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

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Executive Summary

Gulf of Alaska northern rockfish (*Sebastes polyspinis*) are classified as a Tier 3 stock and are assessed using a statistical age-structured model with a full stock assessment produced in even years and a harvest projection stock assessment produced in odd years to coincide with the availability of new trawl survey data (odd years). 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 sets used in this assessment include total catch biomass, fishery age and size compositions, trawl survey abundance estimates, and trawl survey age compositions. For Gulf of Alaska northern rockfish in 2024, we present a full assessment with updated assessment and projection model results to recommend harvest levels for the next two years.

Summary of Changes in Assessment Inputs

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

- Update survey biomass estimates through 2023,
    - Vast-based estimates with a lognormal error structure (instead of the Gamma default),
- Update survey age compositions with 2023 data,
- Update fishery age compositions with 2022 data,
- Update final catch values for 2022 and 2023, and use preliminary catch for 2024,
- Update weight-at-age with data through 2023,
- Update size-at-age transition matrix with data through 2023,
- Change survey age composition input sample sizes to reflect current best practices,
- Update maturity-at-age ogive with data from Conrath (2019).

Changes in assessment methodology:
The following model changes are recommended in the current assessment:

- Change survey biomass negative log likelihood from a normal error structure to a log error structure,

- Base area apportionment on VAST model outputs instead of REMA-smoothed, design-based survey abundance,
- Transition the model from ADMB to RTMB,
  - moves maturity estimation to outside the model.

Summary of Results

A suite of incremental models were run to investigate the effects of changes to the model methodology and input data (described in detail in Appendix 10c).

Model	Description
base	the 2022 SSC accepted model (m22.1)
m22.1	base model run using 2024 data
m22.1a	m22.1 w/lognormal survey biomass likelihood
m22.1b	m22.1a w/updated input sample sizes
m22.1c	m22.1b w/lognormal VAST survey biomass
m24	m22.1c w/updated maturity

The author's preferred model is m24. With the inclusion of data and model changes we see that model m24 produces generally good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivity, and has a negative retrospective Mohn's rho value. Therefore, the recommended 2024 model is utilizing the new information effectively, and we use it to recommend the 2025 ABC and OFL. Of note, is that the survey biomass has declined, though the ABC has increased from the 2023 assessment. This is due, in large part, to the change to a lognormal NLL for survey biomass (see Appendix 10c). Additionally, it should be noted that all models estimate higher levels of survey, spawning, and total biomass if the survey biomass NLL weighting is changed from the current 0.25 to 1.0 (see Appendix 10c, *Alternative models* section). If the survey likelihood is given a greater weight it raises the survey, spawning, and total biomass for all years, even with the low 2023 survey biomass estimate. That is to say, that the data and framework changes incorporated indicate a larger population from the previous assessment. There are no recommended reductions from max ABC.

ABC recommendation
The m24 projected age 2+ total biomass for 2025 is 96,967 t. The recommended ABC for 2025 is 5,077 t, the maximum allowable ABC under Tier 3a. This ABC is a 5% increase compared to the 2024 ABC of 4,816 and a 9% increase from the projected 2025 ABC from the prior assessment. The 2025 GOA-wide OFL for northern rockfish is 6,064 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 GOA northern rockfish are summarized in the following table, with the recommended ABC and OFL values in bold.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity/Status	2024	2025	2025*	2026*
M (natural mortality)	0.059	0.059	0.059	0.059
Tier	3a	3a	3a	3a
Projected total (age 2+) biomass (t)	94,319	93,088	96,967	95,374
Projected female spawning biomass	38,118	36,510	40,392	38,675
$B_{100\%}$	82,350	82,350	84,695	84,695
$B_{40\%}$	32,940	32,940	33,878	33,878
$B_{35\%}$	28,822	28,822	29,643	29,643
F_{OFL}	0.074	0.074	0.074	0.074
maxF_{ABC}	0.061	0.061	0.062	0.062
F_{ABC}	0.061	0.061	0.062	0.062
OFL (t)	5,750	5,548	**6,064**	5,848
*max*ABC (t)	4,816	4,647	5,077	4,896
ABC (t)	4,816	4,647	**5,077**	4,896
	As determined *last* year for:		As determined *this* year for:	
Status	2023	2024	2024	2025
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on an estimated catch of 1,170 t for 2024 and estimates of 1,827 t and 1,695 t used in place of maximum permissible ABC for 2025 and 2026.

Area Allocation of Harvest

The following table shows the recommended ABC apportionment for 2025 and 2026. Please refer to the Area Allocation of Harvests section of this document for the apportionment rationale for GOA northern rockfish.

		Western	Central	Eastern	Total
Area Apportionment		55.71%	44.28%	0.02%	100%
2025	ABC (t)	2,828	2,248	1	5,077
2025	OFL (t)				6,064
2026	ABC (t)	2,727	2,168	1	4,896
2026	OFL (t)				5,848

Responses to SSC and Plan Team Comments on Assessments in General

"The SSC supports the JGPT's recommendation that stock assessment authors transition from the ADMB RE variants to the rema framework, which implements the same model variants in a single framework with several improvements."(SSC, Oct 2022)

Apportionment was previously transitioned from the ADMB RE model to the rema framework (Williams *et al.* 2022). However, the rema framework uses the design-based survey biomass estimates as inputs. As this model uses VAST-based estimates of survey abundance we propose using VAST-based area biomass estimates for determining apportionment. These VAST-based estimates are described in detail in Appendix 10c.

Responses to SSC and Plan Team Comments Specific to this Assessment

"The SSC supports the GOA GPT recommendations to investigate potential mechanisms for the underlying pattern [to the fishery length composition] and recommends the authors consider whether a selectivity time block, to account for changes in the fishery (i.e., POP rebuilding), is appropriate and improves fit to the compositional information." (SSC December 2022)

A selectivity-at-age timeblock was examined, though results did not improve the compositional fit. The authors will continue examining timeblock implementation, as well as exploring using a length-based selectivity for early years of the fishery and exploring the stability of the size-at-age transition matrix over time (currently has a single time block).

"The SSC notes the MCMC on the estimates of q include a long right tail with unrealistic values of q. The SSC requests the authors investigate a model run with a fixed M." (SSC December 2022)

Estimates of q appear better behaved in the current assessment. The authors examined a model run with a fixed M, though with the tight CV on the M prior results were essentially the same.

"The SSC also requests the following for future assessments: bubble plots of Pearson residuals for all age and length data, including the sign and scale of residuals; and inclusion of a figure showing changes in previous VAST estimates due to updating with new survey information." (SSC December 2022)

Pearson and one-step ahead residual plots are presented, as well as a figure showing previous VAST estimates.

"The SSC reiterates its past support of empirical research projects on maturity and skip spawning, perhaps with industry partnership."(SSC December 2022)

Examinations of maturity and skip spawning are ongoing. The biological maturity ogive has been updated with additional data (Conrath 2019) and maturity estimation has been moved out of the model to facilitate future examinations of functional (skip spawning) rates on model outputs.

Introduction

Biology and Distribution

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

Little is known about the life history of northern rockfish. Like other *Sebastes* species, northern rockfish are ovoviviparous with internal fertilization. Northern rockfish have a mean relative fecundity of 109.6 embryos/g for specimens captured in May, and higher relative frecundity with body size (Conrath 2019). Observations during research surveys in the Gulf of Alaska indicate that parturition (larval release) occurs in the spring and is completed by summer. Larval northern rockfish cannot be unequivocally identified to species at this time, even using genetic techniques, so information on larval distribution and length of the larval stage is unknown. The larvae metamorphose to a pelagic juvenile stage, but there is no information on when these juveniles become demersal.

Little information is available on the habitat of juvenile northern rockfish. Studies in the eastern Gulf of Alaska and Southeast Alaska using trawls and submersibles have indicated that several species of juvenile (< 20 cm) red rockfish (Sebastes spp.) associate with benthic nearshore living and non-living structure and appear to use the structure as a refuge (Carlson and Straty 1981; Krieger 1993). Freese and Wing (2003) also identified juvenile (5 to 10 cm) red rockfish (*Sebastes spp*.) associated with sponges (primarily *Aphrocallistes spp.*) attached to boulders 50 km offshore in the GOA at 148 m depth over a substrate that was primarily a sand and silt mixture. Only boulders with sponges harbored juvenile rockfish, and the juvenile red rockfish appeared to be using the sponges as shelter (Freese and Wing 2003). Although these studies did not specifically observe northern rockfish, it is likely that juvenile northern rockfish also utilize similar habitats. Length frequencies of northern rockfish captured in NMFS bottom trawl surveys and observed in commercial fishery bottom trawl catches indicate that older juveniles (>20 cm) are found on the continental shelf, generally at locations inshore of the adult habitat (Pers. comm. Dave Clausen).

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

Trawl surveys and commercial fishing data indicate that the preferred habitat of adult northern rockfish in the Gulf of Alaska is relatively shallow rises or banks on the outer continental shelf at depths of about 75-150 m (Clausen and Heifetz 2002). The highest concentrations of northern rockfish from NMFS trawl survey catches appear to be associated with relatively rough (variously defined as hard, steep, rocky or uneven) bottom on these banks (Clausen and Heifetz 2002). Heifetz (2002) identified rockfish as among the most common commercial fish captured with gorgonian corals (primarily *Callogorgia*, *Primnoa*, *Paragorgia*, *Fanellia*, *Thouarella*, and *Arthrogorgia*) in NMFS trawl surveys of Gulf of Alaska and Aleutian waters. Krieger and Wing (2002) identified six rockfish species associated with gorgonian coral (*Primnoa spp*.) from a manned submersible in the eastern Gulf of Alaska. Research focusing on non-trawlable habitats found rockfish species often associate with biogenic structure (Du Preez and Tunnicliffe 2011; Laman *et al.* 2015). However, most of these studies did not specifically observe northern rockfish, and more research is required to determine if northern rockfish are associated with living structure, including corals, in the Gulf of Alaska, and the nature of those associations if they exist. Recent work on black rockfish (Sebastes melanops) has shown that larval survival may be higher from older female spawners (Berkeley *et al.* 2004). The black rockfish population has shown a distinct reduction in the proportion of older fish in recent fishery samples off the West Coast of North America, raising concerns if larval survival diminishes with spawner age. Bruin *et al.* (2004) examined Pacific ocean perch (*S. alutus*) and rougheye rockfish (*S. aleutianus*) for senescence in reproductive activity of older fish and found that oogenesis continues at advanced ages. Leaman (1991) showed that older individuals have slightly higher egg dry weight than their middle-aged counterparts. Some literature suggests that environmental factors may affect the condition of female rockfish that contributes to reproductive success (Hannah and Parker 2007; Rodgveller *et al.* 2012; Beyer *et al.* 2015). However, relationships on fecundity or larval survival at age have not yet been evaluated for northern rockfish or other rockfish in Alaska. Stock assessments for Alaska groundfish have assumed that the reproductive success of mature fish is independent of age.

Stock Structure

Gulf of Alaska northern rockfish grow significantly faster and reach a larger maximum length than Aleutian Islands northern rockfish (Clausen and Heifetz 2002). Though, Aleutian Islands northern rockfish and GOA northern rockfish have an observed maximum age of 72 years. There have been two studies on the genetic stock structure of northern rockfish. One study of northern rockfish provided no evidence for genetically distinct stock structure when comparing samples from near the western Aleutian Islands, the western GOA, and Kodiak Island (Gharrett *et al.* 2003). The results from that study were considered preliminary, and sample sizes were small. Consequently, the lack of evidence for stock structure did not necessarily confirm stock homogeneity. A more recent study did find spatial structure on a relatively small scale for northern rockfish sampled from several locations in the Aleutian Islands and Bering Sea (Gharrett *et al.* 2012). Currently, genetic structure of northern rockfish in the GOA is being reevaluated with low coverage whole genome resequencing using data from millions of markers (W. Larson, personal communication). Preliminary results indicate that there is spatial structure and associated ecotypes.

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

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

Fishery

Description of the Directed Fishery

In the Gulf of Alaska, northern rockfish are generally caught with bottom trawls identical to those used in the Pacific ocean perch (*S. alutus*) fishery. Many of these nets are equipped with so-called "tire gear" in which automobile tires are attached to the footrope to facilitate towing over rough substrates. Most of the catch has been taken during July (Figure 10-2), the directed rockfish trawl fishery in the Gulf of Alaska opens in May, though Council Amendment 113 to the Fishery Management Plan for the Groundfish of the Gulf of Alaska; Central Gulf of Alaska Rockfish Program Adjustments changes the start date of the fishery to April 1, beginning in 2025. Rockfish trawlers usually direct their efforts first toward Pacific ocean perch because of its higher value relative to other rockfish species. After the TAC for Pacific ocean perch has been reached and NMFS closes directed fishing for this species, trawlers switch and target northern rockfish. With implementation of the Central Gulf Rockfish Pilot Project in 2007, catches have been spread out more throughout the year.

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

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

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

Management Measures

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

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

In November, 2006, NMFS issued a final rule to implement Amendment 68 of the GOA groundfish Fishery Management Plan for 2007 through 2011. This action implemented the Central GOA Rockfish Pilot Program (RPP). The intention of this Program was to enhance resource conservation and improve economic efficiency for harvesters and processors in the rockfish fishery. An additional objective was to spread out the fishery in time and space, allowing for enhanced market conditions for product and reducing the pressure of what was an approximately two-week fishery in July. The primary rockfish management groups in this program are northern rockfish, Pacific ocean perch, and pelagic shelf rockfish.

A summary of key management measures and a time series of catch, ABC and TAC are provided in Tables 10-8 and 10-3, respectively.

Catch Patterns

Total commercial catch (t) of northern rockfish in the GOA for the years 1961-2024 is summarized by foreign, joint venture, and domestic fisheries (Table 10-3 and Figure 10-1). Catches of GOA northern rockfish during the years 1961-1976 were estimated as 5% of the foreign GOA Pacific ocean perch catch in the same years. A Pacific ocean perch trawl fishery by the U.S.S.R. and Japan began in the Gulf of Alaska in the early 1960's. This fishery developed rapidly with massive efforts by the Soviet and Japanese fleets. Catches peaked in 1965 when a total of nearly 350,000 metric tons (t) were caught, but declined to 45,500 t by 1976. Some northern rockfish were likely taken in this fishery, but there are no available summaries of northern rockfish catches for this period. Foreign catches of all rockfish were often reported simply as "Pacific ocean perch" with no attempt to differentiate species. The only detailed analysis of bycatch in slope rockfish fisheries of the Gulf of Alaska is that of Ackley and Heifetz (2001) who examined data from the observer program for the years 1993-95. Consequently, our best estimate of northern rockfish catch from 1961-1976 comes from analysis of the ratio of northern rockfish catch to Pacific ocean perch catch in the years 1993-1995. For hauls targeting on Pacific ocean perch, northern rockfish composed 5% of the catch (Ackley and Heifetz 2001).

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

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

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

Catches of GOA northern rockfish during the years 1993-2024 were available directly from NMFS domestic fisheries observer data. Northern rockfish were removed from the slope rockfish assemblage and managed with an individual TAC beginning in 1993. As a consequence, directly reported catch for northern rockfish has been available since 1993. Catch of northern rockfish was reduced after the implementation of a northern rockfish specific TAC in 1993. Most of the catch since 1993 has been taken in the Central GOA, where the majority of the northern rockfish exploitable biomass is located. Gulfwide catches for the years 1993-2024 have ranged from 1,129 t to 5,966 t. Annual ABCs and TACs have been relatively consistent during this period and have varied between 3,000–6,000 t. In 2001, catch of northern rockfish was below TAC because the maximum allowable bycatch of Pacific halibut (*Hippoglossus stenolepis*) was reached in the central Gulf of Alaska for "deep water trawl species," which includes northern rockfish. Catches of northern rockfish were near their TAC's in 2003 – 2016, however in 2017 catch was 48% of the TAC and has remained low in subsequent years; the 2024 projected catch is likely to reach <30% of the TAC (Table 10-3; Figure 10-2). Consultation with industry representatives suggested the low catch to TAC ratio since 2017 is largely driven by the fleet targeting alternative higher value species. Research catches of northern rockfish have been relatively small and are listed in Table 10a-1 in Appendix 10A.

Bycatch and Discards

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

Total FMP groundfish catch estimates in the GOA rockfish fishery from 2020–2024 are shown in Table 10-4. As an average for the GOA rockfish fishery during 2020–2024, 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 10-5). However, the amounts from northern rockfish targeted hauls are likely 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. Since the 2022 assessment the prohibited species catch has remained similar for Chinook salmon and increased substantially for non-chinook salmon and golden king crab. Prohibited species catch has remained at similar levels for Pacific halibut (Table 10-6). It should be noted that these catch rates are for all rockfish fisheries, not just northern rockfish.

In summary, northern rockfish are most likely to be associated with other rockfish fisheries and the bycatch of non-rockfish species in the northern rockfish 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 10-7) of northern rockfish are show for 1993–2024. These rates are generally considered to be low and are consistent with other GOA rockfish species. There is an uptick in discard rates in 2024, likely associated with the poor market conditions and reduction in targeting northern rockfish. These discard rates are generally similar to those in the GOA for Pacific ocean perch and dusky rockfish. Discard mortality is assumed to be 100% for GOA northern rockfish.

Data

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

Source	Data	Years
NMFS Groundfish survey	Survey biomass	1990-1999 (triennial), 2001-2021 (biennial), 2023*
	Age composition	1990-1999 (triennial), 2003-2021 (biennial), 2023*
U.S. trawl fishery	Catch	1961-2020, 2021-2024*
	Age composition	1998-2002, 2004-2006, 2008-2020 (biennial), 2022*
	Length composition	1991-1997, 2003, 2007-2021 (biennial), 2023*

Fishery

Catch

Catch of northern rockfish ranges from 185 t to 17,430 t during 1961-2024. Detailed descriptions of catch are provided in Table 10-3 and Figure 10-1. This is the commercial catch history used in the assessment model. In response to Annual Catch Limits (ACLs) requirements, assessments now document all removals including catch that is not associated with a directed fishery. Estimates of all removals not associated with a directed fishery including research catches are available and are presented in Appendix 10a. In summary, annual research removals have typically been less than 10 t and very little is taken in recreational or Pacific halibut fisheries. These levels likely do not pose a significant risk to the northern rockfish stock in the GOA.

Age and Size Composition

Observers aboard fishing vessels and at onshore processing facilities have provided data on size and age composition of the commercial catch of northern rockfish. Ages were determined from the break-and-burn method (Chilton and Beamish 1982). Length compositions are presented in Table 10-9 and Figure 10-3 and age compositions are presented in Table 10-10 and Figure 10-4; these tables also include associated annual sample sizes and number of hauls sampled for the age and length compositions. The fishery age compositions indicate that stronger than average year-classes occurred around the year 1976 and 1984. The fishery age compositions from 2004 and 2006 also indicate that the 1996-1998 year-classes were strong. There are few younger fish observed in the age compositions for more recent years. The clustering of several large year-classes in each period is most likely due to aging error. Length composition data show a slight increase in the size of fish caught, this is well aligned with the lack of younger fish observed in the fishery age compositions for the same time periods.

Survey

Biomass Estimates from Trawl Surveys

Bottom trawl surveys were conducted in the GOA triennially from 1984–1999 and biennially from since 2001. The surveys provide an index of biomass and age composition data, and growth characteristics. The trawl surveys have used a stratified random design to sample fishing stations that cover all areas of the GOA out to a depth of 1,000 m (in some surveys only to 500 m). Generally, attempts have been made through the years to standardize the survey design and the fishing nets used, but there have been some exceptions to this standardization. In particular, much of the survey effort in 1984 and 1987 was by Japanese vessels that used a very different net design and a different survey design than what has been the standard used by U.S. vessels throughout the surveys. To deal with this problem the 1980s survey data have been excluded from this assessment.

Gulf-wide biomass estimates from the VAST model-based index are presented in Table 10-11 and Figure 10-5. The author's preferred model uses VAST with a lognormal error distribution to model positive catch rates instead of the GAP default gamma distribution (see Appendix 10b). The spatial distribution of the catches of northern rockfish in the 2019, 2021, and 2023 surveys are shown in Figure 10-6. The magnitude of catch varies greatly with several large tows typically occurring in each survey. The precision of some of the biomass estimates has been low and is reflected in the high CVs associated with some survey biomass estimates of northern rockfish that are the result of few very large catches during the survey. In 2001, a single very large survey haul of northern rockfish greatly increased the biomass estimates and resulted in wide confidence bounds. The haul in 2001 was the largest individual catch (14 t) of northern rockfish ever taken during a GOA survey; this tow accounted for 58.7% of total survey catch by mass in that year. In contrast, the 2005 and 2007 survey had several large hauls of northern rockfish in the Central Gulf with similar confidence bounds. The 2023 survey provided the lowest abundance estimates to date (65% percent difference from the survey mean). Given the patchy distribution and variable survey catches of this species it is unclear whether this is a sampling effect or a population trend. Due to the substantial variability observed in the design-based index this assessment is using the VAST model-based index of abundance, though trawl survey biomass from a design-based estimator is also presented per SSC request (Table 10-12).

Age and Size Composition

Ages for northern rockfish were determined from the break-and-burn method (Chilton and Beamish 1982). These age compositions (Table 10-13 and Figure 10-7) indicate that recruitment of northern rockfish is highly variable. The 1990 and 1996 surveys show especially strong year-classes from the period around 1975-77; although they differ as to which specific years were greatest, likely due to age determination errors. The 1993, 1996, and 1999 age compositions also indicate that the 1983-85 year-classes may be stronger than average. Recent age compositions (2005-2011) indicate that the 1996-98 year-classes may also be stronger than average, which is in agreement with recent age compositions obtained from the commercial fishery described above. Trawl surveys provide size composition data for northern rockfish but are not used directly in the current age structured assessment model. In years with age readings, trawl survey size composition data are multiplied by an age-length key (computed from length-stratified otolith collections) to obtain survey age compositions. Similar to the fishery length compositions discussed above, the proportion of older fish been increasing since the mid to early 2000s with few younger fish observed.

Maturity Data

In previous stock assessments for northern rockfish, age at maturity was based on a logistic curve fit to ovarian samples collected from female northern rockfish in the central GOA in the spring of 1996 (n=75, C. Lunsford pers. comm. July 1997, Heifetz et al. Chilton (2007) provides additional information (n=157) for maturity-at-age, this study collected ovarian samples from female northern rockfish throughout the year in 2000 and 2001. In a report submitted to the GOA Groundfish Plan Team in September 2010, the two studies were compared and the advantages and disadvantages of the different approaches for studying maturity (histology versus visual inspection) were discussed (Rodgveller *et al.* 2013). Due to the relatively small sample sizes for each study, the close proximity in time for each study (4 years apart compared to the 51 year time series used in this assessment), and the large difference in the age at 50% maturity (12.8 years used in previous assessments compared to 8 years obtained by Chilton 2007), these data were combined to estimate an intermediate maturity-at-age rather than consider time-dependent changes in maturity (Figure 10-8). More recently, reproductive potential was examined by Conrath (2019) (n=274), while this analysis focused on maturity-at-length, ages are available for the dataset (C. Conrath pers. comm. 2023). Conrath (2019) has reported skip spawning in northern rockfish, the impacts of which are not currently incorporated into the assessment as the spatial and temporal aspects are unknown. The data from Conrath (2019) were combined with the maturity data from the previous two studies (Figure 10-9) to generate updated maturity oogive (Figure 10-8). All of the samples from Conrath (2019) were for mature fish, greater than age-12, therefore the biological maturity curve was minimally effected.

Analytical approach

General Model Structure

The basic model for GOA northern rockfish is described as a separable age-structured model and was implemented using AD Model Builder software (Fournier *et al.* 2012). The assessment model is based on a generic rockfish model developed in a workshop held in February 2001 (Courtney *et al.* 2007) and follows closely the GOA Pacific ocean perch model (Hulson *et al.* 2021). This assessment model has now been transitioned out of ADMB and is implemented using RTMB (Kristensen 2024). The northern rockfish model is fit to a time series extending from 1961-2024. 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 10-10). The parameters, population dynamics, and equations of the model are shown below:

Parameter	Definition
y	Year
a	Age class
l	Length bin
w_a	Vector of estimated weight at age, $a_0 \rightarrow a_+$
m_a	Vector of estimated maturity at age, $a_0 \rightarrow a_+$
a_0	Age at first recruitment
a_+	Age when age classes are pooled
μ_r	Average annual recruitment, log-scale estimation
μ_f	Average fishing mortality
σ_r	Recruitment variability
ε_y^r	Annual recruitment deviation
ε_a^r	Initial recruitment deviation by age
ϕ_y	Annual fishing mortality deviation
fS_a	Vector of fishery selectivity at age, $a_0 \rightarrow a_+$
sS_a	Vector of survey selectivity at age, $a_0 \rightarrow a_+$
δ	Logistic slope parameter
a_{50}	Logistic age at 50% selectivity
$n^*\, y$	Input sample size
M	Natural mortality
$F_{a,y}$	Fishing mortality by age class and year, $fS_a\mu_f e^{\epsilon}$

Parameter	Definition
$Z_{a,y}$	Total mortality by age class and year, $F_{a,y} + M$
$T_{a,a'}$	Aging error matrix
$T_{a,l}$	Size at age transition matrix
q	Survey catchability coefficient
SB_y	Annual female spawning biomass

Equations describing population dynamics.

First year

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

Subsequent years

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

Annual spawning biomass

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

Equations describing observation data.

Equation	Description
$S_a = \dfrac{1}{1 + e^{-\delta(a - a_{50})}}$	Logistic selectivity
$\hat{C}_y = \sum_{a_0}^{a_+} \dfrac{N_{a,y} F_{a,y} (1 - e^{-Z_{a,y}})}{Z_{a,y}} w_a$	Catch
$F_{a,y} = f S_a F_y = f S_a e^{\mu_f + \phi_y}$	Fishing mortality
$\hat{I}_y = q \sum_{a_0}^{a_+} N_{a,y}\, s S_a w_a$	Bottom trawl survey biomass index
$\hat{P}_{a,y} = \dfrac{N_{a,y} s S_a}{\sum_a^{a+} N_{a,y}\, s S_a} T_{a,a'}$	Bottom trawl survey age composition
$\hat{P}_{a,y} = \dfrac{\hat{C}_{a,y}}{\sum_a^{a+} \hat{C}_{a,y}} T_{a,a'}$	Fishery age composition

Equation	Description
$\hat{P}_{l,y} = \frac{\hat{C}_{l,y}}{\sum_{l}^{l+} \hat{C}_{l,y}} T_{a,l}$	Fishery length composition

Likelihood components

Likelihood Equation	Component	Model Weight (λ)
$\mathcal{L} = \lambda \sum_{y} \ln\left(\frac{C_y + 1^{-5}}{\hat{C}_y + 1^{-5}}\right)^2$	Catch	5, 50
$\mathcal{L} = \lambda \sum_{y} \left[\ln(\sigma_y) + 0.5\left(\frac{\ln(I_y/\hat{I}_y)}{\sigma_y}\right)^2\right]$ where $\sigma_y = \sqrt{\ln\left(1 + \frac{SE(I_y)^2}{I_y^2}\right)}$	Trawl survey biomass	0.25
$\mathcal{L} = \lambda \sum_{y} -n_y^* \sum_{a_0}^{a_+} (P_{a,y} + 1^{-5}) \ln(\hat{P}_{a,y} + 1^{-5})$	Age compositions	0.5
$\mathcal{L} = \lambda \sum_{y} -n_y^* \sum_{l}^{l_+} (P_{l,y} + 1^{-5}) \ln(\hat{P}_{l,y} + 1^{-5})$	Length compositions	0.5
$\mathcal{L} = \lambda \left[\frac{\sum_y \left(\epsilon_y^r + \frac{\sigma_R^2}{2}\right)^2}{2 \cdot \sigma_R^2}\right]$	Recruitment deviation penalty	1.0
$\mathcal{L} = \lambda \sum_{y} \phi_y$	Fishing mortality deviation penalty	0.1
$\frac{1}{2\sigma_\theta^2} \ln\left(\frac{\theta}{\theta_{prior}}\right)^2$	Prior penalties for $M, q, \sigma_r, a_{50}, \delta$ θ parameter estimate, σ_θ^r prior uncertainty θ_{prior} prior mean	

Description of Alternative Models

A suite of incremental models were run to investigate the effects of changing the survey biomass negative log likelihood from normal to lognormal error, refining the survey age composition input sample sizes to account for age and growth variability, and transitioning the model framework from ADMB to RTMB. The base model was estimated using both ADMB and RTMB, the results are near identical (Appendix 10c), therefore the models presented here were estimated using the RTMB model framework.

The models examined were:

Model	Description
base	the 2022 SSC accepted model (m22.1)
m22.1	base model run using 2024 data
m22.1a	m22.1 w/lognormal survey biomass likelihood
m22.1b	m22.1a w/updated input sample sizes
m22.1c	m22.1b w/lognormal VAST survey biomass
m24	m22.1c w/updated maturity

Parameters Estimated Outside the Assessment Model

A von Bertalanffy growth curve was fitted, for both sexes combined, to survey size at age data from 1990-2021 using length-stratified methods (Quinn and Deriso 1999; Bettoli and Miranda 2001). 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 length-weight relationship for combined sexes, using the formula $W = aL^b$, where W is weight in grams and L is fork length in mm, a = 0.0783 and b = 2.0742. Previous parameters are available from Heifetz and Clausen (1991); Courtney *et al.* (1999); and Malecha *et al.* (2007). The estimated parameters for the growth curve from length-stratified methods are:
L_∞ = 41.29 cm, κ = 0.17, and t_0 = -0.20.

Weight-at-age was constructed with weight at age data from the same data set used to estimate length at age. Mean weight-at-age is approximated by the equation:

$$W_a = W_\infty\left(1 - e^{(-\kappa(age - t_0))}\right)^b.$$

The estimated growth parameters from length-stratified methods are:
W_∞ = 1054 g, κ = 0.18, t_0 = -0.04, and b = 3.03.

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

For the RTMB model maturity at age was removed from the model (see below) and estimated using logistic regression (GLM) in R (R Core Team 2024). The fit to observations of maturity-at-age is shown in Figure 10-8.

Parameters Estimated Inside the Assessment Model

The estimates of natural mortality (*M*) and catchability (*q*) are computed with the use of lognormal prior distributions as penalties that are added to the overall objective function in order to constrain parameter estimates to reasonable values and to speed model convergence. Arithmetic means and standard errors (μ, σ) for the lognormal distributions were provided as inputs to the model. The standard errors for selected model parameters were estimated based on multivariate normal approximation of the covariance matrix. The prior mean for natural mortality of 0.06 is based on the estimate provided by Heifetz and Clausen (1991) using the methods of Alverson and Carney (1975). Natural mortality is a difficult parameter to estimate within the model so we assign a "tight" prior CV of 5%. Catchability is a parameter that is unclear for rockfish, so while we assign it a prior mean of 1 (assuming all fish in the area swept are captured and there is no herding of fish from outside the area swept, and that there is no effect of untrawlable grounds), we assign it a less precise CV of 45%. This allows the parameter more freedom than that allowed to natural mortality. These methods are also used in the GOA Pacific ocean perch and GOA dusky rockfish assessments.

Parameters for the logistic function describing maturity-at-age estimated conditionally in the ADMB model, as well as all other parameters estimated conditionally, were identical to estimating maturity-at-age independently via GLM. 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 ADMB assessment model allows for uncertainty in maturation to be incorporated into uncertainty for key model results (e.g., ABC), though estimates of other parameters are not effected.

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

The numbers of estimated parameters from model 24 are:

Parameter	Symbol	Number
Natural mortality	M	1
Catchability	q	1
Log mean recruitment	μ_r	1
Spawners per recruit levels	$F_{35\%}, F_{40\%}, F_{50\%}$	3
Recruitment deviations	τ_y	112
Average fishing mortality	μ_F	1
Fishing mortality deviations	ϕ_y	64
Logistic fishery selectivity	$a_{f50\%}, \delta_f$	2
Logistic survey selectivity	$a_{s50\%}, \delta_s$	2
Total		187

Evaluation of model uncertainty is obtained through a Markov Chain Monte Carlo (MCMC) algorithm (Monnahan 2018). The MCMC was setup with 5 chains over 2,000 iterations, with a warmup of 400 iterations. There were six divergences after the warmup, the minimum effective sample size was 461, and the maximum Rhat was 1.021. 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 5th and 95th percentiles of the MCMC samples).

Results

Model Evaluation

The author's preferred model is model m24. The examined models were:

Model	Description
base	the 2022 SSC accepted model (m22.1)
m22.1	base model run using 2024 data
m22.1a	m22.1 w/lognormal survey biomass likelihood
m22.1b	m22.1a w/updated input sample sizes
m22.1c	m22.1b w/lognormal VAST survey biomass
m24	m22.1c w/updated maturity

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 selectivity, (3) a good visual fit to length and age compositions, and (4) parsimony. For clarity, the majority of the incremental model fits and comparisons can be found in Appendix 10c. We've presented results for multiple models because the 2022 and 2024 models differ in either data inputs or model structure, there are no meaningful differences observed between ADMB and RTMB modeling software. Fits to m24 and the base model(s) are presented herein.

Model likelihoods and key estimated parameters and outputs are shown below for a comparison of RTMB and ADMB results for the base model. Likelihoods, parameters, and output values are near exact, differences can be attributed to rounding error between the two programs. Further examination of similarities in the software change can be found in Appendix 10c.

Table 10-1. Likelihood values for comparing the GOA northern rockfish coded in ADMB and RTMB.

Likelihood	RTMB	ADMB	difference
Catch	0.0907	0.0907	0.0000
Survey	6.0219	6.0219	0.0000
Fish age	40.1766	40.1766	0.0000
Survey age	69.1597	69.1598	0.0001
Fish size	67.9073	67.9072	-0.0001
Recruitment	8.6402	8.6402	0.0000
F regularity	5.4574	5.4574	0.0000
SPR penalty	0.0000	0.0000	0.0000
M prior	0.0140	0.0140	0.0000
q prior	0.0520	0.0520	0.0000
Sub total	197.5198	197.5198	0.0000
L maturity		23.5012	
C maturity		46.7265	
Sum maturity		70.2277	

Table 10-2. Key parameters and output values for comparing the GOA northern rockfish coded in ADMB and RTMB.

Item	RTMB	ADMB	difference
M	0.0595	0.0595	0.0000
q	0.8649	0.8649	0.0000
Log mean recruitment	3.5039	3.5039	0.0000
Log mean F	-3.5839	-3.5839	0.0000
A50 fishery	8.2372	8.2372	0.0000
Delta fishery	1.9187	1.9187	0.0000
A50 survey	9.0936	9.0936	0.0000
Delta survey	4.3192	4.3192	0.0000
2023 Total biomass	95,559.2189	95,559.2000	-0.0189
2023 Spawning biomass	39,462.5860	39,462.6000	0.0140
2023 OFL	5,935.1641	5,935.1600	-0.0041
2023 FOFL	0.0736	0.0736	0.0000
2023 ABC	4,971.6482	4,971.6500	0.0018
2023 FABC	0.0613	0.0613	0.0000

Updating the base model with 2024 data (m22.1) results in a slight increase in estimated female spawning and total biomass (Figure 10-11), adding in all proposed model and data changes (m24) increases these values again, though recruitment estimates (Figure 10-15) and fishing mortality (Figure 10-13) are similar between all three models. However, the majority of this increase is due to changing to the lognormal survey biomass likelihood (Tables 10-14 and 10-15; see Appendix 10c).

The intermediate changes (m22.1a, m22.1b, m22.1c, and maturity update [m24]) incorporate logical steps to change the model structure to be more inline with current prevailing methodology, or updating to the best available data. As such, these changes should be incorporated. Using a lognormal error structure for estimating the survey biomass negative log likelihood (NLL) is generally considered a norm within statistical age-structured assessments. Changing to an ISS that accounts for aging error and growth variability is procedurally a more accurate method of determining input sample size for composition data, as such it should be adopted where available. The lognormal-VAST model provides a ‘flatter’ fit for survey biomass which aligns with our understanding of this species population dynamics (e.g., large biannual swings in survey abundance are not likely for a long-lived species), and it performs slightly better (less variable) than the GAP default methodology. The previous maturity estimate for this stock was based upon 232 samples from two studies, the Conrath (2019) study adds an additional 274 samples. Given the low maturity sample size, any additional data should be incorporated to inform a biological maturity ogive.

With the inclusion of these data and model changes we see that model m24 produces generally good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivity. Therefore, the recommended 2024 model is utilizing the new information effectively, and we use it to recommend the 2025 ABC and OFL. Of note, is that the survey biomass has declined, though the ABC has increased from the 2023 assessment. This is due, in large part, to the change to a lognormal NLL for survey biomass (Tables 10-14 and 10-15; see Appendix 10c). Additionally, it should be noted that all models estimate higher levels of survey, spawning, and total biomass if the survey biomass NLL weighting is changed from the current 0.25 to 1.0 (see Appendix 10c, Alternative models section). So if the survey likelihood is given a greater weight it raises the survey, spawning, and total biomass for all years, even with the low 2023 survey biomass estimate. That is to say, that the data and framework changes incorporated indicate a larger population from the previous assessment.

Time Series Results

Key results have been summarized in Tables 10-14 –– 10-19. In general, model predictions continue to fit the data well (Figures 10-1, 10-3, 10-4, 10-5, 10-7)

Definitions
Spawning biomass is the biomass estimate of mature females in tons. Total biomass is the biomass estimate of all northern rockfish age-2 and greater in tons. Recruitment is measured as number of age-2 northern rockfish. Fishing mortality is fully-selected *F*, meaning the mortality at the age the fishery has fully selected the fish.

Biomass and Exploitation Trends
The estimates of current population abundance indicate that it is dominated by fish from the 1993 and 1998 year-classes (Table 10-16). Since the early 1990s the total biomass estimated in the model plateaued close to 200,000 t through the early 2000s and has been decreasing since (Figure 10-11). Similarly, the spawning biomass estimated in the model has also been decreasing since the mid 2000s. From 1990 on, total biomass is generally following the trend observed in the fit to VAST model-based survey biomass index (Figure 10-5).

The estimated selectivity curve for the fishery and survey data suggested a pattern similar to previous assessments for northern rockfish (Figure 10-8). The commercial fishery targets slightly smaller and (likely) younger fish and the survey should sample a larger range of ages. Ninety-five percent of northern rockfish are selected in the fishery by age 10. The age at 50% selection is 8.9 for the survey and 8.1 for the fishery, age at 50% maturity is estimated at 10.4 years.

Goodman *et al.* (2002) suggested that stock assessment authors use a "management path" graph as a way to evaluate management and assessment performance over time. In the management path we plot the ratio of fishing mortality to F_{OFL} ($F_{35\%}$) and the estimated spawning biomass relative to $B_{35\%}$. Harvest control rules based on $F_{35\%}$ and $F_{40\%}$ and the tier 3b adjustment are provided for reference. The historical management path for northern rockfish has been above the F_{OFL} adjusted limit for only a few years in the 1960s. In recent years, northern rockfish have been above $B_{35\%}$ and below $F_{35\%}$ (Figure 10-12). The trajectory of fishing mortality has remained below the $F_{40\%}$ level most of the time and below $F_{35\%}$ in all years except 1964-76 during the period of intense fishing for Pacific ocean perch. Parameter estimates from this year's model were similar to the previous northern rockfish assessment (Table 10-14). Selectivity estimates for the fishery and the survey are similar, but with the survey selectivity increasing somewhat more gradually with age. Fishery and survey selectivity occurs at slightly younger ages than the age of maturity (Table 10-16 and Figure 10-8). The fishing mortality rate *F* has been fairly consistent since 1990 (Figure 10-13), and the exploitation rate has been generally around the long-term average (Figure 10-14), though has declined in the past few years.

Recruitment
Recruitment estimates show a high degree of uncertainty, but indicate several large year-classes in the early and late 1970's, early 1980's and mid 1990's (Tables 10-17 and 10-19 and Figure 10-15). Recruitment since 2005 has been considerably lower than the 1970–2005 time period. There is no clear trend between recruitment and spawning stock biomass (Figure 10-10). Fits to the fishery and survey age compositions were reasonable with this year's recommended model (Figures 10-16 and 10-17). However, the fishery age compositions have a number of outlier values present in early years (Figure 10-18).

Increasing proportions of GOA northern rockfish in the plus age or length groups for both survey and fishery composition indicate a substantial number of individuals are successfully surviving natural and fishing mortality to attain old age and large size.

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 10-19) and credible intervals (Table 10-18). We also use these posterior distributions to show uncertainty around time series estimates such as total biomass, recruitment, and spawning biomass (Figures 10-20–10-24).

Table 10-18 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. The distributions of these parameters are slightly skewed with higher MLE estimates than MCMC medians for current spawning and total biomass and ABC, indicating possibilities of higher biomass estimates (Figure 10-19). Uncertainty estimates in the time series of spawning biomass also result in a skewed distribution towards higher values, particularly at the end of the time series and into the 15 year projected times series (Figure 10-20).

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 -0.272, indicating that the model substantially increases the estimate of female spawning biomass in recent years as data is added to the assessment. The retrospective female spawning biomass and the relative difference in female spawning biomass from the model in the terminal year are shown in Figure 10-@ref(fig:ssb_retro). This retrospective pattern in spawning biomass is mimicked, in part, by the spawning biomass from stock assessments for GOA northern rockfish from 2009-2024 (Figure 10-22). Essentially, whenever this assessment has received new data, or modified the model framework there has been an increase in estimated biomass. Additionally, retrospective estimates or total biomass and recruitment as also provided (Figures 10-@ref(fig:tot_bio_retro) and 10-@ref(fig:rec_retro)).

Harvest recommendations

Amendment 56 Reference Points

Amendment 56 to the GOA Groundfish Fishery Management Plan defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Northern rockfish in the GOA are managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$,,equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. Estimation of the $B_{40\%}$ reference point requires an assumption regarding the equilibrium level of recruitment. In this assessment, it is assumed that the equilibrium level of recruitment is equal to the average of age-2 recruitments between 1979 and 2022. 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 2024 estimates of these reference points are:

$B_{100\%}$	$B_{40\%}$	$B_{35\%}$	$F_{40\%}$	$F_{35\%}$
84,695	33,878	29,643	0.062	0.074

Specification of OFL and Maximum Permissible ABC

Female spawning biomass for 2024 is estimated at 40,392 t. This is above the $B_{40\%}$ value of 33,878 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 2024, yields the following ABC and OFL:

ABC	OFL
5,077	6,064

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

For each scenario, the projections begin with the vector of 2024 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2025 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2024. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch after 2024 is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2025, are as 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 2024 and 2025, F is set equal to a constant fraction of $maxF_{ABC}$, where this fraction is equal to the ratio of the realized catches in 2021-2023 to the ABC recommended in the assessment for each of those years. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In many fisheries the ABC is routinely not fully utilized, so assuming an average ratio catch to ABC will yield more realistic projections.)
- Scenario 3: In all future years, F is set equal to 50% of $maxF_{ABC}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

- Scenario 4: In all future years, F is set equal to the 2019-2023 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
- Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

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

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios (Tables 10-20– 10-22). 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.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2024, it does not provide the best estimate of OFL for 2025, because the mean 2024 catch under Scenario 6 is predicated on the 2024 catch being equal to the 2024 OFL, whereas the actual 2024 catch will likely be less than the 2024 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

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 items were considered and summarized.

Assessment considerations

Level 1. In recent assessments the GOA northern rockfish assessment model has resulted in a negative retrospective pattern, which is interpreted as the model continually increases spawning biomass as new data are added (-0.20 in 2018, -0.24 in 2020, and -0.27 in the current assessment, Figure 10-@ref(fig:ssb_retro)). While the assessment fits to composition data from the survey (age) and fishery (age) are generally adequate (Figures 10-4 and 10-7), the fishery length compositions (Figure 10-3) are misaligned, though this fit has improved with the increase in the length plus group size in 2022. Changing from a design-based model to a VAST-based estimate has made the survey biomass estimates more realistic (less overall fluctuation) though the model continues to fit these data poorly. There is some question as to the efficacy of this trawl survey for developing indices of northern rockfish abundance. The items described here have been an issue for assessing northern rockfish for some time, we scored this category as Level 1, as the level of concern has not changed.

Population dynamics considerations

Level 2. Recruitment since 2005 has been considerably lower than in 1970–2005. There is increasing proportions of GOA northern rockfish in the plus age groups for both survey and fishery age composition that indicates a substantial number of individuals are successfully surviving natural and fishing mortality to attain older ages and larger sizes. There is a reduction in body condition in recent years for young rockfish, though how this propagates through time is unclear. Skip spawning has been observed for this species, the spatial and temporal extent which 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.

Environmental/Ecosystem considerations

Level 1. Environmental mechanisms for changes in survival 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 (estimated using non-targeted data) have recently been in decline. However, given the continued lack of biological and habitat information for northern rockfish, we scored this category as Level 1, as the level of concern has not changed.

Fishery performance

Level 1. Fishers usually direct their efforts first toward Pacific ocean perch because of its higher value relative to northern rockfish. After the TAC for Pacific ocean perch has been reached and NMFS closes directed fishing for this species, trawlers switch and target northern rockfish. The directed GOA northern rockfish fishery is concentrated on a limited number of highly productive locations. The patterns of fishing and percent of TAC taken have substantially changed from past years, though the performance is due to limited market demand, therefore we scored this category as Level 1.

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Level 2: Increased concerns	Level 1: Normal	Level 1: Normal

We have ranked three categories as ‘Level 1: Normal’ and one as a ‘Level 2, Increased concerns’. The GOA northern rockfish assessment appears to fit available data well, the 2023 GOA trawl survey was undertaken as planned and data are included in this year’s assessment, and the fishery and environmental considerations appear to be within normal bounds. Because GOA northern rockfish ABC is has not been fully utilized in recent years 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

Apportionment for GOA northern rockfish has been based upon area estimates from the design-based survey abundance. The assessment uses a model-based (VAST, Thorson *et al.* 2015) index of abundance, which does not always align with the design-based area estimates. For consistency, we propose to change apportionment to be based upon the model-based index of abundance. Clarification of the change to VAST-based apportionment can be found in Appendix 10c. The rema smoothed, design-based and VAST area biomass estimates are on the same scale, though there is greater variability present in the central GOA for the VAST biomass (Figure 10-33).

Area apportionments from the Vast-based estimates for GOA northern rockfish are 55.71% for the Western area (up from 52.65% in 2022), 44.28% for the Central area (down from 47.33% in 2022), and 0.02% for the Eastern area (same as 2023). The changes are due to the more slightly frequent catches of northern rockfish in the western GOA during the 2023 survey Figure 10-6, and change to VAST-based apportionment. Applying the apportionments to the recommended ABC for northern rockfish results in 2,828 t for the Western area, 2,248 t for the Central area, and 1 t for the Eastern area for 2025. For management purposes, the small ABC of northern rockfish in the Eastern area (1 t) is combined with the Other Rockfish complex.

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 (2023) is 1,325 t. This is less than the 2023 OFL of 5,927 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 2024:

a. If spawning biomass for 2024 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2024 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2024 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 (Tables 10-20– 10-22).

If the mean spawning biomass for 2036 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 2026 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2026 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2026 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2036 If the mean spawning biomass for 2036 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 Tables 10-20– 10-22, 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 0.068.

Ecosystem Considerations

In general, a determination of ecosystem considerations for GOA northern rockfish is hampered by a lack of biological and habitat information. However, a review of the most recent (2024) GOA Ecosystem Status Report did not reveal strong evidence of declining trends in indicators which results in strong concern for northern rockfish. Information regarding the FMP, non-FMP, and prohibited species caught in rockfish target fisheries to help understand ecosystem impacts by the northern fishery (Tables 12-4 - 12-6).

Ecosystem Effects on the Stock

Prey availability/abundance trends: Unfortunately, there is no information on the food habits of larval or post-larval rockfish to help determine possible relationships between prey availability and year-class strength. Moreover, identification to the species level for field collected larval slope rockfish is difficult. Visual identification is not possible, though genetic techniques allow identification to species level for larval slope rockfish. Some juvenile rockfish found in inshore habitat feed on shrimp, amphipods, and other crustaceans, as well as some mollusk and fish. Adult northern rockfish feed on euphausiids. Euphausiids are also a major item in the diet of walleye pollock. Changes in the abundance of walleye pollock could lead to a corollary change in the availability of euphausiids, which could then impact northern rockfish. Prey availability and nutritional quality appeared to be approximately average in 2023, with potential for improvement in 2024. Northern rockfish body condition in 2023 returned close to average, and could be expected to remain in that range in 2024 (after being below-average since 2013)(O'Leary *et al.* 2023). Limited information on biomass of euphausiids and calanoid copepod in 2024 indicate average to above average availability, and a potential increase from 2023 Whelan (2024). Shrimp (potential juvenile prey) CPUEs declined between the 2021 and 2023 NOAA bottom trawl surveys in Chirikof, Kodiak, and Yakutat (Laman and Dowlin 2023b).

Predator population trends: There is no indication of increased predation, but there is potential for decreased competition for zooplankton from low returns of pink salmon in 2024. Potential predators include Pacific halibut and other large fish, which have remained at relatively lower population biomass. Competitors for zooplankton prey could be reduced in 2024 due to unexpected low returns (in an even/low return year) of pink salmon (Whitehouse 2023). Other zooplanktivorous competitors include Pacific Ocean perch, which remains in high abundance, and walleye pollock. Pink salmon are expected to have higher/odd year returns in 2025, potentially bringing an increased competition for prey resources. Predator effects would likely be more important on larval, post-larval, and small juvenile northern 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 of other species.

Changes in physical environment: Changes in structural habitat present a potential concern for northern rockfish. Vertical structure, including sponges, corals, and rocky habitat, is important habitat for northern 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). A continued multi-year decline (with high uncertainty) in relative abundance of sponges, structural habitat of importance, presents an ongoing concern for northern rockfish. Observations in 2023 from AFSC's fishery-independent bottom trawl survey and fisheries-dependent observer data of non-target catches (both not designed to target structural epifauna) show relative stability until 2015 followed by a continual 9 year decline in the GOA wide index through 2023 to a historic low value Whitehouse (2023). The declines in sponges appear to be driven by trends in western GOA (Shumagin and to a lesser extent Kodiak regions).

Benthic thermal conditions for adults (banks along shelf edge approximately 75-150m) in 2024 were approximately average, while larval rockfish growth may have benefited from warm spring/summer surface waters (primarily in the eastern GOA)(satellite-derived data, Lemagie and Callahan 2024; Seward Line, Danielson and Hopcroft 2024). The 2023/2024 El Niño event brought warmer surface temperatures to the GOA in the winter, but it was moderate and short-lived, resulting in approximately average surface temperatures by spring in the western GOA and continued warm surface waters through the spring in the eastern GOA. Larval surveys in Shelikof Strait in 2023 observed a decline to below average (from 2019 and 2021) of larval rockfish [not identified to species; Rogers and Axler (2023)], which may or may not be in response to a cooler 2023 spring and/or reduced zooplankton availability in that year. AFSC bottom trawl survey data revealed slight decrease in depth in northern rockfish distribution within the GOA (1990-2023, Laman and Dowlin 2023a). Surface waters in 2025 are predicted to cool with the development of a weak La Niña (Lemagie and Callahan 2024).

Fishery Effects on the Ecosystem

Fishery-specific contribution to bycatch of HAPC biota: In the GOA, bottom trawl fisheries for pollock, deepwater flatfish, and Pacific ocean perch account for most of the observed bycatch of coral, while rockfish fisheries account for little of the bycatch of sea anemones, sea whips, and sea pens. The bottom trawl fisheries for Pacific ocean perch and Pacific cod and the pot fishery for Pacific cod account for most of the observed bycatch of sponges (Table 10-5).

Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components: The directed slope rockfish trawl fishery that begins in April is concentrated in known areas of abundance and typically lasts only a few weeks. The annual exploitation rates on rockfish are thought to be quite low. Insemination is likely in the fall or winter, and parturition is likely to occur in the spring. While reproductive activities are probably not directly affected by the commercial fishery, there is evidence of skip spawning often caused by a lack of fertilization (Conrath 2019). If fishing were to reduce the population substantially or cause significant localized depletion it would be possible to increase the amount of observed skip spawning within the stock.

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

Fishery contribution to discards and offal production: Fishery discard rates of northern rockfish during 2009-2022 have been 1.5-9.1%.

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

Fishery-specific effects on EFH living and non-living substrate: Unknown, but the heavy-duty "rockhopper" trawl gear commonly used in the fishery can disturb seafloor habitat. Table 10-5 shows the estimated bycatch of living structure such as benthic urochordates, corals, sponges, sea pens, and sea anemones by the GOA rockfish fisheries. The average bycatch of corals/bryozoans and sponges by rockfish fisheries are a large proportion of the catch of those species taken by all Gulfwide fisheries.

Data Gaps and Research Priorities

Life history and habitat utilization

There is little information on larval, post-larval, or early life history stages of northern rockfish. Habitat requirements for larval, post-larval, and early stages are mostly unknown. Habitat requirements for later stage juvenile and adult fish are anecdotal or conjectural. Research needs to be done on the bottom habitat of the major fishing grounds, on what HAPC biota are found on these grounds, and on what impact bottom trawling may have on these biota. Given the substantial influence of maturity-at-age on management quantities (i.e., ABC) and observations of skip spawning (Conrath 2019) we strongly suggest that continued research be devoted to collecting maturity-at-age data for northern and other Gulf of Alaska rockfish.

Assessment Data

The highly variable design-based biomass estimates for northern rockfish from bottom trawl survey suggest that the stratified random design of the surveys does a relatively poor job of assessing stock condition of northern rockfish and that a different survey approach may be needed to reduce the variability in biomass estimates. In particular, the last CIE review report recommended that assumptions about extending area-swept estimates of biomass in trawlable versus untrawlable grounds may impact catchability assumptions. The AFSC is currently undertaking a study on habitat classifications so that assumptions about catchability, in particular, time-dependent changes in catchability, can be more rigorously established. To address some of these issues the design-based index has been replaced with a model-based survey biomass index generated by a Vector Autoregressive Spatio-Temporal (VAST) model. The benefits of the VAST model-based approach to survey index standardization are that as a delta-model it partitions the likelihood of trawl survey observations between encounter probability and positive catch rate components, and accounts for spatial and spatio-temporal correlations in survey catch rates. However, this model could benefit from continued examination of appropriate parameterization for northern rockfish which are found in highly "patchy" distributions. Given the high precision of VAST outputs it may prove valuable to incorporate an error inflation parameter to increase the variance in VAST models and explore the effect low survey model variance has on resulting assessment outputs.

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Tables

Table 10-3. 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	Foreign	Joint Venture	Domestic	Total	ABC	TAC	% TAC
1961	800			800			
1962	3,250			3,250			
1963	6,815			6,815			
1964	12,170			12,170			
1965	17,430			17,430			
1966	10,040			10,040			
1967	6,000			6,000			
1968	5,010			5,010			
1969	3,630			3,630			
1970	2,245			2,245			
1971	3,875			3,875			
1972	3,880			3,880			
1973	2,820			2,820			
1974	2,550			2,550			
1975	2,520			2,520			
1976	2,275			2,275			
1977	622			622			
1978	553			554			
1979	666	3		670			
1980	809	1		810			
1981	1,469			1,477			
1982	3,914			3,920			
1983	2,705	911		3,618			
1984	494	497	10	1,002			
1985	1	11	70	185			
1986	1	56	237	248			
1987		1	427	483			
1988[1]			1,107	1,107			
1989			1,527	1,527			
1990			1,697	1,716			
1991[2]			4,528	4,528			
1992			7,770	7,770			
1993[3]			4,820	4,820	5,760	5,760	84
1994			5,966	5,966	5,760	5,760	104
1995			5,635	5,635	5,270	5,270	107
1996			3,340	3,340	5,720	5,270	63
1997			2,935	2,935	5,000	5,000	59
1998			3,055	3,055	5,000	5,000	61
1999			5,409	5,409	4,990	4,990	108
2000			3,333	3,333	5,120	5,120	65
2001			3,133	3,133	4,880	4,880	64
2002			3,339	3,339	4,770	4,770	70
2003			5,256	5,256	5,530	5,530	95
2004			4,811	4,811	4,870	4,870	99
2005			4,522	4,522	5,091	5,091	89
2006			4,958	4,958	5,091	5,091	97
2007[4]			4,187	4,187	4,938	4,938	85
2008			4,052	4,052	4,549	4,549	89

Year	Foreign	Joint Venture	Domestic	Total	ABC	TAC	% TAC
2009			3,952	3,952	4,362	4,362	91
2010			3,902	3,902	5,098	5,098	77
2011			3,443	3,444	4,854	4,854	71
2012			5,077	5,077	5,507	5,507	92
2013			4,879	4,879	5,130	5,130	95
2014			4,277	4,278	5,324	5,324	80
2015			3,944	3,945	4,999	4,999	79
2016			3,437	3,434	4,004	4,004	86
2017			1,836	1,835	3,786	3,786	48
2018			2,440	2,359	3,685	3,685	64
2019			2,748	2,748	4,528	4,528	61
2020			2,375	2,385	4,312	4,312	55
2021			2,376	2,376	5,358	5,358	44
2022			1,898	1,898	5,147	5,147	37
2023			1,325	1,325	4,964	4,964	27
2024[5]			1,129	1,129	4,815	4,815	23

[1]Slope rockfish assemblage management implemented by NPFMC.
[2]Slope rockfish divided into 3 management subgroups: Pacific ocean perch, shortraker/ rougheye, and other slope rockfish.
[3]A fourth management subgroup, northern rockfish, was created.
[4]Central Gulf Rockfish Pilot Project implemented for rockfish fishery.
[5]Catch through 2024-10-16.

Table 10-4. FMP species incidental catch estimates in tons for Gulf of Alaska rockfish targeted fisheries. Blanks = Confidential because of less than three vessels, or not caught. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN 2022-10-28.

Species Group	2019	2020	2021	2022	2023	2024
Arrowtooth Flounder	733	890	2,523	2,823	860	1,278
Atka Mackerel	824	602	674	867	459	380
BSAI Skate and GOA Skate, Other	26	10	19	14	22	11
Flathead Sole	40	95	135	74	32	62
GOA Deep Water Flatfish	39	19	19	35	16	12
GOA Demersal Shelf Rockfish	56	11	5	5	7	7
GOA Dusky Rockfish	2,151	2,061	2,669	2,483	3,101	2,079
GOA Rex Sole	117	189	99	132	73	83
GOA Shallow Water Flatfish	34	22	33	30	32	22
GOA Skate, Big	5	6	4	6	8	4
GOA Skate, Longnose	28	24	31	31	30	21
GOA Thornyhead Rockfish	177	138	113	215	123	88
Halibut	0	2	0		3	3
Northern Rockfish	2,313	2,317	2,303	1,813	1,279	1,048
Octopus	9	1	1	1	1	2
Other Rockfish	669	522	975	869	751	268
Pacific Cod	322	170	660	670	447	350
Pacific Ocean Perch	22,258	22,881	27,399	26,358	26,665	21,998
Pollock	686	647	1,559	1,588	2,074	2,407
Rougheye Rockfish	320	89	162	221	210	156
Sablefish	801	647	893	995	809	649
Sculpin	53	30				
Shark	62	33	32	17	6	31
Shortraker Rockfish	269	225	240	181	237	212

Table 10-5. 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 2022-10-28.

Species Group	2020	2021	2022	2023	2024
Benthic urochordata	0.12	0.01	3.69	0.01	Conf
Bivalves	0	0.04	Conf	0.02	Conf
Bristlemouths	Conf	-	-	-	-
Brittle star unidentified	0.01	0.05	0.02	0.01	0
Capelin	Conf	-	-	-	-
Corals Bryozoans - Corals Bryozoans Unidentified	0.17	1.73	0.32	0.84	0.3
Eelpouts	Conf	Conf	Conf	-	-
Eulachon	0.1	-	-	-	-
Giant Grenadier	302.08	252.11	197.39	148.21	72.21
Greenlings	3.5	3.43	3.8	2.41	0.94
Grenadier - Rattail Grenadier Unidentified	1.73	0.19	1.87	5.52	Conf
Hermit crab unidentified	0	0.01	0.01	Conf	Conf
Invertebrate unidentified	Conf	0.06	0.01	0	0.02
Lanternfishes (myctophidae)	0.02	0.05	-	0.05	Conf
Misc crabs	0.1	0.1	0.09	0.04	0.05
Misc crustaceans	0.07	0.06	0.05	0.16	0
Misc fish	87.16	164.01	87.2	98.37	33.63
Misc inverts (worms etc)	0	0	Conf	0.01	Conf
Other osmerids	0.98	0.08	0.08	Conf	0.02
Pacific Hake	0.03	-	-	-	-
Pandalid shrimp	0.17	0.29	0.09	0.02	0.03
Scypho jellies	3.52	3.19	0.93	1.79	8.26
Sea anemone unidentified	1.24	1.78	0.93	0.31	0.96
Sea pens whips	0	Conf	0.02	0.01	0.01
Sea star	1.14	1.5	1.31	1.08	0.77
Snails	0.08	1.18	0.11	0.05	1.88
Sponge unidentified	0.52	1.22	5.97	25.3	3.7
Squid	31.8	27.77	43.36	32.09	25.06
State-managed Rockfish	53.11	12.35	33.26	2.97	7.74
Stichaeidae	Conf	-	Conf	Conf	-
urchins dollars cucumbers	0.91	0.23	0.22	0.09	0.11
Birds - Northern Fulmar	-	Conf	-	-	-
Gunnels	-	Conf	-	-	-
Pacific Sand lance	-	Conf	-	-	-
Sculpin	-	23.52	39.54	26.21	16.27
Smelt (Family Osmeridae)	-	0.23	0.27	0.03	0.08
Misc deep fish	-	-	Conf	-	-
Polychaete unidentified	-	-	Conf	Conf	-
Birds - Shearwaters	-	-	-	Conf	-
Pacific Sandfish	-	-	-	Conf	-
Birds - Black-footed Albatross	-	-	-	-	Conf

Table 10-6. Prohibited Species Catch (PSC) estimates reported in tons for halibut and herring, and thousands of animals for crab and salmon, by year, for the GOA rockfish fishery 2014-2018. Source: NMFS AKRO Blend/Catch Accounting System PSCNQ via AKFIN 2022-10-28.

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

Table 10-7. Gulf of Alaska discard rates rates (percent of the total catch discarded within management categories) of northern rockfish.

Year	% discard	Year	% discard	Year	% discard
1993	26.5	2004	7.8	2015	4.6
1994	17.7	2005	4.2	2016	5.5
1995	12.7	2006	9.1	2017	7.9
1996	16.6	2007	2.6	2018	3.6
1997	28.0	2008	4.9	2019	5.6
1998	18.4	2009	3.1	2020	1.4
1999	11.3	2010	1.5	2021	1.6
2000	10.0	2011	3.9	2022	1.5
2001	17.7	2012	2.5	2023	1.9
2002	10.0	2013	4.1	2024	6.1
2003	9.4	2014	3.8		

Table 10-8. Summary of key management measures for northern rockfish in the Gulf of Alaska.

Year	Measure
1988	The slope rockfish assemblage, including northern rockfish, was one of three management groups for Sebastes implemented by the North Pacific Management Council. Previously, Sebastes in Alaska were managed as "Pacific ocean perch complex" or "other rockfish"
1991	Slope assemblage split into three management subgroups with separate ABCs and TACs: POP, shortraker/rougheye rockfish, other slope species
1993	Designated as a subgroup of slope rockfish with separate ABC and TAC
1999	Eastern GOA divided into West Yakutat and East Yakutat/Southeast Outside due to trawl closure in Eastern GOA. The ABC and TAC for northern rockfish in Eastern GOA allocated to West Yakutat ABC as part of "other slope rockfish".
2000	Amendment 41 prohibited trawling in the Eastern Gulf (40 degrees W). Preliminary age-structured model results presented to PT
2001	Assessed with an age structured model using AD Model Builder software.
2007	Amendment 68 created the Central Gulf Rockfish Pilot Project
2012	NPFMCs Central GOA Rockfish Program implemented
2024	Amendment 113 change the season start date to May 1, beginning in 2025, remove the catcher vessel (CV) cooperative quota (CQ) cap, and revise the processing and harvesting caps.

Table 10-9. Fishery length compositions for northern rockfish in the Gulf of Alaska. Lengths below 15 are pooled and lengths greater than 45 are pooled. Survey size compositions are not used in model.

Length (cm)	1991	1992	1993	1994	1995	1996	1997	2003	2007	2009	2011	2013	2015	2017	2019	2021	2023
15	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
16	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
17	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
18	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
19	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
20	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
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	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.001	0.000	0.000	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.001
25	0.002	0.000	0.000	0.000	0.004	0.000	0.006	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.000	0.000
26	0.003	0.000	0.001	0.000	0.007	0.000	0.014	0.001	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.000
27	0.004	0.000	0.001	0.001	0.009	0.001	0.020	0.002	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.002	0.000
28	0.007	0.001	0.002	0.002	0.008	0.002	0.021	0.002	0.002	0.001	0.000	0.002	0.002	0.002	0.002	0.001	0.001
29	0.010	0.003	0.005	0.004	0.010	0.003	0.021	0.007	0.002	0.001	0.001	0.003	0.004	0.010	0.001	0.004	0.001
30	0.023	0.006	0.010	0.007	0.013	0.007	0.019	0.012	0.007	0.004	0.001	0.003	0.005	0.007	0.003	0.005	0.003
31	0.041	0.015	0.024	0.017	0.015	0.006	0.014	0.031	0.009	0.009	0.002	0.006	0.009	0.010	0.006	0.007	0.001
32	0.072	0.032	0.046	0.030	0.021	0.013	0.015	0.045	0.023	0.010	0.005	0.004	0.010	0.014	0.005	0.010	0.005
33	0.123	0.053	0.079	0.070	0.043	0.028	0.029	0.071	0.038	0.020	0.011	0.009	0.011	0.020	0.014	0.014	0.006
34	0.180	0.094	0.109	0.116	0.081	0.058	0.054	0.075	0.060	0.038	0.023	0.019	0.018	0.030	0.021	0.026	0.012
35	0.196	0.139	0.156	0.175	0.127	0.122	0.115	0.084	0.085	0.077	0.051	0.036	0.033	0.030	0.035	0.029	0.024
36	0.145	0.157	0.166	0.199	0.156	0.177	0.159	0.075	0.105	0.098	0.076	0.066	0.054	0.043	0.055	0.045	0.032
37	0.091	0.154	0.127	0.171	0.164	0.189	0.173	0.083	0.124	0.111	0.103	0.099	0.110	0.067	0.075	0.060	0.056
38	0.047	0.131	0.100	0.100	0.135	0.149	0.150	0.102	0.138	0.110	0.106	0.120	0.139	0.118	0.095	0.087	0.089
39	0.023	0.095	0.068	0.053	0.086	0.103	0.091	0.111	0.127	0.116	0.120	0.137	0.153	0.162	0.139	0.142	0.135
40	0.012	0.061	0.048	0.025	0.040	0.066	0.052	0.095	0.109	0.121	0.128	0.122	0.142	0.170	0.153	0.158	0.158
41	0.007	0.033	0.033	0.012	0.021	0.037	0.024	0.079	0.081	0.104	0.124	0.124	0.115	0.134	0.141	0.150	0.169
42	0.003	0.013	0.018	0.007	0.015	0.018	0.012	0.057	0.045	0.073	0.103	0.100	0.089	0.087	0.101	0.117	0.141
43	0.003	0.004	0.005	0.005	0.011	0.008	0.005	0.039	0.023	0.043	0.073	0.070	0.048	0.046	0.069	0.068	0.087
44	0.002	0.004	0.001	0.003	0.008	0.004	0.002	0.016	0.011	0.028	0.038	0.041	0.028	0.026	0.039	0.041	0.045
45	0.006	0.004	0.000	0.005	0.020	0.009	0.001	0.012	0.009	0.035	0.033	0.038	0.023	0.022	0.042	0.033	0.036
Sample size	75.3	69.1	50.4	42.9	59.3	46.5	31.1	75.3	93.5	83.3	72.0	89.8	100.0	57.9	77.1	64.5	54.2

Table 10-10. Fishery age compositions for northern rockfish in the Gulf of Alaska.

Age	1998	1999	2000	2001	2002	2004	2005	2006	2008	2010	2012	2014	2016	2018	2020	2022
2	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
3	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
4	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	0.002	0.000	0.000
5	0.000	0.006	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000
6	0.004	0.003	0.024	0.011	0.000	0.015	0.000	0.006	0.000	0.000	0.000	0.003	0.000	0.002	0.004	0.003
7	0.006	0.006	0.005	0.055	0.032	0.008	0.021	0.002	0.006	0.000	0.007	0.010	0.002	0.005	0.013	0.005
8	0.034	0.000	0.015	0.024	0.151	0.036	0.045	0.046	0.020	0.012	0.000	0.003	0.034	0.022	0.013	0.002
9	0.022	0.042	0.019	0.031	0.070	0.111	0.066	0.064	0.026	0.024	0.003	0.010	0.021	0.015	0.017	0.010
10	0.032	0.013	0.043	0.038	0.055	0.176	0.147	0.070	0.078	0.032	0.022	0.009	0.018	0.034	0.028	0.019
11	0.058	0.029	0.031	0.049	0.042	0.050	0.164	0.132	0.068	0.060	0.041	0.011	0.020	0.045	0.054	0.014
12	0.070	0.039	0.058	0.042	0.044	0.035	0.052	0.070	0.048	0.115	0.027	0.041	0.010	0.040	0.028	0.010
13	0.094	0.049	0.053	0.053	0.047	0.036	0.017	0.048	0.093	0.072	0.094	0.066	0.011	0.031	0.022	0.014
14	0.094	0.062	0.048	0.051	0.032	0.028	0.031	0.034	0.076	0.052	0.105	0.049	0.028	0.023	0.019	0.027
15	0.068	0.127	0.074	0.040	0.031	0.027	0.038	0.034	0.030	0.068	0.077	0.077	0.062	0.032	0.022	0.027
16	0.078	0.065	0.094	0.053	0.047	0.032	0.026	0.020	0.022	0.052	0.057	0.090	0.051	0.038	0.013	0.029
17	0.034	0.058	0.067	0.084	0.068	0.015	0.019	0.016	0.012	0.028	0.089	0.061	0.075	0.035	0.022	0.018
18	0.034	0.042	0.060	0.060	0.067	0.025	0.031	0.038	0.006	0.018	0.048	0.071	0.087	0.063	0.030	0.018
19	0.022	0.019	0.024	0.044	0.032	0.046	0.026	0.028	0.012	0.016	0.022	0.066	0.059	0.062	0.032	0.027
20	0.026	0.023	0.022	0.027	0.026	0.058	0.033	0.020	0.022	0.024	0.026	0.061	0.067	0.057	0.056	0.043
21	0.044	0.032	0.010	0.035	0.023	0.035	0.045	0.040	0.020	0.022	0.012	0.025	0.097	0.042	0.060	0.050
22	0.050	0.029	0.043	0.018	0.021	0.029	0.024	0.050	0.016	0.032	0.010	0.022	0.070	0.062	0.050	0.029
23	0.036	0.075	0.034	0.033	0.013	0.023	0.026	0.036	0.038	0.014	0.009	0.015	0.028	0.045	0.050	0.050
24	0.030	0.042	0.046	0.033	0.029	0.011	0.009	0.024	0.050	0.014	0.024	0.028	0.021	0.032	0.026	0.037
25	0.022	0.010	0.022	0.044	0.044	0.012	0.009	0.010	0.028	0.034	0.021	0.011	0.030	0.022	0.045	0.072
26	0.024	0.026	0.029	0.042	0.028	0.021	0.005	0.012	0.030	0.030	0.024	0.027	0.013	0.022	0.032	0.053
27	0.012	0.016	0.014	0.013	0.011	0.039	0.026	0.018	0.022	0.016	0.033	0.027	0.016	0.026	0.017	0.029
28	0.010	0.042	0.021	0.020	0.008	0.029	0.031	0.018	0.006	0.020	0.038	0.022	0.007	0.015	0.035	0.035
29	0.026	0.036	0.024	0.009	0.010	0.012	0.024	0.034	0.014	0.014	0.010	0.010	0.008	0.020	0.019	0.014
30	0.020	0.023	0.041	0.018	0.011	0.017	0.028	0.032	0.026	0.024	0.024	0.032	0.016	0.035	0.024	0.027
31	0.006	0.029	0.019	0.020	0.011	0.011	0.007	0.022	0.028	0.014	0.012	0.018	0.015	0.026	0.011	0.040
32	0.010	0.013	0.014	0.013	0.011	0.008	0.002	0.006	0.034	0.024	0.010	0.013	0.021	0.020	0.019	0.026
33	0.012	0.003	0.010	0.009	0.010	0.009	0.007	0.006	0.032	0.028	0.015	0.018	0.015	0.025	0.032	0.034
34	0.000	0.006	0.002	0.004	0.005	0.007	0.017	0.012	0.018	0.038	0.015	0.008	0.008	0.018	0.030	0.031
35	0.002	0.006	0.003	0.002	0.000	0.009	0.005	0.012	0.018	0.020	0.019	0.011	0.010	0.012	0.011	0.026
36	0.000	0.000	0.003	0.002	0.003	0.009	0.005	0.020	0.006	0.004	0.022	0.014	0.003	0.011	0.013	0.018
37	0.002	0.006	0.002	0.011	0.005	0.003	0.002	0.008	0.018	0.008	0.014	0.013	0.005	0.011	0.013	0.021
38	0.006	0.003	0.002	0.007	0.000	0.003	0.002	0.000	0.018	0.010	0.014	0.010	0.008	0.008	0.022	0.026
39	0.002	0.003	0.005	0.000	0.002	0.001	0.005	0.002	0.012	0.012	0.010	0.009	0.008	0.006	0.022	0.014
40	0.004	0.003	0.007	0.002	0.005	0.001	0.000	0.002	0.006	0.014	0.012	0.011	0.008	0.005	0.017	0.013
41	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.002	0.010	0.005	0.003	0.011	0.003	0.009	0.016
42	0.000	0.006	0.002	0.000	0.000	0.004	0.002	0.002	0.008	0.004	0.002	0.005	0.003	0.006	0.017	0.014
43	0.002	0.003	0.003	0.000	0.000	0.003	0.002	0.002	0.004	0.002	0.003	0.003	0.008	0.008	0.009	0.021
44	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004	0.000	0.010	0.002	0.004	0.005	0.002	0.015	0.005
45	0.000	0.000	0.003	0.000	0.003	0.004	0.000	0.000	0.022	0.014	0.019	0.015	0.018	0.015	0.028	0.032
Sample size	25.2	39.2	54.6	44.4	55.3	74.6	49.0	53.9	68.7	69.9	87.4	100.0	86.6	84.4	62.8	76.2

Table 10-11. GOA northern rockfish biomass estimates, standard errors, and confidence intervals, based on results of NMFS bottom trawl surveys using a geostatistical general linear mixed model (VAST) estimator used in model 24.

Year	Biomass (t)	SE	Lower CI	Upper CI
1990	87,797	17,239	54,009	121,584
1993	105,725	19,121	68,248	143,202
1996	136,274	24,910	87,451	185,098
1999	112,015	21,134	70,592	153,438
2001	136,499	27,109	83,366	189,632
2003	105,609	20,570	65,292	145,925
2005	228,949	43,691	143,314	314,584
2007	147,430	27,723	93,092	201,767
2009	76,662	14,212	48,806	104,518
2011	130,259	28,850	73,713	186,805
2013	167,978	35,485	98,428	237,528
2015	86,481	18,118	50,968	121,993
2017	173,694	37,243	100,698	246,689
2019	152,495	34,338	85,192	219,798
2021	95,868	22,345	52,073	139,664
2023	56,370	14,608	27,739	85,001

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

Year	Biomass (t)	SE	Lower CI	Upper CI
1990	107,076	45,482	17,931	196,222
1993	104,992	36,853	32,760	177,224
1996	98,965	26,596	46,838	151,093
1999	242,187	147,109	0	530,521
2001	343,614	205,475	0	746,344
2003	66,310	31,955	3,677	128,943
2005	358,999	132,432	99,432	618,565
2007	221,226	84,579	55,451	387,002
2009	89,896	28,888	33,276	146,515
2011	173,642	67,117	42,092	305,192
2013	370,454	220,613	0	802,855
2015	48,933	16,689	16,223	81,644
2017	150,326	67,890	17,261	283,391
2019	86,725	30,706	26,542	146,908
2021	90,670	31,688	28,562	152,779
2023	31,758	17,049	0	65,175

Table 10-13. Survey age compositions for northern rockfish in the Gulf of Alaska.

Age	1990	1993	1996	1999	2001	2003	2005	2007	2009	2011	2013	2015	2017	2019	2021	2023
2	0.000	0.000	0.003	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
3	0.001	0.003	0.002	0.000	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.002	0.003	0.001	0.002	0.003	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001
5	0.029	0.009	0.002	0.011	0.006	0.035	0.001	0.001	0.003	0.000	0.000	0.000	0.001	0.003	0.002	0.001
6	0.054	0.011	0.011	0.003	0.013	0.021	0.014	0.007	0.000	0.000	0.001	0.001	0.002	0.002	0.002	0.002
7	0.027	0.011	0.006	0.009	0.041	0.014	0.037	0.004	0.007	0.000	0.004	0.006	0.002	0.004	0.019	0.000
8	0.041	0.064	0.021	0.009	0.016	0.096	0.052	0.029	0.015	0.002	0.004	0.006	0.009	0.010	0.007	0.009
9	0.054	0.120	0.041	0.042	0.038	0.126	0.047	0.091	0.022	0.003	0.002	0.006	0.008	0.020	0.023	0.031
10	0.045	0.065	0.053	0.028	0.072	0.056	0.061	0.058	0.051	0.015	0.006	0.023	0.003	0.038	0.014	0.011
11	0.058	0.103	0.085	0.079	0.061	0.036	0.047	0.074	0.071	0.019	0.023	0.011	0.015	0.014	0.021	0.042
12	0.035	0.044	0.076	0.069	0.040	0.029	0.033	0.063	0.053	0.023	0.028	0.007	0.015	0.023	0.033	0.015
13	0.054	0.049	0.077	0.054	0.063	0.021	0.011	0.083	0.060	0.040	0.032	0.012	0.011	0.025	0.019	0.017
14	0.082	0.040	0.040	0.056	0.049	0.051	0.021	0.031	0.062	0.039	0.038	0.020	0.011	0.009	0.009	0.023
15	0.097	0.024	0.033	0.078	0.050	0.033	0.012	0.017	0.038	0.021	0.052	0.050	0.014	0.013	0.013	0.017
16	0.051	0.052	0.039	0.092	0.054	0.043	0.020	0.026	0.034	0.029	0.070	0.055	0.030	0.025	0.028	0.042
17	0.051	0.031	0.017	0.016	0.045	0.000	0.032	0.020	0.021	0.059	0.044	0.073	0.043	0.032	0.019	0.013
18	0.007	0.040	0.034	0.072	0.058	0.018	0.031	0.010	0.033	0.017	0.070	0.055	0.038	0.043	0.022	0.007
19	0.011	0.028	0.054	0.019	0.029	0.030	0.008	0.020	0.033	0.016	0.031	0.030	0.037	0.046	0.040	0.006
20	0.066	0.004	0.088	0.013	0.022	0.061	0.039	0.028	0.027	0.023	0.037	0.045	0.040	0.039	0.053	0.014
21	0.066	0.023	0.028	0.030	0.017	0.012	0.046	0.033	0.016	0.022	0.013	0.066	0.056	0.079	0.043	0.030
22	0.046	0.034	0.031	0.022	0.012	0.021	0.019	0.038	0.010	0.029	0.023	0.022	0.040	0.032	0.047	0.024
23	0.019	0.044	0.030	0.025	0.027	0.011	0.012	0.049	0.027	0.021	0.029	0.027	0.044	0.046	0.033	0.029
24	0.009	0.044	0.033	0.030	0.045	0.007	0.012	0.011	0.041	0.039	0.033	0.014	0.014	0.050	0.030	0.031
25	0.010	0.046	0.027	0.020	0.029	0.014	0.021	0.012	0.046	0.031	0.030	0.025	0.023	0.038	0.050	0.042
26	0.034	0.007	0.052	0.015	0.042	0.025	0.025	0.014	0.026	0.015	0.011	0.020	0.014	0.024	0.022	0.016
27	0.006	0.017	0.014	0.034	0.012	0.030	0.022	0.027	0.017	0.047	0.033	0.023	0.027	0.012	0.033	0.032
28	0.012	0.022	0.015	0.025	0.009	0.054	0.037	0.028	0.014	0.034	0.032	0.024	0.026	0.015	0.013	0.032
29	0.002	0.006	0.028	0.024	0.024	0.035	0.036	0.030	0.030	0.018	0.035	0.017	0.026	0.016	0.020	0.011
30	0.010	0.000	0.006	0.016	0.021	0.016	0.038	0.033	0.013	0.027	0.015	0.027	0.013	0.005	0.029	0.017
31	0.010	0.002	0.007	0.024	0.014	0.000	0.023	0.024	0.012	0.023	0.037	0.021	0.014	0.015	0.021	0.042
32	0.009	0.010	0.004	0.045	0.019	0.000	0.040	0.016	0.025	0.022	0.002	0.029	0.046	0.026	0.010	0.059
33	0.005	0.005	0.015	0.010	0.011	0.041	0.018	0.010	0.022	0.025	0.014	0.025	0.034	0.027	0.023	0.030
34	0.000	0.006	0.007	0.008	0.008	0.010	0.046	0.019	0.011	0.030	0.024	0.014	0.021	0.018	0.035	0.021
35	0.000	0.006	0.005	0.000	0.017	0.012	0.027	0.014	0.012	0.052	0.009	0.020	0.041	0.028	0.029	0.017
36	0.000	0.009	0.000	0.003	0.004	0.007	0.024	0.023	0.021	0.036	0.031	0.018	0.035	0.007	0.021	0.009
37	0.000	0.001	0.007	0.000	0.000	0.019	0.011	0.009	0.019	0.035	0.036	0.035	0.026	0.010	0.023	0.032
38	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.014	0.028	0.039	0.017	0.010	0.025	0.030	0.014	0.007
39	0.000	0.014	0.002	0.012	0.002	0.003	0.011	0.005	0.013	0.017	0.019	0.020	0.030	0.012	0.025	0.009
40	0.000	0.002	0.000	0.002	0.010	0.011	0.011	0.010	0.010	0.019	0.012	0.035	0.030	0.024	0.015	0.030
41	0.000	0.000	0.000	0.003	0.009	0.000	0.004	0.004	0.008	0.030	0.018	0.018	0.017	0.021	0.014	0.003
42	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.001	0.007	0.028	0.023	0.012	0.011	0.011	0.027	0.013
43	0.000	0.000	0.004	0.000	0.000	0.000	0.004	0.002	0.005	0.014	0.007	0.009	0.013	0.016	0.014	0.011
44	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.003	0.007	0.008	0.003	0.016	0.030	0.022	0.011	0.039
45	0.000	0.000	0.000	0.000	0.007	0.000	0.026	0.010	0.029	0.030	0.052	0.052	0.068	0.072	0.071	0.163
Sample size	49.0	33.0	91.0	43.0	86.0	25.0	61.0	127.0	171.0	94.0	101.0	117.0	123.0	99.0	155.0	50.0

Table 10-14. Likelihood values for GOA northern rockfish models examined for 2024.

Likelihood	M22.1	M22.1a	M22.1b	M22.1c	M24
Catch	0.073	0.077	0.094	0.099	0.099
Survey	8.112	3.207	3.321	-0.644	-0.644
Fish age	45.196	45.220	46.563	46.370	46.370
Survey age	72.936	73.050	84.160	84.339	84.339
Fish size	61.345	61.224	63.048	63.140	63.140
Recruitment	9.662	9.701	9.975	9.913	9.913
F regularity	5.593	5.621	5.783	5.779	5.779
SPR penalty	0.000	0.000	0.000	0.000	0.000
M prior	0.025	0.014	0.015	0.041	0.041
q prior	0.104	0.008	0.010	0.173	0.173
Objective function	203.045	198.122	212.969	209.209	209.209

Table 10-15. Estimates of key parameters for GOA northern rockfish models examined for 2024.

Parameter/Estimate	M22.1	M22.1a	M22.1b	M22.1c	M24
M	0.059	0.060	0.059	0.059	0.059
q	0.815	0.943	0.937	0.767	0.767
Log mean recruitment	3.503	3.534	3.528	3.518	3.518
Log mean F	-3.649	-3.691	-3.703	-3.699	-3.699
A50 fishery	8.128	8.125	8.085	8.091	8.091
Delta fishery	1.875	1.873	1.846	1.851	1.851
A50 survey	8.830	8.822	8.855	8.875	8.875
Delta survey	4.058	4.045	4.110	4.132	4.132
2023 Total biomass	90,674	96,979	96,614	96,992	96,992
2023 Spawning biomass	37,429	40,193	39,979	40,189	40,485
2023 OFL	5,592	6,012	5,967	5,976	6,112
2023 FOFL	0.074	0.074	0.073	0.073	0.075
2023 ABC	4,686	5,037	5,001	5,008	5,115
2023 FABC	0.061	0.061	0.061	0.061	0.062

Table 10-16. Model estimated numbers (thousands), fishery selectivity, and survey selectivity of northern rockfish in the Gulf of Alaska based on the preferred model. Also shown are schedules of age-specific weight and female maturity.

Age	Abundance	Percent Mature	Weight	Selectivity Fishery	Selectivity Survey
2	10,951	0	28.6	0.00	0.01
3	9,871	1	74.6	0.00	0.01
4	8,963	1	138.8	0.00	0.03
5	7,725	2	214.9	0.01	0.06
6	6,066	5	296.8	0.03	0.11
7	4,726	9	379.6	0.15	0.21
8	3,660	17	459.9	0.46	0.35
9	2,577	29	535.2	0.81	0.52
10	3,815	46	604.3	0.95	0.69
11	1,864	63	666.5	0.99	0.82
12	2,976	78	721.7	1.00	0.90
13	1,651	88	770.3	1.00	0.95
14	1,991	94	812.6	1.00	0.97
15	2,848	97	849.2	1.00	0.99
16	2,323	98	880.7	1.00	0.99
17	2,087	99	907.6	1.00	1.00
18	1,591	100	930.6	1.00	1.00
19	1,800	100	950.1	1.00	1.00
20	996	100	966.7	1.00	1.00
21	918	100	980.7	1.00	1.00
22	1,924	100	992.5	1.00	1.00
23	3,441	100	1,002.5	1.00	1.00
24	2,507	100	1,010.9	1.00	1.00
25	3,045	100	1,017.9	1.00	1.00
26	6,600	100	1,023.9	1.00	1.00
27	3,432	100	1,028.9	1.00	1.00
28	3,089	100	1,033.1	1.00	1.00
29	4,251	100	1,036.6	1.00	1.00
30	5,855	100	1,039.5	1.00	1.00
31	1,037	100	1,042.0	1.00	1.00
32	1,396	100	1,044.1	1.00	1.00
33	1,460	100	1,045.8	1.00	1.00
34	2,005	100	1,047.3	1.00	1.00
35	789	100	1,048.5	1.00	1.00
36	1,785	100	1,049.5	1.00	1.00
37	1,499	100	1,050.4	1.00	1.00
38	984	100	1,051.1	1.00	1.00
39	1,997	100	1,051.7	1.00	1.00
40	3,236	100	1,052.2	1.00	1.00
41	1,102	100	1,052.6	1.00	1.00
42	1,732	100	1,053.0	1.00	1.00
43	1,343	100	1,053.3	1.00	1.00
44	1,000	100	1,053.5	1.00	1.00
45	799	100	1,053.7	1.00	1.00
46	731	100	1,053.9	1.00	1.00
47	1,240	100	1,054.1	1.00	1.00
48	1,984	100	1,054.2	1.00	1.00
49	547	100	1,054.3	1.00	1.00
50	456	100	1,054.4	1.00	1.00
51	4,338	100	1,054.6	1.00	1.00

Table 10-17. Comparison of 2022 estimated time series of female spawning biomass, 6+ biomass (age 6 and greater), catch/(6+ biomass), and the number of age-2+ recruits for northern rockfish in the Gulf of Alaska compared with 2020 estimates.

	Spawning biomass		6+ biomass		Catch/6+ biomass		Age-2+ recruits	
Year	Previous	Current	Previous	Current	Previous	Current	Previous	Current
1977	19,280	22,198	71,058	79,850	0.009	0.008	21.6	21.0
1978	21,387	24,838	77,896	86,919	0.007	0.006	61.5	70.2
1979	24,115	28,244	85,139	96,312	0.008	0.007	42.4	41.0
1980	27,377	32,259	91,524	103,302	0.009	0.008	22.3	22.7
1981	30,988	36,554	98,146	110,112	0.015	0.013	20.1	23.3
1982	34,471	40,551	112,949	127,386	0.035	0.031	23.8	27.3
1983	36,896	43,359	122,570	137,298	0.030	0.026	33.2	34.3
1984	39,407	46,282	128,407	143,462	0.008	0.007	40.8	41.1
1985	43,218	50,632	135,814	151,638	0.001	0.001	18.4	24.1
1986	47,775	55,813	144,118	160,811	0.002	0.002	64.5	64.9
1987	52,651	61,243	153,924	170,976	0.003	0.003	30.2	36.5
1988	57,460	66,389	165,107	182,286	0.007	0.006	15.4	16.5
1989	61,723	70,790	170,772	189,082	0.009	0.008	21.0	23.0
1990	65,441	74,605	185,546	204,193	0.009	0.008	23.7	25.2
1991	68,867	78,205	193,647	213,710	0.023	0.021	9.7	10.3
1992	71,045	80,635	194,990	215,297	0.040	0.036	20.8	24.2
1993	71,854	81,752	193,140	213,796	0.025	0.023	14.6	16.3
1994	73,870	84,119	194,146	214,983	0.031	0.028	13.4	14.4
1995	75,129	85,631	190,306	210,927	0.030	0.027	9.7	9.9
1996	75,964	86,551	188,267	209,307	0.018	0.016	51.4	51.4
1997	77,104	87,638	186,807	207,860	0.016	0.014	34.1	34.4
1998	77,740	88,138	184,914	205,776	0.017	0.015	20.9	22.9
1999	77,752	87,982	181,552	201,951	0.030	0.027	23.2	23.4
2000	76,279	86,334	184,793	204,875	0.018	0.016	39.9	41.4
2001	75,549	85,461	187,771	207,454	0.017	0.015	16.4	17.6
2002	74,932	84,733	188,492	208,070	0.018	0.016	12.0	13.3
2003	74,504	84,254	189,339	208,431	0.028	0.025	15.0	16.8
2004	73,719	83,478	191,973	210,942	0.025	0.023	7.7	8.7
2005	73,627	83,407	190,430	209,088	0.024	0.022	3.5	3.8
2006	73,941	83,676	187,668	206,010	0.026	0.024	3.5	3.8
2007	74,079	83,689	184,488	202,654	0.023	0.021	5.7	6.3
2008	74,344	83,784	180,004	197,784	0.023	0.020	4.8	5.1
2009	74,261	83,465	174,022	191,222	0.023	0.021	5.8	6.1
2010	73,639	82,535	167,406	183,995	0.023	0.021	6.5	6.2
2011	72,361	80,892	160,779	176,822	0.021	0.019	6.5	7.0
2012	70,623	78,758	154,122	169,547	0.033	0.030	5.3	4.5
2013	67,525	75,242	145,864	160,694	0.033	0.030	3.8	3.5
2014	64,082	71,394	137,968	152,096	0.031	0.028	5.7	5.8
2015	60,669	67,614	130,807	144,403	0.030	0.027	5.0	3.3
2016	57,319	63,939	123,859	136,665	0.028	0.025	6.7	6.3
2017	54,230	60,554	117,228	129,296	0.016	0.014	5.7	3.9
2018	51,975	58,017	112,686	124,125	0.021	0.019	7.5	5.2
2019	49,547	55,296	107,621	118,049	0.026	0.023	8.3	6.4
2020	47,015	52,447	102,714	112,387	0.023	0.021	9.4	7.7
2021	44,738	49,829	98,216	106,830	0.024	0.022	10.2	9.2
2022	42,555	47,283	94,330	101,752	0.020	0.019	10.8	10.1
2023		45,061		97,650		0.014		10.5
2024		43,228		94,699		0.012		11.0

Table 10-18. Estimates of key parameters andoutputs with MCMC estimates of mean, median, standard deviations σ_MCMC, and 95% Bayesian credible intervals (BCI) derived from MCMC.

Parameter	mu	mu MCMC	Median MCMC	σ MCMC	BCI Lower	BCI Upper
F40	0.062	0.064	0.062	0.021	0.028	0.109
spawn_bio	40,405	39,737	37,540	12,720	20,619	69,195
ABC	5,079	5,220	4,902	2,515	1,626	11,197
M	0.059	0.059	0.059	0.003	0.054	0.065
q	0.767	0.825	0.809	0.192	0.495	1.242

Table 10-19. Estimated time series of number at age-2 recruits (thousands), total biomass, and female spawning biomass with 95% confidence bounds for northern rockfish in the Gulf of Alaska, from this year's model MCMC results.

	Age 2+ recruits			Total biomass			Spawning biomass		
Year	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
1,977	28,256	588	93,587	90,013	62,952	132,006	22,500	13,926	35,480
1,978	60,727	1,077	143,726	99,210	70,262	144,619	25,046	16,081	38,763
1,979	45,558	771	124,921	109,561	78,323	158,277	28,336	18,828	42,840
1,980	23,589	602	76,765	120,322	86,632	172,869	32,210	22,050	47,877
1,981	21,758	624	69,468	131,025	94,588	187,288	36,391	25,474	53,381
1,982	27,674	826	77,542	140,834	101,989	201,133	40,339	28,517	58,933
1,983	35,832	943	93,525	147,921	106,777	211,655	43,130	30,448	63,266
1,984	39,491	1,582	93,132	155,263	111,727	222,496	46,017	32,422	67,662
1,985	23,419	578	76,896	164,886	119,175	236,144	50,276	35,601	73,149
1,986	68,681	15,859	127,289	176,079	127,995	250,842	55,324	39,436	79,686
1,987	32,839	1,261	79,437	187,313	137,008	265,735	60,629	43,656	86,756
1,988	18,015	744	50,182	197,928	145,321	280,165	65,711	47,519	93,540
1,989	22,630	1,879	53,273	207,211	152,307	292,694	70,101	51,044	99,606
1,990	24,789	2,593	52,831	215,131	158,302	303,480	73,905	54,056	104,901
1,991	10,653	452	34,058	221,426	163,195	312,295	77,460	56,802	109,931
1,992	23,853	4,467	48,294	223,638	164,224	316,798	79,815	58,288	113,514
1,993	16,349	1,103	39,504	221,275	160,621	315,757	80,849	58,467	115,791
1,994	14,206	1,265	33,479	220,706	159,459	316,356	83,124	59,908	119,518
1,995	8,942	520	26,866	217,711	156,181	314,977	84,574	60,451	122,471
1,996	52,648	27,497	89,601	215,131	153,231	312,785	85,474	60,635	124,577
1,997	33,345	7,936	65,406	215,054	152,817	313,710	86,562	61,438	126,366
1,998	23,410	2,049	53,378	215,620	153,014	315,200	87,063	61,537	127,403
1,999	21,722	2,415	50,011	216,204	153,106	316,460	86,901	61,203	127,415
2,000	43,320	18,921	78,516	215,060	151,125	316,926	85,232	59,645	125,737
2,001	16,079	1,310	38,963	216,076	151,203	319,236	84,325	58,936	124,850
2,002	13,329	1,068	33,007	217,052	151,209	322,346	83,540	58,136	124,097
2,003	17,081	2,831	35,739	217,384	150,891	324,385	82,974	57,448	123,926
2,004	8,199	710	20,567	214,971	147,955	323,456	82,081	56,244	123,611
2,005	3,775	297	10,877	211,952	144,619	320,108	81,889	55,796	124,097
2,006	3,804	338	10,729	208,049	140,670	317,220	82,064	55,495	125,146
2,007	6,067	851	14,371	202,595	135,750	311,642	82,013	54,898	125,918
2,008	5,075	503	13,704	196,907	130,888	303,744	82,067	54,466	126,732
2,009	5,923	643	14,980	190,525	125,657	295,272	81,739	53,756	126,924
2,010	6,196	680	16,222	183,618	120,076	286,611	80,829	52,728	126,442
2,011	6,872	878	17,229	176,356	114,214	277,287	79,231	51,154	124,756
2,012	4,386	440	12,484	169,240	108,408	267,995	77,150	49,327	122,507
2,013	3,477	324	10,933	160,291	101,062	257,012	73,693	46,342	118,169
2,014	5,421	610	14,854	151,503	93,612	245,264	69,893	43,175	113,240
2,015	3,437	244	11,832	143,320	87,083	234,264	66,151	40,185	108,406
2,016	5,701	623	16,388	135,577	81,075	223,762	62,499	37,394	103,550
2,017	3,801	246	14,202	128,455	75,525	214,223	59,131	34,729	98,825
2,018	5,081	256	20,675	123,075	71,704	206,682	56,605	32,926	94,789
2,019	6,487	280	28,877	117,364	67,524	198,297	53,896	30,909	90,892

	Age 2+ recruits			Total biomass			Spawning biomass		
Year	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
2,020	8,646	280	42,708	111,592	63,058	189,884	51,061	28,785	86,968
2,021	11,081	295	55,722	106,655	59,488	182,701	48,458	26,862	83,203
2,022	15,316	320	89,614	102,384	55,999	176,293	45,925	24,993	79,653
2,023	16,932	336	104,040	99,380	53,304	172,364	43,714	23,299	76,214
2,024	21,762	386	128,885	97,921	52,256	172,041	41,896	22,043	73,472

Table 10-20. Set of projections of female spawning biomass for northern 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 maximum F	5-year average F	No Fishing	Overfishing	Approaching overfished
2024	42,092	42,092	42,092	42,092	42,092	42,092	42,092
2025	39,861	40,370	40,271	40,431	40,685	39,697	39,861
2026	36,685	38,589	38,205	38,813	39,790	36,089	36,685
2027	33,939	36,598	36,414	37,424	39,072	33,012	33,802
2028	31,672	34,047	34,924	36,299	38,573	30,528	31,188
2029	29,945	31,980	33,762	35,462	38,327	28,655	29,210
2030	28,703	30,442	32,947	34,929	38,354	27,313	27,779
2031	27,905	29,388	32,492	34,716	38,677	26,444	26,836
2032	27,525	28,785	32,401	34,841	39,324	26,011	26,339
2033	27,532	28,598	32,672	35,321	40,320	25,972	26,245
2034	27,861	28,756	33,267	36,131	41,652	26,254	26,480
2035	28,405	29,155	34,103	37,194	43,251	26,746	26,931
2036	29,054	29,678	35,077	38,409	45,016	27,334	27,484
2037	29,723	30,242	36,103	39,685	46,856	27,932	28,055

Table 10-21. Set of projections of Fishing mortality for northern 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 maximum F	5-year average F	No Fishing	Overfishing	Approaching overfished
2024	0.013	0.013	0.013	0.013	0.013	0.013	0.013
2025	0.062	0.024	0.031	0.019	0.000	0.074	0.062
2026	0.062	0.023	0.031	0.019	0.000	0.074	0.062
2027	0.062	0.062	0.031	0.019	0.000	0.072	0.074
2028	0.058	0.062	0.031	0.019	0.000	0.067	0.068
2029	0.054	0.058	0.030	0.019	0.000	0.062	0.063
2030	0.052	0.055	0.030	0.019	0.000	0.059	0.060
2031	0.050	0.053	0.029	0.019	0.000	0.057	0.058
2032	0.049	0.052	0.029	0.019	0.000	0.056	0.056
2033	0.049	0.051	0.029	0.019	0.000	0.055	0.056
2034	0.049	0.051	0.029	0.019	0.000	0.055	0.056
2035	0.050	0.051	0.030	0.019	0.000	0.056	0.057
2036	0.051	0.052	0.031	0.019	0.000	0.057	0.058
2037	0.052	0.053	0.031	0.019	0.000	0.059	0.059

Table 10-22. Set of projections of Fishing yield for northern 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 maximum F	5-year average F	No Fishing	Overfishing	Approaching overfished
2024	1,170	1,170	1,170	1,170	1,170	1,170	1,170
2025	5,077	1,968	2,577	1,585	0	6,064	5,077
2026	4,710	1,826	2,463	1,532	0	5,559	4,710
2027	4,410	4,745	2,373	1,493	0	5,012	5,256
2028	3,892	4,474	2,305	1,465	0	4,337	4,525
2029	3,519	4,007	2,222	1,448	0	3,867	4,016
2030	3,265	3,663	2,135	1,440	0	3,549	3,668
2031	3,115	3,445	2,093	1,445	0	3,361	3,458
2032	3,049	3,324	2,091	1,464	0	3,273	3,353
2033	3,084	3,317	2,143	1,500	0	3,301	3,368
2034	3,173	3,371	2,230	1,544	0	3,394	3,450
2035	3,311	3,478	2,328	1,591	0	3,535	3,581
2036	3,443	3,588	2,437	1,640	0	3,678	3,717
2037	3,620	3,739	2,534	1,694	0	3,873	3,906

Figures

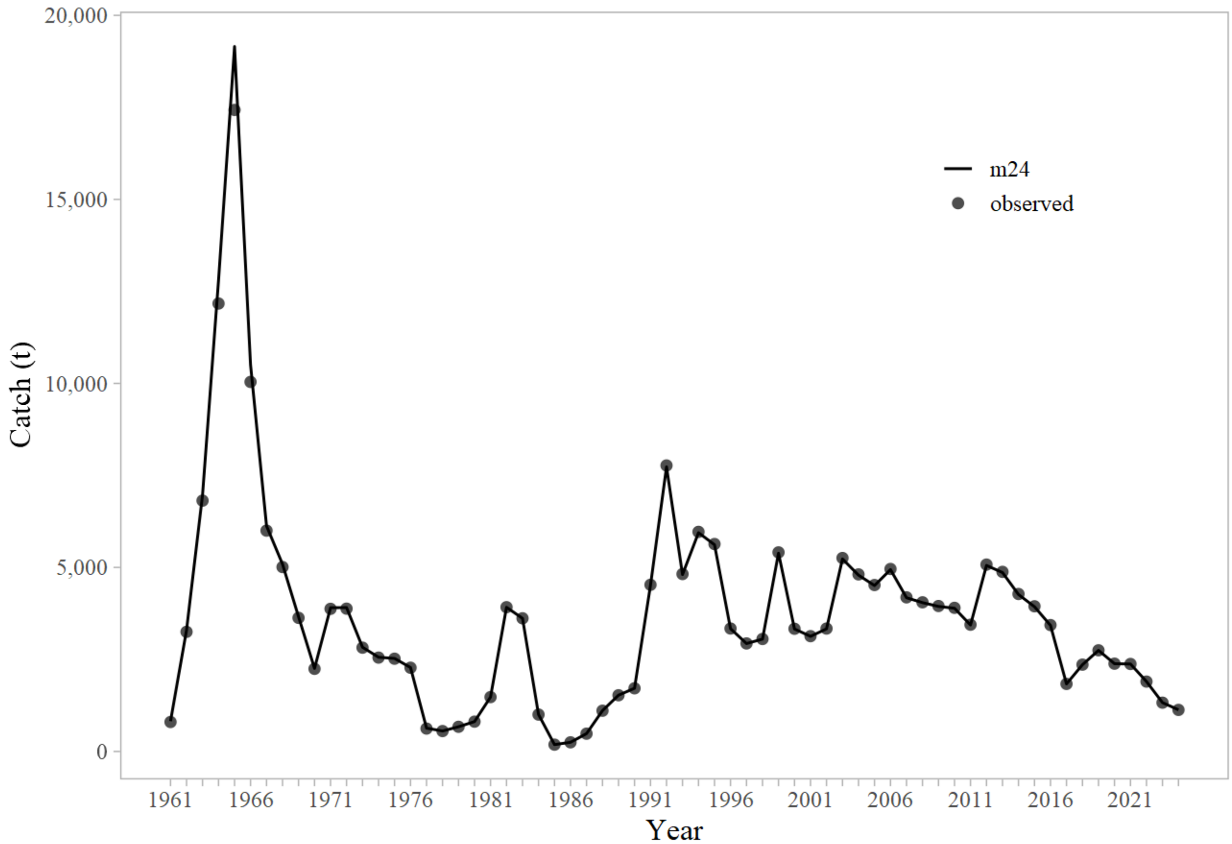


Figure 10-1. Observed and estimate commercial catch of GOA northern rockfish in the Gulf of Alaska from the 2024 model (m24).

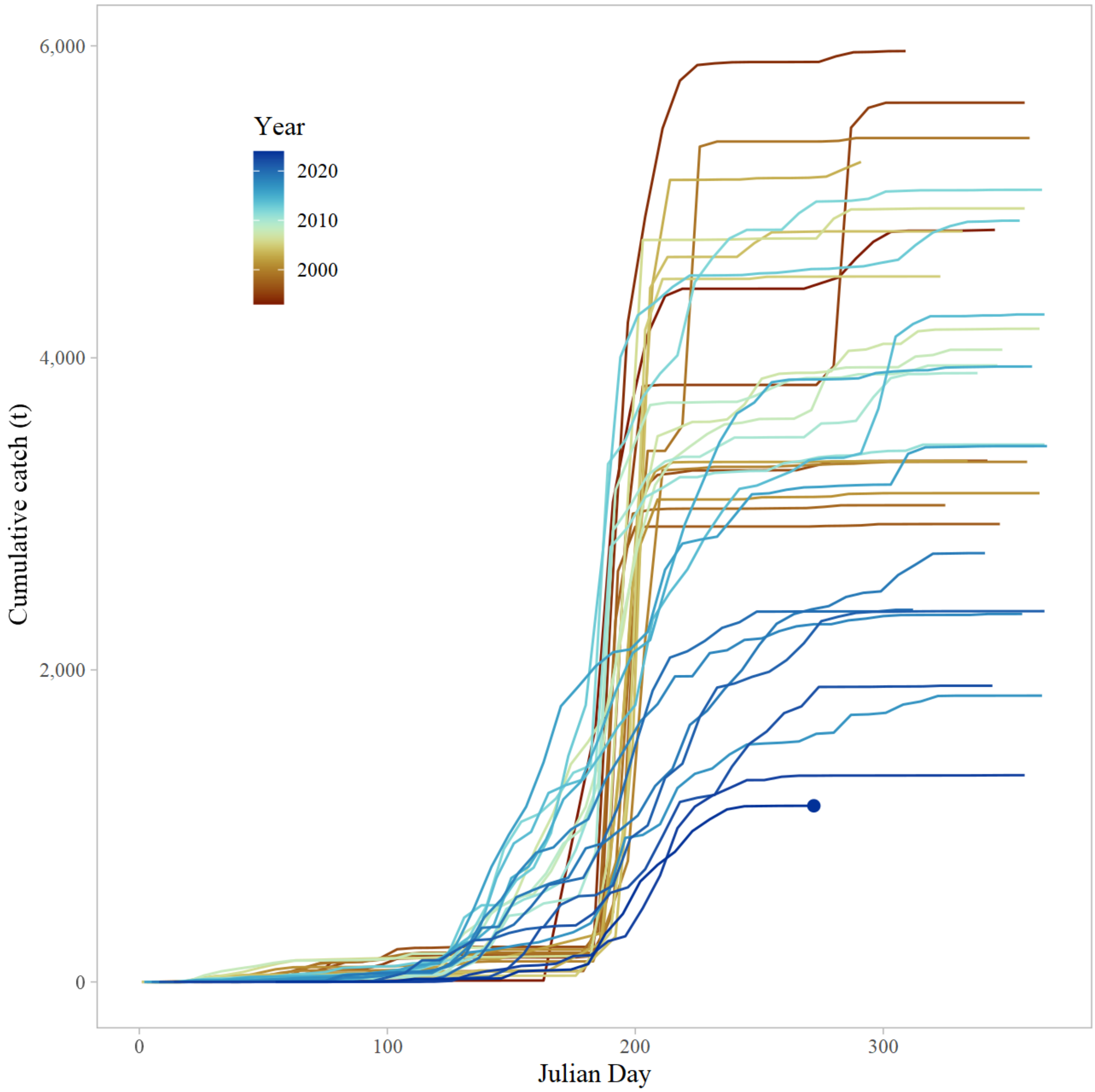


Figure 10-2. Annual Gulf of Alaska northern rockfish cumulative catch by Julian day. The dot indicates catch in the current year.

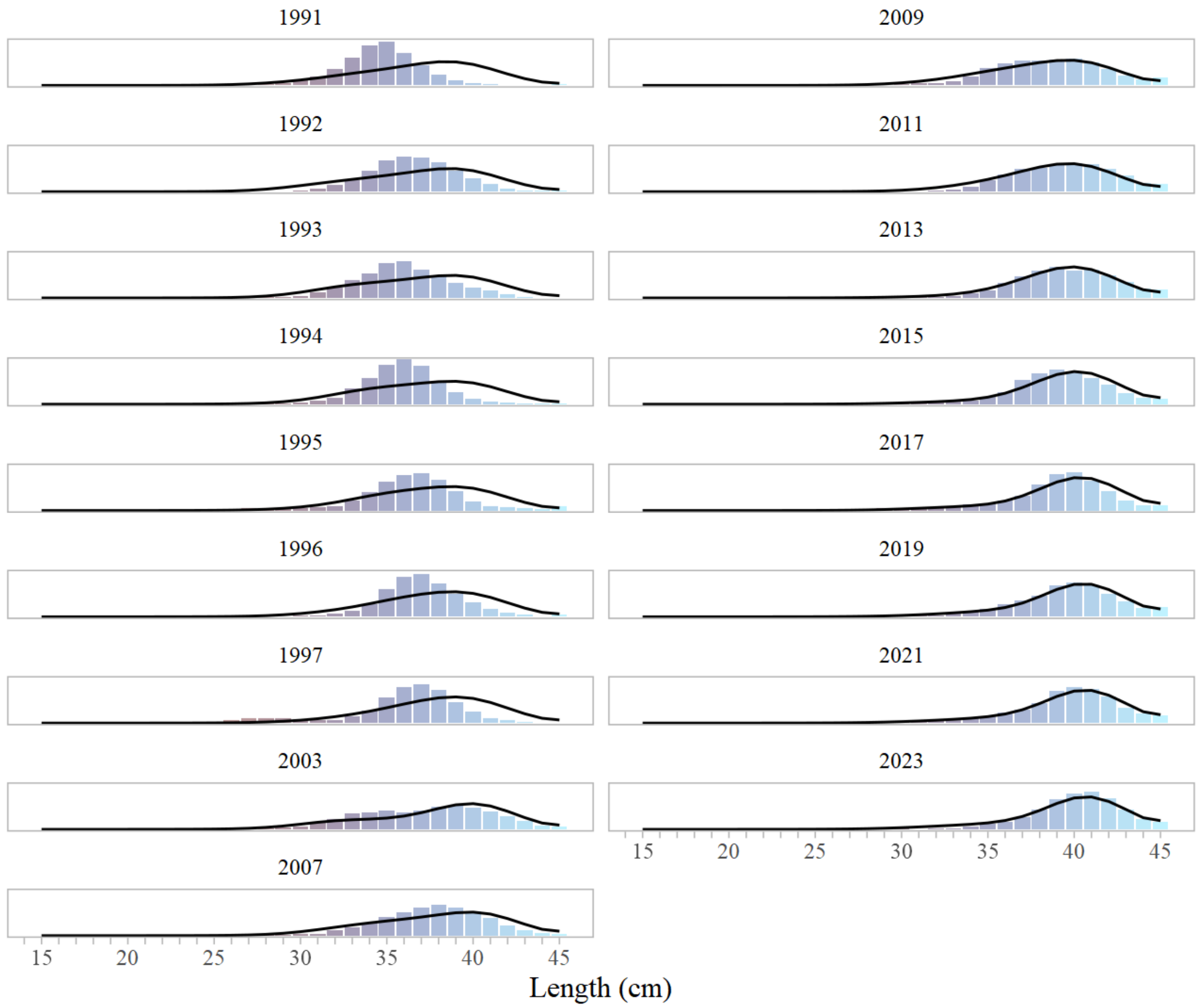


Figure 10-3. Annual fishery length composition plots. Bars are observed values, lines are estimated values.

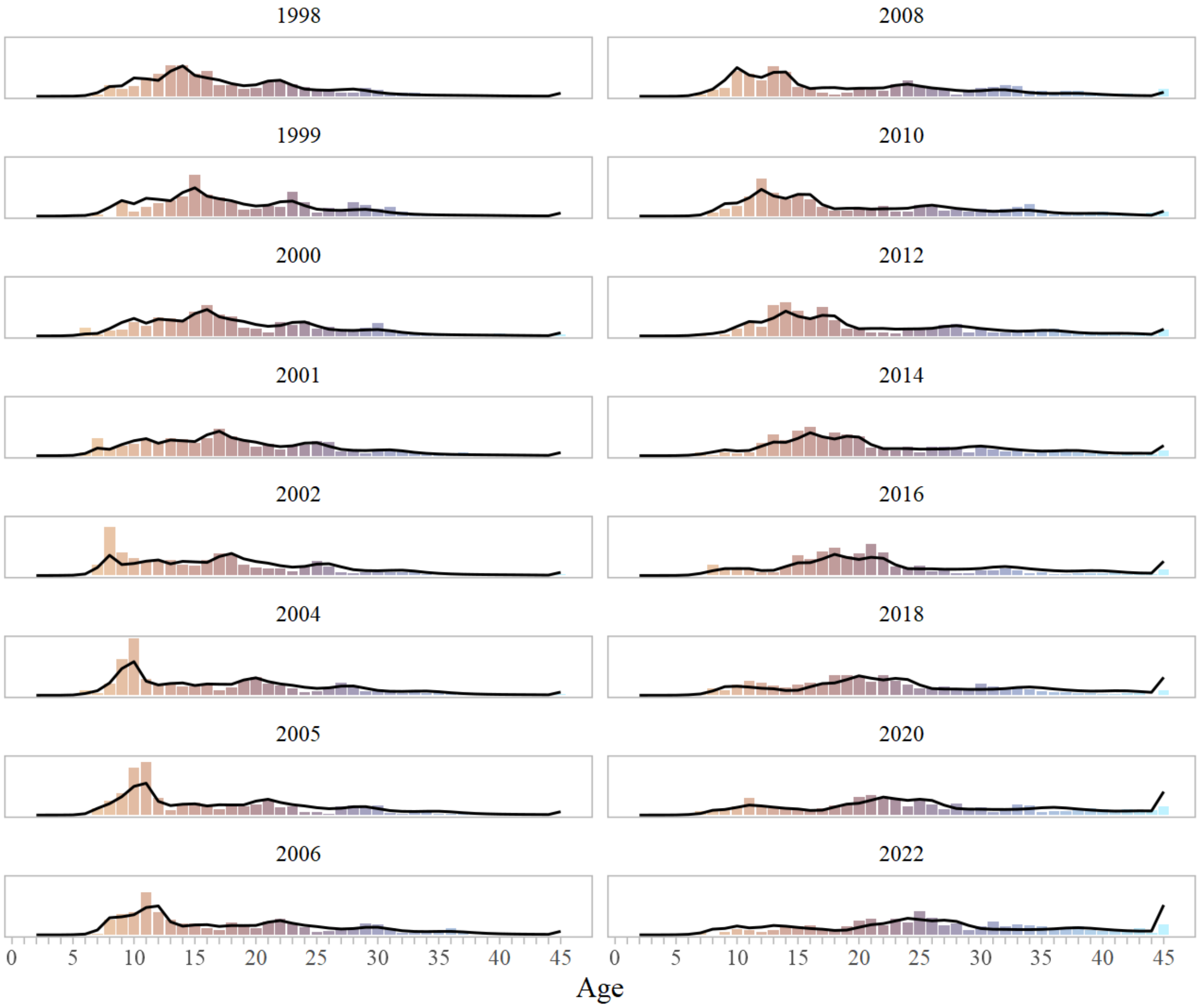


Figure 10-4. Annual fishery age composition plots. Bars are observed values, lines are estimated values.

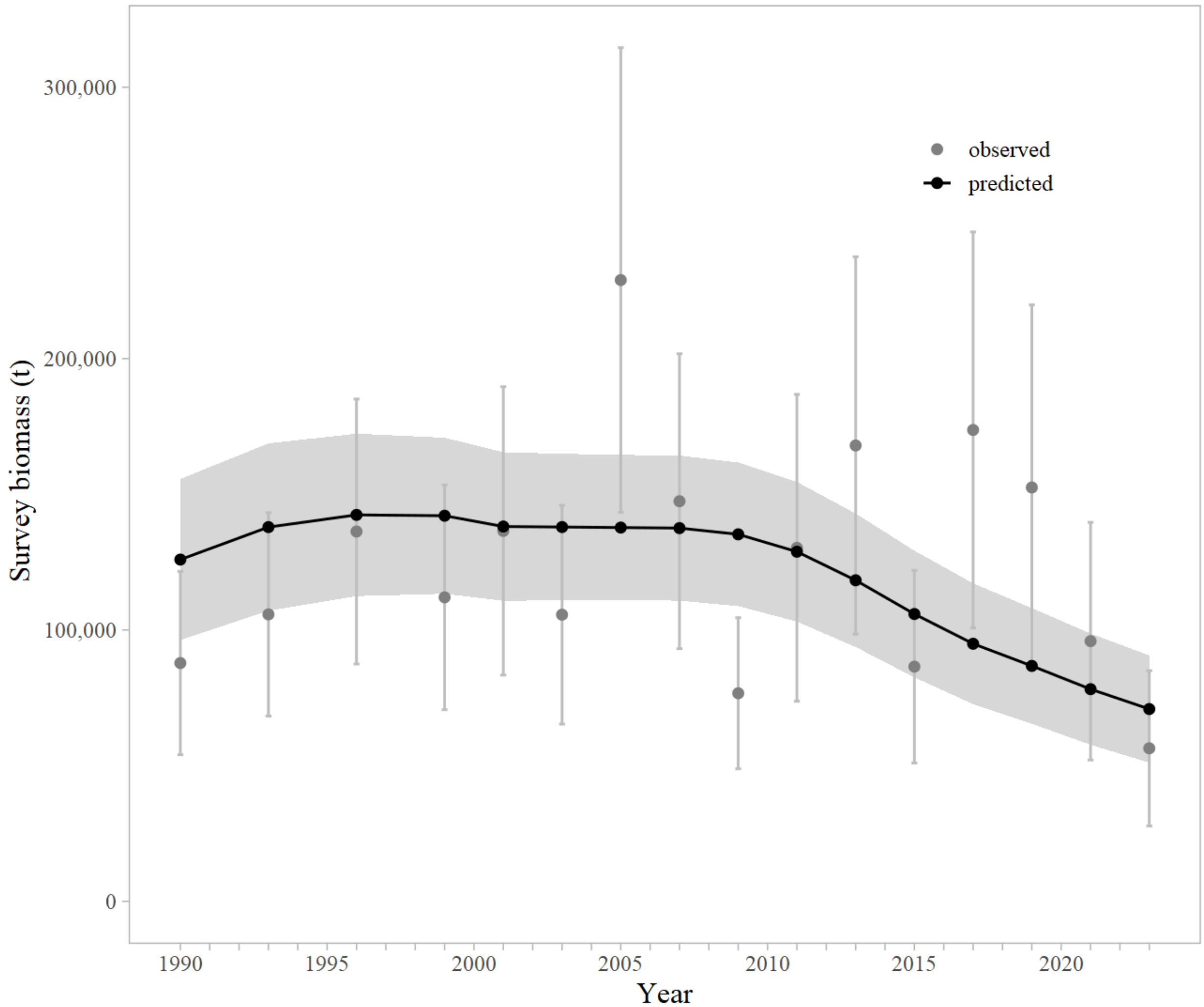
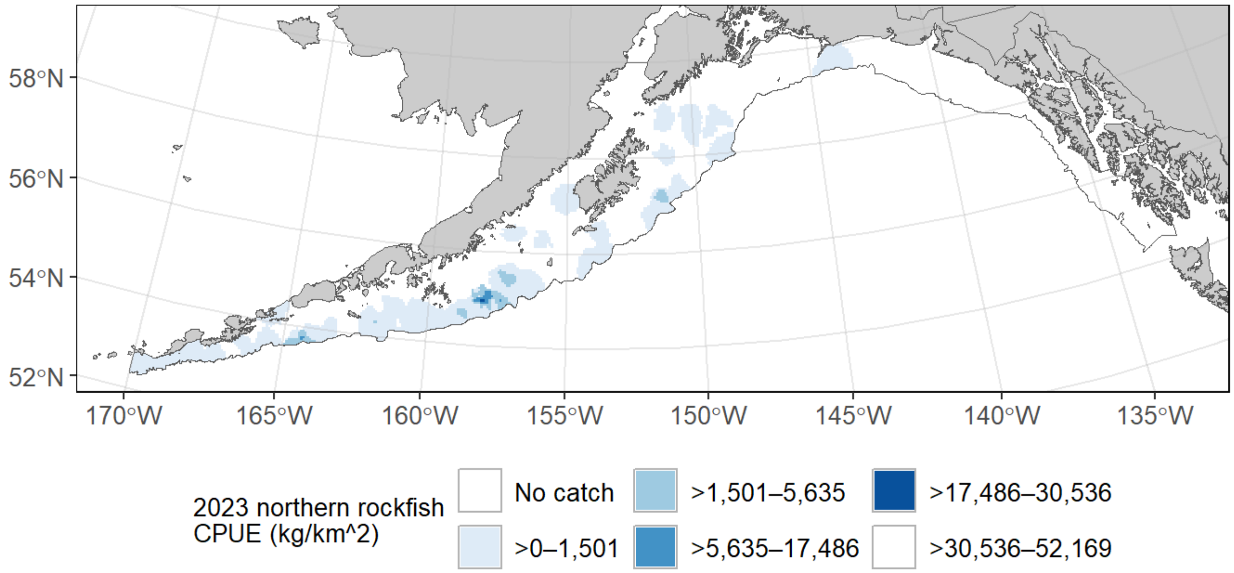
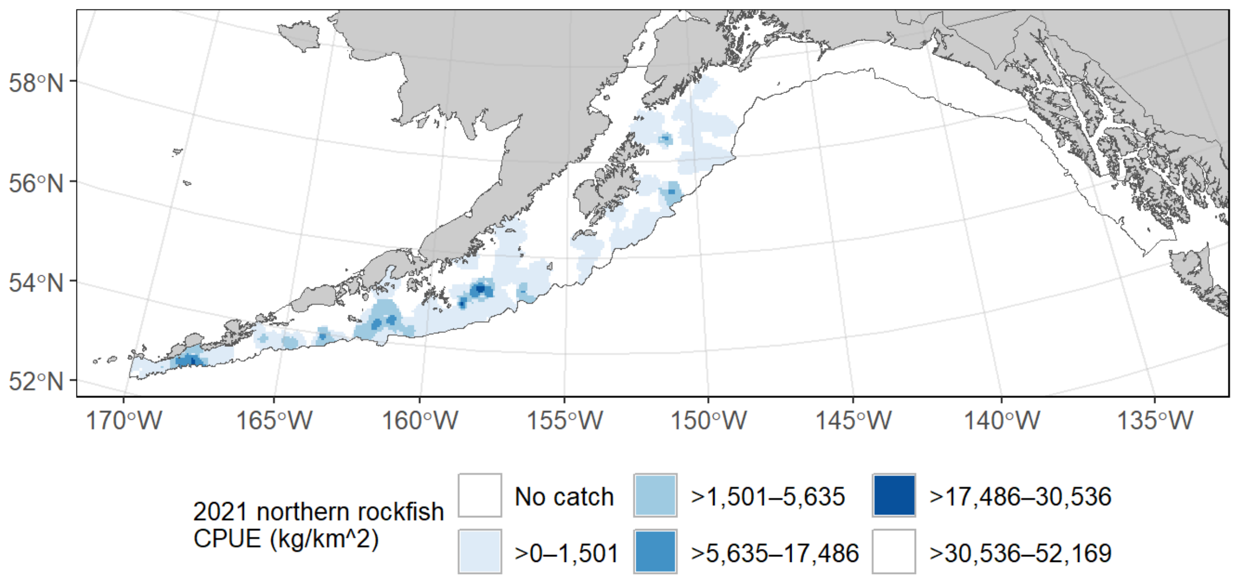


Figure 10-5. Observed (geostatistical model-based estimates) and predicted GOA northern rockfish trawl survey biomass based on the 2024 recommended model. Error bars are approximate asymptotic 95% confidence intervals of model error, the shaded area is the 95% confidence intervals for the predicted biomass.


58°N
56°N
54°N
52°N
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
2023 northern rockfish CPUE (kg/km^2)
No catch
>0–1,501
>1,501–5,635
>5,635–17,486
>17,486–30,536
>30,536–52,169


58°N
56°N
54°N
52°N
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
2021 northern rockfish CPUE (kg/km^2)
No catch
>0–1,501
>1,501–5,635
>5,635–17,486
>17,486–30,536
>30,536–52,169

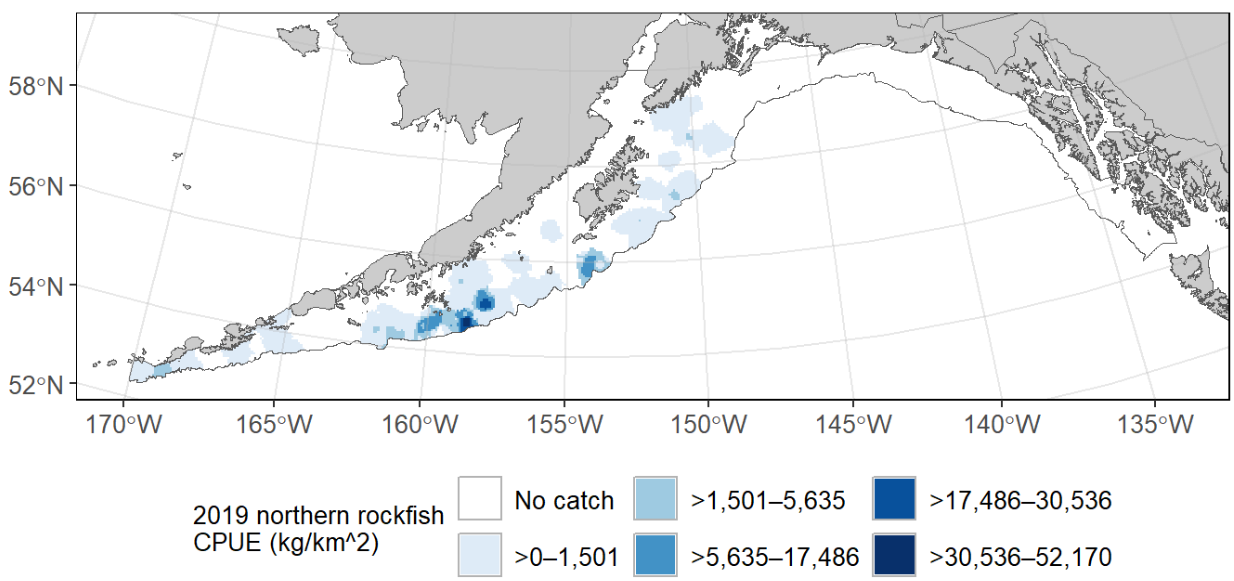

58°N
56°N
54°N
52°N
170°W
165°W
160°W
155°W
150°W
145°W
140°W
135°W
2019 northern rockfish CPUE (kg/km^2)
No catch
>0–1,501
>1,501–5,635
>5,635–17,486
>17,486–30,536
>30,536–52,170

Figure 10-6. Spatial distribution of northern rockfish in the Gulf of Alaska during the last three NMFS trawl surveys.

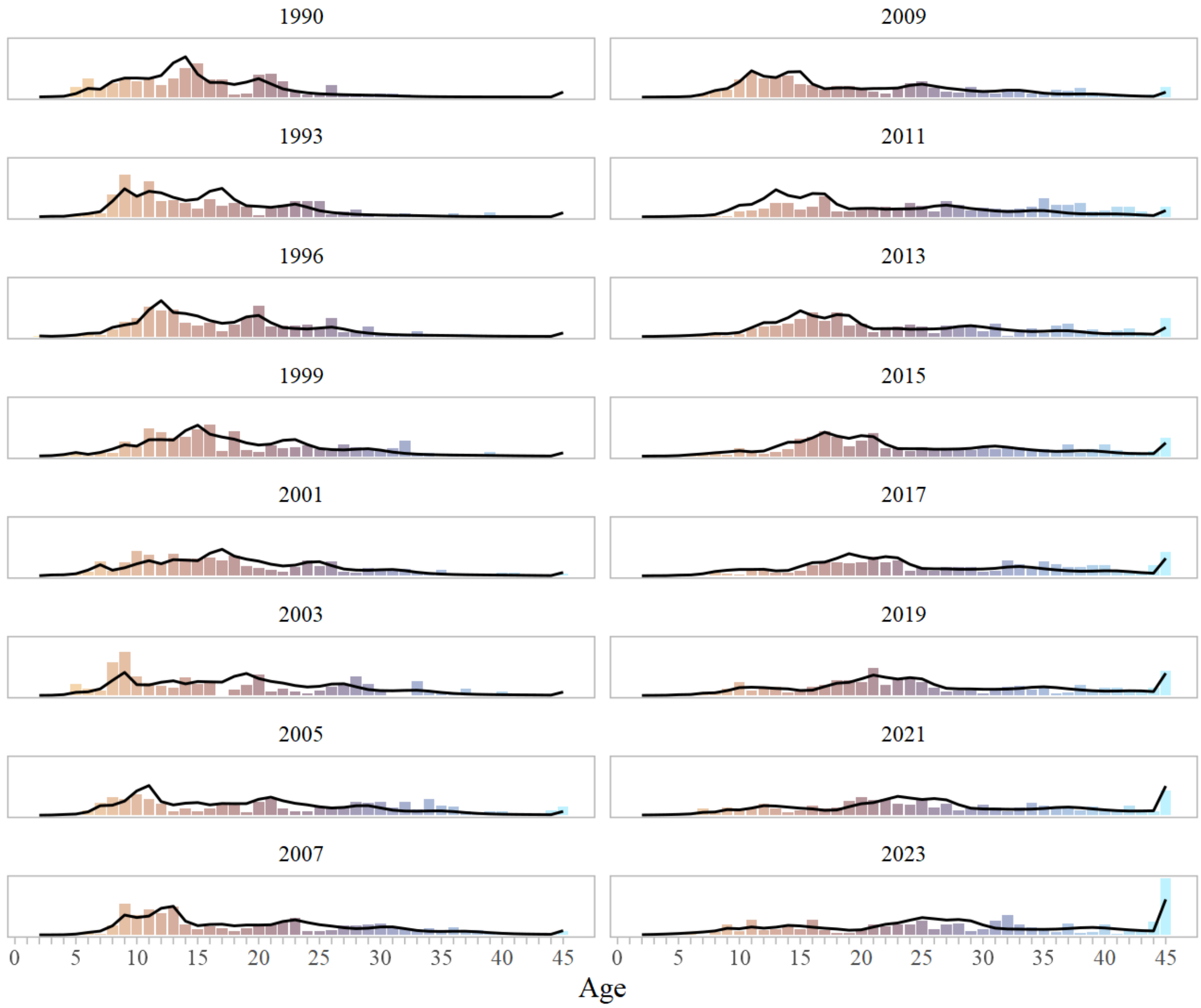


Figure 10-7. Annual survey age composition plots. Bars are observed values, lines are estimated values.

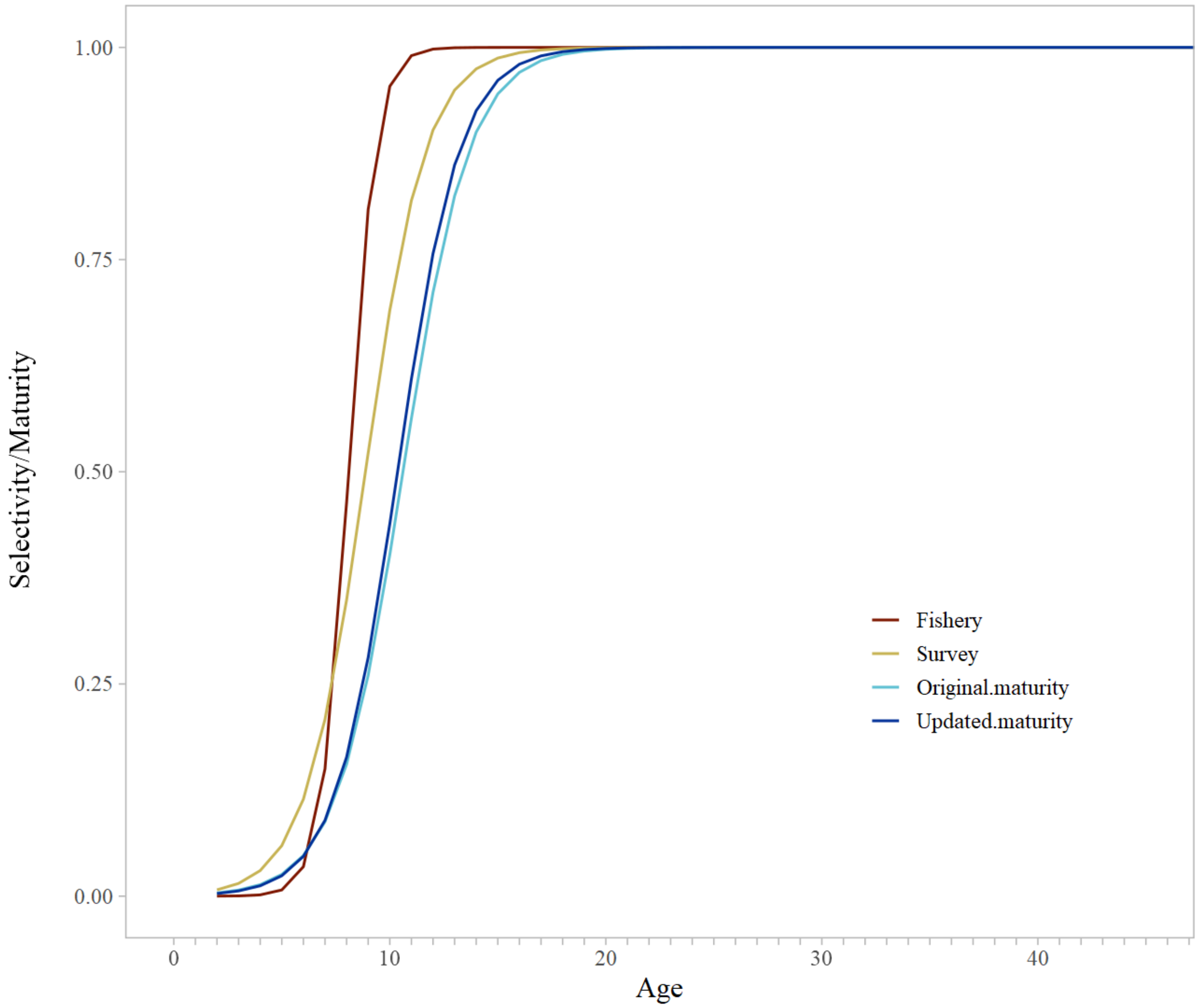


Figure 10-8. GOA northern rockfish estimated fishery and survey selectivities for the 2024 model and maturity estimates from the ADMB model and a generalized linear model with updated maturity information.

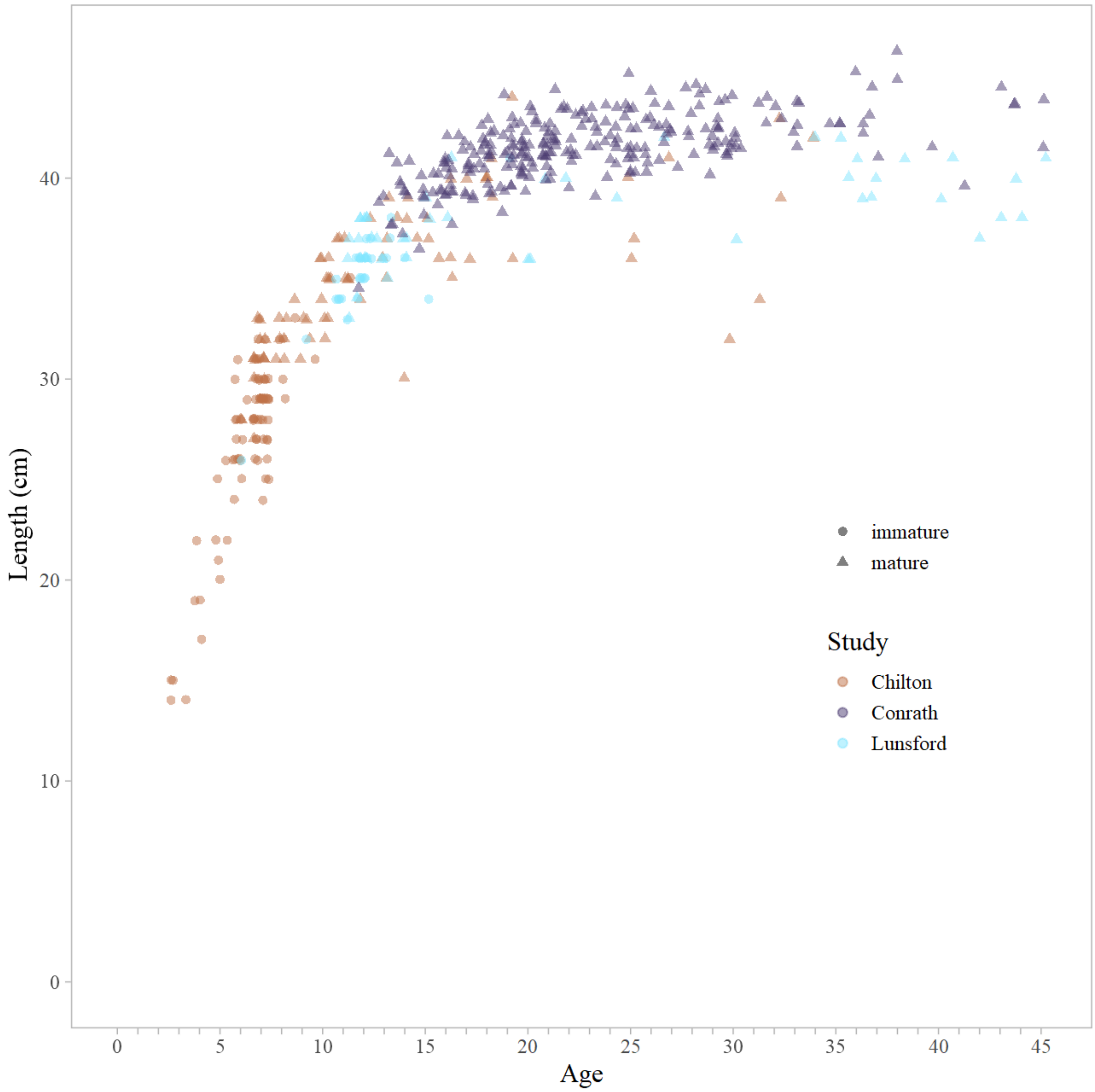


Figure 10-9. GOA northern rockfish estimated fishery and survey selectivities for the 2024 model and maturity estimates from the ADMB model and a generalized linear model with updated maturity information.

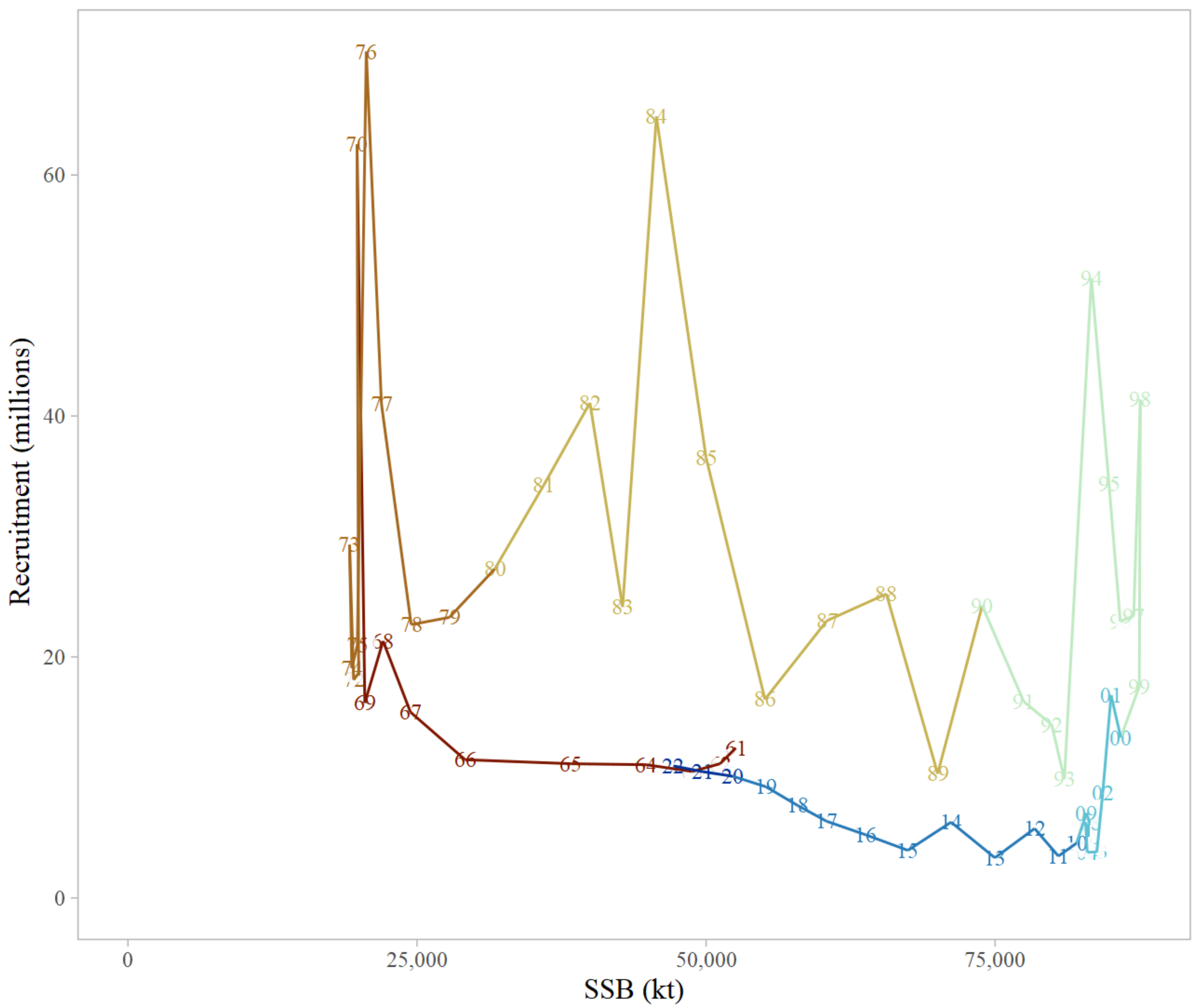


Figure 10-10. Scatterplot of spawner-recruit estimates for the GOA northern rockfish author's recommended model for 20224.

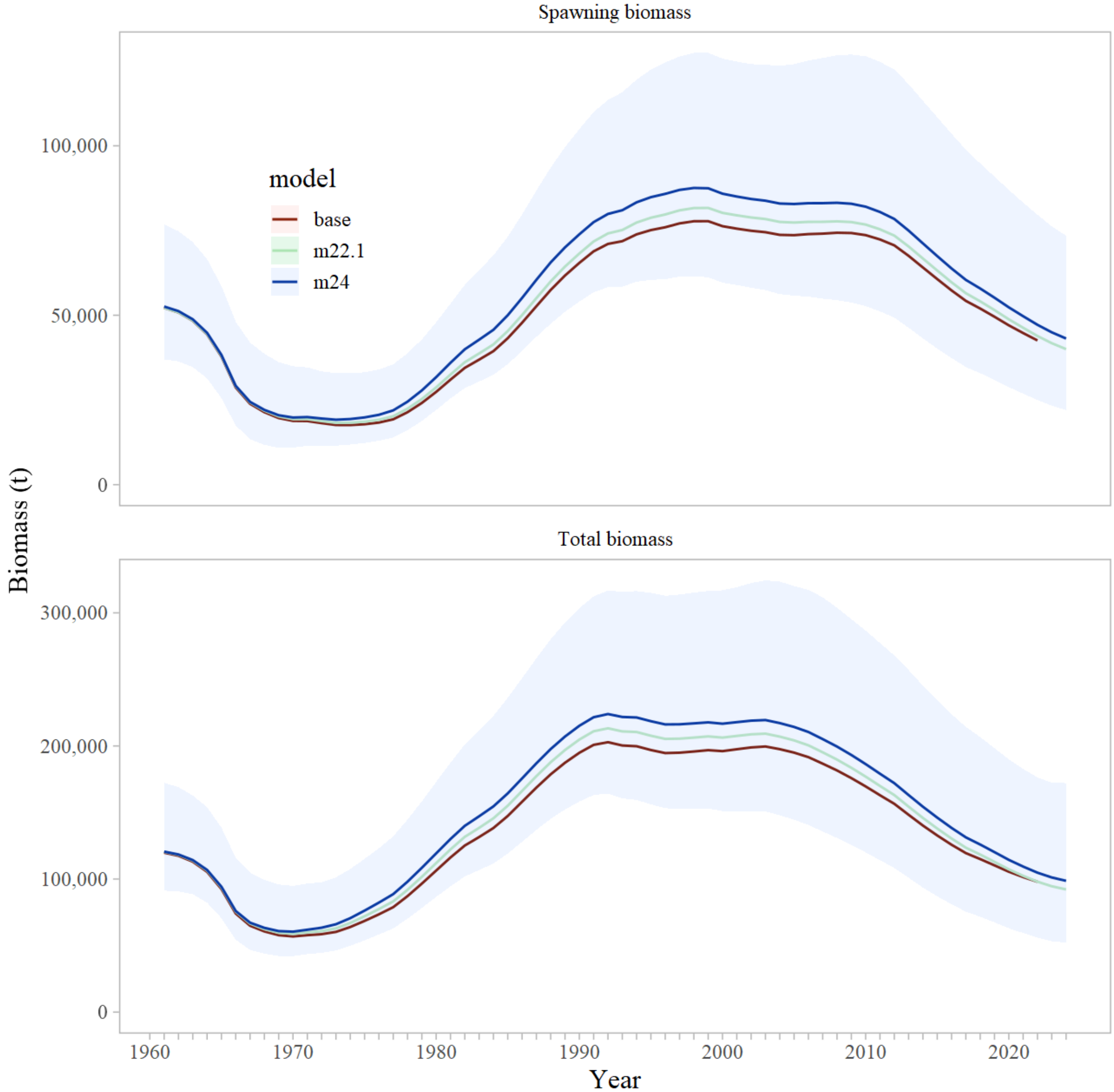


Figure 10-11. Time series of estimated female spawning and age 2+ total biomass for GOA northern rockfish from the 2024 model (m24), the 2022 SSC accepted model with 2022 data (base) and 2024 data (m22.1). The 95% credible intervals are from m24.

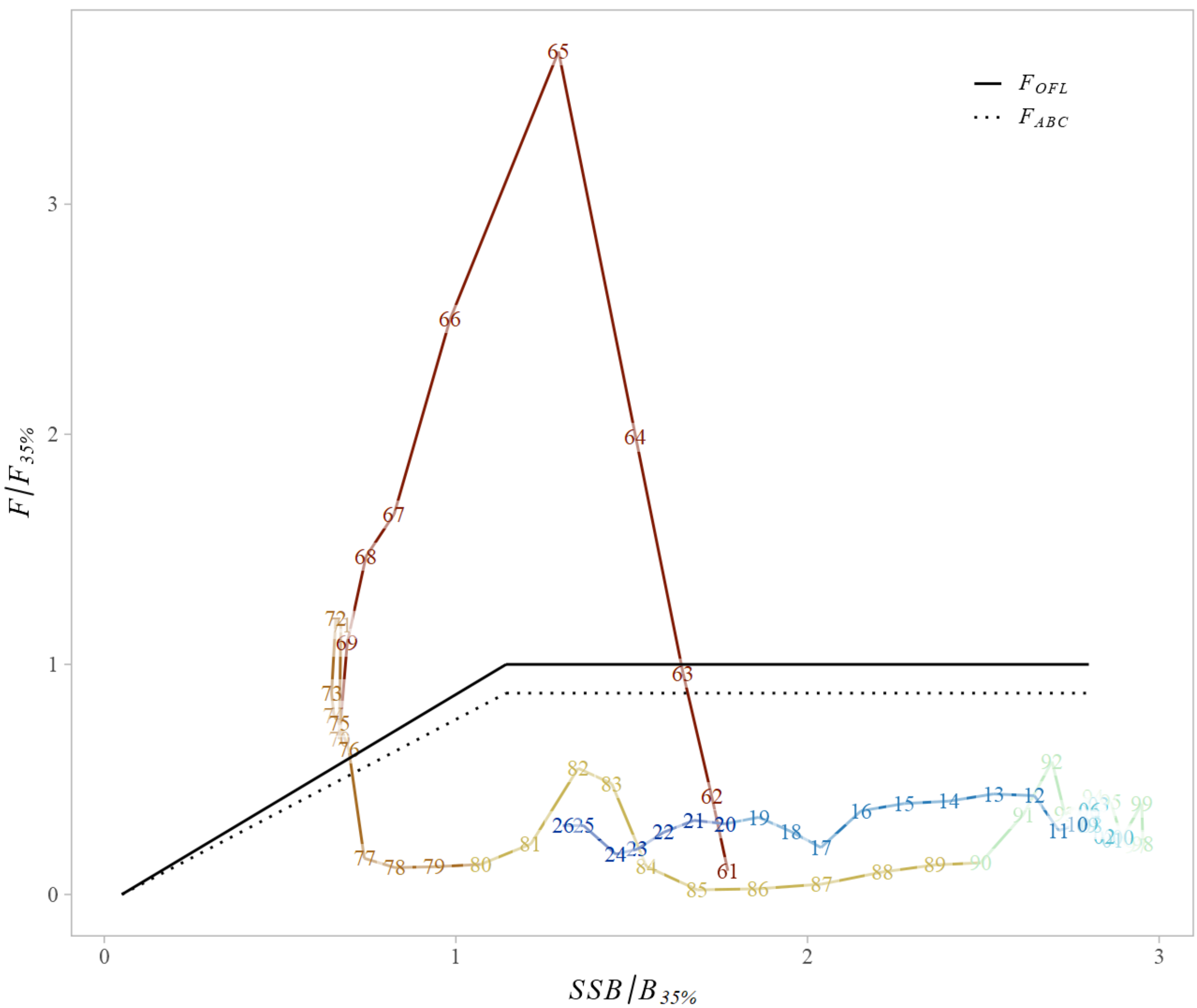


Figure 10-12. Time series of northern rockfish estimated spawning biomass (SSB) relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ for author recommended model.

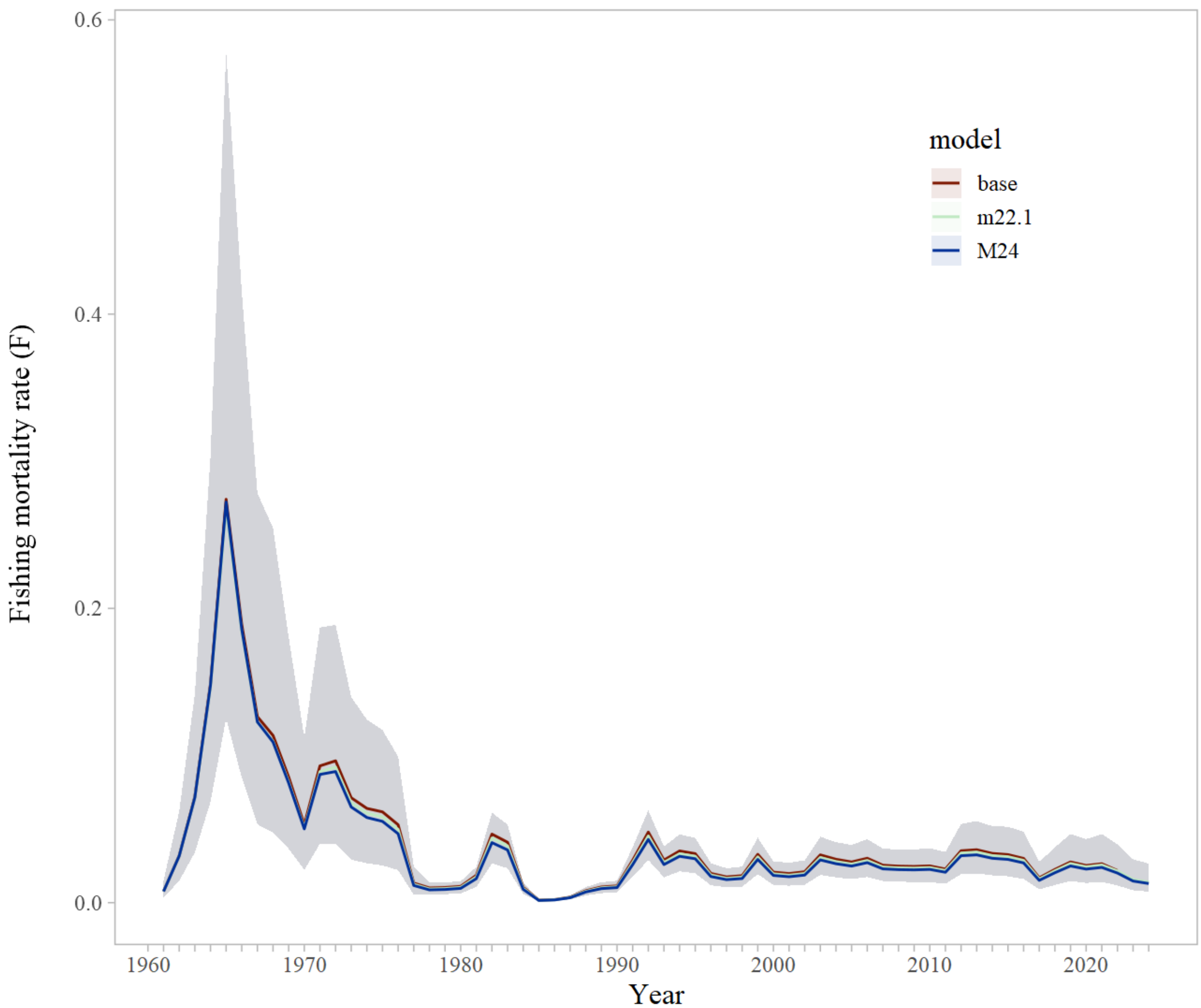


Figure 10-13. Time series of estimated fully selected fishing mortality for GOA northern rockfish from the 2024 model (m24), the 2022 SSC accepted model with 2022 data (base) and 2024 data (m22.1). The 95% credible intervals are from m24.

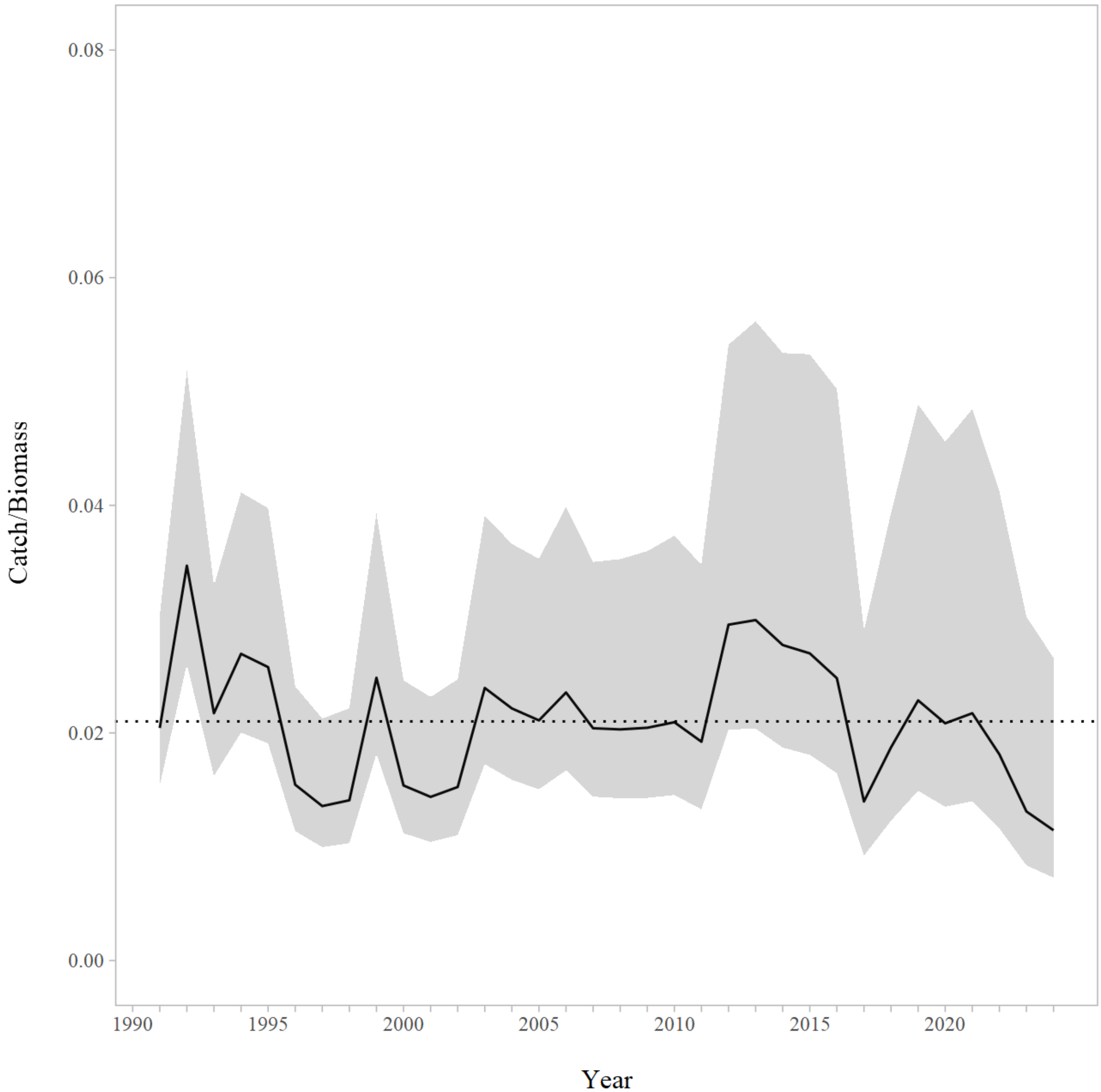


Figure 10-14. Time series of estimated Gulf of Alaska northern rockfish catch/age 2+ biomass ratio with approximate 95% confidence intervals. Observed catch values were used for 1990-2024, the 2024 catch values were estimated using an expansion factor. The horizontal dashed line is the mean value for the entire dataset.

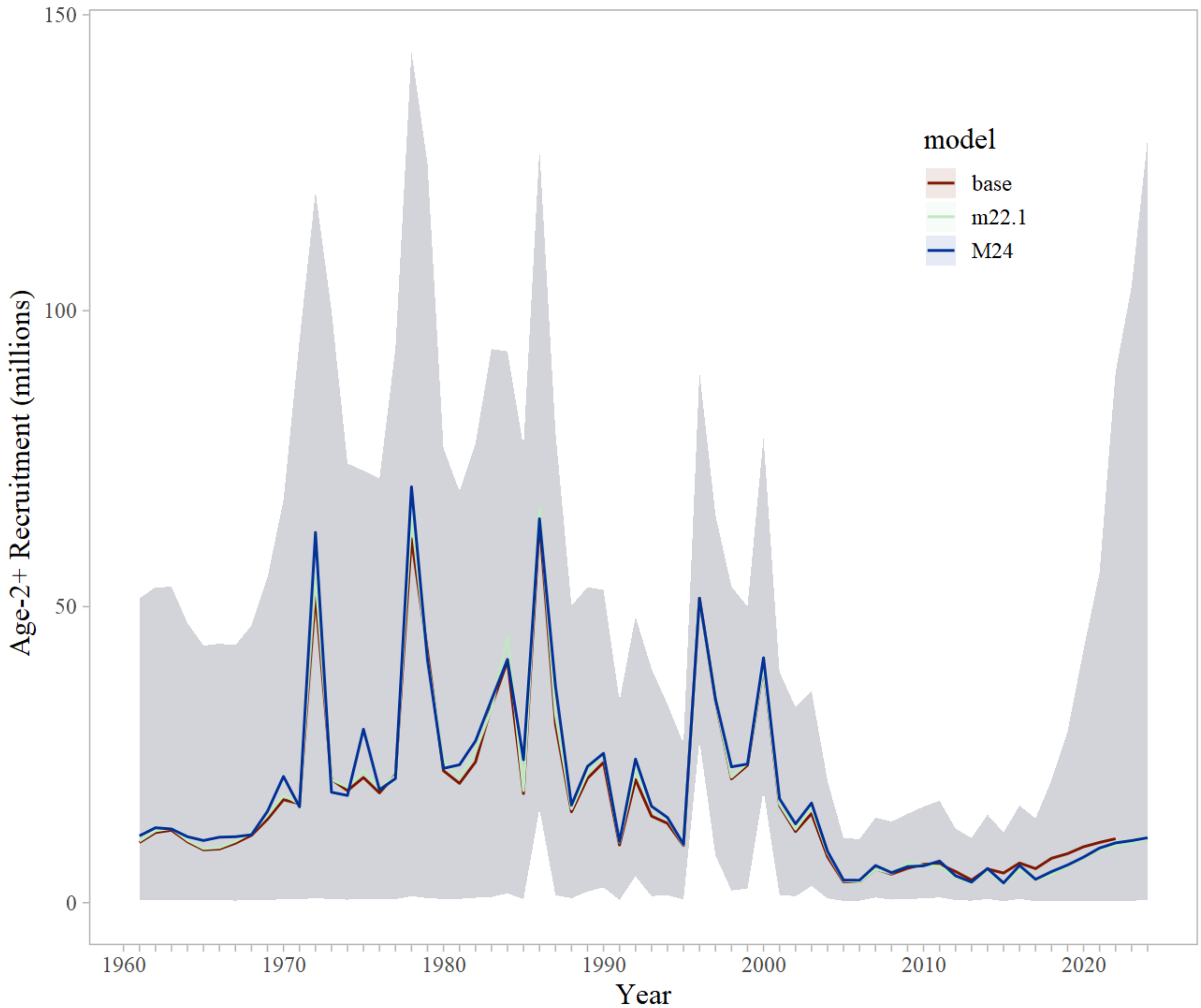


Figure 10-15. Time series of estimated age-2 GOA northern rockfish recruitment from the 2024 model (m24), the 2022 SSC accepted model with 2022 data (base) and 2024 data (m22.1). The 95% credible intervals are from m24.

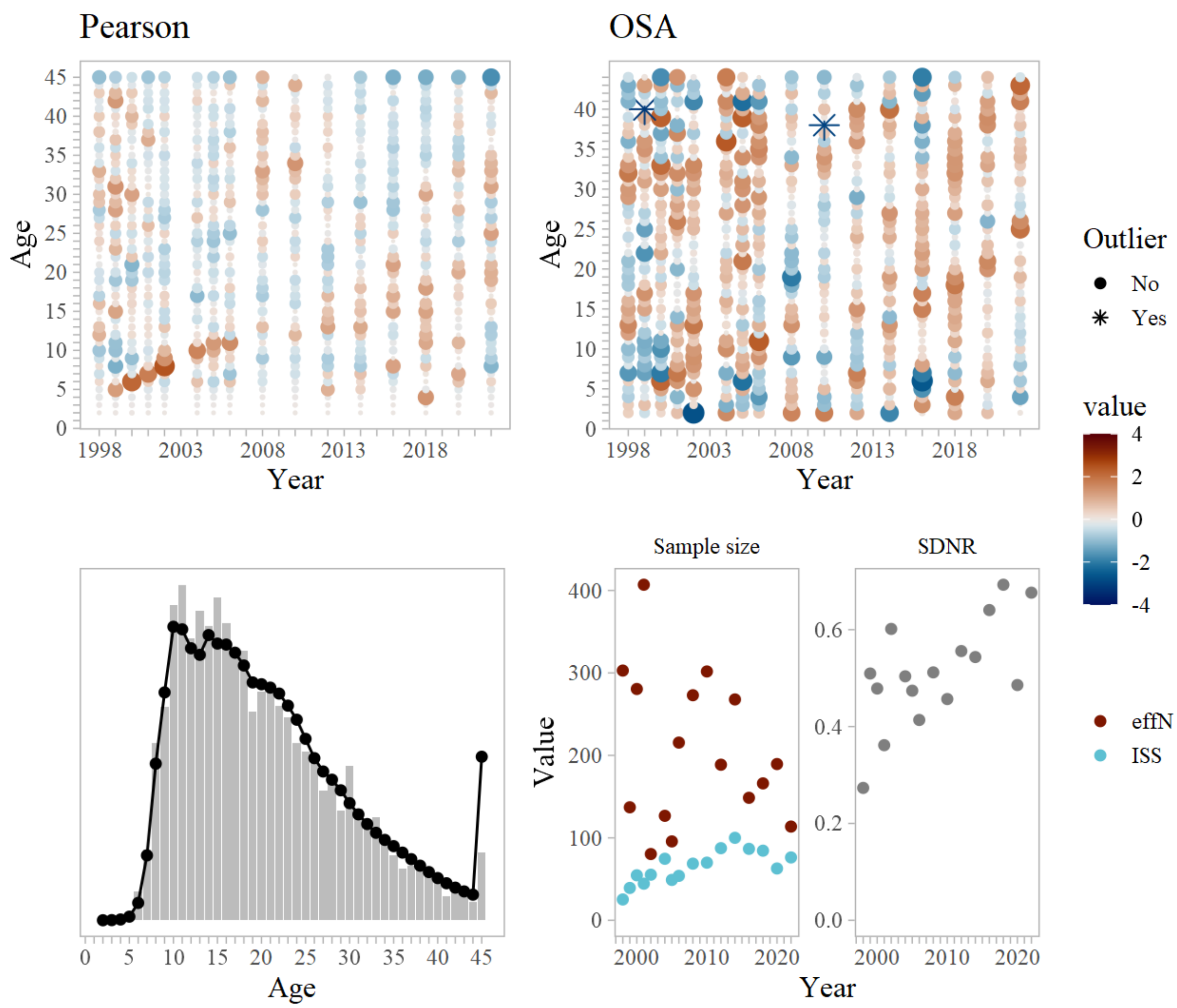


Figure 10-16. Fishery age composition Pearson and one-step ahead residual plots (top of panel). Aggregate composition plot (observed = gray bars, estimated = black line), and sample sizes (lower panel). Outliers are residuals that are >3, effN is effective sample size, ISS is the input sample size, SDNR is the standard deviation of normalized residuals.

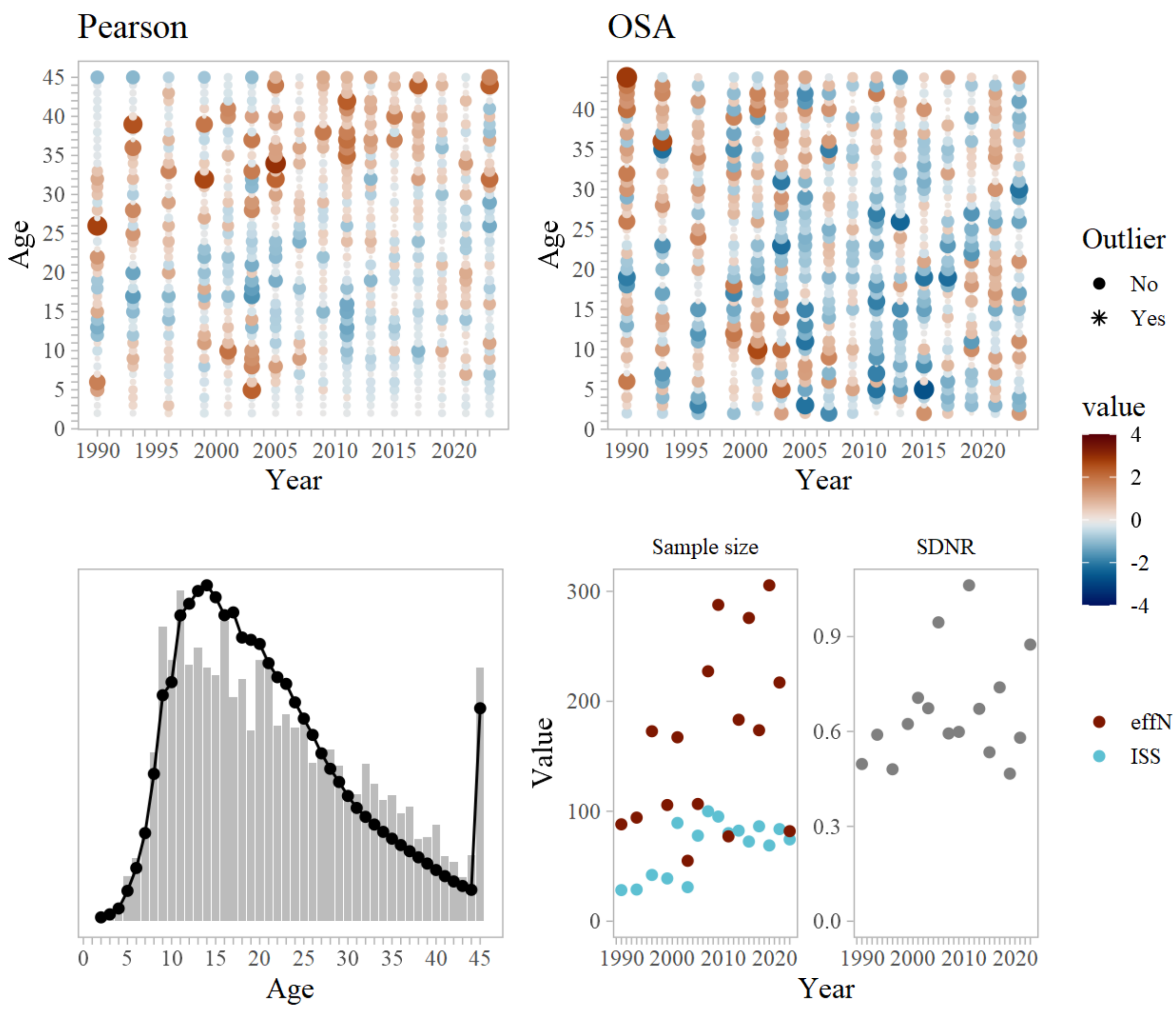


Figure 10-17. Survey age composition Pearson and one-step ahead residual plots (top of panel). Aggregate composition plot (observed = gray bars, estimated = black line), and sample sizes (lower panel). Outliers are residuals that are >3, effN is effective sample size, ISS is the input sample size, SDNR is the standard deviation of normalized residuals.

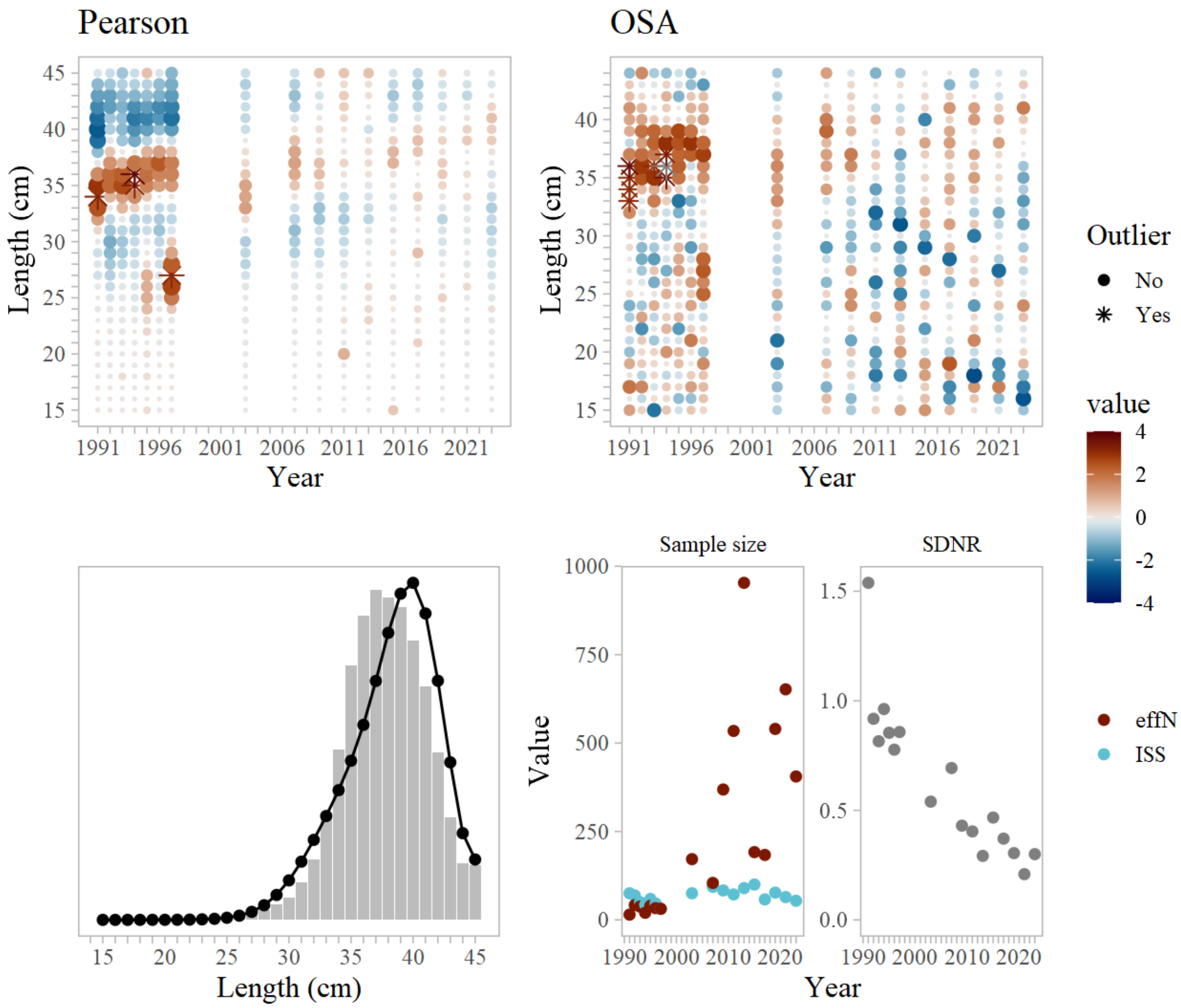


Figure 10-18. Fishery length composition Pearson and one-step ahead residual plots (top of panel). Aggregate composition plot (observed = gray bars, estimated = black line), and sample sizes (lower panel). Outliers are residuals that are >3, effN is effective sample size, ISS is the input sample size, SDNR is the standard deviation of normalized residuals.

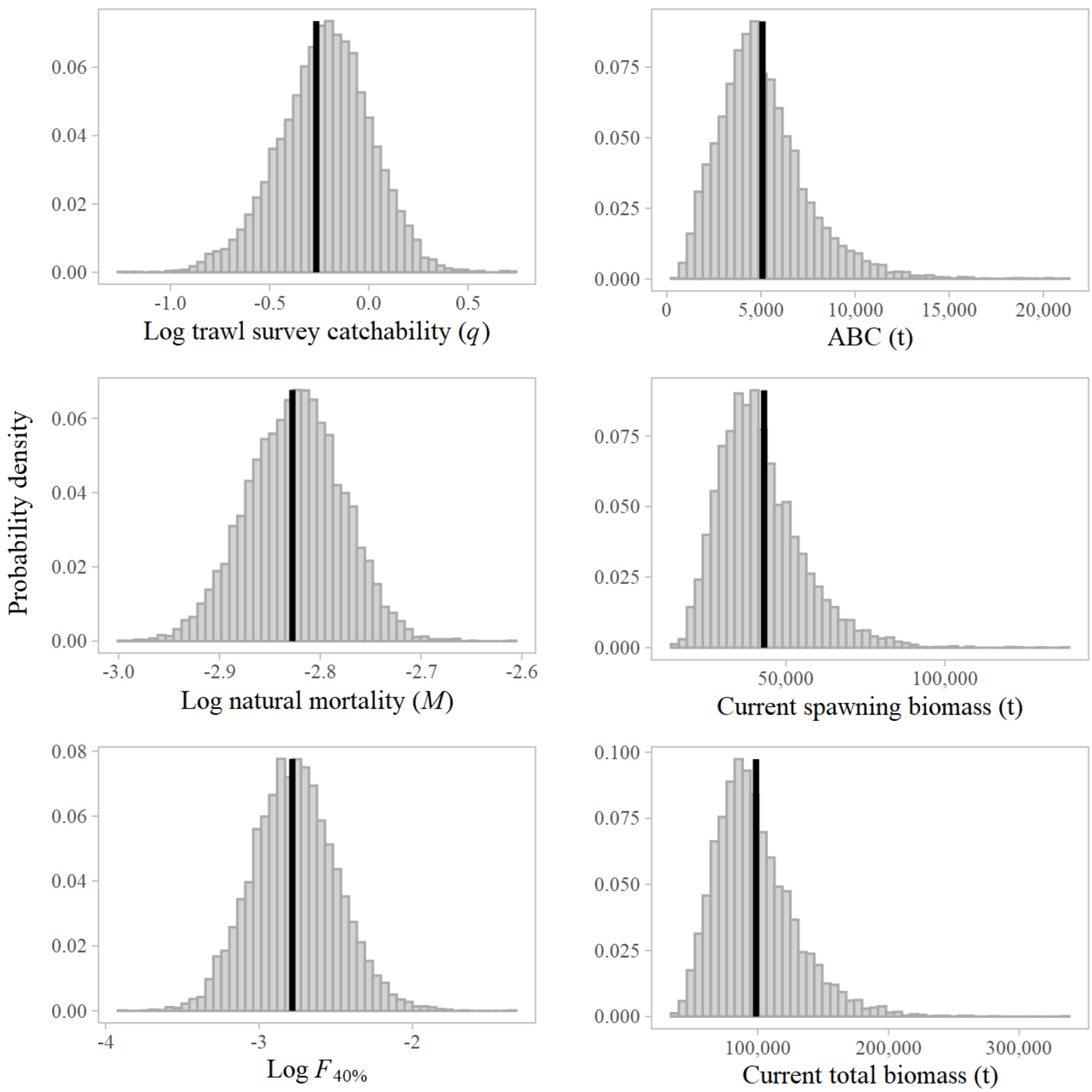


Figure 10-19. Histograms of estimated posterior distributions for key parameters derived (or estimated, in the case of *q*) from the MCMC for GOA northern rockfish. Vertical black lines represent the maximum likelihood estimate for comparison with the MCMC results.

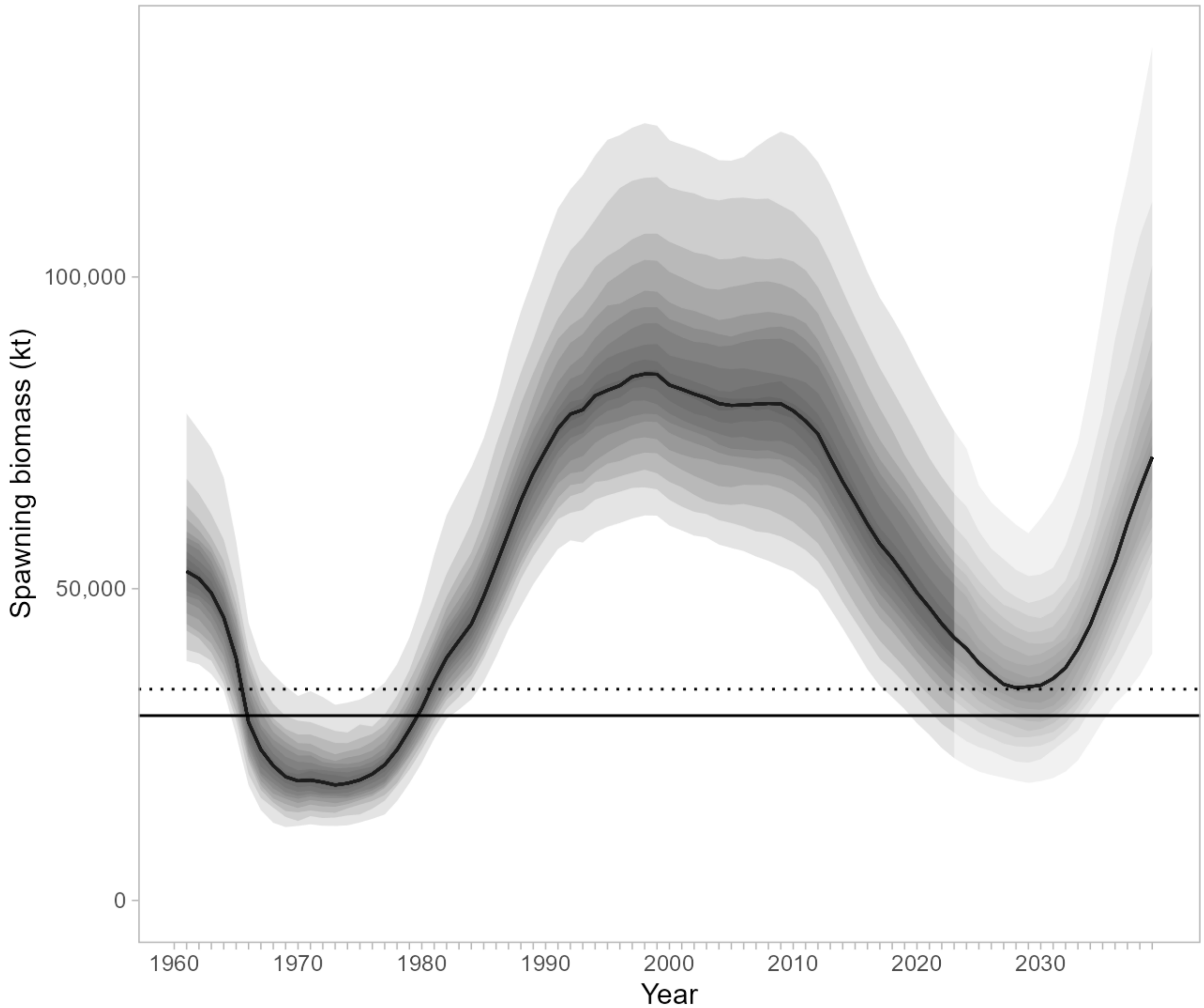


Figure 10-20. Median northern rockfish spawning stock biomass from MCMC simulations with Bayesian credible intervals including projections for 2025-2039, when managing under Scenario 2. Assumes the same average yield ratio forward in time. Dotted horizontal line is $B_{40\%}$ and solid horizontal line is $B_{35\%}$ based on recruitments from 1977-2022. Each shade is 5% of the posterior distribution.

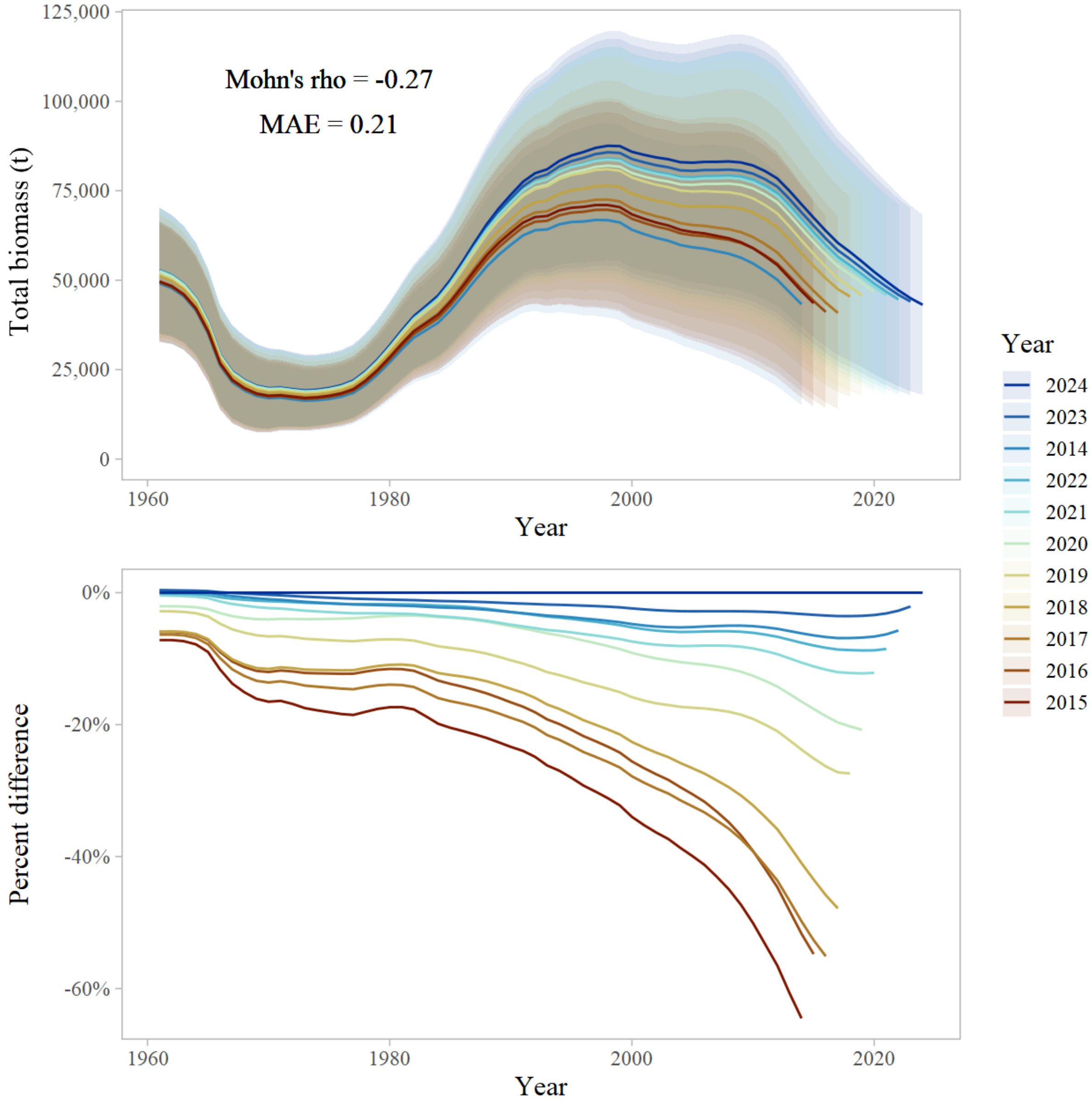


Figure 10-21. Retrospective peels of estimated female spawning biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC (upper panel) and the percent difference from the terminal year estimates (lower panel).

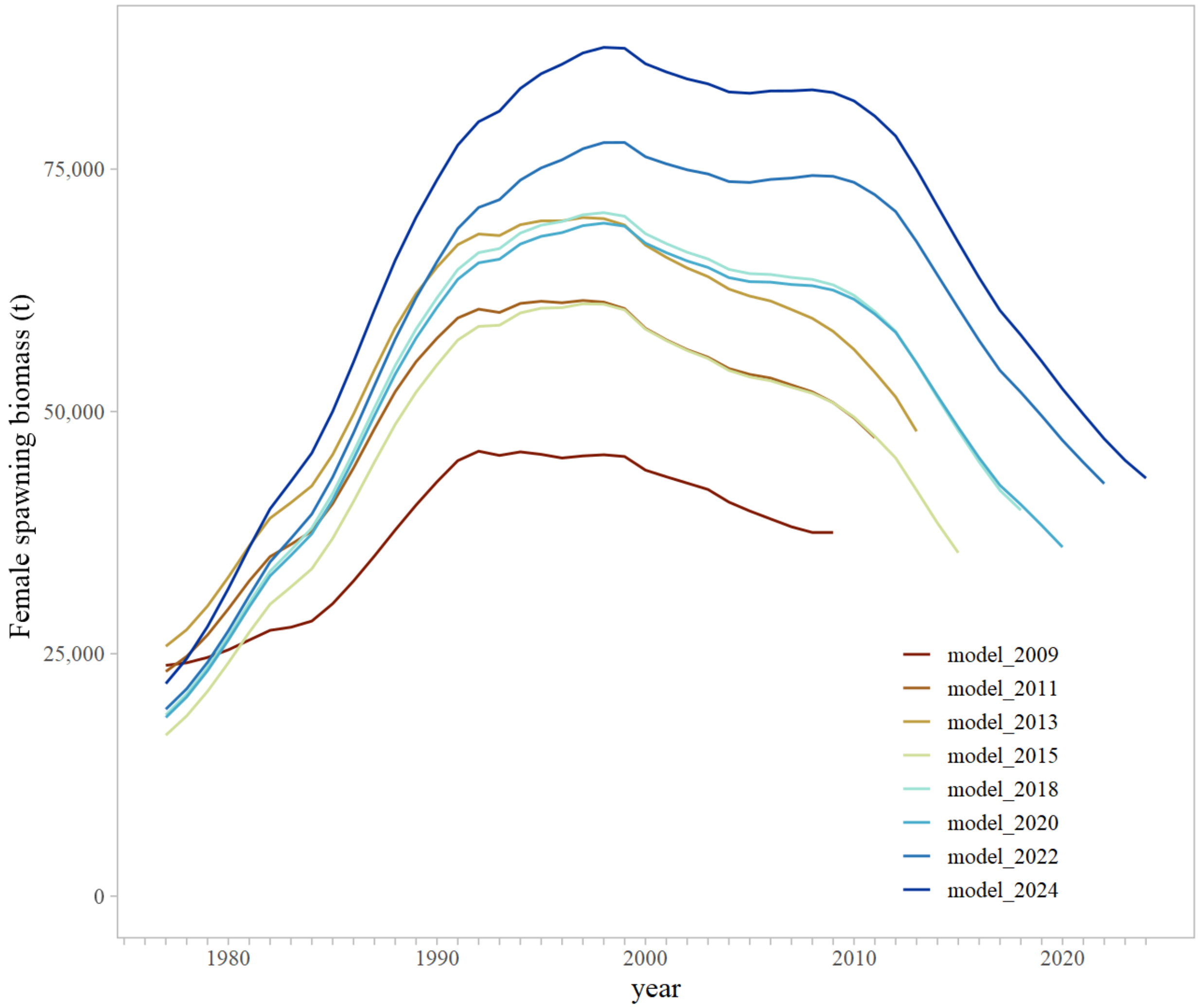


Figure 10-22. Gulf of Alaska northern rockfish spawning biomass estimates from the 2009-2024 Stock Assessment and Fishery Evaluation reports.

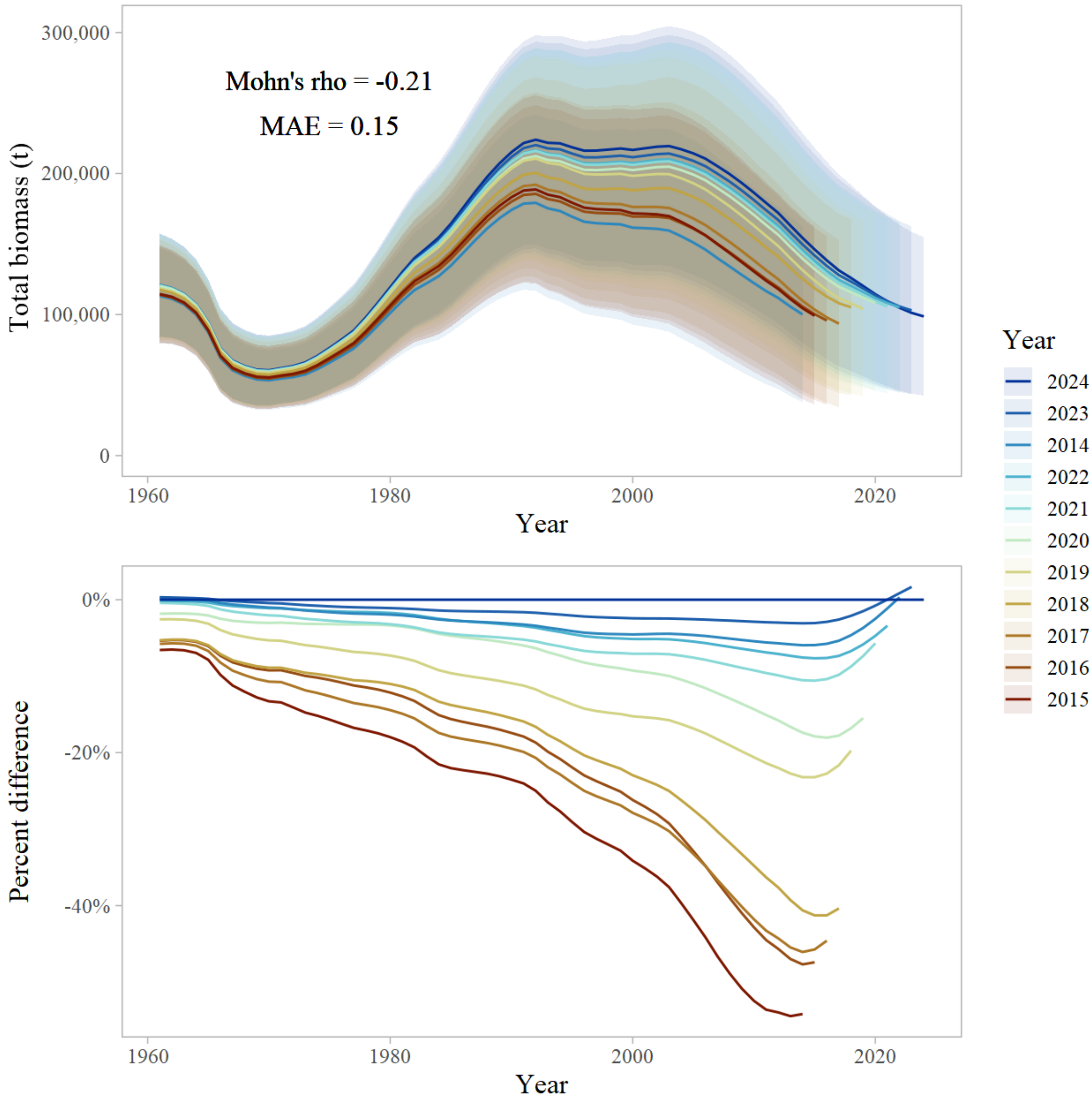


Figure 10-23. Retrospective peels of estimated total biomass for the past 10 years from the recommended model with 95% credible intervals derived from MCMC (upper panel) and the percent difference from the terminal year estimates (lower panel).

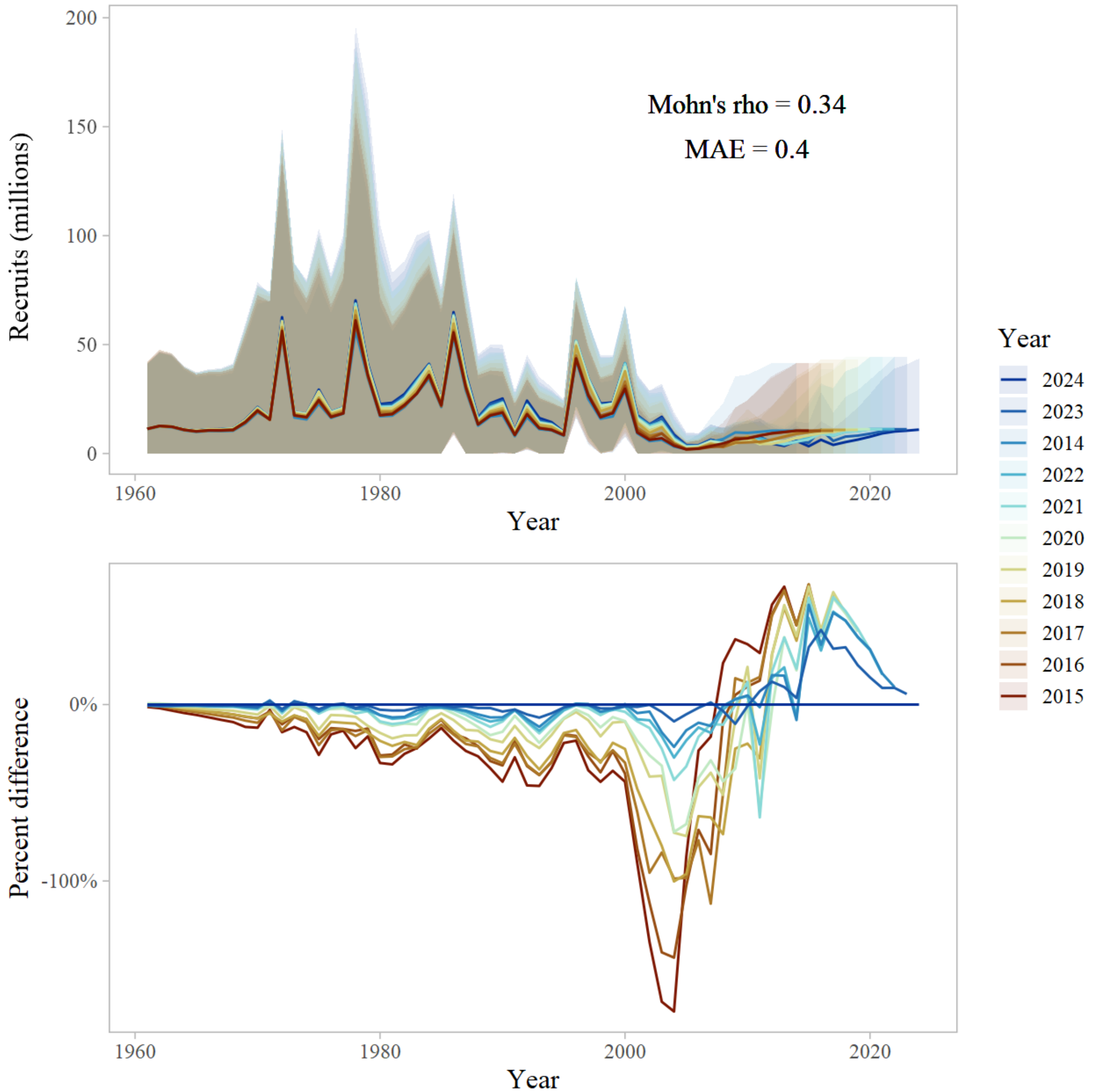


Figure 10-24. Retrospective peels of estimated recruitment for the past 10 years from the recommended model with 95% credible intervals derived from MCMC (upper panel) and the percent difference from the terminal year estimates (lower panel).

Appendix 10a. Supplemental catch data

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

Year	Other	Trawl	Recreational	Total
2010	<1	<1		<1
2011	<1	11		11
2012	<1	<1		<1
2013	<1	19	<1	18
2014	<1	<1		<1
2015	<1	8		8
2016	<1			<1
2017	<1	7		7
2018		<1		<1
2019	<1	5		5
2020	<1	<1		<1
2021		6		6
2022		<1		<1
2023		2		2

References

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

Appendix 10b: 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 2023

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

```
R (>=4.3.3), INLA (24.02.09), TMB (1.9.15), TMBhelper (1.4.0), VAST (3.11.0),
FishStatsUtils (2.13.0)
```

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.

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

Appendix 10c: Model comparisons

Variants of many of these comparisons were presented and accepted during the groundfish Plan Team September 2024 meeting. The models have been updated to present results using 2024 data, where applicable.

Transition the model from ADMB to RTMB

Introduction

The `ADMB` program is in the process of an 'orderly shutdown of development' (see: ADMB) and `TMB` (Template Model Builder) is a viable alternative for fishery stock assessment development. `TMB` is widely seen as the successor to `ADMB`, though there are some noted differences (e.g., `TMB` has no native phasing, so all parameters are estimated simultaneously). `RTMB` allows for accessing most of the utility found in `TMB` but the models can be written entirely in `R` rather than `C++` (Kristensen 2024).

To compare model outputs the last full model accepted by the SSC for northern rockfish with the model 22.1 (ADMB) was converted to RTMB code (RTMB). `Model 22.1` has historically had a tight prior on *M* (mean 0.06, CV 0.05), and fixed σ^r at 1.5.

The RTMB model was run using the same data (through 2022), and parameter inputs and bounds (if any) as the ADMB model.

Results

Outputs are equivalent (total biomass, spawning biomass, etc.) and the likelihoods are generally the same or within a few decimal points, when comparing the ADMB and RTMB models. That is, the RTMB model is effectively recreating the ADMB model, differences can generally be attributed to differences in how the two programs round values. There is no discernible differences between model selectivities, biomass estimates and composition data, the percent differences between models are < 0.0005% (Figures 10c-25 & 10c-26).

Table 10-23. Likelihood values for comparing the GOA northern rockfish coded in ADMB and RTMB.

Likelihood	RTMB	ADMB	difference
Catch	0.0907	0.0907	0.0000
Survey	6.0219	6.0219	0.0000
Fish age	40.1766	40.1766	0.0000
Survey age	69.1597	69.1598	0.0001
Fish size	67.9073	67.9072	-0.0001
Recruitment	8.6402	8.6402	0.0000
F regularity	5.4574	5.4574	0.0000
SPR penalty	0.0000	0.0000	0.0000
M prior	0.0140	0.0140	0.0000
q prior	0.0520	0.0520	0.0000
Sub total	197.5198	197.5198	0.0000
L maturity		23.5012	
C maturity		46.7265	
Sum maturity		70.2277	

Table 10-24. Key parameters and output values for comparing the GOA northern rockfish coded in ADMB and RTMB.

Item	RTMB	ADMB	difference
M	0.0595	0.0595	0.0000
q	0.8649	0.8649	0.0000
Log mean recruitment	3.5039	3.5039	0.0000
Log mean F	-3.5839	-3.5839	0.0000
A50 fishery	8.2372	8.2372	0.0000
Delta fishery	1.9187	1.9187	0.0000
A50 survey	9.0936	9.0936	0.0000
Delta survey	4.3192	4.3192	0.0000
2023 Total biomass	95,559.2189	95,559.2000	-0.0189
2023 Spawning biomass	39,462.5860	39,462.6000	0.0140
2023 OFL	5,935.1641	5,935.1600	-0.0041
2023 FOFL	0.0736	0.0736	0.0000
2023 ABC	4,971.6482	4,971.6500	0.0018
2023 FABC	0.0613	0.0613	0.0000

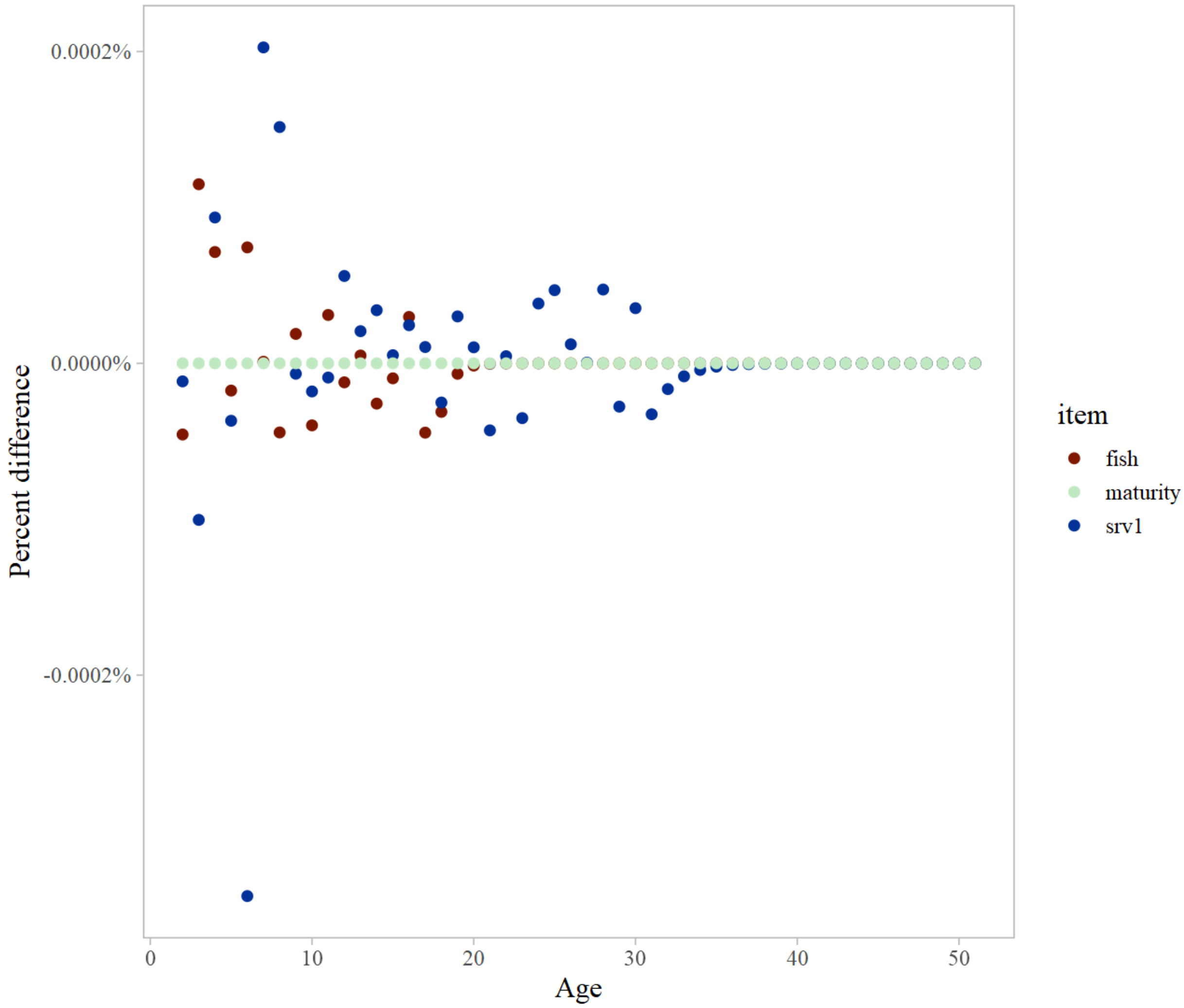


Figure 10-25. Percent difference for selectivity (fishery and survey) and maturity between the ADMB and RTMB models using equivalent data and parameter inputs.

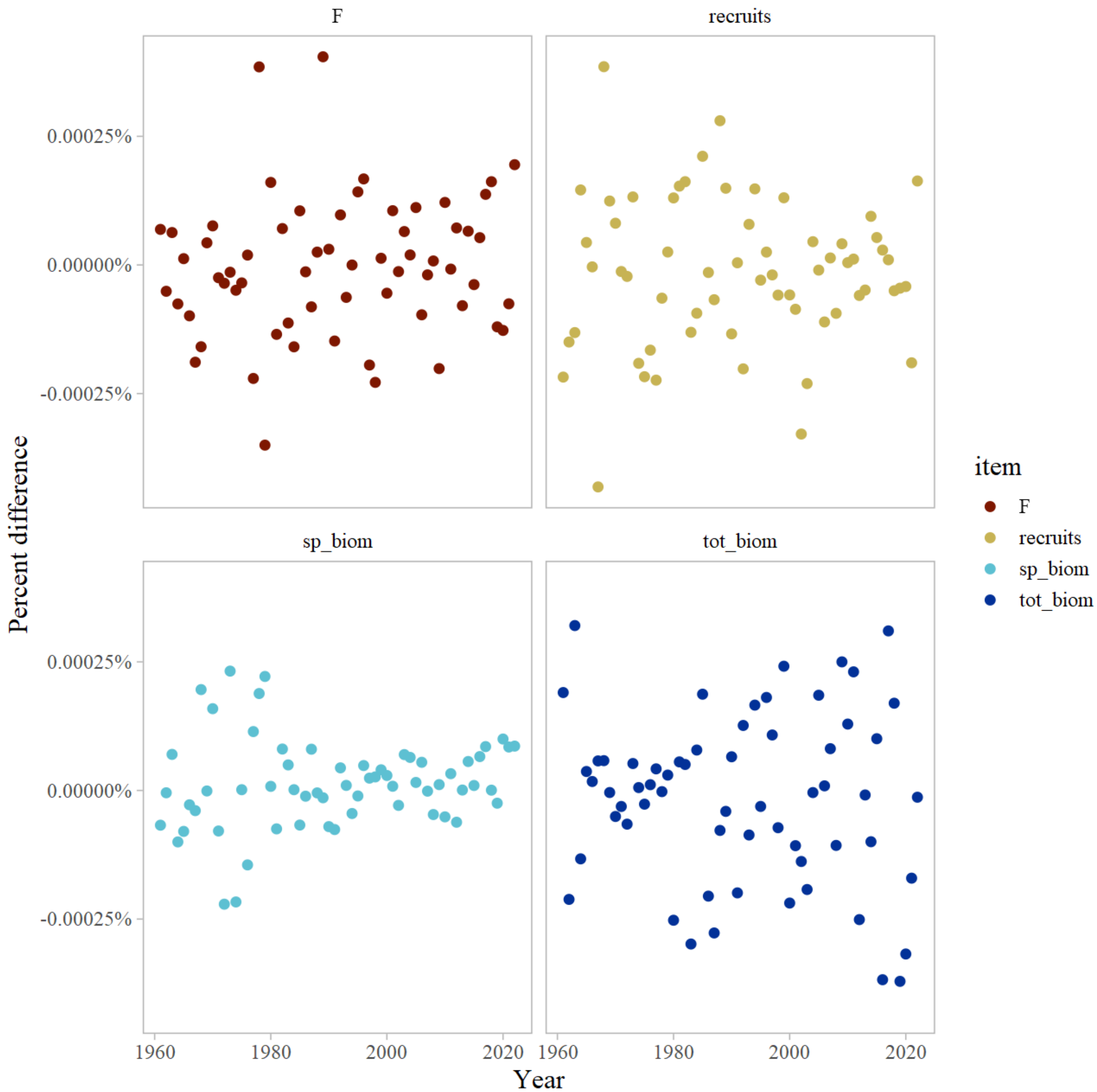


Figure 10-26. Percent difference for fishing mortality (F), recruitment, spawning biomass and total biomass between the ADMB and RTMB models using equivalent data and parameter inputs.

Change survey biomass negative log likelihood

Introduction

The base model (m22.1) estimates the survey biomass negative log likelihood with a normal error structure

$$\mathcal{L} = \lambda \sum_{y} \frac{\left(I_y - \hat{I}_y\right)^2}{2SE\left(I_y\right)^2}.$$

We propose adopting the more standard lognormal error structure negative log likelihood error structure to the objective function:

$$\mathcal{L} = \lambda \sum_{y} \left[log(\sigma_y) + 0.5\left(log(I_y/\hat{I}_y)/\sigma_y\right)^2 \right]$$

where

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

and I_y are annual survey biomass observations, $\hat{I}_y$ are estimated annual survey biomass, y is year, σ_y is annual survey biomass log standard error estimated using method of moments, and λ is the likelihood weight and $SE(I_y)$ is the annual survey biomass standard error. The lognormal error structure is more appropriate for these data and is more commonly used for assessment models. A comparison will be shown between model 22.1 (normal error structure) and updated model results (model 22.1a).

Results

Changing to a lognormal error structure for the survey biomass likelihood results in an increase in estimated total and female spawning biomass, with an associated increase in B_{40} and $maxABC$, and a decrease in the survey biomass likelihood.
Model likelihoods and key parameter estimates are shown in (Tables 10c-25 and 10c-26).

Change survey age composition input sample sizes

Introduction

Survey age composition input sample sizes (ISS, see Hulson and Williams 2024a) are now available via the (afscISS R package on github, Hulson and Williams 2024b). These sample sizes are corrected for growth variability and aging error and should more accurately reflect the annual sample sizes than the currently used 'hybrid method'. The hybrid method is the $\sqrt{no.hauls * no.samples}$ scaled to a max of 100. The data input changes are shown using the updated M22.1a described above.

Results

Updating the survey input sample size (ISS) results in a slight increase in estimated total and female spawning biomass, and associated management parameters. Model likelihoods and key parameter estimates are shown in (Tables 10c-25 and 10c-26).

Trawl survey biomass examinations

Introduction

The AFSC Groundfish Assessment Program (GAP) implements a default VAST model to estimate bottom trawl survey biomass. The default model uses Poisson-delta model with a Gamma error structure for 'when present' observations, with 750 knots (see Appendix 10b). However the VAST model currently used for GOA dusky rockfish, and recommended for use in the northern rockfish assessment (Williams *et al.* 2023), uses a lognormal error structure for 'when present' observations. Survey biomass inputs vary between VAST models (Figure 10c-27) however, the assessment models produces similar outputs for all survey inputs (Figure 10c-28). This is likely due, in part, to the down-weighting of the survey likelihood by 0.25.

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 northern 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.

Further examination of the current GAP recommended default model and lognormal error model is warranted so model residuals were examined. The default VAST (Gamma) model residuals show similar deviation from observed values (Figure 10c-29) than the VAST (lognormal) model (Figure 10c-30). Therefore our recommendation is to use VAST with a lognormal error structure as it maintains the use of the delta model (reduced bias), has same # of knots as default GAP settings, has similar residual diagnostics and is precautionary relative to default GAP settings.

Table 10-25. Model likelihood values for incremental GOA northern rockfish model changes. M22.1 is the SSC accepted 2022 model using 2024 data, M22.1a updates to a lognormal error structure survey likelihood, M22.1b uses adjusted ISS values, M22.1c changes from Gamma to lognormal VAST survey abundance, and M24 updates maturity. Note: M22.1 and the remaining models are not directlly comparable due to the change in the survey negative log likelihood.

Likelihood	M22.1	M22.1a	M22.1b	M22.1c	M24
Catch	0.073	0.077	0.094	0.099	0.099
Survey	8.112	3.207	3.321	-0.644	-0.644
Fish age	45.196	45.220	46.563	46.370	46.370
Survey age	72.936	73.050	84.160	84.339	84.339
Fish size	61.345	61.224	63.048	63.140	63.140
Recruitment	9.662	9.701	9.975	9.913	9.913
F regularity	5.593	5.621	5.783	5.779	5.779
SPR penalty	0.000	0.000	0.000	0.000	0.000
M prior	0.025	0.014	0.015	0.041	0.041
q prior	0.104	0.008	0.010	0.173	0.173
Objective function	203.045	198.122	212.969	209.209	209.209

Table 10-26. Estimates of key parameters and outputs for incremental GOA northern rockfish model changes. M22.1 is the SSC accepted 2022 model using 2024 data, M22.1a updates to a lognormal error structure survey likelihood, M22.1b uses adjusted ISS values, M22.1c changes from Gamma to lognormal VAST survey abundance, and M24 updates maturity. Note: M22.1 and the remaining models are not directlly comparable due to the change in the survey negative log likelihood.

Parameter/Estimate	M22.1	M22.1a	M22.1b	M22.1c	M24
M	0.059	0.060	0.059	0.059	0.059
q	0.815	0.943	0.937	0.767	0.767
Log mean recruitment	3.503	3.534	3.528	3.518	3.518
Log mean F	-3.649	-3.691	-3.703	-3.699	-3.699
A50 fishery	8.128	8.125	8.085	8.091	8.091
Delta fishery	1.875	1.873	1.846	1.851	1.851
A50 survey	8.830	8.822	8.855	8.875	8.875
Delta survey	4.058	4.045	4.110	4.132	4.132
2023 Total biomass	90,674	96,979	96,614	96,992	96,992
2023 Spawning biomass	37,429	40,193	39,979	40,189	40,485
2023 OFL	5,592	6,012	5,967	5,976	6,112
2023 FOFL	0.074	0.074	0.073	0.073	0.075
2023 ABC	4,686	5,037	5,001	5,008	5,115
2023 FABC	0.061	0.061	0.061	0.061	0.062

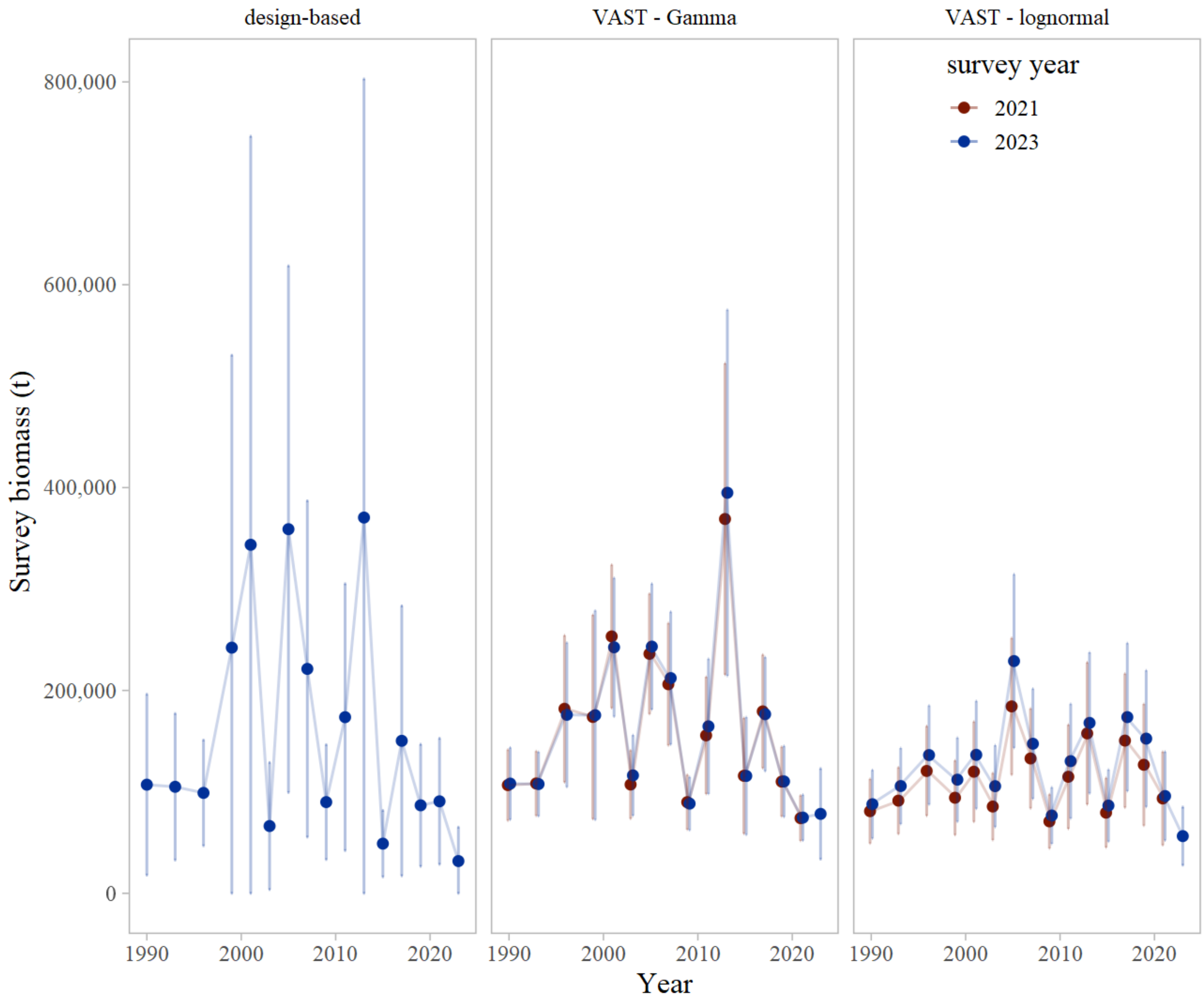


Figure 10-27. Survey input model estimates with 95% confidence intervals. The VAST-based inputs are shown for 2021 and 2023 as the estimates change with the addition of new data.

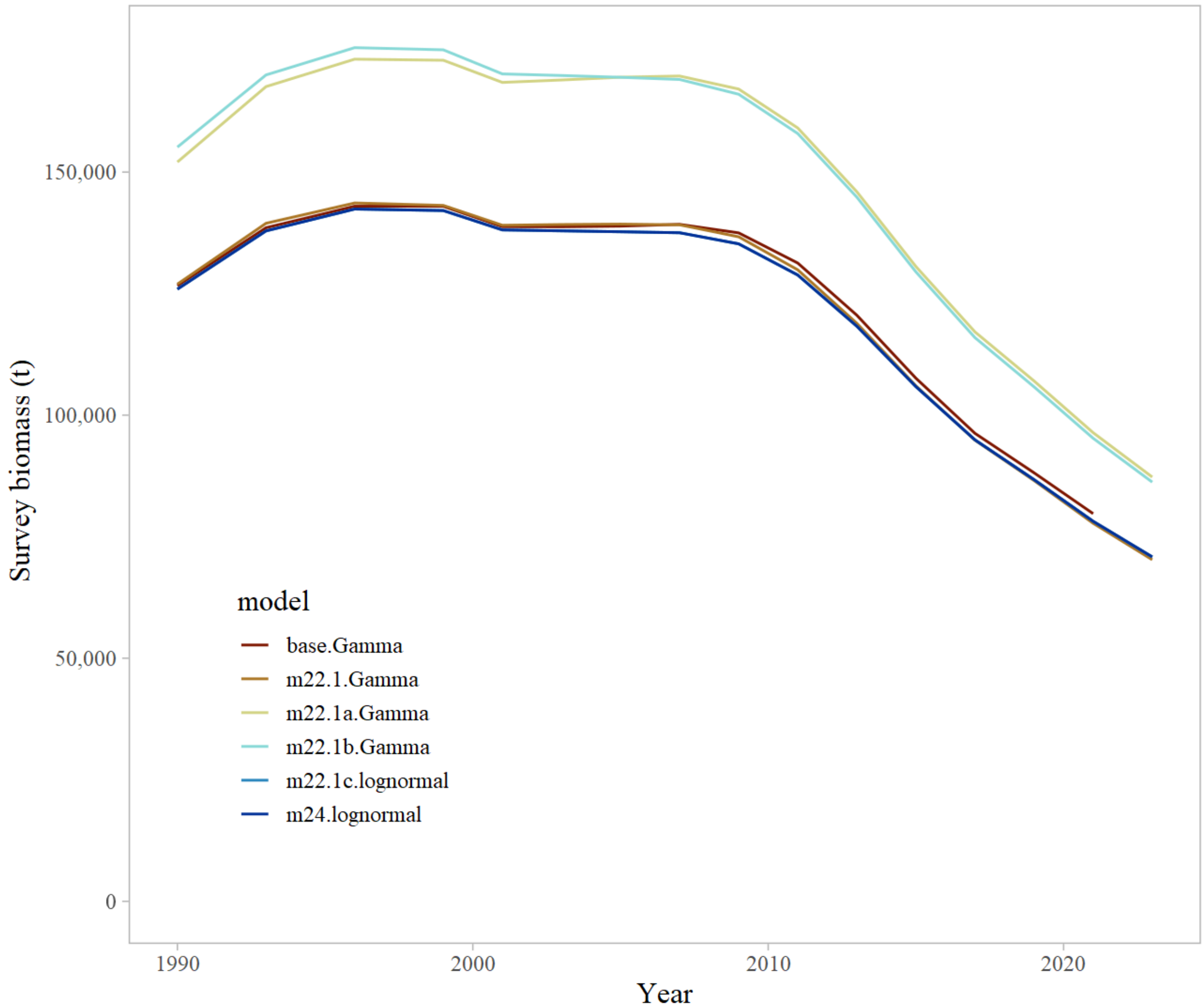


Figure 10-28. Survey biomass estimates from all explored models.

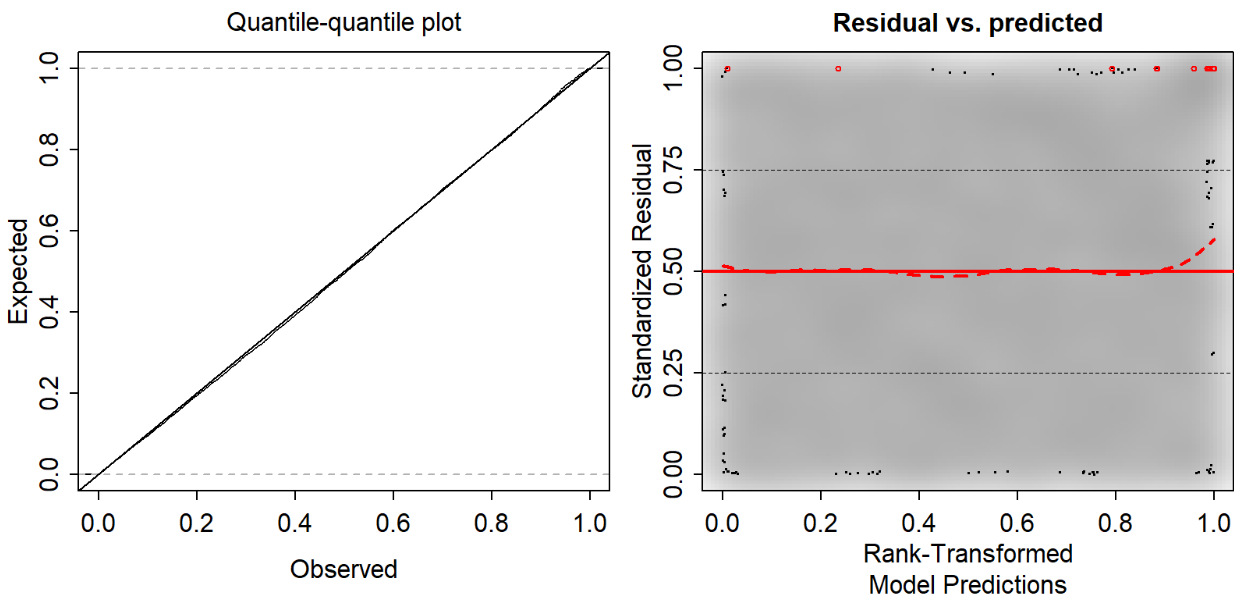


Figure 10-29. Default VAST (Gamma) model quantile residuals.

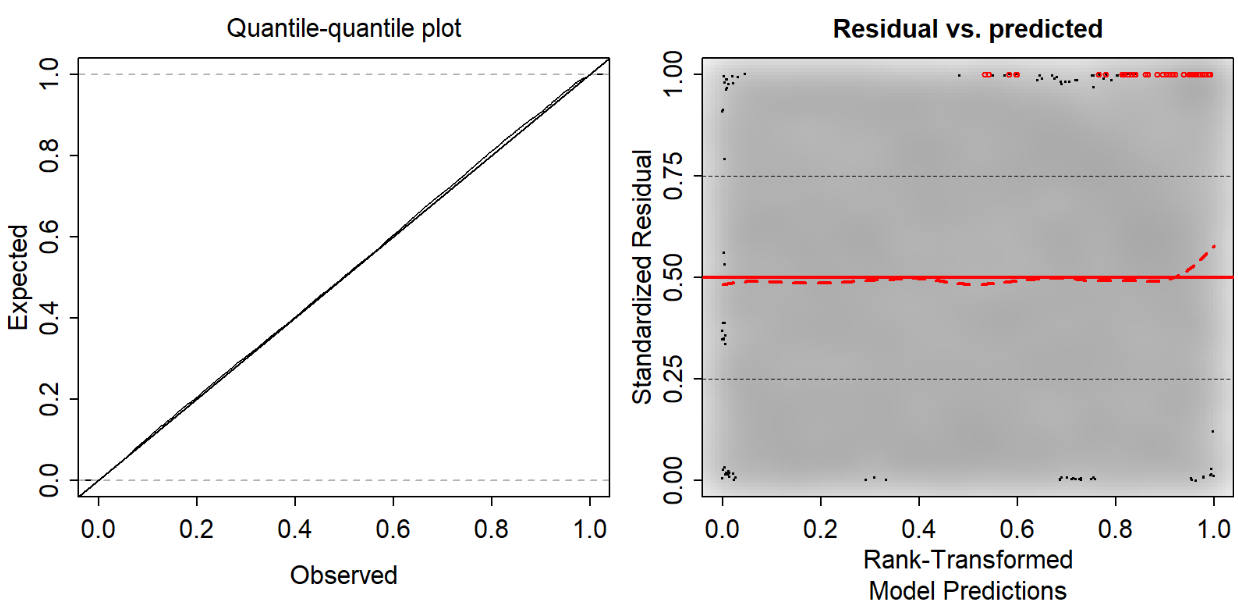


Figure 10-30. Vast (lognormal) quantile residuals.

Maturity

The inclusion of biological maturity data from Conrath (2019) is described in the *Data* section of this report.

Results

Updating the maturity results in a slight increase in estimated female spawning biomass, all other likelihoods and parameters are the same as for m22.1c. Model likelihoods and key parameter estimates are shown in (Tables 10c-25 and 10c-26).

Change to VAST-based apportionment

Introduction

Apportionment for GOA northern rockfish has been based upon area estimates from the design-based survey abundance. The assessment uses a model-based (VAST, Thorson *et al.* 2015) index of abundance, which does not always align with the design-based area estimates. For consistency, we propose to change apportionment to be based upon the model-based index of abundance.

The 'standard' apportionment scenario has been to use the REMA (Sullivan and Balstad 2022) random effects model to smooth the area apportionments. One issue with the model-based index and REMA analysis is that northern rockfish catch in the eastern GOA has been consistently low or zero (Figures 31 and 32). Due to this sparseness both the `VAST` and `REMA` models have had convergence issues for the eastern GOA. In order to address this, the eastern GOA is dropped from the estimated index of abundance. There is 1 t allocated for eastern GOA northern rockfish in the 'Other rockfish' complex for management purposes.

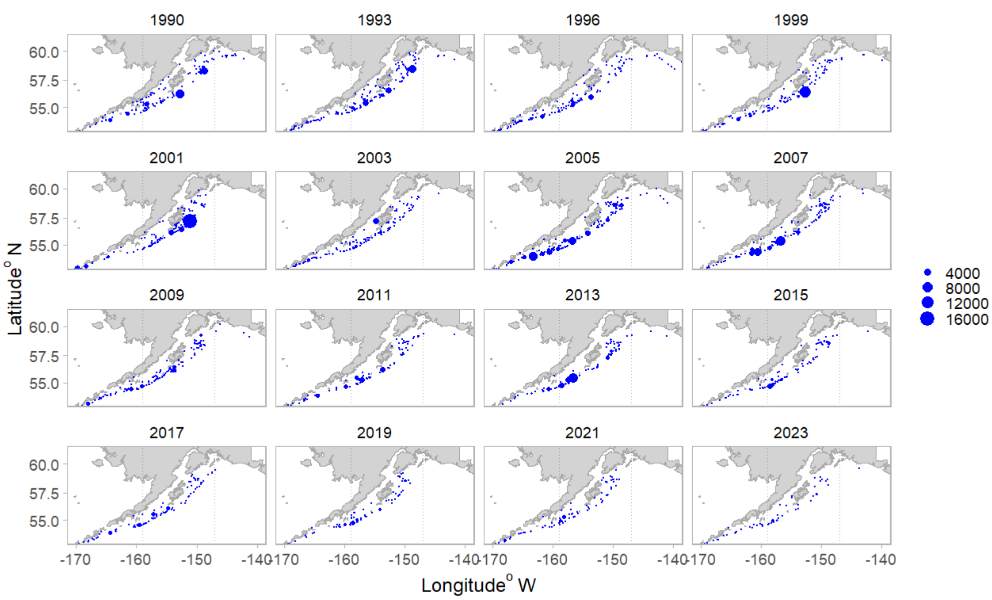


Figure 10-31. Survey catch (numbers) by year.

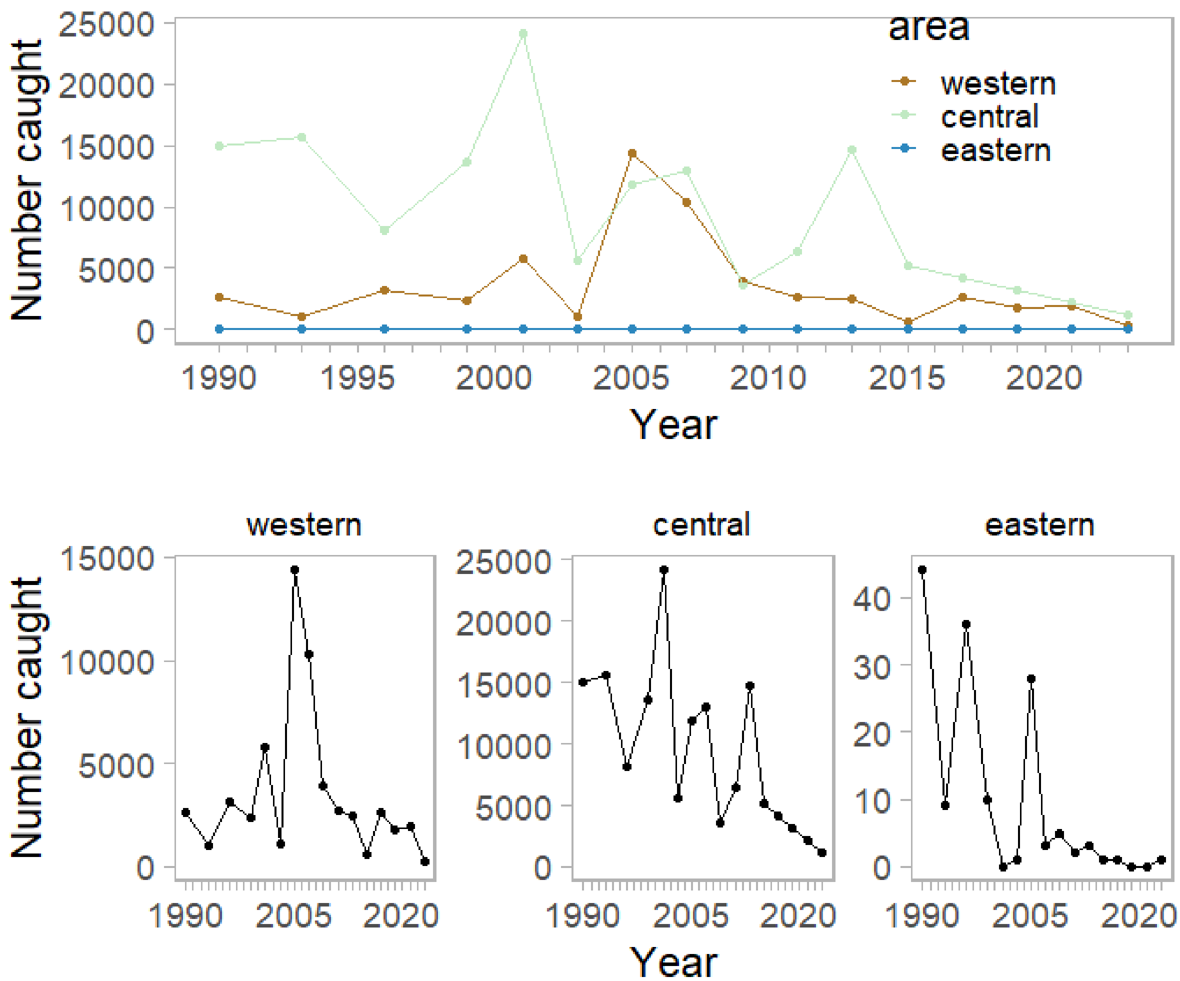
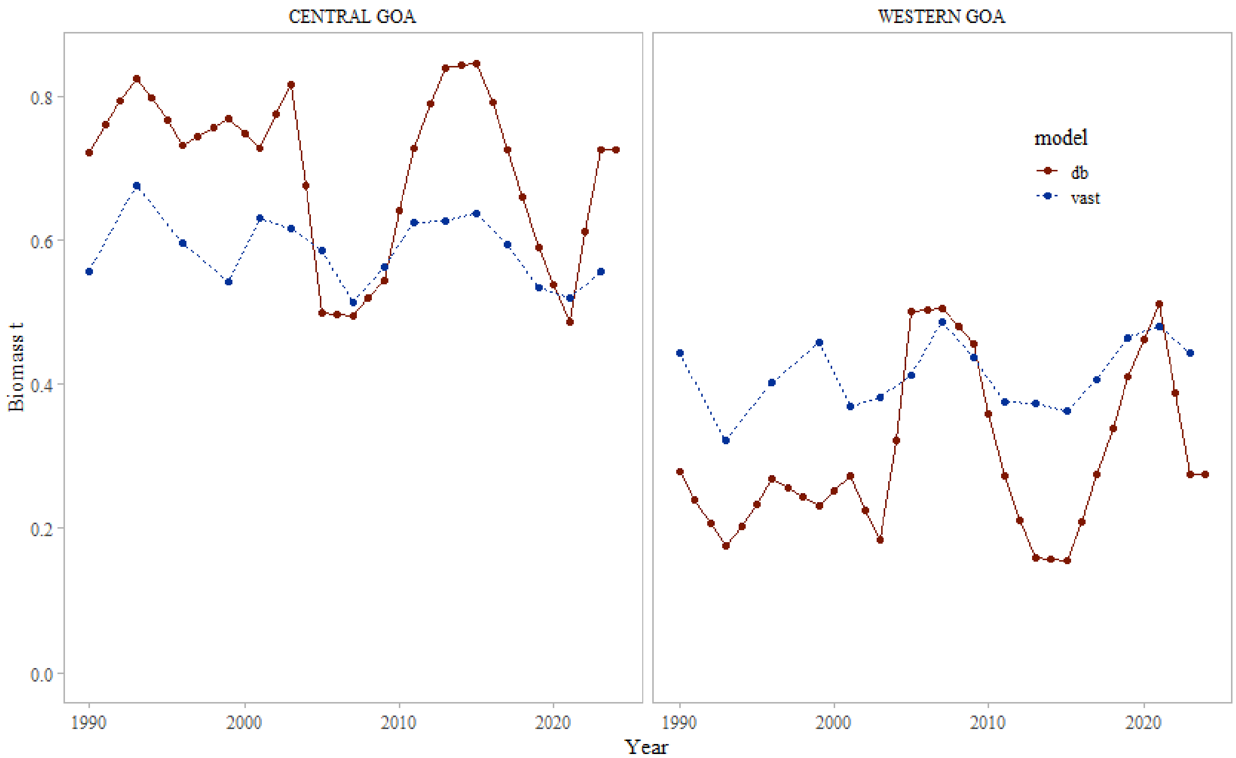


Figure 10-32. Survey catch (numbers) by year and area. Note the different y-axis scales

An examination of design-based (via REMA), and VAST (without REMA smoothing) will be compared. Apportionment examinations will be presented using survey data through 2023.

Results

The REMA smoothed design-based and VAST area biomass are on the same scale, however, when examined as a proportion, VAST exhibits less variability between regions (Figure 10c-33). The design-based model w/REMA would place 72.5% of the biomass in the central GOA in 2023, the VAST model w/o REMA would apportion 55.7%. Overall the VAST-based apportionment is more stable over time than the rema-based model. The SSC had requested an examination of a temporal AR1 function in the VAST-based apportionment methodology, however, repeated attempts were met with non-convergence issues.



Apportionment percent estimates for design-based w/REMA and VAST estimated survey abundance w/o using REMA. The eastern GOA is set at 1t and allocated to the “Other rockfish” complex for all scenarios, and is not shown here.

Year	Area	Design-based w/REMA	VAST
2021	Western	51.3	48.0
	Central	48.7	52.0
2022	Western	38.7	48.0
	Central	61.3	52.0
2023	Western	27.5	44.3
	Central	72.5	55.7
2024	Western	27.5	44.3
	Central	72.5	55.7

Using these apportionment values the area apportionment based on projected 2025 and 2026 ABCs would be:

Year	Area	Design-based w/REMA	VAST
2025	Western	1396	2249
	Central	3680	2827
2026	Western	1346	2168
	Central	3549	2727

Alternate models

Below are some examinations of changing the survey biomass negative log likelihood weighting from 0.25 to 1.0. These models are provided for comparison, but are not put forward as possible changes this assessment cycle as they were not presented at the September 2024 Plan Team meeting. Changing the likelihood weight, increases survey, spawning, and total biomass estimates for all models examined.

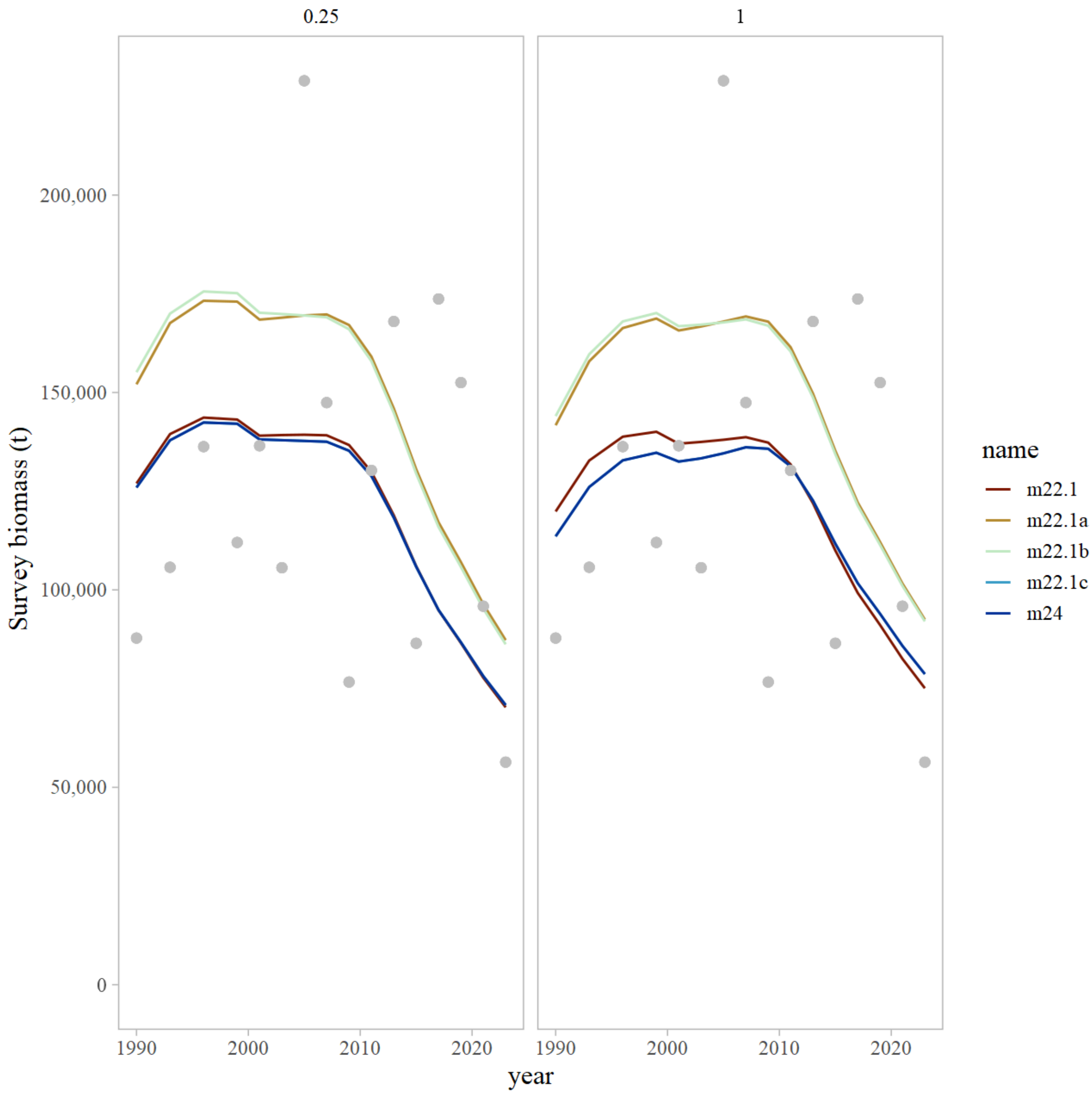


Figure 10-34. Comparison of survey biomass estimates when changing the survey NLL weighting from 0.25 to 1.0. Gray points are VAST-estimated survey biomass.

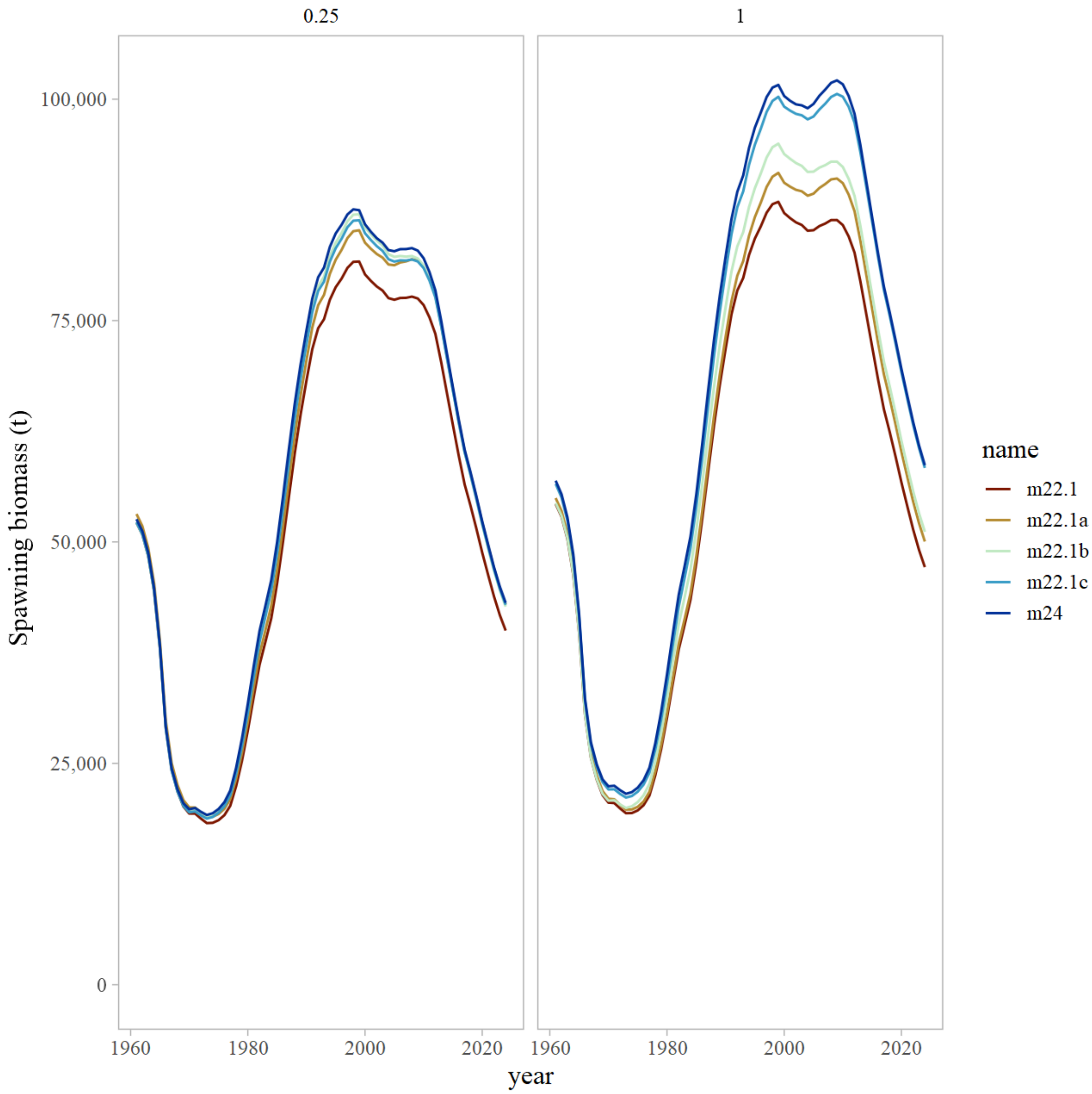


Figure 10-35. Comparison of spawning biomass estimates when changing the survey NLL weighting from 0.25 to 1.0.

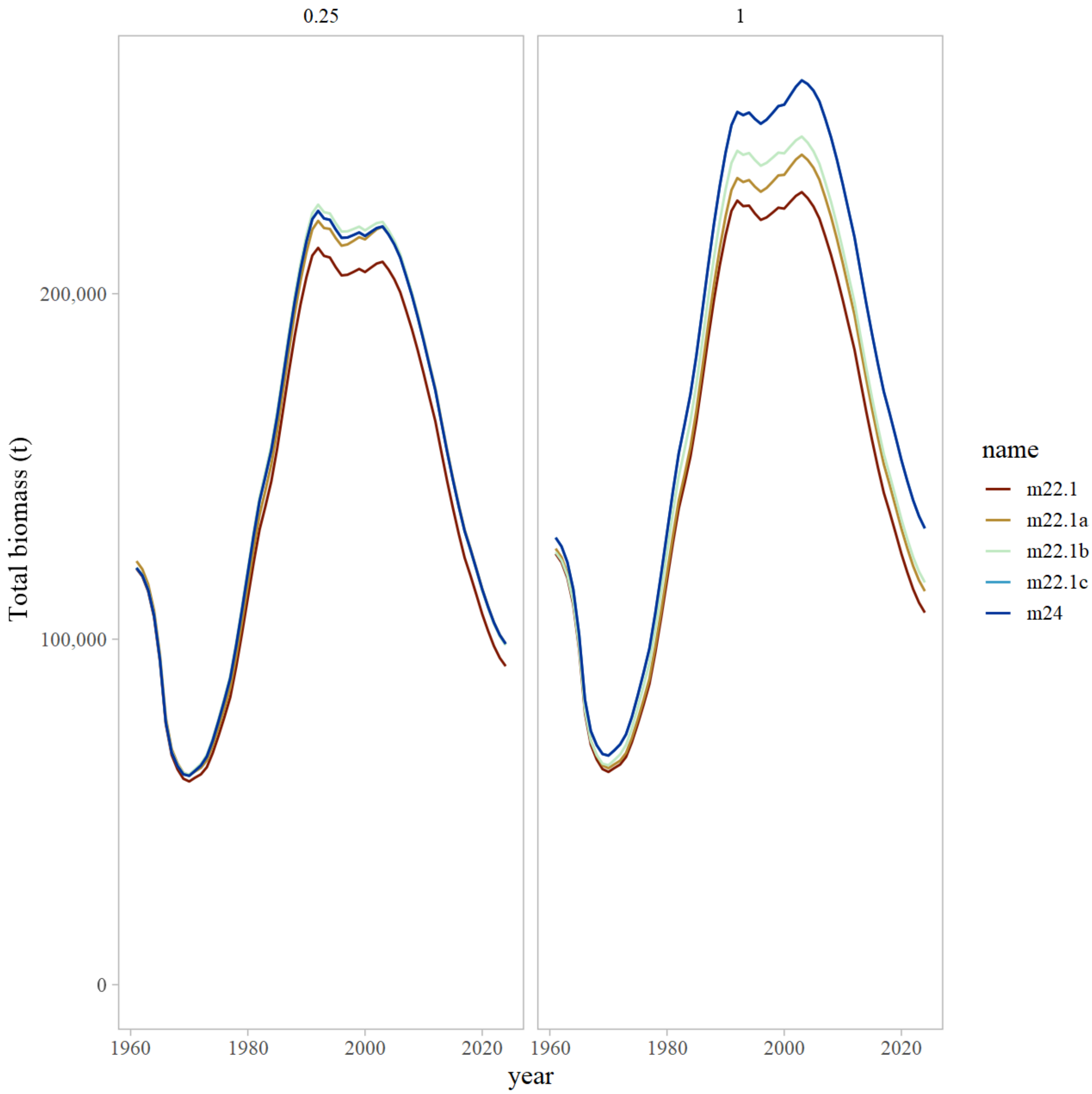


Figure 10-36. Comparison of total biomass estimates when changing the survey NLL weighting from 0.25 to 1.0.

Table 10-27. Model likelihood values for incremental GOA northern rockfish model changes with the weighting on the survey biomass likelihood increased from 0.25 to 1.0. M22.1 is the SSC accepted 2022 model using 2024 data, M22.1a updates to a lognormal error structure survey likelihood, M22.1b uses adjusted ISS values, M22.1c changes from Gamma to lognormal VAST survey abundance, and M24 updates maturity. Note: M22.1 and the remaining models are not directlly comparable due to the change in the survey negative log likelihood.

Likelihood	M22.1	M22.1a	M22.1b	M22.1c	M24
Catch	0.101	0.113	0.137	0.151	0.151
Survey	31.191	11.182	11.447	-5.707	-5.707
Fish age	45.134	45.134	46.334	45.812	45.812
Survey age	73.980	74.883	86.107	86.324	86.324
Fish size	60.867	60.141	62.022	62.569	62.569
Recruitment	9.596	9.785	10.075	10.066	10.066
F regularity	5.647	5.675	5.850	5.910	5.910
SPR penalty	0.000	0.000	0.000	0.000	0.000
M prior	0.049	0.031	0.042	0.151	0.151
q prior	0.216	0.053	0.073	0.519	0.519
Objective function	226.782	206.998	222.087	205.794	205.794

Table 10-28. Estimates of key parameters and outputs for incremental GOA northern rockfish model changes with the weighting on the survey biomass likelihood increased from 0.25 to 1.0. M22.1 is the SSC accepted 2022 model using 2024 data, M22.1a updates to a lognormal error structure survey likelihood, M22.1b uses adjusted ISS values, M22.1c changes from Gamma to lognormal VAST survey abundance, and M24 updates maturity. Note: M22.1 and the remaining models are not directlly comparable due to the change in the survey negative log likelihood.

Parameter/Estimate	M22.1	M22.1a	M22.1b	M22.1c	M24
M	0.059	0.059	0.059	0.058	0.058
q	0.744	0.864	0.842	0.632	0.632
Log mean recruitment	3.551	3.576	3.577	3.604	3.604
Log mean F	-3.728	-3.762	-3.789	-3.854	-3.854
A50 fishery	8.145	8.141	8.101	8.118	8.118
Delta fishery	1.886	1.881	1.854	1.868	1.868
A50 survey	9.084	9.111	9.097	9.116	9.116
Delta survey	4.472	4.488	4.468	4.484	4.484
2023 Total biomass	105,720	111,736	114,220	129,497	129,496
2023 Spawning biomass	44,215	46,905	47,959	54,844	55,130
2023 OFL	6,582	6,989	7,117	8,061	8,183
2023 FOFL	0.073	0.074	0.073	0.073	0.074
2023 ABC	5,514	5,855	5,964	6,753	6,849
2023 FABC	0.061	0.061	0.061	0.060	0.061