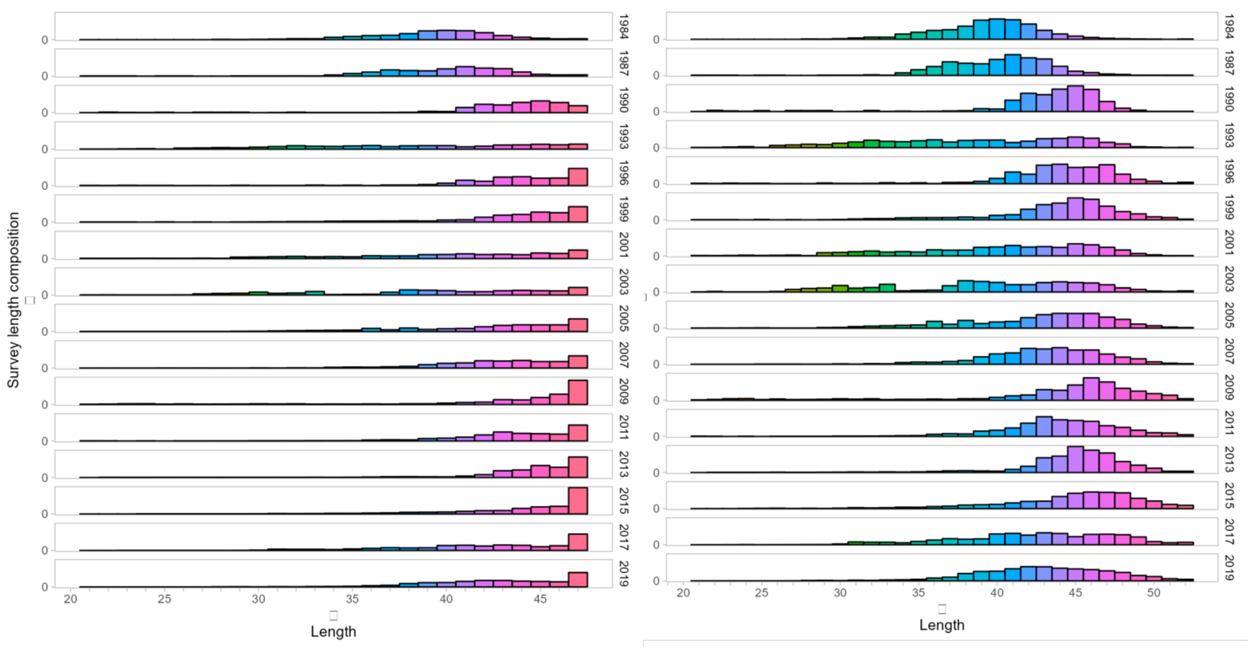


Figure 12c-10. Survey length composition plus group for the default (47 cm) and increased (52 cm) plus groupings. Note: not fit in the model.

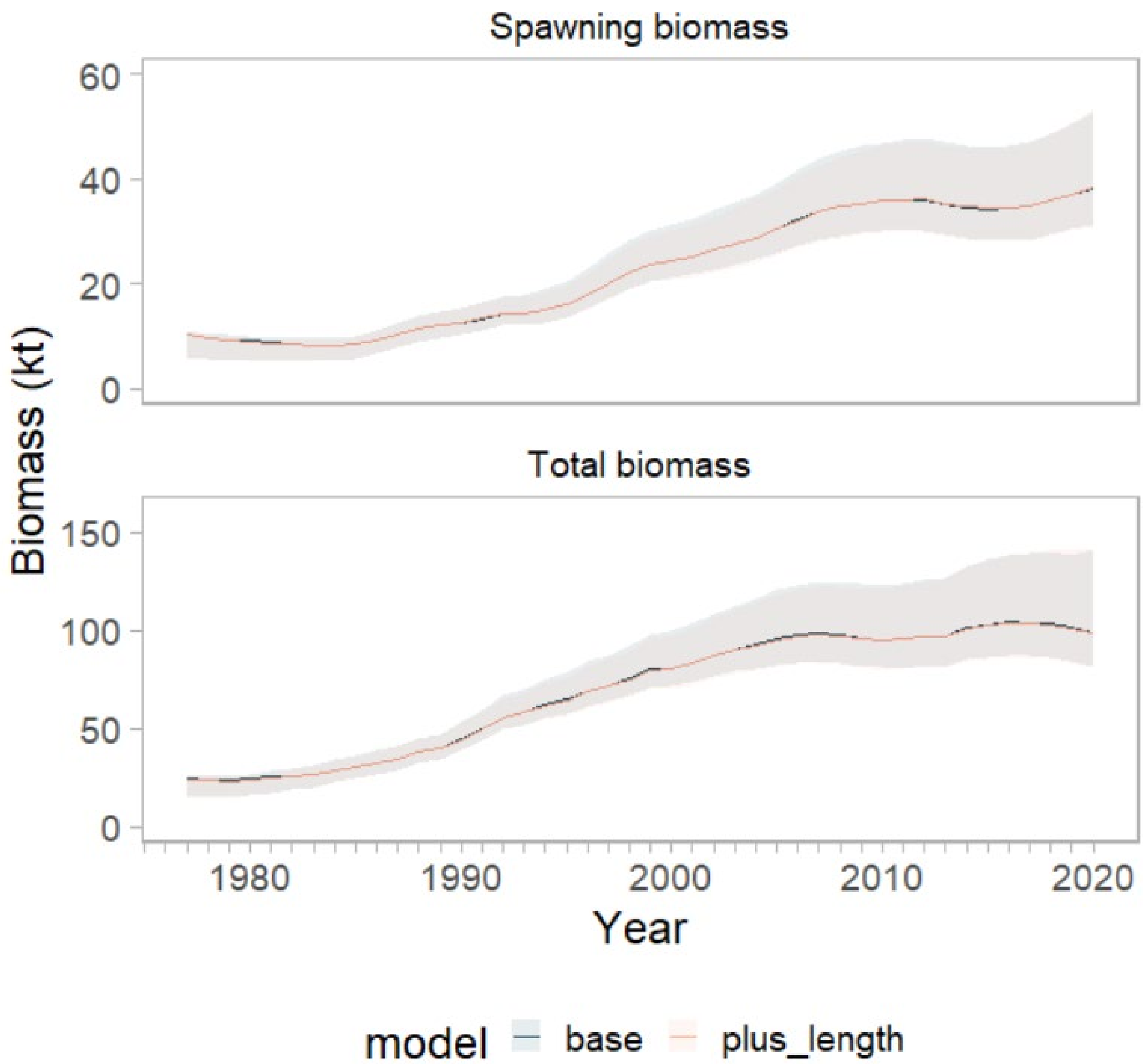


Figure 12c-11. Spawning and total biomass for the base model and increased length plus group models.

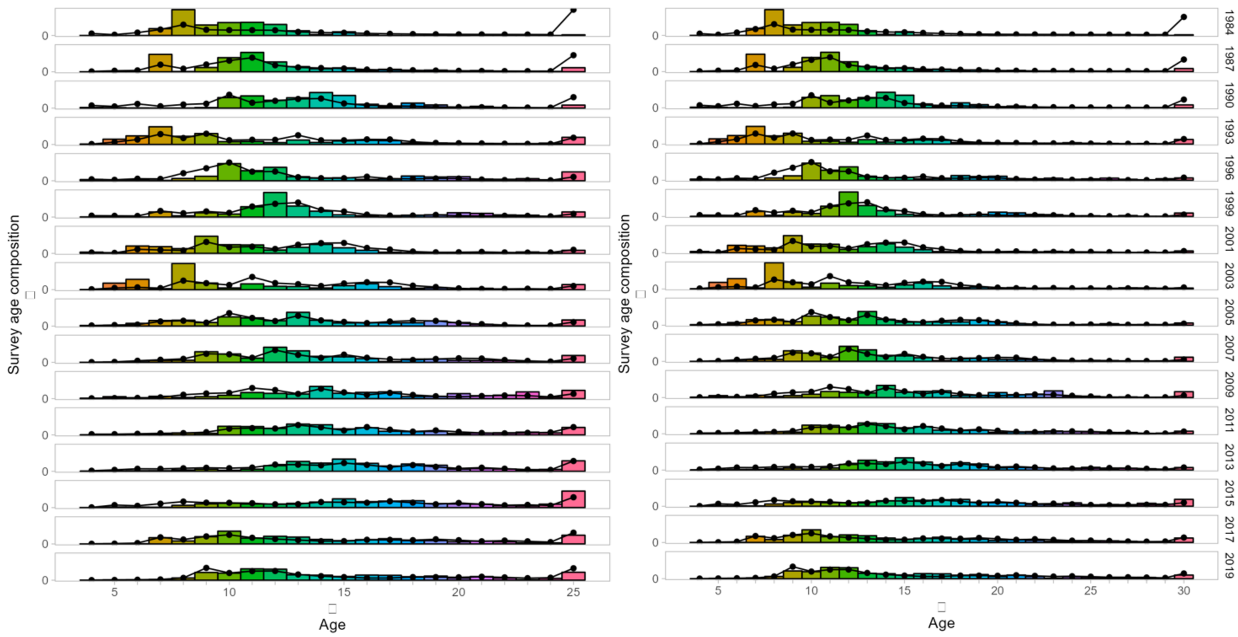

Figure 12c-12. Survey age composition plus group and model fittings for the default (age-25) and increased (age-30) plus groupings.

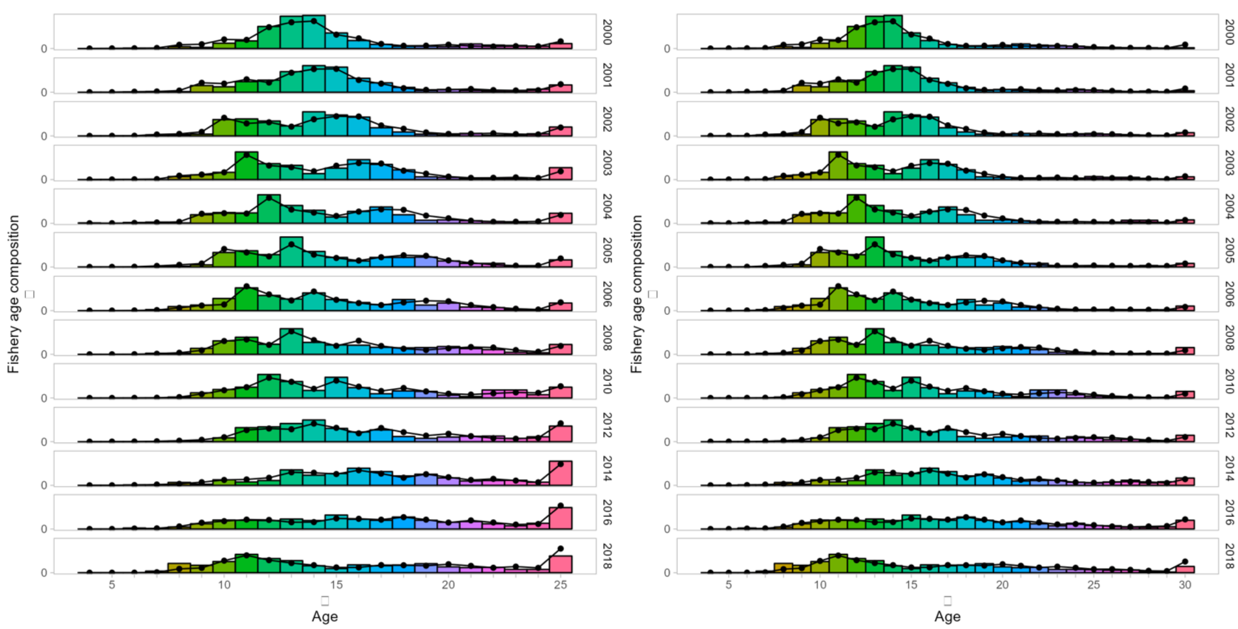

Figure 12c-13. Fishery age composition plus group and model fittings for the default (age-25) and increased (age-30) plus groupings.

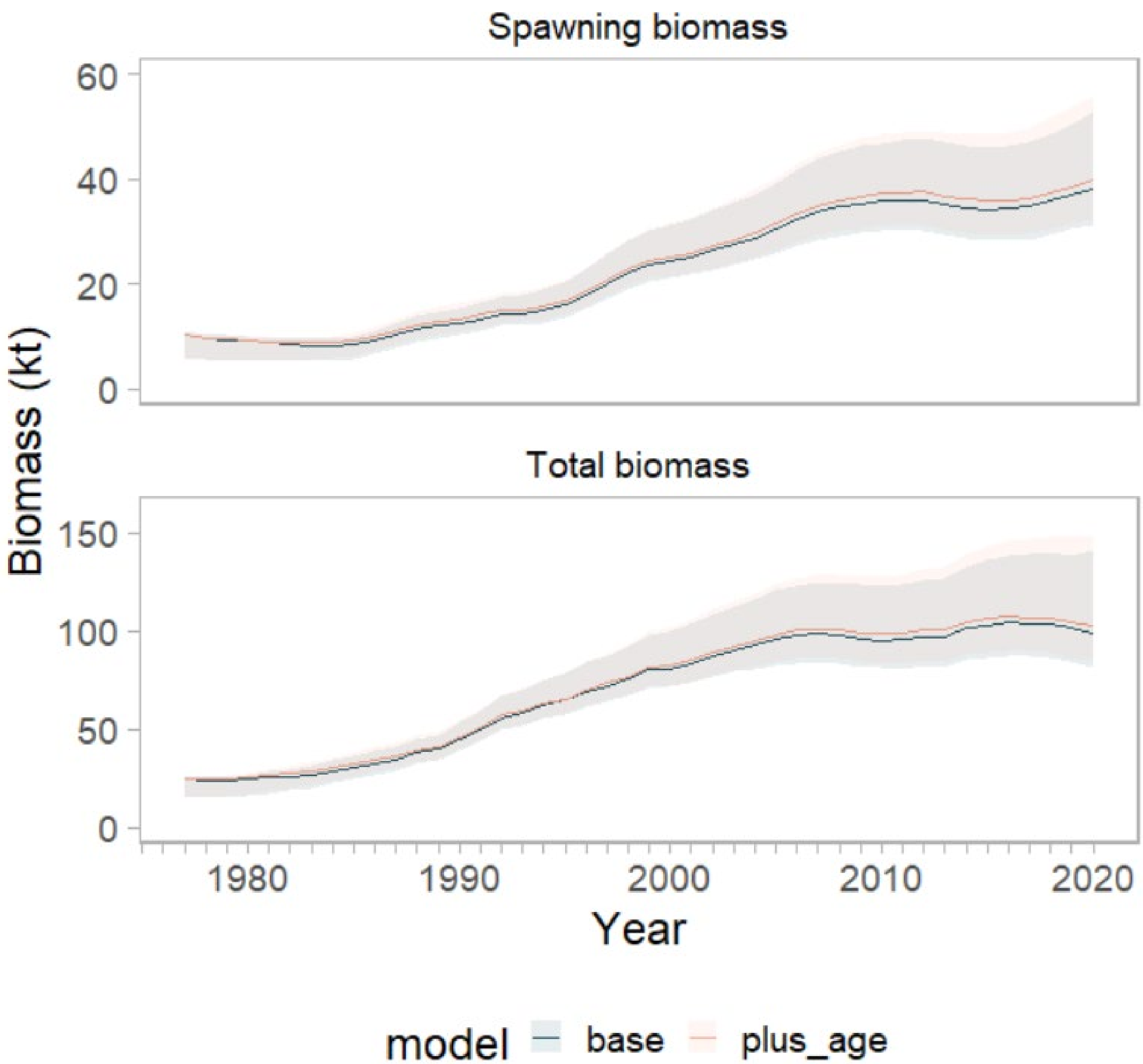


Figure 12c-14. Spawning and total biomass for the base model and increased age plus group models.

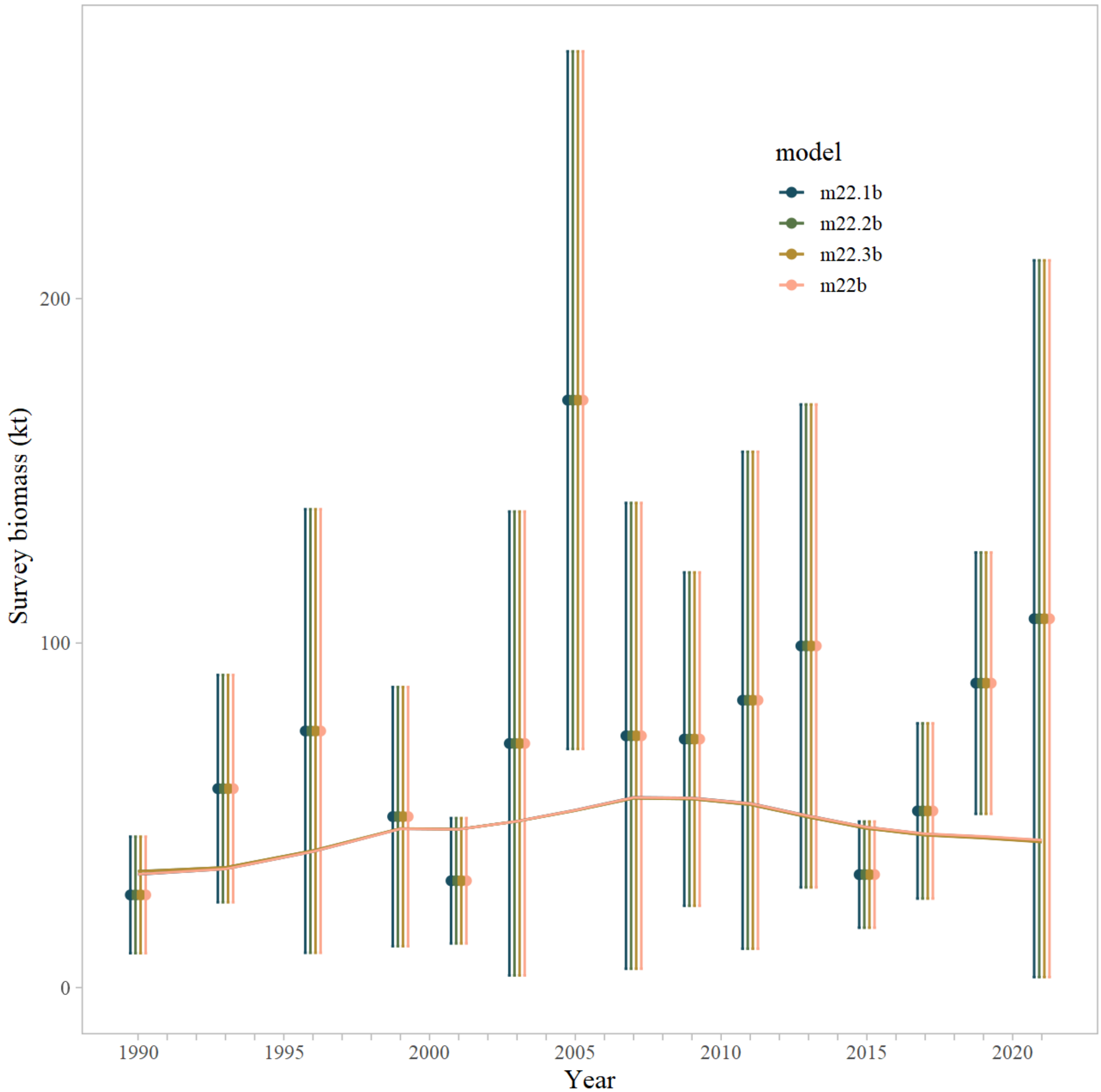


Figure 12c-15. Design-based trawl survey inputs and model results.

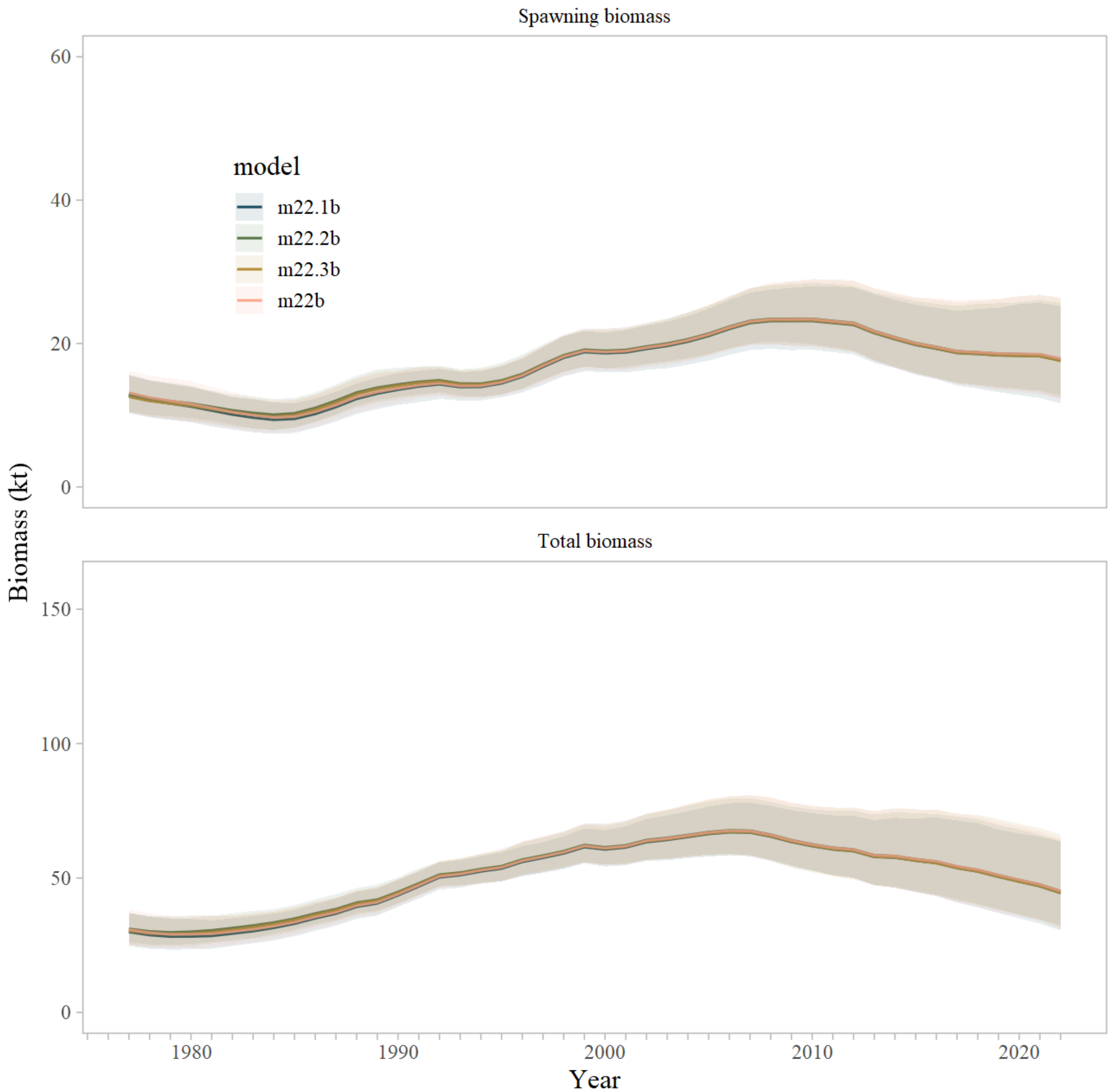


Figure 12c-16. Spawning and total biomass results using different model structures with a design-based trawl survey input

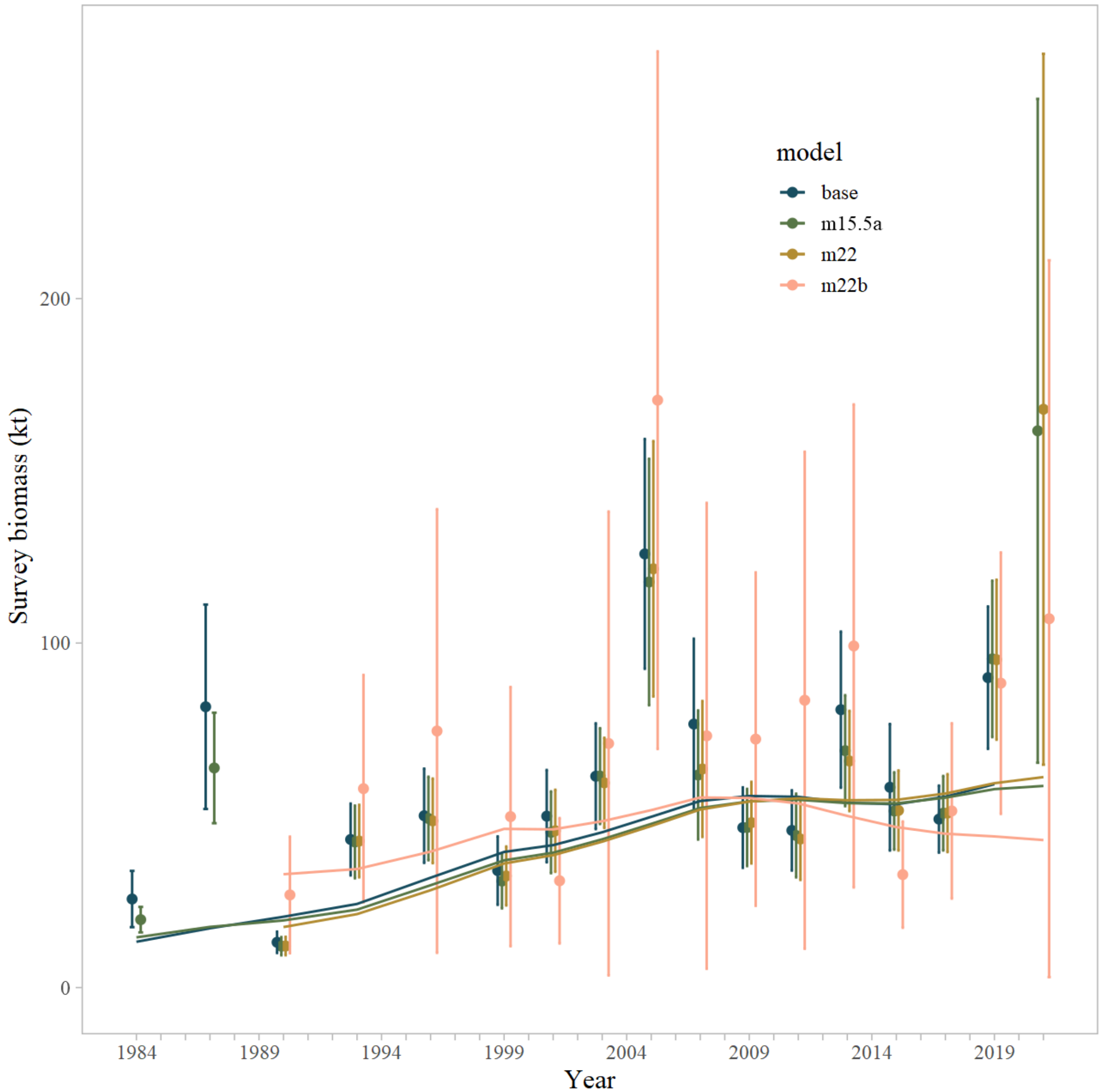


Figure 12c-17. Design-based and VAST trawl survey inputs and model results.

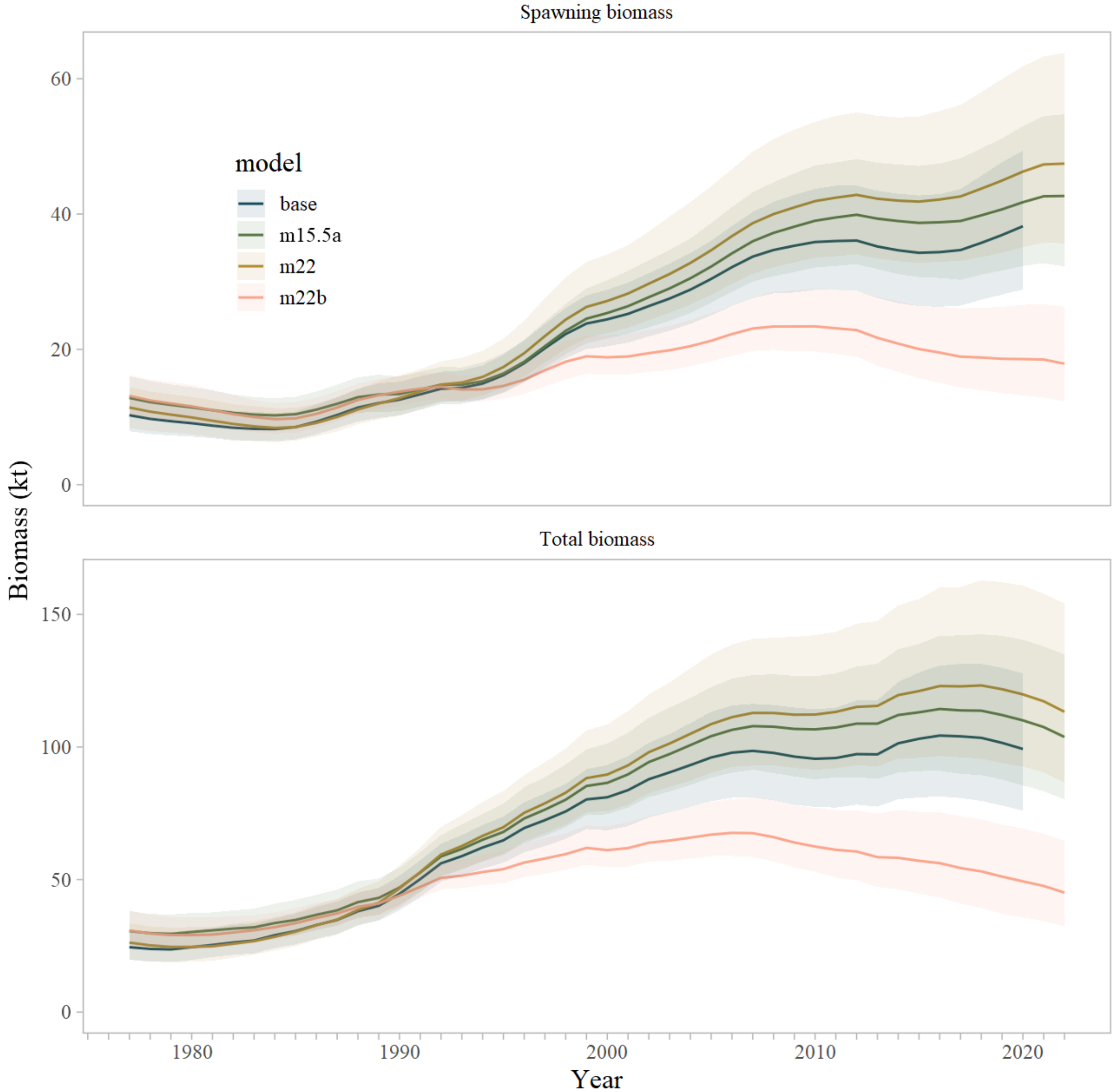


Figure 12c-18. Spawning and total biomass results using different model structures with a design-based or VAST trawl survey input.

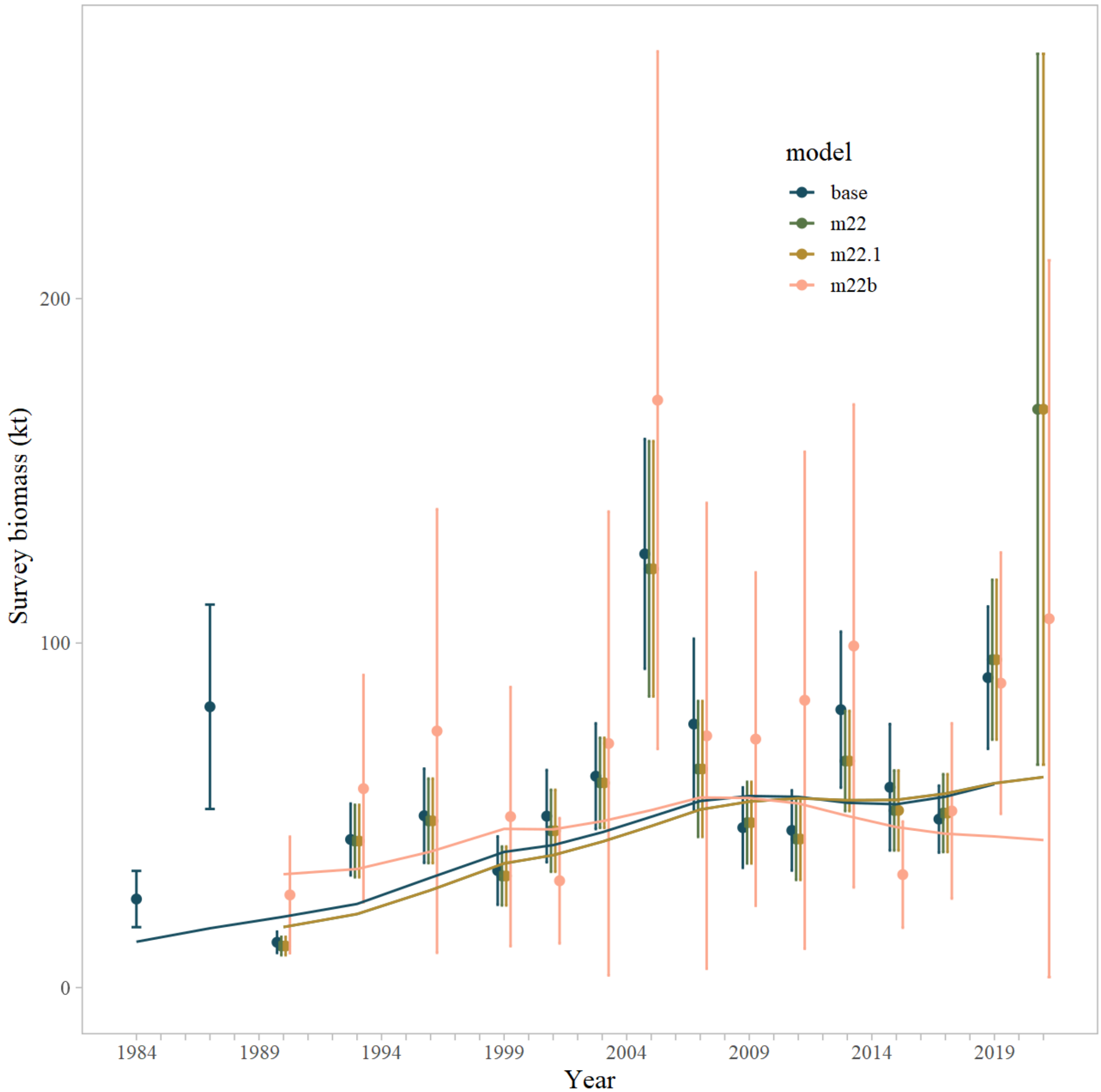


Figure 12c-19. Design-based and VAST trawl survey inputs and model results.

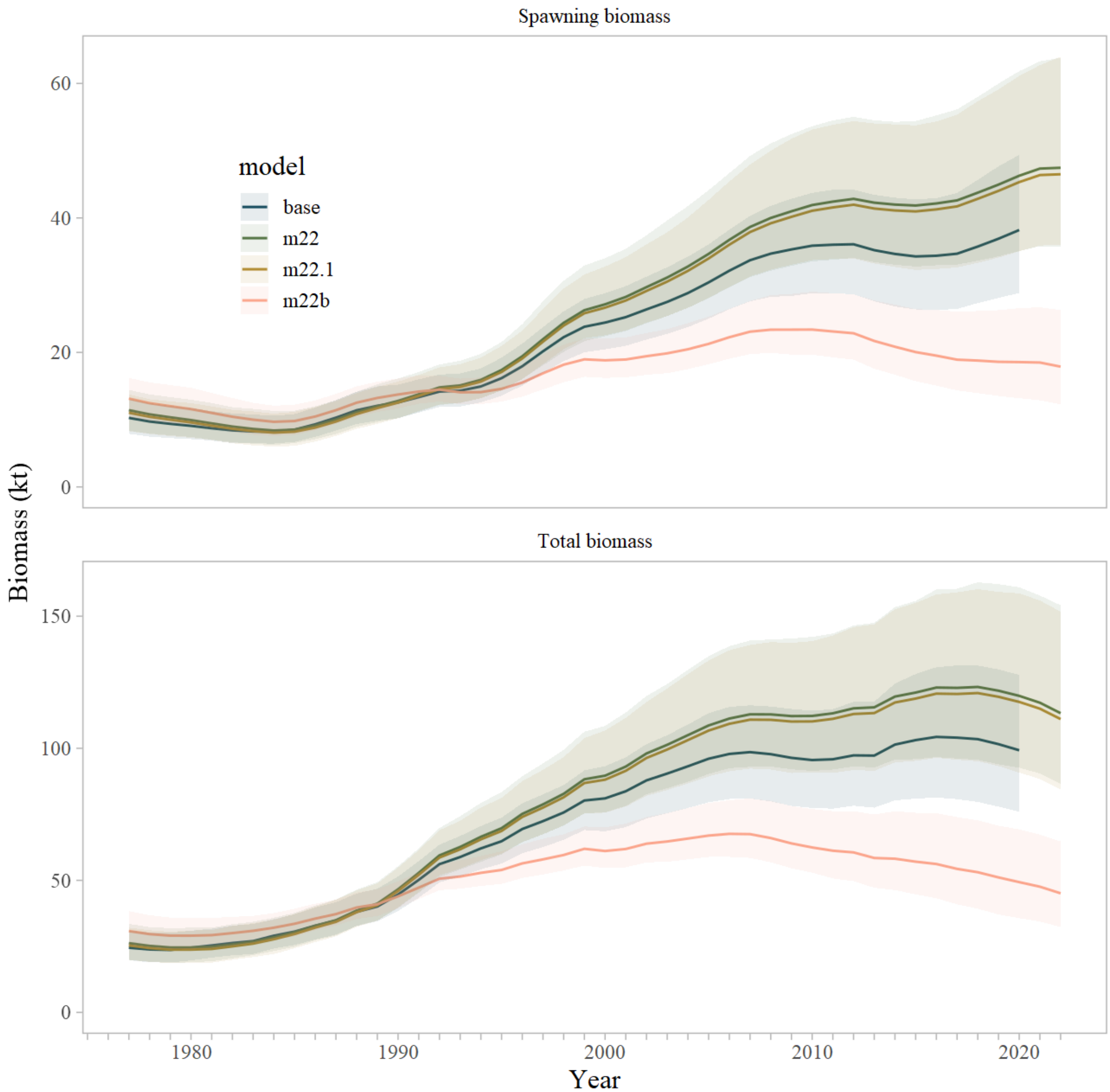


Figure 12c-20. Design-based and VAST trawl survey inputs and model results.

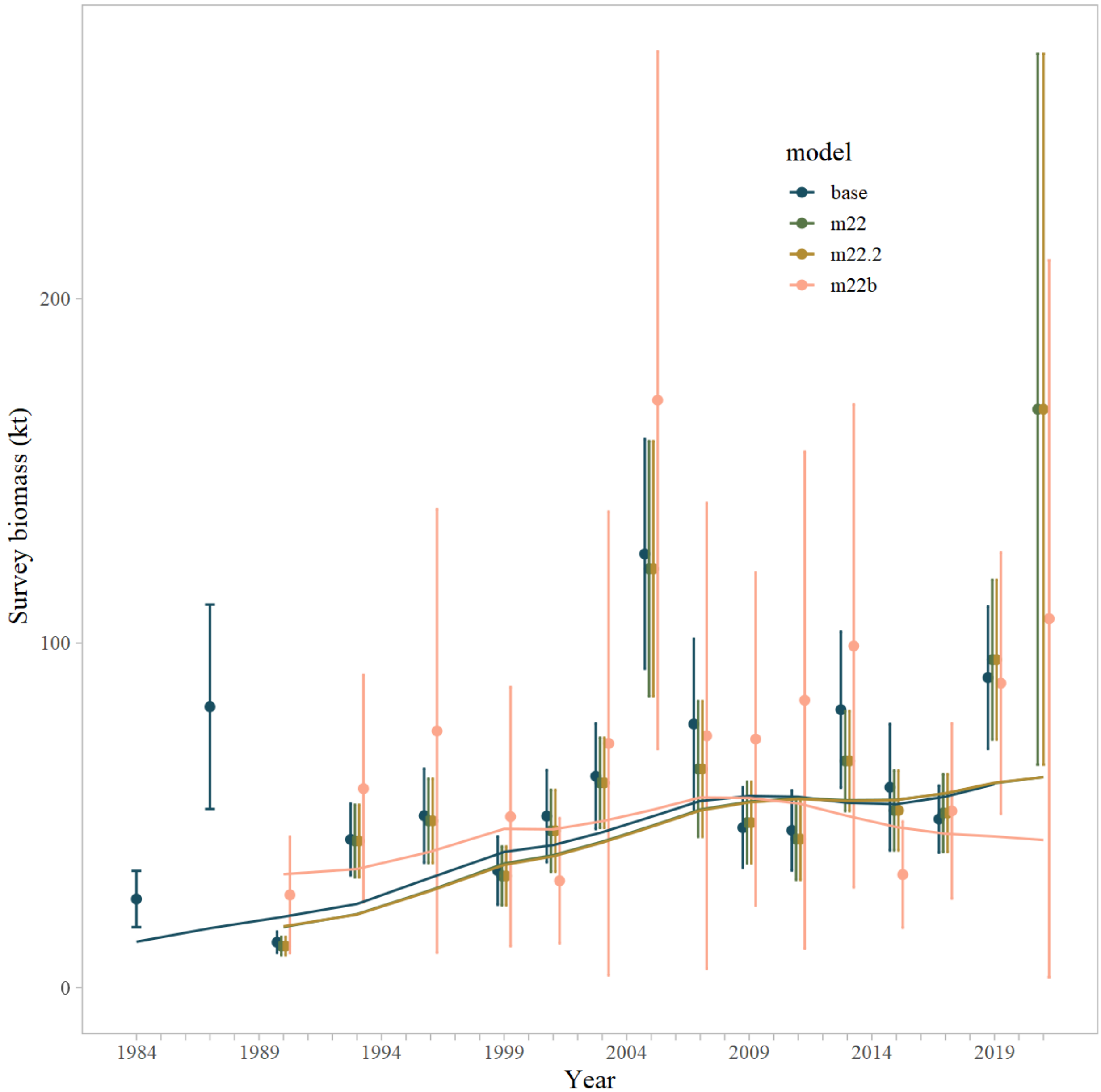


Figure 12c-21. Spawning and total biomass results using different model structures with a design-based or VAST trawl survey input.

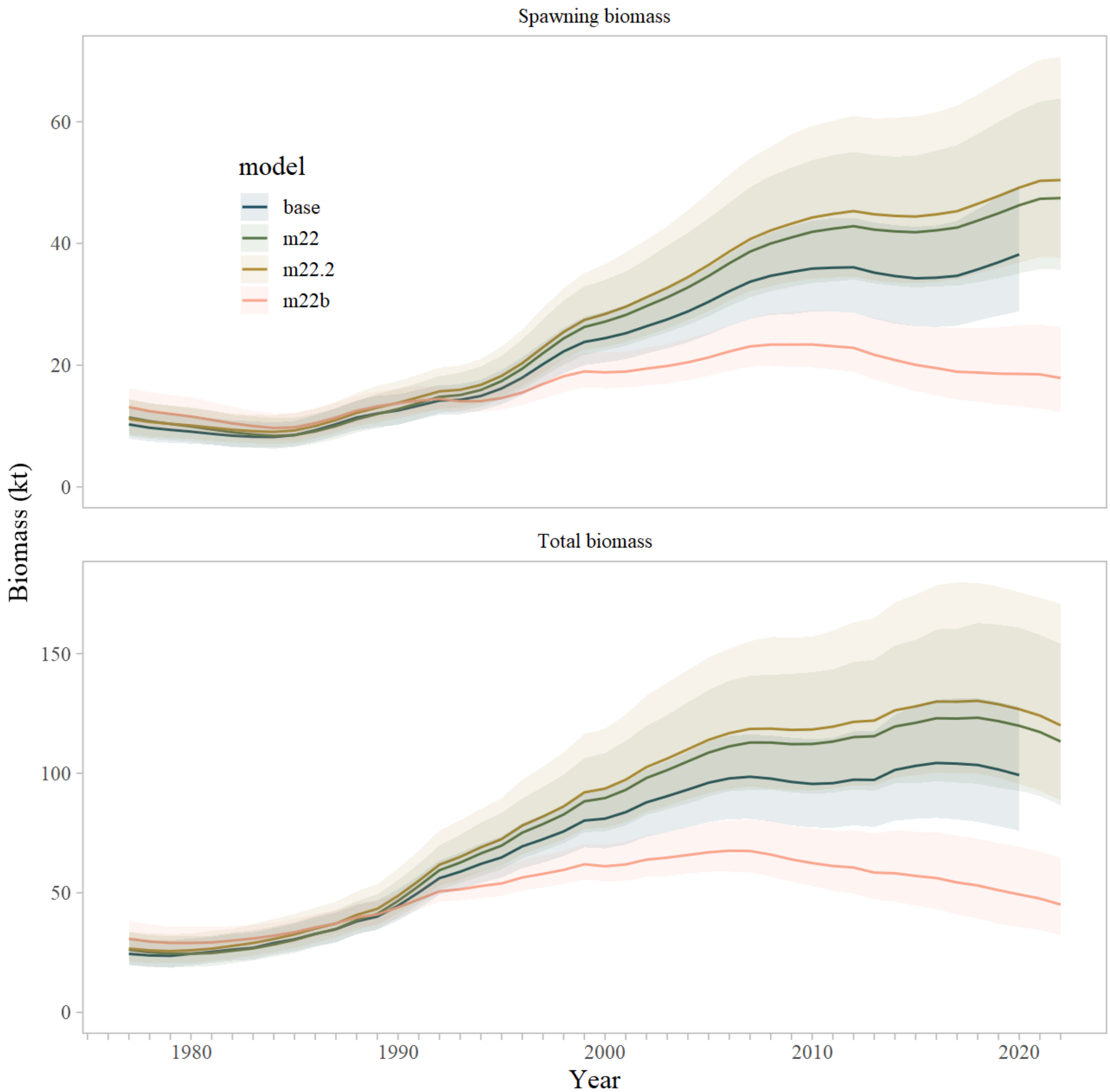


Figure 12c-22. Spawning and total biomass results using different model structures with a design-based or VAST trawl survey input.

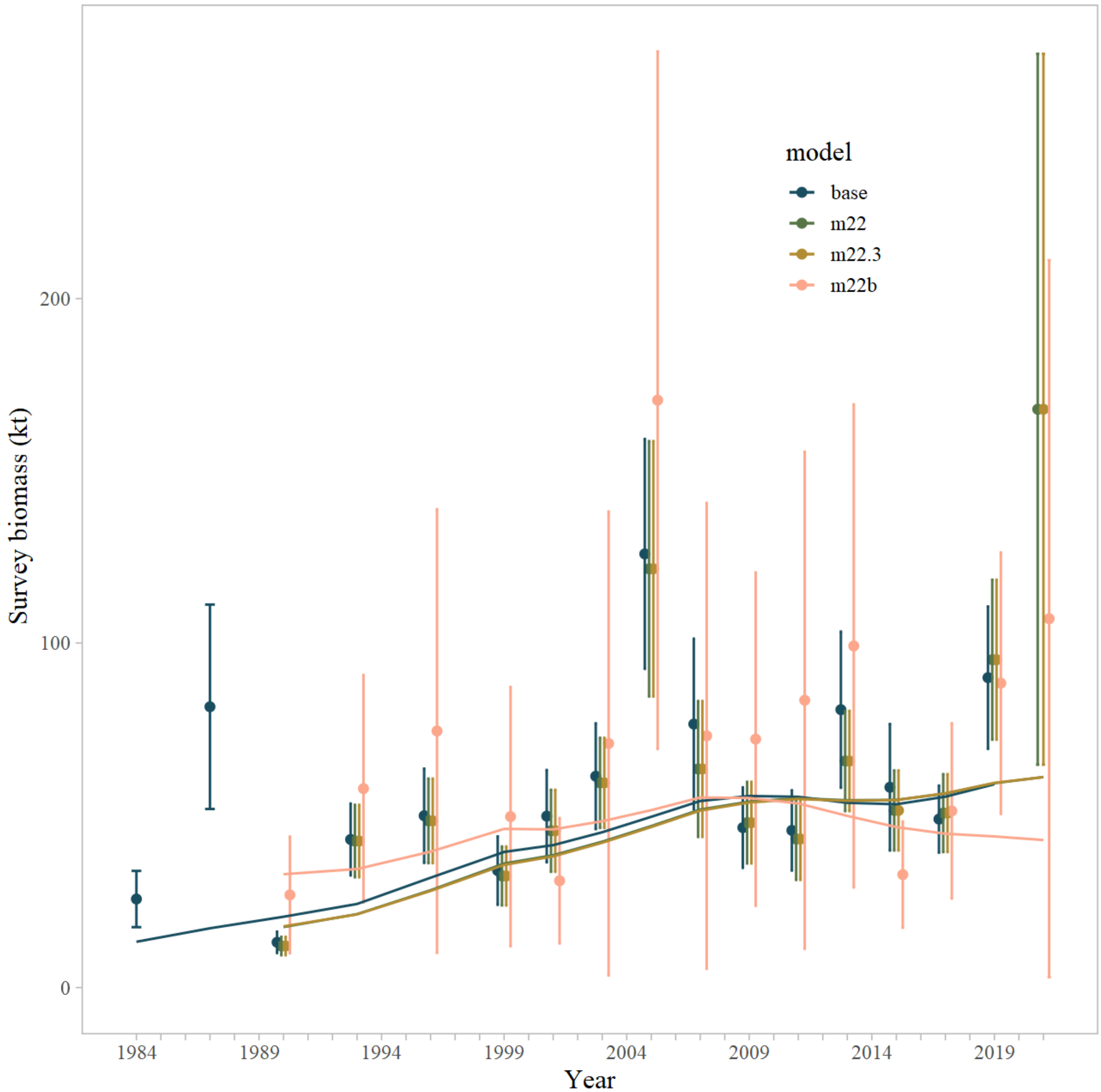


Figure 12c-23. Design-based and VAST trawl survey inputs and model results.

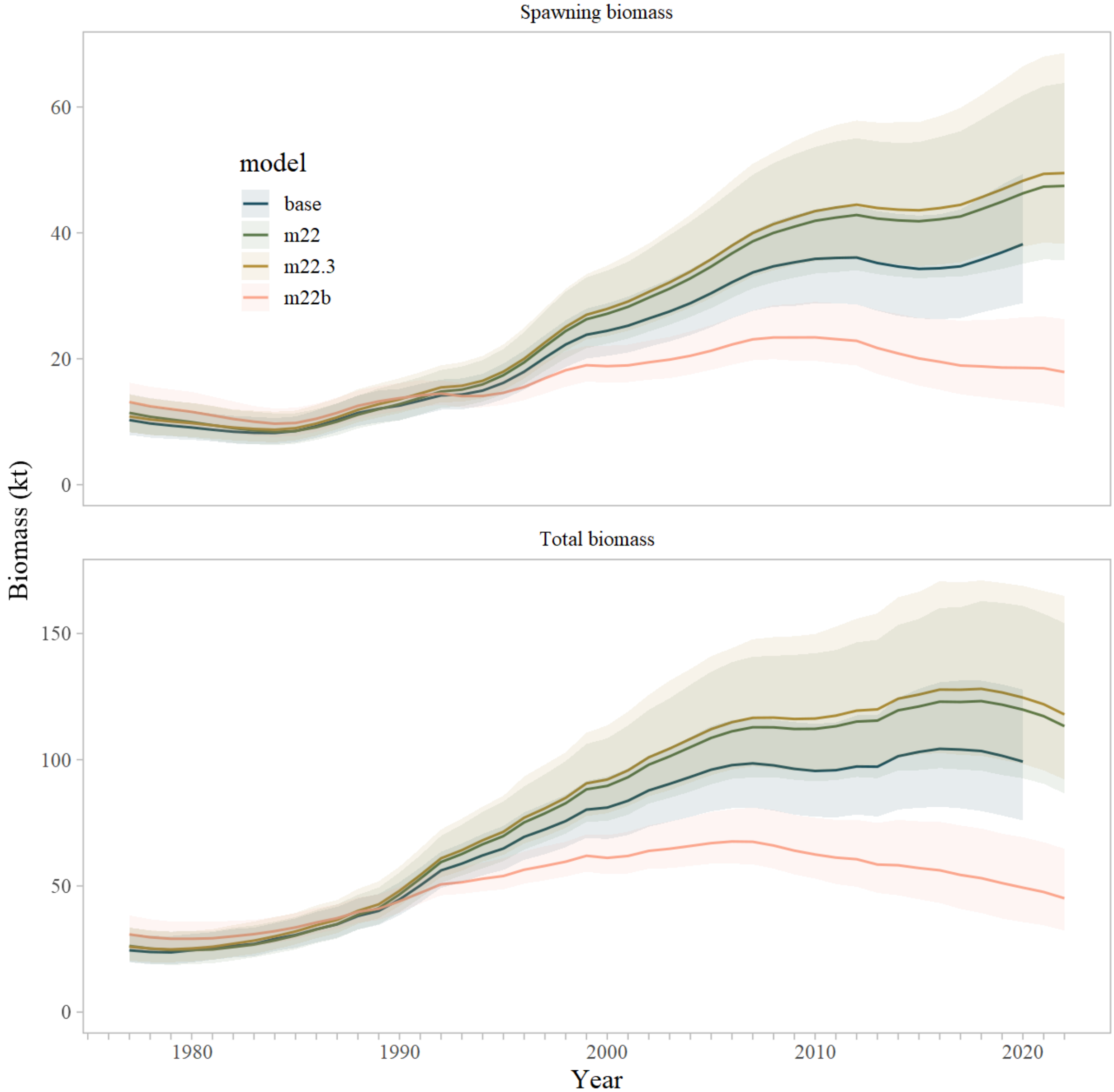


Figure 12c-24. Spawning and total biomass results using different model structures with a design-based or VAST trawl survey input

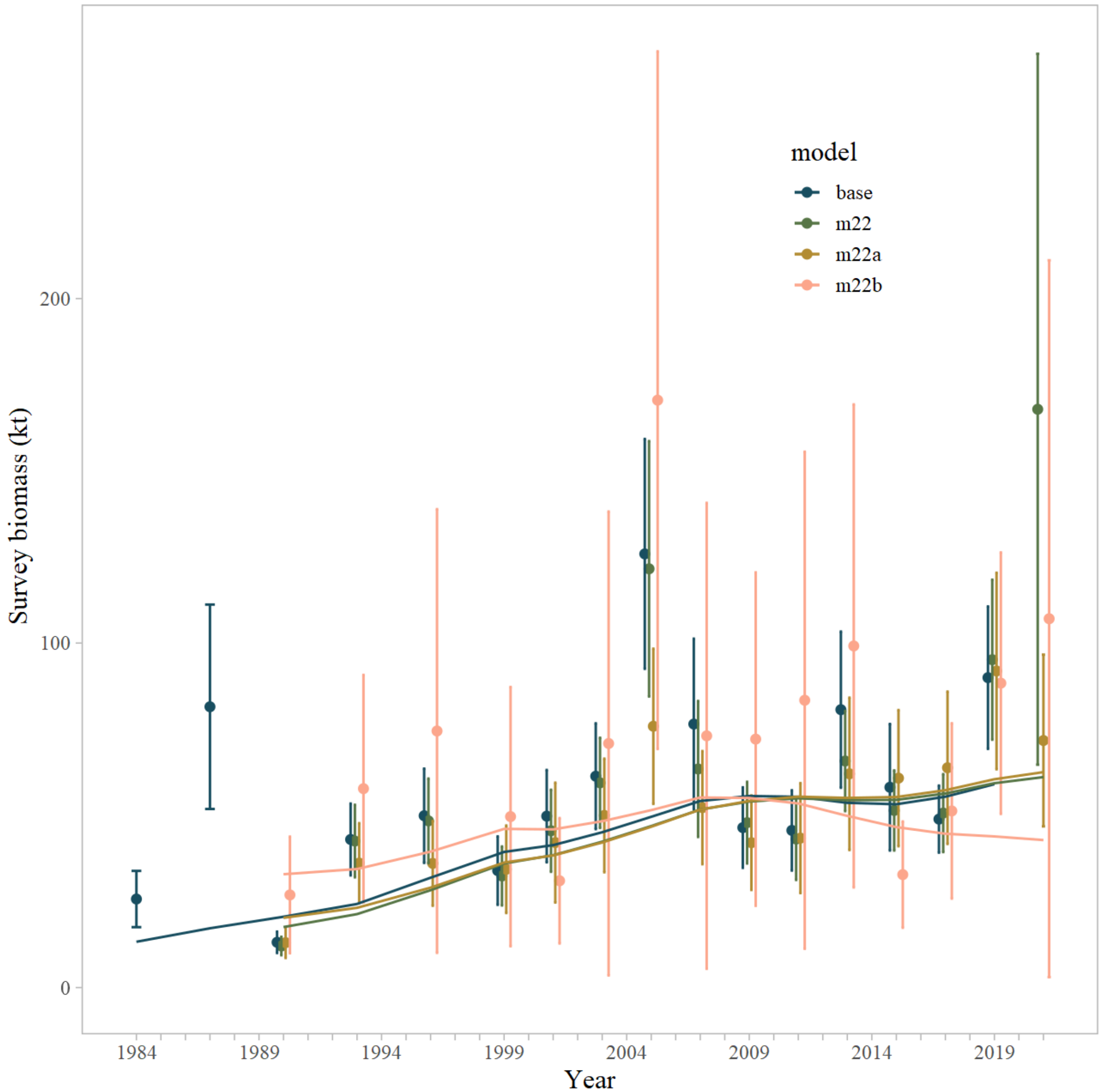


Figure 12c-25. Design-based and VAST (lognormal) trawl survey inputs and model results.

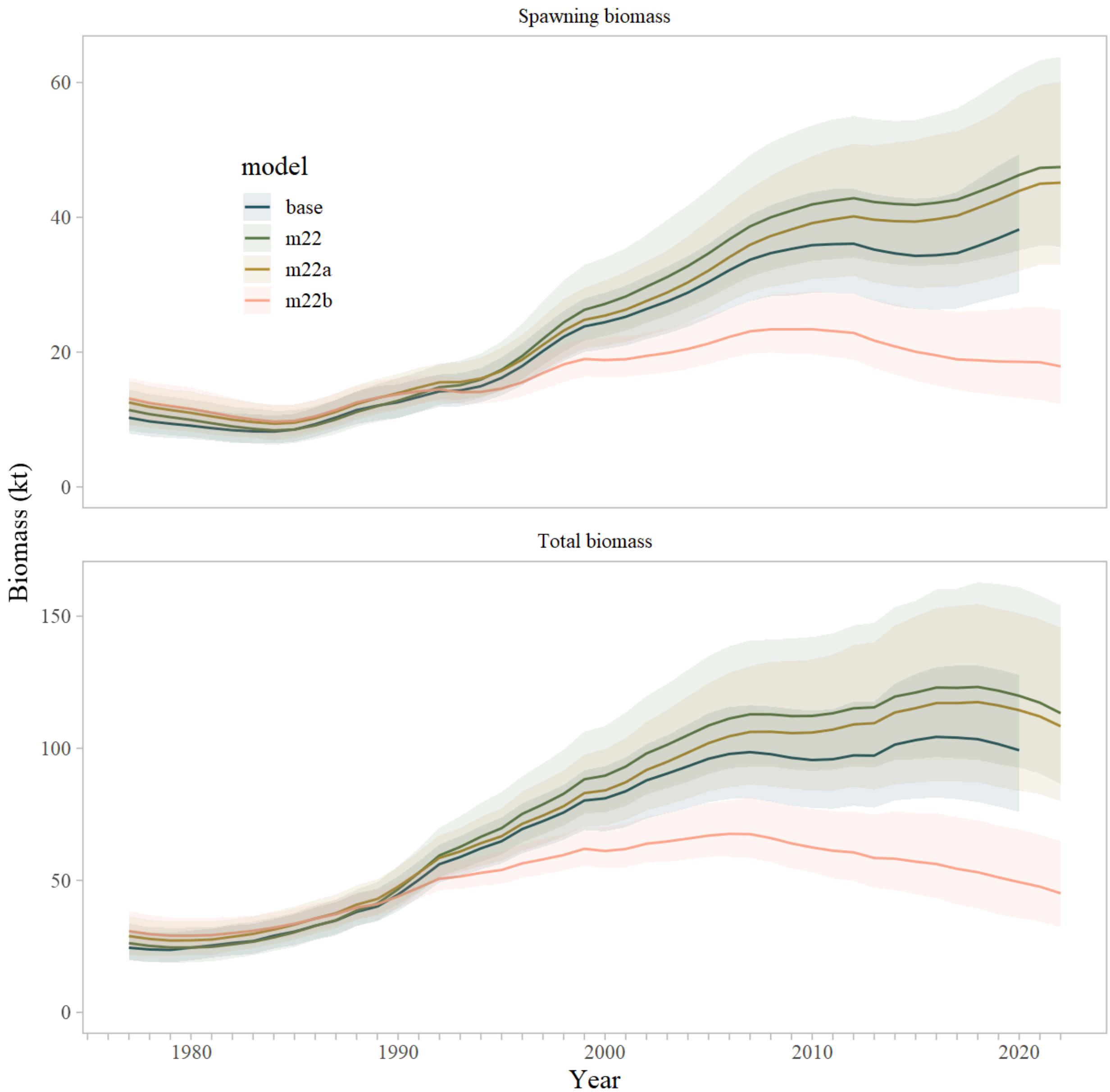


Figure 12c-26. Spawning and total biomass results using different model structures with a design-based or VAST (lognormal) trawl survey input.

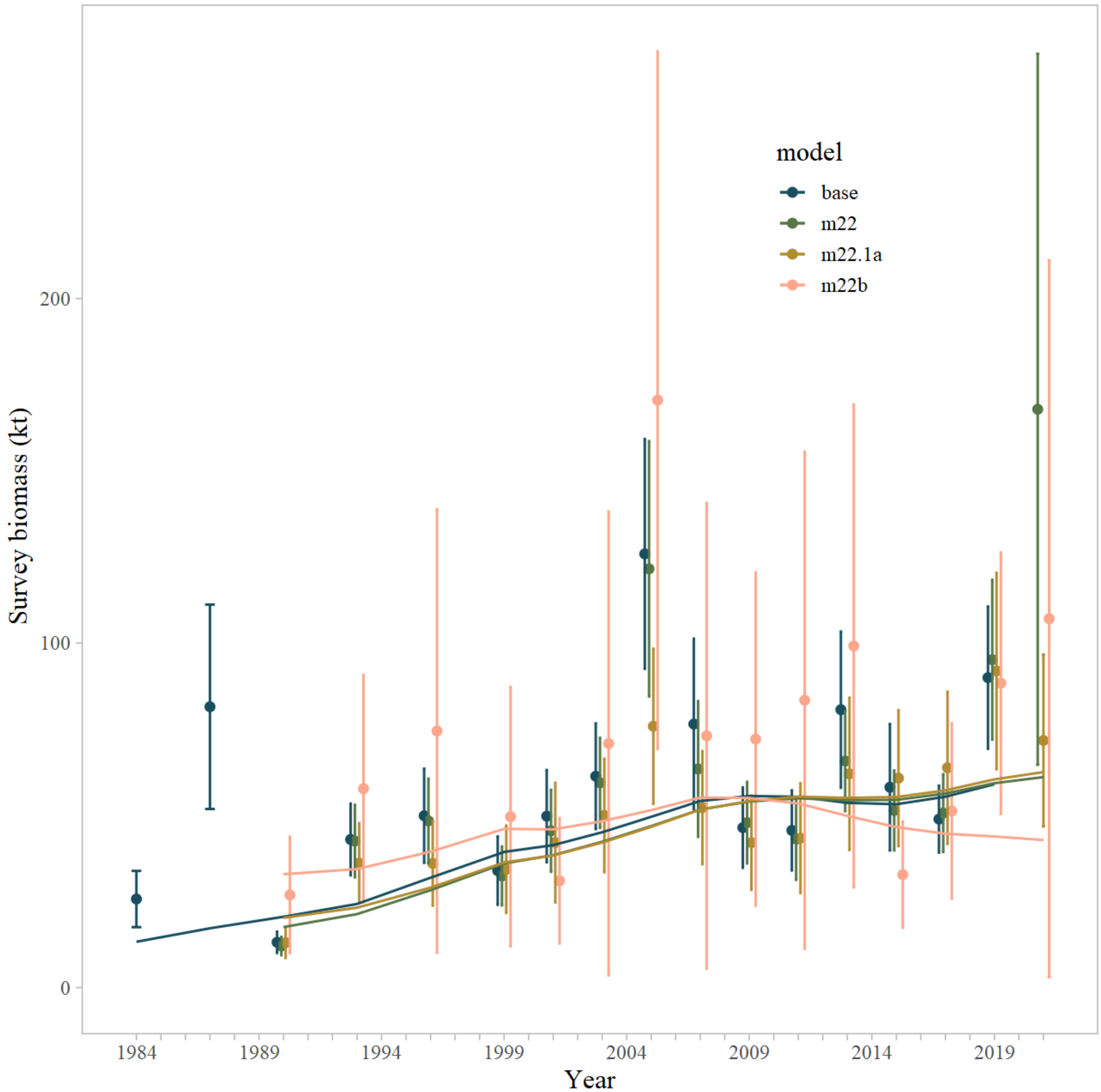


Figure 12c-27. Design-based and VAST (lognormal) trawl survey inputs and model results with increased length plus group.

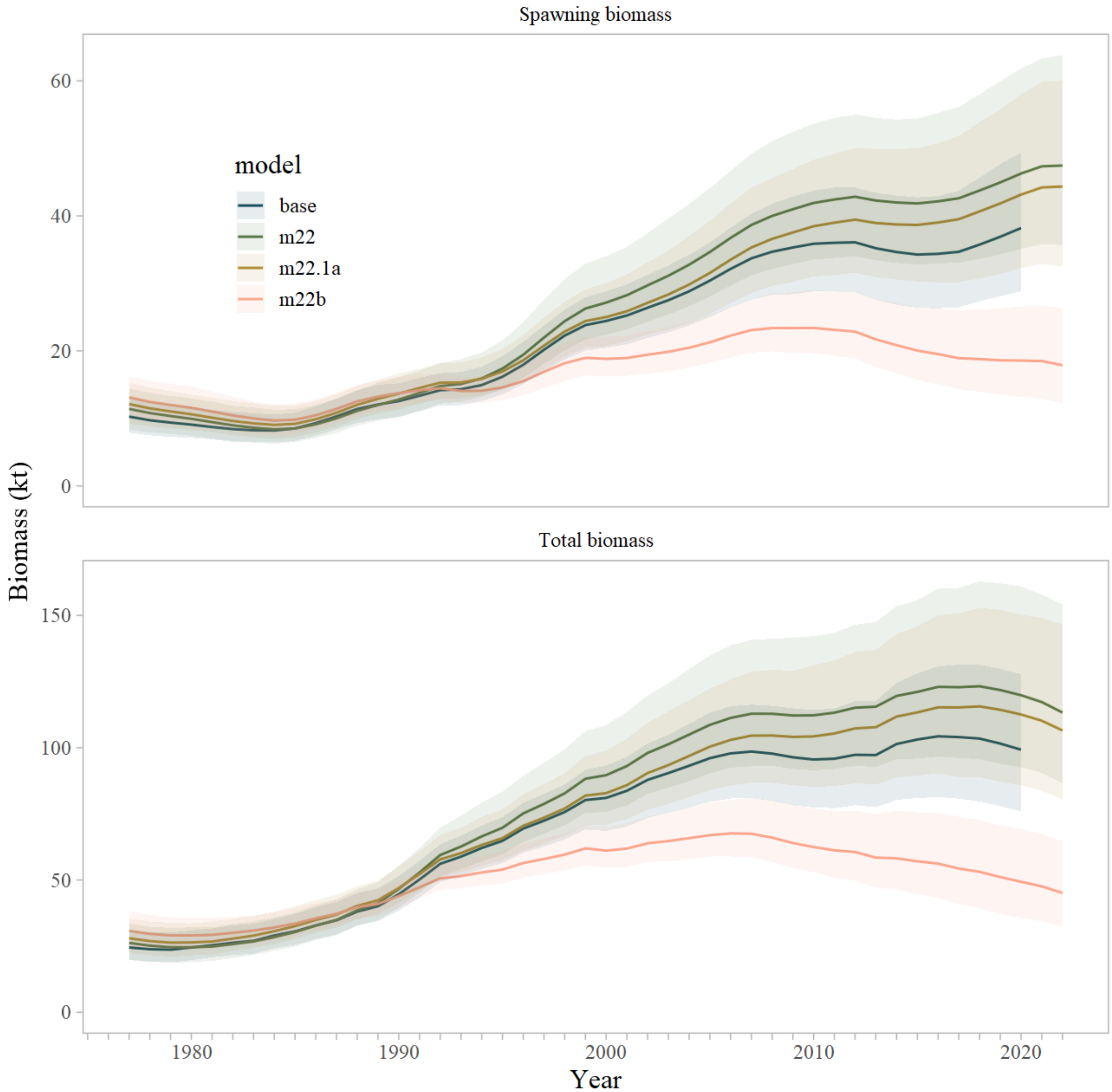


Figure 12c-28. Spawning and total biomass results using different model structures with a design-based or VAST (lognormal) trawl survey input with increased length plus group.

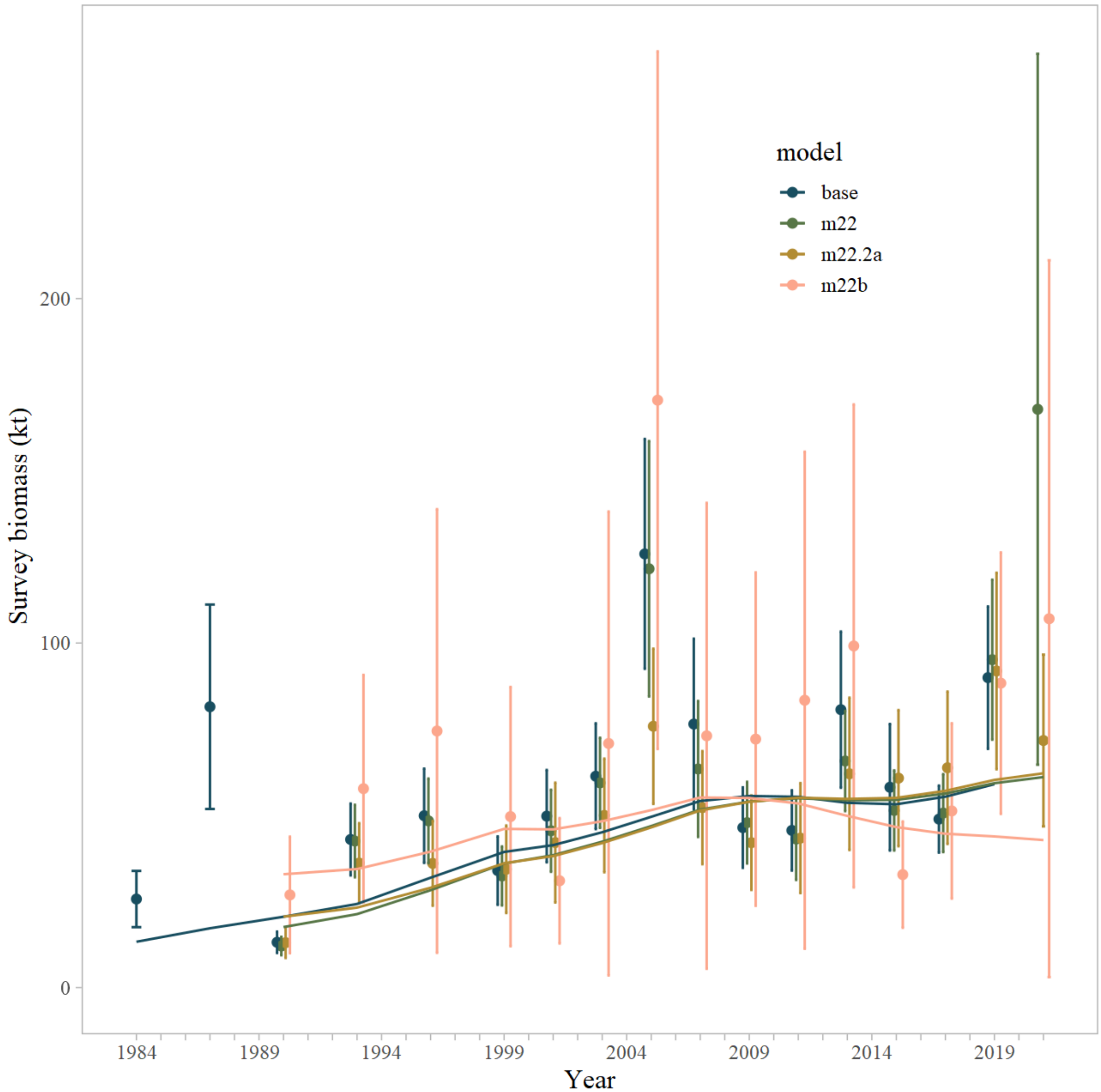


Figure 12c-29. Design-based and VAST (lognormal) trawl survey inputs and model results with increased age plus group.

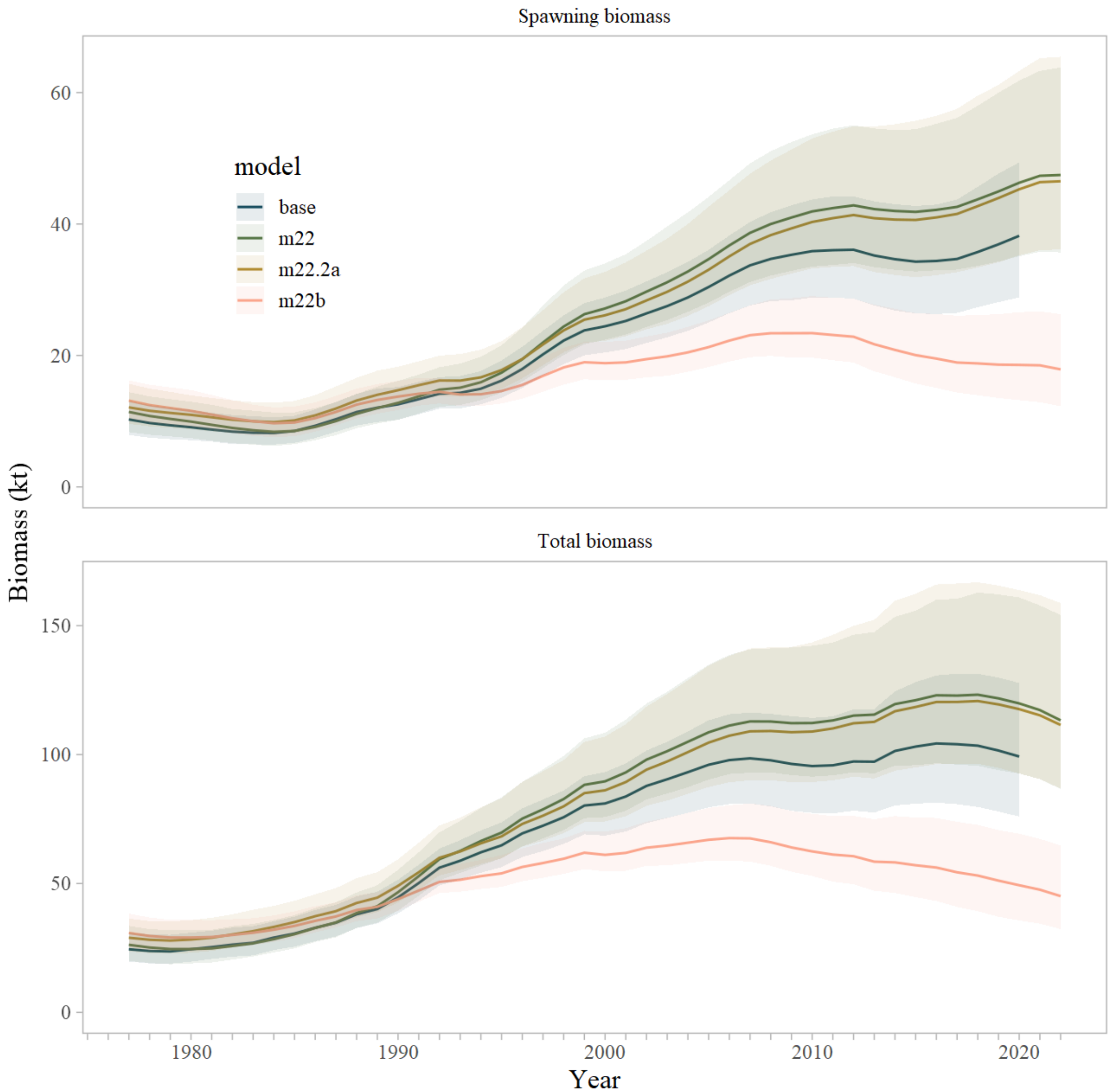


Figure 12c-30. Spawning and total biomass results using different model structures with a design-based or VAST (lognormal) trawl survey input with increased age plus group

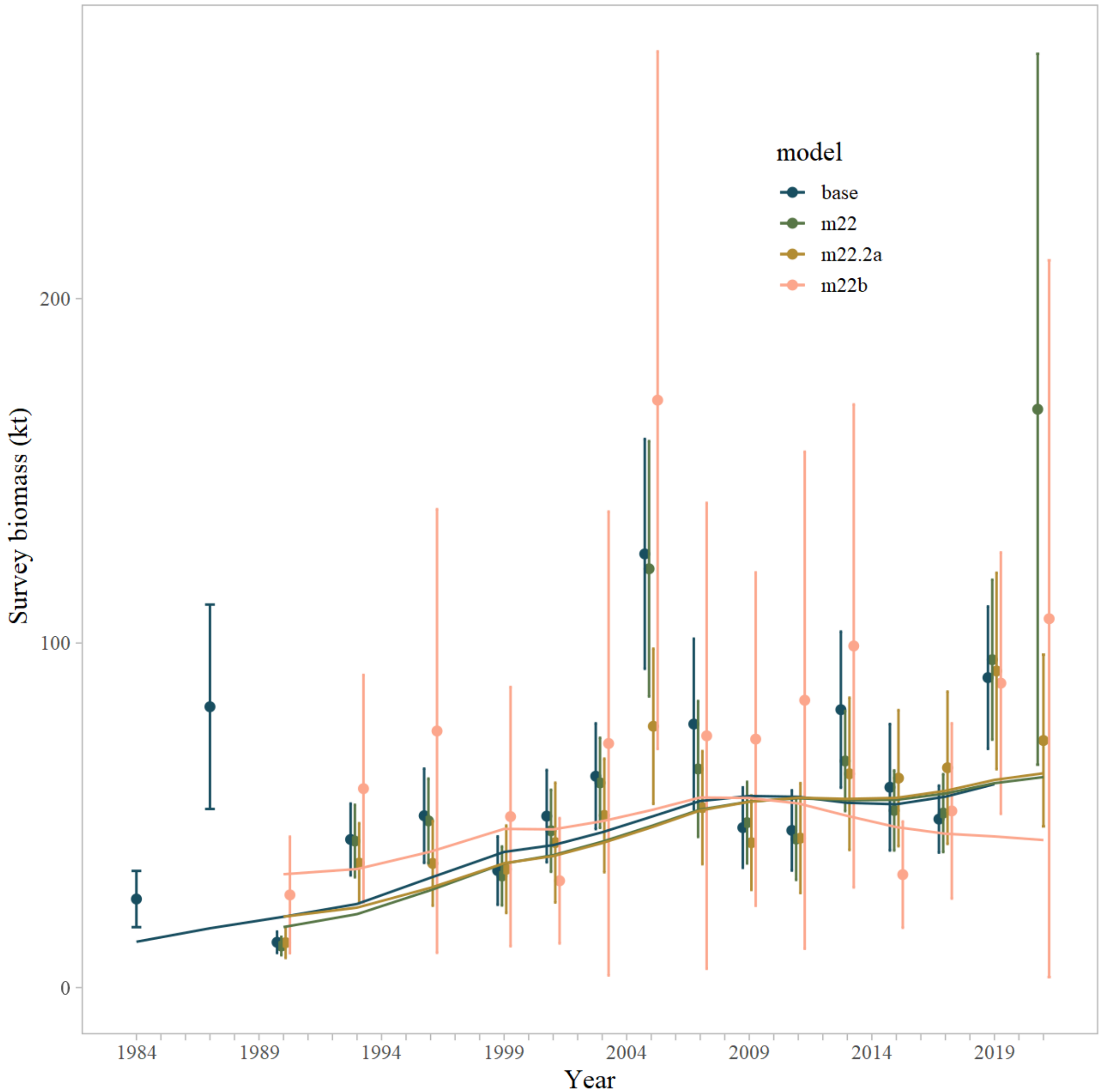


Figure 12c-31. Design-based and VAST (lognormal) trawl survey inputs and model results with increased age and length plus groups.

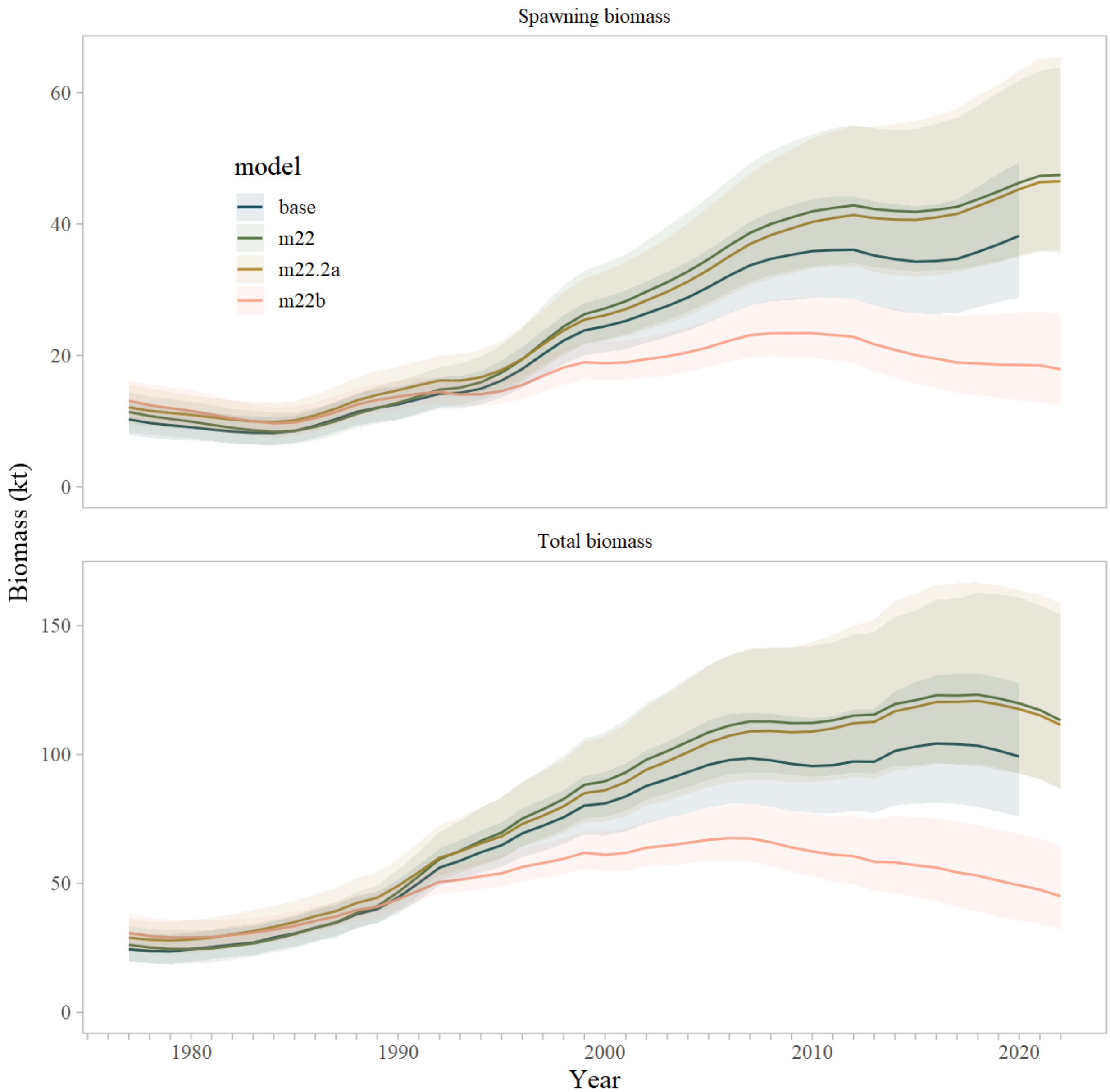


Figure 12c-32. Spawning and total biomass results using different model structures with a design-based or VAST (lognormal) trawl survey input with increased age and length plus groups.