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

The Status of Chilipepper Rockfish (*Sebastes goodei*) in U.S. Waters off California, Oregon, and Washington in 2025

July 28, 2025

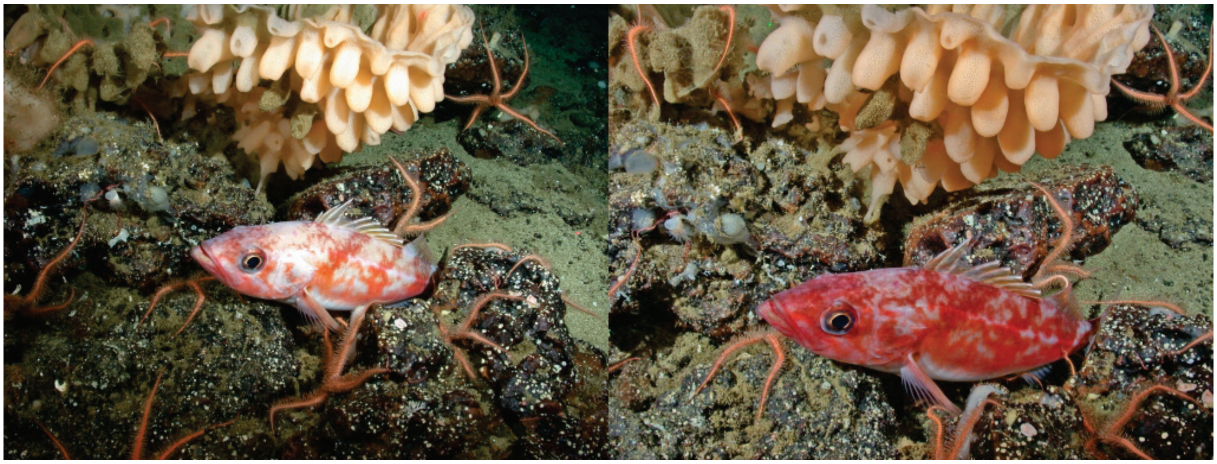

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Photo Credit: NMFS SWFSC. *In*: Butler, J., M. Love, and T. Laidig. 2012. A Guide to the Rockfishes, Thornyheads, and Scorpionfishes of the Northeast Pacific. University of California Press.
Description from Butler et al. (2012; page xi): "*The ability to rapidly change color and pattern (often in just a few seconds) is most obvious in those species that routinely both swim in the water column and rest on the sea floor (e.g., bocaccio, chilipepper, halfbanded, shortbelly, squarespot, stripetail, and widow rockfishes). In these species, fish lying on, or adjacent to, substrate are heavily mottled, spotted, and blotched. That same individual swimming in the water column lacks most or all patterning and is often drab*."

DISCLAIMER

Common Acronym Definitions:

ABC: Acceptable Biological Catch
ACL: Annual Catch Limit
CAAL: Conditional age-at-length
CalCOFI: California Cooperative Oceanic Fisheries Investigations
CALCOM: California Cooperative Groundfish Survey Database
CDFW (formerly CDFG): California Department of Fish and Wildlife (formerly Fish and Game)
CI: Confidence Interval
CPFV: Commercial Passenger Fishing Vessel (aka "party" or "charter" boats, or "PC mode")
CPUE: Catch-per-unit-effort
CRFS: California Recreational Fisheries Survey
GEMM: Groundfish Expanded Mortality Multiyear [report]
GMT: Groundfish Management Team of the PFMC
IFQ: Individual Fishing Quota
MRFSS: Marine Recreational Fisheries Statistics Survey
MSST: Minimum Stock Size Threshold (i.e., 25% of unfished spawning output for rockfishes)
MSY: Maximum Sustainable Yield
NMFS: National Marine Fisheries Service
NOAA: National Oceanic and Atmospheric Administration
NWFSC: Northwest Fisheries Science Center
ODFW: Oregon Department of Fish and Wildlife
OFL: Overfishing Limit
PacFIN: Pacific Fisheries Information Network
PFMC: Pacific Fishery Management Council
PR: Private/Rental recreational boat (aka private boat or "skiff")
PSMFC: Pacific States Marine Fisheries Commission
RecFIN: Recreational Fisheries Information Network
RREAS: Rockfish Recruitment and Ecosystem Assessment Survey (NMFS, SWFSC)
SPR: Spawning Potential Ratio; the ratio of equilibrium spawning output under fished and unfished conditions
SSC: Scientific and Statistical Committee of the PFMC
STAR: Stock Assessment Review (Panel)
STAT: Stock Assessment Team
SWFSC: Southwest Fisheries Science Center
WCGBTS: West Coast Groundfish Bottom Trawl Survey
WCGOP: West Coast Groundfish Observer Program
WDFW: Washington Department of Fish and Wildlife
YOY: Young-of-the-year, i.e., age-0 fish

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Executive Summary

Stock

This assessment reports the status of the chilipepper rockfish (*Sebastes goodei*), also known simply as "chilipepper," in U.S. waters off the coast of California, Oregon, and Washington. Although relatively few chilipepper are observed off the coast of Washington, landings from that state have been included in the analysis to facilitate coastwide management based on a single assessment model. Information about stock structure from genetic analyses and tagging studies is outdated and/or has insufficient sampling effort to detect evidence of reproductive isolation or movement patterns. Analyses conducted for this assessment suggest that patterns of adult growth (length-at-age) are similar across the assessed range. Most catches were taken by trawl gear in California, north of Point Conception (34° 27′ N. lat.), following World War II until roughly the year 2000 when large-scale spatial closures went into effect. No data are available to inform trends in chilipepper abundance in Mexican waters. Based on these general findings, the population dynamics are modeled as a single, "coastwide" stock in U.S. waters from the U.S./Mexico border (roughly 32.5° N. latitude) to the U.S./Canada border (49° N. lat.).

Chilipepper rockfish in U.S. waters are currently managed south of 40° 10′ N. latitude (roughly Cape Mendocino, California) with a species-specific harvest specification. North of Cape Mendocino, chilipepper are a component stock in the PFMC's northern shelf rockfish complex.

Catches

Prior to World War II, chilipepper rockfish were landed primarily by commercial hook and line gears (the dominant gear type of the era), followed by an abrupt switch to trawl gears after the war (Figure a). Landings by hook and line gear types, as a fraction of total landings, increased during the 1980s and 1990s, as did landings by net gears, but have since declined. Significant declines in landings since the 2000s across all gears have been due to regulatory action in response to evidence of declining rockfish populations at the time. Recreational catches of chilipepper peaked around 1970, accounting for roughly 20% of total fishing mortality at that time. Since the war, the California trawl fleet has accounted for most landings in all but a few years. In recent years, the trawl fleet continues to be the dominant source of landings (Table a). Recent landings by commercial hook and line gears have represented less than 10% of trawl landings. Recreational landings increased dramatically in 2023 and 2024 due to closures of nearshore waters, resulting in increased fishing effort in depths inhabited by chilipepper rockfish, and direct targeting of the species in some areas. Despite this increase in recreational landings, the trawl fishery still accounted for over 80% of total fishing mortality (catch + dead discards) in 2023-2024.

Table a. Recent catches (mt) by fleet and total catch (mt) summed across fleets for the assessed region. HKL = hook and line, TWL = trawl, Comm. = all commercial gears, Rec. = recreational, and Pt. Conc. = Point Conception, CA.

Year	North CA HKL	South CA HKL	CA TWL	OR + WA Comm.	CA Net	Rec. N. of Pt. Conc.	Rec. S. of Pt. Conc.	TWL discard	Total Catch
2015	0.9	0.2	176.1	1.8	0.0	0.0	5.8	20.6	205.6
2016	0.4	0.1	76.6	4.6	0.0	0.0	5.4	3.3	90.4
2017	2.7	0.2	157.4	56.7	0.0	0.1	2.5	10.5	230.2
2018	2.5	0.4	344.3	17.4	0.0	0.0	2.0	24.2	390.8
2019	13.7	0.3	530.6	34.8	0.0	0.1	5.8	55.7	641.1
2020	19.8	0.4	643.3	34.5	0.0	0.1	1.6	65.4	765.1
2021	27.1	1.3	700.7	46.1	0.1	0.2	3.7	83.0	862.2
2022	37.9	1.7	740.4	21.7	0.0	1.1	3.6	59.7	866.2
2023	59.9	2.2	928.1	18.0	0.0	146.1	34.3	74.2	1262.9
2024	66.2	3.3	936.0	8.9	0.0	56.0	35.8	87.0	1193.2

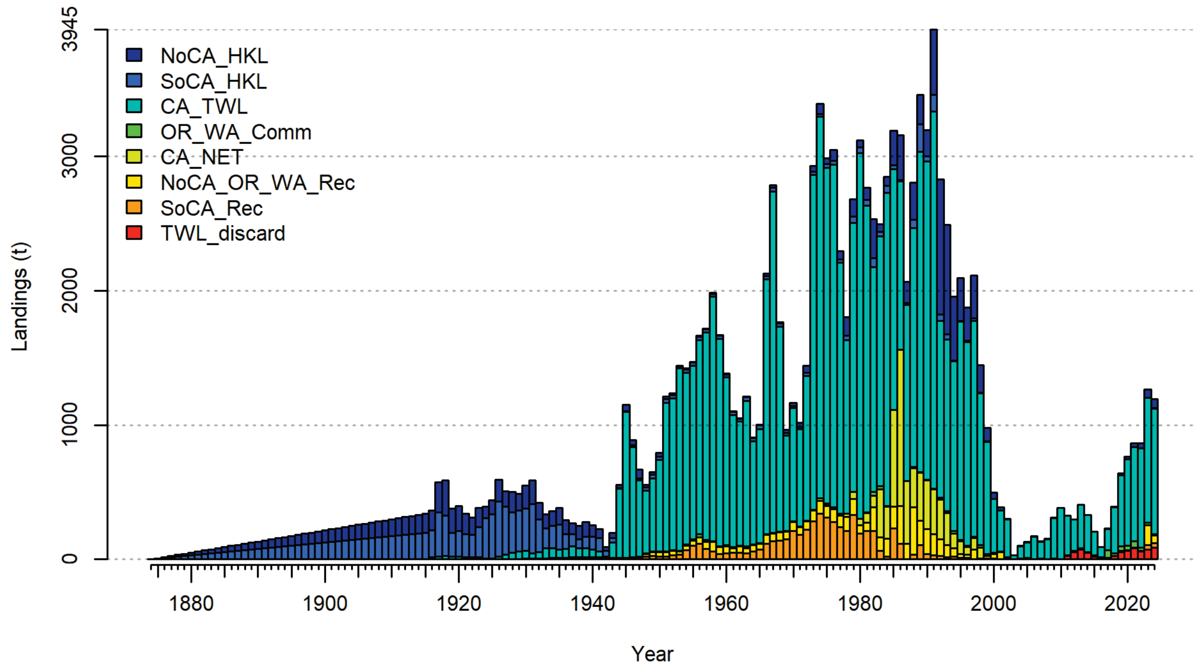


Figure a. Estimated coastwide landings (mt) of chilipepper rockfish, 1875-2024, by model fleet. Discarded dead catch from the IFQ trawl fishery is modeled as a separate fleet to account for differences in size composition between retained and discarded catch, and due to the magnitude of discarded catch from the IFQ trawl fleet relative to other, non-trawl gears.

Data and assessment

This is the first benchmark assessment of chilipepper rockfish since 2007. An update to that assessment was conducted in 2015, followed by a catch-only update to correct errors in historical landings in 2017. A catch-only projection based on the 2017 update was completed in 2023 (Wetzel 2023). Due to significant changes in best practices for assessments and available data sources since 2007, the stock assessment team re-analyzed all data sources used in the previous assessment, and updated the model structure to reflect current best practices.

The 2025 chilipepper model is structured as a single, sex-disaggregated population, spanning U.S. waters from Mexico to Canada. The model operates on an annual time step covering the period 1875 to 2024 (not including forecast years) and assumes an unfished equilibrium population prior to 1875. Although not explicitly spatial, the model defines some fishing fleets by gear, and others by gear and area. While this "fleets as areas" approach assumes population trends and biological characteristics are the same across the assessed area, it allows the size and age structure of catches to reflect area-specific fleets where appropriate. Population dynamics are modeled for ages 0 through 35, with age 35 being the accumulator age. Population length bins were defined every 1 cm from 7 to 60 cm, and data length bins were set every 2 cm from 8 to 60 cm. The model is conditioned on catch from two sectors (commercial and recreational) divided among eight fishing fleets. Four "survey" fleets represent fishery-independent time series of relative abundance: two fishery-independent trawl surveys, one ichthyoplankton survey of spawning output, and one index of age-0 recruitment. Size and age composition data include lengths from 1975-2024 and ages from 1978-2024, with intermittent gaps in each data type. Recruitment is assumed to be related to spawning output via the Beverton-Holt stock recruitment relationship with log-normally distributed, bias corrected process error. Growth was estimated within the model, informed largely by age composition data conditioned on length bins. All catch was assumed to be known with high precision (log-scale standard error of 0.05).

Fishing fleets were specified for both recreational and commercial sectors. While the previous assessment combined all recreational fishing modes and areas into a single fleet, we split the recreational sector into two main fleets according to area (north or south of Point Conception, CA), as suggested in the 2015 update assessment (Field et al. 2015). Dead recreational discards were combined with retained catch as they represent a small fraction of total fishing mortality. The commercial sector was represented by eight fleets. The primary commercial fleet in terms of landings is the California trawl fleet, which is modeled as two fleets representing retained catch and discarded catch. Two commercial fleets representing hook-and-line and longline gear types, were differentiated by area fished (waters off California, north and south of Point Conception). The commercial net fishery in California, with landings primarily during the 1980s and 1990s, was modeled as a separate fleet. Commercial landings north of California (almost entirely from Oregon) were summed across areas and gears and modeled as a single fleet, with trawl landings representing the majority of catch from that area.

Given that previous assessments differed with respect to time-varying treatments of selectivity and growth, the stock assessment team (STAT) made considerable efforts to evaluate alternative hypotheses using the most recent data and modeling framework. Although there was evidence of time-varying growth (see Appendix A by Nick Grunloh), sensitivity analyses did not find that changes in growth (specifically, the parameter *k* in the von Bertalanffy growth model) significantly affected estimated population dynamics over the modeled time period. Therefore, growth is assumed constant, or averaged over time, in the base model. To evaluate the effects of time-varying selectivity in the trawl fleet, a flexible ("2D") selectivity option that allows for variation over size and time was compared to assumptions of constant selectivity and a simplified, time-blocking approach. The STAT concluded that the simpler, time-blocking approach captured a significant fraction of variation in size-based selectivity over time, while requiring fewer parameters than the 2D approach.

Stock spawning output and dynamics

The last catch projection for chilipepper rockfish (Wetzel 2023) was based on a 2017 update of the 2007 benchmark assessment. The 2023 catch projection estimated spawning output to be at 74% of unfished levels in 2023. The current assessment estimates that relative spawning output ("depletion") in 2023 was between 70% and 115% of the unfished equilibrium level, with a higher point estimate of 93% (Table b). Spawning output in 2025 is centered around 9.9 trillion eggs (~95% asymptotic interval: 6.3-13.6 trillion). Relative to the updated unfished level, the 2025 assessment estimates the stock to be above target biomass with high probability, with a point estimate for stock status of 83% of unfished spawning output in 2025. Although assessment uncertainty is likely underestimated (see Evaluation of Uncertainty in the main text), the current model produces a 95% confidence interval for depletion of 63% - 104% in 2025 (Table b).

Estimates of historical chilipepper spawning output declined from unfished levels in the second half of the 19th century until about 2000 (Figure b, Figure c), after which multiple regulatory actions limiting catch of shelf rockfish species were put into place. Although chilipepper was never declared overfished, it is frequently caught with bocaccio (*Sebastes paucispinis*), which was declared overfished in 1999. Efforts to avoid bocaccio and other depleted rockfish stocks reduced fishing pressure on chilipepper. Estimates of increasing biomass after 2000 are driven by reduced fishing pressure, assumptions about average stock productivity, and evidence of a few very strong recruitment events.

Table b. Estimated recent trend in spawning output (billions of eggs) and the fraction unfished and the 95-percent intervals for the model area.

Year	Spawning output	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2015	7457	4678	10237	0.626	0.459	0.792
2016	8318	5225	11410	0.698	0.513	0.882
2017	9392	5924	12860	0.788	0.581	0.994
2018	10392	6580	14203	0.872	0.646	1.097
2019	11178	7106	15251	0.938	0.698	1.177
2020	11631	7414	15849	0.976	0.730	1.221
2021	11726	7491	15961	0.984	0.740	1.228
2022	11491	7351	15632	0.964	0.728	1.200
2023	11057	7076	15038	0.927	0.703	1.152
2024	10467	6654	14281	0.878	0.664	1.092
2025	9925	6263	13587	0.832	0.628	1.037

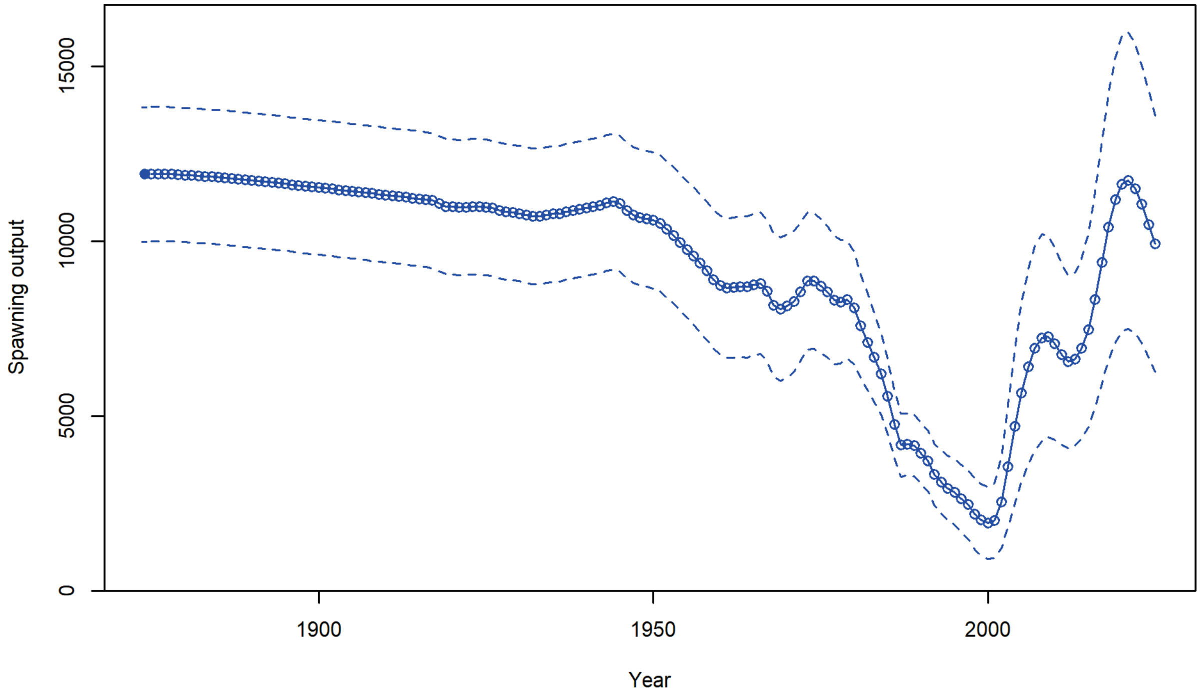


Figure b. Time series of estimated spawning output (trillions of eggs) for the 2025 chilipepper rockfish model. Area between the dashed lines represents the 95% asymptotic confidence interval.

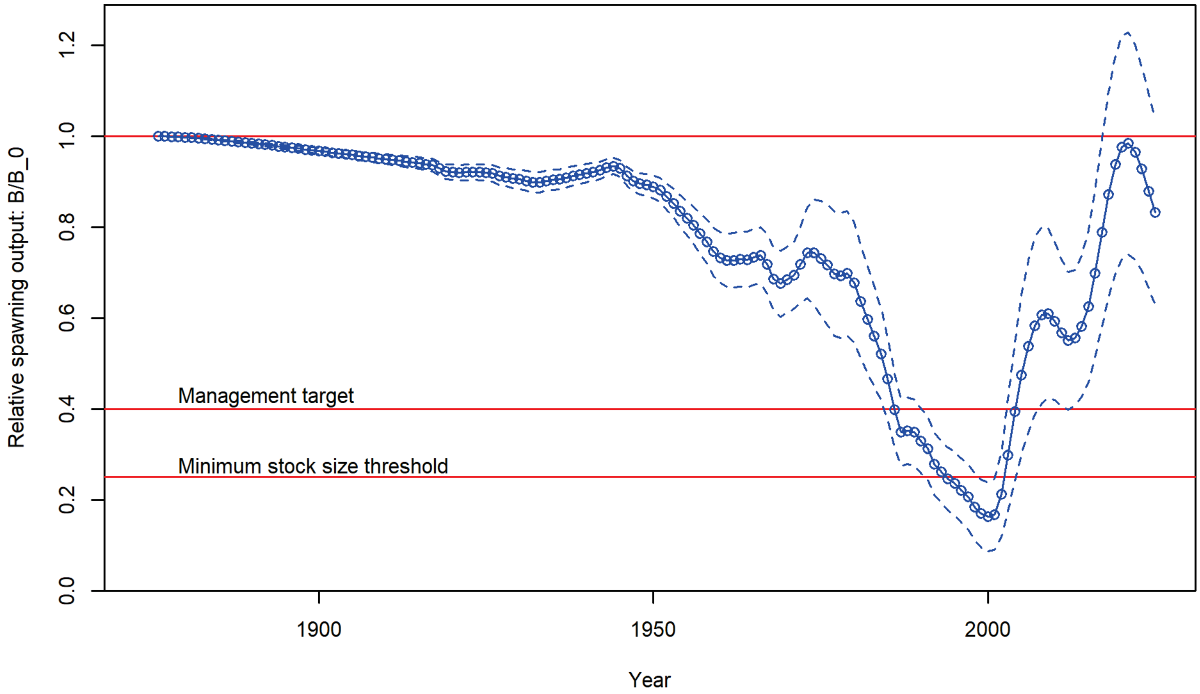


Figure c. Spawning output relative to unfished spawning output chilipepper rockfish, 1875-2024, with 95% asymptotic confidence interval (dashed lines). The target level of spawning output (40% of unfished) and minimum stock size threshold (25% of unfished) are shown as horizontal lines for reference.

Recruitment

Inter-annual recruitment variability is large for chilipepper rockfish, with one of the largest estimated recruitment events (1999) occurring around the time of minimum stock size. Average recruitment was based on a Beverton-Holt stock recruitment relationship with steepness fixed at 0.72 (the mean of the prior). The input value for the standard deviation of log-scale recruitment was 1.0. Recruitment patterns in the base model were largely consistent with previous update assessments, showing strong estimated recruitments in 1984, 1999, and 2013 (Figure d, Table c). The model's estimate of recruitment in 2024 is driven in part by the juvenile (RREAS) index. Until additional years of size and age data become available to verify the strength of the 2024 year class, the precision of this estimate will remain low and the strength of the 2024 year class should be interpreted with caution.

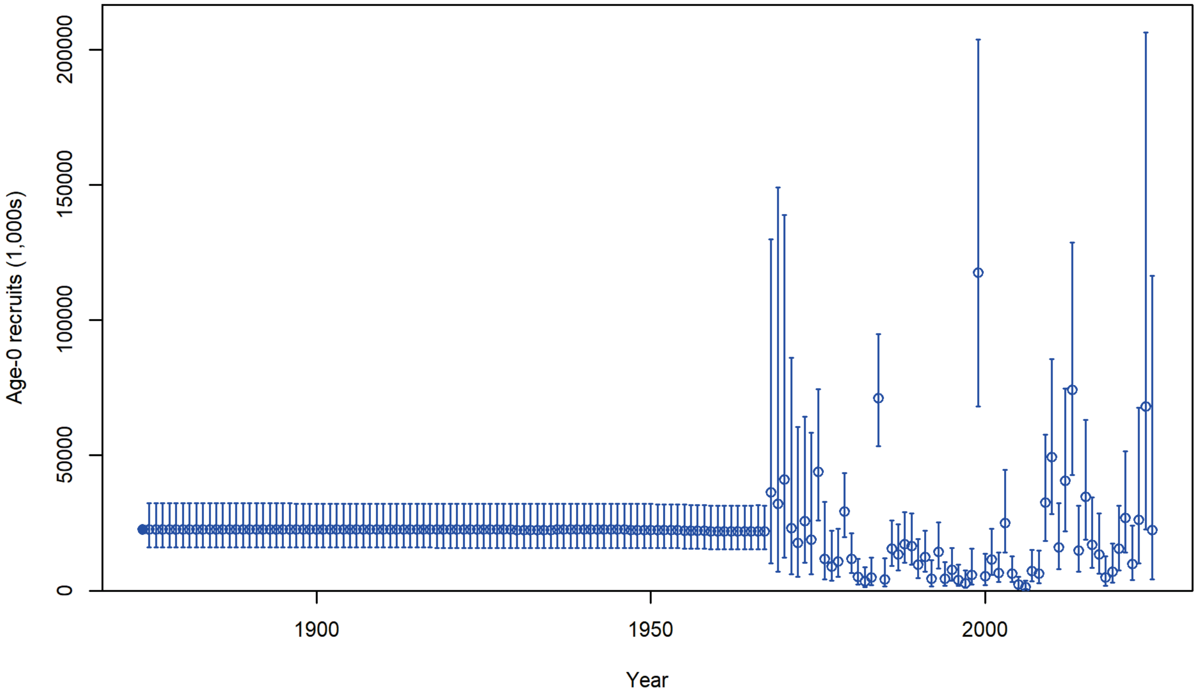


Figure d. Time series of estimated recruitment (1000's of age-0 fish) in the chilipepper base model.

Table c. Estimated recent trend in recruitment (1,000s) and recruitment deviations with 95 percent intervals for the model area. * Recruitment in 2025 is equal to the stock-recruitment curve.

Year	Recruitment (1,000s)	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2015	34600	18951	63172	0.922	0.492	1.351
2016	16900	8301	34406	0.190	-0.400	0.779
2017	13443	6331	28541	-0.055	-0.706	0.596
2018	4819	1831	12685	-1.092	-2.022	-0.162
2019	7063	2854	17479	-0.718	-1.569	0.134
2020	15418	7550	31485	0.059	-0.549	0.667
2021	26998	14146	51524	0.618	0.104	1.133
2022	9842	4022	24083	-0.389	-1.225	0.448
2023	26252	10191	67625	0.596	-0.307	1.500
2024	68168	22524	206308	1.438	0.324	2.552
2025*	22297	4271	116413	0	-1.960	1.960

Exploitation status

Based on the best available historical catch reconstructions, exploitation rates of chilipepper rockfish exceeded target levels from the mid-1980s through the 1990s (Figure e). Exploitation rates since the 2000s have been well below target, with an increasing trend in recent years (Table d). Estimated spawning output dropped briefly below the MSST during the mid-1990s, but has exceeded target levels since the mid-2000s (Figure e).

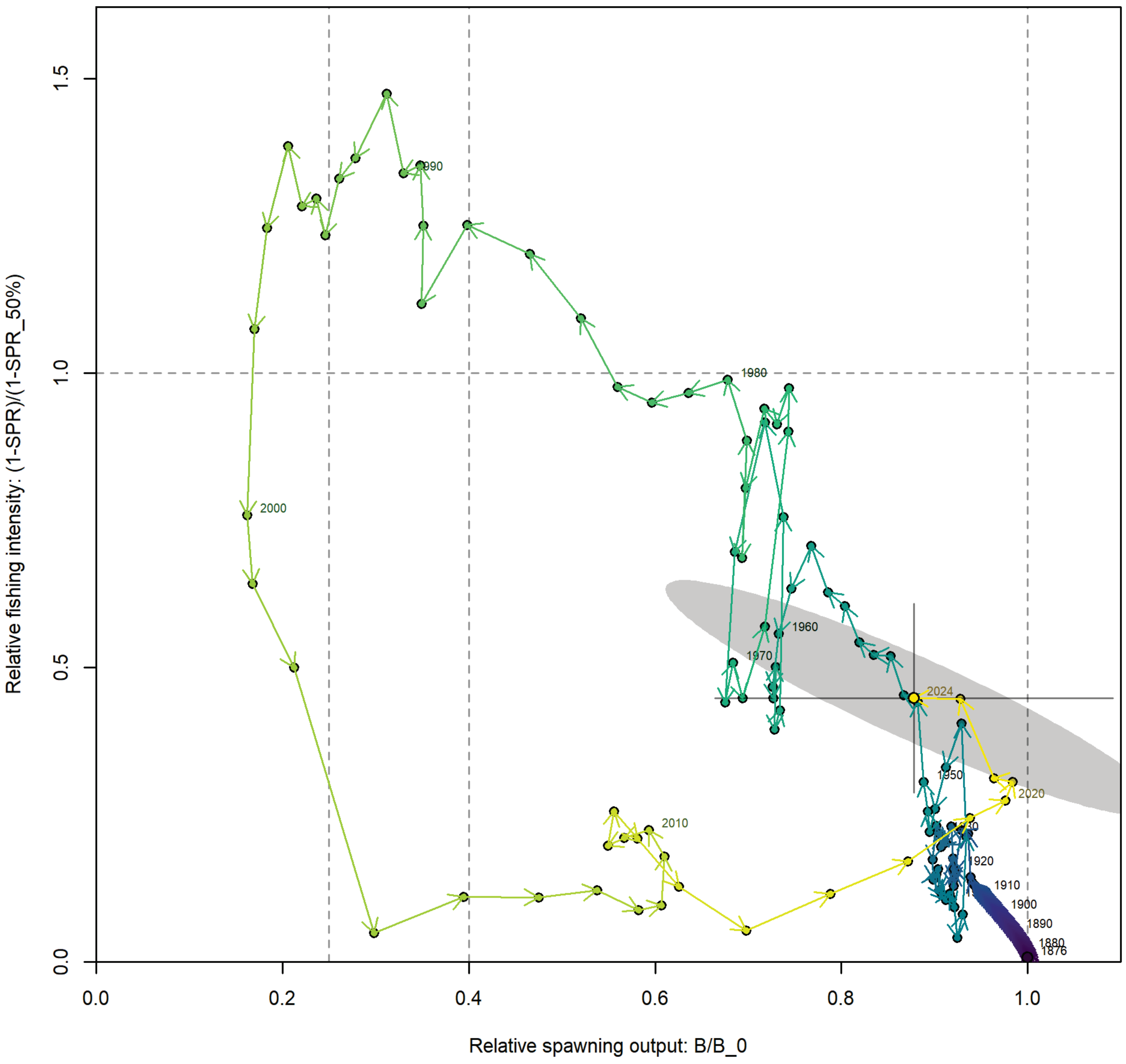


Figure e. "Phase" plot illustrating the rate of fishing intensity relative to the target level (vertical axis) versus the annual spawning output relative to the unfished level (horizontal axis), 1875-2024. Uncertainty around estimates of relative spawning output and fishing intensity in 2024 is represented by the shaded ellipse and crosshairs around that point.

Table d. Estimated recent trend in fishing intensity relative to target, (1-SPR)/(1-SPR 50%). SPR is the spawning potential ratio in equilibrium given the exploitation rate, and uncertainty in this quantity is shown as 95% asymptotic confidence intervals. Exploitation rates (and 95% C.I.s) in this table assume exploitable biomass consists of age 3+ fish.

Year	(1-SPR)/ (1-SPR 50%)	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2015	0.127	0.071	0.183	0.006	0.003	0.008
2016	0.053	0.029	0.077	0.002	0.001	0.003
2017	0.115	0.064	0.165	0.005	0.003	0.007
2018	0.170	0.098	0.242	0.008	0.005	0.010
2019	0.244	0.144	0.343	0.012	0.007	0.017
2020	0.274	0.165	0.384	0.014	0.009	0.020
2021	0.305	0.186	0.425	0.017	0.011	0.023
2022	0.312	0.191	0.433	0.018	0.012	0.025
2023	0.446	0.286	0.606	0.028	0.018	0.039
2024	0.447	0.287	0.608	0.028	0.017	0.038

Ecosystem considerations

Chilipepper are reasonably well-sampled throughout their life history relative to most rockfishes, in larval surveys, pelagic juvenile young-of-the-year (YOY) surveys and bottom trawl surveys, and there is a considerable body of literature, in addition to the results of past stock assessments, on the dynamics and ecosystem interactions throughout these stages. Both larval and pelagic juvenile abundance, as well as estimates of year class strength from previous stock assessments, clearly indicate considerably interannual variability in recruitment, which is typically thought to be primarily a function of variable growth and mortality in late larval or early juvenile life history stages, which is in turn related to large-scale variability in environmental conditions (Field et al. 2010, Ralston et al. 2013, Schroeder et al. 2019). Past stock assessments have also identified interannual variability in growth, which analyses presented here also conclude as considerable (Appendix A), as well as a nontrivial amount of interannual variability in reproductive output in response to environmental conditions (Beyer et al. 2024). Consistent with research into drivers of interannual variability in pelagic YOY, variability growth and reproductive output has also been either shown or suggested to vary in response to environmental conditions, although the potential for density-dependent processes as contributing factors have been less thoroughly evaluated. Much of that information is more rigorously synthesized in analysis supporting the risk table (Section 4.3.1).

Reference points

Management reference points for the coastwide stock (Table e) suggest that stock status is above target, with a point estimate of 83% of unfished spawning output in 2025 (95% asymptotic confidence interval: 63% - 104%). Long-term equilibrium yield based on Spawning Potential Ratio (SPR) proxy harvest rates is 2114 mt coastwide (95% asymptotic confidence interval: 1588 – 2639 mt), compared to 2230 mt based on the SB40% proxy and 2421 mt based on the peak of the yield curve given a Beverton-Holt stock-recruitment relationship with steepness fixed at 0.72. Exploitation rates represent catch as a fraction of age 3+ biomass.

Table e. Chilipepper base model reference points and 95% asymptotic intervals.

Reference Point	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output (billions of eggs)	11,922	10,006	13,839
Unfished Age 3+ Biomass (mt)	50,121	41,265	58,976
Unfished Recruitment (R0, 1000s of fish)	22,734	14,697	30,770
Spawning Output (2025, billions of eggs)	9,925	6,263	13,587
Fraction Unfished (2025)	0.832	0.628	1.037
Reference Points Based SB40% Proxy for SB_{MSY}			
Proxy Spawning Output SB40%	4,769	4,002	5,536
SPR Resulting in SB40%	0.458	0.458	0.458
Exploitation Rate Resulting in SB40%	0.089	0.080	0.098
Yield with SPR Based on SB40% (mt)	2,230	1,672	2,787
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (SPR50)	5,319	4,464	6,174
SPR 50%	0.5	--	--
Exploitation Rate Corresponding to SPR50	0.077	0.070	0.085
Yield with SPR50 at SB SPR (mt)	2,114	1,588	2,639
Reference Points Based on Assumed MSY Values			
Spawning Output at MSY (SB MSY)	3,056	2,563	3,548
SPR MSY	0.329	0.323	0.334
Exploitation Rate Corresponding to SPR MSY	0.136	0.121	0.151
MSY (mt)	2,421	1,807	3,035

Management performance

Chilipepper rockfish in U.S. waters are currently managed south of 40° 10′ N. latitude (roughly Cape Mendocino, California) with a species-specific harvest specification. North of Cape Mendocino, chilipepper are a component stock in the PFMC’s northern shelf rockfish complex. Total mortality estimates for chilipepper rockfish south of 40° 10′ N. latitude have been well below the Annual Catch Limit since 2015 (Table f). Estimates of total mortality reported here are from the Groundfish Expanded Mortality Multiyear (GEMM) report.

Previous assessments have allocated yield to these areas as follows: 93% to the southern area (species-level ACL), and 7% as a species-specific contribution to the OFL/ABC/ACL for the northern shelf rockfish complex. An analysis of biomass distribution over the past five years (2019-2024), based on the WCGBTS index created for this assessment, supports the same yield allocation. Extending the analysis to include all years of the survey (2003-2024) produces the same allocation estimate.

Table f. Evaluation of Management Performance for chilipepper rockfish. * In this table, total mortality (mt) North of 40° 10′ N. latitude is reported for chilipepper rockfish only, but since chilipepper is managed as part of a stock complex in this area, the OFL/ABC/ACL are defined for the complex as a whole. * The Groundfish Expanded Mortality Multiyear (GEMM) report on total mortality for 2024 was not yet released when this assessment was prepared.

South of 40° 10′ N. latitude (harvest specifications set for chilipepper alone)

Year	OFL (mt)	ABC (mt)	ACL (mt)	Total Mortality (mt)
2015	1703	1628	1628	204
2016	1694	1619	1619	92
2017	2727	2607	2607	128
2018	2623	2507	2507	299
2019	2652	2536	2536	413
2020	2521	2410	2410	665
2021	2571	2358	2358	749
2022	2474	2259	2259	814
2023	2401	2183	2183	1213
2024	2346	2121	2121	*

North of 40° 10′ N. latitude (chilipepper is a component of the northern shelf rockfish complex)

	Shelf Rockfish Complex (harvest specifications)			Chilipepper
Year	OFL (mt)	ABC (mt)	ACL (mt)	Total Mortality (mt)
2015**	2209	1944	1944	7
2016**	2218	1953	1953	10
2017	2303	2049	2049	98
2018	2302	2048	2048	105
2019	2309	2054	2054	236
2020	2302	2048	2048	110
2021	1888	1511	1511	110
2022	1821	1450	1450	62
2023	1614	1283	1283	64
2024	1610	1278	1278	*

Unresolved problems and major uncertainties

- Likelihood profiles indicate that input data were informative for estimating natural mortality (M) but not steepness (*h*). The available data are only weakly informative about the steepness parameter (*h*) of the assumed Beverton-Holt stock recruitment relationship, and model output is highly sensitive to this parameter. The base model fixes steepness at the mean of the prior probability distribution ($h = 0.72$). When estimated, the parameter central tendency is much lower ($h \sim 0.4$, i.e., suggesting a less productive stock), despite the fact that the largest estimated recruitment (in 1999) occurred near the lowest biomass level.
- Skewed sex ratios observed in the catch may be caused by sex-specific natural mortality rates, sex-specific selectivity, or a combination of the two. The base model assumes that natural mortality rates vary by sex, and that selectivity is independent of sex.
- Future assessments would benefit from additional research into sources of chilipepper ageing error. The model's fit to the conditional age-at-length data displayed large, positive residuals for males at the upper edge of their size range in several year/fleet combinations. Large, positive residuals were also detected for females in some year/fleet combinations, with a greater-than-expected number of females that were older than expected, given their length. Sex-specific sizes and ages should be evaluated further (e.g., by revisiting original datasheets, examining otolith morphology, or reviewing archived biological samples) to resolve uncertainties about notable outliers
- Although results provided in an appendix to the stock assessment suggested the presence of time-varying growth, sensitivity analyses indicated minimal influences on model results. Thus, the model assumed that growth is time-invariant. Analyses of time-varying growth in the model were limited to variation in the parameter 'k' from the von Bertalanffy growth function. Temporal variation in L_∞ (potentially correlated with k) may have a greater effect on model results.
- Model fit to the WCGTS index, particularly in the early part of the time series, warrants further investigation, including additional work on index standardization.
- Catchability (q) estimates for trawl survey indices are counter-intuitive (i.e., near or greater than 1). Indices of abundance from these surveys are not used to inform absolute abundance, but additional research is needed to understand the scale implied by the model-based abundance estimates.
- Further evaluation is needed regarding the inclusion of a depth effect in the Triennial survey index, given that fits to the WCGBTS were improved by inclusion of depth as a covariate.
- Historical catch reconstructions are subject to uncertainty stemming from issues with species identification and the spatiotemporal extent of data collection, highlighting the need for uncertainty estimates comparable to those used for model-based indices.
- There is uncertainty in mean productivity estimates when applying a sum-to-zero constraint on recruitment deviation, potentially due to inaccurate assumptions about the stock-recruitment relationship. See Appendix B, Requests #4 and #17 for additional details.
- Estimation of selectivity and associated time blocking remain difficult for this assessment.

Decision table and harvest projections

Alternative states of nature defined by three values of the Beverton-Holt steepness parameter (*h*) were identified during the STAR panel, representing uncertainty that was not accounted for by the base model. A “low-productivity” alternative (*h*=0.38) and “high-productivity” alternative (*h*=0.97) are presented in addition to the base model (*h*=0.72). Population dynamics were forecast 12 years ahead for each state of nature, assuming two different catch projections requested during the STAR panel (Table g; see also Appendix B, Request 18). Catch projections for 2025-2026 and fleet allocations for 2027-2036 were provided for each area and fleet by representatives on the GMT. Yields associated with the Overfishing Limit (OFL), Acceptable Biological Catch (ABC), and the assumed buffer to account for scientific uncertainty in the ABC, are provided in Table h. Since spawning output is estimated to be above the management target (40% of unfished), Annual Catch Limits (ACLs) are equal to the ABC. Projections assume a relatively strong 2024 year class (see the “Recruitment” section of the Executive Summary).

Table g. 12-year projections (2025 – 2036) for chilipepper rockfish according to three alternative states of nature. Columns represent low, medium (base case), and high states of nature, and rows range over different assumed catch levels (the default harvest control rule, and constant catches equal to the MSY proxy). Spawning output units are billions of eggs.

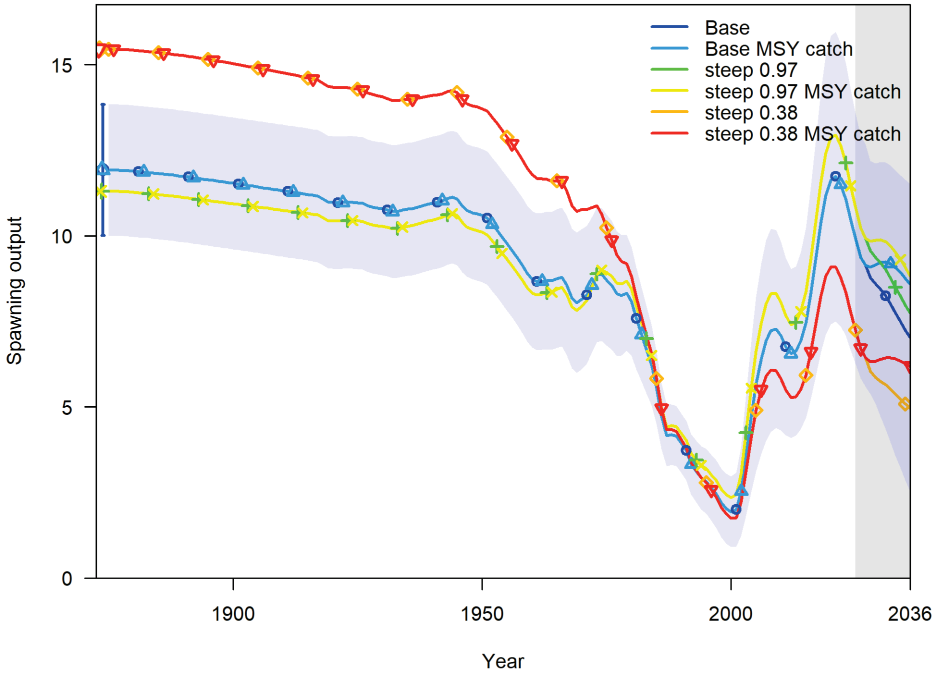
		Low Productivity (steepness = 0.38)		Base Model (steepness = 0.72)		High Productivity (steepness = 0.97)	
	ACL=ABC catch	spawning output	% of unfished	spawning output	% of unfished	spawning output	% of unfished
2025	1599*	7247	46.9%	9925	83.2%	10836	95.9%
2026	1522*	6704	43.4%	9369	78.6%	10212	90.3%
2027	3211	6435	41.6%	9133	76.6%	9927	87.8%
2028	3086	6041	39.1%	8778	73.6%	9559	84.6%
2029	3010	5854	37.9%	8597	72.1%	9369	82.9%
2030	2960	5744	37.2%	8437	70.8%	9205	81.4%
2031	2901	5642	36.5%	8242	69.1%	9006	79.7%
2032	2821	5520	35.7%	8006	67.2%	8764	77.5%
2033	2725	5379	34.8%	7746	65.0%	8494	75.2%
2034	2621	5232	33.9%	7483	62.8%	8221	72.7%
2035	2525	5091	32.9%	7235	60.7%	7965	70.5%
2036	2439	4962	32.1%	7014	58.8%	7736	68.4%
	SPR Proxy MSY catch	spawning output	% of unfished	spawning output	% of unfished	spawning output	% of unfished
2025	1599*	7247	46.9%	9925	83.2%	10836	95.9%
2026	1522*	6704	43.4%	9369	78.6%	10212	90.3%
2027	2114	6435	41.6%	9133	76.6%	9927	87.8%
2028	2114	6312	40.8%	9078	76.1%	9835	87.0%
2029	2114	6333	41.0%	9149	76.7%	9863	87.3%
2030	2114	6391	41.4%	9217	77.3%	9875	87.4%
2031	2114	6431	41.6%	9231	77.4%	9823	86.9%
2032	2114	6434	41.6%	9180	77.0%	9701	85.8%
2033	2114	6400	41.4%	9071	76.1%	9519	84.2%
2034	2114	6339	41.0%	8923	74.8%	9300	82.3%
2035	2114	6264	40.5%	8752	73.4%	9062	80.2%
2036	2114	6184	40.0%	8572	71.9%	8821	78.0%

Table h. Projections of potential OFLs (mt), ABCs (mt), estimated spawning output (billions of eggs), and fraction unfished. Projections assume catches are equal to the ABC starting in 2027, and based on default values for a "category 1" assessment (sigma=0.5 and Pstar = 0.45). Catch estimates for 2025 and 2026 (1598.72 and 1521.61 mt, respectively) were provided by the Groundfish Management Team (GMT).

Year	Predicted OFL (mt)	ABC (mt)	Buffer	Spawning output	Fraction Unfished
2025	--	--	--	9925	0.832
2026	--	--	--	9369	0.786
2027	3434.3	3211.1	0.935	9133	0.766
2028	3318.1	3085.8	0.930	8778	0.736
2029	3250.8	3010.3	0.926	8597	0.721
2030	3210.7	2960.2	0.922	8437	0.708
2031	3163.1	2900.5	0.917	8242	0.691
2032	3090.3	2821.4	0.913	8006	0.672
2033	2997.8	2725.0	0.909	7746	0.650
2034	2899.1	2620.8	0.904	7483	0.628
2035	2805.2	2524.7	0.900	7235	0.607
2036	2721.5	2438.5	0.896	7014	0.588

Estimated stock trajectories associated with Table g are shown as Figure f. For all projections, spawning output and depletion estimates decline over the course of the 12-year projection (2025-2036). Declines accelerated in the ABC catch streams relative to the equilibrium MSY catch streams for each state of nature. The models that assume high steepness start closer to the estimated unfished level (approximately 95% of the unfished level in 2025) and decline less rapidly than the base model and models with low steepness. The only scenario where spawning output declines below target levels is the low steepness model combined with ABC catches, which suggests that stock status could decline to approximately 32% of unfished spawning output by 2036.

Because the stock is estimated to be above target biomass and all assumed 12-year catch alternatives are equal to or greater than MSY, projected stock status declines in every scenario outlined above, as fishing reduces the stock to target levels. Under the default harvest control rule, this 'fishing down' of the stock temporarily estimates yields greater than the estimated SPR=50% proxy for Maximum Sustainable Yield (MSY), which the base model estimates as 2114 mt per year.



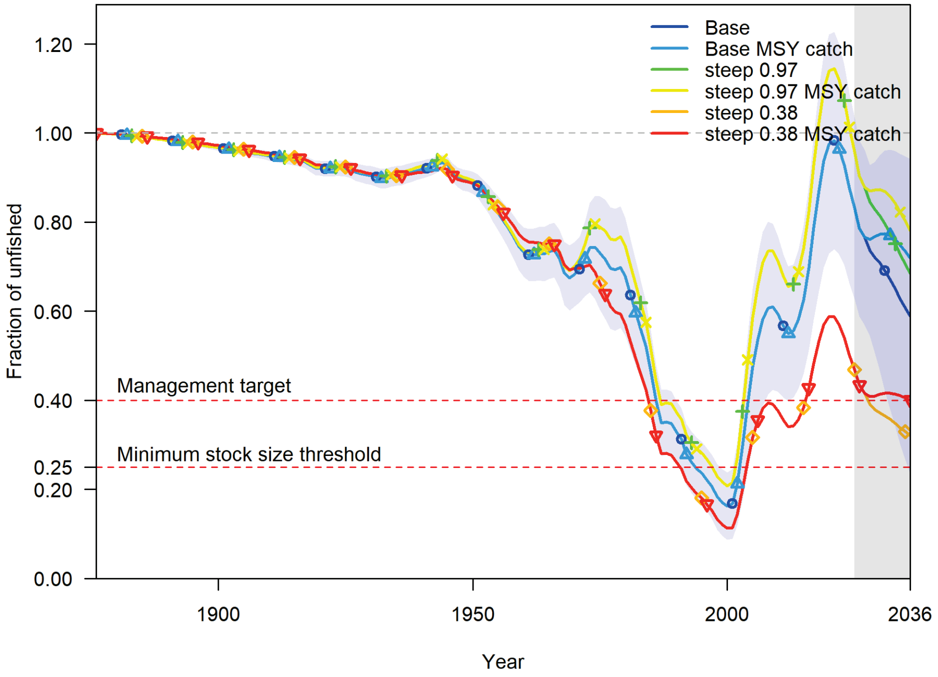


Figure f. Estimated 2025-2036 projections of spawning output in trillions of eggs (top panel, shaded area) and relative spawning output ("Fraction of unfished"; bottom panel, shaded area) for: a) the base model (Beverton-Holt "steepness" = *h* = 0.72), b) a high-productivity alternative state of nature (*h* = 0.97), and c) a low-productivity alternative state of nature (*h* = 0.38). Catch projections under each state of nature include SPR Proxy MSY catches held constant at 2114 mt per year and the default rockfish harvest control rule catch stream ("ABC" in Table h) from the base model represent the alternative catch projections in each state of nature.

Research and data needs

- Addressing the underlying productivity in the spawner-recruit relationship (“steepness”) remains a key research and data need for West Coast rockfish stocks. This model, like most West Coast rockfish models, continues to use the mean of the prior distribution from a meta-analysis, despite a suite of issues and concerns related to the inability to appropriately update that analysis.
- Among the ongoing efforts to better develop priors or other information to inform steepness include an effort to use a life-history based approach based on Mangel et al. (2010), in preparation as Beyer et al. (in prep), for which chilipepper are one of four species under evaluation. This approach suggests that steepness values considerably higher than that used in the meta-analysis are plausible, although the study needs to be completed and other considerations discussed before this work is ready for application, and the work would benefit from additional research into some of the life-history based relationships to better inform future implementation.
- Ongoing research provides strong insights into the environmental mechanisms related to variability in recruitment, as well as variability in growth and reproductive output. Such research should remain a high priority, particularly with respect to the potential to better inform forecasting.
- Further investigation of the relative importance of time-varying growth on chilipepper population dynamics is needed. Evidence suggests that growth variation is auto-correlated (possibly at multiple time scales; Appendix A), and methods to model this within the assessment may be needed, including correlations between growth parameters (e.g., k and $L\infty$).
- Further exploration of cohort and density-dependent effects at the assemblage level (particularly for co-occurring species like bocaccio, yellowtail, and widow rockfishes) may increase our understanding about variation in growth rates for chilipepper rockfish.
- Prioritize completion of analysis of the historic CalCOFI data from central California to expand the time series for future assessments.
- Further development of the spatiotemporal models would improve index standardization. This may include the use of barrier meshes to account for geographic barriers and unique coastline features. Residual diagnostics should be evaluated by depth, especially for demersal species, to decide whether to include a depth effect in the model (even when including anisotropy to account for variables like depth).
- Examination of factors contributing to skewed sex ratios in the catch is needed, e.g., sex-specific natural mortality, selectivity, and/or discards.
- Age validation for chilipepper rockfish is needed. Standardization of ageing methods is also needed to minimize ageing error, including both “traditional” (break-and-burn) methods and ages derived from FT-NIRS (scanning and modeling).
- A small number of ages derived from FT-NIRS were included using a unique ageing error matrix, yet model selection did not indicate a bias between FT-NIRS and traditional ageing methods. Visual inspection suggests a consistent bias toward younger FT-NIRS ages for older fish. This may reflect limitations in the bias structures available in the ageing error software, supporting an improved understanding about differences between FT-NIRS and traditional break-and-burn ages.
- Selectivity estimation remains a challenge for this assessment due to complex and changing management measures. Further investigation into time-blocking and/or a more structured spatiotemporal modeling (e.g., by length groups or age) approach could clarify how to incorporate management and gear changes in future models by indicating which size/age might be affected by such changes.
- This assessment attempts to account for multiple brooding of larger, older female chilipepper with respect to larval production and reproductive output. However, both the spatial and temporal variability associated with this phenomenon could be better understood. An improved understanding of the environmental factors associated with variable reproductive output,

including multiple brooding, could also lead to an improved interpretation of the CalCOFI larval abundance time series, as it is likely that some of the high variance observed in that time series relates to interannual variability in reproductive output, relative to simple sampling variance alone. Additionally, ongoing efforts positively identify chilipepper larvae from the earliest part of the CalCOFI time series would greatly benefit the ability of that time series to inform the model.

- Additional biological research on skip spawning, functional maturity, and environmentally driven variation in brooding frequency is needed to improve estimates of fecundity.
- Although there is a reconstruction of historical rockfish landings for California waters, the current reconstruction does not explicitly account for the expansion of both fixed gear and trawl fisheries into deeper habitats, further from port, over time (as discussed in Miller et al. 2014 and the 2017 catch reconstruction review; PFMC 2017). Ongoing catch reconstruction efforts are also focused on efforts to quantify the uncertainty associated with both historical and recent catches (Grunloh et al. 2017), the completion of these efforts would better allow for this uncertainty to be accounted for in future assessment models.
- A better understanding about the portion of the population in Mexican waters may be supported by habitat suitability mapping.
- Continued research on density-independent effects on YOY survival, especially for integration into future risk tables. This includes developing an inshore-offshore index for the southern population and exploring moving average approaches to link the "minty-spicy" temperature index to recruitment dynamics.
- A better understanding about predator-prey dynamics would improve our understanding about time-varying natural mortality.
- If the at-sea hake fishery begins targeting hake in waters off California, and bycatch rates increase, collection of biological data (lengths, otoliths) from chilipepper will be useful for future assessments.

Scientific uncertainty

The base model’s estimate of the log-scale standard deviation (“sigma”) of the overfishing limit (OFL) in 2025 is 0.2284. This is less than the Scientific and Statistical Committee’s default value of sigma = 0.5 for a category 1 assessment, so harvest projections in this document assume an initial sigma of 0.5.

Risk Table

For chilipepper, there is a considerable body of literature relating various aspects of productivity to environmental factors, including patterns of variability associated with adult growth and reproductive output, early larval dynamics (parturition timing, ocean transport and survival), through processes associated with pelagic juvenile growth, abundance and distribution. A common thread is that adult growth and reproductive output, larval condition and growth, and pelagic juvenile abundance, all appear to be greater during cool, high productivity ocean conditions, which are typically associated with a negative Pacific Decadal Oscillation (PDO) and/or positive North Pacific Gyre Oscillation (NPGO), and more specifically with a higher proportion of subarctic (“minty”) rather than subtropical (“spicy”) source waters occurring within the California Current Ecosystem. Further, euphausiid (krill) abundance, a key forage resource for all life history stages, are generally higher during these cooler environmental phases. Throughout 2024, summer and fall NPGO values were negative (indication of reduced southward transport), which would be consistent with poorer condition and lower reproductive output for chilipepper. However, for winter and spring of 2025, PDO values have been negative, and subsurface waters off of central California (35-37° N) have been among their “mintiest” (most subarctic) since 2015. The “minty” conditions are consistent with both greater pelagic juvenile abundance and recruitment based on the current assessment model (see section 4.3.1). Thus, most environmental information is consistent with estimates of above average 2024 recruitment in the base model, as well as with an expectation of above average recruitment for the 2025 year class, which is not evaluated in the base model. See Table i for a summary of potential factors affecting stock productivity.

Table i. 'Risk Table' for chilipepper to document ecosystem and environmental factors potentially affecting stock productivity and uncertainty, or other concerns arising from the stock assessment. Level 1 is favorable, Level 2 is neutral, and Level 3 is unfavorable.

Ecosystem and environmental conditions	Assessment data inputs	Assessment model fits and structural uncertainty
Larval production and condition: Based on 2024- 2025 NPGO, may be neutral to unfavorable, but signals are somewhat mixed Recruitment: Index used in assessment. High diversity and abundance of the YOY groundfish assemblage community in 2024 consistent. Environmental conditions are favorable for 2025 (minty/subarctic), high preliminary survey catch rates. Overall, favorable for recruitment Prey: Most evidence suggests abundant forage, favorable conditions, positive Predators: Ongoing long-term increases in abundance, but no evidence of recent sharp increases, neutral Growth: Recent years potentially unfavorable in near term (based on autocorrelation in growth variability), neutral	Historically and currently among most important commercial species in California, catch reconstruction and recent catch data are reliable, favorable Robust age data to inform assessment, modest aging error concerns need resolution, neutral to favorable Robust information on reproductive ecology, but better data on functional maturity and role of multiple brooding would be helpful, neutral to favorable Several informative fishery independent indices that span life history stages, including larval production/spawning output (CalCOFI), settled juvenile and mature adult biomass (WCGBTS), and pelagic YOY abundance (RREAS), favorable	Good fits to age and length composition data. Generally good fits fishery-independent survey data, particularly in more recent years, favorable Several abundance indices help inform recent recruitment and population forecasts (e.g., WCGBTS, RREAS), favorable Selectivity functions are not always well behaved, unfavorable Evidence for time-varying growth in data, but growth assumed to be time-invariant within the model, neutral Likelihood profiles indicate that natural mortality is well informed, but steepness is not well informed. Steepness provides axis of uncertainty for decision table, neutral
Level 1, favorable (medium agreement, robust evidence)	Level 1, favorable (high agreement, robust evidence)	Level 2, neutral (medium agreement, medium evidence)

1 Introduction

1.1 Basic Information

Chilipepper rockfish (*Sebastes goodei*) are a mid-size, semi pelagic rockfish found primarily in shelf and shelf-break waters off California, where they have been among the most important commercial and recreational rockfish species in both historical and contemporary groundfish fisheries. They are described as “streamline” rockfish species, an elongate fish with reduced head spines, similar in appearance to both the more diminutive shortbelly rockfish (*S. jordani*) and the considerably larger bocaccio (*S. paucispinis*) (Love et al. 2002; Love 2011). The Latin name honors the 19th century ichthyologist George Brown Goode, who served the Smithsonian Institution and was also the United States Commissioner for Fish and Fisheries from 1887 to 1888. The common name was derived from the observation that long strings of these bright red fish resemble a string of drying chilis (Davis 1949). They have been one of the most important commercially targeted rockfishes in southern and central California waters since the 1880s, and are important component of recreational fisheries as well.

Chilipepper’s distribution is generally described as ranging from Queen Charlotte Sound in British Columbia to Bahia Magdalena in Baja California Sur (Westrheim 1965; Eschmeyer et al. 1983; Love et al. 2002). Historically, they were uncommon north of Cape Blanco (Oregon) and south of Punta Colnett (Baja California Norte), and past assessments have not included the minor catches north of Oregon nor south of the U.S./Mexico border. This assessment expands the spatial footprint of the stock to include Washington waters, consistent with the stock definition for chilipepper adopted by the PFMC. The region of greatest abundance and the historically highest catches have generally been between Point Conception and Cape Mendocino, California. Alverson et al. (1964) reported only trace catches of chilipepper rockfish in resource surveys conducted in the 1960s off Oregon and Washington, all of which was noted between approximately 200 and 300 fathoms. More recent survey data may indicate somewhat greater biomass in recent years off Oregon waters, and indeed recent catches have been considerably greater than historical catches for this region as well.

1.1.1 Stock structure

Wishard et al. (1980) conducted the only known genetic study of stock structure, from samples collected between 34° and 40° N. They concluded that chilipepper was unusual in its very low levels of allozyme variability, with no suggestion of population substructure. An extensive review of phylogenetic relationships among *Sebastes* found that chilipepper rockfish were most closely related to the two species with which they generally resemble morphologically; shortbelly rockfish (*S. jordani*) and bocaccio (*S. paucispinis*), with a lineage that dated back approximately 6 million years (Hyde and Vetter 2007). No substantive investigations into stock structure have been published since that time, however with respect to demographic considerations, Field and Ralston (2005) evaluated spatial patterns in recruitment variability based on regional catch at age models, and concluded that recruitment is largely synchronous throughout most of the range of chilipepper, between Cape Blanco and Point Conception. This suggests strong demographic connectivity, consistent with the suggestion of a single stock, although there were insufficient data to include recruitment estimates or trends south of Point Conception. Following the 2015 stock assessment, Solinger (2019) revised and updated that analysis with over a decade of newly available age data and reached similar conclusions.

Ralston et al. (1998) assessed chilipepper rockfish and defined the stock as the combined Eureka, Monterey, and Conception International North Pacific Fisheries Commission (INPFC) areas, i.e., U.S. waters south of roughly Cape Blanco, Oregon. Field (2007) extended the assessed area to include all of

Oregon. Although relatively few chilipepper are observed off the coast of Washington, landings from that state have been included in the current analysis to facilitate coastwide management based on a single assessment model. Information about stock structure from genetic analyses and tagging studies is outdated (e.g., Wishard et al. 1980) and/or has insufficient sampling effort to detect evidence of reproductive isolation or movement patterns. An analysis of rockfish evolution by Hyde and Vetter (2007) was able to detect cryptic speciation in what came to be known as vermilion and sunset rockfishes. They found no similar evidence for chilipepper, although the sampling design may not have been configured to address that question. Analyses conducted for this assessment suggest that patterns of adult growth (length-at-age) are similar across the assessed range. Most catches were taken by trawl gear in California, north of Point Conception (34° 27′ N. lat.), following World War II and roughly until the year 2000 when large-scale spatial closures went into effect. No data are available to inform trends in chilipepper abundance in Mexican waters. Based on these general findings, and the observed synchrony in recruitment described above, the population dynamics are modeled as a single, "coastwide" stock in U.S. waters from the U.S./Mexico border (roughly 32.5° N. latitude) to the U.S./Canadian border (49° N. lat.).

1.2 Map

A map of the assessment area with selected coastal features is provided as Figure 1.

1.3 Life History

Chilipepper are part of a very speciose genus of rockfishes (*Sebastes*) in the California Current ecosystem, an ecosystem characterized by strong seasonal, interannual and interdecadal variability in ocean conditions and subsequent productivity of most important fishery species. Like all *Sebastes*, chilipepper are primitively viviparous and bear live young at parturition. While many exploited rockfishes have slow growth rates, are late to mature and have great longevity (many live to 100 years or more; Love et al. 2002, Berkeley et al. 2004), chilipepper generally have a "faster" life history; they mature between the ages of 2 and 4, have relatively fast growth rates, and reach a maximum age close to 35, although relatively few individuals older than 25 years are observed in age composition data.

Adult fish tend to be most abundant in large schools between 100 and 300 meters, often in midwater. Chilipepper are among the species of rockfish that can rapidly change color and pattern; when in midwater they are often solidly pigmented with brown on the back and pink on the flanks, but within seconds of settling on the seafloor they become darker and more blotched and patterned (Love 2011; Butler et al. 2012). Settled juveniles can be found in shallow water, but rapidly move to greater depths with size and age, and there are strong ontogenetic patterns throughout their life history, with larger and older individuals typically found at greater depths. While often found midwater, Love et al. (2002) describe the benthic habitat associations of adult chilipepper schools as including boulder fields and other high relief substrata, as well as occasionally low-relief cobblestones. Despite bocaccio being a known predator of chilipepper, the two species may co-occur in large semi-pelagic schools. They are rarely observed in visual surveys (ROV or submersible), being observed with far less frequency than species that have considerably lower abundance (such as cowcod, yellowtail rockfish or vermilion rockfish). One interesting anecdotal visual survey observation suggests that this could be due to differences in their response to threats. During a benthic survey using a manned submersible, a large mixed school of chilipepper and bocaccio was observed above rocky habitat ~10 m in front of the submersible. As the submersible approached, the bocaccio descended to the benthic habitat and were counted in the survey while the chilipepper rose into the water column above the submersible and were out of the transect.

1.4 Ecosystem Considerations

Chilipepper are well to reasonably well sampled throughout their life history; in larval surveys, pelagic juvenile young-of-the-year (YOY) surveys and bottom trawl surveys, and there is a considerable body of literature, in addition to the results of past stock assessments, on the dynamics and ecosystem interactions throughout these stages. Both larval and pelagic juvenile abundance, as well as estimates of year class strength from previous stock assessments, clearly indicate considerably interannual variability in recruitment, which is typically thought to be primarily a function of variable growth and mortality in late larval or early juvenile life history stages, which is in turn related to large-scale variability in environmental conditions (Field et al. 2010, Ralston et al. 2013, Schroeder et al. 2019). Past stock assessments have also identified interannual variability in growth, which analyses presented here also conclude as considerable (Appendix A), as well as a nontrivial amount of interannual variability in reproductive output in response to environmental conditions (Beyer et al. 2024). Consistent with research into drivers of interannual variability in pelagic YOY, variability growth and reproductive output has also been either shown or suggested to vary in response to variable environmental conditions, although the potential for density-dependent processes as contributing factors have been less thoroughly evaluated. Much of that information is more rigorously synthesized in analysis supporting the risk table (Section 4.3.1).

With respect to trophic interactions, adult chilipepper have been described as midwater foragers, with euphausiids, forage fishes (such as anchovies, Pacific hake, and mesopelagic fishes), and small squids among key prey items (Love et al. 2002). With respect to predation mortality, pelagic juvenile rockfishes of all species, including chilipepper, are among one of the most important forage taxa identified in a meta-analysis of predator food habits studies in the California Current. Key predators of pelagic juveniles including seabirds, salmon, lingcod, tunas and marine mammals (Szoboszlai et al. 2015, Warzybok et al. 2018). Adults are consumed by larger piscivorous fishes, such as bocaccio and lingcod, as well as marine mammals. Predation by Humboldt squid (*Dosidicus gigas*) was documented during a period of range expansion of that species between the early 2000s and approximately 2010, although adult rockfish were a relatively minor component of the diet during that period, the abundance of squid for several years was novel and predation on some prey items potentially substantial (Field et al. 2013).

1.5 Fishery Information

Chilipepper have historically been one of the most important rockfish species in California fisheries. In one of the earliest accounts, Jordan and Evermann (1898) described chilipepper as being “taken in abundance about the Coronados Islands, Santa Catalina, and the Cortez Banks.” Rockfish landings were far greater Southern California Bight in the early 20th century, and chilipepper were described as the “second most important rockfish in southern California rockfish fisheries” (after vermillion) by Walford (1930), and as “one of three leading Southern California species” (along with vermillion and bocaccio) by Roedel (1948).

In central California, chilipepper were also among the most important commercial targets for rockfish fisheries. Although there is relatively little data on the species composition of rockfish catches in those early years, Phillips (1939) reported on the species composition of rockfish from the Monterey wholesale fish markets between April 1937 and March 1938, in which 30.8% of the landings by weight were chilipepper rockfish (with 39.4% bocaccio and 7.9% yellowtail rockfish). Monterey Bay area ports were the most productive along the coast during that period, accounting for 51% of all landings between 1936 and 1940, with San Francisco accounting for another 20%. Catches and landings of rockfish in more northern California ports were minimal until the introduction of the balloon trawl fishery in the early

1940s, during the development of new markets for frozen rockfish by the military to support the war effort. After that development, trawl gear rapidly surpassed hook and line gear in accounting for most California rockfish landings, particularly in the northern ports of Eureka and Fort Bragg, where chilipepper made up a smaller fraction of the commercial catch (Scofield 1948, Phillips 1939).

Along the U.S. West Coast, rockfish landings increased sharply following the post-war period, with a transition from largely hook-and-line caught fish to largely trawl caught. A spike in foreign fishery landings took place during the 1960s and 1970s (Rogers 2003), followed by the more rapid development of the fishery by U.S. participants throughout the 1980s and 1990s, when catches of rockfish peaked. Within California waters, chilipepper continued to represent one of the most important commercial targets, often second only to bocaccio with respect to total landings. As documented in Miller et al. (2014), commercial fisheries landings were made from deeper water habitats, generally further from ports and exposed to more inclement weather, such that chilipepper became an even more important target for commercial fisheries during this period. During the period of more rigorous sampling of the species composition of rockfish market categories in California commercial fisheries, chilipepper catches tend to co-occur and be reported in chilipepper, bocaccio and mixed rockfish market categories, and chilipepper rockfish scored high on an index of reliability of landings estimates within these fisheries (Pearson et al. 2008). Landings began to decline throughout the 1990s in response to declines in abundance of many key target species, such as bocaccio and widow rockfish, and in response to the mandates to rebuild co-occurring populations during the late 1990s and early 2000s.

Recreational fishing effort in California for fishes other than big game fish such as tunas and salmon were relatively modest in California until about 1928, when Commercial Passenger Fishing Vessels (CPFVs) popularized recreational fishing (Croker 1940; Young 1969). Initially, most effort was in the waters of the Southern California Bight; however, party boat fisheries soon became popular in central California regions (particularly Monterey Bay area ports). Chilipepper were historically important in southern California recreational fisheries, but less so in central California fisheries due to their deeper depth distribution (Miller and Gotschall 1965). However, the importance of chilipepper in recreational catches from both regions increased over time, particularly in the CPFV fleets which were able to access more distant and deeper waters, such as Cordell Bank in central California. In this way, recreational fisheries mirrored the pattern observed in commercial fisheries, in which catches (and thus presumably effort) moved to deeper waters, generally further from ports and exposed to more inclement weather with time (Miller et al. 2014).

Miller and Gotshall (1965) and Ralston et al. (2010), among other sources provide more information about recreational rockfish fishery catch trends and species compositions (Ralston et al. 2010 is the source for historical recreational catches). In general, recreational catches have rarely represented more than 10% or so of the historical total catch. Since the late 1990s and early 2000s recreational catches have been minimal until very recently, as a result of spatial closures implemented to help rebuild co-occurring overfished stocks, such as bocaccio, cowcod and canary rockfishes. However, recreational fisheries catches have increased sharply in recent years as access to deeper habitats for recreational fishing has increased.

1.6 Summary of Management History and Performance

Chilipepper rockfish in U.S. waters are currently managed south of 40° 10′ N. latitude (roughly Cape Mendocino, California) with a species-specific harvest specification. North of Cape Mendocino, chilipepper are a component stock in the PFMC’s northern shelf rockfish complex.

Prior to establishment of the U.S. EEZ in 1976, chilipepper were caught by domestic fleets from the late 1800s, with the addition of foreign and joint-venture fisheries starting in the 1960s (Rogers 2003). The Rockfish Conservation Area (RCA) closures to commercial fishing, and corresponding constraints on recreational fishing to exclude deeper waters (particularly in central California) dramatically reduced fishing opportunities for chilipepper rockfish starting in the early 2000s. Landings (or retention) are permitted in all existing fishing activities. For bottom trawl fishing, trip limits were constrained largely due to limits on bocaccio rockfish, at the time one of the shelf rockfish species declared overfished and a species that co-occurs with chilipepper. Trawl landings of chilipepper during this time tended to be greatest south of 40º10' during periods in which the seaward line of the RCA is set at 150 fm, although there were occasional catches of chilipepper shoreward of the RCA as well. As most of the chilipepper biomass is found in the core area of the RCAs, catches have been far lower than OFLs. Table 1 compares the OFL, ABC, and ACL for chilipepper south of Cape Mendocino to estimates of total mortality from the GEMM report.

Amendment 32 to the Pacific Coast Groundfish Fishery Management Plan re-opened sections of the non-trawl RCA and both the Cowcod Conservation Areas. This action provides access to about 4,600 square miles that had been closed for decades. In the Southern California Bight, the Cowcod Conservations areas were closed while smaller Groundfish Exclusion Areas were opened to protect critical habitat and deep-sea corals and sponges. New gears (e.g., non-bottom contact hook-and-line gear) have proven successful at targeting healthy stocks such as chilipepper and yellowtail rockfish, while avoiding impacted demersal species.

In addition to being affected by some of the above-mentioned spatial closures, recreational anglers in California have a daily bag and possession limit for the Rockfish-Cabezon-Greenling (RCG) species group, which includes Chilipepper Rockfish. In 1971, a 20-fish bag limit for rockfish was replaced with a 15-fish limit, after which the limit was reduced to 10 fish in 2000 and has remained the same since. Gear restrictions for sport fishermen were first implemented in 2000, allowing no more than one line with three hooks. The following year, the number of hooks per line was reduced from three to two, and this limit (one line, two hooks) is still in effect as of the time of writing. Current seasonal restrictions on recreational rockfish fishing vary by month, management area, depth, and species group.

1.7 Fisheries off Canada, Alaska, and/or Mexico

Although chilipepper are abundant throughout most California waters, their relative abundance declines sharply in waters north of southern Oregon, and they are only rarely encountered in Canadian waters. Their abundance off Baja California Norte, Mexico, is also poorly described and no robust historical or recent landings estimates are available. Early CalCOFI larval abundance data suggests that there could have been a non-trivial biomass in this region during the 1950s and 1960s, however recent IMOCECAL (Investigaciones Mexicanas de la Corriente de California) data have not been evaluated to ascertain whether chilipepper remain a significant fraction of the rockfish community in this region. A better understanding about the portion of the population in Mexican waters may be supported by habitat suitability mapping.

2 Data

The STAT presented an online overview of available data sources for the chilipepper rockfish assessment during the PFMC Data Workshop held on January 23, 2025. A graphical summary of data sources used in the base model is provided as Figure 2.

2.1 Fishery-dependent data

Fishery-dependent data were split into eight fleets, described below with abbreviations used in many figures and tables throughout this document.

1. Hook and line gears from California, north of Point Conception (“NoCA_HKL”)
2. Hook and line gears from California, south of Point Conception (“SoCA_HKL”)
3. Trawl gear types from California (“CA_TWL”)
4. Commercial gears, combined, from Oregon and Washington (“OR_WA_Comm”)
5. Net gears from California (“CA_NET”)
6. Recreational fishing (all types) north of Point Conception, including Oregon and Washington (“NoCA_OR_WA_Rec”)
7. Recreational fishing (all types) south of Point Conception (“SoCA_Rec”)
8. Trawl discard with mortality rates applied (“TWL_discard”)

2.1.1 Landings

A summary of total removals is provided as Table 2 and Figure 3. Since WWII, the California trawl fleet has accounted for most removals in all but a few years. In recent years, the trawl fleet continues to be the dominant source of landings (Figure 4).

2.1.1.1 Commercial

Commercial data sources used in the chilipepper assessment span the period 1916 – 2024, with an assumed linear ramp in catch from 1875 to the first year of available data (Table 2). This is consistent with reports of a developed rockfish fishery in California in 1875, going back as far as 1860, however there is considerable uncertainty in estimates of historical catch (Phillips, 1957). A comparison of coastwide landings used in the 2017 update shows very close agreement (Figure 5), which is reassuring because the STAT reconstructed the entire time series from original sources for this assessment.

Combined estimates of commercial chilipepper catch [mt] from Oregon and Washington amount to less than 1% of historical removals over the modeled time period. Oregon estimates were obtained from A. Whitman (ODFW, pers. comm.), and Washington estimates were obtained from PacFIN. All gears and areas were combined into a single commercial fleet north of the California/Oregon border.

Estimates of commercial landings [mt] in California are derived from two primary data sources: first, a cooperative port sampling program (California Cooperative Groundfish Survey, CCGS) that collects information including species composition (i.e. the proportion of species by weight landed in a sampling stratum) and biological data (lengths, sex, maturity, otoliths), and second landing receipts (sometimes called “fish tickets”) collected by CDFW that are a record of pounds landed in a given stratum. A map of CCGS port complexes is provided as Figure 6. Strata in California are defined by market category, year, quarter, gear group, port complex, and disposition (live or dead). Although many market categories are named after actual species, catch in each market category can consist of several species, and many species are landed across multiple market categories. This was especially true for rockfish catches prior to 2000 (Figure 7). Fishers have historically used rockfish market categories not only to sort catch by species, but also to sort catch according to price per pound, size, or other factors.

Species composition samples collected by CCGS port biologists are stored in the CALCOM database, and used to partition catch recorded in market categories to individual species. These “expanded” catches are estimated in CALCOM and are also made available via PacFIN. PacFIN is a repository for commercial landings data since 1981, and California's estimated chilipepper catches from the database are nearly identical to those in CALCOM (Figure 8). CALCOM also contains estimated catches from 1978-1980.

Prior to 1981, a variety of sources were available to reconstruct chilipepper catches. Working backwards in time from 1980, these are:

- 1978-1980. CALCOM; the database containing CCGS port sample data (species compositions and biological data such as lengths and ages). Species composition sampling began in 1978 and has been applied to landing receipt data for this time period to estimate catches.
- 1969-1977. Species composition estimates from the earliest available samples (1978-1982, depending on available data in each region) were applied to landing receipts over this time period. We refer to these data as the "ratio estimates."
- 1966-1976. Catches by foreign countries as estimated by Rogers (2003). These were added to the California trawl fleet.
- 1948-1968. Estimates of catch from Oregon waters, landed in California (J. Field, SWFSC). These estimates were not part of the Ralston et al. (2010) catch reconstruction, and were added to the California trawl fleet.
- 1916-1968. Ralston et al. (2010) created a catch reconstruction for California, applying available species composition data to time series of total rockfish landings. These estimates are stratified by species, year, region, and course gear categories (trawl and non-trawl).
- 1875-1915. A linear ramp was used to represent catches leading up to the first year of the Ralston et al. commercial reconstruction.

2.1.1.2 Bycatch in the At-Sea Hake fishery

This assessment is the first chilipepper assessment to include bycatch from the at-sea hake fishery (1966-2024). Estimated bycatch was unusually large in 1991 (Figure 9). Years with larger bycatch amounts correspond with a more southern distribution of fishing in that year (Figure 10). Regulations prohibit processing of catch south of 42 degrees N. latitude (the CA/OR border), but catcher vessels delivering to motherships can still fish south of 42 degrees if catch is delivered north of 42 degrees. If fishing south of 42 degrees becomes more common in the future, it is reasonable to expect chilipepper bycatch to increase. If that occurs, collection of biological data for chilipepper should be considered to aid future stock assessment efforts. To date, chilipepper biological data have not been collected by the observer program. Bycatch data were provided by Vanessa Tuttle (NMFS, NWFSC).

2.1.1.3 Recreational

Estimates of recreational removals in this assessment span the period 1928 – 2024 (Figure 2). Estimates prior to 1980 are based on Ralston et al. (2010; see more details on historical recreational fisheries in section 1.5). Over the modeled period, recreational fleets have accounted for just under 8% of total removals (Table 2). Per recommendations outlined in the 2015 assessment, we define separate recreational fleets north and south of Point Conception, and explore time blocks for selectivity in each fleet to account for large-scale spatial closures. Recreational catch [mt] in Oregon and Washington makes up a small fraction of total recreational landings. Recreational landings [mt] from Oregon were provided by A. Whitman (ODFW).

From 1980-2003, the Marine Recreational Fisheries Statistics Survey (MRFSS) executed a dockside (angler intercept) sampling program in Washington, Oregon, and California. Data from this survey are available from the Recreational Fisheries Information Network (RecFIN). RecFIN serves as a repository for recreational fishery data for California, Oregon, and Washington (www.recfin.org).

MRFSS was replaced with state-run sampling programs beginning January 1, 2004. For California, this marked the beginning of the California Recreational Fisheries Survey (CRFS). Among other improvements to MRFSS, CRFS provides higher sampling intensity, finer spatial resolution (6 districts vs. 2 regions), and onboard CPFV sampling (Figure 11).

Recreational landings were combined across “modes” (party/charter boats, private/rental boats) and districts/areas into two recreational fleets, north and south of Point Conception.

2.1.2 Discards

Field (2007) and Ralston et al. (1998) noted that reports of commercial discards were historically a very small fraction of total landings. For example, Heimann and Miller (1960) reported a bycatch rate of approximately 0.8% for chilipepper from a bottom trawl fishery off Morro Bay, California between August 1957 and July 1958, and Heimann (1963) reported discard rates of approximately 0.4% for bottom trawls made between Pigeon Point and Point Sur, California in 1960. Consequently, we assumed that discards were negligible prior to implementation of large-scale closed areas and trip limits in the 2000s.

The STAT estimated commercial discard ratios (discard/landings) based on West Coast Groundfish Observer Program’s (WCGOP) Groundfish Expanded Mortality Multiyear (GEMM) report. Recent landings and discard estimates from the report (2019-2023) were used to estimate a trawl discard ratio (discard/landings) of roughly 0.09, for use in forecasting discards from the trawl discard fleet (Figure 12). WCGOP’s provides observer data on discarding practices across sectors since 2003. Length data from the observer program were used to estimate the size distribution of discarded catch. Discards prior to 2011 (the beginning of the trawl IFQ fishery) were combined with catches. Discards from 2011 to 2024 are modeled as a separate fleet to reflect changes in the size composition of the catch over time (see the next section on biological data).

Methods used to determine recreational discard mortality have changed significantly over time. Under MRFSS, catch estimates were stratified into sampler-examined retained catch (Type A), angler-reported dead discard and otherwise unavailable retained catch (Type B1), and angler-reported fish that were discarded live (Type B2). The reliability of angler-reported catch and disposition (live/dead) is unknown for this data set. Under CRFS, catch estimates since 2005 are adjusted to account for estimates of depth-dependent discard mortality. These methods have changed over time, as well. We use the CRFS estimates of total mortality from RecFIN without modification.

2.1.3 Biological data

This section describes fishery-dependent length and age composition data used in the assessment. Descriptions of biological characteristics such as adult growth (length at age, weight at length), reproductive biology (maturity, fecundity), and estimates of natural mortality rates are found in the “Biological Parameters” section. Units for body length in all data sets were standardized to fork length in cm. Sample sizes for fishery-dependent length compositions (number of lengths, and number of samples/hauls/trips depending on the source) are provided in Table 3. Age composition sample sizes for fishery-dependent data sources are provided by fleet, year, and sex in Table 4.

Input sample sizes for lengths from California commercial fleets are equal to the number of port samples by year and fleet. Input sample sizes for the Oregon commercial fleet are based on Stewart and Hamel (2014), as implemented in the pacfintools R package. Trawl discard lengths from WCGOP use input sample sizes equal to the number of observed hauls. Recreational input sample sizes for length compositions represent the number of trips and are defined as observed trips for onboard observer data sources, or unique sample identifiers for dockside sampling programs (MRFSS and CRFS).

Length compositions for commercial catch in the model are "expanded" to represent a catch-weighted distribution of lengths by fleet, area, and year. Insufficient samples are available to develop length compositions for Washington (commercial or recreational). For Oregon, commercial length compositions (all gears combined) were provided by A. Whitman (ODFW), based on the pacfintools R package developed by the NWFSC. For the Oregon data, years with fewer than 100 fish sampled were excluded from the model.

Commercial length compositions for retained fish in California were expanded using the procedures developed for CALCOM. These expansions differ from the default approach used by the "pacfintools" package. Specifically, differences in mean length by market category (Figure 13) and port complex (Figure 14) are accounted for in the CALCOM expansion routine. The documentation for pacfintools indicates that default stratification is by state, gear, and year. To allow for variation in mean length across market category and port complex, and for consistency with previous stock assessments, the STAT used the length composition expansion routine from CALCOM, which stratifies by year, gear group, port complex, and market category. Stratification by landing disposition (live/dead) is also accounted for in CALCOM's length expansion routine, but a negligible amount of chilipepper is landed live. Lengths for commercial discards were obtained from the WCGOP (Figure 15). Commercial length compositions by fleet, year, and size bin are shown in Figure 16.

Recreational length compositions (Figure 16) are unweighted in the base model. Based on CRFS methods for allocation of sampling effort, sample sizes should be roughly proportional to catch by stratum. However, this is untested, and may not be sufficient to capture differences in mean size across strata in unweighted comps. Standardized methods for catch-weighted length compositions from recreational fisheries are in preparation (E. Dick, SWFSC, and J. Edwards, PSMFC, pers. comm.). Sources of recreational length data include onboard observer programs in Southern California during the 1970s and 1980s (Collins and Crooke, unpublished report; Ally et al. 1991). The 1970s data extend the time series back before the beginning of the MRFS sampling program. Length data from Ally et al. (1991) were used in place of MRFSS data from 1985-1989 in Southern California due to larger sample sizes. Another onboard observer program for CPFVs in the central California region collected length information from 1987-1998 (Monk et al. 2016). Sampling in this program was limited to Monterey Bay in 1987, but subsequent years included sampling across the core range for chilipepper, and were used in place of relatively limited MRFSS samples for the period 1988-1998 and, importantly, bridged the gaps in MRFSS sampling from 1990-1992 (all modes) and through 1995 in the northern California charter boat fleet. Starting in 2004, all recreational length composition data came from CDFW's CRFS data via RecFIN.

All age data in the current assessment are modeled as conditional on length. Sample sizes are numbers of fish aged (Table 4). Some observed age/length combinations were clear errors and removed from the data. These are noted in the data file, and the original data record is commented out to help identify the change. A novel approach to age estimation (Helser et al. 2019; details below) was used in the current assessment for two years of recreational age structures (2023-2024) collected by CDFW. For chilipepper, the size compositions for the fish sampled for ages and the fish regularly sampled using the CRFS protocol were similar in those two years, and therefore the ages were included in the base model.

Age data from Fourier Transformed Near-Infrared Spectroscopy (FT-NIRS)

Over the past five years, NOAA Fisheries has undertaken a strategic initiative to develop the methodology and application of using Fourier Transformed Near-Infrared Spectroscopy (FT-NIRS) as a more efficient, rapid and cost-effective means of developing age estimates to inform stock assessments. All seven NMFS science centers have been involved in the initiative, with an overarching goal of operationalizing the approach across NOAA ageing labs. In the fall of 2024, the PFMC SSC Groundfish Subcommittee conducted a review of the FT-NIRS methodology for use in fish age estimation for groundfish stock assessments of U.S. West Coast species. The review focused specifically on applications to sablefish, Pacific hake, and rougheye/blackspotted rockfish, however the review included presentations of analyses by the team of researchers at the Alaska Fishery Science Center (AFSC) who led the initiative and have been developing methods for species such as northern rockfish, walleye pollock, and Pacific cod in Alaskan waters.

As summarized in the SSC and GFSC reports from the methodology review (PFMC 2024), otoliths are exposed to near infrared light, and the absorbance profiles of the resulting spectra can be quantified using a spectrometer (Helser et al. 2019, Benson et al. 2024). Relating the absorbance profile to traditional age estimates (typically from break and burn methods) provides the basis for the age estimation, and although predictions to the observed data are subject to uncertainty, this uncertainty can be quantified. To provide the most robust age estimates from the spectral data, both the AFSC and NWFSC have developed "deep learning" methods to improve age predictions. Estimates developed for chilipepper were developed by John Wallace and Emily Wallingford (NWFSC) using a fully connected neural network (FCNN) modeling approach. During the review, concerns were raised regarding some bias in the FT-NIRS estimates, particularly for sablefish in which FT-NIRS tends to overpredict relative to traditional age estimates at younger ages (positive bias) and underpredict at older ages (negative bias). One contributing factor could be that there are typically fewer data from older fish available to include in the training models, thus there is more potential for bias or uncertainty for those ages. The review noted that effects of bias on the older ages in stock assessment outputs could be minimal when aggregated into the "plus group" of older ages within the stock assessment model.

The SSC concluded that sablefish and potentially chilipepper assessments during the 2025 assessment cycle could include a relatively small number of FT-NIRS age estimates, with sensitivity of assessment results provided to assess the effects of inclusion of these data. Many chilipepper were aged using traditional methods and scanned for FT-NIRS, with most of the scans taking place at the Santa Cruz lab. The NWFSC (John Wallace, pers. Com; https://github.com/John-R-Wallace-NOAA/JRWToolBox) then developed a FCNN model for chilipepper based on 4816 reference ages (from traditional methods) and model estimates (Figure 17). Qualitatively and visually, the model does appear to exhibit some of the concerning characteristics that were noted earlier in models of age estimates from FT-NIRS relative to traditional age estimates for sablefish and rougheye/blackspotted rockfish, in that there was some indication of bias towards younger age estimation in the FCNN model. However, agreement was overall quite strong between the two estimates when all scanned data were considered, and the ageing error estimation program did not detect a clear bias in the FT-NIRS ages relative to the traditional ages. Between this observation, and the recognition that only a very small number of FT-NIRS ages are included in the base model (the 2004 triennial trawl survey, and 2023 and 2024 recreational fisheries, the latter of which exhibit dome-shaped selectivity with lower selectivity on larger, older fish), the STAT is comfortable using a small number of FT-NIRS based ages in the base model. Additional research, analysis and model development should take place before a larger number of FT-NIRS based age estimates are used in future assessments or updates.

2.1.4 Fishery-dependent abundance Indices

Two fishery-dependent indices of abundance were included in previous stock assessments: an index developed from trawl logbook data, and a recreational CPUE index derived from onboard observer data. These are not included in the 2025 base model. Since it has been nearly 20 years since the last benchmark assessment, fishery-independent surveys such as the WCGBTS and the RREAS have developed informative, long-term, time series for chilipepper rockfish. See section 2.6 for a description of the trawl logbook index and recreational onboard observer index.

2.2 Fishery-Independent Data

The 2025 chilipepper rockfish base model includes four fishery-independent data sources: the Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey (WCGBTS), the Alaska Fisheries Science Center/Northwest Fisheries Science Center West Coast Triennial Shelf Survey (Triennial Survey), the Southwest Fisheries Science Center California Cooperative Oceanic Fisheries Investigations (CalCOFI) ichthyoplankton survey, and the Southwest Fisheries Science Center Rockfish Recruitment and Ecosystem Assessment Survey (RREAS).

2.2.1 NWFSC West Coast Groundfish Bottom Trawl Survey

The Northwest Fishery Science Center has conducted combined shelf and slope trawl surveys, the West Coast Groundfish Bottom Trawl Survey (WCGBTS) since 2003, based on a random-grid design from depths of 55 to 1280 meters. Additional details on this survey and design are available in the abundance and distribution reports by Keller et al. (2008), Keller et al. (2014) and Bradburn et al. (2011). The survey design typically relies on the use of four vessels per year, with some exceptions based on funding, covid and other impacts, which fish from north to south along the entire U.S. West Coast in two passes, one beginning in late May and the other beginning in early October. Each vessel is assigned to a roughly equal number of randomly selected grid cells, and the design is intended to account for vessel-specific differences in catchability.

Chilipepper rockfish are frequently encountered in this survey, occurring in approximately 13% of the sampled trawls (which extend to over 1200m, so the percentage of positive observations within the habitat range for the species is much greater). They are encountered throughout nearly the entire latitudinal range of the survey, and between the shallowest depths sampled to at least 464 meters of depth, but with a mean latitude of capture of approximately 38.4 N and a mean depth of 166 meters (Keller et al. 2014).

To develop a relative abundance index from this dataset, geostatistical models of biomass density were fit using Template Model Builder (TMB) (Kristensen et al. 2016, Anderson et al. 2022), as configured within the {indexwc} R package (Johnson et al. 2025), consistent with the accepted practices guidelines for West Coast groundfish stock assessments. A plot of the survey index is provided as Figure 18, and model diagnostics (quantile plots) are provided as Figure 19. Estimates of biomass were predicted using a grid based on available survey locations, and a map of the spatial residuals to the model fit is provided as Figure 20. The index suggests that the highest catch rates for the stock occurred between 2004 and 2008, with a steep drop following that peak and variable but consistent (slow) increase in abundance since that time.

During the STAR panel, the STAT plotted residuals from the geostatistical model against haul depth, revealing a pattern that suggested a peak in chilipepper density at intermediate depths (see Request 12 in Appendix B). The STAT found that inclusion of a depth covariate improved the fit of the geostatistical model, regardless of whether the model assumed an isotropic or anisotropic spatial process. The relative trend changed only a small amount, but the index was better fit by the assessment model when the depth covariate was included, based on a reduction in the negative log likelihood of slightly more than 2 points (Figure 21). With the depth covariate, annual biomass estimates from geostatistical model were reduced by about 15%, on average, resulting in a survey catchability estimate that was more consistent, although still larger than expected, with the assessment estimates of vulnerable biomass (q=1.8 with the depth covariate, vs. q=2.3 without the depth covariate). The STAT recommends further research into assessment methods, as well as geostatistical modeling for trawl survey indices, with specific attention to estimation of population scale.

2.2.2 Alaska Fisheries Science Center/Northwest Fisheries Science Center West Coast Triennial Shelf Survey

Until the development of the WCGBTS, a primary source of fishery independent information for most managed and assessed groundfish species along the U.S. West Coast was the triennial trawl survey conducted between 1977 and 2004 (Weinberg et al. 2002). The consensus from recent data workshops has been to exclude 1977 data, due to concerns related to differences in survey protocols, the depth distribution of the survey, and the number of bad performance tows and "waterhauls," in which few benthic organisms were noted (Zimmermann et al. 2001).

In most early years of the triennial survey, the survey did not include a large fraction of chilipepper habitat; from 1980 through 1986 the survey only sampled to just south of the Gulf of the Farallones (San Francisco region, approximately 37° N) and did not sample the region of Monterey Bay and further south, where a considerable fraction of chilipepper biomass is found. From 1989-onward the survey extended to approximately Point Conception, CA (34.5 N), thus covering a larger fraction, albeit still not the entirety, of chilipepper habitat given the relatively high abundance in the waters throughout the Southern California Bight. A similar shift occurred in the depths sampled for this survey; between 1980 and 1995 the survey sampled depths from 55 to 366 meters (the 1977 did not sample as shallow, and the 1977 data are not used in this index), while from 1995 through 2004 the survey sampled depths between 55- and 500-meters depth. Subtle changes (several weeks) in the timing of some earlier surveys have led some analysts to treat the index from this survey as two separate time series. Due to the many other changes that could complicate this modest seasonal shift, the index was not modeled separately for the two time periods. Additional details regarding this survey, including the history of the transition between this survey and the ongoing West Coast Groundfish Bottom Trawl Survey, can be found in Keller et al. (2017).

To develop a relative abundance index from this dataset, geostatistical models of biomass density were fit using Template Model Builder (TMB) (Kristensen et al. 2016, Anderson et al. 2022), consistent with the accepted practices guidelines for West Coast groundfish stock assessments. A plot of the survey index is provided as Figure 22, model diagnostics are provided as Figure 23 and a map of the spatial residuals to the model fit is provided as Figure 24. There was insufficient time during the STAR panel to investigate depth covariates for the Triennial survey index as identified in the WCGBTS data (see Section 2.2.1), but the STAT recommends that future assessments evaluate depth covariates during development of indices of abundance from the Triennial survey as well.

2.2.3 Southwest Fisheries Science Center California Cooperative Oceanic Fisheries Investigations (CalCOFI) ichthyoplankton survey

The California Cooperative Oceanic and Fisheries Investigations (CalCOFI) survey began in 1951, in order to help evaluate the oceanographic and ecosystem drivers of the decline in the California sardine population. The survey samples zooplankton and ichthyoplankton with a 505-um bongo net, which is a double-ring net system attached to a central frame and towed obliquely through the water column. Chilipepper are one of only several *Sebastes* species for which larvae are readily identifiable using morphometric methods (Moser et al. 1977, Moser et al. 2000), however the morphometric criteria for chilipepper were developed later than the criteria for other rockfishes such as shortbelly (*S. jordani*), bocaccio (*S. paucispinis*), and cowcod (*S. levis*); as larval chilipepper are harder to ID at younger ages. Older larvae (a week or so of age) are more likely to exhibit the conclusive features that allow species specific identification. Thus, until recently many of the historical collections did not identify chilipepper in initial plankton sorting efforts. Efforts to re-analyze those early samples, while maintaining analysis of ongoing collections, have been ongoing for the past two decades. Consequently, the current time series of historical data is considerably more spatially and temporally robust than it was for the 2007 chilipepper stock assessment (W. Watson, SWFSC, pers. comm.).

Although egg or larval abundance data from CalCOFI surveys are no longer directly used for stock assessments of coastal pelagic species, they have continued to be used in assessments of other groundfish species. Specifically, larval abundance data have been used in stock assessments of bocaccio since the mid-1990s through the most recent (Jacobson et al. 1996, MacCall 2003, He and Field 2017), as well as in cowcod stock assessments since 2002 (Butler et al. 2002, Dick and He 2019) and an assessment of shortbelly rockfish (Field et al. 2007). In all these examples, the assumption has always been that larval abundance reflects relative female spawning output, and selectivity of this dataset is mapped to this value within the model while accounting for size-dependent fecundity. Larval abundance data have also been used in assessments of California sheephead (Alonzo et al. 2004), and were found to be correlated with recruitment in the assessment of California halibut (Coates et al. 2025). Until recently, data from this survey were generally limited to species that can be morphologically identified, but with genetic identification (e.g., Thompson et al. 2017), there are increasing opportunities to extend the application of this dataset to other species. Identification of larvae from samples taken during the 1950s was identified as a research recommendation during the STAR panel review.

Data

Tow data from the CalCOFI survey were obtained from 1951 to 2023. From Ed Webber (SWFSC) and William Watson (SWFSC) we also obtained data from a subset of these tows (846 tows from years 1992, 1994, 1996, 1998, 1999, 2002-2006) that had been recounted more accurately for chilipepper larvae, which we substituted for the existing counts.

For this analysis, we used only tow types C1 (CalCOFI One Meter Oblique Tow, 0.8 m^2 mouth area, 1-m diameter) and CB (CalCOFI Oblique Bongo Tow, 0.4 m^2 mouth area, 0.71-m diameter). We also excluded port (P) net side samples prior to 1997 due to use of a different mesh size. The mesh size for all remaining samples was either 0.55 or 0.505 microns.

For spatial subsetting, we excluded the nearshore SCCOOS stations, and included only tows between lines 60 and 93.3 (inclusive) and station <= 80. This encompasses the primary CalCOFI sampling region off central and southern California, and excludes far offshore stations, where chilipepper larvae are unlikely to occur.

For temporal subsetting, we excluded years 1985 to 1990, as these samples had not been reliably sorted for chilipepper. We also excluded data from lines <= 73.3 (central region) for the years 1959 and earlier, as these samples had also not been reliably sorted for chilipepper. We also only included data collected from November to April, when most chilipepper larvae are expected in the plankton. For analysis, tows from November and December were assigned to the following spawn year, and 365 was subtracted from their Julian sample dates.

Finally, if both net sides (S and P) were processed from the same tow, we averaged them. This resulted in a total sample size of 10,234 tows from 64 years (missing years: 1971, 1974, 1977, 1985, 1986, 1987, 1988, 1989, 1990). See Table 5 for a summary of the data filtering steps. Figure 25 shows the spatial and temporal coverage of all retained samples.

Model

We modeled larval density (larvae_10m2) using a spatial GLM with the package sdmTMB (Anderson et al. 2022). The model included Julian date (GAM smoother with k=4) to account for seasonality (Figure 26), a spatial random field, and IID spatiotemporal random fields. Since there were 6 years (1952, 1983, 1993, 1995, 1997, 1999) with sampling but no detections of chilipepper, we modeled year effects using time-varying (random walk) intercepts rather than as fixed effects. This allowed us to retain these years, which are informative about abundance being relatively low (the fixed year effect model is unable to estimate an index and associated uncertainty for years with no positive catches). Prior testing indicates that for years with positive catches, there is little difference between these two model structures, and that for years without positive catches, the time-varying intercept model produces low index values of reasonable magnitude. A Tweedie error distribution was used, and found to be suitable from diagnostic plots (Figure 27).

Predictions were made to a grid of 74 standard CalCOFI stations (lines 60 to 93.3 and station <= 80) for Julian date 32 (around the peak of larval abundance). These predictions were summed to generate a coastwide index, with bias correction turned on (Figure 28, Figure 29). The same model was also used to generate regional (southern, central) indices (Figure 30), by summing together the predictions for just the central area stations (line<76.7) or southern area stations (line>=76.7). For the regional indices, years were excluded post-hoc if a region had no sampling in that year (all values would be extrapolated). This only affected the central region.

2.2.4 Southwest Fisheries Science Center Rockfish Recruitment and Ecosystem Assessment Survey (RREAS)

Data

The Fishery Ecology Division of the Southwest Fishery Science Center has conducted a standardized pelagic juvenile trawl survey (the Rockfish Recruitment and Ecosystem Assessment Survey, RREAS) during May-June every year since 1983 (Ralston et al. 2013; Sakuma et al. 2016; Field et al. 2021). A primary purpose of the survey is to estimate the abundance of pelagic juvenile rockfishes (*Sebastes* spp.) and to develop indices of year-class strength for use in groundfish stock assessments on the U. S. West Coast. This is possible because the survey samples young-of-the-year rockfish when they are ~100 days old, an ontogenetic stage that occurs after year-class strength is established, but well before cohorts recruit to commercial and recreational fisheries. This survey has encountered tremendous interannual variability in the abundance of the species that are routinely indexed, as well as high apparent synchrony in abundance among the ten most frequently encountered species (Ralston et al. 2013, Schroeder et al. 2019). Past assessments have used data from this survey to provide indices of year-class strength (as relative age 0 abundance), including assessments for Canary rockfish (Langseth et al. 2023), Blue/Deacon Rockfish (Dick et al. 2018), Widow Rockfish (Adams et al. 2019), Bocaccio (He et al. 2015), Shortbelly Rockfish (Field et al. 2007) and Chilipepper Rockfish (Field 2015).

Historically (1983-2003), the survey was conducted between 36°30' and 38°20' N latitude (the 'core area' from approximately Carmel to just north of Point Reyes, CA). However, starting in 2004 the spatial coverage of the RREAS expanded to cover from the U.S./Mexico border to Cape Mendocino. Additionally, since 2001 data are available from comparable surveys conducted by the Pacific Whiting Conservation Cooperative (PWCC) and the NWFSC (2001-2009), which later evolved into the NWFSC "Pre-recruit" survey (2011-present) for waters off Oregon and Washington (Field et al. 2021). Coastwide data have revealed both spatial differences in species composition (e.g., north and south of Point Conception) and interannual shifts in the distribution of most pelagic juvenile rockfishes (Ralston and Stewart, 2013; Field et al. 2021). As the core area index seems to have failed to capture the magnitude of the 1999 year class for most stocks, the recommendations from the juvenile rockfish survey workshop held in 2005 were to use only the coastwide data (since 2001) for juvenile indices rather than the longer-term 'core area' indices unless a convincing case could be made otherwise. Here we used data from 2001 to 2024, the period for which we have coastwide coverage. On account of the COVID-19 pandemic, sampling in 2020 was very limited and restricted to the historical core area (Santora et al. 2021), so this year is excluded in all models. Note that in the years 2010 and 2012, sampling did not span the entire coastwide spatial domain, with data sparse or lacking from northern CA, OR, and WA. The year 2022 lacks sampling in northern CA. These years were included in the models for coastwide stocks (e.g., widow and chilipepper), but 2010 and 2012 were excluded for the yellowtail rockfish northern index. Assessors may want to consider a sensitivity with these years excluded, particularly for species with a more northern distribution. Catch per tow was adjusted to a common age of 100 days to account for interannual differences in age structure (Ralston et al. 2013), as has been done for prior assessment indices using this dataset.

Data from these surveys also supports process studies seeking to better understand the oceanographic processes leading to strong or weak year classes in adult groundfish populations. Survey data also provide insights into the drivers and consequences of climate-driven shifts in both the abundance and spatial distribution of other epipelagic micronekton, such as krill, coastal pelagic species, and mesopelagic fishes, as well as many of the seabirds and marine mammals that prey upon them. Such data are routinely reported in the CCIEA and other ecosystem status reports. More details about these research efforts can be found on the project storymap page.

Model

For the index model, we first examined species occurrence in samples across the entire survey domain. If there was evidence of a hard range boundary (e.g., the species was never observed south of Point Conception), then we excluded the regions where the species was never observed. Depending on the geographic scope of assessment, we may also have applied other geographic subsettings, e.g., only CA waters. If there were years in the final geographic domain with no or very sparse sampling, those years were also excluded.

Since catch (and sampling) varied over space and time, we modeled catch using a spatial GLM with the package sdmTMB (Anderson et al. 2022). The 100-day standardized catch per tow was modeled as a function of fixed year effects along with Julian date (GAM smoother with k=4) to account for seasonality (Figure 31), a spatial random field, and IID spatiotemporal random fields. If there were years with sufficient sampling but where no fish of the focal species were caught, then we modeled year effects instead using time-varying (random walk) intercepts. This allowed us to retain these years, which are informative about abundance being relatively low (the fixed year effect model is unable to estimate an index and associated uncertainty for years with no positive catches). Prior testing indicates that for years with positive catches, there is little difference between these two model structures, and that for years without positive catches, the time-varying intercept model produces low index values of reasonable magnitude.

We fit the model using 3 different error structures: Tweedie, delta-lognormal, and delta-gamma. In all rockfish species examined so far, dharma quantile residuals from model simulations suggested that Tweedie distribution was the best (Figure 32), so this is the model we proceeded with. The Tweedie model also best reproduced the observed proportion of zeros in the data based on simulations from the fitted model. For all species except yellowtail (see below), the Julian date effect showed a decline in catch towards the end of the sampling season, as juveniles begin to settle out of the water column.

For the index, predictions from the model were made for all active sample stations within the geographic domain, for the mean Julian date, for each year. Predictions were added together for each year to produce the index (Figure 33, Figure 34). Active stations are those regularly and consistently sampled, and are located on a semi-regular grid spanning the sampling region. Previous work has found that interpolating to a finer spatial grid has little impact on the resulting index.

Two indices were generated for chilipepper rockfish: One using data since 2001 (Figure 33, same as the other coastwide indices generated), and once using historical data back to 1984 (Figure 35, Figure 36; 1983 was excluded because no chilipepper were caught that year). For both time periods, a coastwide index was generated with no spatial subsetting (all data from CA, OR, and WA were used). For the index using the historical data, which before 2001 was only collected in central CA, this involved extrapolation to regions outside of central CA. For both models, there were no years with zero positive catches (excluding 2020 and 1983).

Recruitment of young fish to the population is known to vary both spatially and temporally for Chilipepper. See section 4.3.1 for a summary of factors affecting juvenile growth, survival and recruitment dynamics, including associated references.

2.2.5 Biological Data

This section describes fishery-independent length and age composition data used in the assessment. Descriptions of biological characteristics such as adult growth (length at age, weight at length), reproductive biology (maturity, fecundity), and estimates of natural mortality rates are found in the "Biological Parameters" section.

Composition data from fishery-independent sources came from the Triennial Survey and the WCGBTS. Data from 1977 were excluded from the Triennial Survey due to known issues with that year, but in other years sample sizes were in the 1000s of fish (Table 6, Figure 37). Length compositions from the WCGBTS were available for all years from 2003-2024, with the exception of 2020 (Table 7, Figure 38). Age compositions were available for all years of the WCGBTS where there were length data, with sample sizes ranging from 349-873 ages per year (Table 8).

For the 2007 benchmark, it was reported that age data from the Triennial trawl survey were unavailable, as age estimates had been based on surface-read ages, rather than ages estimated using break and burn methods. However, prior to the 2015 update assessment, the SWFSC located age structures from several triennial survey years, specifically for 1983 (n=734), 1992 (n=246), 1998 (n=439) and 2001 (n=487). Additionally, age structures from the 2004 triennial survey were aged for this assessment using FT-NIRS methods (Table 8; also see section 2.1.3). Despite extensive efforts and searches in Alaska Fishery Science Center warehouses prior to the 2015 update, age structures from 1977, 1986, 1989 and 1995 triennial surveys could not be relocated.

2.3 Ageing Error

Within-reader estimates of precision for ages read for previous assessments were carried into this assessment (constant CV of 10%). For ages estimated in preparation for the 2025 assessment, the AgeingError software package (Punt et al. 2025) was used to evaluate between-reader bias and variability. Cross-reads between fish aged by D. Pearson (SWFSC, retired) and T. Johnson (NWFSC) were evaluated and found to be unbiased with a constant CV of roughly 24% (n=200). Analysis of age predictions from a Neural network model of FT-NIRS otolith scans (J. Wallace, NWFSC, retired) showed that a constant CV model with no bias was appropriate, although with greater variability (CV near 30%). However, see the research recommendation section for suggestions related to estimation of ageing error matrices for model-predicted ages.

2.4 Biological Parameters

2.4.1 Natural Mortality

Hamel (2015) developed a method for combining meta-analytic approaches to relating the natural mortality rate M to other life-history parameters such as longevity, size, growth rate and reproductive effort, to provide a prior on M. In that same issue of ICESJMS, Then et al. (2015), provided an updated data set of estimates of M and related life history parameters across many fish species, from which to develop an M estimator for fish species in general. They concluded by recommending M estimates be based on maximum age (A_{max}) alone, based on an updated Hoenig non-linear least squares (nls) estimator $M = 4.899 A_{max}^{-0.916}$. The approach of basing M priors on maximum age alone was one that was already being used for west coast rockfish assessments. However, in fitting the alternative model forms relating M to A_{max}, Then et al. did not consistently apply their transformation. In real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of M to A_{max}. Therefore, it would be reasonable to fit all models under a log transformation. This was not done.

Revaluating the data used in 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 (as in Hamel 2015)), the point estimate for M is:

$$M = 5.4/A_{max}$$

Hamel and Cope (2022) further refined estimation of M by appropriately accounting for sources and of error in both Amax and M. They recommend a prior defined as a lognormal distribution with median 5.4/Amax, as above, and log-scale standard deviation of 0.31.

The oldest chilipepper rockfish in California (the center of chilipepper rockfish distribution; source: CALCOM) was a 39-year-old female landed by a vessel using trawl gear in 2004 near Monterey, California. The next few oldest fish, a 35-year-old male and a few 34-year-old females have also been observed, any of which represent the 99.99% quantile within rounding error (n=53,847 ages). No older fish were observed in Oregon samples (max. age = 29), although sample sizes were small by comparison.

The prior for female natural mortality is defined as a lognormal with mean ln ($5.4/A_{max}$) and SE = 0.31. Using a female maximum age of 35 the point estimate and median of the prior is 0.154 (with a log-space value of -1.869). Natural mortality of males was modeled as an exponential offset with no explicit prior.

2.4.2 Growth

2.4.2.1 Length at age

For this assessment, an extensive analysis of adult growth (Appendix A) was conducted to evaluate spatio-temporal variation. The previous benchmark assessment (Field 2007) assumed that the growth coefficient (*k*) of the von Bertalanffy model for length-at-age varied over time. We also found evidence of time-varying growth based on fits external to the stock assessment model, although time-varying selectivity could produce patterns in the data that are confounded with variation in growth.

The base model assumes constant growth, estimating parameters within the model. Alternative models with variable growth are evaluated as sensitivities, but not found to significantly alter the estimated dynamics. Currently, methods for reference point calculations are an active area of research for models with time-varying biology, and future assessments may wish to revisit the inclusion of time-varying growth. In particular, models with time-varying asymptotic size, perhaps correlated with *k* and exhibiting low-frequency variability, may have a greater influence on population dynamics.

2.4.2.2 Weight at length

Revised estimates of chilipepper weight-at-length were calculated using data from the WCGBTS. There appears to have been an error in the calculation used for the previous assessments (Figure 39), but this has little effect as it is roughly equivalent to changing the (arbitrary) units of spawning output in the model. Estimates of biomass, yield, and depletion show little difference as a result of the change.

2.4.3 Maturity

Maturity was updated for the 2015 update assessment (see Field et al. 2015 for details) based on the results of Beyer et al. (2015). Maturity status for that assessment was based on gross macroscopic evaluation, and future chilipepper assessments may consider revising the maturity relationship based on functionally mature fishes (Lefebvre and Field 2015). The 2025 assessment model uses the same estimates for maturity-at-length as in the 2015 assessment (Figure 40).

The 2007 assessment used macroscopic maturity estimates from over 10,000 fish sampled during port sampling or survey activities to develop maturity at length curves, and estimated that 50% of females matured at a length of 25.7 cm. For the 2015 update, a more comprehensive evaluation of maturity, based on both macroscopic and histological analysis, and including evaluations of regional variability, were conducted and described. In brief, in advance of the 2015 update, ovarian tissue samples from reproductive ecology and other investigations were processed histologically (n=565) to inform macroscopic assignments of maturity, detect abortive maturation and atresia (mass resorption of developing oocytes), and determine if secondary broods (see fecundity discussion) may be identified at early or later stages than possible macroscopically.

Results are reported more comprehensively in Lefebvre et al. (2018), and there was considerable discussion on abortive maturation and atresia in the 2015 assessment and the 2018 publication. Regional variability in maturity was also explored, and we found that maturity estimates varied slightly by region, such that L50 and L95 were slightly greater (by 3 and 2 cm, respectively) in central California relative to southern California fish. Estimates obtained by temporally restricting samples to the period of peak ovarian development before peak parturition (September to January), when assignment of maturity based on macroscopic evaluation is most accurate, resulted in small a decrease (0.5 cm) in the length of 50% maturity, but also reduced the sample size. With respect to abortive maturation (mass resorption of developing oocytes), those studies found that females collected in September and October showed normal development for the reproductive season, but that females collected in November and December, when the vast majority of mature females have vitellogenic (stage 3) or eyed larvae (stage 4), abortive maturation was found to be occurring in 92% of the fish identified macroscopically as stage 2 (pre-vitellogenesis, again most fish were stage 3 or 4). This suggests that these females were likely incapable of successfully producing a brood of larvae in the current spawning season.

To evaluate how sensitive maturity estimates were to these phenomena, maturity curves were re-estimated using the temporally restricted subsamples, such that females with stage 1 ovaries were considered immature, as were those with stage 2 ovaries from November – January. With the data we had at the time, we found that there was a negligible decrease in the combined and southern California L50 estimates, and a counter-intuitive modest increase in the central California L50. The most substantive change was an increase in L95 estimates for all areas (flattening the curve). Atresia was also frequently observed in smaller individuals, however most individuals generally displayed low (5% or less oocytes) or moderate (> 5–25% of oocytes) downregulation. Ultimately, the histological data were considered to be too sparse to rely on exclusively , and the 2015 assessment pooled the previously used historic macroscopic data with the recent data (from all regions) in order to update physiological maturity estimates. Consequently, the 2015 updated maturity curve estimated a slightly smaller size at maturity for female chilipepper (50% mature at 24.4 cm FL, 95% at 35.2 cm) than the 2007 model. We continue to use these parameters for the current benchmark, although future work should include additional data analysis in order to revisit the potential impacts of abortive maturation and atresia in developing a more robust functional maturity curve.

2.4.4 Fecundity

This assessment assumes that fecundity (F) is a power function of female body length (L), based on the relationship, $F = aL^b$. Dick et al. (2017) conducted a meta-analysis of fecundity for the genus *Sebastes*, reporting values for *b* (3.790) and *a* (1.00579E-07) for chilipepper rockfish. Since the exponent of the fecundity-length relationship is greater than the exponent of the fecundity-weight relationship, weight-specific fecundity (eggs or larvae per gram female body weight) also increases with size. These parameter values estimate fecundity in millions of eggs. Since Stock Synthesis tracks fish in 1000s, the reported values of spawning output are in billions of eggs.

Later research found that chilipepper rockfish can produce multiple broods in a year, and that the probability of occurrence is size-dependent (Lefebvre et al. 2018). Dick and He (2019) evaluated the sensitivity of cowcod population dynamics to multiple brooding by multiplying the “brood” fecundity-length relationship from Dick et al. (2017) by a factor of 1+x, where x is the probability of a female producing a second brood, given body length, i.e., 1 + Pr{multiple brooding | length}. Since data for the prevalence of multiple brooding at length were not available for cowcod, Dick and He (2109) used estimated values for chilipepper as a proxy, but found that changes in M (when estimated) under alternative fecundity assumptions negated the effects.

Since data on multiple brooding at length are available for chilipepper, we approximated total annual fecundity (assuming at most 2 broods per female per year) using a fitted power function, following the methods used by Dick and He (2019; Figure 41). S. Beyer (AFSC) provided updated estimates of Pr{multiple brooding | length} that included the 2013-15 data from Lefebvre et al. (2018), and added data from 2016-2019 winter spawning seasons. We use estimates from central California only (excluding southern California), as this represents the central part of the chilipepper distribution. The adjustment for length-dependent multiple brooding probability increases the exponent of the fecundity-length relationship (*b*) from roughly 3.8 to 4.2, accelerating the increase in weight-specific fecundity with increasing length.

2.5 Environmental and ecosystem data

Chilipepper are reasonably well sampled throughout their life history; in larval surveys, pelagic juvenile young-of-the-year (YOY) surveys and bottom trawl surveys, and there is a considerable body of literature, in addition to the results of past stock assessments, on the dynamics and ecosystem interactions throughout these stages. Both larval and pelagic juvenile abundance, as well as estimates of year class strength from previous stock assessments, clearly indicate considerably interannual variability in recruitment, which is typically thought to be primarily a function of variable growth and mortality in late larval or early juvenile life history stages, which is in turn related to large-scale variability in environmental conditions (Field et al. 2010, Ralston et al. 2013, Schroeder et al. 2019). Past stock assessments have also identified interannual variability in growth, which analyses presented here also conclude as considerable (Appendix A), as well as a nontrivial amount of interannual variability in reproductive output in response to environmental conditions (Beyer et al. 2024). Consistent with research into drivers of interannual variability in pelagic YOY, variability growth and reproductive output has also been either shown or suggested to vary in response to environmental conditions, although the potential for density-dependent processes as contributing factors have been less thoroughly evaluated. Much of that information is more rigorously synthesized in analyses supporting the risk table (Section 4.3.1).

With respect to trophic interactions, adult chilipepper have been described as midwater foragers, with euphausiids, forage fishes (such as anchovies, Pacific hake, and mesopelagic fishes), and small squids among key prey items (Love et al. 2002). With respect to predation mortality, pelagic juvenile rockfishes of all species, including chilipepper, are among one of the most important forage taxa identified in a meta-analysis of predator food habits studies in the California Current. Key predators of pelagic juveniles including seabirds, salmon, lingcod, tunas and marine mammals (Szoboszlai et al. 2015, Warzybok et al. 2018). Adults are consumed by larger piscivorous fishes, such as bocaccio and lingcod, as well as marine mammals. Predation by Humboldt squid (*Dosidicus gigas*) was documented during a period of range expansion of that species between the early 2000s and approximately 2010, although adult rockfish were a relatively minor component of the diet during that period, the abundance of squid for several years was novel and predation on some prey items potentially substantial (Field et al. 2013).

2.6 Data sources evaluated, but not used in the assessment

Commercial Trawl Logbook Index

Ralston et al. (1998) noted that the previous assessment did not use the logbook data because chilipepper rockfish were not identified to species in the logbooks. Ralston et al. attempted to filter the data in a way that better represented catch rates of chilipepper. Specifically, they identified statistical blocks where most chilipepper rockfish were reported as caught, linking logbooks to port sample data by vessel and date. A subset of blocks, primarily between Monterey and Fort Bragg, was used for the analysis. The data were further subset to include only positive "rockfish" tows, and a linear model was fit to log-transformed catch rates (lbs./hour) of "rockfish" landed predominantly in the chilipepper/bocaccio rockfish market category. The proportion of total rockfish catch that was not either widow or splitnose was then assumed to represent the proportion of chilipepper rockfish, and estimated on a year and port basis. Finally, the model-based "rockfish" index was multiplied by these proportions to create the final index. Ralston et al. noted that the resulting "chilipepper" index declined more slowly than the "rockfish" index, because the importance (i.e., assumed proportion) of chilipepper in the catch increased over time. They found the precision of the index to be surprisingly high (CV=4%), and it was decided to adjust the CV upward to 10% for all years, although this was admittedly an ad-hoc adjustment. While the declining trend in the index is qualitatively consistent with trends estimated from other data sources in the base model (Figure 42), the STAT chose to exclude the trawl logbook index due to the availability of long time series of fishery-independent data now available, and the strong assumptions made about species composition in the original index.

Central California Onboard CPFV Observer Index, 1987-1998

The CDFW (formerly CDFG) Central California Marine Sport Fish Project sampled the Northern and Central California CPFV fleet using onboard observers from 1987-1998. Observers recorded the total catch (kept and released fish) of a subset of anglers during each fishing drift. Catches from drifts occurring at a single CDFW fishing site were aggregated into a “fishing stop.” Each stop in the database is associated with the closest reef structure. Retained fish were measured at the end of the fishing day. Additional details about the survey design, data collected, spatial associations between fishing stops and reef habitat, and the structure of the relational database are described by Monk et al. (2016). This index is often referred to as the “Deb-Wilson Vandenberg” or simply “DWV” index.

As noted by Monk et al. (2016), samples in 1987 were only collected in Santa Cruz and Monterey counties, so this year is often excluded from the index. Further examination of the data revealed that over 90% of chilipepper observed were caught in less than 1% of the fishing stops, consistent with a species that is infrequently targeted by the recreational fleet. The index, as included in the previous assessment, is shown in Figure 43.

CDFW Onboard CPFV Observer Index, 1999-2024

A database of California onboard CPFV observer data now spanning the years 1999-2024 is described by Monk et al. (2014). Due to large-scale spatial closures over multiple decades, an index based on these data was not developed for chilipepper. The STAT recommends that future assessments revisit this data set if recreational anglers have continued access to depths in which chilipepper rockfish are more commonly encountered.

MRFSS Dockside CPFV Index, 1980-1999

Trip-level catch rate data (“Type 3 data”) from MRFSS dockside sampling of CPFVs were downloaded from the NMFS SWFSC. These data are derived from fish sampled in angler bags following completion of a trip, and were aggregated to the trip level using an algorithm developed by Braden Soper (University of California, Santa Cruz).

NWFSC Southern California Shelf Rockfish Hook and Line Survey

Age structures (40/year) from this survey were read to help inform analysis of spatial patterns in growth. As the survey represents only the southern portion of the stock, we did not use lengths or develop an index of abundance, as regional trends may introduce bias in a model for the coastwide stock. This data source should be considered for construction of an index and/or use of length information if a spatially-explicit model is developed for chilipepper, or if the survey expands to cover a greater portion of the population range.

3 Assessment Model

3.1 History of Modeling Approaches Used for this Stock

The first assessment for chilipepper was developed by Henry (1985) using a cohort analysis, however this assessment did not result in a clear picture of stock status and was not used to inform management. The stock was re-assessed the following year (Henry 1986), using an age-structured deterministic population model to estimate MSY and equilibrium yields for two alternative models. The data used in that model included total catch (modeled as a single fishery), age and length data (from a relatively short time period), and triennial survey abundance point estimates from 1977- 1983. The results indicated that the stock was moderately exploited, with "good recent recruitment and the absence of apparent biological stress." The author recommended an ABC of 3563 mt, set at the midpoint of two alternative estimates (the ABC was ultimately set by the PFMC at 3,600 mt). Note that "ABC" at the time was equivalent to what is known as the "OFL."

Subsequently, Rogers and Bence (1993) conducted a length-based assessment using stock synthesis (Methot 1990) for which the modeled time period began in 1980. Their model included a triennial trawl survey index and a recreational CPUE index, as well as age and length data from commercial fisheries, and assuming estimates of natural mortality rate that ranged from 0.15 to 0.20. Rather than present a single base model, the authors provided a set of three models, in which the 1992 biomass ranged from 40,000 to 87,000 mt, and the equilibrium yield (based on the then proxy for FMSY of F35%) ranged from 3,941 to 6,729 mt. Their general conclusions were that the existing ABC of 3600 mt was sufficient to protect the fishery at the $F_{35\%}$ level, and that raising the ABC above this level could be "somewhat optimistic."

Ralston et al. (1998) provided the next assessment of chilipepper, using the stock synthesis age-structured model (Methot 2000) to estimate abundance for the combined Eureka, Monterey, and Conception INPFC areas. The initial year for the 1998 model was 1970, but the model assumed a starting biomass below the unfished equilibrium level, using estimated landings from 1960-69 to generate an initial equilibrium population in 1970. The 1998 model also did not include a stock-recruit relationship. Natural mortality rates were estimated to be 0.22 for females and 0.25 for males. The model assumed four distinct fisheries (trawl, hook-and-line, setnet and recreational), and included a CPUE index derived from the California commercial trawl logbook database, an index of abundance from the triennial trawl survey, and a time series of pelagic juvenile abundance. The 1998 assessment discussed apparently significant changes in mean size at age, which were raised as an important research question, but ultimately applied an approach utilizing time-varying selectivity to fit the length composition data. The 1998 assessment estimated an unfished spawning biomass of 58,500 mt, a 1997 biomass above target levels, and indicated that the exploitation rate had been below the target fishing mortality rate since 1993. Key sources of uncertainty included tension between the two key indices (the trawl logbook index and the triennial trawl survey indices), uncertainty in population projections due to high recruitment variability, and challenges associated with discerning changes in selectivity from changes in growth and size at age.

The 2007 stock assessment (Field 2008) was developed in Stock Synthesis II (SS2), the precursor to SS3, and included a newly developed catch reconstruction, with the catch history extended back to 1892. Fleet structure was identical to the previous Ralston et al. model, with commercial trawl, hook and line and setnet fleets, along with a recreational fleet. The 2007 model also included the trawl fishery CPUE index used in the 1998 assessment, along with a recreational fishery index based on CPFV observer data (1987-1998), the triennial trawl survey (1980-2004), the (then) newly initiated West Coast Groundfish Bottom Trawl Survey (WCGBTS), and an index of age 0 abundance from the Rockfish Recruitment and Ecosystem Assessment Survey. The model was well informed by age data from commercial fisheries, but with more limited survey age data, and all age data were treated as marginal age compositions, rather than conditional-age-at-length data. Steepness in the 2007 model was fixed at 0.57 based on the updated Dorn prior (Dorn 2002), natural mortality was fixed at 0.16 for females, 0.20 for males, and selectivity curves were based on logistic curves for the trawl fishery, the hook and line fishery, and the two surveys, while the double-normal selectivity curve was used for both the setnet and recreational fisheries. Time varying growth was estimated internally in the model, implemented with time block offsets for the growth coefficient, K, using time period blocks that were informed by major shifts in the signal for the Pacific Decadal Oscillation.

The 2007 assessment estimated that exploitation rates had been high and spawning biomass had declined sharply through the late 1980s and 1990s, to roughly 26-29% of the unfished level between 1995 and 1999. However, sharp reductions in fishing mortality also began in the late 1990s, in response to rebuilding requirements for co-occurring species such as bocaccio and canary rockfish. These occurred in combination with an extremely strong recruitment event in 1999, a year in which most West Coast groundfish experienced strong recruitment (for chilipepper this remains the strongest estimated recruitment event for this population). This resulted in a rapid increase in abundance and spawning output, such that the 2007 estimate of relative spawning output ("depletion") was 71% of the estimated unfished level. The model estimated an MSY proxy (harvest associated with an SPR of 50%) of 2099 tons.

The 2015 assessment update (Field et al. 2015) used an updated version of the Stock Synthesis model, updated historical catch estimates, updated maturity and fecundity relationships, and additional years of data for all fisheries and ongoing surveys. Most of these additions or changes resulted in only minor changes to model assumptions or fits, and model results were generally consistent with the 2007 assessment. However, concerns were raised regarding how time-varying growth was modeled in that assessment, based on the observation that when additional time blocks were added for growth variability in the recent time period, the model estimated unusually low growth rates. This raised concerns regarding the robustness of catch projections if growth was mis-parameterized. Ultimately the final model simply extended the duration of the terminal time block from the 2007 model to resolve this challenge, resulting in a terminal growth estimate slightly above the long term mean. The fact that marginal age contributions were used (rather than conditional age at length), coupled with the greater availability of age data for small individuals from fisheries independent surveys (which were limited in previous assessments), were likely contributing factors to these challenges. The update estimated a depletion in 2015 of 67%, and an equilibrium MSY from the SPR 50% proxy of 2115 metric tons.

Subsequent to the 2015 assessment update, errors were discovered to have taken place in the historical catch reconstruction. Consequently, in 2017 there was an additional "catch-only" update, in which only historical catches were updated. The revised historical (pre-1968) catches were reduced by about 18,550 mt, representing 30 percent of the total previously used for the period 1916-1968, leaving 44,194 mt of catches during that period. The resulting OFL estimates from the 2017 model were slightly greater than the corresponding estimates from the 2015 model, primarily because recent catches were less than previously assumed. Another catch only update was conducted in 2023 (Wetzel 2023) to update OFL and ACL values for upcoming management cycles.

The reported units of spawning output changed across assessments, but a comparison of age 1+ biomass (Figure 44) is possible going back to the assessment of Ralston et al. (1998).

3.2 Response to STAR Panel Recommendations from Previous Assessment

The STAR Panel report from the 2007 chilipepper rockfish assessment had the following recommendations for future research and data collection.

The following were recommended for the next assessment:

- Reconstruct the chilipepper rockfish catch history using all available data including catch by gear and by region. The reconstruction should include an envelope of high and low values to set bounds for exploration of alternative catch histories. The Panel notes that the SWFSC has made significant progress in retrieving detailed historical landings data, which will facilitate catch reconstructions. As has been recommended previously by a variety of STAR Panels, the reconstruction of historical rockfish landings needs to be done comprehensively across all rockfish species to ensure efficiency and consistency.

  STAT response: Historical catch reconstructions were specified as a Council priority shortly after the 2007 assessment, and revisions to the historical catch were made in later update assessments.

- Read chilipepper rockfish otoliths from the triennial and combination bottom trawl surveys to provide better data on the early stages of growth and possible time-variations in growth

  STAT response: Only one year of chilipepper ages from the triennial survey, made available using FT-NIRS technology. Traditional (break-and-burn) ages are now available for most years from the WCGBTS (aka "combination" bottom trawl survey).

- Explore use of conditional age-at-length data rather than coupled age- and length-composition data

  STAT response: Completed in the new assessment.

- Explore time-varying growth as influenced by environmental changes

  STAT response: This was evaluated in later updates, but linkages to the PDO were unclear. An analysis of time-varying growth has been included as Appendix A of this assessment, but further research is needed regarding environmental drivers of time-varying growth.

- Explore possible spatial structuring of the data and model

  STAT response: Although genetic analyses are lacking for chilipepper, there is no strong evidence of spatial differences in growth (see Appendix A). The data in the current assessment were partitioned into "fleets as areas" to account for spatial differences in selectivity.

- The next STAT should have full access to raw data from the NWFSC trawl survey

  STAT response: No longer an issue.

Recommendations in 2007 "for the longer term" included:

- Age-validation of chilipepper rockfish should be pursued

  STAT response: This recommendation is still outstanding, and the STAT also recommends this be done.

- Develop a fishery-independent time series using fixed sites and volunteer anglers who use standard protocols and are properly supervised

STAT response: This now exists south of Point Conception, but sampling does not extend into the central part of the chilipepper range. Other hook and line surveys have greater latitudinal coverage, but only sample nearshore waters not occupied by chilipepper rockfish.

- Establish a meta-database that provides a comprehensive overview of all relevant data sources and sufficient information to correctly interpret the data

  STAT response: This has not been completed and will require coordination among several Federal and state agencies. The STAT also supports this recommendation.

- Establish an accessible database for rockfish catch histories by species, including envelopes of high and low values for each species to set bounds for exploration of alternative catch histories

  STAT response: Significant progress has been made on historical catch reconstructions, except for recommended 'envelopes' of uncertainty.

- Relevant raw data, updated in a timely manner, should be readily accessible to assessment authors in on-line databases that are user-friendly

  STAT response: Significant progress has been made, largely due to the efforts of PacFIN and RecFIN staff at the PSMFC.

- Develop comprehensive descriptive analyses of recreational fisheries and fleets to assist in interpretation of recreational CPUE and length-composition data

  STAT response: Per the 2015 stock assessment recommendation, this assessment includes refinements to the structure of recreational fleets (e.g., separation of fleets north/south of Point Conception), length compositions dating back to 1975, and limited CAAL data from recent CDFW sampling efforts.

- Develop a concise set of documents that provide details of common data sources and methods used for analyzing the data to derive assessment model inputs

  STAT response: Progress has been made on this request (e.g., metadata for databases, use of standardized R code), although additional documentation would be useful.

3.3 Model Structure and Assumptions

3.3.1 Key Base Model Changes from the Last Assessment

- Beverton-Holt steepness parameter fixed at 0.72 versus 0.57
- Female and male natural mortality estimated versus fixed
- Revised priors for natural mortality and steepness
- Use of conditional age-at-length compositions rather than marginal age composition data
- Use of the CalCOFI ichthyoplankton survey data as an index of spawning output
- Growth rates (length at age) assumed to be constant, but are still estimated within the model
- Removal of fishery-dependent indices of abundance (trawl logbook and recreational indices)

- "Fleets as areas" approach for commercial hook & line fleets, recreational fishery, separation of California trawl and Oregon commercial fleets
- Included bycatch from the at-sea hake fishery
- Addition of trawl discard fleet to account for size differences in retained vs. discarded fish
- Revised fecundity-at-length relationship, with adjustments to account for size-dependent multiple brooding in chilipepper
- Revised weight-at-length relationship
- Applied recruitment bias adjustment following Methot and Taylor (2011) to reduce bias in estimate of initial biomass
- Increase in maximum age and length bins ("plus groups")
- Updated ageing error matrices

3.3.2 Modeling Platform and Structure

The assessment is structured as a single, sex-disaggregated population model, spanning U.S. waters between the U.S./Mexico border to the U.S./Canada border. The model operates on an annual time step covering the period 1875 to 2024 (not including forecast years) and assumes an unfished equilibrium population prior to 1875. Population dynamics are modeled for ages 0 through 35, with age-35 being the accumulator age ('plus group'). The maximum observed age was 34 for males and 39 for females. Population bins were set every 1 cm from 7 to 60 cm, and data bins were set every 2 cm from 8 to 60 cm. The model is conditioned on catch from two sectors (commercial and recreational) divided among eight fishing fleets, and is informed by three fishery-independent time series of relative abundance (two successive trawl surveys and an index of spawning output) and a fishery-independent index of age-0 recruitment. Size and age composition data include lengths from 1975-2024 and ages from 1978-2024, with intermittent gaps in each data type. Recruitment is assumed to be related to spawning output via the Beverton-Holt stock recruitment relationship with log-normally distributed, bias corrected process error. Growth was modeled across a range of ages from 0 through 35. All catches were assumed to be known with high precision (log-scale standard error of 0.05).

Fleets were specified for recreational and commercial sectors. While the previous assessment combined all recreational fishing modes and catch types (retained or discarded) into a single fleet, we split the recreational sector into two main fleets according to area fished (north or south of Point Conception, CA). All recreational modes were combined, and discarded recreational catch was added to landings. The commercial sector was represented by six fleets. Two commercial hook-and-line fleets were differentiated by area fished (north or south of Point Conception). The primary commercial fleet in terms of total removals is a California trawl fleet, modeled separate from a smaller, combined-gear, commercial fleet representing catch north of California (primarily in Oregon). Fleet selectivity was allowed to vary over time, mainly in response to large spatial closures around the turn of the century. Sensitivity to these selectivity assumptions were explored during model development and relative to the base model.

Age and length composition sample sizes were then tuned in the base assessment model using the Francis weighting method (Francis 2011). Weights were applied iteratively for each method until absolute changes in the multiplier were <0.01 for all fleets. Variance adjustments were capped at a value of 1 for conditional age-at-length data, as these represent individual fish ages. Variance adjustments were allowed to exceed 1 for marginal length composition data, as length compositions had been down-weighted to partially account for misspecification of the multinomial distribution.

Data source weights (or emphasis factors) can also be specified in Stock Synthesis (i.e., "lambdas"). In this assessment, there was no clear reason to down-weight (or up-weight) data sources relative to each other (apart from the application of Francis weights to the composition data and additive variances to some indices), so all likelihood components were assumed to have equal emphasis (λ=1) in the base case model. Some data sources that were considered during model explorations, but ultimately rejected, were retained in the Stock Synthesis input data file and excluded from the likelihood by setting λ=0 in the control file (i.e., the commercial trawl logbook index and the recreational onboard observer index). This allows the STAT to observe the implied fit to the data source without having it affect the estimation process.

A prior distribution was specified for male and female natural mortality following a meta-analytic approach (see section 2.4.1 for more details). A lognormal prior for natural mortality was applied when estimating female natural mortality (mean = -1.86895, standard deviation = 0.31), and male natural mortality was modeled as an exponential offset with no explicit prior. A beta prior (mean=0.72, SD=0.16) was applied when estimating steepness of the Beverton-Holt stock recruitment curve. The steepness prior was originally developed from a west coast groundfish meta-analysis (Dorn 2002), has been periodically updated, and is provided by the PFMC SSC in each management cycle. In the base model, natural mortality parameters are estimated for both females and males (exponential offset from females), and steepness is fixed at the prior mean of 0.72.

This assessment used a recent version of Stock Synthesis 3 (version 3.30.23.1, optimized). The basic population dynamic equations used in Stock Synthesis 3 can be found in Methot and Wetzel (2013). The R package “r4ss” (Taylor et al. 2021) was used to visualize model output and greatly assisted with model development and evaluation.

3.3.3 Model Parameters

The population dynamics model has many parameters, some estimated using the available data and some fixed at values from external analyses and/or the available literature. Estimated and fixed parameter values in the base model, excluding recruitment deviations, are listed in Table 9 and Table 10. A total of 106 parameters were estimated in the base model, including 57 recruitment deviations and twelve forecast deviations.

Natural mortality was estimated for females and informed by a prior distribution, and estimated for males as an exponential offset with no prior (see section 2.4.1). The pre-STAR base model fixes the Beverton-Holt steepness parameter at 0.72, the mean of the prior distribution. Initial (equilibrium) recruitment was also estimated. Recruitment deviations from the stock-recruitment relationship were estimated in the base model from 1968 – 2024. Recruitment variation about the stock recruitment curve was fixed at 1.0, a value tuned to the estimated recruitment deviation RMSE plus a slight adjustment upward to account for unmeasured process error.

Time-invariant growth parameters were estimated for each sex (Brody growth coefficient (k), lengths at age 20, and the CVs of length at age 0 and age 20) using the Schnute parameterization (Schnute 1981) of the von Bertalanffy growth function, where males were estimated as an exponential offset of female parameters. Length at age 0 for both sexes was fixed at 7.3 cm based on observations of settled YOY chilipepper rockfish around the month of July (see Appendix A for more details). The CV of the distribution of length-at-age, CV(L(a)), in the base model is defined by a linear interpolation between the lower and upper ages specified in the Schnute parameterization of von Bertalanffy growth. Weight at length parameters were fixed at values externally estimated from WCGBTS observations.

Selectivity for all fishing fleets was specified by variations of a 6-parameter “double-normal” function form in SS3. This form allows for logistic-like shapes, ‘domed’ shapes, and many other variations, but in all cases some of the 6 parameters were fixed or bypassed by options available in SS3. Time blocks were included in the model to allow changes in selectivity when major regulatory changes occurred. These include a change in 1991 due to the sort requirement for bocaccio rockfish, a change in 2001 to account for establishment of the Cowcod Conservation Areas in Southern California, and a change in 2000 representing the overfished declaration for bocaccio rockfish. Regulations pertaining to bocaccio rockfish also affect chilipepper, as the two species are frequently caught together.

An additive variance parameter was estimated for the CalCOFI index. Fecundity has been shown to vary in time (Beyer et al. 2015), introducing additional uncertainty into an index designed to track parental biomass via spawning output. The RREAS index tracks cohort strength of pelagic juvenile rockfish, but realized recruitment to the adult population may still be affected by post-settlement, density dependent mortality. The additive variance parameter for this survey was fixed at 0.683, calculated from the input sigma-r value (1.0) minus the mean of annual input observation errors from the standardized index.

3.3.4 Key Assumptions and Structural Choices

Major structural assumptions included fixing the steepness stock recruitment parameter and estimating sex-specific natural mortality parameters, but assuming sex-invariant selectivity parameters. This favors the hypothesis that higher natural mortality for males explains the skewed sex ratio at older ages in the catch. An alternative hypothesis is that males become less available to the fishing gear. The base model estimates male natural mortality as an offset to female natural mortality with no prior, as joint priors for female and male natural mortality parameters are not currently available (either directly estimated or as an offset). Due to the use of discard "fleets" rather than estimated retention curves, it was not possible to model the interaction between discarded catch and retained catch as a result of regulatory changes or time blocks on discard size compositions. However, discards make up a relatively small fraction of total removals for this species, and the discard length composition data seems to provide good information about the long-term average size of discarded catch, at least since the beginning of the trawl IFQ fishery. An advantage of including discard length compositions (rather than simply adding discarded catch to landings), is retaining potential information about recruitment given the smaller average size of discarded catch.

All age data in the model were entered using the conditional-age-at-length (CAAL) format. For each fleet, year, and sex, the proportion of observed ages in each length data bin are entered, improving estimation of growth and reducing correlations associated with fitting to both marginal lengths and marginal ages from the same fish.

3.3.5 Bridging Analysis

The last benchmark assessment for chilipepper rockfish was almost 20 years ago. The PFMC terms of reference for update assessment requires that updates retain similar model structures to the last benchmark. As a result, many aspects of the previous model have changed (see partial list in section 3.3.1). In addition, most data sets were completely re-analyzed, and time series of existing data were extended through 2024 whenever possible.

For those reasons, complete tracking of changes since the last assessment is not practical. As described in the sensitivities section, changes in the Beverton-Holt steepness parameter and the estimated rates of natural mortality are not sufficient to account for estimated changes in population dynamics. Some factors can be ruled out. For example, estimated catches have remained very similar since the 2017 catch-only update assessment, and should therefore not significantly affect population dynamics or scale (Figure 5). Revised methods for estimation of the WCGBTS have changed the magnitude of relative biomass estimates in early years of the index (Figure 21). Bias-correction to ensure mean-unbiased biomass estimates has become standard practice, following the method of Methot and Taylor (2011). The previous benchmark pre-dated that study, as a result all subsequent updates do not include a bias correction term in the likelihood. The choice of whether recruitment deviations should sum to zero (as they did in previous assessments) can also have an effect.

To compare patterns in scale and trend between the current base model and the 2017 catch-only update, we modified the pre-STAR base model to match the 2017 values of steepness, natural mortality (sex-dependent), weight-length, fecundity, recruitment configuration (devs sum to zero, no bias ramp), no CalCOFI index, fitting to fishery-dependent indices, and removing data after 2016. Despite having completely different likelihood weights (lambdas), fleet structure, marginal vs. conditional age-at-length compositions, revised fishery-independent indices, input variance adjustments, etc., the two models are very similar in scale and trend (Figure 45).

3.4 Base Model Results

3.4.1 Parameter Estimates

A total of 106 parameters were estimated in the model, 57 of which were recruitment parameters, 27 were selectivity parameters, and 12 of which were forecast deviations. Model parameters were evaluated for stability and precision along likelihood profile gradients, by ensuring that no model parameters were up against a lower or upper bound, and had sufficiently low gradients (Table 9, Table 10). Parameter precision was also monitored by looking at asymptotic standard deviations to assess the variability associated with point estimates.

Estimates of length at age from the model (Figure 46) are consistent with external fits (Appendix A). The CV of length at age zero for females was typical (~10%) but variability in length at age 20 was best fit by a smaller value of roughly 4%. Male CVs of length at age were larger than their female counterparts, and the offset for the male CV at age 20 was poorly estimated (large SE) and ultimately fixed. The point estimate of natural mortality for females (M_female = 0.165 yr^{-1}) was generally consistent with both the prior distribution and fixed values used in previous stock assessments. Natural mortality for males was estimated as an exponential offset parameter (0.266), producing an estimate of male M = 0.216 yr^{-1} (also like fixed values used in previous assessments).

Parameters of the Beverton-Holt stock recruitment relationship (Figure 47) included steepness (fixed at the prior mean of 0.72), estimated log-scale unfished recruitment (log R0 = 10.032), and variability in recruitment deviations (Figure 48) was iteratively tuned to a value of 1.0, slightly larger than the standard deviation of the estimated log-scale recruitment deviations. Recruitment deviations were forced to sum to zero. The method of Methot and Taylor (2011) was used to estimate annual variation in bias correction factor (Figure 49).

Selectivity curves estimates for most fleets were asymptotic in the terminal year, with the exception of the trawl discard 'fleet' and the recreational fleet in Southern California (Figure 50). Fleets with time-blocked selectivity were often best fit by asymptotic curves in the early time periods and/or estimates of selectivity at large sizes were imprecise and fixed (Figure 51, Figure 52, Figure 53, Figure 54). Selectivity for the two trawl surveys were unstable, switching between domed shapes and asymptotic shapes that only excluded very small fish. The STAT found that simple selectivity curves based on a minimum length or age fit these data almost as well as more complicated functional forms, and had the advantage of being stable across a range of other parameter values. This assumption was tested during the STAR panel and remained unchanged in the final base model. Selectivity for the CalCOFI index is tied to spawning output via the fecundity relationship, and the RREAS recruitment survey is configured to select only age-0 fish.

3.4.2 Fits to the Data

Residuals to length composition and age composition fits to the model were explored during model development. In addition to information about regulatory changes, the identification of residual patterns helped to sort out which set of a priori selectivity time blocks were the most appropriate given the data. Alternative model configurations were also explored during model development to minimize residual trends.

Fits from the base model to time-aggregated length compositions, by fleet, show that the model can reproduce differences in observed lengths between sexes in most fleets (Figure 55). Fits to the sex-specific lengths from the California trawl fleet, the primary source of landings, are generally good, except for large positive residuals associated with large, male fish in several years (Figure 56). It's unclear whether this is due to model misspecification or errors in the data. Evidence of strong cohorts is visible in several fleets. A particularly large residual is evident in the fit to WCGBTS lengths (Figure 57; again, associated with an excess of large males).

For each fleet with composition data, we compared observed mean lengths summarized from the length data to predicted mean lengths, and mean ages from the CAAL data to predicted mean age (Figure 58 through Figure 67). Model predictions for the California trawl fleet were generally good for length compositions, although the model predicted younger mean ages than were observed for the period 1980-2000. Alternative selectivity parameterizations explored during the STAR panel did not improve fits to mean ages (see research recommendations).

Fits to abundance indices (both arithmetic- and log-scale) are shown in Figure 68 through Figure 71. The model was not able to fit three years (2004, 2005, and 2007) from the early period of the WCGBTS, despite investigation by the STAT and during the STAR panel. Inclusion of a depth effect in the index standardization model improved fit to the index by >2 NLL points, but ultimately the lack of fit was left as a research recommendation. Fits to the RREAS survey were among the best in the model, suggesting that the index is informative for estimation of recent recruitment strength. However, estimates of recent recruitment should be viewed with caution until age and length information become available to verify the size of recent year classes.

Model predictions are plotted against time series of relative abundance from the trawl logbook index (Figure 72) and recreational onboard observer index (Figure 73) for reference only. The base model was not fit to either fishery-dependent indices, although model predictions are not inconsistent with general declining trends in both indices.

3.4.3 Population Trajectory

The base model's estimates of spawning output over time (in billions of eggs) show declines associated with the development of the trawl fleet following World War II through the 1990s (Figure 74). Spawning output is estimated to have fallen below the MSST, if only briefly, around the year 2000 (Figure 75). Significant reductions in catch in subsequent years have likely led to increases in stock size, although estimated rates of population increase are uncertain and driven in part by the assumed value of steepness in the stock-recruitment relationship.

Estimates of recruitment deviations are largely consistent with previous stock assessments for chilipepper, with the largest cohorts being estimated in 1984, 1999, and 2013 (Figure 76). The current assessment also estimates an above-average recruitment in 2024 based in part on the influence of the RREAS index of age-0 chilipepper. On average, recruitment was below average in the 1990s and 2000s, with the notable exception of 1999. Several above-average cohorts are estimated to have entered the population between 2009 and 2015, followed by a few years of lower-than-average recruitment.

Chilipepper rockfish spawning output was estimated to be 9.9 trillion eggs in 2025 (~95% asymptotic interval: 6.3-13.6; Table 11), which equates to a "depletion" level of 83% (~95% asymptotic interval: 63%-104%) in 2025. Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output. Long-term, sustainable yield based on the proxy MSY harvest rate (SPR 50%) is 2114 mt (~95% asymptotic interval: 1588-2639). Time series of spawning output and other relevant population quantities are in Table 12.

3.5 Model Diagnostics

3.5.1 Convergence

Model convergence was checked during development of a base model by ensuring that

- The final gradient of the likelihood surface was less than 0.0001 (see '-hess_step', below)
- Parameters were checked to ensure that they were not hitting a minimum or maximum bound
- A search for a better minimum was conducted using jittered starting values ("jitter fraction" in r4ss function "jitter" set = 0.2). A total of 100 jittered runs were performed for the base model.
- A model run using the "–hess_step" option was compared to the base model
- The base model was run using the -phase N option, starting the optimization in the N-th phase

No parameter estimates were near the bounds (min or max), and the gradient of the base model was effectively zero after using the "-hess_step" command-line option. A comparison of likelihoods, parameter estimates, and derived quantities showed that results based on the –hess_step run were indistinguishable from the base. Across all 100 jittered runs, the model found no minima lower than the base case likelihood (2633.05). Starting the model from different optimization phases had no effect on the final likelihood (Table 13).

3.5.2 Likelihood Profiles

Likelihood profiles were performed across three major sources of uncertainty: natural mortality (M), initial recruitment (R0), and steepness (h). An individual profile was completed for each data type (e.g., lengths, ages, indices) and parameter combination to derive the relative importance of each data set to parameter estimation. In addition, profiles for each data set within a data type (i.e., a "Piner" plot) were produced for each of the three parameters listed above.

The profile over log(R0) from 9.5 to 10.75 showed better fits to age data overall at larger sizes, but a univariate profile interval of roughly 9.7 to 10.4 (Figure 77, Table 14). The WCGBTS composition data (ages and lengths) were better fit by smaller values of R0, although the index was better fit by larger values.

Total NLL for the profile over female natural mortality (with male natural mortality estimated as an offset), favored values roughly between 0.14 and 0.19. The WCGBTS index was better fit by larger female M values, while other data sources were either uninformative or showed lack of fit for only high values of female M (Figure 78, Table 15).

The profile over Beverton-Holt steepness (*h*), shows that total NLL is minimized near 0.4, but values between 0.3 and roughly 0.55 are within the 95% univariate confidence interval. Age data and indices seem to have improved fits at lower steepness values, while length data and recruitment deviations are more consistent with intermediate values, although length and recruitment contain little information overall for this parameter (Figure 79, Table 16, Table 17).

A bivariate likelihood profile over steepness and female natural mortality reveals that steepness is not well estimated by the model, given the data, and that the prior mean (h=0.72) falls outside the 95% bivariate confidence interval (Figure 80). Female natural mortality, on the other hand, seems to be relatively well informed, with a value in the range of 0.15 to 0.2, and generally consistent with the prior. The STAT noted that the use of a sum-to-zero constraint on the recruitment deviations changed the bivariate likelihood profile, relative to the pre-STAR base that did not enforce the constraint. Without a sum-to-zero constraint, the model can shift the mean recruitment to better fit the data if the value of steepness is fixed at a value that is otherwise inconsistent with the data. As observed in Request #4 (Appendix B), this is less of an issue when steepness is estimated in the model.

3.5.3 Sensitivity Analyses

We evaluated sensitivity of the base model to several alternative model structures and data set configurations. These included:

- A ‘drop-one’ approach to identify the impact of various sets of information on model outputs. Data were removed by fleet (i.e., all composition and trend data associated with a particular fleet)
- Comparison of model outputs using alternative weighting methods (‘Francis’ and ‘McAllister-Ianelli’)
- Inclusion of fishery-dependent data sources used in the last assessment, but not in the 2025 base model, and increasing the emphasis (likelihood component multiplier, or ‘lambda’) of the WCGBTS and/or CalCOFI index.
- Comparison of the base model (time-invariant growth) to models with annual deviations in the von Bertalanffy ‘*k*’ parameter, or an index for multiplicative deviations in *k* based on externally estimated annual deviations in chilipepper length at age (Appendix A).
- Comparison of the base model (with time-blocked selectivity in the trawl fleet) to models with constant trawl selectivity and a flexible, semi-parametric selectivity function that varies over time and size (Xu et al. 2019)
- Assuming natural mortality was the same for both sexes
- Estimation of steepness and natural mortality (male and female)

Additional sensitivity analyses were conducted during the STAR panel. See Appendix B for details.

“Drop-one” analysis

We evaluated the influence of data associated with each survey fleet on model estimates by removing all data types (indices, lengths, and ages), one fleet at a time. Figure 81 shows model outputs (time series of spawning output, depletion and recruitment) when data from each survey fleet were sequentially removed from the model. In the case of the triennial and WCGBT surveys, this included the associated compositional (age and length) data, although for the WCGBTS we also evaluated the sensitivity of only removing the index and leaving the compositional data in the model, given the challenges in fitting the index combined with the importance of the age composition data in particular for informing growth.

The greatest changes among these sequential data removals were observed with the removal of the CalCOFI, the triennial and the WCGBTS data (Table 18). The removal of any one of these three sources resulted in a more optimistic estimate of relative abundance in very recent years. Removing each of these surveys also resulted in a modest increase in the estimated unfished spawning output. For the run without CalCOFI data, this was associated with a generally more optimistic perception of relative stock status, with a similar (but more modest) result for the run without the triennial trawl survey data. For the runs without the WCGBTS data, the results from both runs were of a considerably more pessimistic estimation of both spawning output and relative abundance between approximately 1970 and 2020, with the greatest differences observed in the years between approximately 2005 and 2015. The key driver of these differences is that recruitments estimated in the model without the survey data were generally far lower than those that included the data, particularly the strength of the 1999 year class, which was less than half as strong in the model without WCGBTS data as the base model. This general pattern held until 2013, when that pattern reversed, and can likely be explained by the paucity of compositional data (particularly age data) during the period in which fisheries landings and catch statistics were sparse. During this period the WCGBTS age and length data were extremely important to estimating recruitment and population trends. Thus, the inclusion of the survey data was associated with a near doubling of the estimated relative spawning output between approximately 2005 and 2015, although differences were less extreme between approximately 2015 and 2025. In nearly all of these cases, the sensitivities suggested that both spawning output, depletion and recruitment were within the estimated uncertainty of the base model, the exception being the very low relative abundance estimated for the 2005-2015 time period when WCGBTS data were excluded.

With respect to changes in parameter estimates, most changes were relatively modest. The most significant change was a fairly substantial increase in the estimated female natural mortality rate (from 0.165 to 0.178) when CalCOFI data were removed, this rate also increased to 0.172 with the removal of the triennial trawl survey data and indices. By contrast, with the removal of the WCGBTS data the natural mortality rate dropped from 0.165 to 0.151 (when all data were removed), and interestingly dropped even more significantly (to 0.140) when only the index data were removed. This suggests that both the relative abundance data and the age compositional data from this survey are highly informative with respect to natural mortality, which should be expected given the robust amount of age data available during an extended period for which fishing mortality was minimal.

Due to the poor fit for several of the early years of the WCGBTS index (specifically 2004-2007), and given that the “leave one out” sensitivity analysis suggested that the more influential indices on model results and stock status were the WCGBTS and the CalCOFI index, we also ran models in which those indices were upweighted (lambdas set to 10 rather than 1), to evaluate whether this could significantly improve the fits to the index, and how that would influence the model result. For the scenario in which the WCGBTS index was upweighted, the resulting spawning output, relative abundance (depletion) and recruitment estimates scaled upwards considerably for most of the time series, particularly during the mid-2000s when several of the survey years were underfit by the base model. Interestingly, the fit to the index improves very slightly, but still barely grazes the lower error bars for the 2004-2005 and 2007 survey index estimates (the 2006 data point is well fit), despite the model estimating that the stock was nearly at the unfished level during this time period. This was also associated with an increase in the magnitude of the 1999 recruitment event, as well as a substantial increase in the model estimated natural mortality rate (0.218 rather than 0.165 for females). However, the terminal depletion estimate did not vary by more than a percentage point from that of the base model (91% of the unfished level in 2025, relative to 83% in the base model). By contrast, when the CalCOFI index is upweighted, the model result is somewhat more pessimistic, with a downward scaling of abundance and recruitment and a considerably more pessimistic ending depletion value (61% of unfished, rather than 83%). The estimated natural mortality rate for females is considerably lower (0.13) in this scenario as well. In both of these scenarios, the model results are well outside of the base model uncertainty bounds for a large fraction of the modeled time period, although in all cases the terminal abundance estimate is well above target levels.

Evaluation of alternative data-weighting methods

The base model adjusts the input sample sizes of composition data following Francis (2011; method TA1.8) to reduce the effects of known problems with the use of a multinomial likelihood in this context (overdispersion and correlation). Since input sample sizes for marginal length compositions represent the number of trips, hauls, or port samples (rather than the number of fish measured), the STAT allowed the iterative tuning procedure to "upweight" sample sizes for length data. However, since the input sample sizes for CAAL data are numbers of fish, the maximum 'weight' was capped at one, i.e., the 'tuned' input sample size could not exceed the number of fish actually aged. This cap was used for CAAL data from the combined commercial fleets off Oregon and Washington, as well as the combined recreational fleets north of Point Conception. Length composition data was 'upweighted' for only one fleet: the commercial hook-and-line fishery south of Point Conception. McAllister and Ianelli ("M.I."; 1997) suggested an alternative approach to addressing the issues of overdispersion and correlation. A comparison of data weights for composition data using these two methods is in Table 19. Likelihoods between these two sensitivity analyses are not comparable due to the use of different data weights, but parameter estimates and associated derived quantities are shown in Table 20. The M.I. approach had larger weights for the composition data, on average, with the notable exception of the WCGBTS age data, for which the M.I. weight was almost 1/20th of the weight based on the Francis method. The M.I. approach also 'upweighted' three length data sets, compared to only one being upweighted using the Francis approach, and down weighted the two age data sets that were capped at one using the Francis approach. Spawning output estimates based on M.I. weights were generally smaller, but with a similar trend to the base model (Figure 82). Punt (2017) found that the M.I. method was inferior to Francis (2011), so the latter was used to tune initial sample sizes in the base model.

Effect of including fishery-dependent abundance indices and changing survey emphasis factors

We also explored the sensitivity of the model to the inclusion of data sources used in the 2007 benchmark and 2015 update assessments, but not included in this model, specifically the trawl fishery CPUE index and the central/northern California recreational fishery CPUE index (Figure 83, Table 21). As in these earlier assessments, the inclusion of the trawl fishery CPUE index results in a more optimistic estimation of abundance and relative stock status, while the recreational fishery CPUE results in a more pessimistic estimation. These results were associated with slight increases in the estimated female natural mortality rate (when trawl cpue included) and decreases (when the rec fishery CPUE was included), although the change was relatively modest (approximately 0.01 increase and decrease, respectively). When the two are both included, the resulting estimates are slightly more pessimistic, but much closer to the base model than the sensitivity with the recreational index alone. In all of these sensitivities, the model estimates of spawning output and depletion are well within the uncertainty bounds of the base model.

Time-varying growth analysis

As described in section 4.3.1, the previous benchmark and update assessments for chilipepper rockfish estimated variation in growth (length-at-age) over time. For this assessment, an analysis of spatio-temporal variation in growth from 1978 to 2024 was conducted external to the model (Appendix A). To evaluate model sensitivity to alternative specifications of time-varying growth, we compared models with 1) annual deviations in the von Bertalanffy '*k*' parameter, 2) constant k, as in the pre-STAR base model, and 3) deviations in k linked to a multiplicative index estimated externally (Appendix A). Use of the index was intended to invoke a pattern of variability consistent with chilipepper biology in terms of both amplitude and frequency. The STAT notes that this third approach would use the length-at-age data twice, and would therefore not be considered as a base model. The intent of this sensitivity is to evaluate the impact of time-varying growth on the population dynamics of chilipepper. The model with annual deviations in k (1978-2024, a period informed by composition data) had a large gradient (~0.1), even after attempts to start from alternative initial values. We therefore used the -hess_step option, reducing the gradient to nearly zero within the local minimum. Comparing results from the models with freely estimated annual deviations in k, deviations driven by the analysis from Appendix A, and constant k revealed similar trends in spawning output, depletion, and recruitment (Figure 84, Figure 85). Associated likelihood values (all runs used the pre-STAR base model data-weights), estimated parameters, and select derived quantities are provided as Table 22. The STAT recommends further research into this topic for future assessments. Models evaluated here are relatively simple, and only account for variability in a single parameter, although correlations between growth parameters (e.g., k and asymptotic maximum size) are well-known and worthy of consideration. Trends and/or autocorrelation in time-varying growth may also have greater impacts on population dynamics than those demonstrated in this sensitivity analysis. This analysis was not repeated for the final (post-STAR) base model, as the methodology required further development, as noted above.

Selectivity parameterization for the trawl fleet

We compared the pre-STAR base model (with time-blocked selectivity in the trawl fleet, changing around the year 2000) to models with constant trawl selectivity and a flexible, semi-parametric selectivity function that varies over time and size (Xu et al. 2019). The time-blocked selectivity (base) model reduced the total NLL by over 26 points with the addition of 2 parameters and had little effect on the model results (Table 23, Figure 86). The flexible, "2D" approach by Xu et al. increased the total NLL due to the additional "Parm_dev" likelihood component, but fits to the lengths were (not surprisingly) improved. This approach adds over 1300 parameters to the model, but was included as a sensitivity to evaluate how a very flexible selectivity parameterization would affect model results. Deviations from the underlying logistic curve suggest a shift in selectivity around 2000, when large spatial closures were taking effect (Figure 87). Ultimately, the STAT chose the time-blocked approach as it showed improved fits to the data with a relatively parsimonious parameterization.

Assumptions about natural mortality parameterization and Beverton-Holt steepness

If the final base model is changed to assume that natural mortality is the same for both females and males ("saving" one parameter), it increases natural mortality to 0.22 (to account for 'missing' males) and increases the NLL by over 25 points, mainly due to degraded fits to the composition data (Table 24). Population scale with sex-invariant M is increased, and current stock status is slightly less depleted (Figure 88). If steepness is estimated, along with sex-specific M parameters, the estimates of female and male M increase slightly (Table 24).

3.5.4 Retrospective Analysis

A retrospective analysis was conducted by sequentially removing up to 5 years of data from the base model starting with 2024. Sequential removal of the data produced mild retrospective patterns, with each 'peel' (successive removal of a single years' data) estimating a lower unfished spawning output and a slightly lower fraction of unfished spawning output in the end year, relative to the base model (Figure 89). Mohn's rho values were calculated using the r4ss function "SSmohnsrho" (Table 25).

3.6 Unresolved Problems and Major Uncertainties

- Likelihood profiles indicate that input data were informative for estimating natural mortality (M) but not steepness (*h*). The available data are only weakly informative about the steepness parameter (*h*) of the assumed Beverton-Holt stock recruitment relationship, and model output is highly sensitive to this parameter. The base model fixes steepness at the mean of the prior probability distribution (*h* = 0.72). When estimated, the parameter central tendency is much lower (*h* ~ 0.4, i.e., suggesting a less productive stock), despite the fact that the largest estimated recruitment (in 1999) occurred near the lowest biomass level.
- Skewed sex ratios observed in the catch may be caused by sex-specific natural mortality rates, sex-specific selectivity, or a combination of the two. The base model assumes that natural mortality rates vary by sex, and that selectivity is independent of sex.
- Future assessments would benefit from additional research into sources of chilipepper ageing error. The model's fit to the conditional age-at-length data displayed large, positive residuals for males at the upper edge of their size range in several year/fleet combinations. Large, positive residuals were also detected for females in some year/fleet combinations, with a greater-than-expected number of females that were older than expected, given their length. Sex-specific sizes and ages should be evaluated further (e.g., by revisiting original datasheets, examining otolith morphology, or reviewing archived biological samples) to resolve uncertainties about notable outliers
- Although results provided in an appendix to the stock assessment suggested the presence of time-varying growth, sensitivity analyses indicated minimal influences on model results. Thus, the model assumed that growth is time-invariant. Analyses of time-varying growth in the model were limited to variation in the parameter '*k*' from the von Bertalanffy growth function. Temporal variation in L_∞ (potentially correlated with k) may have a greater effect on model results.
- Model fit to the WCGTS index, particularly in the early part of the time series, warrants further investigation, including additional work on index standardization.
- Catchability (q) estimates for trawl survey indices are counter-intuitive (i.e., near or greater than 1). Indices of abundance from these surveys are not used to inform absolute abundance, but additional research is needed to understand the scale implied by the model-based abundance estimates.
- Further evaluation is needed regarding the inclusion of a depth effect in the Triennial survey index, given that fits to the WCGBTS were improved by inclusion of depth as a covariate.
- Historical catch reconstructions are subject to uncertainty stemming from issues with species identification and the spatiotemporal extent of data collection, highlighting the need for uncertainty estimates comparable to those used for model-based indices.
- There is uncertainty in mean productivity estimates when applying a sum-to-zero constraint on recruitment deviation, potentially due to inaccurate assumptions about the stock-recruitment relationship. See Appendix B, Requests #4 and #17 for additional details.
- Estimation of selectivity and associated time blocking remain difficult for this assessment.

4 Management

4.1 Reference Points

Chilipepper rockfish spawning output was estimated to be 9.9 trillion eggs in 2025 (~95% asymptotic interval: 6.3 – 13.6; Table 11), which equates to a "depletion" level of 83% (~95% asymptotic interval: 63%-104%) in 2025. Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output. Long-term, sustainable yield based on the proxy MSY harvest rate (SPR 50%; Figure 90) is 2114 mt (~95% asymptotic interval: 1588-2639).

4.2 Harvest Projections and Decision Tables

Harvest projections assuming GMT-specified catches in 2025-2026, and ABC=ACL catches from 2027 onward are in Table 26.

Alternative states of nature defined by three values of the Beverton-Holt steepness parameter (*h*) were identified during the STAR panel, representing uncertainty that was not accounted for by the base model. A "low-productivity" alternative (*h*=0.38) and "high-productivity" alternative (*h*=0.97) are presented in addition to the base model (*h*=0.72). Population dynamics were forecast 12 years ahead for each state of nature, assuming two different catch projections requested during the STAR panel (; see also Appendix B, Request 18). Catch projections for 2025-2026 and fleet allocations for 2027-2036 were provided for each area and fleet by representatives on the GMT. Yields associated with the Overfishing Limit (OFL), Acceptable Biological Catch (ABC), and the assumed buffer to account for scientific uncertainty in the ABC, are provided in Table 27. Since spawning output is estimated to be above the management target (40% of unfished), Annual Catch Limits (ACLs) are equal to the ABC. Projections assume a relatively strong 2024 year class (see the "Recruitment" section of the Executive Summary).

4.3 Evaluation of Scientific Uncertainty

For the base model, the reported 'sigma' (log-scale uncertainty around the OFL value for the first forecast year, i.e., 2025; Ralston et al. 2011) is 0.232, less than the proxy value for category 1 stocks (0.5).

4.3.1 Risk Table information for Chilipepper rockfish

Contributions from John Field, Isaac Schroeder, Elliott Hazen and Jarrod Santora

Summary

To identify and evaluate environmental drivers of chilipepper (*Sebastes goodei*) recruitment and productivity, we evaluated what is known about drivers at important life history stages. For chilipepper, a common thread is that adult growth and reproductive output, larval condition and growth, pelagic juvenile abundance, all appear to be greater during cool, high productivity ocean conditions, which are typically associated with a negative Pacific Decadal Oscillation (PDO) and/or positive North Pacific Gyre Oscillation (NPGO), and more specifically in many cases with a higher proportion of subarctic ("minty") rather than subtropical ("spicy") source waters occurring within the California Current Ecosystem. Further, euphausiid (krill) populations, an important prey for both pelagic juveniles and adult life history stages, are generally higher during these cooler environmental phases. Herein, we provide an overview of the suite of environmental relationships that have been documented or suggested for this stock, with a focus on source-water variability as a key factor associated with both reproductive output and early life history survival (and thus subsequent recruitment), and review environmental influences among a wide range of life history stages of chilipepper.

In brief, throughout 2024, summer and fall NPGO values were negative (indication of reduced southward transport), which would be consistent with poorer condition and lower reproductive output for chilipepper. However, for winter and spring of 2025, PDO values have been negative, and subsurface waters off of central California (35-37° N) have been among their "mintiest" (most subarctic) since 2015.

The “minty” conditions are consistent with a greater fraction of subarctic waters, which are consistent with both greater pelagic juvenile abundance and recruitment based on the current assessment model. Thus, there is consistent environmental information to support the above average 2024 recruitment estimate in the base model, and to indicate that above average recruitment is also likely for the 2025 year class.

Primer on source-water variability and ocean modeling

Building on the work of Schroeder et al. (2019), which documented the relationship as well as potential mechanisms between winter source-water variability and observed spring pelagic juvenile young-of-the-year (YOY) rockfish abundance for ten species of winter-spawning rockfishes, the risk table for chilipepper makes extensive use of the ‘spiciness index’ to evaluate environmental drivers of recruitment. The logic is that subsurface ocean conditions are characterized by spiciness, which is a variable that describes how temperature and salinity change in a way that maintains water density and captures variability while density remains constant (Flament 2002). In this way, spiciness provides an indication of a water mass's origins, with cool/fresh "minty" spice values being indicative of subarctic conditions (Pacific Subarctic Upper Waters), and warmer, saltier "spicy" values representing waters of subtropical origin (Pacific Equatorial Waters). More subarctic, or “minty” waters also tend to be higher in dissolved oxygen at their origin, relative to Pacific equatorial waters.

For this risk table synthesis, an ocean modeling reanalysis product (which also assimilates historical observations) was used to evaluate connections between contemporary estimates of spiciness and chilipepper recruitment. For a consistent monthly, spatial and depth resolved dataset of ocean temperature and salinity, the Glorys Global Ocean Physics Reanalysis (GLORYS12V1 product; https://doi.org/10.48670/moi-00021) was used for spiciness indices. Although validation efforts related to GLORYS estimates of spiciness are ongoing, there is evidence that GLORYS does capture fine scale oceanographic features in the California Current Ecosystem (Amaya et al. 2023). For individual months, monthly values were spatially averaged over 35-37° N over an area 250 to 500 km offshore. Correlations between depth-derived spiciness (surface-300 m) per month (from January-June) were calculated to evaluate the potential of spiciness as an indicator of both empirical YOY chilipepper abundance as well as recruitment estimates and recruitment deviations from the current stock assessment.

Spawning output and larval productivity and dynamics

Like all *Sebastes* spp., relative fecundity (the number of eggs or larvae produced per unit of female body weight or length) increases with female size and age, and both this length-based fecundity and the probability of producing a second brood (which is greater in larger, older fish) are accounted for within the base assessment model (Lefebvre et al. 2018). Total reproductive output (larval production) at any given size or age is variable from year to year, and that bioenergetic trade-offs resulting from variable ocean conditions are key factors in year-to-year changes in reproductive investment (Harvey et al. 2011). Schroeder et al. (2019) hypothesized that in addition to being associated with more favorable recruitment conditions for late larval and early juvenile life history stages, source waters with subarctic origins could also influence reproduction of adult rockfish at depth of their habitats, consistent with the results of Beyer et al. (2024).

Beyer et al. (2024) report on interannual variability in the reproductive output of four species of rockfish, including chilipepper, spanning between the mid-1980s and 2019. Results suggest that both oceanographic conditions and female condition influenced the year-specific estimate of the slope parameter for the length-fecundity relationship, indicating larger fish with greater energetic reserves had disproportionately greater larval production, particularly when ocean conditions were cooler and more productive, with a greater proportion of subarctic source waters (Positive NPGO) during August-October, prior to the spawning season (January-March). Total brood size declined from 30 to 51% during low fecundity years relative to the high fecundity years, a significant range but also a lower range than the single brooding species (yellowtail and widow rockfish). This suggests that the probability of producing a second (or more) brood is part of the means by which the multiple brooding species vary their reproductive output in response to environmental and bioenergetic dynamics (Lefebvre et al. 2018, Beyer et al. 2021). In short, these results also provide strong evidence for environmental and bioenergetic drivers of interannual variability in reproductive output (e.g., total larval production by spawning females). In the short term, these analyses would suggest that all else equal, larval production is likely to be lower than expected based on population abundance and demographics alone for the current (2025) brood year. However, the weak relationship between larval production and year class strength would suggest that factors associated with greater early life history survival and subsequent pelagic YOY abundance may be more important than those associated with reproductive output.

In addition to larval production, larval condition (generally inferred by larval size or otolith core width at parturition) can influence early survival and subsequent year class strength. Both maternal and environmental influences on larval condition are documented in rockfishes, although most research has focused on nearshore species. In one study, a maternal influence on oil globule volume for chilipepper was noted (Stafford et al. 2014), although the relationship was not statistically significant. A more recent study of pelagic larvae from CalCOFI collections evaluated spatial and temporal variability in otolith core width at extrusion (parturition), and found evidence of both maternal and environmental conditions on larval chilipepper condition, which were in turn related to early larval rockfish growth rate and survival (Fennie et al. 2024). Essentially, larval chilipepper rockfish growth rate during winter was related to source water variability within southern California the previous fall. Ongoing efforts are expanding these investigations to more rigorously compare larval and pelagic juvenile YOY otolith core widths and the extent to which these proxies for larval condition relate to both oceanographic conditions and subsequent estimates of recruitment from both the RREAS and the stock assessment recruitment estimates.

Juvenile growth, survival and recruitment dynamics

Similar to the recent published work on larval otolith growth and survival rates (Fennie et al. 2024), otolith microstructure analyses are ongoing to quantify otolith width at birth, late larval and pelagic juvenile growth rates, and age to support development of year-specific YOY growth models. Integrating these metrics with environmental variables can enhance our understanding of mechanisms through which ocean conditions shape year-class strength. Similarly, quantifying variability in birthdate distributions of pelagic juveniles has confirmed substantial interannual variability in the timing of successful recruitment, such that greater pelagic juvenile abundance is associated with greater survival of individuals that undergo parturition earlier in the spawning season (Ralston et al. 2013).

An index of pelagic juvenile (young-of-the-year, YOY) chilipepper rockfish, derived from the RREAS data are included in the stock assessment, and suggest strong recruitment in 2024 (reflected in the base model). This year class strength might have otherwise been underpredicted if inferred by environmental conditions alone, given the near average spiciness values observed in Spring of 2024 (Schroeder et al. 2019, unpublished data). However, for winter and spring of 2025, PDO values have been negative, and subsurface (roughly 150-250 meters depth) offshore waters off of central California (35-37° N) have been among their “mintiest” (most subarctic) since 2015. As described above, spiciness gives an indication of a water mass's origins, with cool/fresh "minty" spice values indicative of subarctic conditions, and hot/salty "spicy" values of equatorial origin. The “minty” conditions are consistent with greater pelagic juvenile abundance of chilipepper and other winter-spawning rockfishes (Schroeder et al. 2019; Santora et al. 2021). In an evaluation of this index of spiciness with both the recruitment estimates and recruitment deviations estimated in this assessment for the 1993-2024 time period, there is also a strong correlation (Spearman rho=-0.71 to recruitment, -0.70 to recruitment deviations, $p<0.01$), which would indicate that the 2025 year class should be expected to be well above average (Figure 91**,** Figure 92). Interestingly, ocean conditions further north (e.g., north of Cape Mendocino) have been closer to long-term average levels, suggesting that oceanographic conditions may be less favorable for the northern stocks previously evaluated with respect to pelagic YOY indices (Schroeder et al. 2019), such as widow and yellowtail rockfish.

In addition to the species-specific index of YOY, a recent coastwide analysis of the pelagic groundfish community assemblage structure (Gasbarro et al. 2025) found that years of high productivity were associated with both high estimates of diversity, as well as different pelagic YOY assemblages relative to those seen predominantly in years of low productivity (Santora et al. 2021). Although Gasbarro et al. (2025) used data through 1990-2023, the analysis was updated using 2024 survey data, and the results suggest that in 2024 the abundance and diversity of groundfish was higher than it had been since the peak abundance levels of 2015 (Santora et al. 2017), and that this high abundance was associated with greater species richness and diversity throughout the range of the survey. Based on preliminary data from the RREAS 2025 survey, catch rates of pelagic juvenile chilipepper, as well as many groundfish species more generally, have been higher than the long-term average. This is consistent with the very "minty" (subarctic) waters observed for the winter and early spring of 2025 off of central California (35-37° N), and would suggest that above, to significantly above average recruitment conditions are likely for 2024 (as currently estimated in the model) and 2025 (not yet in the modeled period).

Indices of age 0 and 1 chilipepper (individuals 16 cm or smaller) from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) have also been evaluated over both space and time (Tolimieri et al. 2020). In recent years (2021-2024), the relative abundance for fish in this age and size range showed values slightly above average for 2021 and 2022, consistent with a slightly above average recruitment in 2021 estimated in the base model, with slightly below average recruitment in 2023 and 2024. However, these data are already in the model as part of the WCGBTS index, and thus are not explicitly discussed in the risk table. The spatial distribution patterns and trends in this index are included here (Figure 93) for additional consideration.

Time-varying growth of adults

Time varying growth has been suggested or documented for a number of groundfish species along the U.S. West Coast, such as Pacific hake, sablefish and many others (Stawitz et al. 2015, Johnson et al. 2025). For chilipepper, both the 2007 benchmark and 2015 update assessments included time varying growth, implemented through time blocks on offset parameters to the growth coefficient (K) that were informed by the timing of significant shifts in the PDO, such that periods of more rapid growth were associated with negative PDO conditions (e.g., cool SST years). Time-varying growth was more rigorously revisited for the current assessment (see Appendix A), and indeed growth was observed to vary considerably over time, although the phenomena is not explicitly accounted for in the base model. The analysis indicates that periods of above and below average growth varied throughout the 1980s and 1990s, and growth conditions between approximately 2005 and 2009, and again between 2015 and 2017, were relatively poor. Those time periods were associated with unusual ocean conditions, including the large marine heatwave that took place between 2014 and 2016, however they also occurred in time periods that followed some of the strongest recruitment events estimated in the current assessment (1999 and 2013). This might suggest that density dependent processes could be important, which has also been suggested for other groundfish species. The observation of significant autocorrelation in the time-varying growth analysis could also reflect either, or both, some response to climate dynamics or some type of density-dependent process. If this cyclic pattern holds, it would suggest that a period of low growth may be observed in the relatively near future, however the pattern and the drivers are not well understood.

Trophic considerations

With respect to trophic interactions, chilipepper are midwater foragers, with euphausiids, forage fishes (such as anchovies, Pacific hake, and mesopelagic fishes), and small squids among key prey items (Love et al. 2002). More recent food habits data from WCGBTS (123 fish between 2005-2008), although relatively sparse, are highly consistent with this generalization, with krill and small fishes (such as myctophids, juvenile Pacific hake, and other rockfishes) among the most frequently occurring prey, along with various cephalopods and other crustaceans. With respect to predation mortality, pelagic juvenile rockfishes of all species, including chilipepper, are among one of the most important forage taxa identified in a meta-analysis of predator food habits studies in the California Current. Key predators of pelagic juveniles include seabirds (e.g., common murre), salmon, lingcod, and other piscivorous fishes (Szoboszlai et al. 2015, Warzybok et al. 2018), while adults are also consumed by larger piscivorous fishes, such as bocaccio and lingcod, as well as marine mammals such as California sea lions. Most of these forage taxa have been at above average abundance for 2024, and although many predator populations have been increasing, most have been doing so at consistent rates over recent decades, suggesting modest potential for sharp, recent increases in predation mortality. Consequently, foraging conditions can be considered favorable, and predation mortality is considered neutral.

See for a summary of potential factors affecting stock productivity.

4.4 Regional Management Considerations

Chilipepper rockfish are managed south of Cape Mendocino with a species-specific OFL, ABC, and ACL. North of Cape Mendocino, chilipepper are part of the northern shelf rockfish complex. Allocation of OFL between these two areas in previous assessments assigned 93% of yield to the southern region, and the remaining 7% to the northern shelf rockfish complex. An analysis of biomass distribution over the past five years based on the WCGBTS for this assessment (2019-2024) supports the same yield allocation. Extending the analysis to include all years of the survey (2003-2024) produces the same allocation.

As noted earlier, if the at-sea hake fishery begins targeting hake in waters off California, and bycatch rates for chilipepper increase as a result, the collection of biological data (e.g., lengths, otoliths) from chilipepper will be useful for future assessments.

4.5 Research and Data Needs

4.5.1 Progress since the last assessment

The 2007 benchmark assessment (Field 2007) called for additional research on several topics. These included improvements to historical catch reconstructions, specifically a comprehensive reconstruction across all rockfish stocks rather than independent efforts. Significant progress was made by Ralston et al. (2010) and Karnowski et al. (2014) for California and Oregon. Estimates of uncertainty in historical landings are still needed. Maturity estimates were updated for the 2015 update assessment, and size-based fecundity estimates were updated by Dick et al. (2017) for brood-fecundity and Lefebvre et al (2018) for multiple-brooding. Ageing error, although still a priority, has been better quantified via several rounds of double-reads across labs and ageing experts. The current assessment includes an extensive analysis of time-varying growth (Appendix A), although methods to incorporate time-varying biology in stock assessments are still evolving. The 2007 assessment called for additional research into the effects of large-scale spatial closures (e.g., the RCAs and CCAs) on stock assessment results. The current assessment incorporates time-varying selectivity based on these closures, but additional research into this topic is still needed. Lastly, the 2007 benchmark assessment called for analysis of trends south of Point Conception, identifying the CalCOFI survey as a potential source. This assessment includes the CalCOFI index of spawning output, using years in which samples were collected both south and north of Point Conception.

The 2015 update assessment echoed the concerns of the 2007 benchmark with respect to time-varying growth, and we have made progress on that front (Appendix A). Reproductive biology was also mentioned, and updated as the STAT has described in this assessment. The call for use of conditional age-at-length data has been answered, with the current model using CAAL compositions exclusively, and producing reasonable estimates of growth. Lastly, the RREAS survey was updated, included in the current assessment, and evaluated in the context of oceanographic conditions (section 4.3.1).

4.5.2 Research and Data needs identified during in the current assessment

- Addressing the underlying productivity in the spawner-recruit relationship ("steepness") remains a key research and data need for West Coast rockfish stocks. This model, like most West Coast rockfish models, continues to use the mean of the prior distribution from a meta-analysis, despite a suite of issues and concerns related to the inability to appropriately update that analysis.
- Among the ongoing efforts to better develop priors or other information to inform steepness include an effort to use a life-history based approach based on Mangel et al. (2010), in preparation as Beyer et al. (in prep), for which chilipepper are one of four species under evaluation. This approach suggests that steepness values considerably higher than that used in the meta-analysis are plausible, although the study needs to be completed and other considerations discussed before this work is ready for application, and the work would benefit from additional research into some of the life-history based relationships to better inform future implementation.
- Ongoing research provides strong insights into the environmental mechanisms related to variability in recruitment, as well as variability in growth and reproductive output. Such research should remain a high priority, particularly with respect to the potential to better inform forecasting.
- Further investigation of the relative importance of time-varying growth on chilipepper population dynamics is needed. Evidence suggests that growth variation is auto-correlated (possibly at multiple time scales; Appendix A), and methods to model this within the assessment may be needed, including correlations between growth parameters (e.g., k and $L\infty$).
- Further exploration of cohort and density-dependent effects at the assemblage level (particularly for co-occurring species like bocaccio, yellowtail, and widow rockfishes) may increase our understanding about variation in growth rates for chilipepper rockfish.
- Prioritize completion of analysis of the historic CalCOFI data from central California to expand the time series for future assessments.
- Further development of the spatiotemporal models would improve index standardization. This may include the use of barrier meshes to account for geographic barriers and unique coastline features. Residual diagnostics should be evaluated by depth, especially for demersal species, to decide whether to include a depth effect in the model (even when including anisotropy to account for variables like depth).
- Examination of factors contributing to skewed sex ratios in the catch is needed, e.g., sex-specific natural mortality, selectivity, and/or discards.
- Age validation for chilipepper rockfish is needed. Standardization of ageing methods is also needed to minimize ageing error, including both "traditional" (break-and-burn) methods and ages derived from FT-NIRS (scanning and modeling).
- A small number of ages derived from FT-NIRS were included using a unique ageing error matrix, yet model selection did not indicate a bias between FT-NIRS and traditional ageing methods. Visual inspection suggests a consistent bias toward younger FT-NIRS ages for older fish. This

may reflect limitations in the bias structures available in the ageing error software, supporting an improved understanding about differences between FT-NIRS and traditional break-and-burn ages.

- Selectivity estimation remains a challenge for this assessment due to complex and changing management measures. Further investigation into time-blocking and/or a more structured spatiotemporal modeling (e.g., by length groups or age) approach could clarify how to incorporate management and gear changes in future models by indicating which size/age might be affected by such changes.
- This assessment attempts to account for multiple brooding of larger, older female chilipepper with respect to larval production and reproductive output. However, both the spatial and temporal variability associated with this phenomenon could be better understood. An improved understanding of the environmental factors associated with variable reproductive output, including multiple brooding, could also lead to an improved interpretation of the CalCOFI larval abundance time series, as it is likely that some of the high variance observed in that time series relates to interannual variability in reproductive output, relative to simple sampling variance alone. Additionally, ongoing efforts to positively identify chilipepper larvae from the earliest part of the CalCOFI time series would greatly benefit the ability of that time series to inform the model.
- Additional biological research on skip spawning, functional maturity, and environmentally driven variation in brooding frequency is needed to improve estimates of fecundity.
- Although there is a reconstruction of historical rockfish landings for California waters, the current reconstruction does not explicitly account for the expansion of both fixed gear and trawl fisheries into deeper habitats, further from port, over time (as discussed in Miller et al. 2014 and the 2017 catch reconstruction review; PFMC 2017). Ongoing catch reconstruction efforts are also focused on efforts to quantify the uncertainty associated with both historical and recent catches (Grunloh et al. 2017), the completion of these efforts would better allow for this uncertainty to be accounted for in future assessment models.
- A better understanding about the portion of the population in Mexican waters may be supported by habitat suitability mapping.
- Continued research on density-independent effects on YOY survival, especially for integration into future risk tables. This includes developing an inshore-offshore index for the southern population and exploring moving average approaches to link the "minty-spicy" temperature index to recruitment dynamics.
- A better understanding about predator-prey dynamics would improve our understanding about time-varying natural mortality.
- If the at-sea hake fishery begins targeting hake in waters off California, and bycatch rates increase, collection of biological data (lengths, otoliths) from chilipepper will be useful for future assessments.

5 Acknowledgements

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7 Auxiliary Files

Files archived with the 2025 chilipepper assessment:
Chili_2025.ctl
Chili_2025.dat
forecast.ss
Report.sso
starter.ss
Files with population numbers at age x year x sex (.csv format)
Folder containing plots and html files from the base model using the “r4ss” package

8 Tables

Table 1: Evaluation of Management Performance for chilipepper rockfish south of 40 10 N. latitude. North of this, chilipepper is managed as part of the shelf rockfish complex. Note that total mortality estimates reported here are for the entire coast, based on the Groundfish Expanded Mortality Multiyear (GEMM) report, and therefore an overestimate of total mortality in the southern area. The GEMM report estimate for 2024 was not yet released when this assessment was prepared. Previous assessments have allocated yield to these areas as follows: 93% to the southern area (species-level ACL), and 7% as a species-specific contribution to the OFL/ABC/ACL for the northern shelf rockfish complex

Year	OFL (mt)	ABC (mt)	ACL (mt)	COASTWIDE Total Mortality (mt)
2015	1703	1628	1628	210
2016	1694	1619	1619	102
2017	2727	2607	2607	225
2018	2623	2507	2507	404
2019	2652	2536	2536	649
2020	2521	2410	2410	775
2021	2571	2358	2358	859
2022	2474	2259	2259	876
2023	2401	2183	2183	1277
2024	2346	2121	2121	1193.2*

* Preliminary estimate based on 2025 assessment

Table 2: Total removals (mt) of chilipepper rockfish by year and fleet definition. See section 2.1 for fleet descriptions.

Year	NoCA HKL	SoCA HKL	CA TWL	OR_WA Comm	CA NET	NoCA OR WA_Rec	SoCA Rec	TWL discard	Grand Total
1875	3.4	4.9	0.0	0.0	0.0	0.0	0.0	0.0	8.3
1876	6.8	9.7	0.0	0.0	0.0	0.0	0.0	0.0	16.5
1877	10.3	14.6	0.0	0.0	0.0	0.0	0.0	0.0	24.8
1878	13.7	19.4	0.0	0.0	0.0	0.0	0.0	0.0	33.1
1879	17.1	24.3	0.0	0.0	0.0	0.0	0.0	0.0	41.4
1880	20.5	29.1	0.0	0.0	0.0	0.0	0.0	0.0	49.6
1881	24.0	34.0	0.0	0.0	0.0	0.0	0.0	0.0	57.9
1882	27.4	38.8	0.0	0.0	0.0	0.0	0.0	0.0	66.2
1883	30.8	43.7	0.0	0.0	0.0	0.0	0.0	0.0	74.4
1884	34.2	48.5	0.0	0.0	0.0	0.0	0.0	0.0	82.7
1885	37.6	53.4	0.0	0.0	0.0	0.0	0.0	0.0	91.0
1886	41.1	58.2	0.0	0.0	0.0	0.0	0.0	0.0	99.3
1887	44.5	63.1	0.0	0.0	0.0	0.0	0.0	0.0	107.5
1888	47.9	67.9	0.0	0.0	0.0	0.0	0.0	0.0	115.8
1889	51.3	72.8	0.0	0.0	0.0	0.0	0.0	0.0	124.1
1890	54.7	77.6	0.0	0.0	0.0	0.0	0.0	0.0	132.3
1891	58.2	82.5	0.0	0.0	0.0	0.0	0.0	0.0	140.6
1892	61.6	87.3	0.0	0.0	0.0	0.0	0.0	0.0	148.9
1893	65.0	92.2	0.0	0.0	0.0	0.0	0.0	0.0	157.2
1894	68.4	97.0	0.0	0.0	0.0	0.0	0.0	0.0	165.4
1895	71.9	101.9	0.0	0.0	0.0	0.0	0.0	0.0	173.7
1896	75.3	106.7	0.0	0.0	0.0	0.0	0.0	0.0	182.0
1897	78.7	111.6	0.0	0.0	0.0	0.0	0.0	0.0	190.3
1898	82.1	116.4	0.0	0.0	0.0	0.0	0.0	0.0	198.5
1899	85.5	121.3	0.0	0.0	0.0	0.0	0.0	0.0	206.8
1900	89.0	126.1	0.0	0.0	0.0	0.0	0.0	0.0	215.1
1901	92.4	131.0	0.0	0.0	0.0	0.0	0.0	0.0	223.3
1902	95.8	135.8	0.0	0.0	0.0	0.0	0.0	0.0	231.6
1903	99.2	140.7	0.0	0.0	0.0	0.0	0.0	0.0	239.9
1904	102.6	145.5	0.0	0.0	0.0	0.0	0.0	0.0	248.2
1905	106.1	150.4	0.0	0.0	0.0	0.0	0.0	0.0	256.4
1906	109.5	155.2	0.0	0.0	0.0	0.0	0.0	0.0	264.7
1907	112.9	160.1	0.0	0.0	0.0	0.0	0.0	0.0	273.0
1908	116.3	164.9	0.0	0.0	0.0	0.0	0.0	0.0	281.2
1909	119.8	169.8	0.0	0.0	0.0	0.0	0.0	0.0	289.5
1910	123.2	174.6	0.0	0.0	0.0	0.0	0.0	0.0	297.8
1911	126.6	179.5	0.0	0.0	0.0	0.0	0.0	0.0	306.1
1912	130.0	184.3	0.0	0.0	0.0	0.0	0.0	0.0	314.3
1913	133.4	189.2	0.0	0.0	0.0	0.0	0.0	0.0	322.6
1914	136.9	194.0	0.0	0.0	0.0	0.0	0.0	0.0	330.9
1915	140.3	198.9	0.0	0.0	0.0	0.0	0.0	0.0	339.1
1916	143.7	203.7	14.4	0.0	0.0	0.0	0.0	0.0	361.8
1917	223.4	328.7	22.4	0.0	0.0	0.0	0.0	0.0	574.4
1918	262.3	299.4	26.2	0.0	0.0	0.0	0.0	0.0	588.0
1919	181.8	179.4	18.3	0.0	0.0	0.0	0.0	0.0	379.5
1920	185.5	194.8	18.6	0.0	0.0	0.0	0.0	0.0	398.9
1921	153.5	170.0	15.4	0.0	0.0	0.0	0.0	0.0	338.8
1922	131.8	167.3	13.2	0.0	0.0	0.0	0.0	0.0	312.4
1923	142.0	224.3	14.3	0.0	0.0	0.0	0.0	0.0	380.5
1924	82.0	299.9	8.2	0.0	0.0	0.0	0.0	0.0	390.1
1925	104.5	327.9	6.7	0.0	0.0	0.0	0.0	0.0	439.1
1926	166.1	408.4	20.2	0.0	0.0	0.0	0.0	0.0	594.7
1927	118.0	353.5	36.9	0.0	0.0	0.0	0.0	0.0	508.5
1928	150.9	301.0	47.4	0.0	0.0	1.5	0.3	0.0	501.0
1929	125.3	302.3	56.0	0.0	0.0	2.9	0.6	0.0	487.1

Year	NoCA HKL	SoCA HKL	CA TWL	OR_WA Comm	CA NET	NoCA OR WA_Rec	SoCA Rec	TWL discard	Grand Total
1930	170.9	315.7	58.6	0.0	0.0	3.3	0.8	0.0	549.4
1931	175.5	364.2	40.2	0.0	0.0	4.5	1.1	0.0	585.5
1932	123.0	243.7	47.8	0.0	0.0	5.6	1.4	0.0	421.5
1933	103.4	150.8	73.1	0.0	0.0	6.7	1.7	0.0	335.7
1934	106.6	170.0	70.5	0.0	0.0	7.8	1.9	0.0	356.8
1935	124.1	184.6	62.8	0.0	0.0	8.9	2.2	0.0	382.6
1936	101.9	109.4	66.7	0.0	0.0	10.0	2.2	0.0	290.2
1937	81.1	89.7	80.8	0.0	0.0	11.9	4.5	0.0	267.9
1938	103.7	63.7	68.2	0.1	0.0	11.7	3.8	0.0	251.1
1939	109.5	84.6	70.6	0.1	0.0	10.2	3.3	0.0	278.2
1940	86.1	95.7	55.8	0.2	0.0	14.7	2.1	0.0	254.6
1941	66.7	97.3	43.3	0.2	0.0	13.6	2.0	0.0	223.0
1942	30.3	43.3	11.2	0.3	0.0	7.2	1.0	0.0	93.3
1943	39.1	30.8	116.8	1.2	0.0	6.9	1.0	0.0	195.8
1944	27.6	4.2	515.6	2.0	0.0	5.7	0.8	0.0	556.0
1945	44.2	8.7	1084.5	2.5	0.0	7.6	1.1	0.0	1148.5
1946	38.2	16.4	817.3	1.8	0.0	13.0	1.9	0.0	888.5
1947	66.2	16.6	566.8	1.6	0.0	10.3	6.9	0.0	668.3
1948	20.0	23.9	465.5	3.2	0.0	20.5	20.2	0.0	553.3
1949	20.1	27.7	544.7	3.4	0.0	26.6	26.1	0.0	648.7
1950	28.7	24.0	684.1	2.2	0.0	32.4	22.4	0.0	793.8
1951	18.7	28.1	1107.6	3.1	0.0	37.0	18.9	0.0	1213.4
1952	14.5	20.6	1132.4	4.5	0.0	32.2	29.9	0.0	1234.1
1953	5.3	14.7	1357.7	2.6	0.0	27.5	32.3	0.0	1440.1
1954	9.8	21.0	1278.5	11.6	0.0	34.1	66.9	0.0	1421.9
1955	4.2	24.2	1291.8	10.6	0.0	40.7	99.7	0.0	1471.2
1956	6.1	26.2	1444.1	24.9	0.0	45.4	117.5	0.0	1664.1
1957	4.2	24.5	1545.0	13.4	0.0	52.4	77.8	0.0	1717.3
1958	7.7	20.7	1820.7	4.2	0.0	71.5	58.7	0.0	1983.4
1959	6.2	20.4	1545.0	3.9	0.0	56.3	37.5	0.0	1669.3
1960	9.9	22.3	1248.0	8.9	0.0	51.6	45.7	0.0	1386.3
1961	6.4	21.1	985.9	7.9	0.0	31.5	50.9	0.0	1103.8
1962	6.6	18.2	922.6	8.5	0.0	44.1	50.6	0.0	1050.6
1963	6.0	26.7	1082.1	18.0	0.0	36.5	43.5	0.0	1212.7
1964	2.7	22.3	767.4	7.7	0.0	48.3	56.8	0.0	905.1
1965	4.5	28.0	848.2	3.4	0.0	45.9	70.7	0.0	1000.7
1966	19.6	23.4	1899.6	3.0	0.0	66.7	116.6	0.0	2128.9
1967	19.9	28.3	2539.6	4.0	0.0	60.6	133.0	0.0	2785.4
1968	9.6	27.1	1525.4	2.6	0.0	63.9	138.5	0.0	1767.1
1969	19.7	20.9	708.5	2.6	2.9	57.4	150.2	0.0	962.2
1970	24.2	14.2	843.3	2.0	1.9	66.6	212.8	0.0	1164.9
1971	33.2	14.9	726.6	2.1	2.3	55.7	182.2	0.0	1016.9
1972	53.0	23.4	1077.9	1.1	2.1	61.4	222.8	0.0	1441.8
1973	45.5	21.5	2494.4	1.0	5.7	81.9	280.5	0.0	2930.3
1974	79.1	16.0	2843.2	0.9	15.4	96.5	341.0	0.0	3392.1
1975	46.3	24.8	2501.2	1.9	15.5	87.9	310.1	0.0	2987.7
1976	80.2	29.0	2548.4	1.3	14.1	94.5	278.5	0.0	3046.1
1977	63.2	21.8	1869.1	0.5	15.7	86.0	238.2	0.0	2294.4
1978	138.7	30.4	1293.1	0.6	25.8	102.1	211.6	0.0	1802.3
1979	131.4	45.2	2004.1	0.8	53.5	117.9	330.2	0.0	2683.1
1980	53.4	42.4	2720.1	2.6	45.4	64.4	191.5	0.0	3119.9
1981	87.9	44.9	2281.5	5.8	72.5	61.5	210.7	0.0	2764.8
1982	289.3	68.8	1671.2	28.2	85.4	179.1	210.0	0.0	2531.9
1983	56.8	35.0	1856.7	26.4	357.6	99.6	62.5	0.0	2494.6
1984	67.1	53.6	2334.5	3.1	236.0	136.6	19.0	0.0	2850.0
1985	256.7	28.1	1791.8	3.3	719.4	163.6	227.8	0.0	3190.8
1986	331.8	12.6	1251.8	2.3	1162.7	277.7	117.8	0.0	3156.6
1987	156.9	16.1	1311.5	0.8	465.1	114.3	3.0	0.0	2067.7
1988	274.8	64.1	1779.1	8.6	289.3	354.0	35.2	0.0	2805.0

Year	NoCA HKL	SoCA HKL	CA TWL	OR_WA Comm	CA NET	NoCA OR WA_Rec	SoCA Rec	TWL discard	Grand Total
1989	218.4	208.0	2380.3	4.7	361.3	178.1	107.6	0.0	3458.4
1990	192.0	39.1	2370.1	3.1	364.5	184.8	40.2	0.0	3194.0
1991	489.3	120.5	2810.2	5.2	333.8	154.2	31.8	0.0	3945.1
1992	1005.9	46.5	1319.8	13.4	296.0	124.0	23.5	0.0	2829.1
1993	814.4	36.7	1280.2	9.9	238.8	93.0	14.9	0.0	2487.9
1994	477.9	7.0	1261.8	19.0	107.7	62.4	21.4	0.0	1957.1
1995	319.0	5.8	1624.5	10.0	93.6	31.8	9.0	0.0	2093.7
1996	247.3	6.8	1518.4	9.9	57.7	20.6	12.2	0.0	1873.0
1997	318.2	18.2	1608.0	11.0	82.9	72.8	1.0	0.0	2112.3
1998	204.8	4.0	1131.9	19.9	77.6	1.0	6.5	0.0	1445.8
1999	101.3	2.9	835.6	5.5	9.7	18.4	6.1	0.0	979.5
2000	46.9	0.5	400.3	0.9	6.1	33.8	7.8	0.0	496.4
2001	24.4	0.8	306.5	0.7	4.9	50.6	1.3	0.0	389.2
2002	2.6	0.8	285.4	0.3	0.2	5.9	7.0	0.0	302.2
2003	0.1	0.1	27.3	1.6	0.1	0.0	0.3	0.0	29.5
2004	2.9	0.2	90.2	0.0	0.9	0.0	6.0	0.0	100.2
2005	3.2	0.2	117.9	0.1	0.1	1.0	7.8	0.0	130.3
2006	6.1	0.1	164.1	0.0	0.2	0.1	1.6	0.0	172.2
2007	4.1	0.3	123.5	0.0	0.2	0.1	6.6	0.0	134.9
2008	4.9	1.0	147.3	0.0	0.1	0.0	2.9	0.0	156.2
2009	0.6	0.3	304.9	1.6	0.0	0.0	2.1	0.0	309.5
2010	0.1	0.1	381.4	0.4	0.0	0.0	2.8	0.0	384.9
2011	0.7	0.1	292.4	1.3	0.0	0.0	5.3	25.3	325.1
2012	1.0	0.2	235.0	0.6	0.0	0.0	7.7	54.4	298.9
2013	0.8	0.3	322.7	1.8	0.0	0.0	7.2	74.1	407.0
2014	1.0	0.3	274.6	1.1	0.0	0.0	7.9	47.0	331.9
2015	0.9	0.2	176.1	1.8	0.0	0.0	5.8	20.6	205.6
2016	0.4	0.1	76.6	4.6	0.0	0.0	5.4	3.3	90.4
2017	2.7	0.2	157.4	56.7	0.0	0.1	2.5	10.5	230.2
2018	2.5	0.4	344.3	17.4	0.0	0.0	2.0	24.2	390.8
2019	13.7	0.3	530.6	34.8	0.0	0.1	5.8	55.7	641.1
2020	19.8	0.4	643.3	34.5	0.0	0.1	1.6	65.4	765.1
2021	27.1	1.3	700.7	46.1	0.1	0.2	3.7	83.0	862.2
2022	37.9	1.7	740.4	21.7	0.0	1.1	3.6	59.7	866.2
2023	59.9	2.2	928.1	18.0	0.0	146.1	34.3	74.2	1262.9
2024	66.2	3.3	936.0	8.9	0.0	56.0	35.8	87.0	1193.2
Grand Total	13953.7	11657.7	92960.6	624.1	5624.7	4685.1	5639.2	684.4	135829.5
% of Total	10.3%	8.6%	68.4%	0.5%	4.1%	3.4%	4.2%	0.5%	100%

Table 3: Length composition sample sizes for fishery fleets. See text for descriptions of sample sizes. See section 2.1.3 for details.

	Commercial No. CA HKL		Commercial So. CA HKL		Commercial CA Trawl		Commercial Oregon		Commercial CA Net		WCGOP IFQ Trawl Discard		Recreational No. CA, OR, WA		Recreational So. CA	
Year	Samp	Lengths	Samp	Lengths	Samp	Lengths	Samp	Lengths	Samp	Lengths	Hauls	Lengths	Trips	Lengths	Trips	Lengths
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106	3258
1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	178	8875
1977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111	6524
1978	0	0	0	0	60	1024	0	0	0	0	0	0	0	0	123	8128
1979	10	280	0	0	70	1628	0	0	0	0	0	0	0	0	0	0
1980	4	67	0	0	60	1027	0	0	0	0	0	0	12	180	22	666
1981	4	97	0	0	41	619	0	0	0	0	0	0	5	93	21	768
1982	10	211	0	0	78	1620	0	0	0	0	0	0	8	209	33	522
1983	3	58	0	0	109	2080	0	0	11	151	0	0	9	218	11	451
1984	1	17	5	67	166	4587	0	0	24	470	0	0	16	689	8	108
1985	9	275	4	65	211	6631	0	0	34	648	0	0	28	1792	50	1651
1986	7	170	3	45	127	3766	0	0	26	540	0	0	23	1971	43	1777
1987	1	26	5	95	138	4163	0	0	23	406	0	0	19	427	47	4073
1988	0	0	3	100	144	4441	0	0	19	330	0	0	44	4009	50	3331
1989	1	16	9	210	128	4328	0	0	17	402	0	0	57	3833	55	4685
1990	2	54	0	0	150	4804	0	0	42	722	0	0	15	608	0	0
1991	39	1799	0	0	155	7450	0	0	19	457	0	0	14	420	0	0
1992	74	2647	1	14	85	3697	0	0	31	795	0	0	33	1788	0	0
1993	74	3539	0	0	92	4480	0	0	28	974	0	0	34	2201	5	28
1994	69	3576	0	0	89	3640	0	0	30	860	0	0	23	1416	11	79
1995	16	705	0	0	79	3539	0	0	26	722	0	0	14	631	2	16
1996	22	1046	3	42	92	3262	0	0	12	315	0	0	18	734	7	29
1997	29	1252	5	101	109	4411	0	0	11	430	0	0	19	611	5	7
1998	21	810	3	21	88	2994	2	82	7	263	0	0	9	315	5	17
1999	8	410	0	0	66	2980	0	0	0	0	0	0	5	532	13	68
2000	9	364	0	0	37	1668	0	0	0	0	0	0	5	198	14	95
2001	9	395	0	0	42	2021	3	56	0	0	0	0	4	212	2	89
2002	2	63	0	0	45	1822	0	0	0	0	0	0	4	140	8	98
2003	0	0	0	0	13	565	1	15	0	0	0	0	1	2	0	0
2004	0	0	0	0	42	1712	0	0	0	0	0	0	1	1	49	298
2005	0	0	0	0	15	442	1	30	1	25	0	0	2	5	53	288
2006	3	70	0	0	21	634	0	0	0	0	49	210	1	1	61	332
2007	5	150	0	0	26	984	3	3	0	0	101	440	5	7	59	482
2008	6	118	2	46	47	1331	0	0	0	0	103	445	5	27	47	276
2009	0	0	0	0	44	1544	10	224	0	0	129	547	2	2	63	231
2010	0	0	1	16	40	1450	7	77	0	0	60	247	1	2	73	356
2011	0	0	0	0	13	556	4	36	0	0	196	894	2	2	85	633
2012	0	0	0	0	29	1249	8	46	0	0	261	1216	5	5	67	703
2013	0	0	0	0	28	1101	10	42	0	0	409	1919	3	11	75	730
2014	0	0	2	53	38	1344	11	41	0	0	577	2658	2	6	57	663
2015	0	0	3	65	39	1447	23	162	0	0	430	1699	6	15	35	427
2016	0	0	1	11	33	1387	12	146	0	0	153	526	2	2	39	433
2017	0	0	1	14	33	1260	35	678	0	0	135	505	6	13	42	191
2018	0	0	0	0	64	2995	48	452	0	0	288	1229	5	14	42	231
2019	2	72	0	0	77	4554	69	645	0	0	441	1952	9	14	51	318
2020	1	24	1	12	87	3692	20	176	0	0	334	1504	0	0	3	54
2021	6	195	1	18	70	2014	39	310	0	0	413	1854	7	17	20	177
2022	6	164	0	0	32	1495	35	479	0	0	402	1742	21	98	41	208
2023	1	11	1	12	38	1559	28	379	0	0	361	1871	129	3137	111	999
2024	3	50	3	50	49	2042	25	261	0	0	0	0	58	1029	102	1322

Table 4: Age composition sample sizes (number of fish) for fishery-dependent sources by fleet, year, and sex.

fleet name	year	females	males	unsexed	total
NoCA_HKL	1980	2	0	0	2
NoCA_HKL	1983	7	1	0	8
NoCA_HKL	1985	99	3	0	102
NoCA_HKL	1986	123	5	0	128
NoCA_HKL	1987	14	3	0	17
NoCA_HKL	1988	4	1	0	5
NoCA_HKL	1989	9	0	0	9
NoCA_HKL	1990	12	3	0	15
NoCA_HKL	1991	285	132	0	417
NoCA_HKL	1992	582	163	0	745
NoCA_HKL	1993	369	63	0	432
NoCA_HKL	1994	199	26	0	225
NoCA_HKL	1995	185	64	0	249
NoCA_HKL	1996	125	39	0	164
NoCA_HKL	1997	198	10	0	208
NoCA_HKL	1998	263	59	0	322
NoCA_HKL	1999	147	18	0	165
NoCA_HKL	2000	117	44	0	161
NoCA_HKL	2001	73	55	0	128
NoCA_HKL	2002	10	28	0	38
NoCA_HKL	2003	3	0	0	3
NoCA_HKL	2007	46	2	0	48
NoCA_HKL	2008	24	5	0	29
NoCA_HKL	2009	1	0	0	1
CA_TWL	1978	447	112	0	559
CA_TWL	1979	270	60	0	330
CA_TWL	1980	717	335	0	1052
CA_TWL	1981	475	224	0	699
CA_TWL	1982	825	392	0	1217
CA_TWL	1983	1721	581	0	2302
CA_TWL	1984	2539	1035	0	3574
CA_TWL	1985	2126	1145	0	3271
CA_TWL	1986	1285	712	0	1997
CA_TWL	1987	1638	880	0	2518
CA_TWL	1988	1472	938	0	2410
CA_TWL	1989	1631	924	0	2555
CA_TWL	1990	978	700	0	1678
CA_TWL	1991	962	636	0	1598
CA_TWL	1992	1363	714	0	2077
CA_TWL	1993	1325	680	0	2005
CA_TWL	1994	448	285	0	733
CA_TWL	1995	895	502	0	1397
CA_TWL	1996	455	343	0	798
CA_TWL	1997	1095	618	0	1713
CA_TWL	1998	1486	646	0	2132
CA_TWL	1999	1464	613	0	2077
CA_TWL	2000	707	288	0	995
CA_TWL	2001	448	318	0	766
CA_TWL	2002	729	294	0	1023
CA_TWL	2003	201	97	0	298
CA_TWL	2004	661	285	0	946
CA_TWL	2005	286	63	0	349
CA_TWL	2007	340	118	0	458
CA_TWL	2008	363	72	0	435
CA_TWL	2009	599	106	0	705
CA_TWL	2010	287	15	0	302
CA_TWL	2011	4	2	0	6
CA_TWL	2012	210	137	0	347
CA_TWL	2013	315	92	0	407
CA_TWL	2014	258	42	0	300
CA_TWL	2019	58	18	0	76
CA_TWL	2020	61	42	0	103
CA_TWL	2021	44	16	0	60
CA_TWL	2022	42	17	0	59
CA_TWL	2023	46	9	0	55
CA_TWL	2024	42	5	0	47
OR_WA_Comm	2019	33	7	0	40
OR_WA_Comm	2020	35	5	0	40
OR_WA_Comm	2021	36	4	0	40
OR_WA_Comm	2022	32	8	0	40
OR_WA_Comm	2023	34	6	0	40
OR_WA_Comm	2024	35	5	0	40
CA_NET	1983	64	4	0	68
CA_NET	1984	41	0	0	41
CA_NET	1985	218	46	0	264
CA_NET	1986	358	53	0	411
CA_NET	1987	328	38	0	366
CA_NET	1988	161	58	0	219
CA_NET	1989	273	41	0	314
CA_NET	1990	320	110	0	430
CA_NET	1991	74	22	0	96
CA_NET	1992	317	85	0	402
CA_NET	1993	158	29	0	187
CA_NET	1994	154	38	0	192
CA_NET	1995	59	1	0	60
CA_NET	1996	36	1	0	37
CA_NET	1997	58	5	0	63
CA_NET	1998	85	8	0	93
NoCA_OR_WA_Rec	2023	0	0	59	59
NoCA_OR_WA_Rec	2024	0	0	48	48

Table 5: Description of data filtering steps and resulting sample sizes (number of tows and total count of chilipepper rockfish) used for the CalCOFI larval abundance index.

Description	Number of Tows	Number of chilipepper
All tows C1 and CB tows, excluding P net sides prior to 1997	46,496	3,251
Exclude SCOOS stations	45,969	3,251
Include only line>=60 & line<=93.3 & station<=80	20,390	3,148
Exclude years 1985-1990	19,052	3,147
Excluded lines <= 73.3 for years 1959 and earlier	18,145	3,146
Include only months 11, 12, 1, 2, 3, 4	10,846	3,023
Average S and P net sides for same tow	10,234	2,917.5

Table 6: Length composition sample sizes for the triennial bottom trawl survey. Data from 1977 are not included in the 2025 stock assessment.

year	sex_grouped	n_tows	n	n_stewart_hamel	input_n
1977	all	50	4806	121	121
1977	sexed	50	4806	121	121
1977	unsexed	0	0	0	0
1980	all	12	1151	29	29
1980	sexed	12	1151	29	29
1980	unsexed	0	0	0	0
1983	all	17	1526	41	41
1983	sexed	17	1526	41	41
1983	unsexed	0	0	0	0
1986	all	14	1847	34	34
1986	sexed	14	1847	34	34
1986	unsexed	0	0	0	0
1989	all	88	6798	213	213
1989	sexed	88	6624	213	213
1989	unsexed	3	174	7	7
1992	all	53	3056	128	128
1992	sexed	52	3055	126	126
1992	unsexed	1	1	2	1
1995	all	73	3985	177	177
1995	sexed	73	3721	177	177
1995	unsexed	3	264	7	7
1998	all	81	3992	196	196
1998	sexed	75	3668	182	182
1998	unsexed	13	324	31	31
2001	all	76	3151	184	184
2001	sexed	73	3010	177	177
2001	unsexed	5	141	12	12
2004	all	88	4656	213	213
2004	sexed	87	4537	211	211
2004	unsexed	7	119	17	17

Table 7: Length composition sample sizes for WCGBTS survey.

year	sex_grouped	n_tows	n	n_stewart_hamel	input_n
2003	all	82	2484	199	199
2003	sexed	73	2348	177	177
2003	unsexed	13	136	31	31
2004	all	79	3283	191	191
2004	sexed	77	3214	187	187
2004	unsexed	7	69	17	17
2005	all	86	3704	208	208
2005	sexed	84	3576	204	204
2005	unsexed	7	128	17	17
2006	all	69	2679	167	167
2006	sexed	68	2613	165	165
2006	unsexed	1	66	2	2
2007	all	68	2495	165	165
2007	sexed	66	2472	160	160
2007	unsexed	2	23	4	4
2008	all	80	2209	194	194
2008	sexed	80	2192	194	194
2008	unsexed	4	17	9	9
2009	all	77	2111	187	187
2009	sexed	63	1753	153	153
2009	unsexed	17	358	41	41
2010	all	106	2091	257	257
2010	sexed	94	1666	228	228
2010	unsexed	25	425	60	60
2011	all	81	1058	196	196
2011	sexed	76	980	184	184
2011	unsexed	10	78	24	24
2012	all	100	1249	243	243
2012	sexed	92	1117	223	223
2012	unsexed	18	132	43	43
2013	all	93	1083	225	225
2013	sexed	77	890	187	187
2013	unsexed	21	193	51	51
2014	all	124	1728	301	301
2014	sexed	116	1607	281	281
2014	unsexed	18	121	43	43
2015	all	102	1031	247	247
2015	sexed	91	891	221	221
2015	unsexed	16	140	38	38
2016	all	111	1445	269	269
2016	sexed	94	1176	228	228
2016	unsexed	22	269	53	53
2017	all	93	905	225	225
2017	sexed	88	867	213	213
2017	unsexed	8	38	19	19
2018	all	93	985	225	225
2018	sexed	92	978	223	223
2018	unsexed	3	7	7	7
2019	all	52	659	126	126
2019	sexed	51	658	123	123
2019	unsexed	1	1	2	1
2021	all	126	1382	306	306
2021	sexed	99	1021	240	240
2021	unsexed	34	361	82	82
2022	all	107	1167	260	260
2022	sexed	101	1085	245	245
2022	unsexed	14	82	34	34
2023	all	92	1022	223	223
2023	sexed	81	858	196	196
2023	unsexed	18	164	43	43
2024	all	108	1168	262	262
2024	sexed	93	1018	225	225
2024	unsexed	22	150	53	53

Table 8: Age composition sample sizes from fishery-independent surveys used in the base model. See text for details regarding allocation of small, unsexed fish to sexed compositions.

Survey	Year	Female	Male	Unsexed	N
WCGBT_Survey	2003	339.5	323.5	0	663
WCGBT_Survey	2004	421.5	321.5	0	743
WCGBT_Survey	2005	477.5	354.5	0	832
WCGBT_Survey	2006	349	247	0	596
WCGBT_Survey	2007	344	246	0	590
WCGBT_Survey	2008	374.5	322.5	0	697
WCGBT_Survey	2009	315.5	300.5	0	616
WCGBT_Survey	2010	403	403	0	806
WCGBT_Survey	2011	312	335	0	647
WCGBT_Survey	2012	473	360	0	833
WCGBT_Survey	2013	377.5	305.5	0	683
WCGBT_Survey	2014	455	418	0	873
WCGBT_Survey	2015	356.5	251.5	0	608
WCGBT_Survey	2016	399	321	0	720
WCGBT_Survey	2017	293	247	0	540
WCGBT_Survey	2018	280.5	219.5	0	500
WCGBT_Survey	2019	211.5	137.5	0	349
WCGBT_Survey	2021	253	247	0	500
WCGBT_Survey	2022	276	230	0	506
WCGBT_Survey	2023	297	209	0	506
WCGBT_Survey	2024	270	237	0	507
Triennial_Survey	1983	340	394	0	734
Triennial_Survey	1992	135	111	0	246
Triennial_Survey	1998	197	240	0	437
Triennial_Survey	2001	252	233	0	485
Triennial_Survey	2004	340	291	0	631

Table 9: Summary of base model parameters.

Parameter	Number Estimated	Bounds (low, high)	Prior Distribution (Mean, SD) - Type	Point Estimate	Transformed Value	Std. Err. (Pt. Est.)
General Biology						
Natural mortality (*M*) - *female*	1	(0.01, 0.5)	(-1.869, 0.31) - Lognormal	0.165		0.012
Nat. mortality (*M*) - *male (offset)*	1	(-0.5, 1)	-	0.266	0.216	0.045
Ln (R_0)	1	(8, 13)	-	10.032	22733.6	0.180
Steepness (*h*)	0	(0.201, 0.999)	(0.72, 0.16) - "Full Beta"	0.720		-
Growth						
Length at age 0 - *female*	0	(5, 15)	-	7.300		-
Length at age 20 - *female*	1	(44, 52)	-	47.901		0.219
von Bertalnaffy k - f*emale*	1	(0.15, 0.25)	-	0.197		0.003
CV(L(age 0)) - *female*	0	(0.01, 0.2)	-	0.105		-
CV(L(age 20)) - *female*	1	(0.01, 0.15)	-	0.039		0.003
Length at age 0 - *male (offset)*	0	(-0.6, 0)	-	0.000	7.300	-
Length at age 20 - *male (offset)*	1	(-0.8, 0)	-	-0.328	34.497	0.008
von Bertalnaffy k - *male (offset)*	1	(0.2, 1)	-	0.526	0.333	0.031
CV(L(age 0)) - *male (offset)*	0	(-1, 1)	-	0.236	0.133	-
CV(L(age 20)) - *male (offset)*	0	(-1, 2)	-	0.100	0.043	-
Indices						
Extra SD - CalCOFI	1	(0, 1)		0.355		0.081
Extra SD - RREAS	0	(0, 1)	-	0.683		-
Recruitment Deviations						
SD of log-scale rec devs (sigma-R)	0	(0, 2)		1.00		-
Main Recruitment Deviation Parameters				Min	Max	maxSE
1968-2024	57	(-4, 4)	-	-2.252	2.477	0.906
Selectivity (see separate table)						
Summary of model parameters (see separate table for selectivity parameters)						
Number of parameters in model	164					
Number of estimated parameters	106	(including 12 forecast devs)				
Number within 1% of bound	0					

Table 10: Log-scale catchability coefficients (‘LnQ’), additive variance parameters (‘Q_extraSD’) and selectivity parameters from the base model. All catchability coefficients (‘LnQ’) are analytical estimates. LnQ values for the CA_TWL and NoCA_OR_WA_Rec fleets are shown for reference, but these indices are not included in the likelihood (see main text for details).

Parameter Label in SS3 (fleet # in parentheses)	Value	Estimated	Phase	Min	Max	Parm_StDev
LnQ_base_CA_TWL(3)	-4.994	_	-1	-15	0	_
LnQ_base_NoCA_OR_WA_Rec(6)	-12.637	_	-1	-15	0	_
LnQ_base_WCGBT_Survey(9)	0.590	_	-1	-15	3	_
LnQ_base_Triennial_Survey(10)	0.219	_	-1	-15	3	_
LnQ_base_CalCOFI_Survey(11)	-3.776	_	-1	-15	0	_
Q_extraSD_CalCOFI_Survey(11)	0.355	Yes	1	0	1	0.081
LnQ_base_RREAS_YOY_Survey(12)	-5.050	_	-1	-15	0	_
Q_extraSD_RREAS_YOY_Survey(12)	0.683	_	-1	0	1	_
Size_DblN_peak_NoCA_HKL(1)	40.9735	Yes	3	10	59	2.35091
Size_DblN_top_logit_NoCA_HKL(1)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_NoCA_HKL(1)	4.39925	Yes	3	0.01	12	0.32016
Size_DblN_descend_se_NoCA_HKL(1)	7	_	-3	0.01	12	_
Size_DblN_start_logit_NoCA_HKL(1)	-999	_	-3	-1000	-998	_
Size_DblN_end_logit_NoCA_HKL(1)	10	_	-3	-12	12	_
Size_DblN_peak_SoCA_HKL(2)	23.7993	Yes	3	8.5	59.5	0.90849
Size_DblN_top_logit_SoCA_HKL(2)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_SoCA_HKL(2)	1.2	_	-3	0.5	15	_
Size_DblN_descend_se_SoCA_HKL(2)	7	_	-3	0.01	12	_
Size_DblN_start_logit_SoCA_HKL(2)	-999	_	-3	-1000	-998	_
Size_DblN_end_logit_SoCA_HKL(2)	10	_	-3	-12	12	_
Size_DblN_peak_CA_TWL(3)	44.9044	Yes	3	10	59	1.66004
Size_DblN_top_logit_CA_TWL(3)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_CA_TWL(3)	4.55625	Yes	3	0.01	12	0.206183
Size_DblN_descend_se_CA_TWL(3)	7	_	-3	0.01	12	_
Size_DblN_start_logit_CA_TWL(3)	-999	_	-3	-1000	-998	_
Size_DblN_end_logit_CA_TWL(3)	10	_	-3	-12	12	_
Size_DblN_peak_OR_WA_Comm(4)	42.7525	Yes	3	10	59	6.38687
Size_DblN_top_logit_OR_WA_Comm(4)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_OR_WA_Comm(4)	4.55947	Yes	3	0.01	12	0.871433
Size_DblN_descend_se_OR_WA_Comm(4)	7	_	-3	0.01	12	_
Size_DblN_start_logit_OR_WA_Comm(4)	-999	_	-3	-1000	-998	_
Size_DblN_end_logit_OR_WA_Comm(4)	10	_	-3	-12	12	_
Size_DblN_peak_CA_NET(5)	46.9908	Yes	3	10	59	1.7738
Size_DblN_top_logit_CA_NET(5)	-6	_	-3	-10	10	_

Parameter Label in SS3 (fleet # in parentheses)	Value	Estimated	Phase	Min	Max	Parm_StDev
Size_DblN_ascend_se_CA_NET(5)	4.42563	Yes	3	0.01	12	0.217864
Size_DblN_descend_se_CA_NET(5)	7	_	-3	0.01	12	_
Size_DblN_start_logit_CA_NET(5)	-999	_	-3	-1000	-998	_
Size_DblN_end_logit_CA_NET(5)	10	_	-3	-12	12	_
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.8942	Yes	3	10	59	2.46261
Size_DblN_top_logit_NoCA_OR_WA_Rec(6)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.13617	Yes	3	0.01	12	0.229126
Size_DblN_descend_se_NoCA_OR_WA_Rec(6)	7	_	-3	0.01	12	_
Size_DblN_start_logit_NoCA_OR_WA_Rec(6)	-999	_	-3	-1000	-998	_
Size_DblN_end_logit_NoCA_OR_WA_Rec(6)	10	_	-3	-12	12	_
Size_DblN_peak_SoCA_Rec(7)	24.7079	Yes	3	8.5	50	1.02101
Size_DblN_top_logit_SoCA_Rec(7)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_SoCA_Rec(7)	2.92383	Yes	3	0.5	10	0.364116
Size_DblN_descend_se_SoCA_Rec(7)	3.31823	Yes	3	0.01	8	0.64822
Size_DblN_start_logit_SoCA_Rec(7)	-10	_	-3	-11	-10	_
Size_DblN_end_logit_SoCA_Rec(7)	-1.11196	Yes	3	-12	12	0.302647
Size_DblN_peak_TWL_discard(8)	29.5523	Yes	3	10	50	1.56611
Size_DblN_top_logit_TWL_discard(8)	-6	_	-3	-10	10	_
Size_DblN_ascend_se_TWL_discard(8)	4.16685	Yes	3	0.5	8	0.370267
Size_DblN_descend_se_TWL_discard(8)	3.19313	Yes	3	0.01	8	0.592072
Size_DblN_start_logit_TWL_discard(8)	-10	_	-3	-11	-10	_
Size_DblN_end_logit_TWL_discard(8)	-10	_	-3	-11	-10	_
SizeSel=1_BinLo_WCGBT_Survey(9)	3	_	-99	1	10	_
SizeSel=1_BinHi_WCGBT_Survey(9)	54	_	-99	53	55	_
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.6041	Yes	3	10	59.5	5.09178
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.15685	Yes	3	0.5	10	0.614889
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.8295	Yes	3	8.5	59.5	5.08479
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.8242	Yes	3	0.5	15	0.486629
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.7915	Yes	3	10	59	1.12358
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.28981	Yes	3	0.01	12	0.313352
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.6778	Yes	3	8.5	50	2.07561
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.75181	Yes	3	0.5	10	0.468246
Size_DblN_descend_se_SoCA_Rec(7)_BLK2repl_1875	7	_	-3	0.01	8	_
Size_DblN_end_logit_SoCA_Rec(7)_BLK2repl_1875	10	_	-3	-12	12	_
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.73193	Yes	3	0.5	10	0.454487
Size_DblN_descend_se_SoCA_Rec(7)_BLK2repl_1875	7	_	-3	0.01	8	_
Size_DblN_end_logit_SoCA_Rec(7)_BLK2repl_1875	10	_	-3	-12	12	_

Table 11: Chilipepper base model reference points and 95% asymptotic intervals.

Reference Point	**Estimate**	**Lower Interval**	**Upper Interval**
Unfished Spawning Output (billions of eggs)	11,922	10,006	13,839
Unfished Age 3+ Biomass (mt)	50,121	41,265	58,976
Unfished Recruitment (R0, 1000s)	22,734	14,697	30,770
Spawning Output (2025, billions of eggs)	9,925	6,263	13,587
Fraction Unfished (2025)	0.832	0.628	1.037
Reference Points Based SB40%			
Proxy Spawning Output SB40%	4,769	4,002	5,536
SPR Resulting in SB40%	0.458	0.458	0.458
Exploitation Rate Resulting in SB40%	0.089	0.080	0.098
Yield with SPR Based On SB40% (mt)	2,230	1,672	2,787
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (SPR50)	5,319	4,464	6,174
SPR50	0.5	--	--
Exploitation Rate Corresponding to SPR50	0.077	0.070	0.085
Yield with SPR50 at SB SPR (mt)	2,114	1,588	2,639
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB MSY)	3,056	2,563	3,548
SPR MSY	0.329	0.323	0.334
Exploitation Rate Corresponding to SPR MSY	0.136	0.121	0.151
MSY (mt)	2,421	1,807	3,035

Table 12: Time series of population estimates from the base model. Spawning output is in billions of eggs.

Year	Total Biomass (mt)	Spawning output	Total Biomass Age 3+ (mt)	Fraction Unfished	Age-0 Recruits (1,000s)	Total Mortality (mt)	(1-SPR)/ (1-SPR50%)	Exploitation Rate
1875	52043	11922	50121	1	22734	8.27	0.0033	0.0002
1876	52036	11920	50114	1.000	22733	16.54	0.0066	0.0003
1877	52022	11915	50100	0.999	22732	24.82	0.0099	0.0005
1878	52003	11908	50080	0.999	22731	33.09	0.0132	0.0007
1879	51978	11899	50056	0.998	22729	41.36	0.0165	0.0008
1880	51949	11889	50027	0.997	22727	49.63	0.0198	0.0010
1881	51916	11878	49994	0.996	22725	57.90	0.0231	0.0012
1882	51879	11865	49957	0.995	22723	66.18	0.0264	0.0013
1883	51839	11851	49918	0.994	22720	74.45	0.0296	0.0015
1884	51797	11836	49875	0.993	22717	82.72	0.0329	0.0017
1885	51752	11820	49831	0.991	22715	90.99	0.0362	0.0018
1886	51705	11804	49784	0.990	22711	99.26	0.0395	0.0020
1887	51656	11787	49735	0.989	22708	107.53	0.0427	0.0022
1888	51605	11769	49685	0.987	22705	115.81	0.0460	0.0023
1889	51553	11751	49633	0.986	22701	124.08	0.0493	0.0025
1890	51499	11733	49579	0.984	22698	132.35	0.0526	0.0027
1891	51445	11714	49525	0.982	22694	140.62	0.0559	0.0028
1892	51389	11694	49469	0.981	22691	148.89	0.0591	0.0030
1893	51332	11675	49413	0.979	22687	157.17	0.0624	0.0032
1894	51274	11655	49356	0.978	22683	165.44	0.0657	0.0034
1895	51216	11635	49297	0.976	22679	173.71	0.0690	0.0035
1896	51157	11614	49239	0.974	22675	181.98	0.0723	0.0037
1897	51097	11594	49179	0.972	22671	190.25	0.0756	0.0039
1898	51037	11573	49119	0.971	22667	198.52	0.0788	0.0040
1899	50976	11552	49059	0.969	22663	206.80	0.0821	0.0042
1900	50915	11531	48998	0.967	22659	215.07	0.0854	0.0044
1901	50853	11510	48937	0.965	22655	223.34	0.0887	0.0046
1902	50791	11489	48875	0.964	22650	231.61	0.0920	0.0047
1903	50729	11467	48813	0.962	22646	239.88	0.0953	0.0049
1904	50666	11446	48751	0.960	22642	248.16	0.0986	0.0051
1905	50603	11424	48688	0.958	22638	256.43	0.1019	0.0053
1906	50540	11403	48626	0.956	22633	264.70	0.1052	0.0054
1907	50477	11381	48563	0.955	22629	272.97	0.1085	0.0056
1908	50414	11360	48500	0.953	22625	281.24	0.1118	0.0058
1909	50350	11338	48436	0.951	22620	289.51	0.1152	0.0060
1910	50286	11316	48373	0.949	22616	297.79	0.1185	0.0062
1911	50222	11294	48309	0.947	22611	306.06	0.1218	0.0063
1912	50158	11272	48246	0.945	22607	314.33	0.1251	0.0065
1913	50094	11250	48182	0.944	22602	322.60	0.1284	0.0067
1914	50029	11229	48118	0.942	22598	330.87	0.1317	0.0069
1915	49965	11207	48054	0.940	22593	339.15	0.1350	0.0071
1916	49900	11185	47989	0.938	22589	361.85	0.1436	0.0075
1917	49822	11159	47912	0.936	22583	574.44	0.2177	0.0120
1918	49564	11072	47654	0.929	22565	587.98	0.2233	0.0123
1919	49323	10989	47413	0.922	22547	379.50	0.1523	0.0080
1920	49294	10978	47386	0.921	22545	398.94	0.1597	0.0084
1921	49251	10964	47345	0.920	22542	338.85	0.1379	0.0072
1922	49267	10970	47360	0.920	22543	312.35	0.1280	0.0066
1923	49304	10983	47397	0.921	22546	380.49	0.1535	0.0080
1924	49275	10976	47369	0.921	22545	390.11	0.1580	0.0082
1925	49238	10966	47331	0.920	22542	439.11	0.1759	0.0093
1926	49161	10942	47254	0.918	22537	594.68	0.2301	0.0126
1927	48953	10873	47047	0.912	22522	508.48	0.2020	0.0108
1928	48843	10838	46938	0.909	22515	501.04	0.1994	0.0107
1929	48752	10809	46848	0.907	22508	487.09	0.1952	0.0104
1930	48683	10787	46779	0.905	22503	549.39	0.2172	0.0117
1931	48566	10749	46663	0.902	22495	585.51	0.2307	0.0125
1932	48430	10704	46527	0.898	22485	421.51	0.1729	0.0091
1933	48454	10713	46552	0.899	22487	335.66	0.1398	0.0072
1934	48551	10749	46650	0.902	22495	356.80	0.1476	0.0076
1935	48619	10775	46717	0.904	22501	382.57	0.1570	0.0082
1936	48656	10789	46753	0.905	22504	290.15	0.1211	0.0062
1937	48770	10830	46867	0.908	22513	267.88	0.1117	0.0057
1938	48891	10874	46988	0.912	22522	251.11	0.1046	0.0053
1939	49014	10917	47110	0.916	22532	278.24	0.1148	0.0059

Year	Total Biomass (mt)	Spawning output	Total Biomass Age 3+ (mt)	Fraction Unfished	Age-0 Recruits (1,000s)	Total Mortality (mt)	(1-SPR)/ (1-SPR50%)	Exploitation Rate
1940	49099	10948	47194	0.918	22538	254.63	0.1056	0.0054
1941	49196	10981	47291	0.921	22546	223.01	0.0930	0.0047
1942	49311	11020	47405	0.924	22554	93.34	0.0401	0.0020
1943	49530	11092	47623	0.930	22569	195.82	0.0803	0.0041
1944	49630	11131	47723	0.934	22577	555.97	0.2127	0.0116
1945	49380	11076	47472	0.929	22566	1148.52	0.4044	0.0242
1946	48596	10869	46687	0.912	22521	888.53	0.3300	0.0190
1947	48121	10738	46214	0.901	22492	668.33	0.2590	0.0145
1948	47900	10669	45996	0.895	22477	553.29	0.2202	0.0120
1949	47811	10639	45910	0.892	22470	648.65	0.2547	0.0141
1950	47648	10591	45748	0.888	22459	793.84	0.3055	0.0174
1951	47368	10511	45468	0.882	22441	1213.45	0.4408	0.0267
1952	46724	10332	44825	0.867	22398	1234.08	0.4528	0.0275
1953	46117	10161	44221	0.852	22357	1440.11	0.5189	0.0326
1954	45375	9953	43483	0.835	22304	1421.86	0.5214	0.0327
1955	44721	9764	42832	0.819	22255	1471.17	0.5428	0.0343
1956	44084	9579	42199	0.803	22206	1664.09	0.6040	0.0394
1957	43330	9363	41450	0.785	22145	1717.28	0.6271	0.0414
1958	42599	9152	40723	0.768	22084	1983.42	0.7058	0.0487
1959	41692	8893	39821	0.746	22005	1669.28	0.6337	0.0419
1960	41161	8733	39296	0.732	21954	1386.30	0.5566	0.0353
1961	40950	8659	39091	0.726	21930	1103.81	0.4667	0.0282
1962	41030	8667	39174	0.727	21933	1050.57	0.4476	0.0268
1963	41160	8694	39305	0.729	21941	1212.72	0.5010	0.0309
1964	41131	8684	39276	0.728	21938	905.12	0.3947	0.0230
1965	41389	8751	39534	0.734	21960	1000.66	0.4266	0.0253
1966	41537	8793	39682	0.738	21973	2128.91	0.7558	0.0536
1967	40619	8557	38762	0.718	21896	2785.37	0.9155	0.0719
1968	39236	8169	37301	0.685	36342	1767.09	0.6956	0.0474
1969	39086	8048	36909	0.675	32104	962.22	0.4401	0.0261
1970	40334	8148	37315	0.683	41008	1164.93	0.5078	0.0312
1971	41892	8273	39061	0.694	23028	1016.94	0.4477	0.0260
1972	44027	8554	41023	0.717	17606	1441.80	0.5694	0.0351
1973	45556	8857	43696	0.743	25607	2930.33	0.9008	0.0671
1974	45082	8866	43438	0.744	18716	3392.06	0.9744	0.0781
1975	43883	8709	41746	0.730	43879	2987.70	0.9126	0.0716
1976	42786	8550	40773	0.717	11612	3046.09	0.9396	0.0747
1977	41916	8308	38998	0.697	8985	2294.44	0.8042	0.0588
1978	41351	8261	40423	0.693	10781	1802.31	0.6861	0.0446
1979	40598	8329	39694	0.699	29277	2683.07	0.8848	0.0676
1980	38455	8079	37194	0.678	11722	3119.87	0.9887	0.0839
1981	35947	7583	33931	0.636	5187	2764.83	0.9662	0.0815
1982	33620	7108	32795	0.596	3512	2531.92	0.9500	0.0772
1983	31124	6672	30718	0.560	4880	2494.60	0.9764	0.0812
1984	28564	6201	27871	0.520	71154	2849.96	1.0926	0.1023
1985	25867	5551	24223	0.466	4251	3190.82	1.2020	0.1317
1986	24750	4749	20286	0.398	15415	3156.62	1.2517	0.1556
1987	24228	4160	23610	0.349	13451	2067.67	1.1177	0.0876
1988	24758	4190	23482	0.351	17228	2804.96	1.2499	0.1195
1989	24331	4150	23107	0.348	16531	3458.38	1.3525	0.1497
1990	23033	3930	21631	0.330	9493	3193.96	1.3394	0.1477
1991	21800	3719	20557	0.312	12345	3945.10	1.4742	0.1919
1992	19571	3320	18744	0.278	4292	2829.08	1.3647	0.1509
1993	18223	3108	17318	0.261	14402	2487.90	1.3305	0.1437
1994	16870	2931	16319	0.246	4386	1957.08	1.2338	0.1199
1995	15927	2819	14933	0.236	7660	2093.68	1.2966	0.1402
1996	14640	2633	14210	0.221	4030	1872.97	1.2826	0.1318
1997	13409	2459	12855	0.206	2830	2112.26	1.3855	0.1643
1998	11793	2190	11464	0.184	5875	1445.75	1.2459	0.1261
1999	11277	2028	10351	0.170	117648	979.48	1.0740	0.0946
2000	12029	1934	9453	0.162	5255	496.38	0.7584	0.0525
2001	16520	1999	9247	0.168	11504	389.17	0.6421	0.0421
2002	21690	2531	21121	0.212	6631	302.16	0.4991	0.0143
2003	26233	3552	25277	0.298	25088	29.49	0.0484	0.0012
2004	29720	4702	28817	0.394	6281	100.17	0.1099	0.0035
2005	32183	5661	30537	0.475	2184	130.27	0.1089	0.0043
2006	33429	6409	33001	0.538	1414	172.21	0.1208	0.0052
2007	33434	6942	33236	0.582	7243	134.89	0.0872	0.0041
2008	32489	7236	32234	0.607	6321	156.21	0.0955	0.0048
2009	31135	7270	30401	0.610	32546	309.50	0.1787	0.0102

Year	Total Biomass (mt)	Spawning output	Total Biomass Age 3+ (mt)	Fraction Unfished	Age-0 Recruits (1,000s)	Total Mortality (mt)	(1-SPR)/ (1-SPR50%)	Exploitation Rate
2010	29839	7070	28580	0.593	49301	384.87	0.2232	0.0135
2011	29571	6757	26597	0.567	16093	325.09	0.2104	0.0122
2012	31046	6552	27545	0.550	40535	298.88	0.1973	0.0109
2013	33541	6626	31407	0.556	74126	407.02	0.2548	0.0130
2014	36927	6926	33015	0.581	14853	331.91	0.2089	0.0101
2015	41854	7457	36908	0.626	34600	205.56	0.1271	0.0056
2016	46615	8318	44980	0.698	16900	90.36	0.0529	0.0020
2017	50757	9392	48277	0.788	13443	230.18	0.1149	0.0048
2018	53396	10392	52098	0.872	4819	390.80	0.1699	0.0075
2019	54315	11178	53374	0.938	7063	641.08	0.2436	0.0120
2020	53450	11631	52942	0.976	15418	765.11	0.2741	0.0145
2021	51416	11726	50554	0.984	26998	862.22	0.3054	0.0171
2022	48901	11491	47412	0.964	9842	866.19	0.3119	0.0183
2023	46711	11057	44752	0.927	26252	1262.86	0.4460	0.0282
2024	44605	10467	43148	0.878	68168	1193.16	0.4473	0.0277
2025	43491	9925	40513	0.832	22297	1598.72	0.5847	0.0395

[end of time series table]

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Table 13: Diagnostic results from starting the base model at different phases of the optimization routine.

Estimation start phase	Neg. Log Likelihood	max. gradient	Used -hess_step?
1 (base)	2633.05	0	yes
2	2633.05	1.04757e-03	no
3	2633.05	6.35030e-04	no
4	2633.05	3.72520e-03	no
5	2633.05	3.75120e-03	no

Table 14: Likelihoods, estimated parameters, and select derived quantities from a likelihood profile over the natural mortality parameter for females (M). Male natural mortality was estimated in each run as an exponential offset, i.e. Male M = (Female M) * exp(offset parameter).

Label	M_fem= 0.1	M_fem= 0.12	M_fem= 0.14	M_fem= 0.16	M_fem= 0.165	M_fem= 0.18	M_fem= 0.2
N.Parms	106	106	106	106	106	106	106
TOTAL	2652.75	2641.59	2635.48	2633.15	2633.05	2633.78	2636.84
Survey	36.425	32.014	29.893	29.257	29.272	29.631	30.717
Length_comp	572.210	569.880	568.864	569.040	569.289	570.424	572.955
Age_comp	2016.47	2014.58	2012.80	2011.38	2011.06	2010.31	2009.59
Recruitment	26.663	24.790	23.879	23.460	23.398	23.288	23.232
Parm_priors	0.978	0.329	0.049	0.007	0.025	0.124	0.350
NatM_uniform_Fem_GP_1	**0.1**	**0.12**	**0.14**	**0.16**	**0.165249**	**0.18**	**0.2**
L_at_Amax_Fem_GP_1	47.861	47.884	47.896	47.900	47.901	47.901	47.899
VonBert_K_Fem_GP_1	0.199	0.198	0.198	0.197	0.197	0.197	0.196
CV_young_Fem_GP_1	0.106	0.105	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.038	0.038	0.038	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	**0.516**	**0.418**	**0.342**	**0.280**	**0.266**	**0.228**	**0.184**
L_at_Amax_Mal_GP_1	-0.323	-0.325	-0.327	-0.328	-0.328	-0.329	-0.330
VonBert_K_Mal_GP_1	0.522	0.523	0.525	0.526	0.526	0.527	0.528
CV_young_Mal_GP_1	0.238	0.238	0.238	0.236	0.236	0.235	0.234
SR_LN(R0)	9.125	9.419	9.693	9.961	10.032	10.232	10.518
Q_extraSD_CalCOFI_Survey(11)	0.292	0.296	0.319	0.347	0.355	0.376	0.402
Size_DblN_peak_NoCA_HKL(1)	40.325	40.624	40.817	40.950	40.974	41.019	41.033
Size_DblN_ascend_se_NoCA_HKL(1)	4.393	4.405	4.406	4.401	4.399	4.391	4.377
Size_DblN_peak_SoCA_HKL(2)	23.594	23.656	23.719	23.783	23.799	23.845	23.907
Size_DblN_peak_CA_TWL(3)	44.168	44.339	44.577	44.833	44.904	45.114	45.411
Size_DblN_ascend_se_CA_TWL(3)	4.575	4.562	4.558	4.556	4.556	4.558	4.561
Size_DblN_peak_OR_WA_Comm(4)	40.435	40.979	41.658	42.481	42.753	43.558	45.263
Size_DblN_ascend_se_OR_WA_Comm(4)	4.392	4.425	4.473	4.537	4.559	4.625	4.773
Size_DblN_peak_CA_NET(5)	47.112	47.073	47.034	47.001	46.991	46.960	46.906
Size_DblN_ascend_se_CA_NET(5)	4.476	4.459	4.443	4.429	4.426	4.416	4.402
Size_DblN_peak_NoCA_OR_WA_Rec(6)	42.067	42.702	43.254	43.769	43.894	44.244	44.678
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.088	5.109	5.123	5.134	5.136	5.142	5.147
Size_DblN_peak_SoCA_Rec(7)	24.340	24.461	24.576	24.681	24.708	24.783	24.880
Size_DblN_ascend_se_SoCA_Rec(7)	2.850	2.876	2.899	2.919	2.924	2.938	2.955
Size_DblN_descend_se_SoCA_Rec(7)	3.529	3.473	3.409	3.338	3.318	3.261	3.182
Size_DblN_end_logit_SoCA_Rec(7)	-1.540	-1.407	-1.275	-1.145	-1.112	-1.019	-0.894
Size_DblN_peak_TWL_discard(8)	29.102	29.238	29.379	29.515	29.552	29.659	29.801
Size_DblN_ascend_se_TWL_discard(8)	4.151	4.155	4.160	4.165	4.167	4.171	4.177
Size_DblN_descend_se_TWL_discard(8)	3.233	3.223	3.210	3.197	3.193	3.181	3.164
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.277	51.321	51.428	51.564	51.604	51.709	51.830
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.148	4.147	4.151	4.155	4.157	4.160	4.163
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.716	48.767	48.796	48.825	48.829	48.832	48.812
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.869	4.854	4.840	4.827	4.824	4.815	4.801
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.110	33.300	33.473	33.727	33.792	33.962	34.168
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.169	3.202	3.229	3.278	3.290	3.319	3.352
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.057	30.210	30.393	30.612	30.678	30.871	31.152
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.684	3.699	3.719	3.744	3.752	3.775	3.809
Bratio_2025	0.435	0.587	0.715	0.812	0.832	0.878	0.916
SSB_unfished	12550	12131	11895	11883	11922	12150	12825
Totbio_unfished	45401	46545	48345	51111	52044	55274	61682
Recr_unfished	9184	12317	16210	21189	22734	27781	36982
Dead_Catch_SPR	1263	1486	1734	2026	2114	2392	2885
OFLCatch_2025	1180	1831	2567	3385	3617	4317	5457

Table 15: Likelihoods, estimated parameters, and select derived quantities from a likelihood profile over the logarithm (base *e*) of unfished recruitment (‘logR0’) for age-0 fish.

Label	logR0=9.5	logR0=9.75	logR0=10	logR0=10.25	logR0=10.5	logR0=10.75
N.Parms	106	106	106	106	106	106
TOTAL	2638.20	2634.39	2633.07	2633.72	2635.82	2638.77
Survey	30.541	29.307	29.216	29.986	31.318	32.907
Length_comp	569.843	569.091	569.205	570.272	572.219	574.874
Age_comp	2012.20	2011.76	2011.16	2010.31	2009.19	2007.81
Recruitment	25.490	24.226	23.466	23.050	22.851	22.773
Parm_priors	0.116	0.008	0.017	0.105	0.240	0.393
NatM_uniform_Fem_GP_1	0.133	0.148	0.163	0.178	0.191	0.203
L_at_Amax_Fem_GP_1	47.912	47.907	47.901	47.898	47.898	47.901
VonBert_K_Fem_GP_1	0.198	0.197	0.197	0.197	0.196	0.196
CV_young_Fem_GP_1	0.106	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.038	0.038	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.362	0.313	0.271	0.235	0.206	0.182
L_at_Amax_Mal_GP_1	-0.326	-0.327	-0.328	-0.329	-0.329	-0.329
VonBert_K_Mal_GP_1	0.526	0.526	0.526	0.526	0.525	0.524
CV_young_Mal_GP_1	0.236	0.236	0.236	0.236	0.236	0.236
SR_LN(R0)	**9.500**	**9.750**	**10.000**	**10.250**	**10.500**	**10.750**
Q_extraSD_CalCOFI_Survey(11)	0.312	0.330	0.352	0.376	0.399	0.420
Size_DblN_peak_NoCA_HKL(1)	40.926	40.991	40.982	40.862	40.626	40.290
Size_DblN_ascend_se_NoCA_HKL(1)	4.430	4.419	4.402	4.375	4.337	4.292
Size_DblN_peak_SoCA_HKL(2)	23.695	23.744	23.793	23.839	23.879	23.912
Size_DblN_peak_CA_TWL(3)	44.611	44.736	44.885	45.036	45.169	45.266
Size_DblN_ascend_se_CA_TWL(3)	4.569	4.561	4.557	4.555	4.554	4.554
Size_DblN_peak_OR_WA_Comm(4)	41.566	42.074	42.664	43.362	44.190	45.115
Size_DblN_ascend_se_OR_WA_Comm(4)	4.474	4.509	4.552	4.608	4.679	4.759
Size_DblN_peak_CA_NET(5)	47.167	47.095	47.005	46.880	46.715	46.514
Size_DblN_ascend_se_CA_NET(5)	4.456	4.442	4.428	4.412	4.397	4.381
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.343	43.624	43.867	44.046	44.131	44.102
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.143	5.141	5.137	5.130	5.120	5.106
Size_DblN_peak_SoCA_Rec(7)	24.543	24.621	24.698	24.772	24.836	24.889
Size_DblN_ascend_se_SoCA_Rec(7)	2.894	2.908	2.922	2.935	2.946	2.955
Size_DblN_descend_se_SoCA_Rec(7)	3.407	3.369	3.324	3.277	3.234	3.199
Size_DblN_end_logit_SoCA_Rec(7)	-1.322	-1.222	-1.124	-1.034	-0.957	-0.898
Size_DblN_peak_TWL_discard(8)	29.300	29.421	29.537	29.651	29.747	29.822
Size_DblN_ascend_se_TWL_discard(8)	4.156	4.161	4.166	4.171	4.174	4.176
Size_DblN_descend_se_TWL_discard(8)	3.220	3.208	3.195	3.180	3.167	3.156
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.846	51.722	51.617	51.509	51.403	51.283
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.183	4.170	4.158	4.147	4.137	4.128
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	49.115	48.999	48.853	48.637	48.389	48.128
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.869	4.848	4.827	4.803	4.780	4.761
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.381	33.556	33.770	33.911	33.975	33.957
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.213	3.244	3.286	3.309	3.314	3.302
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.446	30.547	30.663	30.776	30.877	30.952
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.730	3.739	3.750	3.761	3.770	3.774
Bratio_2025	0.601	0.717	0.821	0.906	0.972	1.017
SSB_unfished	10867	11247	11831	12688	13909	15634
Totbio_unfished	43340	46831	51376	57344	65206	75658
Recr_unfished	13360	17154	22027	28283	36316	46630
Dead_Catch_SPR	1494	1753	2069	2460	2952	3581
OFLCatch_2025	1876	2600	3491	4573	5877	7448

Table 16: Likelihoods, estimated parameters, and select derived quantities from a likelihood profile over the Beverton-Holt steepness parameter (h), for values from 0.3-0.6. ** An equilibrium fishing mortality level associated with the proxy MSY harvest rate for rockfish ($F_{SPR=50\%}$) is not possible with steepness values of 0.3 and lower, as equilibrium yield goes to zero between steepness values of 0.3 and 0.35.

Label	h=0.3	h=0.35	h=0.4	h=0.45	h=0.5	h=0.55	h=0.6
N.Parms	106	106	106	106	106	106	106
TOTAL	2630.15	2628.92	2628.78	2629.17	2629.82	2630.57	2631.34
Survey	22.901	23.276	24.048	24.979	25.939	26.852	27.683
Length_comp	570.928	569.911	569.343	569.037	568.899	568.875	568.935
Age_comp	2007.48	2008.88	2009.84	2010.49	2010.90	2011.12	2011.21
Recruitment	25.838	24.725	24.010	23.561	23.306	23.192	23.182
Parm_priors	3.000	2.125	1.536	1.108	0.782	0.528	0.328
NatM_uniform_Fem_GP_1	0.189	0.180	0.174	0.169	0.166	0.165	0.164
L_at_Amax_Fem_GP_1	47.859	47.865	47.872	47.878	47.884	47.889	47.893
VonBert_K_Fem_GP_1	0.197	0.197	0.197	0.197	0.197	0.197	0.197
CV_young_Fem_GP_1	0.105	0.105	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.039	0.039	0.039	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.217	0.235	0.248	0.258	0.264	0.268	0.269
L_at_Amax_Mal_GP_1	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328
VonBert_K_Mal_GP_1	0.526	0.526	0.527	0.527	0.527	0.527	0.527
CV_young_Mal_GP_1	0.237	0.237	0.237	0.237	0.237	0.237	0.237
SR_LN(R0)	10.751	10.528	10.366	10.249	10.166	10.108	10.070
SR_BH_steep	**0.3**	**0.35**	**0.4**	**0.45**	**0.5**	**0.55**	**0.6**
Q_extraSD_CalCOFI_Survey(11)	0.289	0.289	0.293	0.299	0.308	0.318	0.329
Size_DblN_peak_NoCA_HKL(1)	40.929	41.079	41.146	41.168	41.160	41.133	41.094
Size_DblN_ascend_se_NoCA_HKL(1)	4.387	4.407	4.417	4.421	4.421	4.419	4.414
Size_DblN_peak_SoCA_HKL(2)	23.864	23.843	23.827	23.816	23.808	23.803	23.800
Size_DblN_peak_CA_TWL(3)	45.343	45.258	45.178	45.107	45.048	45.000	44.962
Size_DblN_ascend_se_CA_TWL(3)	4.573	4.572	4.569	4.567	4.564	4.562	4.560
Size_DblN_peak_OR_WA_Comm(4)	44.496	43.912	43.460	43.206	43.018	42.890	42.811
Size_DblN_ascend_se_OR_WA_Comm(4)	4.721	4.668	4.625	4.602	4.585	4.573	4.566
Size_DblN_peak_CA_NET(5)	46.849	46.953	47.009	47.038	47.048	47.045	47.034
Size_DblN_ascend_se_CA_NET(5)	4.410	4.419	4.424	4.427	4.428	4.429	4.428
Size_DblN_peak_NoCA_OR_WA_Rec(6)	44.318	44.294	44.233	44.164	44.097	44.037	43.986
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.150	5.154	5.154	5.152	5.150	5.147	5.143
Size_DblN_peak_SoCA_Rec(7)	24.799	24.773	24.753	24.737	24.725	24.717	24.711
Size_DblN_ascend_se_SoCA_Rec(7)	2.940	2.936	2.932	2.930	2.927	2.926	2.925
Size_DblN_descend_se_SoCA_Rec(7)	3.237	3.259	3.277	3.291	3.301	3.309	3.314
Size_DblN_end_logit_SoCA_Rec(7)	-1.006	-1.035	-1.060	-1.078	-1.092	-1.101	-1.107
Size_DblN_peak_TWL_discard(8)	29.679	29.645	29.617	29.595	29.579	29.567	29.559
Size_DblN_ascend_se_TWL_discard(8)	4.172	4.172	4.171	4.170	4.170	4.169	4.168
Size_DblN_descend_se_TWL_discard(8)	3.175	3.179	3.183	3.186	3.188	3.190	3.192
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.074	51.188	51.277	51.349	51.409	51.461	51.507
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.116	4.125	4.132	4.137	4.142	4.146	4.149
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.511	48.723	48.843	48.906	48.932	48.931	48.913
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.794	4.811	4.821	4.827	4.830	4.831	4.830
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.900	33.890	33.868	33.846	33.828	33.814	33.805
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.306	3.308	3.306	3.303	3.300	3.297	3.295
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.598	30.600	30.600	30.604	30.611	30.622	30.636
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.728	3.733	3.736	3.738	3.741	3.743	3.746
Bratio_2025	0.371	0.432	0.493	0.555	0.615	0.672	0.726
SSB_unfished	18271	16285	15002	14108	13453	12953	12563
Totbio_unfished	84990	73957	66957	62221	58881	56460	54678
Recr_unfished	46656	37329	31756	28249	25990	24536	23625
Dead_Catch_SPR	0**	479	1266	1614	1796	1905	1981
OFLCatch_2025	2929	2865	2883	2953	3056	3178	3309

Table 17: Likelihoods, estimated parameters, and select derived quantities from a likelihood profile over the Beverton-Holt steepness parameter (h), for values from 0.65-0.95.

Label	h=0.65	h=0.7	h=0.72	h=0.75	h=0.8	h=0.85	h=0.9	h=0.95
N.Parms	106	106	106	106	106	106	106	106
TOTAL	2632.08	2632.78	2633.05	2633.44	2634.05	2634.65	2635.27	2636.02
Survey	28.414	29.046	29.272	29.585	30.043	30.431	30.762	31.046
Length_comp	569.06	569.22	569.29	569.40	569.60	569.81	570.01	570.20
Age_comp	2011.19	2011.11	2011.06	2010.99	2010.84	2010.68	2010.53	2010.38
Recruitment	23.243	23.348	23.398	23.476	23.612	23.745	23.872	23.989
Parm_priors	0.174	0.059	0.025	-0.015	-0.046	-0.022	0.090	0.398
NatM_uniform_Fem_GP_1	0.164	0.165	0.165	0.166	0.167	0.168	0.169	0.170
L_at_Amax_Fem_GP_1	47.897	47.900	47.901	47.902	47.904	47.906	47.908	47.909
VonBert_K_Fem_GP_1	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197
CV_young_Fem_GP_1	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.268	0.267	0.266	0.264	0.262	0.259	0.256	0.254
L_at_Amax_Mal_GP_1	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328
VonBert_K_Mal_GP_1	0.527	0.526	0.526	0.526	0.526	0.526	0.526	0.526
CV_young_Mal_GP_1	0.236	0.236	0.236	0.236	0.235	0.235	0.235	0.235
SR_LN(R0)	10.047	10.034	10.032	10.029	10.029	10.032	10.037	10.042
SR_BH_steep	**0.65**	**0.7**	**0.72**	**0.75**	**0.8**	**0.85**	**0.9**	**0.95**
Q_extraSD_CalCOFI_Survey(11)	0.340	0.351	0.355	0.361	0.370	0.378	0.385	0.391
Size_DblN_peak_NoCA_HKL(1)	41.047	40.995	40.974	40.942	40.889	40.839	40.791	40.747
Size_DblN_ascend_se_NoCA_HKL(1)	4.408	4.402	4.399	4.395	4.389	4.382	4.377	4.371
Size_DblN_peak_SoCA_HKL(2)	23.799	23.799	23.799	23.800	23.802	23.803	23.805	23.807
Size_DblN_peak_CA_TWL(3)	44.933	44.911	44.904	44.896	44.884	44.875	44.869	44.864
Size_DblN_ascend_se_CA_TWL(3)	4.558	4.557	4.556	4.556	4.555	4.555	4.554	4.554
Size_DblN_peak_OR_WA_Comm(4)	42.768	42.753	42.752	42.757	42.772	42.794	42.820	42.846
Size_DblN_ascend_se_OR_WA_Comm(4)	4.561	4.560	4.559	4.560	4.561	4.563	4.565	4.567
Size_DblN_peak_CA_NET(5)	47.018	46.999	46.991	46.978	46.958	46.937	46.918	46.900
Size_DblN_ascend_se_CA_NET(5)	4.427	4.426	4.426	4.425	4.423	4.422	4.421	4.419
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.943	43.907	43.894	43.877	43.852	43.832	43.814	43.798
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.140	5.137	5.136	5.135	5.132	5.130	5.128	5.126
Size_DblN_peak_SoCA_Rec(7)	24.709	24.708	24.708	24.708	24.710	24.711	24.713	24.715
Size_DblN_ascend_se_SoCA_Rec(7)	2.924	2.924	2.924	2.924	2.924	2.924	2.924	2.924
Size_DblN_descend_se_SoCA_Rec(7)	3.317	3.318	3.318	3.318	3.318	3.317	3.316	3.315
Size_DblN_end_logit_SoCA_Rec(7)	-1.110	-1.112	-1.112	-1.112	-1.111	-1.110	-1.108	-1.107
Size_DblN_peak_TWL_discard(8)	29.555	29.553	29.552	29.552	29.553	29.554	29.556	29.558
Size_DblN_ascend_se_TWL_discard(8)	4.168	4.167	4.167	4.167	4.166	4.166	4.166	4.165
Size_DblN_descend_se_TWL_discard(8)	3.192	3.193	3.193	3.193	3.193	3.193	3.193	3.193
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.551	51.590	51.605	51.623	51.649	51.671	51.688	51.702
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.153	4.156	4.157	4.158	4.160	4.162	4.163	4.164
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.882	48.845	48.830	48.805	48.764	48.723	48.684	48.648
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.828	4.825	4.824	4.823	4.820	4.817	4.814	4.811
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.798	33.793	33.791	33.789	33.786	33.783	33.780	33.777
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.292	3.291	3.290	3.289	3.287	3.285	3.284	3.282
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.653	30.671	30.678	30.689	30.706	30.723	30.738	30.752
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.748	3.751	3.752	3.753	3.755	3.757	3.759	3.761
Bratio_2025	0.774	0.817	0.832	0.854	0.885	0.912	0.934	0.952
SSB_unfished	12254	12007	11922	11809	11649	11521	11417	11332
Totbio_unfished	53353	52365	52044	51627	51076	50663	50353	50121
Recr_unfished	23084	22797	22734	22681	22675	22740	22847	22979
Dead_Catch_SPR	2042	2094	2114	2142	2186	2226	2265	2300
OFLCatch_2025	3442	3568	3617	3686	3792	3887	3971	4045

Table 18: Likelihoods, parameter estimates, and select derived quantiteis associated with “drop one” sensitivity analyses.

Label	Base	No CalCOFI	No RREAS	No Triennial	No WCGBTS	No WCGBTS Index
N.Parms	106	106	106	106	106	106
TOTAL	2633.05	2623.77	2606.21	2512.08	1702.02	2633.29
Survey	29.27	20.63	5.32	26.83	29.74	31.07
Length_comp	569.29	570.43	567.48	541.58	474.57	567.81
Age_comp	2011.06	2008.50	2011.92	1919.94	1178.34	2008.99
Recruitment	23.40	24.09	21.44	23.67	19.35	25.37
Parm_priors	0.0245	0.1025	0.0396	0.0585	0.0019	0.0517
NatM_uniform_Fem_GP_1	0.165	0.178	0.168	0.172	0.151	0.140
L_at_Amax_Fem_GP_1	47.901	47.896	47.892	47.951	47.260	47.847
VonBert_K_Fem_GP_1	0.197	0.197	0.197	0.196	0.204	0.197
CV_young_Fem_GP_1	0.105	0.105	0.105	0.106	0.082	0.104
CV_old_Fem_GP_1	0.039	0.039	0.039	0.038	0.058	0.039
NatM_uniform_Mal_GP_1	0.266	0.237	0.259	0.252	0.267	0.329
L_at_Amax_Mal_GP_1	-0.328	-0.328	-0.329	-0.331	-0.329	-0.327
VonBert_K_Mal_GP_1	0.526	0.525	0.530	0.522	0.514	0.526
CV_young_Mal_GP_1	0.236	0.234	0.231	0.276	0.078	0.243
SR_LN(R0)	10.032	10.221	10.066	10.153	9.965	9.751
Q_extraSD_CalCOFI_Survey(11)	0.355	0.300	0.369	0.373	0.317	0.315
Size_DblN_peak_NoCA_HKL(1)	40.974	40.633	40.912	40.543	43.598	41.299
Size_DblN_ascend_se_NoCA_HKL(1)	4.399	4.352	4.389	4.339	4.629	4.458
Size_DblN_peak_SoCA_HKL(2)	23.799	23.818	23.750	23.818	24.423	23.831
Size_DblN_peak_CA_TWL(3)	44.904	44.900	44.840	44.828	46.328	45.234
Size_DblN_ascend_se_CA_TWL(3)	4.556	4.551	4.553	4.547	4.632	4.581
Size_DblN_peak_OR_WA_Comm(4)	42.753	43.111	42.347	42.752	57.154	43.224
Size_DblN_ascend_se_OR_WA_Comm(4)	4.559	4.593	4.530	4.552	5.522	4.624
Size_DblN_peak_CA_NET(5)	46.991	46.867	46.962	46.808	48.258	47.162
Size_DblN_ascend_se_CA_NET(5)	4.426	4.415	4.422	4.411	4.474	4.447
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.894	43.822	43.824	43.657	47.345	43.924
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.136	5.122	5.132	5.105	5.364	5.170
Size_DblN_peak_SoCA_Rec(7)	24.708	24.726	24.695	24.718	24.729	24.708
Size_DblN_ascend_se_SoCA_Rec(7)	2.924	2.926	2.935	2.922	2.933	2.923
Size_DblN_descend_se_SoCA_Rec(7)	3.318	3.296	3.314	3.355	3.006	3.335
Size_DblN_end_logit_SoCA_Rec(7)	-1.112	-1.093	-1.083	-1.079	-0.990	-1.100
Size_DblN_peak_TWL_discard(8)	29.552	29.561	29.520	29.669	29.475	29.555
Size_DblN_ascend_se_TWL_discard(8)	4.167	4.164	4.184	4.175	4.081	4.172
Size_DblN_descend_se_TWL_discard(8)	3.193	3.195	3.202	3.166	3.280	3.182
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.604	51.642	51.666	51.414	51.783	51.291
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.157	4.156	4.161	4.142	4.131	4.139
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.830	48.599	48.796	48.417	55.594	49.091
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.824	4.805	4.820	4.791	5.215	4.855
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.792	33.860	33.847	33.768	36.317	33.565
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.290	3.296	3.301	3.274	3.813	3.254
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.678	30.853	30.725	30.851	31.132	30.340
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.752	3.770	3.758	3.771	3.859	3.712
Bratio_2025	0.832	0.927	0.833	0.903	0.964	0.878
SSB_unfished	11922	12396	11859	12439	12943	12609
Totbio_unfished	52043	55946	52202	55048	55507	51514
Recr_unfished	22734	27483	23518	25661	21265	17174
Dead_Catch_SPR	2114	2395	2147	2298	2111	1848
OFLCatch_2025	3617	4502	3631	4238	4427	3413

Table 19: Multiplicative adjustments to input sample sizes for length and age composition using two alternative, iterative ‘tuning’ methods (Francis, 2011; McAllister and Ianelli 1997). Weights for CAAL data were not tuned higher than 1, as the input sample sizes represent individual fish.

Fleet identifier	Data type	Tuned Francis Weight (base model)	Tuned M.I. Weight
NoCA_HKL	Lengths	0.549754	1.275011
SoCA_HKL	Lengths	2.604632	6.180662
CA_TWL	Lengths	0.229748	0.601379
OR_WA_Comm	Lengths	0.091690	0.372730
CA_NET	Lengths	0.427312	1.747854
NoCA_OR_WA_Rec	Lengths	0.403535	0.581049
SoCA_Rec	Lengths	0.162278	0.696095
TWL_discard	Lengths	0.020526	0.079056
WCGBT_Survey	Lengths	0.034620	0.141923
Triennial_Survey	Lengths	0.054124	0.182039
NoCA_HKL	CAAL	0.029681	0.153131
CA_TWL	CAAL	0.015459	0.033899
OR_WA_Comm	CAAL	1.000000	0.419436
CA_NET	CAAL	0.064954	0.162369
NoCA_OR_WA_Rec	CAAL	1.000000	0.565174
WCGBT_Survey	CAAL	0.095144	0.004457
Triennial_Survey	CAAL	0.068007	0.167048

Table 20: Likelihoods (not comparable for this sensitivity analysis due to differences in data-weighting approach), parameter estimates, and select derived quantities using two alternative, iterative 'tuning' methods (Francis, 2011; McAllister and Ianelli 1997). Likelihoods and derived quantities are shaded

Label	McAllister-Ianelli weighting	Base; Francis weighting
N.Parms	106	106
TOTAL	3623.83	2633.05
Survey	36.23	29.27
Length_comp	1654.71	569.29
Age_comp	1910.96	2011.06
Recruitment	21.93	23.40
Parm_priors	0.0003	0.0245
NatM_uniform_Fem_GP_1	0.153	0.165
L_at_Amax_Fem_GP_1	47.096	47.901
VonBert_K_Fem_GP_1	0.204	0.197
CV_young_Fem_GP_1	0.100	0.105
CV_old_Fem_GP_1	0.048	0.039
NatM_uniform_Mal_GP_1	0.245	0.266
L_at_Amax_Mal_GP_1	-0.318	-0.328
VonBert_K_Mal_GP_1	0.473	0.526
CV_young_Mal_GP_1	0.143	0.236
SR_LN(R0)	9.941	10.032
Q_extraSD_CalCOFI_Survey(11)	0.356	0.355
Size_DblN_peak_NoCA_HKL(1)	42.056	40.974
Size_DblN_ascend_se_NoCA_HKL(1)	4.514	4.399
Size_DblN_peak_SoCA_HKL(2)	23.876	23.799
Size_DblN_peak_CA_TWL(3)	45.202	44.904
Size_DblN_ascend_se_CA_TWL(3)	4.609	4.556
Size_DblN_peak_OR_WA_Comm(4)	43.242	42.753
Size_DblN_ascend_se_OR_WA_Comm(4)	4.591	4.559
Size_DblN_peak_CA_NET(5)	47.823	46.991
Size_DblN_ascend_se_CA_NET(5)	4.479	4.426
Size_DblN_peak_NoCA_OR_WA_Rec(6)	45.922	43.894
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.289	5.136
Size_DblN_peak_SoCA_Rec(7)	24.554	24.708
Size_DblN_ascend_se_SoCA_Rec(7)	2.925	2.924
Size_DblN_descend_se_SoCA_Rec(7)	3.218	3.318
Size_DblN_end_logit_SoCA_Rec(7)	-1.107	-1.112
Size_DblN_peak_TWL_discard(8)	29.511	29.552
Size_DblN_ascend_se_TWL_discard(8)	4.239	4.167
Size_DblN_descend_se_TWL_discard(8)	3.248	3.193
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	53.431	51.604
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.287	4.157
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	54.947	48.830
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	5.225	4.824
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	34.507	33.792
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.446	3.290
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.609	30.678
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.749	3.752
Bratio_2025	0.795	0.832
SSB_unfished	12156	11922
Totbio_unfished	53200	52043
Recr_unfished	20765	22734
Dead_Catch_SPR	2054	2114
OFLCatch_2025	3413	3617

Table 21: Likelihoods, parameter estimates, and select derived quantities associated with sensitivity runs where fishery-dependent indices from the previous assessment are included in the current base model, and where two fishery-independent indices are “upweighted” (lambda changed from 1 to 10).

Label	Base	Add rec CPUE	Add trawl CPUE	Add rec and trawl CPUE	Upweight CalCOFI	Upweight WCGBTS
N.Parms	106	106	106	106	106	106
TOTAL	2633.05	2637.08	2621.66	2630.71	2675.08	2525.81
Survey	29.27	30.66	17.29	25.25	58.87	-99.49
Length_comp	569.29	571.54	570.46	571.22	567.10	585.71
Age_comp	2011.06	2010.95	2010.75	2010.68	2027.48	2014.79
Recruitment	23.40	23.93	23.07	23.55	21.48	24.18
Parm_priors	0.025	0.001	0.081	0.001	0.145	0.619
NatM_uniform_Fem_GP_1	0.165	0.152	0.175	0.156	0.131	0.218
L_at_Amax_Fem_GP_1	47.901	47.871	47.911	47.882	47.941	47.877
VonBert_K_Fem_GP_1	0.197	0.197	0.197	0.197	0.196	0.197
CV_young_Fem_GP_1	0.105	0.105	0.105	0.105	0.105	0.104
CV_old_Fem_GP_1	0.039	0.039	0.038	0.039	0.038	0.039
NatM_uniform_Mal_GP_1	0.266	0.302	0.243	0.293	0.362	0.149
L_at_Amax_Mal_GP_1	-0.328	-0.328	-0.328	-0.327	-0.328	-0.330
VonBert_K_Mal_GP_1	0.526	0.528	0.523	0.524	0.530	0.525
CV_young_Mal_GP_1	0.236	0.240	0.236	0.240	0.237	0.231
SR_LN(R0)	10.032	9.798	10.214	9.872	9.641	10.838
Q_extraSD_CalCOFI_Survey(11)	0.355	0.323	0.385	0.338	0.281	0.421
Size_DblN_peak_NoCA_HKL(1)	40.974	41.114	40.323	40.549	42.156	40.904
Size_DblN_ascend_se_NoCA_HKL(1)	4.399	4.422	4.329	4.370	4.537	4.348
Size_DblN_peak_SoCA_HKL(2)	23.799	23.772	23.817	23.775	23.726	23.957
Size_DblN_peak_CA_TWL(3)	44.904	45.029	44.807	44.853	44.798	45.427
Size_DblN_ascend_se_CA_TWL(3)	4.556	4.557	4.555	4.555	4.556	4.542
Size_DblN_peak_OR_WA_Comm(4)	42.753	42.441	43.024	42.406	41.702	46.348
Size_DblN_ascend_se_OR_WA_Comm(4)	4.559	4.537	4.583	4.534	4.455	4.800
Size_DblN_peak_CA_NET(5)	46.991	46.983	46.983	47.125	47.412	46.806
Size_DblN_ascend_se_CA_NET(5)	4.426	4.437	4.426	4.450	4.446	4.387
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.894	43.892	43.863	43.443	44.240	45.493
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.136	5.168	5.123	5.133	5.171	5.138
Size_DblN_peak_SoCA_Rec(7)	24.708	24.664	24.735	24.663	24.616	25.077
Size_DblN_ascend_se_SoCA_Rec(7)	2.924	2.918	2.927	2.915	2.913	2.997
Size_DblN_descend_se_SoCA_Rec(7)	3.318	3.335	3.311	3.351	3.371	3.112
Size_DblN_end_logit_SoCA_Rec(7)	-1.112	-1.146	-1.096	-1.160	-1.220	-0.791
Size_DblN_peak_TWL_discard(8)	29.552	29.501	29.585	29.503	29.445	30.301
Size_DblN_ascend_se_TWL_discard(8)	4.167	4.169	4.165	4.167	4.162	4.181
Size_DblN_descend_se_TWL_discard(8)	3.193	3.198	3.187	3.196	3.207	3.076
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.604	51.816	51.503	51.881	50.864	51.878
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.157	4.178	4.146	4.182	4.110	4.162
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.830	49.063	48.398	48.732	49.215	48.688
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.824	4.845	4.790	4.822	4.839	4.782
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.792	33.633	33.518	33.402	33.714	34.305
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.290	3.270	3.210	3.202	3.288	3.366
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.678	30.551	30.817	30.697	30.035	31.393
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.752	3.741	3.764	3.758	3.671	3.835
Bratio_2025	0.832	0.709	0.908	0.764	0.591	0.911
SSB_unfished	11922	11179	12736	11438	12906	14555
Totbio_unfished	52043	47055	57049	48626	51255	73574
Recr_unfished	22734	17995	27291	19389	15383	50912
Dead_Catch_SPR	2114	1798	2416	1894	1746	3688
OFLCatch_2025	3617	2659	4458	2988	2204	7112

Table 22: Likelihoods, parameter estimates, and select derived quantities based on different assumptions of constant and time-varying growth (relative to pre-STAR base). Likelihoods and derived quantities are shaded.

Label	K devs fixed at Appendix A estimates	Estimated annual k deviations	Pre-STAR base
N.Parms	115	161	114
TOTAL	2597.09	2401.00	2597.98
Survey	23.26	21.11	24.51
Length_comp	576.11	538.57	572.24
Age_comp	1972.35	1805.25	1976.25
Recruitment	24.36	24.62	24.92
Parm_priors	1.006	0.125	0.055
NatM_uniform_Fem_GP_1	0.182	0.180	0.171
L_at_Amax_Fem_GP_1	47.894	47.851	48.190
VonBert_K_Fem_GP_1	**0.199**	**0.215**	**0.194**
CV_young_Fem_GP_1	0.104	0.098	0.110
CV_old_Fem_GP_1	0.040	0.036	0.037
NatM_uniform_Mal_GP_1	0.211	0.207	0.261
L_at_Amax_Mal_GP_1	-0.351	-0.341	-0.337
VonBert_K_Mal_GP_1	**0.611**	**0.577**	**0.549**
CV_young_Mal_GP_1	-0.146	-0.100	0.208
CV_old_Mal_GP_1	0.609	0.558	0.148
VonBert_K_Fem_GP_1_ENV_mult	0.342	NA	NA
SR_LN(R0)	10.406	10.325	10.248
Q_extraSD_CalCOFI_Survey(11)	0.309	0.309	0.313
Q_extraSD_RREAS_YOY_Survey(12)	1.249	1.258	1.233
Size_DblN_peak_NoCA_HKL(1)	41.489	43.464	41.247
Size_DblN_ascend_se_NoCA_HKL(1)	4.399	4.492	4.428
Size_DblN_descend_se_NoCA_HKL(1)	5.578	6.470	5.024
Size_DblN_peak_SoCA_HKL(2)	24.265	24.462	24.245
Size_DblN_ascend_se_SoCA_HKL(2)	1.374	1.522	1.410
Size_DblN_descend_se_SoCA_HKL(2)	6.034	5.933	5.781
Size_DblN_peak_CA_TWL(3)	44.982	44.763	44.673
Size_DblN_ascend_se_CA_TWL(3)	4.474	4.462	4.502
Size_DblN_descend_se_CA_TWL(3)	3.122	3.053	2.985
Size_DblN_peak_OR_WA_Comm(4)	42.951	42.483	41.925
Size_DblN_ascend_se_OR_WA_Comm(4)	4.484	4.432	4.476
Size_DblN_peak_CA_NET(5)	46.210	47.336	45.868
Size_DblN_ascend_se_CA_NET(5)	4.313	4.336	4.307
Size_DblN_descend_se_CA_NET(5)	4.290	8.896	3.632
Size_DblN_peak_NoCA_OR_WA_Rec(6)	44.769	45.889	43.491
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.143	5.169	5.090
Size_DblN_descend_se_NoCA_OR_WA_Rec(6)	4.888	4.687	4.321
Size_DblN_peak_SoCA_Rec(7)	24.629	24.341	24.645
Size_DblN_ascend_se_SoCA_Rec(7)	2.937	2.854	2.913
Size_DblN_descend_se_SoCA_Rec(7)	3.073	3.247	3.365
Size_DblN_end_logit_SoCA_Rec(7)	-0.797	-1.022	-1.108
Size_DblN_peak_TWL_discard(8)	30.055	29.968	29.547
Size_DblN_ascend_se_TWL_discard(8)	4.305	4.306	4.182
Size_DblN_descend_se_TWL_discard(8)	3.184	3.193	3.200
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.166	50.647	50.237
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.136	4.068	4.050
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	47.759	51.097	47.410
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.689	4.850	4.717
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	35.598	37.348	33.585
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.663	3.919	3.234
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	31.385	31.539	30.581
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.888	3.920	3.732
VonBert_K_Fem_GP_1_dev_se	**NA**	**0.500**	**NA**
VonBert_K_Fem_GP_1_dev_autocorr	**NA**	**0.000**	**NA**
Bratio_2025	0.603	0.588	0.603
SSB_unfished	14036	13710	13945
Totbio_unfished	64717	62341	61069
Recr_unfished	33071	30485	28215
Dead_Catch_SPR	2774	2636	2509
OFLCatch_2025	3431	3287	2894

Table 23: Likelihoods, parameter estimates, and select derived quantities for alternative treatments of trawl selectivity in California. Likelihoods and derived quantities are shaded.

Label	Constant, asymptotic	Time-blocked	Flexible, 2D
N.Parms	112	114	**1474**
TOTAL	2624.360	2597.980	3832.740
Survey	24.996	24.512	24.855
Length_comp	588.294	572.241	528.587
Age_comp	1986.700	1976.250	1978.840
Recruitment	24.339	24.915	24.449
Parm_priors	0.027	0.055	0.022
Parm_devs	0.000	0.000	1275.980
NatM_uniform_Fem_GP_1	0.166	0.171	0.165
L_at_Amax_Fem_GP_1	48.046	48.190	48.053
VonBert_K_Fem_GP_1	0.195	0.194	0.195
CV_young_Fem_GP_1	0.108	0.110	0.108
CV_old_Fem_GP_1	0.037	0.037	0.037
NatM_uniform_Mal_GP_1	0.283	0.261	0.283
L_at_Amax_Mal_GP_1	-0.346	-0.337	-0.337
VonBert_K_Mal_GP_1	0.580	0.549	0.556
CV_young_Mal_GP_1	0.186	0.208	0.213
CV_old_Mal_GP_1	0.275	0.148	0.166
SR_LN(R0)	10.156	10.248	10.130
Q_extraSD_CalCOFI_Survey(11)	0.317	0.313	0.314
Q_extraSD_RREAS_YOY_Survey(12)	1.249	1.233	1.242
Size_DblN_peak_NoCA_HKL(1)	41.857	41.247	41.544
Size_DblN_ascend_se_NoCA_HKL(1)	4.481	4.428	4.465
Size_DblN_descend_se_NoCA_HKL(1)	5.587	5.024	5.678
Size_DblN_peak_SoCA_HKL(2)	24.216	24.245	24.199
Size_DblN_ascend_se_SoCA_HKL(2)	1.401	1.410	1.385
Size_DblN_descend_se_SoCA_HKL(2)	5.762	5.781	5.749
Size_DblN_peak_CA_TWL(3)	38.303	44.673	NA
Size_DblN_top_logit_CA_TWL(3)	-6.000	-6.000	NA
Size_DblN_ascend_se_CA_TWL(3)	4.095	4.502	NA
Size_DblN_descend_se_CA_TWL(3)	11.467	2.985	NA
Size_DblN_start_logit_CA_TWL(3)	-10.000	-10.000	NA
Size_DblN_end_logit_CA_TWL(3)	-999.000	-999.000	NA
Size_DblN_peak_OR_WA_Comm(4)	41.113	41.925	41.456
Size_DblN_ascend_se_OR_WA_Comm(4)	4.380	4.476	4.431
Size_DblN_peak_CA_NET(5)	46.835	45.868	46.938
Size_DblN_ascend_se_CA_NET(5)	4.381	4.307	4.405
Size_DblN_descend_se_CA_NET(5)	4.795	3.632	4.984
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.765	43.491	43.792
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.101	5.090	5.119
Size_DblN_descend_se_NoCA_OR_WA_Rec(6)	4.514	4.321	4.567
Size_DblN_peak_SoCA_Rec(7)	24.495	24.645	24.586
Size_DblN_ascend_se_SoCA_Rec(7)	2.881	2.913	2.902
Size_DblN_descend_se_SoCA_Rec(7)	3.436	3.365	3.401
Size_DblN_end_logit_SoCA_Rec(7)	-1.121	-1.108	-1.150
Size_DblN_peak_TWL_discard(8)	29.595	29.547	29.509
Size_DblN_ascend_se_TWL_discard(8)	4.214	4.182	4.190
Size_DblN_descend_se_TWL_discard(8)	3.206	3.200	3.209
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	50.969	50.237	50.978
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.105	4.050	4.092
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.680	47.410	49.115
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.780	4.717	4.836
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.922	30.581	30.698
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.796	3.732	3.754
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	NA	33.585	NA
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	NA	3.234	NA
Size_DblN_descend_se_CA_TWL(3)_BLK3repl_1875	NA	19.000	NA
Size_inflection_CA_TWL(3)	NA	NA	31.672
Size_95%width_CA_TWL(3)	NA	NA	6.257
sigmasel_CA_TWL(3)_LEN(10)	NA	NA	1.000
Bratio_2025	0.5925	0.6025	0.5851
SSB_unfished	13487	13945	13333
Totbio_unfished	58072	61069	57435
Recr_unfished	25756	28215	25095
Dead_Catch_SPR	2356	2509	2306
OFLCatch_2025	2566	2894	2543

Table 24: Likelihoods, parameter estimates, and select derived quantities for alternative treatments of natural mortality (*M*) and steepness (*h*). Likelihoods and derived quantities are shaded. Note that variation in assumed values for *h* and *M* effect large changes in the estimated proxy for MSY under the default SPR 50% harvest rate ("Dead_Catch_SPR").

Label	h = 0.72, female M = male M	h = 0.72, sex-specific M (base)	estimate h, sex-specific M
N.Parms	105	106	107
TOTAL	2654.44	2633.05	2628.74
Survey	32.53	29.27	23.77
Length_comp	582.19	569.29	569.50
Age_comp	2016.01	2011.06	2009.56
Recruitment	23.06	23.40	24.21
Parm_priors	0.646	0.025	1.709
NatM_uniform_Fem_GP_1	**0.219**	**0.165**	**0.175**
L_at_Amax_Fem_GP_1	47.650	47.901	47.870
VonBert_K_Fem_GP_1	0.198	0.197	0.197
CV_young_Fem_GP_1	0.102	0.105	0.105
CV_old_Fem_GP_1	0.042	0.039	0.039
NatM_uniform_Mal_GP_1	**0.000**	**0.266**	**0.244**
L_at_Amax_Mal_GP_1	-0.338	-0.328	-0.328
VonBert_K_Mal_GP_1	0.562	0.526	0.527
CV_young_Mal_GP_1	0.221	0.236	0.237
SR_LN(R0)	10.755	10.032	10.414
SR_BH_steep	**0.720**	**0.720**	**0.383**
Q_extraSD_CalCOFI_Survey(11)	0.423	0.355	0.291
Size_DblN_peak_NoCA_HKL(1)	44.271	40.974	41.130
Size_DblN_ascend_se_NoCA_HKL(1)	4.655	4.399	4.415
Size_DblN_peak_SoCA_HKL(2)	23.936	23.799	23.832
Size_DblN_peak_CA_TWL(3)	46.776	44.904	45.203
Size_DblN_ascend_se_CA_TWL(3)	4.593	4.556	4.570
Size_DblN_peak_OR_WA_Comm(4)	57.452	42.753	43.587
Size_DblN_ascend_se_OR_WA_Comm(4)	5.522	4.559	4.637
Size_DblN_peak_CA_NET(5)	48.134	46.991	46.994
Size_DblN_ascend_se_CA_NET(5)	4.417	4.426	4.422
Size_DblN_peak_NoCA_OR_WA_Rec(6)	48.886	43.894	44.255
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.355	5.136	5.154
Size_DblN_peak_SoCA_Rec(7)	24.870	24.708	24.759
Size_DblN_ascend_se_SoCA_Rec(7)	2.971	2.924	2.933
Size_DblN_descend_se_SoCA_Rec(7)	2.771	3.318	3.271
Size_DblN_end_logit_SoCA_Rec(7)	-0.638	-1.112	-1.052
Size_DblN_peak_TWL_discard(8)	29.536	29.552	29.626
Size_DblN_ascend_se_TWL_discard(8)	4.170	4.167	4.171
Size_DblN_descend_se_TWL_discard(8)	3.336	3.193	3.182
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	52.536	51.604	51.250
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.155	4.157	4.130
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	56.635	48.830	48.811
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	5.227	4.824	4.818
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	37.703	33.792	33.876
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	4.035	3.290	3.307
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	32.052	30.678	30.600
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.977	3.752	3.735
Bratio_2025	1.000	0.832	0.473
SSB_unfished	13006	11922	15373
Totbio_unfished	72247	52043	68965
Recr_unfished	46848	22734	33316
Dead_Catch_SPR	**3547**	**2114**	**1077**
OFLCatch_2025	7733	3617	2870

Table 25: Estimates of “Mohn’s rho” from the package r4ss, based on a 5-year retrospective analysis.

Quantity	value
SSB	-0.550
Rec	4.652
Bratio	-0.492
F	0.691
WoodHole_SSB.all	-0.541
WoodHole_Rec.all	2.281
WoodHole_Bratio.all	-0.483
WoodHole_F.all	0.705
AFSC_Hurtado_SSB	-0.110
AFSC_Hurtado_Rec	0.930
AFSC_Hurtado_F	0.138
AFSC_Hurtado_Bratio	-0.098

Table 26: Projections of potential OFLs (mt), ABCs (mt), estimated spawning output (billions of eggs), and fraction unfished. Projections assume catches are equal to the ABC starting in 2027, and based on default values for a “category 1” assessment (sigma=0.5 and Pstar = 0.45). Catch estimates for 2025 and 2026 (1598.72 and 1521.61 mt, respectively) were provided by the Groundfish Management Team (GMT).

Year	Predicted OFL (mt)	ABC (mt)	Buffer	Spawning output	Fraction Unfished
2025	--	--	--	9925	0.832
2026	--	--	--	9369	0.786
2027	3434.3	3211.1	0.935	9133	0.766
2028	3318.1	3085.8	0.930	8778	0.736
2029	3250.8	3010.3	0.926	8597	0.721
2030	3210.7	2960.2	0.922	8437	0.708
2031	3163.1	2900.5	0.917	8242	0.691
2032	3090.3	2821.4	0.913	8006	0.672
2033	2997.8	2725.0	0.909	7746	0.650
2034	2899.1	2620.8	0.904	7483	0.628
2035	2805.2	2524.7	0.900	7235	0.607
2036	2721.5	2438.5	0.896	7014	0.588

Table 27: 12-year projections (2025 – 2036) for chilipepper rockfish according to three alternative states of nature. Columns represent low, medium (base case), and high states of nature, and rows range over different assumed catch levels (the default harvest control rule, and constant catches equal to the MSY proxy). Spawning output units are billions of eggs.

		Low Productivity (steepness = 0.38)		Base Model (steepness = 0.72)		High Productivity (steepness = 0.97)	
	ACL=ABC catch	spawning output	% of unfished	spawning output	% of unfished	spawning output	% of unfished
2025	1599*	7247	46.9%	9925	83.2%	10836	95.9%
2026	1522*	6704	43.4%	9369	78.6%	10212	90.3%
2027	3211	6435	41.6%	9133	76.6%	9927	87.8%
2028	3086	6041	39.1%	8778	73.6%	9559	84.6%
2029	3010	5854	37.9%	8597	72.1%	9369	82.9%
2030	2960	5744	37.2%	8437	70.8%	9205	81.4%
2031	2901	5642	36.5%	8242	69.1%	9006	79.7%
2032	2821	5520	35.7%	8006	67.2%	8764	77.5%
2033	2725	5379	34.8%	7746	65.0%	8494	75.2%
2034	2621	5232	33.9%	7483	62.8%	8221	72.7%
2035	2525	5091	32.9%	7235	60.7%	7965	70.5%
2036	2439	4962	32.1%	7014	58.8%	7736	68.4%

	SPR Proxy MSY catch	spawning output	% of unfished	spawning output	% of unfished	spawning output	% of unfished
2025	1599*	7247	46.9%	9925	83.2%	10836	95.9%
2026	1522*	6704	43.4%	9369	78.6%	10212	90.3%
2027	2114	6435	41.6%	9133	76.6%	9927	87.8%
2028	2114	6312	40.8%	9078	76.1%	9835	87.0%
2029	2114	6333	41.0%	9149	76.7%	9863	87.3%
2030	2114	6391	41.4%	9217	77.3%	9875	87.4%
2031	2114	6431	41.6%	9231	77.4%	9823	86.9%
2032	2114	6434	41.6%	9180	77.0%	9701	85.8%
2033	2114	6400	41.4%	9071	76.1%	9519	84.2%
2034	2114	6339	41.0%	8923	74.8%	9300	82.3%
2035	2114	6264	40.5%	8752	73.4%	9062	80.2%
2036	2114	6184	40.0%	8572	71.9%	8821	78.0%

Table 28: ‘Risk Table’ for chilipepper to document ecosystem and environmental factors potentially affecting stock productivity and uncertainty, or other concerns arising from the stock assessment. Level 1 is favorable, Level 2 is neutral and Level 3 is unfavorable.

Ecosystem and environmental conditions	Assessment data inputs	Assessment model fits and structural uncertainty
Larval production and condition: Based on 2024- 2025 NPGO, may be neutral to unfavorable, but signals are somewhat mixed Recruitment: Index used in assessment. High diversity and abundance of the YOY groundfish assemblage community in 2024 consistent. Environmental conditions are favorable for 2025 (minty/subarctic), high preliminary survey catch rates. Overall, favorable for recruitment Prey: Most evidence suggests abundant forage, favorable conditions, positive Predators: Ongoing long-term increases in abundance, but no evidence of recent sharp increases, neutral Growth: Recent years potentially unfavorable in near term (based on autocorrelation in growth variability), neutral	Historically and currently among most important commercial species in California, catch reconstruction and recent catch data are reliable, favorable Robust age data to inform assessment, modest aging error concerns need resolution, neutral to favorable Robust information on reproductive ecology, but better data on functional maturity and role of multiple brooding would be helpful, neutral to favorable Several informative fishery independent indices that span life history stages, including larval production/spawning output (CalCOFI), settled juvenile and mature adult biomass (WCGBTS), and pelagic YOY abundance (RREAS), favorable	Good fits to age and length composition data. Generally good fits fishery-independent survey data, particularly in more recent years, favorable Several abundance indices help inform recent recruitment and population forecasts (e.g., WCGBTS, RREAS), favorable Selectivity functions are not always well behaved, unfavorable Evidence for time-varying growth in data, but growth assumed to be time-invariant within the model, neutral Likelihood profiles indicate that natural mortality is well informed, but steepness is not well informed. Steepness provides axis of uncertainty for decision table, neutral
Level 1, favorable (medium agreement, robust evidence)	Level 1, favorable (high agreement, robust evidence)	Level 2, neutral (medium agreement, medium evidence)

9 Figures

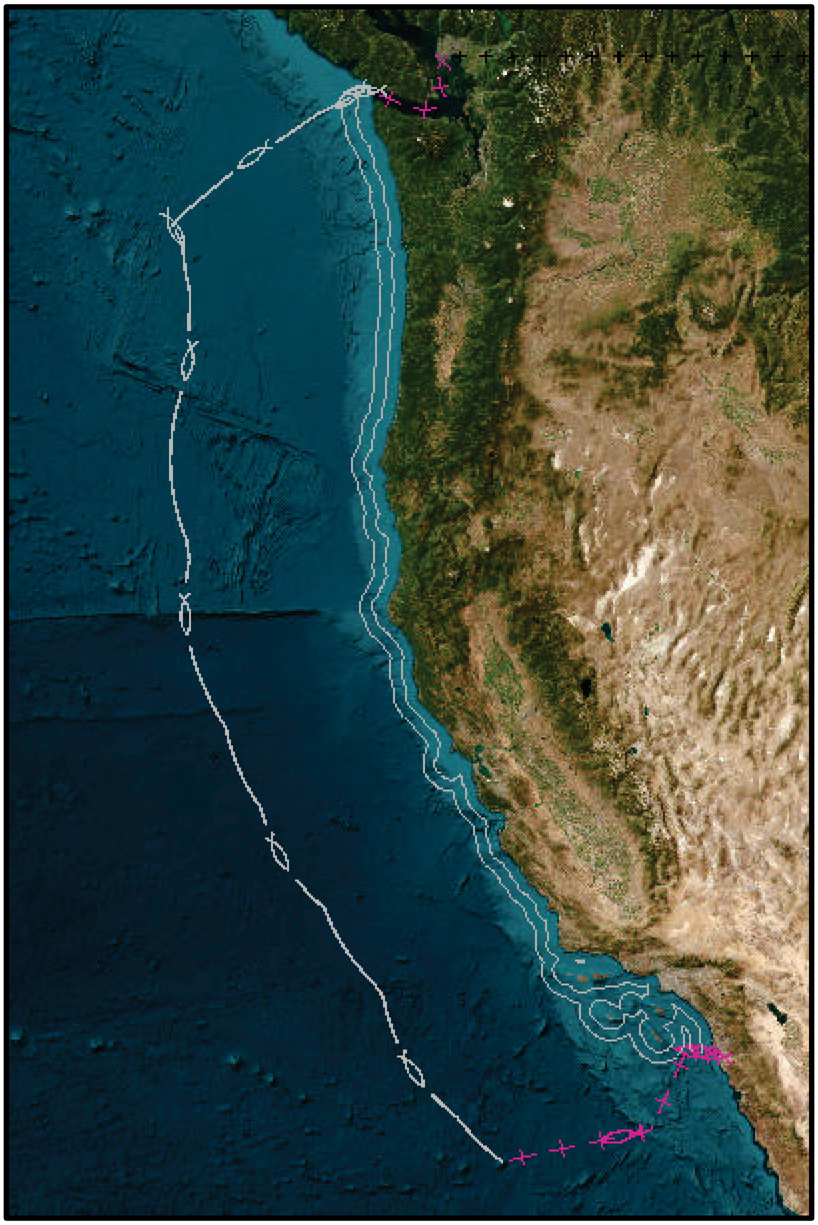


Figure 1: Map of the assessed area. Outlined region represents waters inside the U.S. Exclusive Economic Zone (EEZ) off the coasts of Washington, Oregon, and California. Source: NOAA U.S. Maritime Limits and Boundaries Webmap.

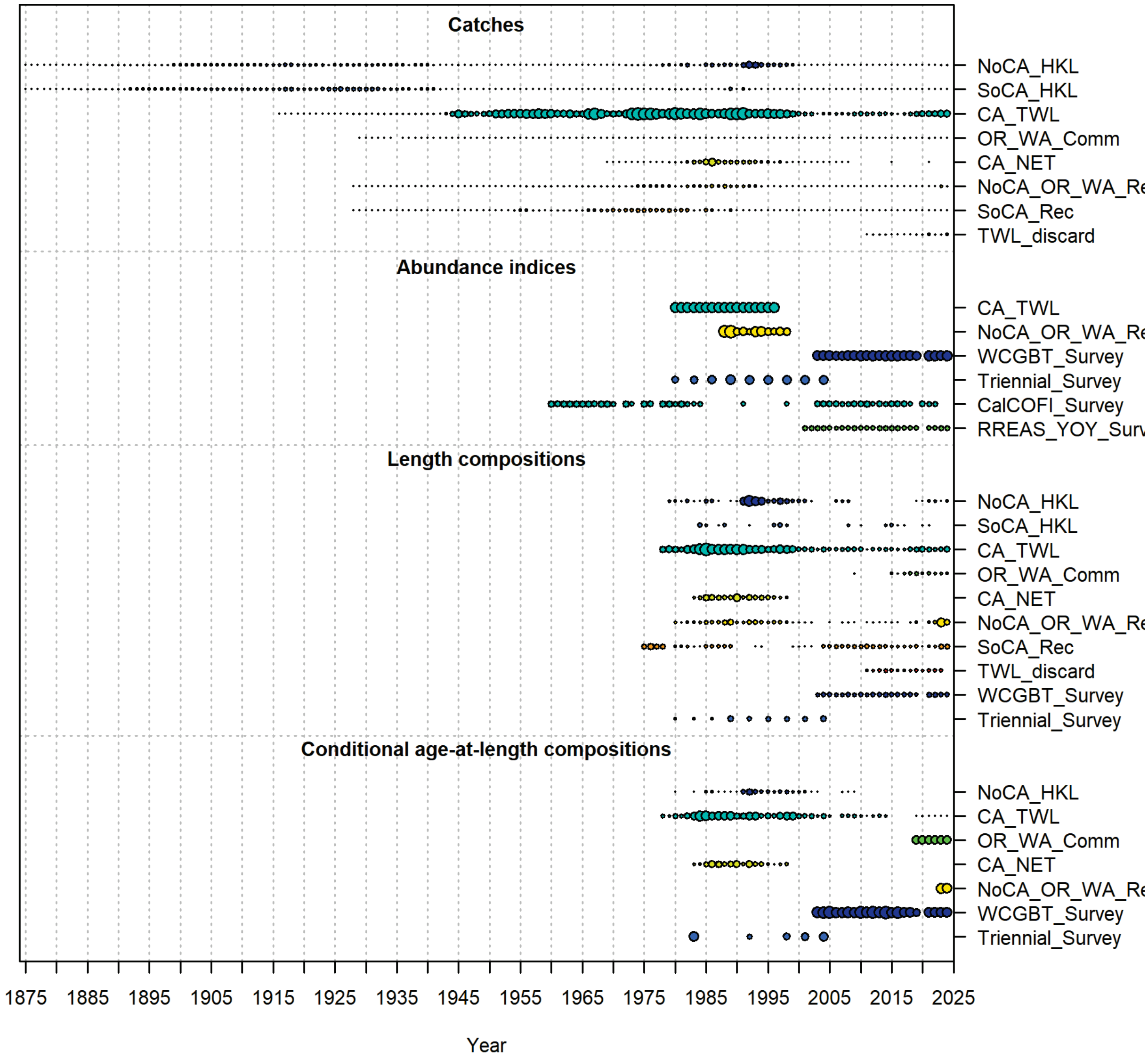


Figure 2: Summary of data sources by year, type, and fleet in the chilipepper base model. Two abundance indices (“CA_TWL” and “NoCA_OR_WA_Rec”) were in previous assessments, but are not included in the likelihood (i.e. not used to fit the 2025 model). Circle areas are relative and comparable only within a data type. Circle sizes are proportional to total catch for catches; to precision for indices; to total sample size for length compositions or conditional age-at-length observations.

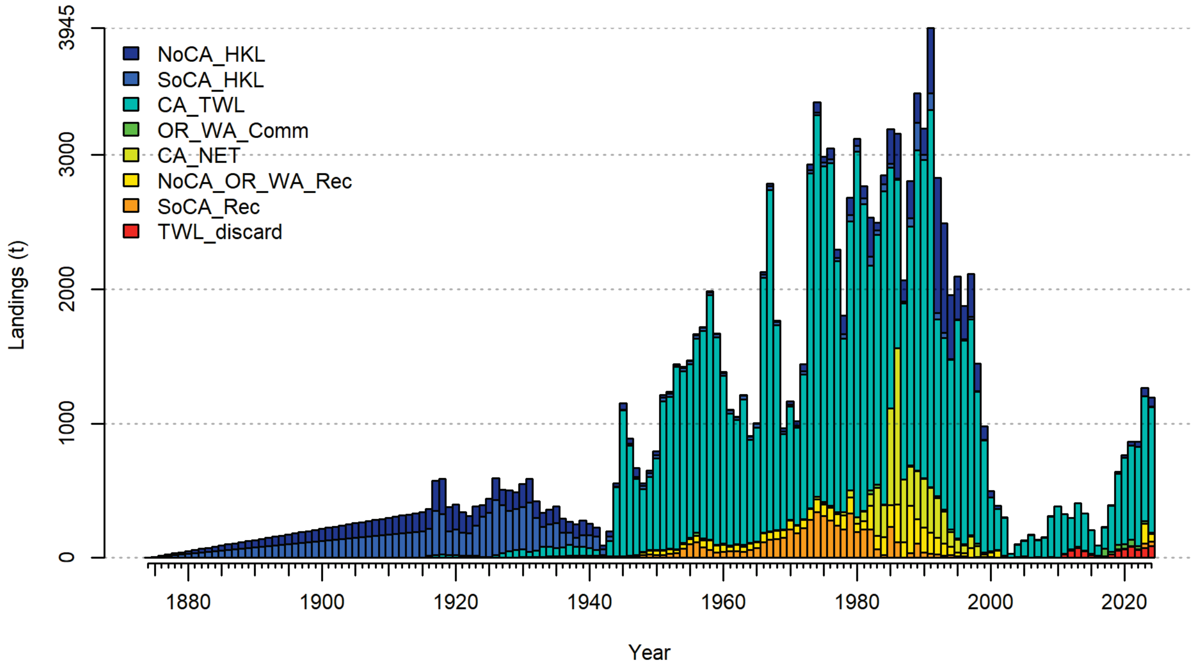


Figure 3: Total catch (mt) by fleet and year (including discards) used in the model. Values are stacked so bar height equals total removals in each year.

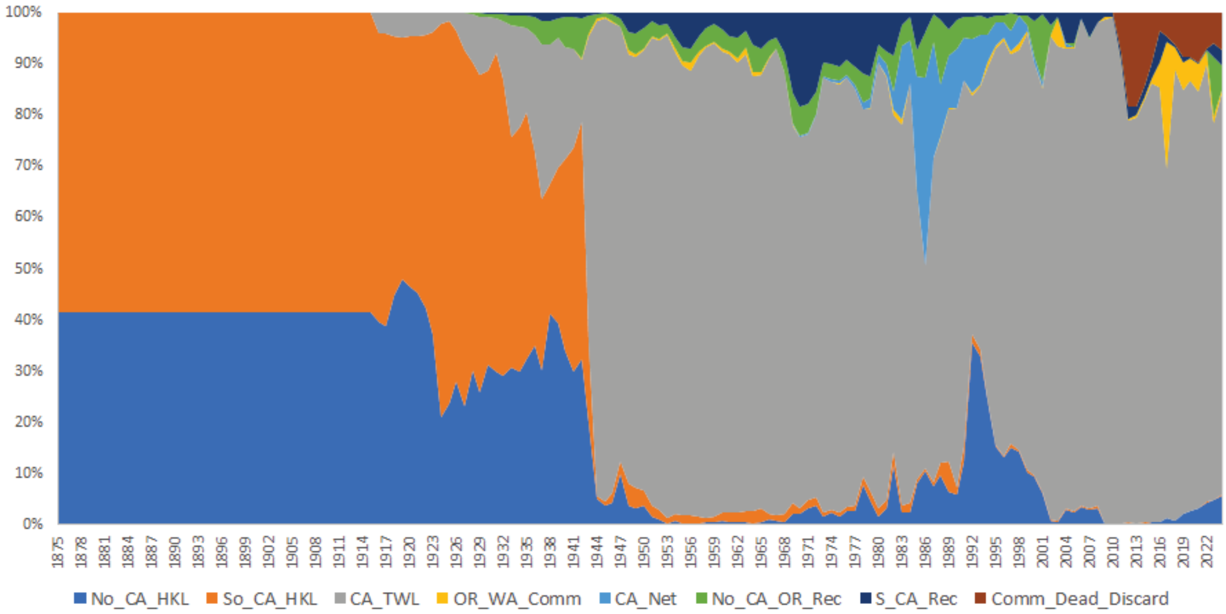


Figure 4: Percentage (vertical axis) of total annual catch by fleet (color) and year (horizontal axis).

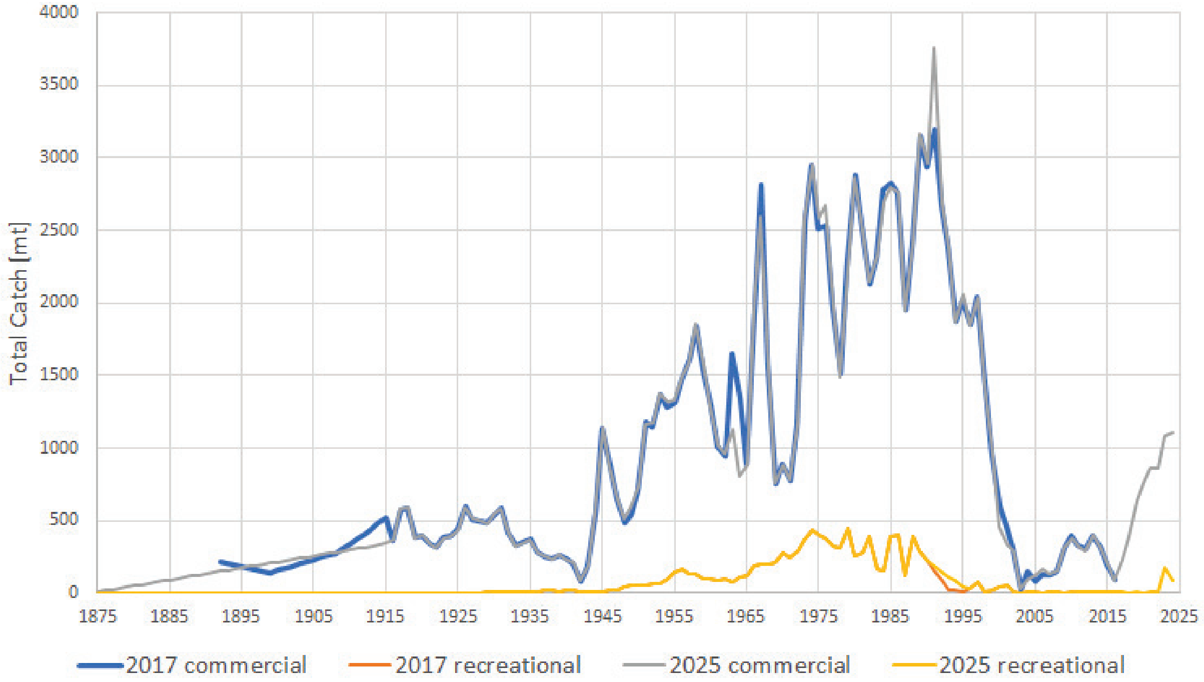


Figure 5: Comparison of catch estimates (mt) by year, sector (commercial or recreational), and assessment year.

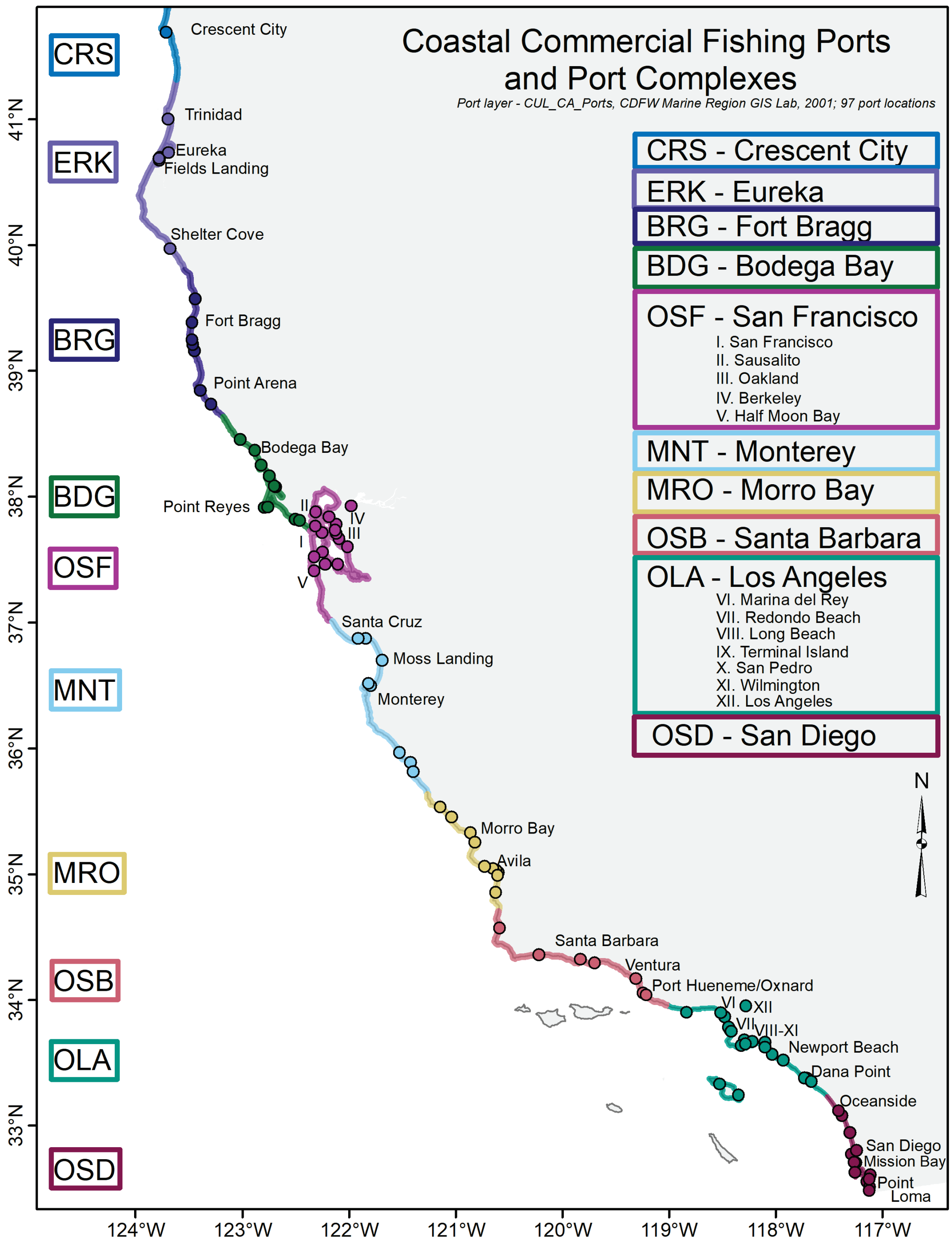


Figure 6: California commercial fishing ports and port complexes sampled by the California Cooperative Groundfish Survey (CCGS).

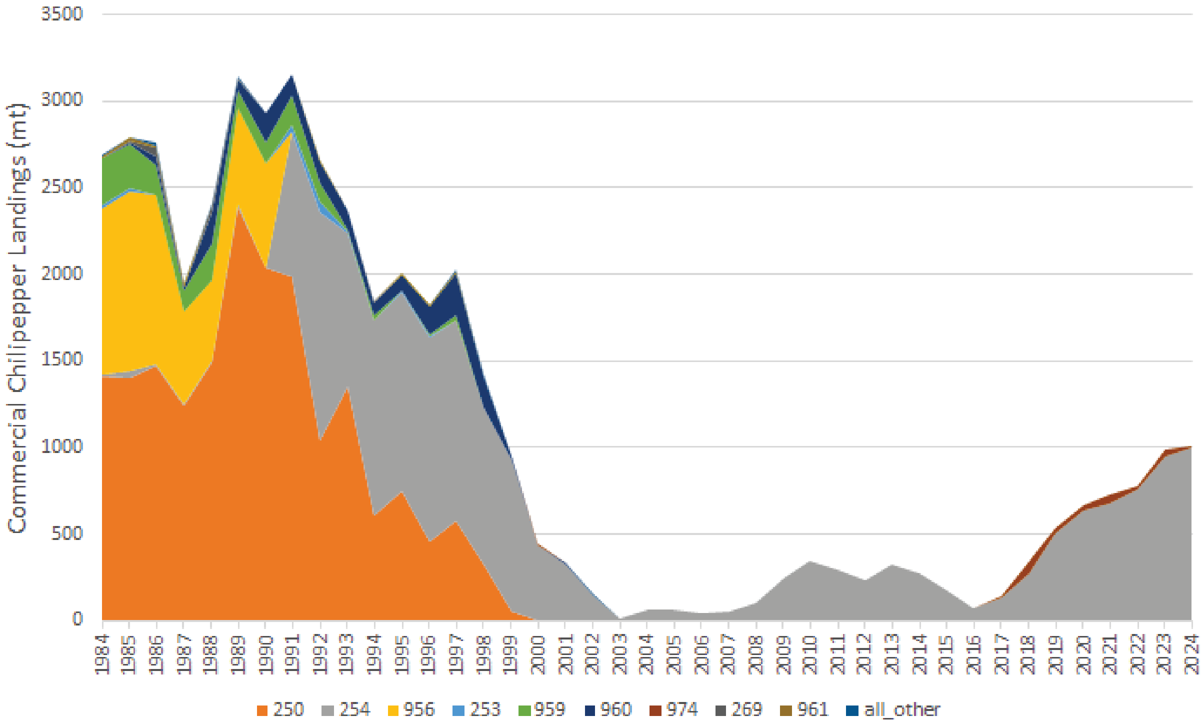


Figure 7: Chilipepper rockfish landings in California by market category and year. The nominal “chilipepper”market category is 254 (gray). Other market categories shown include 250 (Rockfish, unspecified), 956 (Rockfish, group bocaccio/chili), 253 (bocaccio), 959 (Rockfish, Group Red), 960 (Rockfish, Group Small), 974 (Rockfish, shelf), 269 (Rockfish, widow), and 961 (Rockfish, Group Rosefish).

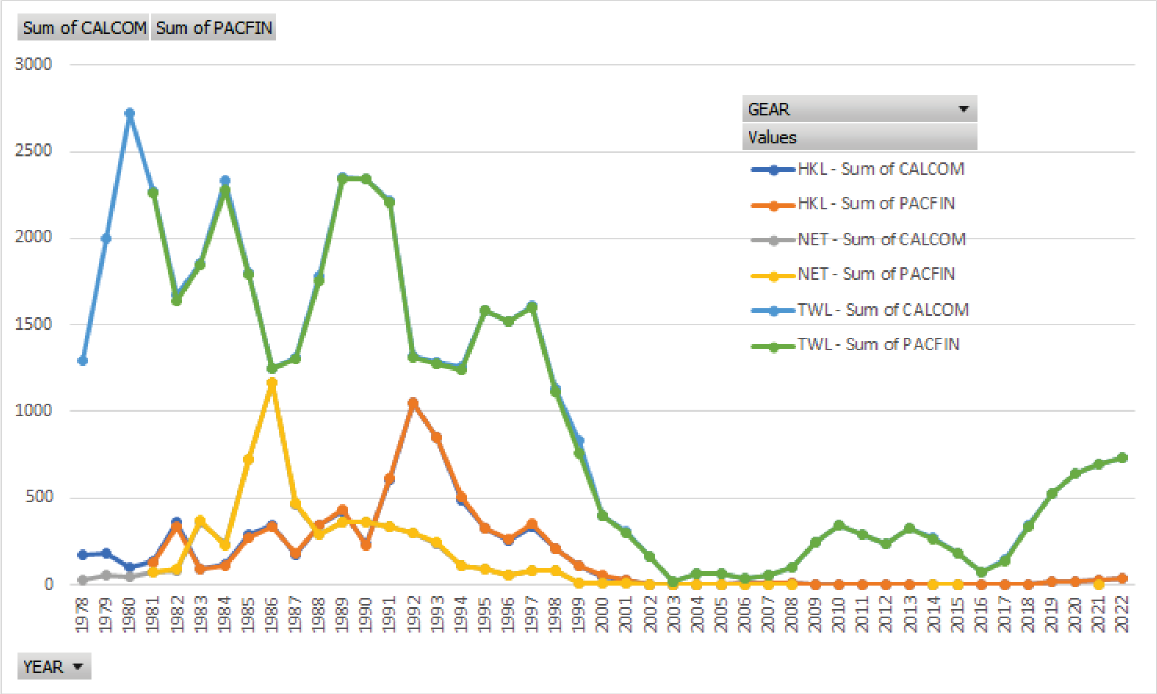


Figure 8: Comparison of catch estimates (vertical axis, in mt) by year, commercial gear group (HKL = hook and line, NET = net gears, TWL = trawl) and source database (CALCOM or PacFIN).

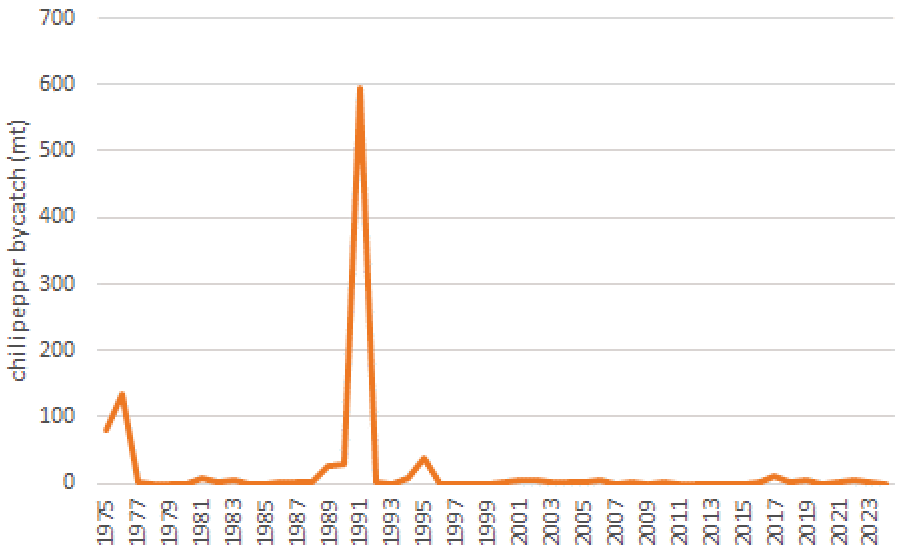


Figure 9: Chilipepper bycatch in the at-sea hake fishery.

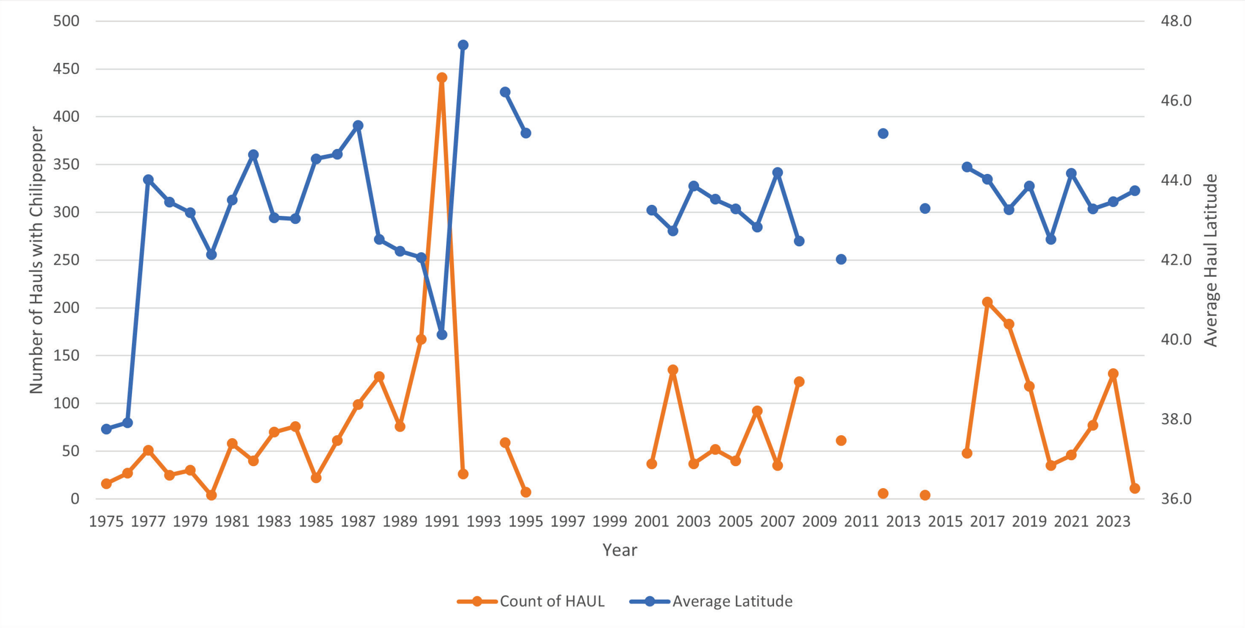


Figure 10: Annual number of observed hauls catching chilipepper rockfish and average latitude fished in the at-sea hake fishery. Years with increased chilipepper bycatch (both encounter rates and total bycatch in mt) correspond with fishing occurring south of 42 degrees N. latitude, on average.

Figure 11: Map of CRFS districts in California. Source: CDFW website.

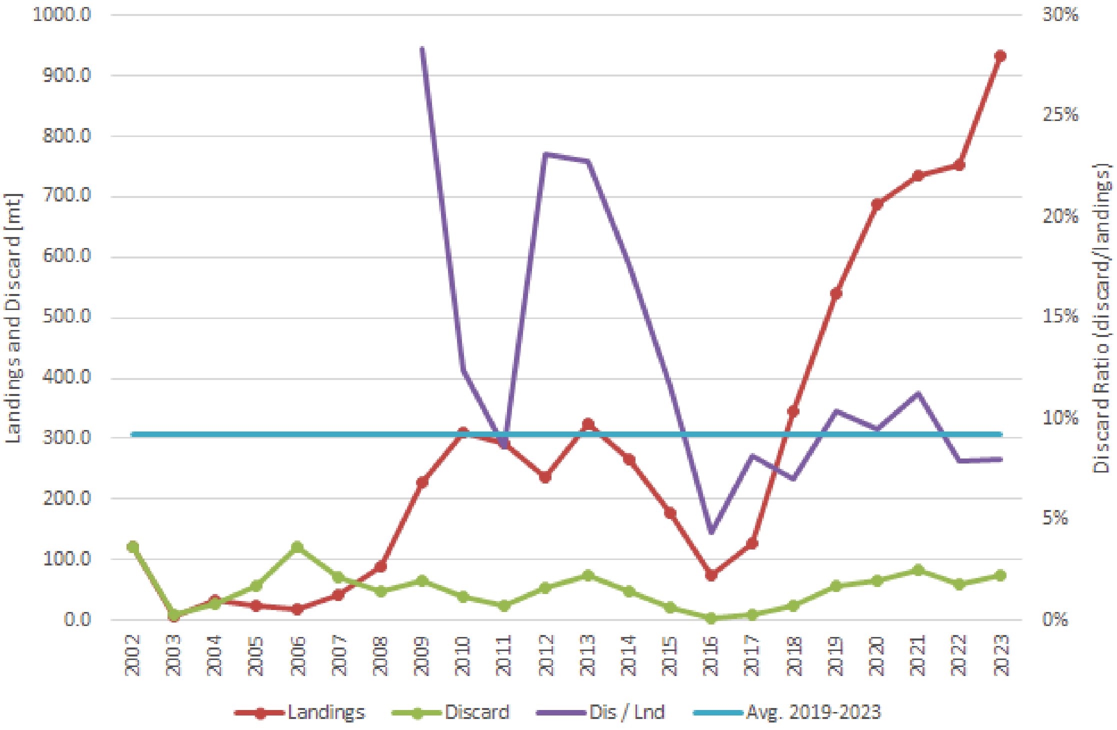


Figure 12: Landings and discards [mt] from all trawl sectors (combined) in the GEMM report. Large discard ratios in early years were driven by regulatory restrictions. Discards from 2019-2023 averaged 9% of landings by weight.

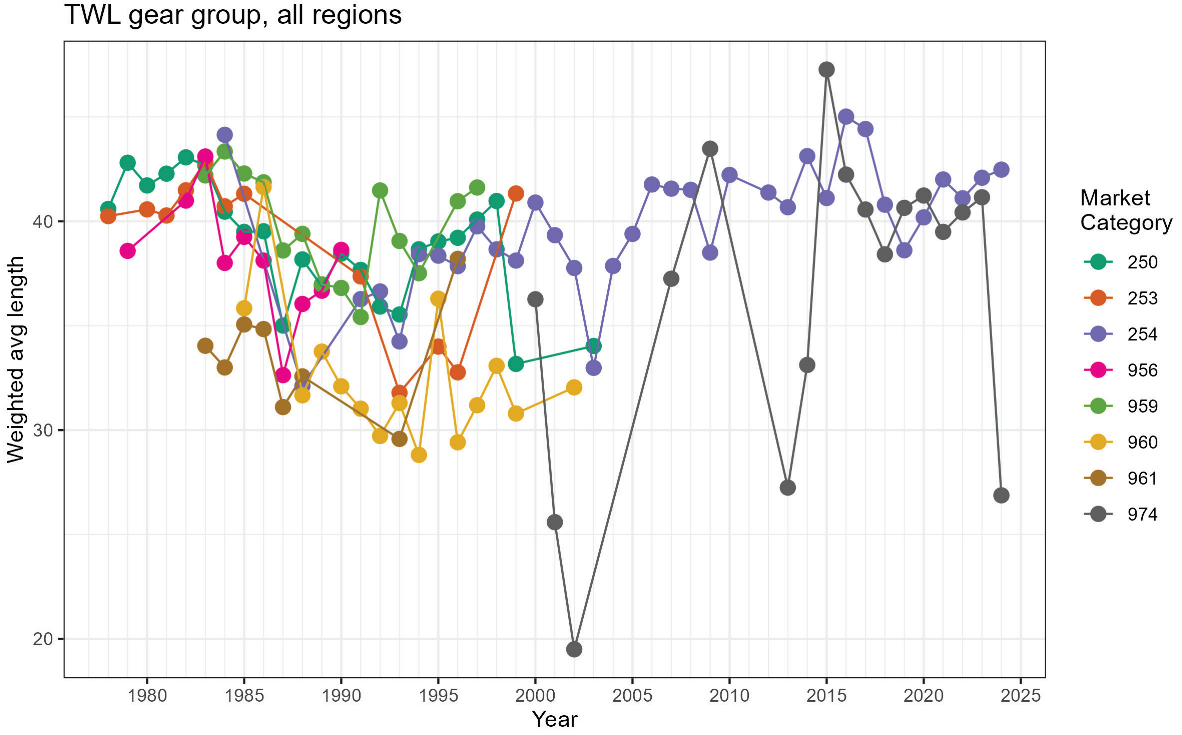


Figure 13: Catch-weighted differences in mean chilipepper fork length [cm] in California, all trawl gears combined, by year and market category.

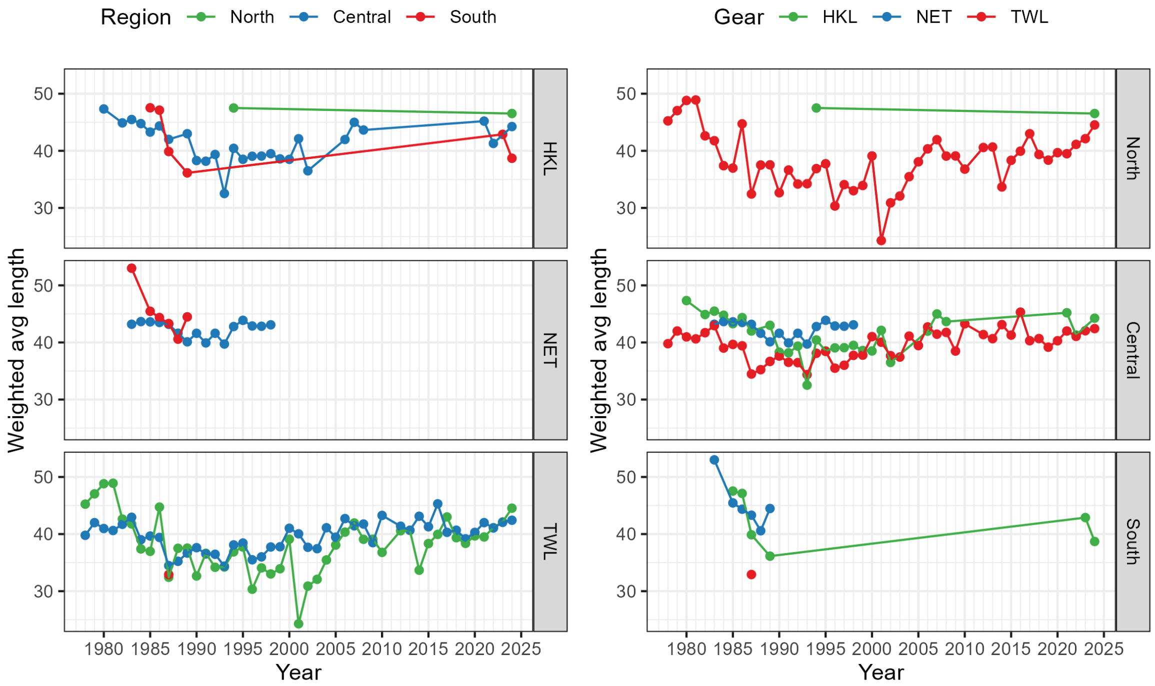


Figure 14: Differences in catch-weighted mean fork length [cm] in California, by year, gear, and region (North = Eureka and Crescent City port complexes, Central = Fort Bragg, Bodega Bay, San Francisco, Monterey, and Morro Bay port complexes, South = Santa Barbara, Los Angeles and San Diego port complexes).

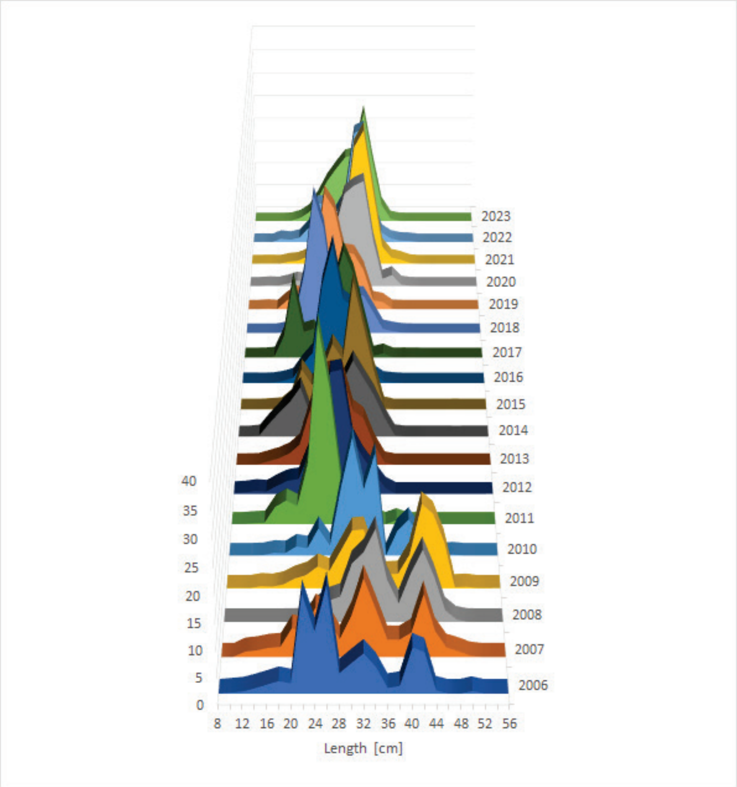


Figure 15: Percentage of lengthed fish (vertical axis) by length bin and year of discarded chilipepper in the trawl fleet, 2006-2023. Note the shift in 2011 at the beginning of the IFQ fishery. Source: WCGOP.

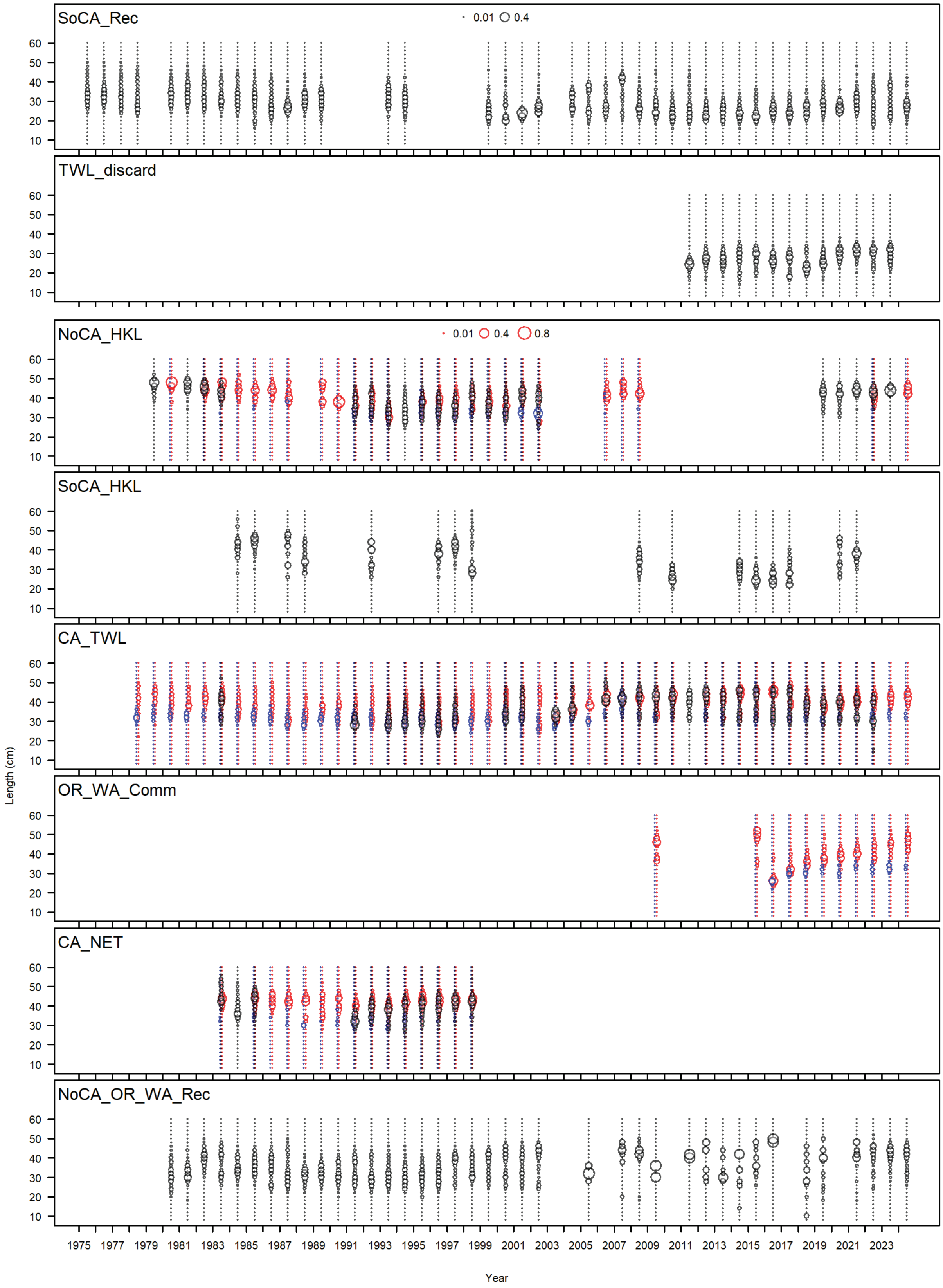
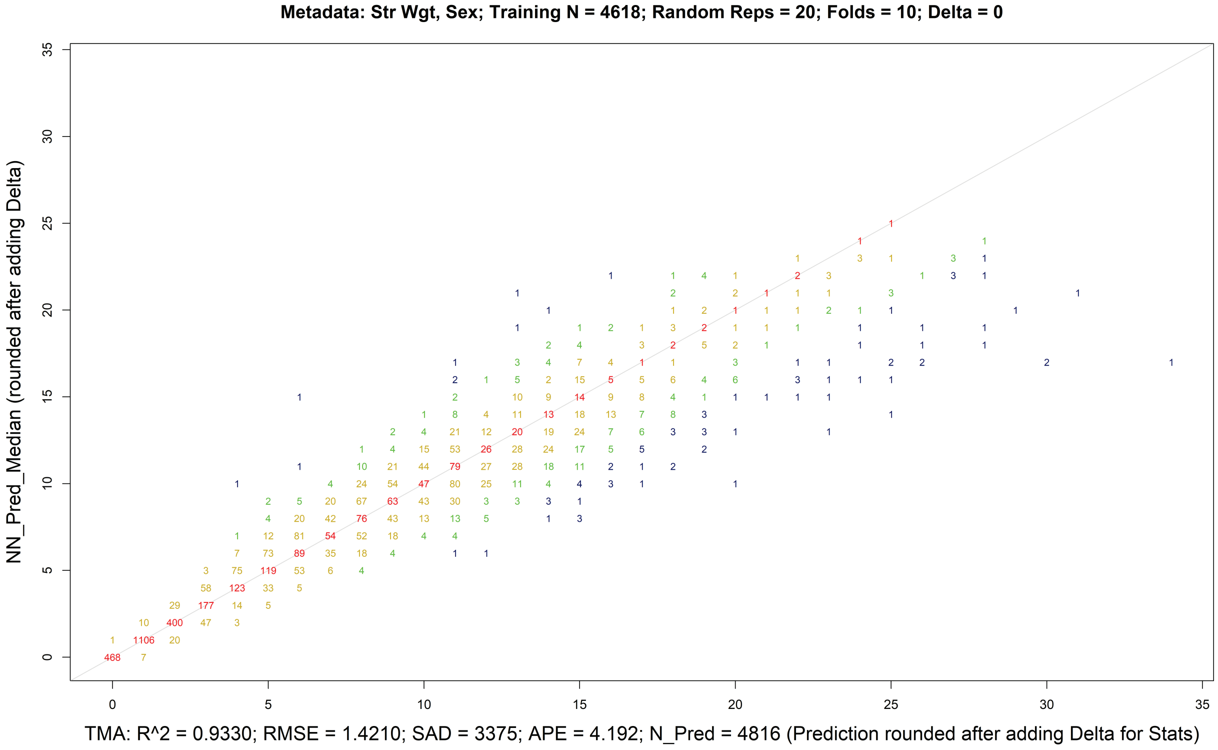


Figure 16: Length composition data from fishery fleets.


Metadata: Str Wgt, Sex; Training N = 4618; Random Reps = 20; Folds = 10; Delta = 0

TMA: R^2 = 0.9330; RMSE = 1.4210; SAD = 3375; APE = 4.192; N_Pred = 4816 (Prediction rounded after adding Delta for Stats)

Figure 17: Traditional age estimates relative to the predictions for the training set of 4618 otoliths used to develop the Neural Network model. Results indicate a bias to younger estimates after approximately age 15.

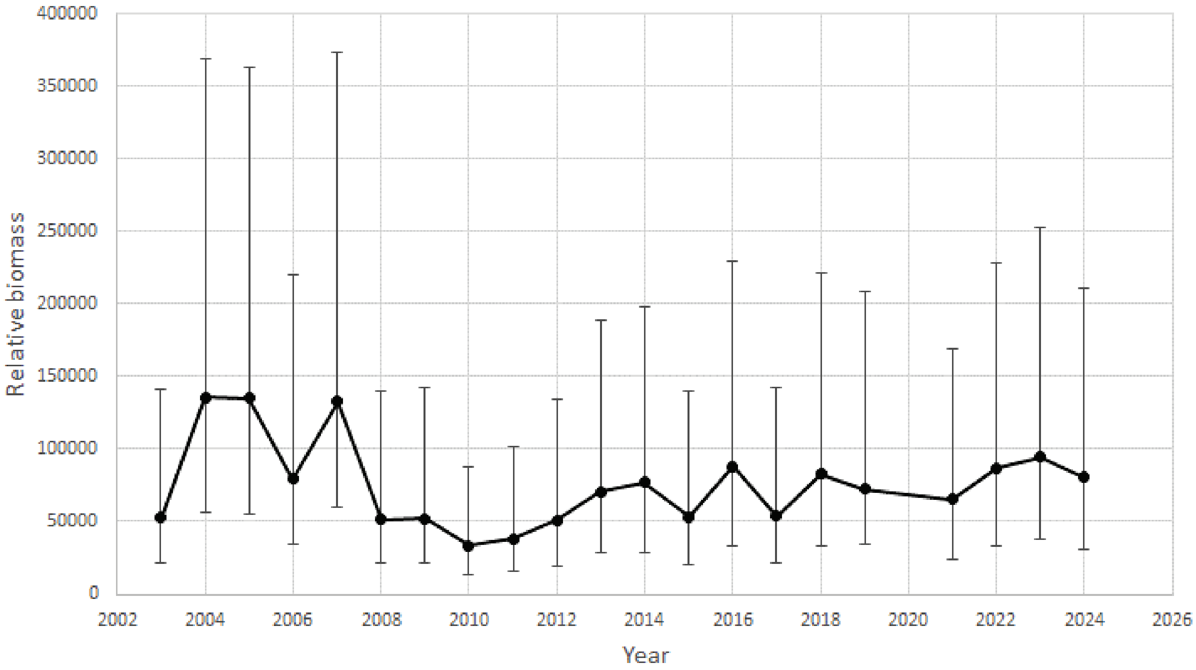


Figure 18: WCGBTS relative abundance index for chilipepper rockfish, updated to include depth effect. See STAR Panel request 12 in Appendix B. Error bars represent +/- 1 S.E. assuming a lognormal distribution. Hauls from Washington were excluded due to a small number of positive observations.

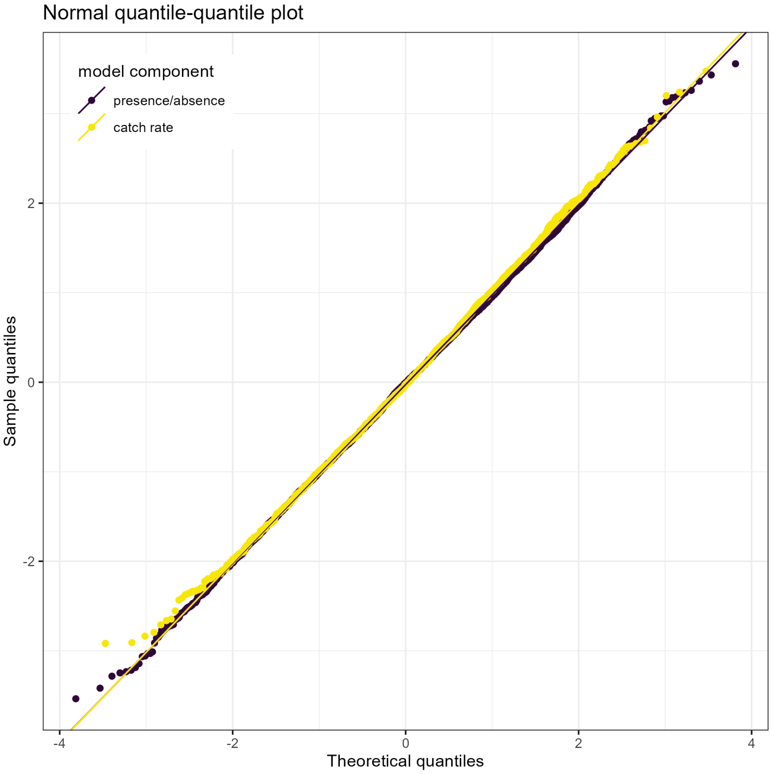


Figure 19: Quantile-quantile plot for component models (binomial and lognormal) of the WCGBTS relative abundance index for chilipepper rockfish.

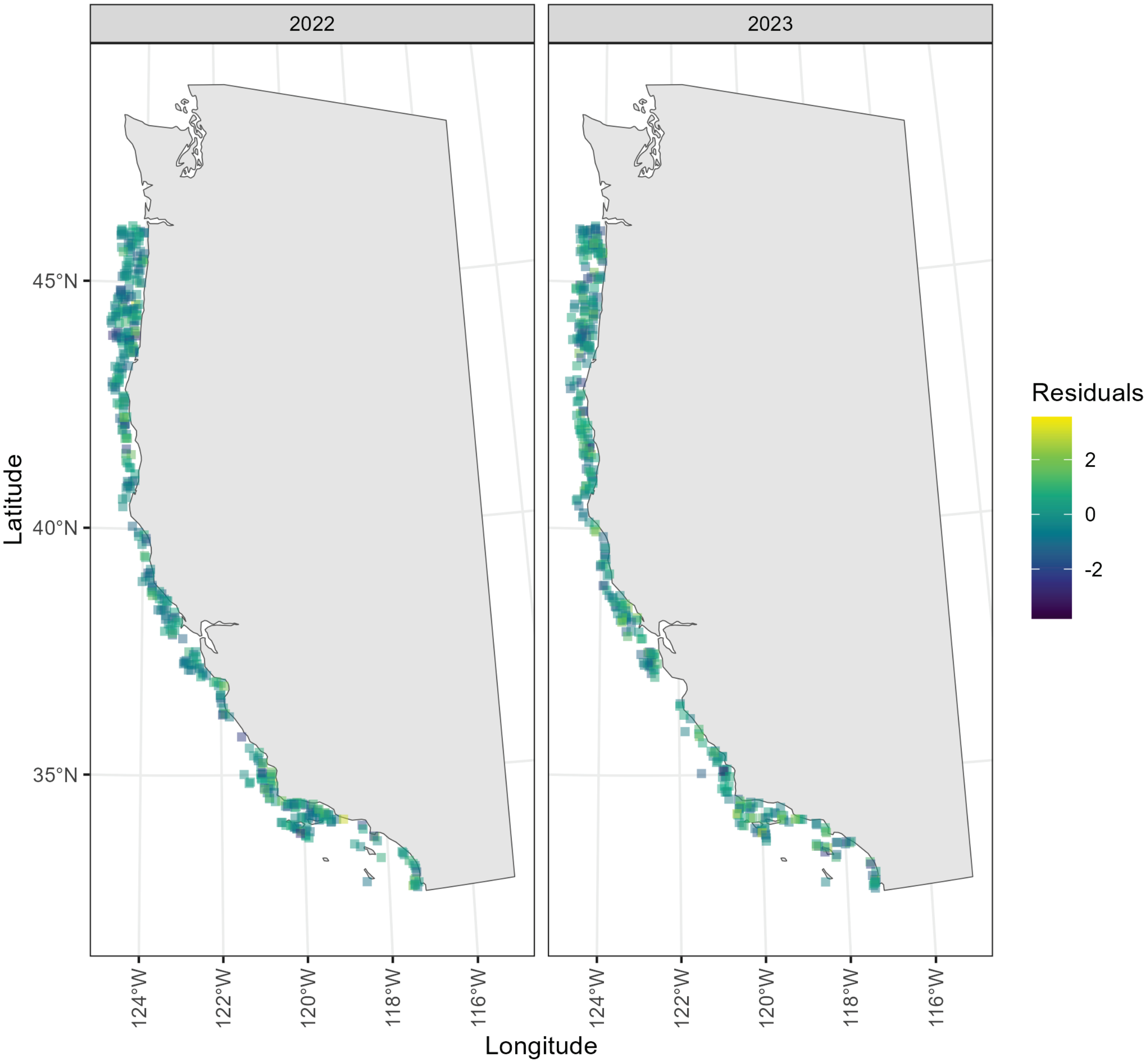


Figure 20: Map of residuals from the WCGBTS index used in the chilipepper rockfish assessment. Example shown is for 2022-2023.

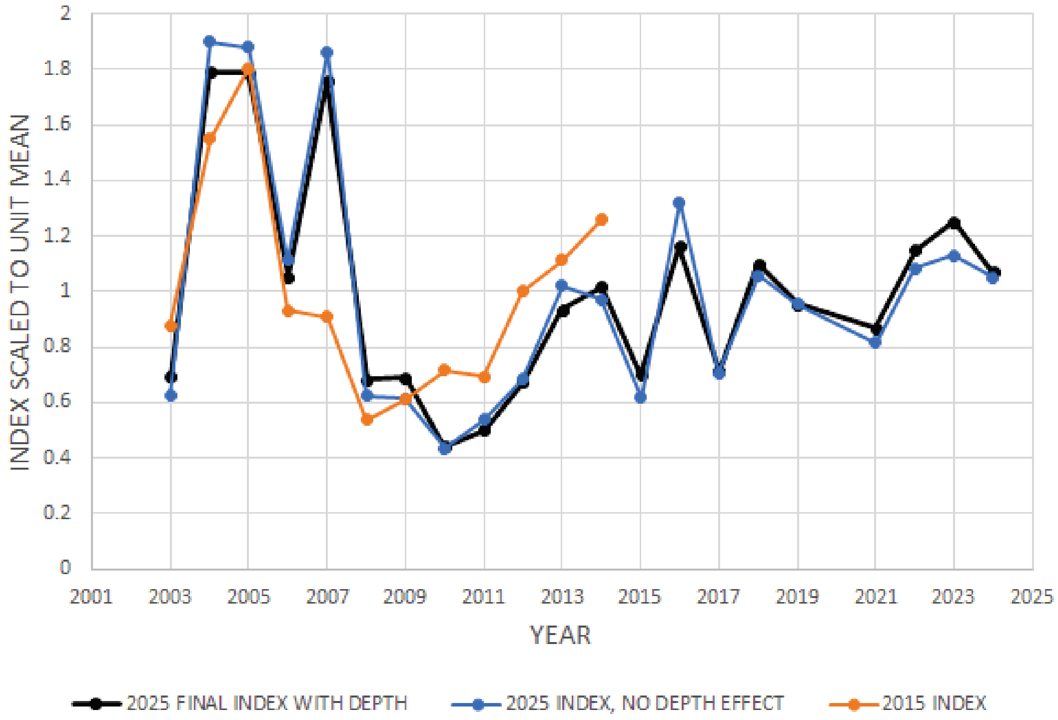


Figure 21: Comparison of WCGBTS indices from the 2015 and 2025 chilipepper stock assessments. The final index used in the 2025 assessment included a depth effect. Each index was rescaled to have a mean equal to 1 to facilitate comparison of trends.

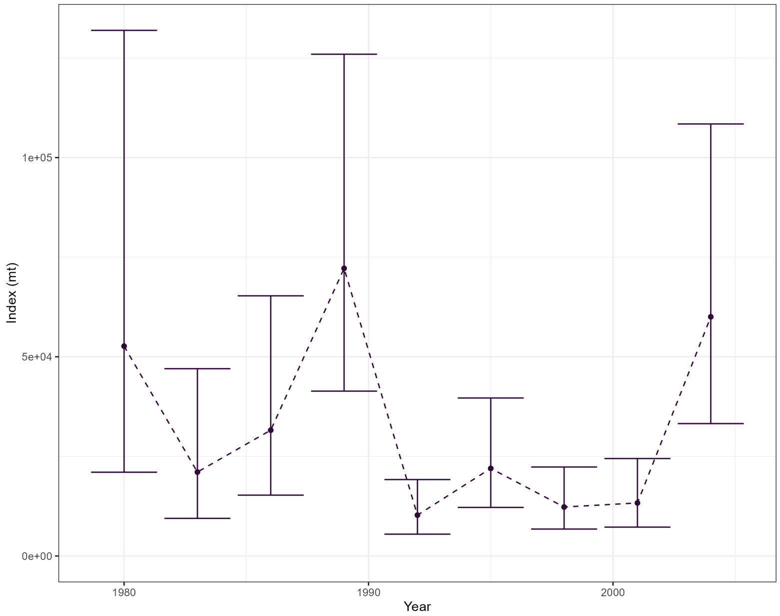


Figure 22: Triennial trawl survey relative abundance index for chilipepper rockfish. Error bars represent +/- 1 S.E. assuming a lognormal distribution. Depth effects for the triennial survey were not explored due to insufficient time.

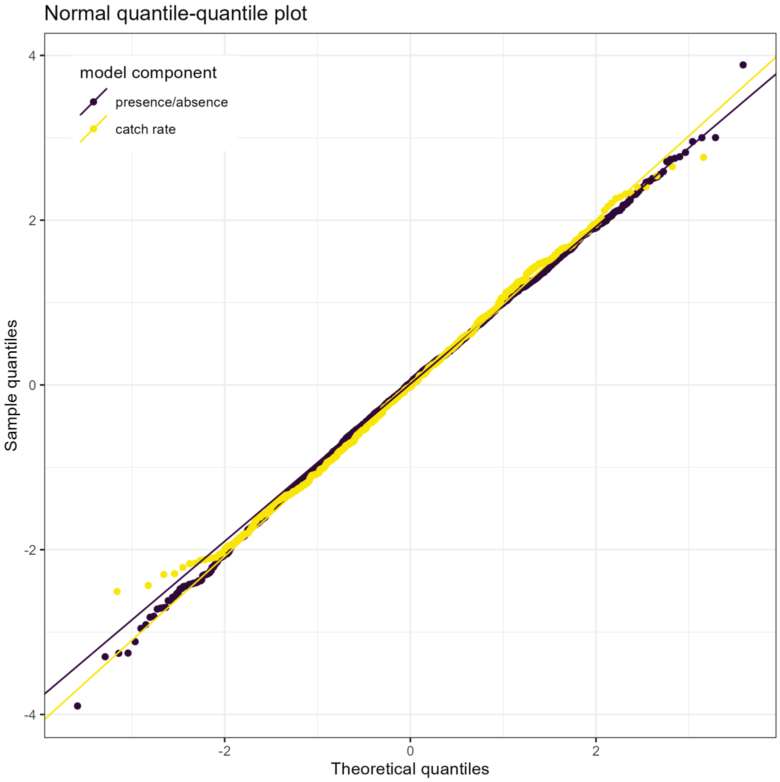


Figure 23: Quantile-quantile plot for component models (binomial and lognormal) of the Triennial trawl survey relative abundance index for chilipepper rockfish.

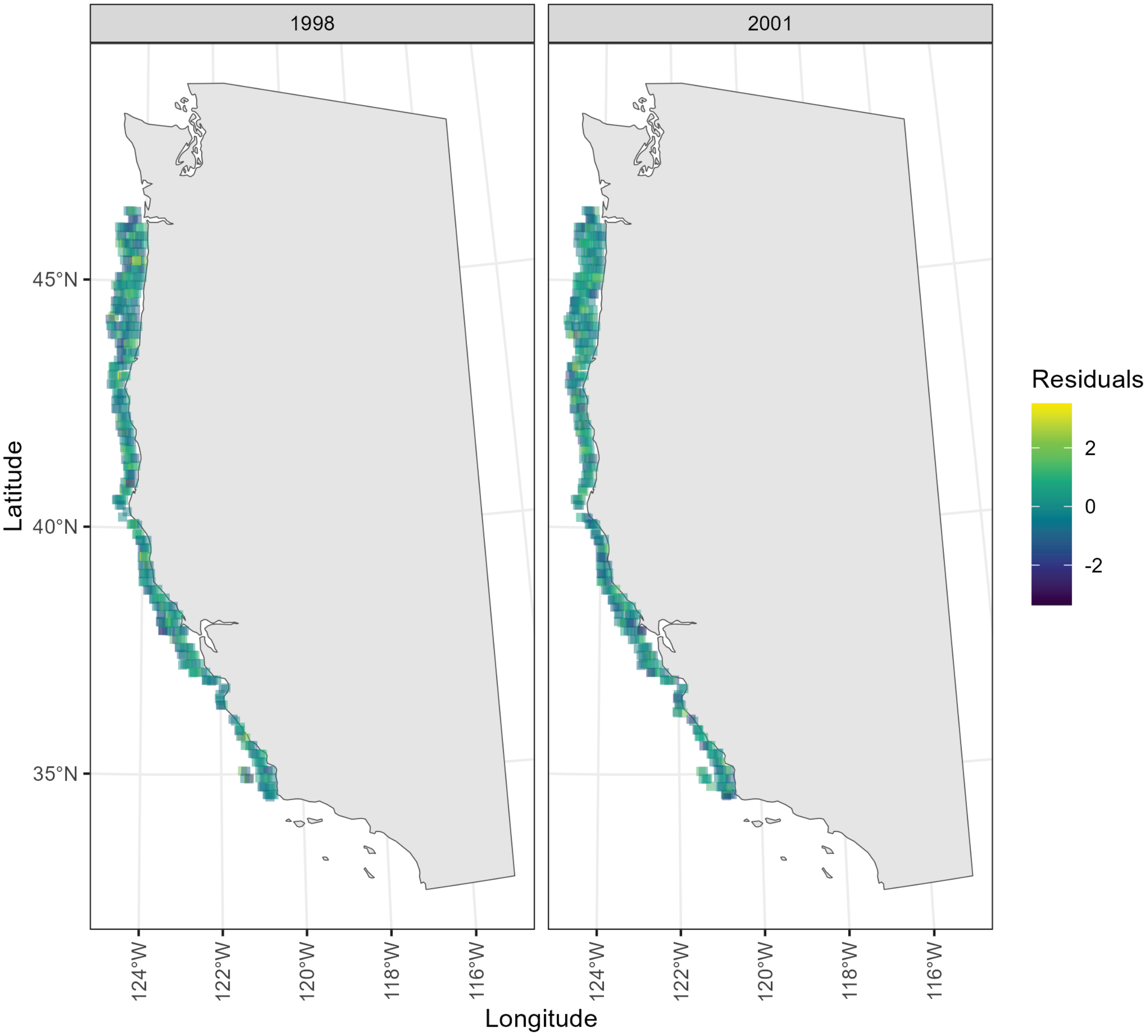


Figure 24: Map of residuals from the Triennial trawl survey index used in the chilipepper rockfish assessment. Example shown is for 1998 & 2001.

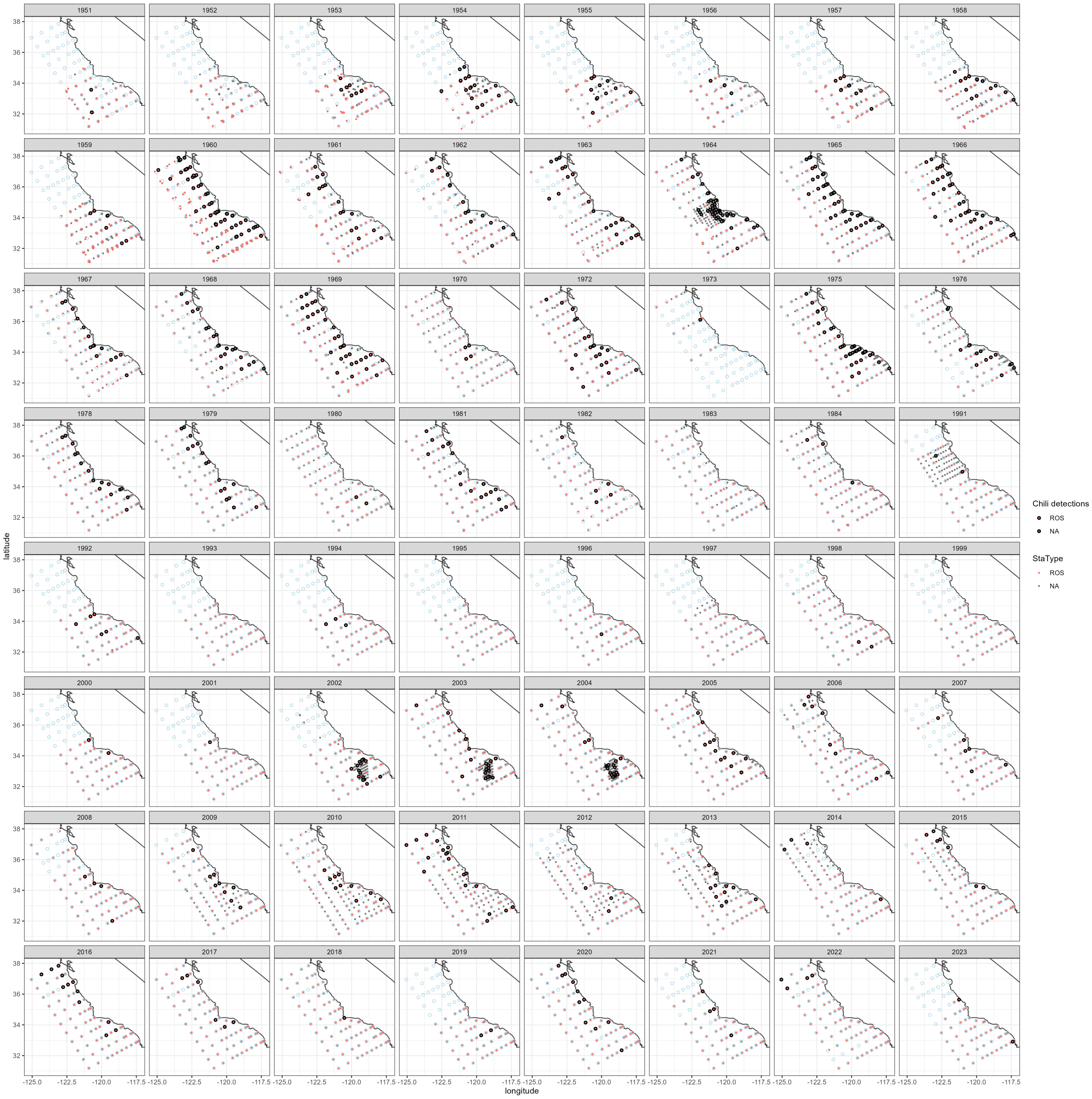


Figure 25: Spatial and temporal distribution of all CalCOFI tows retained for analysis. Light blue open circles are locations of the standard CalCOFI stations. Filled circles are tows, with color indicating whether they are at standard CalCOFI stations or other stations. The filled circles outlined in black are samples with a positive catch of chilipepper.

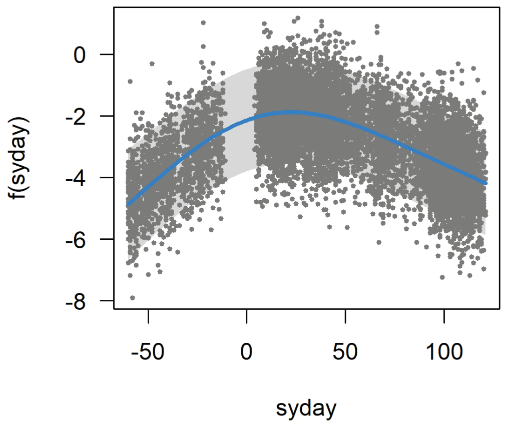


Figure 26: Conditional effect of Julian date (“syday”) on larval chilipepper rockfish density from the CalCOFI survey. Zero on the horizontal axis represents January 1, and negative values represent days in the previous year (as spawning spans winter months). Points are partial randomized quantile residuals, with a smooth function (blue line) illustrating the model prediction.

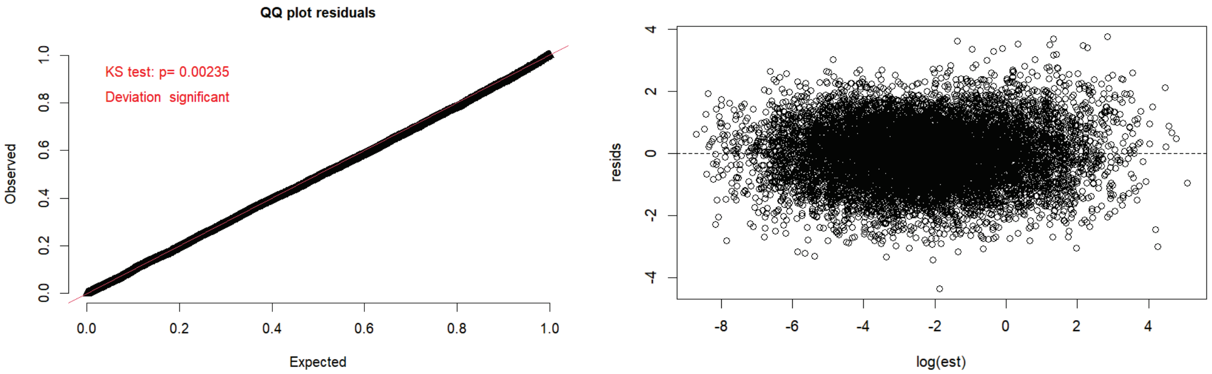


Figure 27: Diagnostic plots for the model of larval chilipepper rockfish from the CalCOFI survey. Q-Q plot for Dharma residuals based on 500 simulations, and plot of predicted values vs. residual. The KS normality test is often statistically significant when sample sizes are large, but there is not strong visual evidence of a meaningful deviation.

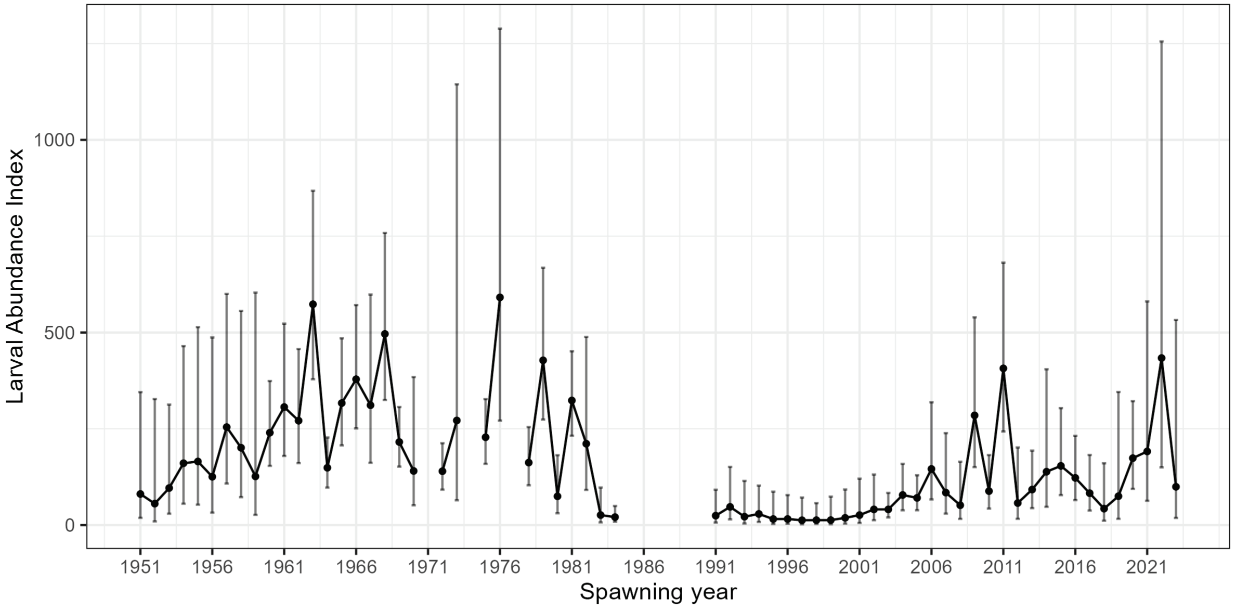


Figure 28: Relative abundance index for larval output of chilipepper rockfish from the CalCOFI survey. Error bars are 95% CI. Although all years are displayed here, years in which fewer than 10% of samples were taken north of Point Conception were excluded from the fitted index. See model fits to indices for final index.

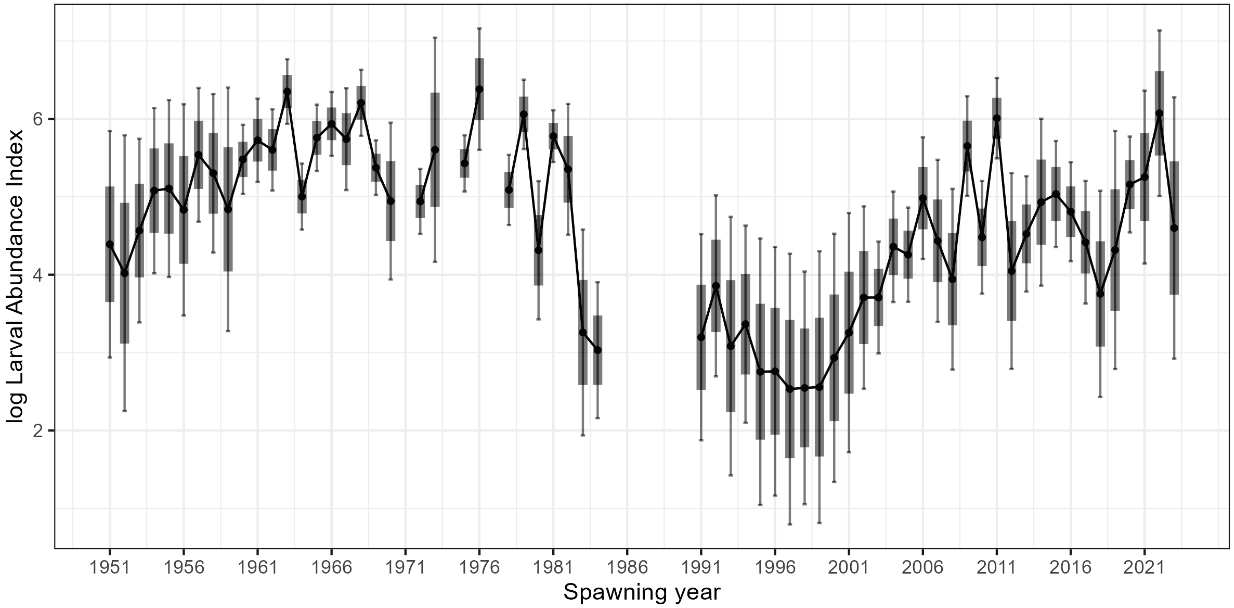


Figure 29: Log abundance index for larval output of chilipepper rockfish from the CalCOFI survey. Error bars are +/- 1 SE (thick bars) and 95% CI (thin bars). Although all years are displayed here, years in which fewer than 10% of samples were taken north of Point Conception were excluded from the fitted index. See model fits to indices for final index.

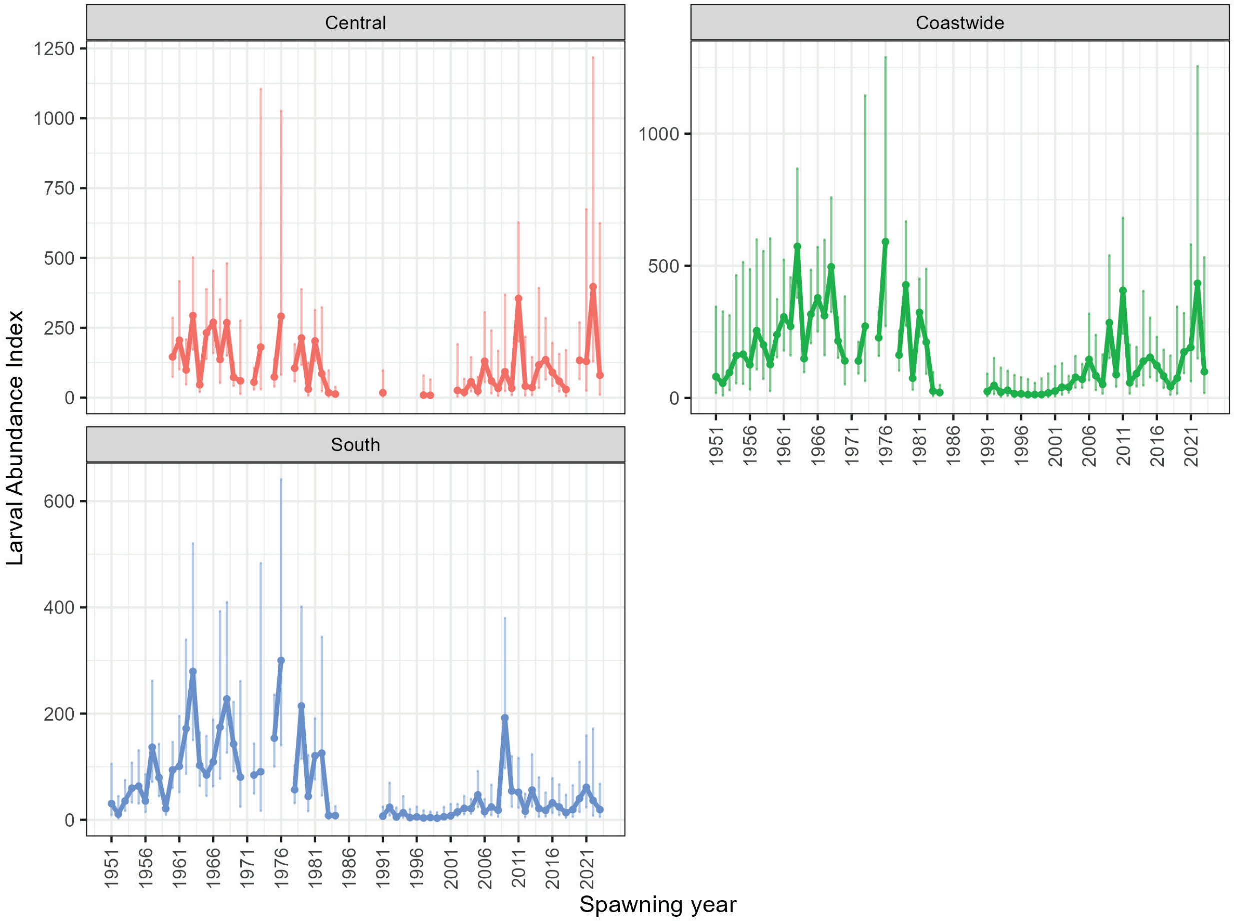


Figure 30: Relative abundance index for larval chilipepper rockfish from the CalCOFI survey, for coastwide (same as Figure 28), central, and south regions. Error bars are 95% CI. The index for the central region excludes years with no sampling in this region.

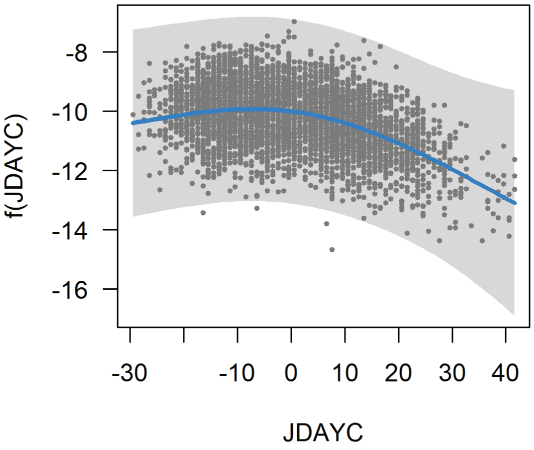


Figure 31: Effect of Julian date (centered by subtracting the mean) estimated in the RREAS index of age-0 recruits. Declines in density are expected over time due to settlement out of the pelagic juvenile stage. Points are partial randomized quantile residuals, with a smooth function (blue line) illustrating the model prediction.

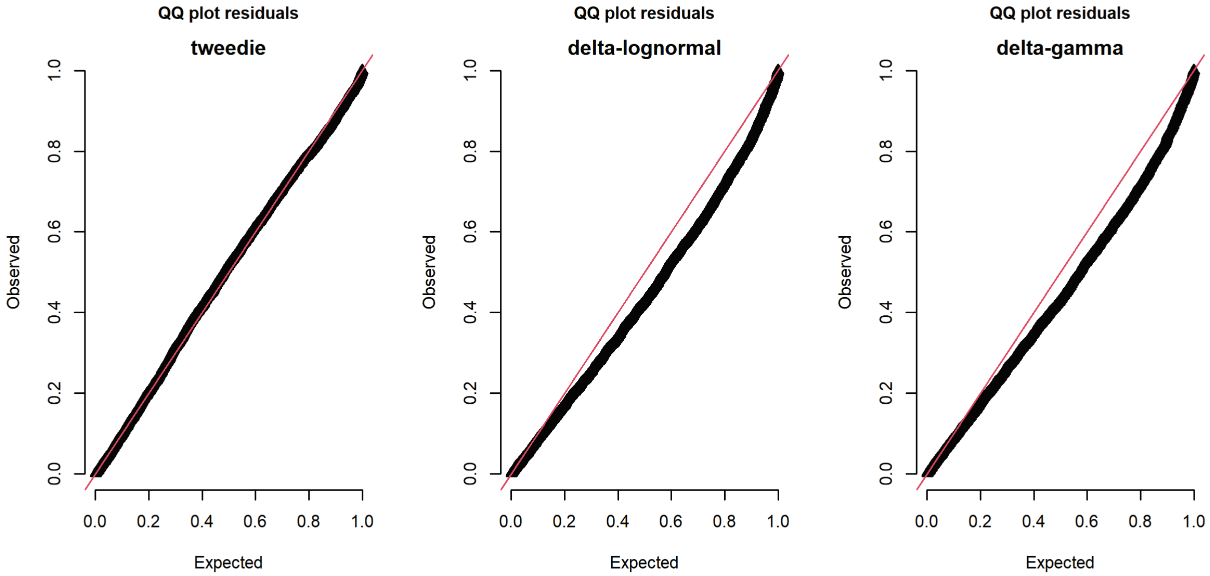


Figure 32: Evaluation of alternative distributional assumptions for the RREAS index of age-0 recruits.

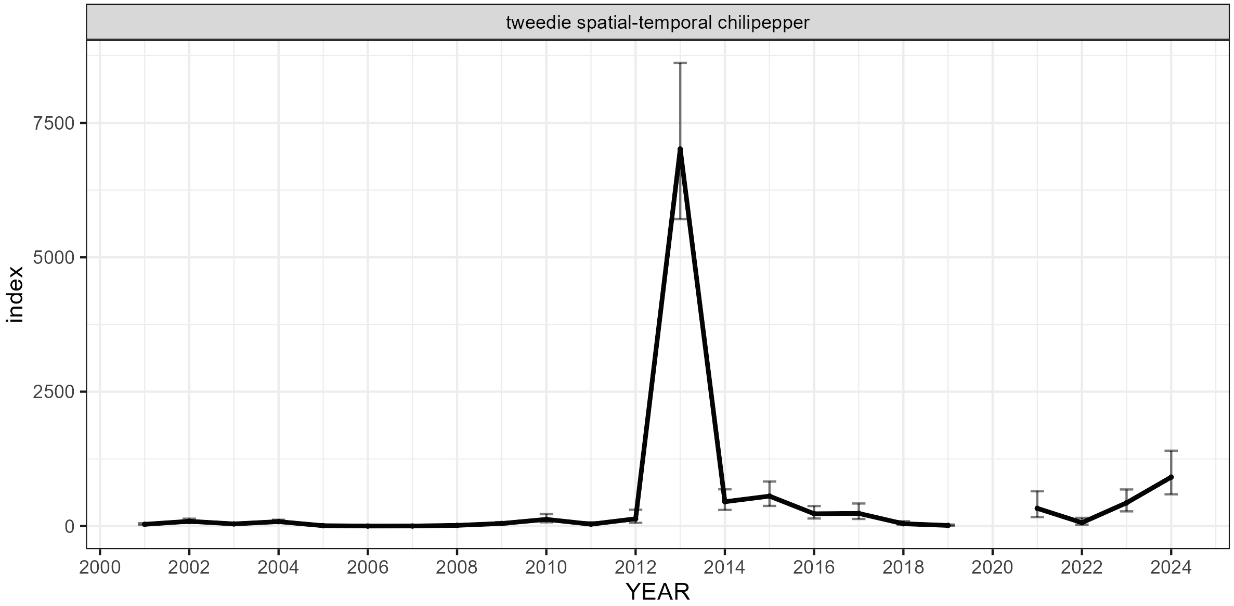


Figure 33: RREAS relative index of age-0 recruits for chilipepper rockfish, 2001-2024. Error bars are 95% CI.

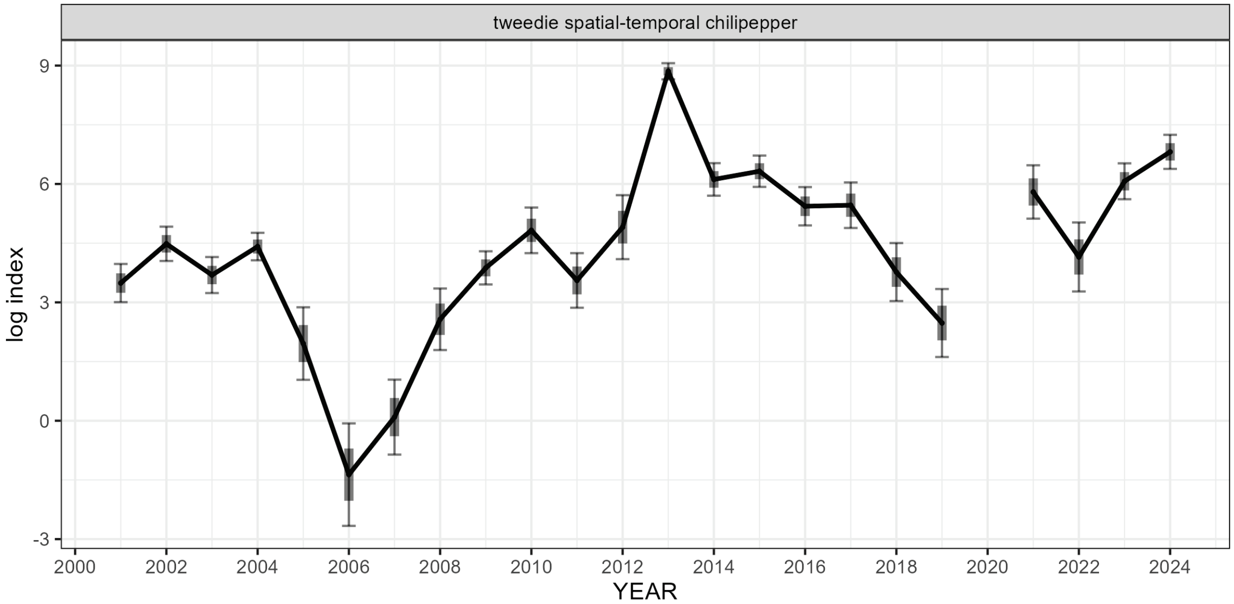


Figure 34: RREAS relative index (log scale) of age-0 recruits for chilipepper rockfish, 2001-2024. Error bars are 95% CI.

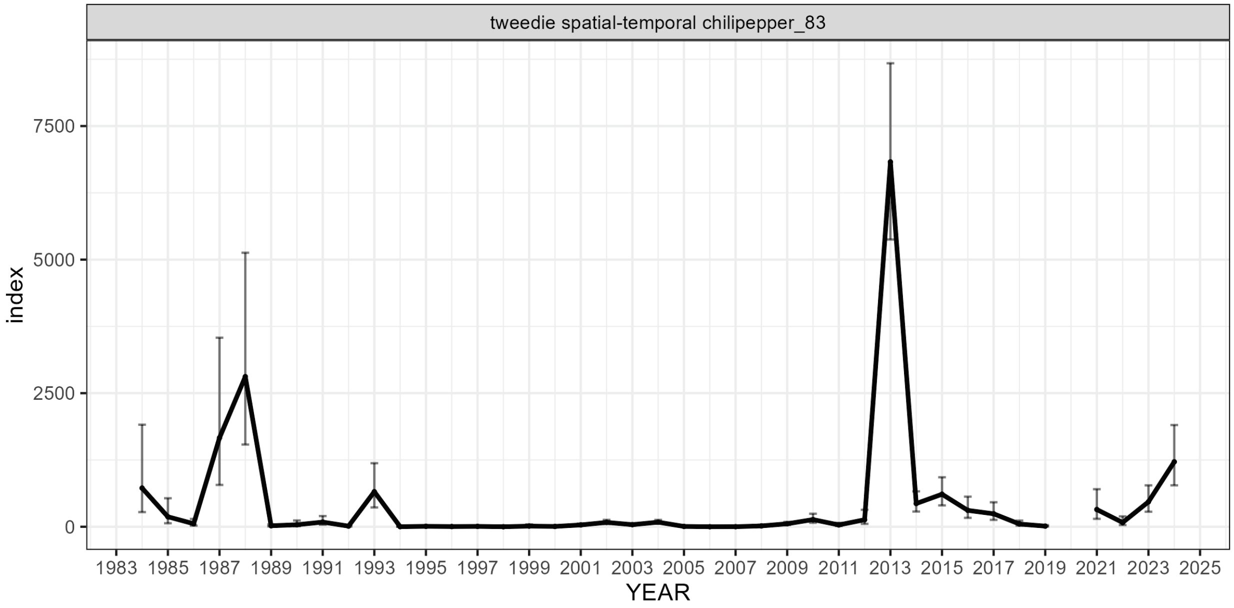


Figure 35: RREAS relative index of age-0 recruits for chilipepper rockfish, 1984-2024. Error bars are 95% CI.

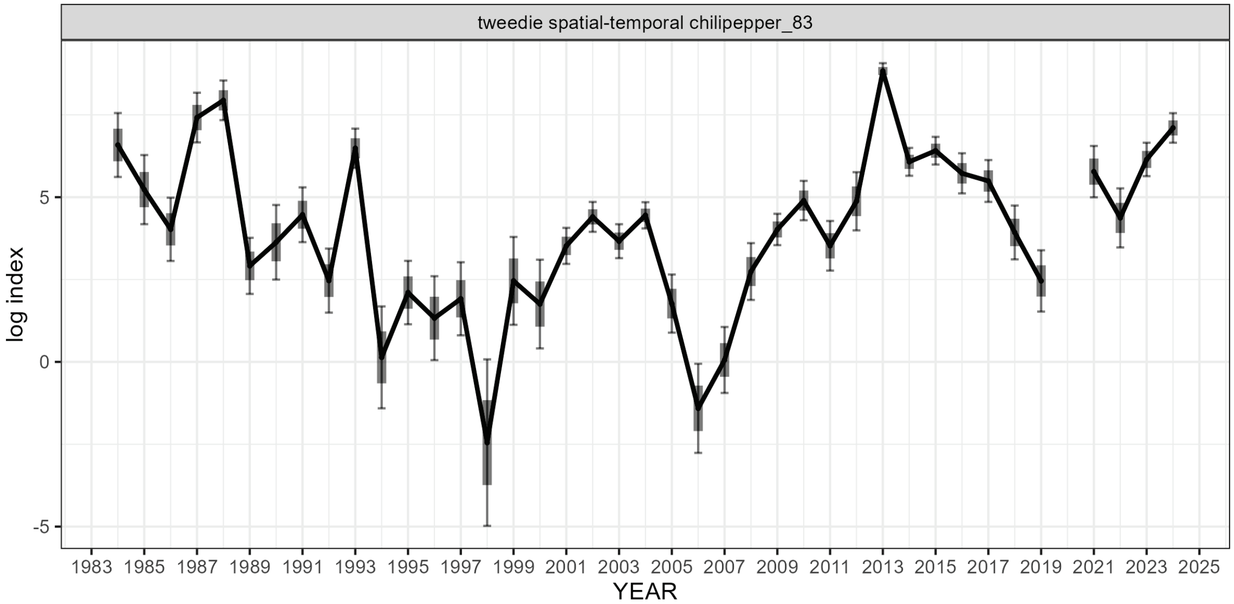


Figure 36: RREAS relative index (log scale) of age-0 recruits for chilipepper rockfish, 1984-2024. Error bars are 95% CI.

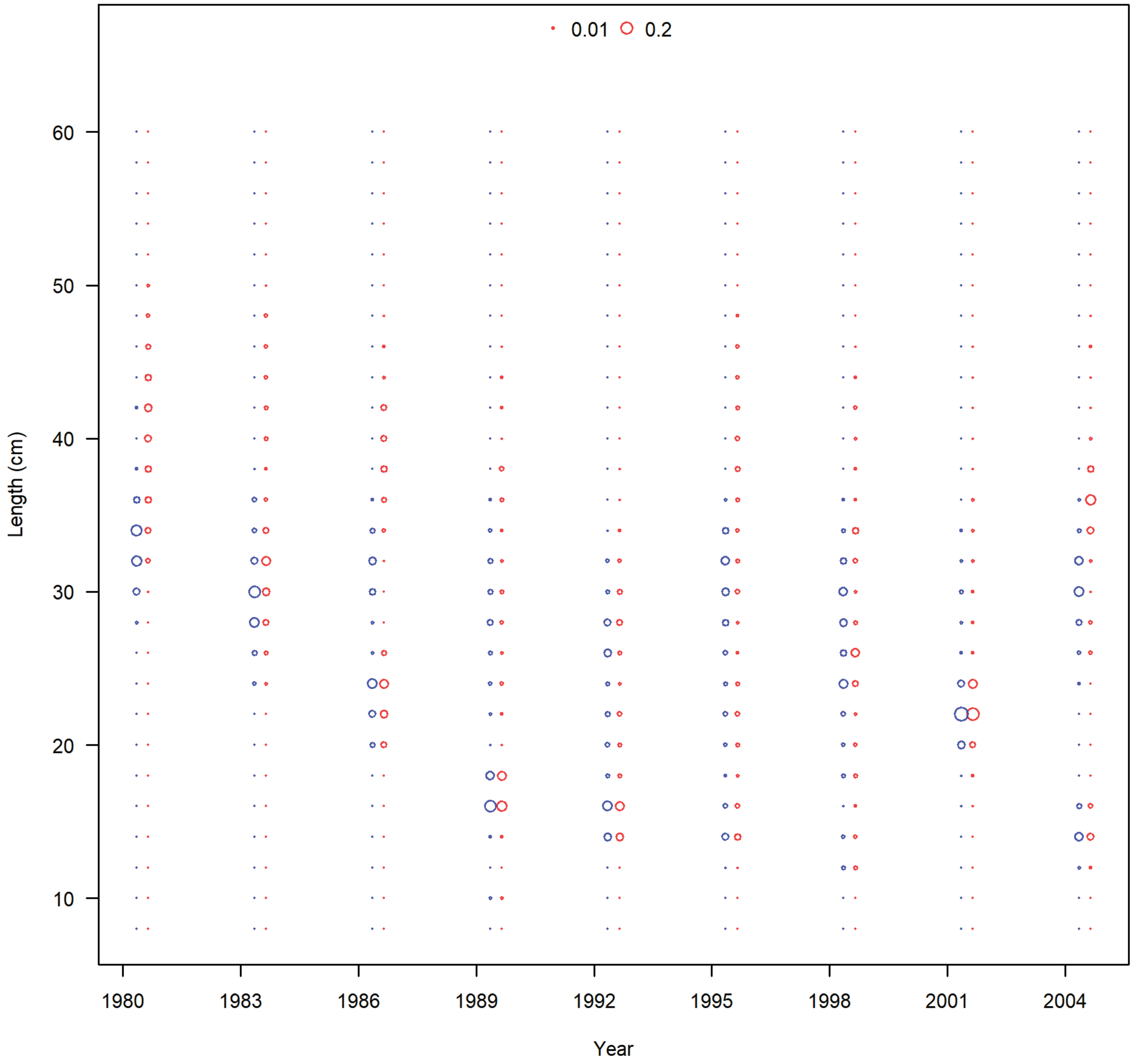


Figure 37: Triennial trawl survey length composition data (fork length in cm). Red circles are females, blue circles are males.

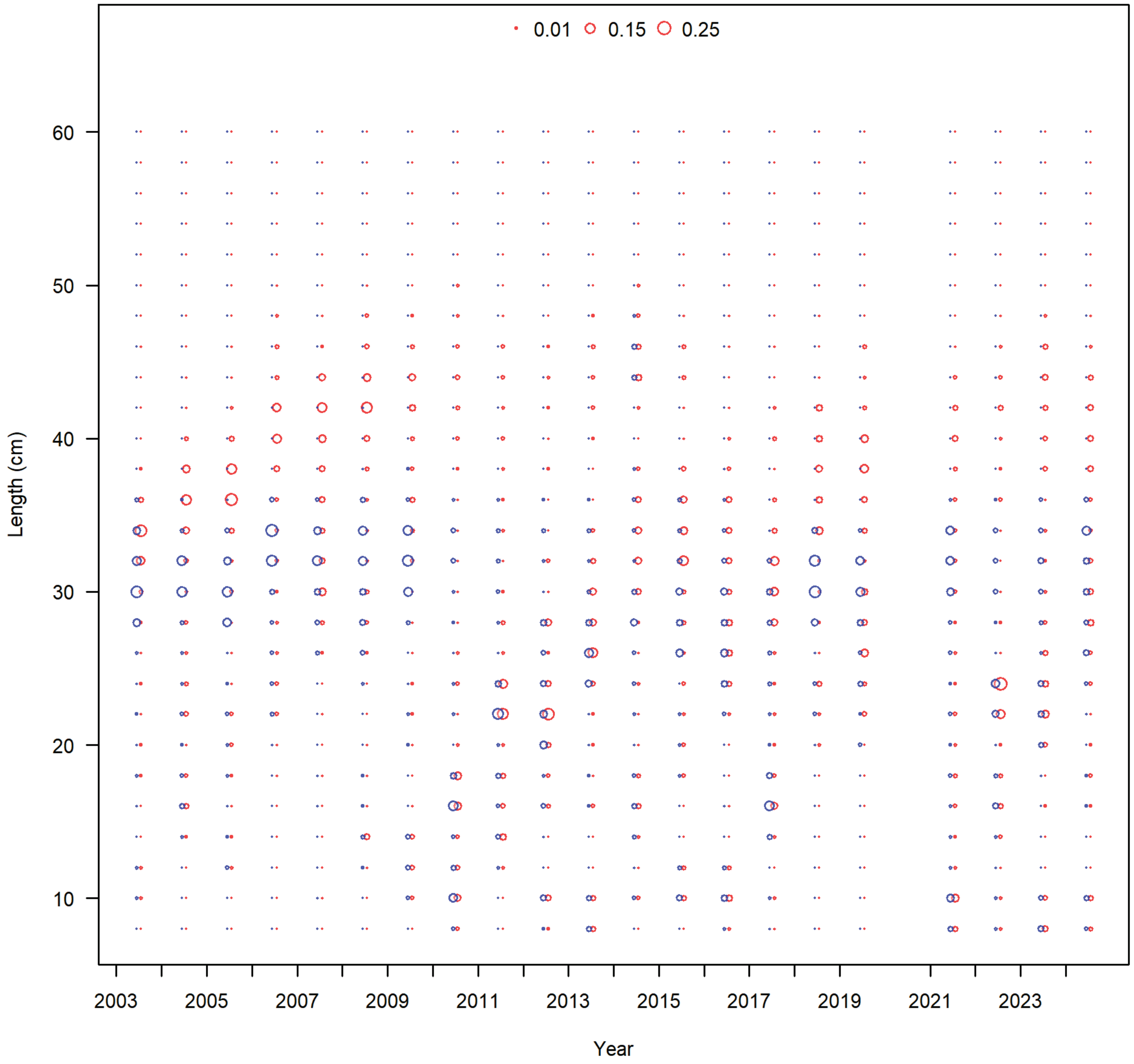


Figure 38: WCGBT survey length composition data (fork length in cm). Red circles are females, blue circles are males.

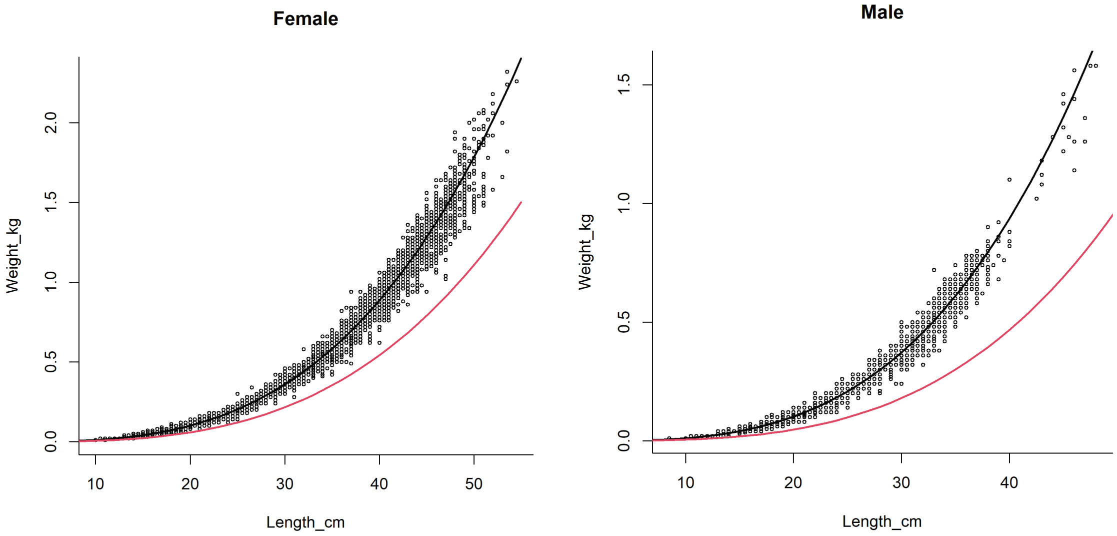


Figure 39: Revised fits (black line) to weight-at-length for female and male chilipepper rockfish. Data are from the WCGBTS. Estimates from the previous assessment are shown in red.

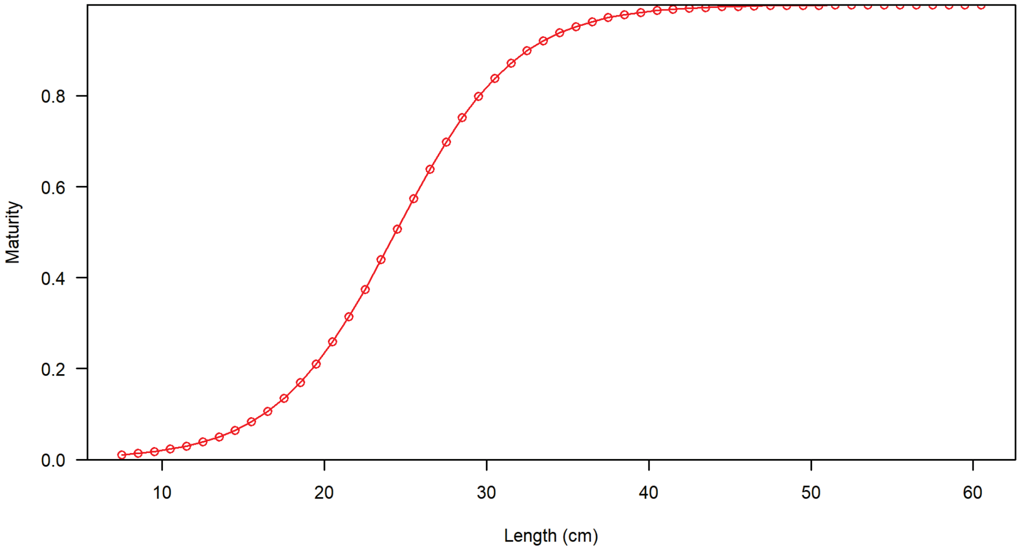


Figure 40: Proportion of mature females as a function of fork length (cm) in the 2025 chilipepper assessment.

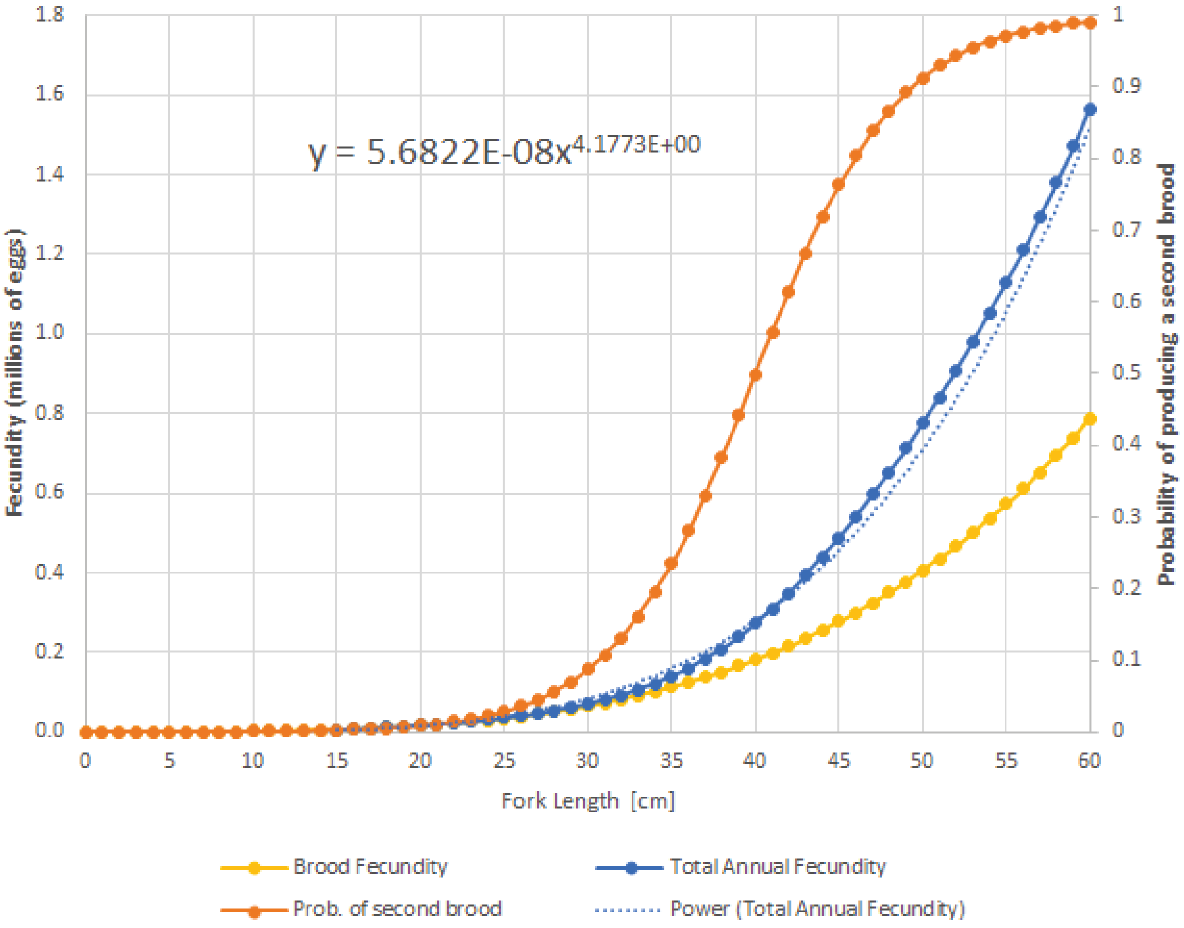


Figure 41: Illustration of method used to estimate total annual fecundity-at-length relationship (blue dotted line; “Power (Total Annual Fecundity)”) based on the brood-specific fecundity-length relationship from Dick et al. (2017; yellow line) and an updated length-based probability of multiple brooding (orange line) using data from central California, 2013-2019 (S. Beyer, AFSC, pers. comm.). See text for details.

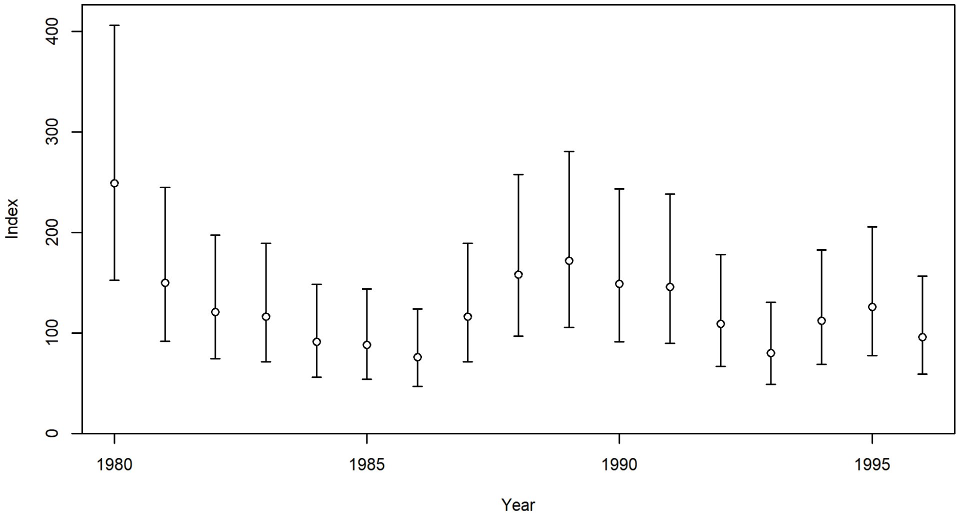


Figure 42: Index derived from commercial trawl logbook data for the 1998 chilipepper stock assessment (Ralston et al. 1998). This index is not used to fit the 2025 assessment, but is compared to model output for reference.

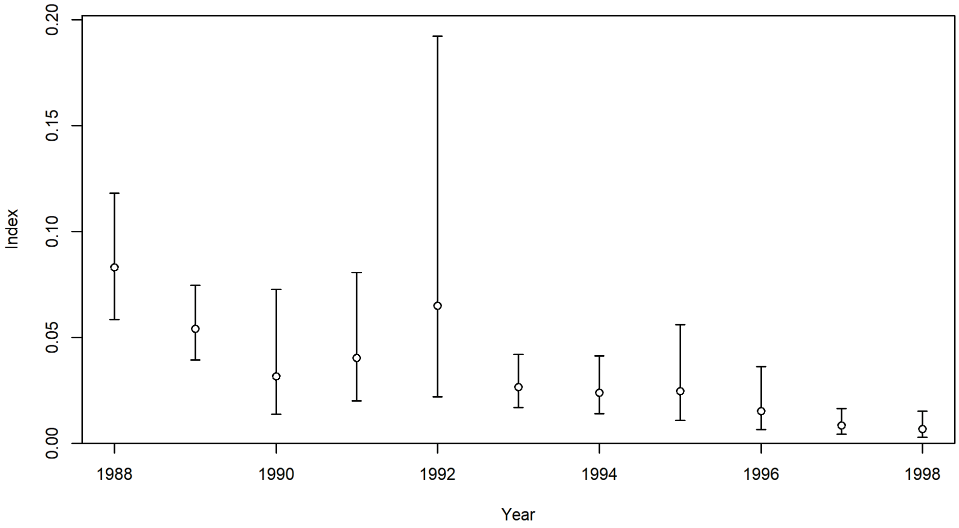


Figure 43: Index derived from recreational onboard observer CPUE data for the 1998 chilipepper stock assessment (Ralston et al. 1998). This index is not used to fit the 2025 assessment, but is compared to model output for reference.

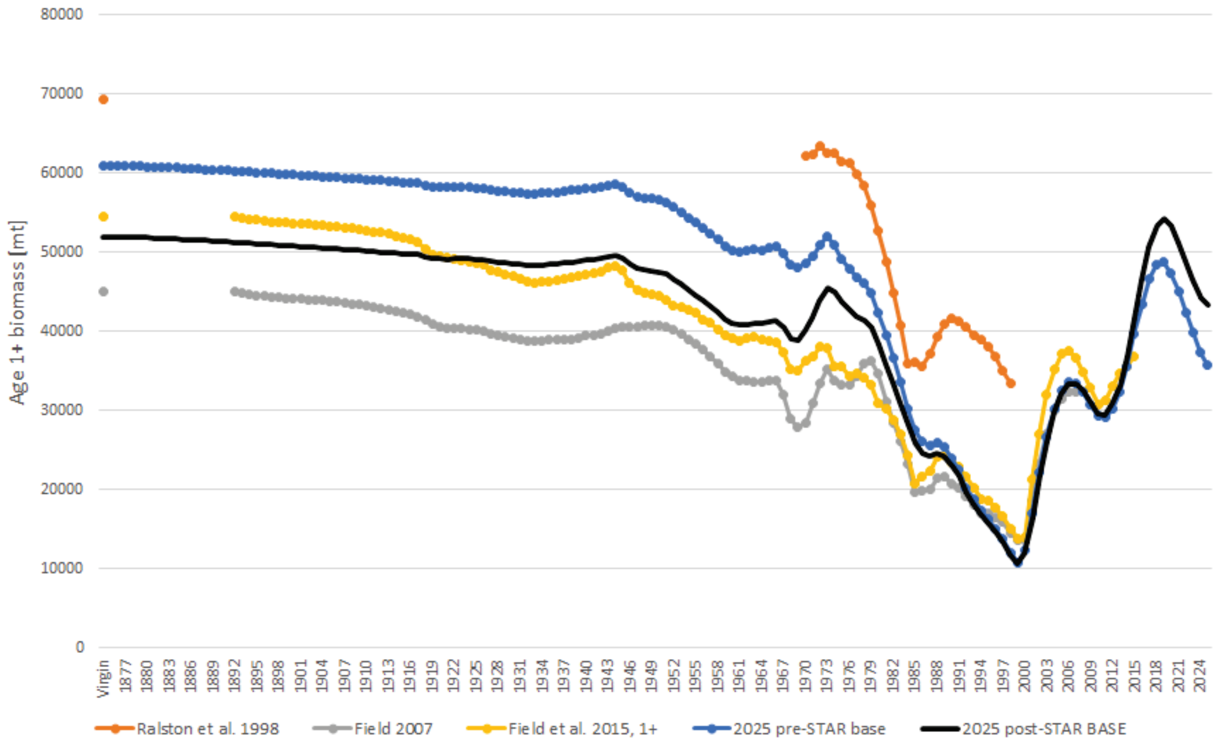


Figure 44: Comparison of trends in age 1+ biomass for previous stock assessments of chilipepper rockfish, including the pre- and post-STAR base models.

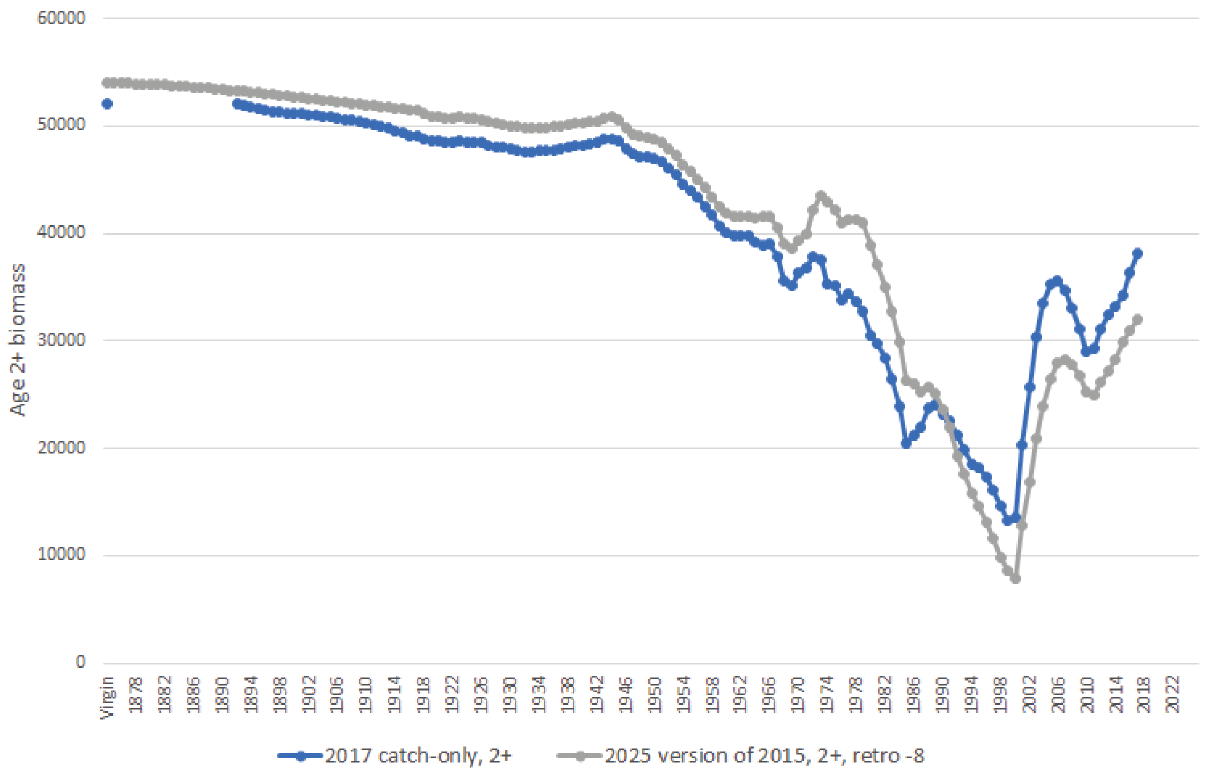


Figure 45: Comparison of age 2+ biomass time series for the 2017 catch-only update and a modified version of the pre-STAR base model. The pre-STAR base was changed to match the 2017 values for

natural mortality, steepness, recruitment deviation configuration, fecundity, and weight-at-length. The CalCOFI index was removed, and fishery-independent indices were included in the likelihood.

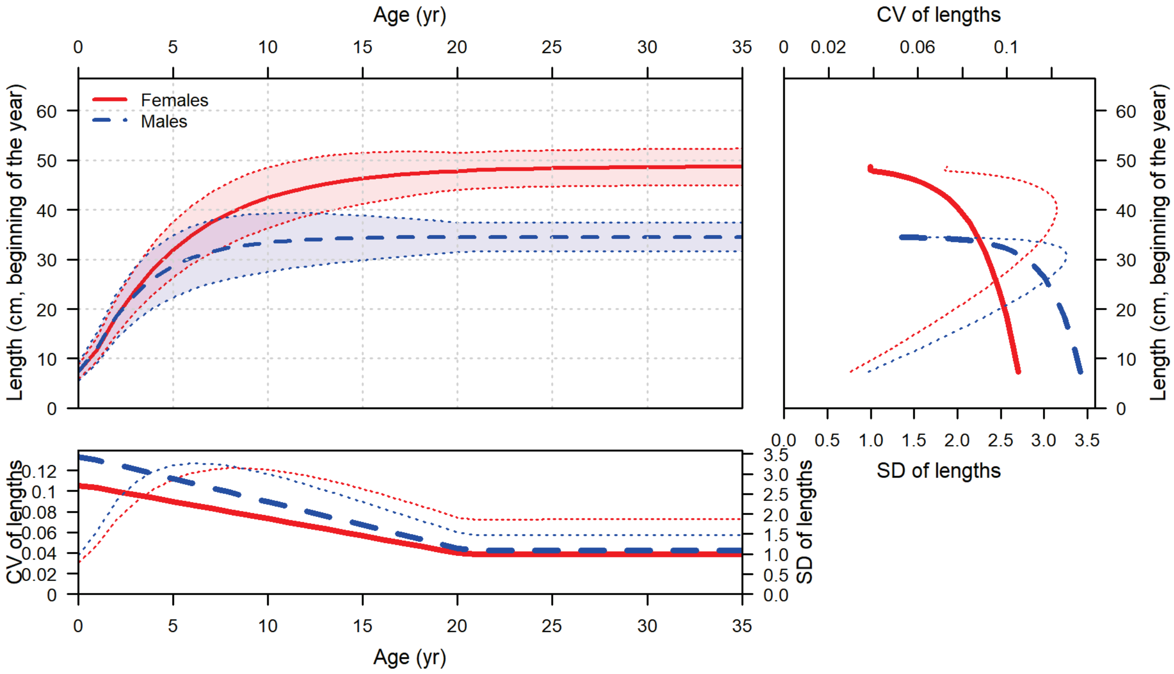


Figure 46: Base model estimates of growth (mean length-at-age by sex) with linear interpolation between estimates of the CV of length at age for ages 0 and 20.

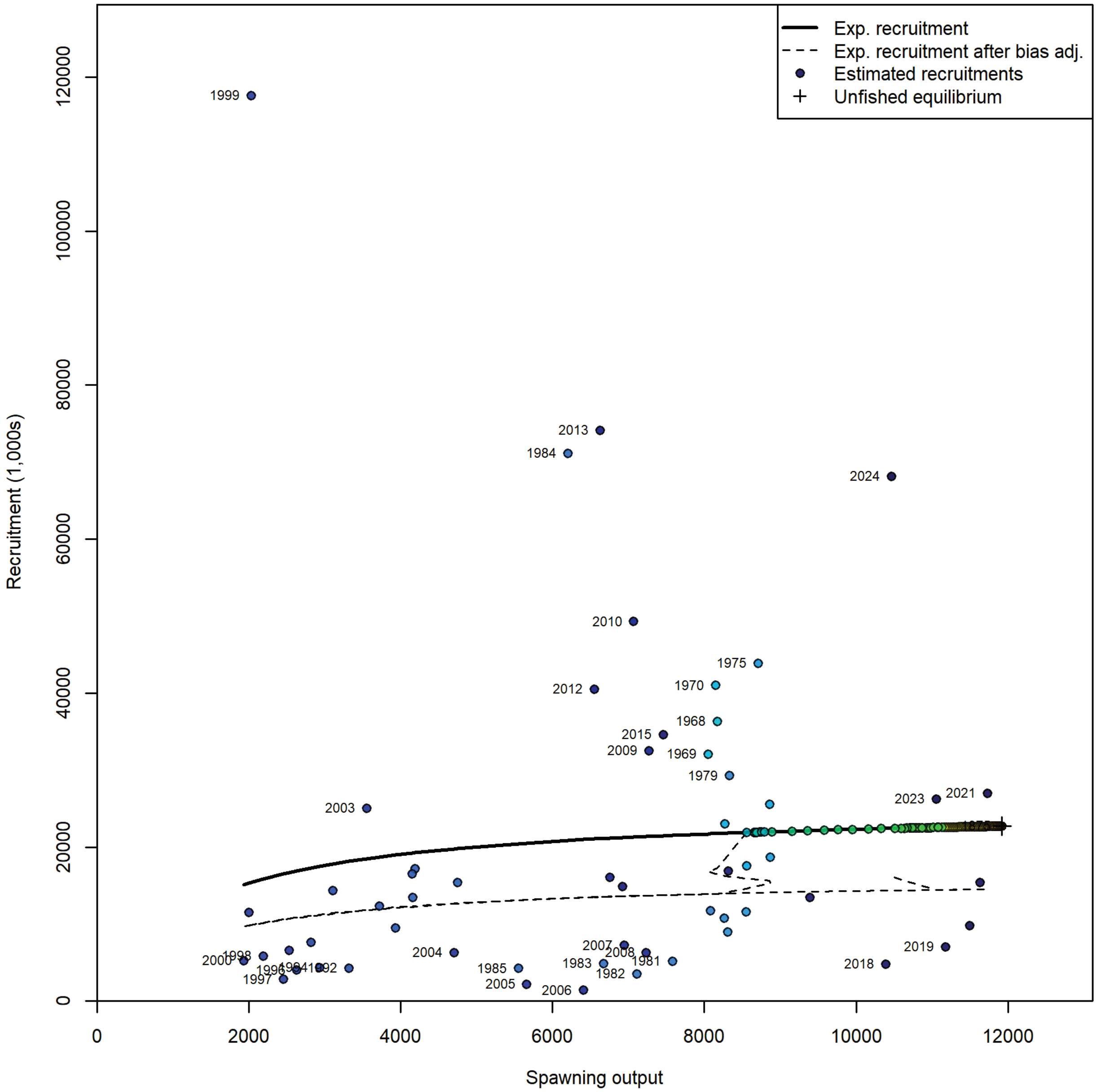


Figure 47: Base model stock-recruitment curve (Beverton-Holt) with steepness fixed at the prior mean (0.72) and estimated recruitment deviations (1968-2024). Recruitment is in 1000s of age-0 fish, and spawning output is in billions of eggs. Note that the precision of the estimated 2024 year class is low. See text for details.

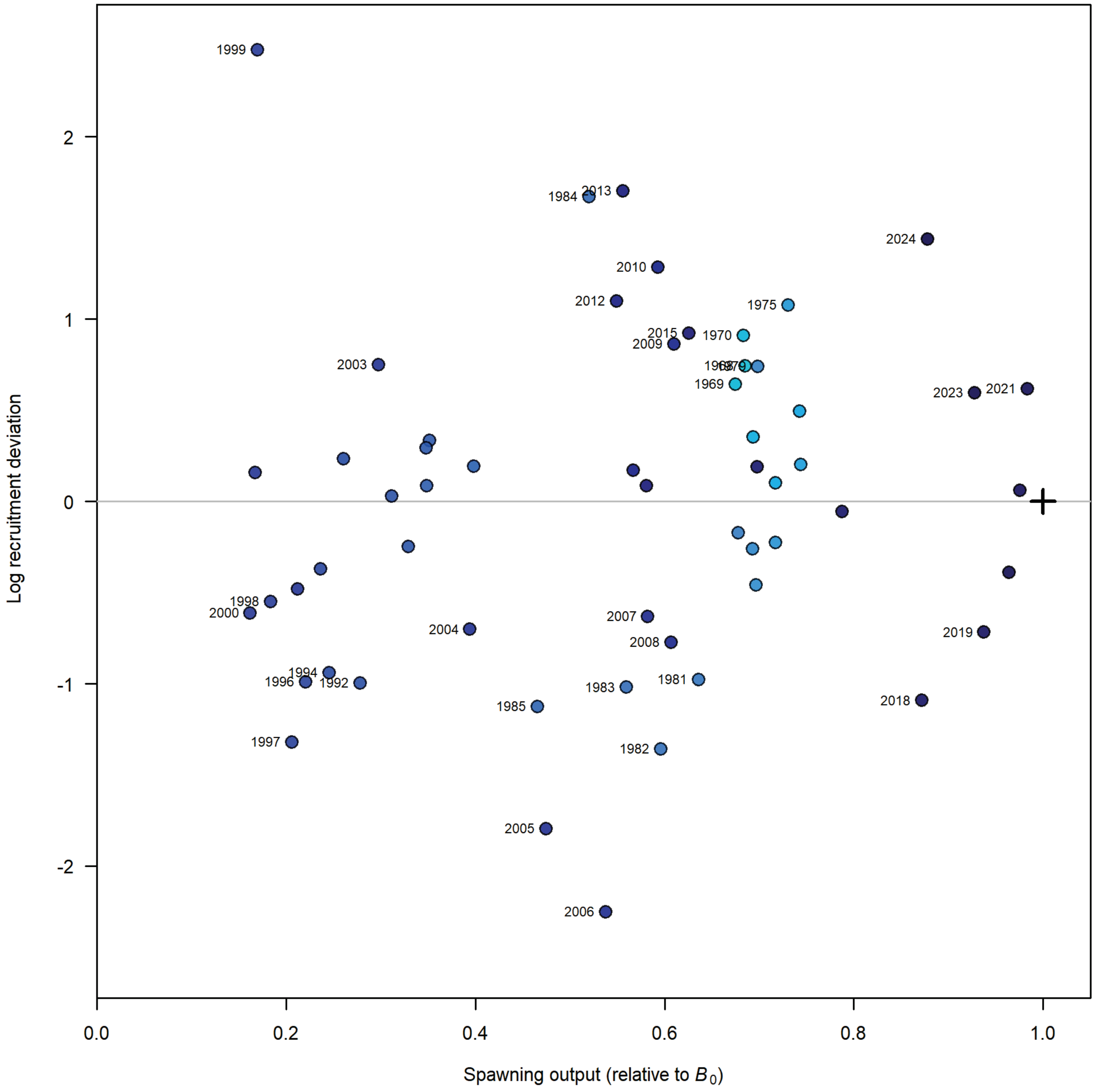


Figure 48: Log-scale residuals around the stock-recruitment curve (1968-2024). Years with deviations having an absolute value greater than 0.5 are labeled.

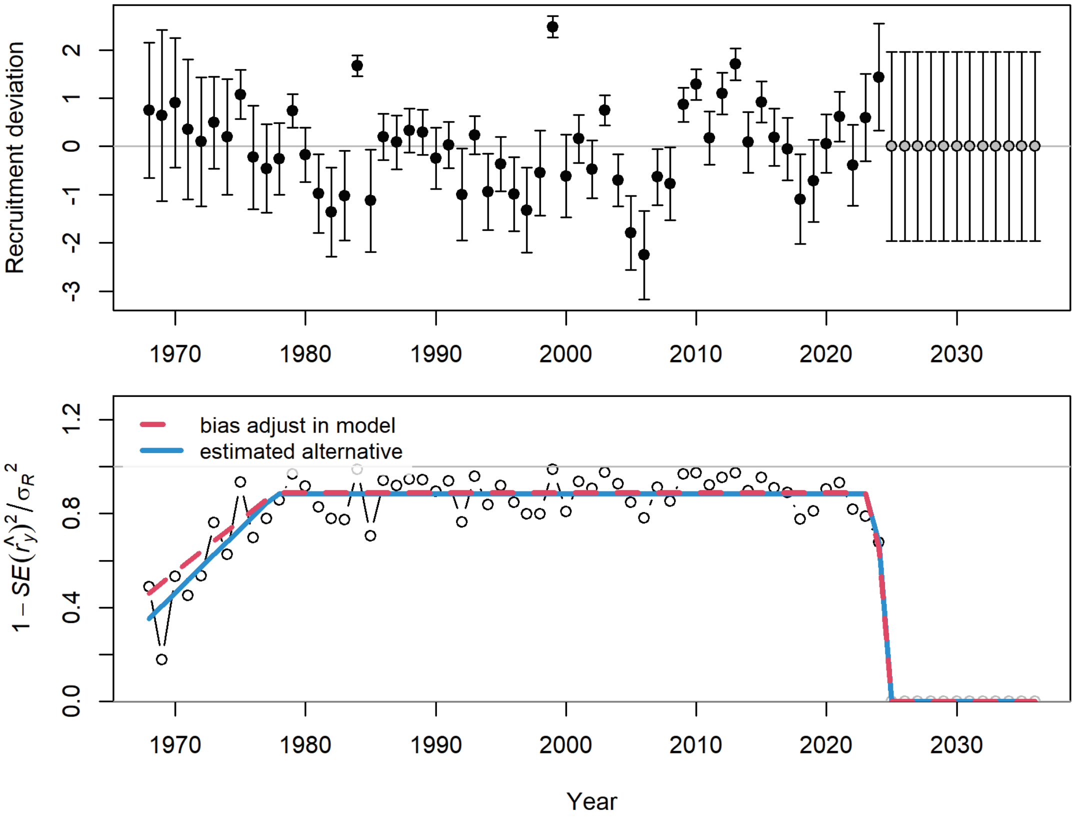


Figure 49: Time series of estimated recruitment deviations (top panel) and model-estimated annual bias adjustment fraction (bottom panel).

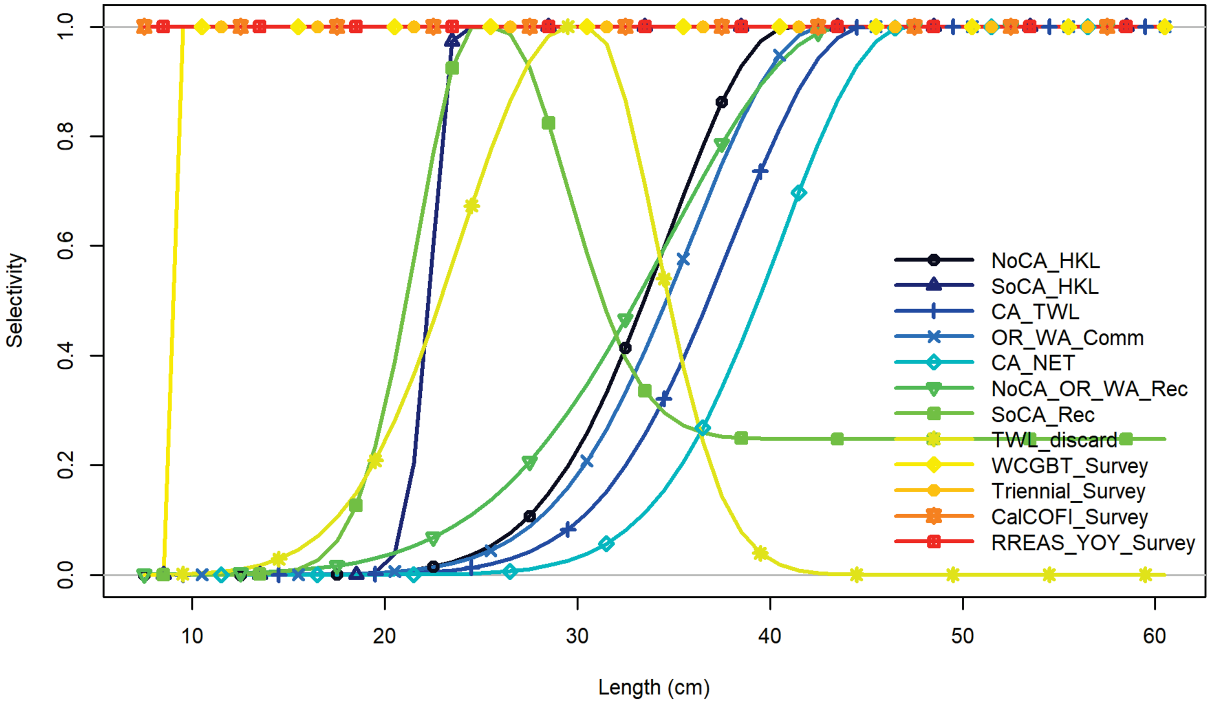


Figure 50: Ending year length-based selectivity curves by fleet in the base model. See figures below for fleets with time-varying selectivity.

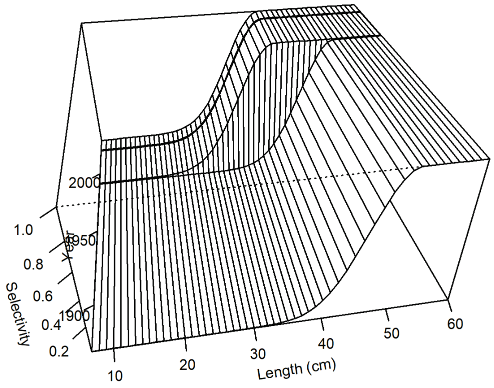


Figure 51: Time-varying selectivity for the Northern California commercial hook and line fleet.

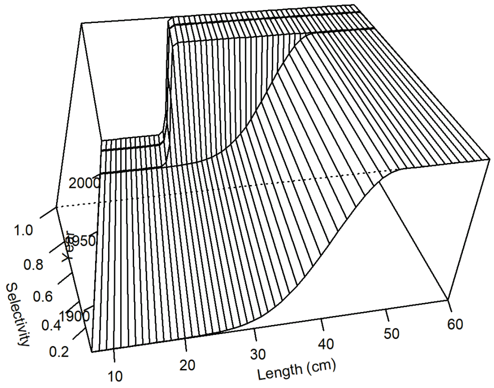


Figure 52: Time-varying selectivity for the Southern California commercial hook and line fleet.

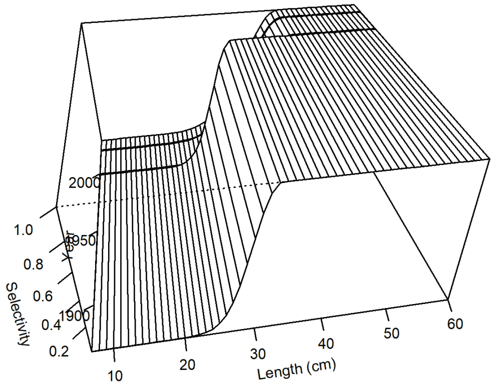


Figure 53: Time-varying selectivity for the California commercial trawl fleet.

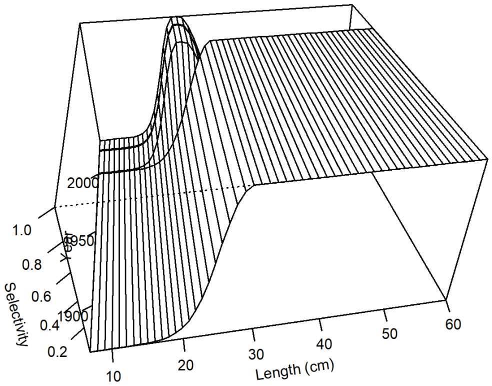


Figure 54: Time-varying selectivity for the Southern California recreational fleet.

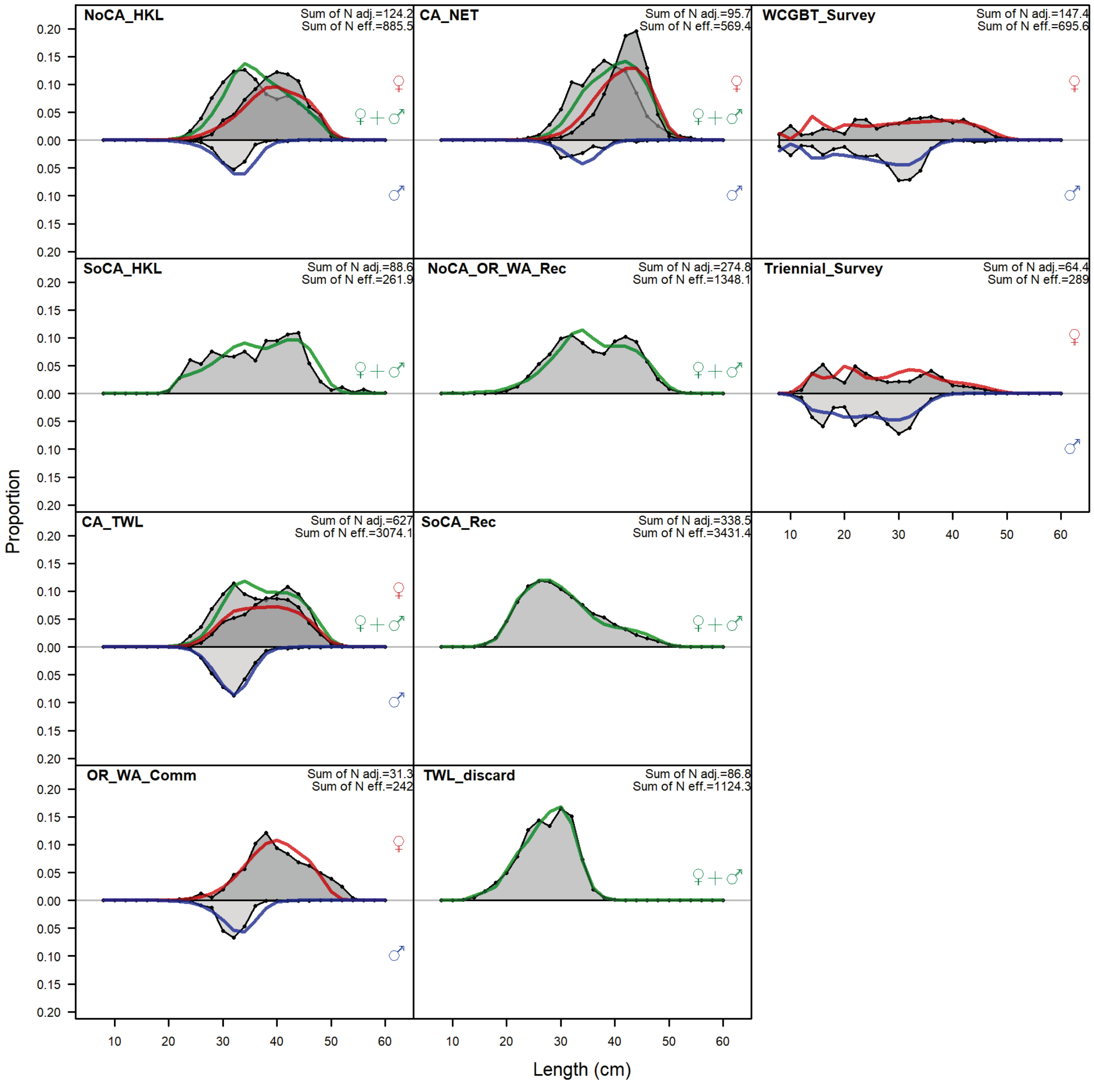


Figure 55: Base model fits to length composition data by modeled fleet, aggregated across time. Colored lines represent model fit (red = female, blue = male, green = combined sexes).

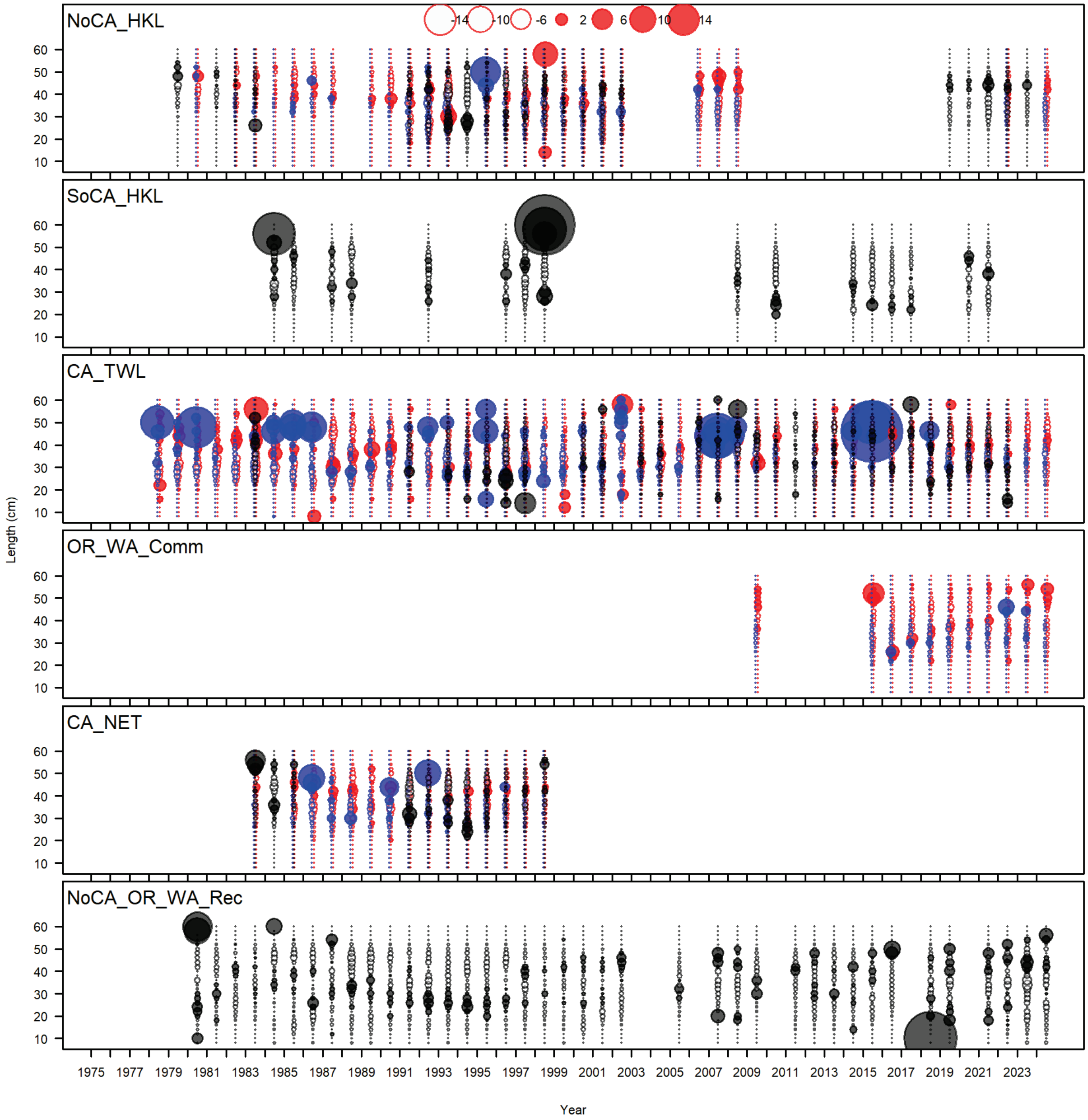


Figure 56: Pearson residuals for base model fits to length compositions by fleet and year (continued in next figure).

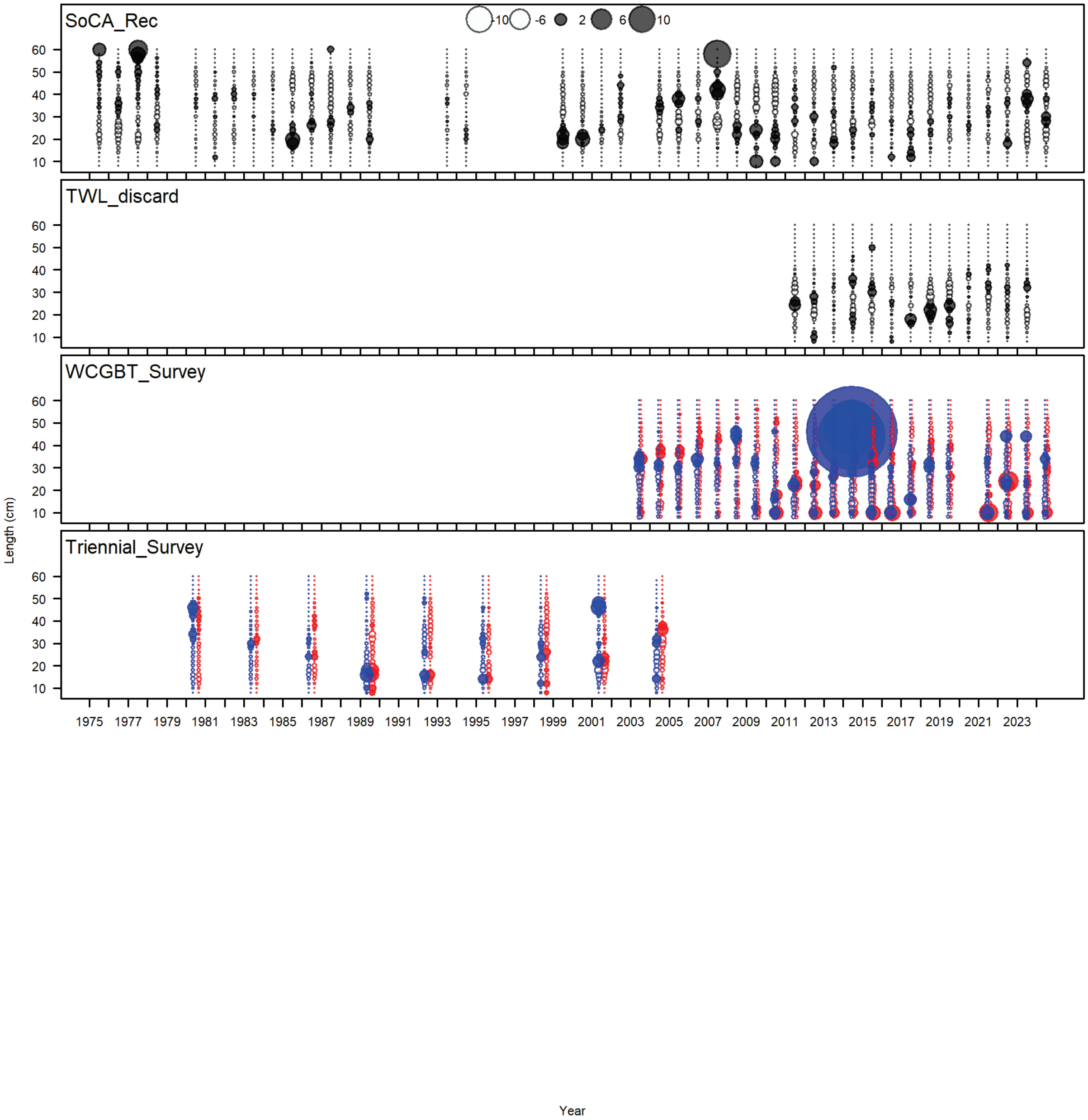


Figure 57: Pearson residuals for base model fits to length compositions by fleet and year (continued).

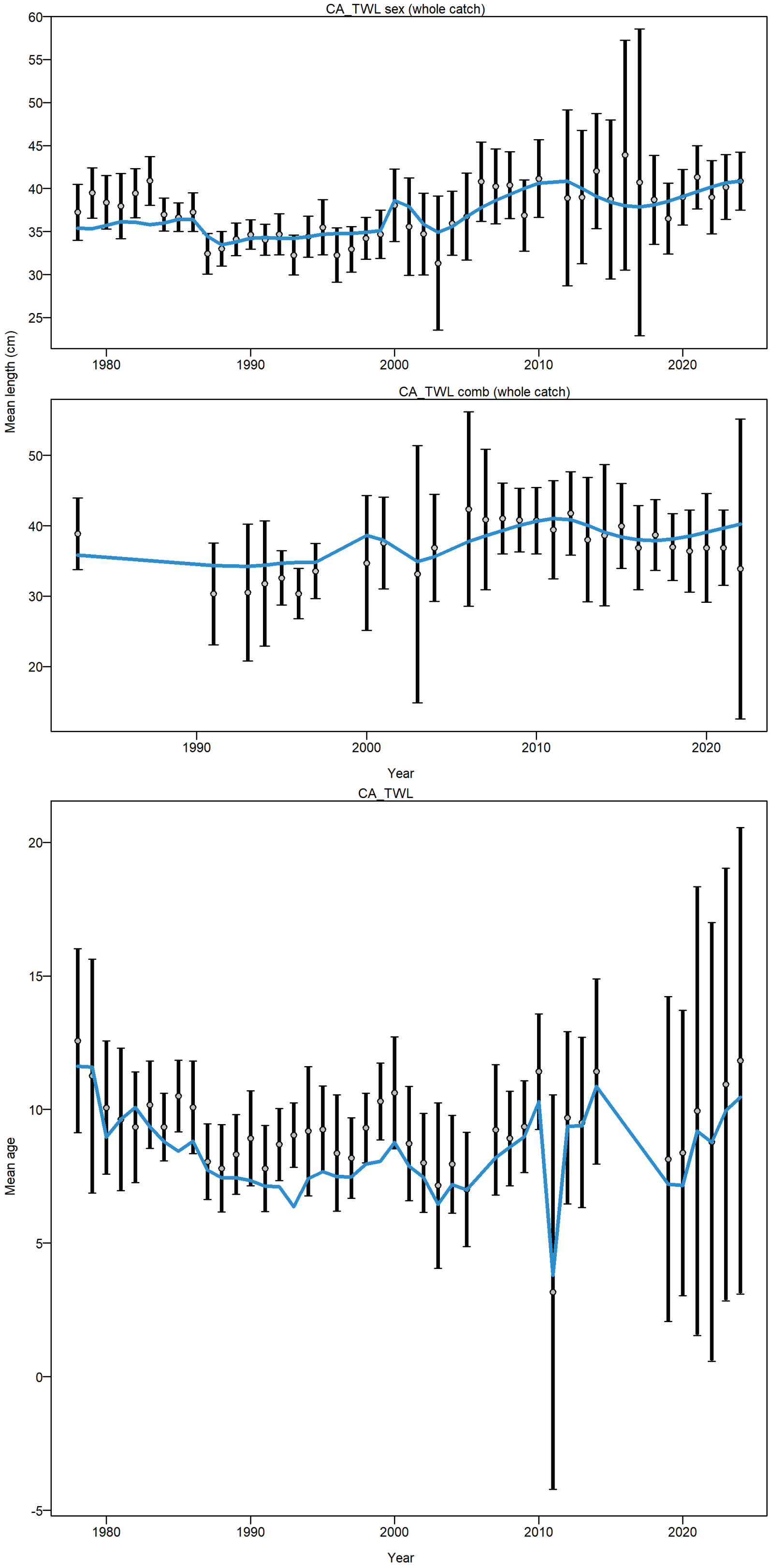


Figure 58: California trawl fleet: mean lengths (cm) for sexed fish (top panel) and unsexed fish (middle panel) for length compositions, and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

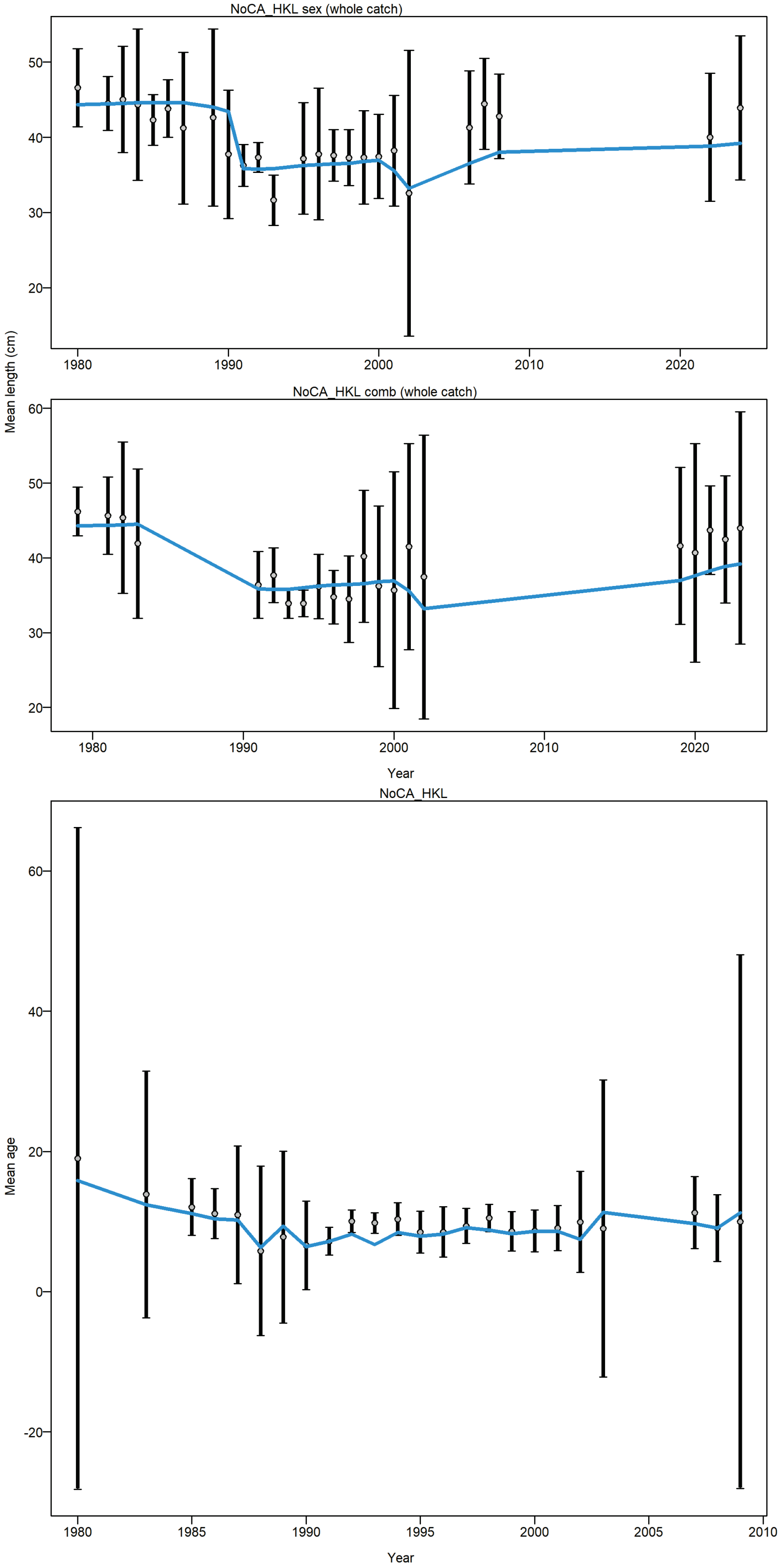


Figure 59: Northern California hook and line fleet: mean lengths (cm) for sexed fish (top panel) and unsexed fish (middle panel) for length compositions, and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

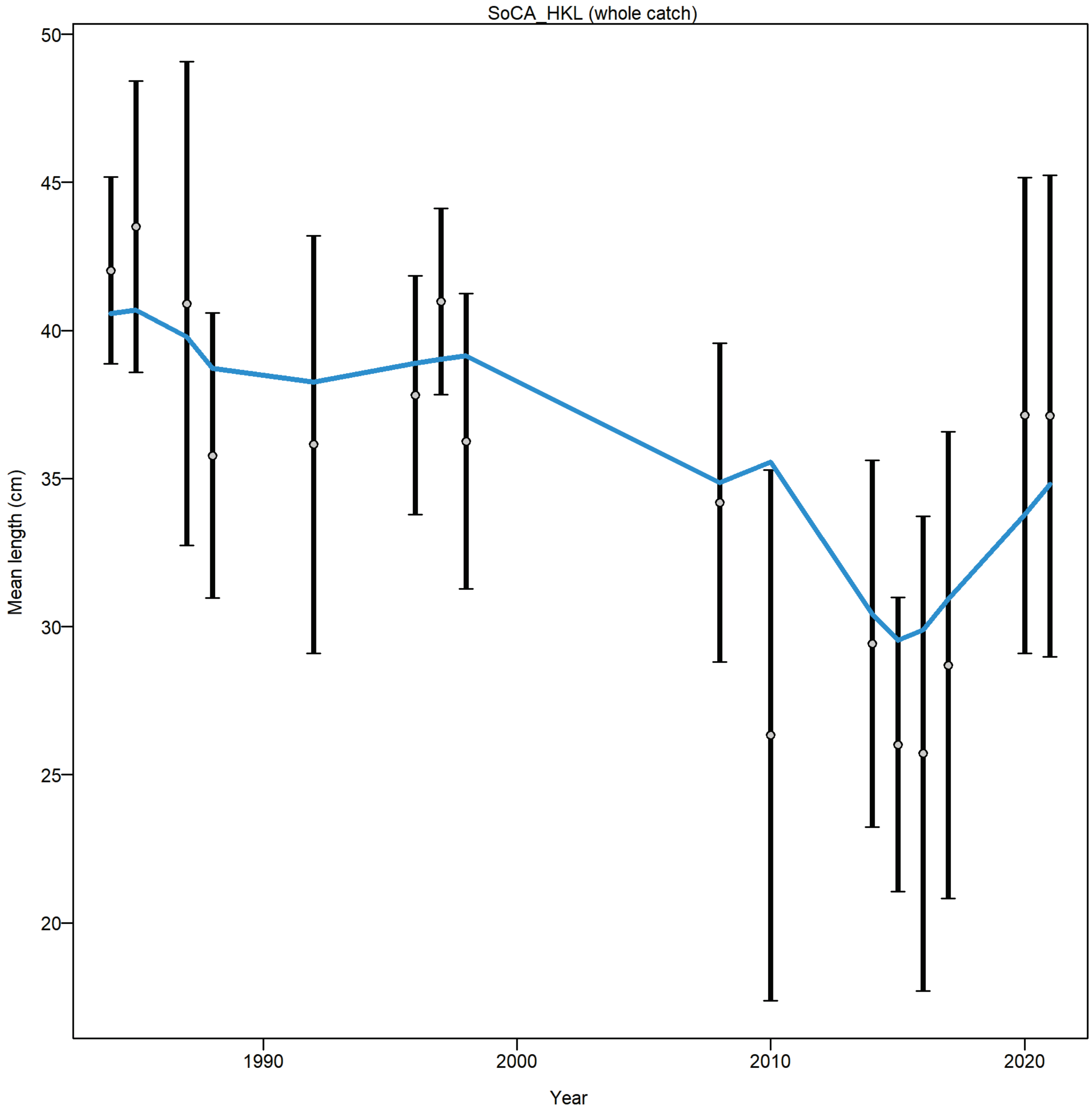


Figure 60: Southern California hook and line fleet: mean lengths (cm) for unsexed fish for length compositions with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

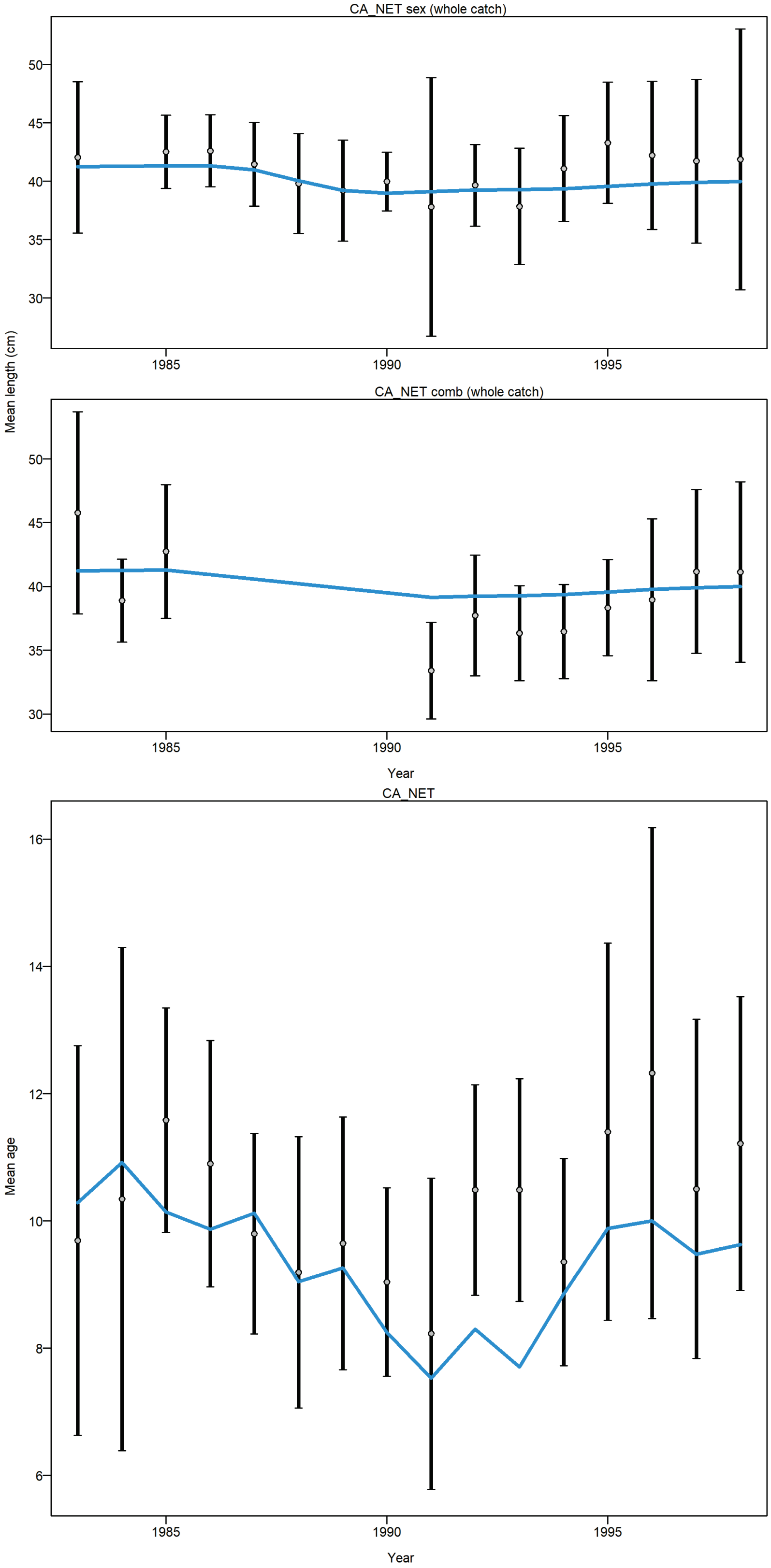


Figure 61: California net fleet: mean lengths (cm) for sexed fish (top panel) and unsexed fish (middle panel) for length compositions, and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

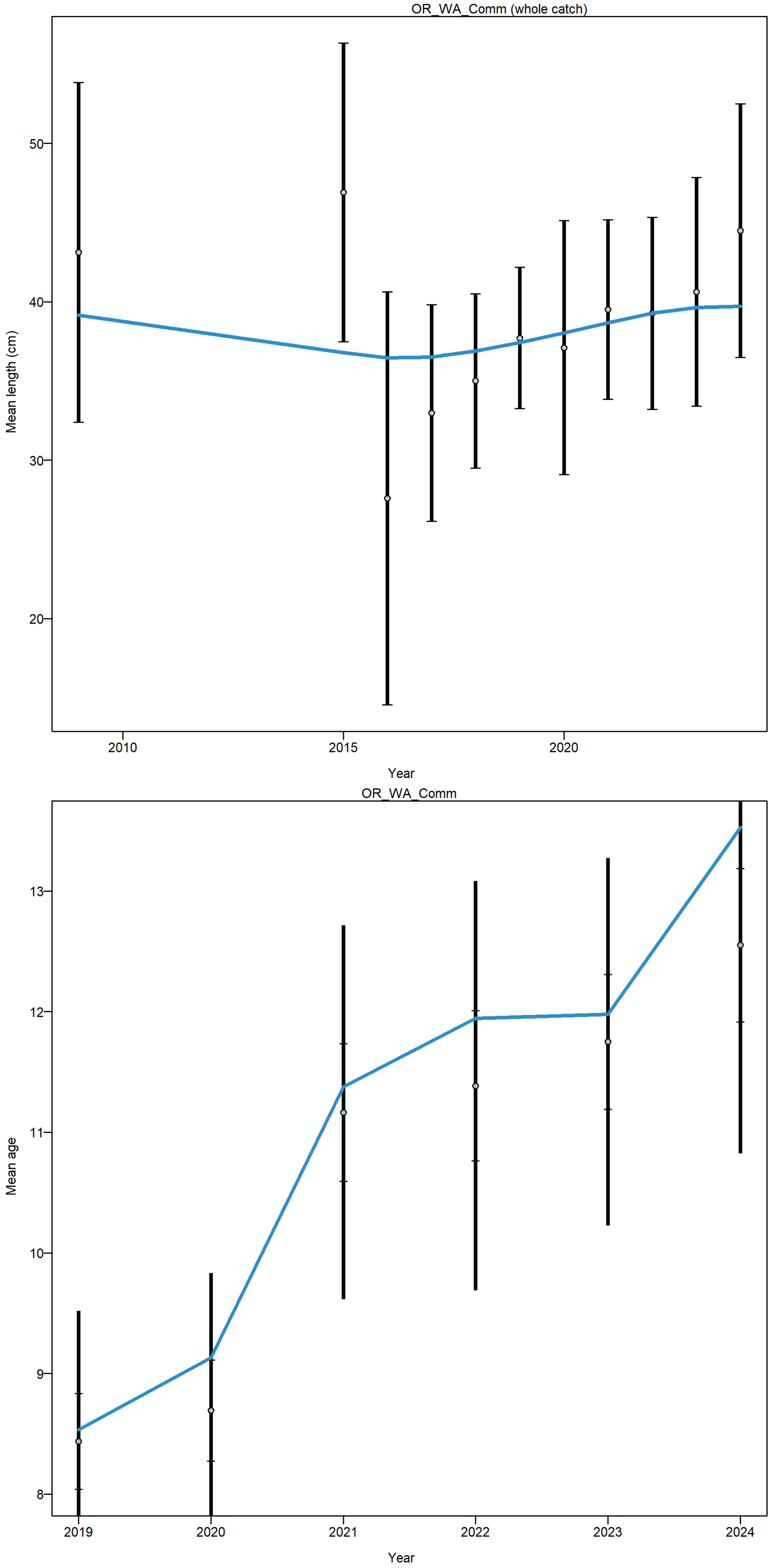


Figure 62: Oregon combined commercial fleets: mean lengths (cm) for unsexed fish (top panel) length compositions, and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

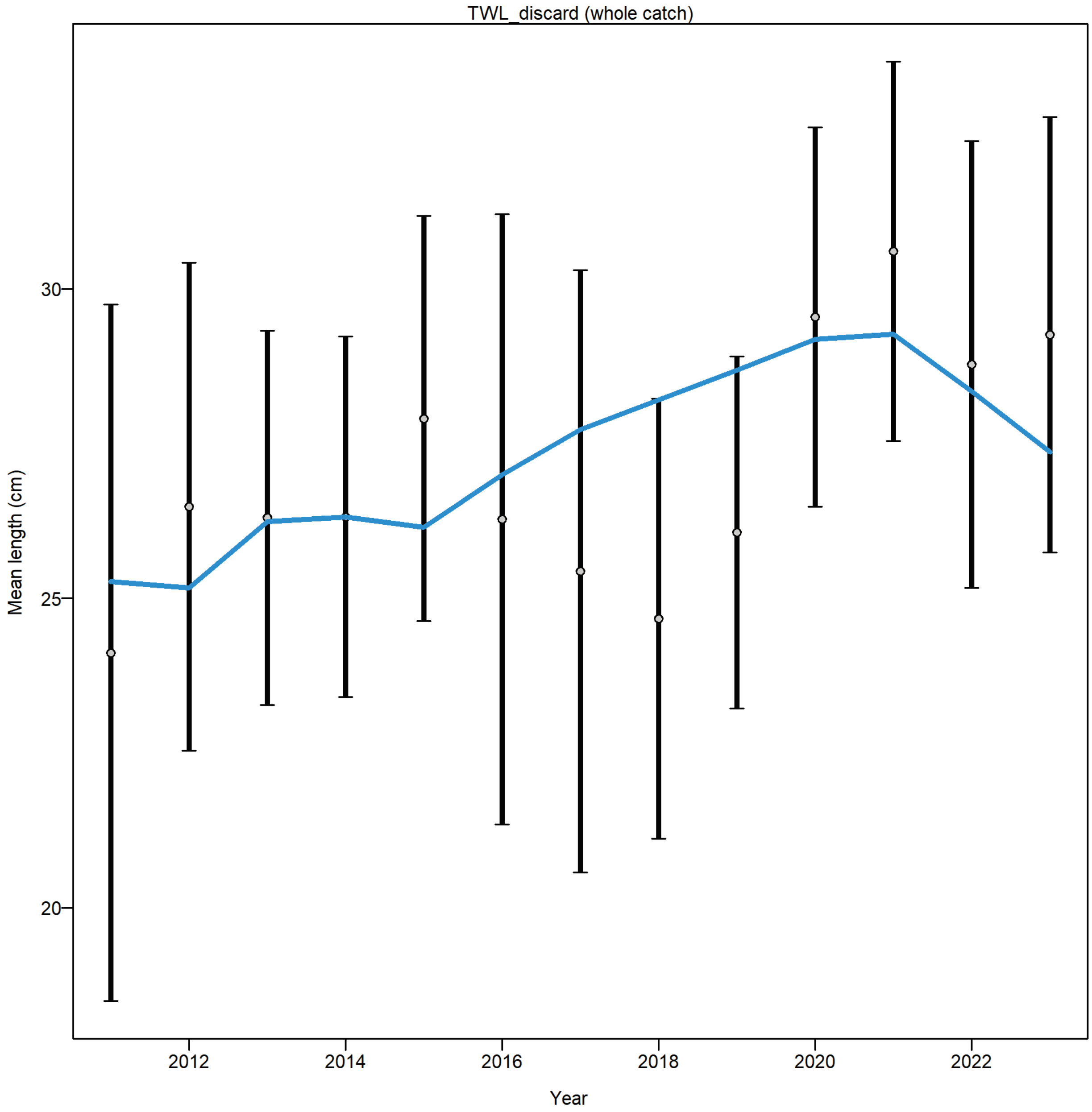


Figure 63: Trawl discard “fleet”: mean lengths (cm) for unsexed fish length compositions, with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

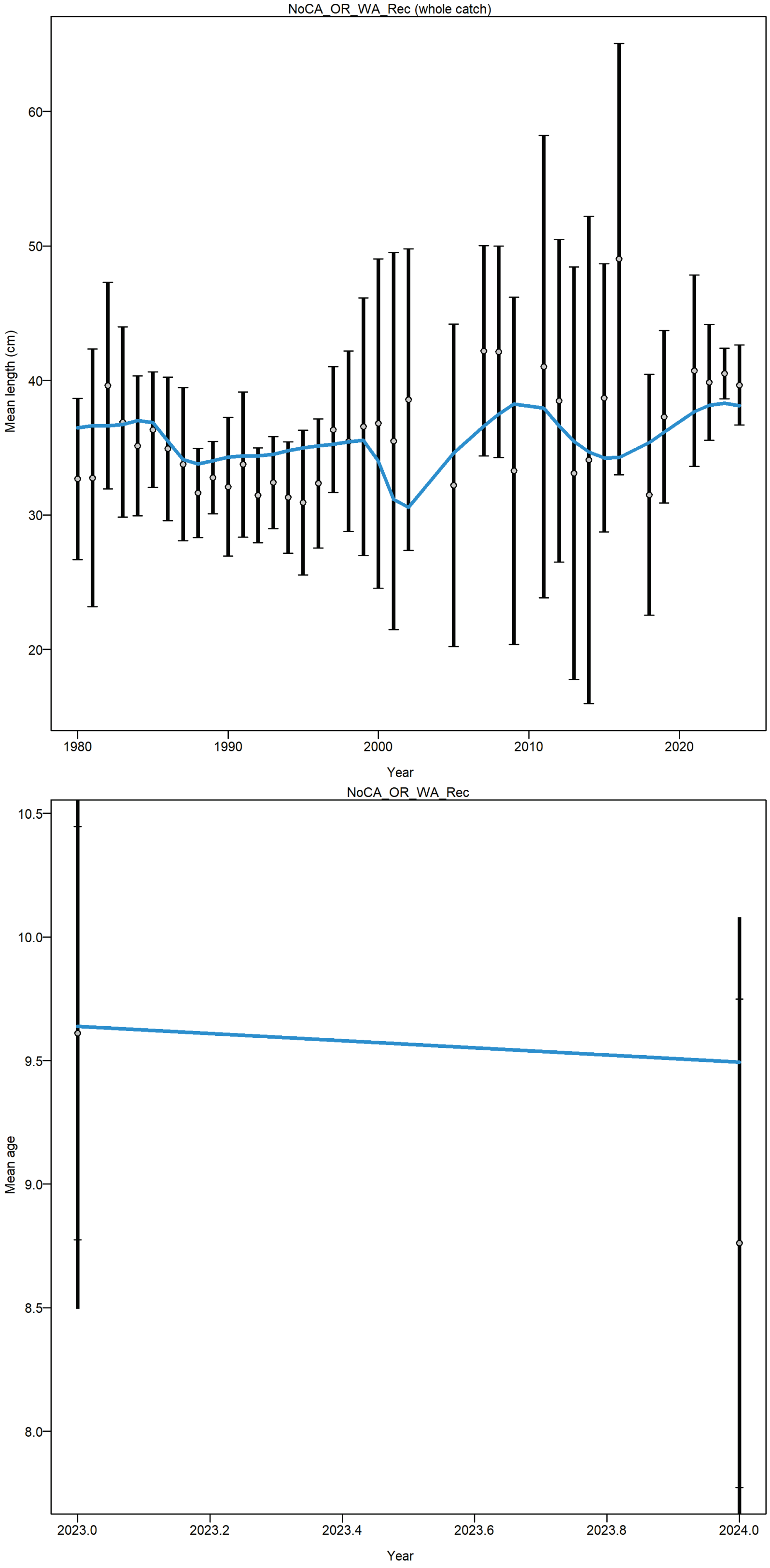


Figure 64: Recreational fleets north of Point Conception: mean lengths (cm) for unsexed fish length compositions (top panel), and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

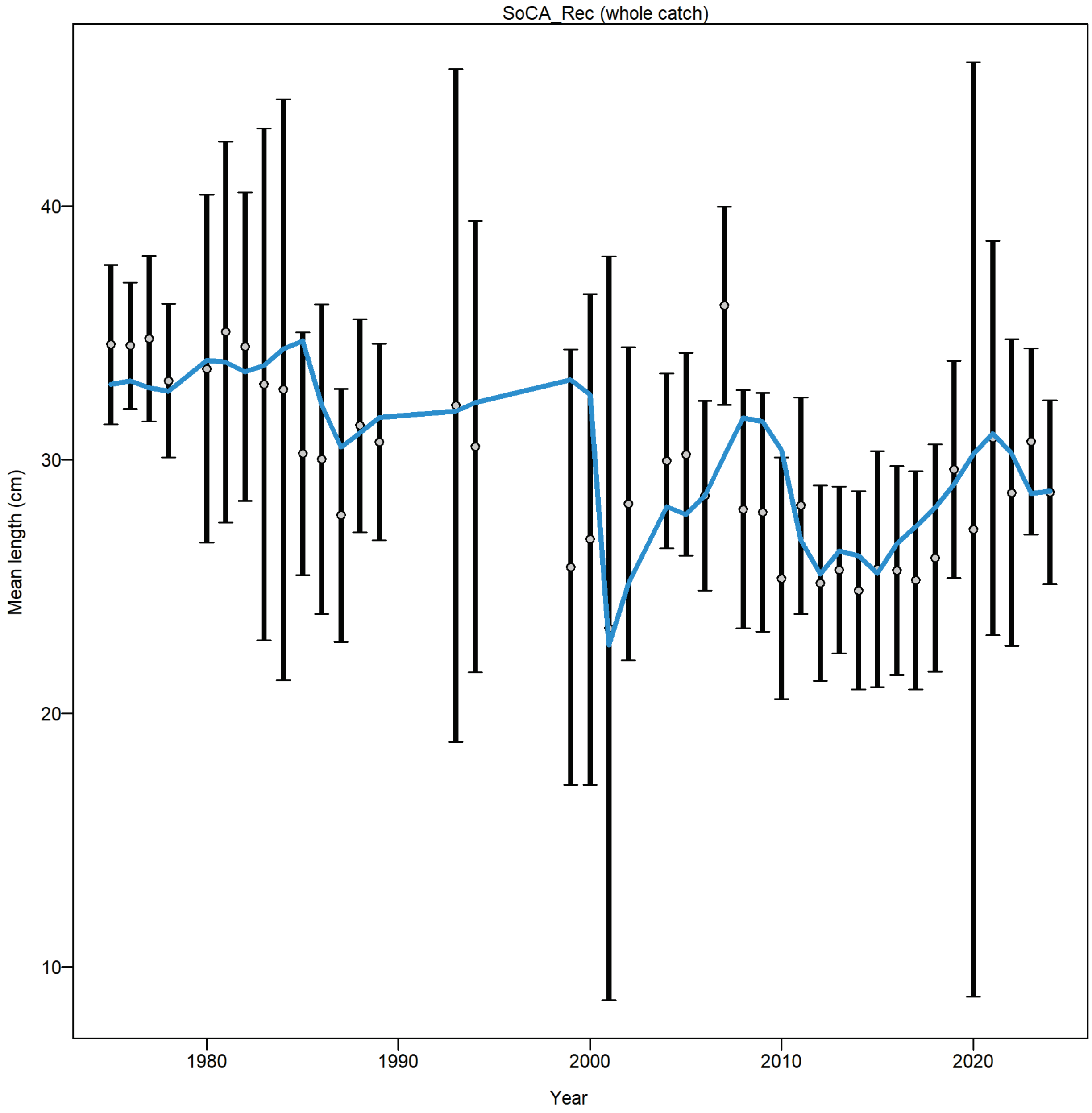


Figure 65: Recreational fleets south of Point Conception: mean lengths (cm) for unsexed fish length compositions with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

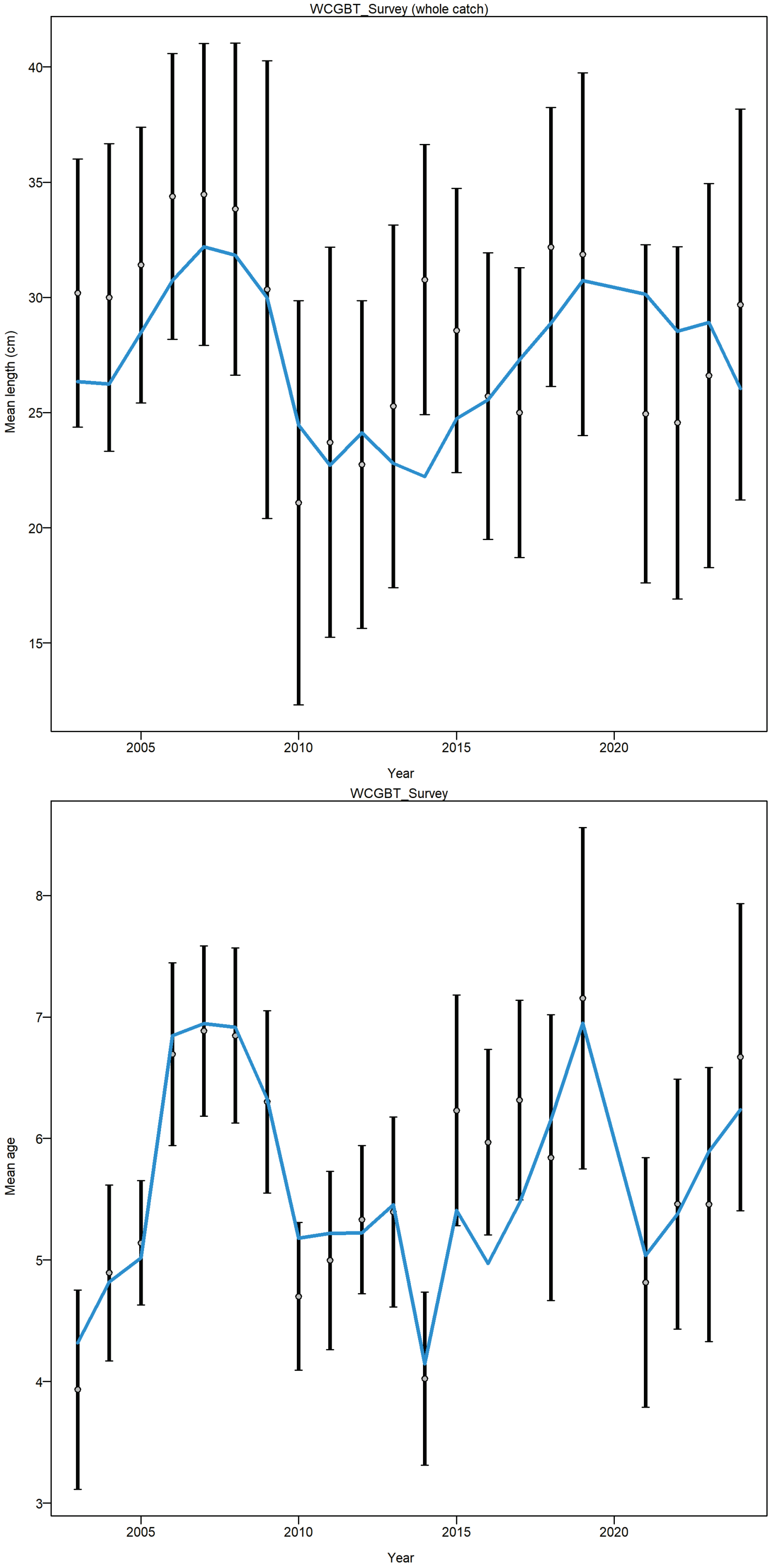


Figure 66: WCGBTS: mean lengths (cm) for sexed fish (top panel) for length compositions, and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

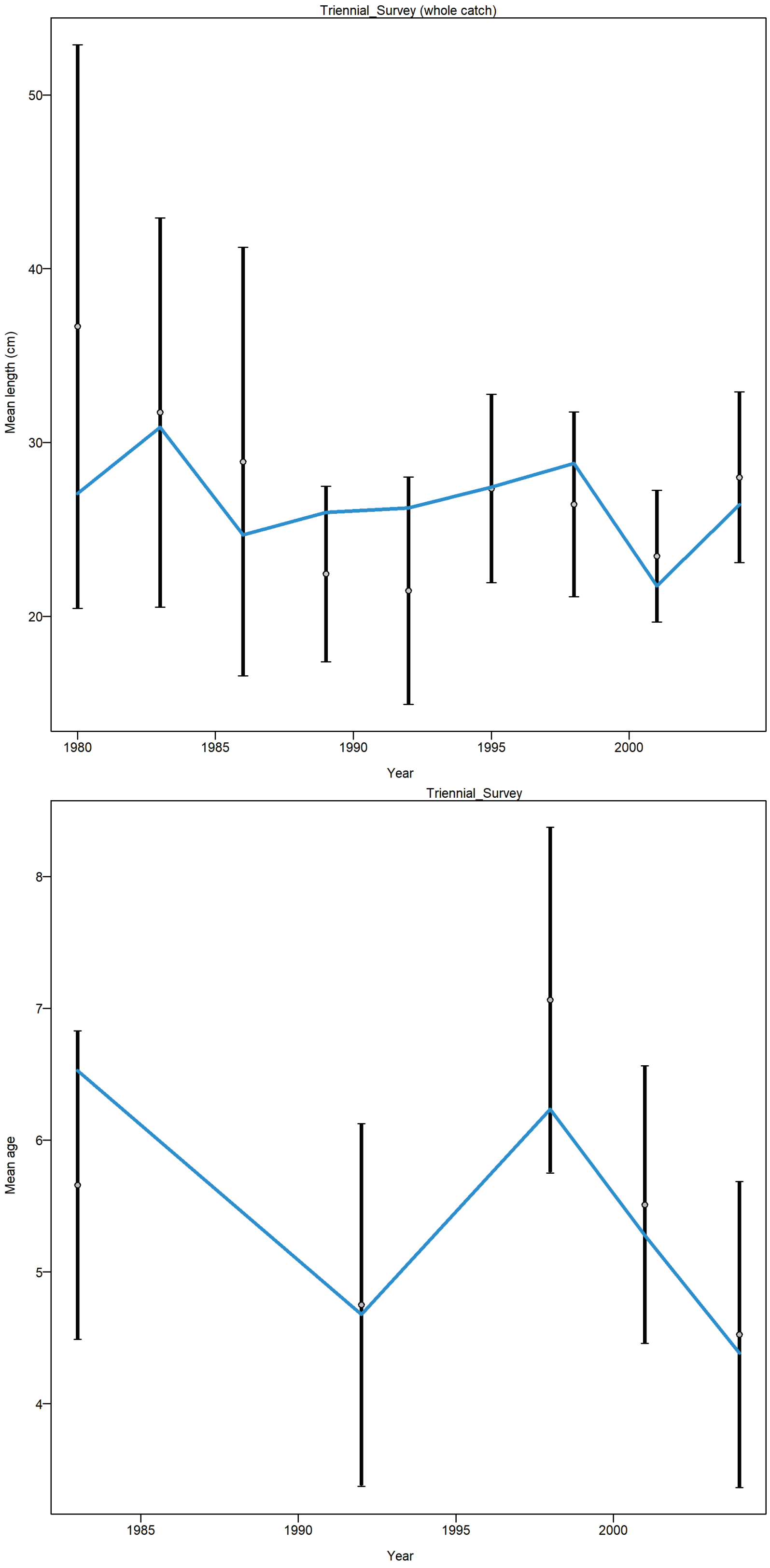


Figure 67: Triennial trawl survey: mean lengths (cm) for sexed fish (top panel) for length compositions, and mean ages (years; bottom panel) from CAAL data with 95% C.I. based on adjusted input sample sizes. Blue lines are the predicted value from the base model.

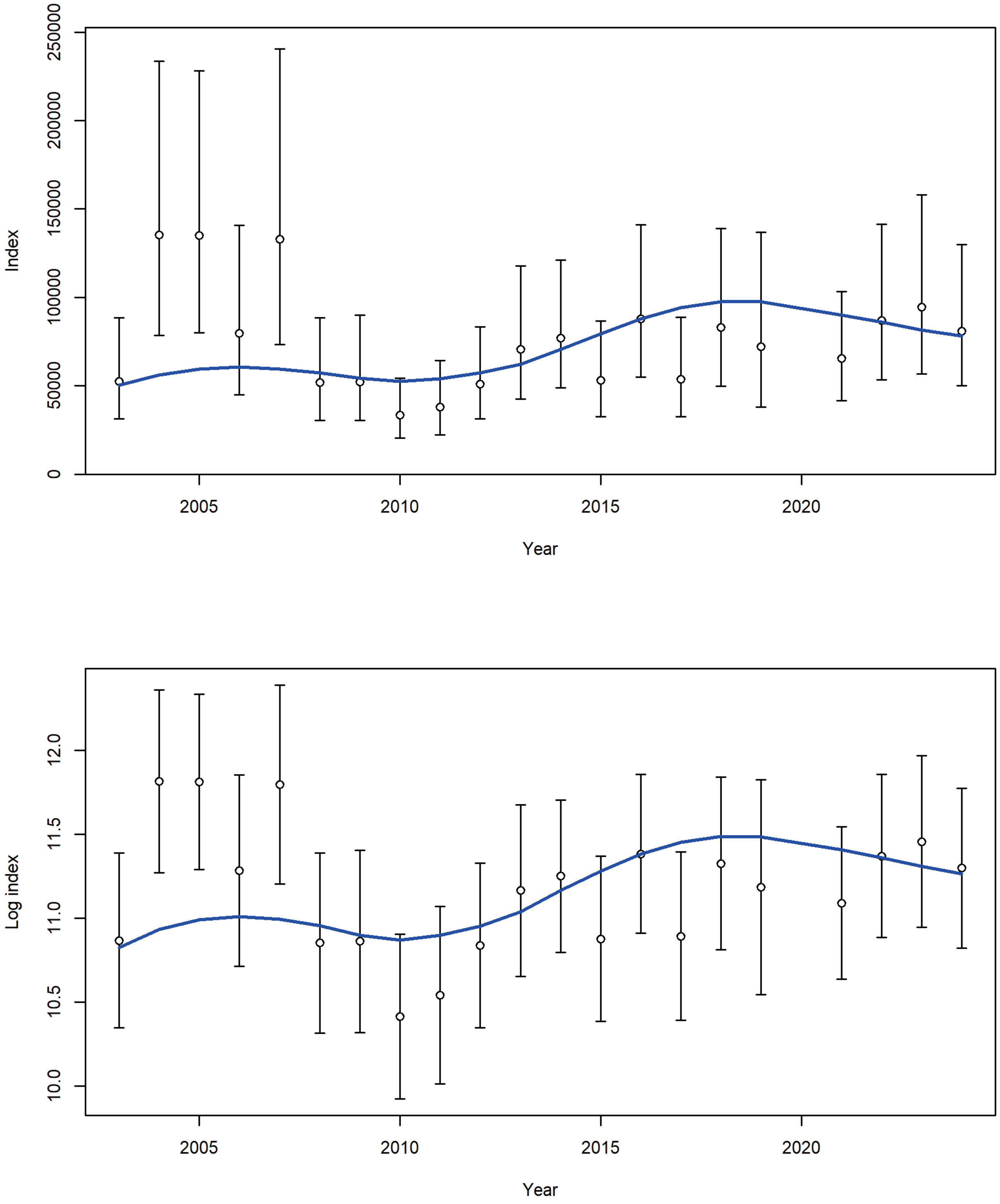


Figure 68: WCGBT survey index of relative abundance. Top panel: Arithmetic scale data with 95% C.I.s based on input SEs. Bottom panel: fit to log-scale index. Blue lines are the predicted values from the base model.

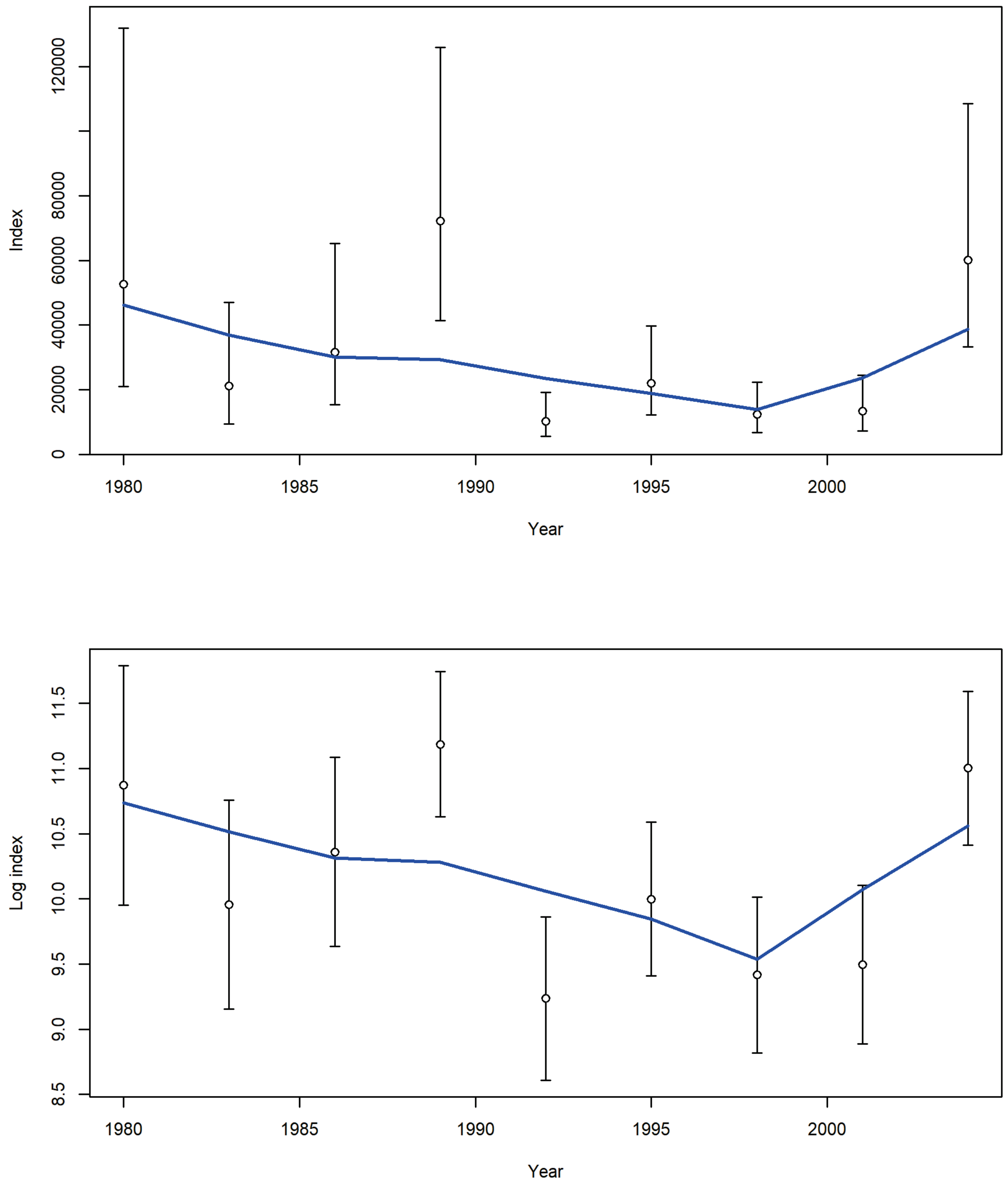


Figure 69: Triennial trawl survey index of relative abundance. Top panel: Arithmetic scale data with 95% C.I.s based on input SEs. Bottom panel: fit to log-scale index. Blue lines are the predicted values from the base model.

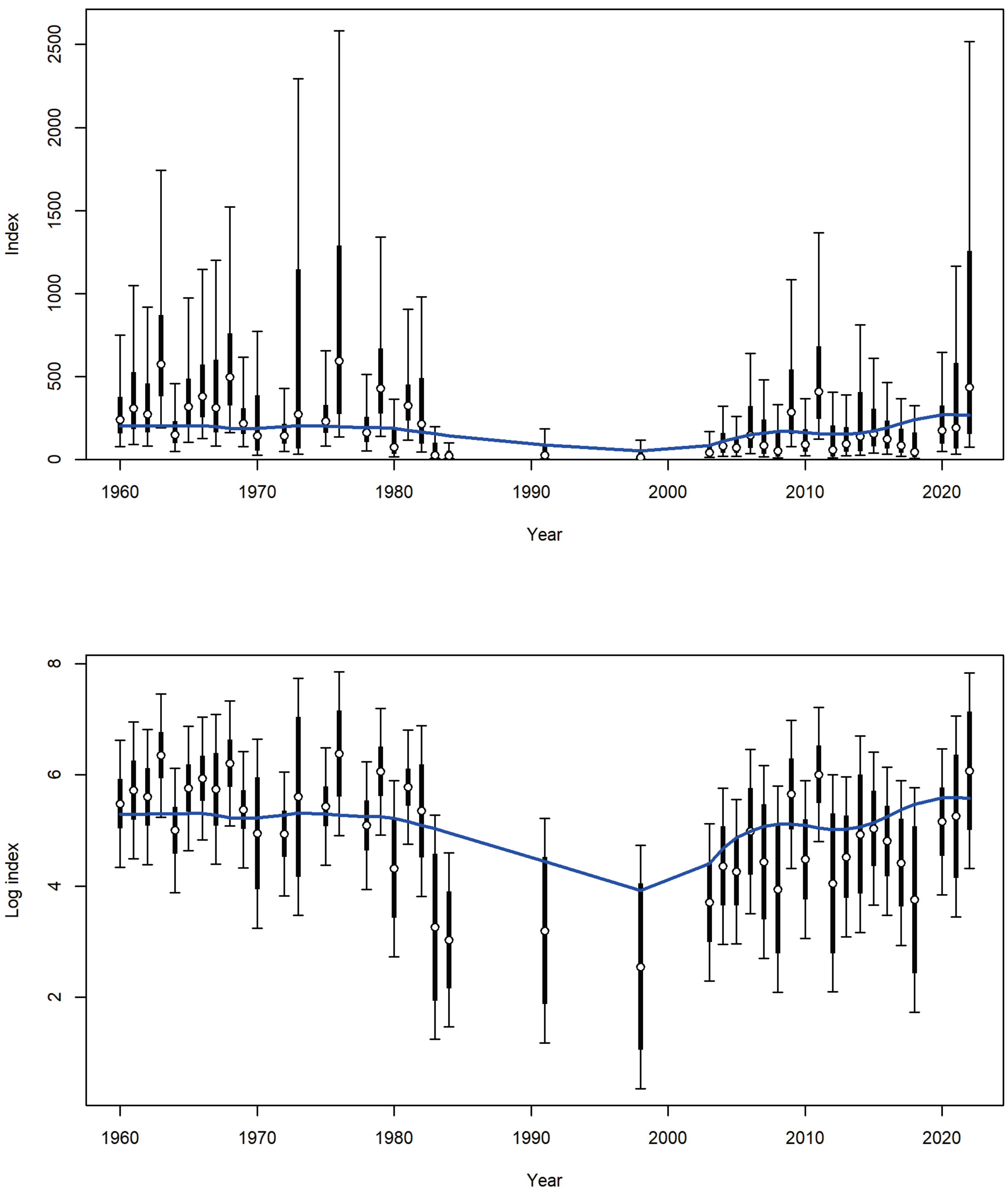


Figure 70: CalCOFI ichthyoplankton survey index of spawning output. Top panel: Arithmetic scale data with 95% C.I.s based on input SEs (thick vertical lines) and with estimated ‘extra’ variance (thin vertical lines with caps). Bottom panel: fit to log-scale index. Blue lines are the predicted values from the base model.

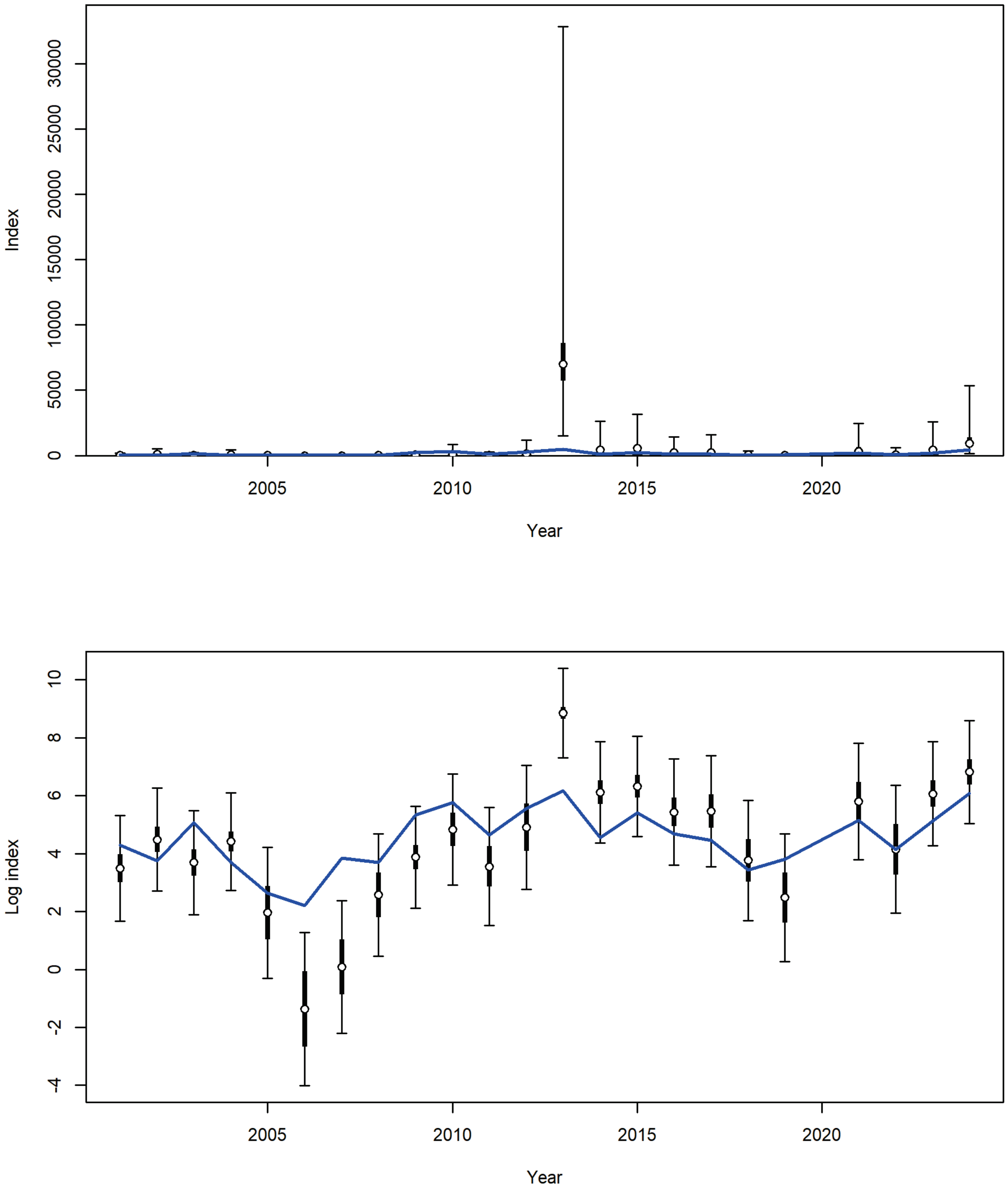


Figure 71: RREAS survey index of age-0 recruitment. Top panel: Arithmetic scale data with 95% C.I.s based on input SEs (thick vertical lines) and with ‘extra’ variance fixed at 0.683 (the difference between recruitment variability (σ_R) and the average annual observation error; thin vertical lines with caps). See Appendix B, request 17). Bottom panel: fit to log-scale index. Blue lines are the predicted values from the base model.

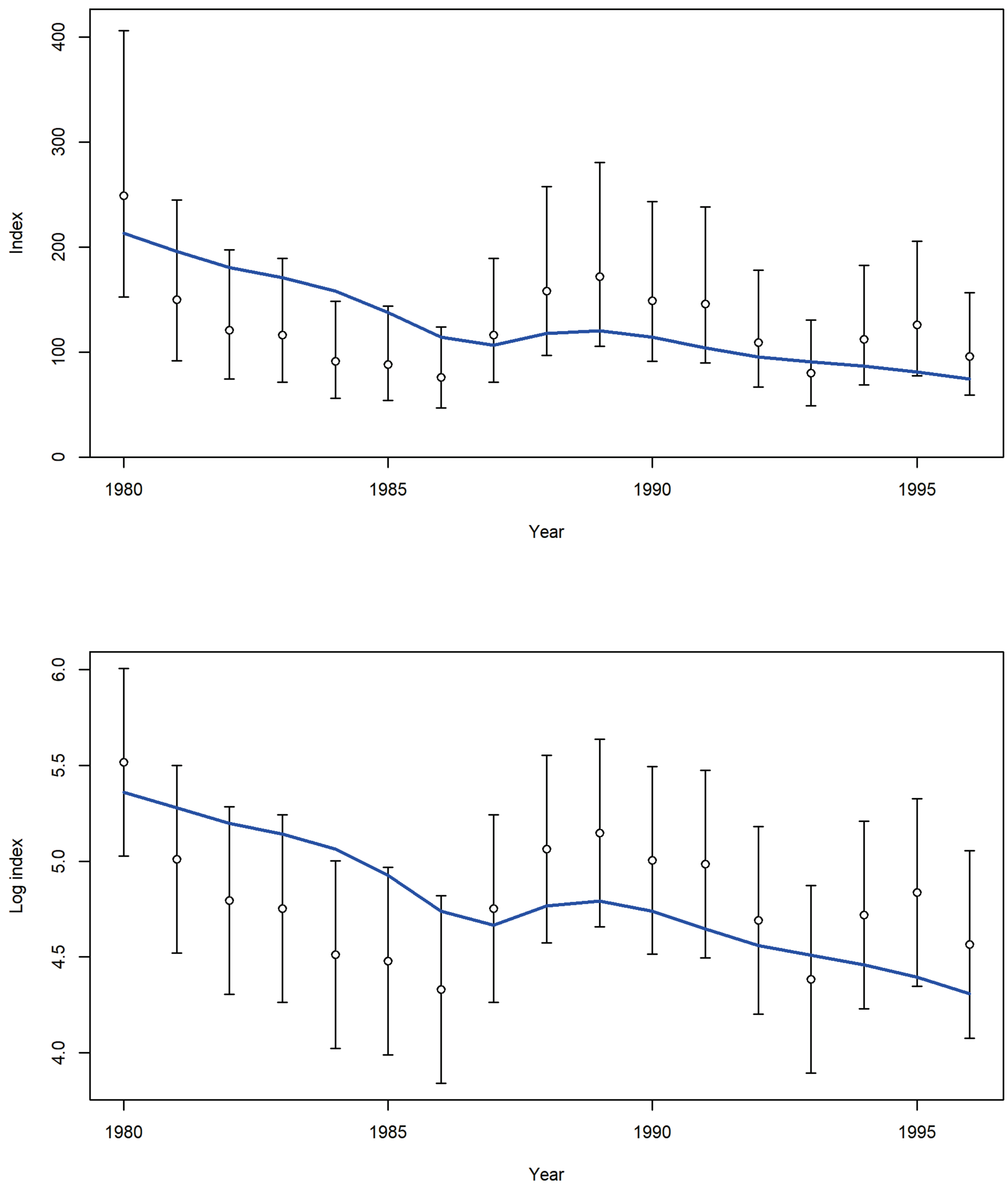


Figure 72: Trawl logbook index of relative abundance (for reference only; **not used to fit model**). Top panel: Arithmetic scale data with 95% C.I.s based on input SEs. Bottom panel: fit to log-scale index. Blue lines are the predicted values from the base model.

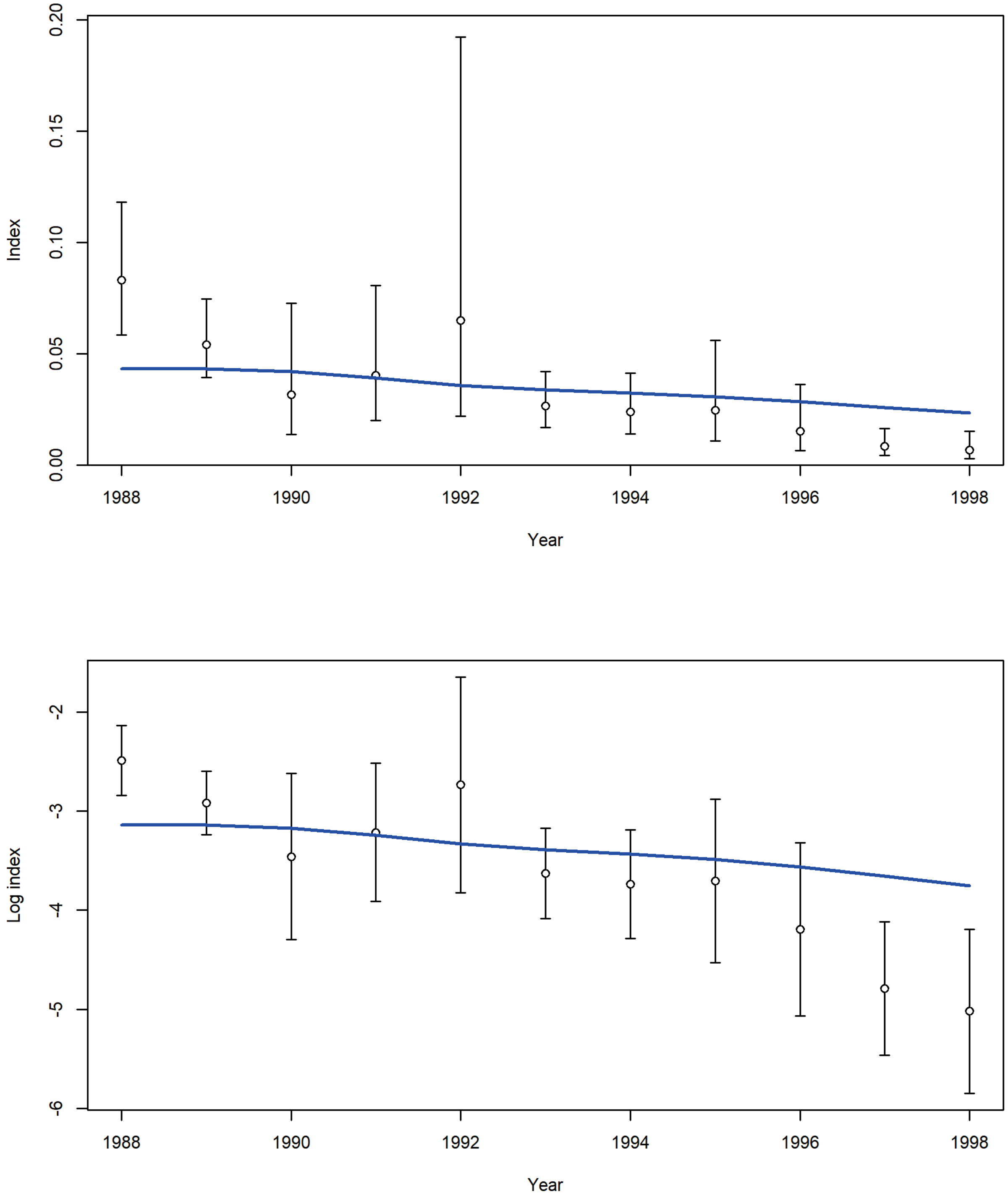


Figure 73: Recreational onboard observer index of relative abundance (for reference only; **not used to fit model**). Top panel: Arithmetic scale data with 95% C.I.s based on input SEs. Bottom panel: fit to log-scale index. Blue lines are the predicted values from the base model.

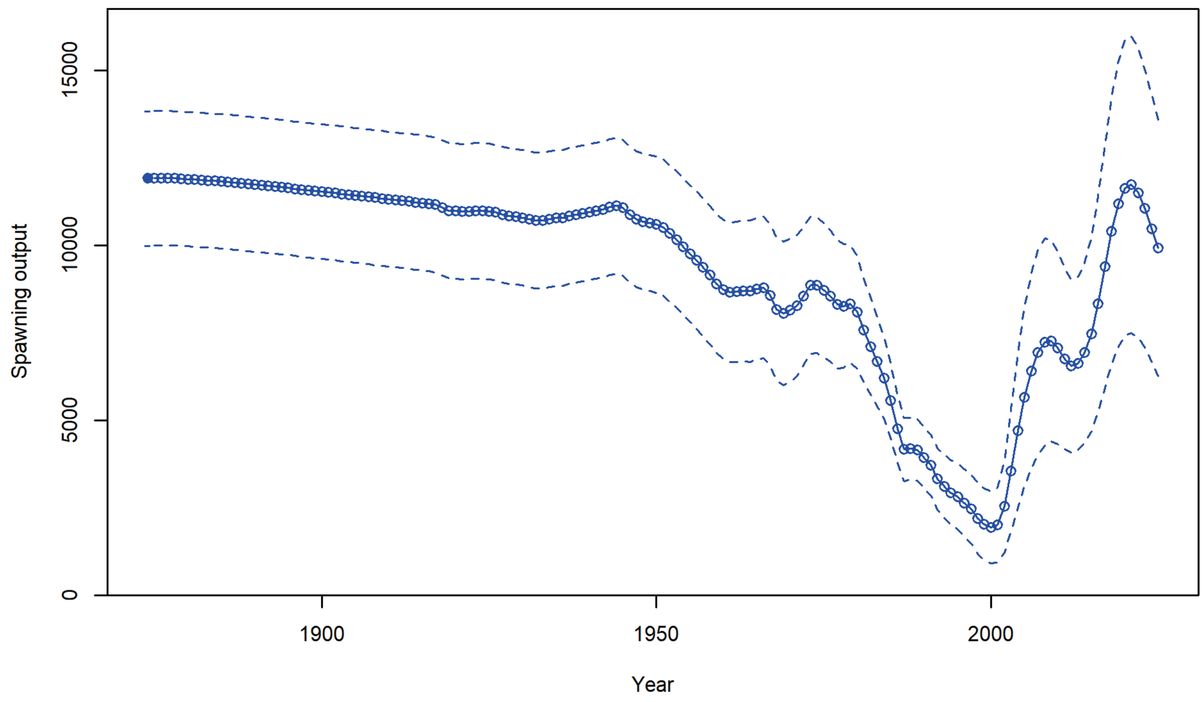


Figure 74: Estimated time series of spawning output in billions of eggs from the base model with 95% asymptotic confidence intervals.

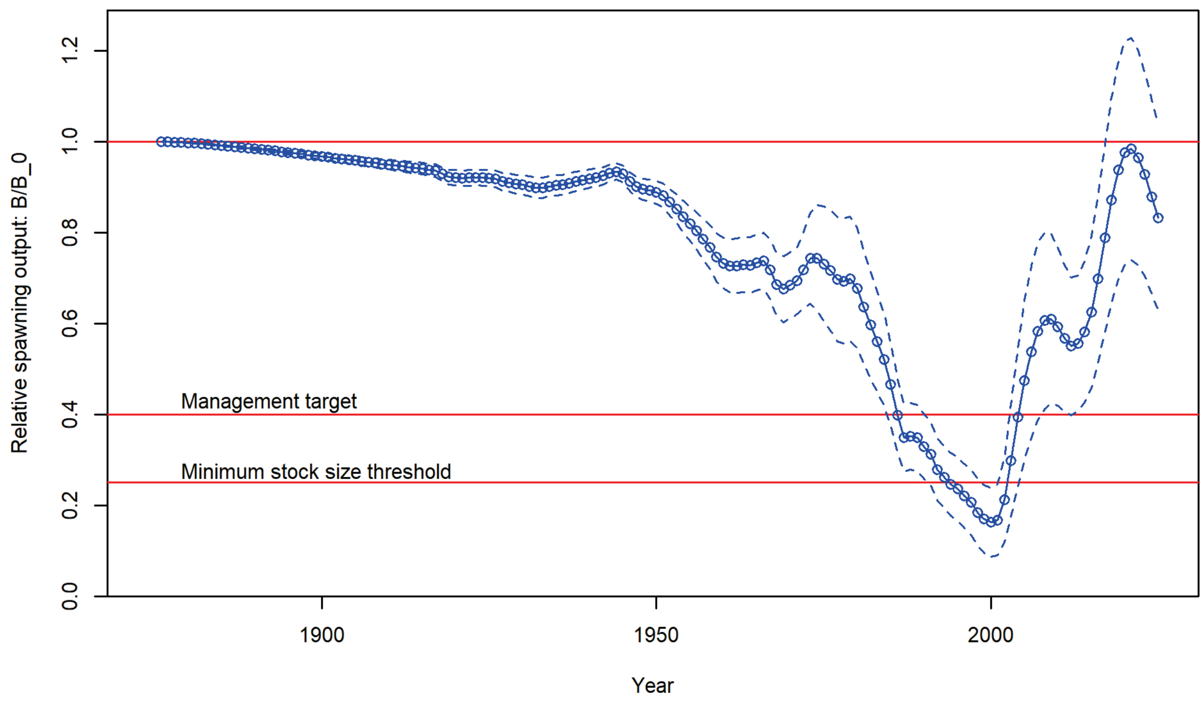


Figure 75: Estimated time series of relative spawning output from the base model with 95% asymptotic confidence intervals. Horizontal lines indicate PFMC target and minimum biomass levels for rockfish.

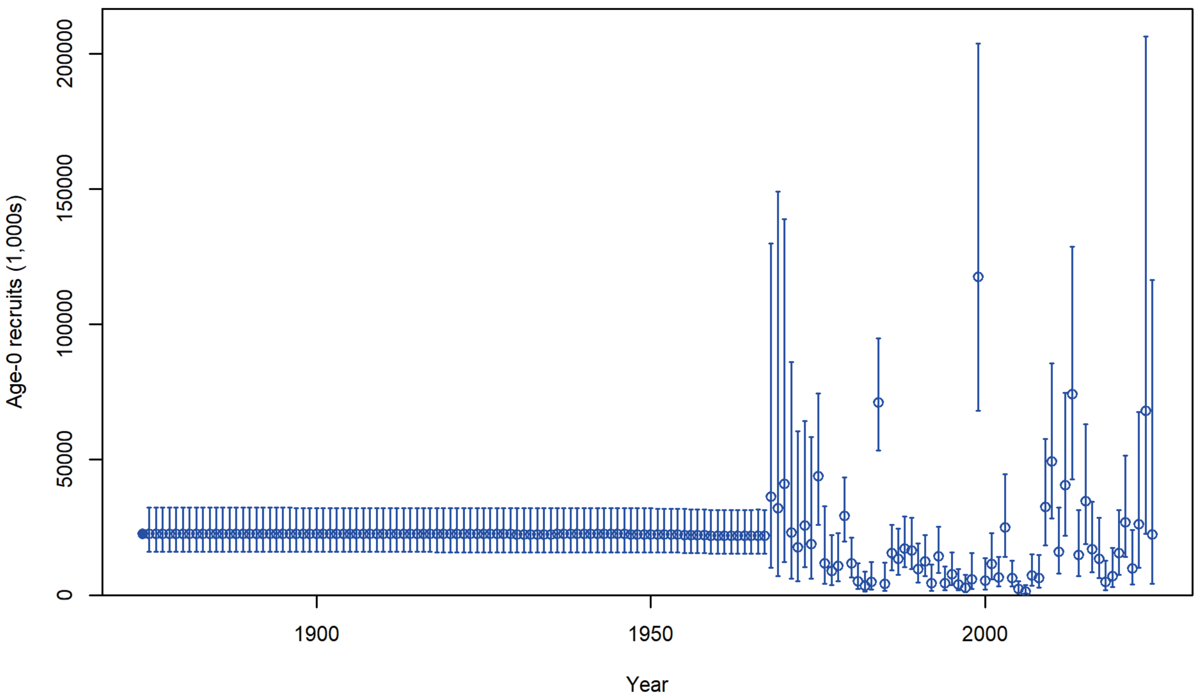
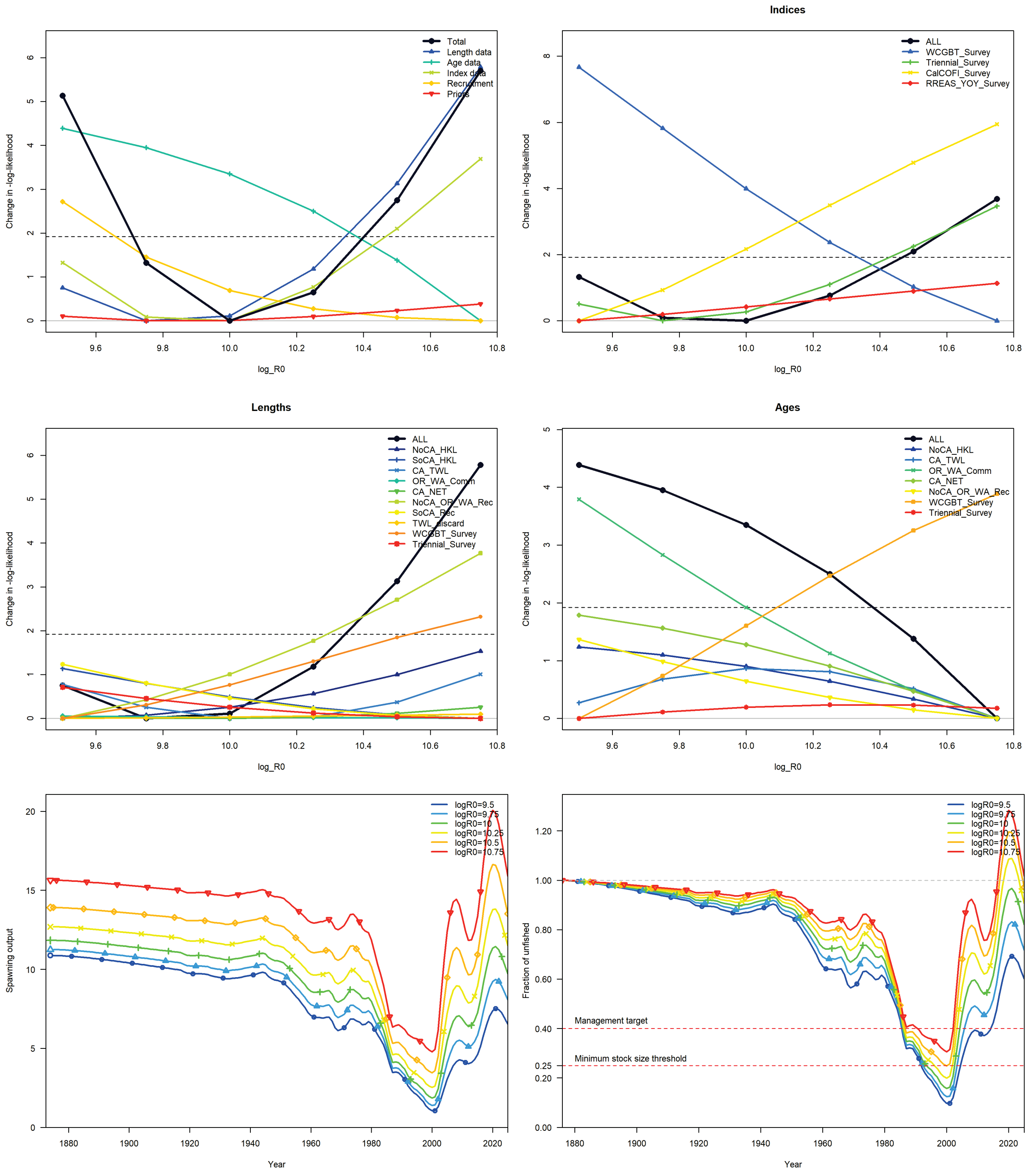


Figure 76: Estimated time series of age-0 recruits (1000s of fish) from the base model with 95% asymptotic confidence intervals.


Indices

Lengths

Ages

Figure 77: Likelihood profiles over R_0 using the base model.

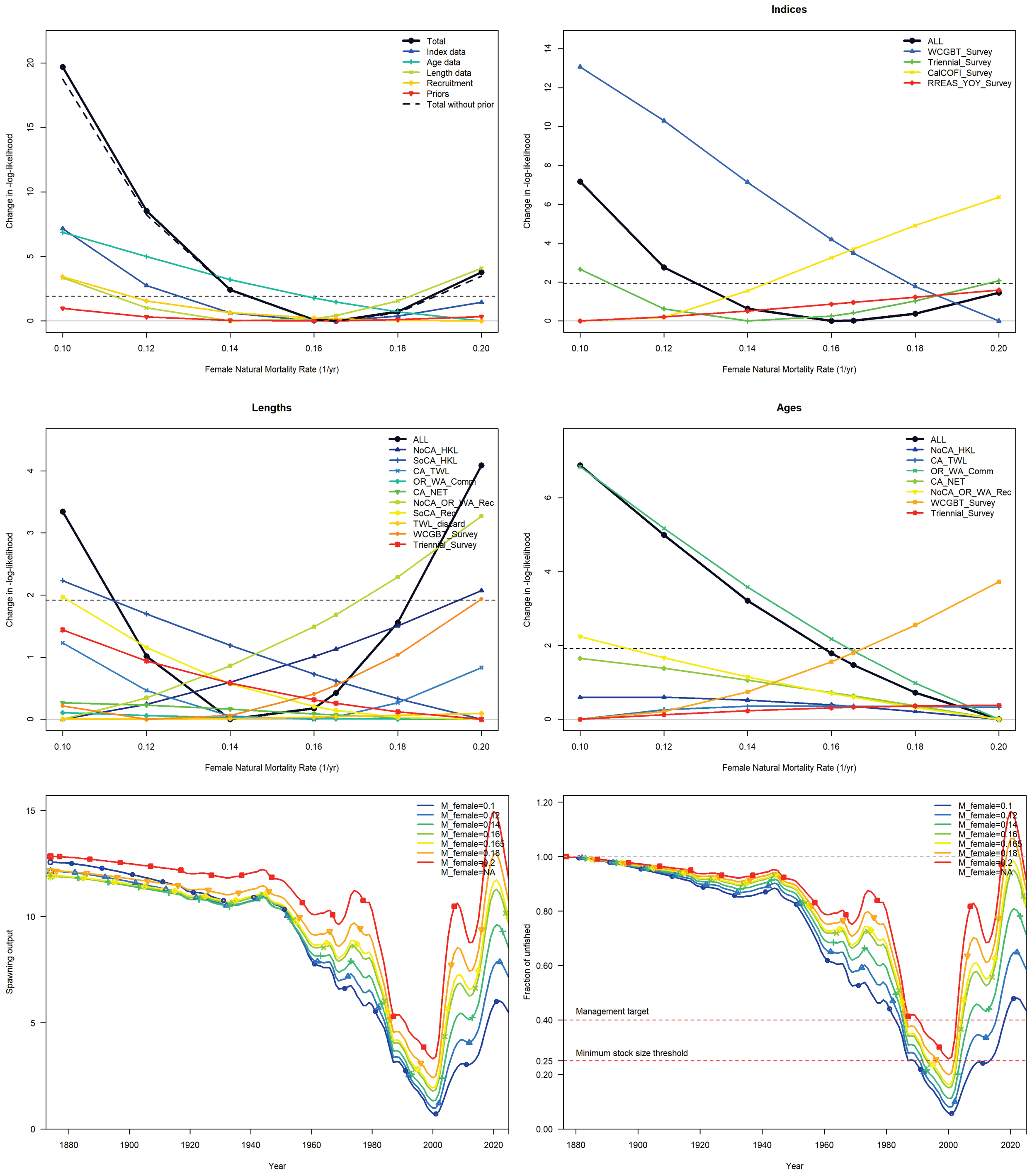


Figure 78: Likelihood profile using the base model over the female natural mortality rate, *M*, allowing male M to be estimated freely in each iteration.

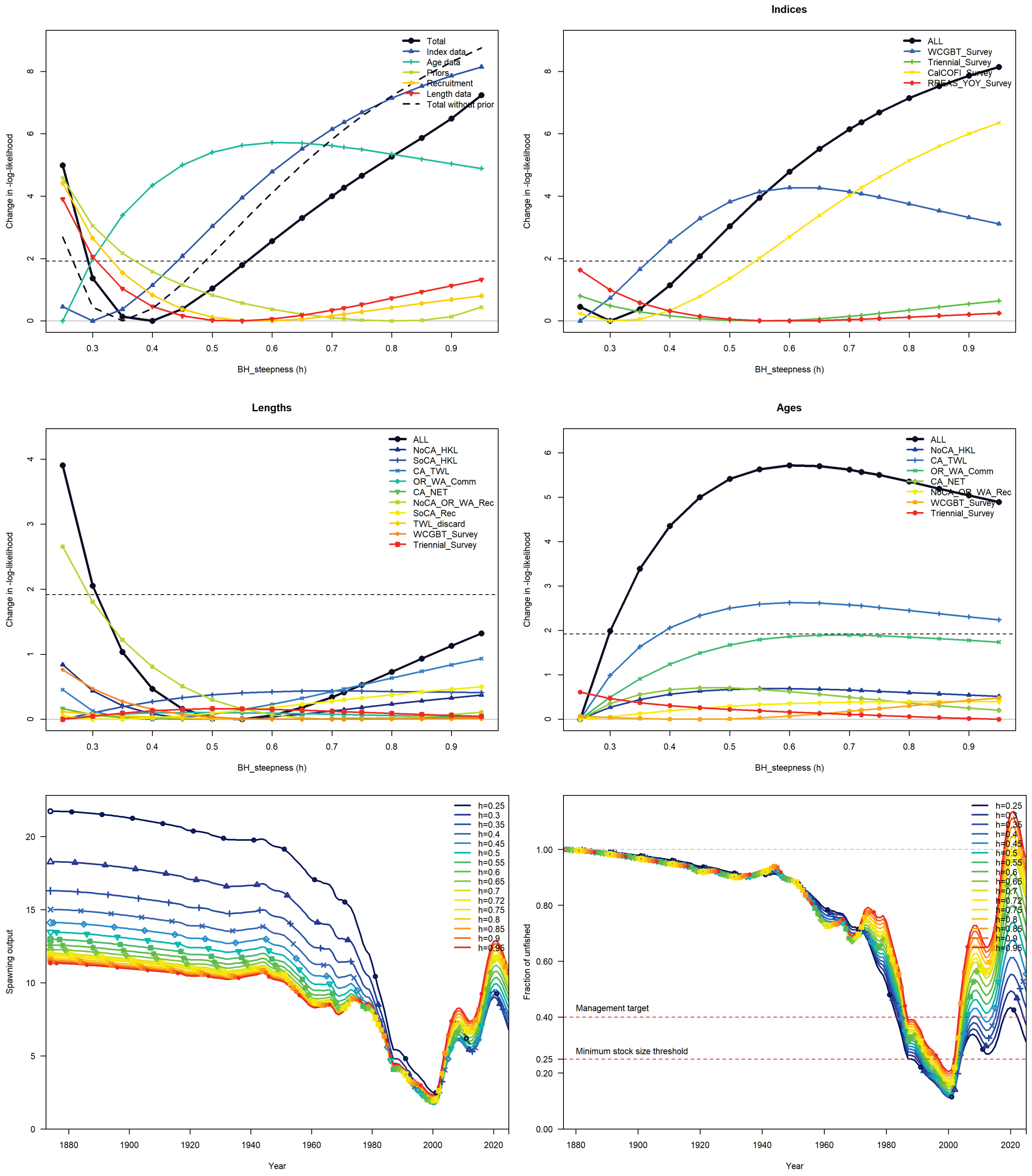


Figure 79: Likelihood profile over Beverton-Holt steepness (h) using the base model.

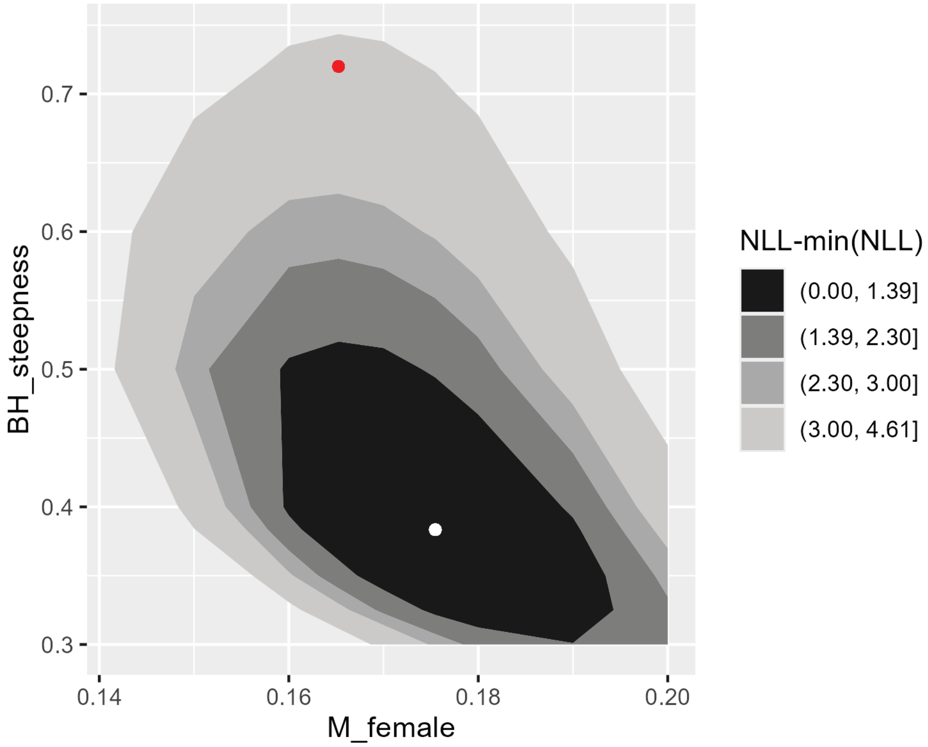


Figure 80: Bivariate likelihood profile over Beverton-Holt steepness and female natural mortality in the final base model that enforces a sum-to-zero constraint on the recruitment deviations. See Appendix B, request 17, for a comparison to the pre-STAR base model that did not have the sum-to-zero constraint. The white point is the minimum of the negative log-likelihood (NLL; with steepness, female M, and male M all estimated). The red point is the base model (estimating female and male M, but fixing steepness at the prior mean (0.72). The contours represent bivariate confidence regions of 75% (black), 90%, 95%, and 99% (light grey). The base model (red point) is within the bivariate 99% confidence region, but outside the 95% region.

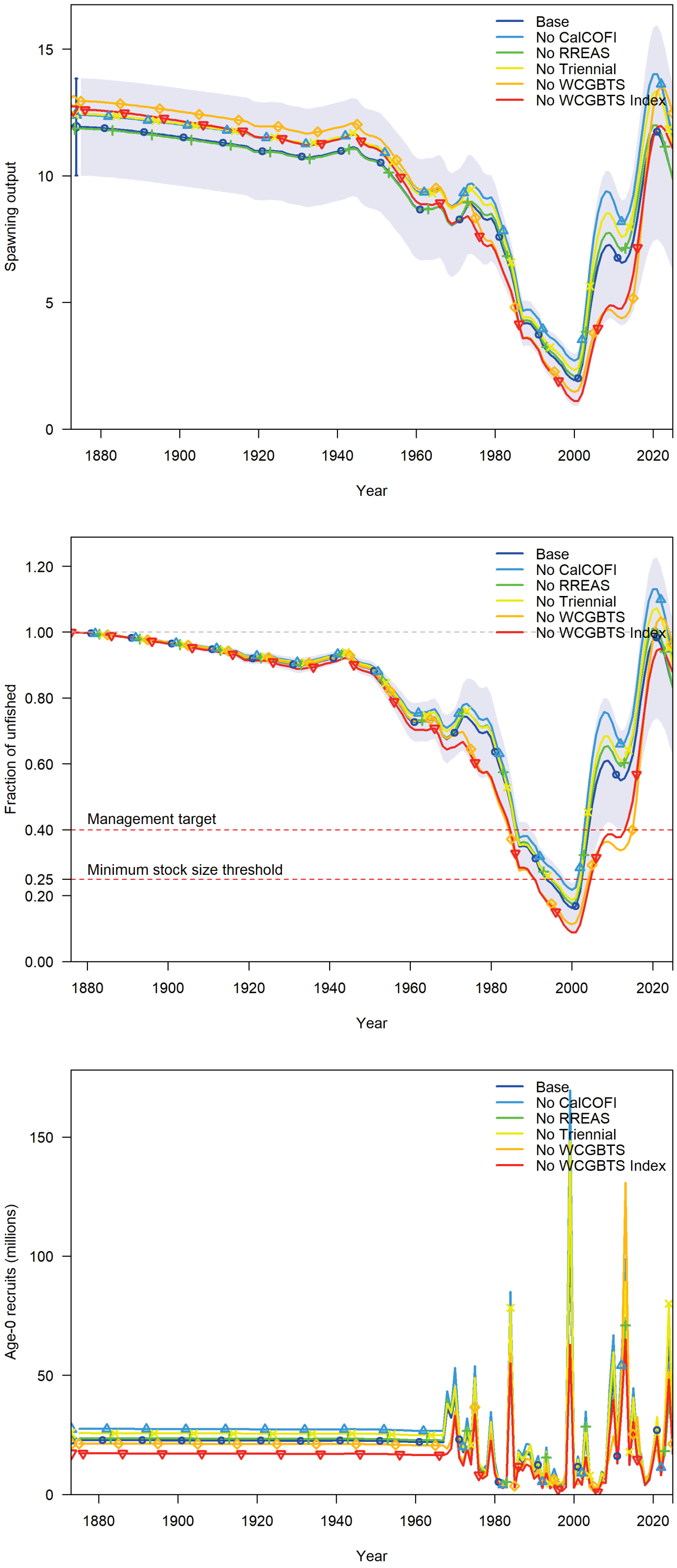


Figure 81: Sensitivity to removal of select data groups. These figures show time series of estimated spawning output (trillions of eggs), depletion and recruitment from a “drop-one” analysis for data sources used in base model (for WCGBTS, includes dropping all compositional and index data, as well as dropping the index only).

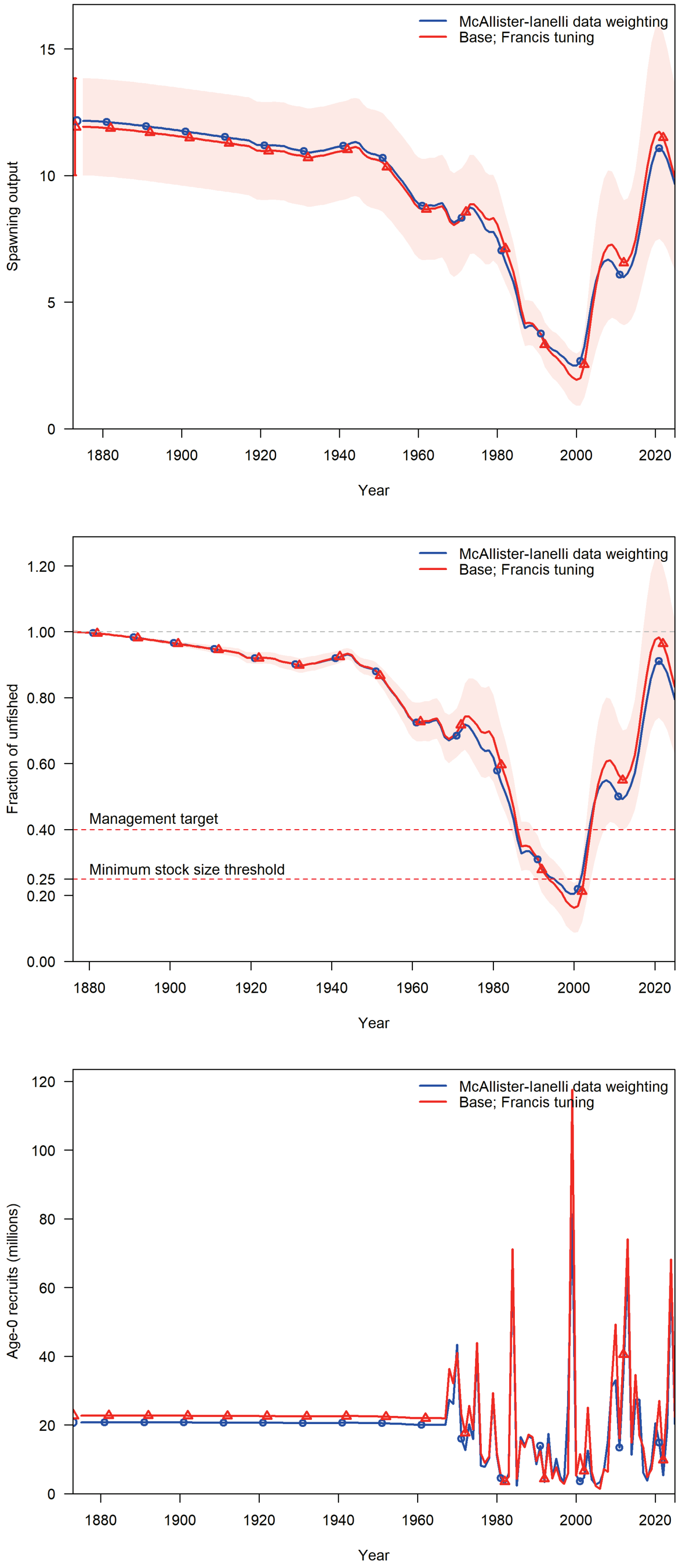


Figure 82: Base model sensitivity to alternative data-weighting methods (Francis vs. McAllister-Ianelli). Time series of spawning output (trillions of eggs, top panel), fraction unfished (middle panel), and recruitment (bottom panel).

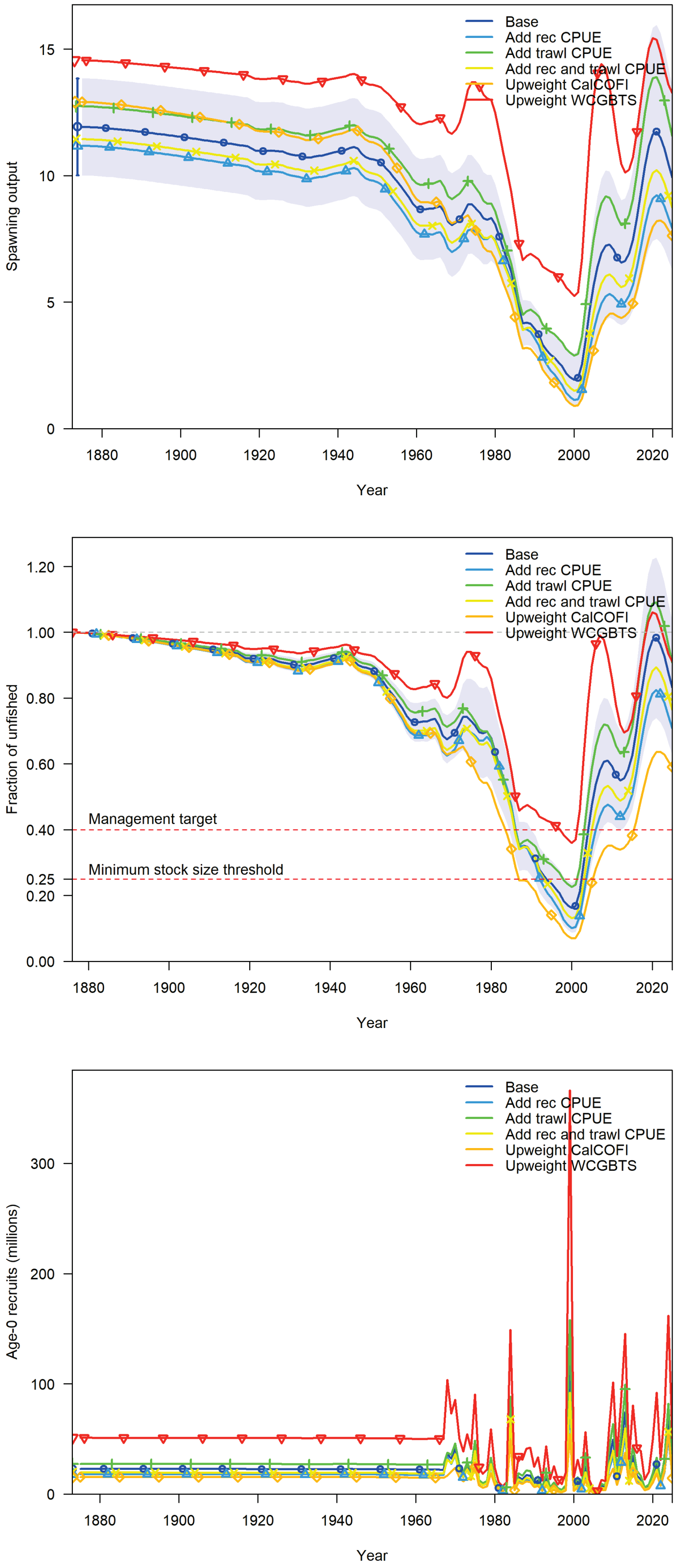


Figure 83: Sensitivity to data set choices and emphasis ("lambda") settings. These figures show spawning output (trillions of eggs), fraction of unfished spawning output, and recruitment estimates when including indices that are currently not included in the base model, as well as when two of the key indices in the base model are substantially upweighted (lambdas set from 1 to 10).

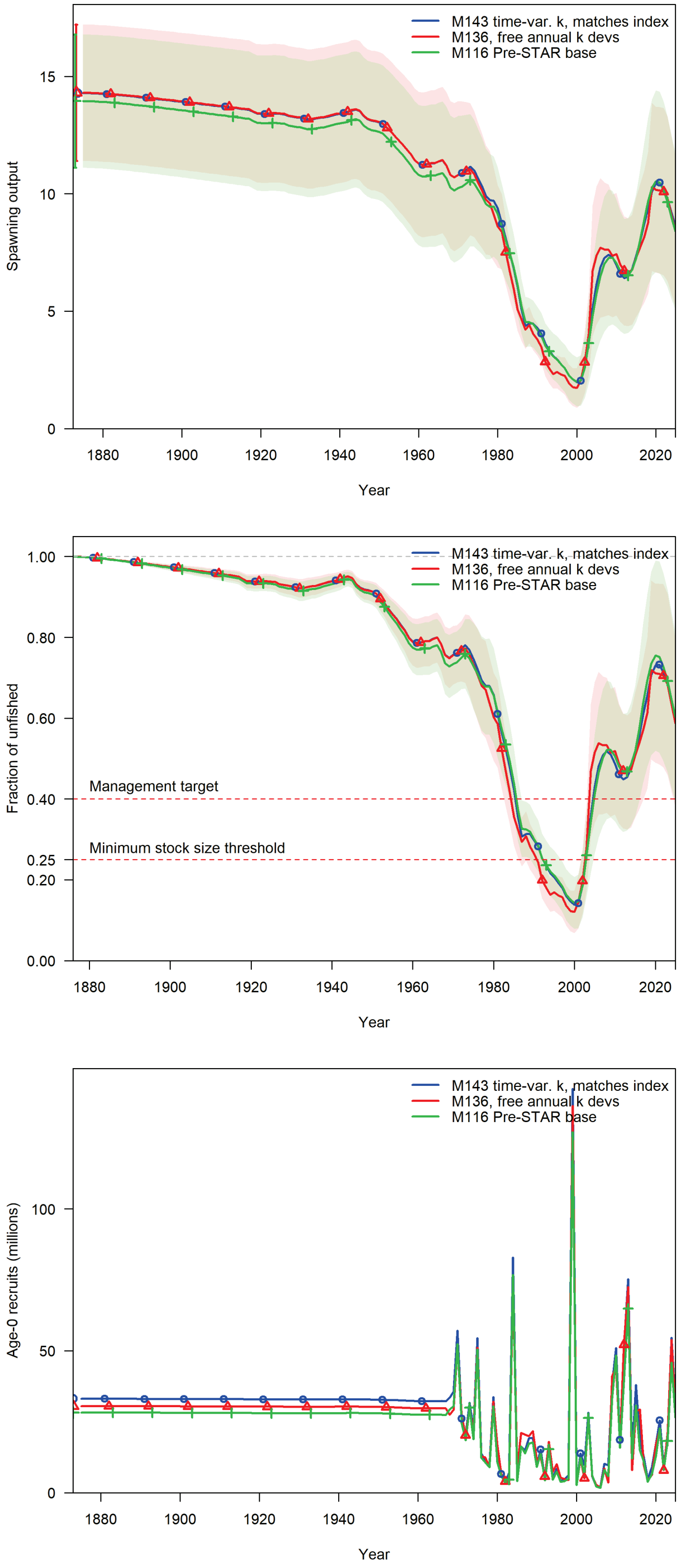
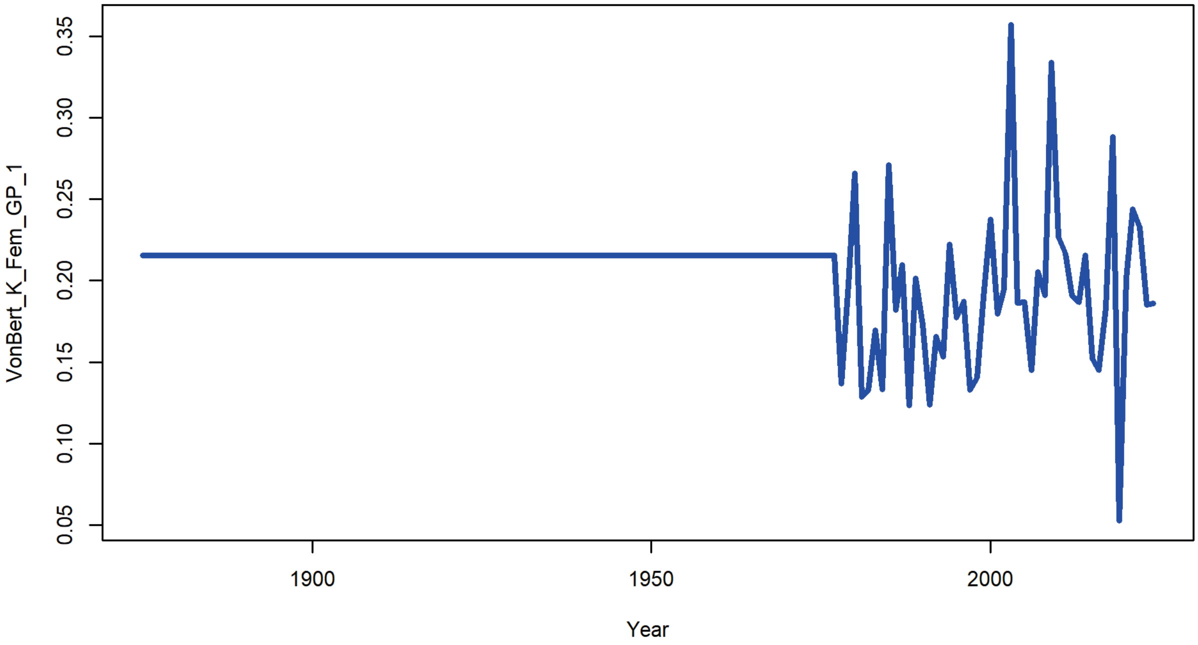


Figure 84: Time series of spawning output (top; trillions of eggs), fraction unfished (middle), and recruitment (bottom) from the pre-STAR base model with alternative parameterizations for the von Bertalanffy growth coefficient (female '*k*'). The female k parameter was estimated in all runs, with fixed multiplicative offsets (1978-2024) from Appendix A (blue line), freely estimated deviations over the same period (red), or held constant (green). Male k was estimated as an offset in all runs.



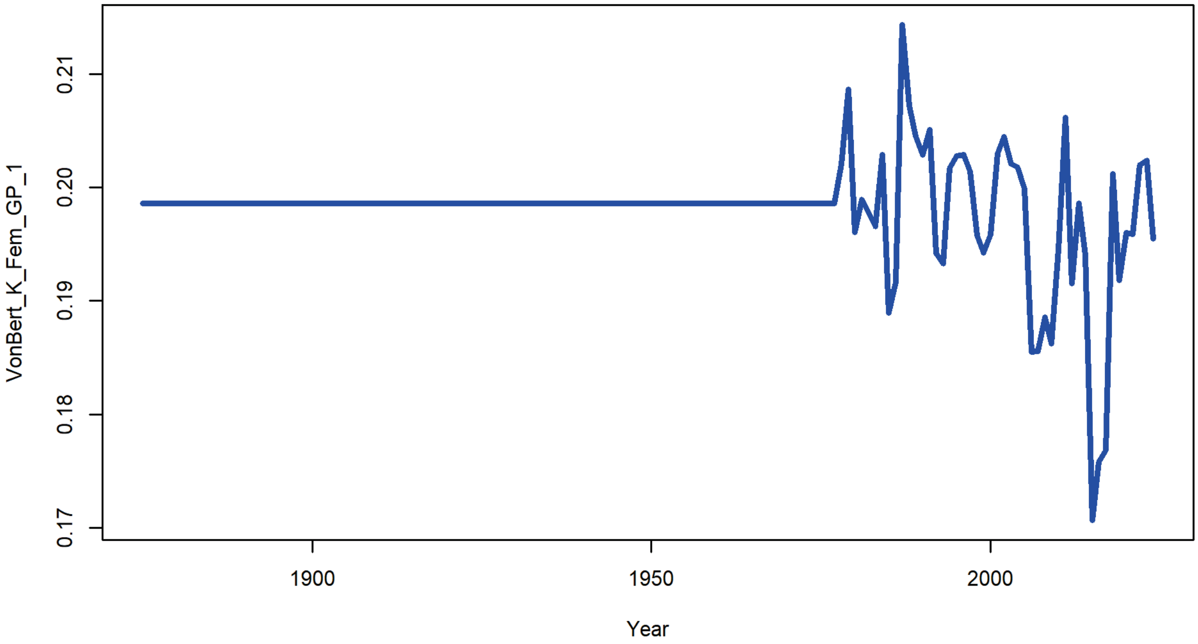


Figure 85: Estimates of annual variation in female ‘*k*’ parameter from the von Bertalanffy growth model. Upper panel: annual deviations from a base parameter value were estimated in the pre-STAR base model, given a S.E. of 0.5 (allowing considerable inter-annual variation; note scale of vertical axis), with had autocorrelation (rho) set to zero. Lower panel: estimated base parameter in the pre-STAR base, forced by externally estimated multiplicative deviations (see Appendix A). Note the reduced magnitude and lower frequency of deviations in the lower panel, relative to the freely estimated deviations in the upper panel.

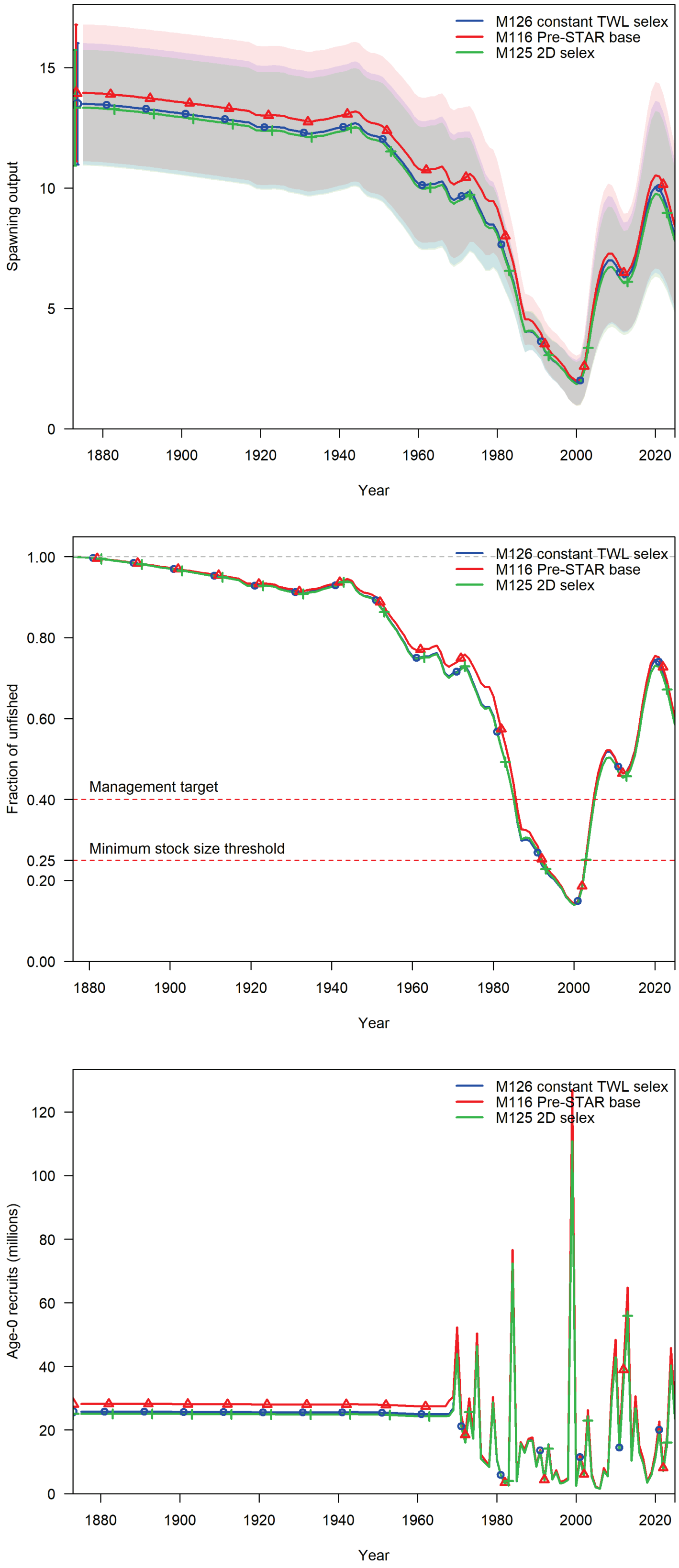


Figure 86: Time series of spawning output (top; trillions of eggs), fraction unfished (middle), and recruitment (bottom) from a sensitivity analysis of alternative selectivity parameterizations for the California trawl fleet in the pre-STAR base model.

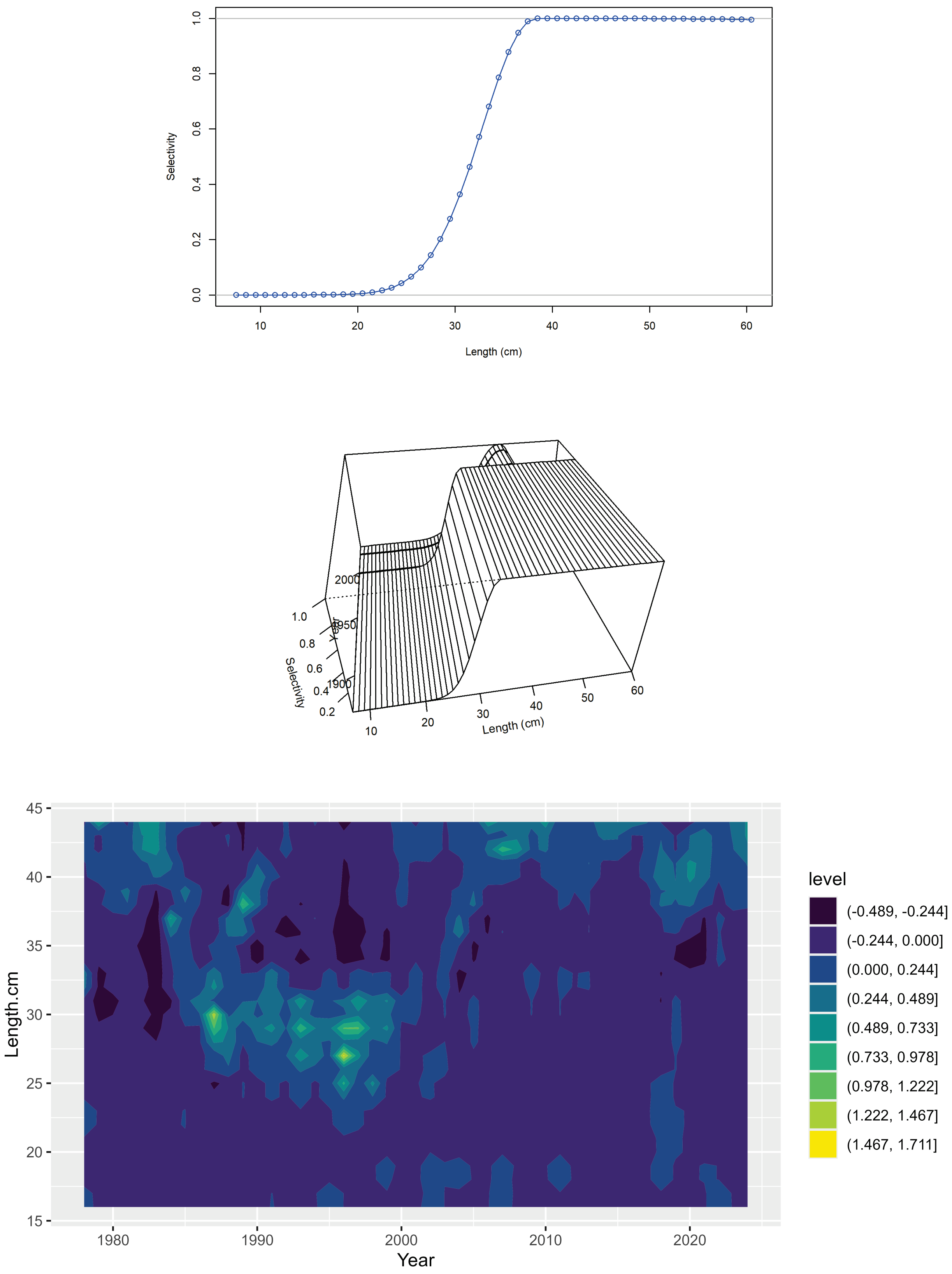


Figure 87: Illustrations of selectivity parameterizations with increasing complexity (top to bottom) for the California trawl fleet: constant (top), time-blocked in year 2000 (middle), deviations by length bin and year from a constant baseline logistic selectivity (bottom).

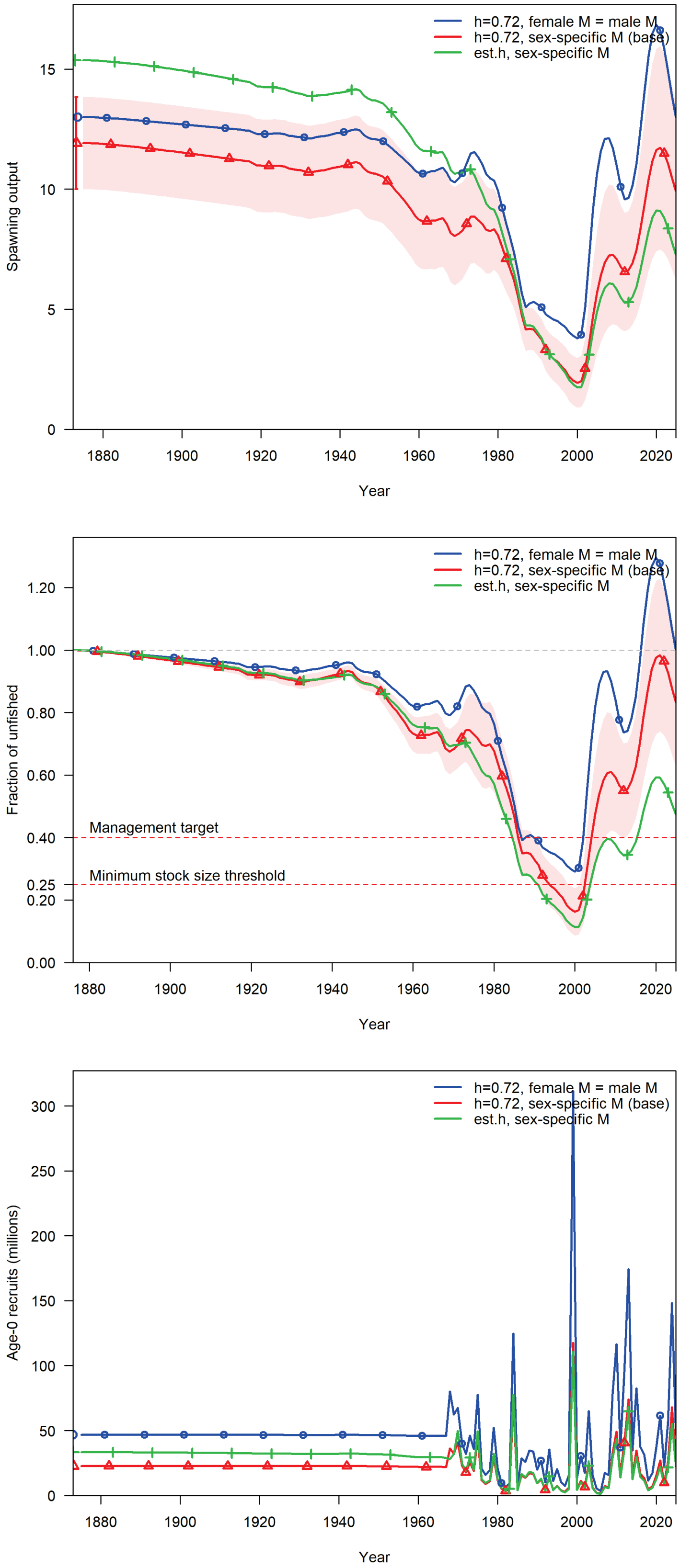


Figure 88: Time series of spawning output (top; trillions of eggs), fraction unfished (middle), and recruitment (bottom) from a sensitivity analysis of alternative steepness assumptions (fixed and estimated) and natural mortality values (estimated as sex-specific and sex-independent).

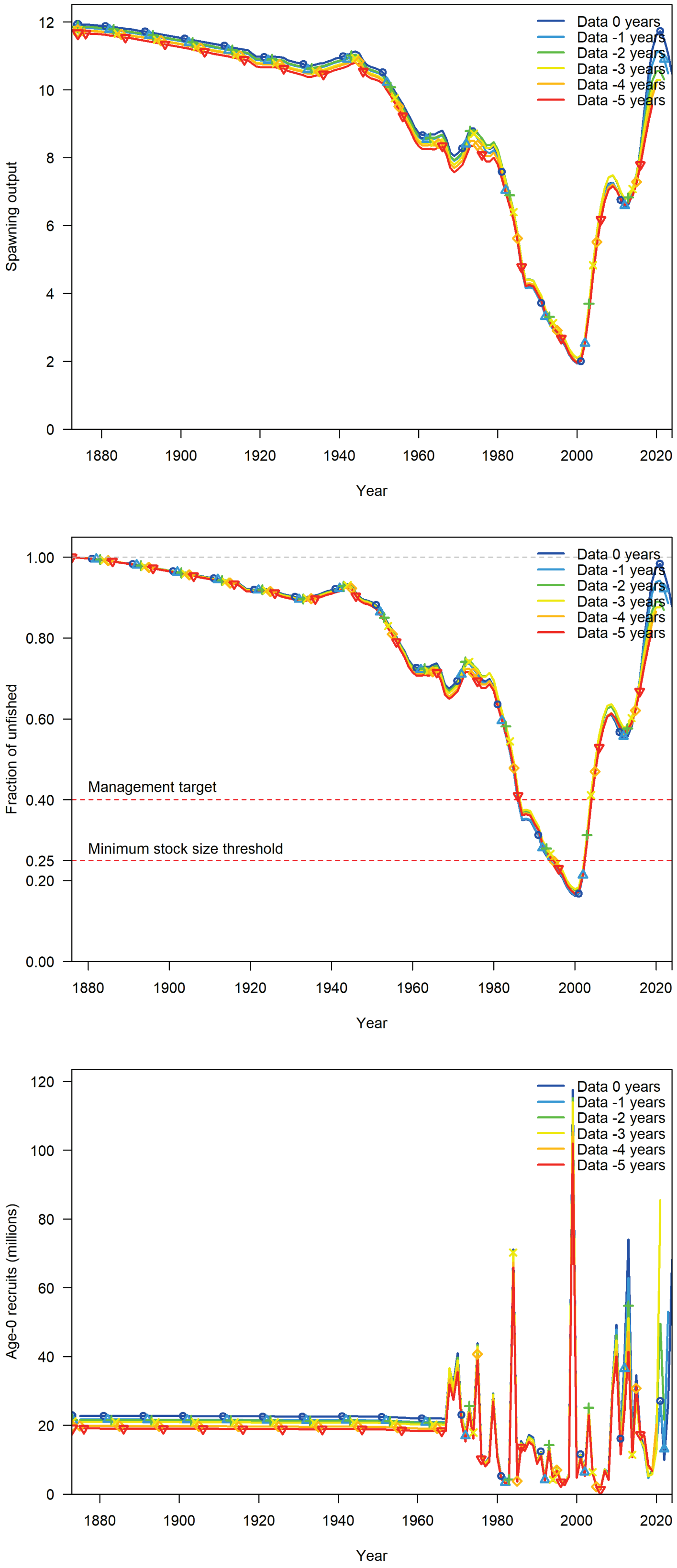


Figure 89: Time series of spawning output (top), fraction unfished (middle), and recruitment (bottom) from a retrospective analysis (sequential removal of 1-5 years of recent data).

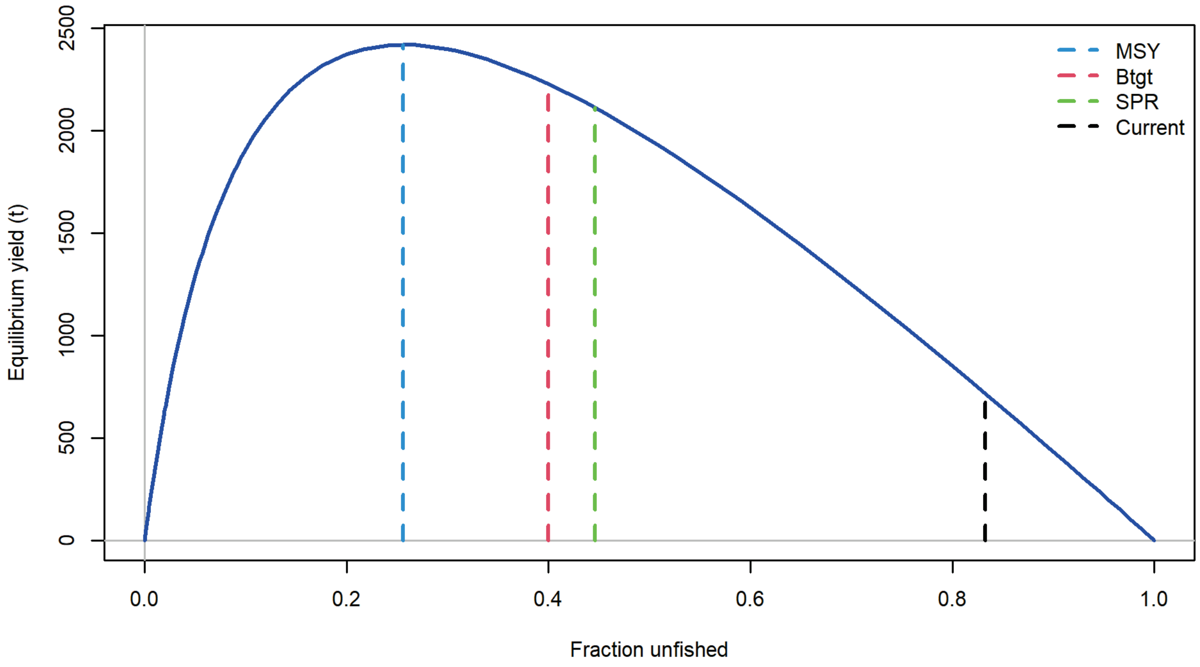


Figure 90: Equilibrium yield curve (mt) as a function of the fraction of unfished spawning output. Blue red, green, and black vertical lines represent equilibrium yield and relative biomass estimates associated with the model-based MSY, target spawning output (Btgt), SPR-based proxy harvest rate (SPR), and the model end-year harvest rate (“Current”), respectively.

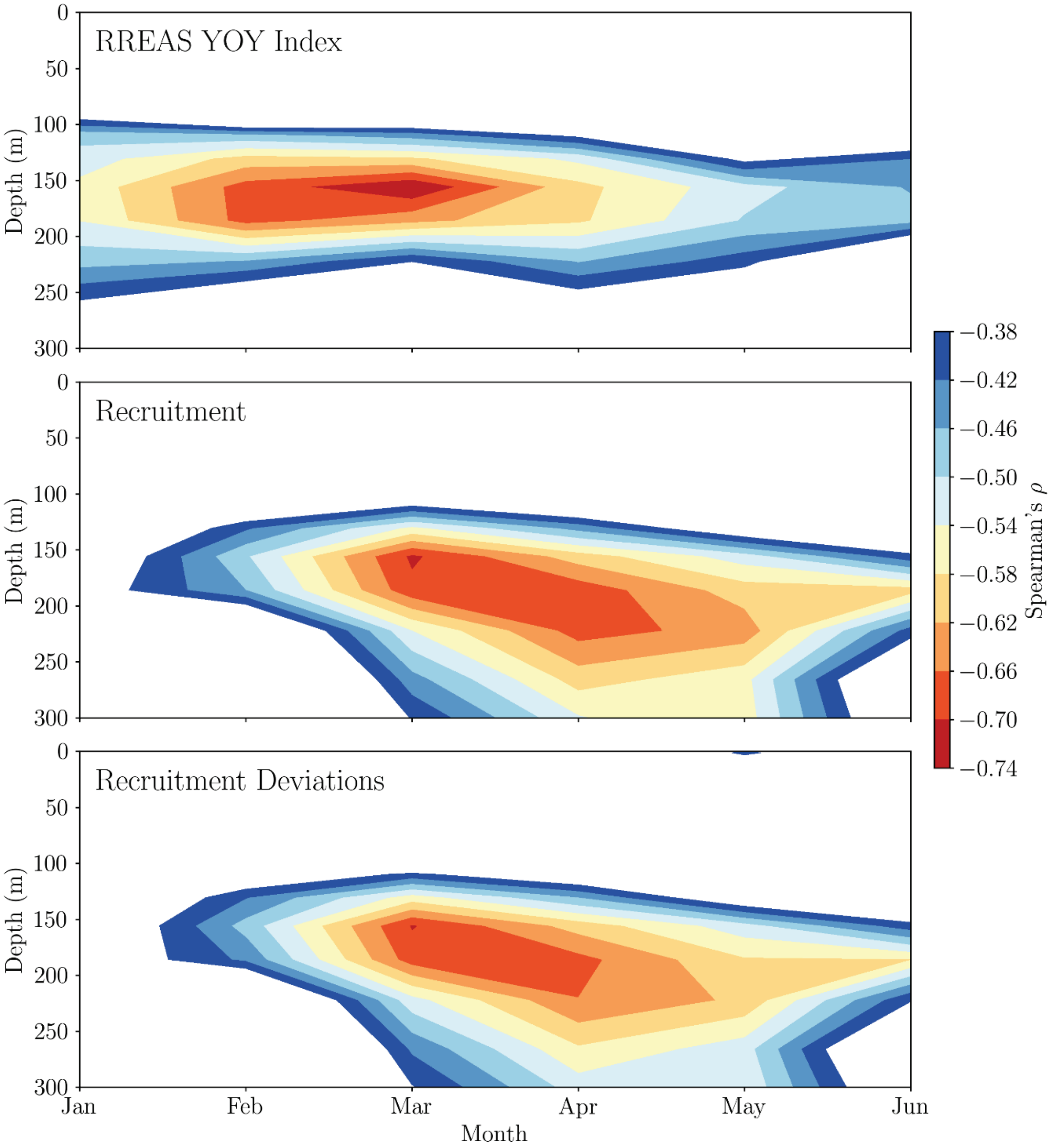


Figure 91: Depth and month when chilipepper has the highest significant correlation with subsurface ocean conditions (1993-2024). Three indicators of chilipepper recruitment variability were used; (top) RREAS YOY index based on midwater trawl survey data; (middle) recruitment estimates from this assessment; and (bottom) recruitment deviations estimates from this assessment. These indices were correlated against subsurface ocean conditions at depths (surface to 500 m) and for individual months (January to June). The subsurface ocean conditions were characterized by a "spiciness" index derived from a consistent monthly, spatial and depth resolved dataset of ocean temperature and salinity, the Global Ocean Physics Reanalysis (GLORYS12V1). Monthly values were spatially averaged over 35-37 N over an area 250 to 500 km offshore. Only significant correlations (p <0.05) are shown in the contour.

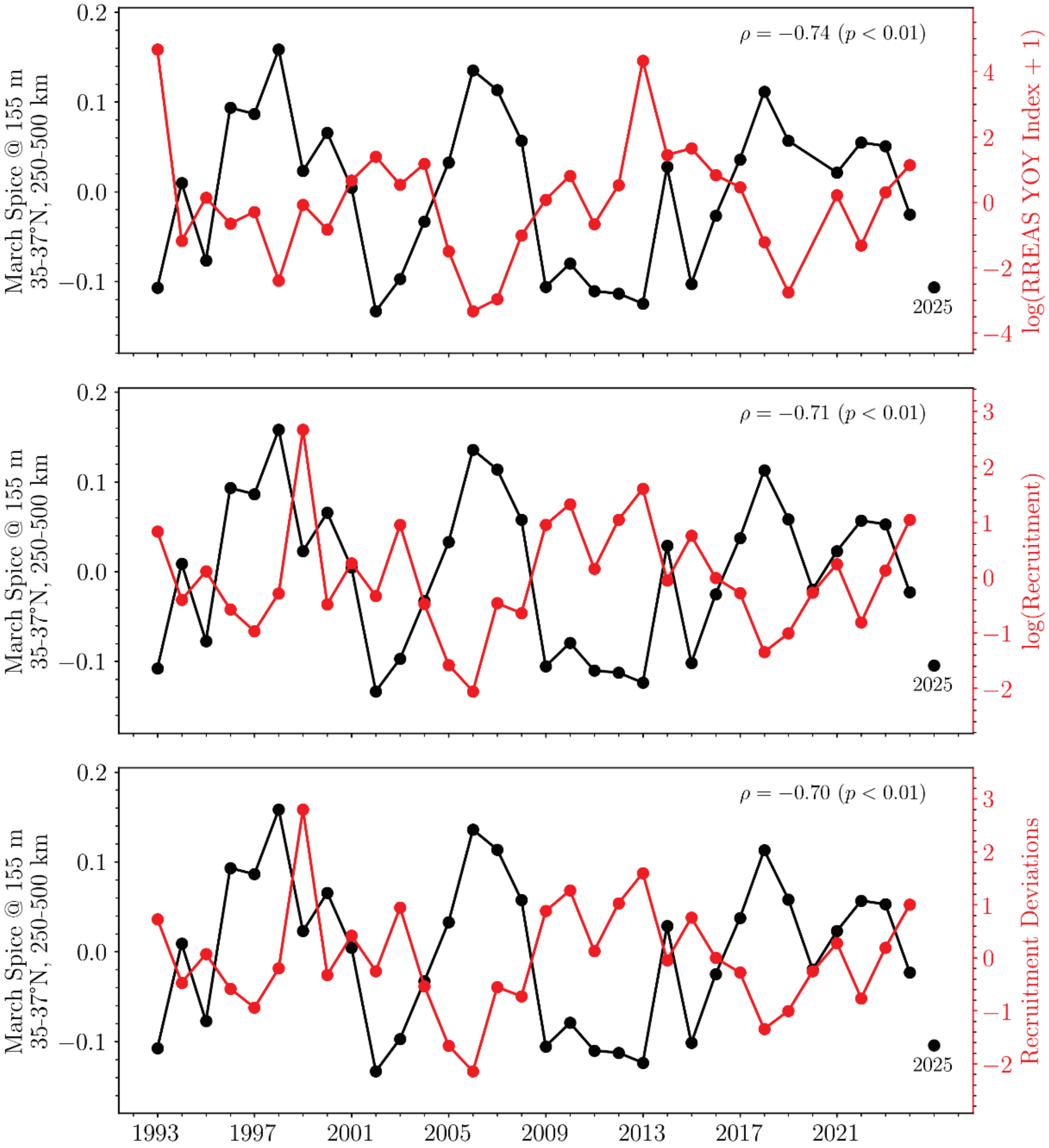


Figure 92: Time series of the recruitment indicators (YOY index, log of recruitment and recruitment deviation estimates from the base assessment model) and the spiciness estimates (spatially resolved spice at 155 m) from the maximum correlation shown in (Figure 91). Includes spiciness estimate for 2025. Correlations are Spearman's rank correlation (*p*) values calculated from time series with long-term trends removed.

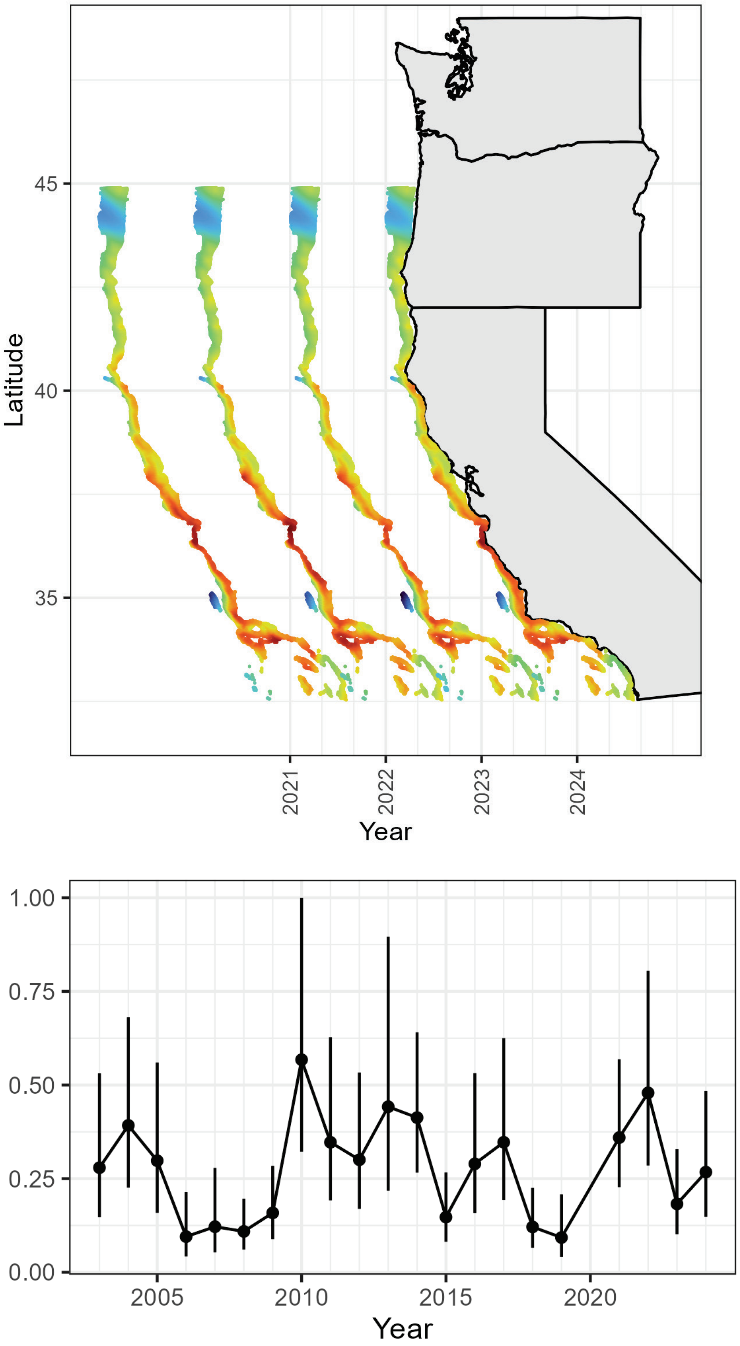


Figure 93: Top panel: Distribution and probability of encounter for settled chilipepper 16 cm and smaller (which should be all age 0 fish, and most age 1 fish) for the most recent four years of West Coast Groundfish Bottom Trawl Survey (WCGBTS) data; bottom panel, relative abundance of age 0 and 1 chilipepper based on the WCGBTS, estimated based on the methods described in Tolimieri et al. (2020).

Appendix A. A Model of Time-Varying Growth in Chilipepper Rockfish

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A Model of Time-Varying Growth in Chilipepper Rockfish

Nicholas R Grunloh

Data

This analysis is based primarily on age/length observations of chilipepper rockfish, grouping data sources into either commercial or survey data types to be analyzed independently and then combined into a single index. Commercial age/length data are included from the Calcom and PacFIN databases, and survey age/length data are included from the NWFSC Combo Survey as well as the NWFSC Southern California HKL Survey.

Commercial Calcom age/length data was filtered to trawl-only observations in northern and central California to make a total of 46,722 observations in years from 1978 to 2024. Additionally, 240 commercial Oregon age/length observations, from PacFIN, were added to the commercial dataset for the years 2019-2024. Combining these data sources, the full commercial dataset then contains 46,962 observations.

The survey data primarily consist of NWFSC Combo Survey data from the `nwfscSurvey` R package [5]. The NWFSC Combo Survey contains 13,317 age/length observations of chilipepper in north, central, and southern California from 2003 to 2024. In recent years, 2019-2024, the combo survey data were combined with age/length observations from the NWFSC Shelf Rockfish Hook and Line Survey in Southern California, as provided by John Harms at the NWFSC, to complete the survey dataset. By combining these survey data sources to full survey dataset contains 13,517 age/length observations representing years 2003-2024 from northern California through Southern California.

Each observation was categorized spatially as being part of a northern, central, or southern region. The north region consists of data with latitudes greater than 40°10', the central region is defined as latitudes between 34°27' and 40°10', and the southern region is defined as latitudes less than 34°27'. Yearly sample size totals from each data-source are reported in Table (1).

Year	Survey		Commercial	
	Combo	HKL	Calcom	PacFIN
1978	-	-	559	-
1979	-	-	330	-
1980	-	-	1094	-
1981	-	-	701	-
1982	-	-	1217	-
1983	-	-	2308	-
1984	-	-	3576	-
1985	-	-	3273	-
1986	-	-	2011	-
1987	-	-	2493	-
1988	-	-	2428	-
1989	-	-	2581	-
1990	-	-	1694	-
1991	-	-	1600	-
1992	-	-	2081	-
1993	-	-	2028	-
1994	-	-	742	-
1995	-	-	1403	-
1996	-	-	803	-
1997	-	-	1718	-
1998	-	-	2135	-
1999	-	-	2091	-
2000	-	-	998	-
2001	-	-	768	-
2002	-	-	1029	-
2003	663	-	309	-
2004	743	-	949	-
2005	833	-	349	-
2006	596	-	-	-
2007	590	-	459	-
2008	698	-	437	-
2009	616	-	787	-
2010	806	-	305	-
2011	647	-	9	-
2012	833	-	348	-
2013	683	-	408	-
2014	873	-	301	-
2015	608	-	-	-
2016	720	-	-	-
2017	540	-	-	-
2018	500	-	-	-
2019	349	40	76	40
2020	-	-	103	40
2021	500	40	60	40
2022	506	40	59	40
2023	506	40	55	40
2024	507	40	47	40

Table 1: Sample size summaries by data-source and year.

Model

Recall the Schnute parameterization [4] of the Von Bertalanffy (VB) growth function,

$$VB(A;\ \kappa, L_{a_1}, L_{a_2}) = L_{a_1} + (L_{a_2} - L_{a_1})\frac{1 - e^{-\kappa(A-a_1)}}{1 - e^{-\kappa(a_2-a_1)}}. \tag{1}$$

This parameterization is convenient for its stability in statistical inference and aligns well with the SS3 parameterization [3]. κ is the instantaneous rate of growth (in length) with age. L_{a_1} is the length at the fixed lower age a_1 and L_{a_2} is the length at the fixed upper age a_2. a_1 and a_2 are chosen to be 0 and 20 respectively so that L_0 and L_{20} are well informed by the available data. L_{20} is modeled along with κ in the following sections so as to be informed by the above mentioned commercial and survey data. L_0 is fixed to the constant 7.3 throughout this study based on the average of $n = 20$ July length measurements of age 0 chilipepper rockfish collected in central California (between Morro Bay and Santa Cruz) in a diving study that ran from 1990-1999 by David Ventresca with California Department of Fish and Wildlife. The age 0 data were provided presently by Tom Laidig at SWFSC.

Given the above VB parameterization of growth, let ℓ_{sti} be the i^{th} observation of chilipepper rockfish fork length with sex s in year t. Similarly let a_{sti} be a matched age observation on the same individual. Assuming normal residual variation of ℓ_{sti} with VB growth at age a_{sti} the following observation model arises naturally,

$$\begin{aligned} &\ell_{sti} = VB(a_{sti};\ \kappa_{st}, L_0, L_{20_{st}}) + \epsilon_{sti} \\ &\epsilon_{sti} \sim N(0, \sigma_s) \quad\ \sigma_s \sim \text{Student}_3(0, 10)\ 1_{\sigma>0}. \end{aligned} \tag{2}$$

Above L_0 is fixed at 7.3 as previously mentioned, but κ_{st} and $L_{20_{st}}$ are modeled as functions of only sex and year. Models accounting for spatial variability in VB growth are considered in Section (4). Ultimately spatial patterns reiterated the results presented here.

To capture time-varying growth the parameters κ_{st} and $L_{20_{st}}$ are further modeled hierarchically as follows,

$$\begin{aligned} \log(\kappa_{st}) &= \mathbb{1}_{0.05<\kappa<0.5}({}_{\kappa}\alpha_s + {}_{\kappa}\beta_t) & {}_{\kappa}\beta_t &\sim N(0, {}_{\kappa}\phi) & {}_{\kappa}\phi &\sim N(0,1)\ 1_{{}_{\kappa}\phi>0} \\ L_{20_{st}} &= {}_{L_{20}}\alpha_s + {}_{L_{20}}\beta_t & {}_{L_{20}}\beta_t &\sim N(0, {}_{L_{20}}\phi) & {}_{L_{20}}\phi &\sim N(0,1)\ 1_{{}_{L_{20}}\phi>0}. \end{aligned} \tag{3}$$

First since κ is a strictly positive quantity, the log is considered for numerical stability. Additionally the domain of $\log(\kappa)$ is limited using a uniform prior such that $\mathbb{1}_{0.05<\kappa<0.5}$. This expedites sampling by more quickly focusing sampling to the relevant order of magnitude of κ_{st}. The parameters ${}_{\kappa}\alpha_s$ model separate intercepts for each sex. This then allows ${}_{\kappa}\beta_t$ to model the effect of each years offset (on the log scale) from the sex intercepts. To empirically encourage partial pooling of information between years the hierarchical prior ${}_{\kappa}\beta_t \sim N(0, {}_{\kappa}\phi)$ is placed on ${}_{\kappa}\beta_t$ to shrink these parameters as much as the ϕ parameter calls for through the data. Simpler models were explored, but the level complexity in this model is called for by the data. Most of the focus in this study was on κ, but the structure of the VB curve clearly correlates estimates of κ with L_{20}. Consequently, L_{20} was given a similar level of model flexibility as κ to allow the parameters to covary. Mirroring the same basic modeling structure for $L_{20_{st}}$ as $\log(\kappa_{st})$ was found to be an effective model for $L_{20_{st}}$. Bayesian inference is given for this model by sampling the posterior distribution of the parameters using the `brms` R package [1] and the NUTS sampler.

Results

Commercial and survey data were fit with independent instances of the above model. Figure(1) shows the model fits to each data set by year and sex. Overall, fit is very reasonable. Models convergence was ultimately good but required 1000 warm-up samples, with thinning every 3 draws. Occasionally it was necessary to restart some chains due to lack of convergence.

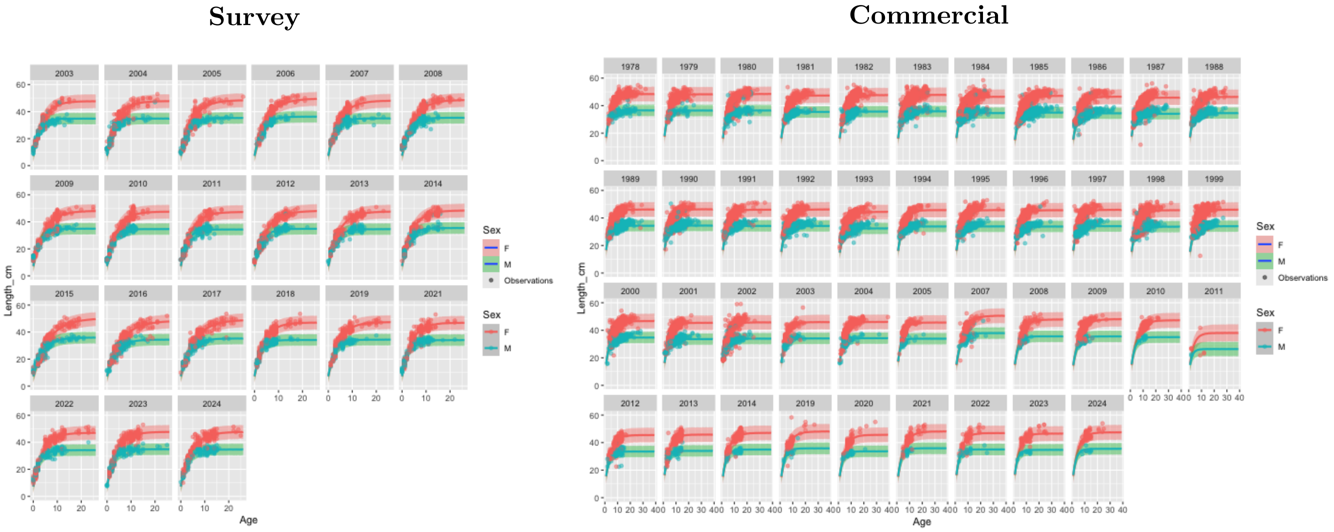

Figure 1: (*left*) Model fit to survey data, by year and sex. (*right*) Model fit to commercial data, by year and sex.

3.1 Combining Commercial/Survey Models

These models were fit independently due to practical limitations in computation time and model flexibility. Ideally these models would be fit jointly to allow the model to balance the influence of each data-source in the final index. An attempt was made at joint analysis of these data by including main effect additive offset parameters for commercial/survey data-type in each of the expressions of (2) and (3) and fitting a single model to all of these data. The resulting model was unstable and run times exceeded a week when run on a fully parallelized 46 core workstation. As a result, we concluded an additive offset modeling data-source was too simple a model to combine the data sources; instead more complex models that consider interactions between data sources and the existing parameters should be considered. This would allow more flexibility in how survey/commercial data could be combined to better align with the signal in the data with the structure of the model to therefore improve model stability. Such a model would be similar to the separate model fits presented here, although would allow the parameters to be estimated jointly, but may lead to extensive run times and/or require lots of RAM to compute.

Since the commercial and survey data were fit independently, some care needs to be taken when combining the resulting indices. The raw posteriors of the κ_{st} from the commercial and survey fits appear approximately proportional in time, however the survey index is shifted (greater) as compared to the commercial index. If these posteriors were naively marginalized together it would introduce an inappropriate amount of uncertainty into the time varying growth index. One way to notice the problem is to look at the estimated posteriors of ${}_{\kappa}\alpha_s$ as seen in Figure (3, $left$). It is clear that the intercepts ${}_{\kappa}\alpha_s$ from the two models are offset by a constant factor which will be referred to hence forth as $\Delta\alpha$. By estimating $\Delta\alpha$ the indices from these separate model fits can be better aligned to combine the separate indices into one collective index of time varying growth that pulls from both data sources. $\Delta\alpha$ is estimated by transforming the posteriors of ${}_{\kappa}\alpha_s$ from each fit so as to first marginalize over sex within a model fit and then subtract the marginalized intercept from the survey fit from that of the commercial fit. A summary of $\Delta\alpha$ is seen Figure (3, $right$) as the stacked histogram. Notice that the offset is consistent between male and female intercepts and roughly estimated around 0.09. Rather than apply the point estimate, $\Delta\alpha$ is maintained as a random variable and subtracted from the survey index to carry forward the full uncertainty of the posteriors into the final index while correcting the offset in the ${}_{\kappa}\beta_t$ as best as possible.

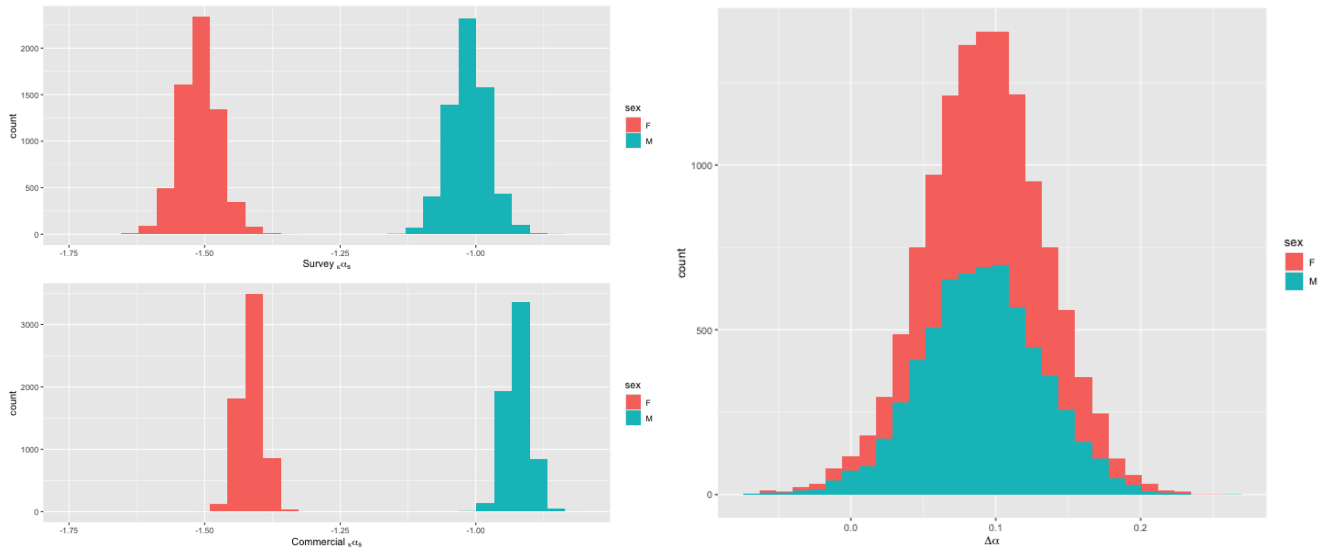

Figure 2: ($left$) ${}_{\kappa}\alpha_s$ posterior distributions. (top) Survey fit. ($bottom$) Commercial fit.
($right$) Stacked histogram showing the posterior of the difference between marginalized ${}_{\kappa}\alpha_s$ parameters.

The latent quantity ${}_{\kappa}\beta_t$ from the above model can then be interpreted as a model-based empirical measure of time varying growth. Since the Von Bertalanffy growth parameter is modeled here as $\log(\kappa)$, a multiplicative index of time varying growth is based on the quantity $e^{{}_{\kappa}\beta_t}$. Figure (3) shows the posteriors of $e^{{}_{\kappa}\beta_t}$ that result from fitting the above model to the commercial and survey data separately and then subsequently correcting the survey index by applying $\Delta\alpha$ as $e^{{}_{\kappa}\beta_t - \Delta\alpha}$.

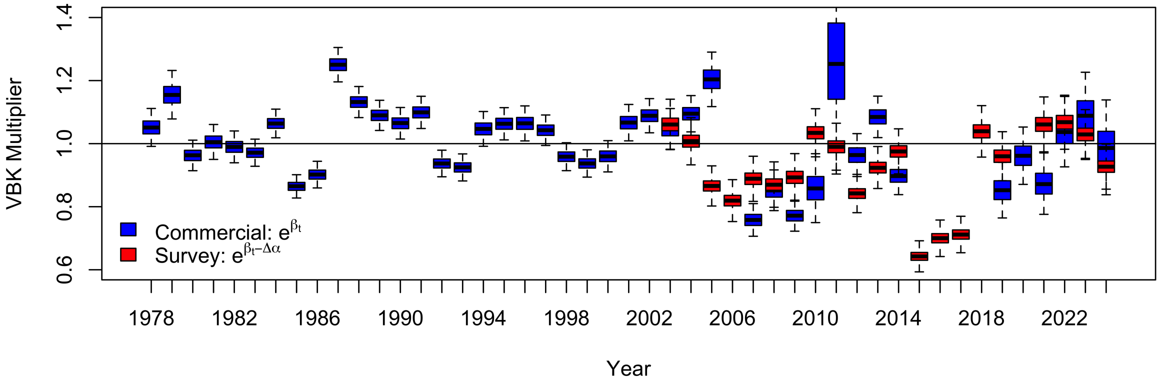

Figure 3: Separate indices of time varying growth as derived from independent fits to the commercial and survey data.

After correcting the survey index, combining the indices simply amounts to marginalizing the posterior draws of each index over data-source. To equally weight the indices this simply amounts to concatenating the samples from each year. When only one data source is available in a given year only the samples from the available index are used. Figure (4) displays the resulting index.

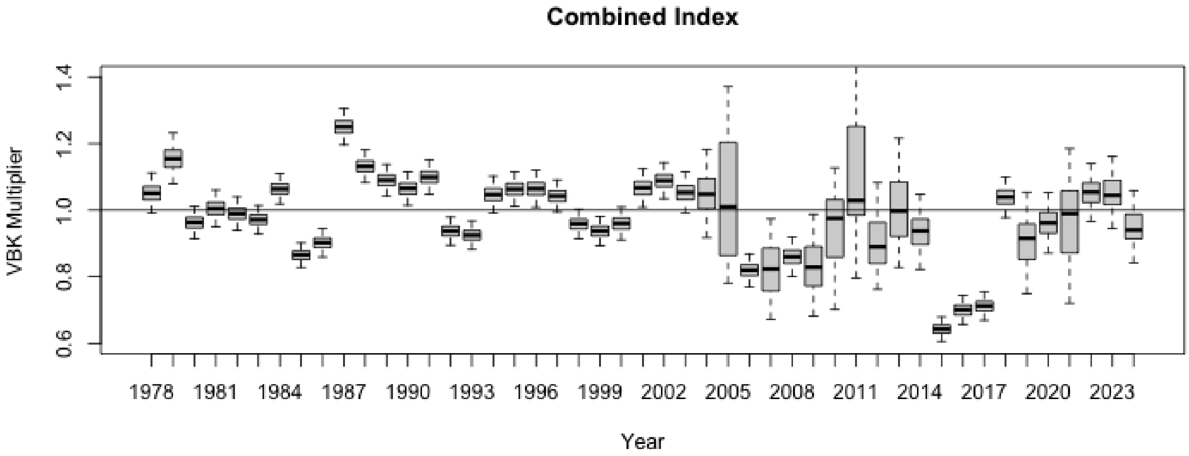

Figure 4: Combined index of time varying growth.

3.2 Autocorrelation

By considering the autocorrelation function [2, ACF] over posterior draws of the combined index of time varying growth we can not only inform a good model of time varying growth, but also inform hypothesis which drive it. Figure (5) shows the ACF as applied to the combined index seen in Figure (4). First, note that the peak of the ACF for a lag of one year (well beyond the limits of significance). This suggests that an AR1 model could be well suited for modeling this index. Second, observe the next most significant peak of the ACF arising around lags of eight or nine years. This is a consequence of the notable eight to nine year periodicity that is apparent in the indices. It is not clear why this cycle appears, but the presence of these features in this model are empirical evidence of a cyclic pattern in growth that may be driven by physical oceanographic phenomena over the modeled period. Furthermore, considering that the years of 2015, 2016, and 2017 in Figure (4) were the last years with notably low index values, this cyclic pattern suggests that a period of low growth may arrive in the near future if the observed cycle were to persist into the future.

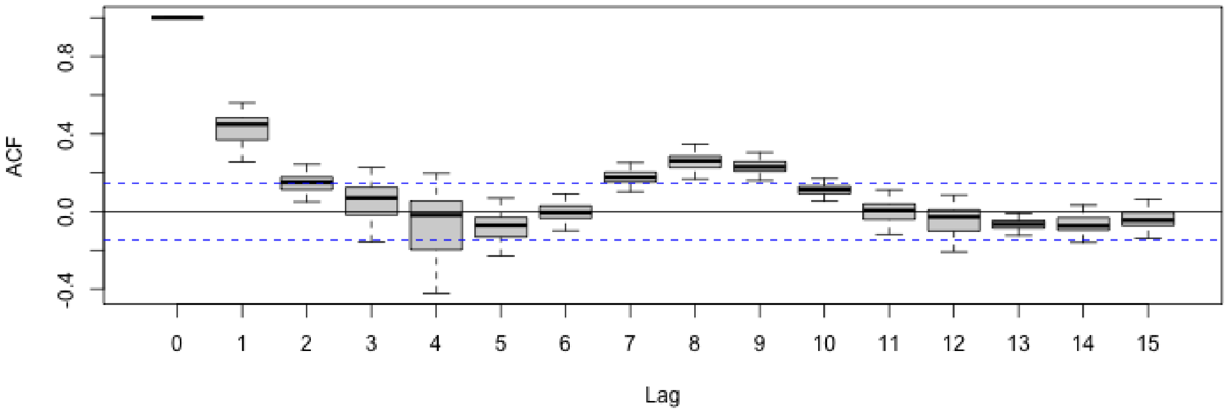

Figure 5: The grey boxplots represent the autocorrelation function as applied to the posterior draws of the combined index (whiskers represent an approximate 2σ interval). The blue dashed lines represent the asymptotic 2σ interval around the classical null hypothesis of 0 autocorrelation.

A Regional Spatio-Temporal Model

The previously presented model can be extended to account for regional, $r \in \{N, C, S\}$, spatial effects as,

$$\begin{gathered}
\ell_{rsti} = VB(a_{rsti};\ \kappa_{rst}, L_0, L_{20_{rst}}) + \epsilon_{rsti} \qquad (4)\\
\epsilon_{rsti} \sim N(0, \sigma_s) \qquad \sigma_s \sim \text{Student}_3(0, 10)\ 1_{\sigma>0}\\
\log(\kappa_{rst}) = \mathbb{1}_{0.05<\kappa<0.5}({}_{\kappa}\alpha_{rs} + {}_{\kappa}\beta_{rst}) \qquad {}_{\kappa}\beta_{rst} \sim N(0, {}_{\kappa}\phi) \qquad {}_{\kappa}\phi \sim N(0,1)\ 1_{{}_{\kappa}\phi>0}\\
L_0 = 7.3 \qquad L_{20_{rst}} = {}_{L_{20}}\alpha_{rs} + {}_{L_{20}}\beta_{rst} \qquad {}_{L_{20}}\beta_{rst} \sim N(0, {}_{L_{20}}\phi) \qquad {}_{L_{20}}\phi \sim N(0,1)\ 1_{{}_{L_{20}}\phi>0}.
\end{gathered}$$

Such a model not only exposes a latent yearly index of growth (i.e. the previous model's ${}_{\kappa}\beta_t$ parameters), but rather this model exposes latent spatio-temporal-varying indices of growth. By fitting this model to the two previously described sources of data the following indices can be derived from the ${}_{\kappa}\beta_{rst}$ parameters.

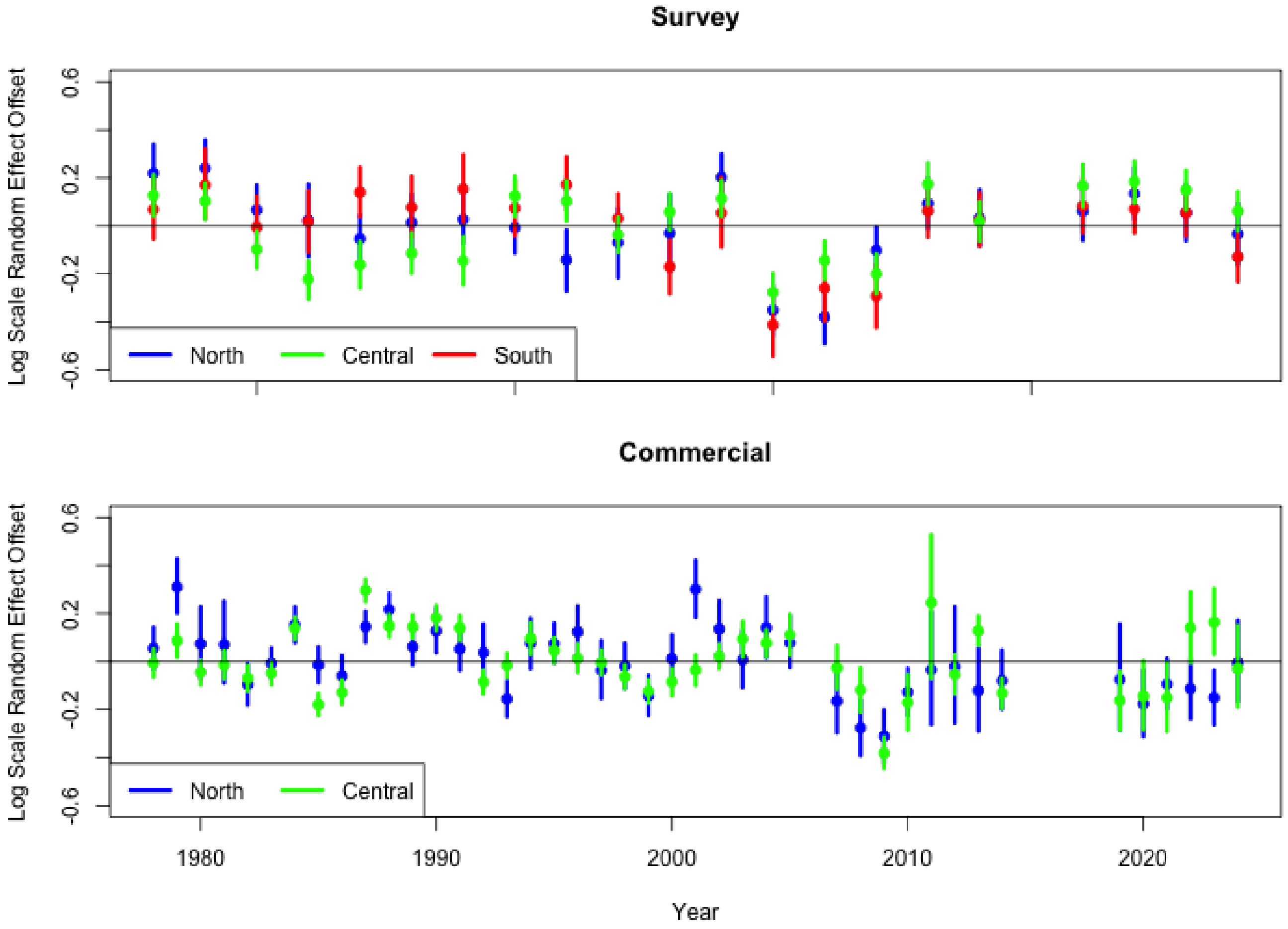

Figure 6: Separate spatio-temporal indices as derived from the survey (*top*) and commercial (*bottom*) data.

Note that while there is nothing in this model to demand similar autocorrelated indexes between regions, the regional indices appear very similar and have very similar autocorrelated structure as the previous time-only indices. The additional accounting of region reveals some subtle patterns in time and space, although this comes at the cost of increasing index variance relative to the time-only model. While the addition of space in the model appears to improve model selection criterion (improved prediction despite the added variance), the longer run times of these models (exceeding a week) and increased index variance made this model a less practical model for the specific purposed of producing an index of time varying growth.

The subtly of spatial difference is further illustrated by the following simplified model, $\mathbb{E}[\ell_{rsi}] = VB(a_{rsi}; \kappa_{rs}, L_0, L_{20_{rs}})$ (i.e. no time). Figure (7) shows fits of this model with only modest differences in VB growth by region marginally. Within a sex, there may be apparent small differences in space, but any seeming spatial patterns within a sex are not persistent between sexes. This suggests that any observed spatial differences that may be observed are not so different to be predictively indistinguishable from noise.

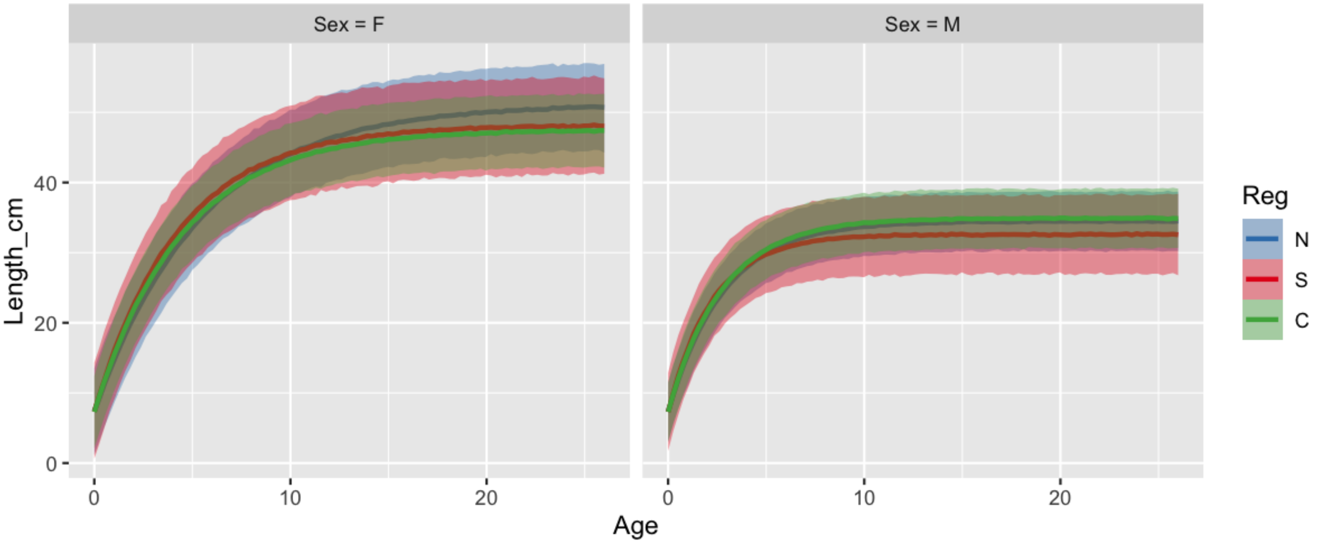

Figure 7: Posterior predictive 95% intervals of the VB function from the simplified spatial model.

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[2] A. John. *Probability and Random Processes for Electrical and Computer Engineers.* Cambridge university press, 2006.

[3] Richard D. Methot, Chantel R Wetzel, Ian G. Taylor, Kathryn Doering, Kelli F. Johnson, and Elizabeth Perl. Stock Synthesis User Manual, 2025.

[4] Jon Schnute. A Versatile Growth Model with Statistically Stable Parameters. *Canadian Journal of Fisheries and Aquatic Sciences*, 38(9):1128–1140, September 1981.

[5] Chantel Wetzel, Kelli Johnson, and Allan Hicks. Northwest Fisheries Science Center Survey.

Appendix B. Stock Assessment Team (STAT) Responses to Stock Assessment Review (STAR) Panel Requests

This section replicates content from the Chilipepper Rockfish STAR Panel Report (Panel requests and responses from the stock assessment team) for the reader's convenience. The full STAR Panel Report is available online.

Stock Assessment Review (STAR) Panel for Chilipepper Rockfish

Southwest Fisheries Science Center Auditorium, NOAA
110 McAllister Way | Santa Cruz CA 95060

June 23-27, 2025

STAR Panel Members
Cheryl Barnes, Oregon State University (Chair)
Allan Hicks, International Pacific Halibut Commission
Kotaro Ono, Center for Independent Experts
Geoff Tingley, Center for Independent Experts

Stock Assessment Team (STAT) Members
EJ Dick, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA
John Field, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA
Nicholas Grunloh, Fisheries Collaborative Program, University of California, Santa Cruz
Tanya Rogers, Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA

STAR Panel Advisors
Thompson Banez, California Department of Fish and Wildlife, Groundfish Management Team (GMT)
Tim Klassen, Reel Steel Sportfishing, Groundfish Advisory Subpanel (GAP)
Marlene A. Bellman, Pacific Fishery Management Council (PFMC)

1 - Request

Explore whether a flexible 2D selectivity parameterization improves model fit to age data from the California trawl fleet. Plot the fit to mean age and mean length using this run. Please also present Pearson residual plots for each.

1 - Rationale

Given the poor fit to mean ages (~ 10 yr fish) and high selectivity of 25 to 30 cm fish from the mid-1980s to 2000s, changes in sex-specific selectivity may be having an effect. If this run improves the fits to mean age and mean length, an alternative selectivity parameterization or time block structure may be considered.

1 - STAT Response

The pre-STAR base model was modified to use the “2D-AR” length-based selectivity function in Stock Synthesis for the California trawl fleet (1978-2024). The standard deviation of the selectivity deviations was fixed at 1. The model was not re-tuned to compare likelihood components. The estimated parameters of the underlying logistic selectivity curve (from which year- and size-specific deviations are estimated) were 32.19 cm for the inflection point and 6.57 cm for the “95% width” parameter (i.e., the difference between the mean and the 95th percentile of the logistic curve). Deviations were estimated for each year and population bin (Fig. 1A), resulting in ~1360 parameters. The change to a more flexible selectivity curve did not visibly improve fits to mean age (Fig. 1B) and the age composition likelihood component increased from 2002.35 to 2006.22, suggesting a slight degradation of fit to age data. The length composition likelihood decreased from 569.09 for the pre-STAR base model to 531.01 for the model with a more flexible length-based selectivity curve. Given the addition of over 1,300 deviation parameters, an improved fit to the length composition data is not surprising. Visually, the change in overall fit to the length data is subtle, with noticeable improvements from 1978 to 1983 (Fig. 1C). Pearson residuals for the conditional age-at-length (CAAL) data showed some reduction in residual size for large males (Fig. 1D and Fig. 1E), though patterns observed in the pre-STAR base model persisted. Pearson residuals for the length composition data (Fig. 1F) show larger extreme deviations when using 2D selectivity, suggesting that the improvement in fit (i.e., decrease in likelihood) is spread across multiple length bins and years. Changes in scale for the residual plots make visual comparison difficult. The STAT plotted the $\log_{10}$ absolute value of the Pearson residuals from each model against each other, grouped by sex (Fig. 1G) and length bin (Fig. 1H). These suggest that improved model fit using the 2D selectivity is driven by better fits to large males.

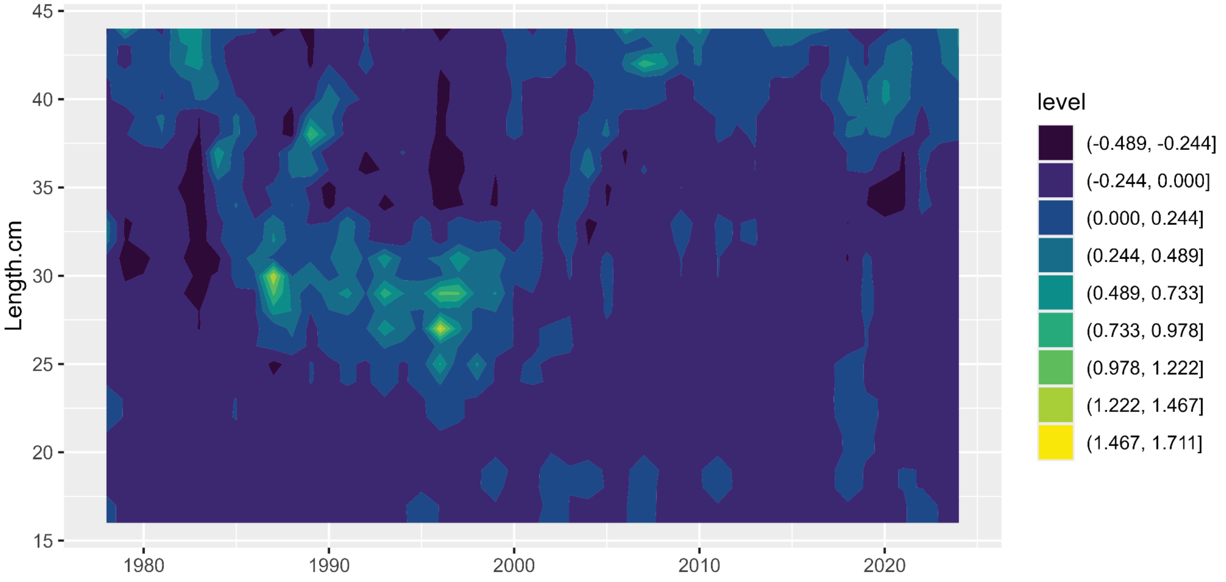


Figure 1A. Contour plot of deviations when estimating a logistic selectivity for the California trawl fleet.

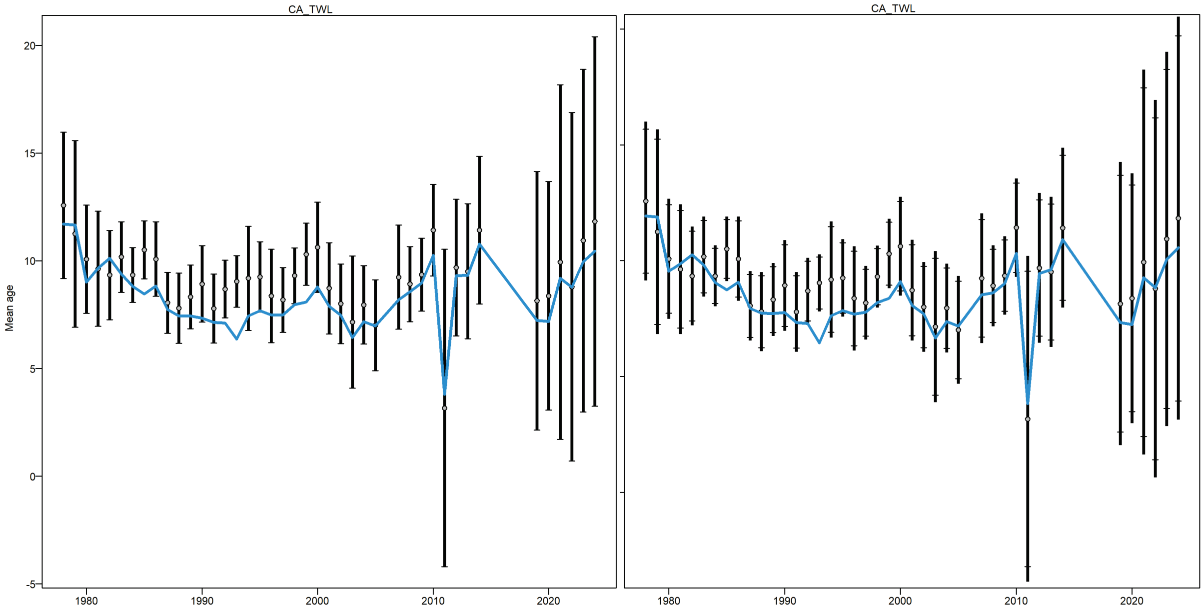


Figure 1B. Observed mean age (points) with 95% confidence intervals based on tuned sample sizes and model predictions of mean age (blue line) for the California trawl fleet. Results from the pre-STAR base model tuned using Francis weights (left) and the model using 2D-AR selectivity for the trawl fleet and the same Francis weights as the pre-STAR base model (i.e., not re-tuned; right) are shown.

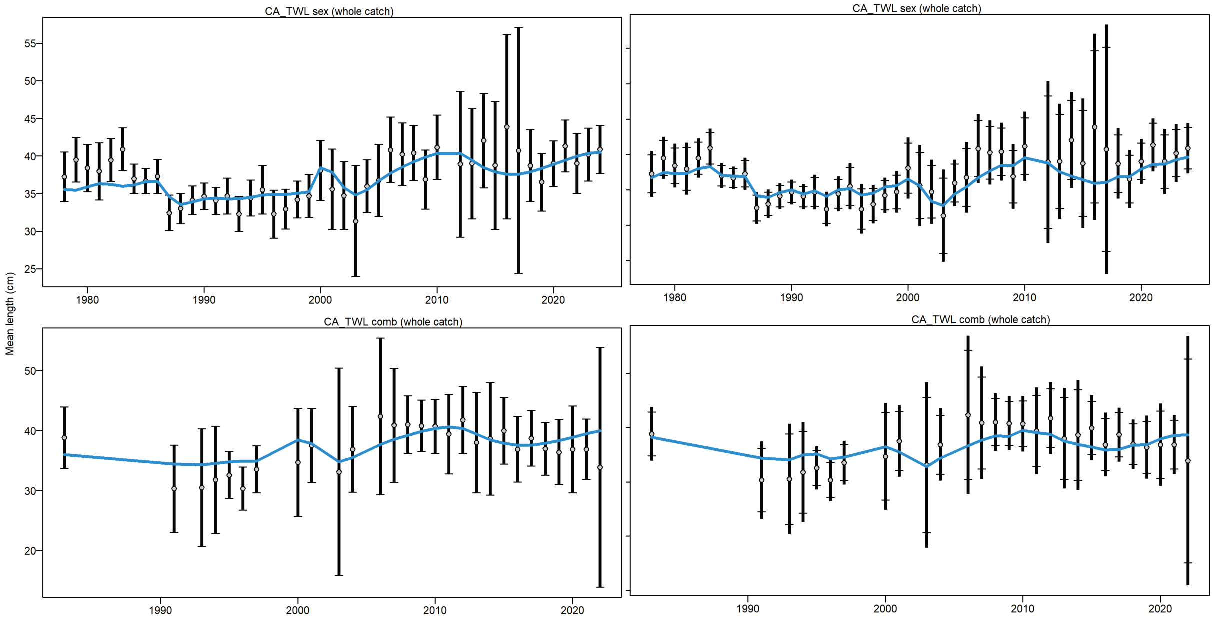


Figure 1C. Observed mean length (points) with 95% confidence intervals based on tuned sample sizes and to model predictions of mean length (blue line) for the California trawl fleet. Results from the pre-STAR base model tuned using Francis weights (left) and the model using 2D-AR selectivity for the trawl fleet using the same Francis weights as the pre-STAR base model (i.e., not re-tuned; right) for sexed (top) and unsexed (bottom) fish are shown. Note differences in the range of the axes.

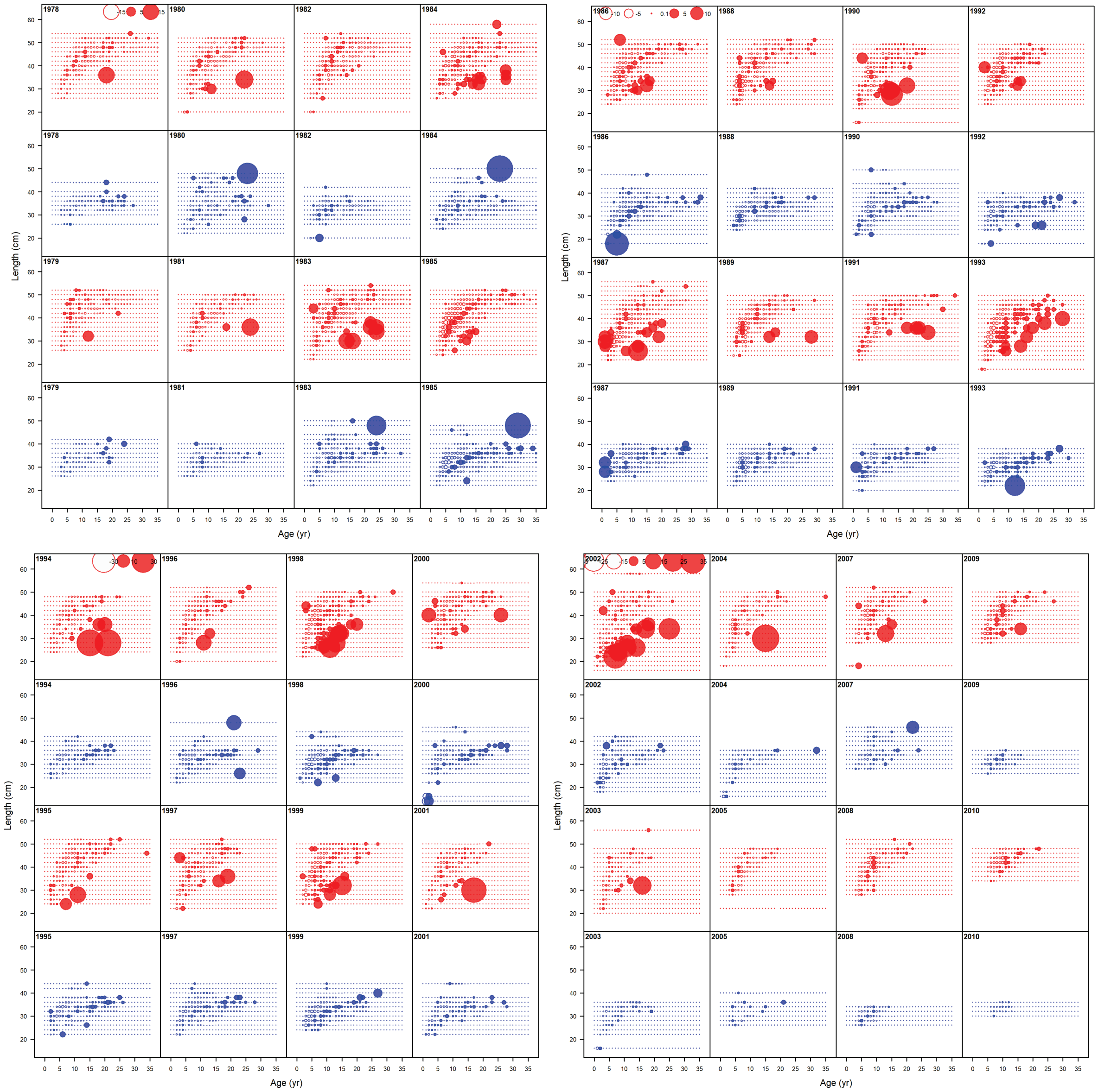


Figure 1D. Pearson residuals for conditional age-at-length data from the California trawl fleet (1978-2010). Length-based selectivity was modeled using the 2D-AR option in Stock Synthesis.

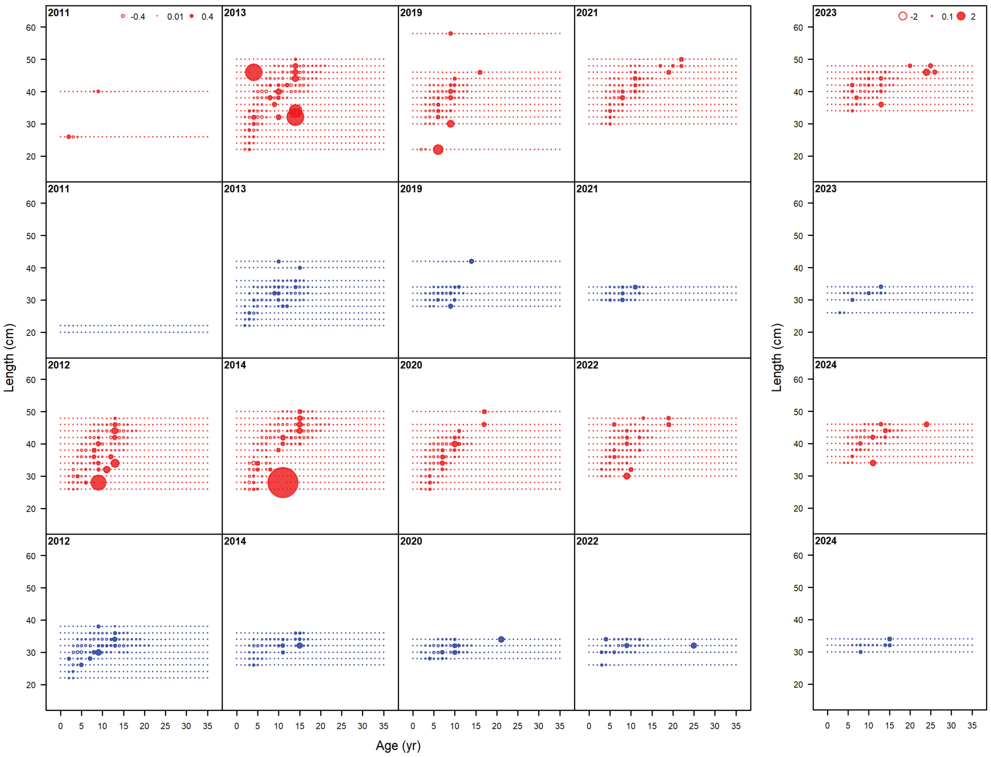


Figure 1E. Pearson residuals for conditional age-at-length data from the California trawl fleet (2011-2024). Length-based selectivity was modeled using the 2D-AR option in Stock Synthesis.

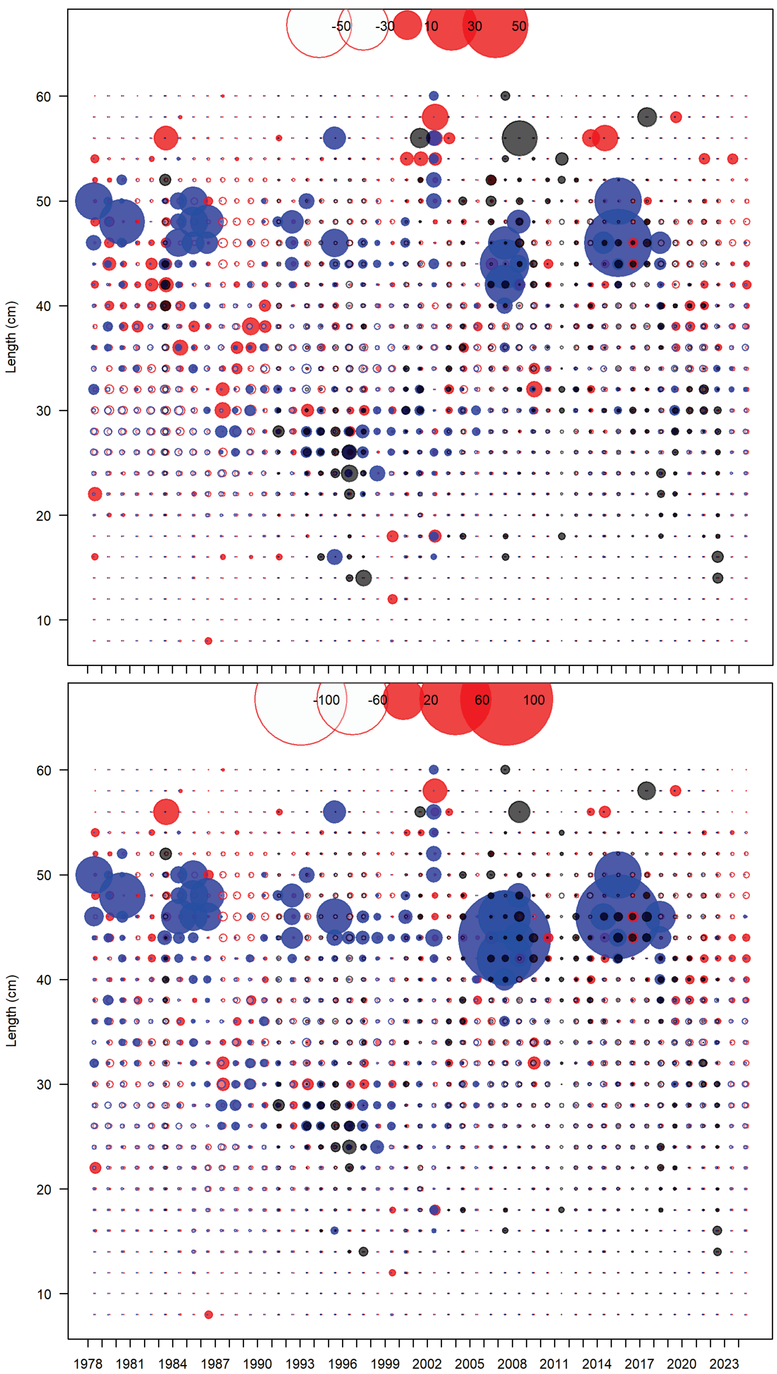


Figure 1F. Pearson residuals for length composition data from the California trawl fleet (1978-2024). Length-based selectivity was modeled using time-blocks from the pre-STAR base model (top) and the 2D-AR option in Stock Synthesis (bottom).

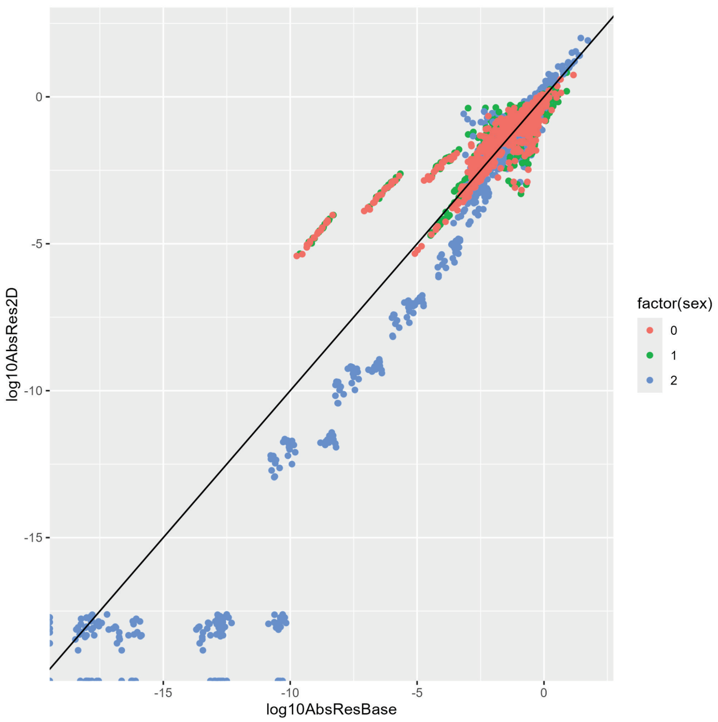


Figure 1G. Log-scale absolute Pearson residuals from the pre-STAR base model (x-axis) compared to log-scale absolute Pearson residuals from the model with flexible (2D) selectivity (y-axis). The 2D selectivity model has smaller residuals for males (sex=2) and some larger residuals for unsexed fish (sex=0) and females (sex=1).

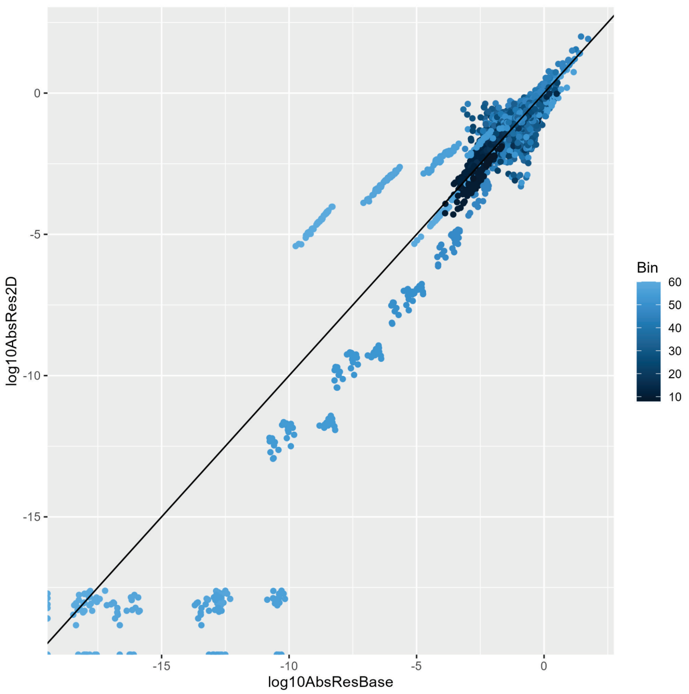


Figure 1H. Log-scale absolute Pearson residuals from the pre-STAR base model (x-axis) compared to log-scale absolute Pearson residuals from the model with flexible (2D) selectivity (y-axis). The 2D selectivity model has smaller residuals for larger males (sex=2) and some larger residuals for very large unsexed fish (sex=0) and females (sex=1).

1 - Panel Conclusion

A freely estimated, time-varying selectivity with many deviation parameters (2D) did not improve the general fits to mean age. There was minor improvement to fits to mean length. There were a few larger residuals with the 2D selectivity model, especially for larger males, which were similar to those from the pre-STAR base model. The 2D selectivity model slightly reduced residuals for larger males, though residuals were still large and model fit worsened slightly for some female and unsexed fish. Thus, the Panel does not recommend proceeding with 2D selectivity.

There was some discussion about changes in gear type (e.g., popularization of ‘rockhopper’ roller gear) in the mid-1980s and 1990s (to explain patterns in Fig. 1A), but there was inadequate information to propose specific time blocking at this time.

2 - Request

Run a sensitivity analysis by replacing dome-shaped selectivity with asymptotic selectivity for the commercial fleets that showed estimation issues with the descending limb parameter based on the MCMC analysis. Plot spawning output, fraction unfished, and recruitment deviations compared to estimates from the pre-STAR base model.

2 - Rationale

The parameters for the descending limb were not well-defined based on the MCMC analysis. Additionally, asymptotic selectivity would simplify the model. If overall fits and predictions do not change with asymptotic selectivity, that would support a more parsimonious model.

2 - STAT Response

MCMC diagnostics of the pre-STAR base model showed that the descending scale parameter of the double-normal (DN) dome-shaped selectivities in the NoCA_HKL, SoCA_HK, CA_TWL, CA_NET, and NoCA_OR_WA_Rec fleets appeared to have improper posteriors (Fig. 2A). Each of these fleets were given asymptotic sigmoidal selectivity by fixing the final selectivity of the DN to inv.logit(10)=0.9999546 and fixing the descending scale to produce a two-parameter sigmoid, with estimated parameters at the DN peak and the DN ascending scale. Time blocks in the model were preserved, allowing for changes in the ‘peak’ and ‘ascending scale’ parameters. Separate model runs were constructed to separately fit asymptotic selectivities for each of the above-mentioned fleets. A final model is shown fitting all of the above fleets jointly with asymptotic selectivities. Spawning output, fraction unfished, and recruitment deviations were mostly indistinguishable from pre-STAR base model estimates (Fig. 2B and Fig. 2C). The only model to show even slight differences in recruitment deviations is the model with only asymptotic selectivity in the CA_NET fleet.

Most models resulted in nearly identical likelihoods (Table 2), though the CA_NET only model shows the greatest increase in negative log-likelihood (NLL). The model with all asymptotic selectivities has four NLL points greater than the pre-STAR base model but it also saves four parameters and therefore seems to be a parsimonious option that doesn’t substantively change results as compared with the pre-STAR base model. The weak identifiability of the dome-shaped selectivities of the pre-STAR base model likely indicates that there is little to no information in the data to inform the descending scale parameters (Fig. 2D). This illustrates the utility of MCMC diagnostics, as the asymptotic standard errors for the descending limb parameters suggested greater precision and would not have revealed this source of model instability.

Table 2. Negative log-likelihood values for each of the fit models. Likelihood components are in the rows.

	NoDome All	NoDomeCA_NET	NoDome SoCA_HKL	NoDome CA_TWL	NoDome NoCA_OR_WA_Rec	NoDome NoCA_HKL	pre-STAR base
N.Parms	109	113	113	113	113	113	114
TOTAL	2624.18	2626.11	2621.95	2622.39	2620.82	2620.51	**2620.26**
Survey	24.2567	**24.1734**	24.5525	24.3505	24.4258	24.4998	24.5754
Length_comp	570.567	571.97	570.691	569.718	568.723	**568.564**	569.086
Age_comp	2004.83	2006.28	2002.38	2003.88	2003.37	2003.19	**2002.35**
Recruitment	24.4337	**23.5844**	24.2486	24.3614	24.2309	24.1945	24.1847

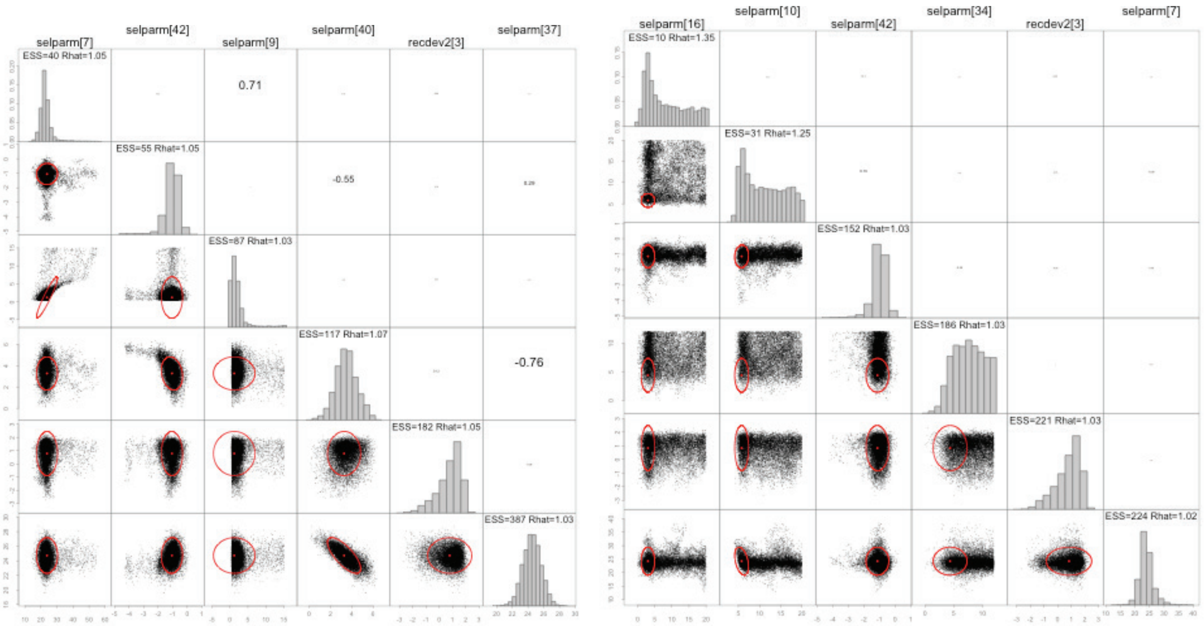


Figure 2A. Pairwise scatterplots and histograms of the slowest converging parameters from the MCMC diagnostics for the pre-STAR base model (left) and the all asymptotic selectivity model (right). Although convergence is not perfect, asymptotic selectivities largely remove the improper posteriors present in the pre-STAR base model.

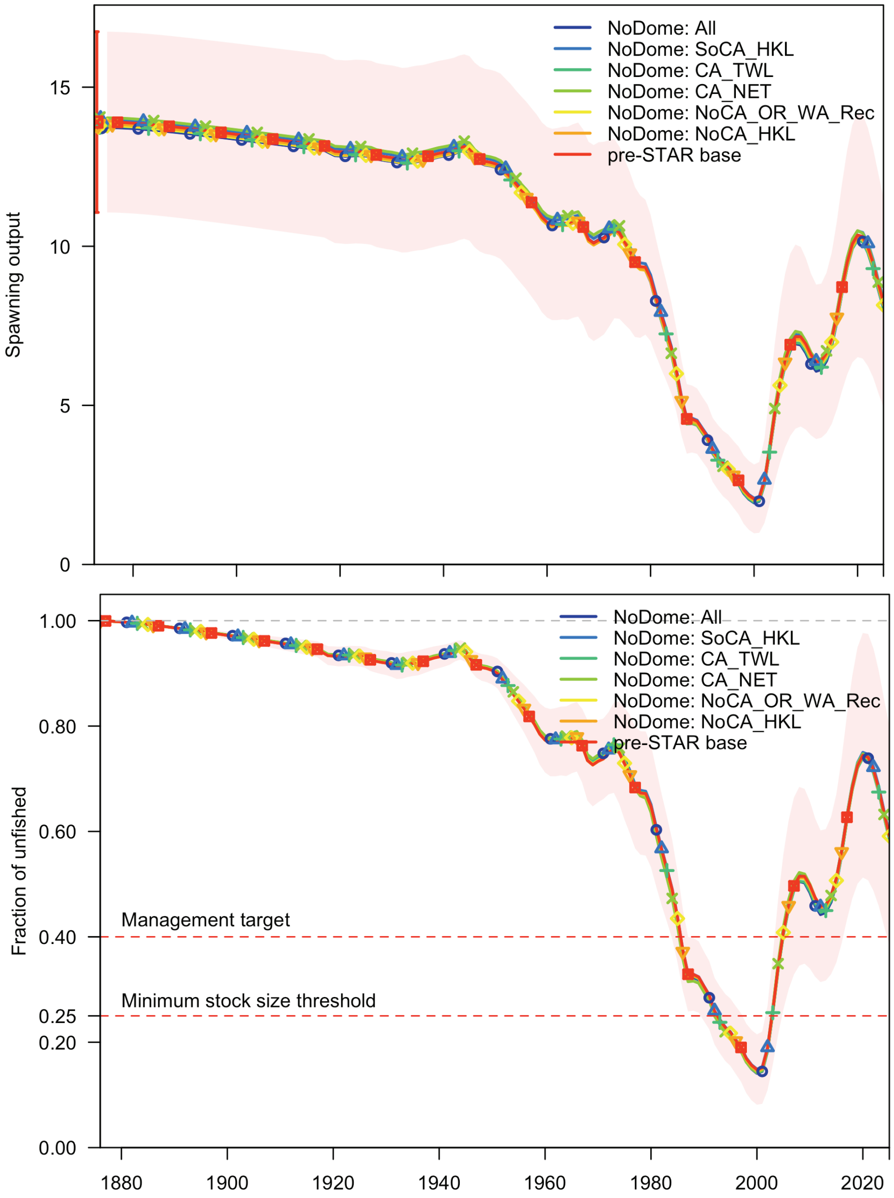


Figure 2B. Spawning output and fraction unfished when replacing dome-shaped selectivities with asymptotic selectivities. Estimates from the pre-STAR base model are also shown.

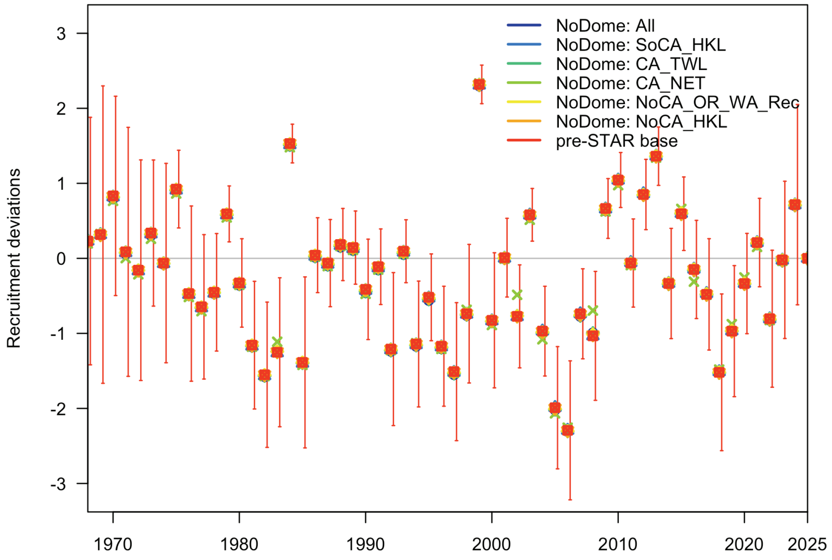


Figure 2C. Recruitment deviations when replacing dome-shaped selectivities with asymptotic selectivities. Estimates from the pre-STAR base model are also shown.

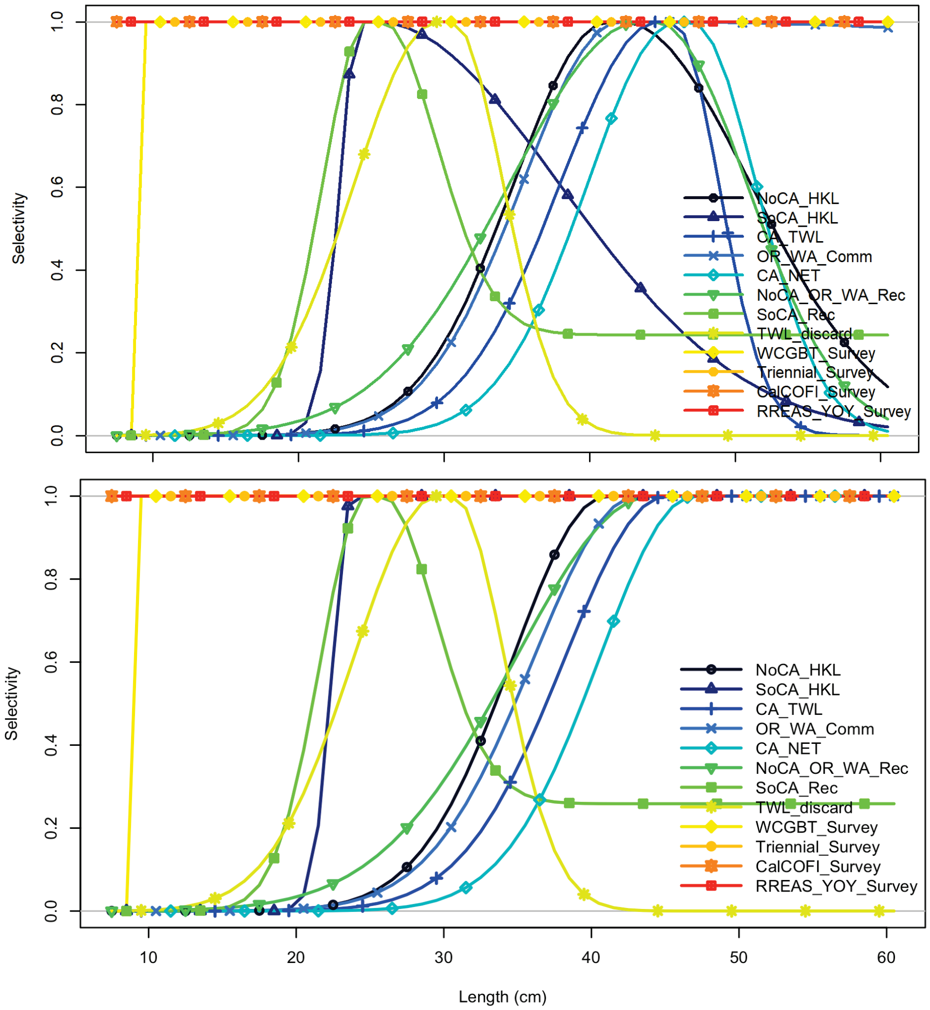


Figure 2D. Fits to pre-STAR base model dome selectivities (top) as compared with the fit asymptotic selectivities (bottom).

2 - Panel Conclusion

The new base model should update selectivity from dome-shaped to asymptotic for all commercial fleets, except for the southern California recreational and trawl discard fleets in defining a new base model. This is supported by a more parsimonious model showing an insignificant increase in the likelihood (approximately 4 units of likelihood resulting from a reduction of 5 parameters).

3 - Request

Re-compute the West Coast Groundfish Bottom Trawl Survey (WCGBTS) index by including a depth effect (WCGBTS_depth). Compare the current WCGBTS index and WCGBTS_depth index in a single plot with confidence intervals.

3 - Rationale

Depth is an important habitat variable for rockfish species. Although the spatial model can capture much of the depth effects (via anisotropy and a spatial field), previous work (Johnson et al. 2019) has shown that including depth can improve model performance.

3 - STAT Response

The STAT received preliminary model runs from Chantel Wetzel and Eric Ward (NWFSC), which led to further investigation as part of Request 12.

3 - Panel Conclusion

Discussion about responses to Request 3 resulted in a new request (see Request 12).

4 - Request

Calculate the mean of the recruitment deviations from the main recruitment estimation period in the pre-STAR base model. Present results from a run with the sum-to-zero constraint for recruitment deviations. Provide a table with the parameters for these two runs along with the sensitivity that fixes recruitment deviations to zero. Please include reference points and plot dynamic B_0.

4 - Rationale

The sum-to-zero constraint for recruitment deviations ensures that reference points are consistent with the assumptions of the model. Without this constraint, reference points implied by the main recruitment estimation period may differ considerably from the reported reference points. This request will provide insight into the magnitude of this potential discrepancy.

4 - STAT Response

The mean of the main period recruitment deviations (1968-2024) in the pre-STAR base model is -0.24498. This model was modified by setting the “Do Recruitment Deviations” option to “Deviation Vector” (option 1), which imposes a sum-to-zero constraint on the recruitment deviations. An initial run was completed without ‘tuning’ the model, so likelihood components could be compared directly to the pre-STAR base model. A subsequent model run adjusted the bias ramp and tuned Francis weights using the same methods applied to the pre-STAR base model. Finally, a model using the pre-STAR base model (with Triennial survey ages added) and no recruitment deviations was run without tuning.

Compared to the pre-STAR base model, models with a sum-to-zero constraint on recruitment deviations have a lower estimate of initial spawning output and similar end-year estimates of spawning output. Therefore, relative spawning output (i.e., fraction unfished) is higher (less depleted relative to unfished levels) in models with the sum-to-zero constraint (Fig. 4A). Recruitment deviations without a sum-to-zero constraint have a negative offset relative to the constrained deviations, resulting in a higher estimate of unfished equilibrium recruitment (R_0; Fig. 4B). Estimates of long-term sustainable yield from the pre-STAR base model are approximately 2500 mt, whereas estimates from models with the sum-to-zero constraint are approximately 2000 mt (similar to the previous assessment, which also used a sum-to-zero constraint). Likelihood components, estimated parameter values, and derived quantities from the four models are provided in Table 4. Estimates of natural mortality are lower for females, with a larger offset for males, in the models with a sum-to-zero constraint. All models assume a steepness (h) of 0.72.

Models with sum-to-zero constraints and the pre-STAR base model include a bias adjustment following the methods of Methot and Taylor (2011). Methot and Taylor (2011) estimated deviations using a sum-to-zero constraint, so it is unclear to the STAT whether the bias adjustment is appropriate for the pre-STAR base model and other models that are fit using maximum likelihood without a sum-to-zero constraint. Posterior distributions for log R_0, based on the diagnostic MCMC runs that did not use a sum-to-zero constraint, suggest a value between 10 and 11, with a mode near 10.3 (Fig. 4C). The log R_0 value estimated by the pre-STAR base model without a sum-to-zero constraint and with a bias correction is 10.24. The log R_0 values estimated by models with a sum-to-zero constraint are slightly below 10.

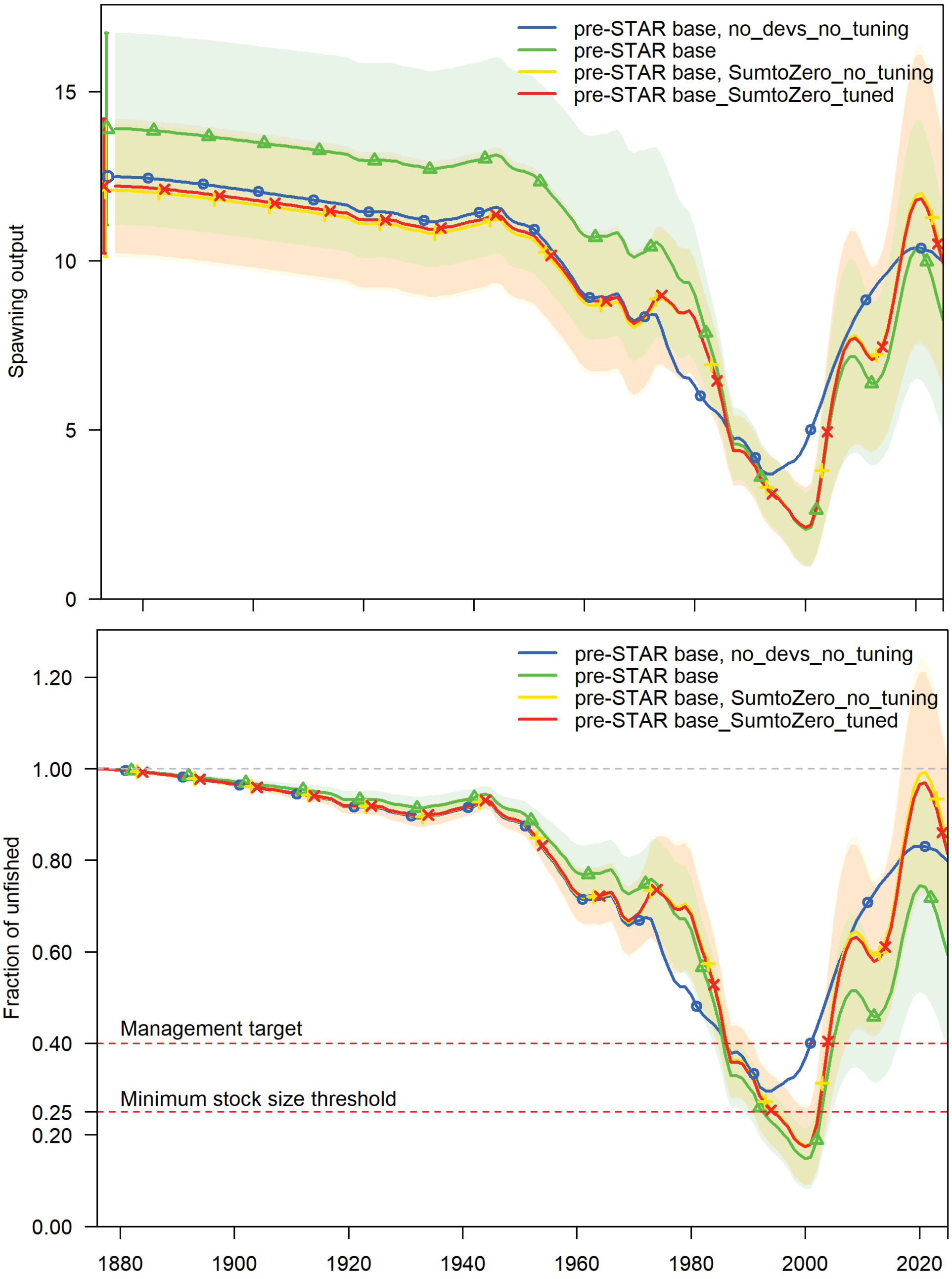


Figure 4A. Spawning output (top) and fraction unfished (bottom) for models with and without a sum-to-zero constraint imposed on recruitment deviations.

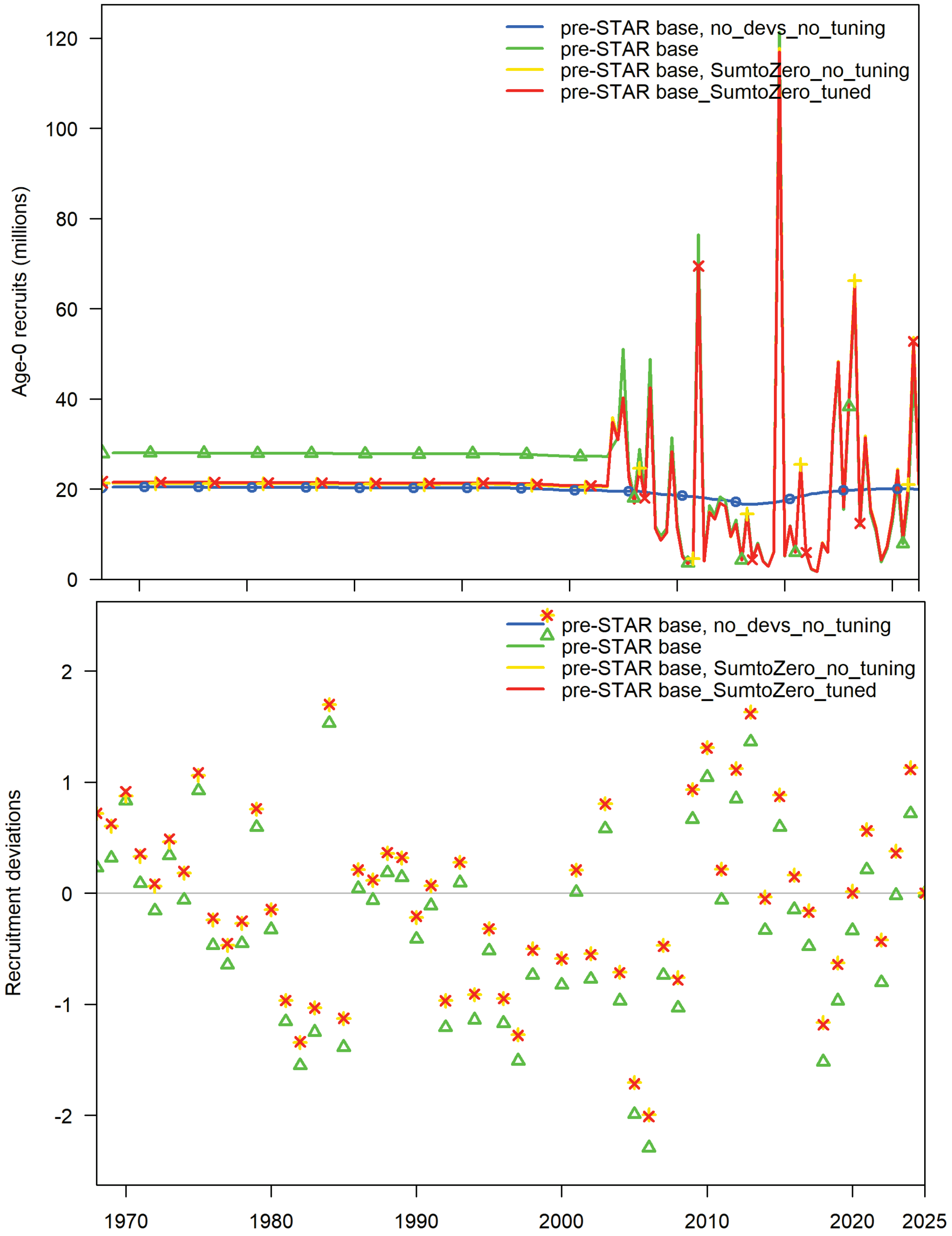


Figure 4B. Age-0 recruits (top) and recruitment deviations from the spawner-recruit curve (bottom) for models with and without a sum-to-zero constraint imposed on recruitment deviations.

Table 4. Comparison of likelihood components, parameter estimates, and derived quantities from models with and without recruitment deviations, as well as unconstrained or ‘sum-to-zero’ recruitment deviations.

Label	pre-STAR base, no_devs_no_tuning	pre-STAR base	pre-STAR base, SumtoZero_no_tuning	pre-STAR base, SumtoZero_tuned
N.Parms	45	114	114	114
TOTAL	3119.280	2620.260	2623.630	2628.760
Survey	47.220	24.575	29.211	28.844
Length_comp	667.444	569.086	569.314	569.318
Age_comp	2404.610	2002.350	2003.130	2008.480
Recruitment	0.000	24.185	21.961	22.102
Parm_priors	0.000	0.053	0.007	0.008
NatM_uniform_Fem_GP_1	0.155	0.171	0.160	0.160
L_at_Amax_Fem_GP_1	48.574	48.169	48.223	48.234
VonBert_K_Fem_GP_1	0.189	0.194	0.194	0.193
CV_young_Fem_GP_1	0.102	0.108	0.109	0.110
CV_old_Fem_GP_1	0.034	0.038	0.037	0.037
NatM_uniform_Mal_GP_1	0.271	0.266	0.291	0.291
L_at_Amax_Mal_GP_1	-0.353	-0.333	-0.333	-0.334
VonBert_K_Mal_GP_1	0.610	0.540	0.542	0.543
CV_young_Mal_GP_1	-0.131	0.203	0.198	0.195
CV_old_Mal_GP_1	0.665	0.112	0.118	0.117
SR_LN(R0)	9.924	10.240	9.964	9.976
Q_extraSD_CalCOFI_Survey(11)	0.421	0.313	0.368	0.363
Q_extraSD_RREAS_YOY_Survey(12)	1.740	1.234	1.217	1.219
Size_DblN_peak_NoCA_HKL(1)	42.278	41.254	41.202	41.222
Size_DblN_ascend_se_NoCA_HKL(1)	4.452	4.438	4.438	4.440
Size_DblN_descend_se_NoCA_HKL(1)	4.270	5.042	4.960	4.943
Size_DblN_peak_SoCA_HKL(2)	24.218	24.245	24.220	24.209
Size_DblN_ascend_se_SoCA_HKL(2)	1.415	1.403	1.392	1.387
Size_DblN_descend_se_SoCA_HKL(2)	5.779	5.766	5.725	5.723
Size_DblN_peak_CA_TWL(3)	44.110	44.699	44.520	44.512
Size_DblN_ascend_se_CA_TWL(3)	4.494	4.512	4.505	4.505
Size_DblN_descend_se_CA_TWL(3)	2.874	2.987	2.983	2.981
Size_DblN_peak_OR_WA_Comm(4)	39.771	42.043	41.527	41.492
Size_DblN_ascend_se_OR_WA_Comm(4)	4.135	4.496	4.447	4.444
Size_DblN_peak_CA_NET(5)	46.184	45.969	45.927	45.919
Size_DblN_ascend_se_CA_NET(5)	4.289	4.321	4.320	4.319
Size_DblN_descend_se_CA_NET(5)	3.949	3.686	3.655	3.642
Size_DblN_peak_NoCA_OR_WA_Rec(6)	44.908	43.503	43.339	43.333
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.117	5.099	5.094	5.093
Size_DblN_descend_se_NoCA_OR_WA_Rec(6)	3.589	4.373	4.318	4.299
Size_DblN_peak_SoCA_Rec(7)	24.536	24.673	24.628	24.626
Size_DblN_ascend_se_SoCA_Rec(7)	2.973	2.920	2.910	2.909
Size_DblN_descend_se_SoCA_Rec(7)	3.160	3.352	3.397	3.400
Size_DblN_end_logit_SoCA_Rec(7)	-0.700	-1.135	-1.186	-1.189
Size_DblN_peak_TWL_discard(8)	29.509	29.501	29.457	29.453
Size_DblN_ascend_se_TWL_discard(8)	4.325	4.173	4.170	4.170
Size_DblN_descend_se_TWL_discard(8)	3.321	3.203	3.208	3.208
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	49.997	50.291	50.412	50.357
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	3.970	4.053	4.062	4.057
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	49.777	47.563	47.511	47.506
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.814	4.734	4.736	4.735
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	36.345	33.490	33.421	33.422
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.792	3.213	3.201	3.201
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	32.168	30.454	30.488	30.482
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	4.059	3.712	3.723	3.722
Bratio_2025	0.798	0.593	0.836	0.813
SSB_unfished	12484	13904	12081	12203
Totbio_unfished	52519	60831	51324	51833
Recr_unfished	20422	27998	21247	21493
Dead_Catch_SPR	1960	2494	2000	2022
OFLCatch_2025	3087	2834	3200	3143

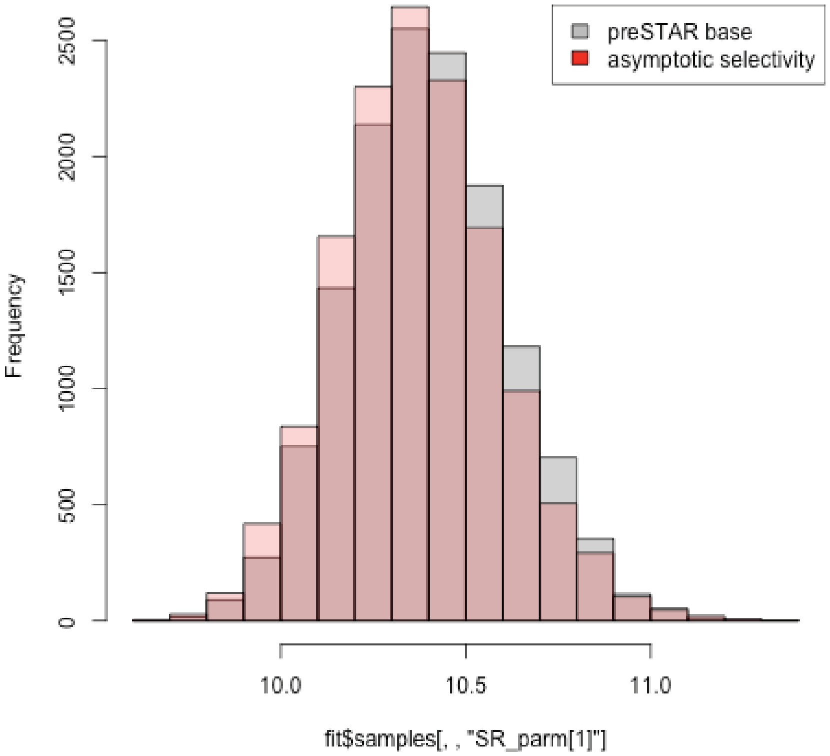


Figure 4C. Posterior distributions for unfished equilibrium recruitment from diagnostic MCMC runs. Recruitment deviations were not subject to the sum-to-zero constraint in either run.

4 - Panel Conclusion

The Panel and STAT discussed this at length without coming to a conclusion. Therefore, a new request was made to further investigate effects of using a sum-to-zero constraint on recruitment deviations (see Request 13). The Panel agreed that estimation of the requested dynamic B_0 was no longer required.

5 - Request

Replot fits to the CalCOFI index of spawning output without confidence intervals.

5 - Rationale

This will enable additional scope for interpretation of model fit to the time series. Including the confidence intervals compresses the y-axis.

5 - STAT Response

The requested figure without confidence intervals was provided (Fig. 5A).

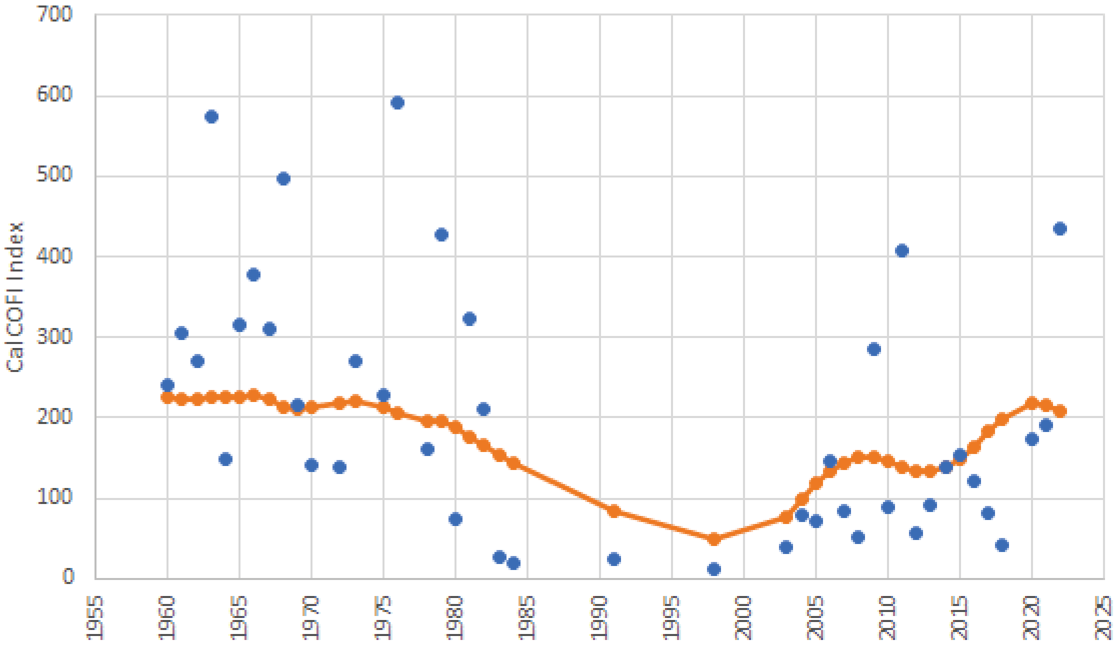


Figure 5A. CalCOFI index of spawning output (blue points) and pre-STAR base model fit to the index (orange points and interpolated line). Confidence intervals were excluded for illustrative purposes.

5 - Panel Conclusion

This plot clarifies the model fit to this index.

6 - Request

Run an additional sensitivity that replaces the coastwide CalCOFI index with the southern CaCOFI index without the early (1950s) estimates. Please plot fits without confidence intervals and investigate why the terminal years in the coastwide index are increasing when regional indices are decreasing.

6 - Rationale

Including the coastwide CalCOFI index increases stock status, whereas separately including central and southern CalCOFI indices decreases stock status. This sensitivity will inform the effects of spatial and spatiotemporal extent of the CalCOFI index on stock status.

6 - STAT Response

The STAT inadvertently used the shorter southern CalCOFI index instead of the central CalCOFI index for sensitivity runs. Corrected and additional runs are now a bit more intuitive (Fig. 6A). With the correct data, the central CalCOFI model is less depleted in the terminal year than the pre-STAR base model (all data, but only years with data from both regions) and the southern CalCOFI index model is more depleted. The “CalCOFI Short south” model is slightly more depleted than the southern model with all data, which is consistent with the observation that the first decade of data (i.e., the 1950s) have low index values that would presumably scale down the fraction unfished. Including data from all years and regions is still nearly identical to the pre-STAR base model.

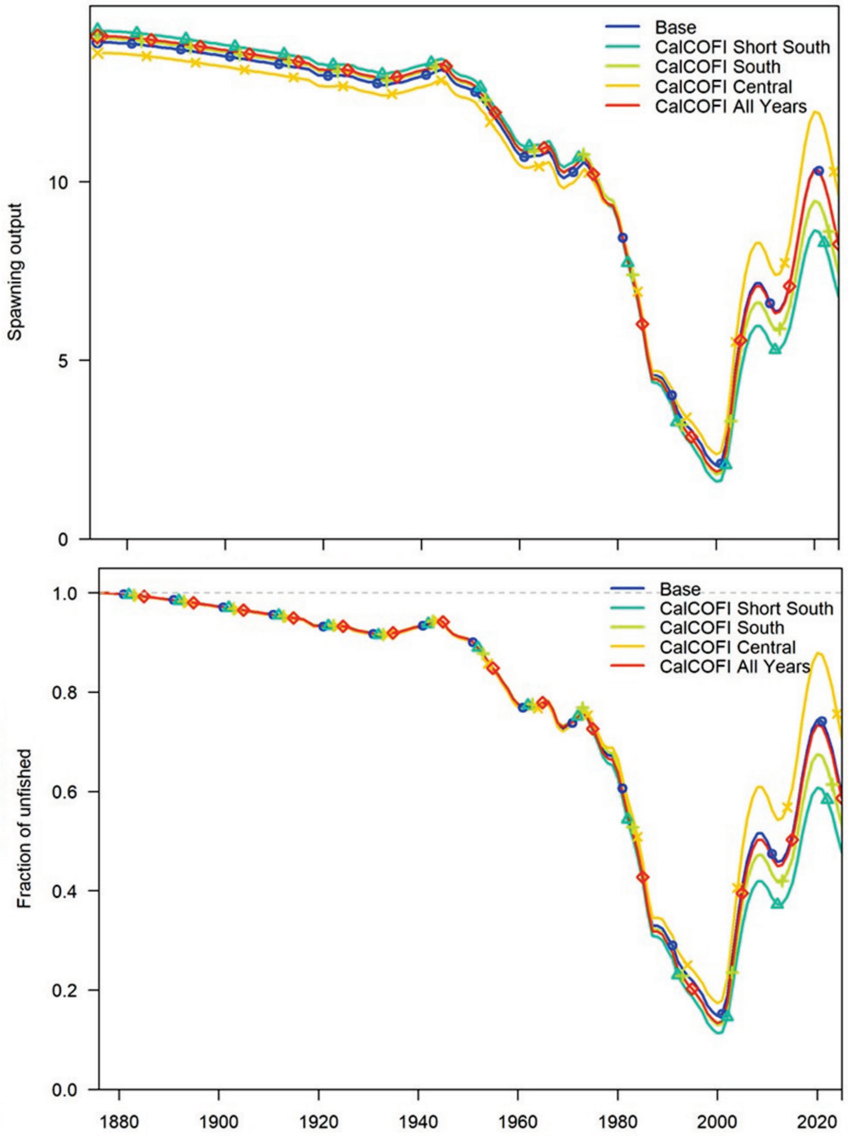


Figure 6A. Spawning output (top) and fraction unfished (bottom) from the pre-STAR base model, and models that included: a) CalCOFI central, b) CalCOFI south, c) CalCOFI “short” south (starting in 1960), and all CalCOFI data (years and areas).

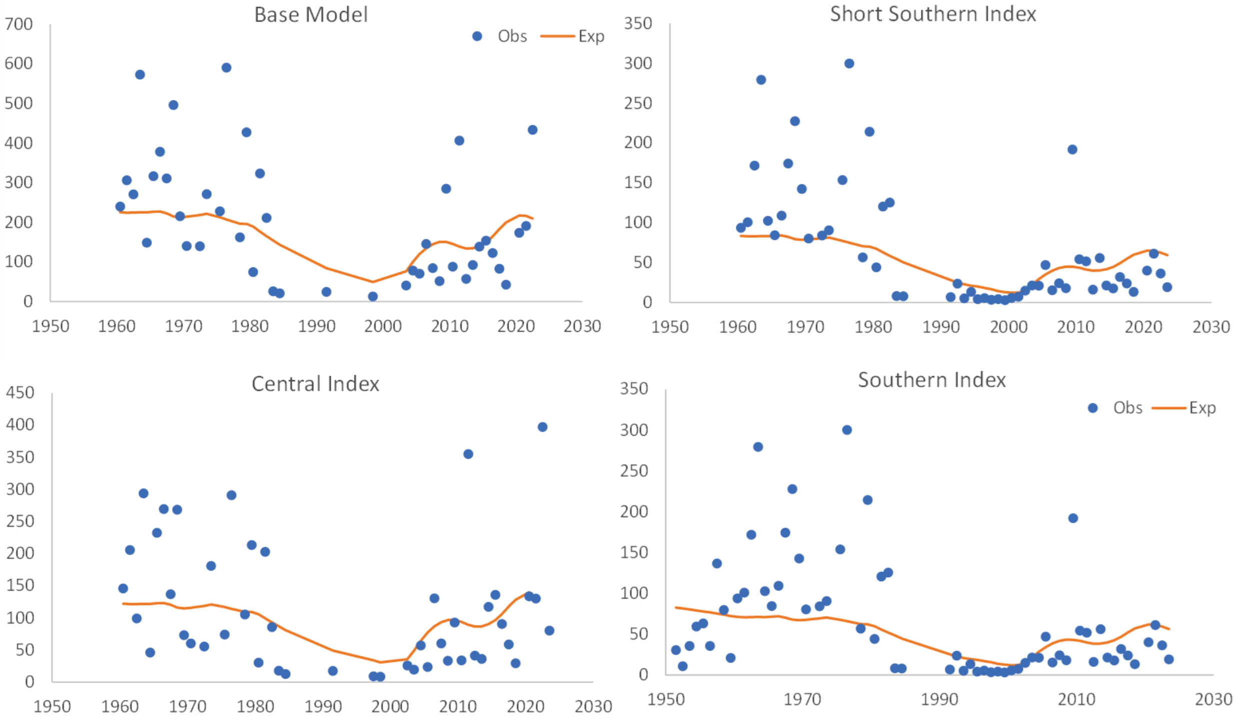


Figure 6B. Model fits (lines) to CalCOFI indices of relative spawning output (arithmetic scale without error bars) for the pre-STAR base model and models that included: a) CalCOFI central, b) CalCOFI south, c) CalCOFI “short” south (starting in 1960), and all CalCOFI data (years and areas).

6 - Panel Conclusion

The odd terminal year discrepancies were resolved and the influence of the different regional components of the CalCOFI index on model results are now more understandable.

7 - Request

Run an additional sensitivity that estimates additive variance for the WCGBTS index.

7 - Rationale

Although there is some justification for estimating additive variance for the CalCOFI index, justification for not estimating additive variance for the WCGBTS is missing. Additive variance may be warranted given poor fit during the early portion of the time series and high q.

7 - STAT Response

The additive variance (“extraSD”) for the WCGBTS was estimated at 0.145, which slightly reduces the influence of the WCGBTS index. This change had little effect on the time series of spawning output, but resulted in a slightly poorer fit to the early years of the index (Fig. 7A). The STAT would prefer not to downweight the index but rather search for alternative model configurations that improve fit.

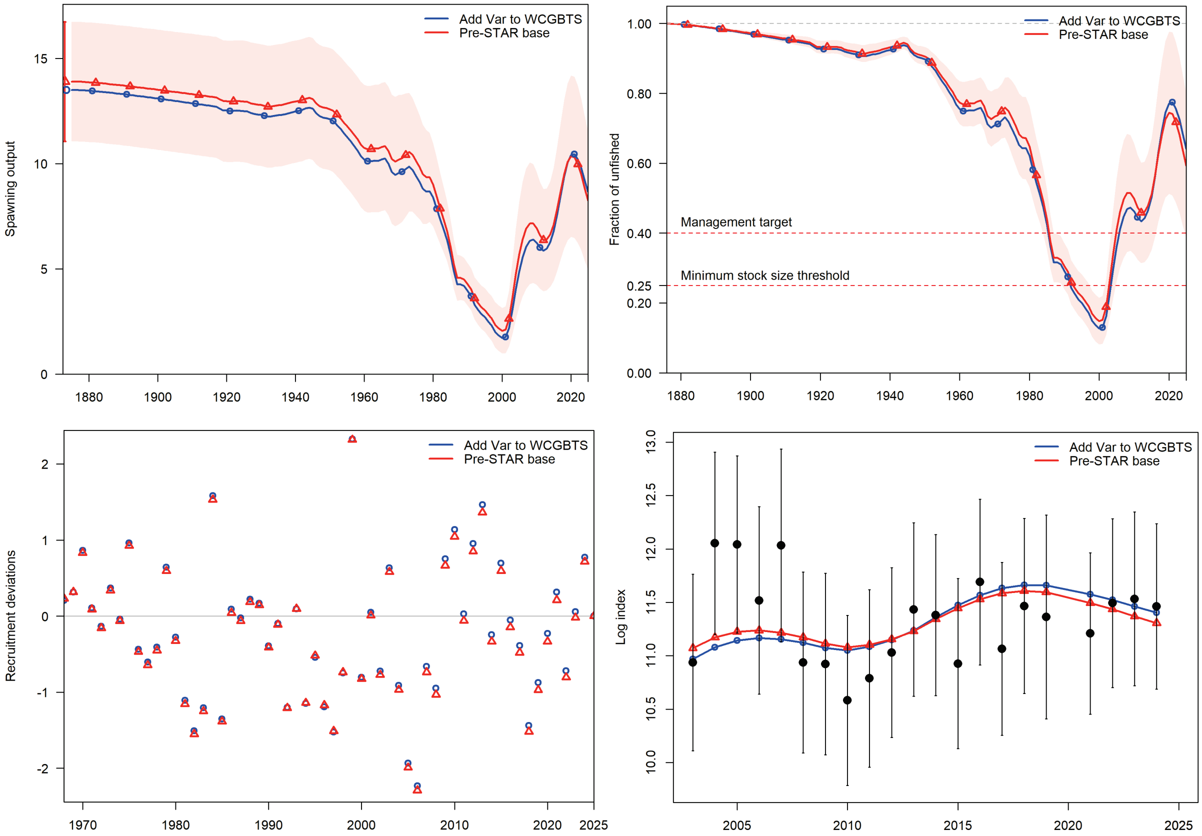


Figure 7A. Spawning output (top left), fraction unfished (top right), recruitment deviations (bottom left), and log-scale fits to the WCGBTS index (bottom left) for the pre-STAR base model and a model that estimates additive variance for the WCGBTS index.

7 - Panel Conclusion

The STAT should explore including a depth effect in the model used to estimate the WCGBTS index (see Request 3) before making a conclusion about estimating additive variance (see Request 12). The Panel agreed that estimation of the requested lnQ was no longer required.

8 - Request

Provide two runs that down-weight all length composition data and age composition by a factor of 2 and 10 using the input sample multiplier (from the final Francis tuned multipliers). Present Pearson residuals for the commercial CA trawl fleet and fits to all fishery-independent indices compared to the pre-STAR base model.

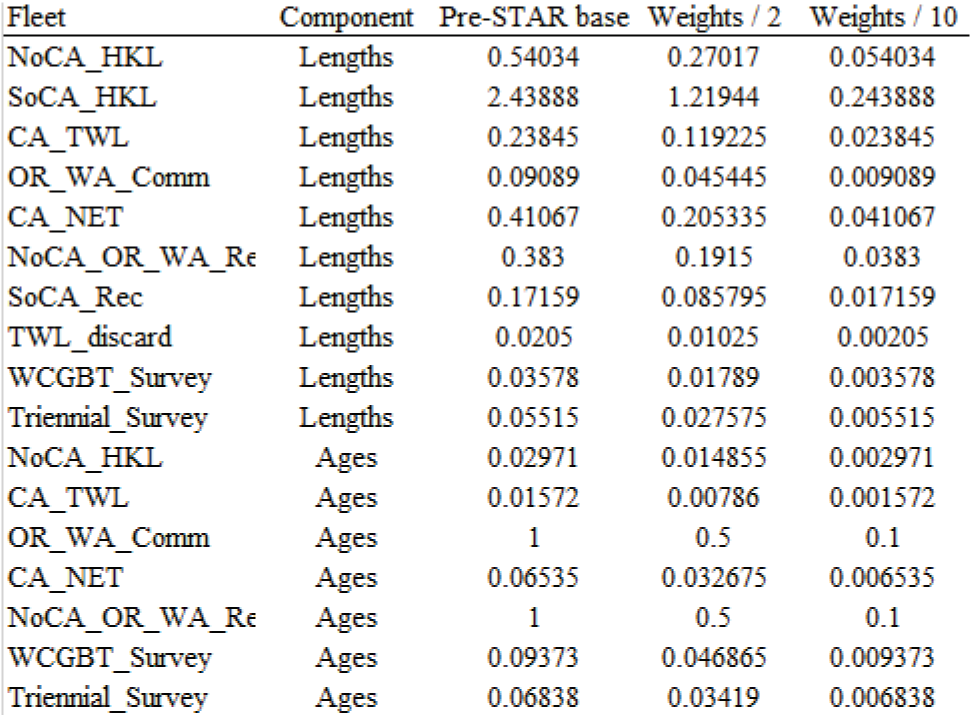
8 - Rationale

It is possible that the composition data are over-weighted.

8 - STAT Response

Two models were run with Francis weights from the pre-STAR base model divided by 2 and 10 (Table 8A). Downweighting the composition data resulted in a more depleted stock and less variable recruitment deviations (Fig. 8).

Table 8. Francis weights from the pre-STAR base model, a model with pre-STAR base model weights divided by 2, and a model with pre-STAR base model weights divided by 10.



Fleet	Component	Pre-STAR base	Weights / 2	Weights / 10
NoCA_HKL	Lengths	0.54034	0.27017	0.054034
SoCA_HKL	Lengths	2.43888	1.21944	0.243888
CA_TWL	Lengths	0.23845	0.119225	0.023845
OR_WA_Comm	Lengths	0.09089	0.045445	0.009089
CA_NET	Lengths	0.41067	0.205335	0.041067
NoCA_OR_WA_Re	Lengths	0.383	0.1915	0.0383
SoCA_Rec	Lengths	0.17159	0.085795	0.017159
TWL_discard	Lengths	0.0205	0.01025	0.00205
WCGBT_Survey	Lengths	0.03578	0.01789	0.003578
Triennial_Survey	Lengths	0.05515	0.027575	0.005515
NoCA_HKL	Ages	0.02971	0.014855	0.002971
CA_TWL	Ages	0.01572	0.00786	0.001572
OR_WA_Comm	Ages	1	0.5	0.1
CA_NET	Ages	0.06535	0.032675	0.006535
NoCA_OR_WA_Re	Ages	1	0.5	0.1
WCGBT_Survey	Ages	0.09373	0.046865	0.009373
Triennial_Survey	Ages	0.06838	0.03419	0.006838

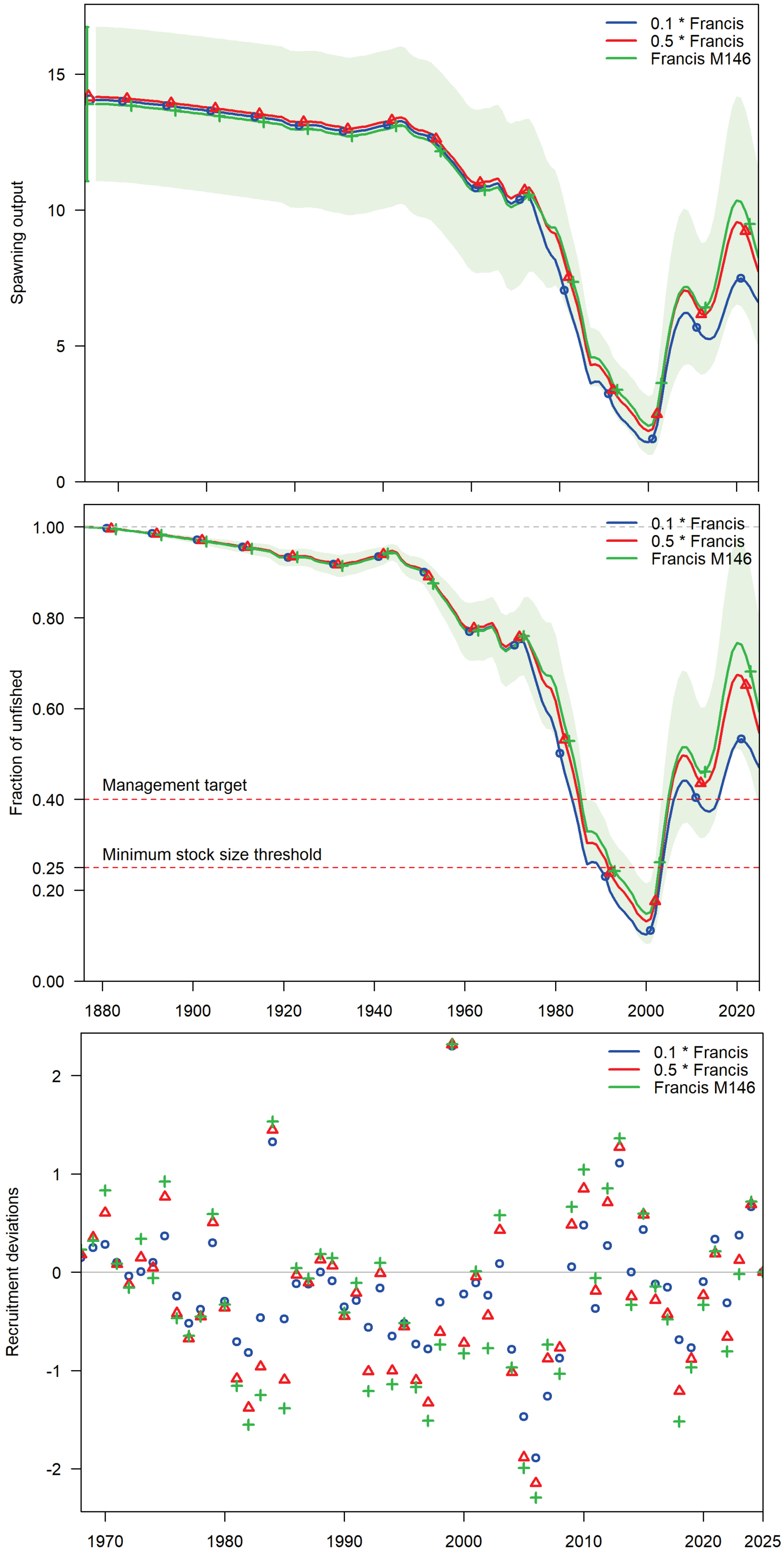


Figure 8. Spawning output (top), fraction unfished (middle), and recruitment deviations (bottom) using Francis weights from the pre-STAR base model, a model with pre-STAR base model weights divided by 2, and a model with pre-STAR base model weights divided by 10.

8 - Panel Conclusion

Downweighting length composition data seems to decrease recruitment deviations and allow other data to change the stock trajectory and stock status. This suggests that there may be some over-weighting of composition data in the pre-STAR base model. The STAT did not have time to show the Pearson residuals and fits to the fishery-independent indices. The Panel acknowledges that responses to other requests should be prioritized first.

9 - Request

Present length-fecundity relationships that depict the variability given different environment regimes alongside the assumed length-fecundity relationship used in the pre-STAR base model. Conduct sensitivities using these alternative length-fecundity relationships with *M* fixed at the value from the pre-STAR base model. Plot spawning output, fraction unfished, and recruitment deviations compared to estimates from the pre-STAR base model.

9 - Rationale

These results will help to characterize the uncertainty in fecundity estimates under varying environmental conditions and could be used to identify an appropriate axis of uncertainty.

9 - STAT Response

The STAT ran the pre-STAR base model with the highest and the lowest length-fecundity relationships (b parameters only, given $F=aL^b$) from the Beyer et al. (2024; Fig. 9A). The STAT ran high and low fecundity scenarios with *M* estimated (as in the pre-STAR base model) and fixed at the pre-STAR base model estimate. The results dramatically scaled estimates of larval production, but had only a modest influence on relative abundance (i.e., depletion or fraction unfished; Fig. 9B). *M* changed only trivially in the low fecundity model, with *M* estimated from 0.1706 to 0.17089. *M* changed more substantively for the high fecundity model, with *M* estimated from 0.1706 to 0.1772. This reflected the increase in age 3+ biomass.

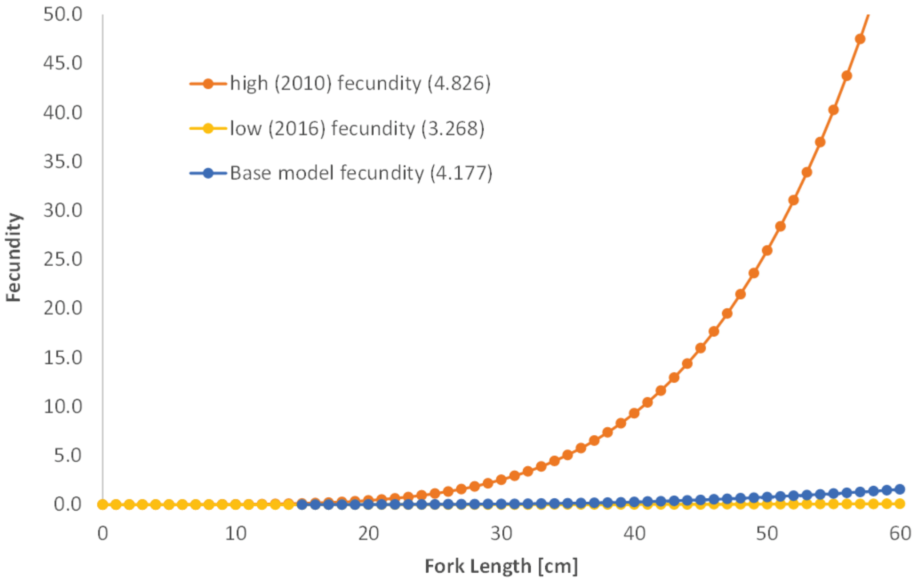


Figure 9A. Alternative length-fecundity relationships used to account for effects of different environmental conditions on stock productivity (i.e., by modifying the exponent for multiple brooding).

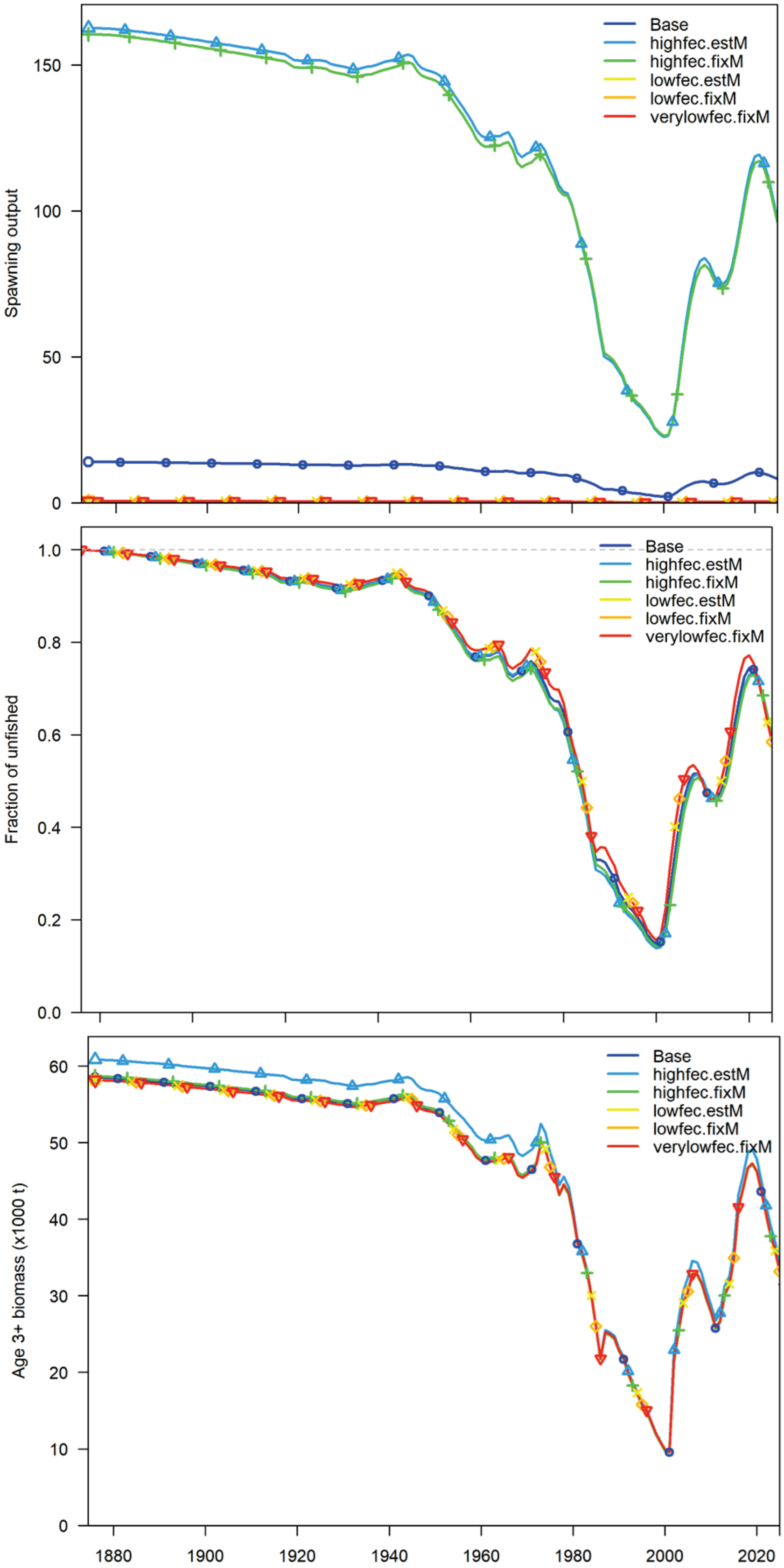


Figure 9B. Spawning output (top), fraction unfished (middle), and age 3+ biomass (bottom) from the suite of models with alternative length-fecundity relationships.

9 - Panel Conclusion

These results were very useful to understand how variability in fecundity translates to uncertainty in stock status. It appears that variability in fecundity has a minor effect on model uncertainty.

10 - Request

Create a squid plot using a 15-year retrospective analysis. This should include recruitment deviation on the y-axis and age on the x-axis, showing the age at which estimated recruitment begins to be informed by data.

10 - Rationale

There are a few large year classes that are important to the stock trajectory, one of which is from 2013. It will be beneficial to understand how long it takes to generate reasonable estimates of recruitment, whether low or high.

10 - STAT Response

The STAT ran 15-year retrospective analyses with and without the Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) index (Fig. 10). The difference was surprisingly small. After a bit more investigation, it appears that there is quite a bit of information for age 0 and 1 yr fish from the WCGBTS. The combination of tuning the RREAS index and not tuning the WCGBTS index essentially upweights the trawl data. The STAT completed several additional runs with the WCGBTS index tuned and the RREAS index upweighted to better understand how each index is informing near-term recruitments. The STAT explored other options to better understand the relative influence of the two indices on early recruitment deviations. This included tuning the WCGBTS (which was untuned in pre-STAR base model) to slightly reduce its estimate of recruitment and decreased tuning of the RREAS index.

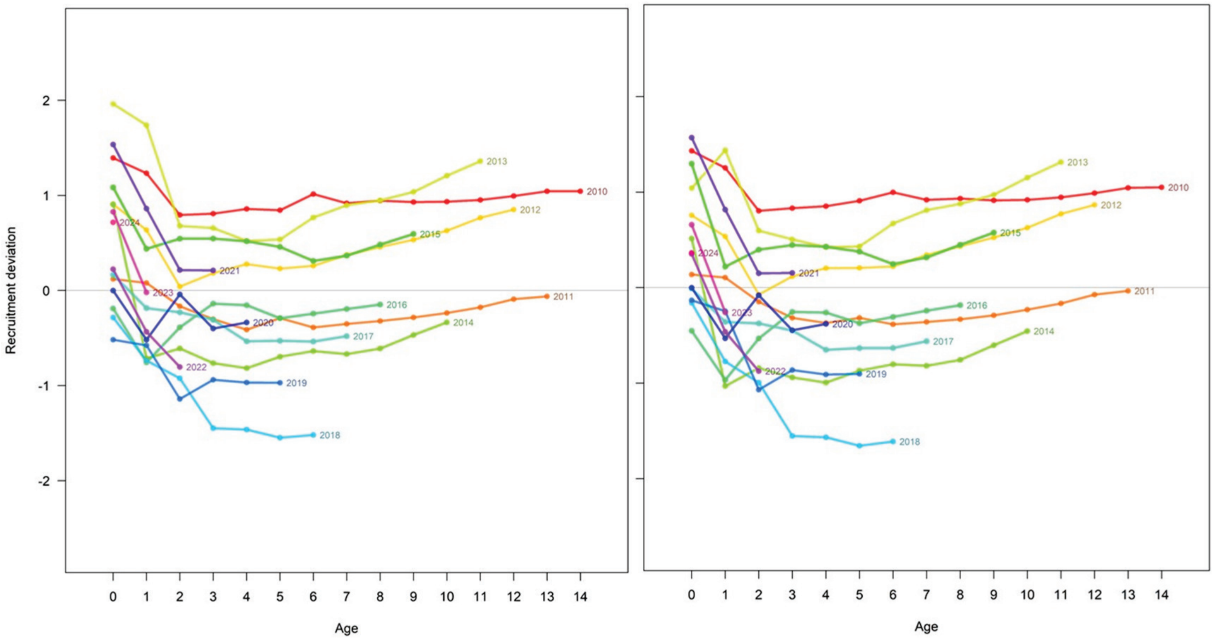


Figure 10. Squid diagnostic plots from the pre-STAR base model with a 15-year retrospective with (left) and without (right) the RREAS pelagic young-of-the-year index.

10 - Panel Conclusion

These plots show the importance of the WCGBTS index in predicting year class strength and that it provides information when the cohort was age 0 yr. Although the RREAS was appropriately weighted and included additive variance, the outcome was that this index had very little weight and virtually no influence on model results. The RREAS index became appropriately more influential when either removing the additive variance or when downweighting the

WCGBTS index. There was concern that the strength of a cohort at age 0 yr was estimated above average and tended to be reduced as the cohort aged in the pre-STAR base model. The Panel realizes that changes to the pre-STAR base model from other requests could modify these conclusions, so there may be a need to revise these figures as part of future requests.

11 - Request

Estimate steepness with and without the sum-to-zero constraint on recruitment deviations. Please use the revised model based on conclusions from earlier requests and calculate the mean of the recruitment deviations from the main recruitment estimation period. Plot spawning output, fraction unfished, age-0 recruits, and recruitment deviations. Please provide a table showing the parameters with reference points, including the SPR proxy for yield.

11 - Rationale

The mean recruitment deviations from the main recruitment estimation period was < 0 without a sum-to-zero constraint. The pre-STAR base model, which fixed steepness at 0.72, may be attempting to reduce recruitment during this period, which included years with low predicted spawning biomass. Reduced recruitment could result from reduced spawning biomass.

11 - STAT Response

The revised base model (i.e., pre-STAR base with asymptotic selectivity curves for fleets with poor MCMC diagnostics in the descending scale parameter; “M160”) was used to complete this request. Estimates of steepness were lower than the prior mean in both runs, resulting in a more depleted stock status. When steepness is estimated, the change in model scale and trend is less pronounced between models with and without the sum-to-zero constraint for recruitment deviations (Fig. 11A) compared to models with steepness fixed at the prior mean of 0.72 (Fig. 11B). When steepness is estimated, the mean recruitment deviation without a sum-to-zero constraint is -0.14. With the constraint, the mean is near zero ($7\text{x}10^{-8}$), as expected. By fixing steepness at a value that is slightly less consistent with the data (i.e., h = 0.72), the simple deviations are scaled down to best fit the data, decreasing productivity and increasing estimates of R_0 and M (Table 11; Fig. 11B).

The current model does not have a precise estimate of steepness (see bivariate likelihood profile over steepness and female M in the main document). The STAT therefore recommends that the assessment continue to fix steepness at 0.72. The current accepted practices also recommend that the Methot and Taylor (2011) method be applied to reduce bias in estimates of unfished equilibrium recruitment. However, that method was developed using the sum-to-zero constraint (“deviation vector” option) in Stock Synthesis. Therefore, the STAT recommends that a revised base model be constructed that a) continues to fix steepness at 0.72, b) continues to use the bias adjustment, and c) enforces a sum-to-zero constraint on recruitment deviations.

Given that the model is sensitive to the treatment of recruitment deviations (sum-to-zero or unconstrained), the STAT recommends that a new assessment be conducted if future research clarifies the preferred approach to estimating recruitment deviations, whether bias adjustment is needed when using maximum likelihood without a sum-to-zero constraint, and the type of deviation vector that gives unbiased parameter estimates when using MCMC. From the results of this analysis, it appears that assumptions about steepness also need to be considered as part of future research recommendations.

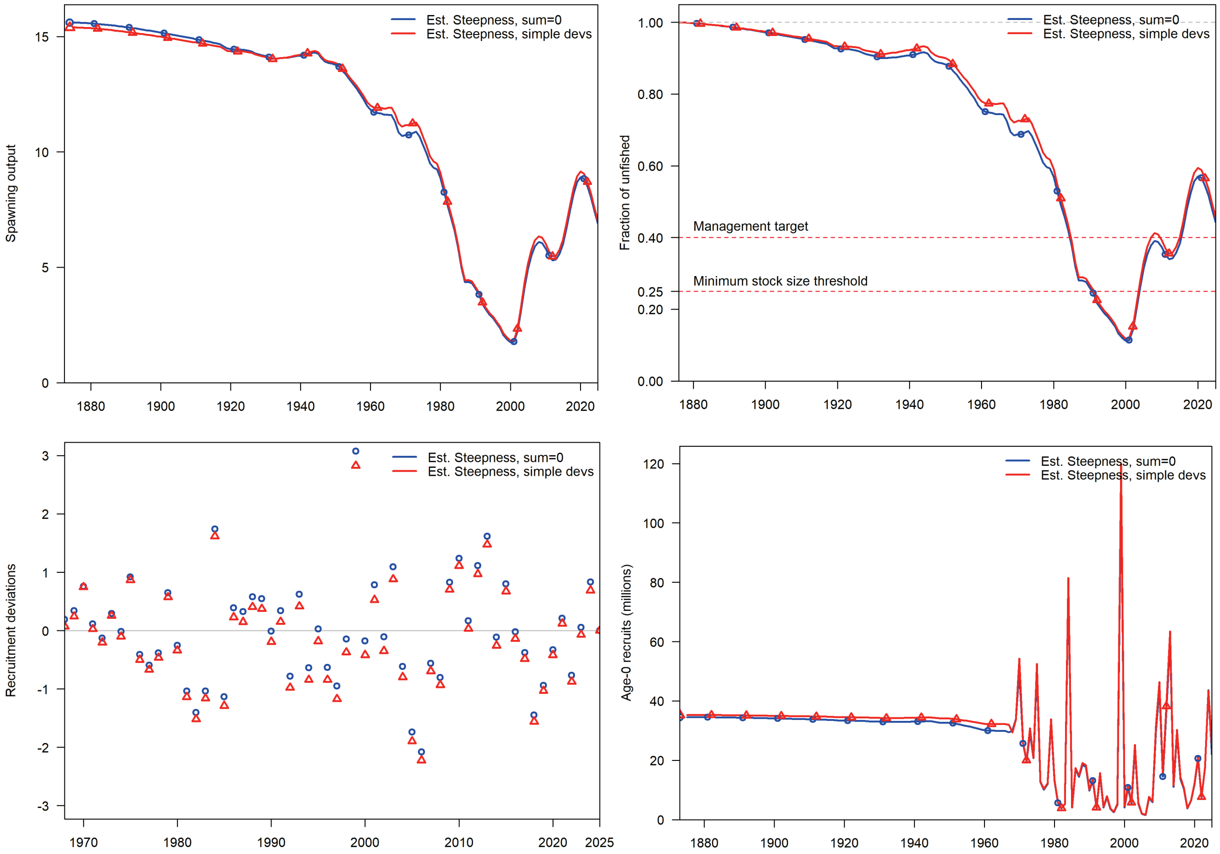


Figure 11A. Spawning output (top left), fraction unfished (top right), recruitment deviations (bottom left), and age-0 recruits (bottom right) for models with steepness estimated and either unconstrained recruitment deviations (red lines and points) or a sum-to-zero constraint on recruitment deviations (blue lines and points).

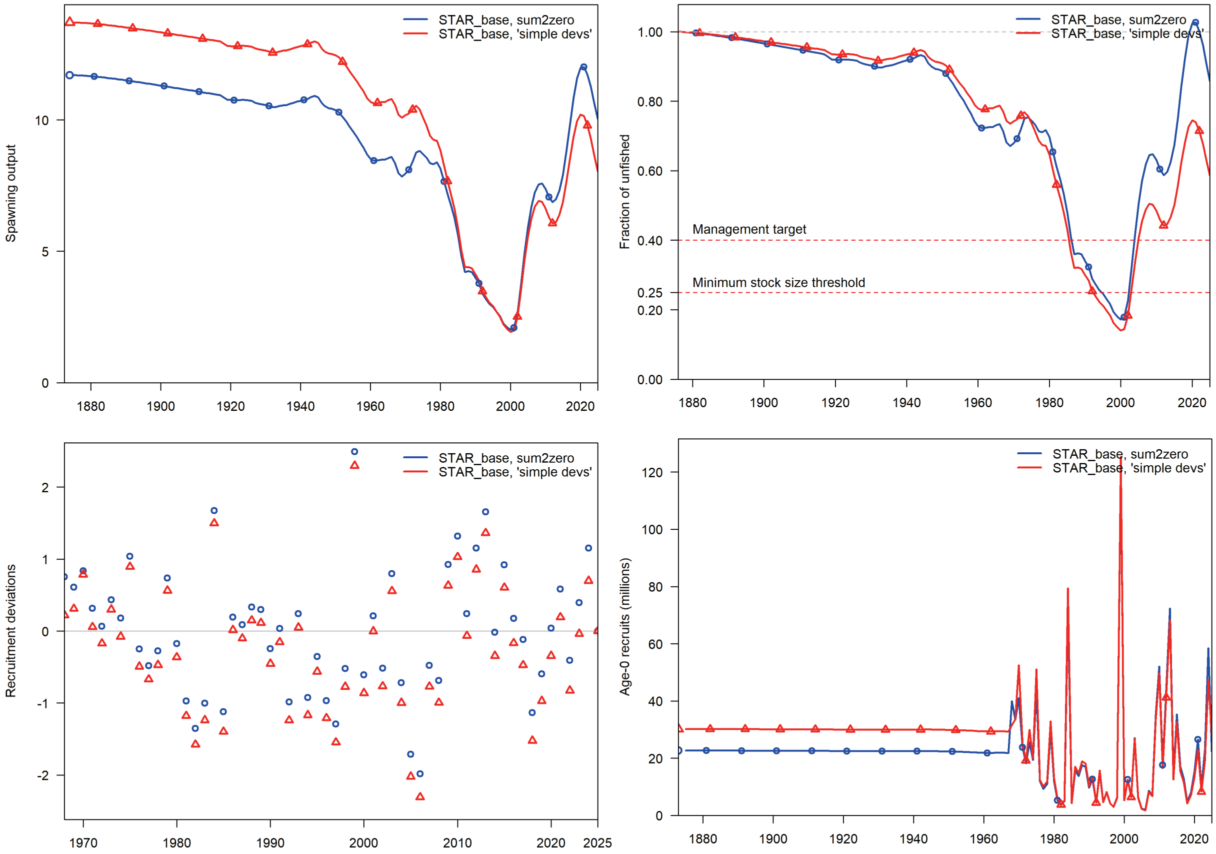
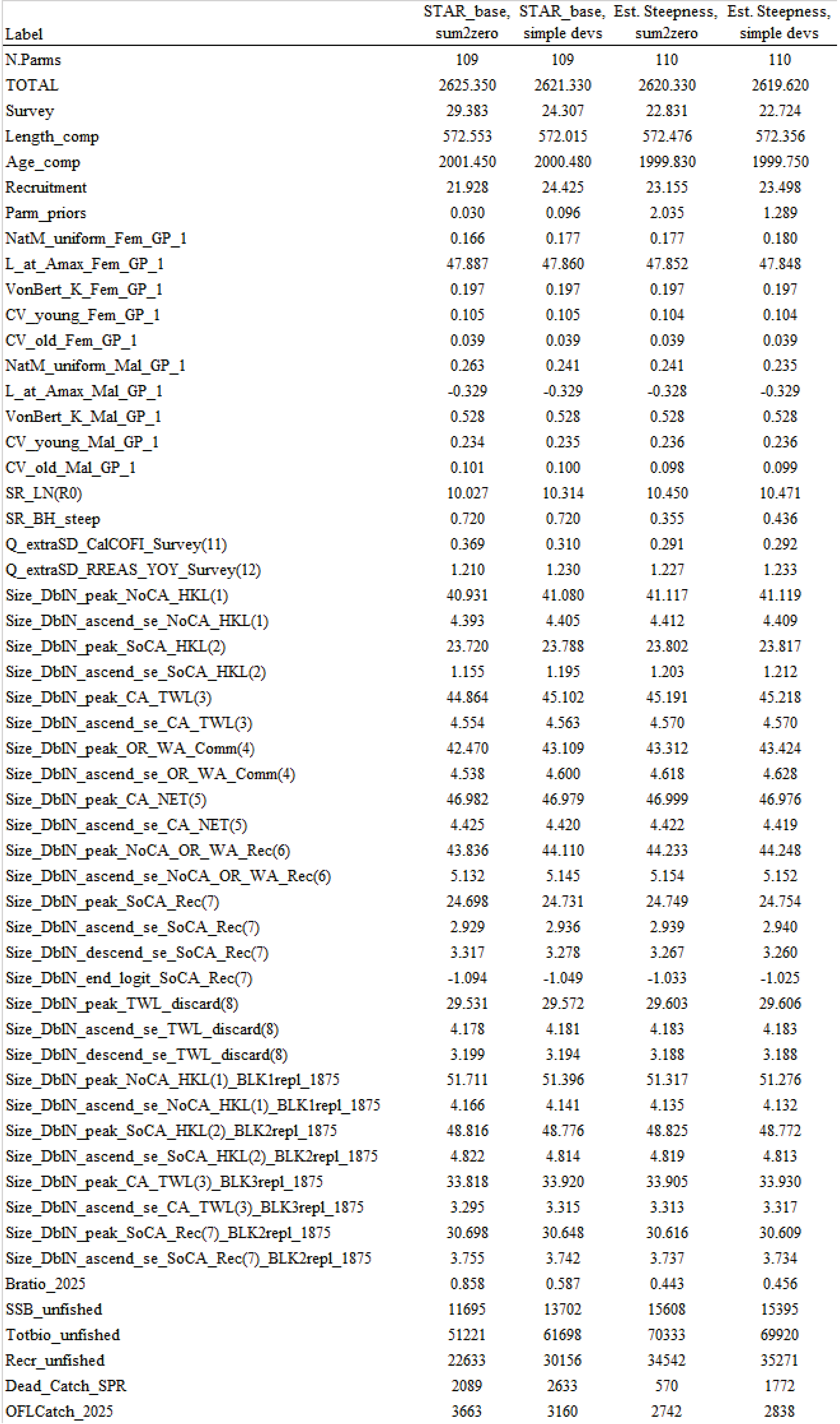


Figure 11B. Spawning output (top left), fraction unfished (top right), recruitment deviations (bottom left), and age-0 recruits (bottom right) for models with steepness fixed at the prior mean of 0.72 and either unconstrained recruitment deviations (red lines and points) or a sum-to-zero constraint on recruitment deviations (blue lines and points).

Table 11. Likelihood components, parameter estimates, and derived quantities from models with steepness fixed or estimated and recruitment deviations either unconstrained or with a sum-to-zero constraint.



Label	STAR_base, sum2zero	STAR_base, simple devs	Est. Steepness, sum2zero	Est. Steepness, simple devs
N.Parms	109	109	110	110
TOTAL	2625.350	2621.330	2620.330	2619.620
Survey	29.383	24.307	22.831	22.724
Length_comp	572.553	572.015	572.476	572.356
Age_comp	2001.450	2000.480	1999.830	1999.750
Recruitment	21.928	24.425	23.155	23.498
Parm_priors	0.030	0.096	2.035	1.289
NatM_uniform_Fem_GP_1	0.166	0.177	0.177	0.180
L_at_Amax_Fem_GP_1	47.887	47.860	47.852	47.848
VonBert_K_Fem_GP_1	0.197	0.197	0.197	0.197
CV_young_Fem_GP_1	0.105	0.105	0.104	0.104
CV_old_Fem_GP_1	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.263	0.241	0.241	0.235
L_at_Amax_Mal_GP_1	-0.329	-0.329	-0.328	-0.329
VonBert_K_Mal_GP_1	0.528	0.528	0.528	0.528
CV_young_Mal_GP_1	0.234	0.235	0.236	0.236
CV_old_Mal_GP_1	0.101	0.100	0.098	0.099
SR_LN(R0)	10.027	10.314	10.450	10.471
SR_BH_steep	0.720	0.720	0.355	0.436
Q_extraSD_CalCOFI_Survey(11)	0.369	0.310	0.291	0.292
Q_extraSD_RREAS_YOY_Survey(12)	1.210	1.230	1.227	1.233
Size_DblN_peak_NoCA_HKL(1)	40.931	41.080	41.117	41.119
Size_DblN_ascend_se_NoCA_HKL(1)	4.393	4.405	4.412	4.409
Size_DblN_peak_SoCA_HKL(2)	23.720	23.788	23.802	23.817
Size_DblN_ascend_se_SoCA_HKL(2)	1.155	1.195	1.203	1.212
Size_DblN_peak_CA_TWL(3)	44.864	45.102	45.191	45.218
Size_DblN_ascend_se_CA_TWL(3)	4.554	4.563	4.570	4.570
Size_DblN_peak_OR_WA_Comm(4)	42.470	43.109	43.312	43.424
Size_DblN_ascend_se_OR_WA_Comm(4)	4.538	4.600	4.618	4.628
Size_DblN_peak_CA_NET(5)	46.982	46.979	46.999	46.976
Size_DblN_ascend_se_CA_NET(5)	4.425	4.420	4.422	4.419
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.836	44.110	44.233	44.248
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.132	5.145	5.154	5.152
Size_DblN_peak_SoCA_Rec(7)	24.698	24.731	24.749	24.754
Size_DblN_ascend_se_SoCA_Rec(7)	2.929	2.936	2.939	2.940
Size_DblN_descend_se_SoCA_Rec(7)	3.317	3.278	3.267	3.260
Size_DblN_end_logit_SoCA_Rec(7)	-1.094	-1.049	-1.033	-1.025
Size_DblN_peak_TWL_discard(8)	29.531	29.572	29.603	29.606
Size_DblN_ascend_se_TWL_discard(8)	4.178	4.181	4.183	4.183
Size_DblN_descend_se_TWL_discard(8)	3.199	3.194	3.188	3.188
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.711	51.396	51.317	51.276
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.166	4.141	4.135	4.132
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.816	48.776	48.825	48.772
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.822	4.814	4.819	4.813
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.818	33.920	33.905	33.930
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.295	3.315	3.313	3.317
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.698	30.648	30.616	30.609
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.755	3.742	3.737	3.734
Bratio_2025	0.858	0.587	0.443	0.456
SSB_unfished	11695	13702	15608	15395
Totbio_unfished	51221	61698	70333	69920
Recr_unfished	22633	30156	34542	35271
Dead_Catch_SPR	2089	2633	570	1772
OFLCatch_2025	3663	3160	2742	2838

11 - Panel Conclusion

The Panel generally agrees with the proposed way forward, which is to consider best practices of using bias correction for recruitment deviations and modelling recruitment deviations along with a steepness fixed at the mean of the prior. It is uncertain whether the bias correction method is appropriate without a sum-to-zero constraint on recruitment deviations. It was noted that when estimating steepness, the difference between constraining recruitment deviations or not was much smaller than when fixing steepness at a larger value. This topic deserves further research.

12 - Request

Predict the WCGBTS index with depth as a covariate and assuming isotropy (all other model configurations unchanged). If a suitable alternative index (as determined by the STAT) is identified, please run a revised base model using this index. Please include information about how the depth effect was modeled and show the marginal effect of depth.

12 - Rationale

An initial WGCBTS index with depth as a covariate (from Request 3) showed large differences in scale and wider confidence intervals compared to the pre-STAR base model index. The analysis was preliminary and changes to the index model setting should be explored further.

12 - STAT Response

Further investigation revealed an incorrect sign in the scaled depth range of the prediction grid. Thus, the model was extrapolating to unobserved depth values, leading to the large difference in scale, high uncertainty, and different trends. This issue was corrected in the new index.

Depth was standardized and included as a quadratic covariate for the binomial and positive models. Isotropy was assumed, as requested. The model was configured as follows:

```
newfit1 <- sdmTMB(formula = catch_weight ~
             0 + fyear + pass_scaled + depth_scaled + depth_scaled_squared,
                      data = data_truncated,
                      mesh = mesh,
                      time = "year",
                      family = delta_lognormal(type="standard"),
                      spatial = "on",
                      spatiotemporal = list("iid", "off"),
                      share_range = TRUE,
                      offset = log(data_truncated$effort),
                      anisotropy = FALSE)
```

The relationship between model residuals and depth was explored for a) the original model without depth and assuming anisotropy, b) the original model without anisotropy, and c) the new model with depth and assuming isotropy (Fig. 12A). Models without depth showed a relationship between the residuals and depth, particularly for the positive component of the delta model. This suggests that anisotropy does not account for depth effects and that depth is informative.

The new index (using correct scaled depth values) had a similar trend and variance estimate as the original index, but was somewhat lower in scale (abundances ~15% smaller when including a depth effect; Fig. 12B).

Marginal effects could not be produced as this required regenerating the mesh and the STAT did not have information about the parameters used to generate the original. As a substitute, the STAT computed the conditional effect of depth by predicting biomass across the range of observed depths at the mean latitude and longitude of the prediction grid for the first year of the survey (Fig. 12C). This shows a peak in biomass around 200 m, with few fish observed at the shallowest depths and deeper than 350 m.

The revised base model was run with this new index without re-tuning (Fig. 12D). Catchability (q) for the revised index was 1.84, compared to a value > 2 for the model without depth. Fits to the survey component and total likelihood improved more than two likelihood points with no change in the number of parameters (Table 12), suggesting a better fit when depth was included. The model fit to the index with depth effects did not require tuning, as the Francis weights were unchanged to the third decimal place.

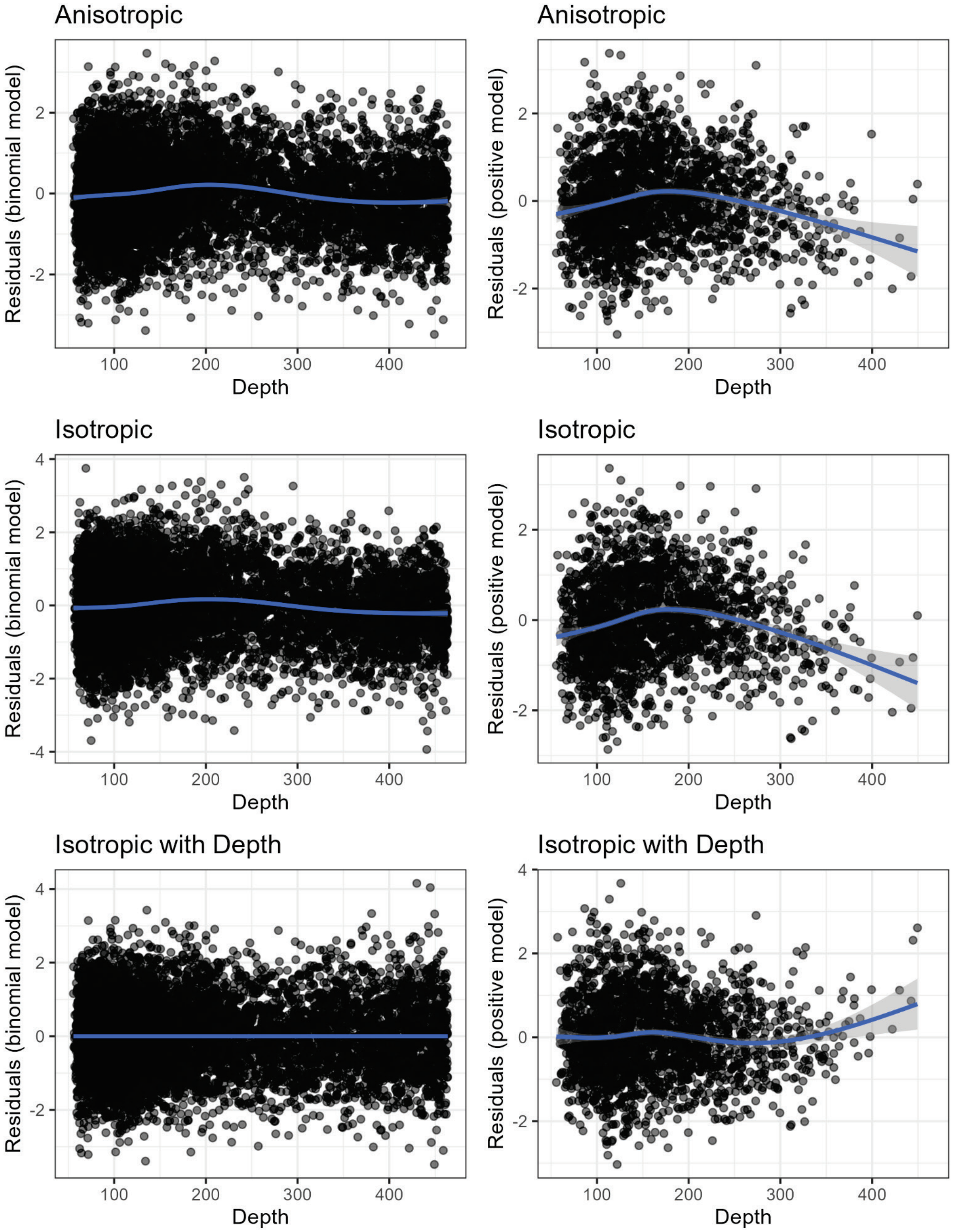


Figure 12A. Model residuals for the original WCGBTS index model that assumed anisotropy and did not include a depth effect (top), a revised WCGBTS index model that assumed isotropy (middle), and a revised WCGBTS index model that assumed isotropy and included a depth effect (bottom). Binomial (left) and positive (right) models are shown.

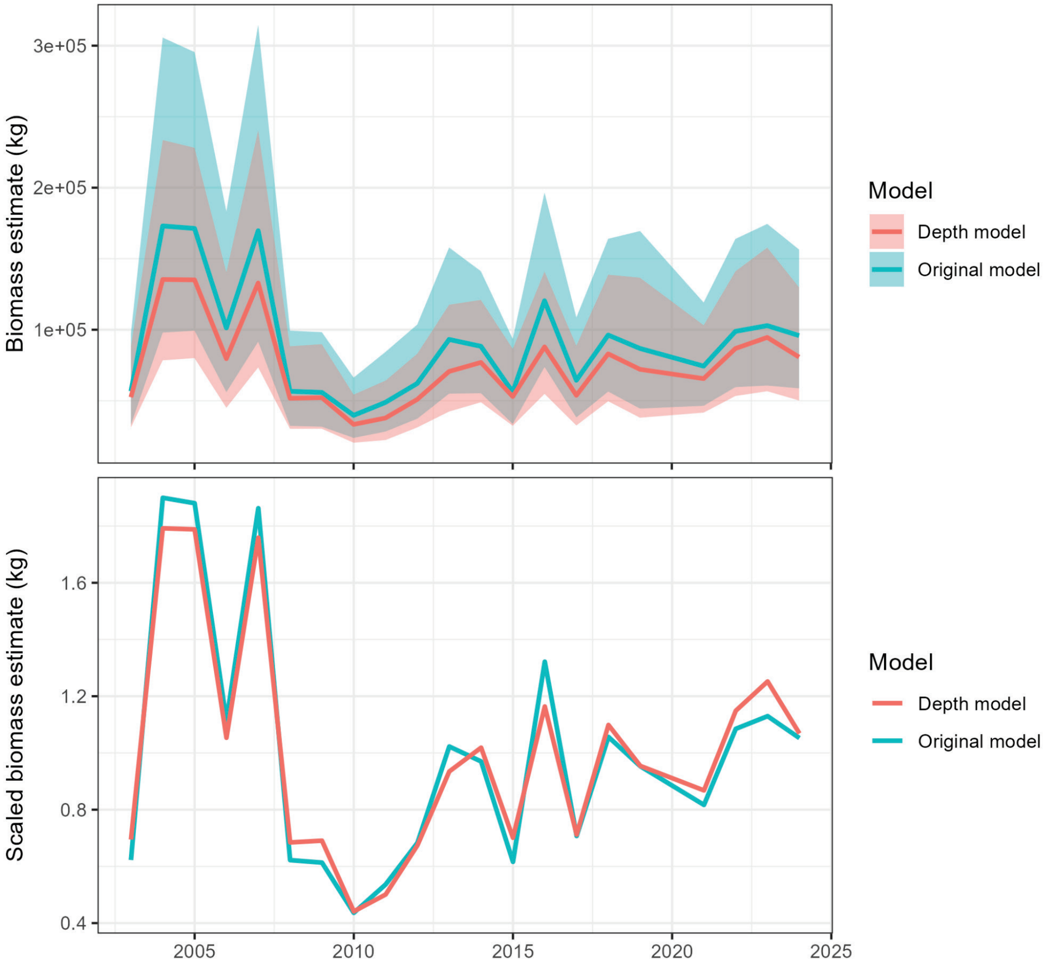


Figure 12B. The original WCGBTS index and a revised WCGBTS index that includes depth as a covariate and assumes isotropy (top). Biomass estimates were also scaled using their respective means (bottom).

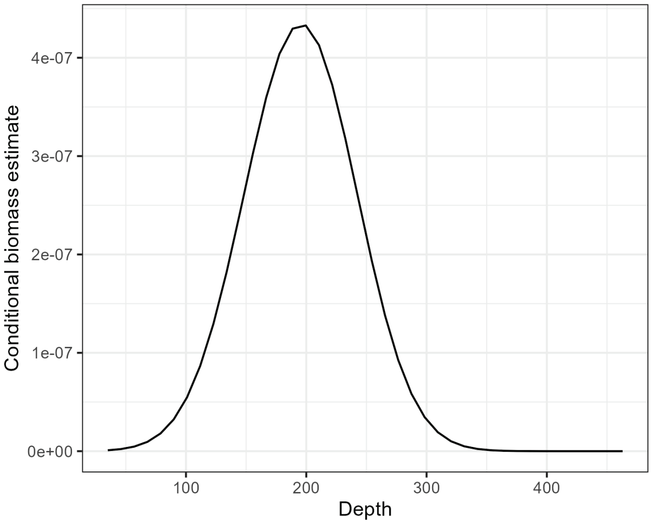


Figure 12C. Conditional effect of depth on biomass (link scale) using the WCGBTS index model. Predicted biomass densities are shown across the full range of observed depths, assuming the mean latitude and longitude of the prediction grid during the first year of the survey.

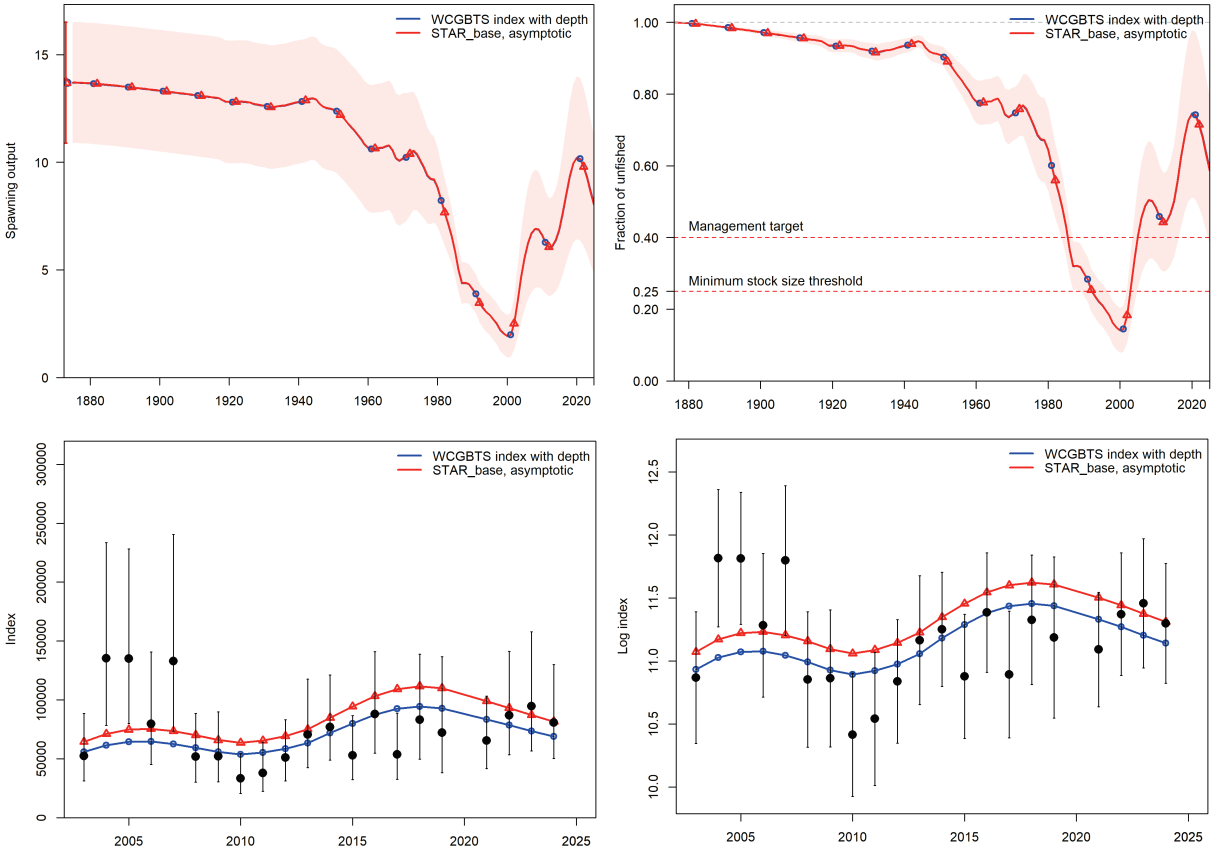
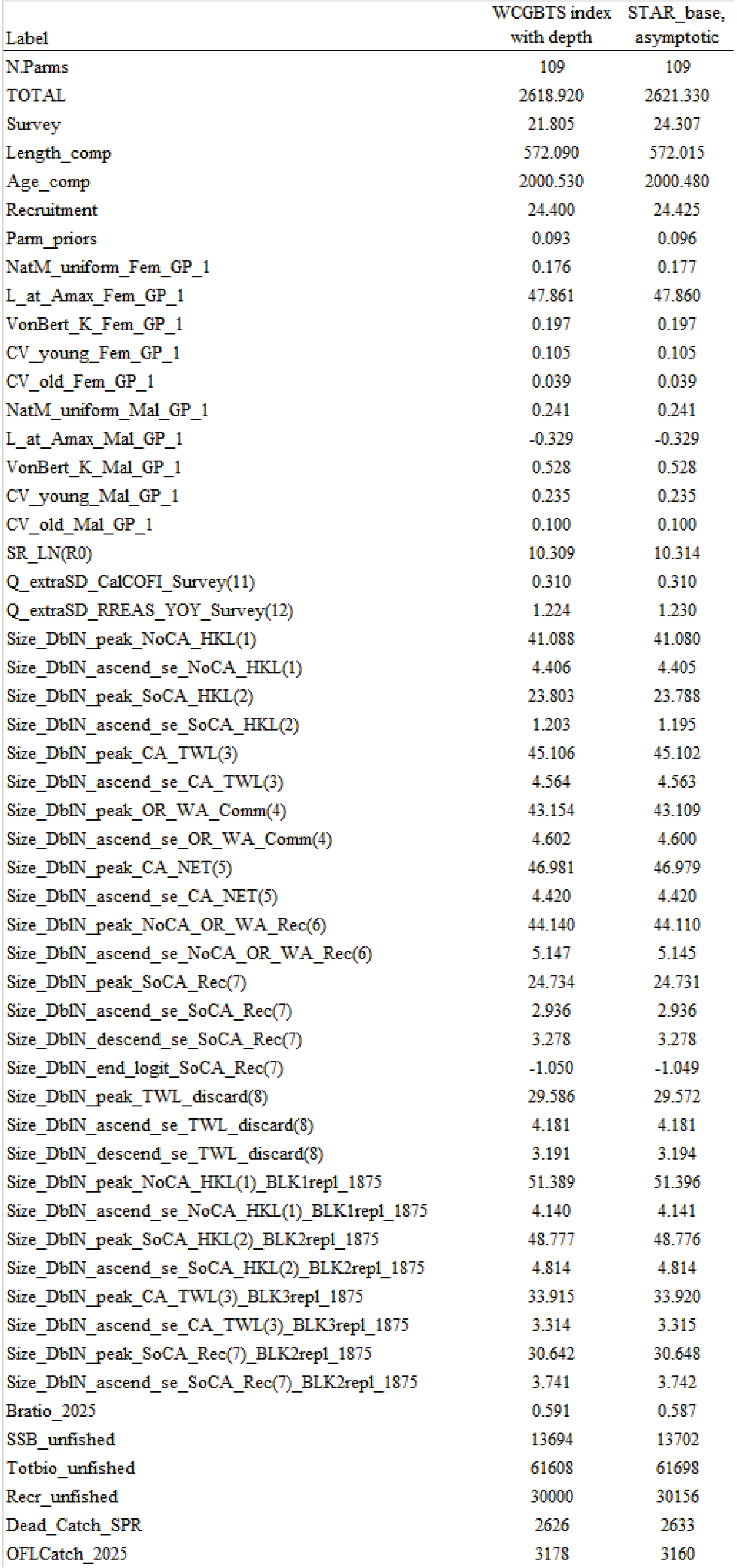


Figure 12D. Spawning output (top left), fraction unfished (top right), model fits to data (arithmetic scale) on the index (bottom left) and log scale (bottom right). Note that fits are not comparable due to a change in index scale when adding depth effect.

Table 12. Likelihood components, parameter estimates, and derived quantities for models fit to WCGBTS indices with and without a depth effect.



Label	WCGBTS index with depth	STAR_base, asymptotic
N.Parms	109	109
TOTAL	2618.920	2621.330
Survey	21.805	24.307
Length_comp	572.090	572.015
Age_comp	2000.530	2000.480
Recruitment	24.400	24.425
Parm_priors	0.093	0.096
NatM_uniform_Fem_GP_1	0.176	0.177
L_at_Amax_Fem_GP_1	47.861	47.860
VonBert_K_Fem_GP_1	0.197	0.197
CV_young_Fem_GP_1	0.105	0.105
CV_old_Fem_GP_1	0.039	0.039
NatM_uniform_Mal_GP_1	0.241	0.241
L_at_Amax_Mal_GP_1	-0.329	-0.329
VonBert_K_Mal_GP_1	0.528	0.528
CV_young_Mal_GP_1	0.235	0.235
CV_old_Mal_GP_1	0.100	0.100
SR_LN(R0)	10.309	10.314
Q_extraSD_CalCOFI_Survey(11)	0.310	0.310
Q_extraSD_RREAS_YOY_Survey(12)	1.224	1.230
Size_DblN_peak_NoCA_HKL(1)	41.088	41.080
Size_DblN_ascend_se_NoCA_HKL(1)	4.406	4.405
Size_DblN_peak_SoCA_HKL(2)	23.803	23.788
Size_DblN_ascend_se_SoCA_HKL(2)	1.203	1.195
Size_DblN_peak_CA_TWL(3)	45.106	45.102
Size_DblN_ascend_se_CA_TWL(3)	4.564	4.563
Size_DblN_peak_OR_WA_Comm(4)	43.154	43.109
Size_DblN_ascend_se_OR_WA_Comm(4)	4.602	4.600
Size_DblN_peak_CA_NET(5)	46.981	46.979
Size_DblN_ascend_se_CA_NET(5)	4.420	4.420
Size_DblN_peak_NoCA_OR_WA_Rec(6)	44.140	44.110
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.147	5.145
Size_DblN_peak_SoCA_Rec(7)	24.734	24.731
Size_DblN_ascend_se_SoCA_Rec(7)	2.936	2.936
Size_DblN_descend_se_SoCA_Rec(7)	3.278	3.278
Size_DblN_end_logit_SoCA_Rec(7)	-1.050	-1.049
Size_DblN_peak_TWL_discard(8)	29.586	29.572
Size_DblN_ascend_se_TWL_discard(8)	4.181	4.181
Size_DblN_descend_se_TWL_discard(8)	3.191	3.194
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.389	51.396
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.140	4.141
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.777	48.776
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.814	4.814
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.915	33.920
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.314	3.315
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.642	30.648
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.741	3.742
Bratio_2025	0.591	0.587
SSB_unfished	13694	13702
Totbio_unfished	61608	61698
Recr_unfished	30000	30156
Dead_Catch_SPR	2626	2633
OFLCatch_2025	3178	3160

12 - Panel Conclusion

Proceed with the new WCGBTS index that accounts for depth and assumes isotropy.

13 - Request

Estimate the peak and ascending variance parameters for selectivity of the WCGBTS and Triennial survey. Use the quick MCMC algorithm to determine how well these parameters are estimated and what reasonable values may be. Keep these survey selectivities as asymptotic and use the assumptions for commercial selectivities as in the "No Dome: All" run (Request 2).

13 - Rationale

The selectivities for these trawl surveys were not estimated in the pre-STAR base model. Forcing many of the commercial selectivities to be asymptotic (as done for Request 2) may improve the ability to estimate survey selectivities.

13 - STAT Response

Using the asymptotic selectivity base model established in Request 2, asymptotic selectivity was added for the WCGBTS and Triennial survey. The ascending scale and peak parameters were estimated using the double normal functional form with the other parameters fixed as asymptotic.

Selparm[55] and selparm[57] are the Triennial peak and ascending scale parameters, respectively. The Triennial survey selectives are poorly estimated, with posterior modes against parameter bounds and a substantial tail in the peak parameter (Fig. 13A). Triennial parameter MLEs are not well reflected in the posteriors. Selparm[51] and selparm[49] are WCGBTS ascending scale and peak, respectively. The WCGBTS selectivity parameters display some multimodality (Fig. 13A). Multimodality is evidence of a nearby local mode, but the prominent mode seems well defined and reasonably well captured by the MLE estimates.

Fitted end-year selectivities with asymptotic selectivities for the WCGBTS and Triennial survey are provided (Fig. 13B). A small improvement to marginal length composition fit at small sizes resulted from fitting the WCGBTS selectivity (Fig. 13C).

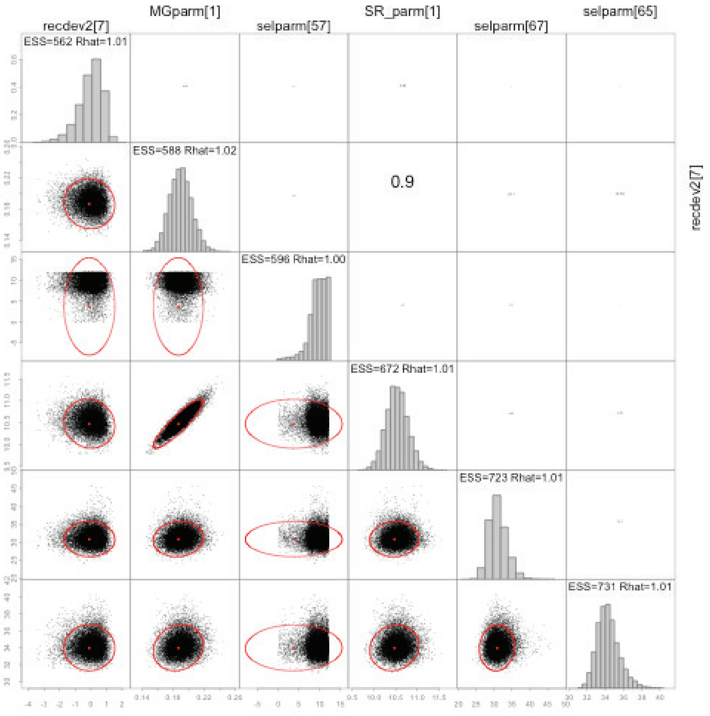
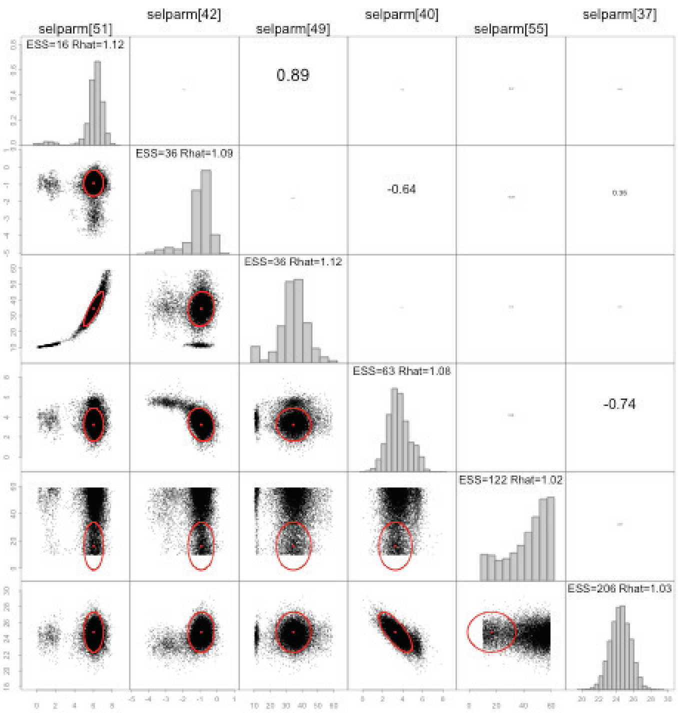


Figure 13A. Bivariate scatter plots and histograms of estimated selectivity parameters for the WCGBTS and Triennial survey, based on Request 13. Selparm[55] and selparm[57] are the Triennial peak and ascending scale parameters, respectively. Selparm[51] and



selparm[49] are WCGBTS ascending scale and peak, respectively.

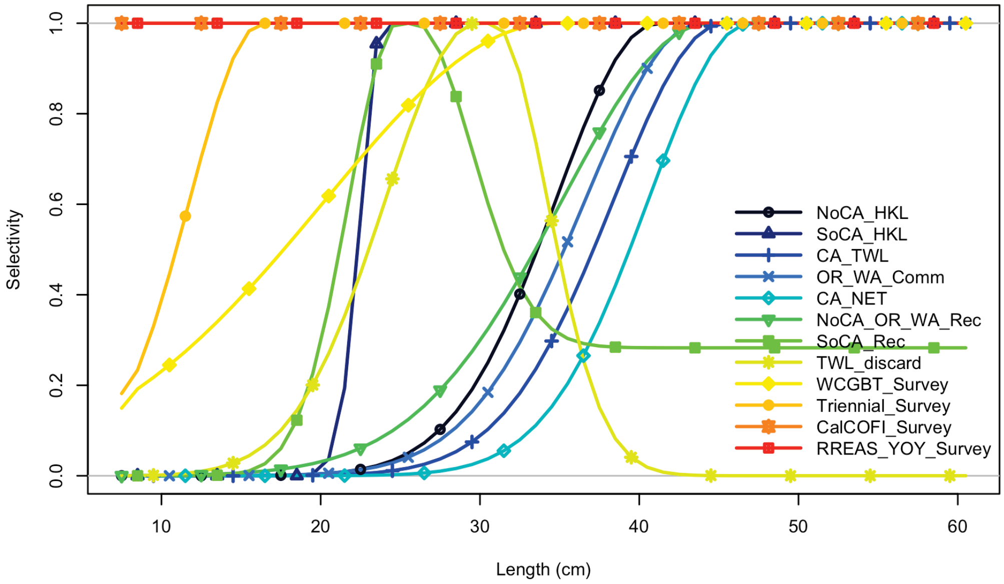


Figure 13B. Fitted end-year selectivities with asymptotic selectivities for the WCGBTS and Triennial survey.

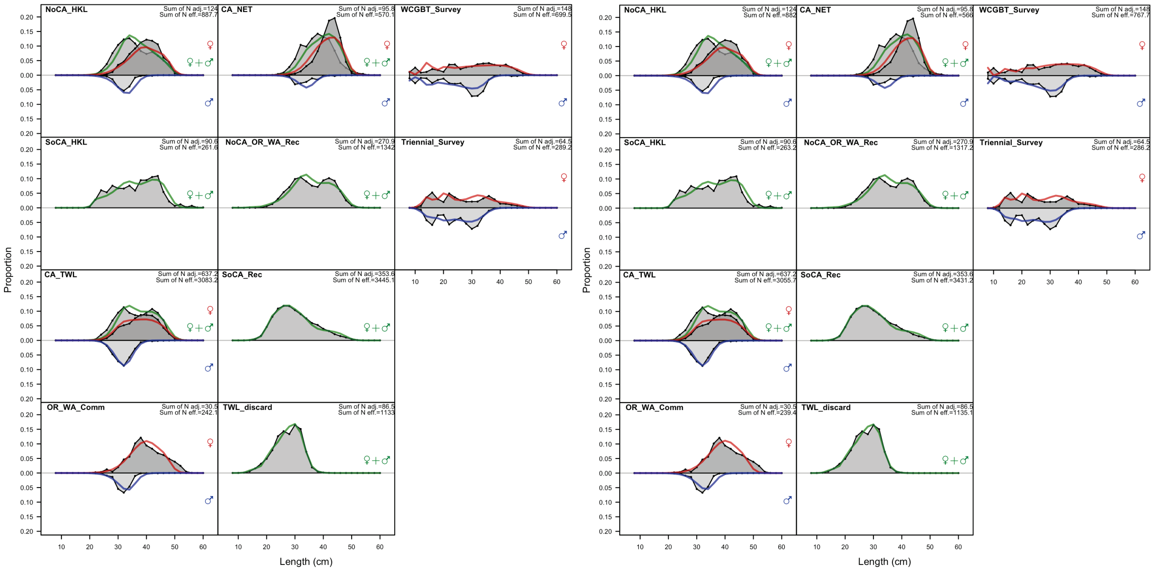


Figure 13C. Fits to marginal length compositions using the asymptotic base model (left) and with the added asymptotic selectivities for the WCGBTS and Triennial survey (right).

13 - Panel Conclusion

The Panel appreciates the work done by the STAT. The MCMC run is very informative and shows that there may be some multimodality in the selectivity parameter estimates. This request prompted Request 16 (evaluating predicted spatial fields).

14 - Request

Examine catch rates in early years (2004 to 2007) of the WCGBTS and compare those to catch rates in later years (2008 to 2024) . This may include creating bubble plots of raw catch rates, identifying the locations and magnitude of the 10 highest catch rates each year, and presenting depth-stratified proportions of zero catch.

14 - Rationale

The early years of the WCGBTS show high index values that are not well represented by the model. A better understanding about spatial distributions of catch will help determine how likely these years are to reflect overall stock abundance.

14 - STAT Response

The STAT worked with GIS analyst, Rebecca Miller (UCSC), to update plots that were initially developed for the 2015 assessment update. These plots show WCGBTS catch rates for the entire California coast (i.e., the region of greatest abundance; Fig. 14A) and for central California (Fig. 14B) during two time periods: 2004 to 2007 and 2008 to 2024. The highest catches are most frequently close to the shelf break (between 125 and 275 m depth), particularly in regions where the continental slope is steep. The results do not suggest substantive changes in the distribution of high and low catches between these two time periods, although this is difficult to discern from the figure alone. A provisional table of the total number of WCGBTS tows, the number of tows positive for chilipepper rockfish, and the year-specific mean CPUE by depth bin between 34 and 42 N is provided (Table 14A). A provisional table showing the year, location, and CPUE of the top 15 catches from the WCGBTS are also provided (Table 14B).

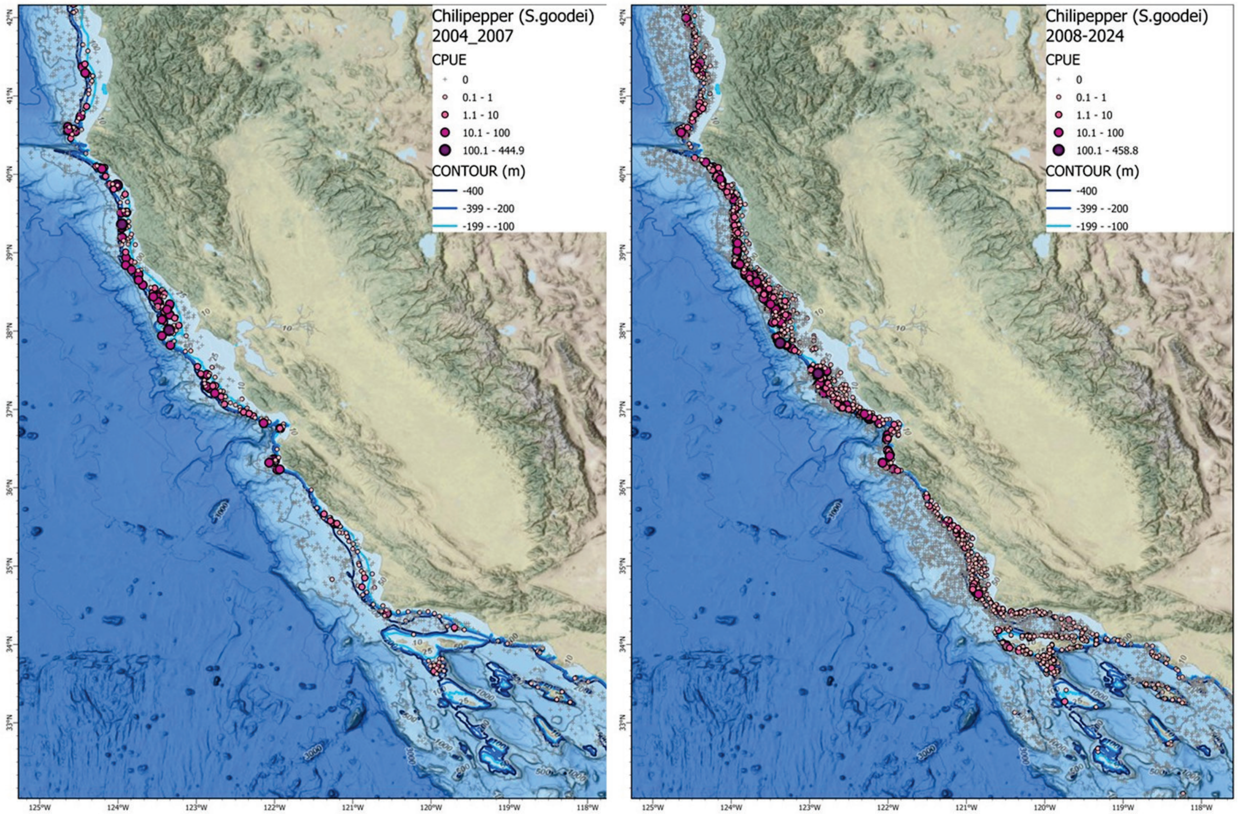


Figure 14A. WCGBTS catch-per-unit-effort (CPUE) from 2004 to 2007 (left) and 2008 to 2024 (right) along the California coast. Depth contours (100, 200 and 400m) are shown.

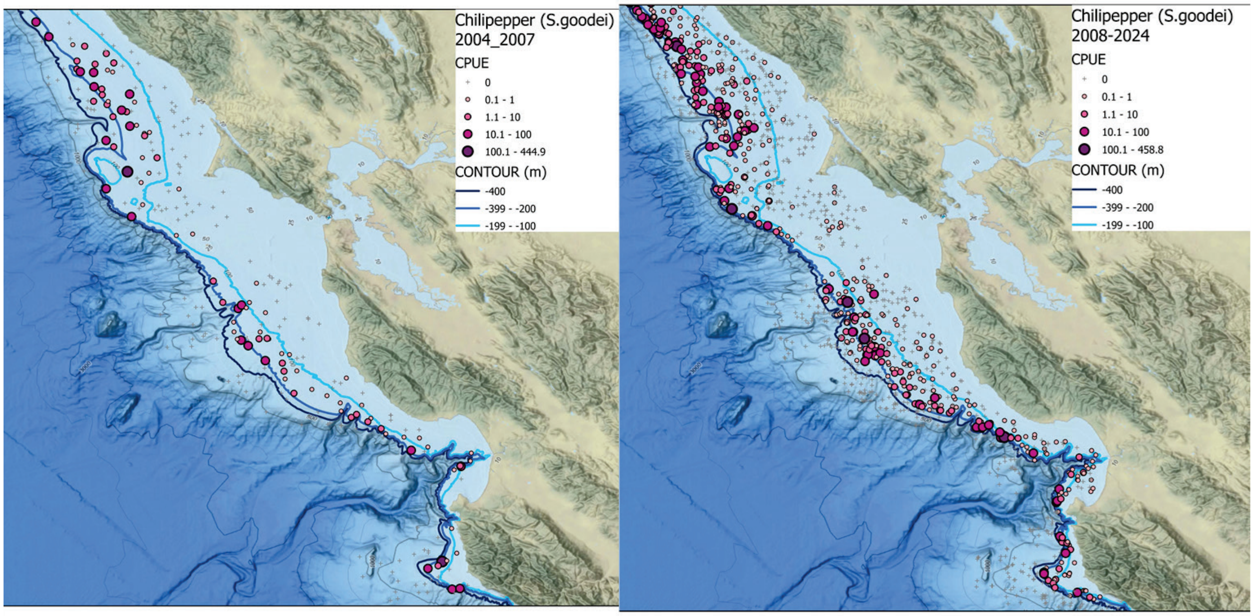
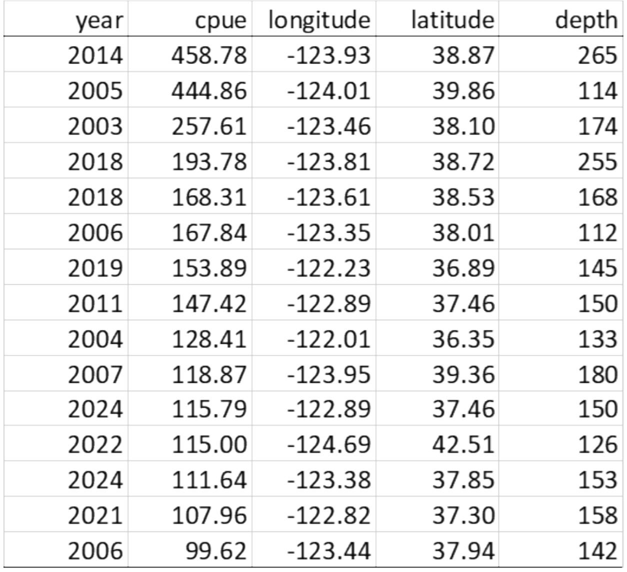


Figure 14B. WCGBTS catch-per-unit-effort (CPUE; kg per ha) from 2004 to 2007 (left) and 2008 to 2024 (right) off central California. Depth contours (100, 200 and 400m) are shown.

Table 14A. Percent positive tows, mean CPUE (kg per ha) per tow, and the number of tows conducted by the WCGBTS. Summarized data were constrained to the area of highest density, between 34 and 42 N, excluding waters off Oregon, Washington, and southern California.

year	% pos 50-125 m	mean cpue pos 50-125m	# tows	% pos 125-275 m	mean cpue pos 125-275m	# tows	% pos 275-550m	mean cpue pos 275-550	# tows
2003	38.18%	0.01	55	83.33%	11.78	54	18.03%	0.02	61
2004	48.33%	0.70	60	75.61%	10.26	41	8.33%	0.00	36
2005	33.72%	5.57	86	76.92%	6.75	52	3.28%	0.01	61
2006	26.23%	2.93	61	69.57%	6.25	46	3.28%	0.02	61
2007	18.18%	0.40	66	66.04%	7.36	53	8.20%	0.00	61
2008	28.40%	0.28	81	72.73%	5.51	44	6.49%	0.02	77
2009	24.18%	0.19	91	58.62%	2.26	58	13.04%	0.14	69
2010	32.94%	0.06	85	73.44%	1.04	64	8.45%	0.03	71
2011	18.52%	0.06	81	77.05%	5.19	61	5.08%	0.01	59
2012	36.73%	0.11	98	85.45%	4.77	55	8.45%	0.26	71
2013	65.52%	1.76	58	90.24%	3.03	41	13.16%	0.02	38
2014	49.37%	0.27	79	77.97%	9.99	59	16.42%	0.01	67
2015	27.47%	0.07	91	74.47%	4.13	47	17.81%	0.38	73
2016	35.21%	0.69	71	88.52%	9.32	61	4.11%	0.05	73
2017	30.95%	0.20	84	74.51%	4.83	51	13.70%	0.34	73
2018	31.25%	0.30	80	68.52%	14.53	54	10.00%	0.01	70
2019	29.41%	0.02	34	73.17%	9.22	41	3.03%	0.00	33
2021	53.61%	0.52	97	68.42%	4.71	57	11.11%	0.37	63
2022	45.35%	0.35	86	73.47%	3.21	49	5.33%	0.01	75
2023	32.10%	0.40	81	71.70%	4.34	53	10.67%	0.11	75
2024	45.00%	0.59	80	81.48%	9.70	54	12.96%	0.07	54

Table 14B. Year, location, depth, and raw CPUE (kg per ha) of the 15 highest catches of chilipepper rockfish from the WCGBTS between 2003 and 2024.



year	cpue	longitude	latitude	depth
2014	458.78	-123.93	38.87	265
2005	444.86	-124.01	39.86	114
2003	257.61	-123.46	38.10	174
2018	193.78	-123.81	38.72	255
2018	168.31	-123.61	38.53	168
2006	167.84	-123.35	38.01	112
2019	153.89	-122.23	36.89	145
2011	147.42	-122.89	37.46	150
2004	128.41	-122.01	36.35	133
2007	118.87	-123.95	39.36	180
2024	115.79	-122.89	37.46	150
2022	115.00	-124.69	42.51	126
2024	111.64	-123.38	37.85	153
2021	107.96	-122.82	37.30	158
2006	99.62	-123.44	37.94	142

14 - Panel Conclusion

The Panel appreciates the work done by the STAT. Plots of the raw data cannot, however, explain higher catches from 2004 to 2007 (i.e., the distribution was much more contracted in spatial range, the overall mean did not seem consistently higher in these years, and fish were found in shallow waters during this time). This issue will be further explored for Request 16.

15 - Request

Estimate the WCGBTS peak and ascending variance selectivity parameters starting the MLE optimization routine at 35 and 6, respectively. Fix the Triennial survey peak selectivity parameter at 58 and the ascending limb parameter at 10 (or a different value if 10 presents any issues). Present the r4ss output and compare likelihoods to the revised base model. Please also try a run that estimates the WCGBTS peak and ascending limb and removes the Triennial survey index, length data, and age data (e.g., setting lambdas to zero).

15 - Rationale

The MCMC analysis supported shallower (slower ascending) survey selectivities with a peak at ≥ 30 cm and a small mode at steeper selectivity with a smaller peak. This request will improve our understanding about the uncertainty across these two scenarios.

15 - STAT Response

The pre-STAR base model with asymptotic selectivities and unconstrained recruitment deviations was used as the starting point for this request. The first part of the request, with estimated parameters for the WCGBTS and fixed parameters for the Triennial survey, produced WCGBTS selectivity estimates that were consistent with the 'mode' of the MCMC reported in Request 13 (Fig. 15A; Table 15). The fixed parameter estimates for the Triennial survey (chosen by visual inspection of the MCMC results in Request 13) produced a curve very similar to the curve in the pre-STAR base model, where only age-0 fish are excluded and all other ages have selectivity equal to one. The STAT views this as support for a simple selectivity curve in the Triennial survey and suggests keeping the original curve (i.e., selectivity = 1 for age-1+ fish). The STAT modified the request slightly, adding an age-based selectivity that set selectivity=0 for age-0 fish, as the length-based selectivity curve requested by the Panel predicted a large number of age-0 fish that were not seen by the survey (see r4ss output for aggregated length compositions). Fits to lengths from the WCGBTS were ultimately degraded by the estimated curve relative to the original pre-STAR base model, as determined by an increase of approximately 4 points in the negative log likelihood component (Table 15). There was minor improvement in fit to the WCGBTS index, as seen by a - 0.6 change in the survey component.

For the second part of the request, the model from part 1 was modified to remove all data types from the Triennial survey. This had no effect on estimated selectivity curves for the remaining fleets (Fig. 15B). Comparison plots of the three runs (base model with asymptotic selectivities, part 1 of this request, and part 2 of this request) show that the estimated stock scale is affected by removal of the Triennial survey, shifting recruitment deviations toward more negative values and shifting R_0 toward more positive values to offset that effect. A similar, but much smaller effect is associated with the changes to survey selectivity in part 1 of this request, relative to the pre-STAR base model.

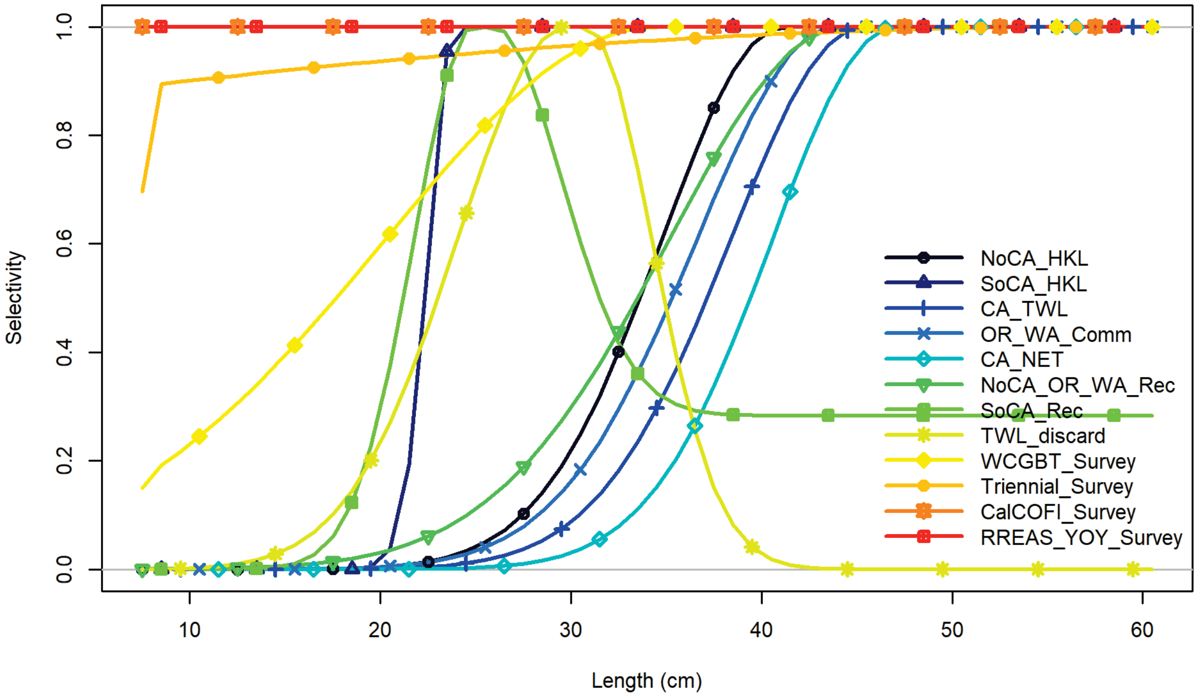


Figure 15A. End-year selectivity curves from the pre-STAR base model with estimated peak and ascending width parameters for the WCGBTS, and fixed selectivity parameters for the Triennial survey.

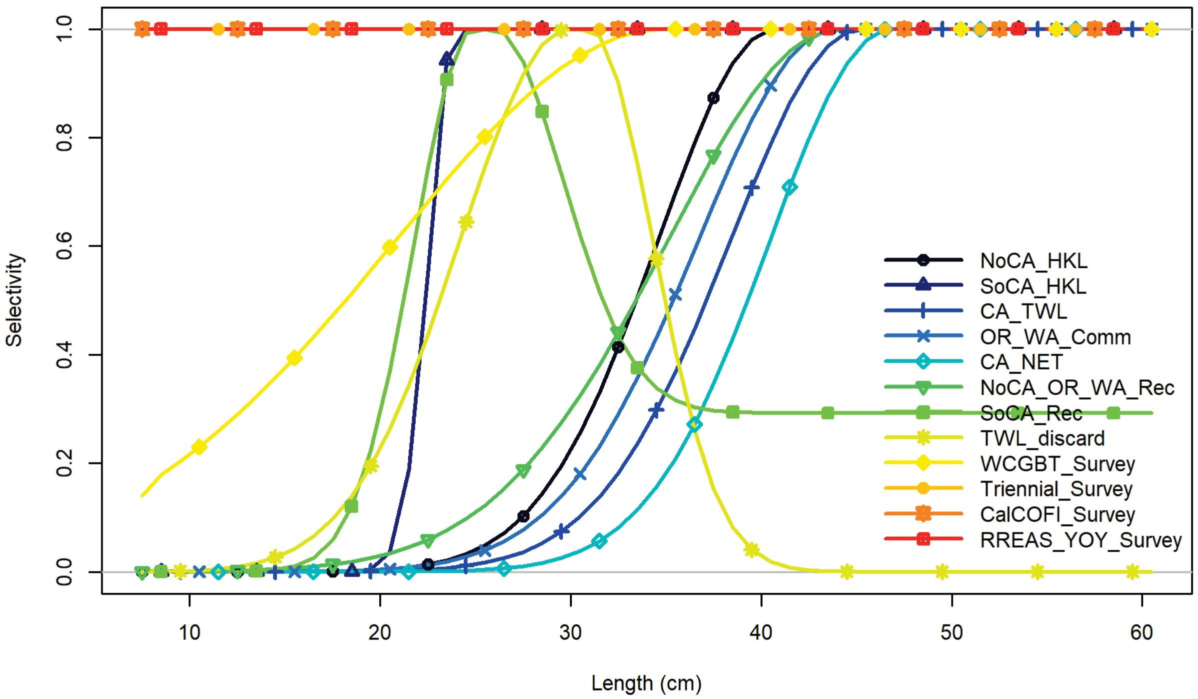


Figure 15B. End-year selectivity curves from the pre-STAR base model with estimated peak and ascending width parameters for the WCGBTS, and the Triennial survey removed from the model.

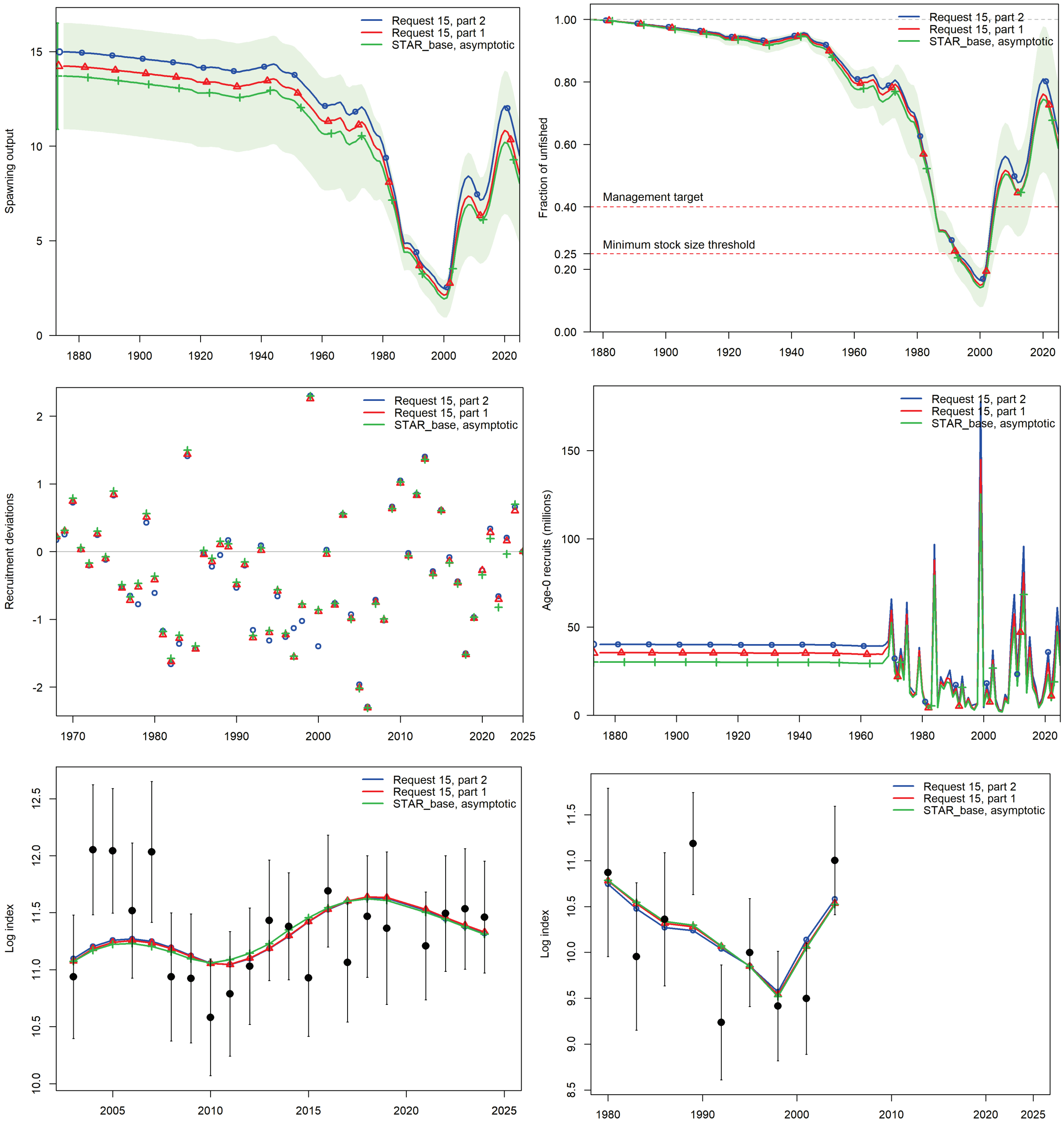


Figure 15C. Spawning output (top left), fraction unfished (top right), recruitment deviations (middle left), age-0 recruits (middle right), log-scale fits to the WCGBTS (bottom left), and log-scale fits to the Triennial survey (bottom right). “Fit” to the Triennial survey index for part 2 is implied with lambda set to zero.

Table 15. Likelihood components, estimated parameters, and derived quantities associated with altering selectivity parameters for the WCGBTS and Triennial survey.

Label	Request 15, part 2	Request 15, part 1	STAR_base, asymptotic
N.Parms	111	111	109
TOTAL	2504.080	2623.980	2621.330
Survey	20.881	23.745	24.307
Length_comp	547.765	576.047	572.015
Age_comp	1910.190	1999.490	2000.480
Recruitment	24.978	24.495	24.425
Parm_priors	0.262	0.191	0.096
NatM_uniform_Fem_GP_1	0.193	0.187	0.177
L_at_Amax_Fem_GP_1	47.948	47.890	47.860
VonBert_K_Fem_GP_1	0.195	0.196	0.197
CV_young_Fem_GP_1	0.106	0.105	0.105
CV_old_Fem_GP_1	0.038	0.039	0.039
NatM_uniform_Mal_GP_1	0.211	0.221	0.241
L_at_Amax_Mal_GP_1	-0.332	-0.329	-0.329
VonBert_K_Mal_GP_1	0.515	0.522	0.528
CV_young_Mal_GP_1	0.283	0.241	0.235
CV_old_Mal_GP_1	0.098	0.099	0.100
SR_LN(R0)	10.598	10.474	10.314
Q_extraSD_CalCOFI_Survey(11)	0.319	0.311	0.310
Q_extraSD_RREAS_YOY_Survey(12)	1.219	1.221	1.230
Size_DblN_peak_NoCA_HKL(1)	40.742	41.136	41.080
Size_DblN_ascend_se_NoCA_HKL(1)	4.345	4.401	4.405
Size_DblN_peak_SoCA_HKL(2)	23.962	23.906	23.788
Size_DblN_ascend_se_SoCA_HKL(2)	1.289	1.259	1.195
Size_DblN_peak_CA_TWL(3)	45.243	45.296	45.102
Size_DblN_ascend_se_CA_TWL(3)	4.557	4.565	4.563
Size_DblN_peak_OR_WA_Comm(4)	43.881	43.833	43.109
Size_DblN_ascend_se_OR_WA_Comm(4)	4.651	4.654	4.600
Size_DblN_peak_CA_NET(5)	46.794	46.973	46.979
Size_DblN_ascend_se_CA_NET(5)	4.400	4.414	4.420
Size_DblN_peak_NoCA_OR_WA_Rec(6)	44.128	44.372	44.110
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.108	5.140	5.145
Size_DblN_peak_SoCA_Rec(7)	24.873	24.844	24.731
Size_DblN_ascend_se_SoCA_Rec(7)	2.956	2.954	2.936
Size_DblN_descend_se_SoCA_Rec(7)	3.282	3.249	3.278
Size_DblN_end_logit_SoCA_Rec(7)	-0.884	-0.929	-1.049
Size_DblN_peak_TWL_discard(8)	29.887	29.757	29.572
Size_DblN_ascend_se_TWL_discard(8)	4.190	4.185	4.181
Size_DblN_descend_se_TWL_discard(8)	3.126	3.158	3.194
Size_DblN_peak_WCGBT_Survey(9)	35.007	34.585	NA
Size_DblN_top_logit_WCGBT_Survey(9)	-6.000	-6.000	NA
Size_DblN_ascend_se_WCGBT_Survey(9)	6.013	6.022	NA
Size_DblN_descend_se_WCGBT_Survey(9)	7.000	7.000	NA
Size_DblN_start_logit_WCGBT_Survey(9)	-999.000	-999.000	NA
Size_DblN_end_logit_WCGBT_Survey(9)	10.000	10.000	NA
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.194	51.365	51.396
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.122	4.135	4.141
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.393	48.771	48.776
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.775	4.806	4.814
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.940	33.997	33.920
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.299	3.322	3.315
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.960	30.791	30.648
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.775	3.757	3.742
Size_DblN_peak_Triennial_Survey(10)	NA	58.000	NA
Size_DblN_top_logit_Triennial_Survey(10)	NA	-6.000	NA
Size_DblN_ascend_se_Triennial_Survey(10)	NA	10.000	NA
Size_DblN_descend_se_Triennial_Survey(10)	NA	7.000	NA
Size_DblN_start_logit_Triennial_Survey(10)	NA	-999.000	NA
Size_DblN_end_logit_Triennial_Survey(10)	NA	10.000	NA
SizeSel=1_BinLo_WCGBT_Survey(9)	NA	NA	3.000
SizeSel=1_BinHi_WCGBT_Survey(9)	NA	NA	54.000
Bratio_2025	0.633	0.597	0.587
SSB_unfished	14983	14233	13702
Totbio_unfished	70061	65718	61698
Recr_unfished	40069	35386	30156
Dead_Catch_SPR	3198	2927	2633
OFLCatch_2025	4170	3613	3160

15 - Panel Conclusion

The likelihood when estimating WCGBTS selectivity was slightly higher than when fixing parameters to produce a knife-edge selectivity. The MCMC results from Request 13 were likely not fully converged on a parameter space that was correlated with two similar peaks. The assumed (fixed) selectivity for the Triennial survey based on MCMC results from Request 13 was essentially the same as the pre-STAR base model. The Panel does not see sufficient reason to remove the Triennial survey given some influence on the model. The Panel supports assumptions about survey selectivity that were made in the pre-STAR base model.

16 - Request

Plot estimated spatial and spatiotemporal fields for both components of the delta-lognormal model used for the WCGBTS index. The spatiotemporal field will only be available for the presence-absence model. The STAT can choose which years to present if there are too many plots but please provide a justification for specific time frame used. Please focus on evaluating differences between the early (2004 to 2007) and late (after 2008) periods to understand the reason for relatively high index values from 2004 to 2007. Please also present values for the estimated “year” effect.

16 - Rationale

The raw data presented as part of Request 14 was informative but cannot explain higher catches from 2004 to 2007 (i.e., the distribution was much more contracted in spatial range, the overall mean did not seem consistently higher in these years, and fish were found in shallow waters during this time). Thus, the impact of these observations on the WCGBTS index standardization model requires further examination into the estimated spatiotemporal field, which is the only component of the model that can vary in time and space.

16 - STAT Response

Plots of the ‘year’ effects (Fig. 16A and Fig. 16B), spatial random fields for the binomial and positive models (Fig. 16D), the spatiotemporal random field for the binomial model (Fig. 16E), and the ‘non-random fields’ that correspond to the depth effect plotted over space (Fig. 16F) are shown below. It appears that the index is driven primarily by the fixed year effect in the positive model, which resembles the raw geometric mean of the positive catch data. The spatiotemporal random field in the binomial model (and the binomial model in general) does not appear to be contributing as much to overall trends. Predictions for central California for two ‘high years’ (i.e., 2004 and 2005) and two ‘low years’ (i.e., 2010 and 2011) show higher values in the ‘high years’, although the difference is more pronounced in the positive model (Fig. 16G).

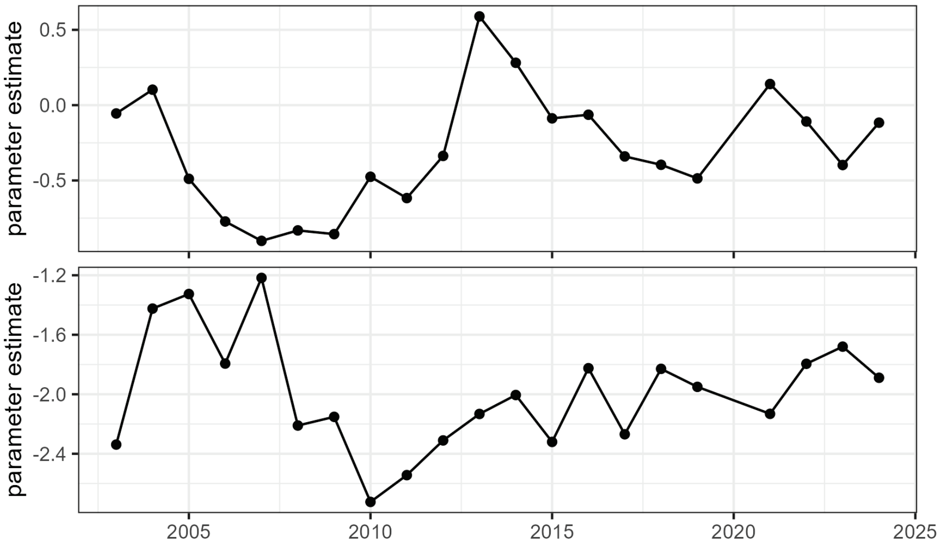


Figure 16A. Parameter estimates for the year effect from the binomial (top) and positive (bottom) components of the WCGBTS index model. Values are on the link scale.

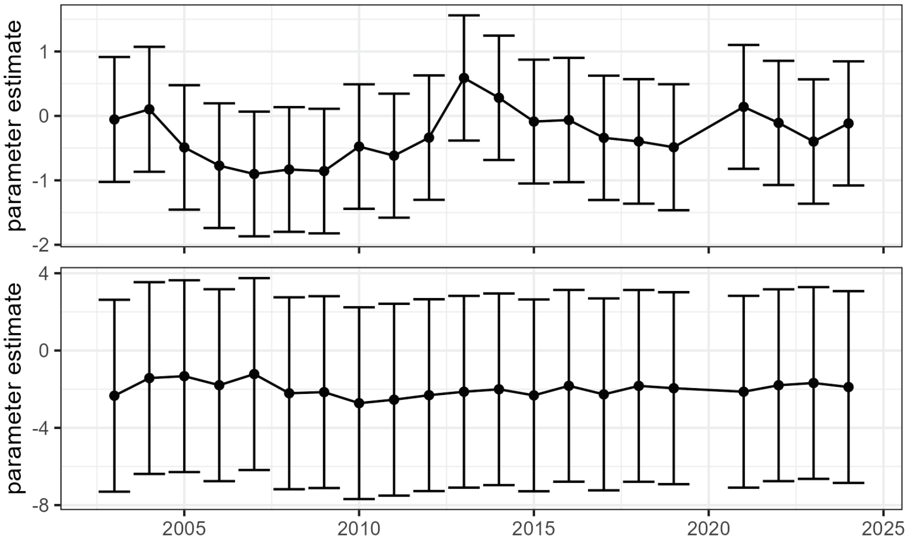


Figure 16B. Parameter estimates for the year effect from the binomial (top) and positive (bottom) components of the WCGBTS index model, with standard errors. The resemblance of the positive model coefficients is obscured when error bars are included.

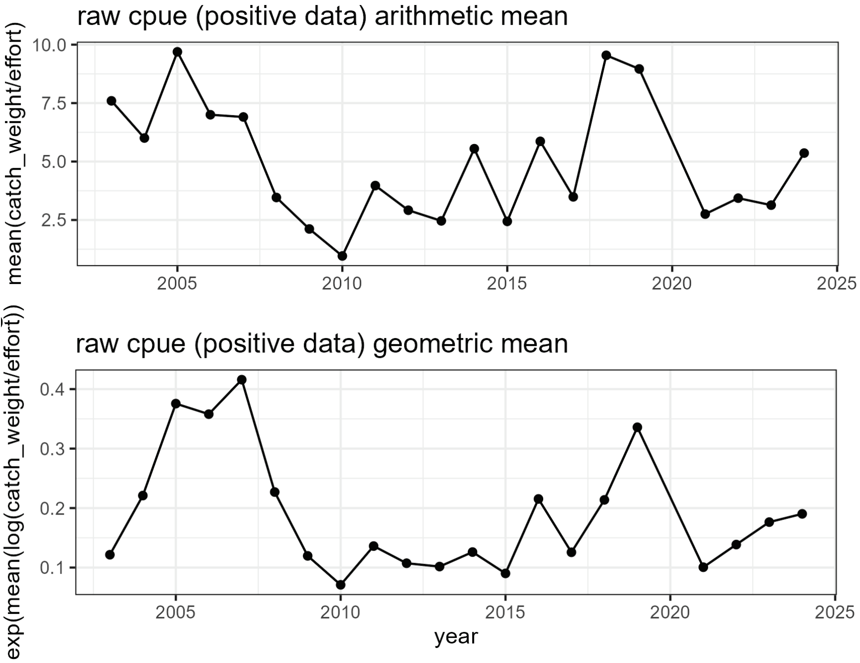


Figure 16C. Arithmetic (top) and geometric (bottom) mean catch-per-unit-effort (CPUE, kg per ha) from the WCGBTS index.

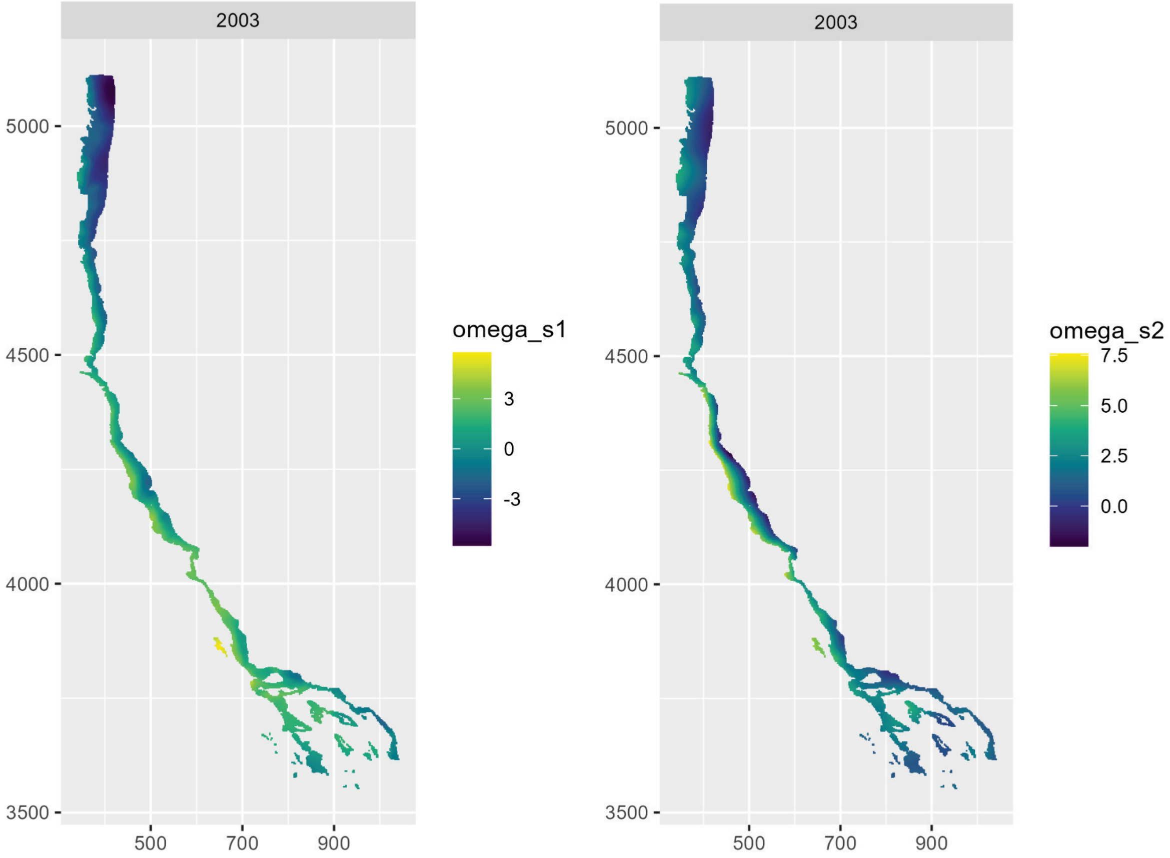


Figure 16D. Spatial random fields for the binomial (left) and positive (right) components of the WCGBTS index model. The spatial random field is shown for 2003, though the effect does not vary by year. Values are on the link scale.

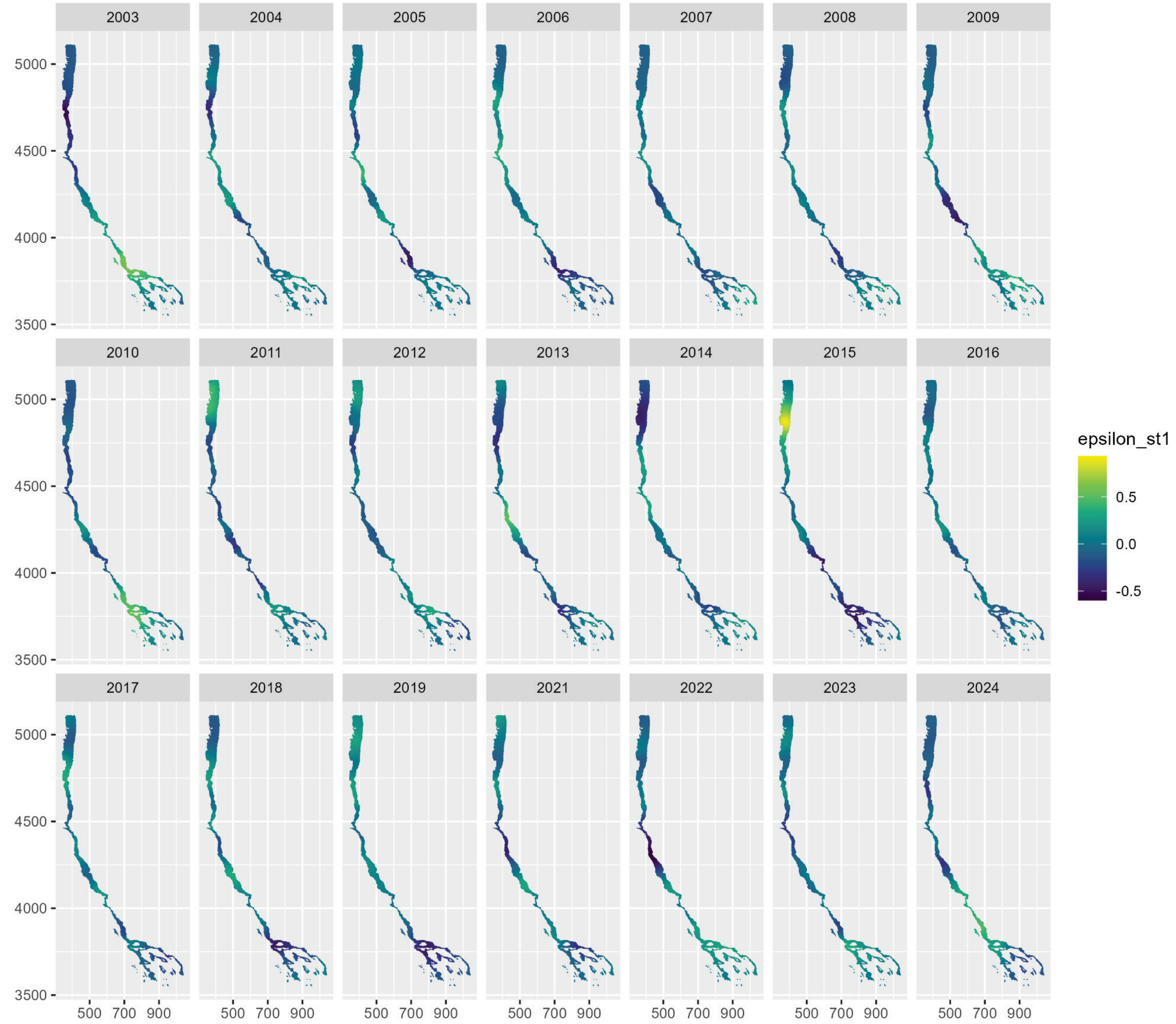


Figure 16E. Spatiotemporal random fields for the binomial component of the WCGBTS index model by year. Values are on the link scale.

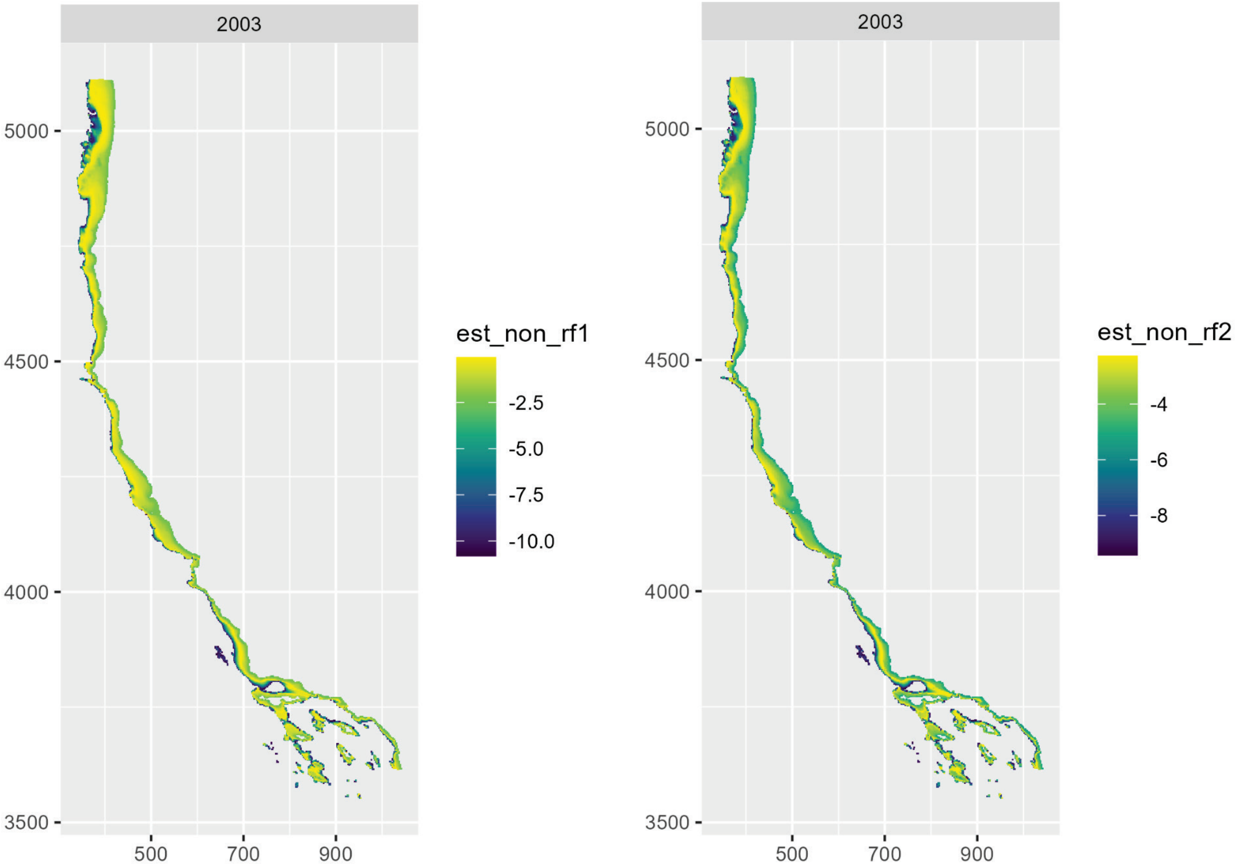


Figure 16F. Non-random fields for the binomial (left) and positive (right) components of the WCGBTS index model. The non-random field is shown for 2003, though the effect does not vary by year. Values are on the link scale.

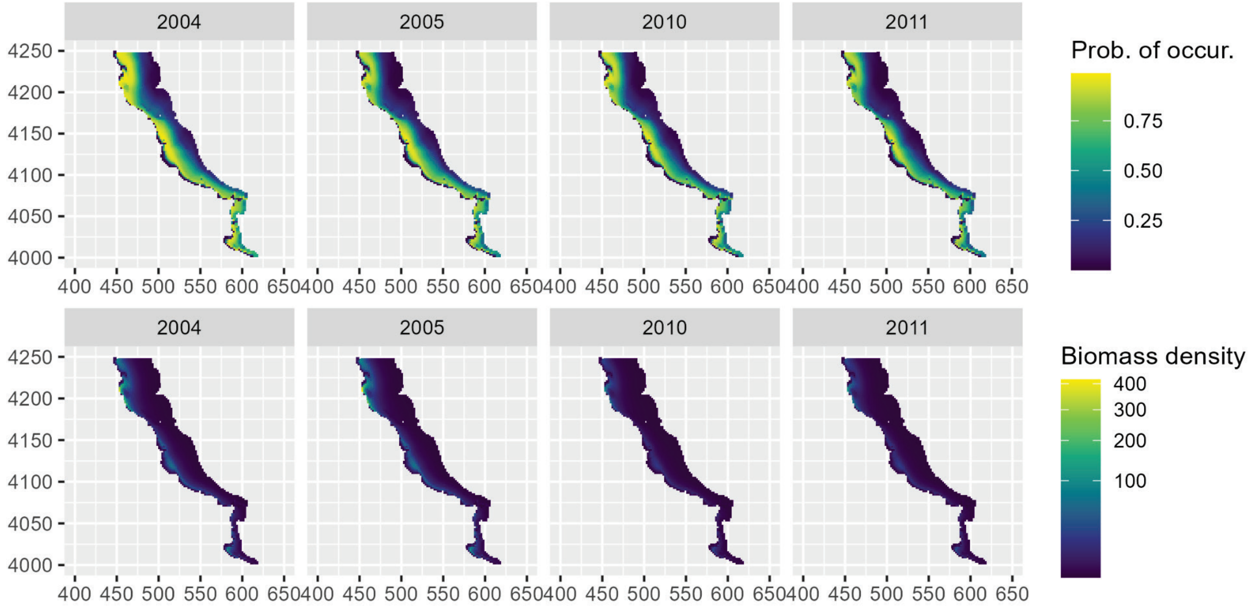


Figure 16G. Predictions from the WCGBTS index model for two 'high years' (i.e., 2004 and 2005) and two 'low years' (i.e., 2010 and 2011). The binomial (top) and positive (bottom) components are shown for central California only. Values are on the response scale.

16 - Panel Conclusion

The Panel appreciates this detailed investigation to identify differences in biomass density.

17 - Request

Run a model with asymptotic commercial and northern recreational selectivities, recruitment deviations with the sum-to-zero constraint, recruitment bias correction tuned, the WCGBTS index that includes a depth effect with assumed isotropy, including additive variance for the RREAS index (fixed to the value of sigma R such that total standard error across all years averages to 1.0), and estimated or fixed selectivity for the WCGBTS and Triennial survey determined by the STAT. Please tune this model, as it will be examined as a potential revised base model.

17 - Rationale

The STAT has provided many investigations, sensitivities, and responses to requests that support revising the pre-STAR base model as described in this request. Request 2 supported asymptotic commercial selectivity. Requests 4 and 11 support the sum-to-zero constraint on recruitment deviations. Request 12 identified the utility of including a depth effect for the WCGBTS spatiotemporal model. Request 10 supported additive variance estimates for the RREAS index. Request 13 examined different survey selectivities, which are pending as part of Request 15. The Panel encourages the STAT to provide their recommendations for survey selectivity.

17 - STAT Response

The STAT constructed a model with the previously mentioned asymptotic selectivity curves, a sum-to-zero constraint on recruitment deviations, steepness fixed at 0.72, a revised WCGBTS index, an additive variance parameter for the RREAS index that was fixed so total mean logSE = sigmaR (1.0), and trawl survey selectivities fixed at 1 for 9.5+ cm fish for the WCGBTS and fixed at 1 for age 1+ fish for the Triennial survey. The model was less stable than the pre-STAR base model, with multiple minima in the region of the best identified solution. Attempts to estimate the

Hessian for the best available solution after tuning the composition data failed. In an effort to stabilize the model, the STAT examined the parameter standard errors from a previous run and identified two parameters with standard errors greater than the MLE: the ascending limb of selectivity for the southern California hook-and-line fleet and the male offset for the CV of length at age 20 yr (Table 17A).

The STAT fixed the “CV_old_Mal_GP_1” parameter at 0.1, fixed the “Size_DblN_ascend_se_SoCA_HKL(2)” parameter at 1.2, and re-estimated and tuned the model. This change appeared to stabilize the model, as evidenced by rapid convergence of the Francis tuning algorithm, successful estimation of the Hessian, and use of the “-hess_step” option to minimize the final gradient. The tuned model was used for a “jitter” analysis of 100 runs with “jitter fraction” of 0.2. The jitter analysis did not find a smaller NLL value than the proposed base model and 97 of the 100 runs found the same solution (NLL = 2633.05). This is evidence (but not proof) that the optimizer has found a global solution. It also suggests that fixing the two parameters resolved issues with convergence. Given that the new model enforces a sum-to-zero constraint, it is unclear to the STAT if the use of MCMC diagnostics to further diagnose the issue is appropriate.

Reference points from the proposed base model suggest a less depleted, but smaller stock than the pre-STAR base model (Table 17B and 17C). This is largely attributed to the change from unconstrained recruitment deviations to including the sum-to-zero constraint while fixing steepness at a value greater than the estimated value (as described in Request 11; Fig. 17A and Fig. 17B). Equilibrium sustainable yields under the proposed base model are similar to those estimated in the previous assessment (Field 2017). In that assessment, the yield based on an $SPR_{50\%}$ harvest rate and applied to the equilibrium biomass at that rate was 2042 mt, compared to 2114 mt in the proposed base model (Table 17B).

Despite having a smaller stock scale, the proposed base model estimates larger recruitments in recent years, which reflects increased influence of the RREAS index. The additive variance (“extraSD”) parameter in the proposed base model is fixed at 0.683, compared to 1.23 when freely estimated.

Likelihood profiles for the Beverton-Holt steepness parameter are provided (Fig. 17C, Fig. 17D, and Table 17D). Likelihood profiles for female natural mortality (*M*; Fig. 17E, Fig. 17F, and Table 17E) and log of unfished recruitment (log R_0) are also provided (Fig. 17G, Fig. 17H, and Table 17F). Note that steepness values ≤ 0.3 are inconsistent with the $F_{SPR=50\%}$ proxy harvest rate, as indicated by an equilibrium yield (“Dead_Catch_SPR”) of zero (Table 17D). When estimated in the proposed final base model, steepness is 0.383. Some likelihood components (e.g., several sources of age data and the WCBTS index) exhibit bi-modality.

The STAT was curious about how unconstrained recruitment deviations would affect likelihood profiles for *h* and/or *M*. A comparison of bivariate likelihood profiles for *h* and *M* from the pre-STAR base model and the proposed final base model is shown in Fig. 17I. The proposed final base model includes other changes, as noted above in Request 11, that result in recruitment deviation estimates that are more negative when steepness is fixed at 0.72. Without a sum-to-zero constraint on recruitment deviations, the model can maintain a similar fit across a wider range of steepness values.

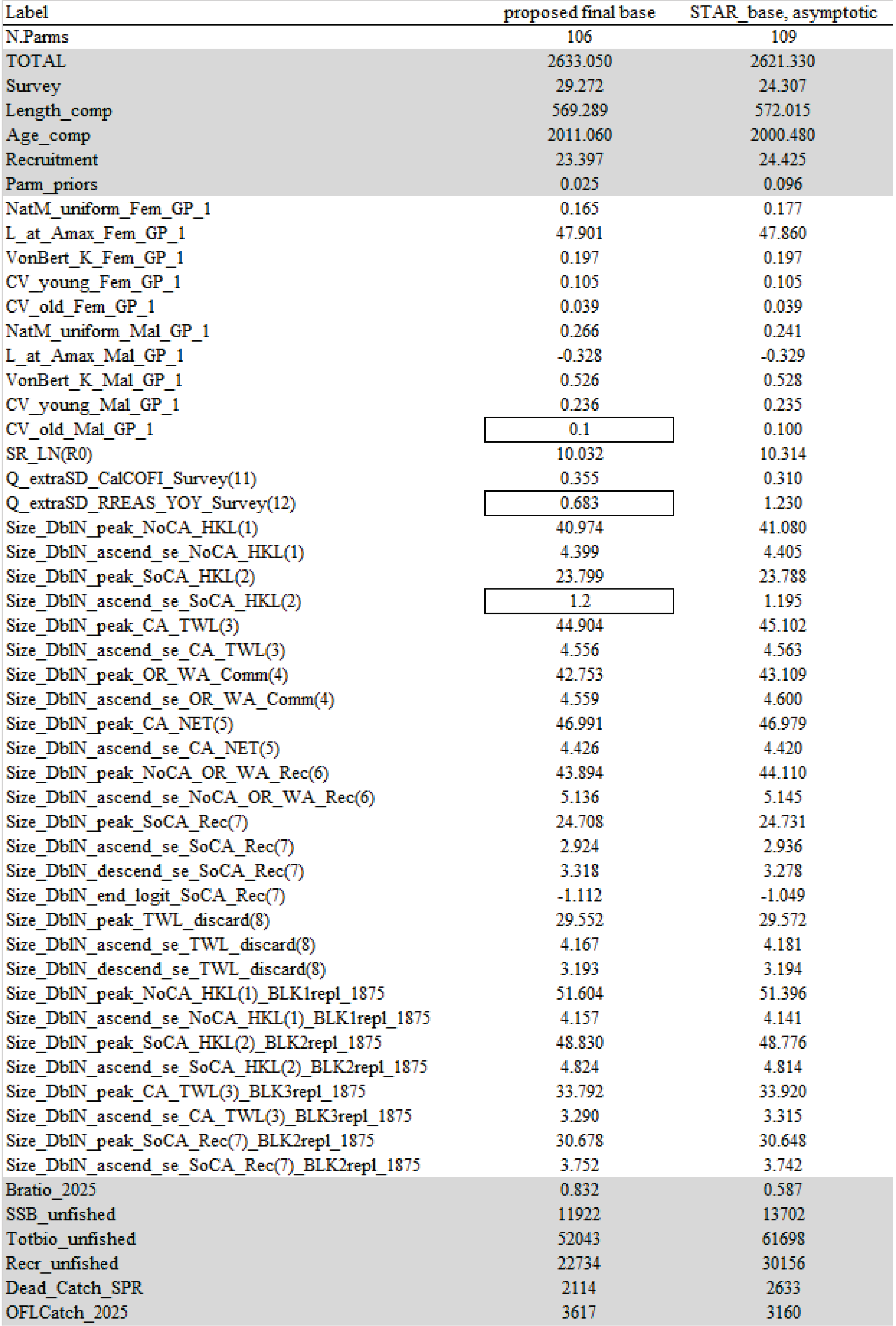
Table 17A. Method used to identify potentially problematic parameters. Grey highlights represent parameters with standard errors greater than the maximum likelihood estimate.

Parameter	Value	Parm_StDev	Parm_StDev/Value
NatM_uniform_Fem_GP_1	0.166	0.012	0.07
L_at_Amax_Fem_GP_1	47.924	0.213	0.00
VonBert_K_Fem_GP_1	0.196	0.003	0.02
CV_young_Fem_GP_1	0.105	0.004	0.04
CV_old_Fem_GP_1	0.038	0.003	0.08
NatM_uniform_Mal_GP_1	0.251	0.044	0.18
L_at_Amax_Mal_GP_1	-0.325	0.009	-0.03
VonBert_K_Mal_GP_1	0.510	0.036	0.07
CV_young_Mal_GP_1	0.213	0.067	0.32
CV_old_Mal_GP_1	0.104	0.170	1.63
SR_LN(R0)	10.049	0.189	0.02
Q_extraSD_CalCOFI_Survey(11)	0.364	0.082	0.22
Size_DblN_peak_NoCA_HKL(1)	40.677	2.315	0.06
Size_DblN_ascend_se_NoCA_HKL(1)	4.382	0.324	0.07
Size_DblN_peak_SoCA_HKL(2)	23.828	2.504	0.11
Size_DblN_ascend_se_SoCA_HKL(2)	1.208	2.199	1.82
Size_DblN_peak_CA_TWL(3)	44.921	1.672	0.04
Size_DblN_ascend_se_CA_TWL(3)	4.556	0.208	0.05
Size_DblN_peak_OR_WA_Comm(4)	43.111	6.340	0.15
Size_DblN_ascend_se_OR_WA_Comm(4)	4.592	0.844	0.18
Size_DblN_peak_CA_NET(5)	46.829	1.756	0.04
Size_DblN_ascend_se_CA_NET(5)	4.422	0.220	0.05
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.810	2.473	0.06
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.138	0.231	0.05
Size_DblN_peak_SoCA_Rec(7)	24.768	1.023	0.04
Size_DblN_ascend_se_SoCA_Rec(7)	2.937	0.363	0.12
Size_DblN_descend_se_SoCA_Rec(7)	3.270	0.645	0.20
Size_DblN_end_logit_SoCA_Rec(7)	-1.107	0.303	-0.27
Size_DblN_peak_TWL_discard(8)	29.520	1.585	0.05
Size_DblN_ascend_se_TWL_discard(8)	4.153	0.376	0.09
Size_DblN_descend_se_TWL_discard(8)	3.201	0.600	0.19
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.733	5.167	0.10
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.163	0.616	0.15
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.483	4.369	0.09
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.811	0.436	0.09
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.658	1.255	0.04
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.268	0.352	0.11
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.798	2.075	0.07
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.767	0.464	0.12

Table 17B. Reference points from the proposed final base model.

Reference Point	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output (billions of eggs)	11,922	10,006	13,839
Unfished Age 3+ Biomass (mt)	50,121	41,265	58,976
Unfished Recruitment (R0, 1000s)	22,734	14,697	30,770
Spawning Output (2025, billions of eggs)	9,925	6,263	13,587
Fraction Unfished (2025)	0.832	0.628	1.037
Reference Points Based SB40%			
Proxy Spawning Output SB40%	4,769	4,002	5,536
SPR Resulting in SB40%	0.458	0.458	0.458
Exploitation Rate Resulting in SB40%	0.089	0.080	0.098
Yield with SPR Based On SB40% (mt)	2,230	1,672	2,787
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (SPR50)	5,319	4,464	6,174
SPR50	0.5	--	--
Exploitation Rate Corresponding to SPR50	0.077	0.070	0.085
Yield with SPR50 at SB SPR (mt)	2,114	1,588	2,639
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB MSY)	3,056	2,563	3,548
SPR MSY	0.329	0.323	0.334
Exploitation Rate Corresponding to SPR MSY	0.136	0.121	0.151
MSY (mt)	2,421	1,807	3,035

Table 17C. Likelihood components, parameter estimates, and derived quantities from the proposed final base model and the model with unconstrained recruitment deviations (and other changes, as noted above). Three parameters (outlined in black) were fixed in the proposed base model.



Label	proposed final base	STAR_base, asymptotic
N.Parms	106	109
TOTAL	2633.050	2621.330
Survey	29.272	24.307
Length_comp	569.289	572.015
Age_comp	2011.060	2000.480
Recruitment	23.397	24.425
Parm_priors	0.025	0.096
NatM_uniform_Fem_GP_1	0.165	0.177
L_at_Amax_Fem_GP_1	47.901	47.860
VonBert_K_Fem_GP_1	0.197	0.197
CV_young_Fem_GP_1	0.105	0.105
CV_old_Fem_GP_1	0.039	0.039
NatM_uniform_Mal_GP_1	0.266	0.241
L_at_Amax_Mal_GP_1	-0.328	-0.329
VonBert_K_Mal_GP_1	0.526	0.528
CV_young_Mal_GP_1	0.236	0.235
CV_old_Mal_GP_1	0.1	0.100
SR_LN(R0)	10.032	10.314
Q_extraSD_CalCOFI_Survey(11)	0.355	0.310
Q_extraSD_RREAS_YOY_Survey(12)	0.683	1.230
Size_DblN_peak_NoCA_HKL(1)	40.974	41.080
Size_DblN_ascend_se_NoCA_HKL(1)	4.399	4.405
Size_DblN_peak_SoCA_HKL(2)	23.799	23.788
Size_DblN_ascend_se_SoCA_HKL(2)	1.2	1.195
Size_DblN_peak_CA_TWL(3)	44.904	45.102
Size_DblN_ascend_se_CA_TWL(3)	4.556	4.563
Size_DblN_peak_OR_WA_Comm(4)	42.753	43.109
Size_DblN_ascend_se_OR_WA_Comm(4)	4.559	4.600
Size_DblN_peak_CA_NET(5)	46.991	46.979
Size_DblN_ascend_se_CA_NET(5)	4.426	4.420
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.894	44.110
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.136	5.145
Size_DblN_peak_SoCA_Rec(7)	24.708	24.731
Size_DblN_ascend_se_SoCA_Rec(7)	2.924	2.936
Size_DblN_descend_se_SoCA_Rec(7)	3.318	3.278
Size_DblN_end_logit_SoCA_Rec(7)	-1.112	-1.049
Size_DblN_peak_TWL_discard(8)	29.552	29.572
Size_DblN_ascend_se_TWL_discard(8)	4.167	4.181
Size_DblN_descend_se_TWL_discard(8)	3.193	3.194
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.604	51.396
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.157	4.141
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.830	48.776
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.824	4.814
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.792	33.920
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.290	3.315
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.678	30.648
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.752	3.742
Bratio_2025	0.832	0.587
SSB_unfished	11922	13702
Totbio_unfished	52043	61698
Recr_unfished	22734	30156
Dead_Catch_SPR	2114	2633
OFLCatch_2025	3617	3160

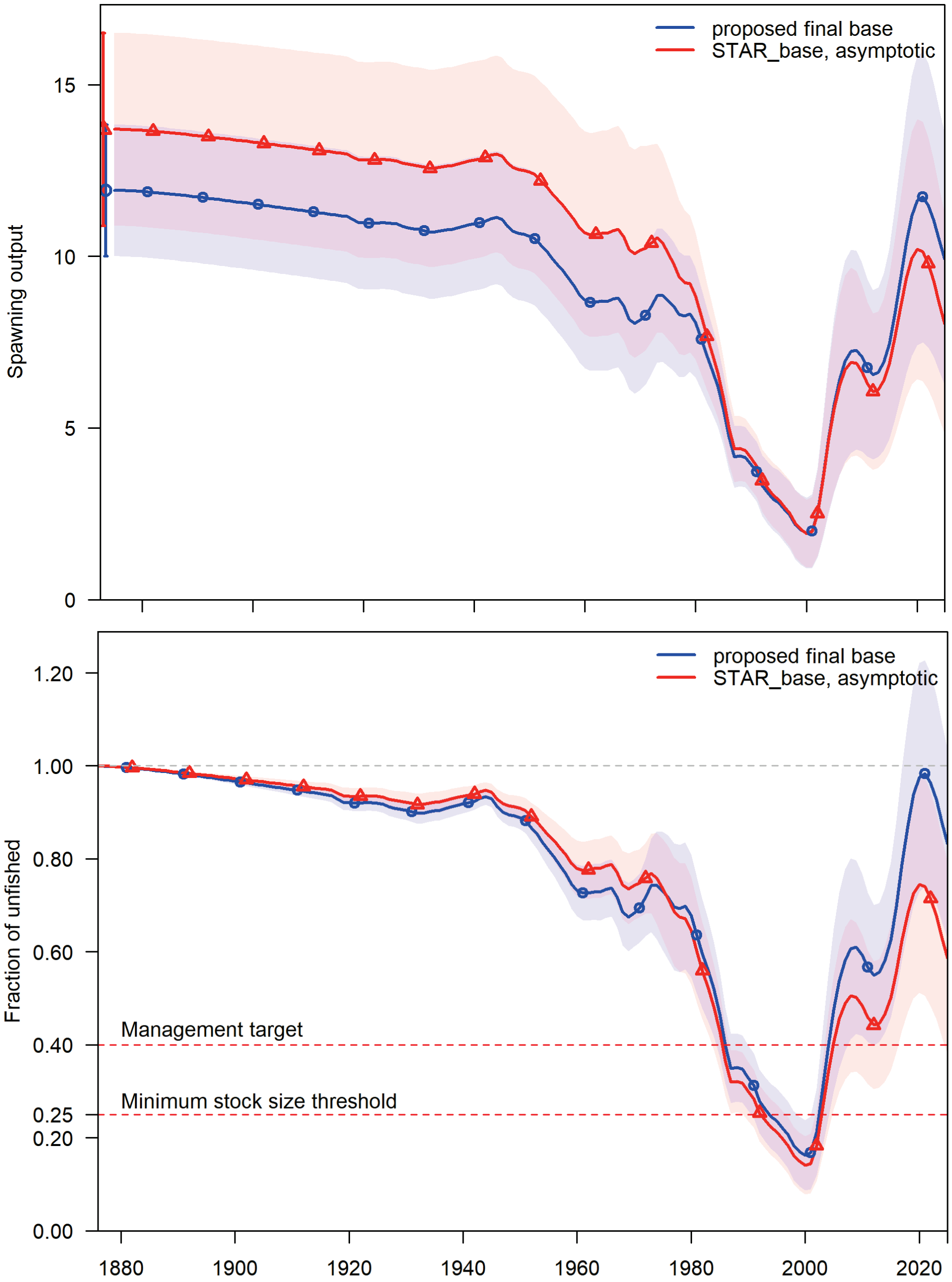


Figure 17A. Spawning output (top) and fraction unfished (bottom) from the model with unconstrained recruitment deviations (red) and the proposed final base model with sum-to-zero deviations and other changes as described in the request (blue). Shaded areas represent 95% asymptotic confidence intervals.

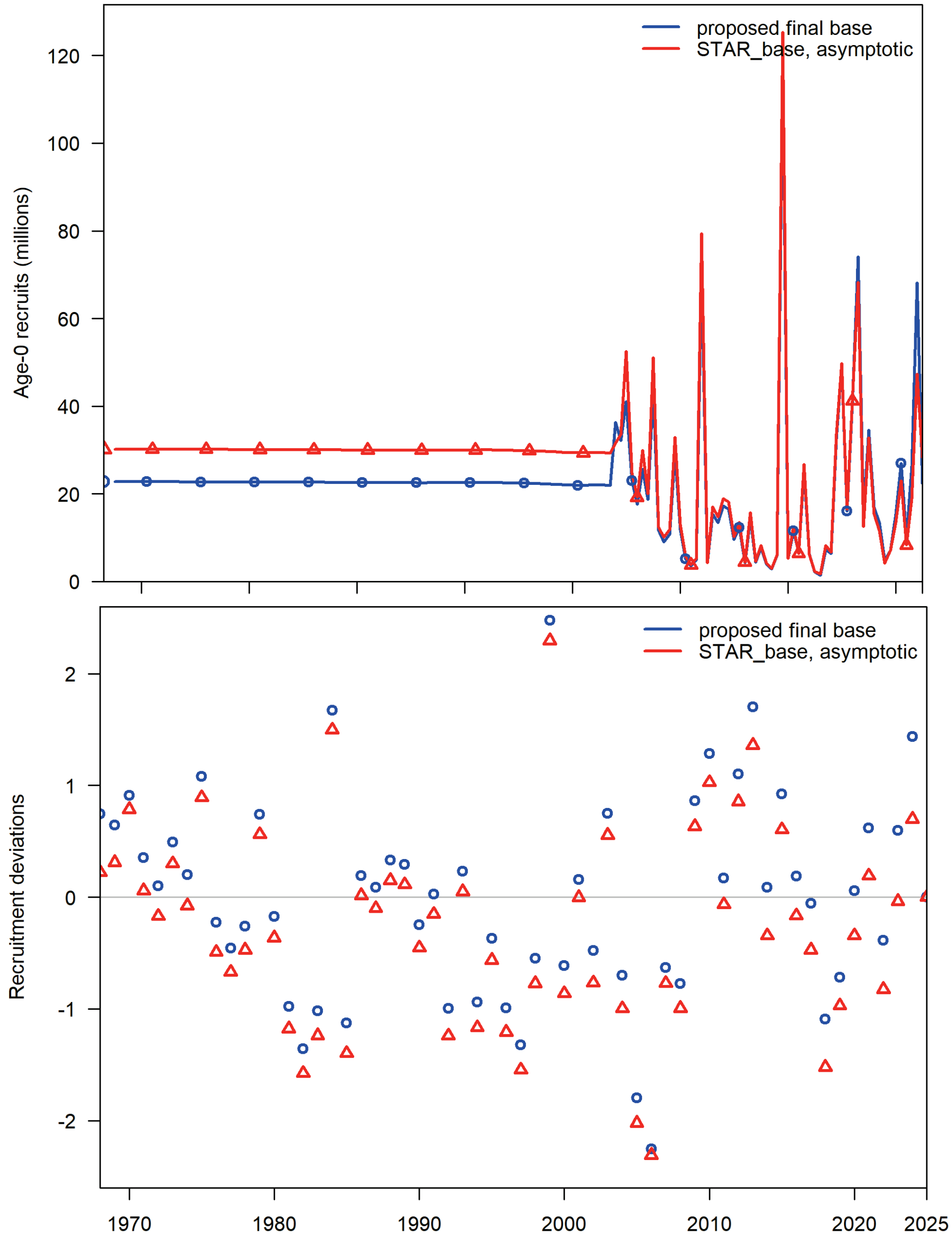


Figure 17B. Age-0 recruits (top) and recruitment deviations (bottom) from the model with unconstrained recruitment deviations (red) and the proposed final base model with a sum-to-zero constraint on recruitment deviations and other changes as described in the request (blue). Shaded areas represent 95% asymptotic confidence intervals.

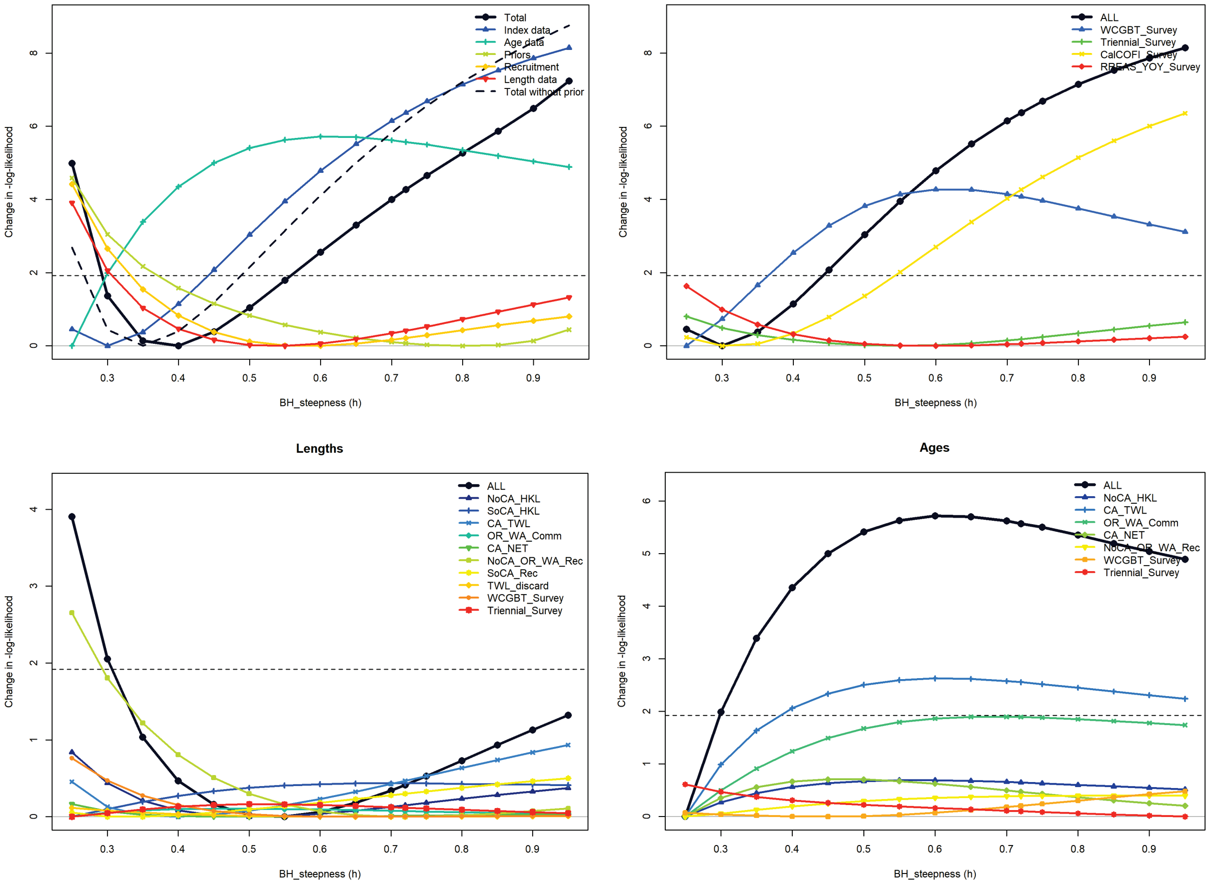


Figure 17C. Likelihood profiles over the Beverton-Holt steepness parameter organized by data type (top left), fleets with indices (top right), fleets with length composition data (bottom left), and fleets with age composition data (bottom left). Components or fleets that show little change over the range of parameter values were excluded.

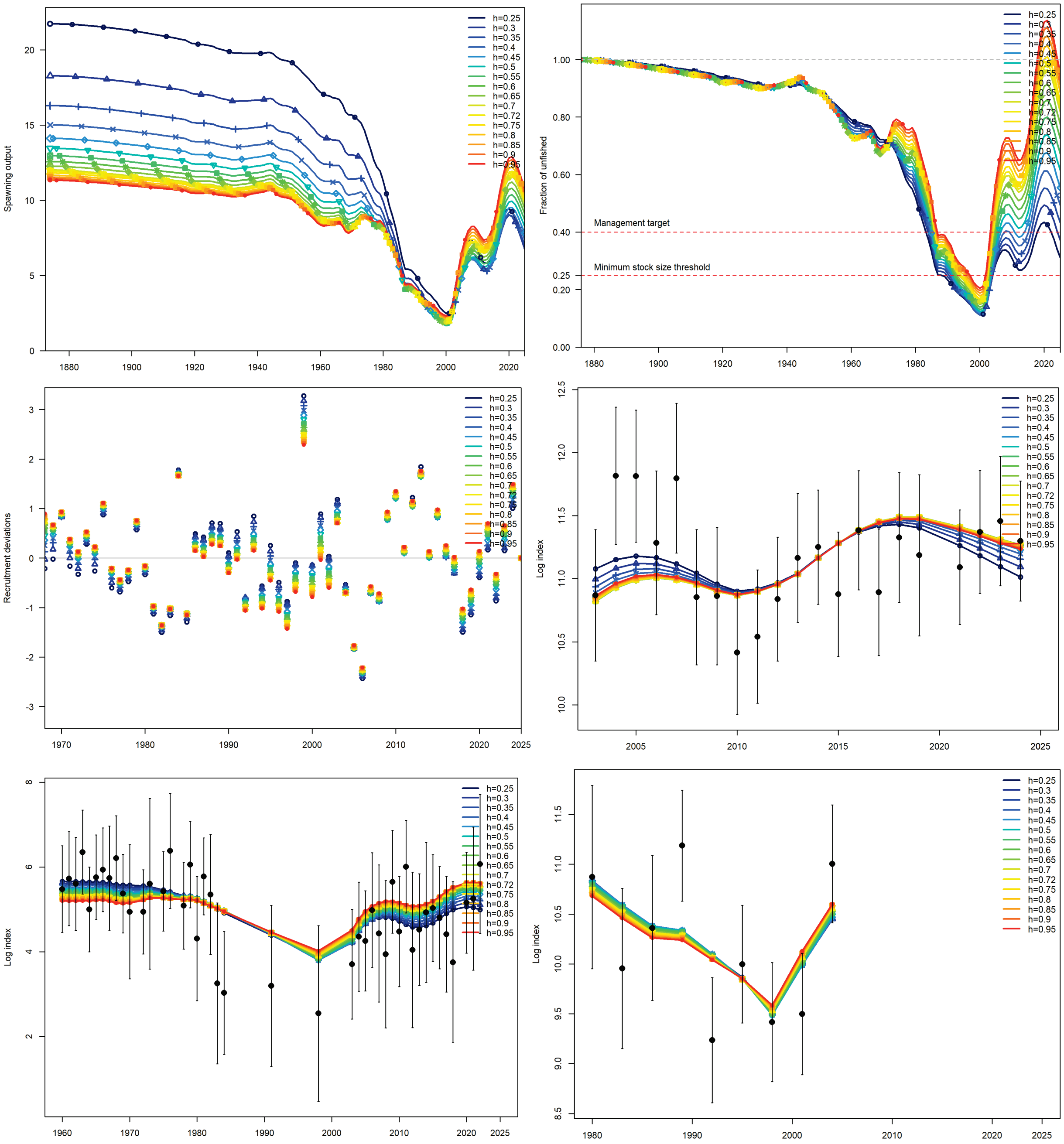


Figure 17D. Likelihood profiles for the Beverton-Holt steepness parameter (*h*). Spawning output (top left), fraction unfished (top right), recruitment deviations (middle left), log-scale fit to WCGBTS index (middle right), log-scale fit to CalCOFI index (bottom left), and log-scale fit to Triennial survey (bottom right) are shown.

Table 17D. Likelihood components, parameter values, and derived quantities from a likelihood profile for steepness.

Label	h=0.3	h=0.35	h=0.4	h=0.45	h=0.5	h=0.55	h=0.6	h=0.65	h=0.7	h=0.72	h=0.75	h=0.8	h=0.85	h=0.9	h=0.95
N.Parms	106	106	106	106	106	106	106	106	106	106	106	106	106	106	106
TOTAL	2630.15	2628.92	2628.78	2629.17	2629.82	2630.57	2631.34	2632.08	2632.78	2633.05	2633.44	2634.05	2634.65	2635.27	2636.02
Survey	22.901	23.276	24.048	24.979	25.939	26.852	27.683	28.414	29.046	29.272	29.585	30.043	30.431	30.762	31.046
Length_comp	570.928	569.911	569.343	569.037	568.899	568.875	568.935	569.055	569.216	569.289	569.403	569.603	569.807	570.007	570.199
Age_comp	2007.48	2008.88	2009.84	2010.49	2010.90	2011.12	2011.21	2011.19	2011.11	2011.06	2010.99	2010.84	2010.68	2010.53	2010.38
Recruitment	25.838	24.725	24.010	23.561	23.306	23.192	23.182	23.243	23.348	23.398	23.476	23.612	23.745	23.872	23.989
Parm_priors	3.000	2.125	1.536	1.108	0.782	0.528	0.328	0.174	0.059	0.025	-0.015	-0.046	-0.022	0.090	0.398
NatM_uniform_Fem_GP_1	0.189	0.180	0.174	0.169	0.166	0.165	0.164	0.164	0.165	0.165	0.166	0.167	0.168	0.169	0.170
L_at_Amax_Fem_GP_1	47.859	47.865	47.872	47.878	47.884	47.889	47.893	47.897	47.900	47.901	47.902	47.904	47.906	47.908	47.909
VonBert_K_Fem_GP_1	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197
CV_young_Fem_GP_1	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.217	0.235	0.248	0.258	0.264	0.268	0.269	0.268	0.267	0.266	0.264	0.262	0.259	0.256	0.254
L_at_Amax_Mal_GP_1	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328	-0.328
VonBert_K_Mal_GP_1	0.526	0.526	0.527	0.527	0.527	0.527	0.527	0.527	0.526	0.526	0.526	0.526	0.526	0.526	0.526
CV_young_Mal_GP_1	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.236	0.236	0.236	0.236	0.235	0.235	0.235	0.235
SR_LN(R0)	10.751	10.528	10.366	10.249	10.166	10.108	10.070	10.047	10.034	10.032	10.029	10.029	10.032	10.037	10.042
SR_BH_steep	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.72	0.75	0.8	0.85	0.9	0.95
Q_extraSD_CalCOFI_Survey(11)	0.289	0.289	0.293	0.299	0.308	0.318	0.329	0.340	0.351	0.355	0.361	0.370	0.378	0.385	0.391
Size_DblN_peak_NoCA_HKL(1)	40.929	41.079	41.146	41.168	41.160	41.133	41.094	41.047	40.995	40.974	40.942	40.889	40.839	40.791	40.747
Size_DblN_ascend_se_NoCA_HKL(1)	4.387	4.407	4.417	4.421	4.421	4.419	4.414	4.408	4.402	4.399	4.395	4.389	4.382	4.377	4.371
Size_DblN_peak_SoCA_HKL(2)	23.864	23.843	23.827	23.816	23.808	23.803	23.800	23.799	23.799	23.799	23.800	23.802	23.803	23.805	23.807
Size_DblN_peak_CA_TWL(3)	45.343	45.258	45.178	45.107	45.048	45.000	44.962	44.933	44.911	44.904	44.896	44.884	44.875	44.869	44.864
Size_DblN_ascend_se_CA_TWL(3)	4.573	4.572	4.569	4.567	4.564	4.562	4.560	4.558	4.557	4.556	4.556	4.555	4.555	4.554	4.554
Size_DblN_peak_OR_WA_Comm(4)	44.496	43.912	43.460	43.206	43.018	42.890	42.811	42.768	42.753	42.752	42.757	42.772	42.794	42.820	42.846
Size_DblN_ascend_se_OR_WA_Comm(4)	4.721	4.668	4.625	4.602	4.585	4.573	4.566	4.561	4.560	4.559	4.560	4.561	4.563	4.565	4.567
Size_DblN_peak_CA_NET(5)	46.849	46.953	47.009	47.038	47.048	47.045	47.034	47.018	46.999	46.991	46.978	46.958	46.937	46.918	46.900
Size_DblN_ascend_se_CA_NET(5)	4.410	4.419	4.424	4.427	4.428	4.429	4.428	4.427	4.426	4.426	4.425	4.423	4.422	4.421	4.419
Size_DblN_peak_NoCA_OR_WA_Rec(6)	44.318	44.294	44.233	44.164	44.097	44.037	43.986	43.943	43.907	43.894	43.877	43.852	43.832	43.814	43.798
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.150	5.154	5.154	5.152	5.150	5.147	5.143	5.140	5.137	5.136	5.135	5.132	5.130	5.128	5.126
Size_DblN_peak_SoCA_Rec(7)	24.799	24.773	24.753	24.737	24.725	24.717	24.711	24.709	24.708	24.708	24.708	24.710	24.711	24.713	24.715
Size_DblN_ascend_se_SoCA_Rec(7)	2.940	2.936	2.932	2.930	2.927	2.926	2.925	2.924	2.924	2.924	2.924	2.924	2.924	2.924	2.924
Size_DblN_descend_se_SoCA_Rec(7)	3.237	3.259	3.277	3.291	3.301	3.309	3.314	3.317	3.318	3.318	3.318	3.318	3.317	3.316	3.315
Size_DblN_end_logit_SoCA_Rec(7)	-1.006	-1.035	-1.060	-1.078	-1.092	-1.101	-1.107	-1.110	-1.112	-1.112	-1.112	-1.111	-1.110	-1.108	-1.107
Size_DblN_peak_TWL_discard(8)	29.679	29.645	29.617	29.595	29.579	29.567	29.559	29.555	29.553	29.552	29.552	29.553	29.554	29.556	29.558
Size_DblN_ascend_se_TWL_discard(8)	4.172	4.172	4.171	4.170	4.170	4.169	4.168	4.168	4.167	4.167	4.167	4.166	4.166	4.166	4.165
Size_DblN_descend_se_TWL_discard(8)	3.175	3.179	3.183	3.186	3.188	3.190	3.192	3.192	3.193	3.193	3.193	3.193	3.193	3.193	3.193
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.074	51.188	51.277	51.349	51.409	51.461	51.507	51.551	51.590	51.605	51.623	51.649	51.671	51.688	51.702
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.116	4.125	4.132	4.137	4.142	4.146	4.149	4.153	4.156	4.157	4.158	4.160	4.162	4.163	4.164
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.511	48.723	48.843	48.906	48.932	48.931	48.913	48.882	48.845	48.830	48.805	48.764	48.723	48.684	48.648
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.794	4.811	4.821	4.827	4.830	4.831	4.830	4.828	4.825	4.824	4.823	4.820	4.817	4.814	4.811
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.900	33.890	33.868	33.846	33.828	33.814	33.805	33.798	33.793	33.791	33.789	33.786	33.783	33.780	33.777
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.306	3.308	3.306	3.303	3.300	3.297	3.295	3.292	3.291	3.290	3.289	3.287	3.285	3.284	3.282
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.598	30.600	30.600	30.604	30.611	30.622	30.636	30.653	30.671	30.678	30.689	30.706	30.723	30.738	30.752
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.728	3.733	3.736	3.738	3.741	3.743	3.746	3.748	3.751	3.752	3.753	3.755	3.757	3.759	3.761
Bratio_2025	0.371	0.432	0.493	0.555	0.615	0.672	0.726	0.774	0.817	0.832	0.854	0.885	0.912	0.934	0.952
SSB_unfished	18271	16285	15002	14108	13453	12953	12563	12254	12007	11922	11809	11649	11521	11417	11332
Totbio_unfished	84990	73957	66957	62221	58881	56460	54678	53353	52365	52044	51627	51076	50663	50353	50121
Recr_unfished	46656	37329	31756	28249	25990	24536	23625	23084	22797	22734	22681	22675	22740	22847	22979
Dead_Catch_SPR	0	479	1266	1614	1796	1905	1981	2042	2094	2114	2142	2186	2226	2265	2300
OFLCatch_2025	2929	2865	2883	2953	3056	3178	3309	3442	3568	3617	3686	3792	3887	3971	4045

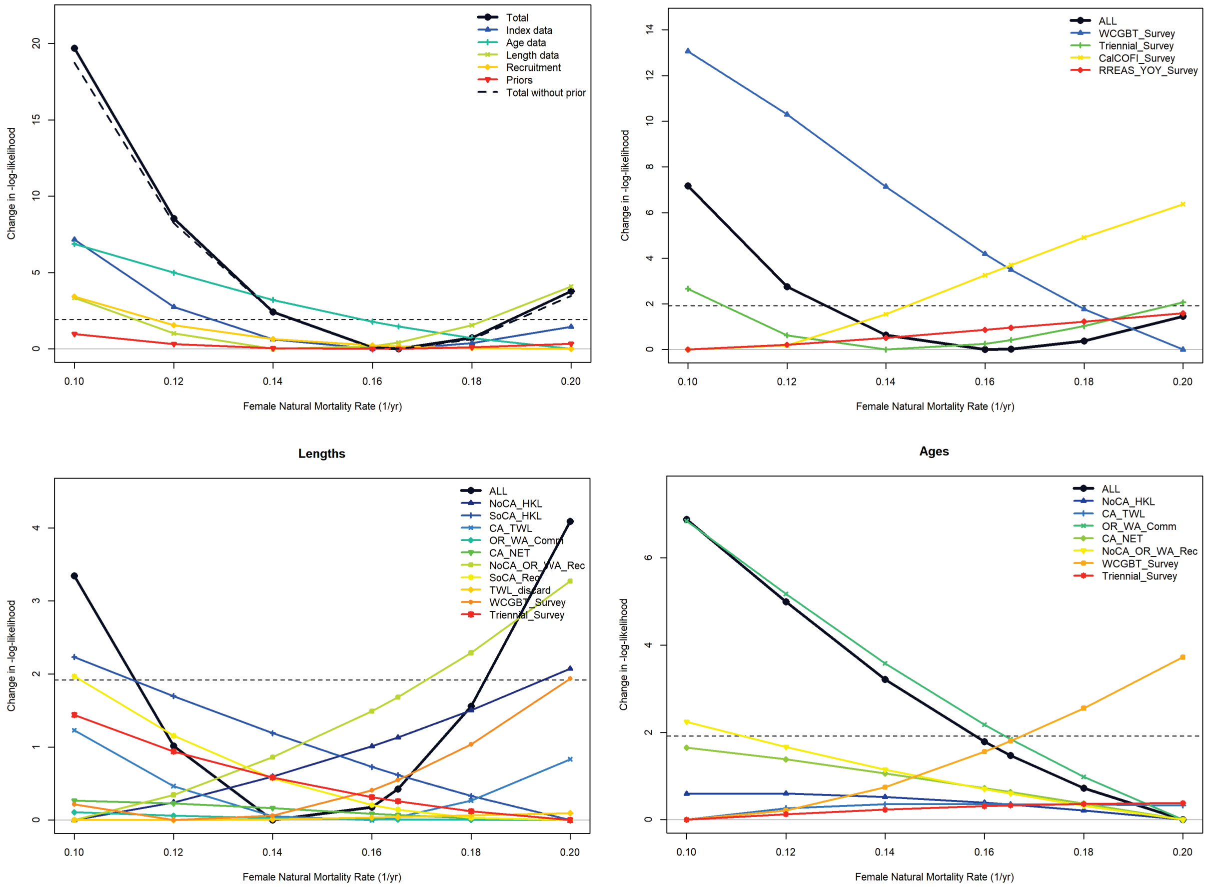


Figure 17E. Likelihood profiles over the female natural mortality (*M*) parameter organized by data type (top left), fleets with indices (top right), fleets with length composition data (bottom left), and fleets with age composition data (bottom left). Components or fleets that show little change over the range of parameter values were excluded.

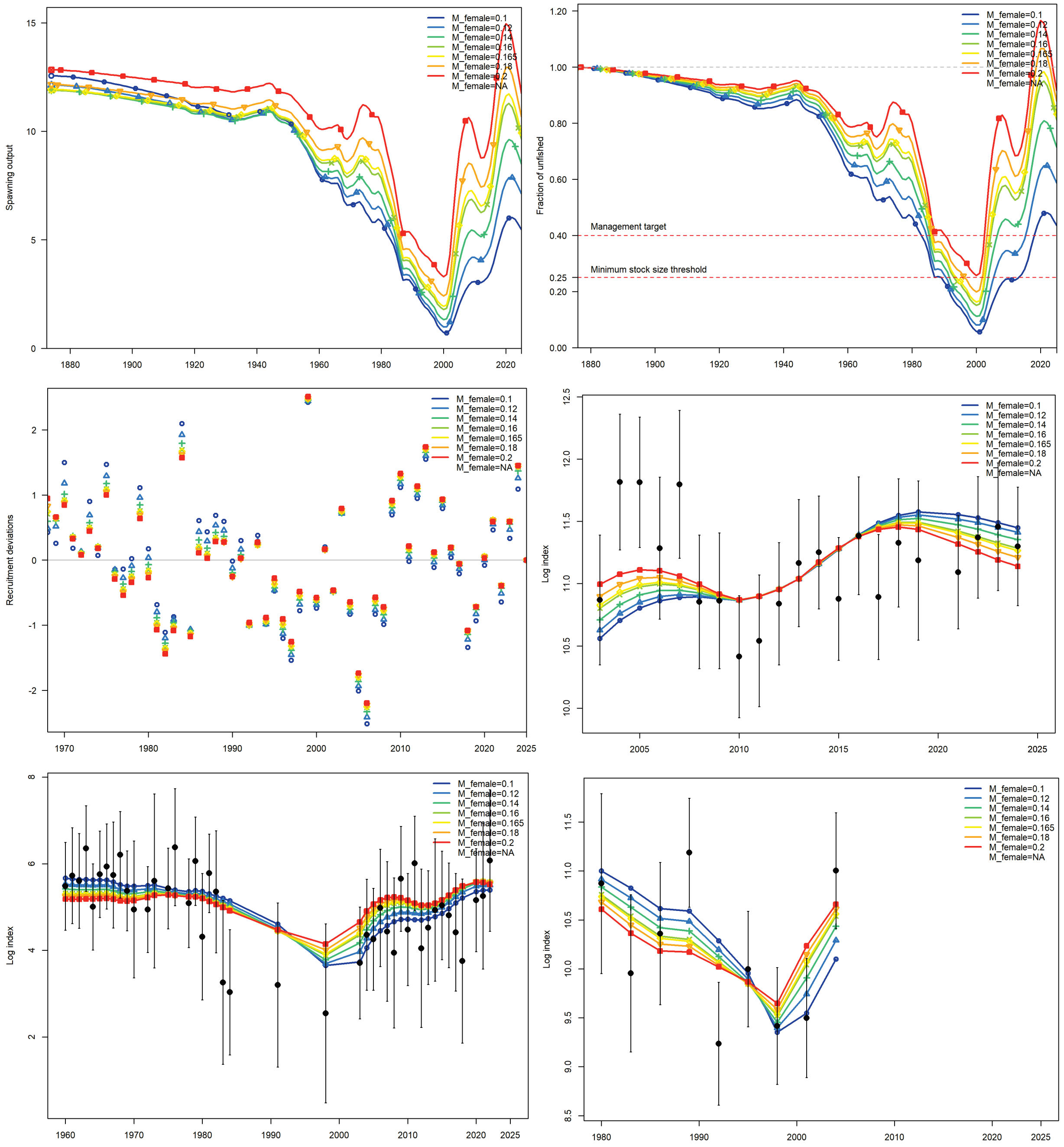
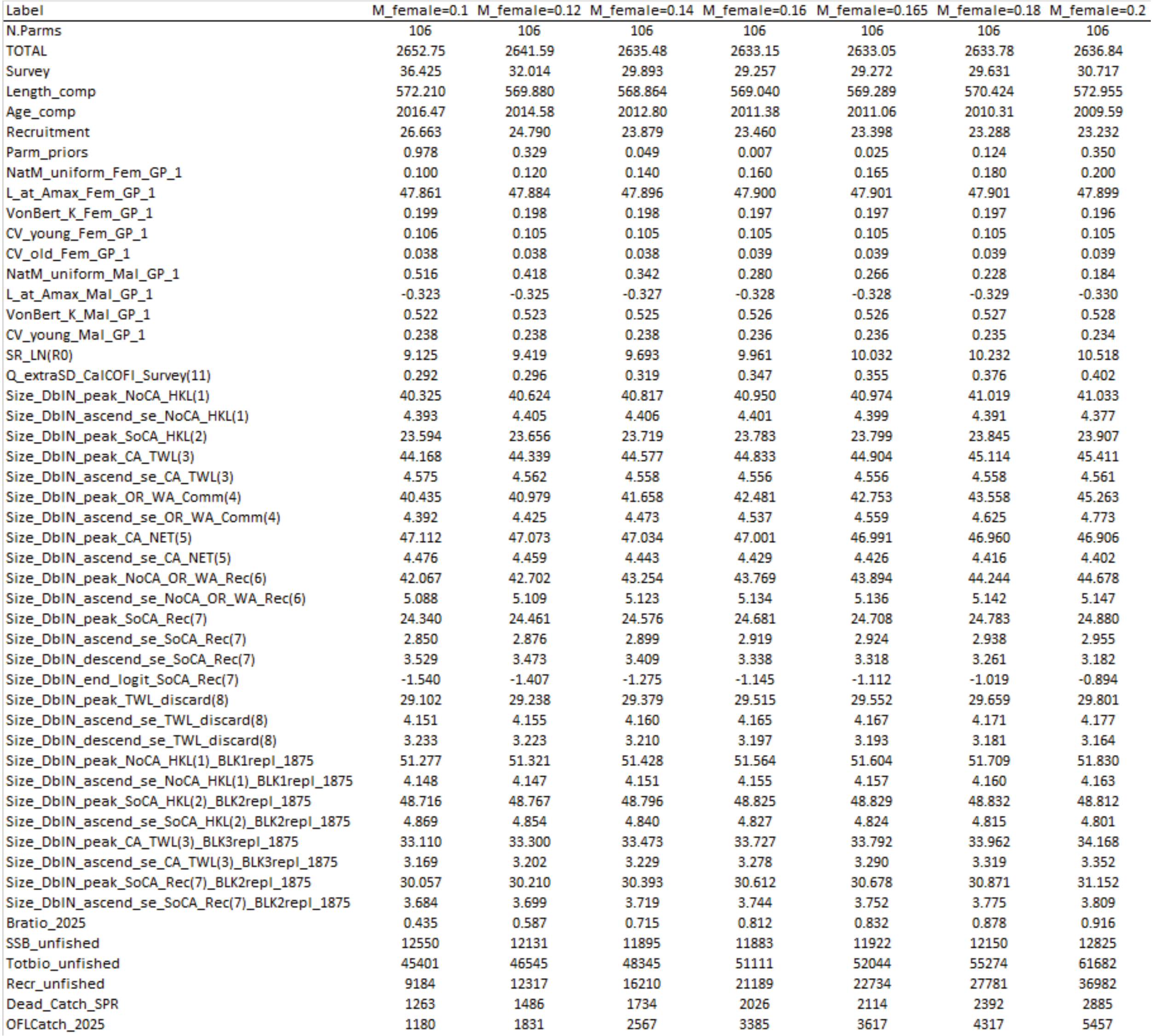


Figure 17F. Likelihood profiles for the female natural mortality (*M*) parameter. Spawning output (top left), fraction unfished (top right), recruitment deviations (middle left), log-scale fit to WCGBTS index (middle right), log-scale fit to CalCOFI index (bottom left), and log-scale fit to Triennial survey (bottom right) are shown.

Table 17E. Likelihood components, parameter values, and derived quantities from a likelihood profile over female natural mortality (*M*). *M* = 0.165 for the proposed base model.



Label	M_female=0.1	M_female=0.12	M_female=0.14	M_female=0.16	M_female=0.165	M_female=0.18	M_female=0.2
N.Parms	106	106	106	106	106	106	106
TOTAL	2652.75	2641.59	2635.48	2633.15	2633.05	2633.78	2636.84
Survey	36.425	32.014	29.893	29.257	29.272	29.631	30.717
Length_comp	572.210	569.880	568.864	569.040	569.289	570.424	572.955
Age_comp	2016.47	2014.58	2012.80	2011.38	2011.06	2010.31	2009.59
Recruitment	26.663	24.790	23.879	23.460	23.398	23.288	23.232
Parm_priors	0.978	0.329	0.049	0.007	0.025	0.124	0.350
NatM_uniform_Fem_GP_1	0.100	0.120	0.140	0.160	0.165	0.180	0.200
L_at_Amax_Fem_GP_1	47.861	47.884	47.896	47.900	47.901	47.901	47.899
VonBert_K_Fem_GP_1	0.199	0.198	0.198	0.197	0.197	0.197	0.196
CV_young_Fem_GP_1	0.106	0.105	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.038	0.038	0.038	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.516	0.418	0.342	0.280	0.266	0.228	0.184
L_at_Amax_Mal_GP_1	-0.323	-0.325	-0.327	-0.328	-0.328	-0.329	-0.330
VonBert_K_Mal_GP_1	0.522	0.523	0.525	0.526	0.526	0.527	0.528
CV_young_Mal_GP_1	0.238	0.238	0.238	0.236	0.236	0.235	0.234
SR_LN(R0)	9.125	9.419	9.693	9.961	10.032	10.232	10.518
Q_extraSD_CalCOFI_Survey(11)	0.292	0.296	0.319	0.347	0.355	0.376	0.402
Size_DblN_peak_NoCA_HKL(1)	40.325	40.624	40.817	40.950	40.974	41.019	41.033
Size_DblN_ascend_se_NoCA_HKL(1)	4.393	4.405	4.406	4.401	4.399	4.391	4.377
Size_DblN_peak_SoCA_HKL(2)	23.594	23.656	23.719	23.783	23.799	23.845	23.907
Size_DblN_peak_CA_TWL(3)	44.168	44.339	44.577	44.833	44.904	45.114	45.411
Size_DblN_ascend_se_CA_TWL(3)	4.575	4.562	4.558	4.556	4.556	4.558	4.561
Size_DblN_peak_OR_WA_Comm(4)	40.435	40.979	41.658	42.481	42.753	43.558	45.263
Size_DblN_ascend_se_OR_WA_Comm(4)	4.392	4.425	4.473	4.537	4.559	4.625	4.773
Size_DblN_peak_CA_NET(5)	47.112	47.073	47.034	47.001	46.991	46.960	46.906
Size_DblN_ascend_se_CA_NET(5)	4.476	4.459	4.443	4.429	4.426	4.416	4.402
Size_DblN_peak_NoCA_OR_WA_Rec(6)	42.067	42.702	43.254	43.769	43.894	44.244	44.678
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.088	5.109	5.123	5.134	5.136	5.142	5.147
Size_DblN_peak_SoCA_Rec(7)	24.340	24.461	24.576	24.681	24.708	24.783	24.880
Size_DblN_ascend_se_SoCA_Rec(7)	2.850	2.876	2.899	2.919	2.924	2.938	2.955
Size_DblN_descend_se_SoCA_Rec(7)	3.529	3.473	3.409	3.338	3.318	3.261	3.182
Size_DblN_end_logit_SoCA_Rec(7)	-1.540	-1.407	-1.275	-1.145	-1.112	-1.019	-0.894
Size_DblN_peak_TWL_discard(8)	29.102	29.238	29.379	29.515	29.552	29.659	29.801
Size_DblN_ascend_se_TWL_discard(8)	4.151	4.155	4.160	4.165	4.167	4.171	4.177
Size_DblN_descend_se_TWL_discard(8)	3.233	3.223	3.210	3.197	3.193	3.181	3.164
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.277	51.321	51.428	51.564	51.604	51.709	51.830
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.148	4.147	4.151	4.155	4.157	4.160	4.163
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	48.716	48.767	48.796	48.825	48.829	48.832	48.812
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.869	4.854	4.840	4.827	4.824	4.815	4.801
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.110	33.300	33.473	33.727	33.792	33.962	34.168
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.169	3.202	3.229	3.278	3.290	3.319	3.352
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.057	30.210	30.393	30.612	30.678	30.871	31.152
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.684	3.699	3.719	3.744	3.752	3.775	3.809
Bratio_2025	0.435	0.587	0.715	0.812	0.832	0.878	0.916
SSB_unfished	12550	12131	11895	11883	11922	12150	12825
Totbio_unfished	45401	46545	48345	51111	52044	55274	61682
Recr_unfished	9184	12317	16210	21189	22734	27781	36982
Dead_Catch_SPR	1263	1486	1734	2026	2114	2392	2885
OFLCatch_2025	1180	1831	2567	3385	3617	4317	5457

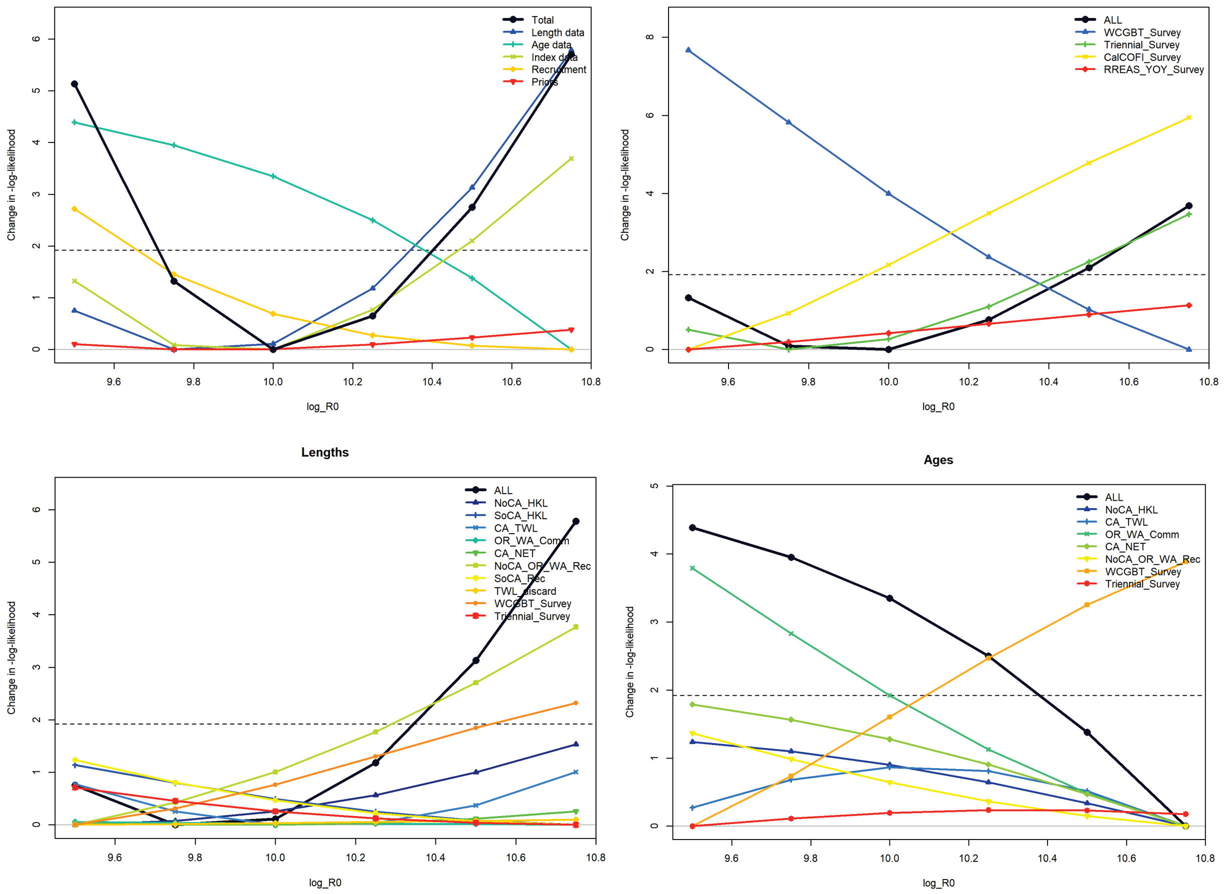


Figure 17G. Likelihood profiles over the log of unfished recruitment (log R_0) parameter organized by data type (top left), fleets with indices (top right), fleets with length composition data (bottom left), and fleets with age composition data (bottom left). Components or fleets that show little change over the range of parameter values were excluded.

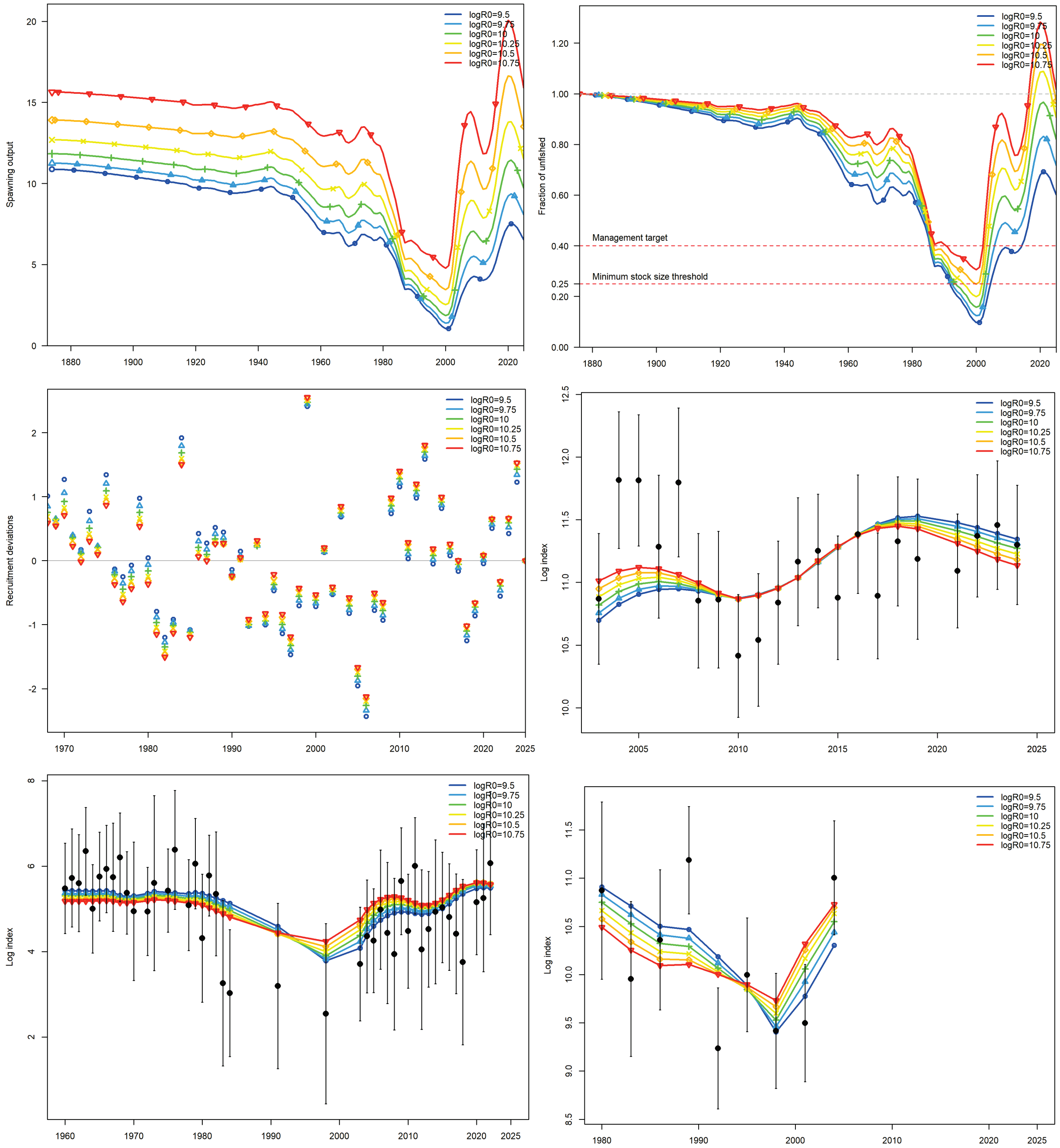
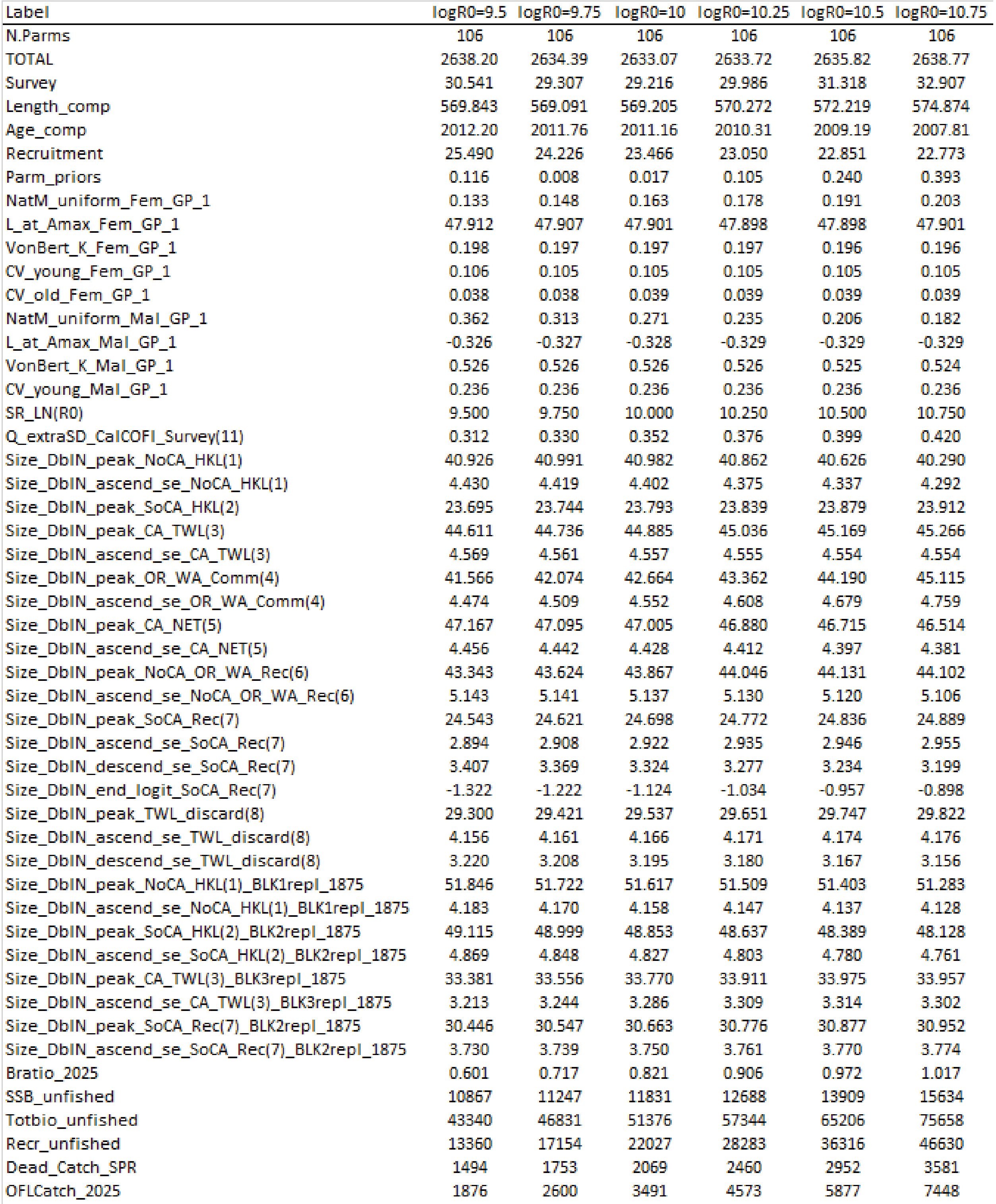


Figure 17H. Likelihood profiles for the log of unfished recruitment (log R_0) parameter. Spawning output (top left), fraction unfished (top right), recruitment deviations (middle left), log-scale fit to WCGBTS index (middle right), log-scale fit to CalCOFI index (bottom left), and log-scale fit to Triennial survey (bottom right) are shown.

Table 17F. Likelihood components, parameter values, and derived quantities from a likelihood profile over log R_0.



Label	logR0=9.5	logR0=9.75	logR0=10	logR0=10.25	logR0=10.5	logR0=10.75
N.Parms	106	106	106	106	106	106
TOTAL	2638.20	2634.39	2633.07	2633.72	2635.82	2638.77
Survey	30.541	29.307	29.216	29.986	31.318	32.907
Length_comp	569.843	569.091	569.205	570.272	572.219	574.874
Age_comp	2012.20	2011.76	2011.16	2010.31	2009.19	2007.81
Recruitment	25.490	24.226	23.466	23.050	22.851	22.773
Parm_priors	0.116	0.008	0.017	0.105	0.240	0.393
NatM_uniform_Fem_GP_1	0.133	0.148	0.163	0.178	0.191	0.203
L_at_Amax_Fem_GP_1	47.912	47.907	47.901	47.898	47.898	47.901
VonBert_K_Fem_GP_1	0.198	0.197	0.197	0.197	0.196	0.196
CV_young_Fem_GP_1	0.106	0.105	0.105	0.105	0.105	0.105
CV_old_Fem_GP_1	0.038	0.038	0.039	0.039	0.039	0.039
NatM_uniform_Mal_GP_1	0.362	0.313	0.271	0.235	0.206	0.182
L_at_Amax_Mal_GP_1	-0.326	-0.327	-0.328	-0.329	-0.329	-0.329
VonBert_K_Mal_GP_1	0.526	0.526	0.526	0.526	0.525	0.524
CV_young_Mal_GP_1	0.236	0.236	0.236	0.236	0.236	0.236
SR_LN(R0)	9.500	9.750	10.000	10.250	10.500	10.750
Q_extraSD_CalCOFI_Survey(11)	0.312	0.330	0.352	0.376	0.399	0.420
Size_DblN_peak_NoCA_HKL(1)	40.926	40.991	40.982	40.862	40.626	40.290
Size_DblN_ascend_se_NoCA_HKL(1)	4.430	4.419	4.402	4.375	4.337	4.292
Size_DblN_peak_SoCA_HKL(2)	23.695	23.744	23.793	23.839	23.879	23.912
Size_DblN_peak_CA_TWL(3)	44.611	44.736	44.885	45.036	45.169	45.266
Size_DblN_ascend_se_CA_TWL(3)	4.569	4.561	4.557	4.555	4.554	4.554
Size_DblN_peak_OR_WA_Comm(4)	41.566	42.074	42.664	43.362	44.190	45.115
Size_DblN_ascend_se_OR_WA_Comm(4)	4.474	4.509	4.552	4.608	4.679	4.759
Size_DblN_peak_CA_NET(5)	47.167	47.095	47.005	46.880	46.715	46.514
Size_DblN_ascend_se_CA_NET(5)	4.456	4.442	4.428	4.412	4.397	4.381
Size_DblN_peak_NoCA_OR_WA_Rec(6)	43.343	43.624	43.867	44.046	44.131	44.102
Size_DblN_ascend_se_NoCA_OR_WA_Rec(6)	5.143	5.141	5.137	5.130	5.120	5.106
Size_DblN_peak_SoCA_Rec(7)	24.543	24.621	24.698	24.772	24.836	24.889
Size_DblN_ascend_se_SoCA_Rec(7)	2.894	2.908	2.922	2.935	2.946	2.955
Size_DblN_descend_se_SoCA_Rec(7)	3.407	3.369	3.324	3.277	3.234	3.199
Size_DblN_end_logit_SoCA_Rec(7)	-1.322	-1.222	-1.124	-1.034	-0.957	-0.898
Size_DblN_peak_TWL_discard(8)	29.300	29.421	29.537	29.651	29.747	29.822
Size_DblN_ascend_se_TWL_discard(8)	4.156	4.161	4.166	4.171	4.174	4.176
Size_DblN_descend_se_TWL_discard(8)	3.220	3.208	3.195	3.180	3.167	3.156
Size_DblN_peak_NoCA_HKL(1)_BLK1repl_1875	51.846	51.722	51.617	51.509	51.403	51.283
Size_DblN_ascend_se_NoCA_HKL(1)_BLK1repl_1875	4.183	4.170	4.158	4.147	4.137	4.128
Size_DblN_peak_SoCA_HKL(2)_BLK2repl_1875	49.115	48.999	48.853	48.637	48.389	48.128
Size_DblN_ascend_se_SoCA_HKL(2)_BLK2repl_1875	4.869	4.848	4.827	4.803	4.780	4.761
Size_DblN_peak_CA_TWL(3)_BLK3repl_1875	33.381	33.556	33.770	33.911	33.975	33.957
Size_DblN_ascend_se_CA_TWL(3)_BLK3repl_1875	3.213	3.244	3.286	3.309	3.314	3.302
Size_DblN_peak_SoCA_Rec(7)_BLK2repl_1875	30.446	30.547	30.663	30.776	30.877	30.952
Size_DblN_ascend_se_SoCA_Rec(7)_BLK2repl_1875	3.730	3.739	3.750	3.761	3.770	3.774
Bratio_2025	0.601	0.717	0.821	0.906	0.972	1.017
SSB_unfished	10867	11247	11831	12688	13909	15634
Totbio_unfished	43340	46831	51376	57344	65206	75658
Recr_unfished	13360	17154	22027	28283	36316	46630
Dead_Catch_SPR	1494	1753	2069	2460	2952	3581
OFLCatch_2025	1876	2600	3491	4573	5877	7448

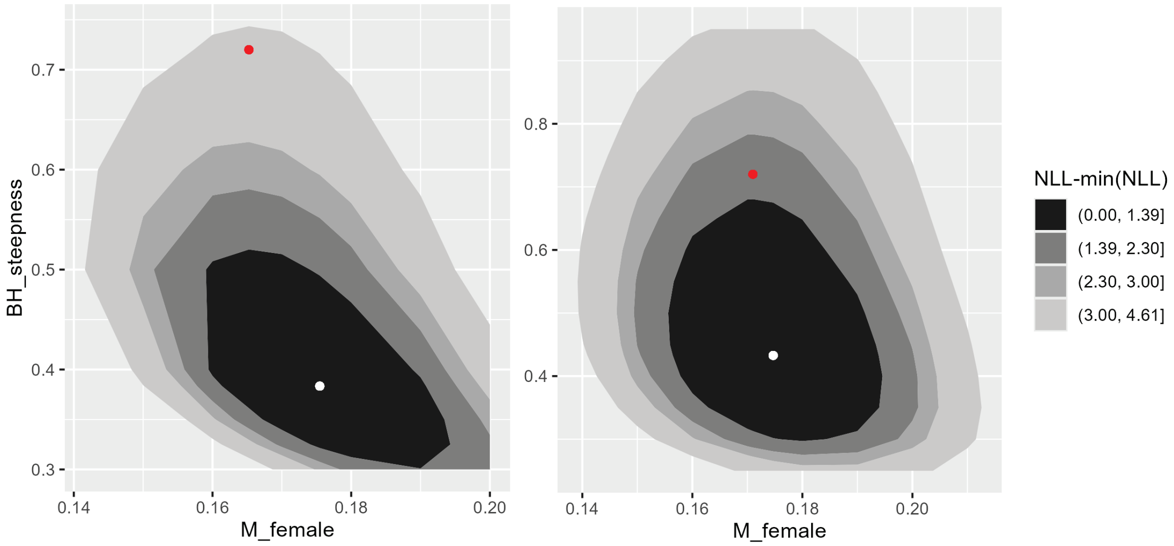


Figure 17I. Bivariate likelihood profiles for Beverton-Holt steepness (*h*) and female natural mortality (*M*) from the proposed base model (left) with a sum-to-zero constraint on recruitment deviations and the pre-STAR base model with unconstrained recruitment deviations (right). White points indicate the minimum NLL and red points indicate the base model for each model run. Contours represent 75%, 90%, 95%, and 99% bivariate confidence regions.

17 - Panel Conclusion

These results are informative and there are no concerns for the proposed final base model. The Panel noted that steepness values changed equilibrium values but also had an effect (although relatively small) on the recent spawning output, whereas the range of natural mortality values mostly affected recent spawning output (and thus OFL). The likelihood for steepness was useful to inform low and high states of nature for decision tables, along with additional sources of uncertainty (see Request 18).

18 - Request

Provide a decision table using steepness (*h*) as the primary axis of uncertainty (low *h* = 0.38, high *h* = 0.97), with the decision table based on the catch time series reflecting full attainment (=ACL) as required by the TOR and alternative catch projections based on constant catch at the MSY proxy yield (2114 t) to bracket the range of catch alternatives in the decision table. If possible, plot spawning output, fraction unfished, age 3+ biomass (t), and relative fishing intensity (1-SPR)/(1-SPR_50%) with management reference points (where appropriate). Please provide this in the post-STAR assessment document and to the STAR Panel, if possible, for inclusion in the STAR Panel report.

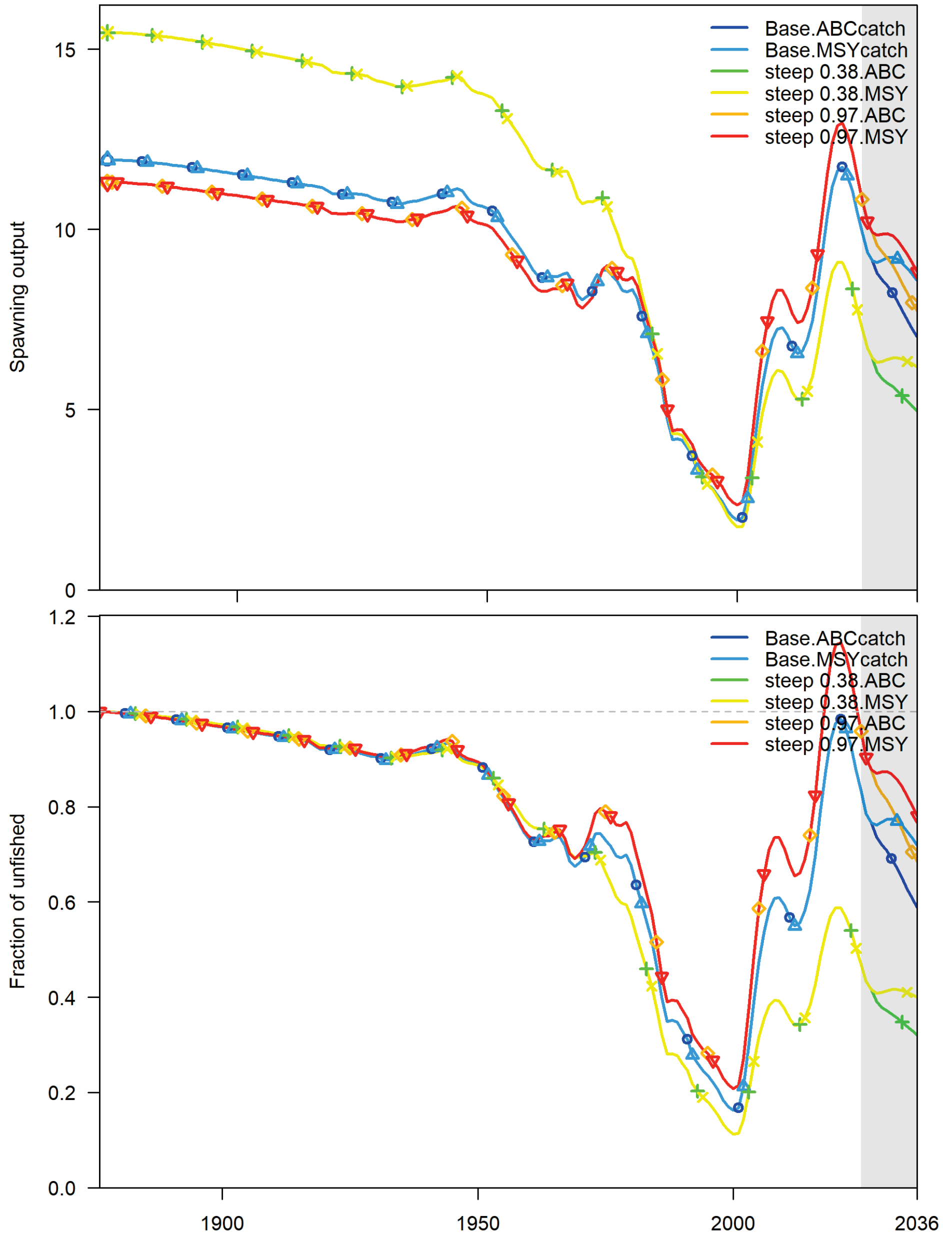
These outputs are necessary to satisfy the Terms of Reference.

18 - Rationale

A few possible options for the axis of uncertainty were considered. However, it quickly became clear that the most appropriate axis of uncertainty was the Beverton-Holt steepness parameter (*h*). The low value of *h* (0.38) was based on the model estimate of steepness and the high value of *h* (0.97) was based on an estimate from Beyer et al. (in prep).

18 - STAT Response

Runs with the three states of nature were conducted: the proposed final base model with a fixed steepness of 0.72, a high state of nature with steepness 0.97, and a low state of nature with steepness 0.38. The two catch streams used were the equilibrium MSY estimate from the base model (2114 t) and the ABC catch stream from the base model (in which 2027 ABC is 3211 t and the 2036 ABC is 2431 t). Catch apportionments were identical to those used for the 2025-2026 forecasts. Estimated stock trajectories are shown as Fig. 18A. For all projections, spawning output and depletion estimates decline over the course of the 12 year projection (2025-2036). Declines accelerated in the ABC catch streams relative to the equilibrium MSY catch streams for each state of nature. The models that assume high steepness start closer to the estimated unfished level (approximately 95% of the unfished level in 2025) and decline less rapidly than the base model and models with low steepness. The only scenario where spawning output declines below target levels is the low steepness model combined with ABC catches, which suggests that depletion could decline to approximately 32% by 2036.



Figures 18A. Model estimates and 2025-2036 projections for: a) the base model ($h = 0.72$), b) high state of nature ($h = 0.97$), and c) low state of nature ($h = 0.38$). Equilibrium MSY (2114 t) and the ABC catch stream (ABC2027 = 3211 t and ABC2036 = 2431 t) from the base model represent the basis for catch projections in each state of nature.

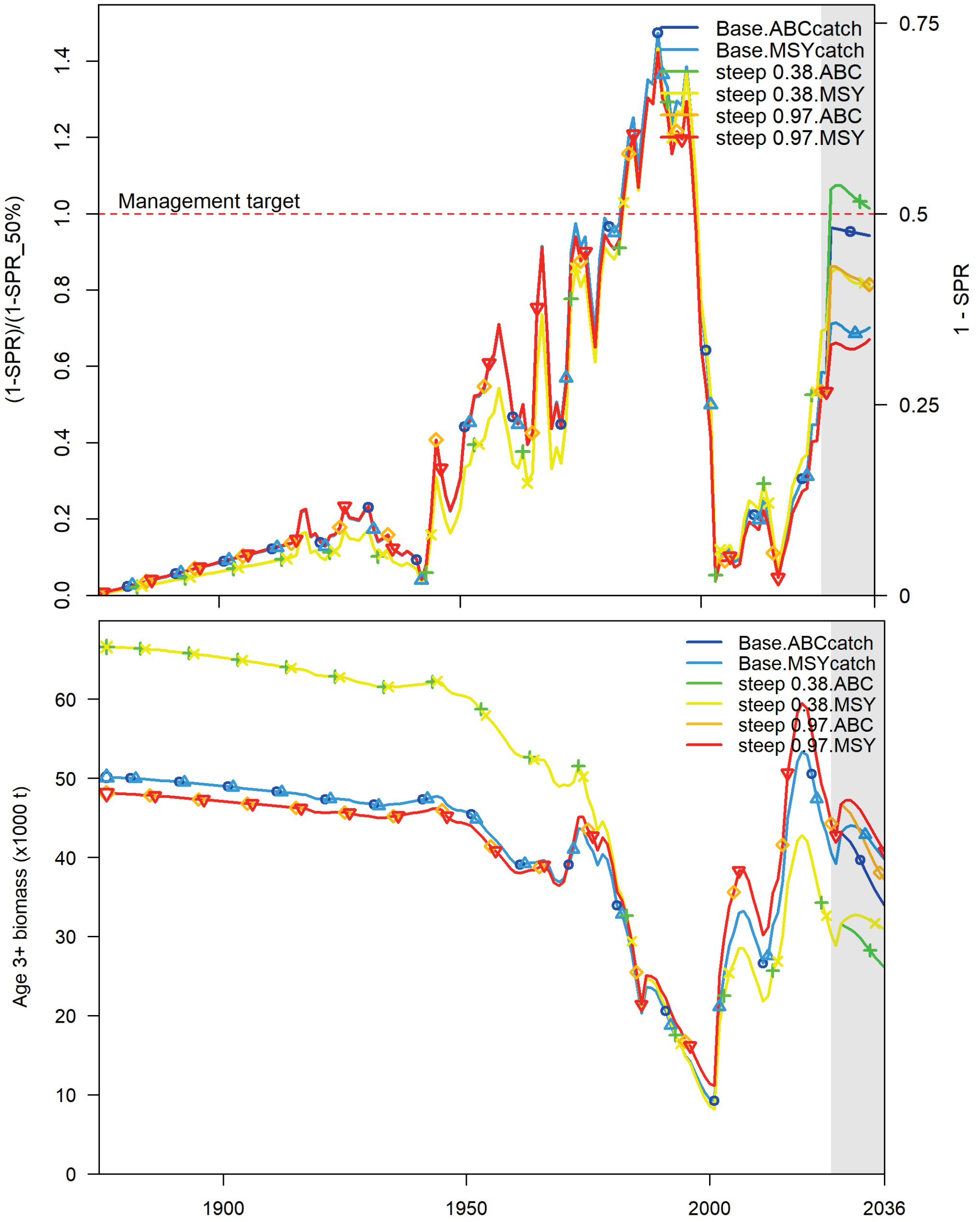
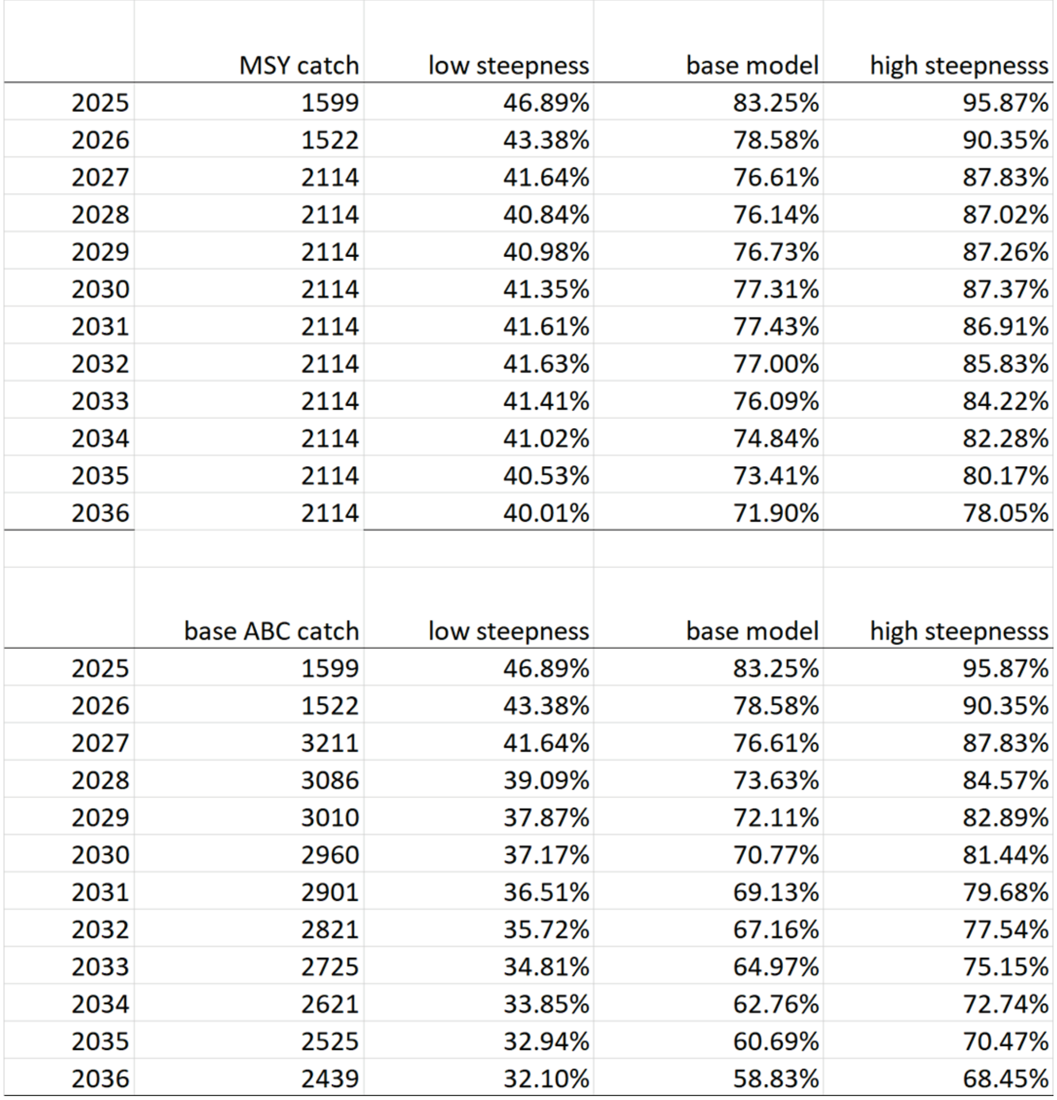


Figure 18B. Model estimates and projections for relative SPR (top) and age 3+ biomass (bottom) for: a) the base model (*h* = 0.72), b) high state of nature (*h* = 0.97), and c) low state of nature (*h* = 0.38). Equilibrium MSY (2114 t) and the ABC catch stream (ABC$_{2027}$ = 3211 t and ABC$_{2036}$ = 2431 t) from the base model represent the basis for the two catch projections in each state of nature.

Table 18. Depletion estimates associated with model projections from the base model (*h* = 0.72), the high state of nature (*h* = 0.97), and the low state of nature (*h* = 0.38) under alternative removal assumptions (equilibrium MSY and the ABC catch stream) for the 2027-2036 time period. Removal assumptions for 2025-2026 are based on existing ABC values.



	MSY catch	low steepness	base model	high steepnesss
2025	1599	46.89%	83.25%	95.87%
2026	1522	43.38%	78.58%	90.35%
2027	2114	41.64%	76.61%	87.83%
2028	2114	40.84%	76.14%	87.02%
2029	2114	40.98%	76.73%	87.26%
2030	2114	41.35%	77.31%	87.37%
2031	2114	41.61%	77.43%	86.91%
2032	2114	41.63%	77.00%	85.83%
2033	2114	41.41%	76.09%	84.22%
2034	2114	41.02%	74.84%	82.28%
2035	2114	40.53%	73.41%	80.17%
2036	2114	40.01%	71.90%	78.05%

	base ABC catch	low steepness	base model	high steepnesss
2025	1599	46.89%	83.25%	95.87%
2026	1522	43.38%	78.58%	90.35%
2027	3211	41.64%	76.61%	87.83%
2028	3086	39.09%	73.63%	84.57%
2029	3010	37.87%	72.11%	82.89%
2030	2960	37.17%	70.77%	81.44%
2031	2901	36.51%	69.13%	79.68%
2032	2821	35.72%	67.16%	77.54%
2033	2725	34.81%	64.97%	75.15%
2034	2621	33.85%	62.76%	72.74%
2035	2525	32.94%	60.69%	70.47%
2036	2439	32.10%	58.83%	68.45%

18 - Panel Conclusion

The Panel thanks the STAT for their timely provision of these model outputs.