Agenda Item G.3
Attachment 2 ***(Electronic Only)***
September 2025

Status of Quillback Rockfish in U.S. Waters off California in 2025

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0 Executive Summary

Stock Description

This benchmark assessment reports the status of quillback rockfish (*Sebastes maliger*) in U.S. waters off the California coast using data through 2024. Quillback rockfish off the coast of California is defined as a stock by the Pacific Fishery Management Council (PFMC). This assessment does not account for quillback rockfish in Oregon waters or other areas off the U.S. West Coast and assumes that these other stocks do not contribute to nor take from the stock being assessed here. There is a potential for regional management of quillback rockfish within California provided additional research on stock structure.

Catches

Quillback rockfish is encountered in both commercial and recreational fisheries throughout its range. In waters off the coast of California, although quillback rockfish is generally not a highly desirable species by recreational fishermen recreational removals are the largest source of fishing mortality and represent approximately 70% of the total removals of quillback rockfish across all years (Table i, Figure i). Recreational removals occur in both private/rental and party/charter modes, which both use hook-and-line gear. Recreational removals slowly increased from the 1960s to 1980, varied around lower amounts through 2015, and increased up to the early 2020s. The value of quillback rockfish in the commercial fishery rose with the development of the live fish fishery in the 1990s. Since 1994, approximately 47% of the commercial landings have been from the live fish fishery. Quillback rockfish are landed in trawl, net and pot gear, but over 99% of commercially landed quillback rockfish are from hook-and-line. The majority of the commercial landings for quillback rockfish occurred between 1990 and 2008, with a small increase from 2016 to 2022.

Table i: Recent removals (mt) by fleet and total removals (mt) summed across fleets.

Year	CA_Commercial (mt)	CA_Recreational (mt)	Total removals (mt)
2015	1.09	7.50	8.59
2016	1.01	8.59	9.61
2017	2.56	10.01	12.57
2018	2.63	10.34	12.97
2019	4.67	11.78	16.45
2020	4.21	10.94	15.15
2021	4.77	11.07	15.83
2022	8.73	10.42	19.15
2023	2.24	2.26	4.50
2024	0.09	1.10	1.19

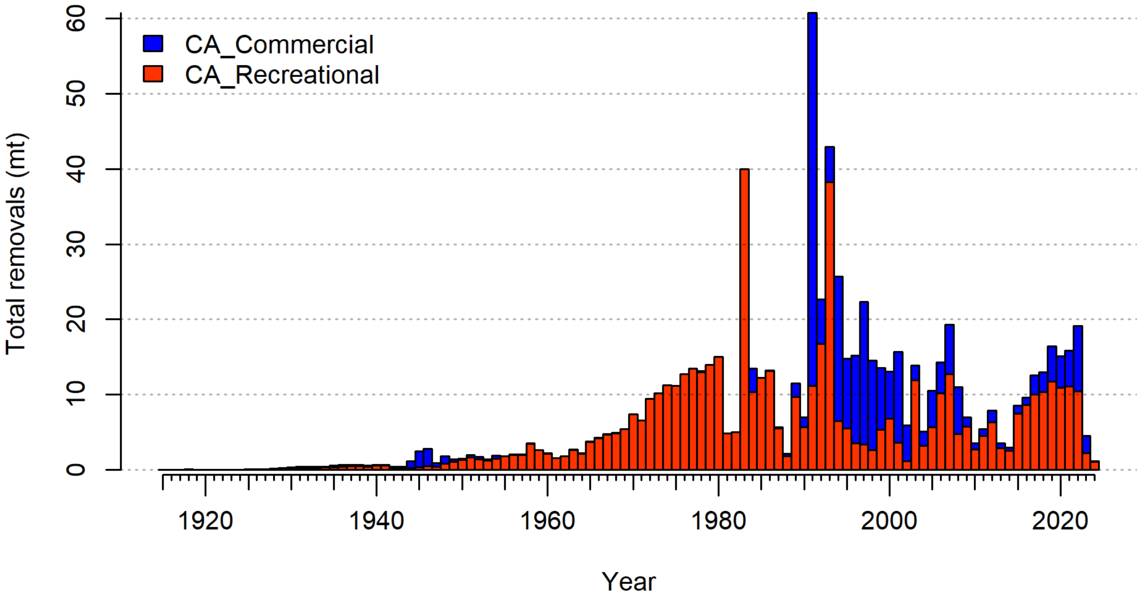

Figure i: Total removals in metric tons (mt) by year for each fleet.

Data and assessment

This is an assessment of the quillback rockfish stock off California. Previously, length-based data-moderate assessments were conducted in 2021 for quillback rockfish off the U.S. West Coast. In 2021, quillback rockfish was assessed with three separate population models, one each for Washington, Oregon, and California. This benchmark assessment, for the California stock only, uses Stock Synthesis 3 (version 3.30.21.1). All of the data sources included in the 2021 data-moderate assessment were re-evaluated for this assessment.

The assessment is a single-area, single-sex model and operates on an annual time step covering the period 1916–2024 and assumes an unfished population prior to 1916. Population dynamics are modeled for ages 0 through 80 in 1 year age bins, with age 80 as the accumulator age. The lengths are binned by 2 cm increments for data and the population is estimated at 1 cm length bins. The model is conditioned on total removals from two fishing fleets, commercial and recreational, and is informed by both fishery-dependent and fishery-independent data. The recreational fleet aggregates the private/rental and party/charter mode catches and lengths. The commercial fleet aggregates catches from all gear types, and the live fish and dead fish fisheries. Commercial lengths are included in the model as well as ages modeled as conditional age-at-length. Discards from the commercial and recreational fleets were estimated externally to the model and added to landings to represent total removals.

The model is fit to three indices of relative abundance, the fishery-independent California Department of Fish and Wildlife (CDFW) remote operated vehicle (ROV) survey and California Collaborative Fisheries Research Program (CCFRP) hook-and-line survey, and the fishery-dependent angler interview CDFW California Recreational Fisheries Survey (CRFS) of the private/rental mode of the recreational fleet. Both of the fishery-independent surveys were developed to monitor California's network of Marine Protected Areas (MPAs) compared to adjacent areas open to fishing and have been reviewed for use in stock assessments.

The model incorporates updated life history information using data from quillback rockfish collected in waters off California. This includes externally estimated relationships for length-based maturity, the length-weight relationship, and fecundity-at-length. Additional available ages conditioned on length that were not collected as part of a survey fleet in the model nor representative of the length distribution of the recreational fleet were included in a growth fleet. This model estimates all growth parameters and fixes natural mortality at the median of the prior (0.068 yr^{-1}), based on a maximum age of 80 years. Year-class strength is estimated as deviations from a Beverton-Holt stock-recruitment relationship beginning in 1940. Steepness of the Beverton-Holt stock-recruitment relationship is fixed at the mean of the prior for U.S. West Coast rockfish at 0.72.

Within-model uncertainty is explicitly included in this assessment through parameter estimation uncertainty, while among-model uncertainty is explored through sensitivity analyses addressing alternative input assumptions such as data treatment and weighting, and model specification sensitivity to the treatment of life history parameters, selectivity, and recruitment. A base model was selected that best fit the observed data while concomitantly balancing the desire to capture the central tendency across those sources of uncertainty, ensure model realism and tractability, and promote robustness to potential model mis-specification.

Stock Biomass and Dynamics

The model estimates that the spawning output of the stock dropped below the management target, but remained above the minimum stock size threshold throughout the late 1990s and later increased through the mid-2000s, before declining back to the target by 2019 (Figure ii, Figure iii). Spawning output has been near, but below, the management target of 40% of unfished spawning output in recent years with the exception of the last year (2025) when it increased above the target (Table ii). The 95% confidence interval for the fraction of unfished spawning output in 2025 ranges from 35%–58%.

Table ii: Estimated recent trend in spawning output (billions of eggs) and the fraction of unfished spawning output and the 95% confidence intervals.

Year	Spawning output (Billions of eggs)	Lower Interval (Billions of eggs)	Upper Interval (Billions of eggs)	Fraction Unfished	Lower Interval	Upper Interval
2015	43.60	29.99	57.21	0.449	0.344	0.554
2016	42.51	29.08	55.95	0.438	0.335	0.541
2017	41.52	28.19	54.85	0.428	0.326	0.529
2018	40.25	26.95	53.55	0.415	0.314	0.516
2019	39.15	25.84	52.47	0.403	0.302	0.504
2020	37.58	24.23	50.93	0.387	0.285	0.489
2021	36.52	23.07	49.98	0.376	0.274	0.479
2022	35.96	22.24	49.68	0.370	0.265	0.475
2023	35.60	21.38	49.81	0.367	0.257	0.476
2024	38.45	23.45	53.46	0.396	0.282	0.510
2025	42.26	26.30	58.21	0.435	0.315	0.555

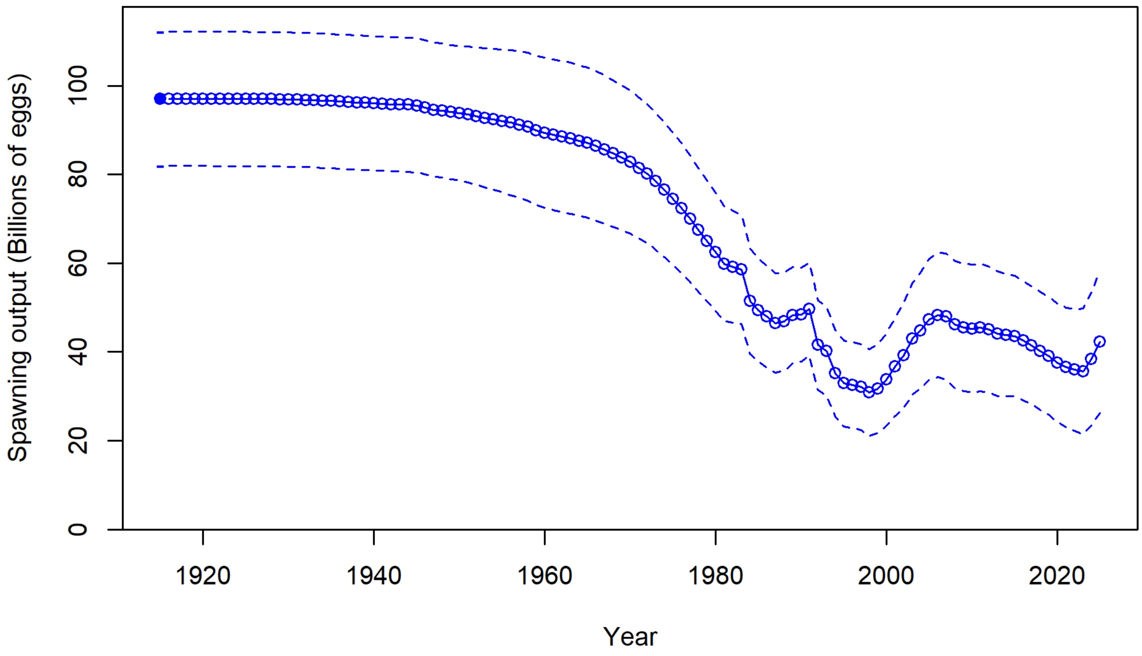

Figure ii: Estimated time series of spawning output (billions of eggs) for the base model with 95% confidence intervals.

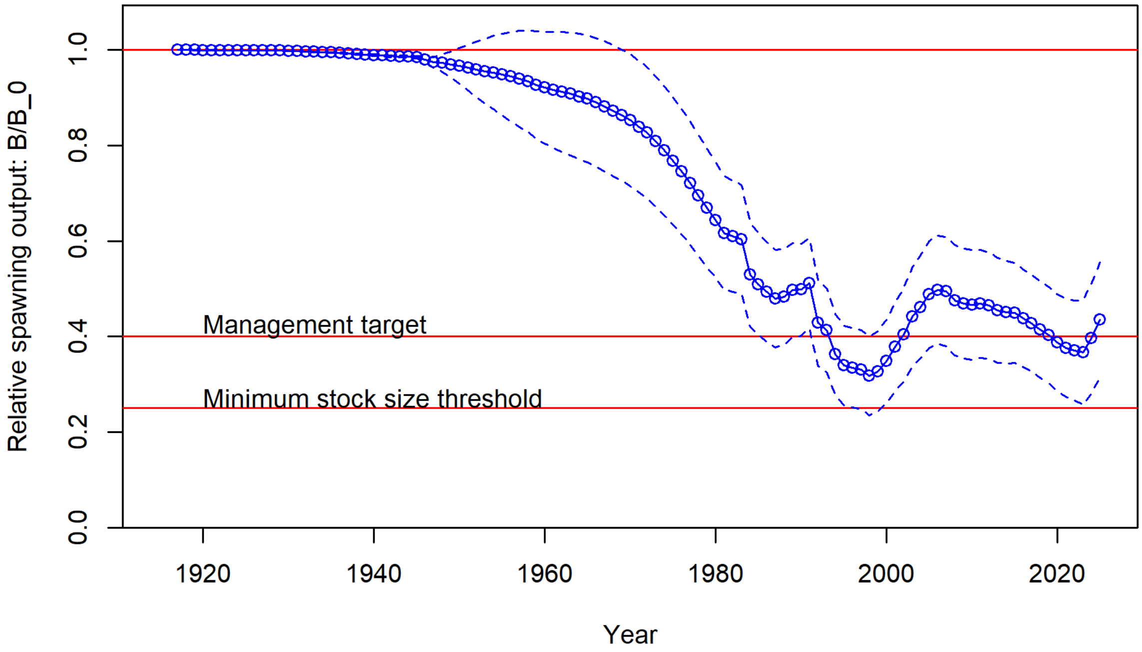

Figure iii: Estimated time series of spawning output relative to unfished spawning output for the base model with 95% confidence intervals.

Recruitment

Over the last ten years the largest recruitment events were estimated to be in 2016 and 2017, and those were either near to or lower than the large recruitment events in 1993 and 1994 (Table iii, Figure iv). Recruitment is estimated to be relatively low from 1995 through 2009. There is little information for quillback rockfish on the drivers of recruitment.

Table iii: Estimated recent trend in recruitment (1,000s) and recruitment deviations and the 95% confidence intervals.

Year	Recruitment (1,000s)	Lower Interval (1,000s)	Upper Interval (1,000s)	Recruitment Deviations	Lower Interval	Upper Interval
2015	23	9	58	-0.441	-1.368	0.485
2016	163	87	306	1.505	0.895	2.115
2017	100	40	247	0.986	0.059	1.913
2018	58	20	171	0.386	-0.753	1.524
2019	67	23	190	0.529	-0.570	1.628
2020	35	12	103	-0.109	-1.244	1.025
2021	36	12	108	-0.082	-1.247	1.083
2022	39	13	119	0.016	-1.166	1.198
2023	39	13	118	0.013	-1.167	1.192
2024	39	13	118	0.000	-1.176	1.176
2025	40	13	120	0.000	-1.176	1.176

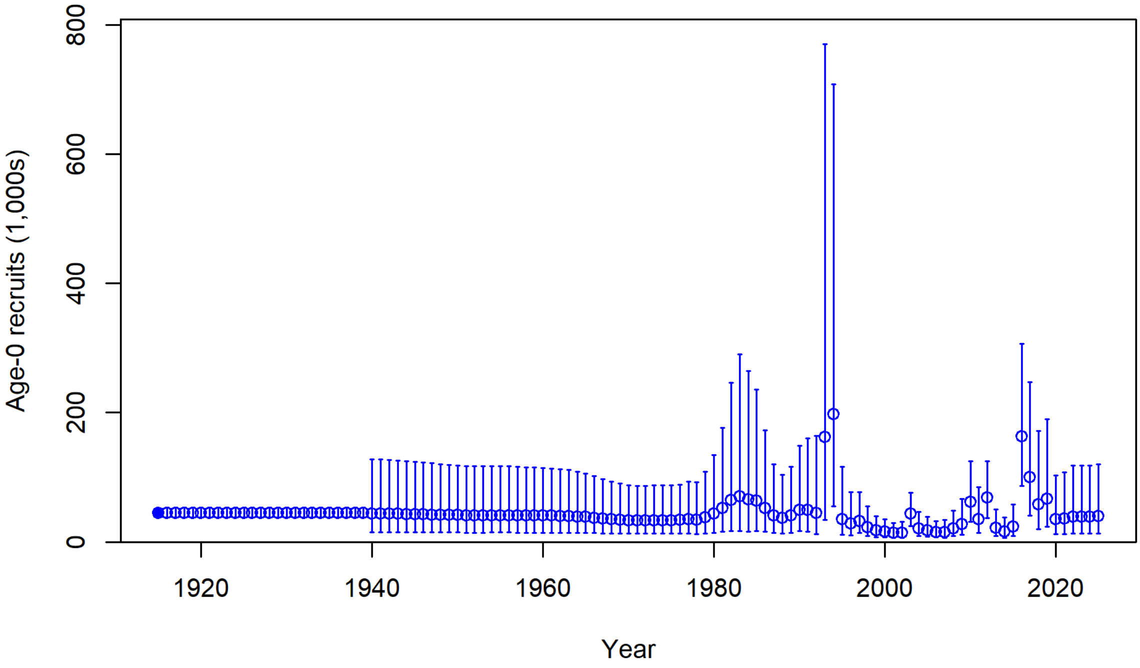

Figure iv: Estimated time series of age-0 recruits (in thousands) for the base model with 95% confidence intervals.

Exploitation Status

Exploitation rates were above the management target of a fishing intensity that leads to a spawning potential ratio of 0.5 during the 1990s. Exploitation rates decreased in the 2010s and have been low during the last few years of precautionary management subsequent to declaration of overfished status in 2023 (Table iv, Figure v, Figure vi).

Table iv: Estimated recent trend in the 1-SPR where SPR is the spawning potential ratio, the exploitation rate, and the 95% confidence intervals.

Year	1-SPR	Lower Interval (SPR)	Upper Interval (SPR)	Exploitation Rate	Lower Interval (Rate)	Upper Interval (Rate)
2015	0.463	0.377	0.550	0.034	0.024	0.044
2016	0.501	0.412	0.590	0.039	0.027	0.050
2017	0.548	0.457	0.639	0.052	0.036	0.067
2018	0.564	0.471	0.657	0.055	0.038	0.071
2019	0.626	0.534	0.717	0.068	0.046	0.089
2020	0.615	0.519	0.711	0.062	0.042	0.082
2021	0.630	0.532	0.728	0.063	0.042	0.084
2022	0.689	0.595	0.783	0.075	0.049	0.100
2023	0.323	0.230	0.417	0.017	0.011	0.024
2024	0.099	0.064	0.134	0.004	0.003	0.006

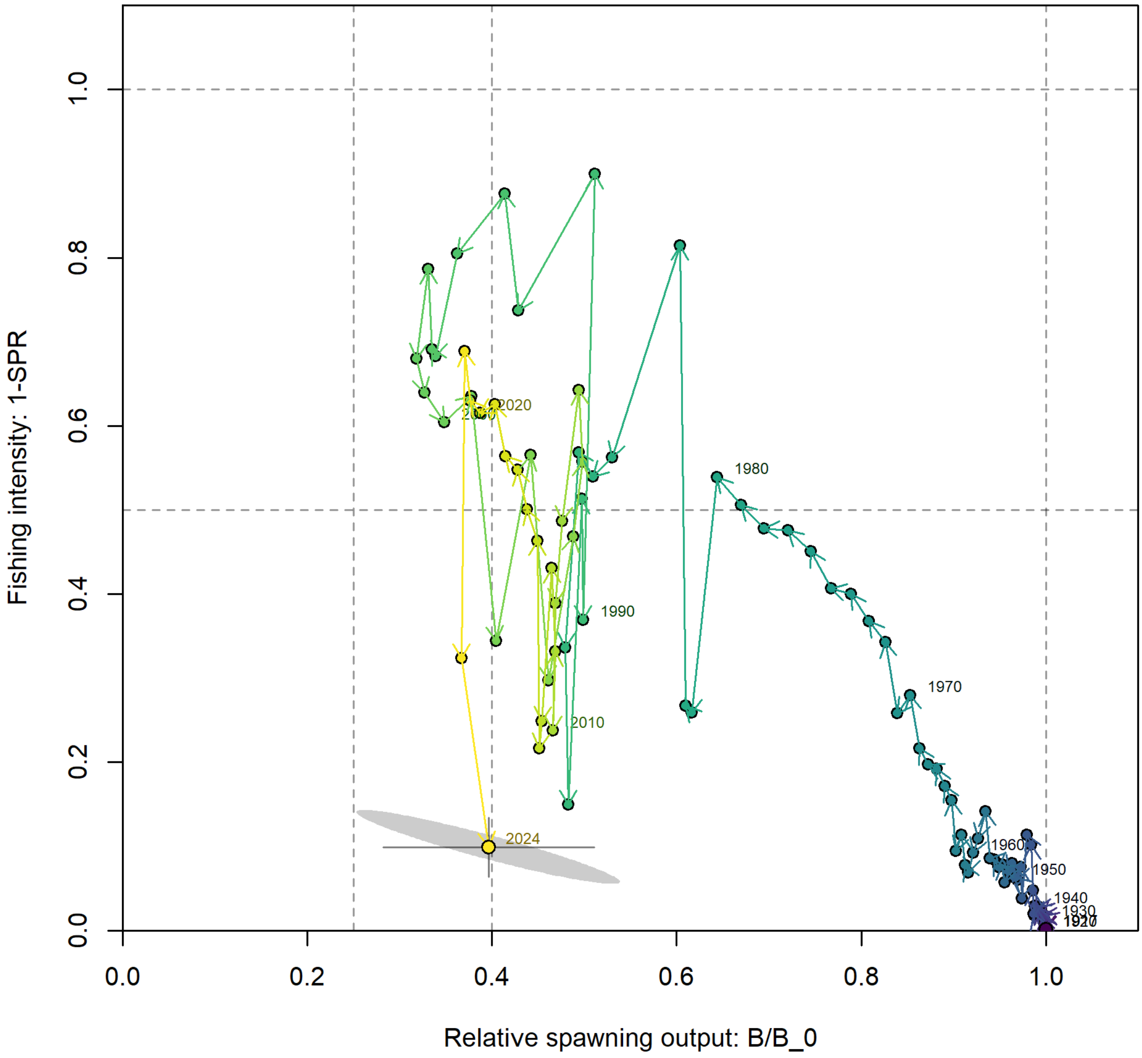

Figure v: Phase plot of fishing intensity versus spawning output relative to unfished. Each point represents the relative spawning output at the start of the year and the relative fishing intensity in that same year. Lines through the final point show 95% confidence intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95% region which accounts for the estimated correlation between the two quantities.

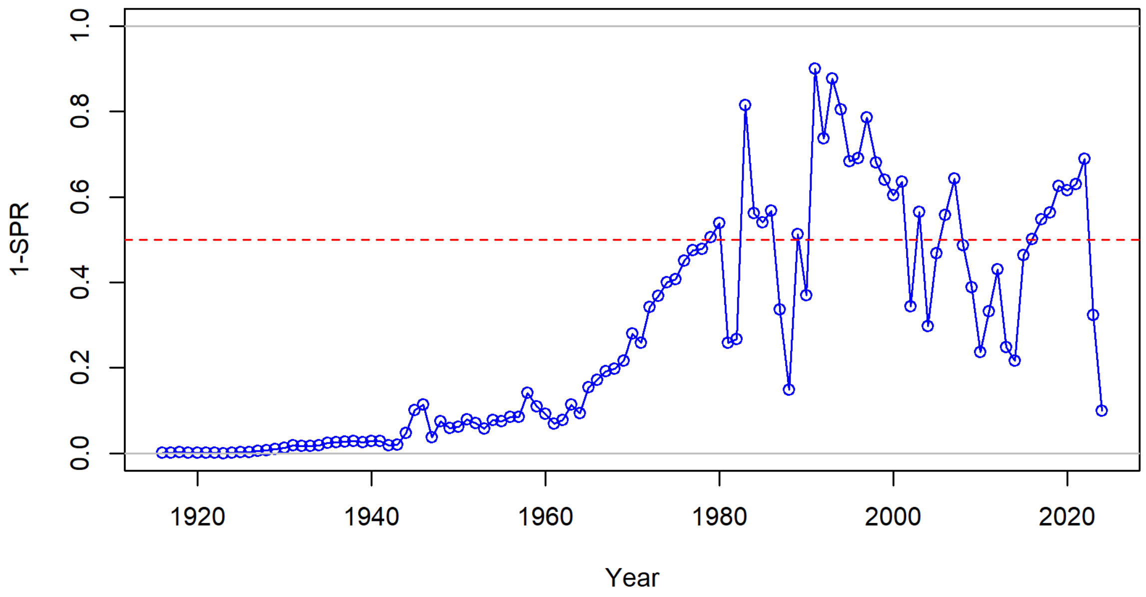

Figure vi: Time series of 1-SPR (spawning potential ratio). The horizontal line is at the 1-SPR target: 1 - 0.5 = 0.5

Ecosystem Considerations

This stock assessment does not explicitly incorporate trophic interactions, habitat factors nor environmental factors into the assessment model, but a brief description of likely or potential ecosystem considerations is provided. As with most other rockfish and groundfish in the California Current, recruitment or cohort (year-class) strength appears to be highly variable for quillback rockfish, with only a modest apparent relationship to estimated levels of spawning output.

Reference Points

Reference points were calculated using the estimated selectivities and catch distribution among fleets in the final year of the model. A list of estimates of the current state of the population, as well as reference points based on 1) a target spawning output relative to unfished of 40%, 2) a spawning potential ratio (SPR) of 0.5, and 3) the model estimate of maximum sustainable yield, are all listed in Table v. Spawning potential ratio is the fraction of expected lifetime reproductive output under a given fishing intensity divided by unfished expected individual lifetime reproductive output. Quillback rockfish off the California coast are managed as a single stock by the PFMC.

Table v: Summary of reference points and management quantities, including estimates of the 95% confidence intervals.

Reference Point	Estimate	Lower Interval	Upper Interval
Unfished Spawning output (Billions of eggs)	97.083	81.153	113.013
Unfished Age 3+ Biomass (mt)	522.330	439.673	604.987
Unfished Recruitment (R0)	44.991	37.601	52.380
2025 Spawning output (Billions of eggs)	42.256	26.298	58.213
2025 Fraction Unfished	0.435	0.315	0.555
Reference Points Based SO40%			
Proxy Spawning output (Billions of eggs) SO40%	38.833	32.461	45.205
SPR Resulting in SO40%	0.458	0.458	0.458
Exploitation Rate Resulting in SO40%	0.048	0.045	0.051
Yield with SPR Based On SO40% (mt)	11.658	9.713	13.603
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning output (Billions of eggs) (SPR50)	43.314	36.207	50.421
SPR50	0.500	—	—
Exploitation Rate Corresponding to SPR50	0.042	0.039	0.044
Yield with SPR50 at SO SPR (mt)	11.087	9.240	12.934
Reference Points Based on Estimated MSY Values			
Spawning output (Billions of eggs) at MSY (SO MSY)	25.550	21.353	29.748
SPR MSY	0.335	0.331	0.339
Exploitation Rate Corresponding to SPR MSY	0.072	0.067	0.077
MSY (mt)	12.530	10.430	14.629

Management Performance

During the last 10 years when quillback rockfish in California was managed within the minor nearshore stock complex, the total removals were above the species' overfishing limit (OFL) contribution from 2015–2022. Since 2023, quillback rockfish in California has had its own reference points. Total removals were above the OFL in 2023 but below the OFL for 2024 (Table vi).

Table vi: Recent trend in overfishing limits (OFL), acceptable biological catches (ABC), the annual catch limits (ACL; set to equal ABC) for quillback rockfish, along with total removals (landings + dead discards) all in metric tons (mt). For 2015-2022, values for OFLs and ACLs represent OFL and ACL contributions of quillback rockfish within the Minor Nearshore Rockfish North and South complexes and are marked with an asterisk (∗). The ACL contribution allocated to California across both complexes is also provided and marked with an asterisk (∗), and is calculated as described in Section 1.5. For 2023-2024, California quillback rockfish was assigned its own OFL, ABC, and ACL, which are provided here as California only values.

Year	OFL* South	ACL* South	OFL* North	ACL* North	ACL* CA	OFL CA	ABC CA	ACL CA	Total removals
2015	5.39	4.49	7.37	6.15	6.26	—	—	—	8.59
2016	5.39	4.49	7.37	6.15	6.26	—	—	—	9.61
2017	5.39	4.49	7.37	6.15	6.26	—	—	—	12.57
2018	5.39	4.49	7.37	6.15	6.26	—	—	—	12.97
2019	5.39	4.49	7.37	6.15	6.26	—	—	—	16.45
2020	5.39	4.49	7.37	6.15	6.26	—	—	—	15.15
2021	5.39	4.19	7.37	5.73	5.84	—	—	—	15.83
2022	5.39	4.19	7.37	5.74	5.84	—	—	—	19.15
2023	—	—	—	—	—	2.11	1.84	1.76	4.50
2024	—	—	—	—	—	2.32	2.01	1.93	1.19

Unresolved Problems and Major Uncertainties

The primary areas of uncertainty for this assessment are the parameters influencing population productivity, i.e., natural mortality and the growth parameters K, and the influence of age data on estimates of recruitment. Model bridging analyses showed that updating biological parameters and data had a large effect on results and had a much greater impact than other changes such as selectivity. Despite improved California-specific data, there is still uncertainty in the growth parameter K and the choice for natural mortality given the available ages, as shown by model profiles across parameters, as well as the strength of recruitment, as shown by sensitivity analyses. Additional sources of uncertainty include unusually high estimated recreational and commercial catches in some years and differences in quillback rockfish size distributions across space.

Decision Table and Harvest Projections

The 2025 stock assessment for quillback rockfish off California was supported as a category 1 determination by the Stock Assessment Review (STAR) panel. A ten-year projection of the OFL, Acceptable Biological Catch (ABC), and annual catch limit (ACL), all based on a P^* of 0.45 and a log-space standard deviation of the overfishing limit σ of 0.5 is included in Table vii. Assumed catches for 2025 and 2026 for this projection were provided by the Groundfish Management Team (GMT), and catches from 2027 onward assume full attainment of the ABC, assuming the ACL is equal to the ABC.

The axis of uncertainty in the decision table is based on the uncertainty around natural mortality (Table viii). Alternative values for natural mortality (M) were used to identify the low ($M = 0.0525$) and high ($M = 0.08$) states of nature, where the base model is assigned a 50% probability of being the true state of nature and both the low and high states of nature are assigned a 25% probability. The proposed decision table assumes full ACL removal during the projection period under alternative catch streams based on a P^* of 0.45.

Table vii: Potential OFLs (mt), ABCs (mt), ACLs (mt), the buffer between the OFL and ABC based on a category 1 sigma of 0.5 and P^* of 0.45, estimated spawning output (billions of eggs), and fraction of unfished spawning output with adopted OFLs and ACLs and assumed catch for the first two years of the projection period.

Year	Adopted OFL (mt)	Adopted ACL (mt)	Assumed Catch (mt)	OFL (mt)	Buffer	ABC (mt)	ACL (mt)	Spawning output (Billions of eggs)	Fraction Unfished
2025	1.50	1.30	1.30	—	—	—	—	42	0.435
2026	1.80	1.50	1.50	—	—	—	—	46	0.475
2027	—	—	—	12.83	0.935	12.00	12.00	50	0.513
2028	—	—	—	13.29	0.930	12.36	12.36	51	0.529
2029	—	—	—	13.61	0.926	12.60	12.60	53	0.541
2030	—	—	—	13.81	0.922	12.73	12.73	53	0.549
2031	—	—	—	13.90	0.917	12.75	12.75	54	0.553
2032	—	—	—	13.91	0.913	12.70	12.70	54	0.555
2033	—	—	—	13.87	0.909	12.61	12.61	54	0.554
2034	—	—	—	13.79	0.904	12.47	12.47	54	0.552
2035	—	—	—	13.69	0.900	12.32	12.32	53	0.550
2036	—	—	—	13.59	0.896	12.17	12.17	53	0.546

Table viii: Decision table with 10-year projections beginning in 2027 for alternative states of nature based around modeling natural mortality (M). All models assume a $P^* = 0.45$. Catch (mt) is from the projections from the base model, and is applied to each state of nature. Catches in 2025 and 2026 are fixed at values provided by the GMT. The alternative states of nature ('Low', 'Base', and 'High') are provided in the columns. Natural mortality is fixed either at the low state of nature (Low M = 0.0525), the base model value (M = 0.068), or the high state of nature (High M = 0.08). Spawning output ('Spawn', in billions of eggs) and fraction of unfished ('Frac') is provided for each state of nature.

Year	Catch (mt)	Low M Spawn	Low M Frac	Base M Spawn	Base M Frac	High M Spawn	High M Frac
2025	1.30	30.67	0.299	42.26	0.435	56.13	0.563
2026	1.50	33.79	0.330	46.12	0.475	60.69	0.608
2027	12.00	36.77	0.359	49.78	0.513	64.94	0.651
2028	12.36	37.78	0.369	51.39	0.529	67.02	0.672
2029	12.60	38.43	0.375	52.54	0.541	68.51	0.687
2030	12.73	38.77	0.378	53.29	0.549	69.48	0.696
2031	12.75	38.86	0.379	53.70	0.553	70.02	0.702
2032	12.70	38.77	0.378	53.85	0.555	70.20	0.704
2033	12.61	38.55	0.376	53.81	0.554	70.13	0.703
2034	12.47	38.24	0.373	53.62	0.552	69.88	0.700
2035	12.33	37.90	0.370	53.36	0.550	69.49	0.697
2036	12.17	37.53	0.366	53.04	0.546	69.03	0.692

Scientific Uncertainty

The model estimate of the log-scale standard deviation of the overfishing limit (OFL) in 2025 is 0.188, lower than the default SSC value of 0.5 for a category 1 assessment, so harvest projections assume an initial sigma of 0.5. The model estimate of uncertainty around the 2025 spawning output is 0.191. Each of these underestimates the overall uncertainty due to the necessity to fix several key population dynamics parameters (e.g., steepness, recruitment variance, natural mortality) and also because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature).

Research and Data Needs

As with most nearshore rockfish stocks additional research and data are needed to understand biological and population processes. The most pressing research and data need is increased collection of age samples as part of regular sampling program efforts. Age data provide information on the productivity of the population and the lack of such information has large effects on estimating population dynamics. Collecting samples of ages (as well as lengths) across the fleets and the full stock area should be prioritized. Understanding population trends across the stock area is also a research and data need. Quillback rockfish are not regularly captured in coastwide trawl surveys, and so fishery-independent surveys that utilize hook and line gear should be continued to be prioritized to increase the length of the time series. These surveys should continue to sample in areas not regularly sampled by the fishing fleet, such as areas closed to fishing, to better understand population dynamics across the full range of the stock.

Risk Table

Information on ecosystem and environmental processes impacting California quillback rockfish along with information related to the stock assessment were used to fill out a 'Risk Table' in Table ix, based on the framework outlined by the California Current Integrated Ecosystem Assessment (CCIEA) team (Golden et al. 2024). Information on the influence of environmental conditions on California quillback rockfish is lacking, and prevents a determination to be made for ecosystem and environmental processes. Given some uncertainties in values from the historical catch reconstructions as well as some gaps in estimates since 1980, limited sampling of age data for use in compositions as well as some gaps in sampling length compositions, but species specific estimates of maturity and fecundity, we consider uncertainties in assessment data indicate an unfavorable determination. Given generally good fits to data, that parameters governing growth and recruitment were estimated with steep profiles but natural mortality and steepness were fixed at prior values and had flat likelihood surfaces, that the magnitude of recruitment deviations was uncertain and influenced by the inclusion of age data, and that a retrospective pattern was present in the model, we consider assessment model fits and structural uncertainty indicate a neutral determination.

Table ix: Risk Table for California quillback rockfish to document ecosystem and environmental factors, as well as data driven factors potentially affecting stock productivity and uncertainty or other concerns arising from the stock assessment. Level 1 is a favorable ranking, Level 2 neutral, and Level 3 unfavorable.

Ecosystem and environmental conditions	Assessment data inputs	Assessment model fits and structural uncertainty
• There is limited information on factors affecting quillback recruitment, habitat, prey and predators, and competitors.	• Catch reconstruction has uncertainty in some historical years due to periods of high and low estimates of sampled catch rates and when rockfish were not always sorted to species • Not captured in bottom trawl surveys. Indices based on fishery-dependent and other fishery-independent sources. Limited effect on population trends. • Age data is limited compared to some other groundfish species and primarily occurs in the most recent 5-10 years. Covers commercial sector and suitable for growth estimation. Young fish remain sparse. • Fewer samples of length data from fishing in recent years due to non-retention • Length and age data are generally fit well across many assumptions. • Species-specific maturity and fecundity with both being collected from most recent years • Generally not a directly targeted species but most catch is landed.	• Recruitment and growth are estimated internally whereas natural mortality and steepness are based on priors. • Profiles and jitters indicate the model is stable and that estimated parameters are genearlly well estimated. • Uncertainty in natural mortality estimates both in terms of uncertainty in longevity as well as limited information by which to clearly estimate value. • Uncertainty in recruitment, particularly the strength of recruitment deviations in the mid 1990s. • Patterns of retrospective bias due to exclusion of age data over time. • Composition and index data were generally well fit. • Data were insufficient to evaluate spatiotemporal variation in biology.
Level is Unknown	Level 3: Unfavorable	Level 2: Neutral

1 Introduction

This benchmark assessment reports the status of quillback rockfish (*Sebastes maliger*) off the coast of California through 2024. The PFMC defined the population of quillback rockfish off California as a unit stock in 2023. Although the definition for the California stock of quillback rockfish is statewide, the range of quillback rockfish in California is primarily north of central California (Figure 1).

1.1 Life History

Quillback rockfish are a demersal, relatively nearshore species within the subgenus *Pteropodus*. The core range of quillback rockfish is relatively broad, from central California to the Gulf of Alaska, with quillback rockfish also found in Puget Sound. Quillback rockfish range from the sub-tidal (as juveniles) to depths of around 275 m (Love et al. 2002). They are commonly found in waters less than 100 m inhabiting both low and high relief complex rocky habitat (Love 1996) and exhibit less determinant ontogenetic migration than some other rockfish. Murie (1991) found quillback rockfish of all sizes in shallower waters, and a lack of small quillback rockfish in deeper depths.

The body coloring of adult quillback rockfish is brown with yellow to orange blotching and light-colored dorsal saddle patches (Love et al. 2002). As their name suggests, quillback rockfish have long dorsal fin spines with deeply incised membranes. The diet of quillback rockfish consists primarily of benthic and pelagic crustaceans, e.g., coonstripe shrimp, and fish, with the proportion of fish contributing to their diet increasing with size (Murie 1991).

Limited studies have evaluated genetic variation in quillback rockfish across the U.S. West Coast. Genetic work has revealed significant differences between Puget Sound and coastal stocks of quillback rockfish (Seeb 1998; Stout et al. 2001), however Seeb (1998) did not find significant differentiation in populations of quillback rockfish between coastal Washington and Alaska. Adult quillback rockfish have high site fidelity; an acoustic telemetry study displaced quillback rockfish 500 m from the capture location and all returned to the original capture site within 30 days (Matthews 1990). Other telemetry studies have found similar patterns of high site fidelity as well as small home ranges for quillback rockfish (Tolimieri et al. 2009; Hannah and Rankin 2011) that could suggest isolation-by-distance as found for other rockfish species.

Quillback rockfish are a long-lived rockfish with the oldest aged specimen at 95 years from British Columbia (Yamanako and Lacko 2001; Love et al. 2002). Along their range, the oldest aged quillback rockfish from southeast Alaska was 92, while the oldest aged quillback rockfish on the U.S. West Coast is 73 from Washington, 63 from Oregon, and 57 from California (C. Stuart, Cal Poly Humboldt, pers. comm.). The availability of life history information for quillback rockfish in California, which is the most southern part of their range, is sparse. A number of studies were undertaken following the 2021 data-moderate quillback rockfish stock assessment in order to better estimate growth, maturity, and fecundity in California, and are described later in this report (see Section 2.4).

Cope et al. (2011) found quillback rockfish to have a vulnerability score of V = 2.222, making it a species of major concern in the productivity susceptibility analysis. This analysis calculated species specific vulnerability scores based on two dimensions: productivity characterized by life history, and susceptibility characterized by how the stock is likely affected by fisheries.

1.2 Ecosystem Considerations

This stock assessment does not explicitly incorporate trophic interactions, habitat factors nor environmental factors into the assessment model, primarily due to the lack of information on the effects of these factors on quillback rockfish. As with most other rockfish and groundfish in the California Current, recruitment or cohort (year-class) strength appears to be highly variable for quillback rockfish, with only a modest apparent relationship to estimated levels of spawning output. The Southwest Fisheries Science Center (SWFSC)'s Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) surveys juvenile rockfish off the coast of California, but does not encounter quillback rockfish and neither does the California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey. There is much less understanding on the recruitment drivers for nearshore species than there are for shelf and slope rockfish. Studies in British Columbia of the CBQ complex (*S. caurinus*, *S. auriculatus*, *S. maliger*) found that both habitat and ocean conditions, i.e., prolonged downwelling and warm ocean temperatures affected CBQ recruitment and settlement (Markel and Lotterhos 2017; Markel and Shurin 2020).

1.3 Current and Historical Fishery Information

Quillback rockfish is encountered in both commercial and recreational fisheries throughout its range. While quillback rockfish is generally not highly desirable by recreational fishermen in waters off the coast of California, recreational removals are the largest source of fishing mortality and represent approximately 70% of the total removals of quillback rockfish across all years (Table 1 and Figure 2). The majority of the commercial landings for quillback rockfish occurred between 1990 and 2008, when its value in the commercial fishery rose with the development of the live-fish fishery in the 1990s. The proportion of landings from the commercial sector was low relative to the recreational sector between 2009 and 2016, then began modest increases in 2022 prior to the California stock being defined and subsequently declared overfished.

The recreational groundfish fishery in the early part of the 20th century was focused on nearshore waters near ports, with expanded activity farther from port and into deeper depths over time (Miller et al. 2014). Prior to the groundfish fishery being declared a federal disaster in 2000, and the subsequent rebuilding period, there were no time or area closures for groundfish. During this period before depth restrictions were implemented, effort was spread over a larger area and filled bag limits with a greater diversity of species from the shelf as well as the nearshore. This resulted in lower catch rates for nearshore rockfish relative to the period after 2000 when depth restrictions starting between 20 to 50 fm (37-92 m) were put in place in various management areas north of Point Conception. This increased effort in nearshore habitats of central and northern California where quillback rockfish are commonly found, kept catch levels high for nearshore rockfish, including quillback rockfish, despite reduced season length.

Prior to the development of the live-fish market in the 1990s, commercial catches of quillback rockfish were relatively low, and quillback rockfish were often landed dead for a relatively low ex-vessel price per pound. Most fish were caught using hook-and-line gear, though some were caught using traps, gill nets, and in some instances, trawl gear. Trawling within three miles of shore, where most quillback rockfish habitat is found, has been prohibited since 1953, and gill nets were banned within three miles of shore in 1994. Whether from directed effort in the nearshore or as incidental catch while targeting other more valuable stocks such as lingcod (*Ophiodon elongatus*), catches were below 0.5 mt from 1916 to 1980, with the exception of four of the five years between 1944–1948.

With the development and expansion of the nearshore live-fish fishery during the 1990s, new entrants in this open access fishery were drawn by a premium ex-vessel price per pound for live fish, resulting in over-capitalization of the fishery. Since 2002, the CDFW has managed 19 nearshore species in accordance with the Nearshore Fisheries Management Plan (Wilson-Vandenberg et al. 2014). In 2003, CDFW implemented a Nearshore Restricted Access Permit system, including the requirement of a Deeper Nearshore Fishery Species Permit to retain quillback rockfish. Permits were issued based on prior landings history and the overall goal of reducing the number of participants to a more sustainable level. The result was a reduction in permits issued from 1,127 in 1999 to 505 in 2003. In addition, reduced trip limits, season closures in March and April, and depth restrictions were implemented to address bycatch of overfished species and associated constraints from their low catch limits. The open access fishery is allowed to retain shelf rockfish species co-occurring with nearshore rockfish species. There is growing concern regarding increased encounters and discard mortality from the open access fleet, given that they are fishing in deeper depths. However, fishing in waters up to 60 fm may result in decreased effort for quillback rockfish as overall effort shifts away from waters where quillback rockfish are most prevalent.

1.4 Management History

Prior to the adoption of the Pacific Coast Groundfish Fishery Management Plan (FMP) in 1982, quillback rockfish were managed through a regulatory process that included the CDFW, the California State Legislature, and the Fish and Game Commission (FGC). With implementation of the Pacific Coast Groundfish FMP, quillback rockfish came under the management authority of the PFMC and were managed as part of the *Sebastes* complex (PFMC 2024).

The recreational bag limit (that included rockfish) was 20-fish from 1967 to 1970, and 15-fish from 1970 to 2000, when it was reduced to the current day bag limit of 10 fish within the rockfish, cabezon, and greenling (RCG) complex. There was no sub-bag limit for quillback rockfish until 2022 when a 1-fish limit was implemented, and later followed by a full prohibition on retaining quillback rockfish in August of 2023.

Between 1999 and 2002, gear regulations went from unlimited hooks and lines to one line per person with no more than two hooks, the current 10 RCG bag limit was enacted, and CDFW created management areas with latitudinal separations to restrict fishing shoreward of depths between 20 to 60 fm depending on the area. The latitudinal boundaries of the management areas and depth closures have fluctuated since 2002, but have remained fairly consistent from 2011–2022 (Figure C-1). MPAs instituted between 2003 and 2012 now encompass 20-30% of the rocky reef habitat within 3 miles of shore in state waters.

Since the early 1980s, a number of federal regulatory measures have been used to manage the commercial rockfish fishery including cumulative trip limits (generally for two- month periods) and seasons. Starting in 1994 the commercial groundfish fishery sector was divided into two components: limited entry and open access with specific regulations designed for each component. Limited entry programs were designed in part to limit bottom contact gears and the open access sector includes trawl and non-trawl gears not making bottom contact, e.g., hook and line. Other regulatory actions for the general rockfish categories included area closures and gear restrictions set for the four different commercial sectors: limited entry fixed gear, limited entry trawl, open access trawl, and open access non-trawl (which includes the nearshore fishery).

In 2000, the PFMC's rockfish management structure changed significantly with the replacement of the *Sebastes* complex with Minor Rockfish North (Vancouver, Columbia, and Eureka International

North Pacific Fisheries Commission (INPFC) areas) and Minor Rockfish South (Monterey and Conception INPFC areas). The optimum yield for these two groups was further divided into Nearshore, Shelf, and Slope rockfish categories with allocations set for limited entry and open access fisheries within each of these three categories. Species were parceled into these new categories depending on primary catch depths and geographical distribution. Quillback rockfish was included in the Nearshore rockfish category for both the Minor Rockfish North and Minor Rockfish South groups.

During the late 1990s and early 2000s, major changes also occurred in the way that California managed its nearshore fishery. The Marine Life Management Act (MLMA), which was passed in 1998 by the California Legislature and enacted in 1999, required that the FGC adopt an FMP for nearshore finfish (Wilson-Vandenberg et al. 2014). It also gave authority to the FGC to regulate commercial and recreational nearshore fisheries through FMPs and provided broad authority to adopt regulations for the nearshore fishery during the time prior to adoption of the nearshore finfish FMP. Within this legislation, the Legislature also included a requirement that commercial fishermen landing nearshore species possess a Nearshore Species Fishery Permit.

Following adoption of the California Nearshore FMP and accompanying regulations by the FGC in fall of 2002, the FGC adopted regulations in November 2002 which established a set of MPAs around the Channel Islands in southern California (which became effective April 2003). The FGC also adopted a restricted access program in December 2002 which established the Deeper Nearshore Species Fishery Permit, to be effective starting in the 2003 fishing year. Also, since the enactment of the MLMA, the PFMC and State coordinated to develop and adopt various management specifications to keep harvest within targets, including seasonal and area closures, depth restrictions, and bag limits to regulate the recreational fishery (Figure C-1) and license and permit regulations, finfish trap permits, gear restrictions, seasonal and area closures, depth restrictions, trip limits, and minimum size limits to regulate the commercial fishery (Figure C-2). The MPAs were later expanded under authority of the Marine Life Protection Act (MLPA) of 1999, creating a network of MPAs which went into place in phases beginning with the central coast in 2007, north central coast in 2010, and the south and north coasts in 2012. The rockfish conservation areas (RCAs) are seasonally adjusted depth limits impacting trawl and non-trawl gears that were initially established in 2002 to protect overfished species. The RCAs also restricted catch of nearshore species to depths less than 30 fm, and in some areas along California to less than 20 fm. Thus, the MPAs and RCAs represent two types of spatial and/or depth closures impacting rockfish.

The state of California has adopted regulatory measures to manage the nearshore fishery based on the harvest guidelines set by the PFMC for the Minor Nearshore Rockfish complexes north and south of 40° 10’ N. Lat. Each complex is managed based on a complex-level OFL and ACL that are determined by summing the species-specific OFL and ACL (ACLs set equal to the ABC) contributions for all stocks managed in the complex. Limits are shared among all commercial and recreational fleets with the various management procedures intended to maintain removals below the complex total OFL and ACL as a whole, rather than on a species by species basis. The nearshore commercial fishery is managed based on bimonthly allowable catches per vessel, that have ranged from 200 to 2,000 pounds per two months since 2000. Fishers operating in the federal open access nontrawl sector and permittees of the California Nearshore Species Fishery Permit are currently subject to the same limits per pound and two month period. However, not all federal open access participants have a California Nearshore Species Fishery Permit. Because quillback rockfish is a species named in the California Nearshore Species Fishery permit, those vessels without the state permit must release any quillback rockfish and therefore their contributions to quillback rockfish mortality are purely from discard.

Quillback rockfish were most recently assessed in 2021. The 2021 assessment indicated that the California population of quillback rockfish was below the minimum stock size threshold (MSST) (Langseth et al. 2021a), and a rebuilding analysis was conducted (Langseth and Wetzel 2022). However, by the November 2021 Council meeting, the National Marine Fisheries Service (NMFS) had not made an overfished declaration because quillback rockfish had not been identified within the Pacific Coast Groundfish FMP as a stock or management unit for California. The PFMC, at its March 2022 meeting, decided to pursue development of an FMP amendment that would more clearly define those groundfish stocks and complexes in need of conservation and management. In June 2023, the PFMC took final action on an amendment to the FMP (Amendment 31, NMFS 2023) to describe stock definitions for a subset of groundfish species, which included removing California quillback rockfish from the Minor Nearshore Rockfish complex. This led to the quillback rockfish stock off California to be declared overfished in December 2023, thereby triggering an updated rebuilding analysis (Langseth 2024). Despite the absence of this declaration prior to 2023, CDFW along with NMFS implemented a recreational one-fish bag limit for quillback rockfish and reduced commercial limits in 2021, and CDFW prohibited quillback rockfish retention in recreational and commercial fisheries in August 2023. This means that California Nearshore Species Fishery permittees were still subject to the same trip limits as the federal open access non-trawl sector, with the exception that any caught quillback rockfish could not be retained. NMFS subsequently closed the commercial nearshore fisheries in federal waters off California north of 36° N. Lat. in September 2023. In order to allow commercial access to other nearshore stocks while minimizing interactions with quillback rockfish, in February 2024 CDFW took emergency action to establish a California Groundfish Restriction Area (CGRA). The CGRA extended from 36° N. Lat. to the California-Oregon border and from an easterly boundary line approximating 20 fm to a westerly boundary of the Exclusive Economic Zone (EEZ). This prohibited commercial groundfish fishing between the 20 fm line and the shoreward boundary of the EEZ. While quillback rockfish remained prohibited, commercial fishing was only allowed for state permitted nearshore groundfish species. This is because fishery data indicate quillback rockfish are rarely encountered in waters shallower than 20 fm. In August 2024, CDFW readopted the emergency action while modifying the southern extent of the CGRA to 37° 07' N. Lat. (Año Nuevo, San Mateo County) in state waters. Nearshore rockfish remained closed in federal waters north of 37° 07' N. Lat.

1.5 Management Performance

The management of quillback rockfish in California changed after the 2021 assessment. When managed within the Minor Nearshore Rockfish North and South complexes, no species-specific OFL or ACL existed. Rather species-specific OFL contributions as well as implied ACL contributions were used to monitor quillback rockfish removals. Because the 40° 10' N. Lat. management line occurs within California waters, allocations for state specific sharing agreements provide a California specific ACL contribution by summing all of the South management contribution to 28.7% of the North management contribution (GMT, pers. comm.). Starting in 2023, quillback rockfish in California were assigned a species-specific OFL, ABC, and ACL based on the results of the 2021 rebuilding analysis (Langseth and Wetzel 2022). Past OFL and ACL contributions during years when California quillback rockfish were managed within a complex, along with the California-specific ACL contribution are provided in Table 2. Also included in Table 2 are California-specific OFL, ABC, and ACL for years when quillback rockfish were managed as a species. These values are compared to total removals and with the exception of 2024, total removals of quillback rockfish have been above ACL contributions and ACLs.

1.6 Fisheries Outside Spatial Domain of This Assessment

Quillback rockfish does not extend south to Mexico and given that the stock is defined as California only we did not consider the fisheries in Alaska or Canada. Assessments in 2021 were also done for Oregon (Langseth et al. 2021c) and Washington (Langseth et al. 2021b). The Oregon assessment estimated spawning stock relative to unfished at 0.47 and was used to inform harvest levels, whereas the Washington assessment was considered too uncertain to provide status determination criteria but was used to inform harvest levels. Quillback rockfish in both states are managed within the Minor Nearshore Rockfish North complex.

2 Data

Data from a wide range of programs were available for possible inclusion in the current assessment model. Descriptions of each data source included in the base model and sources that were explored but not included in the base model are provided in this section. In some cases, alternative treatments of data were explored through sensitivity analyses (see Section 3.5.4).

2.1 Data Sources Used

This assessment updates the data used in the 2021 stock assessment, as well as utilizes additional data, both those collected since the 2021 assessment and those from sources not used in the 2021 assessment. All data sources are specific to California unless otherwise specified. The following types and sources of data used in this assessment are first summarized here, and then discussed in more detail.

1. Total removals (in metrics tons) of quillback rockfish encompassing years 1916–2024 were obtained from several sources:
    a. Commercial landings (1916–2024) come from the California historical reconstruction (Ralston et al. 2010), CalCOM database for the California Cooperative Survey (CalCOM), and Pacific Fisheries Information Network (PacFIN).
    b. Recreational landings (1928–2024) come from the California historical reconstruction (Ralston et al. 2010), and Marine Recreational Fisheries Statistics Survey (MRFSS) and CRFS via Recreational Fishery Information Network (RecFIN). Both MRFSS and CRFS data also include estimates of recreational dead discards.
    c. Commercial dead discards for recent years (2002–2023) come from the Groundfish Expanded Mortality Multi-Year (GEMM) product which aggregates data from a variety of sources including the West Coast Groundfish Observer Program (WCGOP) (Somers et al. 2023).
2. Fishery-dependent length and age composition data were obtained from the following sources:
    a. Commercial composition data come from the California Cooperative Groundfish Survey (CCGS) sampling program in years ranging between 1978–2024 for lengths and 2007–2024 for ages. Data were obtained from PacFIN.
    b. Recreational length composition data from state sampling programs or historical sampling efforts ranged from 1959–1960 and 1980–2024 and were obtained from CDFW, online reports, and RecFIN.
3. Fishery-dependent relative abundance trends were obtained from the following sources:
    a. Recreational catch and effort data from the private/rental mode of the recreational fleet were obtained from CRFS via RecFIN for years 2004–2022.
4. Fishery-independent data, which include length and age composition data and relative abundance trends were obtained from two different surveys:
    a. The California Collaborative Fisheries Research Program (CCFRP) provides an index of abundance and corresponding length and age composition data and was included for years 2017-2024.
    b. The ROV survey by the CDFW in collaboration with Marine Applied Research and Exploration (MARE) provides an index of abundance and corresponding length

composition data, which were included for two super-year periods, 2014–2016 and 2019–2021. Data were combined within each super-year for the index, but used as individual years for length compositions.

   c. Paired age and length samples collected by Jeff Abrams for his thesis at Cal Poly Humboldt (Abrams 2014) are included as a growth fleet in the model to inform internal estimates of growth as well as to inform recruitment patterns.

5. Estimates of life history parameters were generated from various sources, and include:
   a. Updated maturity schedule from fish sampled in California by the SWFSC's Santa Cruz lab with the analysis assuming functional length-at-maturity.
   b. Updated fecundity relationship from fish sampled in California by the SWFSC's Santa Cruz lab and fitting fecundity as a power function of length.
   c. Value for natural mortality based a new compilation of existing age samples along the West Coast of the U.S. and Canada and reconsideration of an appropriate assumed maximum age for California.
   d. Updated weight-at-length relationship as estimated from measured recreational samples in MRFSS and CRFS, as well as from the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey (WCGBTS). These sources were the only ones with measured weights.
   e. Estimates of ageing error for break-and-burn ages were calculated from double reads of otoliths as provided by the Pacific States Marine Fisheries Commission (PSMFC) Cooperative Ageing Project (CAP).

The years of available data as used in the base model are illustrated in Figure 3. Length data are reported as fork length. Any measurements in total length were converted to fork length following the conversion in Echeverria and Lenarz (1984).

2.2 Fishery-Dependent Data

2.2.1 Total Removals

Removals (1916–2024) for quillback rockfish were compiled from multiple data sources. This assessment uses total removals (landings plus dead discards) for all fishing fleets. Sources for total removals are described below. In instances where separate data sources were used for landings and dead discards, each component is described separately. The values for total removals used in the base model are provided in Table 1 and Figure 2.

2.2.1.1 Commercial Landings and Discards Commercial landings for quillback rockfish were combined into a single fleet by aggregating across gear types (nearly all hook and line, either as longline or pole gears) and fish landed live versus dead. This choice was based on similarities in the length distributions among gear types and between fish landed live versus dead within PacFIN samples in areas and years of overlap.

Commercial landings data were available from 1916–2024. Historical landings (1916–1968) were obtained from the California Catch Reconstruction Project (Ralston et al. 2010). The reconstruction covered all of California, but only the northern port groups of Crescent City, Eureka, and Fort Bragg had landings for quillback rockfish. Additional landings caught off the coast of Oregon or Washington but landed in California for 1948–1968 were added to the reconstruction to represent total landings at California ports. These additional landings were small in magnitude; no more than 0.08 mt was landed in any one year and approximately 0.3 mt was landed across all years. Landings for 1969–1980 came from CalCOM, and were negligible for quillback rockfish.

Recent (1981–2024) landings were obtained from PacFIN (extracted 03/14/2025). There were no landings for quillback rockfish within PacFIN for the years 1981–1983, and 1985. Sampling occurred during these years, and so estimates of zero were not due to a lack of sampling. Given that landings in the immediate preceding years were negligible, we kept landings for quillback rockfish in these years at zero, rather than interpolate between years. These years of low landings were immediately followed by an estimate of high landings in 1991 which is the result of procedures used by CalCOM to attribute species-specific landings samples to larger, unsampled landings quantities.

Commercial discard data for quillback rockfish are collected through the National Oceanic & Atmospheric Administration (NOAA)'s WCGOP. Estimates of dead discards in 2002–2023 for each sector of the commercial fleet are provided in the GEMM product (Somers et al. 2023, and publicly available). Dead discards from the GEMM product for California quillback rockfish were added to landings estimates from PacFIN to obtain total removals for 2002–2023. Biological samples of quillback rockfish discards from WCGOP were available from 2004–2022, but were very sparse for all years other than 2022. As there was limited information with which to estimate selectivity of the discards over the majority of years, we added dead discards to landings and used total removals as the catch stream in the model.

Total removals prior to 2002, for which no WCGOP data are available, were calculated based on assuming an average ratio of dead discards to landings (0.25%), based on WCGOP data from the nearshore sector in 2002–2021. The nearshore sector was selected as it most likely represents expected fishery behavior prior to 2002, and data from 2002 to 2021 were used because the ratio of dead discards increased in 2022 and 2023, likely as a consequence of management changes to the fishery. Preliminary estimates of dead discards for 2024 were provided by the Northwest Fisheries Science Center (NWFSC) Fisheries Observation Science (FOS) program on 3/31/2025 and added to landings in that year to obtain total removals for 2024.

2.2.1.2 Recreational Landings and Discards

Recreational removals for quillback rockfish were combined across private/rental and party/charter modes, which both use hook-and-line gear. This choice was based on similarities in the length distributions between these fishing modes within RecFIN samples in areas where both occurred.

Recreational landings data were available from 1928–2024. Historical landings (1928–1980) were obtained from the California Catch Reconstruction Project (Ralston et al. 2010). Since 1980, recreational data sources provide estimates of total removals, which combine landings and dead discards. Data during these years were obtained from the MRFSS (1980–2004; extracted 10/17/2024) and CRFS (2005–2024; extracted 1/24/2025) datasets via the RecFIN website. While the MRFSS dataset includes data from 2004, samples in this year were collected by the CRFS sampling program. Although the MRFSS sampling program also includes removals for 1980, landings from the historical reconstruction were preferred for 1980. This is because Ralston et al. (2010) considered their 1980 estimate to be more reliable than that of MRFSS, and likely survey quality problems related to 1980 being the first year of MRFSS (Karpov et al. 1995; Cope and Key 2009).

Estimates of dead discards for the historical years (1928–1980) were calculated based on an average ratio of dead discards to landings (1.1%) from MRFSS data across all years 1980–2004. A direct breakdown of the landed and dead discarded fish by weight was not available within the

MRFSS data, so the discard ratio was derived by dividing the number of fish discarded dead (not available to be observed by the sampler) by the total number discarded and retained (MRFSS column ESTHARV divided by the sum of columns ESTHARV and ESTCLAIM). Landings and dead discards for the historical years were then added together to obtain estimates of total removals.

A number of years with missing or incomplete estimates for recreational total removals were interpolated by the Stock Assessment Team (STAT) with guidance from CDFW. First, 207 CRFS catch records in RecFIN between 2014–2022 had a zero estimate for dead discards by weight but not by number. Total removals were based on weight, so to ensure these records with zero weight were included, an average weight per fish for dead discards was calculated from records with both weight and number, and used to derive estimates of dead discards in weight. Filling in these gaps increased the estimated total removals from between 0.02 mt to at most 1.2 mt in any one year. Second, the MRFSS sampling program did not sample between 1990–1992, and did not sample party/charter vessels north of San Luis Obispo between 1993–1995. Estimates for the party/charter mode in 1993–1995 were calculated as the average of party/charter removals among MRFSS years (1980–2004) and then added to the private/rental estimates in 1993–1995 to obtain total removals for those years. Estimates of total removals for both the private/rental and party/charter modes in 1990–1992 were obtained as averages from neighboring years. Total removals in 1990 was estimated as the average of total removals from 1987–1989, total removals in 1991 as the average from 1987–1989 and 1993–1995, and total removals in 1992 as the average from 1993–1995. The estimate of total removals in 1993 was one of the largest for the recreational fleet across all years, and so the effects of assuming an average catch in 1991 and 1992 based on the 1993 estimate was explored as a sensitivity analysis (see Section 3.5.4).

The COVID-19 pandemic impacted CDFW CRFS sampling in 2020 and 2021. No sampling occurred at all from April-June, 2020. CDFW provided proxy values for these months (M. Parker, CDFW, pers. comm., 12/4/2024). Total proxy values for quillback rockfish in weight were summed across districts and added to the existing estimate for 2020 from RecFIN. In addition, California recreational total mortality estimates in the “rockfish genus” category were inflated due to CRFS samplers being unable to closely examine catch and identify catch to species. This was a problem for both private/rental and party/charter modes in 2020 and primarily for the party/charter mode in 2021. Some of the rockfish genus mortality was reallocated to other rockfish species for these modes and years and provided by CDFW (provided on 12/5/24). An expected value of rockfish genus mortality in 2020 and 2021 was generated by mode and year according to the average proportion to the total rockfish mortality that this category represented in 2018 and 2019, when regulations were consistent with 2020 and 2021. Mortality above this expected value was attributed to the other species also based on proportions each species represented to the total from 2018 and 2019. Calculations were made by year, mode, and district. The shore-based modes were grouped in with the private/rental mode. Calculations were initially made in numbers of fish because rockfish genus mortality is only recorded this way. Numbers of fish by species were then converted to weight in kilograms based on average weights of fish recorded by the CRFS program by district in 2019. Total reallocated values for quillback rockfish weight were summed across modes and districts and added to existing estimates, which for 2020 was the sum of the proxy value and the estimate from RecFIN, and for 2021 was the estimate from RecFIN.

2.2.2 Composition Data

Sampling programs to determine species compositions of commercially landed catches began in the late 1960s but the first rigorous monitoring programs that included routine collection of biological data (e.g., sex, age, size, maturity) began in 1980. Currently, port biologists employed by PSMFC with the CCGS collect species composition information and biological data from the landed catches of commercial vessels that have completed their fishing trips. The monitoring programs currently in place are generally based on stratified, multistage sampling designs.

The biological characteristics of recreational landings were not consistently sampled for scientific purposes until the late 1970s, although a few studies occurred as early as the late 1950s. The first rigorous monitoring programs that included routine collection of biological data (e.g., sex, age, size, maturity states) began in 1980 by the national MRFSS program under the PSMFC and by state sampling programs. State sampling programs replaced MRFSS in the 2003–2004 period to better support in season management. Currently, port biologists employed by CDFW collect catch, effort, and biological data from the landed catches of recreational vessels that have completed their fishing trips. Onboard sampling also occurs on party/charter vessels.

Twenty-one bins from 10 to 50 cm (2 cm bin size) were used to summarize the length frequency distributions for sources of removals. The first bin includes all observations less than 10 cm and the last bin includes all fish larger than 50 cm. Sixty bins from age 1 to age 60 (1 year bin size) were used to summarize the available age distributions. These ranges encapsulate all ages sampled. Conditional-age-at-length data were used for age compositions, and are described in more detail in Section 3.3.4. Age data used in the model were from break-and-burn otolith reads, as aged by the CAP lab in Newport, Oregon.

Length samples were nearly entirely unsexed, while all age samples included information on sex. Given the limited information in the literature of sexual dimorphism for quillback rockfish (Lenarz and Echeverria 1991), and that the majority of lengths were unsexed, length frequency compositions were calculated combined across sexes and unsexed fish.

2.2.2.1 Commercial Length and Age Composition

The CCGS is the only fishery-dependent sampling program that collects otoliths as part of the sampling design. Length and age samples were collected from commercial landings and extracted from PacFIN (extracted 03/17/2025). Length samples were available starting in 1978, but were very sparse prior to 1991. Lengths were most numerous during the 1990s, and since 2002 the number of length samples has been relatively low. Age samples were available starting in 2007, but only included one fish in 2011 and four in 2012 until being consistently available starting in 2019. Length and age compositions were combined across gear types based on similarities in length distributions among gears in areas where they both occurred.

The length observations were expanded to the sampled cluster level, to account for any fish that were not measured, then to the trip level to account for the relative size of the landing from which the sample was obtained. These expanded length observations were then combined within a year and used for the base model.

The input sample sizes for the expanded commercial length data were calculated via the Stewart Method (I. Stewart, pers. comm., IPHC, and developed at NWFSC) based on a combination of the number of trips and fish by year:

$$\text{Input effN} = N_{\text{trips}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{trips}} < 44$$

$$\text{Input effN} = 7.06 * N_{\text{trips}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \geq 44$$

This same calculation was also used for age composition data when marginal distributions were used, but that was only done as a sensitivity (see Section 3.5.4). For the base model, conditional-age-at-length distributions were used and sample sizes were based on the total number of age samples.

The magnitude of sampling for lengths and ages from the commercial fleet each year is given in Table 3 and Table 4. These tables show both the total number of fish sampled as well as the number of trips by year over which samples were obtained. Table 3 also shows the sample size for expanded length compositions as used in the base model, which was calculated using the formula above. Sparse length and age composition data occurred in several years. Years where sample size for expanded length compositions were less than or equal to five, and years with fewer than 30 samples for conditional-age-at-length were excluded from the base model during fitting. Implications of these choices were tested as a sensitivity (see Section 3.5.4).

Commercial length and age frequency distributions are shown in Figure 4–Figure 6. Commercial lengths initially covered a relatively broad range of sizes, approximately 20 cm to near 50 cm in 1991–2002 (Figure 4). Since 2003, the range of observed sizes has shifted away from smaller sizes, from around 30 cm to near 50 cm. This shift in observed sizes is also reflected in the mean lengths observed by year, which have increased from around 33 cm to around 43 cm between 2000–2016 (Figure 5). The shift in mean size could be due to shifts in fishery behavior, market demand, sampling (there was a shift to more northern port groups during the mid 2000s and early 2010s), changes in the population demographics (e.g., lack of recruitment or presence of a dominant recruitment pulse), and likely a combination of multiple factors. Commercial ages cover a narrow period of years and ages range from around 5 to 45 years old (Figure 6). The range of age at a given length can be broad, and varies by age. Given the limited timeframe over which ages were sampled, patterns of cohorts are not easily discernible.

2.2.2.2 Recreational Length Composition

Recreational length composition data were obtained from a variety of sources. The primary sources of length samples were obtained from the MRFSS sampling program for years 1980–2003 and from the CRFS sampling program for years 2004–2024 via the RecFIN website (extracted on 11/22/2024 for MRFSS and 3/14/2025 for CRFS). Samples with lengths greater than 60 cm (N = 3) and from shore-based and beach-bank modes (N = 6) and using spear gear (N = 2) were not considered representative and so were excluded. Lengths of fish measured by samplers onboard vessels prior to being released (type 3d data; N = 49) were included among the data extracted from the CRFS sampling program. California has no aged samples of quillback rockfish available from recreational sampling within RecFIN, and so only length composition data were used to represent recreational landings.

Age data that could represent the recreational fleet included age samples from CDFW for the private/rental mode and cooperative research samples from SWFSC for the party/charter mode. However, the length distributions were not similar to those in RecFIN from the same time period and not all programs had sufficient sample sizes. Therefore, these ages were not included in the base model, but were used to inform initial parameters of growth (i.e. external estimates of growth; see Section 2.4.5 for details).

Lengths sampled from the Deb Wilson-Vandenberg onboard party/charter observer survey for 1987–1998 were obtained from the SWFSC (Reilly et al. 1998; Monk et al. 2016). Between

1987–1989 and 1993–1998 there were recreational length data for the party/charter mode from both MRFSS and the Deb Wilson-Vandenberg data sets. During data exploration it was determined that the lengths in MRFSS from 1997 and 1998 were collected as part of Deb Wilson-Vandenberg's survey, indicating that these data sources were duplicated for at least these years. In order to avoid known duplicate data for 1997–1998, length data from the MRFSS sampling program for party/charter mode in these years (N = 123) were excluded from the base model.

Length samples collected from a sampling survey in 1992–1998 by CDFW were obtained from online reports (Geibel and Collier 2025, extracted on 1/8/2025). These lengths were limited to a single northern district (Redwood), and were sampled from private/rental vessels only. While limited in spatial scale, these data were collected as part of a robust survey design separate from other sampling programs. This study also represents a large sample size (n = 600), and provides information on a fishing mode not covered by the Deb Wilson-Vandenberg data. The data therefore were included in the length compositions for the base model.

Lastly, historical data were available from two additional sources. A dockside sampling effort was undertaken by CDFW during the 1950s–1970s to collect data from the private/rental and party/charter modes. Data collected from 1958 to 1972 was from Miller and Gotschall (Miller and Gotshall 1965) and Miller and Geibel (Miller and Geibel 1973), however samples of quillback rockfish were only available for 1959–1960. Within these years, 45 quillback rockfish lengths were collected from party/charter vessels and 45 from private/rental vessels. While limited in sample size, these data cover the central to northern districts and represent the only data from this time period, and so these data were included in length compositions for the base model.

The approach to determine the input sample sizes for the recreational length data varied by data source. Some data sources had unique trip numbers within the data such as the Deb Wilson-Vandenberg data and the MRFSS sampling program. For other data sources that lacked a clear trip identifier we used combinations of multiple fields to attempt to estimate unique combinations that represented the number of trips sampled. In general, the number of trips was estimated based on a combination of time, location, and fishery type. The number of trips for length compositions from the CRFS sampling program was estimated using sampling date, sampling site (RecFIN columns COUNTY_NUMBER and INTERVIEW_SITE), fishing area, and mode. The number of trips from Geibel and Collier (2025) was estimated using sampling date and sampling port. The number of trips from Miller and Gotshall (1965) was estimated using sampling year and month, sampling port, and mode. The number of trips from Miller and Geibel (1973) was estimated using sampling year, sampling county, and mode. Collectively, the estimates for the number of trips are meant to represent a reasonable starting point that generally reflects the degree of similarity of information from sampling a given number of likely similar fish within any sampling event.

The magnitude of sampling for lengths from the recreational fleet each year is given in Table 5, which shows the different sampling frequencies employed over different time periods. This table shows both the total number of fish sampled as well as the number of assumed trips by year over which samples were obtained. The highest number of samples has occurred in years since 2004. As was applied for commercial composition data, years where sample size for length compositions were less than or equal to five were excluded from the model during development. Implications of this choice were tested as a sensitivity (see Section 3.5.4). Across all recreational data sources, length frequency data were aggregated across party/charter and private/rental modes based on similarities in length distributions in areas where they both occurred.

The recreational length frequency distribution is shown in Figure 7. The recreational fleet catches slightly smaller fish on average relative to the commercial fleet, but encounters a wider range of sizes, possibly due to the lack of size preference for the recreational fleet and the inclusion of released fish lengths. The distribution of lengths of quillback rockfish observed by the recreational fleet has generally ranged between 20 and 50 cm. Samples in years prior to 1984 were generally of larger fish but had smaller sample sizes than in more recent years. Increases in size can be seen from the early 2000s to approximately 2015, and an influx of smaller sized fish started around 2015. The mean length observed by year shows these patterns more clearly (Figure 8). Fish sizes were larger (around 40 cm) but more variable in the earliest years and declined to around 30 cm in 1990. Starting around 1995, mean length began to increase, and reached a peak slightly below 40 cm in 2013, similar to the trend in commercial lengths. Patterns since 2015 are less clear, though 2024 was a unique year given the regulations prohibiting quillback rockfish retention. The effect of excluding 2024 length data for the recreational fleet was explored as a sensitivity analysis (see Section 3.5.4).

2.2.3 Abundance Indices

Several data sources were explored for potential indices of abundance representing the recreational fleet. The primary survey data sources for recreational fishing are the MRFSS and the CRFS. Both sampling programs conduct angler interviews during dockside sampling for both party/charter and private/rental vessels. The frequency of quillback rockfish in both the MRFSS and CRFS party/charter datasets and the MRFSS private/rental dataset is insufficient to create indices (see Section 2.6). We also found that the Deb Wilson-Vandenberg onboard observer survey, conducted concurrently with MRFSS, contained insufficient observations of quillback rockfish for developing an index. Therefore, the only recreational fishery-dependent index included in the model was a standardized index of abundance modeled using CRFS private/rental dockside angler interview data.

Catch and effort data from the CRFS dockside sampling of private/rental boats between 2004 and 2023 were provided by CDFW (provided on 12/09/2024). This index represents the longest available time series compared to other indices used for the base model. The data included catch by species, number of anglers contributing to the catch, angler-reported area of fishing, gear, county, port, interview site, year, month, and CRFS district. Ultimately, only data through 2022 were used. See Section 10 for details on the data filtering, processing, and model selection. The CRFS private/rental index of abundance was highest in 2006 and has a declining trend through 2022 that is comparable to the value from 2004 (Figure 9).

2.3 Fishery-Independent Data

The base model includes relative abundance indices and length composition data from two primary sources of fishery-independent data: the CCFRP hook-and-line survey and the CDFW ROV survey. Fishery-independent ages included in the base model include those from CCFRP and those collected from the thesis study of Jeff Abrams (Cal Poly Humboldt, Abrams 2014).

2.3.1 California Collaborative Fisheries Research Program

The CCFRP, is a fishery-independent hook-and-line survey designed to monitor nearshore fish populations at a series of sampling locations both inside and adjacent to MPAs (Wendt and Starr 2009; Starr et al. 2015). The CCFRP survey began in 2007 along the central coast of

California and was designed in collaboration with academics, NMFS and CDFW scientists, and fishermen. In 2017, the survey expanded beyond the four MPAs in central California (Año Nuevo, Point Lobos, Point Buchon, and Piedras Blancas) to include the entire California coast. Fish are collected by volunteer anglers aboard party/charter vessels guided by one of the following academic institutions based on proximity to fishing location: Cal Poly Humboldt; Bodega Marine Laboratories; Moss Landing Marine Laboratories; Cal Poly San Luis Obispo; University of California, Santa Barbara; and Scripps Institution of Oceanography. Quillback rockfish were rarely observed south of the Farallon Islands and so this index represents the MPAs and reference sites from the Farallon Islands and north. Surveys consist of fishing with hook-and-line gear for 30-45 minutes within 500 by 500 m grid cells randomly stratified by site within and outside MPAs. All sites are sampled every year. Prior to 2017, all fish were measured for length and released or descended to depth. Since 2017, a subset of quillback rockfish encountered in the reference areas were sampled for otoliths and fin clips.

2.3.2 ROV Survey

ROV surveys have been used to monitor California's mid-depth habitats (30–100 m) since 2004. While surveys have been conducted since 2004, it has been possible to conduct surveys at only a few locations each year. Efforts to systematically select survey locations representative of the full California coastline began in 2014 and a full complement of these locations has taken three years to complete. Therefore, locations monitored in 2014–2016 and 2019–2021 are considered to represent complete surveys and were analyzed by CDFW as two super years centered on the mid-point of each period (2015 and 2020). The survey is a collaboration between CDFW and MARE. The survey was initially developed to assess the MPA network. Sampling has been conducted at MPAs along the entire California coast with 500-meter transects conducted within rocky reef habitat inside and outside each MPA. A full description of survey methods is available in (Lauermann et al. 2017). Data includes counts of fish by species, stereo lengths, and a variety of characteristics of the transect location.

2.3.3 Abundance Indices

Methods used to derive the abundance index from the CCFRP for 2017–2024 are described in Section 10. The lowest value in the index occurs in 2019 and the highest in 2024, with an increasing trend since 2021 (Figure 9). The ROV survey relative abundance index was derived by CDFW staff and the methods are also described in Section 10. For both indices, index predictions for density inside and outside MPAs are weighted by the estimated relative abundance of habitat in those areas, which is 20% for inside MPA sites and 80% for outside MPA sites. The ROV index suggests an increase in abundance between 2015 and 2020 (Figure 9), which was more pronounced inside than outside MPAs.

An additional effort was made by staff at the SWFSC to estimate an absolute abundance estimate of quillback rockfish inside MPAs from the ROV survey data to compare with model estimated abundance (T. Rogers, SWFSC, pers. comm.). The estimates from this effort are described in Section 11, and are not included in the model.

2.3.4 Length and Age Composition

The magnitude of sampling for lengths from fishery-independent sources is given in Table 6, which shows the different sampling frequencies over time. Input sample sizes in the base model were equal to the total number of drifts (for CCFRP) or transects (for ROV) that collected a quillback rockfish. As was done for fishery-dependent sources, years with input sample size less than or equal to five were not included in model fitting, which only occurred in 2016 for ROV samples. The magnitude of sampling for ages from fishery-independent sources is given in Table 7, which includes age samples used in the base model as conditional age-at-length data for the CCFRP and growth fleets, as well as age samples used to inform initial parameters of growth (see Section 2.4.5 for details). Input sample sizes in the base model for conditional ages were equal to the number of ages.

The CCFRP length and age samples were available for years from which the index was calculated, 2017–2024. A total of 1321 length samples were collected, showing smaller sampling effort compared to the recreational fleet during the same years with the exception of 2024. Length compositions were weighted according to whether they were collected inside or outside MPAs using the approximate percentage of habitat inside (20%) and outside (80%) of MPAs. The length frequency distribution for CCFRP is shown in Figure 10. The range of sizes is wider compared to fishery-dependent sources, approximately 15–45 cm, which may be due to sampling areas both open and closed to fishing. A greater proportion of smaller sized fish was sampled after 2020, which is also shown when looking at annual mean sizes (Figure 11). No other strong patterns are evident in the length data. The CCFRP collected 170 otoliths across the years of the index from reference sites only. Ages were sparse and collectively ranged from approximately 5-35 years old with a few older samples and displayed a narrow range of ages within length bins (Figure 12). Ages were generally younger in the CCFRP samples than the commercial samples though the oldest aged fish was observed by CCFRP.

Jeff Abrams conducted a study from 2010–2011 across three ports in northern California; Fort Bragg, Trinidad, and Crescent City (Abrams 2014). He used a stratified random design of distance from port for each of the three locations and sampled across 60 days aboard party/charter vessels. The survey gear was selected to mimic that used by the recreational fishery. The 116 available quillback rockfish otoliths were used as conditional age-at-length within a growth fleet and represent a portion of the coast not included in the CCFRP data. Ages ranged from approximately 10-30 years old, with one older sample near 45, and covered a wide range of length bins (Figure 13).

ROV stereo length samples were available from 2015–2021. Length composition data were included in the model as actual years rather than super years. A total of 679 stereo length samples were available, showing smaller sampling effort compared to the recreational fleet during the same years. As was done for CCFRP samples, length compositions were weighted according to whether they were collected inside or outside MPAs based on the approximate percentage of habitat inside (20%) and outside (80%) of MPAs. The length frequency distribution for ROV is shown in Figure 14 and shows a wider range of lengths than other fleets, from 10–50 cm. The length composition aggregated across all years shows a bimodal distribution with a mode of small fish between 10–25 cm. This is likely because the ROV is a visual survey, that it is able to select smaller fish than sampling with hook and line gear. The mean length of fish observed by the survey was highest in 2015, lowest in 2019, then increased through 2021 (Figure 15).

2.4 Biological Parameters

2.4.1 Natural Mortality

Natural mortality was not directly measured, so life-history based empirical relationships were used. The Hamel and Cope (2022) method for developing a prior on natural mortality (M) for

West Coast groundfish stock assessments combines meta-analytic approaches relating the M rate to other life-history parameters such as longevity, size, growth rate, and reproductive effort to provide a prior for M. They re-evaluated the data used by Then et al. (2015) by fitting the one-parameter A_{max} model under a log-log transformation such that the slope is forced to be -1 in the transformed space (Hamel 2015). The point estimate and median of the prior is:

$$M = \frac{5.4}{A_{\text{max}}}$$

where A_{max} is the maximum age. The prior is defined as a log-normal distribution with parameters $\mu = ln(5.4/A_{\text{max}})$ and $\sigma = 0.31$. Using a maximum age of 80 years, the point estimate and median of the prior for M is 0.068 per year.

The maximum age assumed for calculating natural mortality in the base model was 80 years. The value of 80 was obtained from a database of 34,564 age reads for quillback rockfish from California to Alaska (C. Stuart, Cal Poly Humboldt, pers. comm.) as the maximum age from inside British Columbia waters, and balances the risk associated with a choice of younger samples along the U.S. West Coast and older samples observed in the literature and sampling programs. A maximum age of 95 years for quillback rockfish from southern British Columbia is often referenced in the literature (Yamanako and Lacko 2001; Love et al. 2002; Palsson et al. 2009). Yamanako and Lacko (2001) do not include a figure of the spread of their age estimates, but COSEWIC (2009) provides a figure that appears comparable, and shows the next oldest age sample as 80 years. A maximum age of 90 years from southeast Alaska is also referenced among the age validation literature (Cailliet et al. 2001; Munk 2001; Kerr et al. 2005). Literature estimates were larger than the oldest aged quillback rockfish along the U.S. West Coast (73, 70, and 69), which were sampled from Washington in 1999, and much larger than the oldest aged quillback rockfish among California samples used for this assessment (57, 51, and 46). We are not aware of other species with as large of a range of ages observed from California to Alaska as is seen for quillback rockfish. Given that California samples are from recent years, and relatively sparse compared to samples from other regions, it may be expected that older fish would not be observed.

2.4.2 Weight-at-Length

The length-weight relationship for quillback rockfish was estimated outside the model using available California biological data collected from fishery-independent (WCGBTS) and fishery-dependent (MRFSS and CRFS) data sources (Figure 16). Only measured weight and length values were used; any values from the MRFSS dataset with more than two decimal places were assumed to be calculated from another measurement and were excluded. The estimated length-weight relationship for California quillback rockfish was:

$$W = 1.57769 \times 10^{-5} L^{3.08018}$$

where L is fork length in cm and W is weight in kg.

2.4.3 Maturity

From 2019 to 2025 a total of 88 histological samples were collected from female quillback rockfish caught off the coast of California (16 by CCFRP and 72 by the SWFSC). The samples were read by Melissa Head at the NWFSC for identification of microscopic functional maturity stage. Functional maturity accounts for abortive maturation and the proportion of oocytes in atresia (cellular breakdown and reabsorption), which could indicate skipped spawning (M. Head, NWFSC, pers. comm.). Seven samples were excluded due to uncertainty in whether the female was spent/resting or experienced abortive maturation, due in part to the timing of the collections during the non-spawning months. The remaining 81 samples ranged in size from 21–45 cm. The six females collected from north of Pt. Arena (Crescent City and Eureka) were all mature. The estimated maturity ogive for California quillback rockfish was $L_{50\%}$ = 28.96 cm with a slope of -0.606 (Figure 17). This is slightly smaller than the value of $L_{50\%}$ = 29.2 used in the 2021 assessment, and still consistent with other studies for quillback rockfish along the U.S. West Coast, which provide a range of 26-32 cm (Rosenthal et al. 1982; Echeverria 1987).

2.4.4 Fecundity

The fecundity-at-length was based on ovary samples collected by the SWFSC Santa Cruz lab in 2023 and 2024. Two subsamples were collected from each female. Of the females collected during the spawning months, 24 fish were at stage 2, with pre-fertilized vitellogenic eggs. The fecundity relationship for quillback rockfish was estimated to be equal to:

$$F = 4.216 \times 10^{-8} L^{4.44}$$

where F is fecundity in millions of eggs and L is fork length in cm (Figure 18).

2.4.5 Growth (Length-at-Age)

The majority of length-at-age data available for California quillback rockfish were collected in the last five years. Only 21 otoliths from the WCGBTS were read and available at the time of the 2021 assessment, but efforts during the subsequent reviews resulted in 122 additional age reads by the time the assessment was finalized. However, growth in the final 2021 model did not change throughout the review process and was fixed to the same external fit as the models for Washington and Oregon. Efforts since the 2021 assessment have resulted in substantially more age samples collected and read across a variety of data sources.

A total of 1038 age reads were available from otoliths collected from quillback rockfish off the coast of California from 1985–2024 across a variety of sources (Table 4; Table 7). Ages from the commercial fleet and from CCFRP and Abrams were used in the base model, but the remaining 450 available ages were used in initializing growth parameters and were not included in the base model. The sources of these remaining ages include:

- The WCGBTS (N = 34)
- The SWFSC Groundfish Cooperative Data Collection program during the 2022 fishing season (N = 134)
- The SWFSC life history research activities (N = 96)
- The CDFW purchased quillback rockfish from commercial vessels (N = 6)
- The CDFW groundfish team sampled recreational private/rental vessels (N = 55)
- Fish surrendered to CRFS samplers (N = 111)
- The International Pacific Halibut Commission (IPHC) Fishery Independent Setline Survey (FISS) (N = 5)
- Miscellaneous sampling that could not be tracked to a specific data source (N = 9)

In addition to these 450 age reads not used in the base model, 192 age-zero fish from Diana Baetscher's dissertation work (Baetscher 2019) trapping young-of-the-year rockfish within

Monterey Bay using Standard Monitoring Units for the Recruitment of Fishes (SMURF)s and divers with nets were also available and used to inform initial parameters for growth. The quillback rockfish captured were morphologically identified as gopher (*S. carnatus*), copper, or kelp (*S. atrovirens*) rockfish, but were genetically identified as quillback rockfish.

External estimates of growth from ages across the range of quillback rockfish do not indicate sexually dimorphic growth (C. Stuart, Cal Poly Humboldt, pers. comm.), as also found by Lenarz and Echeverria (1991). A number of the quillback rockfish collected for biological studies targeted females, and so, combined with lack of evidence for sexual dimorphism, we did not estimate dimorphic growth for the California-specific data.

The estimated growth curve from the available data, estimated externally to the base model, was

$$L_\infty = 41.18cm; k = 0.178; t_0 = -0.57cm$$

where L_∞ is the asymptotic average length, K is the growth coefficient with units $year^{-1}$, and t_0 represents the time when the average length was zero (Figure 19). The external estimate of L_∞ is comparable to literature values, while the estimate of K is on the higher side of literature values which vary from 0.06–0.19 (Yamanako and Lacko 2001; Palsson et al. 2009; West et al. 2014). Note that Stock Synthesis typically uses the Schnute parameterization of vonBertalanffy growth, and so t_0 was converted to a value of $L_{age=1} = 10$ cm. The external estimates were used to initialize the growth curve in the model, and differ from the growth parameters ultimately estimated internal to the base model.

2.5 Environmental and Ecosystem Data

This model does not explicitly include environmental or ecosystem data. Quillback rockfish are a rocky habitat associated species and the area of available habitat was considered when developing indices of abundance for the fishery-independent surveys.

2.6 Data Sources Considered But Not Used

2.6.1 National Marine Fisheries Service Survey Indices

The WCGBTS and the Alaska Fisheries Science Center/Northwest Fisheries Science Center West Coast Triennial Shelf Survey (Triennial Survey) collect data off the California coast on rockfish biology and abundance and are commonly incorporated in West Coast groundfish assessments. The Triennial Survey operated between 1977–2004 and WCGBTS has operated since 2003. None of these fishery-independent surveys had adequate sample sizes of quillback rockfish off California to include as abundance indices for this assessment. There were no more than ten positive tows of quillback rockfish in any one year coastwide in the WCGBTS, and only seven positive tows in California. Similarly there were no more than five positive tows of quillback rockfish in any one year coastwide for the Triennial Survey, and only one positive tow in California. Given that indices of abundance were not calculated due to small sample sizes, length composition data from the WCGBTS (N = 39) and Triennial Survey (N = 1) off California were not included in the base model.

2.6.2 Marine Recreational Fisheries Statistics Survey (MRFSS) Dockside Index

We explored the potential to produce a fishery-dependent index of abundance using private/rental angler interview data. Samplers interviewed private/rental anglers at launch ramps and other onshore sites similar to today's CRFS program run by CDFW. Historic MRFSS records retained by CDFW were used to combine angler and trip data (type 1) with sampler examined catch data (type 3). Type 1 data includes information about fishing mode, location, number of anglers, and their primary and secondary target species for the trip. Type 3 data provides catch information by species including the numbers of fish and their lengths. MRFSS samplers collected data on both observed and unobserved fish. Observed fish could be identified to species by the sampler and measured. Unobserved fish were reported by the angler but unavailable to the sampler for a variety of reasons. Because quillback rockfish may not be correctly identified by anglers, we used data only on observed fish. Additionally, using exclusively observed fish simplifies the calculation of effort (number of anglers) contributing to that catch. Data on observed and unobserved fish were collected on separate forms that lead to complications in accounting for all anglers contributing to a given vessel trip when adding the catch of observed and unobserved fish. The first angler interviewed has been referred to as the "leader" and all subsequent anglers as "followers". Combining type 1 and type 3 data accounts for all observed fish caught by leaders and followers. We also included only trips with fishing effort and complete interviews.

We further filtered this dataset to include trips more likely to catch quillback rockfish and therefore better represent possible quillback rockfish effort. Two fishing location fields were used to exclude inland waters such as bays and estuaries. We excluded southern California counties where quillback rockfish is rare. The time of year was organized into two-month "waves", and we excluded the first wave representing January and February. Fishing for rockfish was prohibited in these months in 2003 for some central and northern California districts. We included only trips with angler reported primary targets of bottomfish and rockfish which also excluded years between 1980 to 1992 when species target data was not collected. Finally, we removed a trip in 1993 with an outlier catch of 120 quillback rockfish. While these filters reduced the overall number of samples by an order of magnitude, quillback rockfish remained rare with only about 2.9% positive samples. The index was ultimately not included in the model due to the very low proportion of samples with quillback rockfish, and very large resulting standard deviations around the average catch per unit effort (CPUE), which provided little contrast across the time series.

2.6.3 Deb Wilson-Vandenberg Survey Index

The Deb Wilson-Vandenberg survey has been used to develop an index of abundance for previous nearshore stock assessments. The survey effort was focused around the San Francisco Bay area and did encounter quillback rockfish. The length information is used to inform the length composition of the recreational fleet, but the index was not representative of the assessment area. The majority of quillback rockfish encountered in the survey were from in and around the Farallon Islands and Cordell Bank, both areas that now have large closed areas.

2.6.4 Commercial Passenger Fishing Vessel (CPFV) Logbook Index

Paper logbooks from the commercial passenger fishing vessel (CPFV), i.e. the party/charter mode, as collected by CDFW in their current form began to be used in 1980. This dataset contains individual trip records with information reported by the vessel captain including numbers of fish by species or species group, the port of landing, the 10x10 nautical mile fishing block and depth where the majority of fishing occurred, the number of contributing anglers, and the number of hours spent actively fishing, among other fields. Captains are required to submit a logbook for each trip and compliance rates have varied over time. In 2017, captains were provided with the option to use an electronic logbook, though the paper logbook is still acceptable. Paper logs are limited in species specific fields. Rockfish are either enumerated in a rockfish genus field that is not species-specific or individual species can be noted using a write-in field. Most rockfish are not speciated on the paper log. The electronic log allows for a greater number of species selections using pull-down menus. A general genus category for rockfish also exists in the electronic log and identification to species is not legally required. We explored this data for its potential to produce an index of abundance or to inform our understanding of party/charter effort and fishing dynamics over time in the context of quillback rockfish.

We filtered the data to focus on trips most relevant to quillback rockfish. We excluded trips south of Point Conception where quillback rockfish are rare by excluding fishing blocks numbered greater than 650, and trips occurring between January and March when fishing for rockfish is prohibited. We included only trips where their target was noted as rockfish and only single day trips. Multi-day trips typically target highly migratory species. Quillback rockfish remained rare following these filters with approximately 0.3% of trips catching quillback rockfish. This was deemed insufficient for production of an index.

2.6.5 International Pacific Halibut Commission (IPHC) Fishery-Independent Setline Survey (FISS) Index

The IPHC FISS is designed to provide catch and biological information on Pacific halibut but does retain records on non-target species. The survey is focused in Alaska and British Columbia and does not frequently extend into California waters, however CDFW is aware of 22 quillback rockfish caught in 2014 and five in 2017 in California waters. Age data are available for the five fish from 2017. These data were considered insufficient for inclusion as an index and in length and age compositions, and ages were only included in the initial external estimate of growth.

3 Assessment Model

3.1 History of Modeling Approaches

3.1.1 2010 Data Limited Assessment

Quillback rockfish was first assessed in 2010 using Depletion-Based Stock Reduction Analysis (DB-SRA) which is a data-limited approach that incorporates catch data with priors on select parameters including natural mortality, the ratio of fishing mortality at maximum sustainable yield to natural mortality, current depletion, and the depletion at maximum sustainable yield to estimate overfishing status, but not overfished status (Dick and MacCall 2010). Quillback rockfish was assessed as a single coastwide stock to generate an overall OFL (median of 14.8 mt in 2010) that was then apportioned to each management area based on the proportion of historical catches north and south of 40° 10' N. Lat. Assuming that current depletion was at the management target on average (e.g. 40%), the 2010 assessment found that quillback rockfish had a 52% chance of experiencing overfishing coastwide.

3.1.2 2021 Data Moderate Assessment

In 2021, quillback rockfish was assessed using Stock Synthesis 3 (Methot and Wetzel 2013) with separate catch and length-based (SS-CL) data-moderate models for each of the three states: Washington, Oregon, and California. These models used catch, length composition, and biological data to assess the portion of the stock within the domain of the model without making assumptions about current depletion. As such, both overfishing and overfished status were estimated. The 2021 spawning output relative to unfished in California was estimated at 0.14 (Langseth et al. 2021a). As such, the portion of the stock in California was found to be overfished and was declared overfished in December 2023 after California quillback rockfish was defined as a stock via Amendment 31 to the Pacific Coast Groundfish FMP (NMFS 2023). The 2021 California model fixed steepness at the prior of 0.72 and natural mortality at 0.057 yr^{-1}, which corresponds to a maximum age of 95 years (Langseth et al. 2021a). A primary uncertainty of the 2021 California model was the treatment of growth parameters. Given limited age samples from California, growth was fixed in the model based primarily on samples from Oregon and Washington.

The 2021 assessment was initially reviewed at the Scientific and Statistical Committee (SSC) Groundfish Subcommittee (GFSC) Workshop in June 2021. Additional requests of the STAT were made during the June Council meeting related to use of additional data sources, age samples, and assumptions about selectivity. The STAT responses to these requests were presented during a follow-up review meeting in August 2021. Additional requests were made of the STAT in August related to growth data and assumptions, as well as a rebuilding analysis, and responses to these requests were presented during the mop-up review in September 2021. During the September 2021 Council meeting, the SSC endorsed the assessment as the best scientific information available as a category 2 stock and the outcome of the September 2021 review meeting did not alter that endorsement. The SSC endorsed the assessment for use in stock status determination and the Council adopted the assessment (Langseth et al. 2021a) and rebuilding analysis (Langseth and Wetzel 2022) at the November 2021 Council meeting.

During the process of updating the 2021 rebuilding analysis for the 2023 assessment cycle, public comments were made at the November 2023 Council meeting related to the new rebuilding analysis and the 2021 assessment on which it was based. The Council requested that these comments be reviewed by the SSC GFSC, and the review occurred in January 2024. The GFSC, in their report, “concluded that the issues raised were considered as part of the 2021 stock assessment or not appropriate given the data limitations and Terms of Reference (ToR) for data-moderate assessments at the time…. The SSC continues to recommend use of the 2021 stock assessment and the adoption of the 2023 rebuilding analysis for California quillback rockfish”.

3.2 Response to Most Recent STAR Panel and SSC Recommendations

A STAR panel was not convened for the review of the 2021 California quillback rockfish assessment. Rather, the assessment was reviewed over a series of GFSC meetings, as described above. The following responses are a compilation from across the reviews and SSC statements spanning 2021–2024, and include recommended research and data needs from the 2021 assessment, and recommendations on future work by the GFSC during the January 2024 review. Requests made during the original 2021 reviews in June, August, and September were incorporated within the final 2021 stock assessment report (Langseth et al. 2021a).

3.2.1 Recommended Research and Data Needs from 2021 Assessment

Recommendation: At the time of the assessment due to issues in California data in PacFIN (i.e., condition code) length samples landed live vs. dead from the commercial fleet were unable to be identified. The ability to examine sample sizes and lengths from each type of landings would allow for future assessments to account for a greater range of commercial fishing behavior.

- **Response**: Condition code or disposition is now an available field in PacFIN. For the current assessment, the commercial fleet was not split into multiple fleets based on disposition. Comparisons of fish sold live and dead showed overlapping sizes in years where both were sold and similar frequency distributions combining all years of samples for live and dead.

Recommendation: Improved understanding of where recreational fishing is commonly occurring (areas and depths) and the range of sizes available by depth would better inform the selectivity form, which currently is near the shape for maturity.

- **Response**: Recreational fishing location information at the level of survey districts is available from the CRFS and MRFSS data sets. We explored both the amount of catch and the size distribution of the catch by district in these time periods and compared these to the abundance and sizes of quillback rockfish from the CCFRP and ROV survey programs. Recreational fishing depth is available from CRFS party/charter mode but not from the private/rental mode. Depth information is available from the fishery-independent surveys. We examined all available information on abundance and size distribution with depth as well as how these varied among regions. These explorations were used to inform selectivity forms and time blocks.

Recommendation: Age data were predominantly from Oregon and Washington waters. Collecting length and otolith samples from recreational and commercial catches in California would result in samples from the entire U.S. West Coast informing growth. Otoliths from the WCGBTS survey would also help inform growth. California otoliths identified and aged during model reviews were insufficient to robustly estimate a separate California-specific length-age relationship given the limited sample size of young quillback rockfish from California. More data, particularly of young and old fish, are needed to be able to robustly estimate a California-specific growth curve and confirm whether growth of quillback rockfish differs between California and Washington and Oregon.

- **Response**: Due to a large effort to collect and process quillback rockfish otoliths from California in the last 5 years, we were able to internally estimate a California-specific growth curve. See Section 2 for further details.

Recommendation: Recruitment patterns showed lower than average recruitment in the 2000s. Additional data to support such patterns in recruitment would provide additional support for model estimates.

- **Response**: The current base model continues to show mostly below average recruitment in the 2000s. We looked to other available recruitment deviation estimate time series for deeper nearshore species and found that both the assessment of northern copper rockfish from 2023 (Monk et al. 2023) and the blue and deacon assessment from 2017 (Dick et al. 2018) also showed mostly below average recruitment in that time period.

Recommendation: Catches of quillback rockfish were particularly high in a few years for both the recreational and commercial fleet. Better understanding the factors contributing to these high catches as well as potential resolutions, should they be needed, would aid in ensuring catch time series are accurate.

- **Response**: Unusually high peaks in recreational and commercial catch estimates were investigated. Consideration was given to a variety of options for modification of the time series to explore the effect of these values on model results. Additionally, the sample data in outlier years was examined along with the expansion/estimation procedures that lead to unusually high values. Ultimately, the decision was made to not modify the time series in favor of consistent estimation procedures across all years. Sensitivity to alternative catch time series is presented in section Section 3.5.4.

3.2.2 Recommendations from 2024 GFSC Review

Within the GFSC's report for the January 2024 review, they provided a summary of the issues raised during the review (their Table 1). The following are a subset of the issues from Table 1 that the GFSC concluded were still potential issues:

Recommendation: It is not clear if the maximum age used represents the California component of the population.

- **Response**: We assumed a maximum age of 80 for the 2025 base model. This decision was based on review of the literature and masters thesis work by Claire Stuart at California State Polytechnic University at Humboldt to develop a database of all documented ages from California, Oregon, Washington, British Columbia, and Alaska. This decision is further discussed in Section 2.4 and the implications explored in Section 3.5.3.

Recommendation: The decline in abundance appears to be driven by the estimated decline in recruitment deviates from 1990-2010, some of which may be compensating for unmodelled changes in selectivity.

- **Response**: Selectivity assumptions in the base model were carefully considered and informed by the regulatory history, comparisons of available catch and length data by region and depth, fits to the data, and likelihoods. Selectivity functional forms and time blocks used in the 2025 base model differ from the 2021 model and are detailed in Section 3.3.4. Sensitivities to alternatives are presented in Section 3.5.4.

Recommendation: The current assessment suggests that the current exploitation rate is very high, and this seems inconsistent for a stock with a significant area of its habitat closed to fishing or unfished.

- **Response**: The base model does estimate that fishing intensity was above the target for several years up through 2022 but has since fallen below target in response to regulatory changes. We estimate that approximately 20% of rocky reef habitat within quillback rockfish range is protected by MPAs. Commercial and recreational season closures and depth restrictions also restrict the proportion of quillback rockfish subject to fishing. It is difficult to determine what proportion of the stock has been off limits to fishing over time as these restrictions vary over time and management area and will also have more or less impact given the relative distribution of rocky habitat with depth. Quillback rockfish in central California have likely experienced relatively high fishing intensity given the placement of depth limits and high fishing effort from Bay Area anglers. Consideration was given to closed areas in a variety of ways. Selectivity time blocks are used in acknowledgement of potential impacts of spatial closures over time. Patterns within MPAs are accounted for by both the CCFRP and ROV survey abundance indices and length compositions. Additionally, we explored an areas-as-fleets approach to account for spatial differences in size of fish caught, which could reflect differences in management and access to fishing grounds among these regions. This approach increases complexity and results in sparse data for some fleet/time period combinations. The population trajectory with the areas-as-fleets model was similar to the results when assuming state-wide fleet structure, and are described in more detail in Section 3.5.4.

The GFSC also proposed future work in their report from the January 2024 meeting. Recommendations specific to quillback rockfish, or to assessment teams in general, include:

Recommendation: The prior for h should be revisited given the results of recent assessments and recent advancements in methods for constructing h priors, such as the approach developed by Marc Mangel (e.g., Mangel et al. 2010).

- **Response**: Steepness was fixed at 0.72 with a standard deviation of 0.16 according to the Accepted Practices Guidelines for Groundfish Stock Assessments in 2025 and 2026.

Recommendation: The next assessment of quillback rockfish in California should explore the development of a recreational and/or CCFRP-based index of abundance, comparable to those developed in recent assessments for vermilion (*S. miniatus*), copper, and other nearshore rockfish species.

- **Response**: Three abundance indices were used in the current base model, derived from the CRFS dockside private/rental, ROV, and CCFRP data sets. Detailed descriptions of these indices can be found in Section 10.

Recommendation: The meeting noted that rejecting the 2021 assessment of quillback rockfish would mean that OFLs would be based on DB-SRA, a "catch-only" method of stock assessment, which is known to be very inaccurate (Free et al. 2020). Research should be conducted to assess what constitutes "too uncertain" given the default of returning to the last assessment, especially in the context of assessments for which there are no previous full or data-moderate assessments.

- **Response**: Stock assessment category assignments are made by the SSC based on recommendations from the STAR panels. It is possible that an assessment could be assigned a higher category given the availability of the requisite data types but in conducting and reviewing the assessment, those data types are found to be insufficiently informative. In such cases, the STAR panel may recommend application of additional uncertainty or precautionary measures and we agree that this is an area that would benefit from research.

Recommendation: It was noted that turning off the sum-to-zero constraint on penalty in Stock Synthesis increases the value of terminal year depletion. This issue was not raised in the earlier Public Comment, and the SSC should consider this matter when revising the terms of references and accepted practices documents.

- **Response**: The current base model uses the constraint. We explored relaxing this assumption and found that the pattern for the 2021 assessments persists under assumptions for our base model. However, if recruitment deviations start in 1990 (see Section 3.5.4) and the sum-to-one constraint is relaxed, model results do not deviate. Consequently, this issue is better explained as a consequence of the sparse composition data available for quillback rockfish.

Recommendation: It was noted that the estimated variances for some recruitment deviations exceeded the value of σ_R, which is unusual (though has occasionally been seen in other assessments) and unexpected, and may indicate model misspecification. This issue was not raised in the earlier Public Comment and should form the basis for further exploration and could be a diagnostic for future data-moderate assessments.

- **Response**: Several estimates for the standard deviation of recruitment deviations in the base model continue to be above σ_R, particularly in the 1980s. High uncertainty in recruitment deviations is likely a result of sparse composition data available for quillback rockfish. We explored starting recruitment deviations after the period of higher uncertainty, as described in Section 3.5.4, and results were similar to the base model.

In addition to the responses to specific comments above, we provide some points of response to general concerns repeated over the duration of the 2021 model review:

- The SSC recommended the next quillback rockfish assessment be another data-moderate assessment at their June 2021 meeting, though later recommended deferring that decision at their November 2021 meeting. The present 2025 assessment is being conducted as a full benchmark assessment due to a large effort that has been made to conduct additional biological research and age reads of collected otolith samples.
- Concern was expressed over the influence of fixed parameters on model results in 2021. All growth parameters are estimated within the current base model. Natural mortality (M) and steepness (h) are fixed, as is common for West Coast groundfish assessments,

particularly those with limited data. However, model investigations showed that M can be estimated while maintaining good fits to the 2025 data. While there is uncertainty regarding the potential longevity of quillback rockfish in California, we considered the resulting M estimate to result in unreasonably short longevity and maintained a fixed M in the base model. Sensitivities and the suggested axis of uncertainty for the decision table further explore this uncertainty.

3.3 Model Structure and Assumptions

3.3.1 Modeling Platform and Structure

This assessment was conducted using Stock Synthesis version 3.30.23.1, compiled December 5, 2024 (available online). The R package `r4ss`, version 1.52.0 (Taylor et al. 2021), along with R version 4.4.1 (R Core Team 2024) were used to investigate and plot model fits. The base model is a single-sex (combined across sexes) and single-area model for the coast of California, though quillback rockfish are rarely caught south of Point Conception. The model includes two fishery fleets (commercial and recreational), two survey fleets (the CCFRP hook and line survey, and CDFWs ROV survey), and one growth fleet used to inform estimates of growth internal to the model as well as other population dynamics. The model begins in 1916, which is the earliest year of the commercial catch reconstruction. The population was assumed to be unfished and at an equilibrium age structure at this point.

3.3.2 Model Changes from the Last Assessment

A number of changes have been made in the base model compared to that used in the 2021 assessment (Langseth et al. 2021a). These involve changes in data, data sources used, and model assumptions. The change with the largest effect includes the addition of age data, including the use of commercial and CCFRP conditional-age-at-length distributions, and also the inclusion of the growth fleet to support estimating growth internally in the model as well as other population dynamics. Additional age data were collected during extensive sampling efforts across multiple agencies since the 2021 assessment but were not incorproated in the base model. The effect of the addition of new data on model results is shown in bridging (see Section 3.3.3 below) and through profiles (see Section 3.5.3 below), and the effect of alternative data choices on model results was explored through sensitivity analyses (see Section 3.5.4).

In general, the synthesis and treatment of data has been altered for this assessment based on updated best practices and extensive work by NWFSC to document, reproduce, and standardize data processing steps, along with extensive work by staff at CDFW and PSMFC in providing consistent and accurate data in a more easily obtainable manner. Documenting each change is unnecessary, as these are expected to be minor, but we do highlight changes in the processing of total removals. Changes in processing catch data include different approaches to filling in missing years for commercial landings in 1981–1983 (assumed zero for this assessment rather than interpolating from neighboring years), recreational removals in 1990–1992 (based on average of neighboring years rather than interpolating nearest years); and inclusion of previously omitted quantities by adding missing private/charter sampling for 1993–1995, and including estimates from recent recreational removals reported in numbers but not in weight. For discards, quillback rockfish in California are now separated out in the GEMM and therefore easier to add to commercial landings for obtaining total removals. The process for calculating historical dead discards resulted in a lower ratio of dead discards to landings for commercial data, and a different ratio (based on use of an alternative field) of dead discards to landings for recreational data.

New data sources were available for use in this assessment that were outside the scope of the data-moderate ToR for the 2021 assessment. Two fishery-independent data sources were added to this assessment: the CCFRP and the ROV surveys. Both of these surveys were developed to monitor fish inside the network of MPAs as well as in adjacent areas open to fishing. The assessment also includes a fishery-dependent index of abundance from the recreational private/rental mode. This is the first assessment for quillback rockfish to include age composition data to support estimates of growth and population dynamics within the base model. As such, ageing error is now included in this assessment.

In addition to new data types such as age and survey data, new data sources not available at the time of the 2021 assessment were now available and used in this assessment. New sampling efforts since the 2021 assessment resulted in updated California-specific estimates for fecundity and maturity. The weight-length relationship was also updated using only California data. Historical length data for the recreational fleet from 1959–1960 was recovered from research conducted by Miller and Geibel (Miller and Geibel 1973) and Miller and Gotshall (Miller and Gotshall 1965), and more recent length data for the recreational fleet from 1992–1997 was made available by Miller and Collier (Geibel and Collier 2025). These data were included in the length compositions in the base model.

Lastly, a number of alternative model assumptions were explored and ultimately used for the base model. These include alternative assumptions around maximum age and therefore natural mortality, alternative parameterization of dome-shaped selectivity curves (using three parameter rather than four parameter), and alternative years for blocking selectivity. In addition, data weighting was done according to the algorithm by Francis (2011) as opposed to McAllister and Ianelli (1997), which was the method used for the 2021 assessment. Sample sizes used for recreational sources were included as approximations of the number of trips as opposed to number of fish, which was done for the 2021 assessment.

3.3.2.1 Model Changes During 2025 STAR Panel At the 2025 STAR panel, changes were made to the amount of newly collected age data used within the base model. The version of the base model brought to the STAR panel included commercial (Table 4) and additional (Table 7) sources of age data for quillback rockfish, with all of the additional ages included as a growth fleet. While sources of age data that fall outside normal sampling programs can be incorporated within assessment models as conditional age-at-length data for a growth fleet according to the Accepted Practices Guidelines for Groundfish Stock Assessments, the panel was concerned about the impact these data had on processes other than growth, namely recruitment. The current base model (i.e. the post-STAR base model) includes commercial ages, moved CCFRP ages outside the growth fleet and into the CCFRP fleet, and removed all but the Abrams collected ages from the growth fleet. The effect of the change made during the STAR panel is shown in the bridging analysis (see Section 3.3.3 below) and the details around the effect of including age data as explored during the panel are provided in sensitivity analyses (see Section 3.5.4). Unless specifically stated otherwise, all references in this document to the base model refer to the version accepted during the STAR panel review.

3.3.3 Bridging Analysis from the 2021 Data Moderate Assessment

The exploration of models began by bridging from the 2021 data moderate assessment model to the newest version of Stock Synthesis, version 3.30.23.1. Using the newest Stock Synthesis version resulted in no difference in spawning output from that estimated in 2021 (Figure 21). From there, bridging from the 2021 assessment model to the current base model followed three primary steps:

1. Update life history information to California-specific estimates including natural mortality, growth, length-weight, maturity, and fecundity.
2. Update data inputs to reflect information currently available. Data was updated by data type (catch, compositions including length and age, and indices), which inherently meant updating data for fleets present in the 2021 assessment and then adding data from fleets added into the current base model that were not in the 2021 assessment.
3. Update selectivity blocks and shapes, and reapply data weighting practices.

To arrive at the final base model, additional revisions were made after these three steps to improve model setup and determine the best fit to the data and following standard practices. These included removing composition data with small sample sizes, making revisions to the recruitment bias adjustment and other model setup values, and then making final revisions to data weightings. Current steps were based on the version of the base model presented at the STAR panel review (i.e. the pre-STAR base model). We add a final bridging run to the last step that includes the change in the model made during the STAR panel review to arrive at the current base model (i.e. the post-STAR base model).

A thorough description of the current base model is presented separately below (Section 3.4). This section is intended only to more clearly identify where substantive changes occurred during the bridging analysis. Sensitivities to some of the components within the steps above are included in Section 3.5.4.

Changes in model output due to updating biological relationships are shown in Figures 22–24. Updating fecundity greatly increased spawning output (Figure 22), which is not surprising given the new curve assumed greater fecundity at larger sizes, but did not have a noticeable effect on spawning output relative to unfished or to summary biomass (Figure 23). Updating natural mortality reduced initial spawning output and increased recent spawning output, leading to a greater degree of recovery in spawning output relative to unfished. Updating growth parameters, which at this point in the bridging analysis were entered as fixed parameters and not estimated, also increased recent spawning output, but to a greater degree than natural mortality, resulting in the largest change in spawning output relative to unfished among individual steps. Both of the fixed L_∞ and K values were lower than the fixed values used for the 2021 assessment, which were $L_\infty = 43.04$ cm and $K = 0.199$ (Langseth et al. 2021a). The pattern of change in population dynamics between the 2021 growth assumptions and the new fixed parameters, and between the values assumed for natural mortality were similar to the patterns based on sensitivities and profiles for these two relationships during the 2021 assessment. Changes to growth compressed the pattern in recruitment from the 2021 assessment (Figure 24), which showed peaks in recruitment deviations above one across many years (1987, 1993, 1996, 1999), to large peaks in only two years (1991 and 1995). Other changes to biology did not greatly alter the pattern in recruitment. Collectively, updating the growth curve and natural mortality contributes to the large change in the degree of recovery in spawning output relative to unfished, while updating the fecundity relationship increases the scale of spawning output (though not the scale of $\ln(R_0)$ or summary biomass).

Changes due to updating data streams are shown in Figures 25–26. Overall, updates to data resulted in less overall change in the estimated population trajectory than did updates to the biological relationships. Updating the fishery catch and length composition data resulted in decreased spawning output across all years such that spawning output relative to unfished conditions was minimally changed (Figure 25). When age composition data were included, spawning output increased, and especially so in recent years. This occurred because of increased recruitment both in the largest recruitment events, estimated at 1993 and 1995 at this point in the bridging analysis and in 2012 (Figure 26). When growth was allowed to be estimated, leading to a lower estimate of K and larger estimate for L_∞ similar to that from the 2021 assessment, recruitment increased in the early 1980s (at 1984) and coalesced around a single peak in the mid 1990s (at 1994), leading to a slightly decreased rate of increase in spawning output in later years. The direction of the change in population trajectory with the change in growth parameters is consistent with the results of the profiles from the 2021 assessment for L_∞ but opposite to the pattern observed in the profiles for K (Langseth et al. 2021a). Growth estimation internal to the model is preferred over estimating growth outside the model, although estimates may be influenced by other data types than just conditional age-at-length. Adding the index data, which includes CCFRP, ROV, and the recreational private/rental indices resulted in decreases in spawning output in the 2000s relative to other steps, driven primarily by lower recruitment in the peak year (estimated in 1995 at this point in the bridging analysis). However, these data show stronger pulses of recruitment in more recent years. As was found in the biological bridging steps, including age data used in the estimation of growth caused the largest changes in model trajectories. Collectively however, changes in data resulted in minimal impact on results compared to changes due to updating biological relationships.

Changes due to updating how selectivity as well as reapplying data weighting procedures are shown in Figures 27–28. Overall, changes to selectivity from the 2021 assessment, which included changes to both the time blocks as well as to the form of selectivity (domed versus asymptotic) had limited effect on population trajectory, especially compared to changes in the previous bridging steps. Spawning output increased when selectivity was updated, though changes in spawning output relative to unfished were minimal (Figure 27). A limited effect due to changes in selectivity choices is consistent with results from explorations done throughout the review process for the 2021 assessment (Langseth et al. 2021a). Alternative selectivity treatments were extensively explored during base model selection and are described in sensitivity analyses (see Section 3.5.4 for details). Applying weighting procedures also resulted in limited changes in both spawning output and spawning output relative to unfished. The current base model differed slightly from the pre-STAR base model. Unfished spawning output was similar, but spawning output and therefore spawning output relative to unfished in recent years was lower in the final base model compared to the pre-STAR base model due to a lower peak in recruitment in the mid 1990s (Figure 28).

3.3.4 Key Assumptions and Structural Choices

The base model for quillback rockfish was developed to balance parsimony and realism, with the goal of estimating a spawning output trajectory for the population of quillback rockfish off California. The base model represents a balance among the number of model parameters, the model fits to data, and minimizing the negative log-likelihood, as well as accurately representing fishery dynamics and quillback rockfish biology. The model contains many assumptions to achieve parsimony and uses many different sources of data, including new sources, to estimate population dynamics.

Model specifications were informed by discussions with the PFMC's GMT and Groundfish Advisory Subpanel (GAP) advisers and through comments and discussion during the pre-assessment workshop. Choices related to model structure included a discussion of fleet structure, potential time blocks for selectivity parameters, and the potential ability to estimate growth within the model. Data related choices on maximum age that is used to estimate natural mortality, and acknowledgement of years with high estimated catch were also discussed. These topics and more were explored through a series of investigative model runs to achieve the final base model, either through the bridging analysis (see Section 3.3.3), by profiles (see Section 3.5.3), or through sensitivity analyses (see Section 3.5.4).

The specifications of the assessment are listed in Table 8. Growth and natural mortality are assumed time- and sex-invariant. Population age and length structure is modeled from age 0 (recruitment age) to an accumulator age (plus group) of 80 in 1 year age bins, and from 4 cm (assumed size at birth at the beginning of the year) to an accumulator bin of 59 cm in 1 cm length bins. Data were binned in 1 year increments from 1 to 60 years for age, and in 2 cm increments from 10 to 50 cm for length. Growth is modeled using the Schnute parameterization of von Bertalanffy growth, with two estimated length parameters ($L_{age=1}$ and L_∞), estimated CV for each length parameter, and a growth rate coefficient (K). Growth is assumed to be the same for males and females in this assessment. Year-class strength is estimated as deviations from a Beverton-Holt stock-recruitment relationship, with deviations estimated between 1940–2024 with a fixed σ_R value of 0.6.

As described in the fishery-dependent and survey data sections (see Section 2.2 and Section 2.3) age-frequency data from the commercial fleet, the CCFRP survey fleet, and Abrams research as a growth fleet were compiled as conditional age-at-length distributions by year. This approach has several benefits for analysis above the use of marginal age compositions. First, age structures are generally collected as a subset of the fish that have been measured. If the ages are to be used to create an external age-length key to transform the lengths to ages, then the uncertainty due to sampling and missing data in the key are not included in the resulting age-compositions used in the stock assessment. The second major benefit to using conditional age-composition observations is that in addition to being able to estimate the basic growth parameters inside the assessment model, the distribution of lengths at a given age that is usually controlled by the CV of length at some young age and the CV at a much older age, are also more reliably estimated. This information could only be derived from marginal age-composition observations where very strong and well-separated cohorts existed, and that are quite accurately aged and measured; rare conditions at best. By fully estimating the growth specifications within the stock assessment model, bias due to size-based selectivity and length-stratified ageing is avoided, and known sources of variation are included when estimating growth parameters.

Within-lab ageing error was based on one primary age reader and a second reader producing double reads from 418 otoliths collected from California (Figure 29). An ageing error estimate was made based on these double reads using an ADMB computational tool specifically developed for estimating ageing error (Punt et al. 2008) and using release 1.3.1 of the R package nwfscAgeingError (Thorson et al. 2012) for input and output diagnostics. A series of 24 ageing error models were run to look across the suite of bias and ageing precision. The model selected by AIC (and used in the assessment) assumes the first reader was unbiased and a constant coefficient of variation, i.e., sigma is a linear function of true age.

3.3.5 Model Parameters

There are 121 estimated parameters in the base model. Estimated parameters include one parameter for $\ln(R_0)$, 5 parameters for growth, 97 recruitment parameters, 3 survey catchability parameters, and 15 selectivity parameters (Table 9). Early recruitment deviations are estimated starting in 1940. Main period recruitment deviations begin in 1978, shortly before the majority of length composition data become available, and end in 2021. Late recruitment deviations are estimated 2022–2024, and although forecast recruitment deviation parameters are included in Table 9, they were set to follow the stock-recruit curve.

Parameters were estimated using maximum likelihood estimation and uncertainty is based on the assumption of asymptotic multivariate normality of the maximum likelihood estimate, where the variance-covariance matrix is the inverse of the hessian matrix. Exploratory MCMC runs indicated that posterior distributions largely matched the asymptotic distributions, but took much longer to produce. The parameter where the posterior distribution diverged the most from the maximum likelihood was the descending slope of selectivity for the first commercial block, where the MLE corresponded to a declining (i.e. domed) selectivity shape. The posterior mode matched the MLE, but a larger fraction of the posterior samples were from higher values corresponding to more of an asymptotic shape.

A number of parameters were fixed in the model. Steepness was fixed at 0.72, the mean of the prior. Natural mortality was fixed at 0.068 yr^{-1}, the median of the prior as determined by the maximum age. Other biological parameters were also fixed, as described in the biology section (see Section 2.4), and include the two weight-length parameters, two maturity parameters, and two fecundity parameters. The assumed fraction of females in the population was also fixed, and assumed to be 0.5. The standard deviation of recruitment deviation σ_R was fixed at 0.6.

3.3.5.1 Priors and Constraints on Parameters

Priors were used to determine fixed parameter values for natural mortality and steepness in the base model. The prior distribution for natural mortality was based on the Hamel and Cope (2022) meta-analytic approach with an assumed maximum age of 80 years. The prior assumed a log-normal distribution for natural mortality with a log-standard deviation of 0.31. The prior for steepness assumed a beta distribution with standard deviation of 0.16, as specified by the PFMC ToR. Although there parameters were fixed in the base model, the likelihood component of the priors was included in the final likelihood.

Length and conditional-age-at-length samples are all assumed to follow a multinomial sampling distribution, where the sample size is fixed at the input sample size for the composition data (see Section 2.2). Input sample size is subsequently weighted to account for additional sources of over-dispersion according to the Francis method (Francis 2011) using three iterations (Table 10). Each of the survey data sources are assumed to follow a log-normal distribution with standard error provided as input for each index. Total removals are also assumed to follow a log-normal distribution and were given a fixed value of log-standard deviation of 0.05.

Recruitment deviations during the main period were constrained to sum to zero. Relaxing this assumption showed some variation in the model, however, later explorations during sensitivities showed this to be due to the timing of when main recruitment deviations start (see Section 3.5.4) and not due to the sum-to-one constraint. Given this, and because the constraint allows for a clearer interpretation of management reference points, we keep the constraint in the base model.

3.3.5.2 Selectivity Assumptions

Selectivity reflects the capabilities of the gear as well as a variety of other combined fishing and ecosystem dynamics that determine what sized fish a fleet has access to. All selectivity was assumed to be length-based and initially explored as a three parameter double-normal functional form (length at peak selectivity, and ascending and descending limbs). While the double-normal functional form was used initially, early explorations indicated that asymptotic selectivity was more parsimonious for all but the first time block for the commercial fleet, and therefore an asymptotic functional form was assumed for the majority of fleets by fixing the descending limb parameter at a high value. Selectivity of the growth fleet, which is used to inform estimates of growth and not selectivity, was set at one for all lengths.

Time blocks on selectivity and selectivity forms were explored extensively when setting up the initial model structure, as well as in sensitivities (see Section 3.5.4). California's fisheries are managed with depth and spatial restrictions that likely influence selectivity. For quillback rockfish, we found that larger fish are present at all depths and smaller fish more commonly present in the shallower depths. This is evident in the ROV data and was also observed in British Columbia waters by Murie (1991).

Time-varying selectivity was applied to both the commercial and recreational fleets. Assumptions for the shapes of curves and timing of blocks was driven by a combination of model fits, parsimony, and knowledge of fishery and regulatory dynamics over time. Four time blocks for the commercial fleet allowed separate selectivity parameterizations during the periods 1916–2002, 2003–2013, 2014–2021, and 2022–2024, although the second and final periods were mirrored to one another based on similar estimated parameters when allowed to be separate. The first time block was allowed to be dome-shaped, whereas all other blocks assumed asymptotic selectivity. Dome-shaped selectivity was allowed initially for these later time blocks, but did not improve model fit sufficiently to warrant the extra parameters. The early time period is inclusive of the 1980s and 1990s when the live fish fishery was most active and may have been targeting intermediate-sized fish. The periods between 2003–2013 and 2022–2024 were times of fishery restriction (Figure C-2). A variety of new depth limits, trip limits, and permit structures were implemented around 2003. Trip limits were markedly reduced in 2022 and further limits specific to quillback rockfish occurred in 2023 and 2024. These periods are parameterized as asymptotic curves with a peak at relatively small sized fish that is similar to the peak of the early 1916–2002 period. In contrast, the 2014-2021 period corresponds to modest increases in trip limits and allowable fishing depths. This may have provided greater access to deeper waters where smaller fish are less prevalent, thus shifting the asymptotic curve's peak to the right.

Two time periods were estimated for the recreational fleet in the base model. These were 1928–2016 and 2017–2024. However early explorations included more blocks: 1928–2000, 2001–2016, 2017–2022, and 2023–2024. Dome-shaped selectivity was allowed initially for all time blocks, but did not improve model fit sufficiently to warrant the extra parameters. During the period of 2000 to 2003, recreational depth and season restrictions were implemented for nearshore rockfish for the first time in California (Figure C-1). However, explorations of time blocks before and after that period did not result in meaningfully different selectivity curves and we therefore combined the blocks before and after those regulatory changes. Although a relaxation of early 2000 depth restrictions started in 2017, and increased restrictions on harvest and retention of quillback rockfish started in 2023, which were the reasons for the initial blocking structure, model explorations did not result in meaningfully different selectivity curves, and we therefore combined the blocks after 2017. The length at peak selectivity for the initial block is shifted to the left towards smaller fish, possibly corresponding to fishing dynamics in the very early years with anglers remaining relatively close to shore by choice or due to vessel capacity, as well as later years when they were restricted closer to shore by regulation. In contrast, the next block representing 2017–2024 is shifted to the right representing larger fish as most years during this period correspond to a period of regulatory relaxation.

Constant asymptotic selectivity was used for both survey fleets. The peak corresponds to selection of smaller fish for the CCFRP survey relative to the ROV survey however the ascending limb represents a wider range of sizes observed in the ROV survey compared to CCFRP. This is consistent with differences in survey depths with CCFRP operating to only 60 m depth and ROV extending as deep as 100 m. The ROV is expected to see smaller fish present that may not be caught with the hook size used in the CCFRP survey.

3.4 Base Model Results

3.4.1 Parameter Estimates

The parameter values, both fixed and estimated, along with approximate asymptotic standard errors of estimated parameters are shown in Table 11 and the overall likelihood components by data type are shown in Table 12. Estimates of population size and spawning output relative to unfished over time are shown in Table 13.

The $\ln(R_0)$ was estimated at 3.806. The model estimated growth parameters and variability as $L_{age=1} = 9.347$ (CV = 0.177) cm and $L_{\infty} = 42.82$ (CV = 0.087) cm. The K parameter was estimated as 0.127. The estimated L_{∞} was 1.64 cm larger than the initial externally estimated fixed value, whereas the estimated K value was smaller than the initial externally estimated fixed values. The estimated $L_{age=1}$ value was similar to the initial externally estimated fixed value. The estimated values are within the range of biological parameters observed for quillback rockfish across their range.

Length-based selectivity curves were estimated for the fishery and survey fleets, and length-based selectivity was fixed at 1.0 starting at age 1 for the growth fleet (Figure 30). Model explorations included parameterizing the fleets with double normal selectivity and explorations of time blocks (see Section 3.5.4). The survey fleets did not include time blocks and the double normal selectivity patterns were fixed to reflect asymptotic selectivity. The ROV survey observed a wider range of sizes than the CCFRP survey, though the peak size for the ROV survey was estimated higher, at 39.8 cm compared to 33 cm for CCFRP. The fishery selectivities were all estimated as asymptotic except for the early time period of the commercial fleet that estimated the peak domed selectivity at 37.1 cm, indicating size selection away from larger sized individuals during that period.

The catchability for each of the surveys was estimated comparing observed to expected vulnerable biomass across all years. Estimates are reported in Table 11 in natural log-space. Analytical solutions for catchability to maintain a mean difference in observed versus expected of zero (described in Stock Synthesis as ‘float Q’) gave similar results to when estimating catchability but our preference was to include catchability as an estimated parameter.

The estimated annual recruitment and recruitment deviations are shown in Figures 31 and 32. The strongest recruitment events occurred in 1993 and 1994 and were followed by a period of generally lower than average recruitment until 2010, after which the recruitment pattern has been cyclical. Years with recruitment deviations above the stock-recruit curve after the mid 1990s peak include 2003, 2010, 2012, and 2016–2020. Recruitment prior to the period of deviations, as well as during the forecast period was based on the stock-recruit curve resulting from a value of steepness fixed at 0.72 (Figure 33). Bias adjustment was applied to the annual estimates of recruitment deviations following the pattern of transformed variances as shown in Figure 34.

3.4.2 Fits to the Data

3.4.2.1 Fits to length and age composition The aggregated fits to the length composition are reasonable (Figure 35) given the overall sparseness of data and variable sample sizes by year (Figure 36). The data weighting down weighted the length composition for both catch fleets and both survey fleets, as well as the conditional age-at-length data for the commercial fleet and the growth fleet (Table 10).

The mean lengths observed by year from the commercial fleet were uncertain but the time-varying selectivity captures the changes in mean length relatively well (i.e., fits extend through confidence intervals) for all but the years 1996 and 2007 (Figure 37). The period of positive residuals during 2009–2017 shows that the model does not capture to the same extent the increase in size observed in the commercial length data. Commercial length samples during this time were sparse and are primarily from the two most northern ports. Sensitivities however showed the perceived lack of fit is not as pronounced when years with sparse samples sizes (< 10) were excluded (see Section 3.5.4). There were limited ages available for the commercial fleet from a limited number of years. There are a few remaining large Pearson residuals in individual years, but the mean age from the conditional data were generally well captured by the model (Figure 38 and Figure 39).

The model fit the tails of the aggregated recreational length composition well, but expected a peak length larger than the data suggested (Figure 35). The Pearson residuals were variable by year and showed no patterns of general misfit to the length data (Figure 36). Positive residuals at the edges of the distribution in years before 2004, which are some of the largest residuals, are indicative of widely spread distributions with lower sample size. Recreational length data was fit well for years in which sample sizes were large, covering the range of sizes covered by confidence internals in all years except 1983 and 2013 (Figure 40). Variability in mean length was smaller after 2004, and more uncertain prior to 1993, generally reflecting the availability of samples. There were no regulations nor major changes in the recreational fishery prior to 1999 that would suggest the need for an additional time block to aid in fitting these data. There were no ages available from the recreational fleet collected as part of the CDFW CRFS sampling program.

The fits to length data for the ROV and CCFRP surveys were variable and patterns harder to distinguish given the limited lengths of the time series (Figure 36). The CCFRP mean length was uncertain across years with fits generally reasonable except that the increased mean length in 2019 was not captured (Figure 41). The ROV lengths represent different areas in each of the years sampled. The ROV survey lengths were fit to the individual years of data and indicate an increase in mean size form 2019 to 2021 that was not captured by the model (Figure 42). The difference in mean size for CCFRP in 2017, 2018 and 2024 and slight differences in the residual pattern are likely due to sampling at the Farallon Islands where higher densities of quillback rockfish are observed than at other sites.

Fits to conditional age-at-length data for the CCFRP survey was well fit given the limited sample sizes. In 2019 older and larger quillback rockfish were encountered compared to other years and resulted in an underfitting of the mean age and larger residuals (Figure 43, Figure 44). The Abrams ages in the growth fleet are harder to evaluate, given a selectivity of one across all lengths and no associated survey. There are large Pearson residuals for the growth fleet conditional ages that may be due to age reading errors or the sampling (Figure 45). Fits to the mean age over time (Figure 46) showed no concerning patterns. The Abrams age data in the growth fleet complement the CCFRP ages and provide a more complete picture of quillback rockfish growth across its range in California.

3.4.2.2 Fits to Indices of Abundance

The base model fit the overall trend in the recreational index reasonably well, capturing the confidence range of mean length in nearly all years with the exception of 2004 (Figure 47). The first year of the recreational index was not fit, which may be due to it being the first year of the survey, and therefore not being as representative to the population compared to other years. The change in time varying selectivity in 2017 is evident in the fit to the survey data. Given that fits to the index showed limited residual patterns (see `r4ss` output material) and fits were within confidence intervals no extra standard deviation was included for the recreational index.

The relative indices from the CCFRP and the ROV surveys both indicated increases in the later years which the base model underestimated (Figure 48 and Figure 49). The decreased value in 2019 for CCFRP was not captured by the model and may be a result of factors not considered in index development, i.e., higher than average catches of a midwater species. As was the case for the recreational index, both the CCFRP and the ROV indices were fit well without the need to add extra standard deviation.

3.4.3 Population Trajectory

The estimated spawning output (in billions of eggs) is given in Table 13 and plotted in Figure 50. The estimates of spawning output across time are uncertain with the base model estimating a spawning output of 42.26 in 2025 with a 95% asymptotic confidence interval ranging from 26.3 - 58.21 billions of eggs. The population declined slowly with the onset of fishing, with three periods of large decline in years of high total removals. The population remained at lower levels during 1994–1998 before increasing during 1999–2006. Total removals increased again in 2015 and continued the decline in spawning output through 2023. The population has since increased, likely due to low removals and increased recruitment in 2016–2019. The estimate of total biomass over time is shown in Figure 51.

The estimated spawning output relative to unfished spawning output reached a minimum of 0.318 in 1998 and then increased over the recent time period, with an ending year estimate of 0.435 in 2025 (Figure 52). Approximate 95% confidence interval based on the asymptotic variance estimates show that the uncertainty in the estimated spawning output in 2025 ranges between approximately 32 - 56% of unfished spawning output.

3.5 Model Diagnostics

3.5.1 Convergence

The maximum parameter gradient was 2.2×10^{-4}. Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates to determine if the model found a better minimum. Starting parameters were jittered using the jitter functionality built into Stock Synthesis, using a jitter fraction of 0.5. This was repeated 100 times with 98 out of 100 runs returning to the base model likelihood. A better, lower negative log-likelihood, model fit was not found. Through the jittering and likelihood profiles, we are confident that the base model, as presented, represents the best fit to the data given the assumptions made. There were no difficulties in inverting the Hessian to obtain estimates of variability throughout initial model attempts and all explorations resulted in a positive-definite Hessian.

3.5.2 Retrospective Analysis

A fifteen-year retrospective analysis was conducted by successively removing years of data ranging from 2008–2023 (e.g., “Data -1 Years” corresponds to data through 2023). The estimated spawning output for all retrospectives was lower at the start of the time series and lower in the final model years except for Data -1 and Data -2 years (Figure 53). The estimates of spawning output relative to unfished were within the asymptotic uncertainty of the base model through the first five peels, removing data through 2018 (Figure 54). A substantial amount of data were collected over the past five years for quillback rockfish. Removing more than 5 years of data results in a stock that is estimated within the management precautionary zone in the end year of a peeled model run. Removing 13 to 15 years of data results in changes in the recruitment patterns more dramatically than removing fewer years. When 15 years of data are removed the high recruitment pulse in 1994 is no longer estimated and recruitment is on average higher than other model runs across the entire time series (Figure 55). Estimates of Mohn's ρ, which measures the magnitude of retrospective bias, are provided as per-year averages (Hurtado-Ferro et al. 2015). According to Hurtado-Ferro et al. (2015), Mohn's ρ values on a per-year basis of less than -0.15 are not cause for concern, but should not be taken as lack of true bias.

3.5.3 Likelihood Profiles

Likelihood profiles were conducted for $\ln(R_0)$, steepness (h) and natural mortality values (M) separately, as well as bivariate profiles for steepness and natural mortality, and for growth parameters L_∞ and K separately. The priors for all parameters, including the parameter being profiled, were included in every likelihood model. For example, including the prior on natural mortality across the profiled values of natural mortality provides information on the likelihood contribution of that prior as if it were estimated in the model.

The negative log-likelihood was minimized at a value for $\ln(R_0)$ of 3.806 and was supported most strongly by the recruitment and length data (Figures 56–58). The age composition data supported lower values of $\ln(R_0)$ relative to the base model, at the minimum value profiled, 3.4. The length composition for the recreational fishery supported a $\ln(R_0)$ around 3.6 and the survey data supported higher values around 4.0. The final year estimated fraction unfished ranged from 0.39 to 0.69 for the range of values of $\ln(R_0)$ from 3.4 to 4.3.

Across the negative log-likelihood profile for values of steepness all data types except for the age-composition supported a higher value of steepness at 0.9, which was higher than the base model that fixed steepness at 0.72 (Figures 59–61). The final year estimated fraction unfished was as low as 0.36 with steepness fixed at 0.5 and above the management target of 0.40 for all values greater than and equal to 0.60. There was little overall change in the trajectory across steepness values, particularly for values above 0.72.

The profile over natural mortality suggested the negative log-likelihood was minimized at around $M = 0.08\ \text{yr}^{-1}$, suggesting a lower maximum age than assumed in the base model with fixed natural mortality at $M = 0.068\ \text{yr}^{-1}$ (Figures 62–63). The final year estimated fraction unfished was above the management target for values of natural mortality of 0.065 and higher. None of the data indicate a strong minimum across the values profiled from 0.20 to 1.0 (Figure 64). From values of M of 0.065 to 1.0, the negative log-likelihood changed by less than two points.

A bivariate profile of 192 models over all combinations of natural mortality from 0.04–0.15 and steepness from 0.25–1.0 indicates that the base model is within two negative log-likelihood points of the model with the minimum negative log-likelihood (Figure 65). There are a range of models with a combination of values of M and h that are within the range of acceptable models according to the likelihood (Figure 66), likely due to data limitations and moderate uncertainty in the base model.

The profile over L_∞ indicates the negative log-likelihood was minimized at the value estimated in the model and was supported by the age and length data, especially ages from the CCFRP fleet, and lengths from the recreational and ROV fleets (Figures 67–69). Age and length data supported similar values of L_∞ between 41–45 cm. The final year estimated fraction unfished ranged from 0.36 to 0.57 for the range of values of L_∞ from 40 to 46 cm. Note that for this profile all other growth parameters were estimated, and thus the effects of changes in L_∞ also account for corresponding changes in the other estimated growth parameters.

The profile over K indicates the negative log-likelihood was minimized at the value estimated in the model and was supported by the age data, especially ages from the CCFRP fleet, and the length data, especially lengths from the recreational and ROV fleets (Figures 70–72). Age data supported slightly lower estimates of K from 0.09–0.16, while length data supported slightly higher estimates between 0.10–0.17. The final year estimated fraction unfished ranged from 0.37 to 0.54 for the range of values of K from 0.08 to 0.2. This reflects an opposite pattern to the profile observed during the 2021 stock assessment (Langseth et al. 2021a), which did not include age data. Note that for the K profile reported herein, all other growth parameters were estimated, and thus the effects of changes in K also account for corresponding changes in the other estimated growth parameters.

3.5.4 Sensitivity Analyses

The base model contains substantial uncertainty in both how data were processed, and structural assumptions made. We tested sensitivity to many of these assumptions. Sensitivities were conducted as a single exploration from the base model assumptions and/or data, and were not performed in a cumulative fashion unless specifically noted. In general, structural assumptions regarding population productivity led to the largest changes in model outputs (Figure 73). Most sensitivities, with the exception of those related to omitting age or length data, or alternative structures like areas-as-fleets or no recruitment deviations, led to relatively similar estimates of growth parameters, indicating growth is consistently estimated in the model (Tables 14–18). We divide the sensitivities into five sections: sensitivities to choices affecting population productivity, choices on data weighting and understanding relative contributions of data sources, choices on understanding contributions of age data within the growth fleet as explored during the STAR panel, choices related to how data are prepared, and assumptions around selectivity. We also describe sensitivities done but not included in the document.

3.5.4.1 Population Productivity The base model makes a number of structural assumptions related to population productivity. These assumptions are known to be influential and drive how quickly a population will recover from fishing. In addition, new biological information impacts productivity as was discussed during bridging (see Section 3.3.3). The following sensitivity models fall under population productivity:

- Estimate h: Estimate steepness of the stock-recruit relationship.
- Estimate M: Estimate natural mortality.
- Estimate M and h: Estimate both natural mortality and steepness of the stock-recruit relationship.
- Recdevs in 1990: Turn off estimation of recruitment deviations until 1990, which corresponds roughly to when deviations become informative.

- No recdevs: Turn off estimation of recruitment deviations for all years, which assumes recruitment follows the stock recruitment curve.

- Fix growth at external estimates from 2021 assessment: Fix all growth parameters at the values assumed in the 2021 assessment. This includes $L_\infty = 43.04$ cm and $L_{age=1} = 8.23$ cm, as well as the variability in length at these ages (set to 0.1), and $K = 0.199$. This sensitivity is exploratory and is intended to explore implications of assumptions around productivity, in this case growth.

- Fix growth at external estimates from 2021 assessment but without age data: This sensitivity is the same as the one prior but excludes the ages from the model likelihood. This sensitivity emulates the conditions of the 2021 assessment where age data was not fit within the model. This sensitivity is also exploratory and is intended to explore implications of assumptions around productivity, in this case growth, and how age data inform population productivity.

Structural assumptions in the model that determine population productivity, particularly natural mortality as well as the information available to determine productivity (i.e. age data), were strongly influential on the population trajectory (Figure 74 and Table 14). Natural mortality was estimated to be around 0.08, whether steepness was also estimated or not, and resulted in a greater increase in recovery of the population in the 2000s, which led to a higher value for spawning output relative to unfished in 2025 that was outside the range of uncertainty from the base model. The improvement in total likelihood when estimating natural mortality or steepness was approximately one likelihood unit, with the greatest increase being 1.6 likelihood units when both parameters were estimated. Not estimating recruitment deviations resulted in increased spawning output for all years, but relatively more in recent years than in past years, resulting in higher spawning output relative to unfished in 2025 that was near to the range of uncertainty from the base model. Not estimating recruitment deviation led to degradation in fits to both length and age composition data, as well as in fits to indices, based on likelihood components. Starting recruitment deviations in 1990 led to modest degradation in model fit of around six likelihood units and resulted in little change in population trajectory. While the number of parameters saved would indicate this is a reasonable choice based on an information theoretic approach (i.e. Akaike information criterion (AIC)), we kept the start time for main recruitment deviations to be 1978. We did this to allow the early and initial main recruitment deviations to inform the size structure of the population, which, given length composition data for the recreational fleet in 1980–1990 showing a large decline, along with a significant amount of total removals having occurred by 1990, would not be at equilibrium. Fixing growth at estimates from the 2021 assessment resulted in a greater increase in the recovery of the population in the 2000s similar to that of estimating M or removing recruitment deviations. Model fit however was severely degraded. Interestingly, the magnitude of recovery depends on the information available in the age data. When age data are not included in the model under the same growth parameter values, the recovery of the population is severely reduced and the population never extends above the MSST after the early 1990s. This pattern is due to the different direction of the K profile for this assessment (see Section 3.5.3), which includes age data, compared to the direction of the K profile for the 2021 assessment, which does not include age data (Langseth et al. 2021a). This suggests that productivity comes from more than just model parameter values but also from the information available to the model from data within the constrains of the parameter values.

3.5.4.2 Data Weighting and Contributions

The assessment model contains data from a variety of sources, some of which are expected to be more informative than others. Sampling units from these different data sources are not necessarily comparable (e.g., an observation from a survey index versus an observation of a fish length). Data weighting procedures are objective algorithms that can be used to assign weights to different data sources to optimize the fit of the model to the data. Increased uncertainty or emphasis factors also weight the relative contribution of datasets and can be used to influence contributions of various data types. The following sensitivity models fall under data weighting and contributions:

- McAllister-Ianelli data weighting: Use the algorithm suggested by McAllister and Ianelli (1997) instead of Francis (2011)

- Dirichlet-multinomial data weighting: Apply the algorithm suggested by Thorson et al. (2017) instead of Francis (2011)

- Extra SD: Estimate an extra standard deviation for all survey indices, which include the recreational, CCFRP, and ROV indices. This allows each index to be down-weighted to allow for better fitting of other data sources.

- Remove fleet lengths: Remove contributions from length composition data from the commercial and recreational fleet by setting the emphasis factors for these two elements to zero.

- Remove ages: Remove contributions from conditional age-at-length data from the commercial, CCFRP, and growth fleets by setting the emphasis factors for these three elements to zero.

- Remove indices: Remove contributions from the indices for the recreational, CCFRP, and ROV fleets by setting the emphasis factors for these three elements to zero.

The model was robust to the range of alternative weighting and data contribution sensitivities, with the exception of exclusion of conditional age-at-length data (Figure 75 and Table 15). Excluding age data resulted in a higher estimate for equilibrium spawning output, and lower estimate for recent spawning output, due to reduced magnitude of recruitment deviations and higher L_∞ and K, leading to lower values for spawning output relative to unfished. While excluding length data for the fleet also resulted in differing estimates of growth parameters, L_∞ was estimated to be lower while K higher than base model estimates, offsetting effects on the population trajectory, which was similar to that of the base model. Other sensitivity scenarios showed limited difference from the base model trajectory. While total likelihoods cannot be compared across scenarios, individual components of unchanged data types can be. When excluding age or length data contributions, survey likelihood components are slightly more negative compared to to that from the base model. When adjusting the contribution of survey data, age and length likelihood components are similar to that of the base model. This indicates that the survey indices provided limited signal compared to other data sources.

3.5.4.3 Contributions from Age Data The influence of age data was identified as an important consideration during the STAR panel. The pre-STAR base model incorporated many age sources that were excluded from the final base model. Many of these age data were excluded from the final base model over concerns about their influence on recruitment estimates as well as about uncertainty in how representative the recruitment signals in the data were compared to the true signal. The following sensitivity models were explored during the STAR panel and fall under contributions from age data:

- Include all ages: Include all sources of non-commercial age data as conditional age-at-length compositions for the growth fleet. This represents the preSTAR base model. Years with fewer than 30 age samples within the growth fleet were excluded. Age data for the commercial fleet were not changed. Given the change in data structure, this model was reweighted.

- Exclude all growth fleet ages: Remove conditional age-at-length data from the growth fleet. Age data for the commercial fleet were not changed. Given the change in data structure, this model was reweighted.

- Exclude all growth fleet ages and CCFRP ages: Remove all conditional age-at-length data from the growth fleet and CCFRP fleet. Age data for the commercial fleet were not changed. Given the change in data structure, this model was reweighted.

- Remove ages: Remove contributions from conditional age-at-length data from the commercial, CCFRP, and growth fleets by setting the emphasis factors for these three elements to zero. This run is a repeat from the sensitivities group on data weighting and contributions. It is repeated here for ease of comparisons with the other runs that explore the effects of age data on the model.

These sensitivities show that age data affect the trajectory of the population. Removing the available age data from the model resulted in a pattern of successively lower spawning output and spawning output relative to unfished starting in the late 1990s and extending through to recent years, primarily due to a decreasing recruitment pulse in the mid 1990s (Figures 76–77 and Table 16). This pattern was discussed at length during the STAR panel. While there is a signal in the data for a recruitment event in the mid 1990s, with the exact year ranging between 1993–1995 depending on the age data included in the model, the magnitude of the recruitment event is uncertain. Adding in all sources of age data for the growth fleet as shown in Table 7 greatly increases the magnitude of recruitment in 1994. Using only the Abrams data in the growth fleet, as used for the base model, results in recruitment peaks in 1993 and 1994, whereas using only CCFRP ages results in a recruitment peak in 1995. Without age data, the peak in recruitment is largely reduced, yet still occurs in only a few individual years. For all sensitivities, the range of spawning output among explored runs remain within the confidence bounds of the base model. Growth parameters remain relatively similar to the base model, though K and L_∞ increase when the most amount of ages are removed. This is consistent with results from the K profiles that show a preference for higher values based on the CCFRP and commercial ages (see Section 3.5.3), though as seen from the sensitivities around data weighting and contributions, population dynamics can differ in the absence of age data even under the same parameter values for growth.

3.5.4.4 Data Choices Compiling data for the assessment model required a number of choices and assumptions. The following sensitivity models fall under data choices:

- Remove ageing error: assume no ageing imprecision when reading age samples.

- Reduce large catches: catch estimates for the commercial fleet in 1991 and for the recreational fleet in 1983 and 1993 were particularly large compared to other years. Catch estimates in these years were assumed as averages from nearby years for this scenario. For 1983 and 1991, the average was from the three years before and after; for 1993, the average was from the three years after. Note that adjusting recreational catches in 1993 resulted in changes to values in 1990–1992.

- Smooth catches: catch estimates for the commercial fleet in 1991 and for the recreational fleet in 1984 and 1993 were particularly large compared to other years. However, some years could also be abnormally low compared to other years, but not as noticeably different. For this model a five year moving average (two years on either side) was applied to smooth total removals for all but the first and last two years.

- Areas-as-fleets: structure data for the recreational fleet following an areas-as-fleets approach (Punt 2019). A pattern of larger lengths of quillback rockfish caught in the recreational and commercial fleets, and ROV survey north of Point Arena 38°55′ N. Lat. was discussed at the pre-assessment workshop, suggesting possible differences between regions. In this scenario data from northern districts (Redwood and Wine) were treated as a separate fleet from data from southern districts (all others). New CRFS dockside private/rental indices pertaining to the two recreational fleet areas were applied to their respective regions. The CCFRP and ROV surveys were not split because as indices these are tracking populations trends, and areas-as-fleets still assumes one population. Only the recreational fleet was split (compared to the commercial fleet) because data was present in both areas across the time series, whereas for the commercial fleet, length composition data in the south was sparse and present only in a few years outside of the 1990s while age composition data was only sampled in the north. Due to the difference in data structure for this sensitivity, reweighting was applied.

Choices around inclusion or exclusion of individual data or treatment of how to process and include total removals in the model had generally limited effect on population trajectory and quantities (Figure 78 and Table 17). Estimates of spawning output in recent years are consistent across scenarios, but estimates of unfished spawning output vary, although they remain within the uncertainty bounds of the base model. When large catch values were reduced, unfished spawning output declined, as expected. However, given that estimates of spawning output in recent years were more similar to the base model, lower estimates of unfished spawning output led to higher values for spawning output relative to unfished in 2025. When catch values were smoothed, such that the overall removals across years were not altered, population trajectory was nearly identical to the base model. The areas-as-fleets scenario resulted in generally similar trajectory to the base model, but with estimates for L_∞ higher and estimates for K lower than the base model. The selectivity structure of the areas-as-fleets scenario was different from the base model, and used a greater number of blocks that included the ability to estimate dome-shaped selectivity. The southern recreational fleet was estimated with dome-shaped selectivity whereas the northern fleet was estimated as asymptotic. More numerous and flexible blocks were used because early explorations for areas-as-fleets showed poor fits when using the base model blocks, although model results were similar. The updated blocks were not further refined however, as would be expected for candidate base models, because there was limited difference in population trajectory from the model without areas-as-fleets. When reweighting the areas-as-fleets model, some of the selectivity estimates indicated greatly altered patterns, indicating some model instability. Given this instability, the similar population trajectory to that from the model without areas-as-fleets, and that the spatial coverage of the commercial data was not ideal for a areas-as-fleets approach, we did not think continued exploration of areas-as-fleets worthwhile.

3.5.4.5 Selectivity There are many possible ways to parameterize selectivity in a stock assessment model, and its parameterization is generally a major source of structural uncertainty. Parameterization can relate to the number and years of selectivity blocks, where changes in length or age composition data is reflective of changes to the fishery as opposed to changes in the population, or the type of selectivity form, often either asymptotic or dome-shaped. The following sensitivity models fall under selectivity, with the first two dealing with both the number and year of blocks as well as the type of selectivity, and the remaining dealing with the type of selectivity:

- Full blocking of the recreational and commercial fleets, allowing for dome-shaped selectivity. This scenario assumes the greatest number of blocks, and therefore parameters, among all the selectivity scenarios and was based on discussions with CDFW staff and advisory panel members from the GMT and GAP. Blocks for the commercial fleet were assumed for 1916–2002, 2003–2013, 2014–2021, and 2022–2024. Blocks for the recreational fleet were assumed for 1916–2000, 2001–2016, 2017–2022, and 2023–2024. The rational for these blocks were described previously (see Section 3.3.4)

- Full blocking of the recreational fleet, allowing for dome-shaped selectivity in all blocks except the first, which was assumed asymptotic. The first block was fixed as asymptotic because the estimated descending parameter (parameter 4) in the previous scenario was approximately asymptotic. Blocks for the commercial fleet matched the base model.

- Selectivity allowed to be domed for all fleets, both catch and survey fleets, using the blocking structure from the base model.

- Selectivity allowed to be domed for the commercial fleet using the blocking structure from the base model.

- Selectivity allowed to be domed for the recreational fleet using the blocking structure from the base model.

- Selectivity allowed to be domed for survey fleets.

- Selectivity assumed to be asymptotic for all fleets, both catch and survey fleets, using the blocking structure from the base model.

- Selectivity assumed to be asymptotic for all fleets and without any blocks for the catch fleets.

Parameterization of selectivity, including the number and years of blocks, as well as the type of selectivity generally had limited effect on model trajectory (Figure 79 and Table 18). Simpler blocking designs were preferred over the more complicated full blocking designs based on information theory, and dome-shaped selectivity did not meaningfully improve model fit compared to asymptotic selectivity for nearly all blocks and fleets across scenarios (Table 18). Nearly all scenarios were within the range of model uncertainty from the base model, with the exception of two scenarios. These two scenarios either allowed all selectivity types to be dome-shaped or applied a single selectivity block for each of the recreational and commercial fleets that was asymptotic. For the dome-shaped scenario, although all fleets and blocks were allowed to be dome-shaped, further explorations showed that the combination of allowing dome-shape for the CCFRP and recreational fleet contributed most to changes in spawning output relative to unfished. Model fit improved slightly when all fleets were allowed to be domed (slightly more than two likelihood units for six additional parameters), with the largest changes occurring when commercial and survey selectivity was allowed to be domed (individually these improved model fit by less than one likelihood unit). For the scenario without selectivity blocks, unfished spawning output was lower than the base model, though spawning output relative to unfished was generally comparable to the base model.

3.5.4.6 Sensitivities Not Included in this Document Many more explorations around data use and modeling choices were conducted but are not included in this report. Among data scenarios, using marginal age composition data for the commercial fleet instead of conditional age-at-length data, including length and conditional age-at-length compositions in years with sparse sample size (<=5 for lengths and <30 for ages), excluding the most recent year of recreational length composition data given the difference in the operation of the fleet, excluding sample sizes less than 10 for commercial length composition data, and increasing uncertainty in catch estimates all had minimal impacts on model outputs and are not included. Similarly, among selectivity scenarios, alternative years for blocking the commercial fleet using 2018 instead of 2014 (due to fully realizing increased access to deeper depths for southern port groups made throughout 2017, transferable deeper nearshore permits for 2018, and noticeable changes in mean sizes between 2017 and 2018) had minimal impacts on model outputs and are not included. Sensitivities around estimates of alternative values for longevity, or use of biological relationships from the 2021 assessment were also explored, but given these are shown elsewhere in the report via profiles or bridging, they are not duplicated in this section.

3.5.5 Historical Analysis

The estimated summary age 3+ biomass and estimated spawning output relative to unfished are compared to the same quantities from the 2021 assessment for California quillback rockfish in Figure 80. The estimated spawning output is compared to the 2021 assessment throughout the bridging process in Figures 21–27. Estimated spawning output, summary age 3+ biomass, and spawning output relative to unfished all increased in the 2025 base model compared to the 2021 assessment. Spawning output relative to unfished increased to a level just above the 95% confidence interval of the 2021 assessment model. The compilation of updated life history parameters and data drove the changes in population dynamics.

3.6 Unresolved Problems and Major Uncertainties

The primary area of uncertainty for this assessment is the parameters influencing population productivity and ultimately scale in recent years. Bridging from the 2021 assessment (see Section 3.3.3) provides a detailed progression of changes in spawning output and spawning output relative to unfished between the 2021 and present assessments. Updating biological parameters and adding age data had a large effect on results and had a much greater impact than other changes such as selectivity. Updating the growth curve and natural mortality along with the addition of age data contributed to the large change in the degree of recovery in spawning output relative to unfished. The updates to growth were derived from recent research that was unavailable at the time of the 2021 assessment. This new research provides a considerable improvement in our understanding of quillback rockfish. This highlights the importance of basic life history research and that continued work to refine these estimates and monitor for potential change over time is critical. Despite these improvements to data collection, data are still relatively sparse, and we also still face uncertainty in population scale as it relates to estimates of natural mortality, as is shown by model profiles across this parameter both individually and in combination with steepness. Understanding the reasons for differences in scale observed between this assessment and analysis of ROV survey data (see Section 11) may also help inform questions about scale but more work is needed to understand the extrapolation to a population-wide based estimate.

Catches of quillback rockfish were particularly high in a few years for both the recreational and commercial fleets. Although not affecting estimates of depletion, averaging out these high years of catches affected model scale and therefore estimates of sustainable yield. Averaging out all years however showed little change in model results indicating the overall scale of removals matters more so than increases and decreases around a common mean over time. Changes to catches affecting model scale is true of all models that assume catch is well known, however for quillback rockfish in California the magnitude of the reduction in catch for these years was approximately 20% of the total removals. Resolution on these high catches, should they be needed, would aid in increasing accuracy of catch time series and resulting estimates of sustainable yields.

Lastly, patterns in observed length data showed larger fish in northern areas of California than in southern areas. No single reason for this is known and is likely be due to many reasons including differences in fishing activities, sampling efforts, population growth, or some other underlying biological or environmental process. We explored this effect as it relates to differences in sizes of fish observed in the fishery, and found limited effect on population trajectory, but did not explore potential effects due to differences in population characteristics. While there is no clear evidence to indicate differences in quillback rockfish populations in these regions, further understanding of the reasons for these observed differences may suggest future directions for exploration. Regardless of the reason, increased sampling in these areas and across California as a whole would aid in better understanding quillback rockfish dynamics.

4 Management

4.1 Reference Points

Reference points were calculated using the estimated selectivities and catch distribution among fleets from the final year of the model, 2024. Derived quantities along with reference points at the three management targets for the population at 40% of unfished spawning output, at spawning potential ratio (SPR) of 0.5, and at the internal model estimated maximum sustainable yield (MSY) are shown in Table 19. The equilibrium yield curve in shown in Figure 81.

The 2025 quillback rockfish spawning output relative to unfished is at 43.5% and above the target, though the 95% confidence interval based on the asymptotic variance estimate ranges into the management precautionary zone (Figure 52). The fishing intensity ($1 -$ SPR) first reached the target around 1980 and has varied since. Fishing mortality most recently exceeded the target of 0.5 during 2016–2022 but has recently decreased to below 0.5 (Figure 82).

4.2 Harvest Projections and Decision Tables

The 2025 stock assessment for quillback rockfish off California was supported as a category 1b determination by the STAR panel. A ten-year projection of the base model with total removals equal to the estimated ACL based on the category 1 time-varying σ (0.5) and $P^* = 0.45$ (i.e., termed the "buffer") for years 2027–2036 is shown in Table 20. Average recruitment was assumed during the projection period and selectivity of each fleet was assumed to equal the estimated selectivity in the final year of the model. Total removals were apportioned to each fleet based on the relative fishing morality among fleets in the last four years of the model (i.e. 2021–2024). The removals in 2025 and 2026 were set equal to the recommended fleet-specific values as provided by the GMT (T. Banez, CDFW, pers. comm., 5/14/2025). Catches from 2027 onward assume full attainment of the ABC, assuming the ACL is equal to the ABC.

The axis of uncertainty in the decision table is based on the uncertainty around natural mortality (Table 21). Alternative values for natural mortality (M) were used to identify the low ($M = 0.0525$) and high ($M = 0.08$) states of nature, where the base model is assigned a 50% probability of being the true state of nature and both the low and high states of nature are assigned a 25% probability. The choices for the low and high values for natural mortality were made during the STAR panel and were based on values that approximated the 12.5 and 87.5 percentiles of the estimated OFL in 2025 from the base model. The proposed decision table assumes full ACL removal during the projection period under the base model catch stream based on a $P^* = 0.45$.

4.3 Evaluation of Scientific Uncertainty

The model estimated uncertainty around the 2025 spawning output for quillback rockfish is $\sigma = 0.19$ and the uncertainty around the OFL in 2025 is $\sigma = 0.19$. Both of these underestimate overall uncertainty due to the necessity to fix several population dynamics parameters (e.g., steepness, recruitment deviation variance, natural mortality) and because there is no explicit incorporation of model structural uncertainty (although see the decision table for alternative states of nature). Estimated uncertainty values are less than the default SSC value of 0.5 for a category 1 assessment (although this determination has not yet been finalized for this assessment), so harvest projections assume an initial σ of 0.5, with an increase over time at a rate of 0.075 times the baseline sigma (0.0375 per year).

Based on the considerations, explorations, and diagnostics described previously, we conclude that different treatments and assumptions regarding data preparation, data weightings, and decisions around selectivity blocks and type have limited relative impact on estimates of population scale and status for quillback rockfish, particularly in recent years, compared to choices around stock productivity. Estimates of stock status are sensitive to assumptions regarding the biological parameters that govern productivity and the yield curve, especially the natural mortality rate and the choice to estimate growth in the model. We therefore recommend that biological data, particularly ages, be continued to be collected, ideally as part of established fishery sampling programs, and future research prioritize better understanding of natural mortality for quillback rockfish across the eastern Pacific Ocean.

4.3.1 Risk Table

A risk table for California quillback rockfish is provided in Table ix. Risk tables are divided into ecosystem and environmental conditions, assessment data inputs, and assessment model fits and structural uncertainty. These tables are intended to provide information across these factors in a transparent manner, based on the framework outlined by the CCIEA team (Golden et al. 2024), so as to inform values for scientific uncertainty. Information on the influence of environmental conditions on California quillback rockfish is lacking. As such, no determination on a level to inform uncertainty for the ecosystem and environmental conditions was possible. Determinations for other factors are based on the assumption of a category 1 assessment determination.

Assessment data inputs are described in the data sections of this report, and are visible from model outputs. Some uncertainties exist in values from the historical catch reconstructions and there are some gaps in catch estimates for years or for portions of the fleet since 1980. Age data are an important data input in the base model yet there was limited samples suitable for use in compositions. Instead, the majority of age samples would best be incorporated as a growth fleet, even though only a subset were ultimately included in the base model. While length compositions covered a broader range of years, there was some patchiness in regions where samples were available. Indices were available for some fishery-independent surveys, but the duration over which these covered was short. These inputs suggest an unfavorable categorization. In contrast to uncertainty in available data for the fleets and survey, which is not uncommon for nearshore rockfish species, biological samples were collected in California in recent years and used to derive estimates of fecundity and maturity. These inputs suggest a favorable categorization. Overall, we preferentially weight the many uncertainties in catch, age, and length data higher than the local species-specific estimates of fecundity and maturity, and therefore consider uncertainties in assessment data warrant an unfavorable determination.

Assessment model fits and structural uncertainties are described in the assessment model section of this report. Overall, elements within this factor suggest a range of criteria. Models fits to the data were generally good, including fits to composition and index data. Many parameters that govern productivity including recruitment and growth were estimated internally in the model, and steep profiles and stable jitters suggests these are well-estimated. However, natural mortality and steepness were fixed based on existing priors, and profiles suggest a range of values for these parameters were plausible. There was also uncertainty in the strength of recruitment deviations particularly in the mid 1990s, and insufficient information beyond larger sizes of fish in northern areas by which to determine spatiotemporal variation in biology. Lastly, there was evidence of a strong retrospective bias in the model that aligns with the removal of age data that influence estimates of recruitment. Collectively, these factors suggest a range of categorizations from favorable to unfavorable. As such, we consider uncertainties in assessment models fits and structural uncertainties warrant a neutral determination.

4.4 Regional management considerations

Regional management differences exist across the U.S. West Coast based on various state-specific management measures. Spatial closures, bag limits, and depth restrictions can influence the effect of fishing on populations of a species that can vary by region. Spatial closures are expected to increase the spatial heterogeneity in abundance and size or age structure of fished stocks. This greater spatial variability can complicate the assumptions made in stock assessment models, particularly the assumption that the densities and demographic structure of assessed populations are relatively homogeneous. Although a wide range of factors above and beyond spatial management measures can also lead to violations of those assumptions, the challenge can be particularly important for longer lived populations with lower movement rates, such as quillback rockfish. While spatially explicit assessment models provide a means of more explicitly addressing these challenges, such models are computationally intensive, require robust data from the specific areas being modeled, and may also require detailed information regarding movement and dispersal rates (McGilliard et al. 2015; Berger et al. 2017; Cadrin 2020).

For this assessment, we used a single area statewide model and did not split fleets by management areas in the base model nor explicitly model separate areas by latitude or for areas open versus closed to fishing. Nonetheless, information on closed areas, including both MPAs and closures due to management changes, were incorporated within the base model. Data from MPAs were included within the abundance index and length composition for CCFRP and the ROV. Selectivity blocks were applied within the base model to explain changes in length compositions due to management action restricting certain areas from fishing. Collectively, this is the information available for quillback rockfish to incorporate area closures. Modeling spatial closures more explicitly would require more detailed information from the fishery on where catches and biological samples occur in relation to areas closed in earlier time periods or in relation to areas that will be closed in later time periods, and this information is not available.

We explored the use of an area-as-fleets approach to account for observed differences in the sizes of fish caught in northern areas. Such regional differences can induce spatial structure, and an areas-as-fleets approach can perform well in modeling it when the underlying population is uniform, but can be biased when it is not (Bosley et al. 2022). The assumed areas corresponded to the northern most port groups and districts compared to more southerly locations. This split did not directly align with the 40° 10’ N. Lat. management line utilized for the nearshore rockfish complex in the past but occurred farther south, near Point Arena (38° 55’ N. Lat.). Ultimately, we did not use the areas-as-fleets approach for the base model because the data for the commercial fleet had limited spatial and temporal coverage across both regions in all years, early explorations of the areas-as-fleets sensitivity indicated concerns around model stability, and the results between the current base model and the areas-as-fleets sensitivity were generally similar (see Section 3.5.4). Consequently, while the sizes of fish caught differed in regions, modeling this difference did not greatly alter conclusions about the population. This approach assumes a single stock with common life history characteristics. A more complicated structural assumption of explicitly modeling separate spatial areas was not explored due to a lack of other evidence indicating different populations, and that the increased complexity in doing so would either result in sparse data (if assuming separate models) or require additional assumptions around recruitment allocation and movement among populations (if assuming spatial models).

Federal management of the nearshore rockfish complex, which historically included quillback rockfish, is based on areas north and south of 40° 10’ N. Lat. Since the quillback rockfish stock was defined for California south of 42° N. Lat. (NMFS 2023), and declared overfished in 2023, California quillback rockfish have been managed as their own species. Therefore, yield estimates from the base model are appropriate to the scale of management for quillback rockfish in California.

4.5 Research and Data Needs

Progress on research and data collection recommendations from the last assessment are provided in Section 3.2. To improve our understanding of the quillback rockfish stock in California waters, research and data collection recommendations for this assessment are listed below in general categories. The categories are offered in order of priority while also considering feasibility, as are the elements within each category.

Data sampling needs:

- There are limited age data for quillback rockfish across California arising from fishery-dependent sources. Establishing regular collections of otoliths from the recreational fishery, a large source of mortality, would support future assessments and would improve the understanding of the population structure and life history of quillback rockfish. Several fishery-independent programs have made efforts to collect otoliths but sample sizes are sparse and spatial distributions patchy when considered individually. Expansion of these programs or mimicking of their sampling designs would better allow use of age data in association with a fishing or survey fleet as opposed to a growth fleet. Priority: High

- The assessment area has a mixture of observations from areas experiencing variable fishing mortality. In the region there are likely a mixture of areas: open access rocky reefs that are close to port that are heavily fished, open access rocky reefs that are inaccessible via day-trips that are fished but at lower levels, and rocky reefs that fall within marine protected areas (MPAs) or below depth restrictions. A spatially-explicit assessment model may be able to capture this complexity but will require data from each region, including indices of abundance, composition data, and information on rates of movement between them. Priority: Medium for increased data sampling.

- Future deeper nearshore assessments would benefit from fishery-independent surveys which can increase information available to estimate population trends for these species. A key element for these types of data are the length of time over which they are available. Efforts have been made by CDFW and SWFSC staff to estimate absolute abundance for the entire quillback rockfish stock as well as the portion within MPAs using ROV data (see Section 11), but more research is needed to understand methods to extrapolate from the sampling domain to the population scale. Priority: Medium for increased fishery-independent surveys.

Research to better understand population scale:

- Potential maximum longevity of quillback rockfish in California waters is uncertain. The oldest fish observed in California are younger than those along the rest of the U.S. West Coast. This may be due to low sample size in combination with exploitation. Increased age sampling, as well as comparison with proxy species, across their ranges, may help to resolve some of this uncertainty. Priority: High

- The catch history for quillback rockfish shows extreme high catches in some years. Continued improvement of historical catch reconstructions as well as the effects of quantifying uncertainty on model results is needed. Priority: Medium

- High resolution interpreted substrate maps for areas outside state waters are needed. This would allow for estimation of rocky substrate by fishing district and inside and outside closed areas and use of this information for construction of abundance indices. Priority: Low

Research to better understand population processes:

- Recruitment deviations were variable over time, and in the early years uncertain. Information on the environmental influences on quillback rockfish recruitment would help to validate recruitment deviation estimates. Priority: Medium

- Survey data indicate that large quillback rockfish are distributed across shallow and deeper habitat, while smaller individuals are mainly in the shallow portion of the quillback rockfish range. Further research into the distribution of quillback rockfish by size and the relationship of size to depth, other habitat features, and distance from port may help to better understand assumptions around selectivity shape. Priority: Low

- More detailed information on recreational effort and fishing targets is needed, particularly for the private/rental mode. Explorations of time varying selectivity showed in some cases when depth limits relaxed (moved deeper) catch of quillback rockfish went down and the selectivity pattern became dome-shaped. This is contrary to depth-based expectations for quillback rockfish and may reflect shifts in fishing targets. Information of fishing targets would better inform whether this is the case. Priority: Low

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7 Auxiliary files

Files archived with the 2025 California quillback rockfish assessment:

- 2025_ca_quillback.ctl
- 2025_ca_quillback.dat
- forecast.ss
- Report.sso
- starter.ss
- ss3_win.exe
- r4ss html output and associated figures in 'plots' folder

8 Tables

8.1 Data

Table 1: Total removals (mt) of quillback rockfish in California for the commercial (Comm.) and recreational (Rec.) fleets as used in the assessment model. See text for description of sources.

Year	Comm.	Rec.	Year	Comm.	Rec.	Year	Comm.	Rec.
1916	0.01	0.00	1956	0.04	2.02	1996	11.61	3.56
1917	0.03	0.00	1957	0.06	2.00	1997	19.00	3.35
1918	0.07	0.00	1958	0.10	3.49	1998	11.90	2.68
1919	0.02	0.00	1959	0.04	2.61	1999	8.20	5.34
1920	0.02	0.00	1960	0.02	2.18	2000	6.30	6.80
1921	0.03	0.00	1961	0.02	1.58	2001	12.09	3.60
1922	0.03	0.00	1962	0.02	1.79	2002	4.75	1.17
1923	0.01	0.00	1963	0.06	2.66	2003	1.97	11.88
1924	0.02	0.00	1964	0.03	2.18	2004	1.90	3.18
1925	0.07	0.00	1965	0.10	3.71	2005	4.86	5.70
1926	0.07	0.00	1966	0.04	4.22	2006	4.17	10.16
1927	0.14	0.00	1967	0.08	4.73	2007	6.56	12.71
1928	0.12	0.06	1968	0.07	4.84	2008	6.27	4.74
1929	0.11	0.12	1969	0.00	5.44	2009	1.23	5.73
1930	0.18	0.14	1970	0.00	7.40	2010	0.87	2.69
1931	0.24	0.19	1971	0.00	6.58	2011	0.94	4.50
1932	0.18	0.23	1972	0.00	9.41	2012	1.60	6.30
1933	0.14	0.28	1973	0.00	10.17	2013	0.67	2.90
1934	0.12	0.32	1974	0.00	11.24	2014	0.45	2.55
1935	0.22	0.37	1975	0.00	11.20	2015	1.09	7.50
1936	0.22	0.42	1976	0.00	12.75	2016	1.01	8.60
1937	0.15	0.50	1977	0.00	13.48	2017	2.56	10.01
1938	0.20	0.49	1978	0.11	12.99	2018	2.63	10.34
1939	0.20	0.43	1979	0.00	13.93	2019	4.67	11.78
1940	0.08	0.61	1980	0.00	15.04	2020	4.22	10.94
1941	0.13	0.57	1981	0.00	4.89	2021	4.77	11.07
1942	0.13	0.30	1982	0.00	5.04	2022	8.73	10.42
1943	0.17	0.29	1983	0.00	40.00	2023	2.24	2.26
1944	0.89	0.24	1984	3.06	10.40	2024	0.09	1.10
1945	2.20	0.32	1985	0.00	12.25			
1946	2.30	0.54	1986	0.08	13.18			
1947	0.46	0.43	1987	0.14	5.51			
1948	0.97	0.86	1988	0.28	1.84			
1949	0.34	1.11	1989	1.81	9.71			
1950	0.17	1.35	1990	1.28	5.69			
1951	0.32	1.65	1991	49.51	11.21			
1952	0.27	1.43	1992	5.95	16.74			
1953	0.15	1.22	1993	4.76	38.22			
1954	0.38	1.52	1994	19.22	6.50			
1955	0.02	1.81	1995	9.32	5.49			

Table 2: Recent trend in overfishing limits (OFL), acceptable biological catches (ABC), the annual catch limits (ACL; set to equal ABC) for quillback rockfish, along with total removals (landings + dead discards) all in metric tons (mt). For 2015-2022, values for OFLs and ACLs represent OFL and ACL contributions of quillback rockfish within the Minor Nearshore Rockfish North and South complexes and are marked with an asterisk (∗). The ACL contribution allocated to California across both complexes is also provided and marked with an asterisk (∗), and is calculated as described in Section 1.5. For 2023-2024, California quillback rockfish was assigned its own OFL, ABC, and ACL, which are provided here as California only values.

Year	OFL* South	ACL* South	OFL* North	ACL* North	ACL* CA	OFL CA	ABC CA	ACL CA	Total removals
2015	5.39	4.49	7.37	6.15	6.26	—	—	—	8.59
2016	5.39	4.49	7.37	6.15	6.26	—	—	—	9.61
2017	5.39	4.49	7.37	6.15	6.26	—	—	—	12.57
2018	5.39	4.49	7.37	6.15	6.26	—	—	—	12.97
2019	5.39	4.49	7.37	6.15	6.26	—	—	—	16.45
2020	5.39	4.49	7.37	6.15	6.26	—	—	—	15.15
2021	5.39	4.19	7.37	5.73	5.84	—	—	—	15.83
2022	5.39	4.19	7.37	5.74	5.84	—	—	—	19.15
2023	—	—	—	—	—	2.11	1.84	1.76	4.50
2024	—	—	—	—	—	2.32	2.01	1.93	1.19

Table 3: Summary of the number of commercial length samples and number of trips available for use in the assessment model. Also included is the input sample size used in the assessment model following the formula described in the text. Lengths in years that had an input sample size of less than or equal to 5 were excluded from final model fits, as described in the text.

Year	N Lengths	N Trips	N Input
1978	2	1	1.28
1984	1	1	1.14
1987	1	1	1.14
1991	158	7	28.80
1992	260	32	67.88
1993	97	14	27.39
1994	287	21	60.61
1995	126	17	34.39
1996	132	22	40.22
1997	150	21	41.70
1998	16	3	5.21
1999	580	50	130.04
2000	41	12	17.66
2001	322	33	77.44
2002	17	6	8.35
2004	14	4	5.93
2005	16	2	4.21
2006	19	3	5.62
2007	138	20	39.04
2008	108	17	31.90
2009	39	10	15.38
2010	16	6	8.21
2011	7	5	5.97
2012	15	9	11.07
2013	13	5	6.79
2014	5	5	5.69
2015	20	14	16.76
2016	16	10	12.21
2017	49	14	20.76
2018	31	8	12.28
2019	86	7	18.87
2020	74	10	20.21
2021	34	8	12.69
2022	71	14	23.80
2023	16	8	10.21
2024	3	1	1.41

Table 4: Summary of the number of commercial age samples and number of trips available for use in the assessment model as conditional age-at-length. The number of ages was used as the input sample size in the assessment model. Ages in years that had fewer than 30 samples were excluded from final model fits, as described in the text.

Year	N Ages	N Trips
2007	27	1
2011	1	1
2012	4	3
2019	75	4
2020	73	9
2021	32	8
2022	71	14
2023	16	8
2024	3	1

Table 5: Summary of the number of recreational length samples and number of trips available for use in the assessment model. The number of trips was used as the input sample size in the assessment model. Duplicate private/charter mode lengths from the MRFSS sampling program in 1997-1998 are not included. Lengths in years with the number of trips fewer than or equal to 5 were excluded from final model fits, as described in the text.

Year	N Lengths	N Trips
1959	45	7
1960	45	11
1980	11	10
1981	7	7
1982	8	7
1983	61	32
1984	28	21
1985	36	31
1986	44	34
1987	12	9
1988	94	25
1989	156	72
1990	37	12
1991	6	5
1992	72	27
1993	229	120
1994	175	77
1995	214	50
1996	286	109
1997	186	73
1998	108	46
1999	72	47
2000	46	32
2001	32	22
2002	5	4
2003	56	42
2004	120	40
2005	215	91
2006	417	167
2007	552	168
2008	330	124
2009	321	124
2010	144	77
2011	207	82
2012	270	122
2013	189	100
2014	129	73
2015	376	151
2016	440	140
2017	457	197
2018	423	187
2019	464	194
2021	256	105
2022	409	168
2023	134	63
2024	37	26

Table 6: Summary of the number of fishery-independent length samples, along with the number of drifts or transects or hauls, available for use in the assessment model. See text for description of data sources. The number of drifts or transects was used as the input sample size in the assessment model. Data from the WCGBTS were too sparse to use as length compositions in the assessment model. Lengths in years with input sample size fewer than 5 for each other source were excluded from final model fits, as described in the text.

Year	N Lengths CCFRP	N Drifts CCFRP	N Lengths ROV	N Transect ROV	N Lengths WCGBTS	N Haul WCGBTS
2007	—	—	—	—	19	1
2013	—	—	—	—	1	1
2014	—	—	112	57	4	2
2015	—	—	53	30	—	—
2016	—	—	3	2	—	—
2017	156	61	—	—	2	2
2018	260	106	—	—	—	—
2019	39	30	94	38	—	—
2020	41	33	295	102	—	—
2021	51	34	122	53	—	—
2022	76	51	—	—	—	—
2023	108	57	—	—	—	—
2024	590	108	—	—	13	1

Table 7: Summary of the number of age samples available for use in the assessment model (except commercial, which is shown in Table 4). See text for description of data sources. All data were used to initialize growth parameters. Ages from Abrams were used in the assessment model as conditional age-at-length for the growth fleet, and ages from CCFRP were used in the assessment model as conditional age-at-length for the CCFRP fleet. For Abrams and CCFRP, the number of ages was used as the input sample size.

Year	Abrams	CCFRP	CRFS Surrendered	CDFW commercial	SWFSC Coop	IPHC	CDFW Gfish	SWFSC Research	WCGBTS	Misc.
1985	—	—	—	—	—	—	—	—	—	5
2004	—	—	—	—	—	—	—	—	—	4
2007	—	—	—	—	—	—	—	—	15	—
2010	37	—	—	—	—	—	—	—	—	—
2011	79	—	—	—	—	—	—	—	—	—
2014	—	—	—	—	—	—	—	—	4	—
2017	—	30	—	—	—	5	—	—	2	—
2018	—	55	—	—	—	—	—	—	—	—
2019	—	11	—	6	—	—	—	—	—	—
2020	—	7	—	—	—	—	—	—	—	—
2021	—	8	35	—	—	—	3	—	—	—
2022	—	19	43	—	132	—	43	—	—	—
2023	—	9	17	—	2	—	9	23	—	—
2024	—	31	16	—	—	—	—	73	13	—
Total	**116**	**170**	**111**	**6**	**134**	**5**	**55**	**96**	**34**	**9**

8.2 Assessment Model

Table 8: Specifications and structure of the model.

Section	Configuration
Maximum age	80
Sexes	Sexes combined
Population length bins	4-59 cm by 1 cm bins
Summary biomass (mt) age	3+
Number of areas	1
Number of seasons	1
Number of growth patterns	1
Start year	1916
End year	2024
Data length bins	10-50 cm by 2 cm bins
Data age bins	1-60 by 1 year

Table 9: Number of estimated parameters in the model.

Type	Count
Growth mean	3
Growth variability	2
Stock-recruit	1
Rec. dev. time series	85
Rec. dev. forecast	12
Index	3
Size selectivity	8
Size selectivity time-variation	7

Table 10: Data weightings applied to compositions according to the 'Francis' method. 'Obs.' refers to the number of unique composition vectors included in the likelihood. 'N input' and 'N adj.' refer to the sample sizes of those vectors before and after being adjusted by the the weights. 'CAAL' is conditional age-at-length data.

Type	Fleet	Francis	Obs.	Mean N input	Mean N adj.	Sum N adj.
Length	CA_Commercial	0.380	31	26.6	10.1	313.1
Length	CA_Recreational	0.179	44	75.5	13.5	595.3
Length	CA_CCFRP	0.225	8	60.0	13.5	108.1
Length	CA_ROV	0.174	5	56.0	9.7	48.7
CAAL	CA_Commercial	0.085	39	6.4	1.1	42.9
CAAL	CA_Growth	0.946	24	4.8	4.6	110.2
CAAL	CA_CCFRP	0.367	65	2.6	1.3	84.2

Table 11: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model.

Label	Value	Phase	Bounds	Status	SD	Prior
NatM_uniform_Fem_GP_1	0.068	-2	(0.01, 0.15)	fixed		lognormal(0.067, 0.310)
L_at_Amin_Fem_GP_1	9.35	3	(0, 20)	ok	1.93	none
L_at_Amax_Fem_GP_1	42.82	3	(35, 50)	ok	0.694	none
VonBert_K_Fem_GP_1	0.127	3	(0.03, 0.3)	ok	0.0133	none
CV_young_Fem_GP_1	0.177	3	(0.01, 0.5)	ok	0.0327	none
CV_old_Fem_GP_1	0.0872	3	(0.001, 0.5)	ok	0.00802	none
Wtlen_1_Fem_GP_1	1.58e-05	-9	(0, 0.1)	fixed		none
Wtlen_2_Fem_GP_1	3.08	-9	(2, 4)	fixed		none
Mat50%_Fem_GP_1	28.96	-9	(25, 32)	fixed		none
Mat_slope_Fem_GP_1	-0.606	-9	(-1, 0)	fixed		none
Eggs_scalar_Fem_GP_1	4.22e-08	-9	(-3, 3)	fixed		none
Eggs_exp_len_Fem_GP_1	4.44	-9	(1, 7)	fixed		none
CohortGrowDev	1	-9	(0, 1)	fixed		none
FracFemale_GP_1	0.5	-9	(0.01, 0.99)	fixed		none
SR_LN(R0)	3.81	1	(1, 20)	ok	0.0838	none
SR_BH_steep	0.72	-7	(0.2, 1)	fixed		beta(0.720, 0.160)
SR_sigmaR	0.6	-99	(0.15, 0.9)	fixed		none
SR_regime	0	-99	(-2, 2)	fixed		none
SR_autocorr	0	-99	(0, 0)	fixed		none
Early_RecrDev_1940	-0.0291	5	(-5, 5)	dev	0.591	normal(0.00, 0.60)
Early_RecrDev_1941	-0.0323	5	(-5, 5)	dev	0.59	normal(0.00, 0.60)
Early_RecrDev_1942	-0.0361	5	(-5, 5)	dev	0.589	normal(0.00, 0.60)
Early_RecrDev_1943	-0.0403	5	(-5, 5)	dev	0.588	normal(0.00, 0.60)
Early_RecrDev_1944	-0.0452	5	(-5, 5)	dev	0.586	normal(0.00, 0.60)
Early_RecrDev_1945	-0.0505	5	(-5, 5)	dev	0.585	normal(0.00, 0.60)
Early_RecrDev_1946	-0.0564	5	(-5, 5)	dev	0.583	normal(0.00, 0.60)
Early_RecrDev_1947	-0.0626	5	(-5, 5)	dev	0.581	normal(0.00, 0.60)
Early_RecrDev_1948	-0.0692	5	(-5, 5)	dev	0.579	normal(0.00, 0.60)
Early_RecrDev_1949	-0.0757	5	(-5, 5)	dev	0.578	normal(0.00, 0.60)
Early_RecrDev_1950	-0.0815	5	(-5, 5)	dev	0.576	normal(0.00, 0.60)
Early_RecrDev_1951	-0.0859	5	(-5, 5)	dev	0.575	normal(0.00, 0.60)
Early_RecrDev_1952	-0.0878	5	(-5, 5)	dev	0.574	normal(0.00, 0.60)
Early_RecrDev_1953	-0.0873	5	(-5, 5)	dev	0.573	normal(0.00, 0.60)

Table 11: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

Label	Value	Phase	Bounds	Status	SD	Prior
Early_RecrDev_1954	-0.0857	5	(-5, 5)	dev	0.574	normal(0.00, 0.60)
Early_RecrDev_1955	-0.0849	5	(-5, 5)	dev	0.574	normal(0.00, 0.60)
Early_RecrDev_1956	-0.0854	5	(-5, 5)	dev	0.574	normal(0.00, 0.60)
Early_RecrDev_1957	-0.0879	5	(-5, 5)	dev	0.573	normal(0.00, 0.60)
Early_RecrDev_1958	-0.0906	5	(-5, 5)	dev	0.572	normal(0.00, 0.60)
Early_RecrDev_1959	-0.0926	5	(-5, 5)	dev	0.572	normal(0.00, 0.60)
Early_RecrDev_1960	-0.0949	5	(-5, 5)	dev	0.571	normal(0.00, 0.60)
Early_RecrDev_1961	-0.0985	5	(-5, 5)	dev	0.569	normal(0.00, 0.60)
Early_RecrDev_1962	-0.105	5	(-5, 5)	dev	0.567	normal(0.00, 0.60)
Early_RecrDev_1963	-0.114	5	(-5, 5)	dev	0.565	normal(0.00, 0.60)
Early_RecrDev_1964	-0.128	5	(-5, 5)	dev	0.561	normal(0.00, 0.60)
Early_RecrDev_1965	-0.149	5	(-5, 5)	dev	0.556	normal(0.00, 0.60)
Early_RecrDev_1966	-0.176	5	(-5, 5)	dev	0.55	normal(0.00, 0.60)
Early_RecrDev_1967	-0.208	5	(-5, 5)	dev	0.543	normal(0.00, 0.60)
Early_RecrDev_1968	-0.24	5	(-5, 5)	dev	0.537	normal(0.00, 0.60)
Early_RecrDev_1969	-0.266	5	(-5, 5)	dev	0.532	normal(0.00, 0.60)
Early_RecrDev_1970	-0.282	5	(-5, 5)	dev	0.528	normal(0.00, 0.60)
Early_RecrDev_1971	-0.288	5	(-5, 5)	dev	0.526	normal(0.00, 0.60)
Early_RecrDev_1972	-0.284	5	(-5, 5)	dev	0.526	normal(0.00, 0.60)
Early_RecrDev_1973	-0.276	5	(-5, 5)	dev	0.526	normal(0.00, 0.60)
Early_RecrDev_1974	-0.269	5	(-5, 5)	dev	0.526	normal(0.00, 0.60)
Early_RecrDev_1975	-0.266	5	(-5, 5)	dev	0.526	normal(0.00, 0.60)
Early_RecrDev_1976	-0.255	5	(-5, 5)	dev	0.529	normal(0.00, 0.60)
Early_RecrDev_1977	-0.213	5	(-5, 5)	dev	0.535	normal(0.00, 0.60)
Main_RecrDev_1978	-0.246	2	(-5, 5)	dev	0.547	normal(0.00, 0.60)
Main_RecrDev_1979	-0.127	2	(-5, 5)	dev	0.574	normal(0.00, 0.60)
Main_RecrDev_1980	0.0305	2	(-5, 5)	dev	0.617	normal(0.00, 0.60)
Main_RecrDev_1981	0.216	2	(-5, 5)	dev	0.682	normal(0.00, 0.60)
Main_RecrDev_1982	0.425	2	(-5, 5)	dev	0.772	normal(0.00, 0.60)
Main_RecrDev_1983	0.511	2	(-5, 5)	dev	0.833	normal(0.00, 0.60)
Main_RecrDev_1984	0.461	2	(-5, 5)	dev	0.813	normal(0.00, 0.60)
Main_RecrDev_1985	0.435	2	(-5, 5)	dev	0.754	normal(0.00, 0.60)
Main_RecrDev_1986	0.25	2	(-5, 5)	dev	0.669	normal(0.00, 0.60)
Main_RecrDev_1987	0.00148	2	(-5, 5)	dev	0.596	normal(0.00, 0.60)

Table 11: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

Label	Value	Phase	Bounds	Status	SD	Prior
Main_RecrDev_1988	-0.104	2	(-5, 5)	dev	0.567	normal(0.00, 0.60)
Main_RecrDev_1989	-0.0149	2	(-5, 5)	dev	0.579	normal(0.00, 0.60)
Main_RecrDev_1990	0.19	2	(-5, 5)	dev	0.61	normal(0.00, 0.60)
Main_RecrDev_1991	0.187	2	(-5, 5)	dev	0.651	normal(0.00, 0.60)
Main_RecrDev_1992	0.119	2	(-5, 5)	dev	0.732	normal(0.00, 0.60)
Main_RecrDev_1993	1.41	2	(-5, 5)	dev	0.936	normal(0.00, 0.60)
Main_RecrDev_1994	1.64	2	(-5, 5)	dev	0.728	normal(0.00, 0.60)
Main_RecrDev_1995	-0.0673	2	(-5, 5)	dev	0.658	normal(0.00, 0.60)
Main_RecrDev_1996	-0.25	2	(-5, 5)	dev	0.534	normal(0.00, 0.60)
Main_RecrDev_1997	-0.0846	2	(-5, 5)	dev	0.458	normal(0.00, 0.60)
Main_RecrDev_1998	-0.397	2	(-5, 5)	dev	0.465	normal(0.00, 0.60)
Main_RecrDev_1999	-0.663	2	(-5, 5)	dev	0.431	normal(0.00, 0.60)
Main_RecrDev_2000	-0.774	2	(-5, 5)	dev	0.408	normal(0.00, 0.60)
Main_RecrDev_2001	-0.959	2	(-5, 5)	dev	0.403	normal(0.00, 0.60)
Main_RecrDev_2002	-0.93	2	(-5, 5)	dev	0.418	normal(0.00, 0.60)
Main_RecrDev_2003	0.179	2	(-5, 5)	dev	0.281	normal(0.00, 0.60)
Main_RecrDev_2004	-0.552	2	(-5, 5)	dev	0.415	normal(0.00, 0.60)
Main_RecrDev_2005	-0.721	2	(-5, 5)	dev	0.395	normal(0.00, 0.60)
Main_RecrDev_2006	-0.914	2	(-5, 5)	dev	0.399	normal(0.00, 0.60)
Main_RecrDev_2007	-0.895	2	(-5, 5)	dev	0.425	normal(0.00, 0.60)
Main_RecrDev_2008	-0.57	2	(-5, 5)	dev	0.437	normal(0.00, 0.60)
Main_RecrDev_2009	-0.3	2	(-5, 5)	dev	0.468	normal(0.00, 0.60)
Main_RecrDev_2010	0.525	2	(-5, 5)	dev	0.359	normal(0.00, 0.60)
Main_RecrDev_2011	-0.0552	2	(-5, 5)	dev	0.464	normal(0.00, 0.60)
Main_RecrDev_2012	0.62	2	(-5, 5)	dev	0.302	normal(0.00, 0.60)
Main_RecrDev_2013	-0.514	2	(-5, 5)	dev	0.434	normal(0.00, 0.60)
Main_RecrDev_2014	-0.832	2	(-5, 5)	dev	0.452	normal(0.00, 0.60)
Main_RecrDev_2015	-0.441	2	(-5, 5)	dev	0.473	normal(0.00, 0.60)
Main_RecrDev_2016	1.5	2	(-5, 5)	dev	0.311	normal(0.00, 0.60)
Main_RecrDev_2017	0.986	2	(-5, 5)	dev	0.473	normal(0.00, 0.60)
Main_RecrDev_2018	0.386	2	(-5, 5)	dev	0.581	normal(0.00, 0.60)
Main_RecrDev_2019	0.529	2	(-5, 5)	dev	0.561	normal(0.00, 0.60)
Main_RecrDev_2020	-0.109	2	(-5, 5)	dev	0.579	normal(0.00, 0.60)
Main_RecrDev_2021	-0.0819	2	(-5, 5)	dev	0.594	normal(0.00, 0.60)

Table 11: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

Label	Value	Phase	Bounds	Status	SD	Prior
Late_RecrDev_2022	0.0162	6	(-5, 5)	dev	0.603	normal(0.00, 0.60)
Late_RecrDev_2023	0.0126	6	(-5, 5)	dev	0.602	normal(0.00, 0.60)
Late_RecrDev_2024	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2025	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2026	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2027	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2028	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2029	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2030	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2031	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2032	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2033	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2034	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2035	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
ForeRecr_2036	0	6	(-5, 5)	dev	0.6	normal(0.00, 0.60)
LnQ_base_CA_Recreational(2)	-6.62	2	(-25, 25)	ok	0.16	none
LnQ_base_CA_CCFRP(4)	-11.8	2	(-25, 25)	ok	0.203	none
LnQ_base_CA_ROV(5)	-2.94	2	(-25, 25)	ok	0.274	none
Size_DblN_peak_CA_Commercial(1)	39.8	4	(11, 51)	ok	2.02	none
Size_DblN_top_logit_CA_Commercial(1)	-15	-9	(-20, 20)	fixed		none
Size_DblN_ascend_se_CA_Commercial(1)	3.71	5	(0, 9)	ok	0.509	none
Size_DblN_descend_se_CA_Commercial(1)	15	-5	(0, 20)	fixed		none
Size_DblN_start_logit_CA_Commercial(1)	-999	-9	(-20, 30)	fixed		none
Size_DblN_end_logit_CA_Commercial(1)	-999	-9	(-10, 10)	fixed		none
Size_DblN_peak_CA_Recreational(2)	32.2	4	(11, 51)	ok	1.27	none
Size_DblN_top_logit_CA_Recreational(2)	-15	-9	(-20, 20)	fixed		none
Size_DblN_ascend_se_CA_Recreational(2)	3.66	5	(0, 9)	ok	0.299	none
Size_DblN_descend_se_CA_Recreational(2)	15	-4	(0, 20)	fixed		none
Size_DblN_start_logit_CA_Recreational(2)	-999	-9	(-20, 30)	fixed		none
Size_DblN_end_logit_CA_Recreational(2)	-999	-9	(-10, 10)	fixed		none
Size_DblN_peak_CA_CCFRP(4)	33	4	(11, 51)	ok	2.32	none
Size_DblN_top_logit_CA_CCFRP(4)	-15	-9	(-20, 20)	fixed		none
Size_DblN_ascend_se_CA_CCFRP(4)	4.37	5	(0, 9)	ok	0.379	none
Size_DblN_descend_se_CA_CCFRP(4)	15	-9	(0, 20)	fixed		none

Table 11: Parameter estimates, estimation phase, parameter bounds, estimation status, estimated standard deviation (SD), prior information [distribution(mean, SD)] used in the base model. *(continued)*

Label	Value	Phase	Bounds	Status	SD	Prior
Size_DblN_start_logit_CA_CCFRP(4)	-999	-9	(-20, 30)	fixed		none
Size_DblN_end_logit_CA_CCFRP(4)	-999	-9	(-10, 10)	fixed		none
Size_DblN_peak_CA_ROV(5)	39.8	4	(11, 51)	ok	5.11	none
Size_DblN_top_logit_CA_ROV(5)	-15	-9	(-20, 20)	fixed		none
Size_DblN_ascend_se_CA_ROV(5)	5.57	5	(0, 9)	ok	0.497	none
Size_DblN_descend_se_CA_ROV(5)	15	-9	(0, 20)	fixed		none
Size_DblN_start_logit_CA_ROV(5)	-999	-9	(-20, 30)	fixed		none
Size_DblN_end_logit_CA_ROV(5)	-999	-9	(-10, 10)	fixed		none
Size_DblN_peak_CA_Commercial(1)_BLK1repl_1916	37.1	4	(11, 51)	ok	1.5	none
Size_DblN_peak_CA_Commercial(1)_BLK1repl_2014	46.5	4	(11, 51)	ok	3.48	none
Size_DblN_ascend_se_CA_Commercial(1)_BLK1repl_1916	4.3	5	(0, 9)	ok	0.242	none
Size_DblN_ascend_se_CA_Commercial(1)_BLK1repl_2014	4.15	5	(0, 9)	ok	0.54	none
Size_DblN_descend_se_CA_Commercial(1)_BLK1repl_1916	4.17	5	(0, 9)	ok	0.648	none
Size_DblN_descend_se_CA_Commercial(1)_BLK1repl_2014	15	-5	(0, 20)	fixed		none
Size_DblN_peak_CA_Recreational(2)_BLK2repl_2017	36.8	4	(11, 51)	ok	1.96	none
Size_DblN_ascend_se_CA_Recreational(2)_BLK2repl_2017	3.92	5	(0, 9)	ok	0.415	none
Size_DblN_descend_se_CA_Recreational(2)_BLK2repl_2017	15	-5	(0, 20)	fixed		none

Table 12: Likelihood components by source.

source	values
TOTAL	532.46
Catch	0.00
Equil_catch	0.00
Survey	-26.68
Length_comp	173.69
Age_comp	365.95
Recruitment	19.50
InitEQ_Regime	0.00
Forecast_Recruitment	0.00
Parm_priors	0.00
Parm_softbounds	0.00
Parm_devs	0.00
Crash_Pen	0.00

Table 13: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning output (Billions of eggs)	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits (1,000s)	Total Mortality (mt)	1-SPR	Exploitation Rate
1916	525	97.08	522	1.000	45	0.01	0.001	0.000
1917	525	97.08	522	1.000	45	0.03	0.001	0.000
1918	525	97.07	522	1.000	45	0.07	0.003	0.000
1919	525	97.06	522	1.000	45	0.02	0.001	0.000
1920	525	97.06	522	1.000	45	0.02	0.001	0.000
1921	525	97.05	522	1.000	45	0.03	0.001	0.000
1922	525	97.05	522	1.000	45	0.03	0.001	0.000
1923	525	97.04	522	1.000	45	0.01	0.000	0.000
1924	525	97.04	522	1.000	45	0.02	0.001	0.000
1925	525	97.04	522	1.000	45	0.07	0.003	0.000
1926	525	97.03	522	0.999	45	0.07	0.003	0.000
1927	525	97.01	522	0.999	45	0.14	0.006	0.000
1928	525	96.99	522	0.999	45	0.18	0.008	0.000
1929	524	96.96	522	0.999	45	0.23	0.010	0.000
1930	524	96.91	522	0.998	45	0.32	0.013	0.001
1931	524	96.86	521	0.998	45	0.43	0.018	0.001
1932	524	96.78	521	0.997	45	0.41	0.017	0.001
1933	523	96.71	520	0.996	45	0.41	0.017	0.001
1934	523	96.64	520	0.995	45	0.45	0.019	0.001
1935	523	96.56	520	0.995	45	0.60	0.025	0.001
1936	522	96.46	519	0.994	45	0.63	0.026	0.001
1937	522	96.35	519	0.992	45	0.64	0.027	0.001
1938	521	96.25	518	0.991	45	0.69	0.029	0.001
1939	521	96.14	518	0.990	45	0.62	0.026	0.001
1940	520	96.05	517	0.989	44	0.69	0.028	0.001
1941	520	95.95	517	0.988	44	0.70	0.029	0.001
1942	519	95.85	516	0.987	43	0.43	0.018	0.001
1943	519	95.80	516	0.987	43	0.46	0.019	0.001
1944	518	95.75	516	0.986	43	1.13	0.047	0.002
1945	517	95.57	515	0.984	43	2.51	0.101	0.005
1946	515	95.11	512	0.980	42	2.84	0.114	0.006
1947	512	94.58	509	0.974	42	0.89	0.038	0.002
1948	511	94.43	508	0.973	42	1.82	0.075	0.004
1949	509	94.09	506	0.969	42	1.45	0.060	0.003
1950	507	93.82	504	0.966	41	1.53	0.063	0.003
1951	505	93.53	503	0.963	41	1.96	0.080	0.004
1952	503	93.14	500	0.959	41	1.70	0.070	0.003
1953	501	92.79	498	0.956	41	1.37	0.057	0.003
1954	499	92.49	497	0.953	41	1.90	0.079	0.004
1955	497	92.08	494	0.948	41	1.82	0.075	0.004
1956	494	91.68	492	0.944	41	2.05	0.084	0.004
1957	492	91.22	489	0.940	41	2.06	0.085	0.004
1958	490	90.76	487	0.935	41	3.58	0.142	0.007
1959	486	90.00	483	0.927	41	2.66	0.109	0.006
1960	483	89.42	480	0.921	41	2.20	0.092	0.005
1961	480	88.94	478	0.916	40	1.60	0.069	0.003
1962	478	88.58	476	0.912	40	1.80	0.077	0.004
1963	476	88.19	474	0.908	40	2.72	0.113	0.006
1964	474	87.63	471	0.903	39	2.21	0.094	0.005
1965	471	87.18	469	0.898	38	3.80	0.155	0.008
1966	468	86.44	465	0.890	37	4.26	0.172	0.009
1967	463	85.63	461	0.882	36	4.80	0.192	0.010
1968	459	84.72	456	0.873	35	4.91	0.197	0.011
1969	454	83.81	451	0.863	34	5.44	0.216	0.012
1970	448	82.82	446	0.853	33	7.40	0.280	0.017
1971	441	81.45	439	0.839	33	6.58	0.258	0.015
1972	434	80.25	432	0.827	33	9.41	0.343	0.022
1973	424	78.50	422	0.809	33	10.17	0.368	0.024
1974	414	76.60	412	0.789	34	11.24	0.400	0.027
1975	403	74.48	401	0.767	34	11.20	0.407	0.028

Table 13: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning output (Billions of eggs)	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits (1,000s)	Total Mortality (mt)	1-SPR	Exploita-tion Rate
1976	392	72.38	390	0.746	34	12.75	0.451	0.033
1977	380	69.98	378	0.721	35	13.48	0.476	0.036
1978	367	67.46	365	0.695	34	13.11	0.478	0.036
1979	355	65.04	353	0.670	38	13.93	0.506	0.039
1980	343	62.52	341	0.644	44	15.04	0.539	0.044
1981	330	59.85	328	0.617	53	4.89	0.259	0.015
1982	329	59.20	326	0.610	65	5.04	0.267	0.015
1983	328	58.58	324	0.603	70	40.00	0.815	0.123
1984	295	51.44	290	0.530	66	13.46	0.563	0.046
1985	289	49.46	285	0.509	64	12.25	0.540	0.043
1986	288	47.94	284	0.494	53	13.25	0.568	0.047
1987	287	46.52	283	0.479	41	5.65	0.336	0.020
1988	294	46.86	291	0.483	37	2.12	0.149	0.007
1989	305	48.26	303	0.497	40	11.52	0.513	0.038
1990	308	48.39	305	0.498	50	6.97	0.369	0.023
1991	314	49.65	312	0.511	50	60.73	0.899	0.195
1992	268	41.57	265	0.428	45	22.68	0.737	0.086
1993	259	40.15	256	0.414	162	42.97	0.876	0.168
1994	232	35.19	228	0.362	197	25.72	0.805	0.113
1995	226	32.91	215	0.339	35	14.81	0.683	0.069
1996	233	32.48	224	0.335	28	15.17	0.691	0.068
1997	242	32.09	240	0.331	32	22.35	0.786	0.093
1998	246	30.86	244	0.318	23	14.58	0.680	0.060
1999	256	31.72	255	0.327	18	13.53	0.639	0.053
2000	267	33.80	265	0.348	16	13.10	0.604	0.049
2001	275	36.68	274	0.378	13	15.69	0.635	0.057
2002	277	39.25	276	0.404	14	5.92	0.344	0.021
2003	286	42.93	285	0.442	43	13.85	0.565	0.049
2004	285	44.79	283	0.461	21	5.08	0.297	0.018
2005	290	47.36	287	0.488	18	10.56	0.468	0.037
2006	287	48.34	286	0.498	15	14.33	0.557	0.050
2007	280	47.99	278	0.494	15	19.27	0.643	0.069
2008	266	46.19	265	0.476	21	11.00	0.487	0.042
2009	259	45.50	258	0.469	27	6.96	0.389	0.027
2010	255	45.27	253	0.466	62	3.56	0.237	0.014
2011	254	45.46	251	0.468	35	5.43	0.332	0.022
2012	251	45.11	248	0.465	68	7.91	0.431	0.032
2013	248	44.10	245	0.454	22	3.57	0.249	0.015
2014	249	43.79	246	0.451	16	3.00	0.216	0.012
2015	251	43.60	250	0.449	23	8.59	0.463	0.034
2016	249	42.51	248	0.438	163	9.61	0.501	0.039
2017	248	41.52	244	0.428	100	12.57	0.548	0.052
2018	247	40.25	238	0.415	58	12.97	0.564	0.055
2019	248	39.15	243	0.403	67	16.45	0.626	0.068
2020	249	37.58	246	0.387	35	15.15	0.615	0.062
2021	254	36.52	250	0.376	36	15.83	0.630	0.063
2022	259	35.96	257	0.370	39	19.15	0.689	0.075
2023	261	35.60	259	0.367	39	4.50	0.323	0.017
2024	276	38.45	273	0.396	39	1.19	0.099	0.004
2025	293	42.26	291	0.435	40	1.30	0.099	0.004
2026	309	46.12	306	0.475	41	1.50	0.104	0.005
2027	323	49.78	320	0.513	41	12.00	0.482	0.037
2028	326	51.39	323	0.529	41	12.36	0.481	0.038
2029	328	52.54	325	0.541	42	12.60	0.480	0.039
2030	328	53.29	325	0.549	42	12.73	0.478	0.039
2031	327	53.70	325	0.553	42	12.75	0.477	0.039
2032	326	53.85	323	0.555	42	12.70	0.476	0.039
2033	324	53.81	322	0.554	42	12.61	0.475	0.039
2034	322	53.62	320	0.552	42	12.47	0.473	0.039
2035	320	53.36	317	0.550	42	12.32	0.472	0.039
2036	318	53.04	315	0.546	42	12.17	0.471	0.039

Table 14: Productivity sensitivities. Values of negative log-likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models (columns) relative to productivity. See main text for details on each sensitivity analysis.

	Base	Estimate h	Estimate M	Estimate M and h	Start recdevs in 1990	Turn off recdevs	Fix growth at 2021 values	Fix growth at 2021 values without ages
TOTAL_like	532.463	531.683	531.367	530.825	538.200	650.453	669.138	153.917
Survey_like	-26.677	-26.935	-27.246	-27.337	-27.065	-3.928	-24.729	-31.706
Length_comp_like	173.688	173.092	173.909	173.528	179.685	211.353	211.963	171.323
Age_comp_like	365.950	366.185	366.139	366.228	369.331	443.022	460.833	0.000
Recruitment_like	19.499	19.300	18.336	18.197	16.246	0.000	21.069	14.297
Forecast_Recruitment_like	0.001	0.001	0.001	0.000	0.000	0.000	0.001	0.001
Parm_priors_like	0.001	0.039	0.227	0.207	0.001	0.001	0.001	0.001
Recr_Virgin_thousands	44.991	42.786	68.766	64.474	44.849	57.533	33.206	33.364
SR_LN(R0)	3.806	3.756	4.231	4.166	3.803	4.052	3.503	3.507
SR_BH_steep	0.720	0.896	0.720	0.885	0.720	0.720	0.720	0.720
NatM_uniform_Fem_GP_1	0.068	0.068	0.083	0.082	0.068	0.068	0.068	0.068
L_at_Amax_Fem_GP_1	42.820	42.844	42.992	42.975	42.481	43.126	43.040	43.040
VonBert_K_Fem_GP_1	0.127	0.127	0.125	0.125	0.131	0.104	0.199	0.199
SSB_Virgin	97.083	92.509	101.554	97.781	95.389	115.898	98.982	99.455
SSB_2025	42.256	44.012	60.318	60.355	45.561	58.905	40.386	23.901
Bratio_2025	0.435	0.476	0.594	0.617	0.478	0.508	0.408	0.240
SPRratio_2024	0.099	0.096	0.060	0.060	0.092	0.072	0.103	0.176

Table 15: Data weighting and contribution sensitivities. Values of negative log-likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models (columns) relative to data weighting. See main text for details on each sensitivity analysis. Because of differences in the relative contributions of data for these sensitivities, likelihoods are generally not comparable.

	Base	Dirichlet	McAllister-Ianelli	Index Extra SD	Remove all fleet lengths	Remove all ages	Remove all indices
TOTAL_like	532.463	3017.410	698.127	527.515	387.134	145.778	557.654
Survey_like	-26.677	-27.958	-27.577	-30.713	-28.700	-27.057	0.000
Length_comp_like	173.688	1977.270	303.036	173.950	38.254	163.534	173.803
Age_comp_like	365.950	1009.210	398.070	366.182	362.774	0.000	367.131
Recruitment_like	19.499	36.280	24.594	18.093	14.789	9.299	16.718
Forecast_Recruitment_like	0.001	0.078	0.001	0.000	0.000	0.000	0.000
Parm_priors_like	0.001	22.522	0.001	0.001	0.001	0.001	0.001
Recr_Virgin_thousands	44.991	45.508	45.424	44.443	42.650	43.918	41.534
SR_LN(R0)	3.806	3.818	3.816	3.794	3.753	3.782	3.727
SR_BH_steep	0.720	0.720	0.720	0.720	0.720	0.720	0.720
NatM_uniform_Fem_GP_1	0.068	0.068	0.068	0.068	0.068	0.068	0.068
L_at_Amax_Fem_GP_1	42.820	43.143	42.909	42.875	41.685	43.883	42.963
VonBert_K_Fem_GP_1	0.127	0.121	0.127	0.125	0.152	0.135	0.124
SSB_Virgin	97.083	100.028	99.478	96.105	87.765	105.699	90.177
SSB_2025	42.256	47.770	44.777	41.064	46.318	30.501	34.669
Bratio_2025	0.435	0.478	0.450	0.427	0.528	0.289	0.384
SPRratio_2024	0.099	0.091	0.095	0.101	0.088	0.143	0.118

Table 16: Contributions from age data sensitivities. Values of negative log-likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models (columns) related to age data. See main text for details on each sensitivity analysis. Because of differences in data for these sensitivities, likelihoods are generally not comparable.

	Base	preSTAR base - All ages in	Remove all growth fleet sources	Remove all growth fleet and CCFRP sources	Remove all ages
TOTAL_like	532.463	668.238	382.794	230.334	145.778
Survey_like	-26.677	-26.349	-26.977	-27.292	-27.057
Length_comp_like	173.688	174.184	174.997	176.492	163.534
Age_comp_like	365.950	500.121	221.899	71.895	0.000
Recruitment_like	19.499	20.280	12.871	9.234	9.299
Forecast_Recruitment_like	0.001	0.001	0.001	0.003	0.000
Parm_priors_like	0.001	0.001	0.001	0.001	0.001
Recr_Virgin_thousands	44.991	45.520	46.356	44.779	43.918
SR_LN(R0)	3.806	3.818	3.836	3.802	3.782
SR_BH_steep	0.720	0.720	0.720	0.720	0.720
NatM_uniform_Fem_GP_1	0.068	0.068	0.068	0.068	0.068
L_at_Amax_Fem_GP_1	42.820	42.749	43.114	42.760	43.883
VonBert_K_Fem_GP_1	0.127	0.126	0.127	0.147	0.135
SSB_Virgin	97.083	97.832	103.311	106.073	105.699
SSB_2025	42.256	45.426	40.812	36.162	30.501
Bratio_2025	0.435	0.464	0.395	0.341	0.289
SPRratio_2024	0.099	0.092	0.104	0.117	0.143

Table 17: Data choice sensitivities. Values of negative log-likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models (columns) relative to alternative data choices. See main text for details on each sensitivity analysis. Because of differences in data for these sensitivities, likelihoods are generally not comparable.

	Base	Reduce large catches	Catch as five year moving average	Areas as fleets	Remove ageing error
TOTAL_like	532.463	535.250	532.336	678.111	523.108
Survey_like	-26.677	-25.894	-26.762	-13.236	-26.483
Length_comp_like	173.688	175.372	173.674	280.363	174.471
Age_comp_like	365.950	365.182	366.196	391.890	356.110
Recruitment_like	19.499	20.587	19.224	19.086	19.007
Forecast_Recruitment_like	0.001	0.001	0.001	0.002	0.001
Parm_priors_like	0.001	0.001	0.001	0.001	0.001
Recr_Virgin_thousands	44.991	39.456	44.601	46.968	45.234
SR_LN(R0)	3.806	3.675	3.798	3.849	3.812
SR_BH_steep	0.720	0.720	0.720	0.720	0.720
NatM_uniform_Fem_GP_1	0.068	0.068	0.068	0.068	0.068
L_at_Amax_Fem_GP_1	42.820	42.713	42.844	44.039	42.802
VonBert_K_Fem_GP_1	0.127	0.128	0.126	0.107	0.126
SSB_Virgin	97.083	84.865	96.322	102.213	97.525
SSB_2025	42.256	38.587	42.819	42.753	40.871
Bratio_2025	0.435	0.455	0.445	0.418	0.419
SPRratio_2024	0.099	0.107	0.098	0.093	0.102

Table 18: Selectivity sensitivities. Number of parameters, values of negative log-likelihood, estimates of key parameters, and estimates of derived quantities between the base model and several alternative models (columns) relative to selectivity. See main text for details on each sensitivity analysis.

	Base	All fleets domed	Com domed	Rec domed	Surveys domed	No blocks	All asymptotic	Full rec block with domed	Full rec and com block with domed
Npar	121	127	123	123	123	114	120	130	134
TOTAL_like	532.463	529.53	531.622	532.417	532.083	563.515	535.413	531.256	530.421
Survey_like	-26.677	-27.182	-26.676	-26.686	-26.726	-20.56	-26.494	-27.006	-27.084
Length_comp_like	173.688	170.818	172.711	173.579	173.548	196.939	175.989	172.857	171.409
Age_comp_like	365.95	366.597	366.094	365.951	365.793	366.455	365.408	365.773	366.42
Recruitment_like	19.499	19.294	19.49	19.566	19.465	20.679	20.506	19.628	19.667
Forecast_Recruitment_like	0.001	0	0.001	0.001	0.001	0.001	0	0.001	0.001
Parm_priors_like	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Recr_Virgin_thousands	44.991	51.646	45.045	45.477	45.046	39.567	44.237	46.161	45.947
SR_LN(R0)	3.806	3.944	3.808	3.817	3.808	3.678	3.79	3.832	3.827
SR_BH_steep	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
NatM_uniform_Fem_GP_1	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068
L_at_Amax_Fem_GP_1	42.82	44.562	42.889	42.91	42.934	43.121	42.538	43.3	43.206
VonBert_K_Fem_GP_1	0.127	0.117	0.126	0.126	0.126	0.122	0.13	0.124	0.124
SSB_Virgin	97.083	125.743	97.711	98.734	97.957	86.384	94.4	103.11	102.093
SSB_2025	42.256	64.739	42.485	43.719	42.823	33.098	40.726	46.959	45.754
Bratio_2025	0.435	0.515	0.435	0.443	0.437	0.383	0.431	0.455	0.448
SPRratio_2024	0.099	0.072	0.099	0.096	0.098	0.122	0.102	0.092	0.095

8.3 Management

Table 19: Summary of reference points and management quantities, including estimates of the 95% confidence intervals.

Reference Point	Estimate	Lower Interval	Upper Interval
Unfished Spawning output (Billions of eggs)	97.083	81.153	113.013
Unfished Age 3+ Biomass (mt)	522.330	439.673	604.987
Unfished Recruitment (R0)	44.991	37.601	52.380
2025 Spawning output (Billions of eggs)	42.256	26.298	58.213
2025 Fraction Unfished	0.435	0.315	0.555
Reference Points Based SO40%			
Proxy Spawning output (Billions of eggs) SO40%	38.833	32.461	45.205
SPR Resulting in SO40%	0.458	0.458	0.458
Exploitation Rate Resulting in SO40%	0.048	0.045	0.051
Yield with SPR Based On SO40% (mt)	11.658	9.713	13.603
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning output (Billions of eggs) (SPR50)	43.314	36.207	50.421
SPR50	0.500	—	—
Exploitation Rate Corresponding to SPR50	0.042	0.039	0.044
Yield with SPR50 at SO SPR (mt)	11.087	9.240	12.934
Reference Points Based on Estimated MSY Values			
Spawning output (Billions of eggs) at MSY (SO MSY)	25.550	21.353	29.748
SPR MSY	0.335	0.331	0.339
Exploitation Rate Corresponding to SPR MSY	0.072	0.067	0.077
MSY (mt)	12.530	10.430	14.629

Table 20: Potential OFLs (mt), ABCs (mt), ACLs (mt), the buffer between the OFL and ABC based on a category 1 sigma of 0.5 and P^* of 0.45, estimated spawning output (billions of eggs), and fraction of unfished spawning output with adopted OFLs and ACLs and assumed catch for the first two years of the projection period.

Year	Adopted OFL (mt)	Adopted ACL (mt)	Assumed Catch (mt)	OFL (mt)	Buffer	ABC (mt)	ACL (mt)	Spawning output (Billions of eggs)	Fraction Unfished
2025	1.50	1.30	1.30	—	—	—	—	42	0.435
2026	1.80	1.50	1.50	—	—	—	—	46	0.475
2027	—	—	—	12.83	0.935	12.00	12.00	50	0.513
2028	—	—	—	13.29	0.930	12.36	12.36	51	0.529
2029	—	—	—	13.61	0.926	12.60	12.60	53	0.541
2030	—	—	—	13.81	0.922	12.73	12.73	53	0.549
2031	—	—	—	13.90	0.917	12.75	12.75	54	0.553
2032	—	—	—	13.91	0.913	12.70	12.70	54	0.555
2033	—	—	—	13.87	0.909	12.61	12.61	54	0.554
2034	—	—	—	13.79	0.904	12.47	12.47	54	0.552
2035	—	—	—	13.69	0.900	12.32	12.32	53	0.550
2036	—	—	—	13.59	0.896	12.17	12.17	53	0.546

Table 21: Decision table with 10-year projections beginning in 2027 for alternative states of nature based around modeling natural mortality (M). All models assume a $P^* = 0.45$. Catch (mt) is from the projections from the base model, and is applied to each state of nature. Catches in 2025 and 2026 are fixed at values provided by the GMT. The alternative states of nature ('Low', 'Base', and 'High') are provided in the columns. Natural mortality is fixed either at the low state of nature (Low M = 0.0525), the base model value (M = 0.068), or the high state of nature (High M = 0.08). Spawning output ('Spawn', in billions of eggs) and fraction of unfished ('Frac') is provided for each state of nature.

Year	Catch (mt)	Low M Spawn	Low M Frac	Base M Spawn	Base M Frac	High M Spawn	High M Frac
2025	1.30	30.67	0.299	42.26	0.435	56.13	0.563
2026	1.50	33.79	0.330	46.12	0.475	60.69	0.608
2027	12.00	36.77	0.359	49.78	0.513	64.94	0.651
2028	12.36	37.78	0.369	51.39	0.529	67.02	0.672
2029	12.60	38.43	0.375	52.54	0.541	68.51	0.687
2030	12.73	38.77	0.378	53.29	0.549	69.48	0.696
2031	12.75	38.86	0.379	53.70	0.553	70.02	0.702
2032	12.70	38.77	0.378	53.85	0.555	70.20	0.704
2033	12.61	38.55	0.376	53.81	0.554	70.13	0.703
2034	12.47	38.24	0.373	53.62	0.552	69.88	0.700
2035	12.33	37.90	0.370	53.36	0.550	69.49	0.697
2036	12.17	37.53	0.366	53.04	0.546	69.03	0.692

9 Figures

9.1 Data

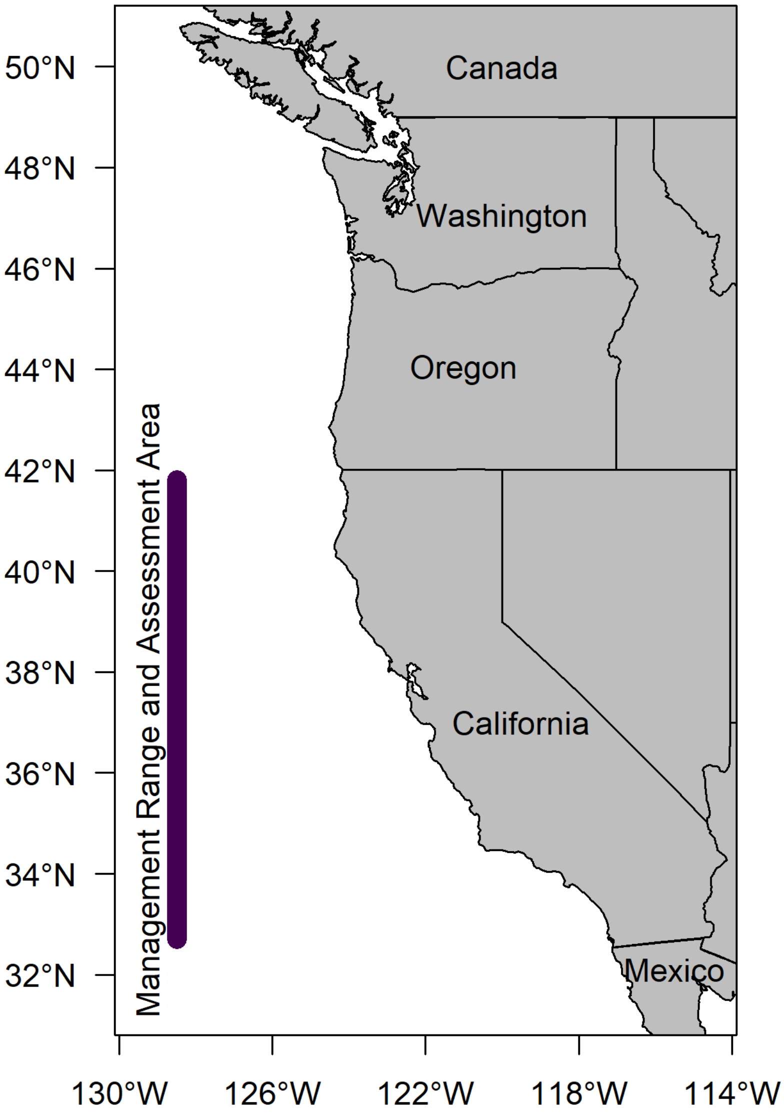


Figure 1: Map of management area and the 2025 assessment area for quillback rockfish off California.

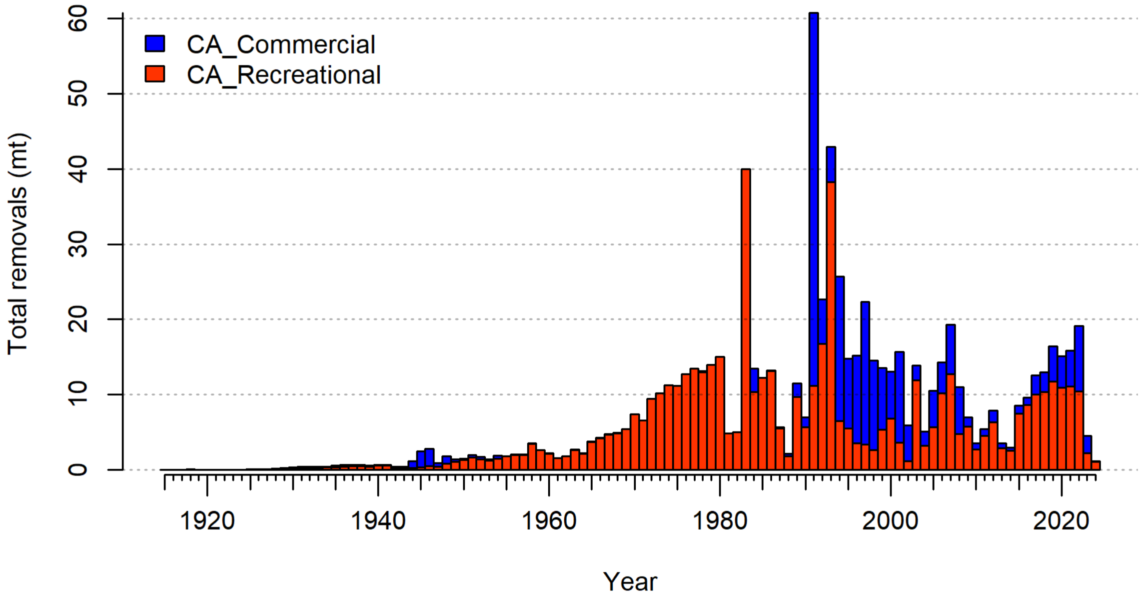


Figure 2: Total removals (mt) for quillback rockfish in California from 1916-2024 for the commercial (blue bars; CA_Commercial) and recreational (red bars; CA_Recreational) fleets.

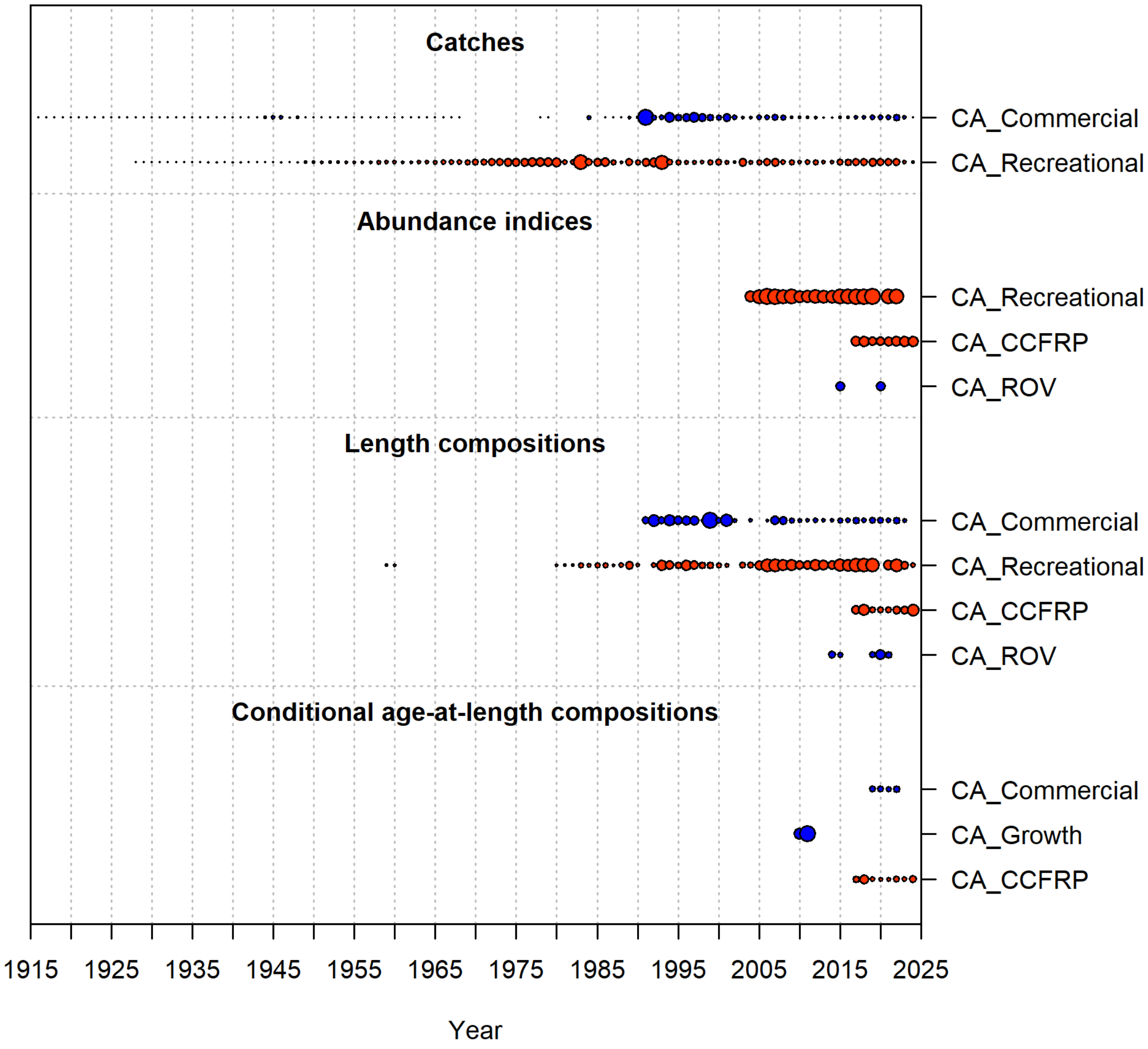


Figure 3: Data available by year for each fleet, where circle area is relative within a data type. Circles are proportional to total removals for catches; to precision for indices; and to total sample size for compositions.

9.1.1 Fishery-Dependent Data

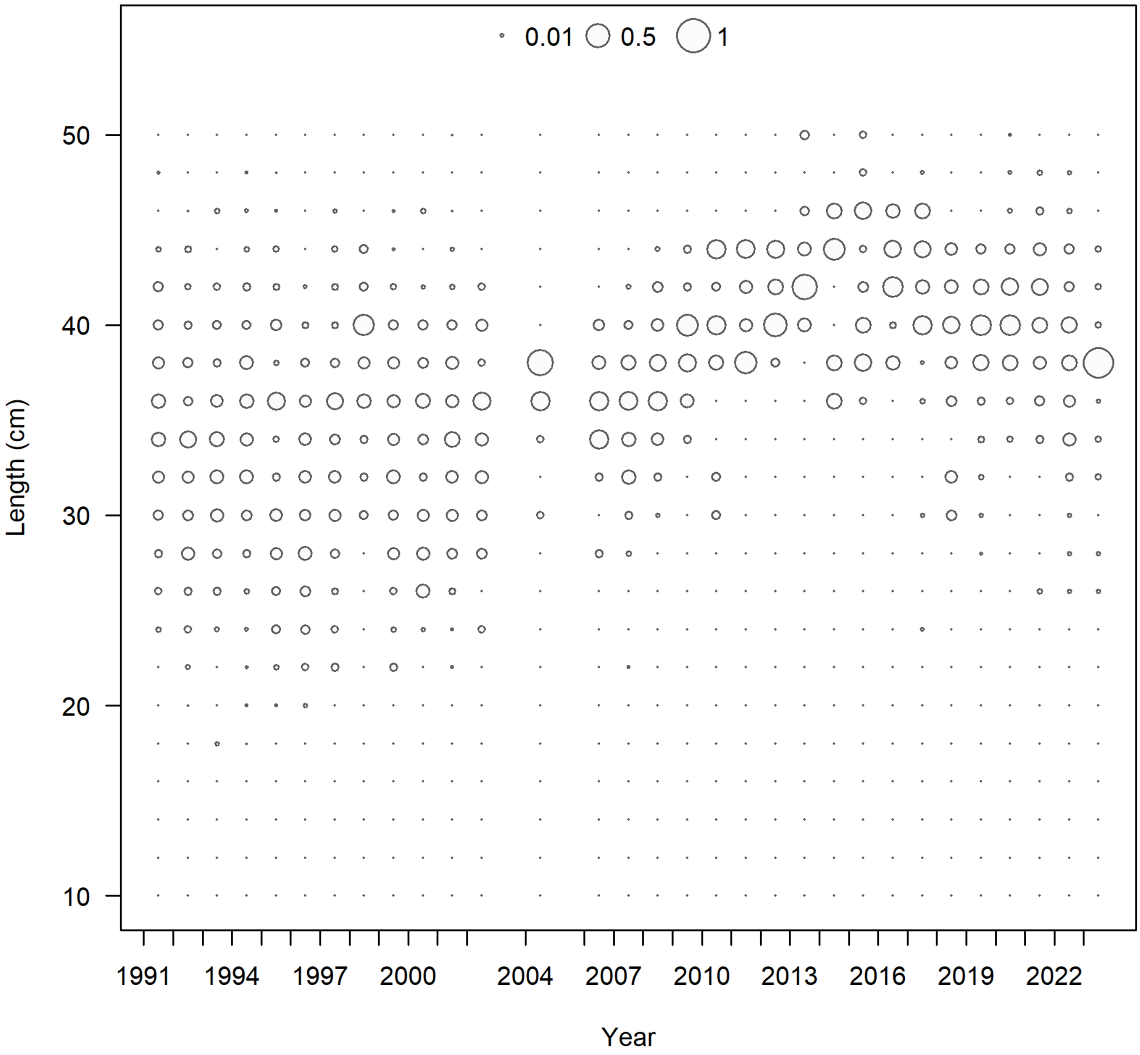


Figure 4: Length composition data for the commercial fleet where bubbles correspond to the proportional sample size by bin within each year.

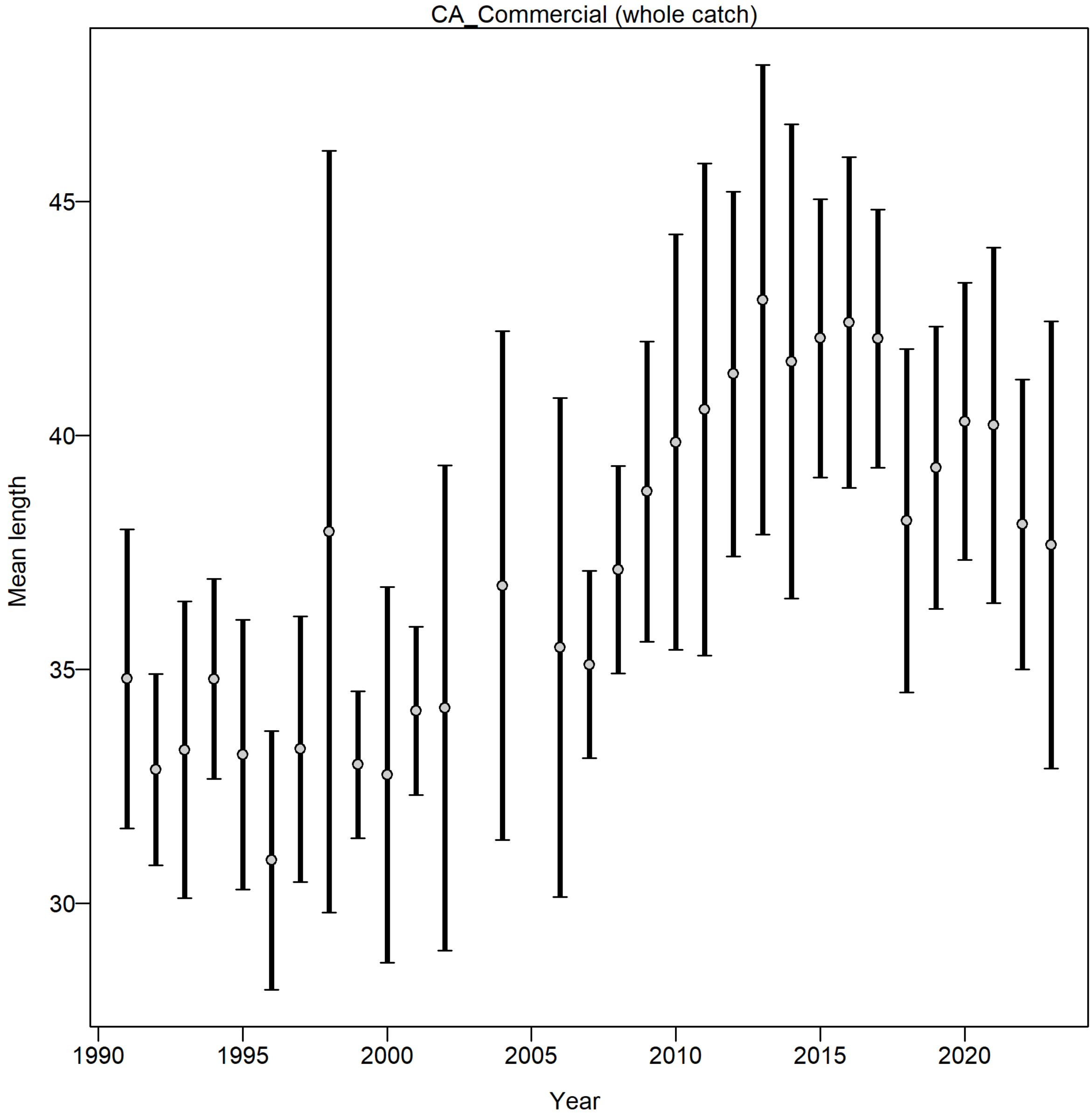


Figure 5: Mean length (cm) for the commercial fleet with 95% confidence intervals based on current samples sizes.

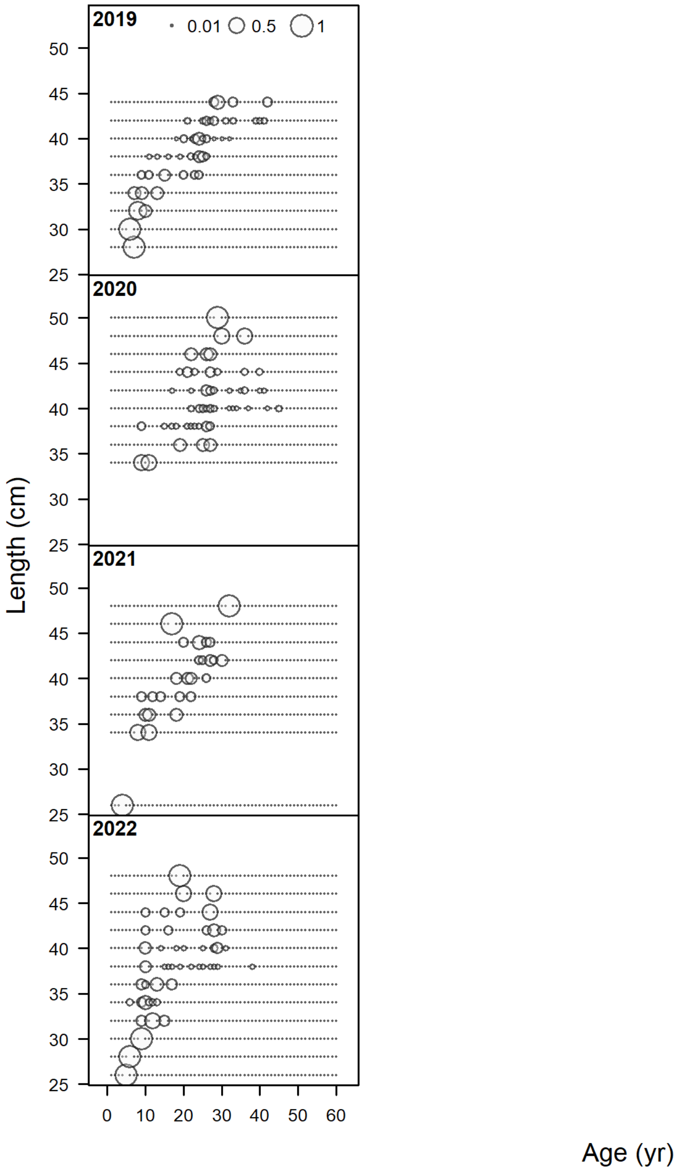


Figure 6: Conditional age-at-length data for the commercial fleet where bubbles correspond to the proportional sample size by age for each length bin.

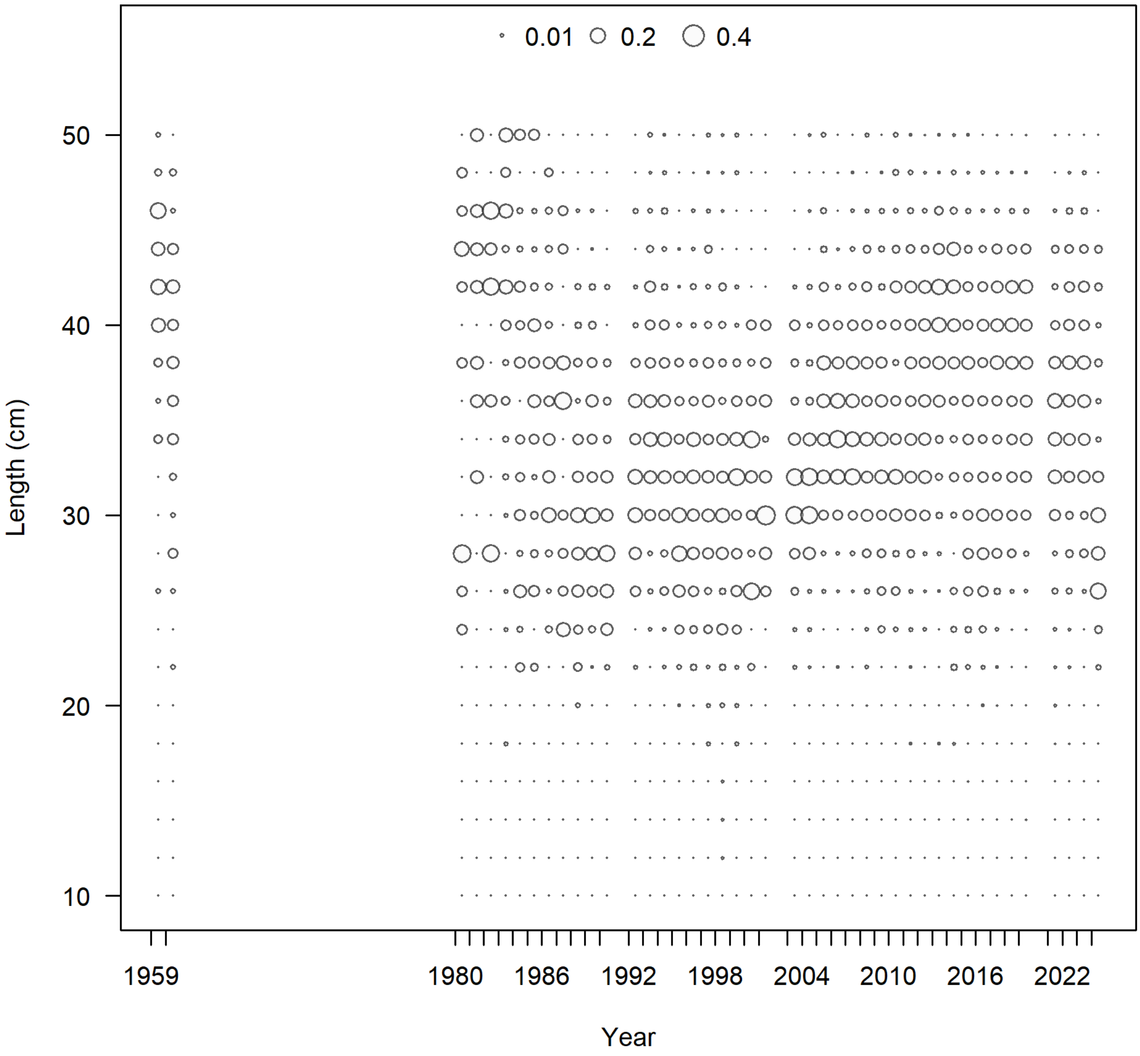


Figure 7: Length composition data for the recreational fleet where bubbles correspond to the proportional sample size by bin within each year.

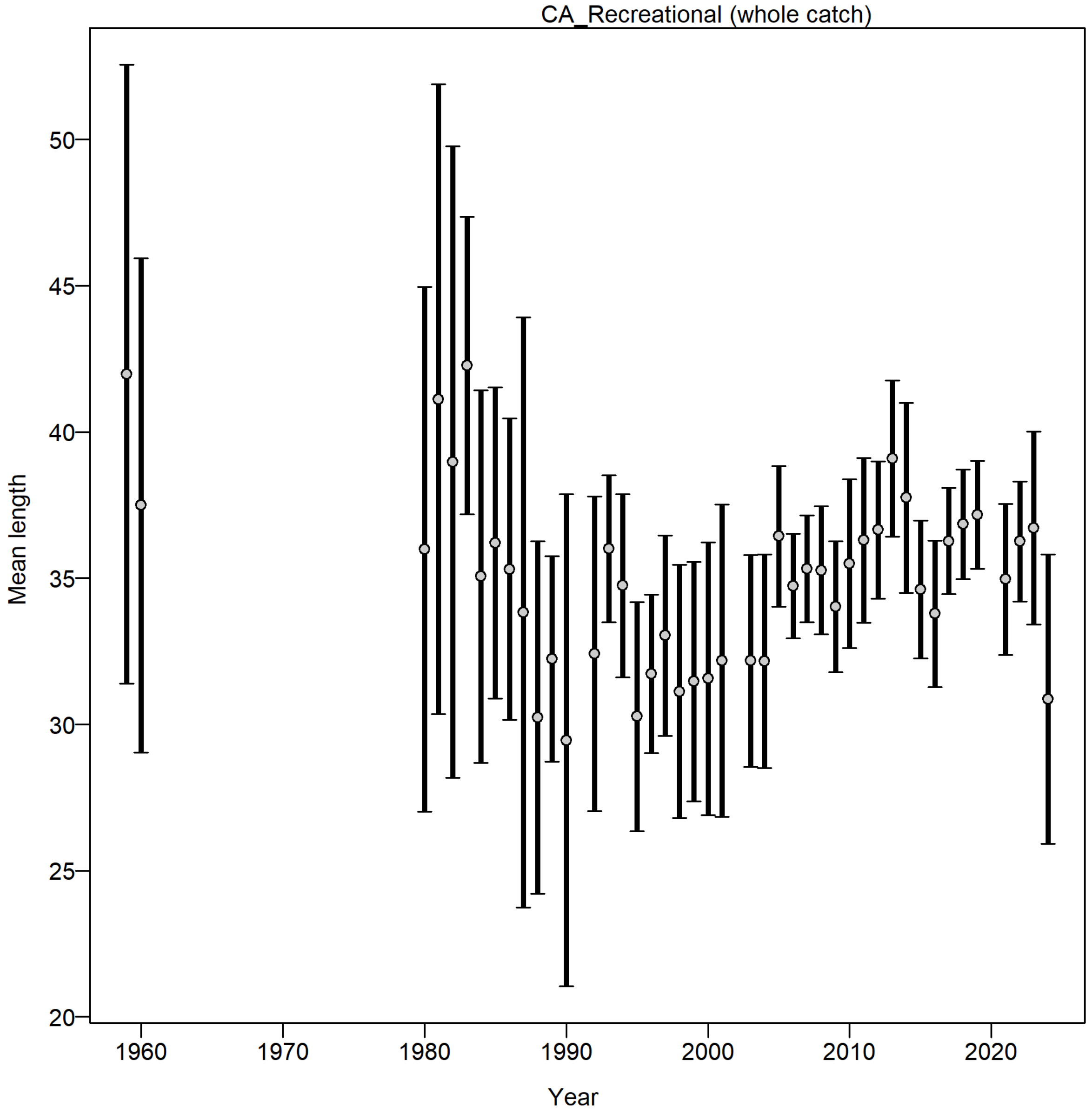


Figure 8: Mean length (cm) for the recreational fleet with 95% confidence intervals based on current samples sizes.

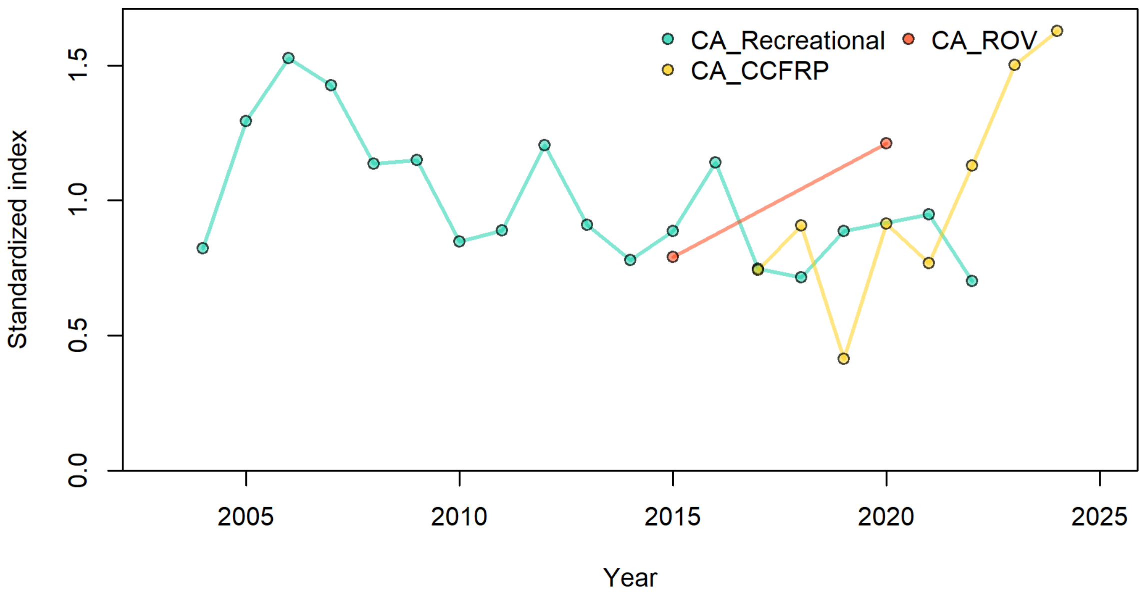


Figure 9: Standardized indices (each scaled to have a mean of 1) used in the base model for the recreational fleet, and the CCFRP and ROV surveys.

9.1.2 Fishery-Independent Data

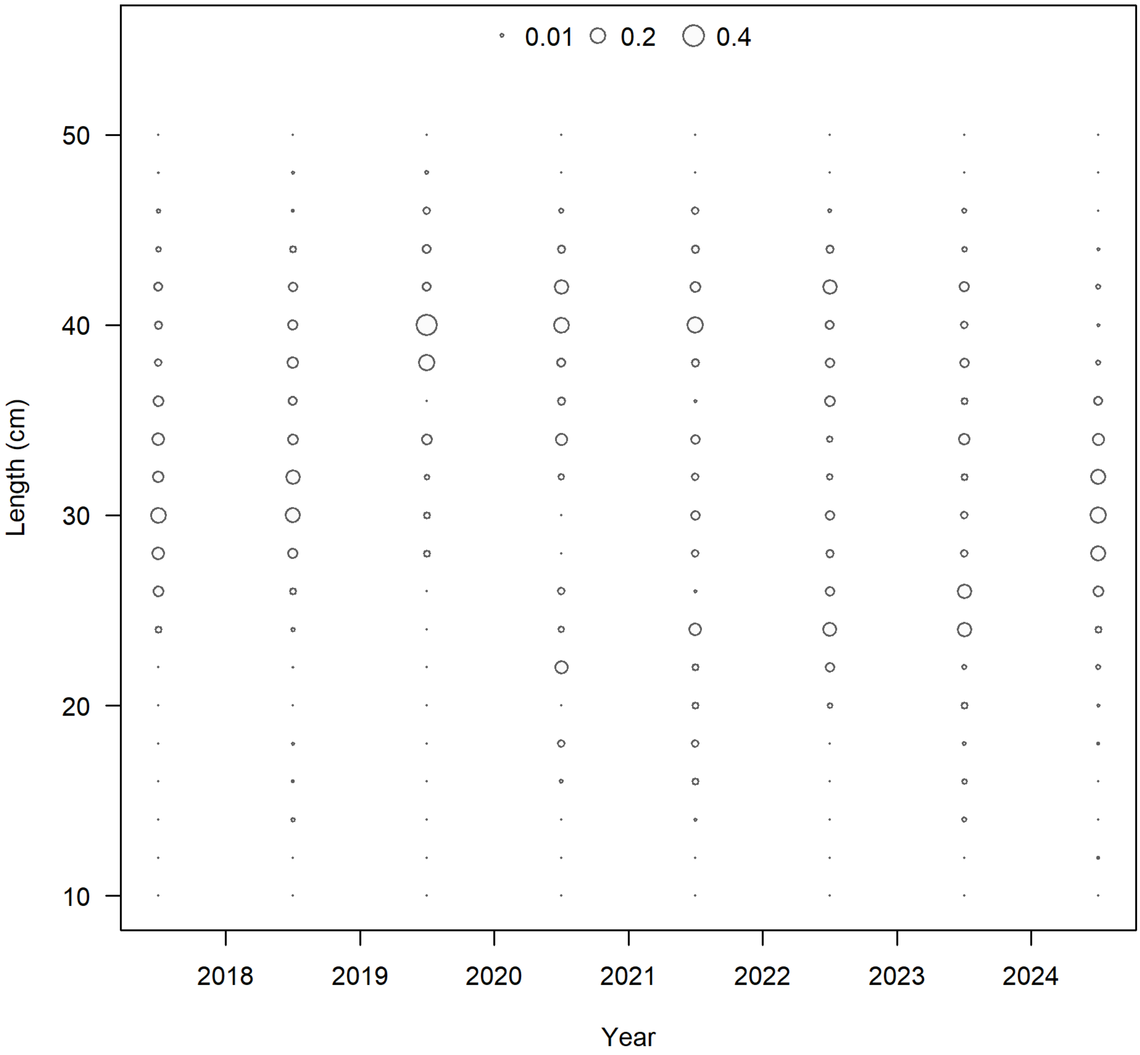


Figure 10: Length composition data for the CCFRP survey where bubbles correspond to the proportional sample size by bin within each year.

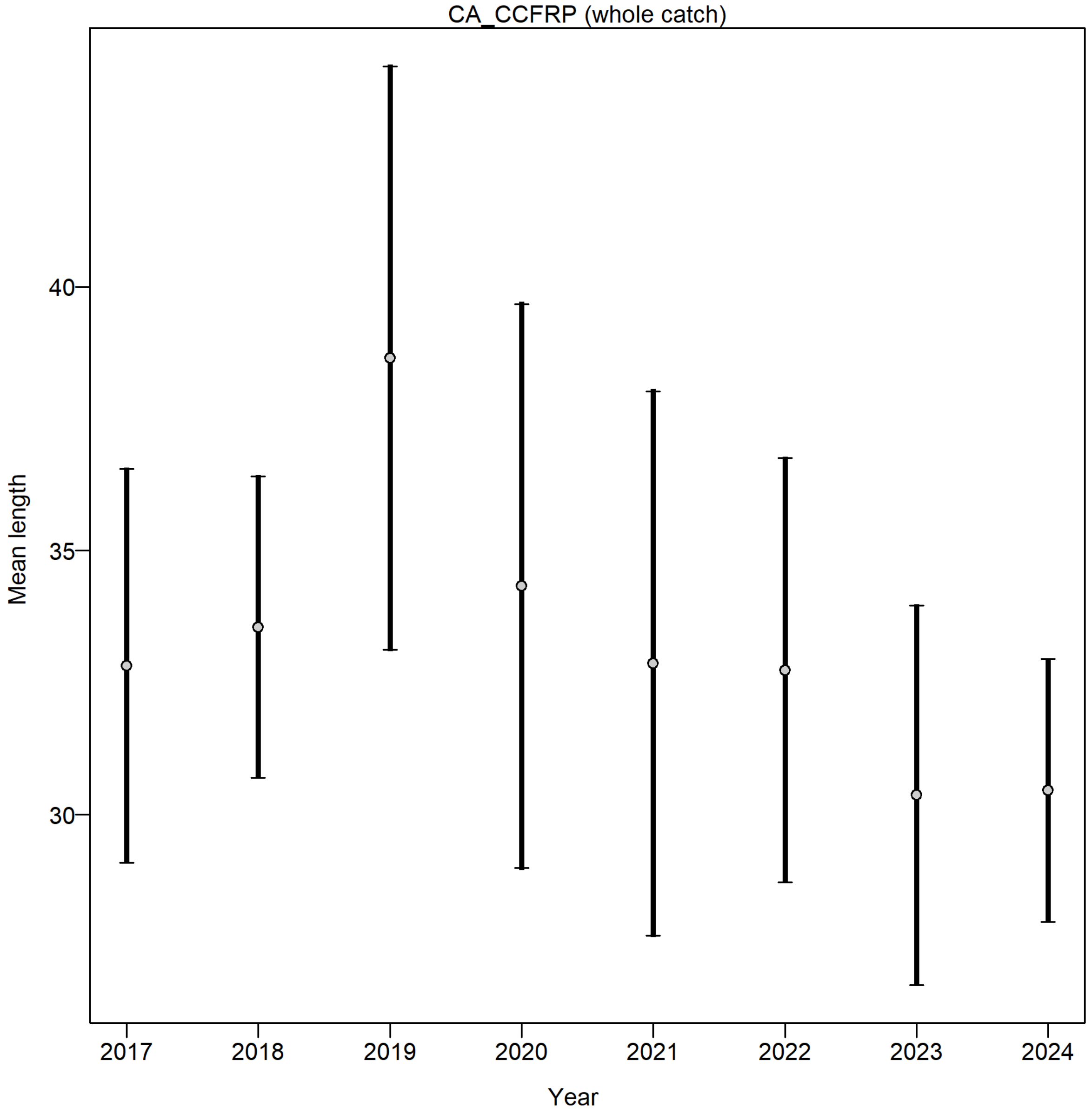


Figure 11: Mean length (cm) for the CCFRP survey with 95% confidence intervals based on current samples sizes.

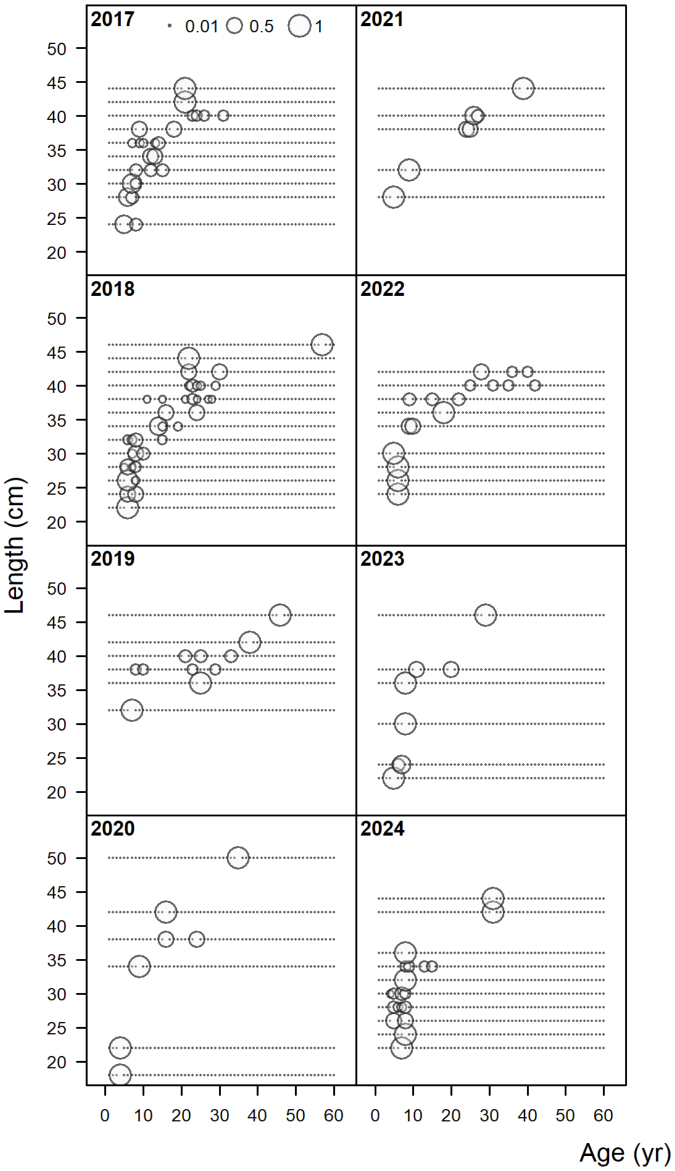


Figure 12: Conditional age-at-length data for the CCFRP fleet where bubbles correspond to the proportional sample size by age for each length bin.

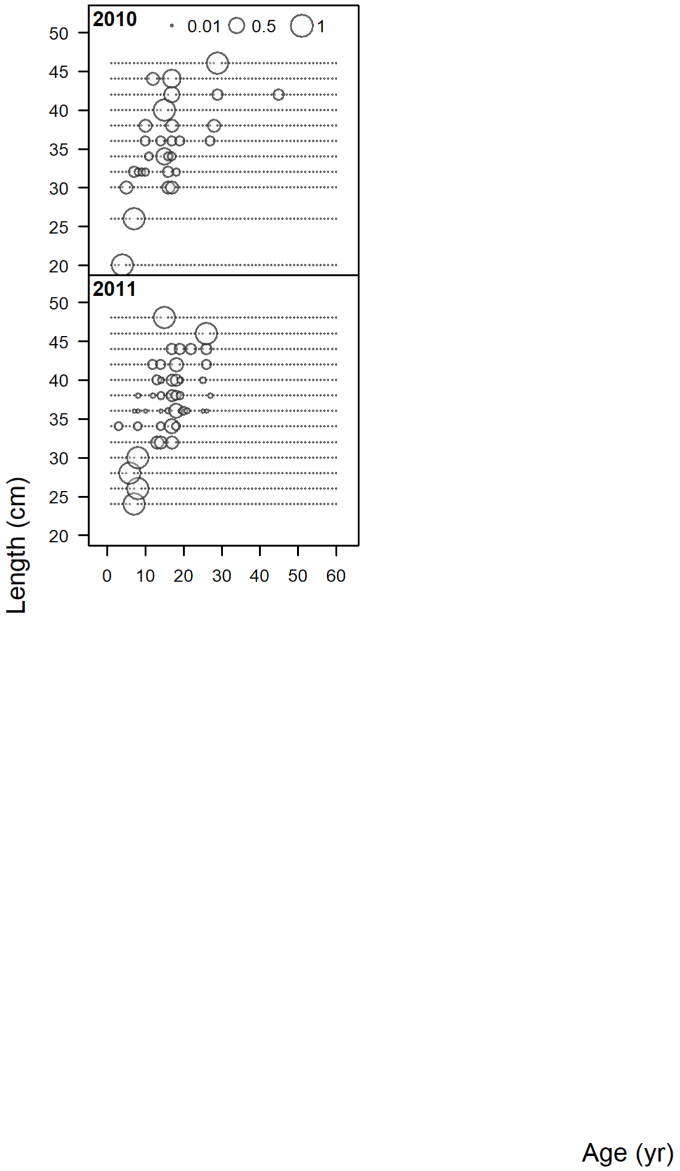


Figure 13: Conditional age-at-length data for the growth fleet based on samples from Abrams where bubbles correspond to the proportional sample size by age for each length bin.

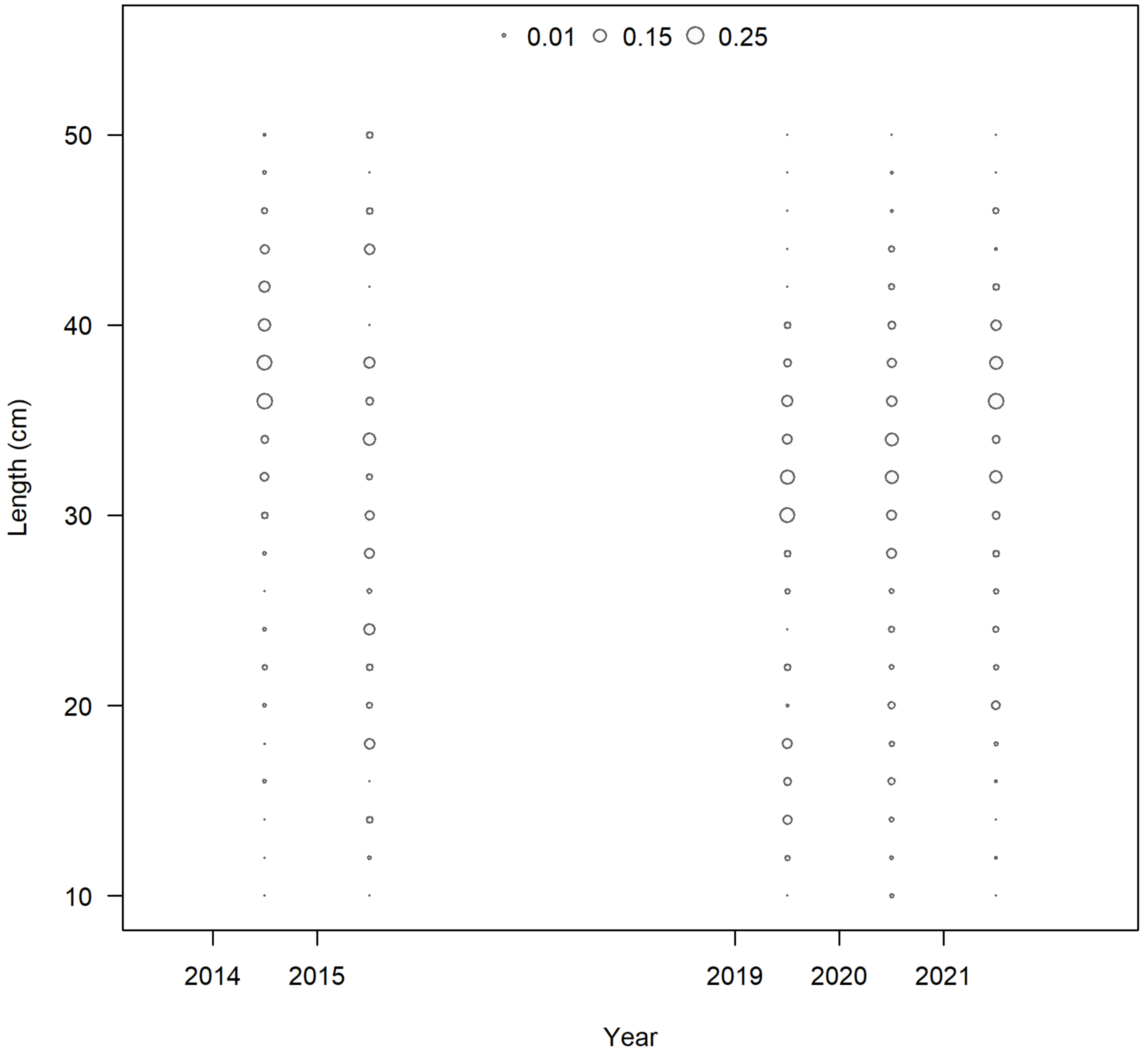


Figure 14: Length composition data for the ROV survey where bubbles correspond to the proportional sample size by bin within each year.

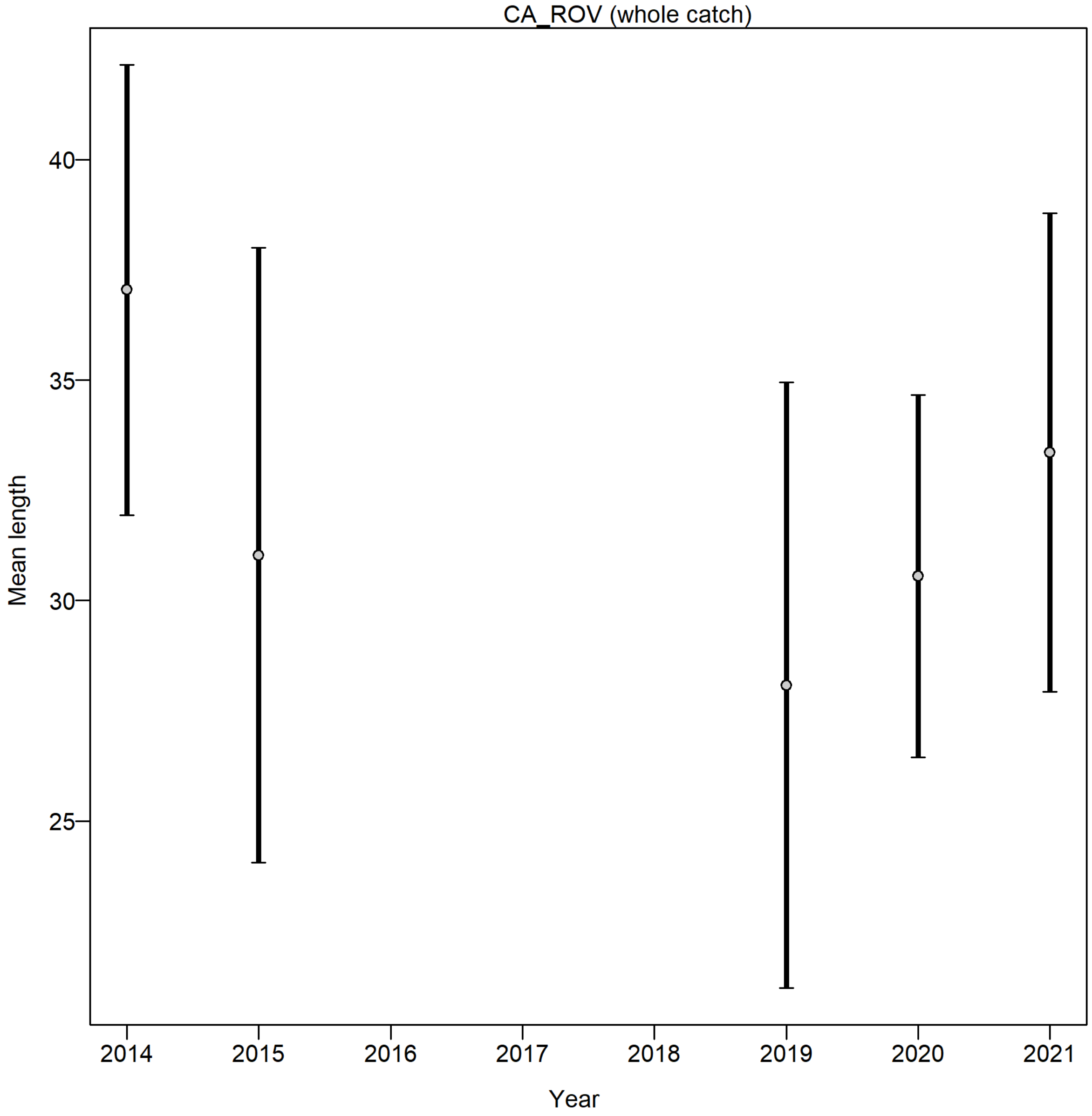


Figure 15: Mean length (cm) for the ROV survey with 95% confidence intervals based on current samples sizes.

9.1.3 Biological Parameters

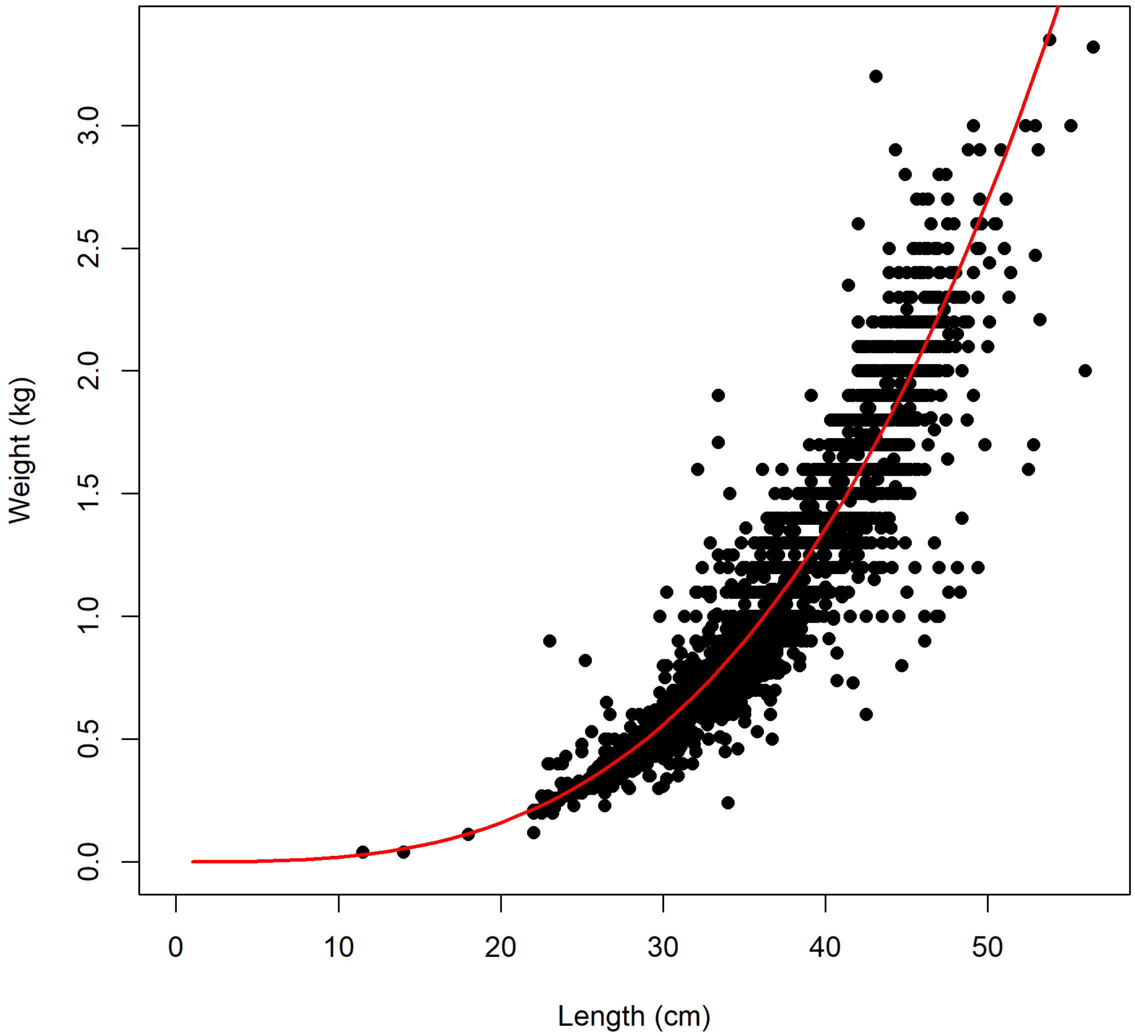


Figure 16: Weight-length relationship (red line) with data (closed circles) for California quillback rockfish.

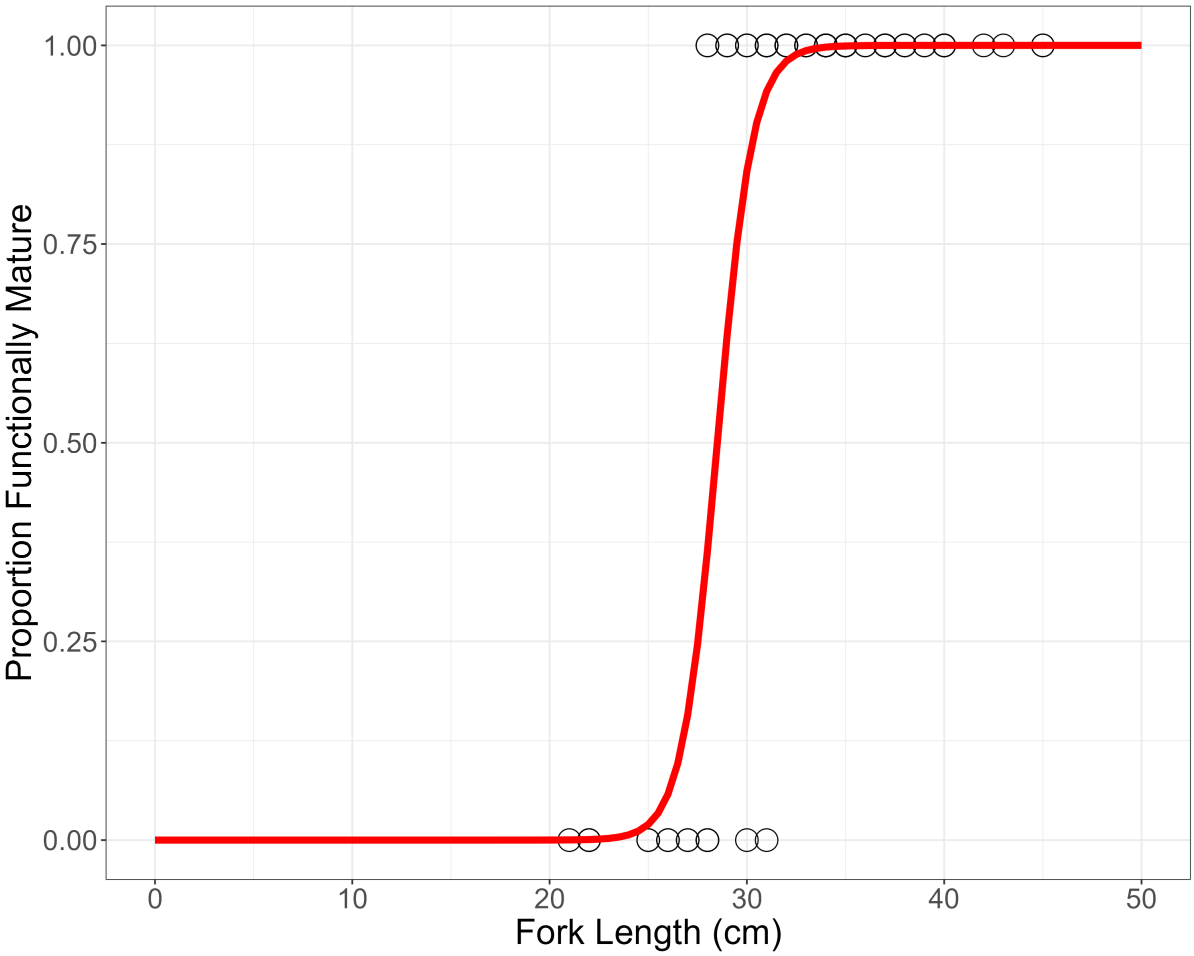


Figure 17: Data (open circles) and the estimated functional maturity (red line) for California quillback rockfish.

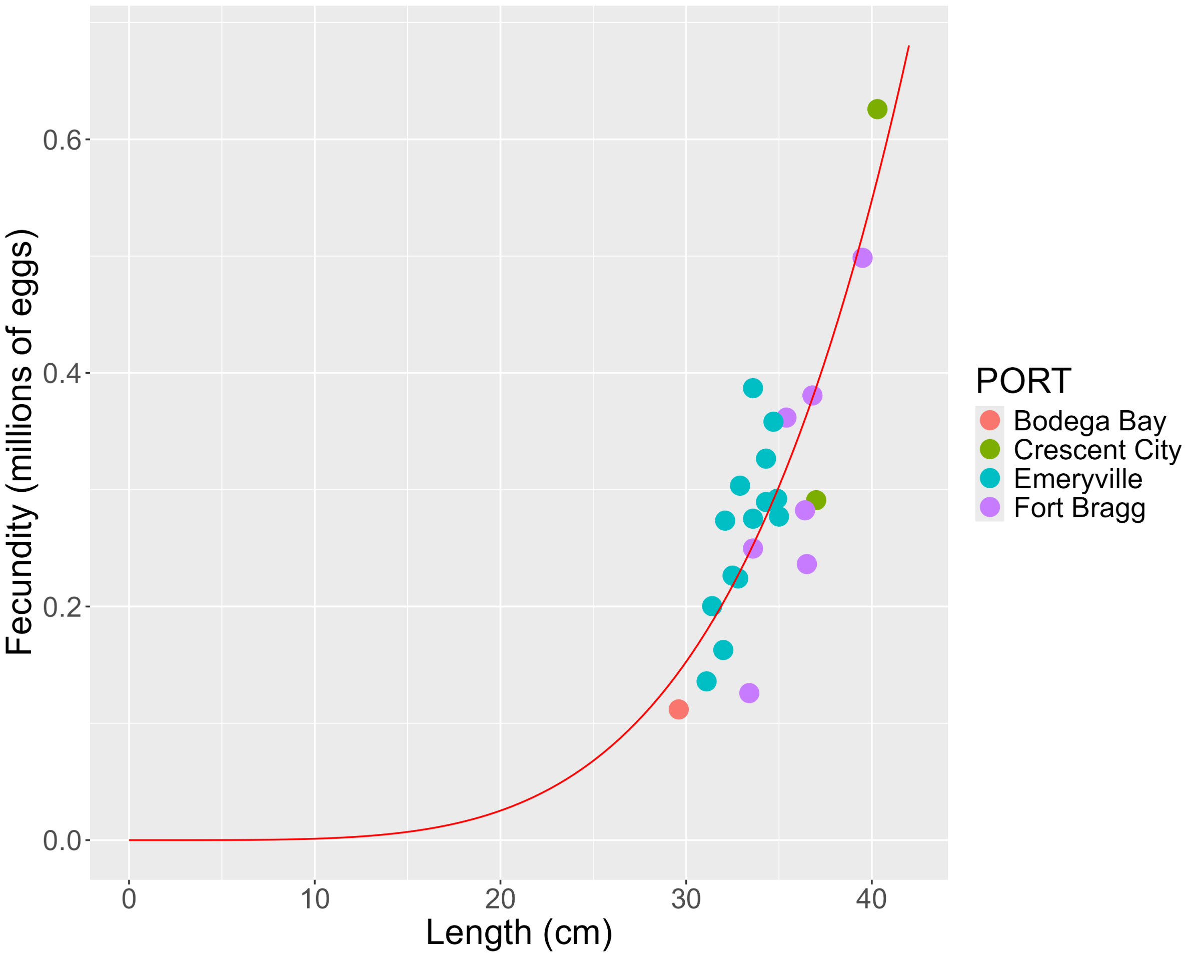


Figure 18: Fecundity (red line) estimated from samples (closed circles) collected by the SWFSC from across the range of California quillback rockfish.

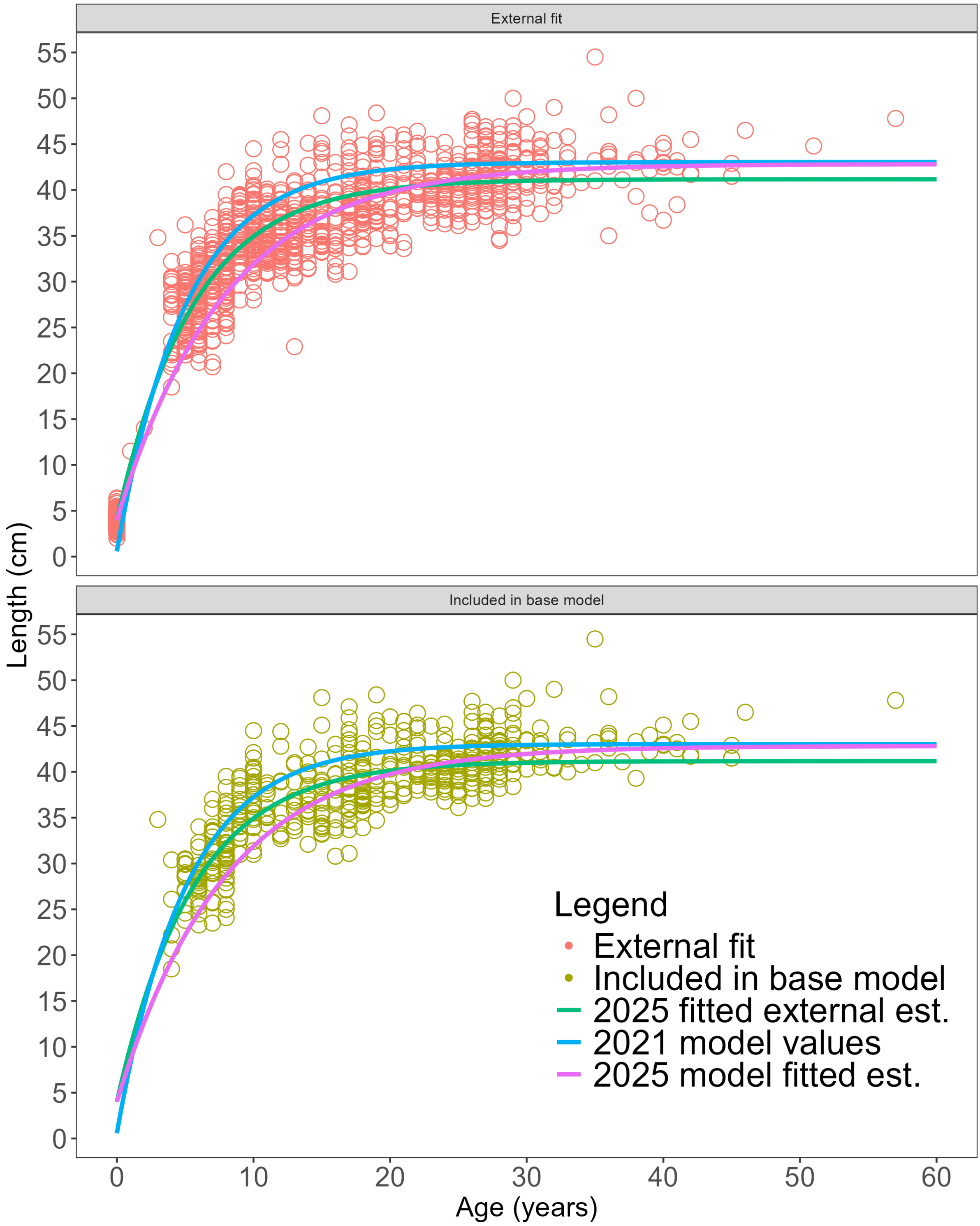


Figure 19: Available length-at-age data for the 2025 stock assessment. Growth curves are provided based on the external estimate (green line) of all data (red open circles; top), and from the internally estimated values (pink) from the subset of the data within the base model (brown open circles; bottom). The fixed growth curve from the 2021 assessment (blue line) is also provided for comparison.

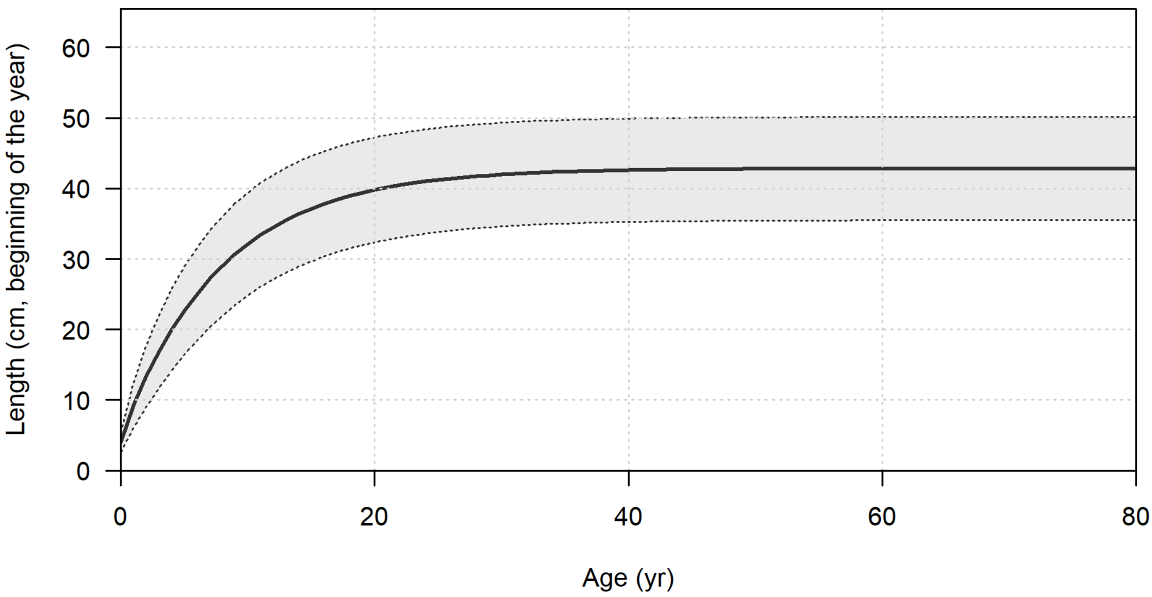


Figure 20: Model estimated length-at-age in the beginning of the year. Shaded area indicates 95% confidence interval of length-at-age around the estimated growth curve.

9.2 Assessment Model

9.2.1 Model Structure and Assumptions

9.2.1.1 Bridging Analysis

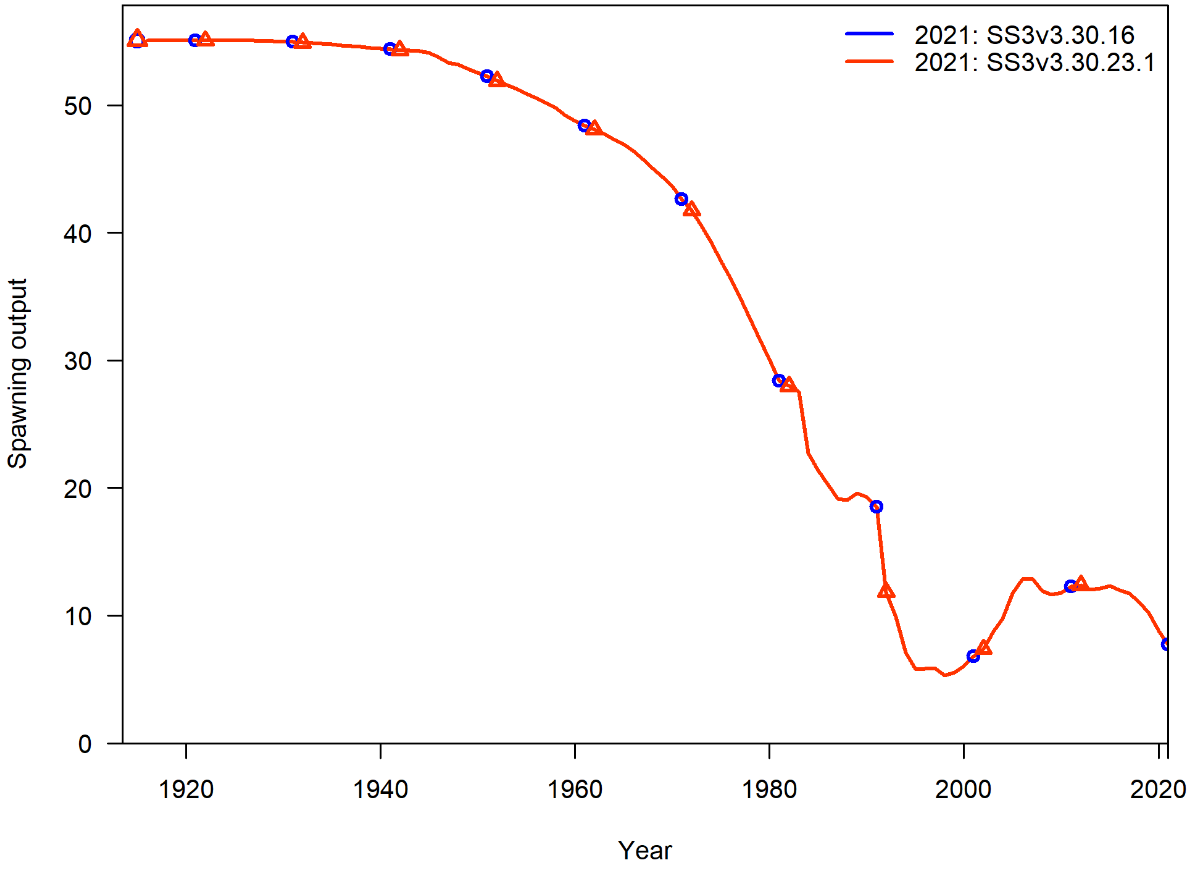


Figure 21: Bridge comparison of estimated spawning output (billions of eggs) of the 2021 assessment with (red line) the newest version of stock synthesis compared to the 2021 version (blue line).

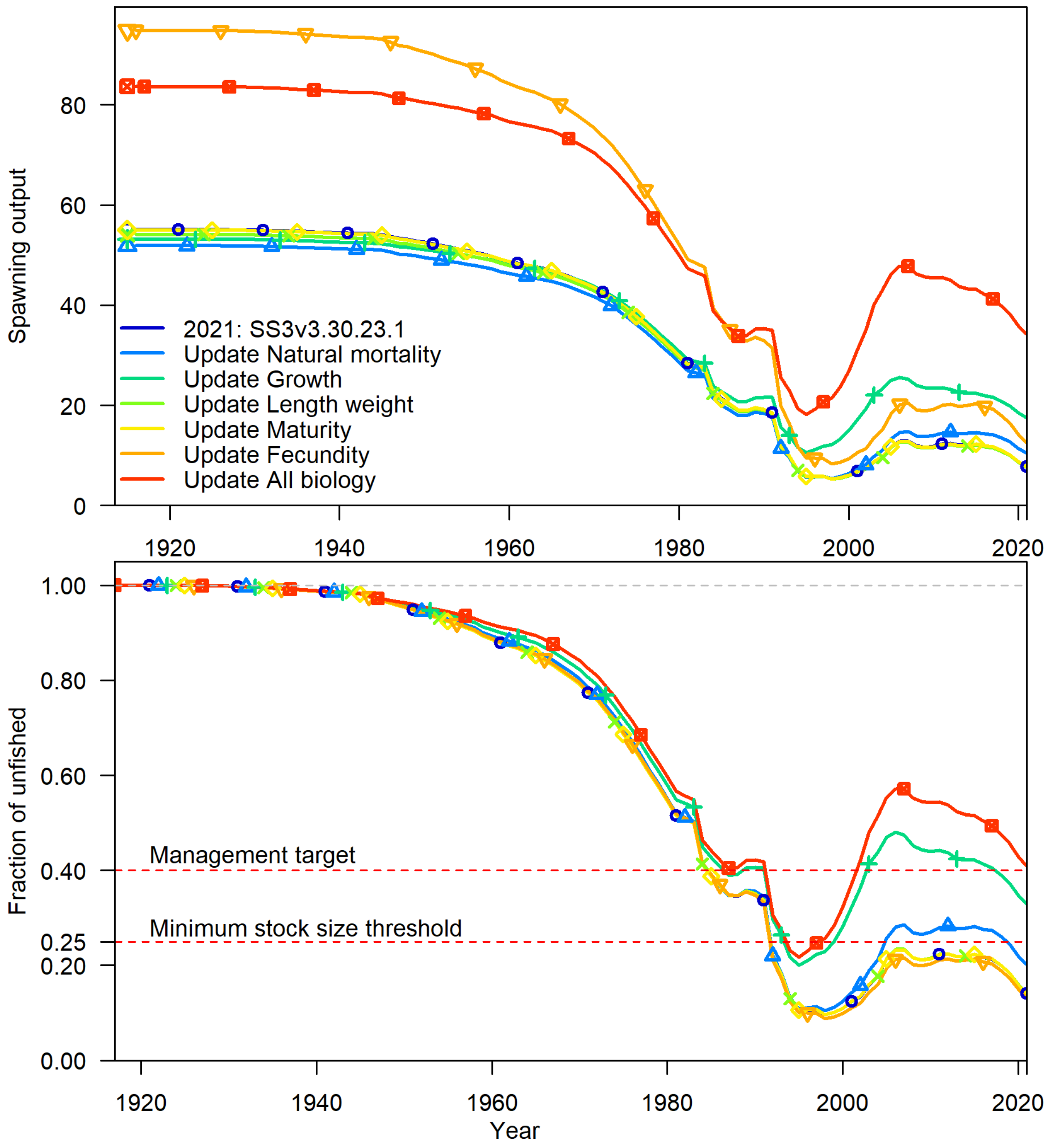


Figure 22: Bridge comparison for biological relationships showing estimated spawning output (billions of eggs, top) and spawning output relative to unfished (bottom). Each change is tested independently based off the 2021 assessment except the final one (Update All Biology), which combines all previous changes.

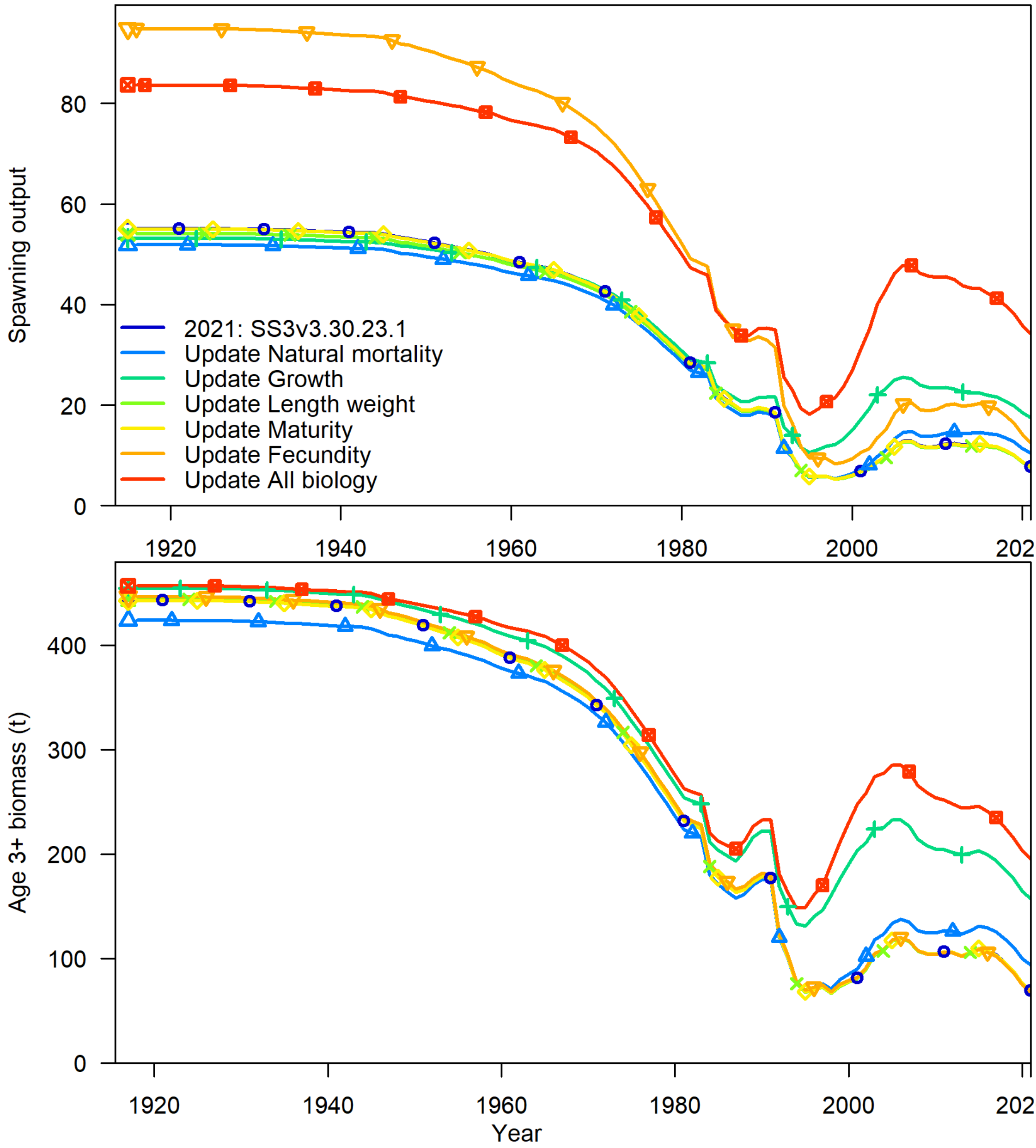


Figure 23: Bridge comparison for biological relationships showing estimated spawning output (billions of eggs, top) and summary biomass (in metric tons, bottom). Each change is tested independently based off the 2021 assessment except the final one (Update All Biology), which combines across all previous changes.

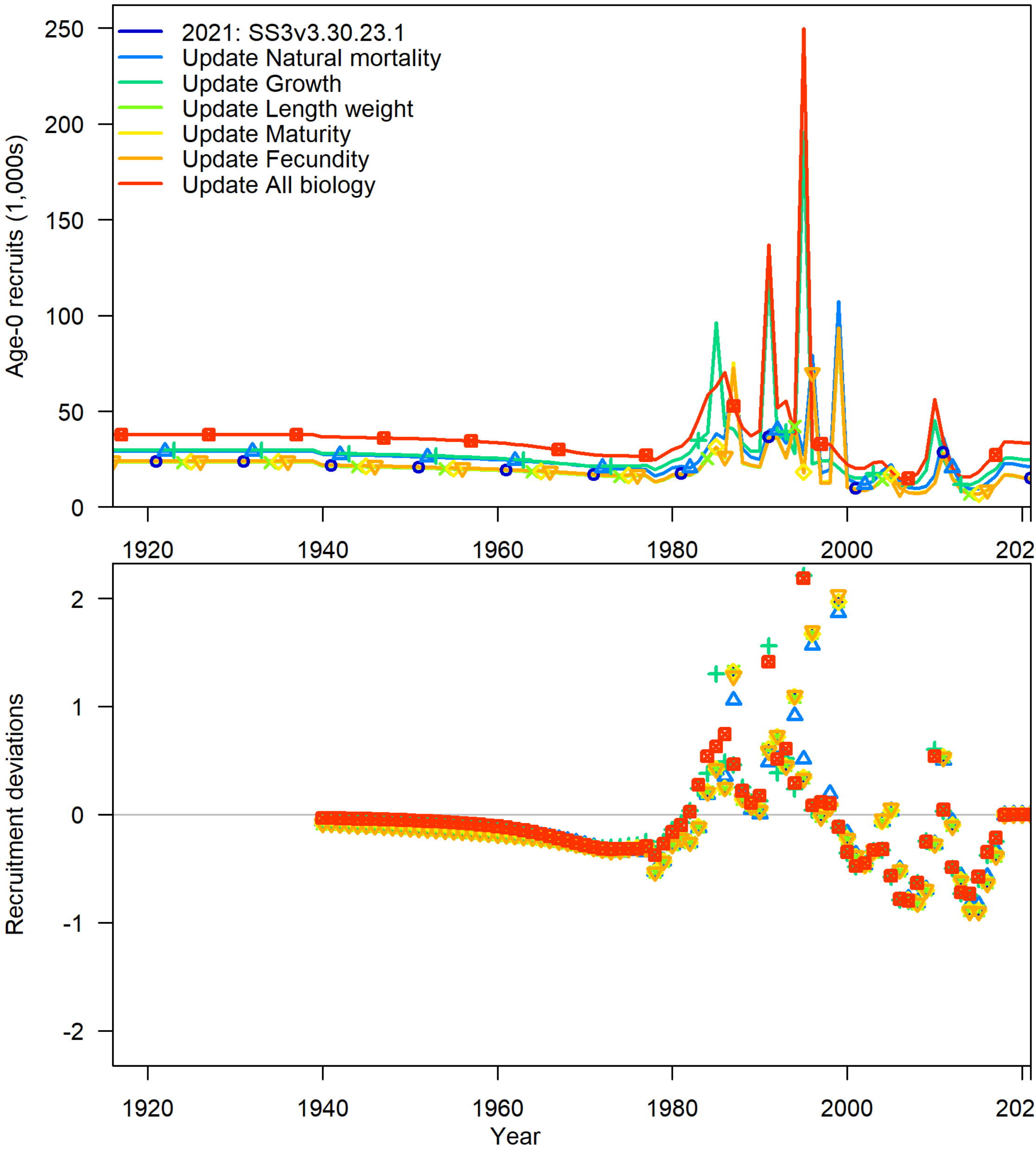


Figure 24: Bridge comparison for biological relationships showing estimated recruitment (thousands, top) and recruitment deviations (bottom). Each change is tested independently based off the 2021 assessment except the final one (Update All Biology), which combines all previous changes.

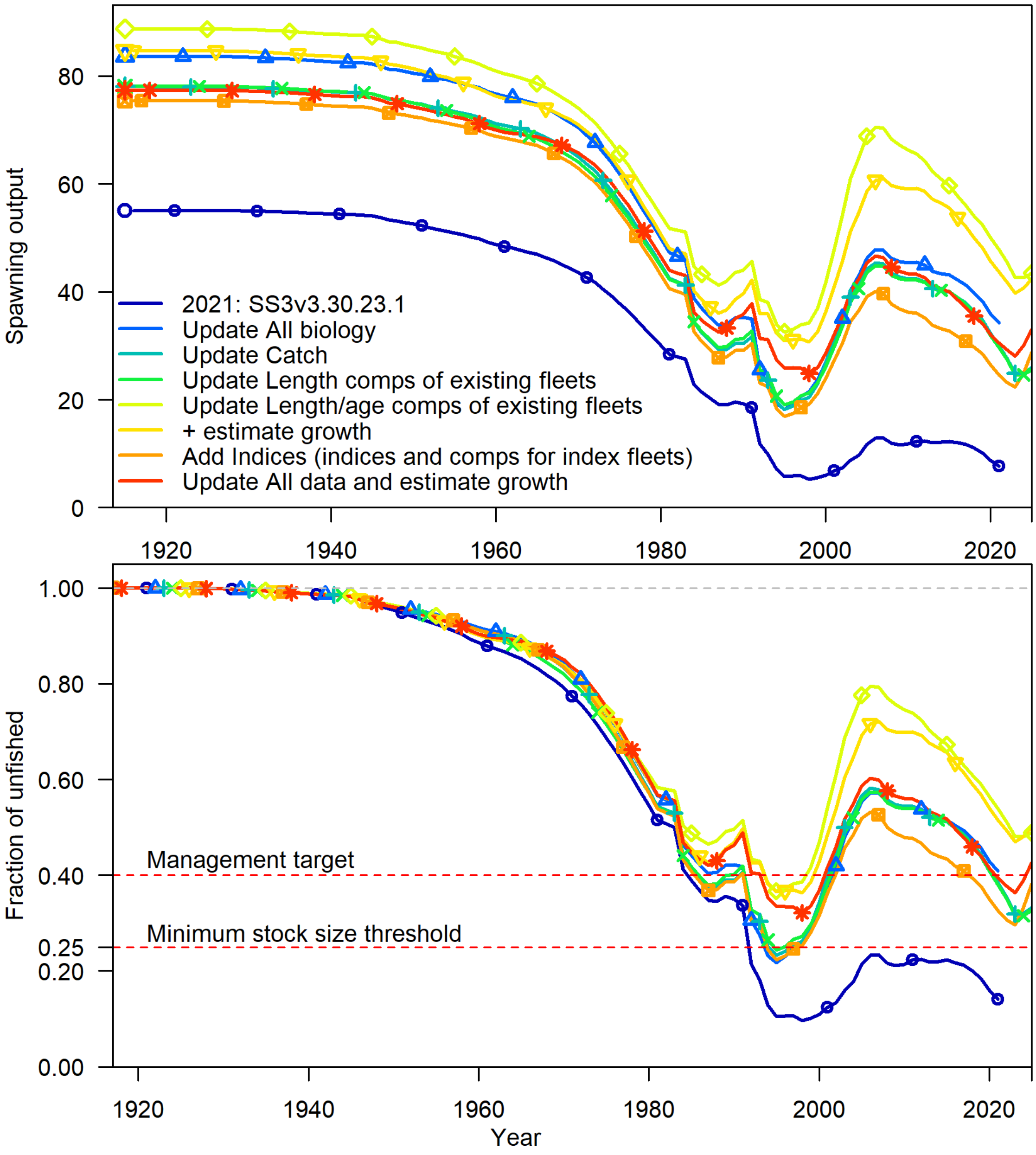


Figure 25: Bridge comparison showing estimated spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) when updating data. The first change (Update Catch) was based off the 2021 assessment with updated biology (Update All Biology; see Figure 22). Subsequent changes were tested independently based off the 2021 assessment with updated biology and catch (Update Catch) except the one labeled with a plus (+), indicating it is based off the previous step, and the final one (Update All Data and Estimate Growth), which combines across all previous changes.

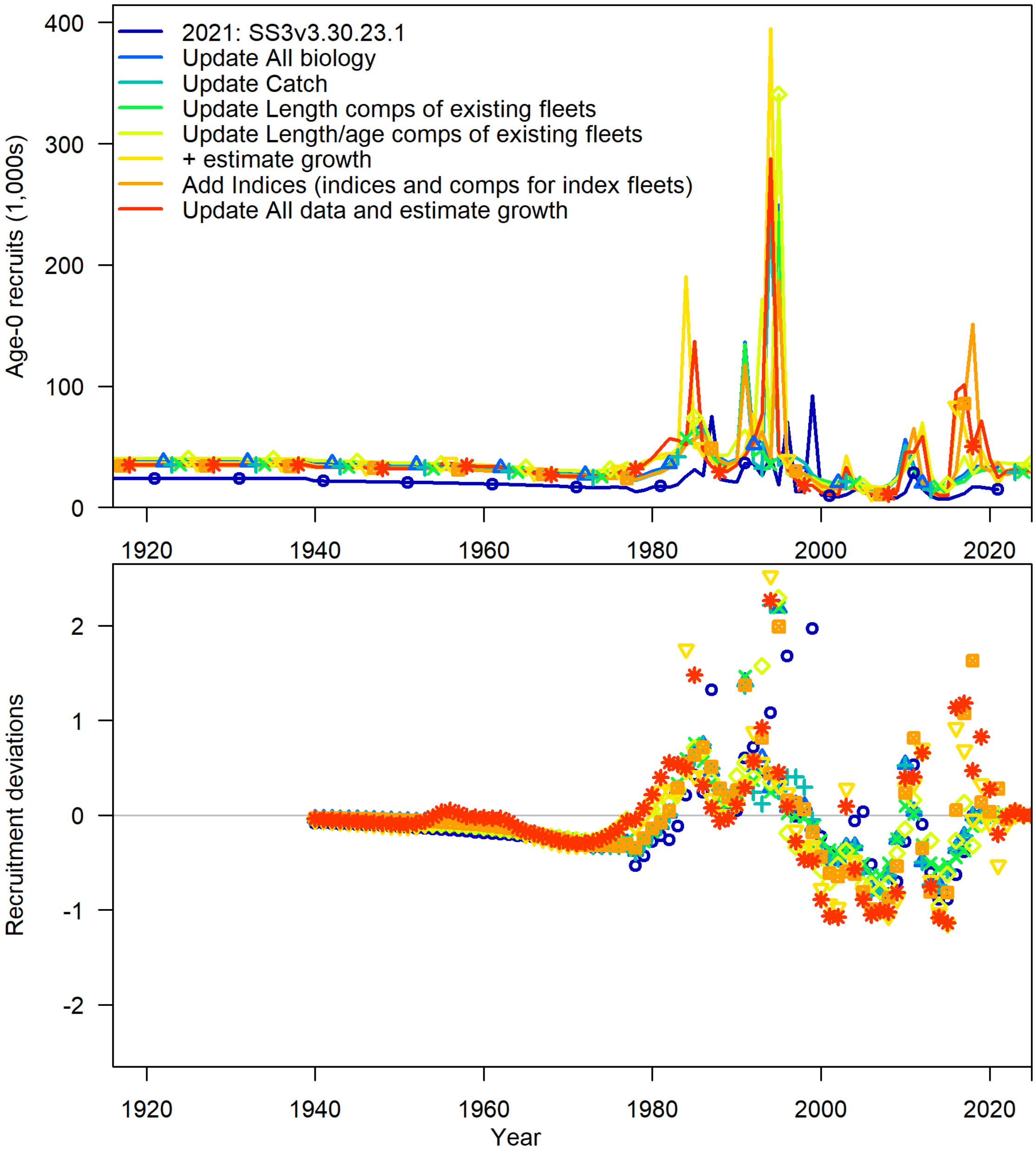


Figure 26: Bridge comparison showing estimated recruitment (thousands, top) and recruitment deviations (bottom) when updating data. The first change (Update Catch) was based off the 2021 assessment with updated biology (Update All Biology; see Figure 24). Subsequent changes were tested independently based off the 2021 assessment with updated biology and catch (Update Catch) except the one labeled with a plus (+), indicating it is based off the previous step, and the final one (Update All Data and Estimate Growth), which combines across all previous changes.

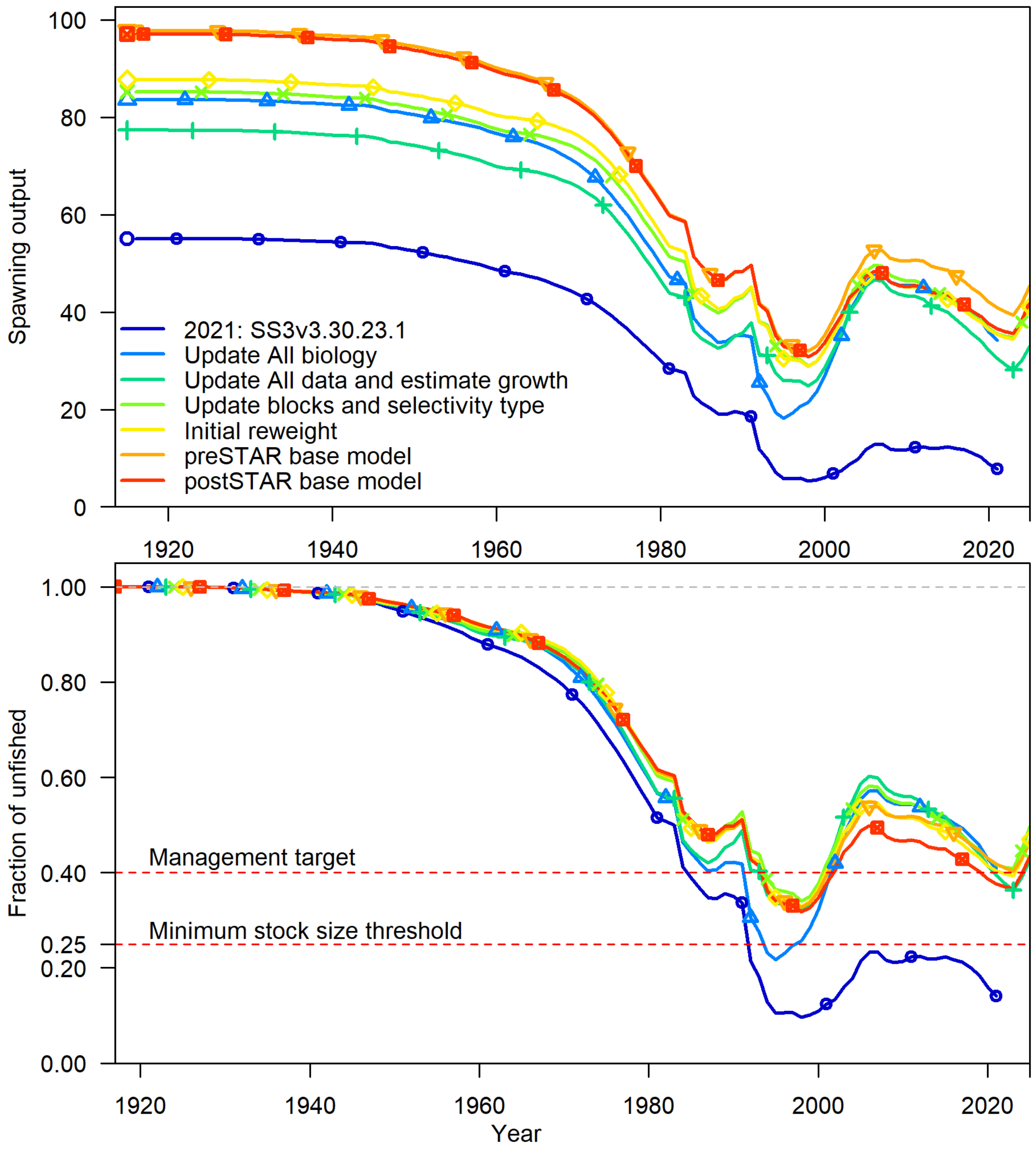


Figure 27: Bridge comparisons showing estimated spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) when updating selectivity and reapplying data weighting procedures. Each step reflects sequential changes leading up to the final base model, which includes additional minor changes as described in the text.

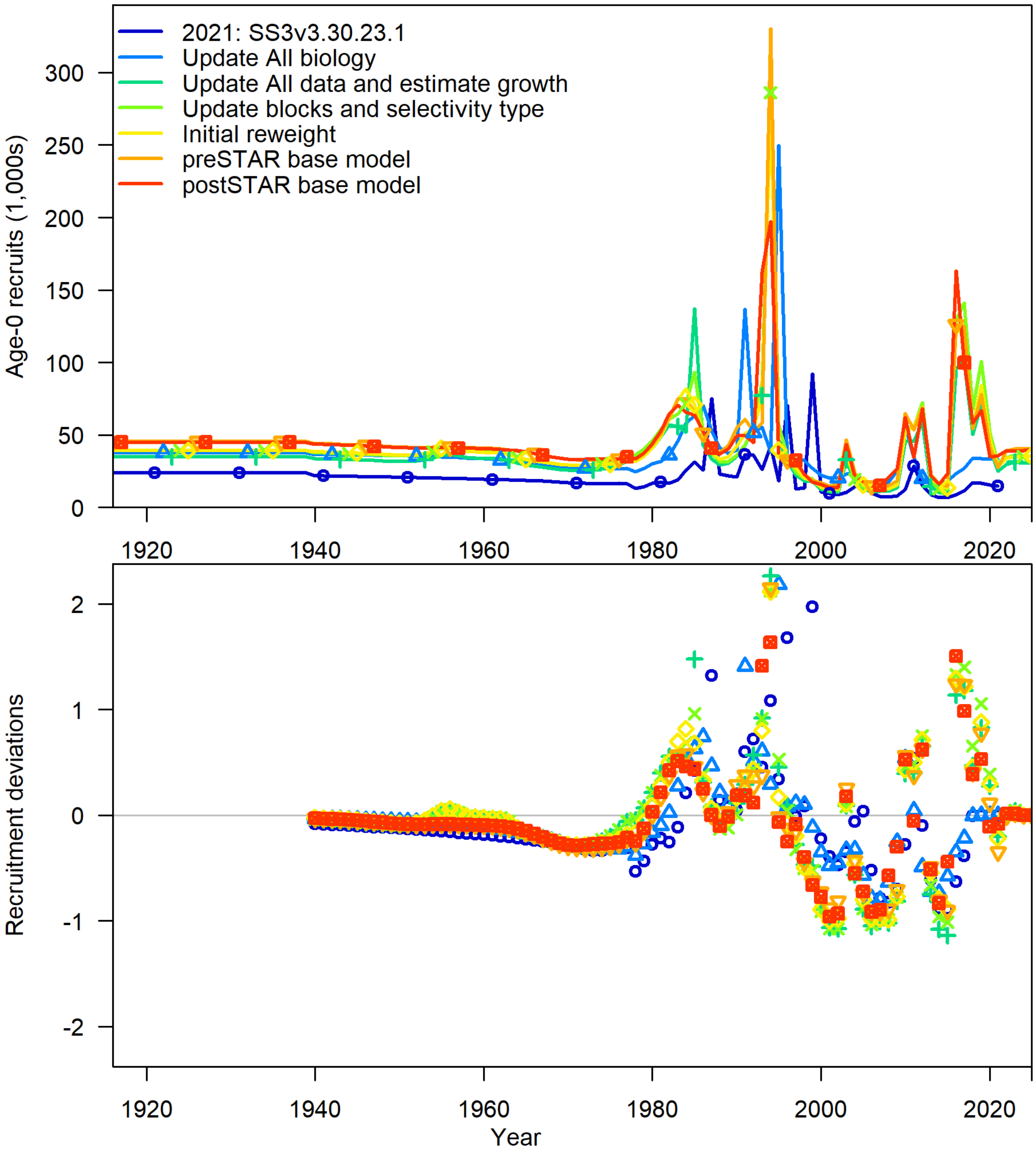


Figure 28: Bridge comparisons showing estimated recruitment (thousands, top) and recruitment deviations (bottom) when updating selectivity and reapplying data weighting procedures. Each step reflects sequential changes leading up to the final base model, which includes additional minor changes as described in the text.

9.2.1.2 Key Assumptions

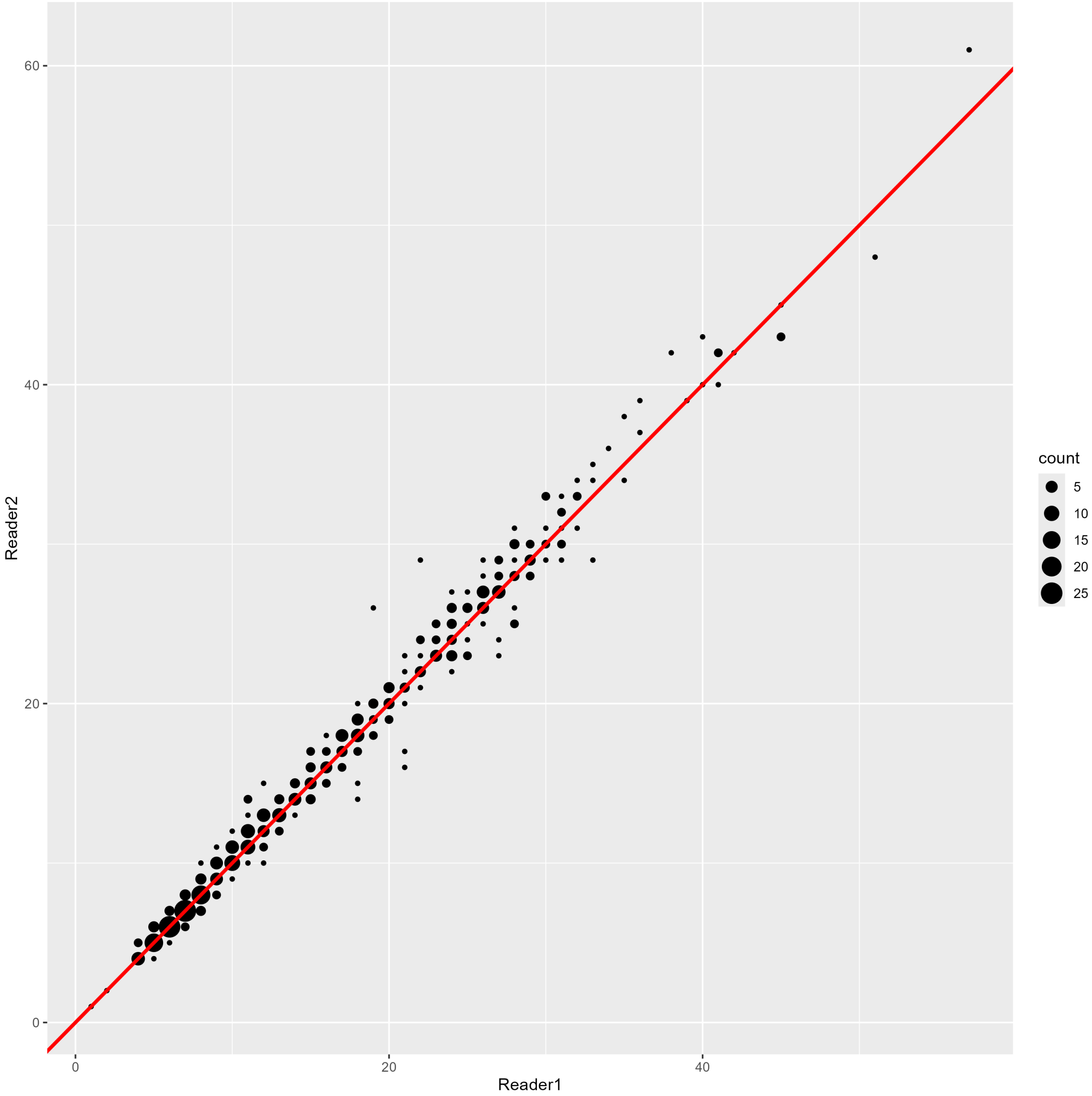


Figure 29: The between-reader ages for quillback rockfish with a 1:1 line representing the same read age. The bubble size represents the number of otoliths in a combination of reads.

9.2.2 Base Model Results

9.2.2.1 Parameter Estimates

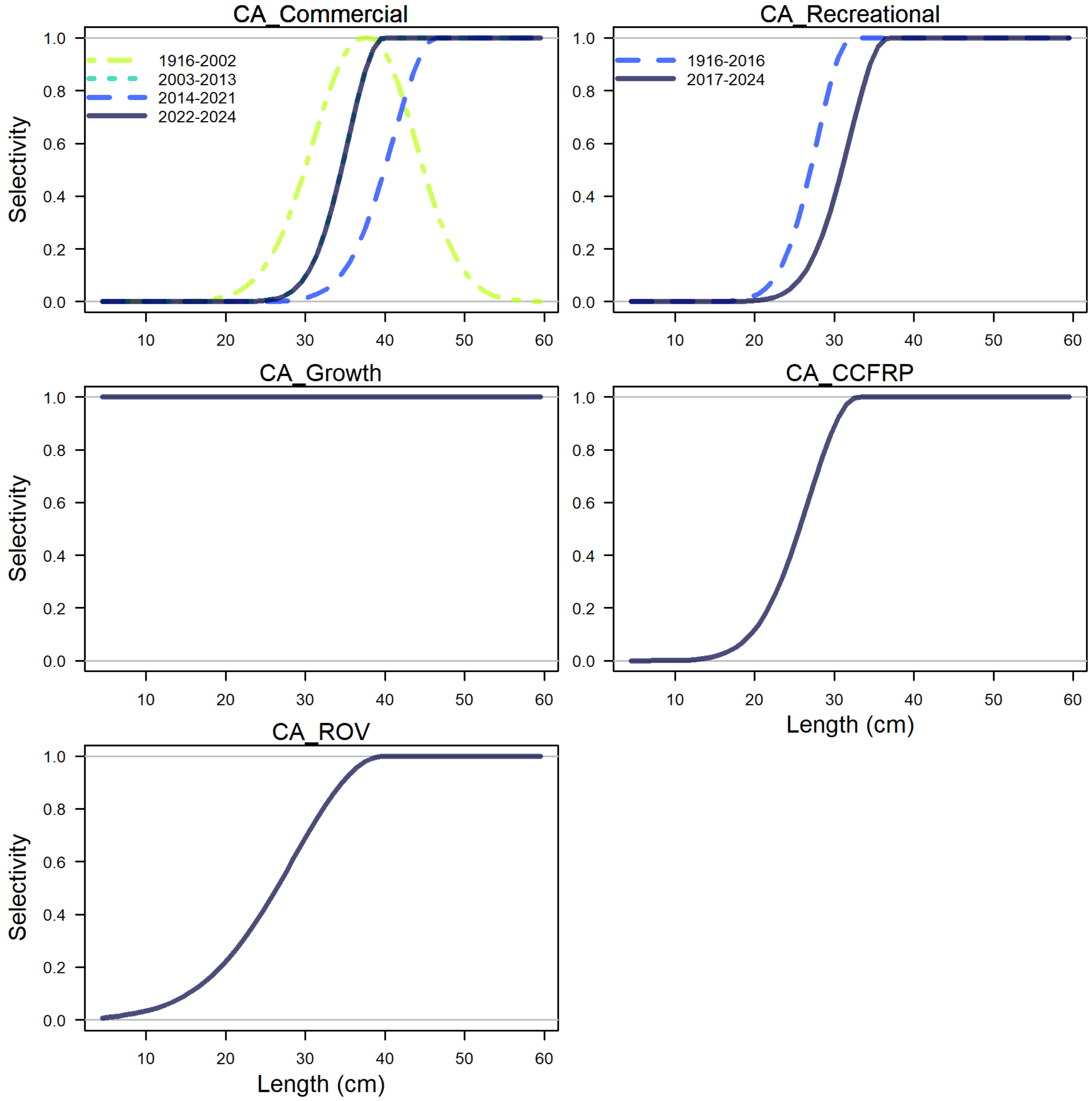


Figure 30: Length-based selectivity showing the time-varying selectivity blocks (in colored lines) for the recreational and commercial fleets as well as the CCFRP, ROV, and growth fleets. Selectivity for the commercial fleet in the 2003–2013 and 2022–2024 blocks are mirrored.

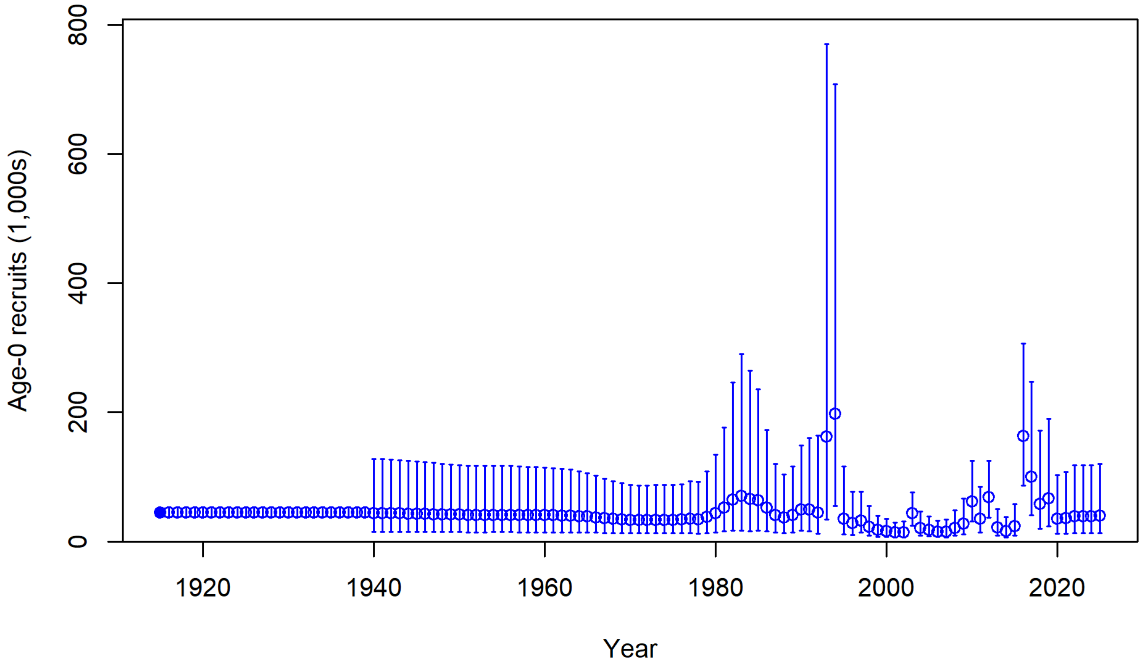


Figure 31: Estimated time series of age-0 recruits with 95% confidence intervals for the base model.

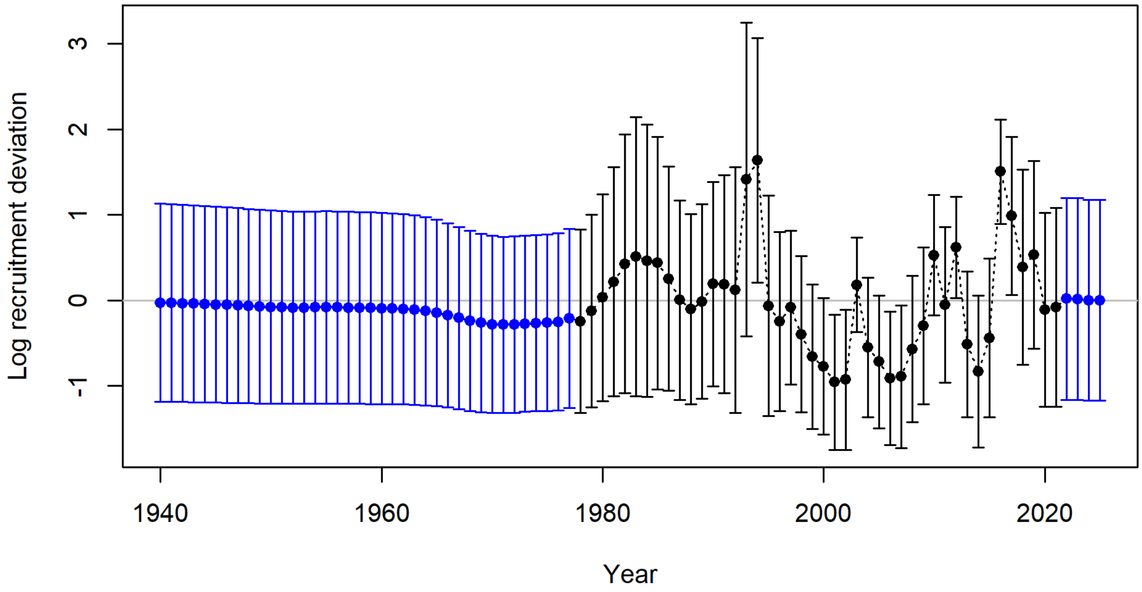


Figure 32: Estimated time series of recruitment deviations with 95% confience intervals for the base model.

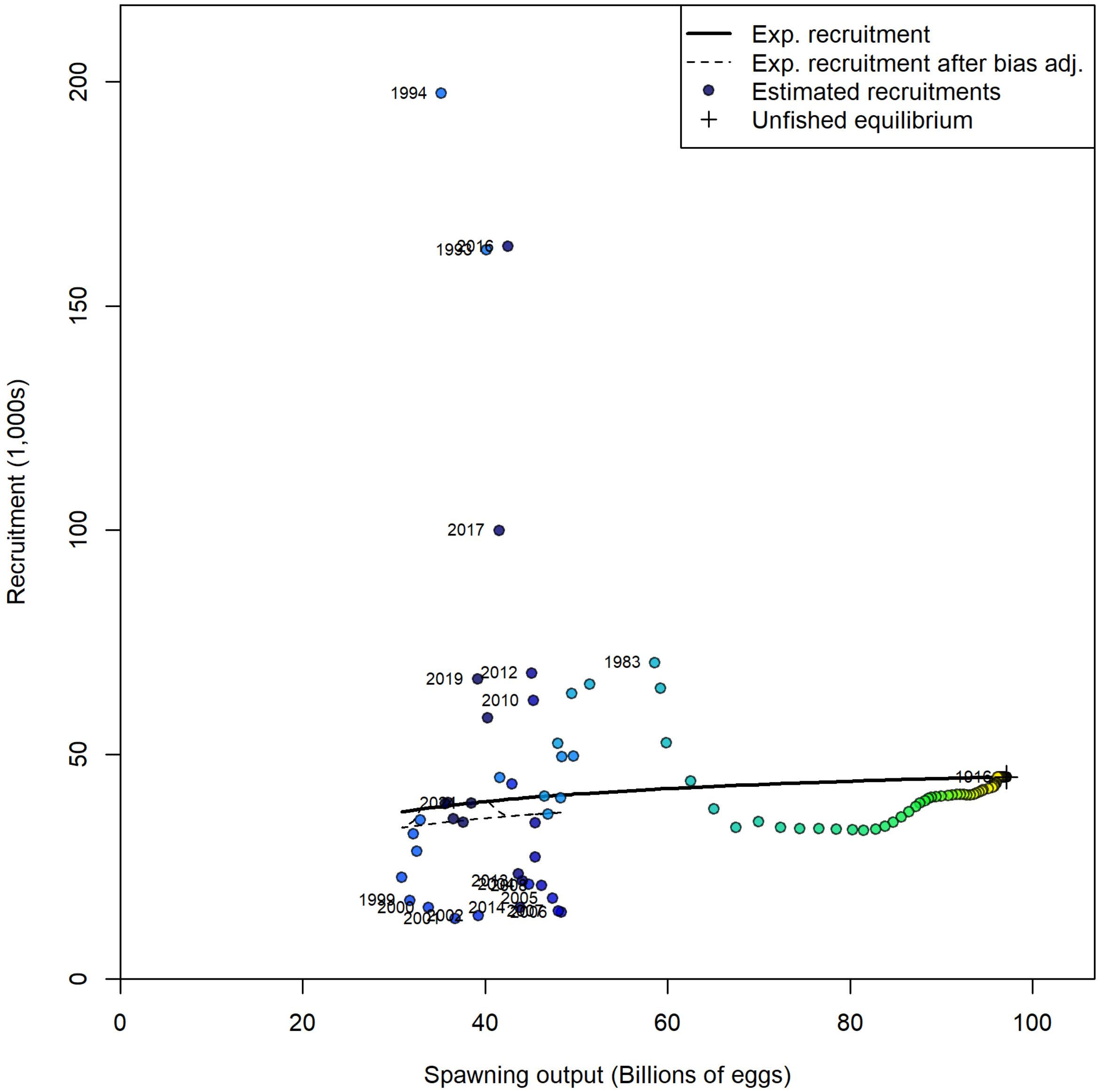


Figure 33: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors indicating later years

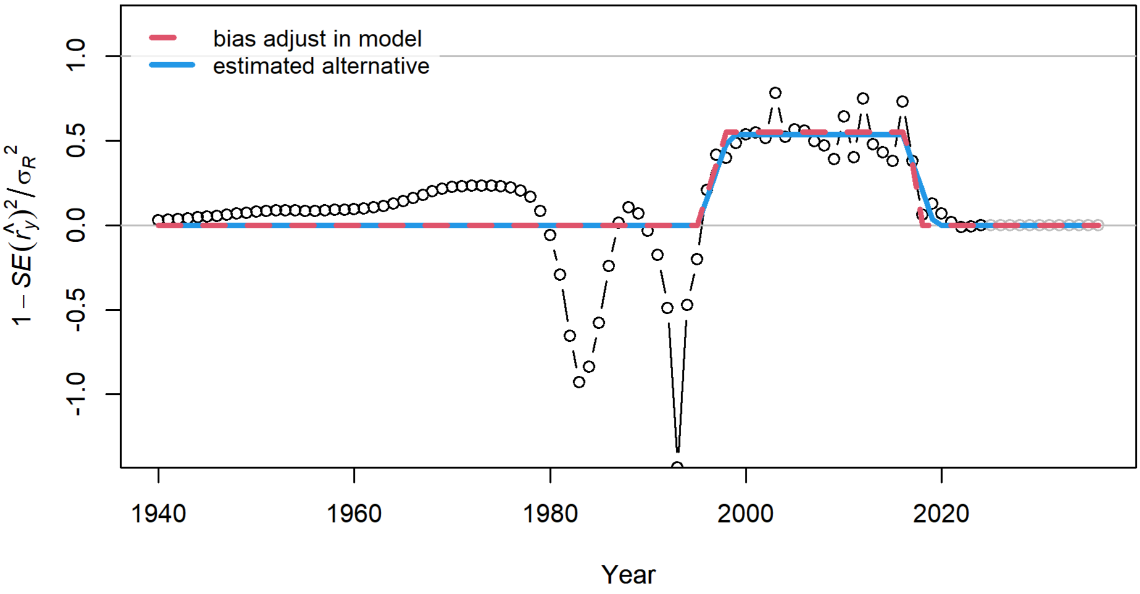


Figure 34: Recruitment bias adjustment applied in the base model. Points are transformed variances. Red line shows current settings for bias adjustment specified in control file. Blue line shows least squares estimate of alternative bias adjustment relationship for recruitment deviations.

9.2.2.2 Fits to Data

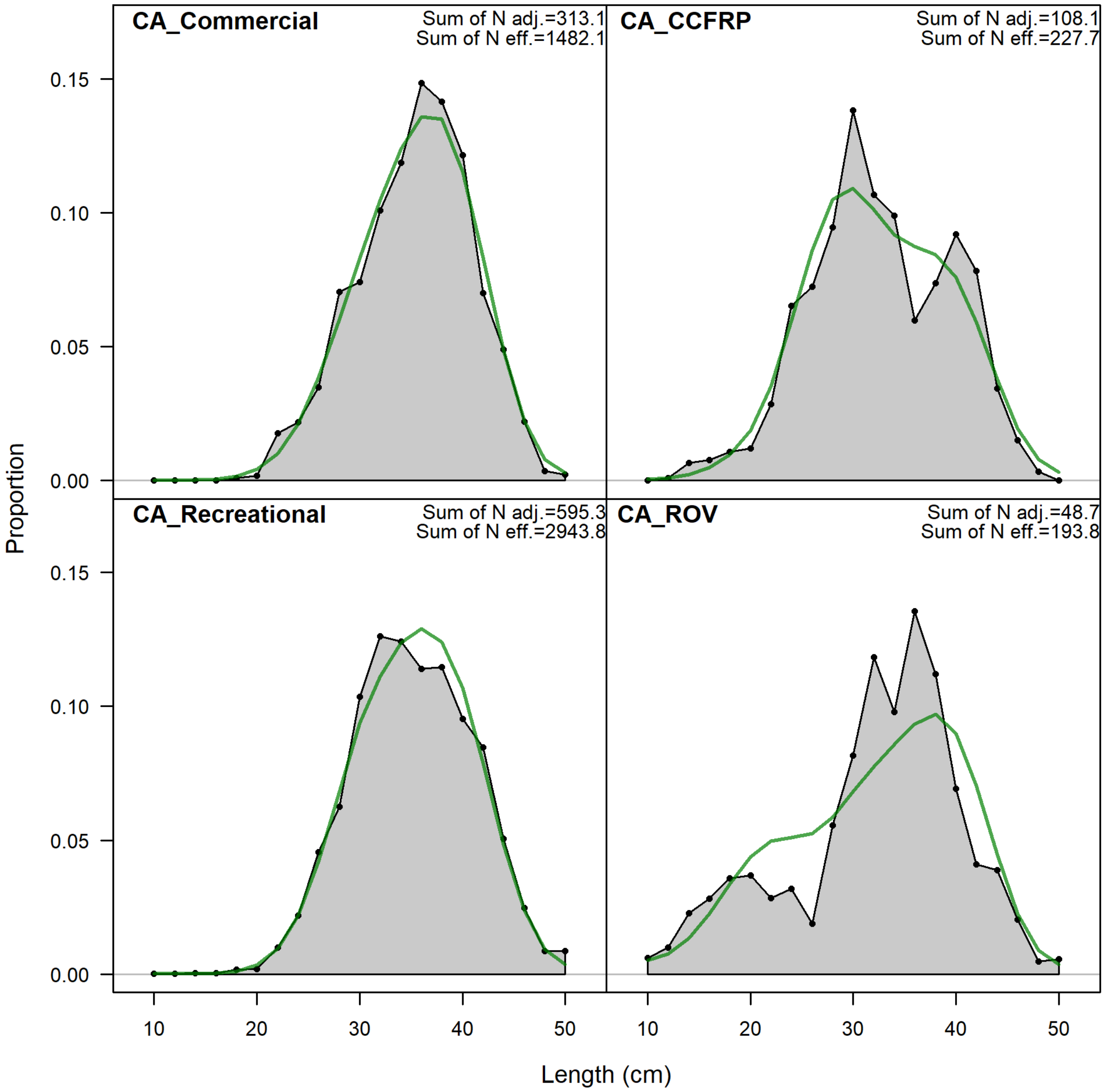


Figure 35: Length composition aggregated across years by fleet within the model with estimated fit to the data.

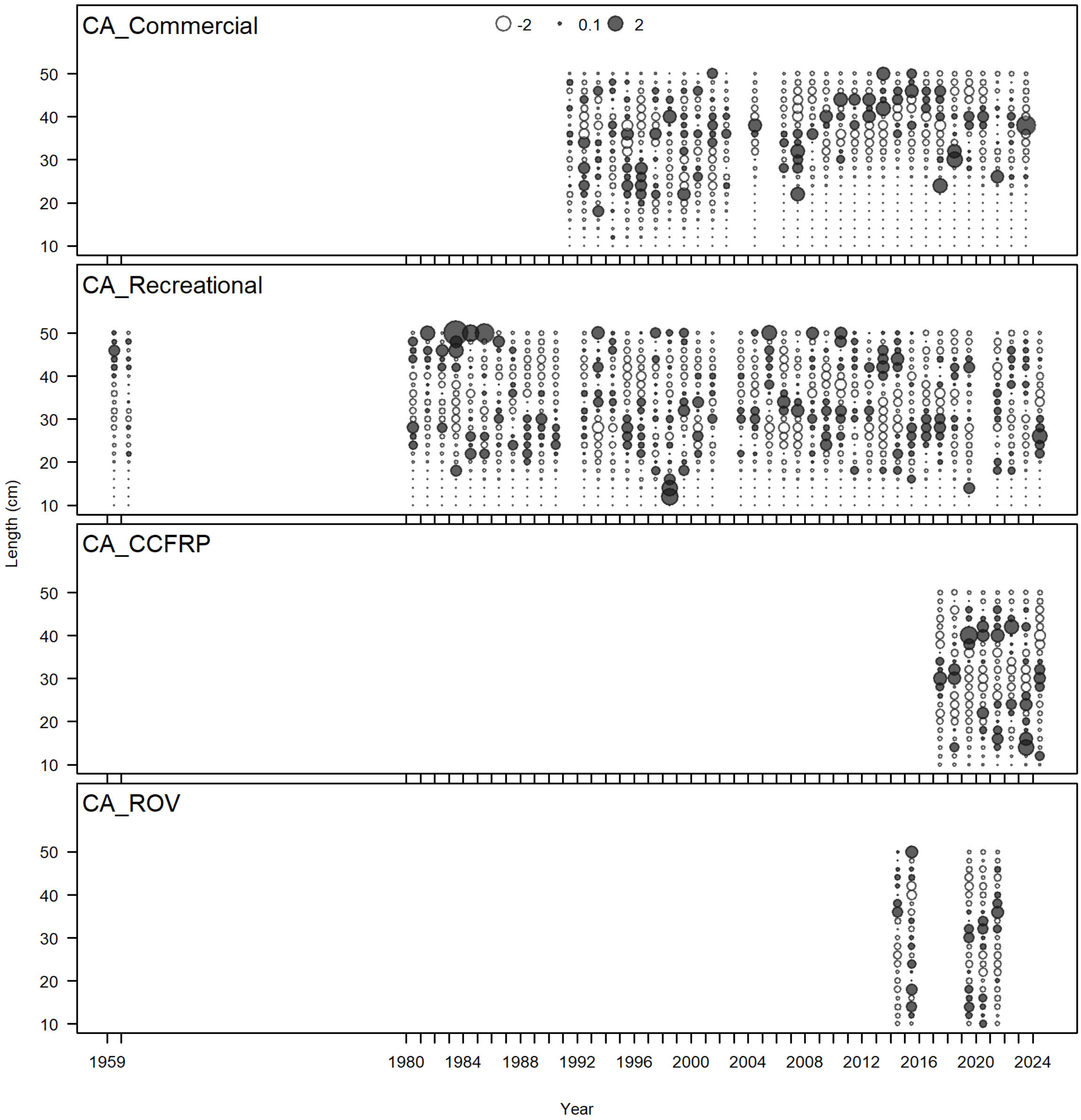


Figure 36: Pearson residuals for fit to length composition data for all fleets. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

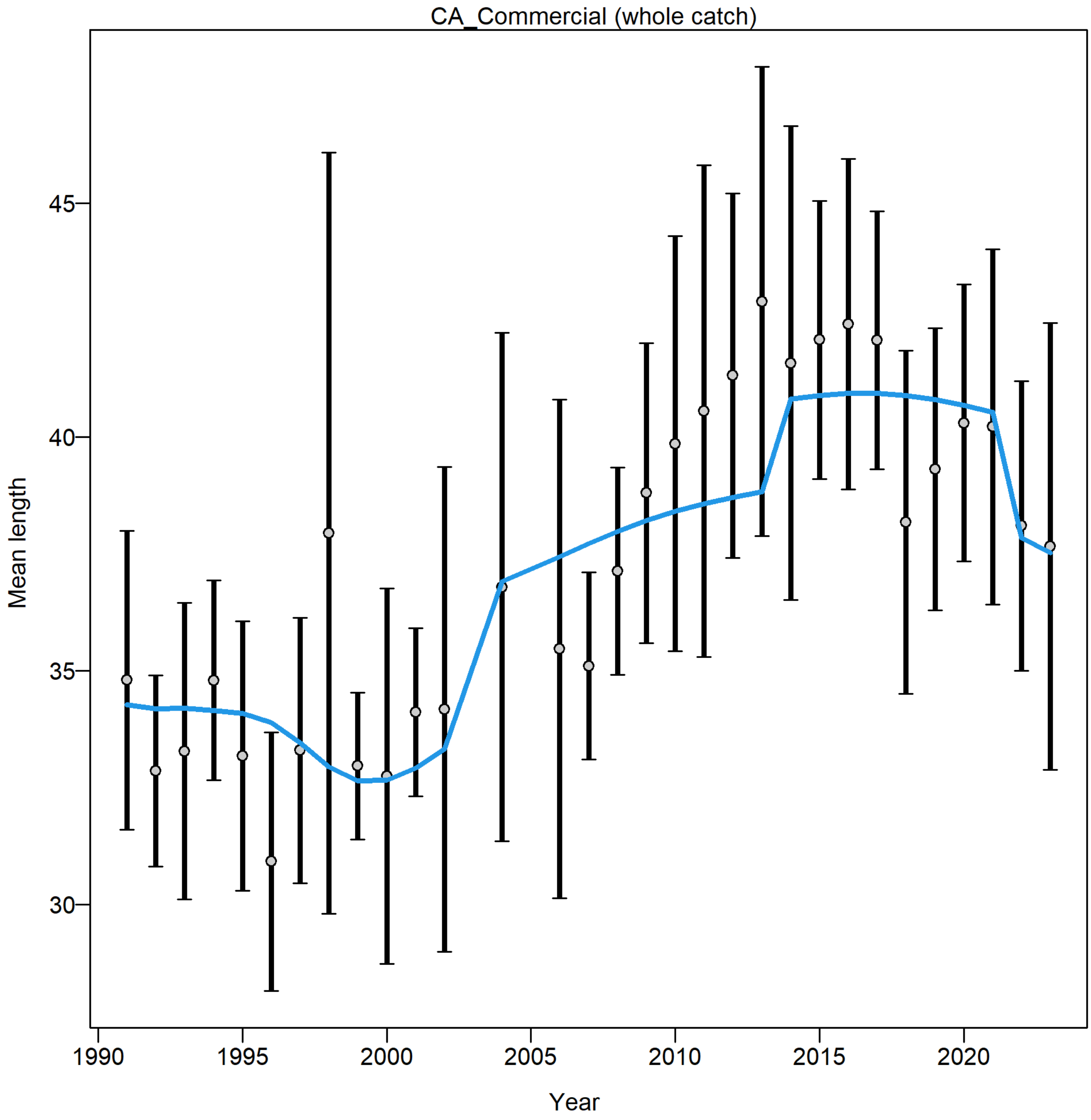


Figure 37: Mean length (cm) for commercial fleet with 95% confidence intervals based on adjusted input sample sizes. The blue line is the model expectation.

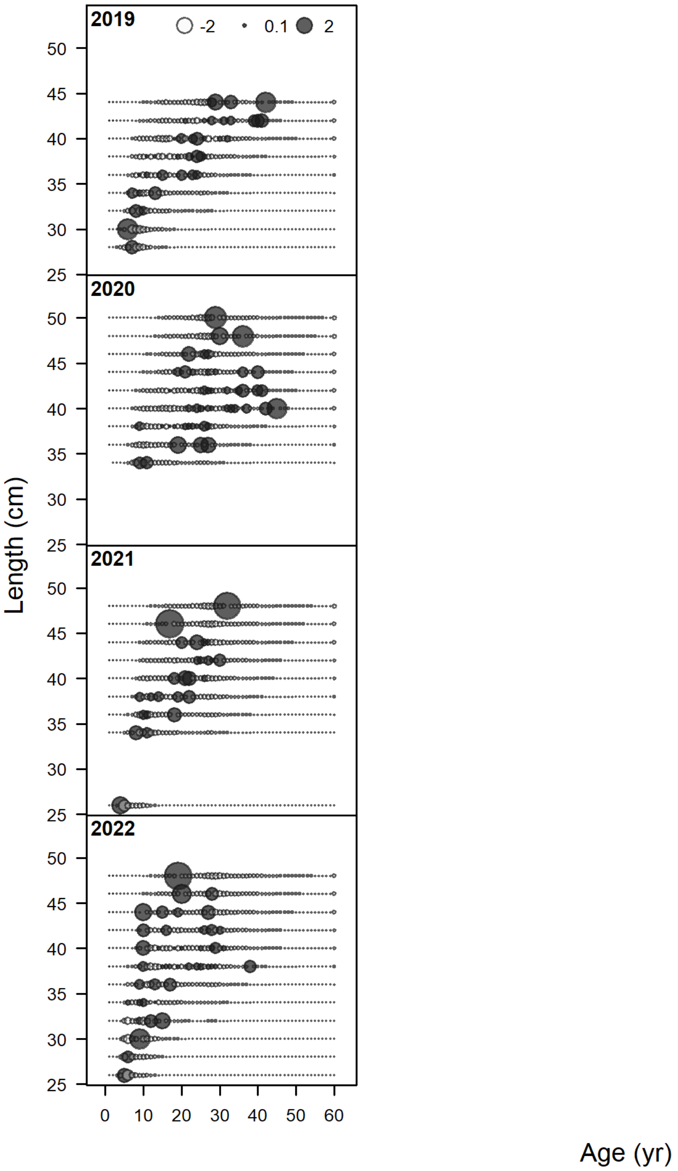


Figure 38: Pearson residuals for the commercial conditional age-at-length composition. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

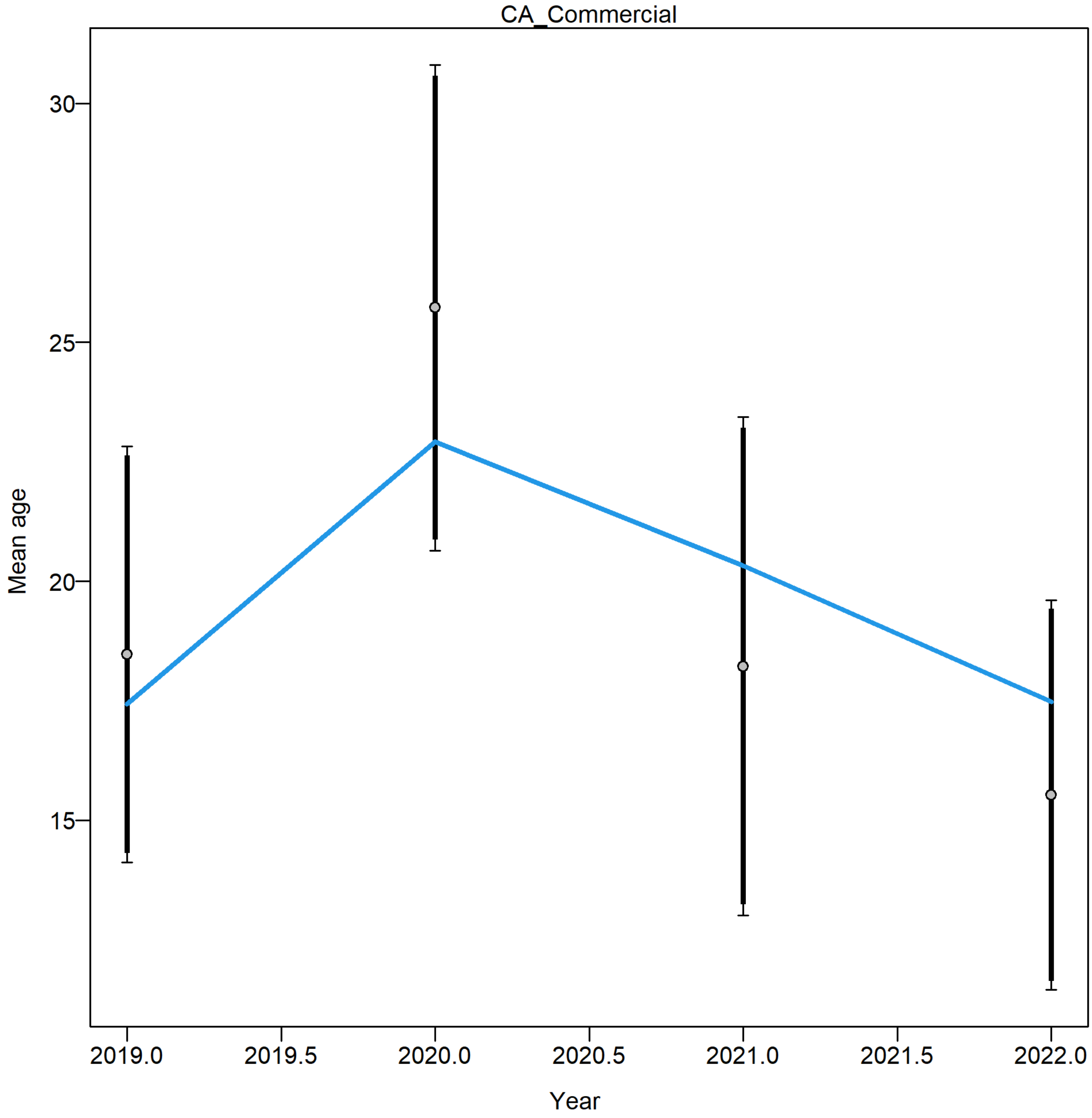


Figure 39: Mean age from conditional age-at-length data (aggregated across length bins) for the commercial fleet with 95% confidence intervals based on current samples sizes. The blue line is the model expectation.

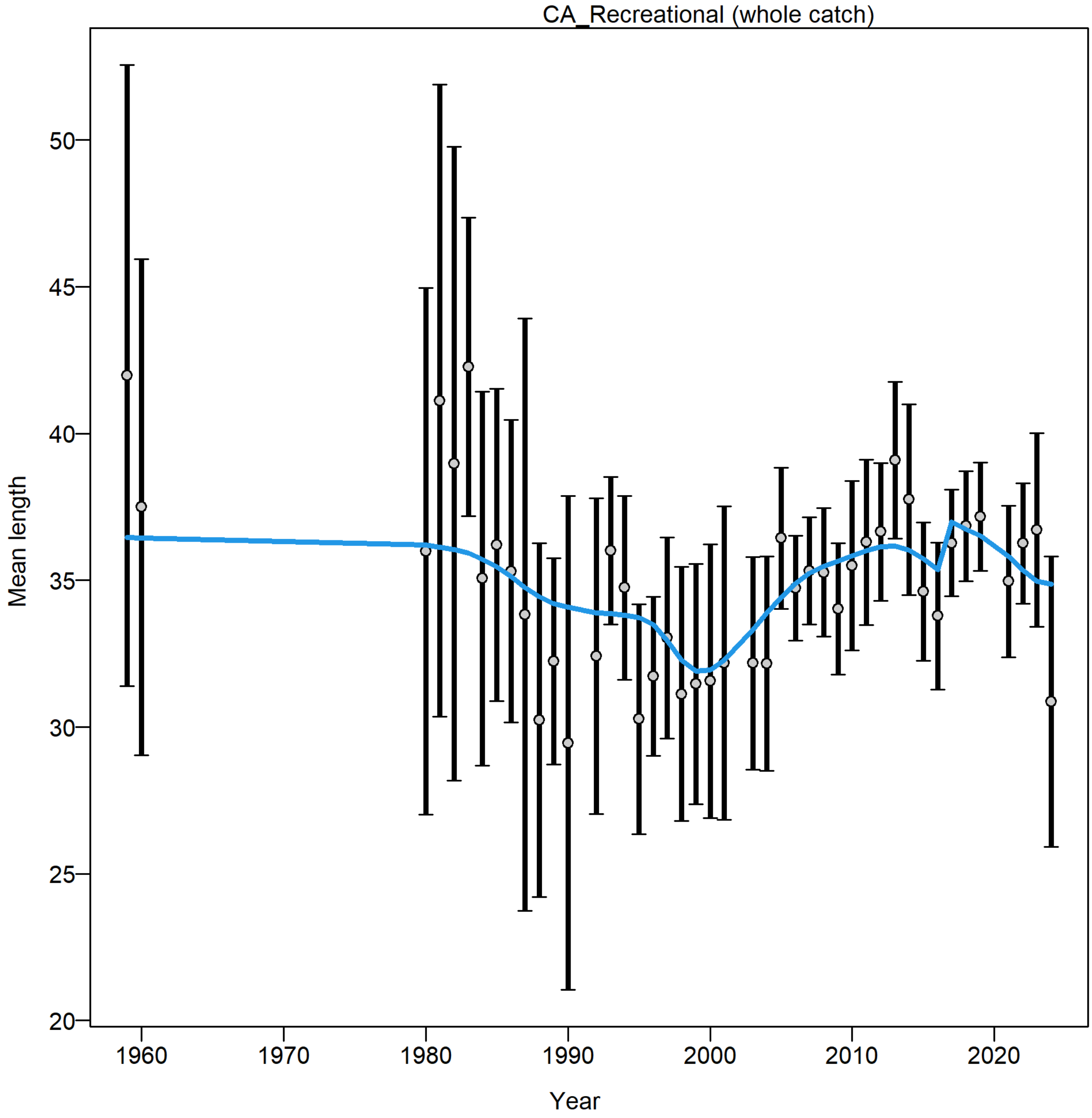


Figure 40: Mean length (cm) for recreational fleet with 95% confidence intervals based on adjusted input sample sizes. The blue line is the model expectation.

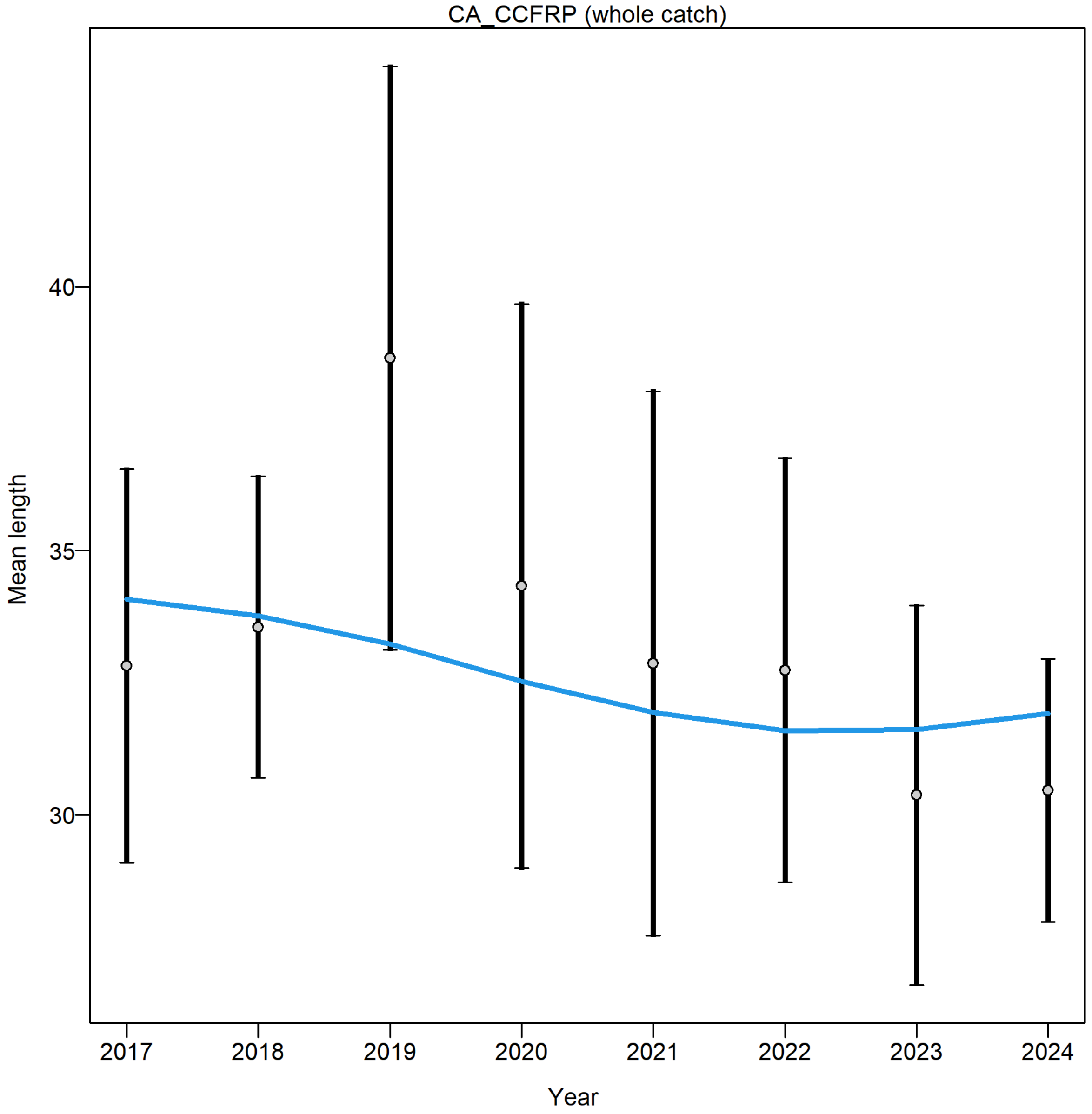


Figure 41: Mean length (cm) for CCFRP with 95% confidence intervals based on adjusted input sample sizes. The blue line is the model expectation.

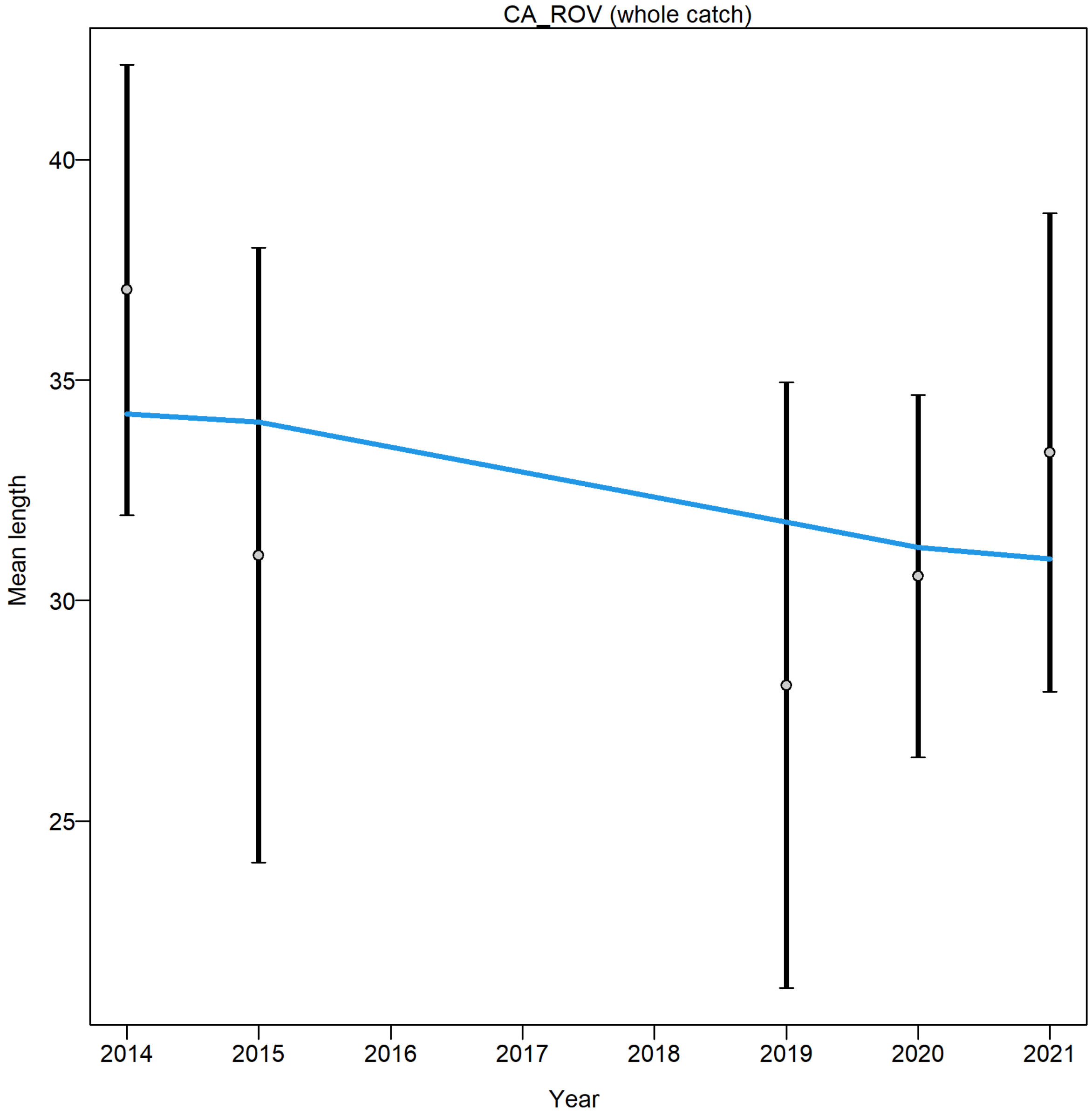


Figure 42: Mean length (cm) for ROV with 95% confidence intervals based on adjusted input sample sizes. The blue line is the model expectation.

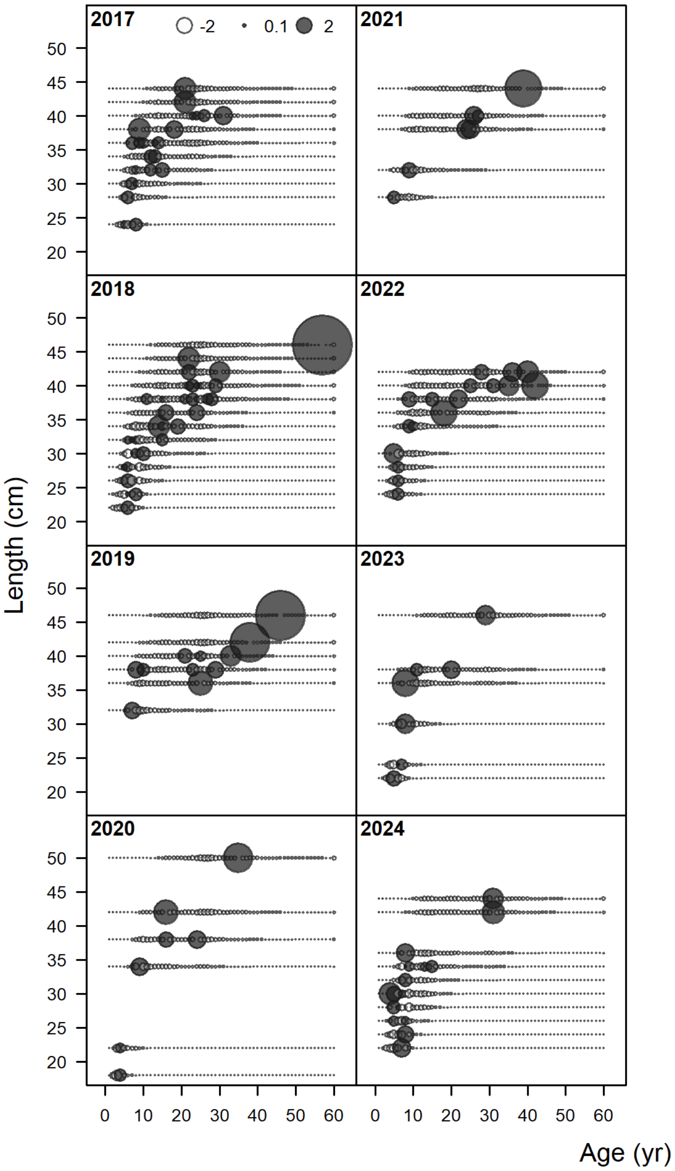


Figure 43: Pearson residuals for the CCFRP survey fleet conditional age-at-length composition. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

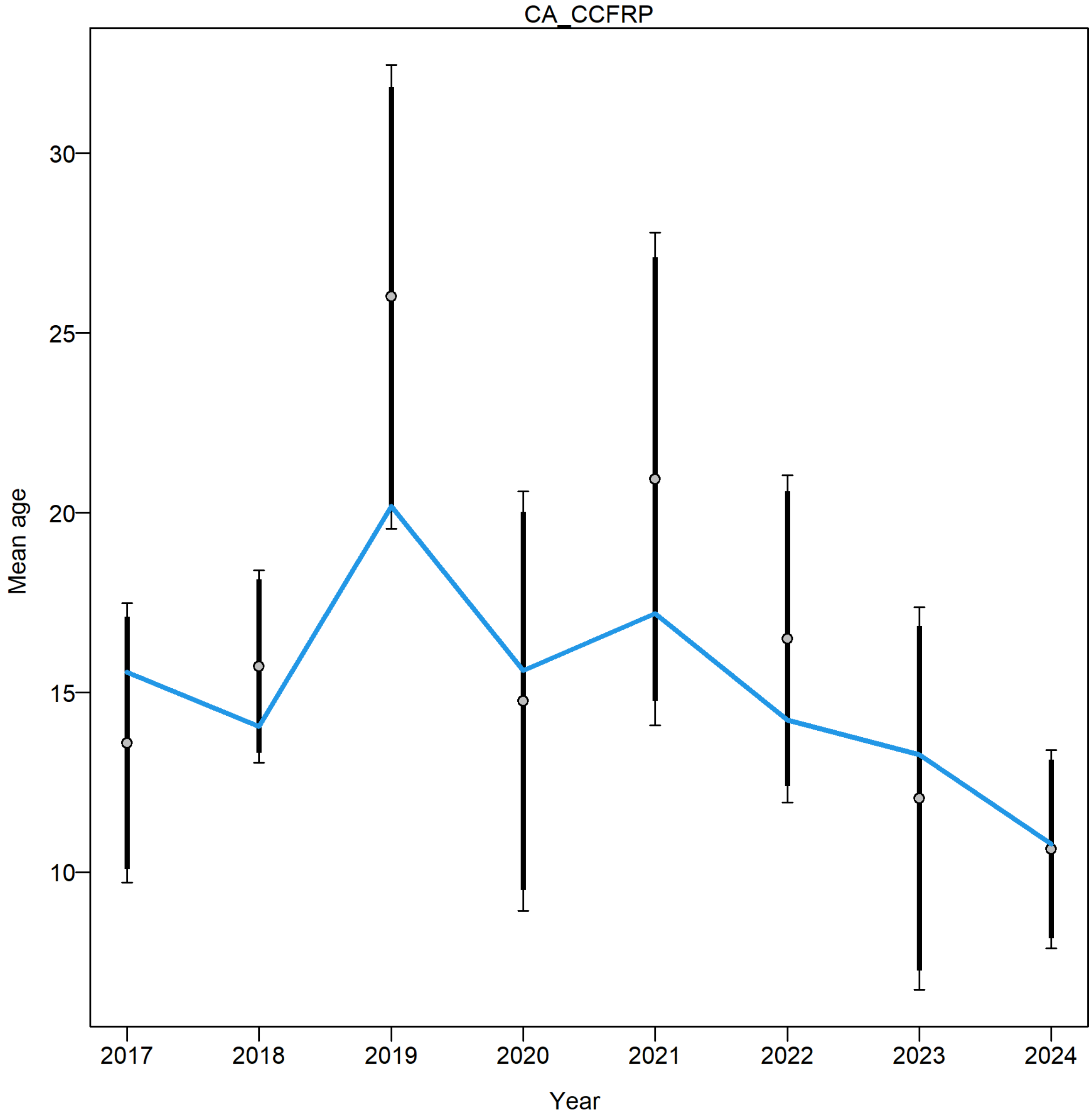


Figure 44: Mean age from conditional age-at-length data (aggregated across length bins) for the CCFRP survey fleet with 95% confidence intervals based on current samples sizes. The blue line is the model expectation.

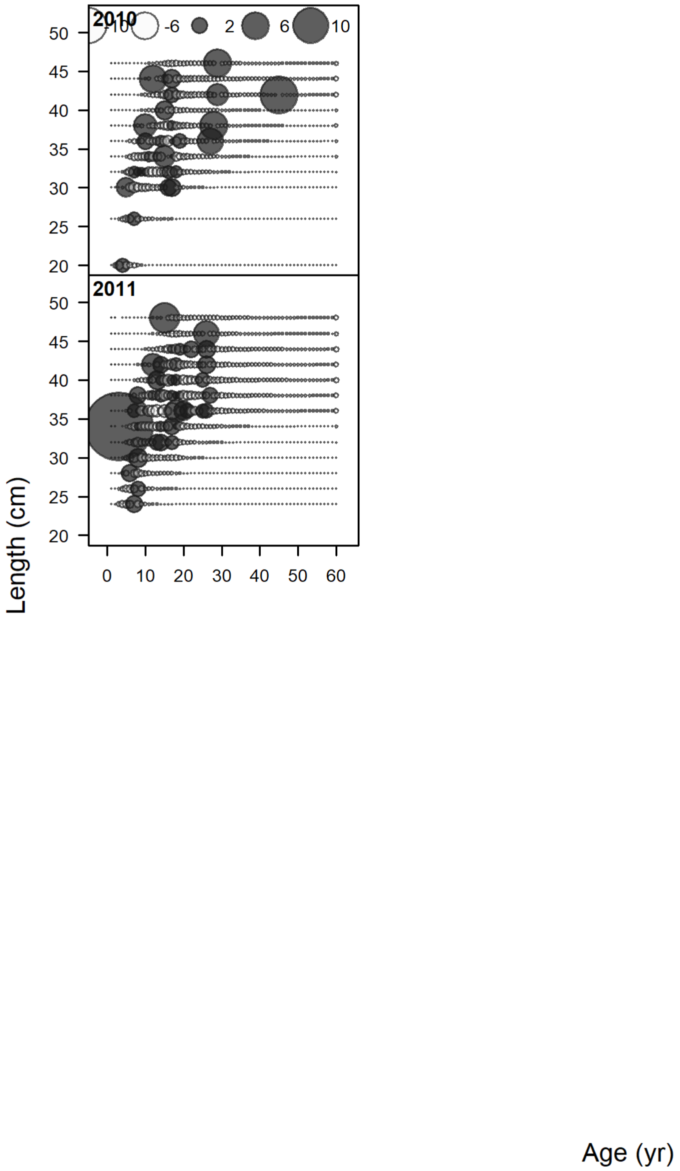


Figure 45: Pearson residuals for the growth fleet conditional age-at-length composition. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

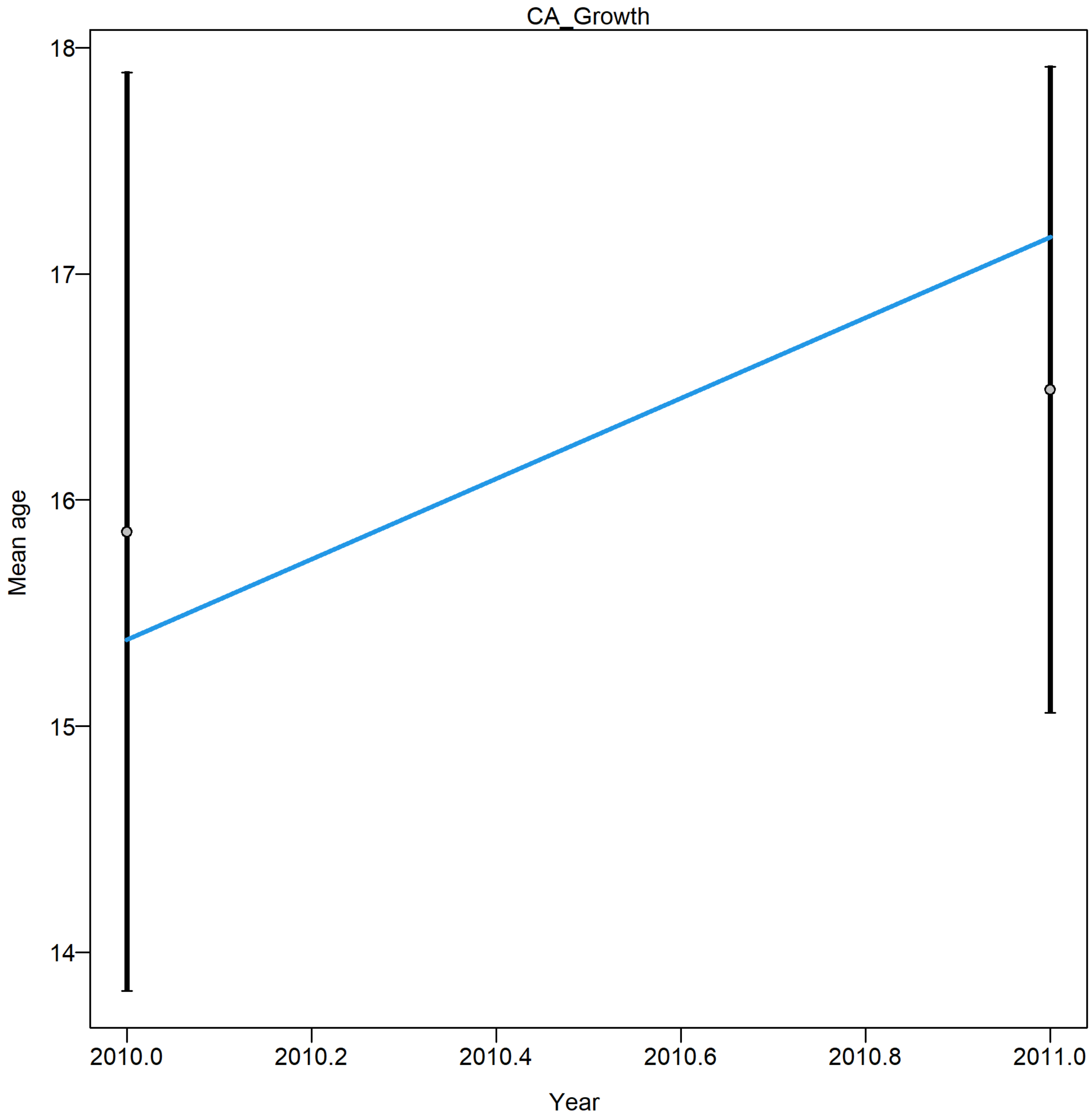


Figure 46: Mean age from conditional age-at-length data (aggregated across length bins) for the growth fleet with 95% confidence intervals based on current samples sizes. The blue line is the model expectation.

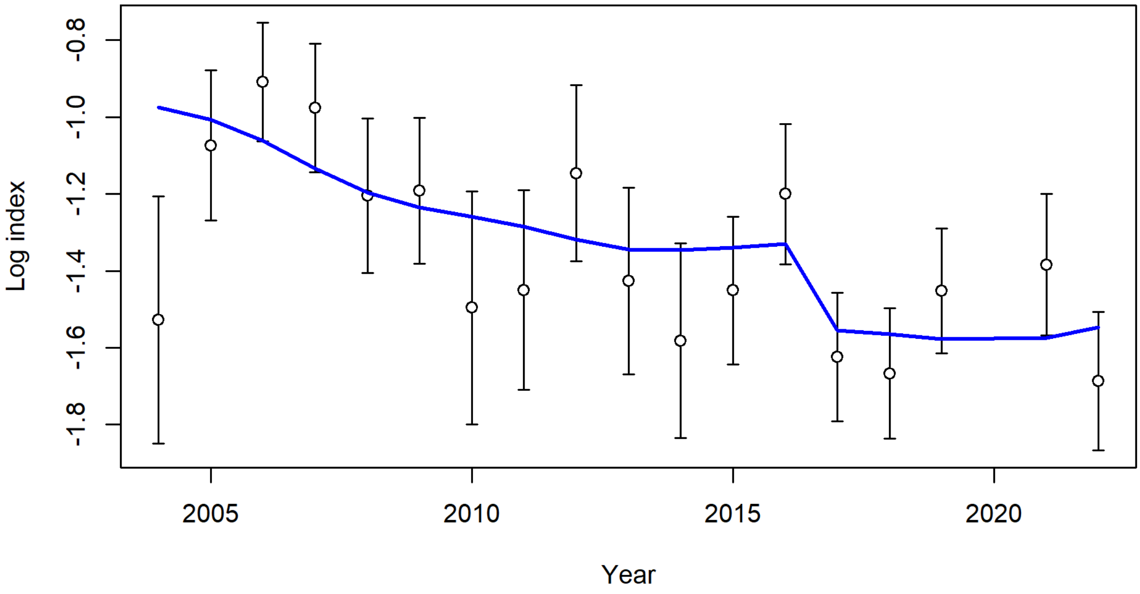


Figure 47: Fit to log index data on log scale for the CRFS dockside private/rental index of abundance. Lines indicate 95% confidence interval around index values based on the model assumption of lognormal error.

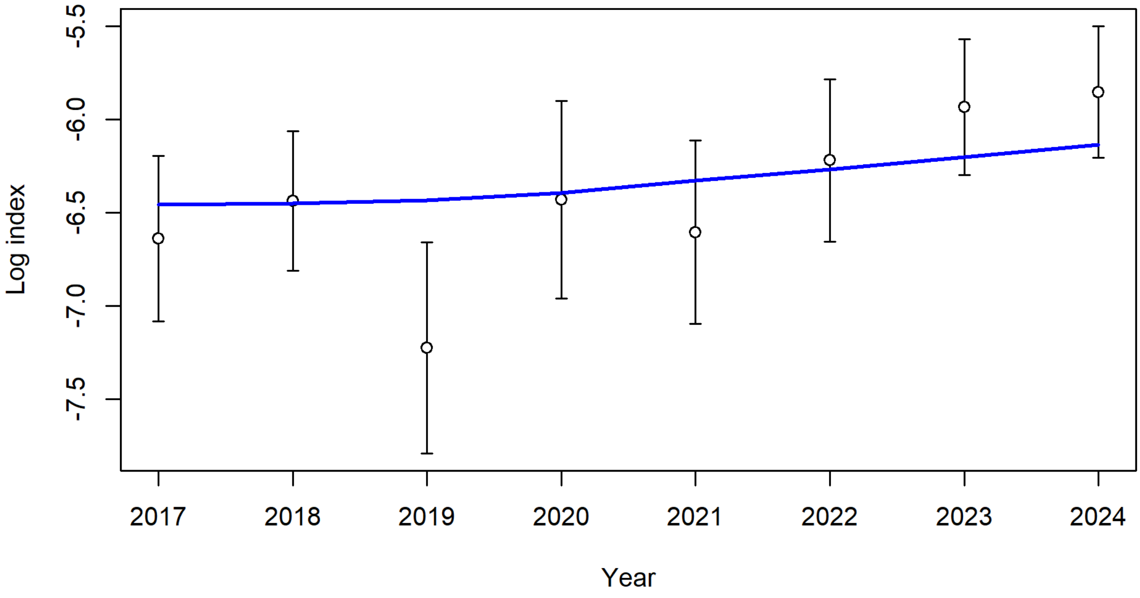


Figure 48: Fit to log index data on log scale for the CCFRP index of abundance. Lines indicate 95% confidence interval around index values based on the model assumption of lognormal error.

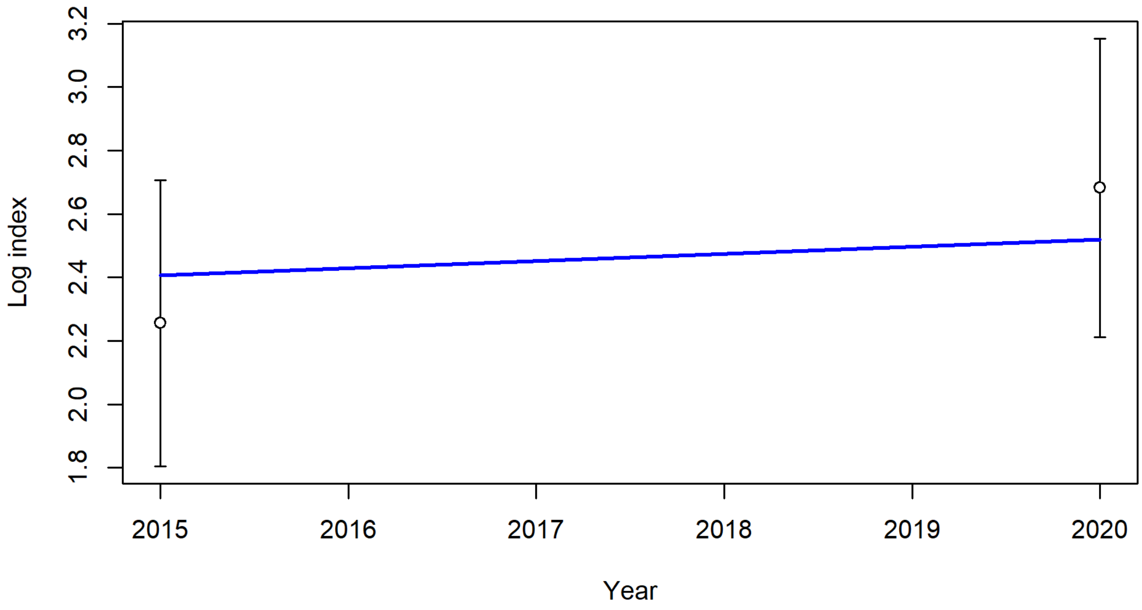


Figure 49: Fit to log index data on log scale for the ROV index of abundance. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error.

9.2.2.3 Population Trajectory

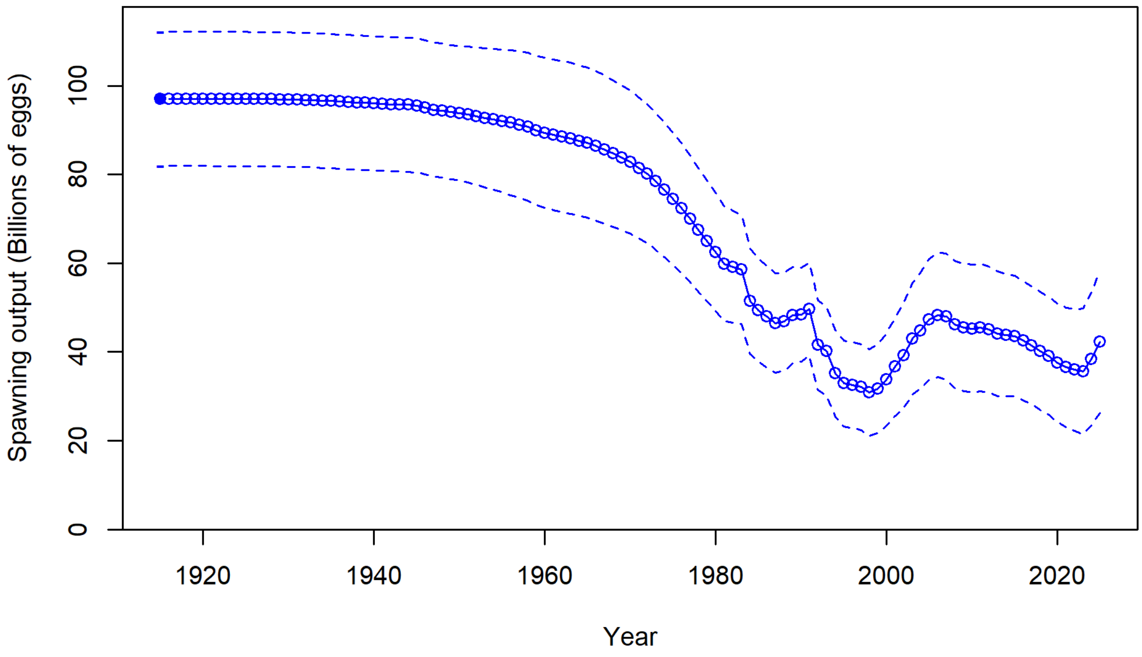


Figure 50: Estimated time series of spawning output in billions of eggs with 95% asymptotic confidence intervals.

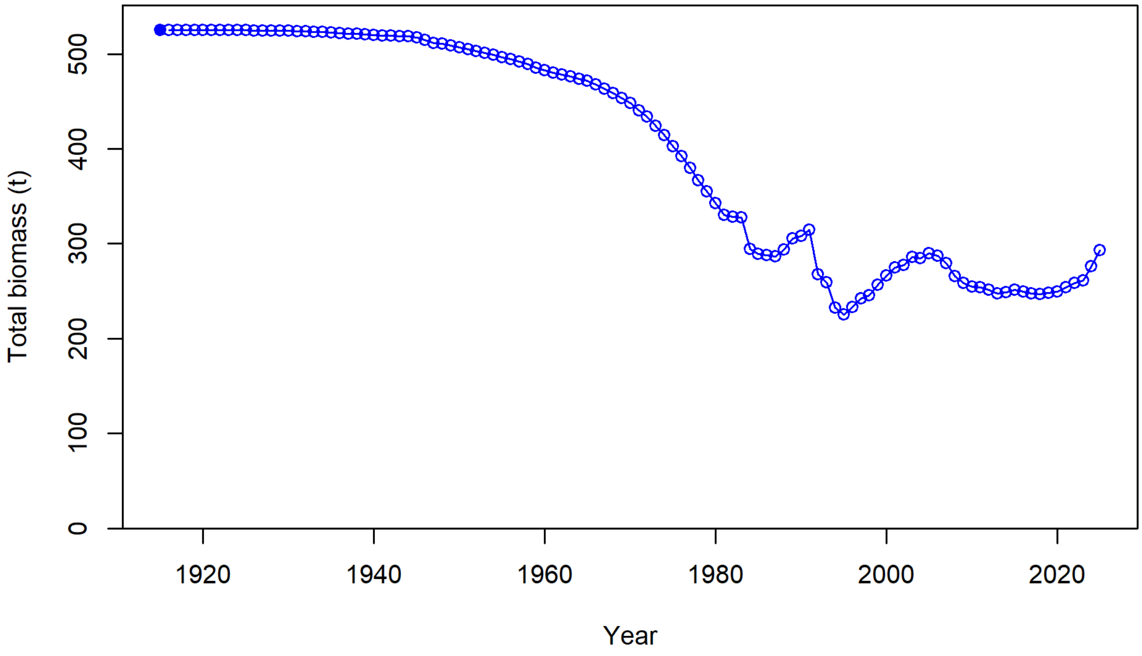


Figure 51: Estimated time series of total biomass (mt).

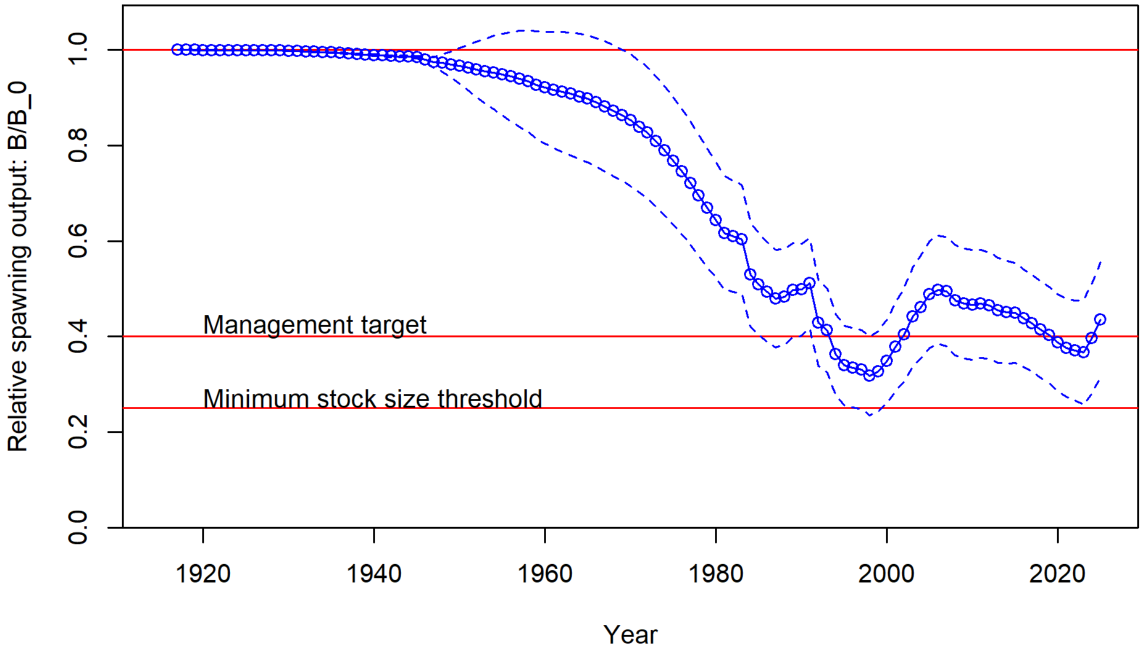


Figure 52: Estimated time series of spawning output relative to unfished with 95% asymptotic confidence intervals.

9.2.3 Model Diagnostics

9.2.3.1 Retrospective Analyses

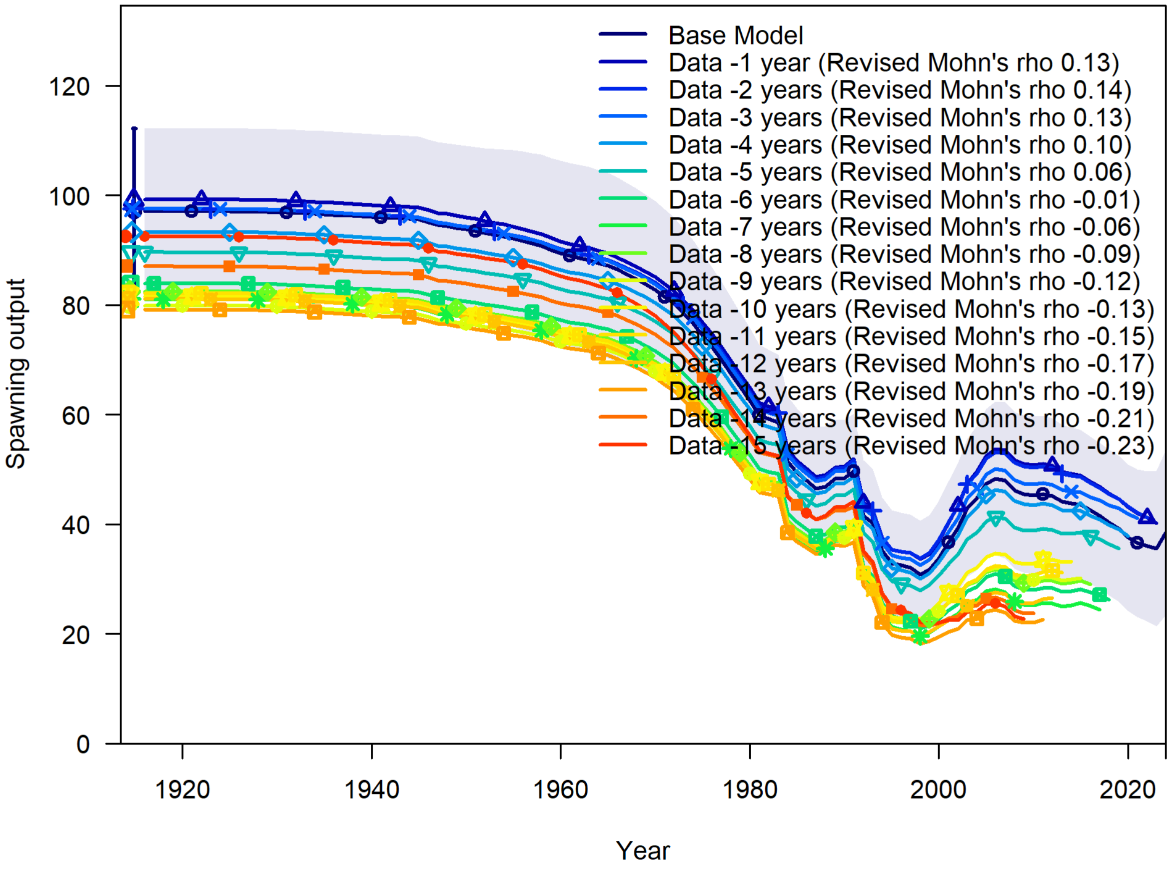


Figure 53: Retrospective results: change in the estimate of spawning output (in billions of eggs) when the most recent 15 years of data are removed sequentially. The uncertainty shown represents the base model. Mohn's rho values are provided as per year averages.

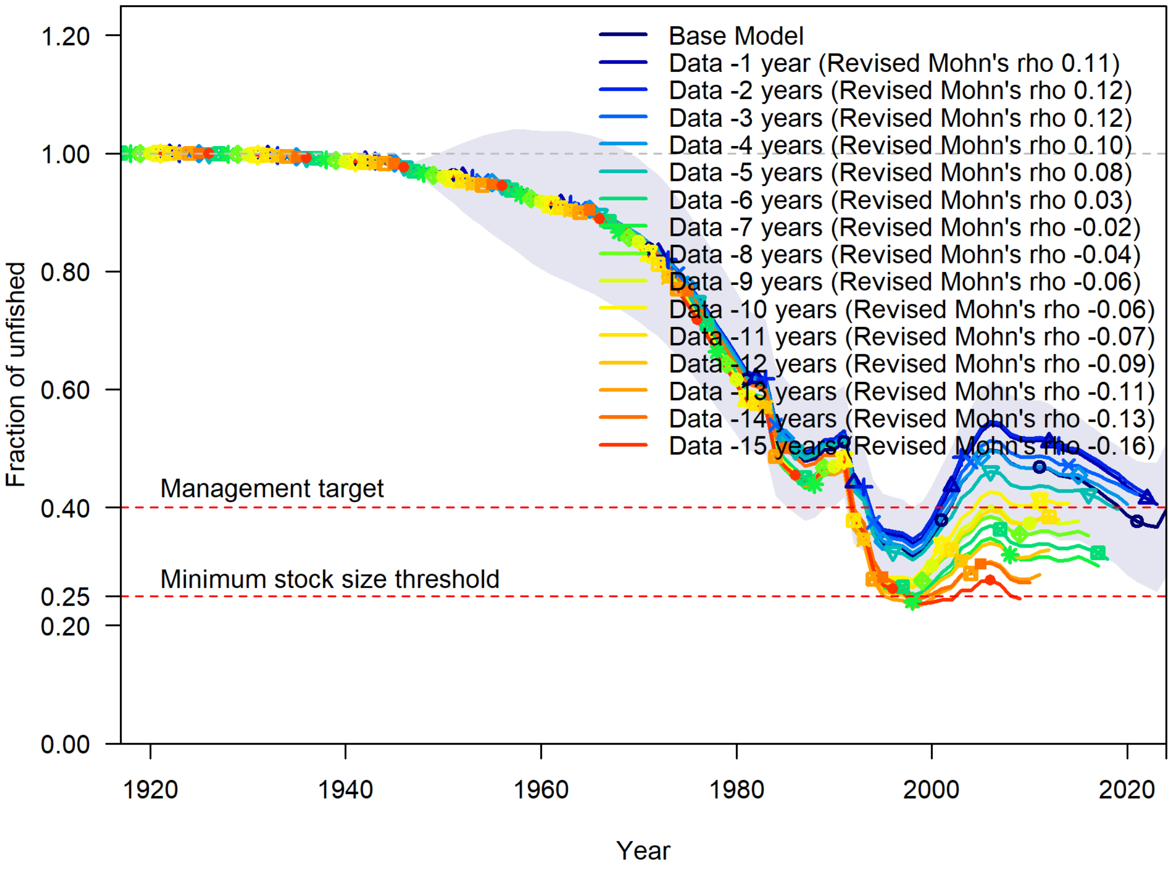


Figure 54: Retrospective results: change in the estimate of the fraction of unfished relative to the start year when the most recent 15 years of data are removed sequentially. The uncertainty shown represents the base model. Mohn's rho values are provided as per year averages.

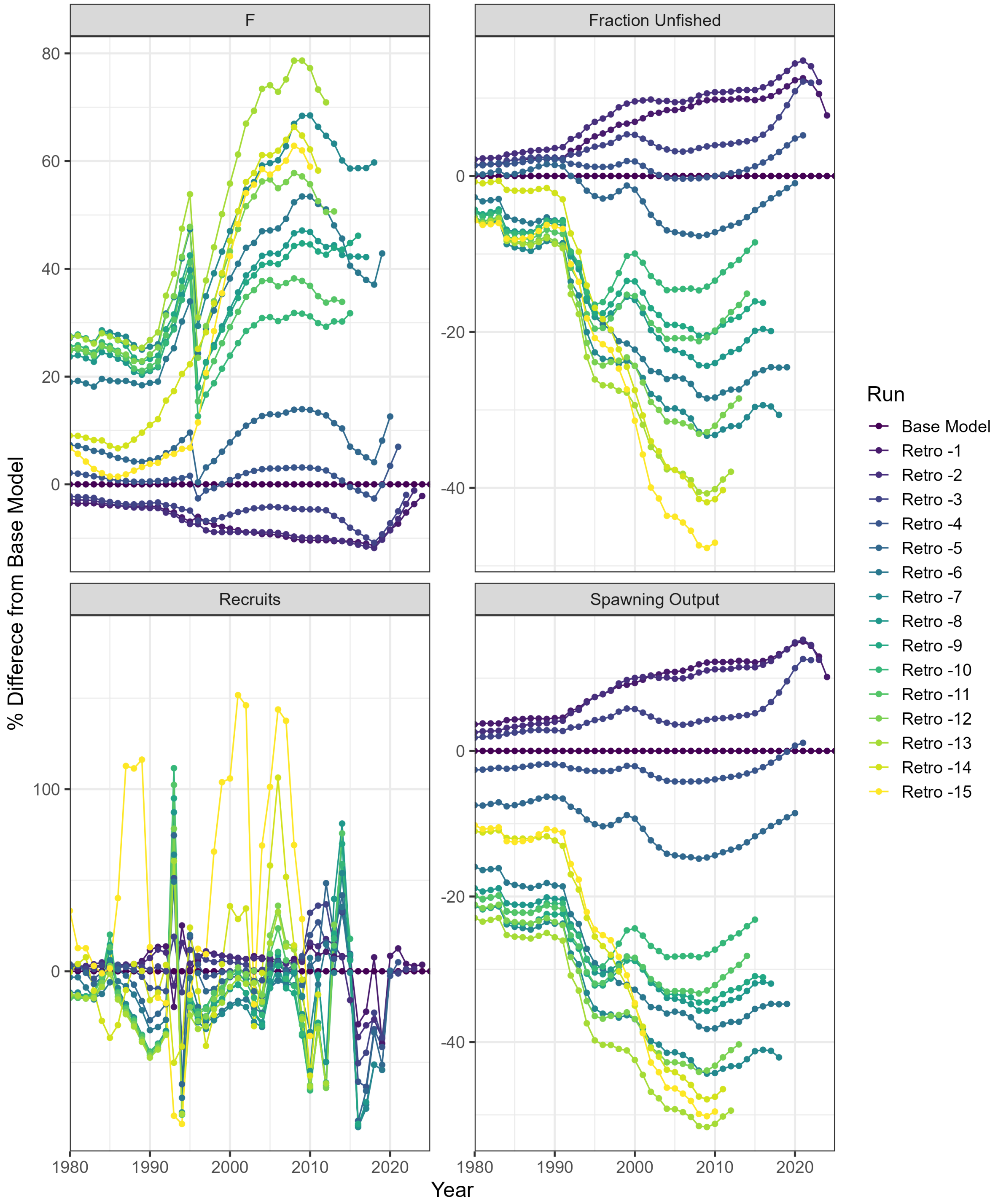


Figure 55: Squid plots of retrospective results relative to the base model for fishing mortality (F), fraction unfished, recruits, and spawning output (in billions of eggs).

9.2.3.2 Likelihood Profiles

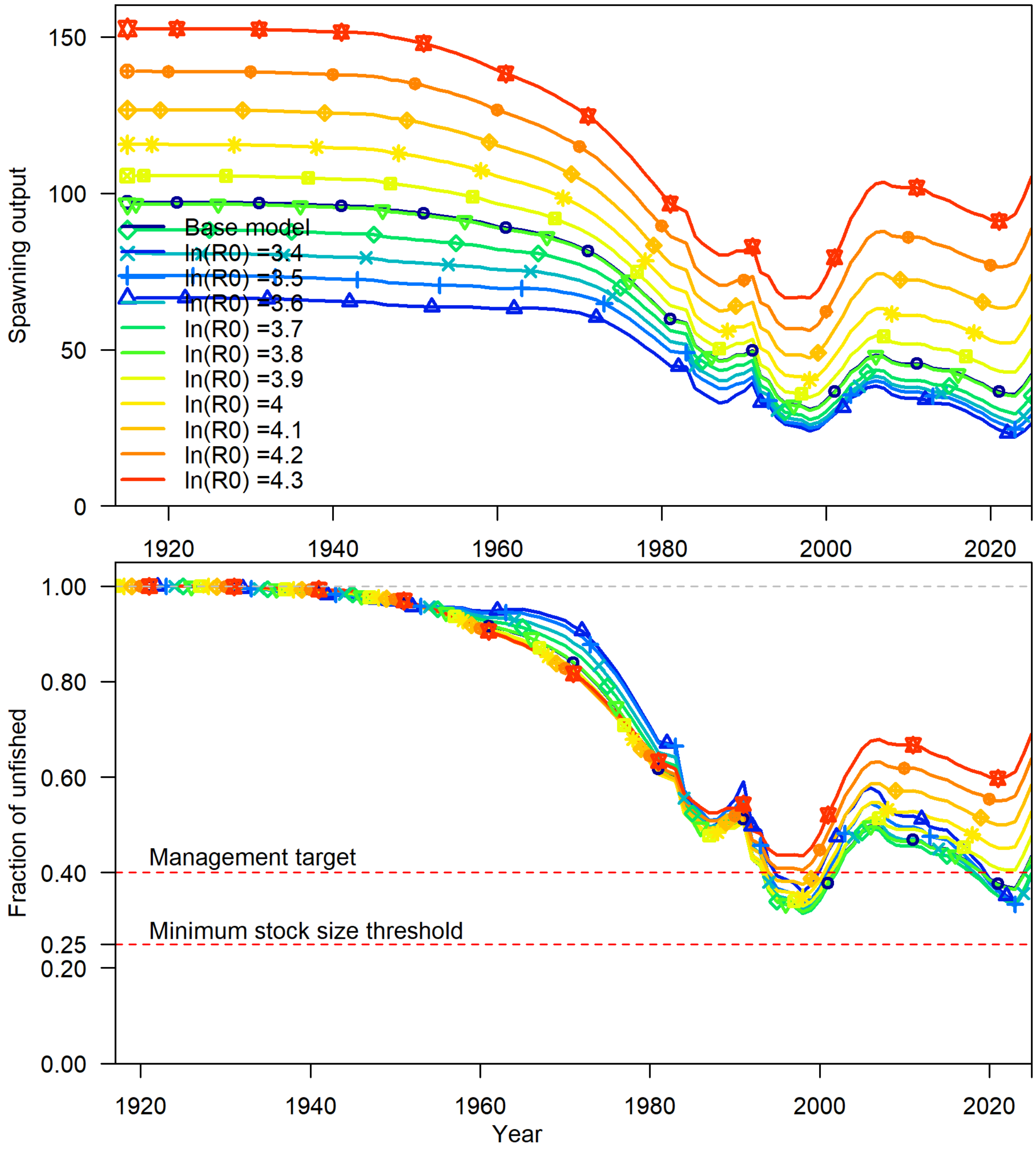


Figure 56: Change in the estimate of spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) across a range of $\ln(R_0)$ values.

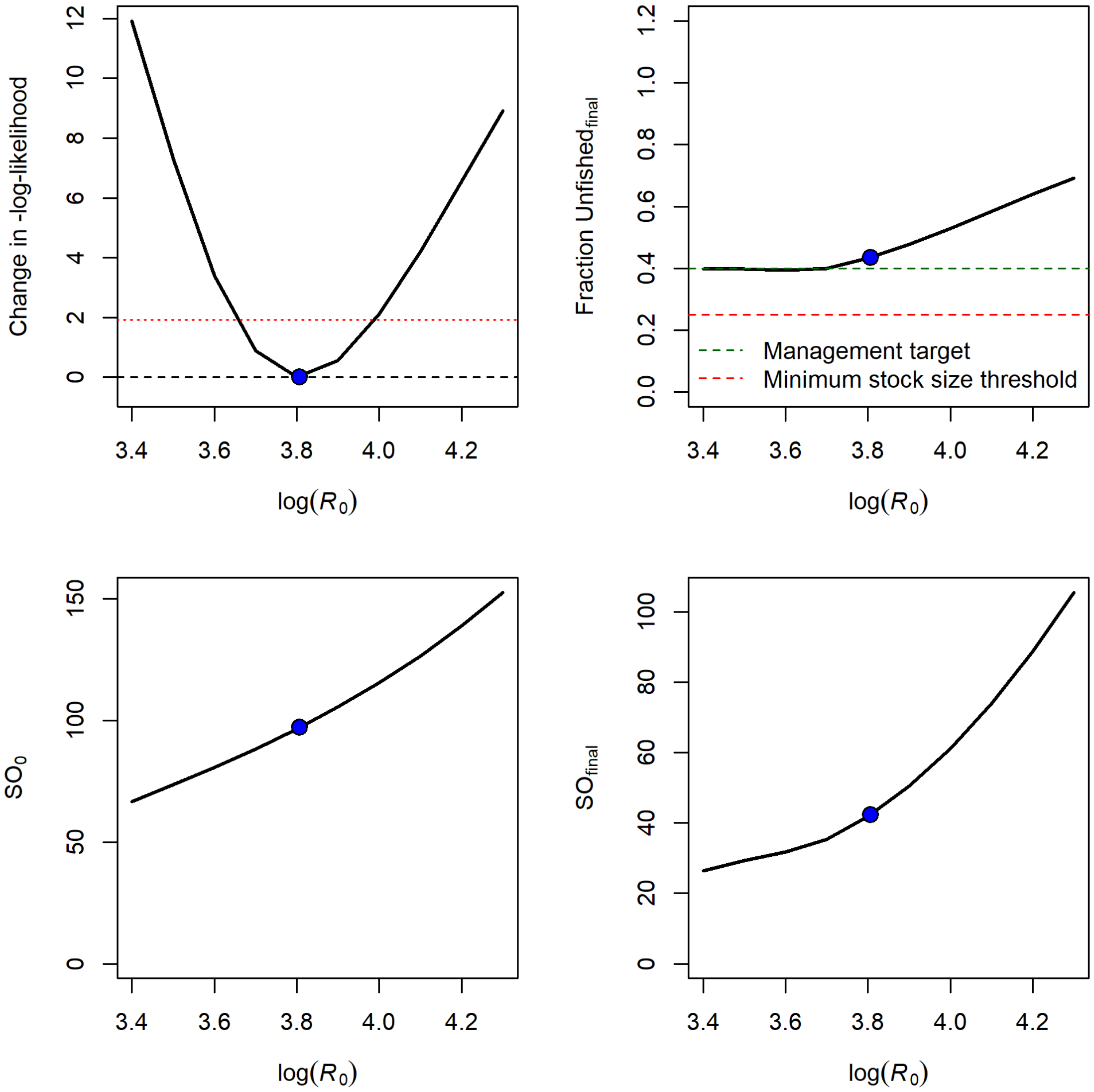


Figure 57: Change in the negative log-likelihood, fraction of unfished spawning output, initial spawning output (in billions of eggs), and final spawning output (in billions of eggs) across a range of ln(R_0) values.

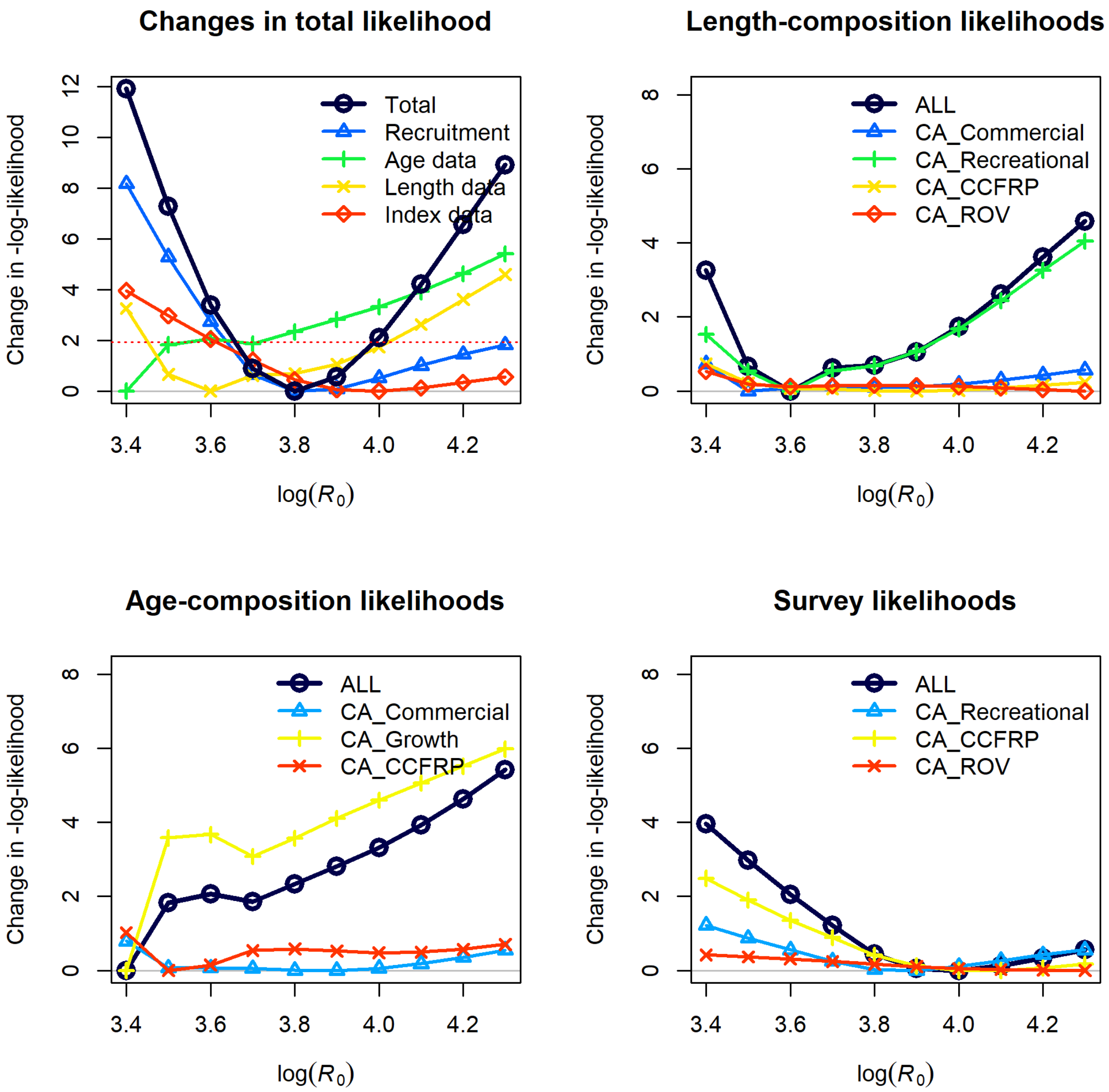


Figure 58: Change in the negative log-likelihood across a range of $\ln(R_0)$ values.

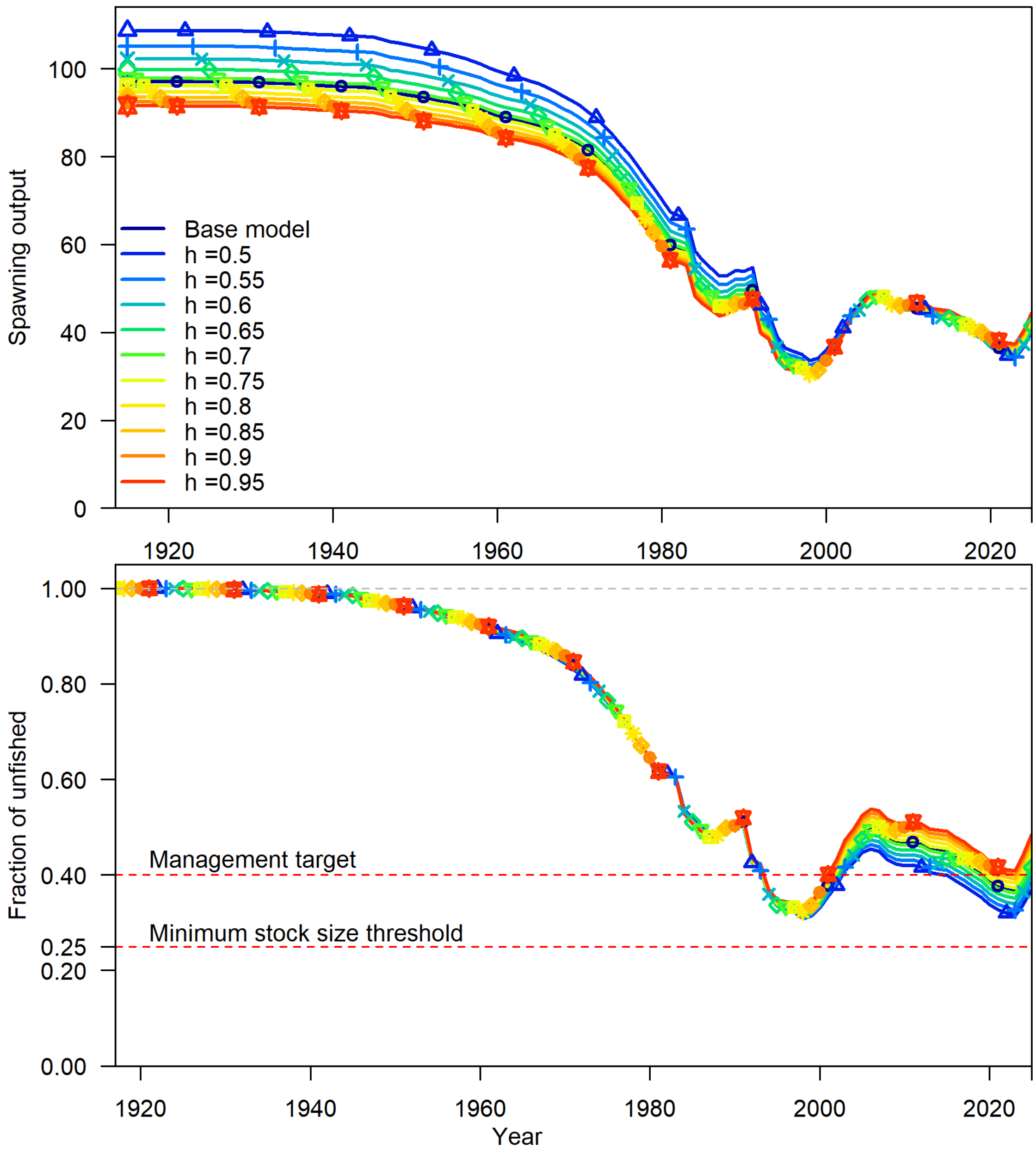


Figure 59: Change in the estimate of spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) across a range of steepness (h) values.

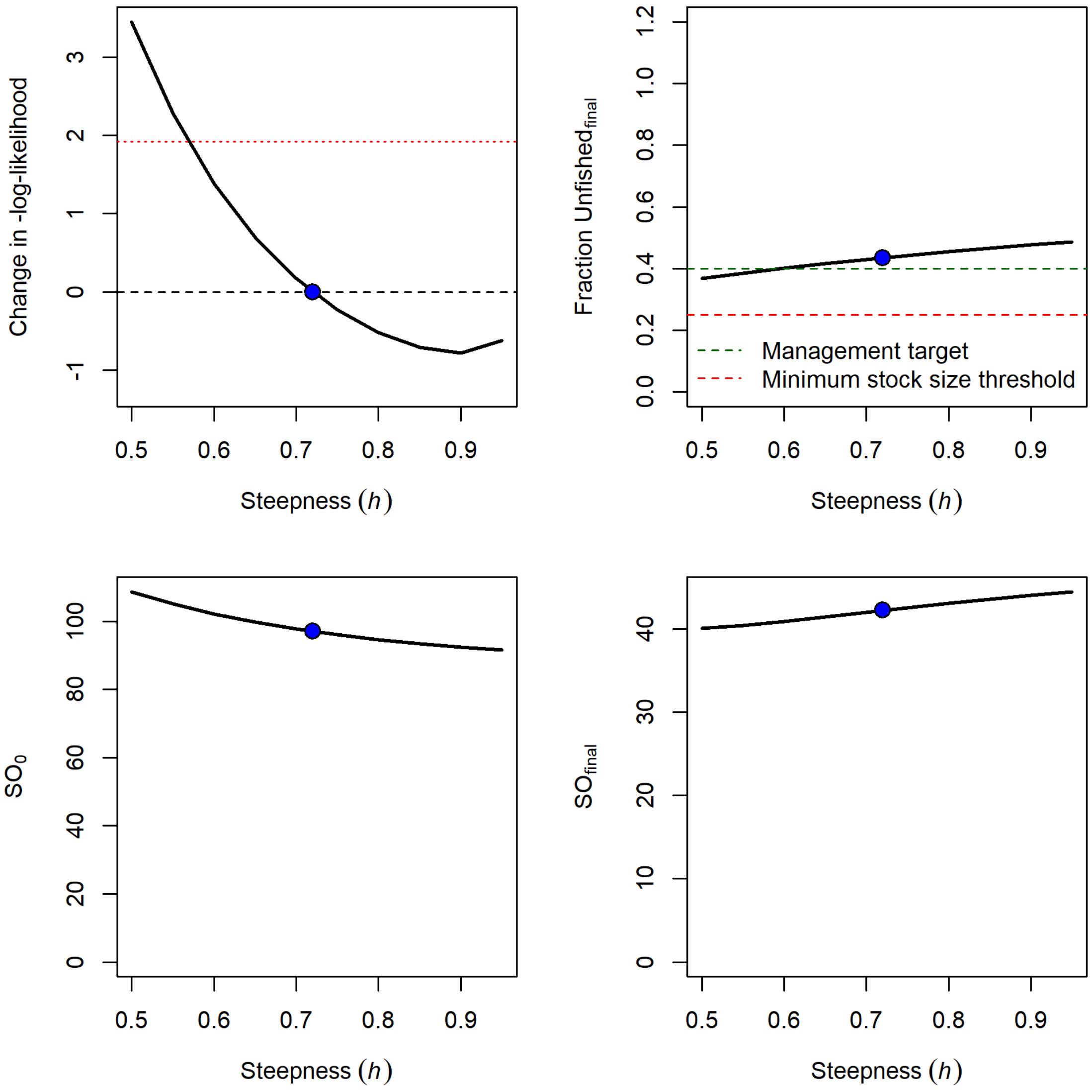


Figure 60: Change in the negative log-likelihood, fraction of unfished spawning output, initial spawning output (in billions of eggs), and final spawning output (in billions of eggs) across a range of steepness values.

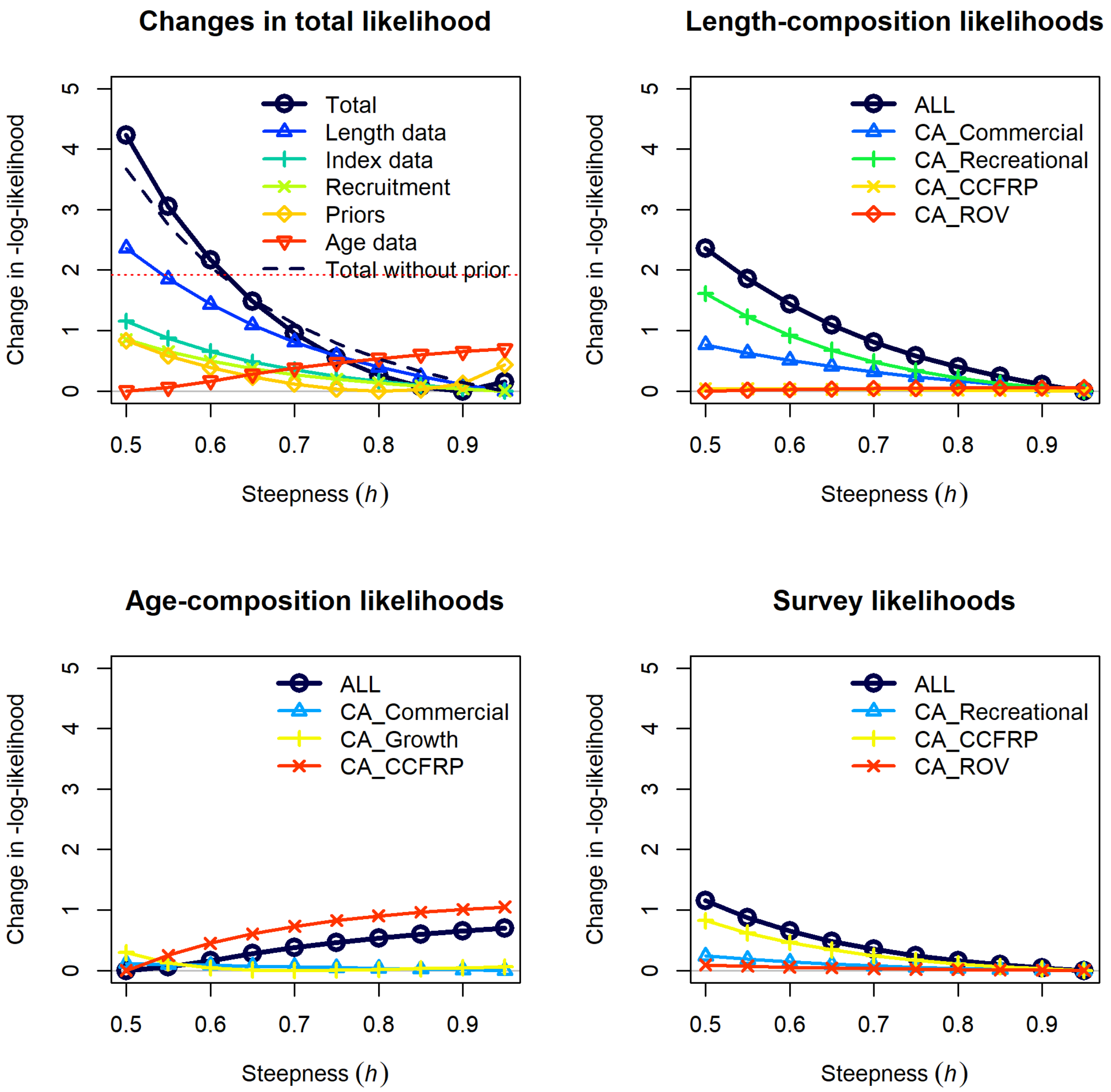


Figure 61: Change in the negative log-likelihood across a range of steepness values.

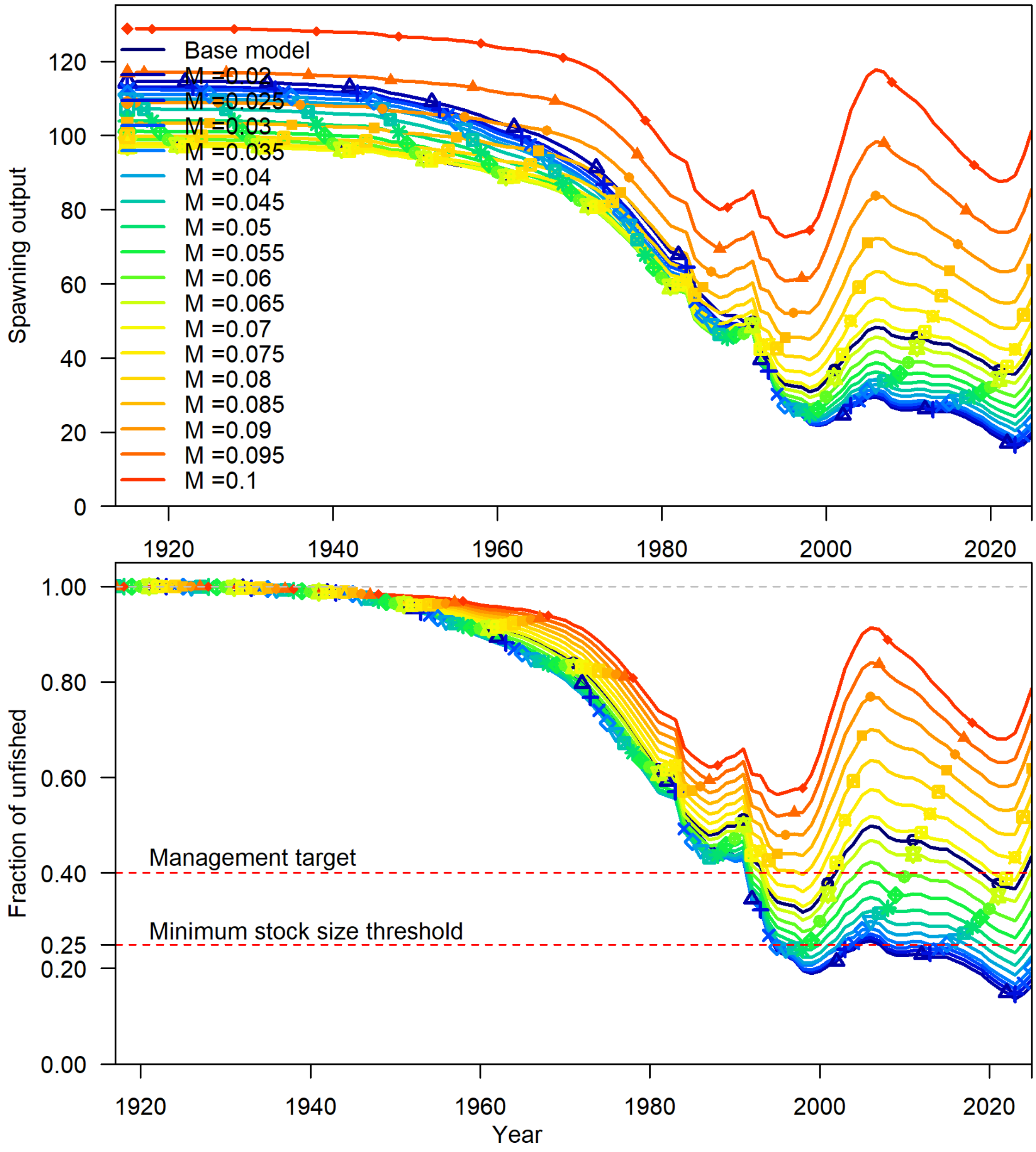


Figure 62: Change in the estimate of spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) across a range of natural mortality (M) values.

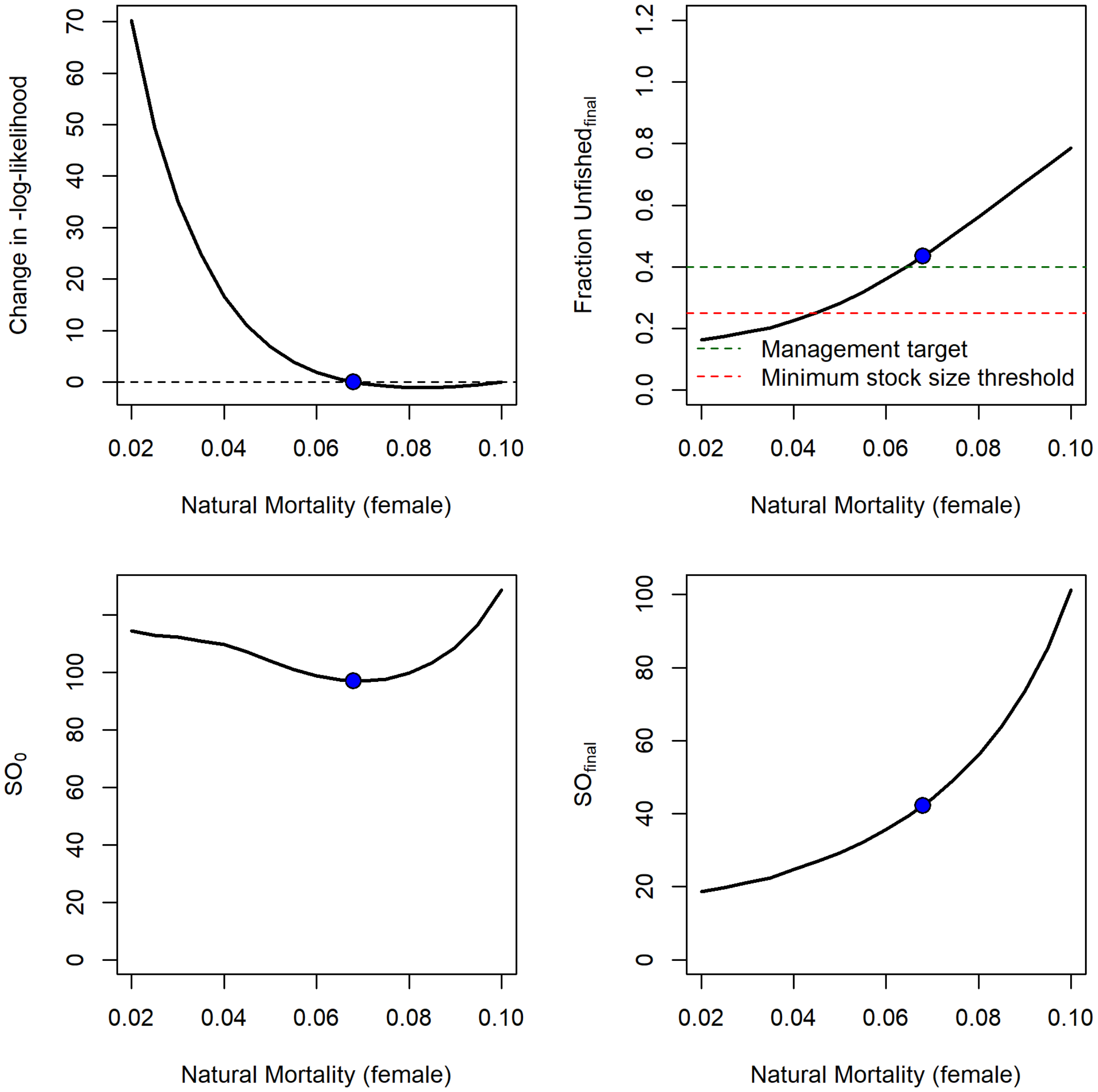


Figure 63: Change in the negative log-likelihood, fraction of unfished spawning output, initial spawning output (in billions of eggs), and final spawning output (in billions of eggs) across a range of natural mortality values.

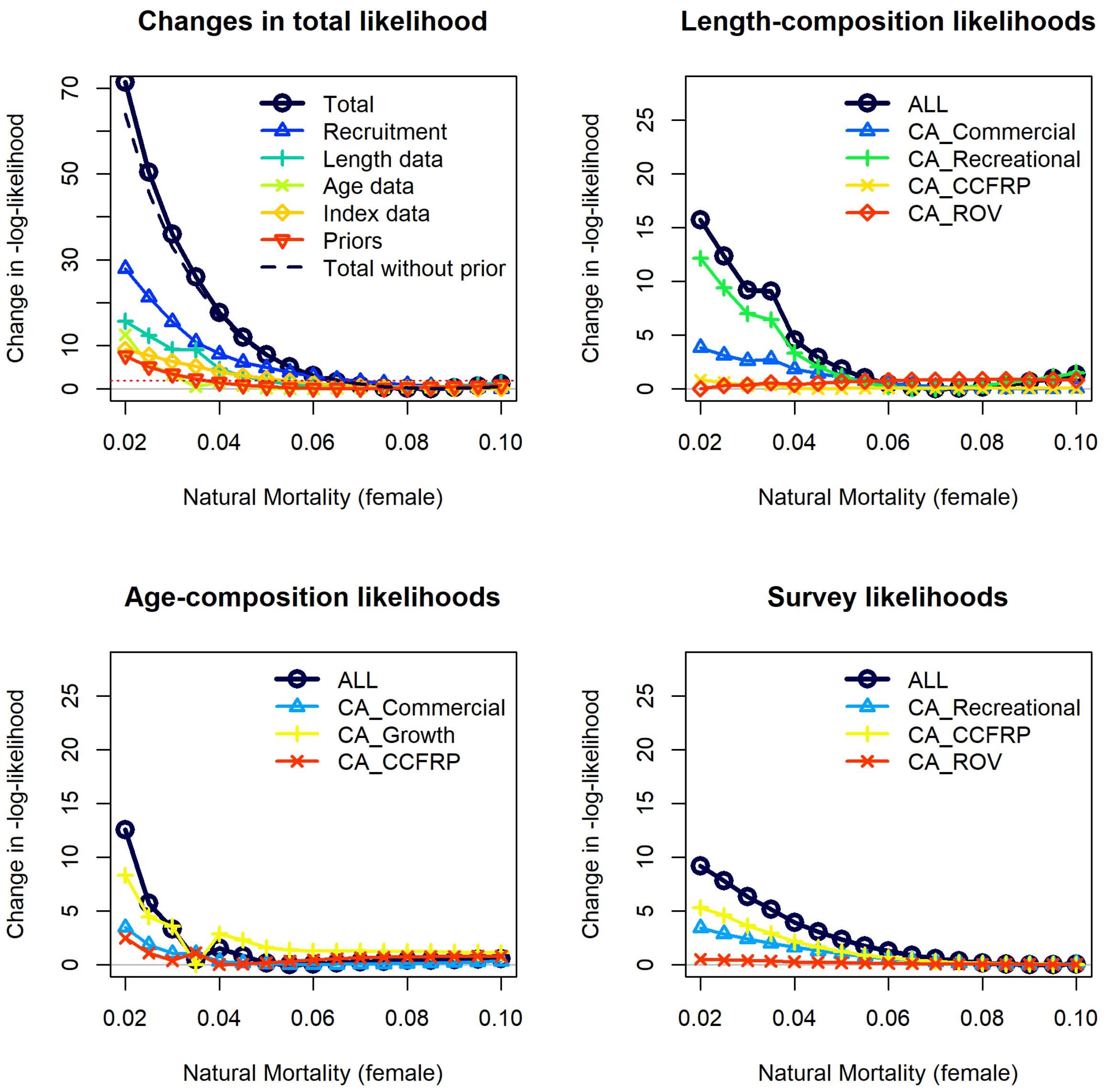
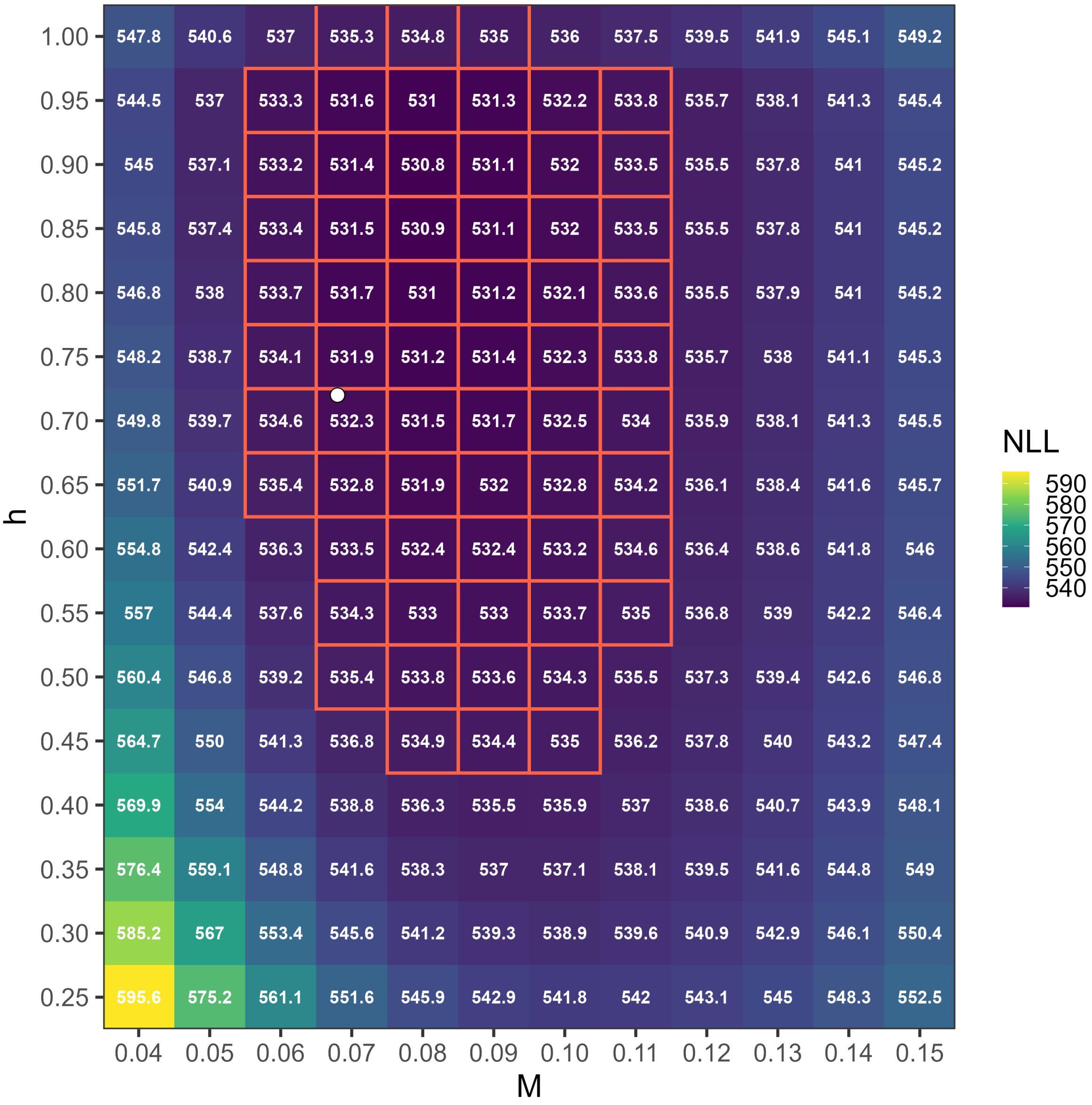


Figure 64: Change in the negative log-likelihood across a range of natural mortality values.



h \ M	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
1.00	547.8	540.6	537	535.3	534.8	535	536	537.5	539.5	541.9	545.1	549.2
0.95	544.5	537	533.3	531.6	531	531.3	532.2	533.8	535.7	538.1	541.3	545.4
0.90	545	537.1	533.2	531.4	530.8	531.1	532	533.5	535.5	537.8	541	545.2
0.85	545.8	537.4	533.4	531.5	530.9	531.1	532	533.5	535.5	537.8	541	545.2
0.80	546.8	538	533.7	531.7	531	531.2	532.1	533.6	535.5	537.9	541	545.2
0.75	548.2	538.7	534.1	531.9	531.2	531.4	532.3	533.8	535.7	538	541.1	545.3
0.70	549.8	539.7	534.6	532.3	531.5	531.7	532.5	534	535.9	538.1	541.3	545.5
0.65	551.7	540.9	535.4	532.8	531.9	532	532.8	534.2	536.1	538.4	541.6	545.7
0.60	554.8	542.4	536.3	533.5	532.4	532.4	533.2	534.6	536.4	538.6	541.8	546
0.55	557	544.4	537.6	534.3	533	533	533.7	535	536.8	539	542.2	546.4
0.50	560.4	546.8	539.2	535.4	533.8	533.6	534.3	535.5	537.3	539.4	542.6	546.8
0.45	564.7	550	541.3	536.8	534.9	534.4	535	536.2	537.8	540	543.2	547.4
0.40	569.9	554	544.2	538.8	536.3	535.5	535.9	537	538.6	540.7	543.9	548.1
0.35	576.4	559.1	548.8	541.6	538.3	537	537.1	538.1	539.5	541.6	544.8	549
0.30	585.2	567	553.4	545.6	541.2	539.3	538.9	539.6	540.9	542.9	546.1	550.4
0.25	595.6	575.2	561.1	551.6	545.9	542.9	541.8	542	543.1	545	548.3	552.5

Figure 65: Bivariate profile of natural mortality (M) and steepness (h) relative with the negative log-likelihood (NLL) value for each model run shown with a white dot indicating the base model values.

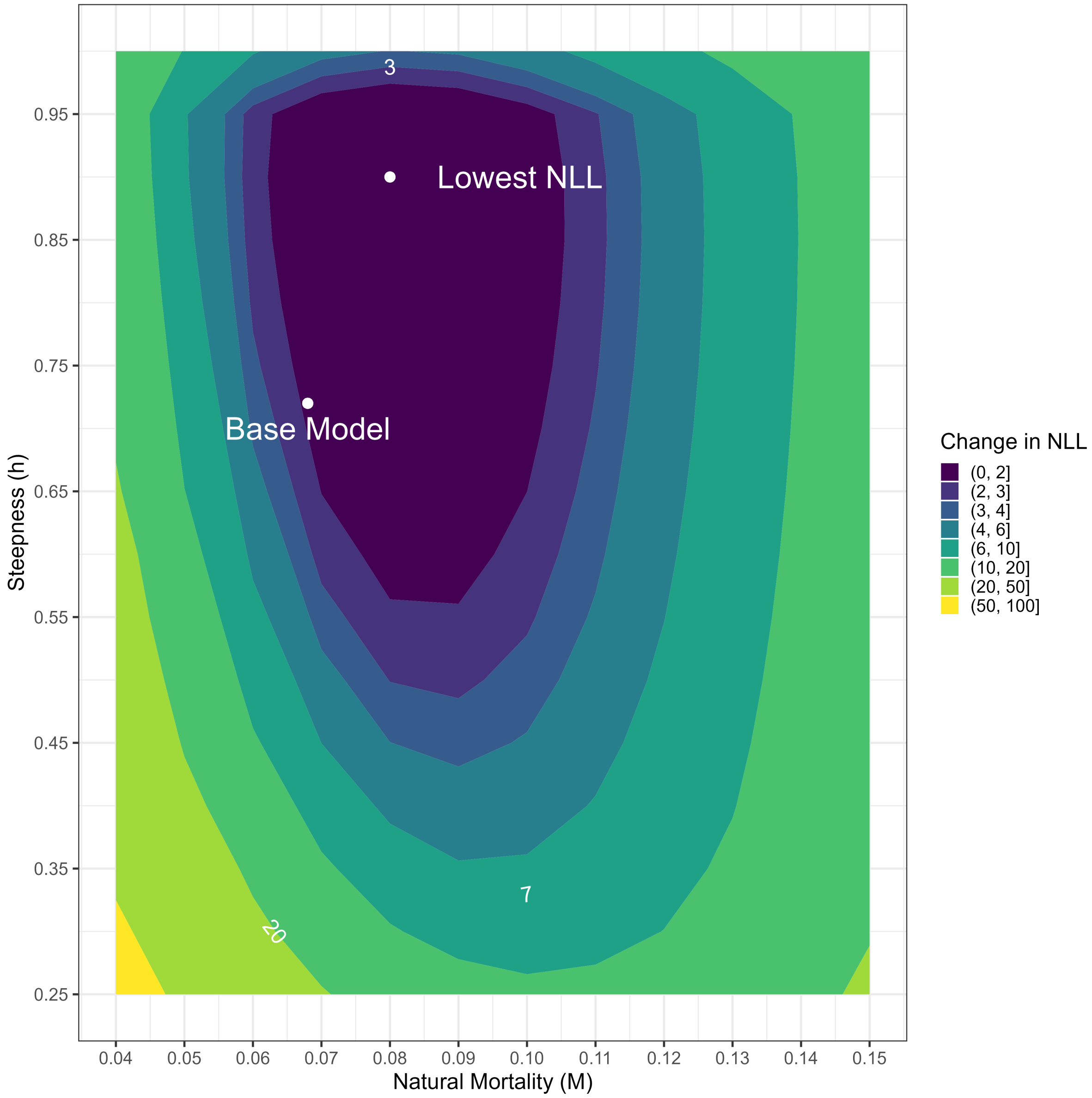


Figure 66: Bivariate profile of natural mortality (M) and steepness (h) relative to the model with the lowest negative log-likelihood (NLL). The model with the lowest NLL has an approximate value of 0.08 for M and 0.9 for h.

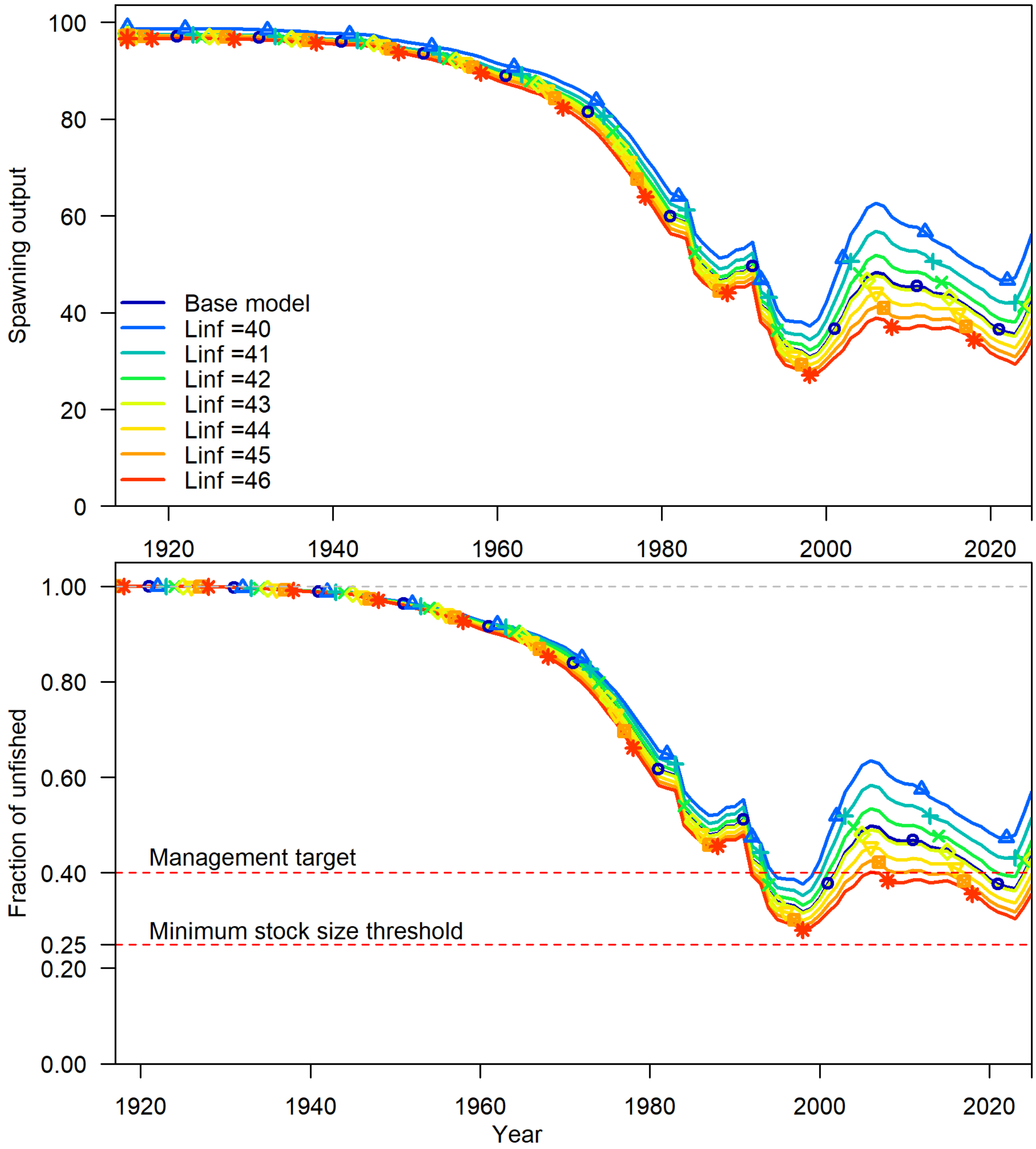


Figure 67: Change in the estimate of spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) across a range of values for asymptotic average length (L_{inf}).

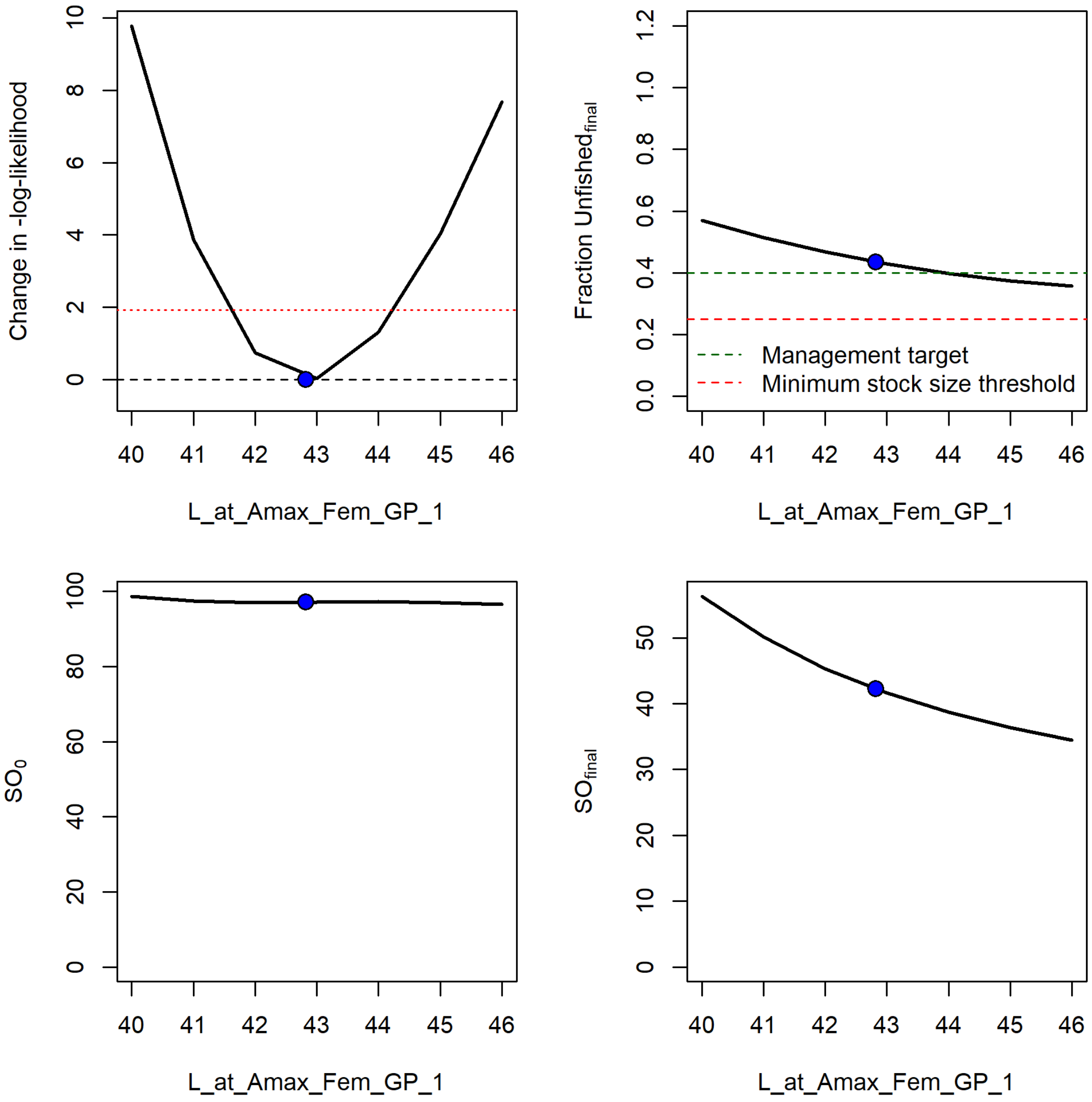


Figure 68: Change in the negative log-likelihood, fraction of unfished spawning output, initial spawning output (in billions of eggs), and final spawning output (in billions of eggs) across a range of values for asymptotic average length.

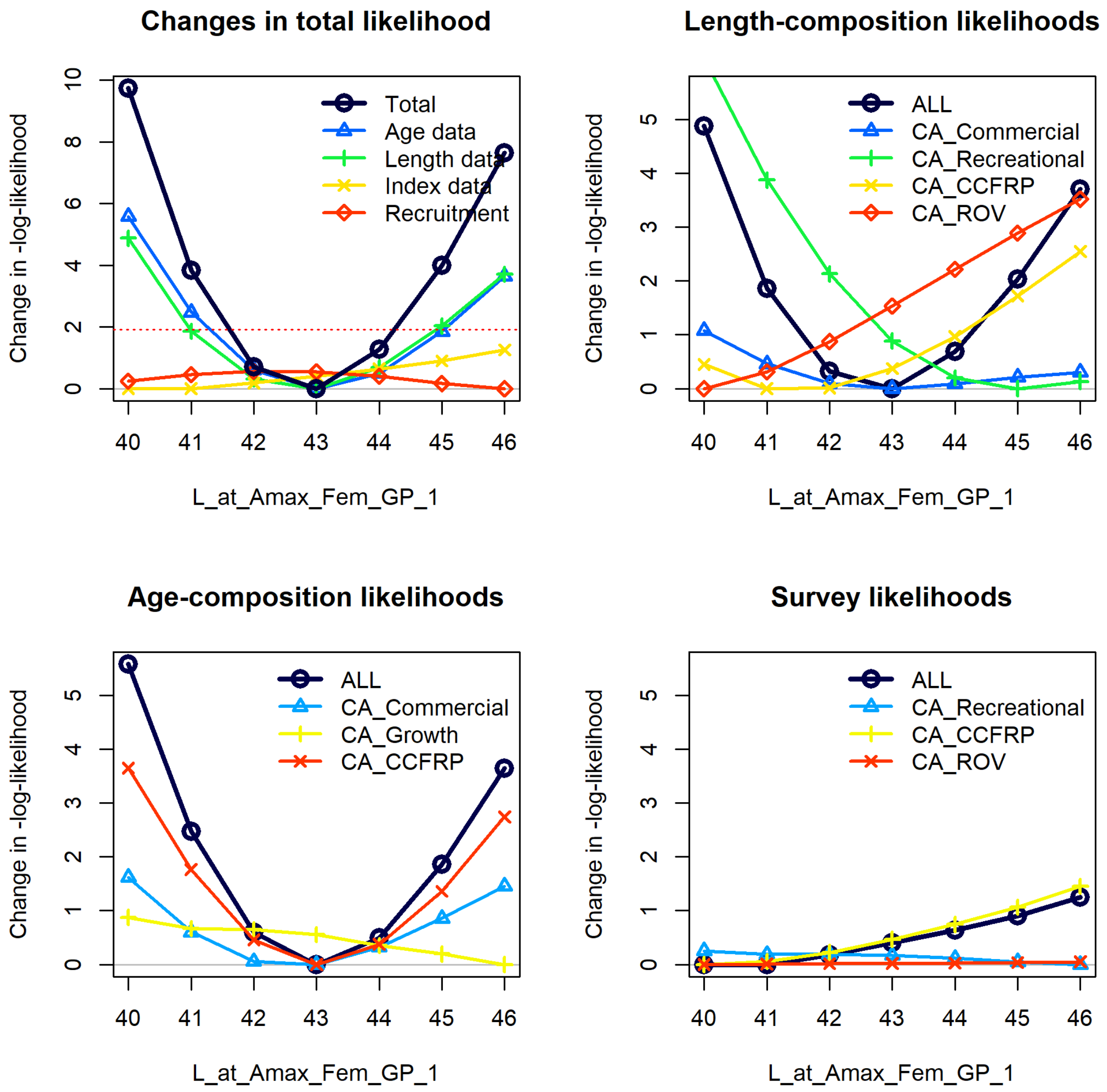


Figure 69: Change in the negative log-likelihood across a range of values for asymptotic average length.

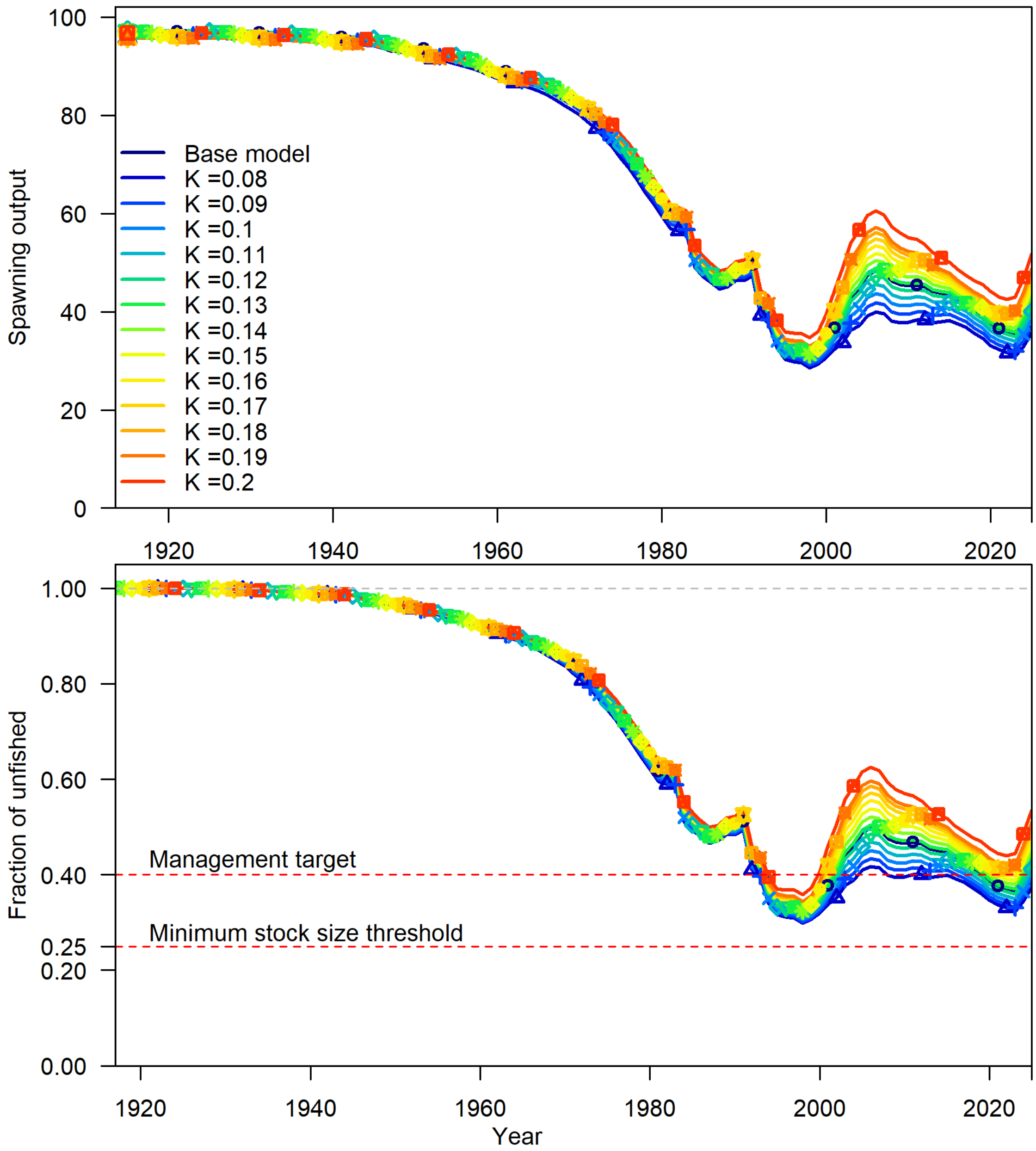


Figure 70: Change in the estimate of spawning output (billions of eggs, top) and spawning output relative to unfished (bottom) across a range of values for growth coefficient K.

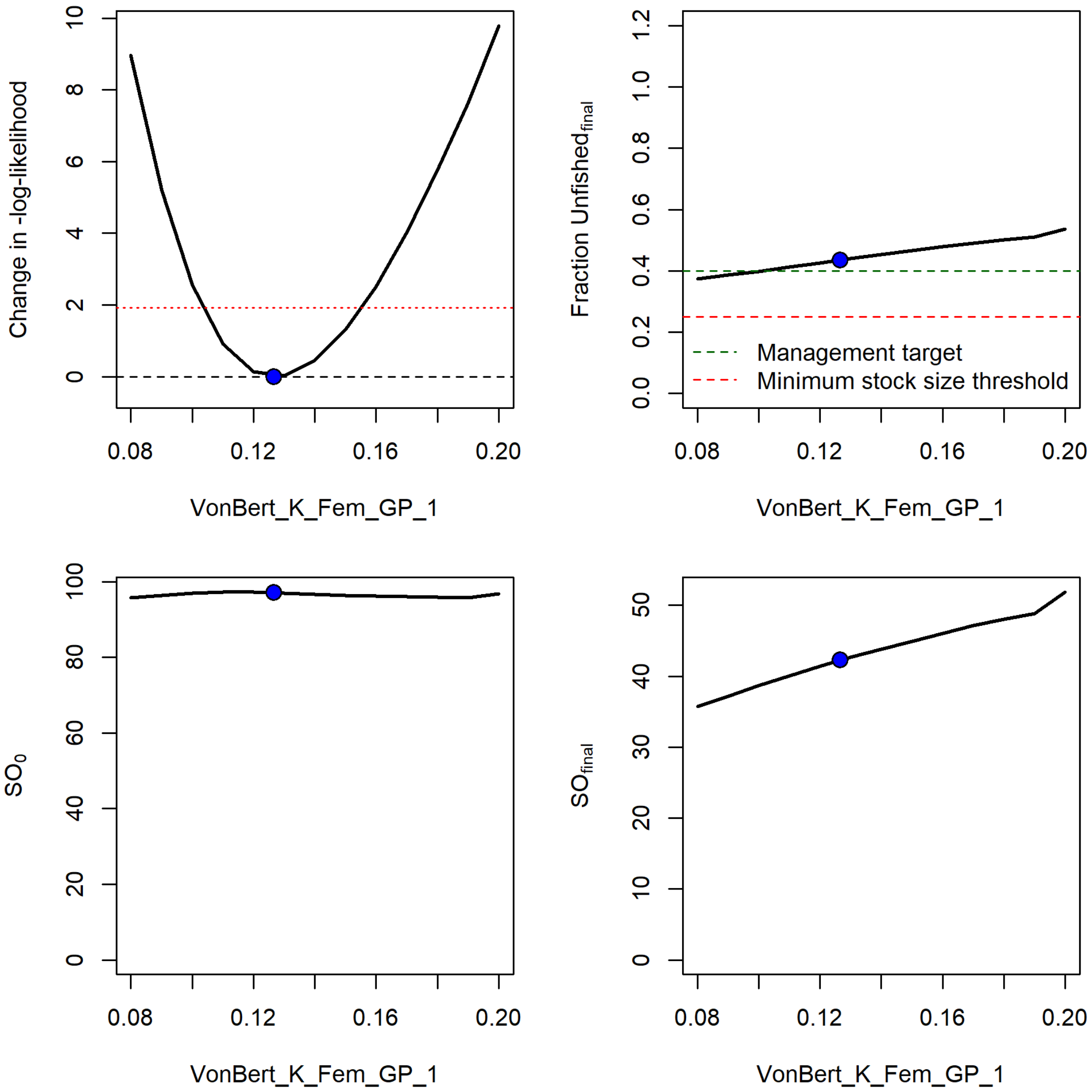


Figure 71: Change in the negative log-likelihood, fraction of unfished spawning output, initial spawning output (in billions of eggs), and final spawning output (in billions of eggs) across a range of values for growth coefficient K.

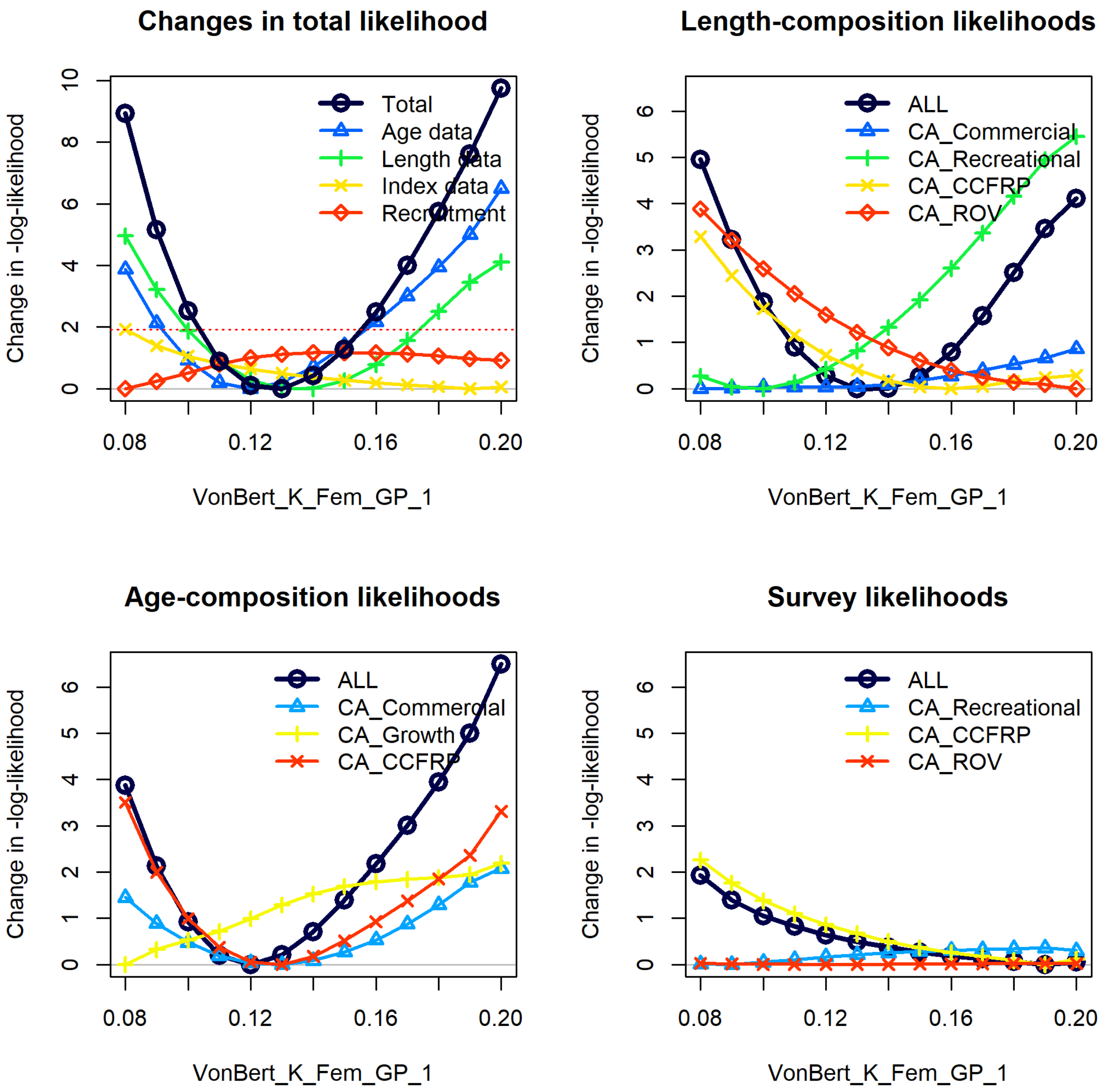


Figure 72: Change in the negative log-likelihood across a range of values for growth coefficient K

9.2.3.3 Sensitivity Analyses

Figure 73: Comparison of various management quantities across all sensitivities. Metrics are terminal year relative spawning output, fishing mortality rate at SPR = 0.5, yield at SPR = 0.5, unfished spawning output, and terminal year spawning output. Bars at the top of the figure represent 95% confidence intervals for the metrics in the base model. See legend for which metric each color represents.

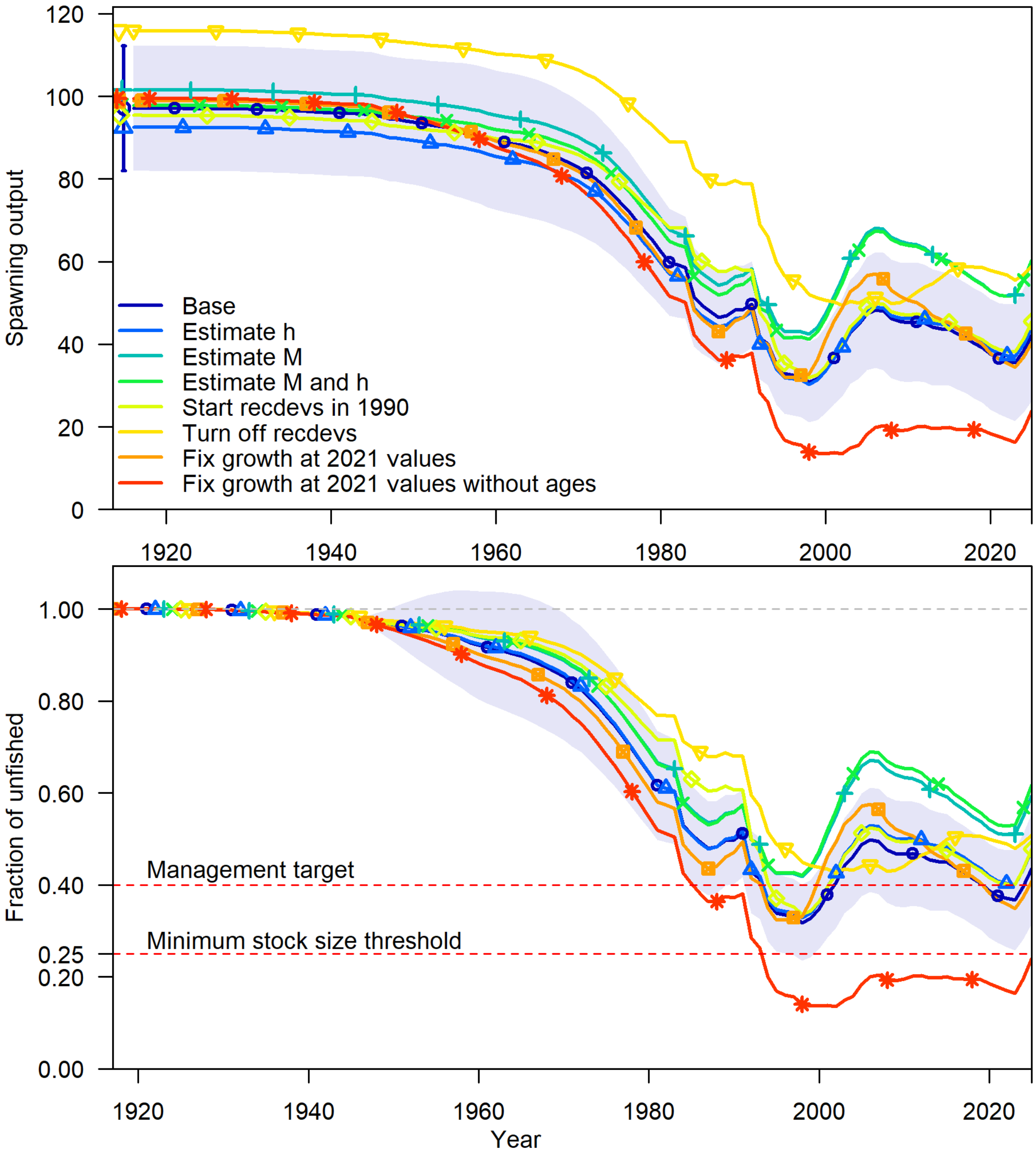


Figure 74: Spawning output (billions of eggs, top), and spawning output relative to unfished (bottom) for productivity related sensitivities.

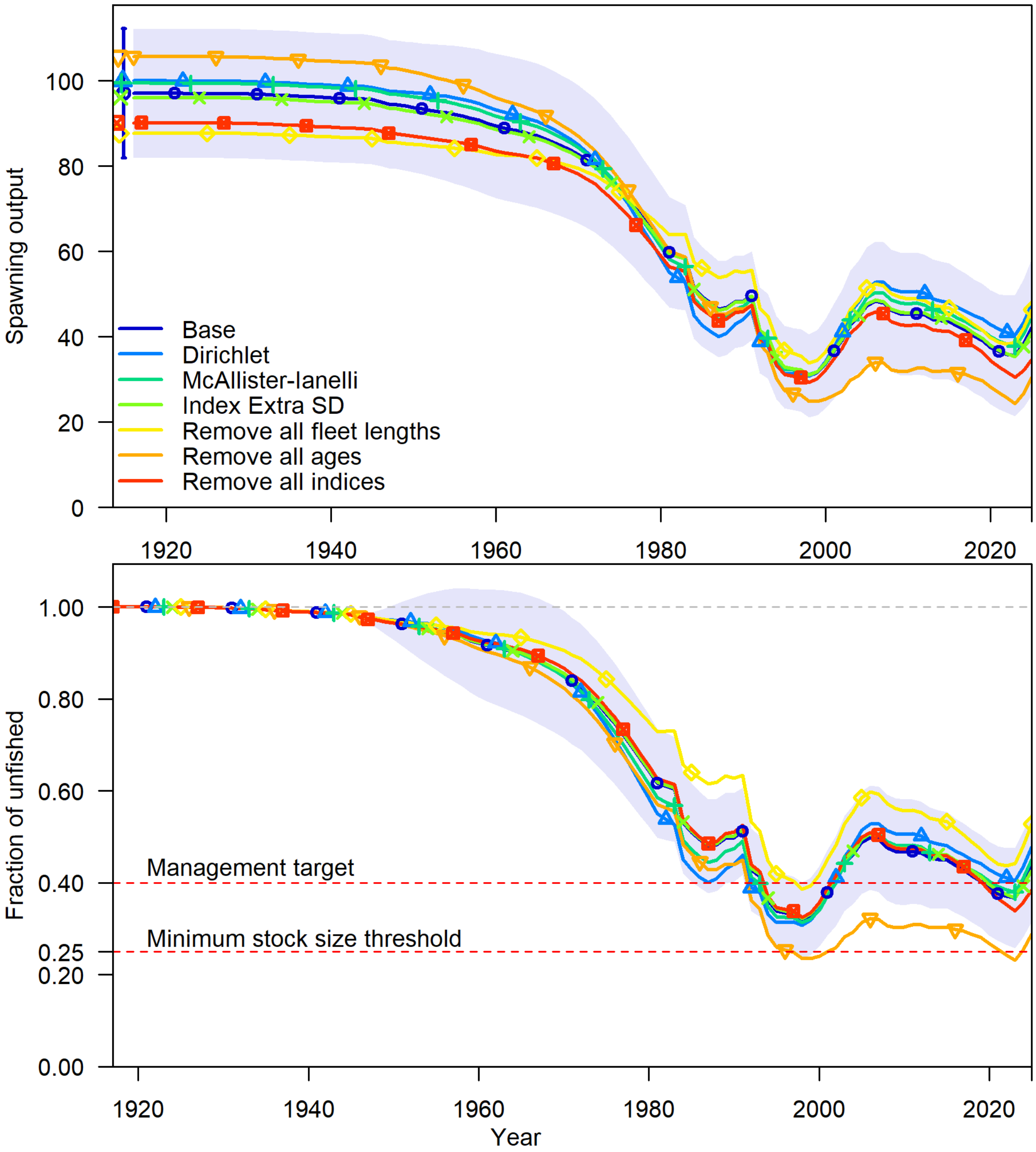


Figure 75: Spawning output (billions of eggs, top), and spawning output relative to unfished (bottom) for sensitivities related to data weighting and contributions.

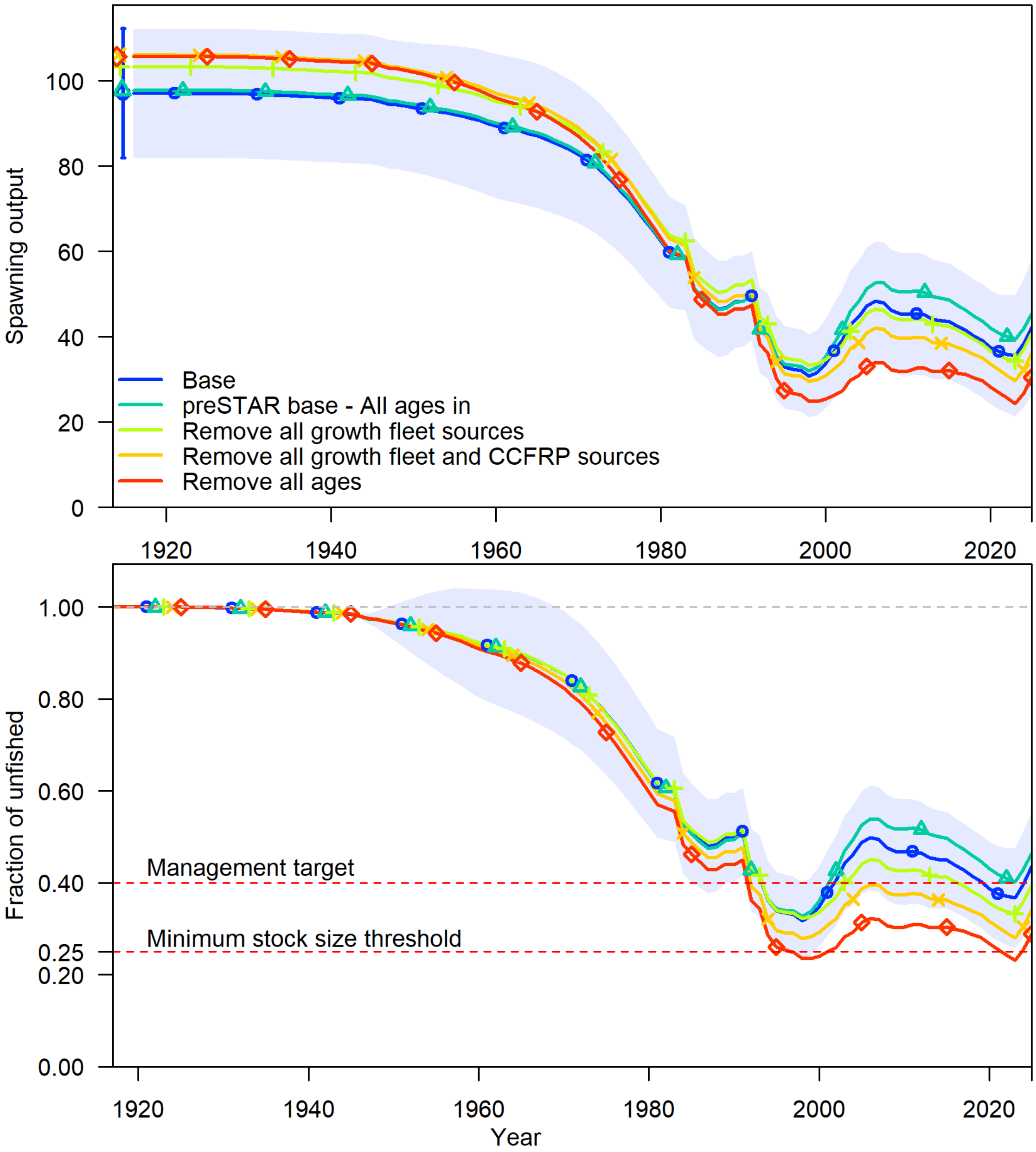


Figure 76: Spawning output (billions of eggs, top), and spawning output relative to unfished (bottom) for sensitivities related to age data contributions.

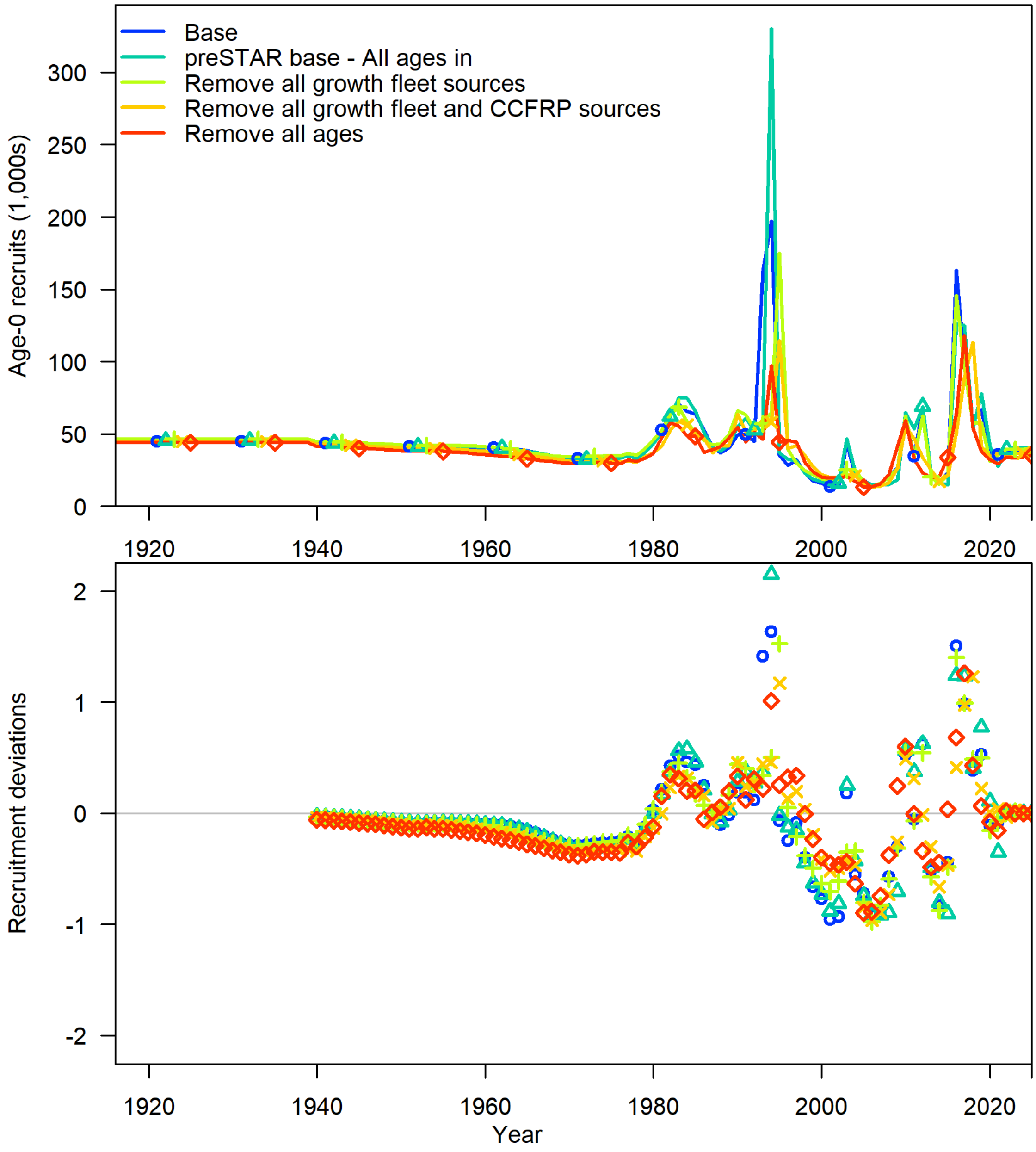


Figure 77: Age-0 recruits (thousands, top), and recruitment deviations (bottom) for sensitivities related to age data contributions.

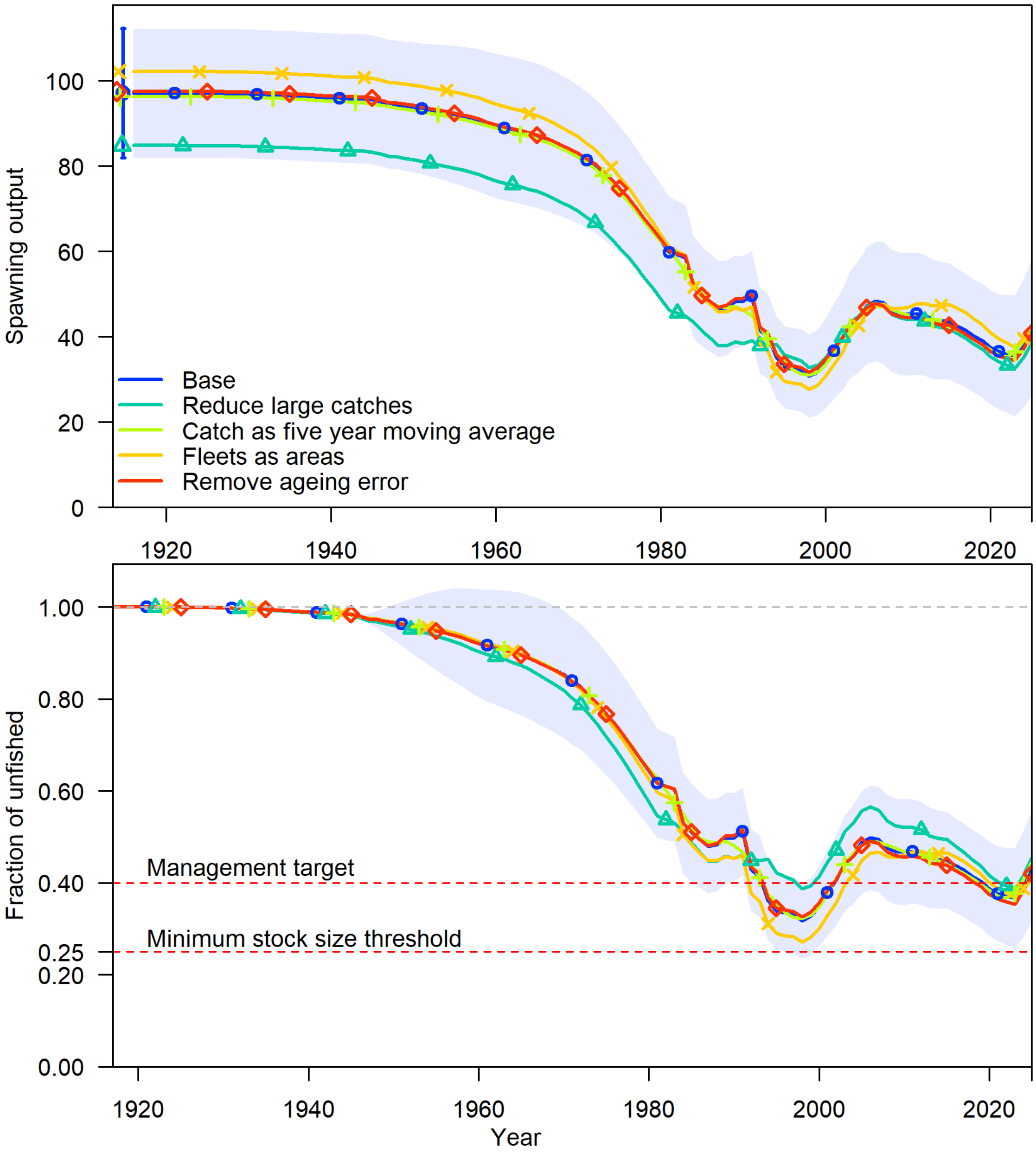


Figure 78: Spawning output (billions of eggs, top), and spawning output relative to unfished (bottom) for data related sensitivities.

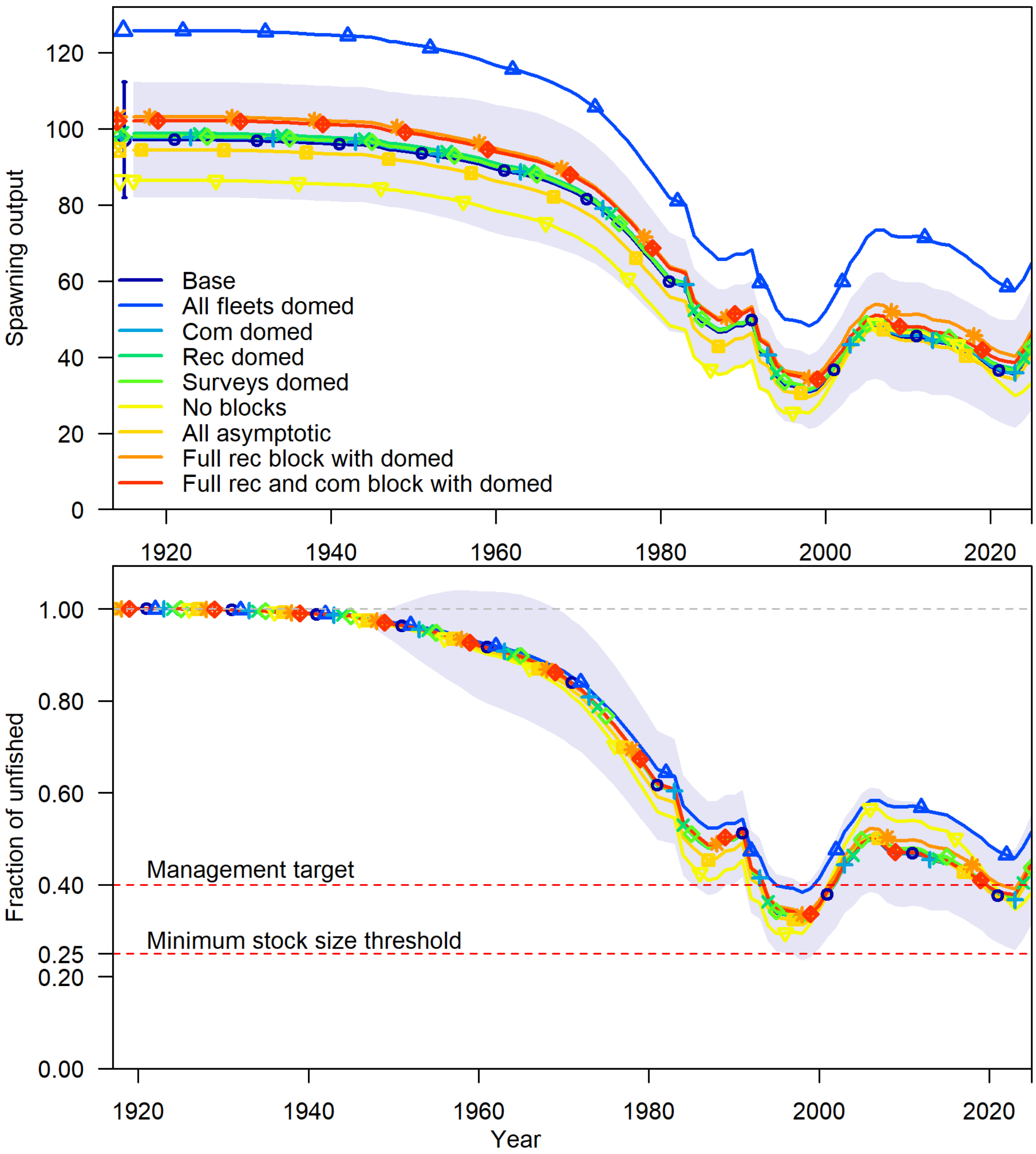


Figure 79: Spawning output (billions of eggs, top), and spawning output relative to unfished (bottom) for selectivity related sensitivities.

9.2.3.4 Historical Analyses

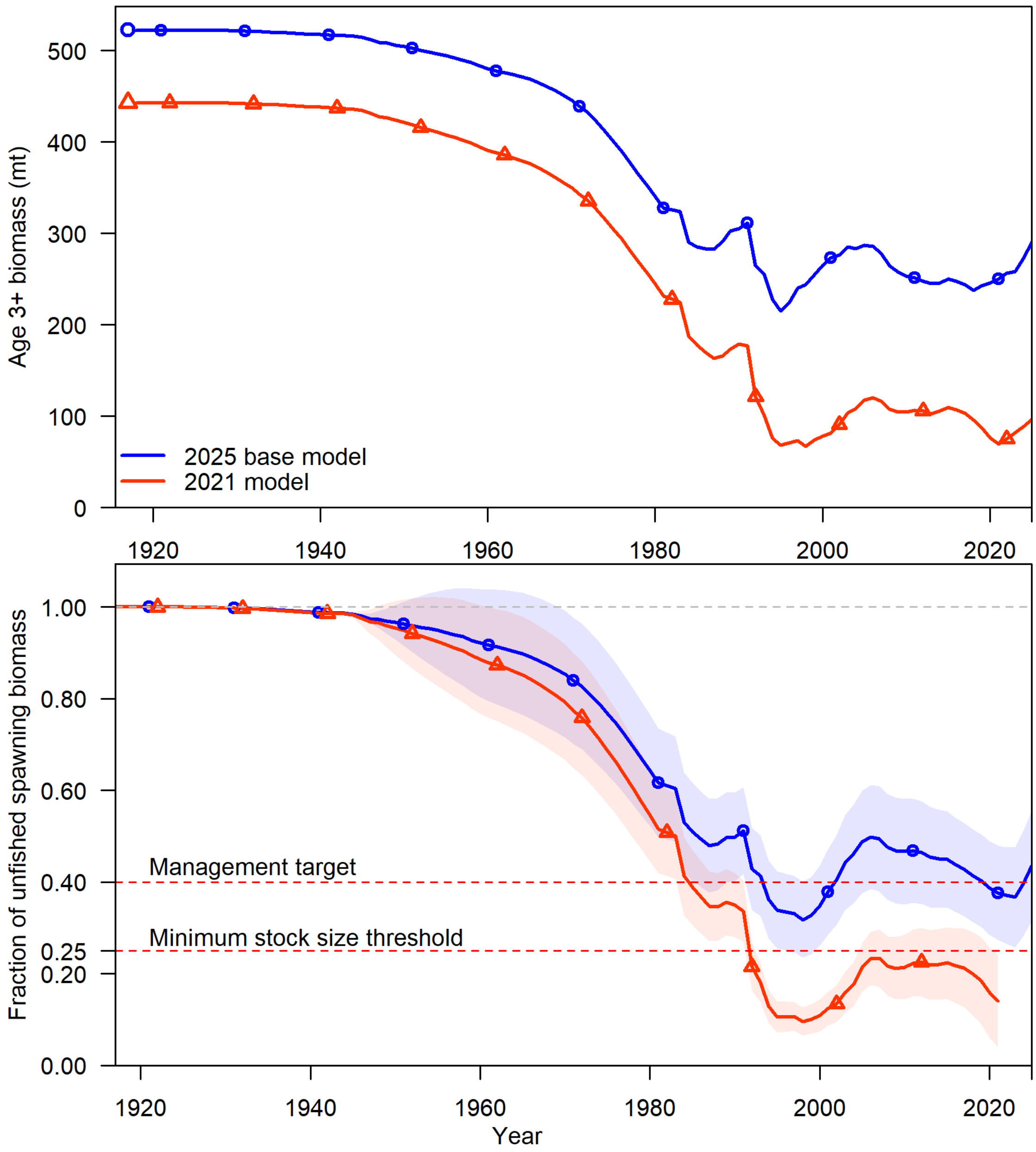


Figure 80: Time series comparisons of summary biomass (in metric tons, top), and spawning output relative to unfished (bottom) with 95% confidence interval from the base model of the 2021 stock assessment and the 2025 base model.

9.3 Management

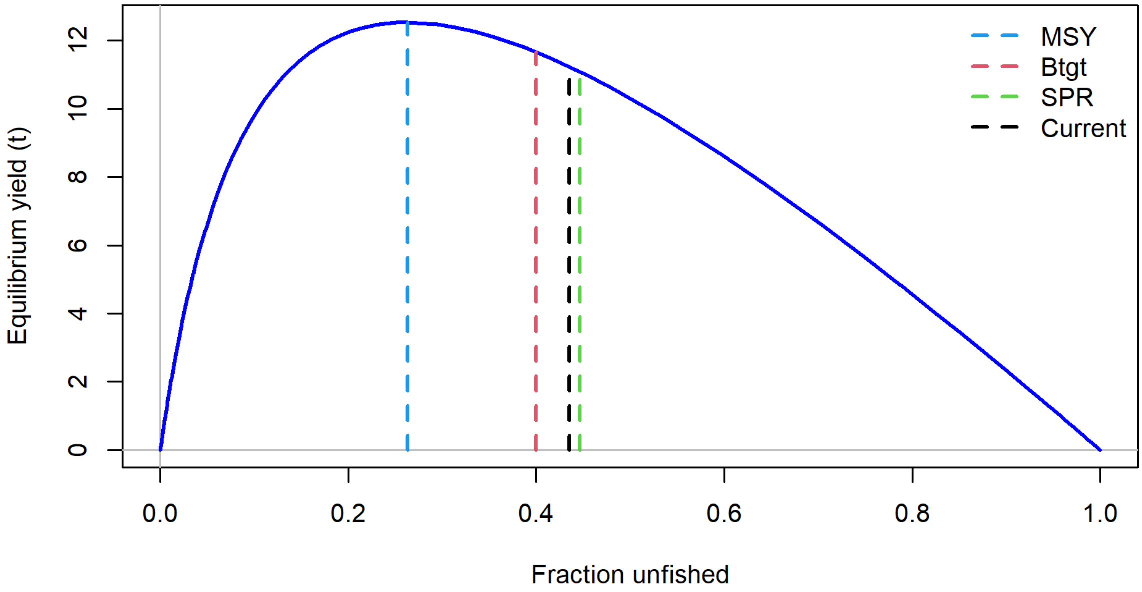


Figure 81: Estimated yield curve with reference points for the base model with yield in mt.

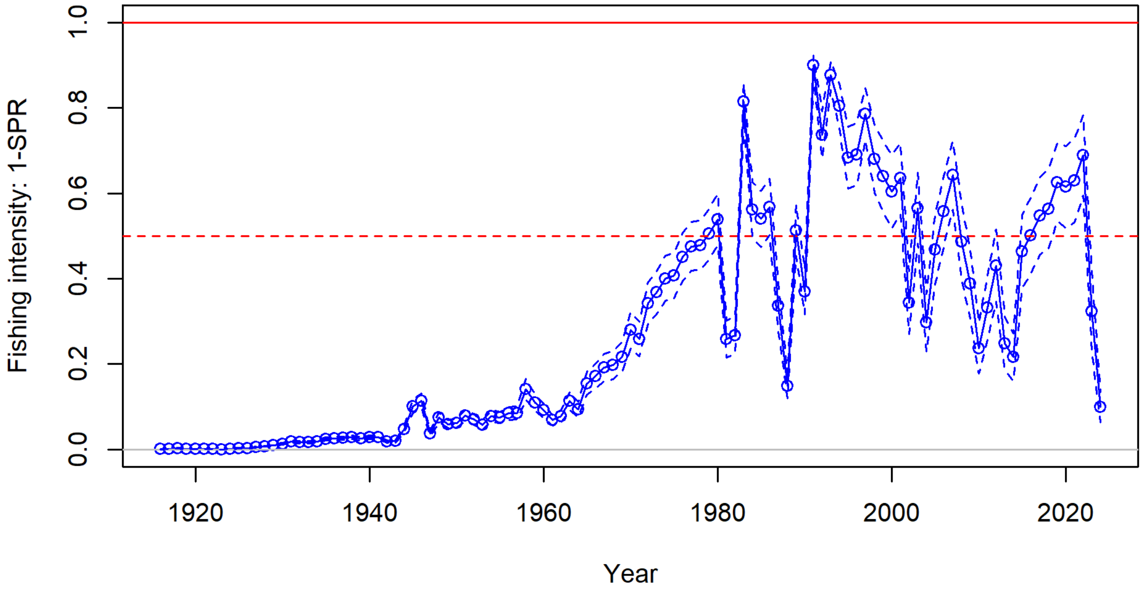


Figure 82: Estimated time series of fishing intensity for the base model with 95% asymptotic confidence intervals. The horizontal line is at the fishing intensity target: 1 - 0.5 = 0.5

10 Appendix A: Indices of Abundances

10.1 CDFW CRFS Private/Rental Boat Dockside Survey

Catch and effort data from the CRFS dockside sampling of private/rental boats between 2004 and 2023 were provided by CDFW. The "i" sample files were used to re-create interview or trip-level data from 2004 to 2014. The CRFS program began producing estimates in a different, annual format in later years and data in this format was used from 2015 to 2023. The data included catch by species, number of anglers contributing to the catch, angler-reported area of fishing, gear, county, port, interview site, year, month, and CRFS district. The catch included the number of fish observed by the CRFS sampler, the number of unobserved retained and released fish reported by the angler.

Quillback rockfish are a relatively rare rockfish species in California and therefore the large majority of recreational trips catch no quillback rockfish. The STAT used many techniques to filter the total private/rental boat dataset to focus on trips that did catch, or had potential to catch, quillback rockfish. Records were limited to the primary private and rental boats public-access sites, PR1 sites, which encompass over 90 percent of the total private boat effort. PR2 sites are more commonly associated with trips targeting highly migratory species and would be unlikely to include quillback rockfish. Given that quillback rockfish are relatively rare, they are lesser known to recreational anglers and may be misidentified. The STAT elected to use only catch data that was observed by a CRFS sampler. Unobserved retained catches and releases were not included.

The remaining data filters are detailed in Table A-1. First, CRFS districts 1 and 2 representing southern California were removed. Data from 2020 was removed due to changes in sampling protocol during the COVID-19 response. Samplers were prohibited from working for a period of the year and when sampling resumed, often could not approach anglers closely enough to identify the catch. Data from 2023 was removed given restrictions on quillback rockfish catch implemented in that year. Only trips occurring in ocean areas (not inland bays and estuaries) and trips using hook and line or troll gear as the primary gear type were retained. Trips during January through March were removed because those months are closed to the fishery in central and northern California. CRFS sample sites where five or fewer quillback rockfish were caught were excluded.

The final step in data filtering further limits the dataset to trips that either caught a quillback rockfish or were likely to catch a quillback rockfish, given associations between quillback rockfish and other species observed in the recreational catch. The method developed by Stephens and MacCall (2004) predicts the probability of catching a target species by constructing a logistic model predicting the target presence based on the presence and absence of other species in the catch. Species that are rarely encountered will provide little information about the likelihood of catching a quillback rockfish. Therefore, we removed species comprising less than 0.1% of the records as well as species that never co-occurred with quillback rockfish. Pacific bonito and Pacific sardine were the only species that never co-occurred with quillback rockfish and represented greater than 0.1% of the records. Catch of the remaining species in a given trip was coded as presence/absence (1/0) and treated as a categorical variable in the Stephens-MacCall logistic regression analysis.

The Stephens-MacCall logistic regression was fit to the remaining set of 52 indicator species (Figure A-1). The top five species with high probability of co-occurrence with quillback rockfish were tiger rockfish, copper rockfish, canary rockfish, lingcod, and rock sole. The species with the lowest probability of co-occurrence were kelp rockfish, starry flounder, California halibut, ocean whitefish, and treefish. These species are not commonly caught during the same trip as quillback rockfish, presumably due to different habitat associations and fishing techniques. The Area Under the Characteristic curve (AUC) for this model is 0.88, a significant improvement over a random classifier (AUC = 0.5). AUC represents the probability that a randomly chosen positive trip would be assigned a higher ranked prediction by the GLM than a randomly chosen trip that did not catch a quillback rockfish. Stephens and MacCall (2004) proposed ignoring trips below a threshold probability, based on a criterion of balancing the number of false positives and false negatives. False positives (FP) are trips that are predicted to catch a quillback rockfish based on the species composition of the catch, but did not. False negatives (FN) are trips that were not predicted to catch a quillback rockfish, given the catch composition, but caught at least one. For the CRFS private/rental boat data set, the threshold probability (0.186) that balances FP and FN excluded 117,458 trips that did not catch a quillback rockfish, and 2,681 trips that caught a quillback rockfish. Given the low prevalence of quillback rockfish in the original data, we retained the false negative trips, assuming that catching a quillback rockfish indicates that a non-negligible fraction of the fishing effort occurred in appropriate habitat. Only "true negatives" based on the baseline threshold (the 117,458 trips that neither caught quillback rockfish, nor were predicted to catch them by the model) were excluded from the index standardization. This final filtering step resulted in a data set of 6,527 samples or trips with almost 60% catching one or more quillback rockfish (Table A-1).

We modeled quillback rockfish catch with an effort offset of angler trips using the R package sdmTMB. Covariates considered included year, month, 3-month time period (wave), and district. Sparse quillback rockfish in the data set meant that many months had no positive quillback rockfish samples and required that we increase the commonly used 2-month wave to three months to improve the distribution of positive samples. There were also several years in which no quillback rockfish were observed in district 3. Several district 3 sites were already removed during the filtering process. Therefore, we included the remaining district 3 sites into district 4. Exploration of alternative negative binomial models showed the full model including all covariates and a year:district interaction had the lowest AIC and log-likelihood but was also equal in these scores to a model excluding wave (Table A-2).

A delta-lognormal distribution was chosen to meet modelling assumptions. However, models with a year-district interactions failed diagnostics and given that patterns among the districts are similar (Figure A-2), we excluded the interaction from the final model which included year, district, and wave.

The final model shows a peak index value in 2006 with a declining trend thereafter but little contrast in the time series overall (Figure A-3) and this trend is also reflected in average CPUE over time. The Q-Q plot indicates a reasonable fit (Figure A-4). Additionally, data simulated by the model produces a proportion of zeroes or samples with no quillback rockfish of 0.413 while the actual proportion of zeroes in the filtered data is 0.411. Final index values are provided in Table A-3.

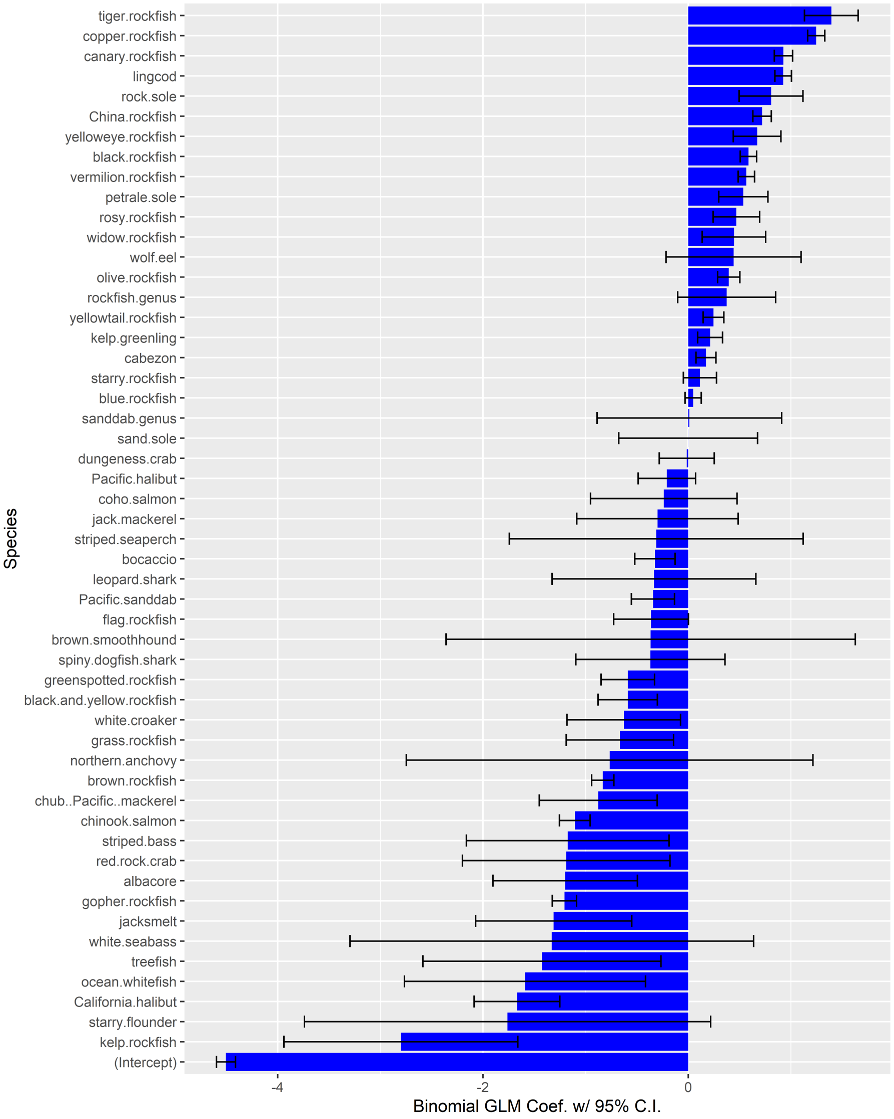


Figure A-1: Species coefficients (blue bars) from the binomial GLM for presence/absence of quillback rockfish in the private/rental boat data. Horizontal black lines are 95% confidence intervals.

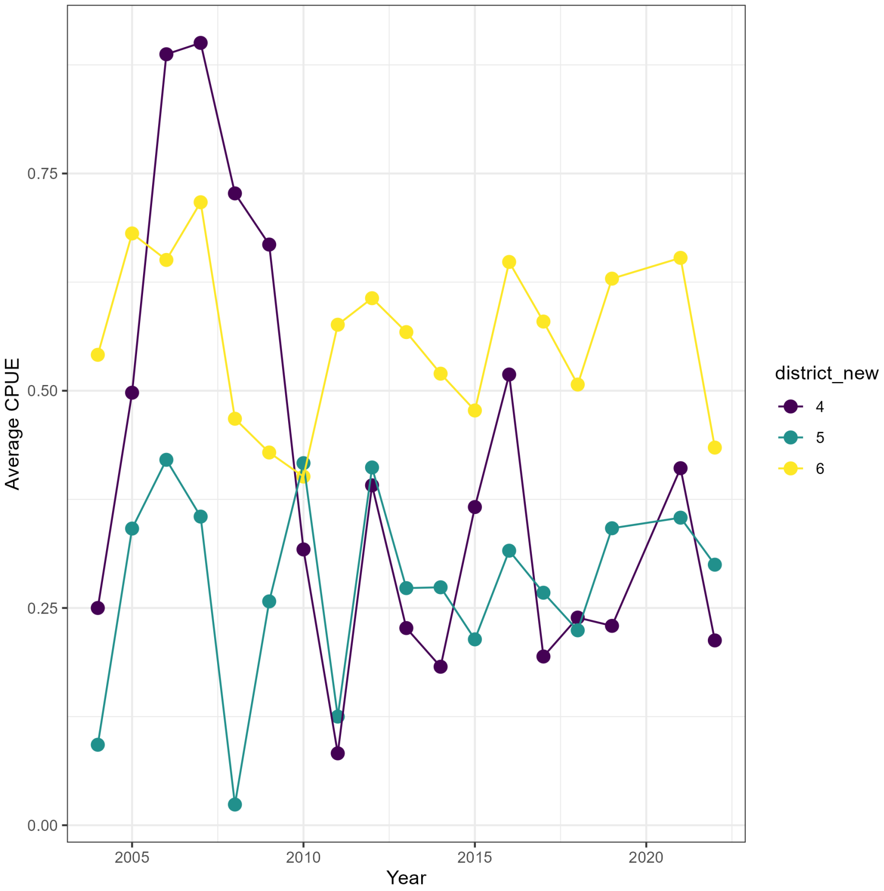


Figure A-2: Average CPUE by CRFS district prior to standardization.

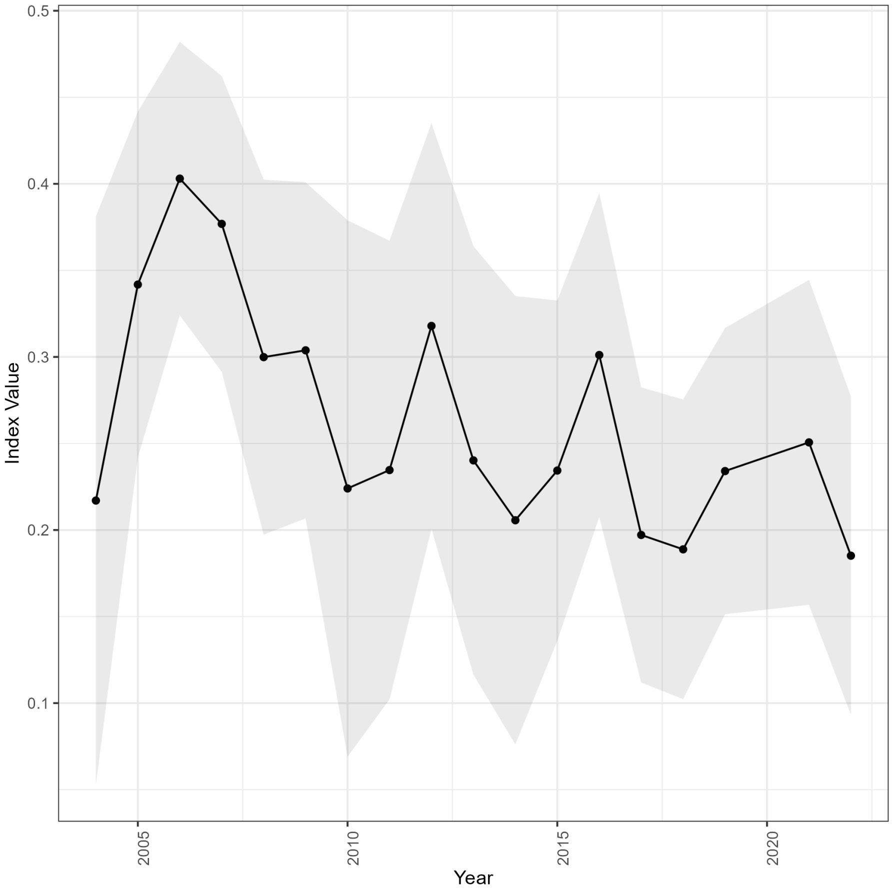


Figure A-3: Index for the CRFS dockside private/rental boat survey.

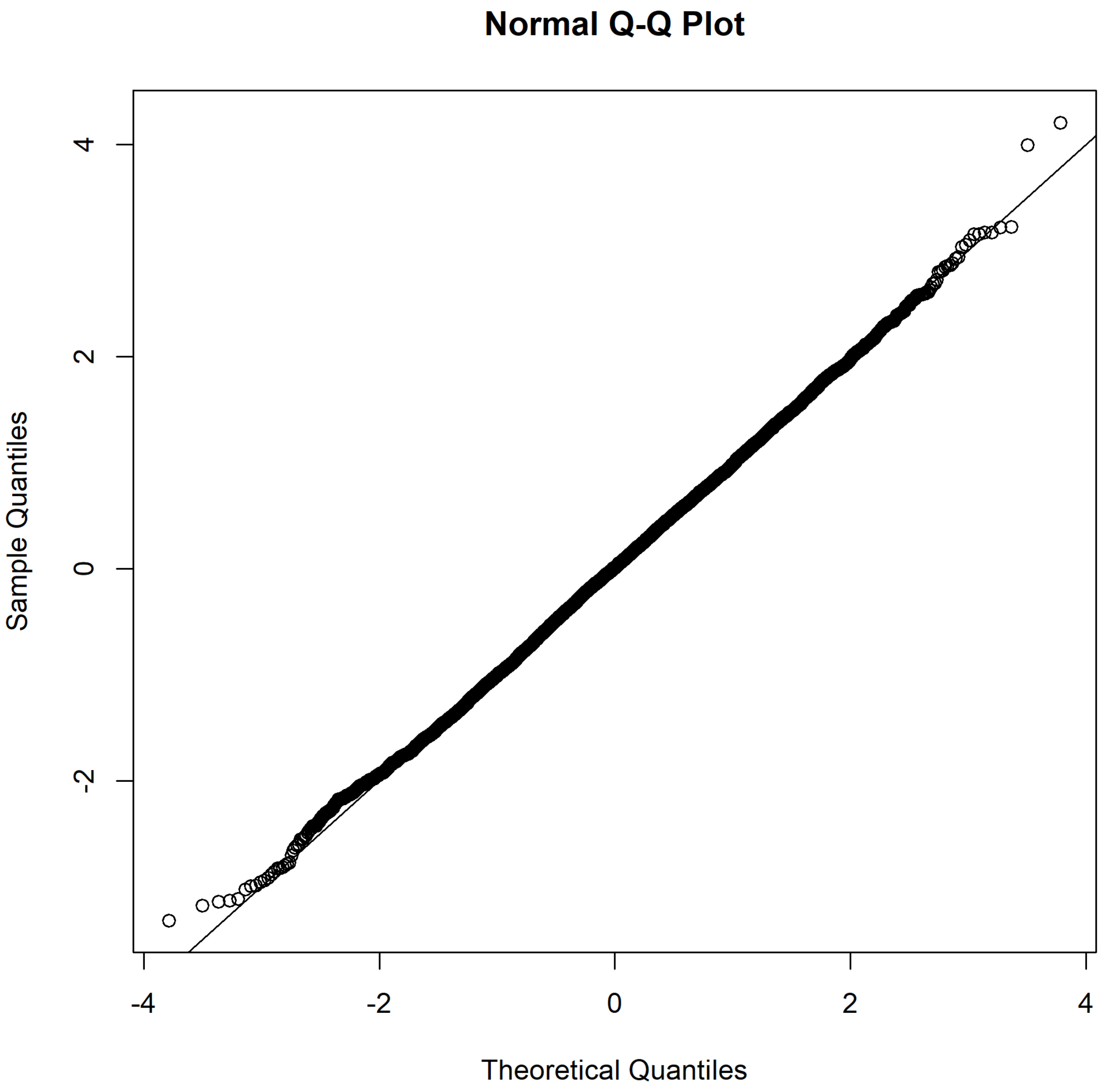


Figure A-4: Q-Q plot for the CRFS dockside private/rental boat survey.

Table A-1: Data filtering steps for the CRFS dockside private/rental boat survey.

Filter	Description	Samples	Positive Samples
District	District > 2	175272	4164
Year	Remove 2020 due to COVID & 2023 due to rule change	167001	3995
Interview Site	Remove Sites <=5 Quillback, Add Remaining SLO County Sites to District 4	138483	3982
Areas fished	Retain trips occuring in ocean areas	132408	3982
Gear	Retain trips with primary gear of hook-and-line or troll	124190	3846
Months fished	Remove Jan-March; recreational rockfish fishery closed	123984	3846
Stephens-MacCall	Remove predicted false negatives	6527	3846

Table A-2: Model selection for the CRFS dockside private/rental boat survey. The final model is bolded in the table. A plus sign indicates the covariate included and a minus sign indicates it is excluded.

District	Month	Wave3	Year	Year:District	df	Δ AIC
+	+	−	+	+	63	0.0
+	+	+	+	+	63	0.0
+	−	+	+	+	57	10.7
+	−	−	+	+	55	55.1
+	+	−	+	−	29	135.4
+	+	+	+	−	29	135.4
+	**−**	**+**	**+**	**−**	**23**	**155.5**
+	−	−	+	−	21	199.6
−	+	−	+	−	27	318.1
−	+	+	+	−	27	318.1
−	−	+	+	−	21	352.6
−	−	−	+	−	19	399.4

Table A-3: Estimated relative index of abundance for the CRFS dockside private/rental boat survey.

Year	Estimate	logSE
2004	0.217	0.164
2005	0.342	0.100
2006	0.403	0.079
2007	0.377	0.085
2008	0.300	0.103
2009	0.304	0.097
2010	0.224	0.155
2011	0.235	0.132
2012	0.318	0.117
2013	0.240	0.124
2014	0.206	0.129
2015	0.234	0.098
2016	0.301	0.093
2017	0.197	0.085
2018	0.189	0.087
2019	0.234	0.083
2021	0.251	0.094
2022	0.185	0.092

10.2 CDFW ROV

Remotely operated vehicle (ROV) surveys have been used to monitor California's network of MPAs in mid-depth habitats since 2004. The surveys are a collaboration between CDFW and Marine Applied Research and Exploration (MARE). A full description of survey methods is available in (Lauermann et al. 2017). Briefly, sampling has been conducted at fixed sites along the entire California coast (Figure A-5) with 500-meter transects conducted within rocky reef habitat inside and outside each MPA (Figure A-6). Available data include counts of fish by species, stereo fish lengths, and a variety of characteristics of the transect location (Table A-4).

The full dataset was filtered for data quality and representativeness of quillback rockfish habitat (Table A-5). The filtered dataset consists of 967 transects conducted across 34 locations (Table A-6). While surveys have been conducted since 2004, it has only been possible to conduct surveys at a few locations each year. Efforts to systematically select survey locations representative of the full California coastline began in 2014 and a full complement of these locations has taken three years to complete. Therefore, locations monitored in 2014-2016 and 2019-2021 are considered to represent complete surveys and were analyzed as two super years centered on the mid-point of each period (2015 and 2020).

Counts of quillback rockfish on each transect were modeled using a negative binomial generalized linear mixed model with the R package glmerMod. While each transect is 500 m in length, the total area visible in the collected video is variable. Therefore, an effort offset representing the log of this area, termed Usable-Area-Fish, was used. Potential covariates for inclusion in the model were evaluated based on their significance in the full model including all variables as well as their correlations among each other. Based on these criteria, temperature, proportion hard bottom, years since protection in an MPA, distance to port, and backsides were not included. Backsides is a variable indicating video footage looking into open water as the ROV travels along high relieve structure. Continuous variables were scaled by centering on the mean and dividing by their standard deviations. AIC values, dispersion, and Q-Q plot fits were examined for a variety alternative error distributions using a simplified model with no random effects and the negative binomial was selected. AIC values and maximum likelihood fits of candidate negative binomial models are shown in Table A-7.

The selected model included site as a random effect, a super year and protection status interaction, the proportion of hard or mixed substrate, average latitude, latitude squared, depth, and depth squared. Latitude squared was included to address non-linearity in the residuals observed in a model with latitude alone. Diagnostics included a Q-Q plot (Figure A-7), Kolmogorov-Smirnov and overdispersion tests, and examination of outliers.

Indices of abundance providing density (fish/hectare) for each super year, both inside and outside of MPAs, were calculated using the 'general linear hypothesis testing' (glht) function from the multcomp package in R. This package allows the calculations of means and confidence intervals from linear combinations of beta coefficients. The estimated means and confidence intervals were back transformed to the response scale (density) by exponentiating the resultant means and upper and lower 95% confidence intervals. Index values were calculated for the following combinations:

- The intercept represents the mean density in reference areas in 2015
- The intercept + the estimate for super year 2020 represents the mean density for reference areas in 2020

- The intercept + the estimate for protection represents the mean density for MPAs in 2015
- The intercept + the estimate for super year 2020 + the estimate for protection represents the mean density for MPAs in 2020

This assumes that all other covariates were held constant at their mean. The resulting indices inside and outside of MPAs were weighted in each super year by the proportion of rocky reef habitat inside and outside MPAs, with 80% outside MPAs and 20% inside based on seafloor mapping within the 100 m depth contour (Table A-8 and Table A-9). The results show an increase in quillback rockfish density both inside and outside MPAs with a greater increase inside.

Fork lengths collected by stereo camera and software for image analysis allow for estimation of the survey selectivity. ROV transects are conducted between 20-120 m depth. In comparison, the CCFRP surveys depths shallower than 20 m but goes no deeper than 60 m to reduce barotrauma.

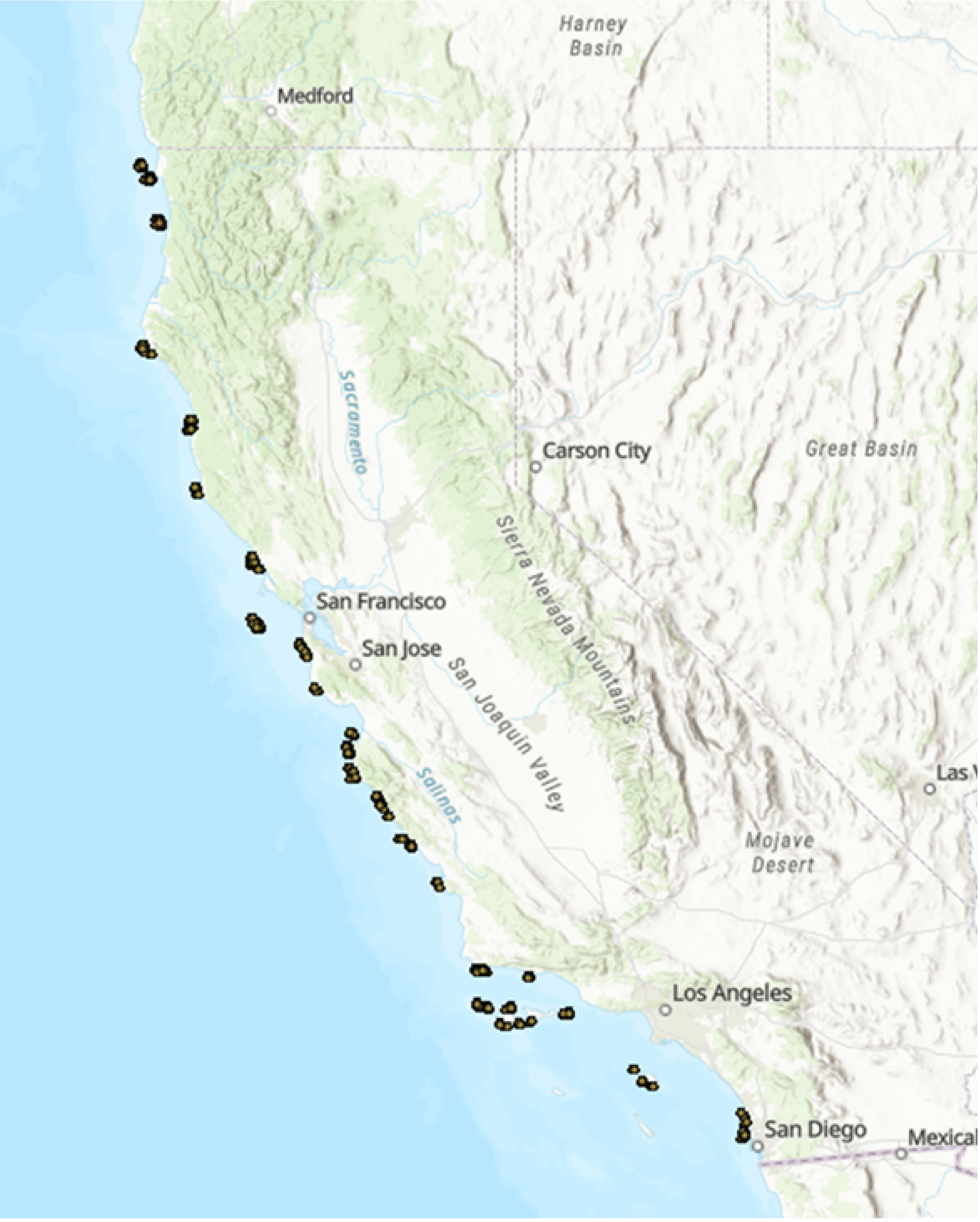


Figure A-5: Sample locations for the California ROV sampling project.

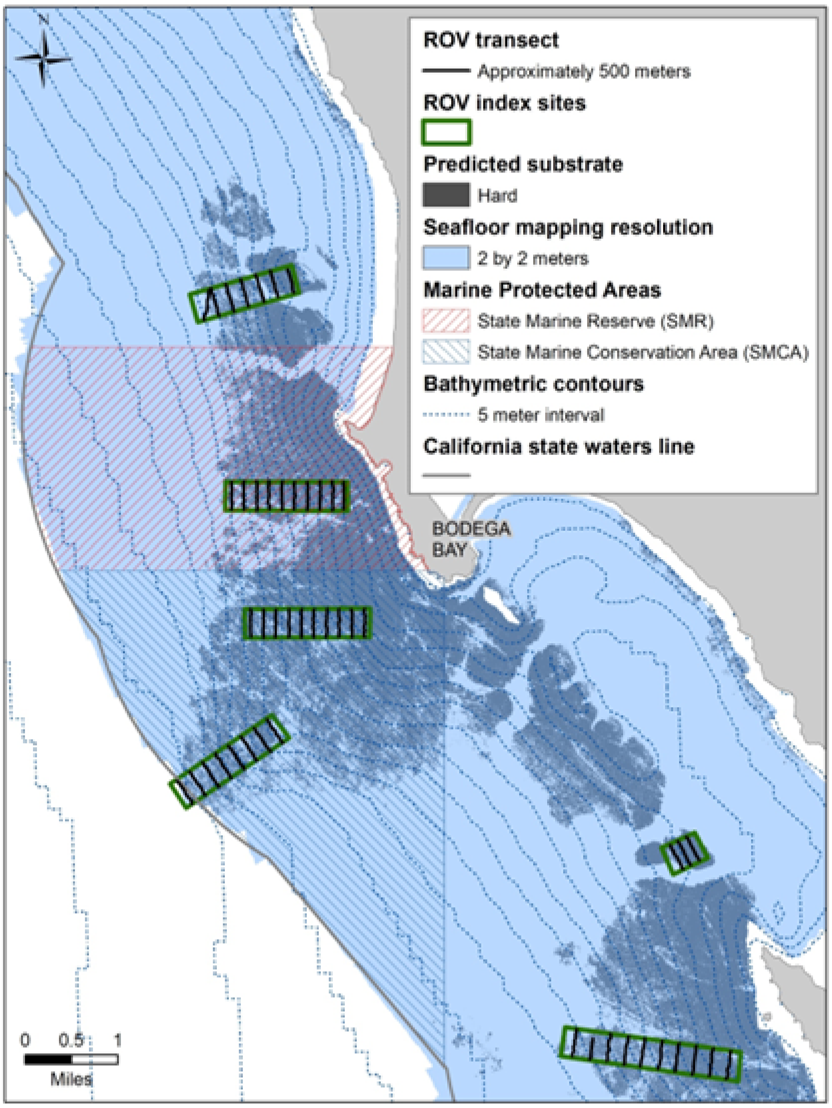


Figure A-6: Sampling design at an example MPA. Boxes identify sampling locations over hard substrate. Transect lines are 500 m long and align with bathymetry contours.

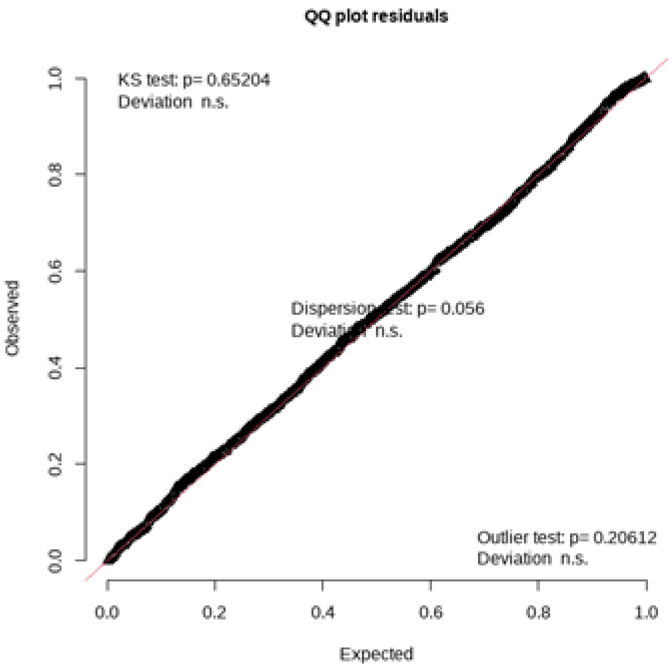


Figure A-7: Q-Q Plot for the ROV abundance index model with results of KS test, dispersion test and outlier test.

Table A-4: Description of variables available for use in the ROV GLMM index analysis.

Variable	Description
SurveyYear	Year in which the actual survey occurred.
SuperYear	Survey coverages are completed over three years resulting in compilation to 2015 (2014-2016) and 2020 (2019-2021). Treated as a categorical factor.
MPAGroup	MPA name that identifies records from MPA sites and associated reference areas.
Site	CDFW and MARE historical site code. A site generally designates a 500 meter wide rectangle with varying length and depth range. May be preferable to use MPA Group given spatial proximate of sites within a group and scale of spatial autocorrelation. Number of transects may not be equal between sites.
Avg_Latitude	Average of latitudinal positions within a transect.
Latitude Squared	The Square of the Avg_Latitude within a transect.
Avg_Longitude	Average of longitudinal positions within a transect.
Avg_Depth	Average depth in meters recorded within a transect.
Depth Squared	Average depth squared was calculated by squaring the Avg_Depth values after scaling so that these values were also centered on the mean.
PropHard	The proportion of hard usable habitat along a transect.
PropMixed	The proportion of mixed usable habitat along a transect.
PropHardMixed	The proportion of hard or mixed usable habitat along a transect.
Protection	Whether the segment in question is in a no take closed Marine Protected Area (1) or open to fishing (0). Treated as a categorical factor.
ProtectionYrs	The number of years the site has been protected since implementation in the survey year.
Portdistance	Distance in meters from nearest port to the centroid coordinates of the sub-unit. Derived from port distance raster layer provided by Becky Miller (SWFSC).
Quillback Rockfish	Total number of quillback rockfish individuals counted within sub-unit.
Usable_Area_Fish	Summed two dimensional area (m^2) of all microframes (one second of ROV area swept) within a sub-unit determined by multiplying Total_XYdist with estimated width at horizontal center of video frame for each microframe, where video parameters are within useable parameters.

Table A-5: ROV data filtering steps.

Filter	Description	Transects Remaining	Quillback Rockfish Remaining	Positive Transects
Start	Prior to Filters	3273	1566	440
South of Point Sur	Removing sample locations south of Point Sur where quillback rockfish are not found	1252	1563	437
Prior to 2014	Removing sampling before 2014 prior to the first full coverage of the state in the first super year 2015 (2014-2016)	1004	1548	434
Depth Range	Relegating the depth range of the analysis to within 110 m depth range where quillback rockfish were observed by the ROV	994	1536	431
Soft Bottom GIS	Removal of any sites where only soft bottom was indicated by GIS layers for seafloor type	967	1535	430

Table A-6: Sampled locations and number of transects per survey year after filtering.

Location	2014	2015	2016	2019	2020	2021	Total
Albion	10	—	—	—	—	—	10
Ano Nuevo	—	9	—	10	—	10	29
Asilomar	—	—	15	—	—	—	15
Big Flat	3	—	—	—	—	—	3
Bodega Bay	—	44	—	38	43	—	125
Cabrillo	7	—	—	—	—	—	7
Carmel Bay	—	—	8	—	—	—	8
Crescent City	4	—	—	—	—	—	4
Cypress Point	—	—	8	10	—	14	32
Duxbury Point	—	3	—	—	—	—	3
Fort Ross	—	1	—	—	—	—	1
Half Moon Bay	—	8	—	—	16	7	31
MacKerricher	12	—	—	—	—	—	12
Mattole Canyon	16	13	—	—	—	—	29
Montara	—	12	—	—	11	10	33
N Farallon Islands	—	—	—	—	10	—	10
Noyo	3	—	—	—	—	—	3
Pacific Grove	—	—	8	—	—	—	8
Pillar Point	—	4	—	—	4	4	12
Point Arena	—	17	—	—	14	11	42
Point Lobos	—	—	16	13	—	20	49
Point St. George	28	12	—	—	19	12	71
Point Sur	—	—	23	22	—	21	66
Portuguese Ledge	—	—	12	12	—	10	34
Reading Rock	22	15	—	—	20	14	71
San Gregorio Reef	—	6	—	—	—	—	6
Saunders Reef	—	8	—	—	—	—	8
SE Farallon Islands	—	27	—	23	23	—	73
Sea Lion Gulch	15	6	—	—	18	20	59
South Cape Mendocino	14	—	—	—	—	—	14
Stewarts Point	—	3	—	—	—	—	3
Ten Mile	21	16	—	—	20	18	75
Tolo Bank	18	—	—	—	—	—	18
Tomales Point	—	3	—	—	—	—	3
Total	173	207	90	128	198	171	967

Table A-7: Model selection for the ROV survey. The final model selected is bolded. A plus sign indicates the covariate included and a minus sign indicates it is excluded.

Model Number	Intercept	Protection	Super Year	Proportion Hard or Mixed	Latitude	Latitude Sq.	Depth	Depth Sq.	Port Distance	Backsides	1/Site	Super Year * Protection	DF	Δ AIC
1	-7.053	+	+	+	+	+	+	+	+	+	+	+	954	-6.3
2	-6.936	+	+	+	+	+	+	+	−	+	+	+	955	-4.0
3	-7.072	+	+	+	+	+	+	+	+	−	+	+	955	-2.6
4	**-6.954**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**−**	**−**	**+**	**+**	**956**	**0.0**
5	-7.360	+	+	+	+	−	+	+	−	−	+	+	953	5.0
6	-6.706	−	+	+	+	+	+	+	−	−	+	−	959	43.8
7	-6.862	+	+	+	+	+	+	+	−	−	+	−	958	44.5
8	-7.095	+	+	+	−	−	+	+	−	−	+	+	958	52.1
9	-7.526	+	+	+	+	+	+	−	−	−	+	+	954	78.2
10	-6.768	+	+	−	+	+	+	+	−	−	+	+	959	94.3
11	-7.550	+	+	+	+	+	−	−	−	−	+	+	955	119.1

Table A-8: Index (fish/hectare) values and confidence limits for inside and outside MPAs in each super year.

Index Value	Estimate	Lower 95% CL	Upper 95% CL
Outside MPA 2015	9.54	5.15	17.66
Outside MPA 2020	12.89	6.77	24.54
Inside MPA 2015	9.52	4.92	18.43
Inside MPA 2020	21.55	11.26	41.25

Table A-9: Weighted index values based on percent of nearshore rocky reef inside (20%) and outside MPAs (80%), as well as confidence limits, log standard error (SE) and percent change in relative abundance between the 2015 and 2020 super years.

Value	2015 Index	2015 log SE	2020 Index	2020 log SE	Percent Change
Estimate	9.54	0.2317	14.62	0.2405	53.34%
Lower 95% CL	5.11	-	7.67	-	
Upper 95% CL	17.81	-	27.88	-	

10.3 CCFRP

The survey design for CCFRP consists of 500 x 500 m cells both within and adjacent to each MPA. On any given survey day site cells are randomly selected within a stratum (MPA and/or reference cells). Party/charter vessels are chartered for the survey and the fishing captain is allowed to search within the cell for a fishing location. During a sampling event, each cell is fished for a total of 30-45 minutes by volunteer anglers. Each fish encountered is recorded, measured, and released (or descended to depth) and can later be linked back to a particular angler. CCFRP samples shallower depths to avoid barotrauma-induced mortality. Starting in 2017, a subset of fish have been retained to collect otoliths and fin clips that provide needed biological information for nearshore species. For the index of abundance, CPUE was modeled at the level of the drift.

The CCFRP data are quality controlled at the time they are key punched and little filtering was needed for the index. Cells not consistently sampled over time or flagged for errors were excluded. The full dataset for northern California contained 2,699 drifts, 19% of which encountered quillback rockfish. After applying filters to remove drifts marked for exclusion or that fished less than two minutes, 2,582 drifts remained for index standardization, with 481 of those drifts encountering quillback rockfish (Table A-10).

From south to north, the CCFRP index includes the following five regions: Southeast Farallon Islands, Bodega Head, Stewart's Point, Ten Mile, and South Cape Mendocino. The southeast Farallon Islands MPA was sampled in 2017, 2018 and 2025 and the average CPUE increased inside and outside the MPA in 2025 relative to 2017 and 2018. The other four MPAs were sampled annually. The final index (Table A-12) represents a similar trend to the arithmetic mean of the annual CPUE (Figure A-8). An interaction between year and region was not considered in model selection due to inconsistent sampling of the Farallon Islands. To account for the closed areas within the MPAs, the interaction of year and MPA/reference site was incorporated in the final model.

A negative binomial generalized linear model was fit to the drift-level data (catch with a log offset for angler hours). Because the average observed CPUE inside MPAs and in the reference sites exhibited differing trends, we explored a year:MPA/reference site interaction, which was selected as the best fit model by AIC (Table A-11), The final model included main effects factors for year, mpa/reference site, and region, a year:mpa/reference interaction, and depth was modeled with a spline. The simulated residuals indicate a good fit of the model (Figure A-10). The model was fit using the sdmTMB R package (version 0.3.0) and residuals simulated in the DHARMa package.

Based on work completed at the SWFSC, we estimate that the percent of rocky reef habitat from Point Conception to the California/Oregon border within California state waters is 892 km^2, of which approximately 23% is in MPAs that prohibit the harvest of groundfish (pers comm. Rebecca Miller, UCSC). There is recreational fishing outside of state waters, but habitat maps are not available at the same 2-m resolution and do not allow for direct comparisons. The final index was weighted, giving 20% of the model weight to MPAs and 80% of model weight to the "open" areas within state waters.

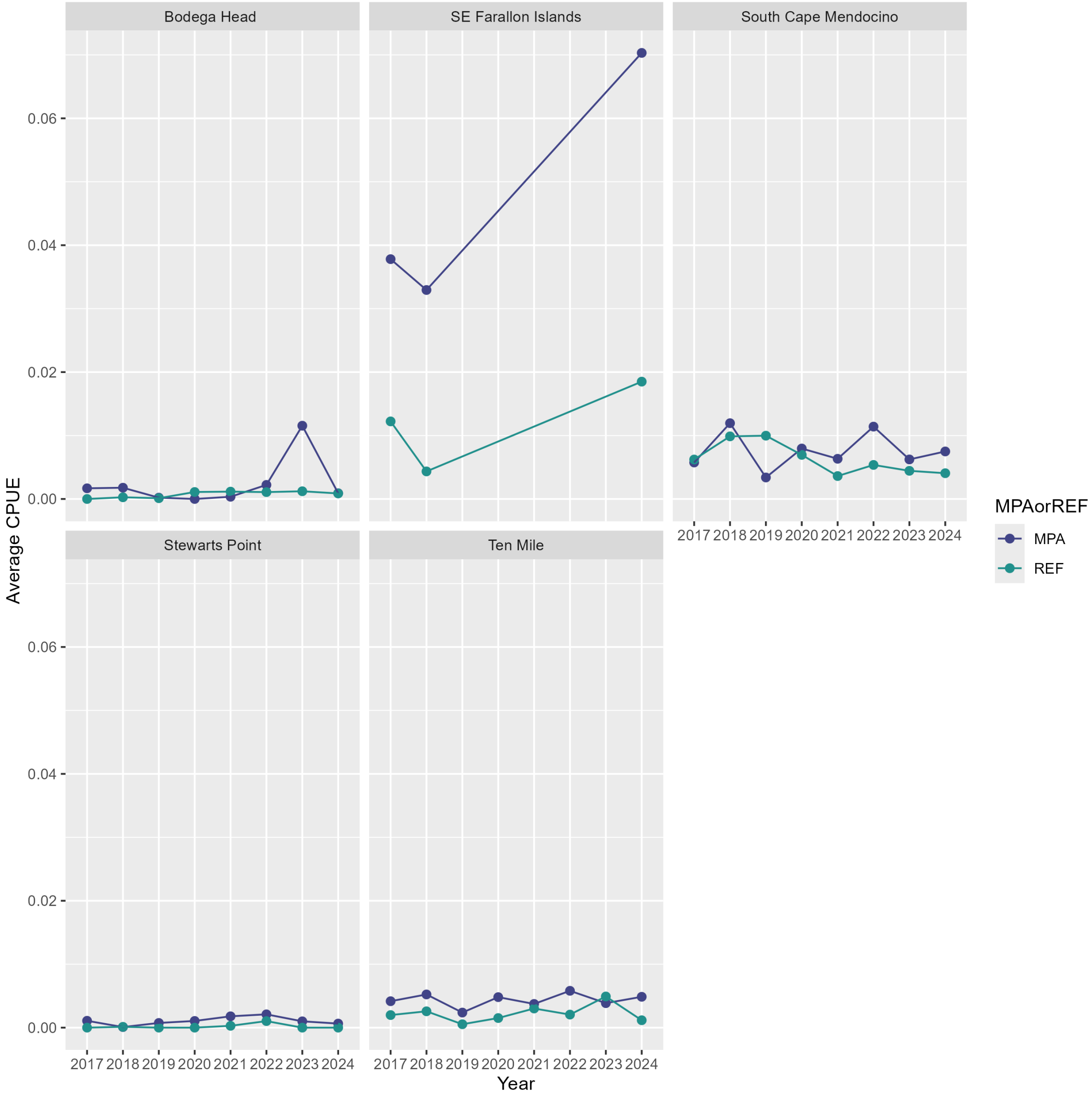


Figure A-8: Average CPUE (fish per angler hour) for each location and site.

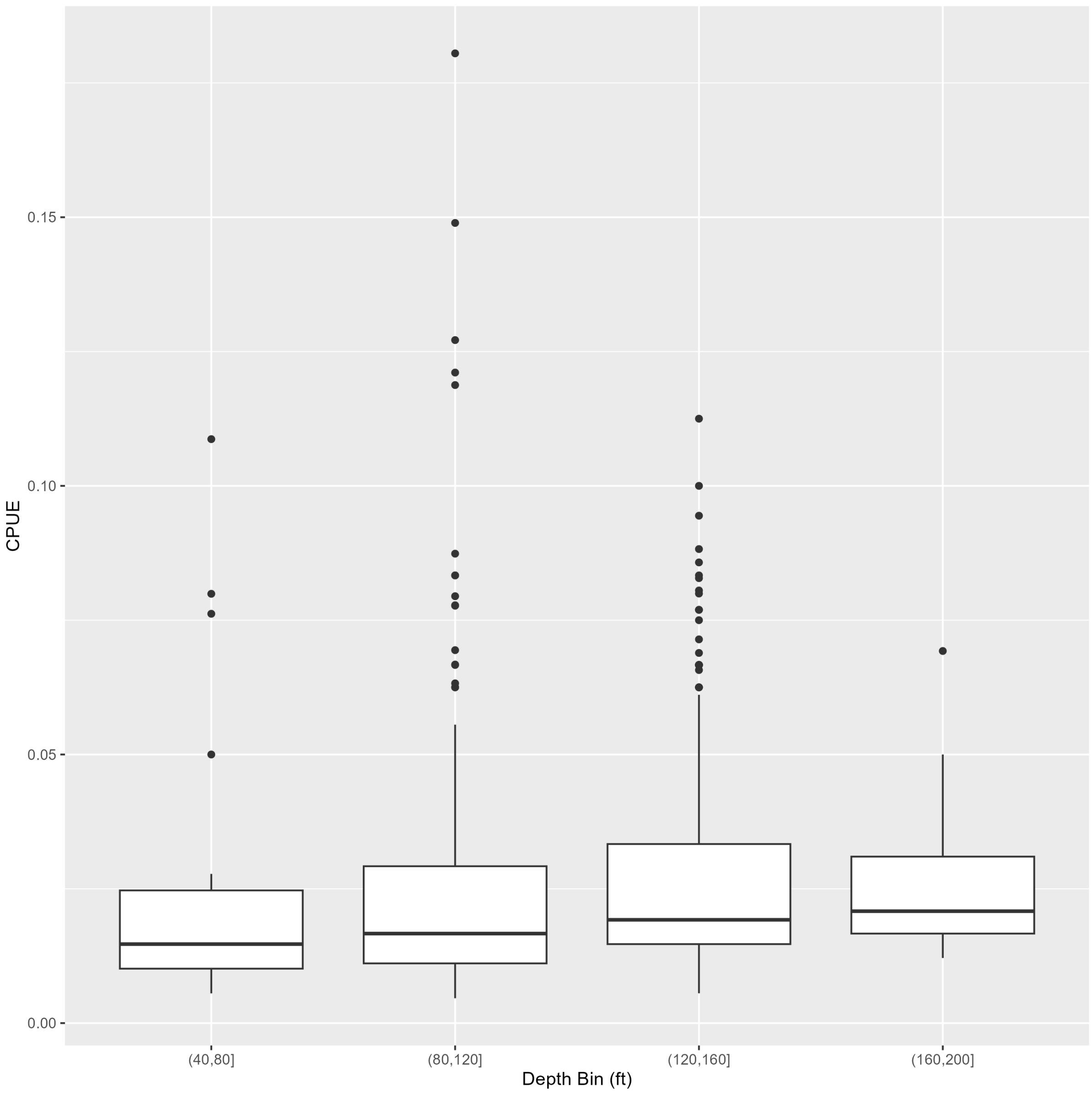


Figure A-9: CPUE across 40 foot depth bins.

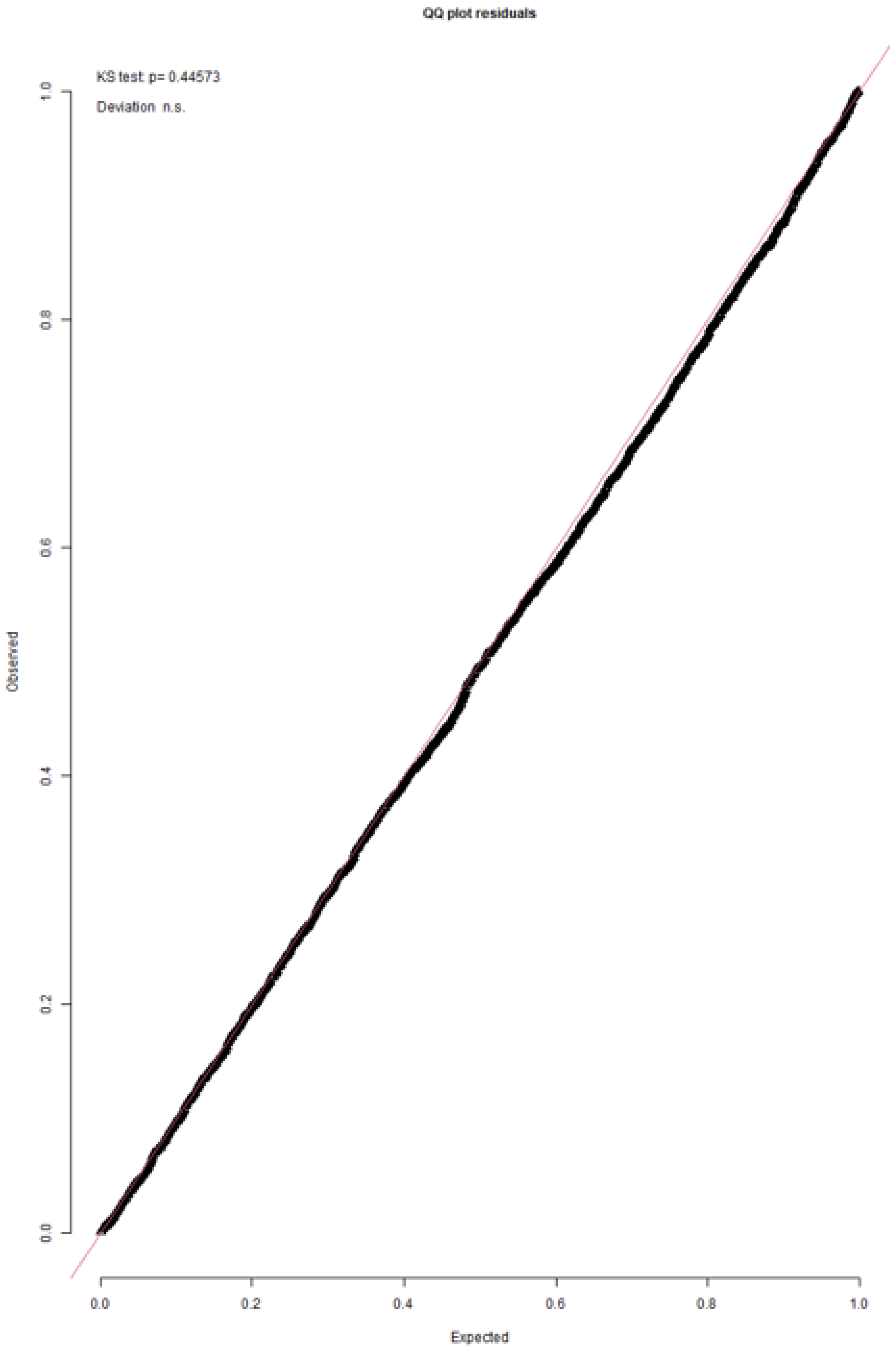


Figure A-10: QQ plot from 500 simulated residuals for the final CCFRP model.

Table A-10: CCFRP data filtering steps.

Filter	Description	Samples	Positive_Samples
None	All data	2699	504
Drift errors	Remove drifts marked for exclusion	2604	483
Time fished	Remove drifts less than two minutes	2582	481

Table A-11: CCFRP model selection with the final model bolded. A plus sign indicates the covariate included and a minus sign indicates it is excluded.

MPA or REF	Depth	Region	Year	Year:MPA or Ref	Effort offset	df	Δ AIC
+	+	+	+	+	+	**26**	**0.0**
+	+	+	+	−	+	19	5.7
−	+	+	+	−	+	18	60.7
+	−	+	+	+	+	21	280.5
+	−	+	+	−	+	14	283.9
+	+	−	+	+	+	23	333.6
+	+	−	+	−	+	16	340.8
−	−	+	+	−	+	13	354.0
−	+	−	+	−	+	15	392.6
+	−	−	+	+	+	17	786.8
+	−	−	+	−	+	10	788.2
−	−	−	+	−	+	9	836.8

Table A-12: Final index and log-standard error for CCFRP.

Year	Index	log SE
2017	0.001	0.227
2018	0.002	0.191
2019	0.001	0.289
2020	0.002	0.271
2021	0.001	0.251
2022	0.002	0.222
2023	0.003	0.185
2024	0.003	0.180

11 Appendix B: Population scale within MPAs

In addition to the relative index of abundance across sampling sites from the ROV survey, an estimate of absolute abundance aggregated across super years for only sites within no-take MPAs was calculated and provided by the SWFSC (T. Rogers, pers. comm., 3/31/2025). The estimate was constrained to only areas within MPAs to align with the design of the ROV survey in monitoring California MPAs. The estimate was intended to serve as a reference point with which to compare with the scale estimated by the base model. Given MPAs occur across a subset of the total quillback rockfish habitat in California, the base model estimate is expected to be higher than that from samples in MPAs. Details of the ROV survey, and the relative abundance index across all sampling sites that was used in the base model have already been provided (see Section 10). A detailed document describing the analysis for the absolute abundance estimate for sampling sites in no-take MPA is available upon request from SWFSC and on the PFMC stock assessment meeting material website.

The total abundance estimate for quillback rockfish in no-take MPAs is 151,934 individuals with a 95% confidence interval of 118,204 – 195,289 for 2015, and 317,274 individuals with a 95% confidence interval of 273,983 – 367,405 for 2020. While not estimated to numbers at size, based on the lengths observed from sampling within MPA sites (as small as 8 cm, which is approximately age 1), the abundance estimate could be expected to cover most ages. While the depth range of survey sampling sites covers 20–100 m, and therefore omits the shallowest areas between 0–20 m, the available depths are expected to capture much of the expected quillback rockfish habitat.

Abundance estimates from the base model were larger than those from the MPA only estimate. For 2015, the estimate from the base model was 354,574 individuals across ages 1+, and 321,841 individuals across ages 3+. For 2020, the estimate from the base model was 533,052 individuals across ages 1+, and 423,641 individuals across ages 3+. Based on assuming numbers for age 3+ individuals, the base model estimates represent a factor of 2.12 and 1.34 times greater than the MPA only estimates for 2015 and 2020, respectively.

12 Appendix C: Regulations History

The following figures represent the regulations history for California's saltwater recreational fishery and nearshore commercial fishery that affect quillback rockfish.

A visualization of the California recreational regulatory history relevant to quillback rockfish is in Figure C-1. The recreational regions are defined based on the following latitudes: Northern (42°00′ N. Lat. to 40°10′ N. Lat.), Mendocino (40°10′ N. Lat. to 38°57′ N. Lat.), San Francisco (38°57′ N. Lat. to 37°11′ N. Lat.), Central (37°11′ N. Lat. to 34°27′ N. Lat.), Southern (34°27′ N. Lat. to US/Mexico border). Not all management areas have been consistently defined over time. The northern and southern management areas have remained the same. From 2001-2003 the Central management area was defined as 40°10′ N. Lat. to 34°27′ N. Lat. In 2004 and again in 2024, the Central area was split into a North-Central and South-Central areas at 36°00′ N. Lat. In 2005, the regions from 40°10′ N. Lat. to 34°27′ N. Lat. were redefined. The North-Central encompasses 40°10′ N. Lat. to 37°11′ N. Lat., Monterey South-Central from 37°11′ N. Lat. to 36°00′ N. Lat., and Morro Bay South-Central from 36°00′ N. Lat. to 34°27′ N. Lat.

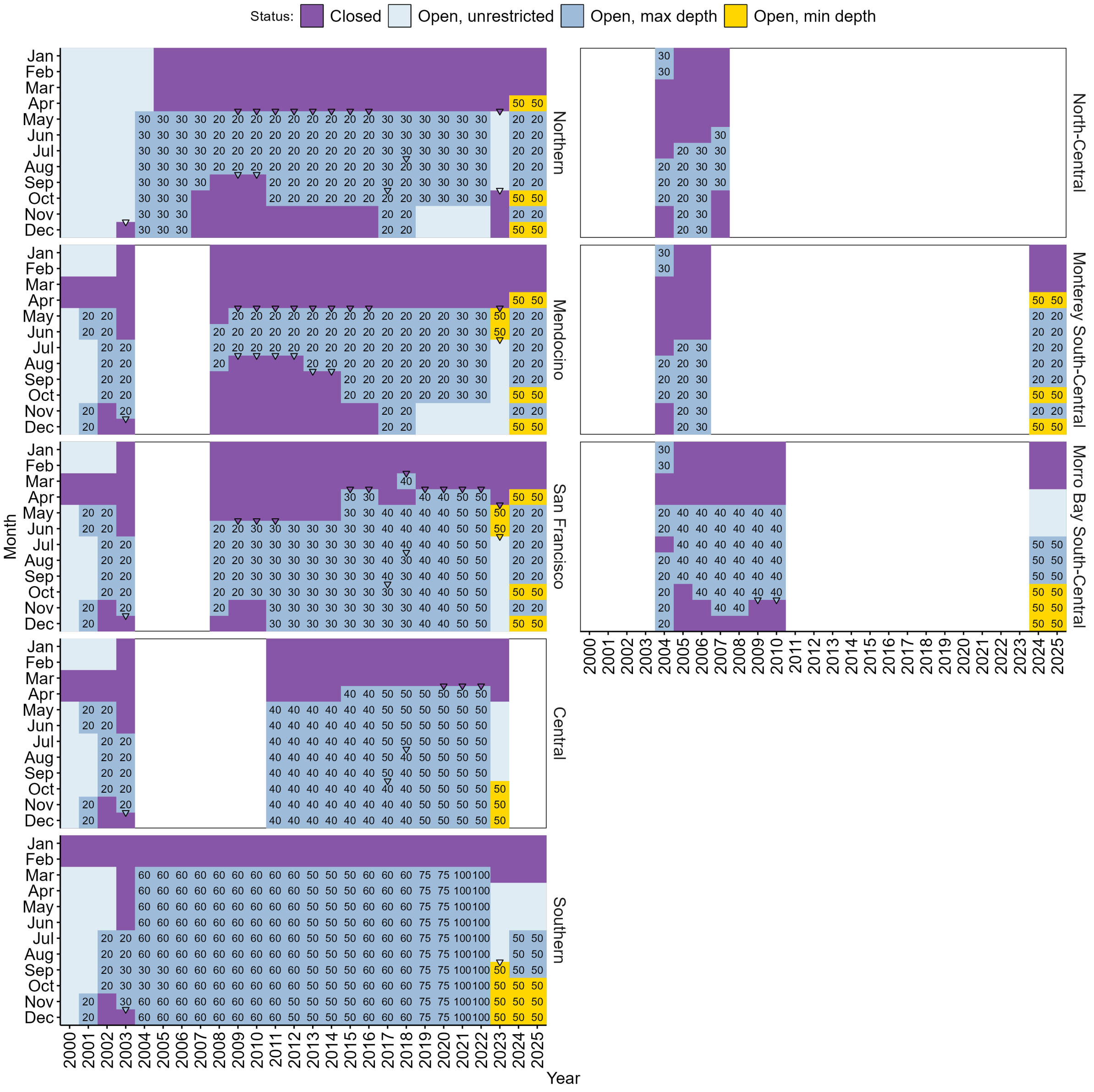


Figure C-1: The CDFW recreational season length and depth restriction for nearshore rockfish by month from 2000 to 2003. A triangle indicates a regulation change mid-month. See the text for additional information.

A visualization of the California commercial regulatory history relevant to quillback rockfish between the years 2000 and 2023 is in Figure C-2. Prior to 2003 nearshore trip limits were different for limited entry fixed gear (LEFG) and open access (OA) sectors, and cells prior to 2003 in figure Figure C-2 are representative of the OA sector. In 2003, trip limits became equivalent for the OA and LEFG sectors. In 2003 CDFW began the limited entry deeper nearshore permit program which capped participants at 280 and the number of permits has declined each year following. Trip limits prior to 2022 were a culmination of all nearshore rockfish species, meaning although the theoretical quillback rockfish maximum is the trip limit, the limit applies to all deeper nearshore species combined during that period and it is likely quillback rockfish were a small fraction of that period limit. Limits specific to quillback rockfish were implemented in 2023.

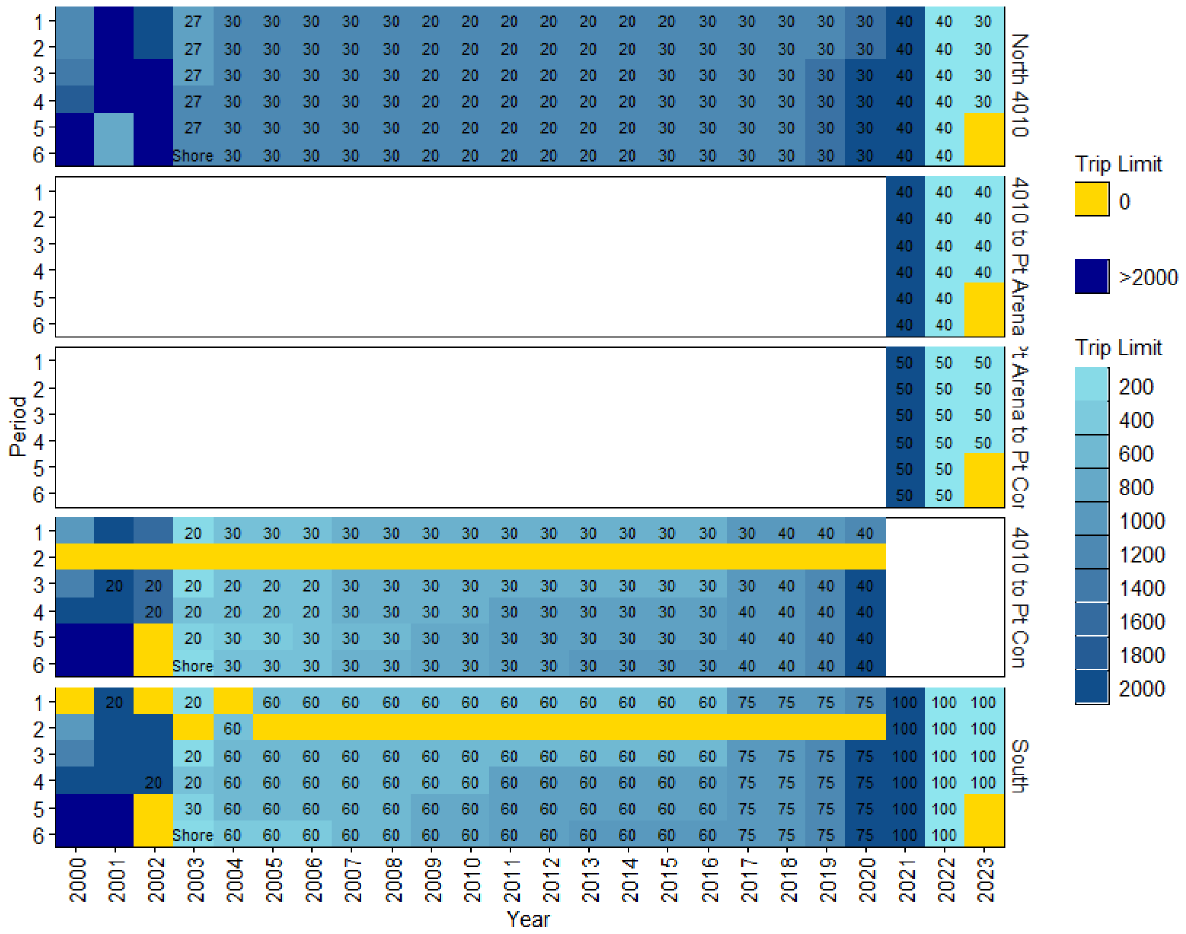


Figure C-2: CDFW commercial nearshore fishing regulations. See the text for additional description.