The Status of Black Rockfish (*Sebastes melanops*) in U.S. Waters off California in 2023

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Cover photo credit:

Photo of Black Rockfish was downloaded from the RecFIN website and taken by Vicky Okimura (WDFW).

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
CCFRP: California Collaborative Fisheries Research Program
CDFW (formerly CDFG): California Department of Fish and Wildlife (formerly Fish and Game)
CPAH: Catch-per-angler-hour
CPFV: Commercial Passenger Fishing Vessel (aka "party" or "charter" boats, or "PC mode")
CPUE: Catch-per-unit-effort
CRFS: California Recreational Fisheries Survey
GMT: Groundfish Management Team of the PFMC
MRFSS: Marine Recreational Fisheries Statistics Survey
MSY: Maximum Sustainable Yield
NMFS: National Marine Fisheries Service
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
PISCO: Partnership for the Interdisciplinary Study of Coastal Oceans
PR: Private/Rental recreational boat (aka private boat or "skiff")
PSMFC: Pacific States Marine Fisheries Commission
RecFIN: Recreational Fisheries Information Network
RREAS: The NMFS SWFSC's Rockfish Recruitment and Ecosystem Assessment Survey
SPR: Spawning Potential Ratio
SSC: Scientific and Statistical Committee of the PFMC
STAR: Stock Assessment Review (Panel)
STAT: Stock Assessment Team
SWFSC: Southwest Fisheries Science Center
WCGOP: West Coast Groundfish Observer Program
WDFW: Washington Department of Fish and Wildlife
YOY: Young-of-the-year

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Executive Summary

Stock

This assessment reports the status of the black rockfish (*Sebastes melanops*) in U.S. waters off the coast of California. The stock dynamics are modeled with two independent assessments to approximate spatial and temporal variation in size composition, exploitation history, recruitment, and other factors affecting stock dynamics. The northern California model represents the portion of the stock in U.S. waters from Point Arena (38° 57.5′ North latitude) to the California-Oregon border (42° N. lat.), and the central California model includes U.S. waters off from Point Arena to the U.S./Mexico border. Recent genetic analyses and tagging studies provide seemingly contradictory evidence about barriers to gene flow in waters off California (see “Research and data needs” section, below). Future assessments could consider alternative model structures (e.g. multi-area models) if sufficient data become available to parameterize adult movement and/or larval dispersal.

Catches

Over the past decade, black rockfish off California have been caught primarily by the recreational fishery, both north and south of Point Arena, although commercial landings are a significant fraction of total mortality in the northern part of the state (Table ES1). The private/rental boat fleet has accounted for the majority of recreational landings, and hook and line gear types account for the majority of recent commercial landings. Only a small fraction of commercial catches were landed in the central region over the past decade, although historical catch estimates suggest that the commercial fishery developed earlier in the central region (Figure ES1). Commercial landings recorded as live fish have been of similar magnitude to dead fish landings in recent years. A peak in estimated landings in the central region around 2013 was driven by increased catch rates observed in both fishery-dependent and fishery-independent data sources (see also the Recruitment section, below). Landings in the north peaked in response to wartime demand in the 1940s, and peaked again in the late 1970s to early 1990s, with annual removals typically in the range of 100-200 mt since the year 2000 (Figure ES2).

Table ES1. Estimated commercial and recreational mortality (mt) of California black rockfish by region and year.

Year	Commercial North	Recreational North	Commercial Central	Recreational Central	Grand Total
2013	30.7	142.6	5.1	220.3	398.7
2014	37.5	180.5	3.9	101.8	323.7
2015	100.1	159.5	4.5	65.8	329.9
2016	62.8	103.6	2.0	61.5	229.8
2017	55.4	74.3	1.0	23.6	154.3
2018	45.0	75.3	1.1	20.4	141.8
2019	49.3	91.3	0.7	18.9	160.2
2020	41.2	74.4	1.2	28.6	145.4
2021	38.1	162.1	1.3	37.1	238.6
2022	56.0	180.5	1.2	31.7	269.4

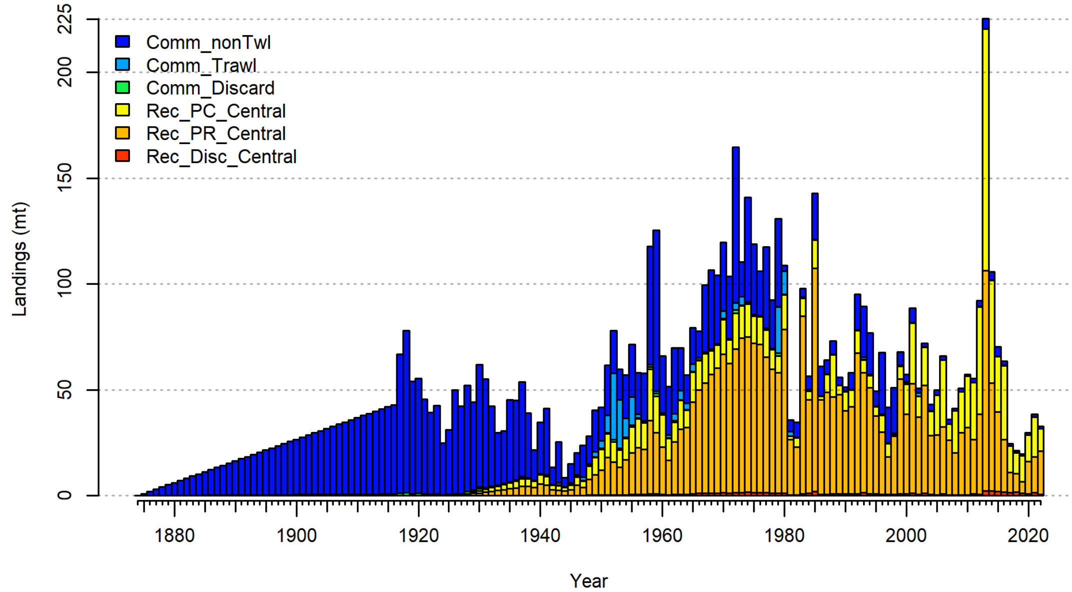

Figure ES1. Estimated landings (mt) of black rockfish in central California, 1875-2022, by fleet. Discarded dead catch is modeled as separate fleets, one commercial and one recreational, to account for differences in size composition between discarded and retained catch.

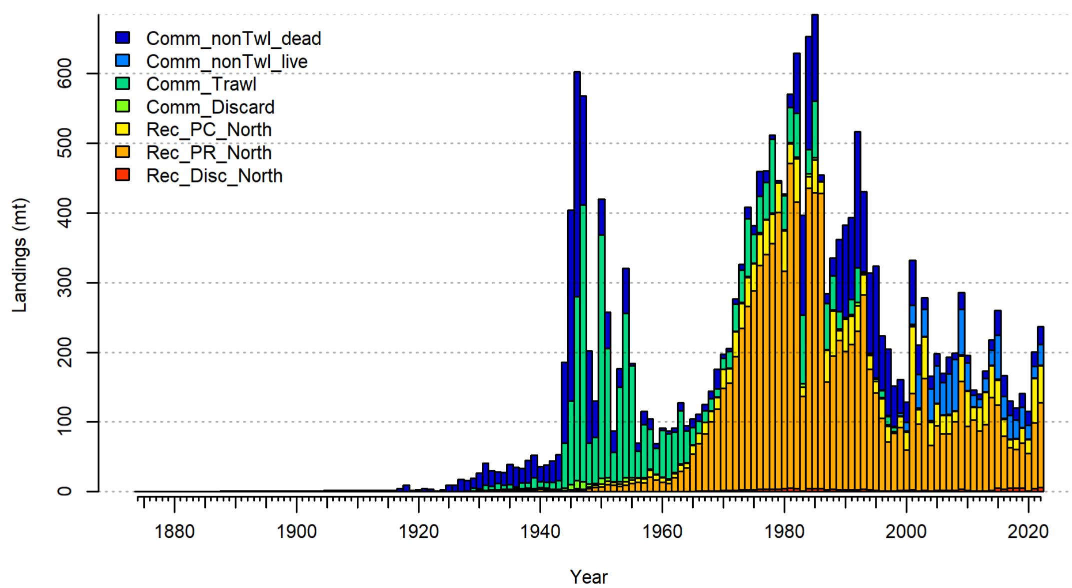

Figure ES2. Estimated landings (mt) of black rockfish in northern California, 1875-2022, by fleet. Discarded dead catch is modeled as separate fleets, one commercial and one recreational, to account for differences in size composition between discarded and retained catch. Note the difference in scale relative to landings in the central region.

Data and assessment

Northern California Model
The assessment is structured as a single, sex-disaggregated population model, spanning U.S. waters from Point Arena to the California-Oregon border. The model operates on an annual time step covering the period 1875 to 2022 (not including forecast years) and assumes an unfished equilibrium population prior to 1875. Population dynamics are modeled for ages 0 through 50, with age-50 being the accumulator age. The maximum observed age was 33 for males and 35 for females. Population bins were set every 1 cm from 5 to 70 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 seven fleets, and is informed by three time series of relative abundance (one fishery-independent survey, one CPUE index from a shore-based recreational sampling program, and one CPUE index from an onboard CPFV observer program). Size and age composition data include lengths from 1978-2022 and ages from 1980-2022, 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 50. All catch was 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 fishing type (CPFV or private boat) and catch type (retained or discarded). All recreational shore modes were combined with the private boat fleet due to their small contribution to overall catch. Discarded catch (CPFV and private boats combined) was modeled as separate fleet due to differences in size composition relative to retained catch, and a lack of sufficient data in an appropriate format to explicitly model retention. The commercial sector was represented by four fleets. Two “non-trawl” fleets representing primarily hook-and-line and longline gear types, but including other minor gears, were differentiated by the condition of landed fish (landed dead or alive), as fish in each group often have different size compositions. Other commercial fleets include a trawl fleet, and a fleet for discarded catch which represents the aggregated, dead discards from all commercial fleets. Fleet selectivity was assumed to be asymptotic for the commercial trawl and non-trawl (landed dead) fleets, and dome-shaped for discard fleets as well as the commercial non-trawl (landed alive) fleet. Sensitivities to these selectivity assumptions were explored during model development and again relative to the base model.

Central California Model
The model for the central region is very similar in structure to the northern model. Black rockfish are rare south of Point Conception (34° 27′ North latitude), so data informing the central California model are primarily from the region between Point Conception and Point Arena. All catches south of Point Arena are included, so results from the central model reflect the area spanning U.S. waters from the US/Mexico border to Point Arena. Model dimensions for year, age bins, and length bins are identical to the northern model. The central model is conditioned on catch from two sectors (commercial and recreational) divided among six fleets, and is informed by four time series of relative abundance (one fishery-independent survey, one CPUE index from a shore-based recreational sampling program, and two CPUE indices from onboard CPFV observer programs operating over different time periods). Size and age composition data include lengths from 1959-2022 and ages from 1980-2022, 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 50. All catch was assumed to be known with high precision (log-scale standard error of 0.05).

Fleets were identical to the northern model, except that the commercial sector was represented by three fleets rather than four. A single "non-trawl" fleet represented hook-and-line, longline, and other minor gears, and included both 'live' and 'dead' conditions as landings of live fish were too small to warrant a separate fleet. Other commercial fleets included a trawl fleet, and a fleet for discarded catch that represented discarded dead fish from both the non-trawl and trawl fleets. Fleet selectivity was allowed to be domed for all commercial and recreational fleets. Sensitivity to these selectivity assumptions were explored during model development and relative to the base model.

Stock biomass and dynamics

The last assessment of black rockfish in California estimated spawning output to be at 33% of unfished levels in 2015 (Cope et al. 2016). The two models in the current assessment estimate 2023 spawning output to be 410 billion eggs (~95% asymptotic interval: 175-645) in the northern area and 136 billion eggs (~95% asymptotic interval: 35-238) in the central area (Tables ES2 and ES3). Statewide, this suggests the stock is near target biomass, at roughly 38% of unfished spawning output, in 2023 (Table ES4). The ratio of estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output is sometimes referred to as "depletion" or the "fraction unfished." In northern California, estimates of spawning output declined rapidly in the 1940s due to wartime demand, recovered briefly, and then declined from the 1970s to late 1990s (Figure ES3). Declines in spawning output began earlier in central California but have been more gradual. Models for both areas estimate consistent increases in spawning output since the late 2000s.

Combining spawning output estimates from both areas, time series for the California stock primarily reflect patterns in the northern model, as the majority of spawning output comes from this area, but declines prior to the 1940s in the central area are also apparent (Figure ES4). Relative to unfished levels, the combined spawning output for the California stock is estimated to have declined below the minimum stock size threshold (25% of unfished spawning output) from 1987-2009 (Figure ES5). However, estimated trends in statewide spawning output have shown a consistent increase since the late 1990s and are currently near target levels.

Table ES2. Recent trends in spawning output (billions of eggs) and spawning output relative to unfished spawning output ("Fraction Unfished") from the northern area base model. Uncertainty intervals are 95% asymptotic estimates.

Year	Spawning Output	Interval	Fraction Unfished	Interval
2013	339	142 - 536	0.301	0.13 - 0.47
2014	352	149 - 556	0.313	0.13 - 0.49
2015	366	154 - 579	0.325	0.14 - 0.51
2016	375	153 - 597	0.333	0.14 - 0.53
2017	393	162 - 624	0.349	0.15 - 0.55
2018	411	174 - 648	0.365	0.16 - 0.57
2019	423	183 - 663	0.376	0.17 - 0.59
2020	427	187 - 667	0.379	0.17 - 0.59
2021	431	193 - 670	0.383	0.18 - 0.59
2022	423	186 - 659	0.376	0.17 - 0.58
2023	410	175 - 645	0.364	0.16 - 0.57

Table ES3. Recent trends in spawning output (billions of eggs) and spawning output relative to unfished spawning output ("Fraction Unfished") from the central area base model. Uncertainty intervals are 95% asymptotic estimates.

Year	Spawning Output	Interval	Fraction Unfished	Interval
2013	63	10 - 115	0.193	0.04 - 0.34
2014	63	8 - 118	0.194	0.04 - 0.35
2015	70	9 - 131	0.215	0.04 - 0.39
2016	81	11 - 151	0.249	0.05 - 0.45
2017	93	13 - 173	0.287	0.06 - 0.51
2018	107	18 - 195	0.329	0.08 - 0.58
2019	118	23 - 213	0.364	0.1 - 0.63
2020	126	27 - 226	0.390	0.11 - 0.67
2021	131	30 - 232	0.404	0.12 - 0.69
2022	134	32 - 235	0.412	0.13 - 0.69
2023	136	35 - 238	0.421	0.14 - 0.7

Table ES4. Recent trends in statewide spawning output (billions of eggs) and spawning output relative to unfished spawning output ("Fraction Unfished") derived from the northern and central area base models.

Year	Spawning Output	Fraction Unfished
2013	401	0.277
2014	415	0.286
2015	436	0.301
2016	456	0.315
2017	486	0.335
2018	518	0.357
2019	542	0.373
2020	554	0.382
2021	562	0.388
2022	557	0.384
2023	547	0.377

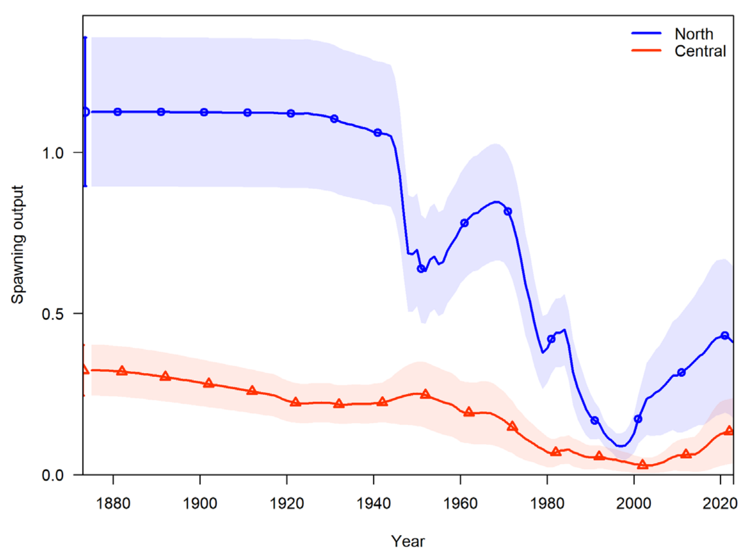

Figure ES3. Estimated spawning output (trillions of eggs) time series for the northern and central area models. Shaded areas represent 95% asymptotic confidence intervals.

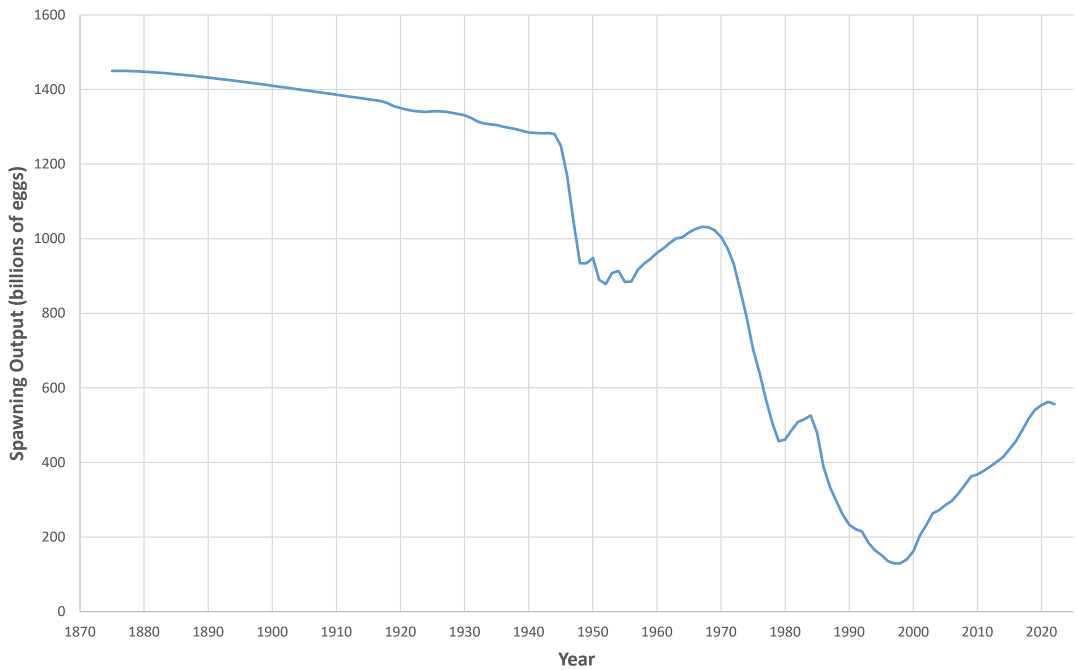

Figure ES4. Combined spawning output (billions of eggs) for the California stock of black rockfish, 1875-2023.

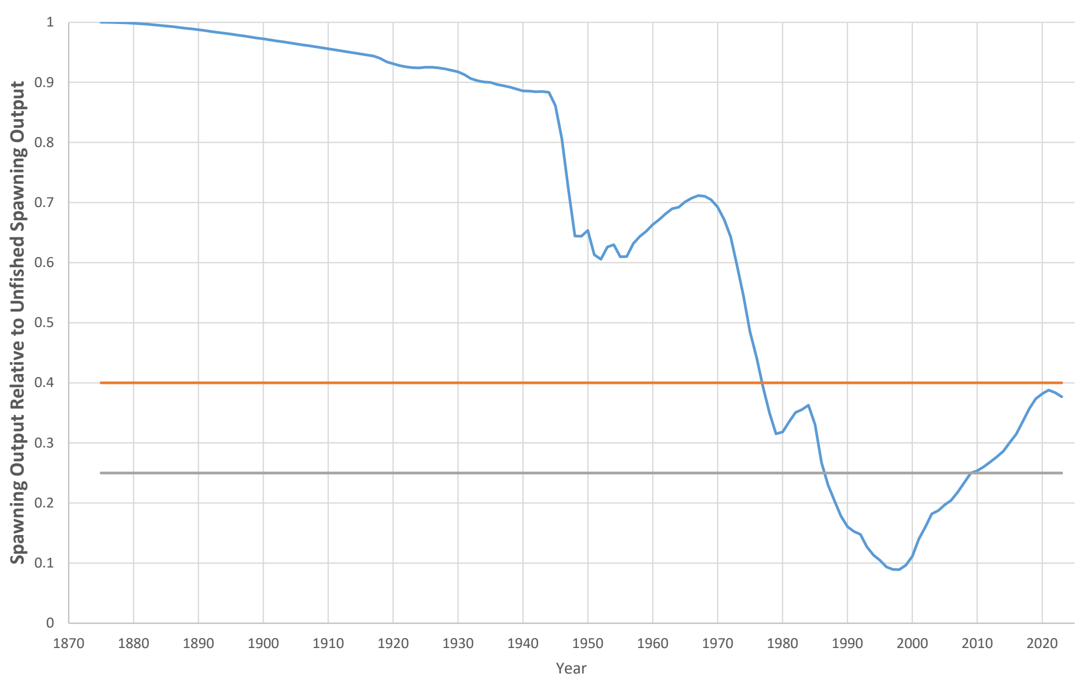

Figure ES5. Spawning output relative to unfished spawning output for the California stock of black rockfish, 1875-2023. The target level of spawning output (40% of unfished) and minimum stock size threshold (25% of unfished) are shown as horizontal lines for reference.

Recruitment

Recruitment patterns in the two sub-area models showed a weak but significant positive correlation (see responses to STAR panel requests). Strong estimated recruitments in 2008 and 2010 in the central area model were above average, but weaker in the northern model (Figures ES6 and ES7). In the central area, the previously mentioned spike in landings around 2013 was preceded by sudden decreases in mean length, suggesting entry of a large year class into the fishery in that region. These patterns were not observed in the north. Large deviations in the 1970s and mid-1990s were estimated in the northern model, but were estimated closer to mean levels in the central area model. Beverton-Holt steepness was fixed at 0.72 in both models.

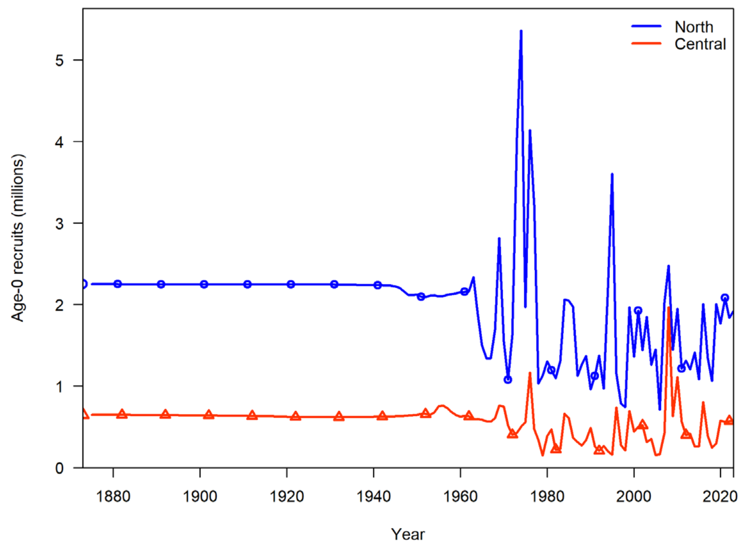

Figure ES6. Time series of estimated recruitment (millions of age-0 fish) in the northern and central area models.

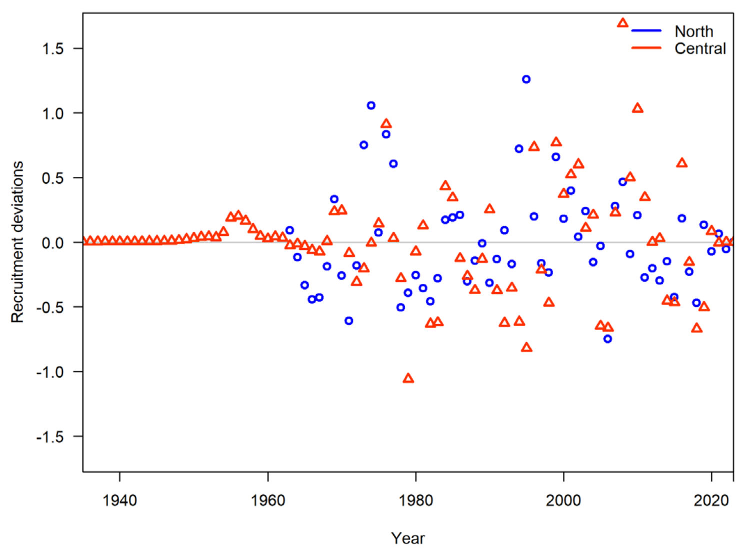

Figure ES7. Comparison of estimated annual recruitment deviations in the northern and central area models.

Exploitation status

Based on the best available historical catch reconstructions, exploitation rates of black rockfish in California increased earlier in the central area (Figure ES8). This is consistent with spatial patterns of population growth and development of infrastructure to support large-scale fisheries in the state. Exploitation rates exceeded target levels in both areas from the 1970s through at least the 1990s. More recent exploitation rates have been variable, but closer to target levels.

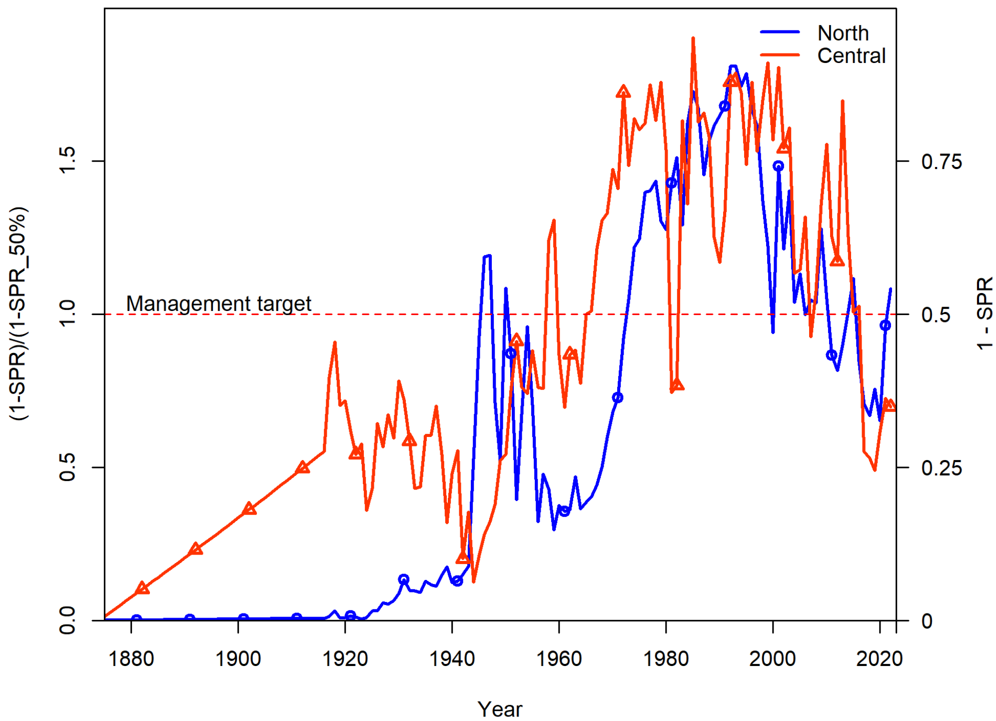

Figure ES8. Fishing intensity (1-SPR) relative to the target level, 1875-2022, by sub-area.

Ecosystem considerations

Ecological information was not explicitly represented in the stock assessment model. This is due to a complicated mechanistic relationship between black rockfish population dynamics and the California Current ecosystem. Some data on predators and prey are available but lack sufficient coverage to inform spatiotemporal dynamics of black rockfish (e.g., natural mortality). A number of studies have investigated potential environmental drivers of black rockfish recruitment (e.g., Caselle et al. 2010; Ralston et al. 2013; Schroeder et al. 2019; Field et al. 2021). Black rockfish have also been identified as a candidate for multispecies indicators of recruitment (along with blue, deacon, darkblotched, widow, and yellowtail rockfishes; Field et al. 2021).

Reference points

Management reference points for the California stock (Table ES5) were derived from the two sub-area models (Tables ES6 and ES7). At the statewide level, stock status is near target (38% of unfished spawning output). Long-term equilibrium yield based on SPR proxy harvest rates is 330 mt statewide, compared to 348 mt based on the SB40% proxy and 382 mt based on the assumed stock-recruitment relationship with steepness fixed at 0.72 in both models.

Unfished spawning output in the northern area is roughly three times larger than the central area, i.e. this assessment estimates that about 75% of statewide spawning output is generated north of Point Arena in the absence of fishing (Tables ES6 and ES7). Current spawning output levels show a similar ratio.

Table ES5. Reference points for the California stock, derived from the sub-area models.

Reference Point	Estimate
Unfished Spawning Output (billions of eggs)	1,450
Unfished Age 8+ Biomass (mt)	5,499
Unfished Recruitment (R0, 1000s)	2,897
Spawning Output (2023, billions of eggs)	546
Fraction Unfished (2023)	0.377
Reference Points Based SB40%	
Proxy Spawning Output SB40%	580
Yield with SPR Based On SB40% (mt)	348
Reference Points Based on SPR Proxy for MSY	
Proxy Spawning Output (SPR50)	647
Yield with SPR50 at SB SPR (mt)	330
Reference Points Based on Estimated MSY Values	
Spawning Output at MSY (SB MSY)	356
MSY (mt)	382

Table ES6. Northern model reference points and 95% asymptotic intervals.

Reference Point	Estimate	Interval
Unfished Spawning Output (billions of eggs)	1,126	926 - 1,326
Unfished Age 8+ Biomass (mt)	4,219	3,651 - 4,787
Unfished Recruitment (R0, 1000s)	2,249	1,493 - 3,005
Spawning Output (2023, billions of eggs)	410	175 - 645
Fraction Unfished (2023)	0.36	0.16 - 0.57
Reference Points Based SB40%		
Proxy Spawning Output SB40%	450	370 - 531
SPR Resulting in SB40%	0.458	0.458 - 0.458
Exploitation Rate Resulting in SB40%	0.16	0.131 - 0.190
Yield with SPR Based On SB40% (mt)	280	239 - 321
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	502	413 - 592
SPR50	0.5	-
Exploitation Rate Corresponding to SPR50	0.137	0.112 - 0.162
Yield with SPR50 at SB SPR (mt)	265	227 - 304
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	276	223 - 330
SPR MSY	0.319	0.313 - 0.325
Exploitation Rate Corresponding to SPR MSY	0.281	0.220 - 0.342
MSY (mt)	307	261 - 353

Table ES7. Central model reference points and 95% asymptotic intervals.

Reference Point	Estimate	Interval
Unfished Spawning Output (billions of eggs)	324	292 - 356
Unfished Age 8+ Biomass (mt)	1,280	1,133 - 1,428
Unfished Recruitment (R0, 1000s)	648	584 - 712
Spawning Output (2023, billions of eggs)	136	35 - 238
Fraction Unfished (2023)	0.42	0.14 - 0.70
Reference Points Based SB40%		
Proxy Spawning Output SB40%	130	117 - 142
SPR Resulting in SB40%	0.458	0.458 - 0.458
Exploitation Rate Resulting in SB40%	0.135	0.127 - 0.142
Yield with SPR Based On SB40% (mt)	68	62 - 75
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	145	130 - 159
SPR50	0.5	-
Exploitation Rate Corresponding to SPR50	0.114	0.108 - 0.120
Yield with SPR50 at SB SPR (mt)	65	59 - 71
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	80	72 - 88
SPR MSY	0.32	0.316 - 0.325
Exploitation Rate Corresponding to SPR MSY	0.24	0.225 - 0.254
MSY (mt)	75	68 - 82

Management performance

Total mortality estimates for the the California stock of black rockfish have not exceeded the ACL since the last assessment (Table ES8).

Table ES8. Evaluation of Management Performance for Black Rockfish. Total Mortality estimates are based on the Groundfish Expanded Mortality Multiyear (GEMM) report. Catch values prior to 2017 are not reported here because black rockfish catch limits were defined across state lines and are not comparable to the California-only estimates used in this assessment. The GEMM report estimate for 2022 was not yet released when this assessment was prepared.

Year	Assessed Area	OFL (mt)	ABC (mt)	ACL (mt)	Total Mortality (mt)
2013	OR - CA	1159	1108	1000	--
2014	OR - CA	1166	1115	1000	--
2015	OR - CA	1176	1124	1000	--
2016	OR - CA	1183	1131	1000	--
2017	CA	349	334	334	171
2018	CA	347	332	332	142
2019	CA	344	329	329	159
2020	CA	341	326	326	117
2021	CA	379	348	348	236
2022	CA	373	341	341	--

Unresolved problems and major uncertainties

- There is conflicting evidence and limited information with which to evaluate black rockfish stock structure, especially off California.
- Productivity of the stock is poorly understood. The current models assume a value of 0.72 for the Beverton-Holt steepness parameter. Additional age data are needed, particularly for the central region, to better inform estimates of natural mortality.
- Much of what we know about the habitat associations and ecological role of black rockfish come from Oregon, Washington, and Alaska.
- Attempts to investigate recruitment indices (RREAS, SWFSC SCUBA) for the fleets-as-areas model configuration were not successful, and there was not enough time to evaluate area-specific indices prior to the STAR panel document deadline (although they have been developed).
- In the northern assessment, the fishery-independent abundance indices are of short duration and insufficient precision to provide much information on recent trends in abundance. Thus, the indices such as CCFRP need to be extended to inform estimates of abundance in the northern area.
- Further research is needed to explain skewed sex ratios among older individuals in the population.

Decision table and projections

Alternative states of nature identified during the STAR panel were used to forecast population dynamics for the California stock assuming low, medium, and high catch projections (Table ES9). Catch projections for 2023-2024 and fleet allocations for 2025-2034 were provided for each area and fleet by state representatives on the GMT. Harvest control rules were applied iteratively, at the state level, based on output from both models. An allocation of the ACL based on the proportion of the OFL from each area was requested by the GMT, and is provided as Table ES10.

Table ES9. 12-year projections (2023 – 2034) for California black rockfish (statewide) according to three alternative states of nature based on the annual rate of natural mortality. Columns represent low, medium (base case), and high states of nature, and rows range over different assumed catch levels corresponding to the forecast catches from each state of nature. Spawning output units are billions of eggs. Catches in 2023-2024 assume full attainment of the ACL as forecast by the 2015 assessment.

P* = 0.45, sigma = 0.5			**Low** Female M = 0.147		**State of nature Base case** Female M = 0.210		**High** Female M = 0.300	
Management decision	Year	Catch (mt)	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
Low Catch	2023	334	494	0.222	547	0.377	872	0.736
	2024	329	477	0.215	530	0.365	847	0.716
	2025	86	457	0.205	513	0.354	824	0.696
	2026	96	471	0.212	532	0.367	837	0.707
	2027	109	487	0.219	558	0.384	858	0.725
	2028	122	506	0.227	590	0.407	885	0.748
	2029	135	528	0.237	627	0.432	912	0.770
	2030	148	555	0.249	664	0.458	933	0.788
	2031	160	586	0.263	700	0.483	948	0.801
	2032	171	618	0.278	731	0.504	957	0.808
	2033	181	651	0.293	758	0.523	960	0.811
	2034	189	683	0.307	781	0.539	960	0.811
Base Catch	2023	334	494	0.222	547	0.377	872	0.736
	2024	329	477	0.215	530	0.365	847	0.716
	2025	224	457	0.205	513	0.354	824	0.696
	2026	236	447	0.201	511	0.353	819	0.692
	2027	249	437	0.196	516	0.356	822	0.694
	2028	261	428	0.192	526	0.363	832	0.702
	2029	270	421	0.189	539	0.372	841	0.711
	2030	277	420	0.189	554	0.382	848	0.716
	2031	282	423	0.190	569	0.392	851	0.719
	2032	285	428	0.193	583	0.402	850	0.718
	2033	286	436	0.196	595	0.410	848	0.716
	2034	287	443	0.199	606	0.418	844	0.713
High Catch	2023	334	494	0.222	547	0.377	872	0.736
	2024	329	477	0.215	530	0.365	847	0.716
	2025	580	457	0.205	513	0.354	824	0.696
	2026	566	384	0.173	458	0.316	771	0.652
	2027	555	313	0.141	412	0.284	732	0.618
	2028	543	249	0.112	374	0.258	704	0.594
	2029	529	204	0.092	344	0.237	682	0.576
	2030	518	181	0.081	321	0.221	664	0.561
	2031	507	174	0.078	303	0.209	649	0.548
	2032	498	172	0.077	290	0.200	637	0.538
	2033	491	173	0.078	278	0.192	627	0.530
	2034	485	174	0.078	268	0.185	619	0.523

Table ES10. Base model estimates of the OFL (mt), ABC (mt), ACL (mt), buffer, spawning output in billions of eggs across California, and relative spawning output by year along with the sub-area allocations of the ACL for the northern and central regions. Buffers are based on the default category 1 uncertainty level (sigma=0.5) and a P-star of 0.45.

Year	OFL (mt)	ABC (mt)	ACL (mt)	Buffer	Spawning Output	Fraction Unfished	Sub-ACL North	Sub-ACL Central
2025	250.1	233.8	223.6	0.935	513.0	0.354	182.0	41.6
2026	265.3	246.8	235.7	0.93	511.5	0.353	190.3	45.5
2027	280.6	259.9	249.1	0.926	516.0	0.356	199.4	49.7
2028	293.2	270.3	261.0	0.922	526.0	0.363	208.1	53.0
2029	302.2	277.1	270.2	0.917	539.4	0.372	215.2	55.0
2030	308.4	281.6	277.2	0.913	554.2	0.382	221.1	56.1
2031	312.6	284.2	282.3	0.909	569.0	0.392	225.6	56.7
2032	315.6	285.3	285.3	0.904	582.8	0.402	228.4	56.9
2033	318.1	286.3	286.3	0.9	595.1	0.410	229.5	56.8
2034	320.5	287.2	287.2	0.896	606.1	0.418	230.5	56.7

Research and data needs

1. There is conflicting evidence and limited information with which to evaluate black rockfish stock structure, especially off California. Future research on larval dispersal, life history traits, adult movement, and genetics south of the California-Oregon border would improve inputs for stock assessments and provide support for the spatiotemporal scale that is most appropriate for modeling black rockfish. Specifically, information about growth, maturity, and mortality north and south of Point Arena could further justify the separation of black rockfish at this location. Further genetic evaluation regarding the extent to which Point Arena may serve as a barrier to gene flow would also be valuable for this stock.
2. Specific estimates of larval dispersal and movement rates at various life stages would further our understanding about connectivity among the three West Coast stocks of black rockfish. Although most black rockfish show moderate to high site fidelity and some degree of homing, a notable proportion of fish appear to cross stock boundaries. Additional research on the directions and distances that black rockfish move in northern California and southern Oregon would help elucidate the degree of intergenerational exchange across this particular stock boundary.
3. Finally, much of what we know about the habitat associations and ecological role of black rockfish come from Oregon, Washington, and Alaska. Research that is specific to central and northern California is needed to fully understand variation in black rockfish life history, population structure, and trophic positioning.
4. Exploration of multiple-area models for the stock is recommended when sufficient data are available to parameterize movement within the model. Directional movement between areas (south to north, as observed in the CCFRP movement data) may partially explain sustained differences in size and age composition throughout the state.
5. Attempts to investigate recruitment indices (RREAS, SWFSC SCUBA) for the fleets-as-areas model configuration were not successful, and there was not enough time to evaluate area-specific indices prior to the STAR panel document deadline (although they have been developed). Future assessments may benefit from an analysis of these recruitment indices representing sub-areas defined in this assessment.
6. Further research is also needed to explain skewed sex ratios among older individuals in the population. This assessment assumes that size-dependent selectivity is equal for both sexes, and does not consider alternative hypotheses such as sex- or age-specific selectivity or age-dependent natural mortality, both of which could also explain, in whole or in part, the reduced fraction of older females in the data.

1 Introduction

1.1 Basic Information

Black rockfish (*Sebastes melanops*; subgenus *Sebastosomus*) are found from the southern Bering Sea and Aleutian Islands to northern Baja California. A few individuals have also been observed in the western North Pacific Ocean (Kai et al. 2013); however, black rockfish are most abundant from Kodiak, AK to northern California. They are common to occasional in central California, and rare south of Point Conception (Love et al. 2002, Field et al. 2021). Black rockfish can occupy depths to 366 m (1,200 ft) but typically form aggregations near high relief habitats shallower than 73 m (240 ft) (Love 2011).

The previous black rockfish stock assessment was spatially stratified at the California-Oregon and Oregon-Washington borders (Cope et al. 2016). Given different management histories and a lack of evidence to support a single stock along the West Coast, state-specific stocks were proposed for black rockfish (PFMC 2022a, 2022b, 2023). Data on genetic differentiation, adult movement, larval dispersal, and some life history traits remain limited, especially for fish in California waters. The current assessment models the California stock using two sub-area models (north and south of Point Arena), given observed differences in the exploitation history, size and age compositions, and trends in relative abundance, as described in the Data and Model sections.

Genetic Differentiation

A study that analyzed microsatellite DNA found no evidence of population structure and weak evidence for isolation by distance for juvenile black rockfish off Washington and Oregon (Miller et al. 2005; Miller and Shanks 2007). The same study found support for genetic divergence among adult black rockfish collected 340 to 460 km apart, thereby distinguishing black rockfish off Washington from those found off southern Oregon. Approximately 35% of genetic samples in the Miller et al. (2005) study were misclassified, suggesting limitations in the methods or representation of samples, recent movement, and/or the existence of genetically distinct groups at a relatively fine spatial scale. Interestingly, microsatellite DNA have illustrated similar fine scale population structure within the Gulf of Alaska but promoted the categorization of black rockfish from Southeast Alaska and Washington into a single group (Seeb 2007).

Another fine scale study that compared black rockfish from Monterey Bay, CA and Garibaldi, OR found a small degree of genetic differentiation (Sivasundar and Palumbi 2010). This differentiation was observed, however, in only one of the six microsatellite loci tested. A more spatially-expansive study found a genetic break at Cape Blanco, OR (Lotterhos et al 2014). Although Cape Blanco may serve as a barrier to gene flow, Lotterhos et al. (2014) note that regular genetic exchange may still take place because of a few long-distance migrants.

Most recently, a study found microsatellite divergence between Alaska and the continental United States as well as a mitochondrial cline near Cape Mendocino (Hess et al. 2023). Based on six microsatellite loci and mitochondrial DNA, the authors found localized genetic discontinuities, which may have resulted from range expansion, isolation by distance, extinction-recolonization events, or the combination of a bet-hedging reproductive strategy (e.g., age-based shifts in the timing of parturition; Sogard et al. 2008) and sweepstakes-like recruitment (Lotterhos and Markel 2012) in black rockfish (Hess et al. 2023). Disparate haplotype frequencies north and south of Point Arena may provide a genetic basis for separately modeling black rockfish population dynamics in northern and central California. However, Hess et al. describe Black Rockfish as “highly resident as adults,” based on wok by Parker (2007) and previous studies. More recent studies have found long-distance movements across the reported genetic breaks in a significant fraction of tagged fish (see Adult Movement section, below). These observations, combined with the availability of methods to examine stock structure using whole genomes, suggest that further validation of the reported barriers to gene flow within California waters is warranted (see Research Recommendations).

Adult Movement

There are numerous reports that most black rockfish display small home ranges. A sizeable percentage (approximately 10 to 30%, depending on the study), however, have moved considerable distances. A small number of black rockfish have also been documented as having undergone considerable migrations (e.g., up to 400 km southward from Puget Sound [Mathews and Barker 1983], approximately 600 km northward from central Oregon [Coombs 1979], and over 900 km northward from central California [Starr et al. 2015]).

The largest data set with relevant movement information comes from a tagging study conducted by the Washington Department of Fish and Wildlife (WDFW) between 1981 and 2014. This WDFW study documented net movements from 5,445 T-bar anchor, coded wire, or PIT tagged black rockfish (Wallace et al. 2010). From these recaptured fish, approximately 75% remained within 10 km of their initial release site. Distance traveled, however, increased with time at liberty and most fish were caught within two years of being tagged (Wallace et al. 2010). Fish that moved greater than 10 km tended to move in the direction opposite their relative release site. For example, fish tagged near Cape Falcon in Oregon generally moved northward whereas fish tagged off northern Washington (i.e., near Cape Elizabeth, La Push, and Neah Bay) generally moved southward. The latter corroborates findings from a study based in Puget Sound, which observed southward movements of 360 to 400 km for three out of eight recaptured fish (Mathews and Barker 1983). Notably, the direction of movements from fish tagged near Grays Harbor off central Washington were split between north and south (Wallace et al. 2010). Size and sex data were not reported, though reported age compositions suggest that these were primarily subadult or adult black rockfish.

The California Collaborative Fisheries Research Program (CCFRP) represents another long-term study that has tagged and recaptured black rockfish (Starr et al. 2015). Of the 65 fish recaptured from 2007 to 2022, the maximum Euclidean distance traveled was 918 km. This considerable northward movement was made by a 35 cm fish that spent 192 days at liberty. The overall mean distance traveled was 180 ± 316 km, with 26.2% of recaptured fish (n = 16) moving greater than 250 km (CCFRP unpublished data). Long-distance travelers were subadults (30.9 ± 4.5 cm fork length) and tended to migrate northward into Oregon waters (Figure 1).

Apart from mark-recapture, a number of acoustic telemetry studies have focused on subadult black rockfish. Two such studies posited an intermediate degree of site fidelity in high relief rocky reefs off Oregon – with some individuals remaining in a single location throughout the study period and others (up to 43%) periodically relocating to other sites (Parker et al. 2007; Hannah and Rankin 2011). Most of the tagged fish showed extensive vertical ranges that are uncommon to nearshore rockfishes (Parker et al. 2008; Hannah and Rankin 2011). An earlier study with nine recaptures found that black rockfish generally remained close to release sites, though one individual moved over 600 km northward, from central Oregon to Puget Sound (Coombs 1979). Another Oregon-based study found northward movements of up to 178 km (DeMott 1983). Telemetry research on black rockfish has been more limited in California. One study in Carmel Bay, however, found regular diel movements offshore (Green and Starr 2011). Like the Oregon- and Washington-based studies, Green and Starr (2011) estimated small home ranges with a fraction of fish (> 1/3) moving considerable distances (in this case, to the north).

Larval Dispersal

The ability to accurately classify juvenile fish to sample locations using otolith microchemistry suggests limited alongshore movement for approximately 60 to 80% of early-stage black rockfish (dispersal distances < 120 km; Miller and Shanks 2004). High classification accuracy may also result from early life stages of black rockfish generally not mixing and/or following similar dispersal pathways off Oregon and Washington. The authors note that limited alongshore movement and a lack of larval mixing among locations may represent the dominant dispersal pattern for black rockfish. However, a sufficient proportion of new recruits may have been supplied by external sources, thereby maintaining genetic diversity (Miller and Shanks 2004).

Lotterhos et al. (2014) estimated dispersal distances of 6 to 184 km per generation, with fish along the Oregon and Washington coasts experiencing lower dispersal capacity relative to those in British Columbia. Potential mechanisms for limited larval dispersal of black rockfish include: large areas of unsuitable habitat (e.g., sand), reproductively unfavorable upwelling conditions (i.e., strong upwelling that advects larvae offshore), and geographic headlands (e.g., Cape Blanco) that act as retention zones (Lotterhos et al. 2014). Although a few long-distance dispersals are not considered ecological relevant, a few migrants per generation can increase gene flow and decrease genetic differentiation (Kinlan and Gaines 2003; Palumbi 2003; Lotterhos et al. 2014). California-specific information about larval dispersal is unavailable for black rockfish.

1.2 Map

A map of the assessment area with selected coastal features is provided as Figure 2.

1.3 Life History

Black rockfish are generally considered nearshore, semi-pelagic rockfish. They are sexually dimorphic, with females growing to larger sizes than males (Lenarz and Echeverria 1986; Bobko and Berkeley 2004). Black rockfish can reach 69 cm, 6 kg, and 56 yr (Love 2011). Growth (length-at-age) estimates for California were reported in the previous stock assessment (Cope et al. 2016), but age and length composition data were updated to estimate von Bertalanffy growth parameters within the current assessment model. In central and northern California, 50% of males reach sexual maturity at 35 cm (6 yr) and 50% of females reach sexual maturity at 41 cm (7 yr) (Echeverria 1987). Some males may mature as small as 25 cm (3 yr) whereas some females may mature as small as 30 cm (5 yr) (Echeverria 1987). Based on estimates of length-at-maturity from the literature, a significant fraction of black rockfish sampled off central California are classified as juveniles or subadults whereas those sampled off northern California represent a more even mix of mature and immature fish (O'Farrell and Botsford 2006; Hamilton et al. 2021).

Black rockfish are viviparous, undergo internal fertilization in early winter, and produce planktonic larvae in late winter and early spring (Boehlert and Yoklavich 1983; Echeverria 1987).The pelagic larval duration is 2 to 4 months, with recruitment to nursery habitats taking place in the late spring and early summer (Wilson et al. 2008). Laboratory experiments suggest that older females tend to undergo parturition earlier in the spawning season (Bobko and Berkeley 2004). Age-based shifts in the timing of parturition has been identified as a bet-hedging strategy (e.g., Sogard et al. 2008) to safeguard against sweepstakes-like recruitment that results from changes in the timing and strength of upwelling events (Lotterhos and Markel 2012; Markel et al 2017). In addition to releasing larvae during more favorable conditions, older black rockfish tend to produce larvae with larger oil globules that promote increased larval growth and decreased mortality due to starvation (Bobko and Berkeley 2004; Berkeley et al. 2004). Black rockfish are highly fecund for live-bearers, with a 6 yr female producing approximately 300,000 embryos per year and a 16 yr female producing nearly 950,000 embryos per year (Bobko and Berkeley 2004).

Recruitment is highly variable, though increases are associated with stronger upwelling, cooler waters, slower larval growth, and longer pelagic phases that promote the onshore transport of later stage pelagic juveniles (Laidig et al. 2007; Wilson et al. 2008; Markel and Shurin 2020). Relatively large post settlement body sizes (≥ 35 mm) likely decrease predation mortality in the nearshore (Markel and Shurin 2020). In California, anomalously warm water has been identified as an indicator of poor recruitment (e.g., Laidig et al. 2007; Wilson et al. 2008). Evidence of strong recruitment along the US West Coast was observed in 1999, 2006, and 2010 (Laidig et al. 2007; Starr et al. 2015; Markel and Shurin 2020). Young-of-the-year (YOY) can be found in nearshore rocky reefs, kelp beds, estuaries (specifically eelgrass habitats), and the intertidal from late spring to early fall (Boehlert and Yoklavich 1983; Studebaker and Mulligan 2008; Dauble et al. 2012).

YOY and juvenile black rockfish in northern California feed primarily on amphipods, copepods, and mysids (Studebaker and Mulligan 2008; Bizzarro et al. 2017). Juveniles and adults predate on jellies, polychaetes, cephalopods, euphausiids, crustaceans, and forage fishes (Bizzarro et al. 2017). Black rockfish become increasingly piscivorous throughout their ontogeny (Bizzarro et al. 2017) and are a prominent predator of YOY rockfishes off northern California (Hobson et al. 2000). As pelagic larvae, black rockfish are subject to predation by siphonophores and chaetognaths. Newly settled individuals are common in the diets of juvenile rockfishes (Reilly et al. 1992) and adults are consumed by lingcod, larger rockfishes, and marine mammals (Steiner 1979; Stein and Hassler 1989).

Although estimates of mortality from the WDFW mark-recapture study have been used to inform the Washington assessment, similar estimates do not exist for black rockfish off California.

1.4 Ecosystem Considerations

Ecological information was not explicitly represented in the stock assessment model. This is due to a complicated mechanistic relationship between black rockfish population dynamics and the California Current ecosystem. Some data on predators and prey are available but lack sufficient coverage to inform spatiotemporal dynamics of black rockfish (e.g., natural mortality). A number of studies have investigated potential environmental drivers of black rockfish recruitment (e.g., Caselle et al. 2010; Ralston et al. 2013; Schroeder et al. 2019; Field et al. 2021). Black rockfish have also been identified as a candidate for multispecies indicators of recruitment (along with blue, deacon, darkblotched, widow, and yellowtail rockfishes; Field et al. 2021).

1.5 Fishery Information

Black rockfish are taken by recreational and commercial fleets in California, but recreational fisheries north of Point Arena (the area referred to as "northern California" in this assessment) have accounted for the majority of statewide removals in recent decades (Figure 3). Within the recreational sector, landings are dominated by the "boat modes" (i.e., private/rental boats and party/charter boats), with relatively minor contributions from shore-based fishing modes. Party/charter boats in California often are referred to as Commercial Passenger Fishing Vessels (CPFVs), and the terms "party boat," "charter," "PC mode" and "CPFV" are used interchangeably in this assessment. Private and rental boats are often abbreviated as "PR" or "PR mode" and occasionally called the "skiff" fleet.

In terms of regional landings, development of the fisheries south of Point Arena ("central California" in this assessment) preceded the northern area by almost 50 years, likely due to a combination of historical trends and events, e.g. population growth, World War II, road construction, employment opportunities, and market demand (Figure 4). Rockfish were landed commercially as early as 1875 (Phillips 1957). Until 1943, when the balloon trawl was introduced (Phillips 1949), the great majority of rockfish landings in California (~95%) were taken by longline (Phillips 1958; Lenarz 1986). Black rockfish became a component of the commercial live-fish fishery that developed in the early 1990s (Reilly 2001; Pearson et al. 2008). In recent years, black rockfish landed alive have accounted for about 50% of the commercial catch in weight (PacFIN 2023).

After WWII, there was a marked expansion in the CPFV fishing industry throughout the state, including a substantial increase in landings in northern California (Young 1969). Salmon were the primary target in the northern part of the state, with shifts in effort to rockfish when salmon were scarce. From 1947-1967, reported landings of rockfish by partyboats were a small component of the catch north of Bodega Bay, but a primary target in Bodega, Bay Area, and central coast ports. Rockfish were a primary target of post-war central California recreational fleets, with 74% of statewide rockfish catch being landed in central and northern ports in 1947, dropping to 34% by 1954 with the rest taken south of Point Conception where black rockfish are scarce (Young 1969). Since the early 1980s, the earliest years for which we have recreational catch surveys in California, black rockfish landed north of Point Arena have averaged about 75% of statewide landings per year (RecFIN 2023).

1.6 Summary of Management History and Performance

Prior to the adoption of the Pacific Coast Groundfish Fishery Management Plan (FMP) in 1982, Black Rockfish were managed through the California state regulatory and legislative processes. With implementation of the FMP, Black Rockfish came under the management authority of the Pacific Fishery Management Council (PFMC) and were managed as part of the *Sebastes* complex. At the time Black Rockfish had not undergone rigorous stock assessment and did not compose a large fraction of the landings so was classified and managed as part of the "Minor Nearshore Rockfish" group.

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

In 2000, the PFMC's rockfish management structure changed significantly with the replacement of the *Sebastes* complex –north and –south areas with Minor Rockfish North (Vancouver, Columbia, and Eureka, International North Pacific Fisheries Commission (INPFC) areas) and Minor Rockfish South (Monterey and Conception INPFC areas only). The OY for these two groups was further divided (between north and south of 40°10' N. lat., Cape Mendocino, California) into nearshore, shelf, and slope rockfish categories with allocations set for Limited Entry and Open Access fisheries within each of these three categories (January 4, 2000, 65 FR 221; PFMC 2002, Tables 54-55). Species were parceled into these new categories depending on primary catch depths and geographical distribution. Black Rockfish was included with the minor nearshore rockfish complex. Currently, Black Rockfish is assigned its own California-specific harvest limits (OFL, ABC, ACL, and Fishery HG). The fishery HG is shared between the non-trawl commercial and recreational fleet.

Both commercial and recreational fleets are subject to marine protected areas (MPAs). An initial set of MPAs around the Channel Islands in southern California became effective in 2003. The MPAs were later expanded under authority of the Marine Life Protection Act (MLPA) enacted in 1999, creating a network of MPAs which went into place in phases beginning with the central coast in 2007, north central coast in 2010, and the south and north coasts in 2012.

The state of California routinely adopts state regulations for groundfish, including Black Rockfish, for consistency with federal regulations developed through the PFMC process. Authority to craft these regulations was granted by the California Legislature to the California Fish and Game Commission (FGC) through passage of the Marine Life Management Act (MLMA) in 1998. As required by this legislation, the FGC adopted the Nearshore FMP and a commercial restricted access permit program in 2002 which established the Deeper Nearshore Species Fishery Permit, to be effective starting in the 2003 fishing year. A Deeper Nearshore Species Fishery Permit is required to retain commercially caught Black Rockfish. In addition to the requirement for a permit, the commercial regulations for Black Rockfish include gear limitations, area-specific bimonthly trip limits and rockfish conservation areas (RCAs). RCAs are seasonally adjusted depth limits impacting trawl and non-trawl gears that were initially established in 2002 to reduce impacts to overfished species. The commercial RCAs restricted fishing from occurring between 20 to 30 fm and 75 to 150 fm along the California coast, with specific depth limitations varying by area and time of year. In the area north of 40° 10′ N. lat., Black Rockfish receives its own species-specific trip limit separate from the other nearshore species. South of 40° 10′ N. lat., Black Rockfish are included in an overall deeper nearshore species bimonthly trip limit.

Similar to the commercial fishery, depth restrictions in the recreational fishery were implemented in the early 2000's to reduce impacts to rebuilding shelf rockfish species. This action shifted recreational groundfish effort into the nearshore waters, generally shallower than 30 fm between 2008 and 2016 in the areas where Black Rockfish are most abundant off California (Figure 5). As shelf rockfish stocks recovered during the 2010s, recreational season and depth regulations relaxed, and longer seasons with deeper depth limits were implemented. In response to results from the 2021 assessments for copper and quillback rockfishes, numerous changes were made to recreational fishery regulations for the 2023 season. These changes include extended closed seasons in all management areas. The open season in most management areas is broken into an all-depth fishery where no depth restrictions apply and an offshore fishery where anglers are required to fish seaward of the 50 fm RCA line. During an offshore fishery, take and possession of nearshore rockfish, cabezon and greenling is prohibited in all waters. These changes in depth restrictions are expected to reduce catch of all nearshore rockfish, including Black Rockfish.

A daily bag and possession limit for the Rockfish Cabezon Greenling (RCG) complex, which includes Black Rockfish, was at 15-fish in prior to 2000, then was reduced to 10-fish and has remained 10-fish since. Within the 10-fish daily bag and possession RCG limit, a sub-bag limit for Black Rockfish of 5 fish was implemented in 2015 to keep catch within harvest limits. Also in 2015, three stock assessments were performed for Black Rockfish in areas separated by the Washington, Oregon, and California state boundaries. The California stock was found to be at a depletion level of 33 percent with an increasing biomass trend. Because this is below the management target and recent catches had been higher than harvest limits, the sub-bag limit was further reduced to three fish within the ten daily RCG limit beginning with the 2017 management cycle. Lower than projected Black Rockfish mortality in the recreational fishery after 2017 resulted in increasing the bag limit in-season from three to four fish in 2019 and ultimately elimination of the sub-bag limit in 2021.

A history of recent Black Rockfish harvest limits and estimated impacts are detailed in Table 1. Limits specific to California started in 2017, whereas previous years' limits included waters off of Oregon. Harvest levels for Black Rockfish have not exceeded the ACL.

1.7 Fisheries off Canada, Alaska, and/or Mexico

Black rockfish are rare south of Point Conception, with possible intermittent dispersal to a few offshore islands. Although sometimes reported as ranging as far south as northern Baja California, they are not common enough in that region to be classified as a significant component of Mexican fisheries. Fisheries north of California, including Canada and Alaska, are detailed in the assessments for Oregon and Washington.

2 Data

The STAT presented an online overview of available data sources for the California black rockfish assessment during the PFMC Data Workshop held February 1, 2023. The STAT also met with industry stakeholders to solicit information relevant to the assessment, and has included a perspective from commercial fisherman Kenyon Hensel (Appendix A). Graphical summaries of data sources used in the northern and central base models are provided as Figure 6 and Figure 7.

2.1 Commercial Fisheries Data

Commercial data sources used in the California assessment span the period 1916 – 2022, with an assumed linear ramp in catch from 1875 to the first year of available data (Figure 3). 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).

2.1.1 Commercial Landings and Discard

Landings

Estimates of commercial landings in California are derived from two primary data sources: a cooperative port sampling program (California Cooperative Groundfish Survey, CCGS) that collects information including species composition data (i.e. the proportion of species by weight landed in a sampling stratum), and landing receipts (sometimes called "fish tickets") that are a record of pounds landed in a given stratum. A map of CCGS port complexes is provided as Figure 8. 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 a given market category can consist of several species. For example, about 5% of fish landed in the "black rockfish" market category (252) were blue rockfish over the period 1981-2022 (PacFIN 2023). Another 1% of fish landed in market category 252 were a mixture of yellowtail, china, and widow rockfish over the same period. Species composition samples collected by CCGS port biologists are used to partition catch recorded in market categories to individual species. These "expanded" catch estimates are used in stock assessments and available from PacFIN.

PacFIN is the repository for commercial landings data since 1981, and estimated catches from the database (queried 4/3/2023) indicate that more than 95% of black rockfish commercial catches (all gears combined) have been landed in northern California counties over the past decade (Figure 9).

Prior to 1981, a variety of sources were available to reconstruct black rockfish 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."
- 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 region (region 2 corresponding to the northern area in this assessment), with all others assigned to the central area. Reconstructed catches are also partitioned into course gear groups, trawl and non-trawl.
- 1875-1916. A linear ramp was used to represent catches leading up to the first year of the Ralston et al. reconstruction.

As noted in the 2015 stock assessment, a few years of commercial catch estimates were considered inaccurate for various reasons, and these were revised by CDFW staff for that assessment. Specifically, these include 1983-1985 for the commercial non-trawl sector, and 1981-1982 for the commercial trawl sector. Details of these changes are provided by Cope et al. (2016), and were adopted without modification in this analysis.

The STAT revisited estimation of landings by sector from the ratio estimator period due to a strange pattern in the allocation of catch among sectors. A large fraction of total landings was assigned to the trawl fleet over this period, with a similarly small allocation to the non-trawl sector. This is inconsistent with estimates prior to and after these years, so we applied species compositions from 1978-1982 in market category 250, by year and gear, and port complex, to total landings to by gear and port complex over the period 1969-1977. We feel that the revised estimates for 1969-1977 (red and blue lines in Figure 10) are much more consistent with the trends before/after from other sources.

Commercial landings in the northern area (Point Arena to the OR/CA border) were trivial prior to about 1920, picking up slowly until wartime demand for fish caused a rapid spike in harvest by trawl and non-trawl gears (Figure 11, upper panel; Table 2). After the war, commercial catch steadily declined until the mid-1960s, rose again through the 1990s with a shift away from trawl landings into non-trawl gears, then declined again to relatively consistent levels over the past two decades.

By comparison, commercial landings in the central area (south of Point Arena) are estimated at slightly above 50 mt per year from 1916-1920, although estimated catches during this early time period are highly uncertain (Figure 11, lower panel; Table 3). By the mid-1950s, commercial catches were on a similar scale to recreational landings, decreasing to only a small fraction of total central area removals by the early 1980s. Commercial harvest increased briefly in the 1990s, but has remained a minor component of total landings since roughly the turn of the century.

Discard

The West Coast Groundfish Observer Program (WCGOP) provides observer data on discarding practices across sectors since 2003. An examination of discard ratios (dead discard / retained catch) did not show any trend over time, with annual estimated discard rates varying from <0.5% to nearly 4.5% (Figure 12).

The STAT also examined estimates of discard mortality ratios based on WCGOP's Groundfish Expanded Mortality Multiyear (GEMM) report. A catch-weighted average discard ratio estimated from the GEMM report produced an estimate of 1.9% for the period 2002-2021 (non-trawl gears). Data from the trawl sector, which is a minor component of recent black rockfish commercial catches, were highly variable and not considered. Due to high levels of inter-annual variability in discard rates, and the low overall percentage of discarded catch in the commercial fishery data, dead commercial discard was estimated as a fixed 1.9% of landings for all years in the assessment.

2.1.2 Commercial Length and Age Compositions

Commercial length data are largely unchanged since the last assessment, with the exception of additional years' data and the use of discard length composition data from WCGOP (Table 4, Table 5). We aggregated catch-weighted length compositions into 2-cm bins (fork length) by year, gear group (trawl, non-trawl dead, and non-trawl alive), and region (north/south of Point Arena). Length sample sizes south of Point Arena (the central area) were insufficient to warrant separate live/dead fleets for the non-trawl gear group, so conditions were aggregated. No trawl length samples were available from the central area, and trawl sample sizes in the north declined after the 1980s. Commercial lengths in the north are consistently larger on average than in the central area, although sample sizes from the central commercial fleet are small (Figure 13).

Commercial age data were updated and amended with recent years' data for this assessment (Table 6, Table 7). No commercial ages are available from the central area. In the northern area, the past three years (2020-2022) have seen significant increases in sample sizes. This is largely due to the implementation of mandatory port sampling for groundfish landings, and the tireless efforts of well-trained, efficient CCGS port samplers stationed in that region. Lastly, we corrected an error in the assignment of age compositions to years in the 2015 assessment, although this had little effect on the outcome (a slightly less depleted stock, and changes to patterns in early rec devs). The corrected age compositions are used in the current assessment.

Northern area commercial lengths

Catches landed dead by non-trawl gear types in the northern area have the largest sample sizes and longest time series for length data among the commercial fleets (Figure 14). Catches landed alive by the same fleet have a smaller proportion of fish larger than 40 cm, possibly reflecting a preference for "plate-size" fish in the live-fish market (Figure 15). Trawl landings, on the other hand, appear to have contained the largest fish, on average, with means consistently above 40 cm (Figure 16). However, this fleet has not contributed significant landings in recent years. Distributions of length from commercial discards are generally stable over time, with mean lengths consistently smaller than 30 cm (Figure 17).

Central area commercial lengths

Due to the small amount of live landings in the central area, commercial non-trawl catches were represented as a single fleet. Even after aggregating across condition types (live/dead), the amount of length data for this fleet was minimal, with only five years included in the model (Figure 18). Due to these small sample sizes, length comps for the commercial discards were assumed to be the same as for the northern area (Figure 17).

Northern area commercial ages

Bubble plots of the northern area age data are provided as Figure 19 (non-trawl fleet, landed dead) and Figure 20 (trawl fleet). No female ages were available in from 1982 in the commercial trawl fleet, so males were entered as male-only to avoid skewing estimated sex ratios (Figure 20). Males in 1984 also appear to be anomalously old for their size, which we revisit in our discussion of fits to the data. Data from a 2019 commercial pilot program conducted by CDFW were included in the base model and CAAL residuals do not appear to be significantly different from other sources. However, the size distribution of fish sampled by that program is quite different from data collected by CCGS, and the STAT understands that the program purchased fish (Figure 21). It's not clear if that is the cause of the shift in size distribution, but there could be an incentive for fishers to sell smaller fish, on average, in that situation. Samples from the pilot program came from northern ports (Crescent City and Eureka). Samples from Morro Bay were also taken, but these were not included due to small sample size.

2.2 Recreational Fisheries Data

2.2.1 Recreational Landings and Discard

Estimates of recreational landings and discard in this assessment span the period 1928 – 2022 (Figure 3) and are derived from three primary sources, described below, and summarized by year, boat mode, and region in Table 8.

Historical recreational landings and discard, 1928-1980

Ralston et al. (2010) reconstructed estimates of recreational rockfish catch and discard in California, 1928-1980. Reported landings of total rockfish were allocated to species based on several sources of species composition data. For this assessment, historical recreational catch was stratified by year, area (north and south of Point Arena), and boat mode (Table 8).

Marine Recreational Fisheries Statistics Survey (MRFSS), 1980-2003

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-era recreational removals for California were originally estimated for two regions: north and south of Point Conception from 1993-2003, and prior to that north and south of the San Luis Obispo / Monterey county line. Data from Albin et al. (1993) have been used in recent assessments to partition catches consistently around Point Conception. For this assessment, we use a similar approach to partition catches north and south of Point Arena.

Partitioning of the catch began with statewide estimates of statewide black rockfish catch in numbers from Ralston et al. (2010) and MRFSS, stratified into party/charter ("PC" mode, aka CPFVs) and private/rental (PR) boat modes (Figure 22). Minor catches in shore modes were aggregated with the PR mode and are labeled here as "PRplus." To partition the catch in numbers north and south of Point Arena, we relied on estimates of catch by coastal county district, 1981-1986, as reported by Albin et al. (1993). The percentage of catch landed from Del Norte through Sonoma counties was used in each of the reported years in Albin et al., and the average fraction of catch from 1984-1986 was used as a starting point for a linear interpolation to the CRFS-era catches. Specifically, the interpolation ended with the average fraction of catches in CRFS districts 5 & 6 from 2005-2007 (Figure 23). For years prior to 1981, we estimated the fraction of catch north of Point Arena using the percentage of boat mode effort by area during the period 1958-1961, roughly 20%, as reported by Miller and Gotshall (1965, their Figure 14). We interpolated between this estimate in 1960 and the average percentage of catch north of Point Arena, 1981-1983, based on Albin et al. Years prior to 1960 were assumed to have the same fraction of catch north of Point Arena (Figure 23).

Once the proportion of catch in each area was estimated, we applied it to the statewide catch in numbers to produce estimates of catch in number by year, area, and mode (Figure 24). Estimates of average fish weight [kg] are available from MRFSS and CRFS at the county and CRFS district level, respectively, by year, area, and mode (Figure 25). We multiplied average weight times estimates of catch in numbers to produce estimates of catch in weight [kg] by year and mode, north and south of Point Arena (Figure 26). Average weights by mode prior to the MRFSS era were taken from Miller and Gotshall (1965) for the central area. For the northern area, average weight was taken from Karpov et al. (1995), assuming the same value for both PC and PR modes (Figure 25).

California Recreational Fisheries Survey (CRFS), 2004-2016

MRFSS was replaced with the California Recreational Fisheries Survey (CRFS) beginning January 1, 2004. Among other improvements to MRFSS, CRFS provides higher sampling intensity, finer spatial resolution (6 districts vs. 2 regions), and onboard CPFV sampling. Estimates of catch from 2005-2022 were downloaded from the RecFIN database, and CRFS estimates from 2004 were retrieved from historical records pending updates to historical data in RecFIN. We assign catch estimates and length data from districts 5 & 6 to the northern area, and all other districts (effectively districts 3 & 4) to the central area (Figure 27).

Recreational Discard

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.

Dead discards are reported by CRFS, and we use those estimates as provided (2005-2022). Patterns in the average weight of discarded fish are consistent with changes to sub-bag limits (e.g. 2015-2020) that would result in a greater fraction of large fish being discarded (Figure 28). Prior to 2005, we approximate total recreational dead discard using a fixed percentage, as this can be easily varied to understand the sensitivity of the model to alternative levels of assumed total discard mortality. Miller and Gotshall (1965, their Table 8) reported the number of black rockfish discarded at sea in 1960 based on observer data from six ports between Bodega Bay and Avila, California. Of the 496 black rockfish caught, 15 (3%) were discarded, and we assume this discard rate for catches prior to 2005.

2.2.2 Recreational Length and Age Compositions

Recreational length composition samples for California were obtained from several sources, depending on the time period and boat mode. Input sample sizes for recreational length composition data were based on the number of observed trips, when available. Other proxies that were used to estimate the number of trips are described below. Input sample sizes and the number of fish measured are provided as Table 4 and Table 5. All lengths obtained in units of total length (TL) were converted to fork length (FL) using the equation FL = -1.421 + 0.983(TL) (Echeverria and Lenarz, 1984).

CPFV length composition data, 1959-1966

The earliest available length data for this assessment were described by Miller and Gotshall (1965), who assembled length samples from CPFV (1959-61, 1966) and private boats (1959, 1966) in the “central” area of this assessment.

California Cooperative Groundfish Survey CPFV Sampling, 1978-1984

Commercial port samplers with the California Cooperative Groundfish Survey sampled landings from CPFVs operating north of Point Conception in the late 1970s and early 1980s. This data set contains sex-specific length information, and along with the Miller and Gotshall data is one of the earliest, high-quality sources of length data available from recreational fleets in central California.

MRFSS Recreational Length Data, 1980-1989 and 1993-2003; also CRFS data from 2004

Unsexed length data of retained fish were collected by MRFSS dockside samplers and downloaded from the RecFIN website. Using county and interview site information, we assigned MRFSS-era length data to CRFS districts and assigned “districts” 5 & 6 to the northern area. For MRFSS length data (1980-2003) the number of trips was approximated based on unique combinations of the variables ID_CODE, INTSITE, and MODE in the Type 3 (sampler-examined catch) data.

Prior to the development of the current RecFIN website, MRFSS and CRFS data were combined into standardized tables. The CRFS data from 2004 are not currently posted on the “main” RecFIN website, but data from this year was available from “MRFSS” databases that also included CRFS data.

CDFW Onboard CPFV Observer (“DWV”) Survey, 1988-1998

Lengths from CPFVs operating primarily out of central California were measured by CDFW onboard observers as part of a recreational survey led by Deb Wilson-Vandenberg and Paul Reilly. This survey is often referred to as the “DWV” survey, and a relational database for this project was developed and documented by Monk et al. 2016.

CRFS Recreational Length Data, 2005-2022

Length data from the CRFS were downloaded from the RecFIN website and used without modification. These include lengths of retained fish by year, mode, and district. Lengths of discarded fish are also available, recorded by onboard CPFV observers (Table 4 and Table 5).

Length compositions from each of these sources were organized into catch fleets (PC, PR+shore, rec discard), survey fleets (DWV) and areas (north, central) for inclusion in the stock assessment model (Figure 29, Figure 30, Figure 31, Figure 32, Figure 33, Figure 34).

Recreational ages

New age data from recreational sources include CDFW samples from 2021 and 2022. This assessment also uses recreational ages from the 2015 assessment (1980-1984), allocated to match the revised fleet and area structure. We tabulated samples sizes for recreational age data by year and source for reference (Table 6, Table 7), and provide bubble plots of the data to visualize the conditional-age-at-length format by fleet and year (Figure 35, Figure 36, Figure 37, Figure 38).

2.2.3 Recreational Abundance Indices (Catch per Unit Effort)

This assessment makes extensive use of time series of relative abundance derived from recreational fishery catch-per-unit-effort (CPUE). These data were often limited in terms of their temporal and/or spatial coverage, and/or required standardization to account for regulatory actions affecting catch rates. Most sources were based on boat modes (private and rental boats, or party and charter boats), as these are the recreational modes that most frequently encounter black rockfish.

2.2.3.1 CRFS Dockside Private Boat Index, 2004-2022

Catch and effort data from CRFS dockside sampling of private boats, 2004-2022, were provided by CDFW for use in this assessment. The data include catch (number of fish) by species, number of anglers (i.e. effort units are angler trips), county, port, interview site, year, month, and CRFS district. We created a 2-month "wave" variable to model seasonal changes in CPUE. The sample size of the unfiltered private boat CPUE data is much larger than the MRFSS CPFV data set, with sampling of all counties in the assessed area, which makes it a promising candidate for a CPUE index of black rockfish.

CRFS Private Boat Index: Data Preparation, Filtering, and Sample Sizes

The impact of bag limits introduced from 2015 to 2020 was unknown, so we examined the proportion of bags with 5 or more black rockfish as well as 10 or more black rockfish. Since individual bag information was not available, we looked at fish per angler trip as a proxy, plotting the proportion of bags with 5 or more black rockfish over time (the largest sub-bag limit). There is a clear pattern of bag size being reduced in 2015, particularly in the northern districts (Figure 39). Given the potential for bias in CPUE, we excluded data from 2015-2020.

Other data filters applied to the PR index data set are listed in Table 9. And the distribution of samples by year and area is provided as Table 10

CRFS Private Boat Index: Model Selection, Fits, and Diagnostics

The counts of black rockfish per trip in the dataset were heavily skewed with a large proportion of zeros. To model the counts, we used a Bayesian zero inflated negative binomial (ZINB) regression model implemented with the 'brms' package in R (Burkner, 2017), which is built upon the Stan (Stan Development Team, 2023) No-U-Turn Sampler (NUTS) (Hoffman and Gelman, 2014). Model selection was based upon the Widely Applicable Information Criterion (WAIC; Watanabe, 2010).

Model development began by considering the simple negative binomial regression model; modeling a single linear predictor with a log link function on the mean of the negative binomial. Main effects of year, district, a 2 month "wave" variable, and target species (prim1Common) were considered. Additionally, the inclusion of year:district and district:wave two-way interaction terms were considered. All variables were found to be highly significant under the simple negative binomial model. However, upon further comparison of the resulting model's predictive distribution for the proportion of zeros, the simple negative binomial model was determined to insufficiently capture the observed proportion of zeros in the data.

Model development continued assuming the ZINB likelihood, which introduces a zero-inflation parameter that is modeled with an additional linear predictor and a logit link function. Model selection for the zero-inflation linear predictor considered main effects for year, district, "wave", and target species (prim1Common), as well as an intercept only model. The WAIC criterion supported inclusion of all main effects as well as a year:district and district:wave interaction terms (Table 11).

The index was created for the July_Aug wave for all sampled years, aggregating posterior distributions in the northern and central districts respectively (Figure 40).

2.2.3.2 Central California Onboard CPFV Observer Index, 1988-1998

In addition to the dockside index described above, this assessment makes use of two indices derived from onboard CPFV observer data and collected during different time periods of the fishery. The primary advantage of onboard observer data is that catch and effort data are based on individual fishing stops (or “drifts”), rather than aggregated at the trip level, and information about actual fishing locations is available, rather than port of landing or interview site. This location information, when combined with recent maps of rocky reef habitat, allows us to associate catch rates (which we assume are proportional to density rather than abundance) with reefs of known area and produce habitat area-weighted CPUE indices.

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.

Central CA Onboard CPFV Index: Data Preparation, Filtering, and Sample Sizes

Catch is the number of black rockfish caught at a fishing stop, but only retained fish were included in this index because associated length compositions were derived from retained catch at the end of the day. Effort is in units of angler-hours, based on the subset of observed anglers at each fishing stop.

As noted by Monk et al. (2016), samples in 1987 were only collected in Santa Cruz and Monterey counties, so we excluded 1987 from the index. The relational database contains information on over 100 individual reefs, and catch is associated with the nearest reef structure. The data are too sparse at the level of individual reefs to estimated changes in catch rate over time, so we aggregated reefs by CRFS district. In addition to removing data from 1987, we examined the distribution of fishing time and removed drifts shorter than 5 minutes. Trips with at least 90% groundfish catch were retained, and the small number of trips in districts 5 & 6 were removed (i.e. this index is only used for the central area). Last, we removed drifts in depths greater than 40fm as catch rates decline in deeper waters (Table 12, Table 13).

Central CA Onboard CPFV Index: Model Selection, Fits, and Diagnostics

Due to the highly skewed count data and large proportion of zeros (86%),a negative binomial regression was evaluated with year, disctrict, 2-month ‘wave’, and depth bin (0-20 and 20-40 fm) effects. An offset term equal to the log of angler hours was used to model catch rates. Model selection considering all 2-way interactions was attempted, but convergence issues limited the number of candidate models. We were able to evaluate all combinations of main effects models and interactions between year and disctrict and between year and depth bin. The BIC-best model included main effects for depth bin, CRFS district, 2-month wave, and year (Table 14) The negative binomial model was able to capture the proportion of zeros in the data set, by year, but predictive distributions of the annual means were imprecise prior to 1993 (Figure 41, Figure 42).

The final DWV index shows a declining trend (Figure 43) with increasing precision over time (Table 15).

2.2.3.3 CDFW Onboard CPFV Observer Index, 1999-2022

Data preparation, filtering, and sample sizes

We queried a database of California onboard CPFV observer data spanning the years 1999-2022. The database structure and contents were described by Monk et al. (2014). Each observation included a unique trip and drift identifier, and a subset of anglers was observed at each drift. Drift-level information included catch of black rockfish in numbers (kept and discarded) including zeros, number of observed anglers, time fished (in minutes), location where drift began (latitude and longitude), year, month, county, CRFS district, depth (in feet), distance from nearest reef habitat (in meters), and unique reef identifier.

Over 65,000 observed drifts from CRFS districts 1 and 2 (southern California) were discarded, as only 49 black rockfish (kept + discarded) were observed over the entire time period. This left 30,595 observed drifts in central and northern California for consideration in the index.The northern region (districts 5 & 6) is sampled to a lesser extent than the central region (districts 3 & 4). The north contains samples ranging from 2008-2022, representing months May-September. By contrast, the central region contains samples ranging from 2001-2022 representing months April-December. In the central region data from 1999-2000 were dropped due to changes in the bag limit and number of hooks per line. Other filters included removal of drifts with effort recorded as zero, removal of missing depths and imputation based on available bathymetry, excluding drifts >5 hours and drifts in bays or unknown locations, and depths <300 ft in districts 3-4 and <150 ft in districts 5-6 based on analysis of catch by depth. Drifts with fewer than 2 or greater than 15 anglers observed were excluded, as well as drifts occurring greater than 100 meters from reef habitat (Table 16).

In the description of the private/rental boat index, we noted a reduction in the fraction of "bags" containing 5 or more black rockfish when bag limits were in effect. The onboard observer data is not affected by this, as observers record both retained and discarded catch and catch rates are based on both kept and discarded fish. Using the onboard observer data, we see that the proportion of discards increased in district 6 during the sub-bag limit, although other districts were not as affected (Figure 44).

Model development, selection, and diagnostics

The counts of black rockfish per trip in the dataset were heavily skewed with a large proportion of zeros. To model the counts, we used a Bayesian zero inflated negative binomial (ZINB) regression model implemented with the 'brms' package in R (Burkner, 2017), which is built upon the Stan (Stan Development Team, 2017) No-U-Turn Sampler (NUTS) (Hoffman and Gelman, 2014). Due to the sparsity of samples, and the potential use of a hierarchical model structure, model selection was based upon the Widely Applicable Information Criterion (WAIC; Watanabe, 2010).

Model development began by considering the simple negative binomial regression model (without zero-inflation); modeling a single linear predictor with a log link function on the mean of the negative binomial. Main effects of year, month, district, and binned depth (i.e. (0,50] (50,100] (100,150] (150,300]) were considered. Additionally, the inclusion of year: district and district:wave two-way interaction terms were also considered. All variables were found to be highly significant under the simple negative binomial model, however the simple negative binomial model was determined to insufficiently capture the observed proportion of zeros in the data. Model exploration was continued under the ZINB likelihood, which introduces a zero-inflation parameter that is modeled with an additional linear predictor and a logit link function. While overly simplistic zero inflation models were not supported by WAIC, ultimately the zero inflation parameter was found to mimic the structure of the NB model (Table 17).

Due to the disparity of samples in the north as compared with samples in the central region (Table 18) a Bayesian hierarchical prior model structure was considered for interaction terms that mirror classical random effects. A'priori interaction terms are assumed to be distributed $N(0, \sigma)$ and $\sigma \sim$Half-Cauchy(0,1). This allows for the inclusion of interaction terms in the zero inflation parameter that would otherwise not be supported due to the lack of samples in some months and/or years in the north. The ZINB model was able to reproduce the observed proportion of zeros in the data, the mean catch, and represented a significant improvement over the model without zero inflation with respect to estimates of the standard deviation of catch relative to the observe values (Figure 45, Figure 46, Figure 47).

The index was created in the month of July for all sampled years, aggregating posterior distributions in the northern and central districts respectively (Figure 48, Figure 49).

2.3 Fishery-Independent Data

2.3.1 California Collaborative Fisheries Research Program (CCFRP)

The California Collaborative Fisheries Research Program (CCFRP) is a standardized hook-and-line survey that monitors species compositions, lengths (nearest cm), catch rates (number of fishes caught per angler hour), and movements (km) of nearshore fish species. Assessments of sex are not routine onboard CCFRP sampling trips. The survey relies on a stratified random design using grid cells that are 500m by 500m in size as the sample unit to collect and compare information inside and outside of California's marine protected areas (MPAs; Starr et al. 2015). CCFRP was established in central California in 2007 and expanded to a state-wide spatial extent in 2017. The original sampling areas off central California were Año Nuevo, Point Lobos, Piedras Blancas, and Point Buchon (Figure 2). Areas added north of Point Conception as part of the statewide expansion included Bodega Head, Stewart's Point, Ten Mile, and Cape Mendocino. Sampling trips took place from July to October in all areas and years except for Cape Mendocino and Ten Mile, which were also sampled in June. The mode for the sampling period was August. CCFRP employs catch and release methods and is not subject to recreational bag limits or other (e.g., size- or season-based) fishery regulations. Additional information can be found at https://www.ccfrp.org/.

At present, CCFRP is the only spatially-expansive fishery-independent survey that samples nearshore, rocky reef habitat along the coast of California. The 2023 black rockfish stock assessment uses a region-specific index of relative abundance derived from CCFRP data to quantify changes through time. Point Arena was used to separate northern (CRFS districts 5 and 6) and central (CRFS districts 3 and 4) California. Given that black rockfish can travel considerable distances (Figure 1, Figure 50), and that black rockfish density varies greatly with latitude along the California coast, we pooled MPA and associated reference sites for all analyses.

Data preparation, filtering, and sample sizes

Drift-level information was identified as most appropriate for CCFRP indices of abundance (PFMC SSC, 2023). We obtained drift-level data from CCFRP on March 28, 2023. Each drift contained information about sampling date, geographic location (longitude and latitude; decimal degrees), depth (ft), and the duration of fishing (hr). The database also included the species and lengths of each fish caught (2007 to 2022). A separate tag recapture database includes species-specific information for fishes that were tagged and released as part of CCFRP sampling and either recaptured on CCFRP trips or caught and reported by commercial or recreational fishers.

The unfiltered CCFRP data set included information from 767 trips, 10,571 drifts, and 212,660 fishes (Table 19). We excluded drifts that took place outside of pre-defined grid cell locations, in areas deeper than 120 ft, or had a duration less than 2 min (n = 1,342). We also excluded drifts south of Point Conception (n = 1,440) because they were located beyond the geographic extent of the stock. A small number of drifts (n = 14) were missing specific geographic locations and were also eliminated from analyses. This filtering process resulted in a total of 7,775 drifts from CCFRP areas in central and northern California, with the greatest sampling effort in CRFS district 3 (Table 20).

To estimate drift-level effort (number of angler hours), we multiplied the number of anglers participating in each drift by the duration of fishing. The number of black rockfish sampled per drift was weighted according by normalized proportions of rocky reef habitat in each CRFS district (Table 21) to account for area- and region-specific trends in relative abundance resulting from differences in the amount of suitable habitat. The normalized area weights were derived following methods developed by R. Miller (UCSC/SWFSC) and described in previous assessments (e.g. Dick et al. 2018). CRFS districts were assigned based on county, with Point Buchon, Piedras Blancas, and Point Lobos assigned to district 3, Año Nuevo, Bodega Head, and Stewart's Point were assigned to district 4, Ten Mile assigned to district 5, and Cape Mendocino assigned to district 6. We divided district-weighted catch by drift-level effort to estimate catch per unit effort (CPUE; number of fish per angler hour). We explicitly represented zeros in the data by including drifts that sampled other species but no black rockfish and by including drifts did not catch any fish. Proportional sampling of black rockfish was greatest in district 4, followed by districts 6, 5, and 3 (Table 22). Design-based indices of CPUE were estimated at regional and statewide scales.

We were specifically interested in modeling the effects of depth on black rockfish distributions and densities because of known diel and seasonal vertical migrations (Green and Starr 2011). Additionally, previous research shows that including depth as a covariate in spatiotemporal models of abundance when mechanistic relationships are weak or non-significant is less problematic than omitting depth when the opposite is true (Johnson et al. 2019). Depth (ft) data, however, were not available for all drifts. This was primarily due to a lack of record keeping at Cape Mendocino and Ten Mile. We used available 2m resolution bathymetric data (R. Miller, UCSC/SWFSC, pers. comm.) to impute missing depths (n = 580), thereby enabling the use of all possible drifts during model fitting.

Finally, we estimated CCFRP length compositions for each region and year. Total length (nearest cm) was measured at Cape Mendocino, Ten Mile, Stewart's Point, Año Nuevo, and Point Lobos. To standardize measurements of length for this assessment, we converted all total lengths (TL) to fork lengths (FL) using the equation: $FL = TL - 0.39437/1.01102$ (CCFRP, unpublished data). We then estimated length frequencies using 2 cm bins. Length frequencies were roughly consistent inside and outside MPAs, with slightly larger fish observed inside MPAs (Figure 51). We pooled site-level information for length frequencies. Black rockfish were generally larger in northern California compared to central California (Figure 52).

Model development, selection, and diagnostics

We used a generalized additive model (GAM) to reflect our expectation that spatiotemporal and environmental covariates have nonlinear effects on black rockfish catch (mgcv package in R; Wood 2011, Wood et al. 2016). Model covariates included region as a factor, a cubic regression spline for year, a tensor product smooth for location (longitude, latitude; decimal degrees), a tensor product interaction of year and location, and a thin plate regression spline for depth (ft). Depth was restricted to six effective degrees of freedom to minimize overfitting. Log-transformed angler effort (hr) was included as an offset and smoothing parameters were selected using restricted maximum likelihood (REML).

We explored both negative binomial and Tweedie GAMs, which jointly estimate probability of occurrence and numerical density for zero-inflated data sets. We used a log link function for both models and did not pre-specify theta for the negative binomial (defining the shape of the distribution) or p for the Tweedie (relating variance to the mean), thereby allowing these parameters to be estimated as part of the fitting process. When modeling unweighted catch, the Tweedie GAM generated higher adjusted R2, higher deviance explained, lower REML, and lower AIC than the negative binomial GAM (Table 23). For these reasons, we used the Tweedie GAM to model districted-weighted catch of black rockfish. Indices generated from Tweedie models also better match the scales of design-based indices and tend to perform well even when the underlying distribution is misspecified (Thorson et al. 2021).

We modeled district-weighted catch (Figure 53) to account for spatial differences in available rocky reef habitat and address slightly different trends in CPUE between northern and central California. We explored separate GAMs for each region, but there were insufficient data with which to model northern California (i.e., Cape Mendocino and Ten Mile) alone. We used data spanning the stock assessment area and the dredge function (MuMIn package in R) to generate the full range of alternative models (Table 24). From these, the full model and the alternative model without region exhibited the lowest negative log likelihood, lowest delta AIC, and highest model weight (Figure 54). There were negligible differences in the performance of these top two models, so we selected the more parsimonious model without region (Table **25**). Partial covariate effects illustrated a general decrease in catch rates with year and depth, an increase in catch rates from south to north, and considerable variation in spatial patterns through time (Figure 55).

Input data for model predictions consisted of year, area-specific means for geographic location (longitude, latitude) and depth (ft), and an effort of 1 hr (making predictions of catch equivalent to CPUE). We predicted catch on the response scale and standard error on the log scale at the statewide and regional scale. We did not predict catch for northern California areas prior to 2017, thereby avoiding the pitfalls associated with predicting outside the spatiotemporal extent of the data. We summed area-specific CPUE in each year to obtain regional indices of abundance. Additionally, we standardized each index by dividing year-specific CPUE by the overall mean (Table 26, Figure 56).

Ages from CCFRP sampling are also included in this assessment (Table 7). Otoliths have been collected since 2017, and represent an important source of age data for the central area.

2.3.2 Abrams Thesis

Jeff Abrams (2014) conducted a research study aboard recreational charter boats from Crescent City Harbor, Trinidad Bay and the Noyo River Harbor. Rocky habitat was identified from high resolution bathymetric data and gridded into 500 m by 500 m cells (California Seafloor Mapping Project, data available from: http://seafloor.otterlabs.org/index.html). During a sampling event, cells were randomly selected to fish. Fish were captured via hook-and-line by researchers, students, or recreational fishers. The charter boat captain was not allowed to search and target fish within the cell. Fishing drifts started at the upcurrent/wind side of the cell and drifted to the opposite edge of the cell, then stopped the clock and reset for another drift (Jeff Abrams, pers. comm.) If it was certain that fishing was occurring over sand, the captain would generally reset. However, because cells were selected with a minimum area of rocky habitat, this was rare.

The NWFSC CAPS laboratory aged several hundred structures from this study that were not aged for the previous assessment. These are used as Conditional Age-at-Length (CAAL) data in the California model (Table 6).

2.3.3 Lea et al. 1999 Nearshore Life History Study

This study was primarily carried out in the 1980s (Lea et al 1999) in central California, and collected life history information for many nearshore species. Data were collected via research cruises, project vessels, as well as the Central California Council of Diving Clubs (Cen-Cal). Data sheets and otoliths discovered by California Department of Fish and Wildlife staff and samples (Table 7) were aged for the 2015 stock assessment and used again in the central area model.

2.4 Biological Data

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 a large number of 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 $M = 4.899A_{max}^{-0.916}$. 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 particular, 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 fish from California aged to date was a 514 mm (fork length), 35-year-old female landed June 1984 in Bodega (the "central" area in this assessment). That particular fish is not included in the assessment due to a small number of samples taken in that year (n=12) by the sampling program. The oldest male was a 474 mm FL, 33-year-old black rockfish landed in Eureka (the "northern" area in this assessment), also in 1984.

The prior for black rockfish in California 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, age and length data were initially fit external to the population dynamics model using the von Bertalanffy growth equation (von Bertalanffy 1957),

$$L_t = L_\infty\ (1\text{-}e^{-k(t-t_0)});$$

where L_t = fork length (mm) of fish at a given age t (years), L_∞ = theoretical average maximum length (mm), k = growth constant (per year), and t_0 = theoretical age at size zero. The parameters L_∞, k, and t_0 were estimated using the nonlinear least squares function in R (R Core Team 2023).

To assess potential sources of variability in age and growth parameters, the STAT examined differences in sex, area, and time. Consistent patterns across our analyses include females growing larger than males, but also representing a smaller fraction of old individuals. These patterns are consistent across areas although there are fewer samples from the central area (south of Point Arena) relative to the northern part of the state (Figure 57). Looking at differences in female and male growth by area, the external fits to the data suggest that maximum size for both sexes may be greater in the central region, however the STAT recommends that more data from older individuals should be collected prior to using these external estimates directly in a stock assessment (Figure 58). Further subdividing the data by sex, area, and time period (1979-1984 and 2001-2022), suggests a possible change in growth over time (Figure 59). Fish in the northern area appear to have been larger at a given age during the earlier time period, although there was insufficient time to explore reasons for this during the current assessment. Data from the central area do not cover a sufficient range of ages in the more recent time period to draw conclusions about differences in maximum size.

2.4.2.2 Weight at length

The weight-length relationship used in the current assessment was estimated from private/rental boat samples of black rockfish, sexes combined (n= 22,046; Source: CDFW). We estimated the parameters of the weight-length relationship ($W=aL^b$) using a log-log regression, and plotted the mean response using the back-transformed and bias corrected value for the ‘a’ parameter (a = 1.707e-05, b = 3.012). We compared this relationship to the values used in the 2015 assessment, as well as values currently used in RecFIN (Figure 60). Following the 2015 assessment, it was determined that the source of the relationship used for the assessment (CDFW onboard CPFV survey, 1988-1998) is unknown, as noted by the lead investigators for that survey (c.f. Monk et al. 2016). Therefore, the current assessment uses parameter values estimated from the private/rental boat data.

2.4.2.3 Analysis of ageing precision and bias

Uncertainty in ageing error was estimated using a collection of 665 black rockfish otoliths with two age reads performed in 2023 by the NWFSC. Of these, 83 otoliths were double read by reader 1 (P. McDonald) and reader 2 (L. Ortiz), and the remainder were double read by reader 2 and reader 3 (J. Hale) (Figure 61). Readers 2 and 3 aged otoliths for the majority of new age composition data used in this assessment, and double reads came from the same sources (CA Commercial, Recreational Biological Groundfish Sampling, CCFRP, Abrams research dataset, and the Commercial Pilot Project).

A separate model was fit for double reads of 781 otoliths performed in 2015-2017 by reader 4 (T. Johnson) and reader 5 (N. Atkins) (Figure 62). Of these, 62 were read twice by reader 5, and 17 were read once by reader 4 and twice by reader 5. This dataset included the double read data (318 otoliths) used in the 2015 black rockfish assessment. This ageing error model applies to all age composition data collected prior to 2015, with the exception of the Abrams research dataset.

Ageing error was estimated using publicly available software (Punt 2008; Thorson et al. 2012). Reader 1, who was more experienced, was assumed to be unbiased. Reader 4 was assumed unbiased in the model for 2015-2017 reads. Several model configurations were explored for bias of the other readers (unbiased, linear, or curvilinear) and precisions of all readers (constant CV, curvilinear standard deviation, or curvilinear CV). The best model was selected using AICc. For the 2023 reads, the best fitting model had no bias among readers and curvilinear CV for all readers (Figure 63, Table 27). A model with curvilinear bias performed similarly (ΔAICc=1.9). For the 2015-2017 reads, removing the oldest aged fish (aged 35 by reader 4 and 17 by reader 5) led to more reasonable parameter estimates, so this was done. The best fitting model had curvilinear bias for reader 5 and curvilinear CV for all readers (Figure 64, Table 27). A model with curvilinear standard deviation performed similarly (ΔAICc=0.3).

The resulting estimates of ageing error indicated a standard deviation in age readings increasing from 0.04 years at age 0 to 6.2 years at age 40 (for 2023 reads), and from 0.06 years at age 0 to 3.6 years at age 40 (for 2015-2017 reads). Ages beyond 40 were assumed to have the same CV (SD/mean) as age 40 fish.

2.4.3 Maturity and Fecundity

Wyllie Echeverria (1987) reported estimates of female black rockfish maturity from California, finding that 50% of females were mature at 40 cm fork length and 7 years of age. Sample sizes were ambiguously reported in that study (n >= 160 for the regression of female proportion mature vs. length). Maturity definitions were based on external gonad morphology, and histological methods were used to examine seasonality of spawning.

The 2015 black rockfish assessment defined maturity at length based on “functional maturity” estimates, which accounts for the effects of abortive maturation, skipped spawning, and follicular atresia. This is in contrast to “biological maturity” which only takes into account physiological development. Claire Rosemond (NOAA NMFS Sea Grant Fellow at Oregon State University) and Melissa Head (NWFSC) kindly shared the results of their recent research on female black rockfish maturity at length and age for use in this assessment, which also focuses on samples taken during the spawning season (n=623). Data were collected primarily off Oregon, and estimates of maturity at size and age reported for both biological and functional maturity. The base models for California both use the logistic, functional maturity at length relationship from their study (intercept = -15.36163 and slope = 0.38061), resulting in a length at 50% maturity of 40.36 cm (Figure 65).

This assessment makes the assumption that fecundity is a power function of female body length, $F = aL^b$. Values for b (4.6851) and a ($1.407e^{-08}$) were taken from Dick et al. (2017). 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.

2.5 Data sources evaluated, but not used in the California assessment

This section has been moved to Appendix B, due to the large number of data sources that were evaluated while preparing the final assessment. While these explorations were an important step in the development of base models, the STAT felt that moving this large section to an appendix would make for a more efficient review of the retained data sources.

3 Model

3.1 History of Modeling Approaches Used for this Stock

The first stock assessment of the California-only stock of black rockfish was conducted in 2015 (Cope et al. 2016). This assessment combined all recreational modes into a single, statewide fleet, and partitioned commercial fleets into two non-trawl (dead/alive) and one trawl. The assessment concluded that the stock was recovering from an overfished state and was in the precautionary zone as of 2015. Previous assessments covering the California coast defined a single stock south of Cape Falcon, Oregon (Ralston and Dick, 2003; Sampson 2007). Each of these assessments used a "fleets as areas" approach, with data from each state kept separate.

3.2 Response to STAR Panel Recommendations from Previous Assessment

The STAR Panel report from the 2015 black rockfish assessment identified unresolved problems and major uncertainties, noting that they applied to both the Washington and California stock. We list these below, and provide updated information on the status of relevant research.

<u>Unresolved problems:</u>

The complexity of SS3 input files makes it difficult to detect errors that may still reside in the input files. None were specifically suggested or thought to occur in the Washington and California models, but this remains unknown.

Considerable efforts were made to ensure that the input files for Stock Synthesis were properly formatted, but the STAT cannot be 100% certain that they are without error.

Standard practices for data preparation need further improvement. The CPUE indices may contain spatial trends that require re-weighting using habitat based weights. The composition data may require post stratification and scaling and the removal of data in years when sampling was inadequate.

We explored habitat-weighted indices of abundance, both during development of the initial fleets-as-areas model, and for the sub-area models (i.e. weighting by the estimated proportion of reef habitat by CRFS district). Our decision to use two sub-area models rather than a fleets-as-areas model was informed by spatial differences in size compositions, exploitation histories, and abundance trends.

<u>Major uncertainties:</u>

The level of cryptic biomass is unknown. The base model has assumed that there is none but this is unlikely to be absolutely true, although there has been considerable fishing at most depths and habitat types coastwide that has not apparently located a concentration of old female fish. It is unlikely that the alternative hide 'em model represents reality either, but some level of domedness in selection is to be expected in some of the fisheries (especially trawl where large fish may be unavailable due to habitat preference, or able to escape).

We explore both domed ("hide 'em") and asymptotic ("kill 'em") selectivity functions in each model, and acknowledge that further research is needed to understand the relative contribution of each hypothesis.

Historical catch history is very uncertain. Sensitivity to this was explored only for plus/minus 50% on the trawl catches. The results were not sensitive in that case but could be sensitive to different trends in the historical catch.

Historical recreational catch reconstructions based on alternative assumptions about the spatial distribution of catch are explored to partially address this uncertainty.

Natural mortality may be poorly determined, especially for California.

Due largely to the efforts of the NWFSC Cooperative Ageing Project, this assessment now includes over 4,000 age estimates, a 100% increase relative to the previous assessment. However, estimation of natural mortality (M) remains a challenge for this assessment as it is influenced by multiple data sources, each of which may be better fit by a different value for M. Also, the majority of ages available for this assessment come from the northern part of the state, which is part of the reason why the estimate of natural mortality in the central area sub-model was fixed at the estimated value from the north.

The stock recruitment relationship is unknown.

The STAT agrees and believes that this relationship is likely to remain unknown for some time. The current assessment models assume that the relationship between stock and recruitment follows a Beverton-Holt functional form, with steepness fixed at 0.72, per the PFMC's accepted practices for groundfish stock assessment. The STAT recommends evaluation of alternative forms of the stock-recruitment curve (e.g. 2- and 3-parameter Ricker alternatives) to better understand how uncertainty in the relationship might affect management advice.

3.3 Transition to the Current Stock Assessment

Dr. Chantel Wetzel (NWFSC) kindly reproduced the results of Cope et al. (2015) using recent versions of Stock Synthesis (V3.30.20.00). Likelihood components and spawning output trajectories were very similar (Table 28, Figure 66), with differences in end-year depletion smaller than 0.1%.

The first alterations to the 2015 model applied to methods for estimating fishing mortality, data weighting, and catches (Figure 67, Table 29). A change from the use of Pope's approximation for annual fishing mortality, as in the 2015 model, to the "hybrid" F estimation method had little effect on spawning output or recruitment. In the 2015 base model, weights were applied only to length composition data, so we applied Francis weights to all composition data sources (lengths and ages) according to the Accepted Practices Guidelines for Groundfish Stock Assessments in 2023 and 2024. This change increased the estimate of unfished spawning output, decreased relative spawning output in the terminal year (from 33% to 28%), and slightly shifted recruitment deviations in most years, with some deviations in the late 1970s changing sign. The application of Francis weights also had an effect on estimates of natural mortality, and a subset of growth and selectivity parameters (Table 29).

Replacing the catches estimated for the 2015 assessment with catches from the 2023 assessment (aggregated to match the 2015 fleet structure) had little effect on the scale of unfished spawning output or relative stock size in 2015. However, the scale of recruitments increased slightly, likely offsetting a small increase in the estimated natural mortality rate relative to the Francis-weighted 2015 model (Table 29, Figure 67).

Starting from the 2015 model with Francis weights applied to all composition data and revised catches (but still using the 2015 statewide fleet structure), we updated biological parameters related to weight at length, length at maturity, and fecundity at length. Since there was no change to the data or catch time series, models in this comparison were not re-weighted. Relative to the 2015 assessment conditioned on 2023 catches, updates to these quantities rescaled estimates of spawning output and recruitment (Figure 68). Revision of the maturity at length relationship resulted in a slightly less depleted stock in 2015, relative to unfished biomass. Subsequent revision to the fecundity at length relationship had little further influence on model parameters, likelihoods, or derived quantities, likely due to the fact that the 2015 assessment already accounted for size-dependent changes in relative fecundity using a different parameterization (Table 30).

At the data workshop held in February 2023, the STAT noted that mean lengths of black rockfish decrease with latitude, and the pattern is persistent over time, spanning the CRFS and MRFSS data sets (1980-present, Figure 69). For this reason, the STAT began development of a fleets-as-areas (FAA) model, with recreational catches divided by area (north and south of Pt. Arena) and mode (PC and PR+shore), commercial catches in divided by gear (but not area, since >90% of commercial catch is in the north).

As is described in the Data section, several fishery-dependent data sets have limited sample sizes in the north relative to the central area. The primary fishery-independent survey, CCFRP, expanded to statewide coverage in 2017, but the resulting statewide time series are too short to adequately inform trends in abundance by themselves at this time. Despite attempts to use area-weighted indices, this resulted in "statewide" fishery-dependent indices producing patterns that largely reflect the trends in central California, the "tail" of the stock's spatial distribution. Similarly, the spatial expansion of fishery-independent indices introduces issues with analysis of the complete time series due to missing data in years prior to the expansion.

Using the FAA model in development at the time, the STAT ran a sensitivity analysis in which the model was fit to all available data, and compared to models fit only to data (i.e. trend and composition data) from either the northern or central area. Catches were kept the same in all runs, i.e., statewide, for consistency. Results showed that the FAA model, conditioned on statewide catches, produced very different outcomes depending on where the data originated throughout the state (Figure 70).

The STAT found that indices of abundance, developed by region, display similarities in the central region that are not apparent in the northern indices (Figure 71, Figure 72). These differences could be driven by a number factors, e.g., spatial differences in recruitment, and/or differences in regional exploitation histories, as already noted (Figure 4). The spatial differences in size composition already mentioned (Figure 69) are discussed in greater detail in the model results section below, noting differences among areas in temporal trends in mean length.

Given the regional differences in size, trend, and exploitation history within California, the STAT decided that separate assessment models for the central and northern regions would be a better approximation of total stock dynamics, compared to a single, fleets-as-areas model for the entire state.

3.4 Northern California Base Model Selection and Evaluation

3.4.1 Model Specifications

The assessment is structured as a single, sex-disaggregated population, spanning U.S. waters from Point Arena to the California-Oregon border. The assessment model operates on an annual time step covering the period 1875 to 2022 (not including forecast years) and assumes an unfished equilibrium population prior to 1875. Population dynamics are modeled for ages 0 through 50, with age-50 being the accumulator age. The maximum observed age was 33 for males and 35 for females. Population bins were set every 1 cm from 5 to 70 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 seven fleets, and is informed by three time series of relative abundance (one fishery-independent survey, one CPUE index from a shore-based recreational sampling program, and one CPUE index from an onboard CPFV observer program). Size and age composition data include lengths from 1978-2022 and ages from 1980-2022, 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 50. All catch was 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 fishing type (CPFV or private boat) and catch type (retained or discarded). All recreational shore modes were combined with the private boat fleet due to their small contribution to overall catch. Discarded catch (CPFV and private boats combined) was modeled as separate fleet due to differences in size composition relative to retained catch, and a lack of sufficient data in an appropriate format to explicitly model retention. The commercial sector was represented by four fleets. Two "non-trawl" fleets representing primarily hook-and-line and longline gear types, but including other minor gears, were differentiated by the condition of landed fish (landed dead or alive), as fish in each group often have different size compositions. Other commercial fleets include a trawl fleet, and a fleet for discarded catch which represents the aggregated, dead discards from all commercial fleets. Fleet selectivity was assumed to be asymptotic for all retained commercial fleets, and dome-shaped for the recreational and commercial discard fleets. Sensitivity to these selectivity assumptions were explored during model development and relative to the base model.

The time-series of data used in the Northern California model are summarized in Figure 6. Sample sizes for age and length compositions used in the model are also summarized (Table 6, Table 4). For yearly, marginal composition data, initial sample sizes for recreational fleets were set at the number of sampled trips, or a proxy based on unique record identifiers in the data set. For the commercial fleets, the initial sample size was set to the number of cluster samples taken by port samplers (two 50-lb clusters per sample, typically). Age-at-length composition sample sizes were set at the number of aged fish in each 2-cm length data bin. 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, and variance adjustments were capped at a value of 1 for each iteration. The Francis method resulted in down-weighting of all fleet sample sizes, except for the commercial non-trawl live and trawl fleets (Table 31).

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) particular 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. 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 northern area 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.

Likelihood components that were minimized in the overall fitting procedure include fleet-specific catch, length composition, and conditional age-at-length composition and also survey, recruitment deviate, parameter prior, and parameter soft-bound components.

This assessment used a recent version of Stock Synthesis 3 (version 3.30.21.00, optimized), which is available via GitHub (https://github.com/nmfs-stock-synthesis/stock-synthesis/releases). The basic population dynamic equations used in Stock Synthesis 3 can be found in Methot and Wetzel (2013). The relevant input files necessary to run the stock assessment are available on the Pacific Fisheries Management council website (https://www.pcouncil.org/stock-assessments-star-reports-stat-reports-rebuilding-analyses-terms-of-reference/groundfish-stock-assessment-documents/). The R package "r4ss" (Taylor et al. 2021) was used to visualize model output and greatly assisted with model development and evaluation.

3.4.2 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. A summary of all estimated and fixed parameter values in the base model, including associated properties, are listed in Table 32 and Table 33. A total of 98 parameters were estimated in the base model, including 60 recruitment deviations from 1963-2022 and two forecast deviations (both equal to 0).

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 1963 – 2022. Recruitment variation about the stock recruitment curve was fixed at 0.6, a value tuned to the estimated recruitment deviation RMSE plus a slight adjustment upward to account for unmeasured process error.

Time-invariant growth parameters (Brody growth coefficient (*k*), lengths at age 20, and the CV of length at age 20) using the Schnute parameterization (Schnute 1981) of the von Bertalanffy growth function were estimated for each gender, where males were estimated as an exponential offset of female parameters. When all growth parameters for both sexes were estimated, the length at age zero for males would hit the lower bound (-1 in offset space) and the CV of that length was unrealistically small (~0.01). Estimated female size at age zero was roughly 5 cm with a CV of 0.1. This is consistent with the typical size of YOY black rockfish in July, i.e. size at settlement in May-June is roughly 4-5 cm (T. Laidig, NMFS, pers. comm.), and also with the 95th percentile of size for pelagic juveniles observed in the SWFSC RREAS survey. Fixing the male offset at zero would average across the two sexes' data (reducing the female estimate), so it seemed reasonable to fix length at age zero at 5 cm for both sexes, and the CV(L(0)) at 0.1. 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. This choice was based on inspection of the relationship between CV(L(a)) and age, by sex, (Figure 73), and we note that the CV(L(a=0)) is roughly 0.1 near age zero and declines with age. Weight at length parameters were fixed at values externally estimated from private/rental boat observations.

Selectivity was assumed to be asymptotic and related to length by a logistic function for both commercial dead catch fleets, and domed for the commercial live fish and discard fleets assuming a double-normal functional form (see Methot and Wetzel 2013 for details). All selectivity parameters were assumed to be time-invariant, except a time block was used to capture changes in selectivity associated with depth restrictions around 2004 (the timing and spatial extent varied slightly by management region over time). Extra standard deviation parameters were estimated for the PR dockside abundance index, as the large sample sizes result in small input variances relative to other indices based on higher resolution catch and effort data, e.g. observed total catch by drift with location information in the onboard CPFV index vs. observed retained catch by trip with port of landing information in the PR index.

Parameters for fecundity at length were fixed at estimates following methods in Dick et al. (2017), and female maturity at length parameters were fixed at logistic "functional maturity" values provided by C. Rosemond and M. Head.

3.4.3 Key Assumptions and Structural Choices

Many of the key assumptions and structural choices made in this assessment were evaluated through sensitivity analysis (section 3.4.9). For consistency, model structural choices were made that were likely to result in the most parsimonious treatment of the available data, either a priori determined or through the evaluation of model goodness of fit. The major structural choices in this assessment were the use of two, independent population models to account for differences in exploitation history, size and age composition, and abundance trends.

Major structural assumptions included fixing the steepness stock recruitment parameter and estimating gender-specific natural mortality parameters, but assuming gender invariant selectivity parameters. This favors the hypothesis that higher natural mortality for females explains the skewed sex ratio at older ages in the catch. An alternative hypothesis is that females become less available to the fishing gear, but continue to contribute to spawning output of the population. The California 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 bag limit 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 over the past 1-2 decades, and may contain information about recruitment.

3.4.4 Evaluation of Model Parameters

Model parameters were evaluated for stability and precision along likelihood profile gradients (section 3.4.9), and against the main assumptions in the base case model (section 3.4.1). Stability was examined by ensuring that model parameters were not up against a lower or upper bound and had sufficiently low gradients (Table 32, Table 33). Parameter precision was also monitored by looking at estimated standard deviations to assess the variability associated with point estimates.

3.4.5 Residual Analysis

Residuals to length composition and age composition fits to the model were explored during model development. The identification of residual patterns helped to sort out which set of a priori selectivity blocks were the most appropriate given the data. Alternative model configurations were also explored during model development in an attempt to minimize residual trends.

Fits to length composition data

Fits from the northern base model to time-aggregated length compositions, by fleet, show that the recreational boat modes (PC and PR), commercial non-trawl (live landings), commercial non-trawl (unsexed dead landings), and CCFRP research lengths are best fit by the model (Figure 74). Predicted length distributions deviated more strongly from the sex-specific commercial composition data and the discard fleets, and the female component of the Abrams research data.

Examination of Pearson residuals for length composition data from commercial fleets shows that the largest deviations in the non-trawl fleet were for females in 1992 and 2002, as well as for recent years (~2018-present) where fits to the sex-specific data were generally poor relative to earlier years (Figure 75). Mean lengths in catches by this fleet have fluctuated from 35-40 cm in the combined-sex data, with slightly larger but less precise mean lengths in the early 1990s for the sex-specific data. Fits to the live-fish component of the non-trawl length composition data are generally good, with the model predicting mean lengths that track an initial increase in mean length over the period 1999-2003 (Figure 76). Fits to lengths from the trawl catch, while capturing the pattern of larger females in most years, tend to be biased high for mean length in the late 1970s and early 1980s, and biased low for years since 1995 (Figure 77). A small number of large, discarded fish appear as large residuals in the commercial discard length compositions, due to the lower mean size of discarded fish overall, relative to the retained catch (Figure 78).

Fits to length compositions for the recreational fleets (PC and PR) are consistent with each other, tracking a general decline in mean length from the 1980s to the late 1990s (Figure 79, Figure 80). Despite this, the base model still under predicts the observed mean sizes for PC catch in the early and mid-1980s, as well as a broad range of observed lengths in the late-1980s PR data. Mean sizes of discarded fish in the northern recreational fishery appear to have increased in 2015, which may reflect discarding practices due to introduction of sub-bag limits for black rockfish (Figure 81). However, these limits were removed in 2021, and mean size in 2022 remained similar to the 2015-2018 values.

Fits to length composition from the survey fleets in the northern base model are best for the CCFRP data, with few large residuals and a slight declining trend in mean length from 2017-2022 (Figure 82). The base model under predicts the number of small females observed by the Abrams study in 2010, and while model predictions are within the range of variability observed in mean length, the predicted trend is declining while observed means show a slight increase over the two-year study period (Figure 83).

Fits to age composition data

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. Marginal age compositions were entered into the model as observations without a likelihood component, having no effect on the model fit, but allowing for comparison of predicted marginal distributions to the data.

We first compared observed mean lengths summarized from the CAAL data to predicted mean lengths in the commercial fleets. Model predictions for the non-trawl fleet (dead landings) were very close to the observed mean lengths and mean ages in all but one year (1984), where observed mean lengths were roughly 5 cm larger than the model prediction (Figure 84). Age data from commercial live-fish fisheries are typically not available due to the effect that otolith removal has on “live-fish” status and associated market price. The base model was able to predict mean lengths and ages very similar to the observed values in the trawl fleet, with the exception of mean age in 1980 (Figure 85). However, see the description of Pearson residuals for the trawl fleet (below).

Age data from recreational fleets in the northern model were limited to just two years, 1982 and 2002, for the PC fleet and one year (2002) for the PR fleet (Figure 86, Figure 87). Predictions of mean length-at-age and mean age were consistent with the data, showing an increase in mean age from roughly 8-10 years in 1982 to 10-12 years in 2002 based on the CPFV fleet data.

Observed ages from the CCFRP survey (only one year in the northern area, 2022) tended to be slightly older at length relative to model predictions, particularly above 30 cm (Figure 88). Fits to the large number of ages from the Abrams study in 2010-2011 were similar in terms of mean length in age, and mean age varied little across the two years. Interestingly, while the observed mean lengths and ages from the Abrams study are both increasing, the model predicts a decline in mean length and a very slight increase in mean age (Figure 83, Figure 89).

Pearson residuals for the non-trawl fleet (dead landings) were generally without pattern, except for 1984, as previously mentioned (Figure 90). A number of years (2007, 2011, 2019, 2020, and 2022) show a similar but less pronounced pattern of positive residuals for males in the 40+ cm range and 15+year range, i.e. males in this size range are older than the model predicts. Fits to the trawl fleet data are less consistent across years, with larger residuals overall (Figure 91).

The limited amount of recreational age data did not have large residual values in the base model, but the number of large females in the 2022 PC data exceeded the model predictions, and males were more widely distributed across lengths and ages than expected (Figure 92). The single year of PR mode ages in the northern model showed positive residuals for older individuals within each length, suggesting that growth in the model predicts more rapid growth than expected given these data (Figure 93).

Although based on sparse data, residuals from the CCFRP survey in the northern model tended to be positive for older ages within a length bin and negative for younger ages in a bin (Figure 94). These data seem to prefer a smaller size at age, similar to the recreational age data. However, this pattern is not apparent in the Abrams data (much larger sample sizes), suggesting that information about growth varies among data sets given the current base model structure (Figure 95).

Fits to indices of abundance

Recreational indices of abundance for the northern model do not show any evidence of strong increasing or decreasing trends, although historically these parts of the state have been sampled much less than the central and southern parts of California. As discussed in Section 3.3, these indices do not display the consistent patterns observed in the central area indices. Neither rec index shows strong patterns in the residuals, but also neither one is strongly correlated with the model predictions (Figure 96, Figure 97).

The CCFRP index only begins in 2017, and future assessments will benefit more from the expanded survey than the current assessment. However, as it represents the only fishery-independent index that is expected to encounter black rockfish throughout the water column, the STAT chose to retain the index, and conducted sensitivity analyses to evaluate its influence in the assessment. The residuals for this index are negative for the first three years (2017-2019) and positive for the last three (2020-2022), with model predictions not matching the rate of increase observed by the survey (Figure 98).

3.4.6 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
- 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

No parameters were hit the bounds (min or max), and the gradient of the base model was 5.93525e-05. Across all 100 jittered runs, the model found no minima lower than the base case likelihood (1106.27). The –hess_step run reported the following:

```
The 2 Hessian step(s) reduced maxgrad from 5.94479e-05 to 0 and NLL by -6.82121e-13.
All output files should be updated, but confirm as this is experimental still.
The fact this was successful gives strong evidence of convergence to a mode
with quadratic log-likelihood surface.
Iterations: 792
```

A comparison of likelihoods, parameter estimates, and derived quantities showed that results based on the –hess_step run were indistinguishable from the base.

3.4.7 Response to STAR Panel Recommendations

Request No. 1: Generate pairwise plots (and calculate correlation coefficients) for all the abundance indices, for years which overlap.

Rationale: The consistency of various abundance indices are evaluated graphically in the report. Pairwise comparison of all abundance indices can provide a more quantitative evaluation of consistency of abundance indices.

STAT Response: The requested plots are shown in Figure 99. Index combinations were separated into fishery-dependent, fishery-independent, and young of the year (YOY) survey categories because insufficient overlap among years prohibited all possible combinations (see Fig. 4 of the stock assessment document for the temporal extent of each index). Fishery-dependent indices (CRFS_PR and CRFS_PCO) were positively correlated. Fishery-independent indices (CCFRP and PISCO) showed weak or no correlation ($p > 0.1$) over the 5-year period that they overlap.
The YOY surveys (RREAS and SWFSC_YOY) were strongly positively correlated ($p < 0.05$). The PISCO and YOY surveys were not included in the base model.

Panel Conclusion: The moderate correlation between the fishery dependent indices suggests some consistency with each other. This may indicate a potential for both indices to inform the model on population trends. The weak relationship between two fishery-independent survey indices may result from the two programs capturing different components of the targeted population.

Request No. 2: Plot natural mortality (M) as a function of steepness (h), given the potential interactions (data from Tables 44 and 45). Provide a steepness profile, while estimating M for females and males.

Rationale: M and h tend to be highly correlated. An examination of LL (log likelihood) values under a varying M and h (over a reasonable range) would help us understand how they interact and how they may influence the assessment of population dynamics.

STAT Response: Based on a profile over the Beverton-Holt steepness parameter from 0.25 to

0.95 in increments of 0.05, natural mortality for females declined from slightly more than 0.3 to slightly less than 0.2 (Figure 100). The estimated offset for males remained fairly constant across all values of steepness.

Panel Conclusion: This exercise demonstrates the inverse relationship between steepness and natural mortality rate. Both measure aspects of the underlying productivity of the stock, but the model requires constraints (priors) on one (or both) in order to estimate the other. This inherent relationship should be considered when defining axes of uncertainty.

Request No. 3: Update the ageing error data to include the errors for before 2015 since only those for after 2015 were applied and plot results relative to the reference base model.

Rationale: Ageing error matrices were developed for two time periods, but only the errors from after 2015 were included. This will better reflect the ageing errors in each period.

STAT Response: The addition of a new ageing error matrix for pre-2015 age data (excluding Abrams age estimates that were produced for this assessment) had very little effect on model likelihoods and estimated parameters changed very little. Small changes to estimated recruitment deviations were evident in the early part of the time series, but this had little impact on time series of spawning output or recruitment (Figure 101), or estimated parameter values (Table 34).

Panel Conclusion: Additional data on aging error represents an informational improvement that should be included in the assessment. The net difference in model spawning output is small. Nevertheless, the new data on aging error should be implemented into the new reference model.

Request No. 4: Provide a sensitivity analysis fitting functional maturity with a spline in addition to the logistic curve applied in the assessment.

Rationale: A spline was fit to data in the Oregon and Washington assessments and the Panel would like the STAT to provide comparable results for California.

STAT Response: Estimates of maturity at length (2-cm length bins up to 64 cm) from the Washington/Oregon models were used to interpolate maturity at length following the population length bin structure in the California model (1-cm bins, 4-70 cm). Estimates from 64-70 cm were based on linear extrapolation of the curve's descending limb (Figure 102). Use of the interpolated functional maturity relationship scaled the spawning output relative to the logistic model for functional maturity, but it did not change relative spawning output significantly (Figure 103). Early recruitment deviations changed slightly, but other estimated model parameters and derived quantities did not change significantly (Figure 104).

Panel Conclusion: Improvements to the maturity ogive were made to the Oregon and Washington assessments that include a spline model where maturity declines slightly at large sizes. Thus, egg production shifts slightly compared to the logistic curve. Impacts on the assessment are minimal when the spline model is used instead of the logistic curve. The spline model should be used in a new reference model so that a consistent approach is applied across all assessments.

Request No. 5: Provide a model run that mirrors selectivity for non-trawl dead and non-trawl live fisheries.

Rationale: The Oregon assessment concluded that these fisheries could be combined. This model run would evaluate the effect of a similar assumption on the northern California assessment.

STAT Response: Mirroring commercial Non-Trawl live selectivity to the logistic selectivity of the dead category (Figure 105) results in small changes in estimated recruitment deviations from the 1980's-mid 1990's (decreases early, and increases around the 1990's; Figure 106). The mirrored model has three fewer parameters and NLL increases by 11.6 points as compared with the base model; other estimated model parameters and derived quantities did not change significantly (Figure 107).

Panel Conclusion: This request was an exploration of an alternative structure for selectivity of these "fleets". The effect on model outcomes was minimal and the statistical justification was not very strong. Therefore, the reference model should not be changed by using this alternative.

Request No. 6: Provide documentation for the data selection criteria for the private/rental boat (PR) dockside index.

Rationale: Selection criteria are intended to extract records that are likely to be informative about black rockfish abundance trends and panel members wanted to better understand how this was done.

STAT Response: The PR dockside data used to generate indices of abundance were selected using the following criteria:

- Excluded data from CRFS districts 1-2
- Removed data from 2015-2020 due to sub-bag limits for black rockfish
- Removed data with angler-reported distance from shore >3 nm
- Retained only hook and line gear (troll targets other species and has 1/10th the catch rate)
- Kept data from May-October (few samples in other months, especially in north)
- Kept trips with primary trip types 'rockfish genus','bottomfish (groundfish)', and 'lingcod' (Table 35)
- From the set of trips with these primary targets, we retained trips with the same secondary targets (i.e. excluding secondary targets such as halibut, crab, or salmon), or with an unknown secondary target.
- The effects of target species on catch rate were explored in the development of the index standardization model.

Panel Conclusion: Information was provided indicating the selection criteria, particularly on "targeting" definition including primary and secondary targets. No further suggestions or comments.

Request No. 7: Please include clarification regarding the Mohn's rho results and what they represent; over a 5 year average as stated in the TOR. Provide a plot to show relative error in ending biomass consistent with best practices described in Legault 2009.

Rationale: The values will be useful in assessing the retrospective pattern. There are multiple options for calculating Mohn's rho in r4ss and thus it is important to understand the mechanism being used. Retrospective error is a particular type of uncertainty and it is important to understand any bias.

STAT Response: Mohn's rho values based on a 5-year peel were -0.188 for spawning output, 0.086 for recruitment, and 0.246 for exploitation rate. This was calculated using the r4ss function "SSmohnsrho," dividing the reported cumulative value by the number of retrospective years (5).

Plots are provided below for time series of spawning output, recruitment, and exploitation rate (Figure 108) and percent change relative to the base model (Figure 109). Removal of the last 1-5 years of data tends to lead to lower estimates of spawning output (back to ~1990, generally not exceeding 20%), higher exploitation rates, and higher recent recruitments. Differences in recent recruitment predictions occur primarily because predictions revert back to the mean of the stock- recruit curve as data are removed.

Panel Conclusion: This request provided the Panel with a diagnostic on the effects of retrospective patterns. One thing to note is that with 5 year peels, an index is eliminated. This distorts the outcomes somewhat. Generally, the Panel had no further recommendations, but noted that this exploration should be considered in the future.

Request No. 8: Provide squid plots showing the age at which recruitment is first detected in the fishery and fishery dependent studies, using the new base model and an updated model including the RREAS and SCUBA young of year surveys.

Rationale: To identify how long it takes for recruitment to be detected in the data from the fisheries or non-young of year surveys. This will help inform how much potential benefit there is for early indications of recent recruitments from the inclusion of the RREAS and SCUBA survey young of year surveys in the assessment. This model will be considered as a potential base model.

STAT Response: The STAT was unable to complete this request during the review. Preliminary results of the analysis were completed for the central area model, but as noted in the request document for that model, long run times in combination with many possible model configurations made it impossible to fully develop a response.

Panel Conclusion: The analysis from the Central California assessment area demonstrates that the RREAS and SCUBA young of year surveys may have potential to inform future recruitment in the projection. However, the STAT did not have time to fully explore incorporation of these data sets in the reference model, including evaluating model diagnostics to ensure the appropriate use of the information. The panel finds such plots to be useful for evaluating whether a recruitment index would be valuable to include in the assessment, and recommends they be included in future black rockfish assessments and other assessments that consider the use of recruitment indices.

Request No. 9: Incorporate the ageing error prior to 2015 and spline fit to the functional maturity to provide a revised reference model.

Rationale: To implement the conclusions of Request No. 4 (the ageing error prior to 2015) and Request No. 5 (functional maturity fit with a flexible spline), which improved the base model.

STAT Response: The corrected ageing error matrix and spline model for functional maturity were included in the model, and Francis weights updated (little change in weights). As noted in the request to revise the maturity relationship, spawning output was slightly scaled upwards, but relative spawning output remained very similar over time (Figure 110). Model likelihoods, parameter estimates, and derived quantities are similar between the pre- STAR base and the updated model (Table 36). Further details of the updated model were presented to the panel using the r4ss html output.

Panel Conclusion: The request was to provide the model run using the updated recommendations for the new reference model. The Panel and the STAT agreed that this new reference model should form the basis for scientific advice going forward to the SSC.

Request No. 10: Generate a bivariate steepness and natural mortality plot (similar to Request No. 3 for central California), provide the 75% confidence region for both the northern and central models.

Rationale: To provide a potential basis for selecting a combination of steepness and natural mortality for a decision table.

STAT Response: The STAT completed bivariate profiles over a range of natural mortality values (0.08-0.30) representing roughly a 95% interval based on the lognormal prior distribution, and steepness values from 0.25 to 0.95. Heat maps showing the NLL, depletion, proxy MSY, and 2023 OFL were provided to the panel showing approximate 75% confidence regions around the minimum based on a chi-square distribution with 2 degrees of freedom (Figure 111). The base model is on the border of the bivariate 75% chi-squared interval. Steepness values of ~0.3 and less are implausible given the proxy FSPR50% harvest rate, as indicated by long-term equilibrium yields equal to zero. The bivariate profile plot with the 95% chi-squared interval is provided below for comparison, showing that the base model falls within the 95% chi-squared interval (Figure 112).

Panel Conclusion: The response to this request included tables with the 95% confidence region as well as those with the 75% originally requested. The results indicate the relationship of the estimates of h and M in the fitting (NLL) and in the subsequent outcomes (depletion, OFL and MSY). However, the Panel agreed that the range at 75% did not capture all the uncertainty inherent in the assessment and, therefore, suggested further examinations using percentiles of the M prior (see Request No. 11 below)

Request No. 11: Use the uncertainty in the prior for natural mortality to obtain possible upper and lower states of nature. Center this uncertainty on the point estimate of the base model and use the M at the 12.5 and 87.5 percentile of the distribution for lower and upper states of nature.

Rationale: To provide a potential basis for selecting natural mortality values for a decision table.

STAT Response: The northern area model estimates female natural mortality (0.2103 yr-1) and male natural mortality (0.1998 yr-1). The log-scale standard deviation of the prior for M is 0.31. The point estimates of M for the high and low states of nature were calculated as $\exp\{\log_e(0.2103) +/- 0.31*1.15\}$, where 1.15 is the z-score corresponding to a two-tailed 75% interval in log space (i.e. plus or minus 1.15 standard deviations from the point estimate). The resulting values of M in arithmetic space for the high and low states of nature are 0.300 and 0.147, respectively. Parameter estimates associated with each state of nature are shown in Table 37.

Estimates of unfished spawning output (Figure 113) are scaled upward under the assumption that M = 0.147 (the ‘low’ state of nature), and downward with M = 0.300 (the ‘high’ state of nature). Trends in spawning output also show greater declines under the low-M scenario (Figure 114), suggesting a larger, less productive stock, and the opposite is seen for the high-M scenario (smaller, more productive stock).

The patterns in estimated recruitment deviations change over the modeled time period, with the high-M model producing the most positive deviations in the mid- to late-1960s, but more negative deviations in other time periods (Figure 115). Similar shifts over time are apparent for the other two models, but overall variation in estimated recruitment deviations is well within the range of uncertainty of the base model.

For the northern area model, the reported 'sigma' (log-space uncertainty around the OFL value for the first forecast year, i.e. 2023) is 0.274.

Panel Conclusion: This response includes the model runs using the updated reference model and the upper and lower states of nature recommended by the STAR panel for use in the decision tables.

3.4.8 Northern California Base-Model Results

Estimates of natural mortality for female and male black rockfish were 0.21 and 0.20, respectively, in waters off California and north of Point Arena. These values are greater than the prior median of 0.154 based on an assumed maximum age of 35, but within the range of uncertainty implied by the prior (Figure 116).

The northern California base model estimated reasonable growth parameters (k, length at age 20, and CV of length at age 20 for females and males; Table 32, Figure 117). Length at age 20 was estimated to be 54.5 cm for females and 47.0 cm for males, with CVs of length at age 20 equal to 0.08 and 0.06, respectively.

Fits to abundance indices in the northern model are generally poor, showing little correlation between model predictions and annual estimates of relative abundance (Figure 96, Figure 97, Figure 98). The rate of increase in abundance implied by the CCFRP index, although of limited duration, was not matched by the model, given the fixed value of steepness. Collection of additional years of data from this ongoing, statewide, fishery-independent survey will be key to inform future trends for black rockfish and other nearshore species.

The model's interpretation of a decline in abundance from the 1980s until the late 1990s with a subsequent increase is consistent with patterns in mean length seen in the recreational composition data (Figure 79, Figure 80). The same pattern is present, but less pronounced, in the commercial non-trawl fishery data (Figure 75).

Estimates of year-class strength in the northern model are largest, in absolute terms, in 1973-74, 1976-77, and 1995 (Figure 118). Viewed as log-scale deviations from the stock-recruitment curve, 1995 is the largest positive deviation and 2006 is the largest negative deviation (Figure 119). In total, the years with log-scale deviations larger than 0.5 include the years mentioned above, as well as 1999 and 1994 (both positive) and 1971, 1978, and 2006 (negative deviations) (Figure 120).

Length-based selectivity curves were estimated for eight of the10 fleets (Figure 121). The PR model selectivity was assumed equal ('mirrored') to the PC mode after independent estimates showed little difference. The PC Onboard index was also mirrored to the combined PC/PR selectivity. Logistic curves estimated for the commercial trawl and non-trawl (landed dead) fleets had inflection points at roughly 45 cm and 36 cm, respectively. The non-trawl (landed live) fleet had a dome-shaped selectivity curve with a greater fraction of small fish vulnerable to the fleet relative to either non-trawl (landed dead) or trawl. Although the non-trawl (live) fleet final selectivity parameter was estimated at a small value (large negative logit value), the standard error was large when estimated so it was fixed at -10 in logit space. Peak selectivity for the commercial discard fleet was around 27 cm, and domed such that discarded dead catch includes fish ranging primarily from about 18-40 cm. The recreational PC and PR fleets (again, sharing the same selectivity parameters) had an estimated peak selectivity of 40 cm, with a heavily domed shape that remained slightly above zero through the maximum size in the model. This shape for the recreational fishery represented the recent time period (2004-2022), before which the data were best fit by an asymptotic selectivity curve with a peak at 34 cm (Figure 122). CCFRP survey selectivity was allowed a flexible, double-normal parameterization, and the length data were best fit by a highly domed curve with a peak at 42 cm, similar to the recreational fleets that use similar gear. After initially mirroring the Abrams selectivity curve to the recreational fleets, a double-normal, dome-shaped selectivity function was estimated allowing for a slightly smaller average fish size being selected relative to the recreational fleets and improving the fit to the length composition data for that fleet. Similar to the non-trawl (live) fleet, the ending selectivity parameter was imprecisely estimated and fixed at -5 in logit space, the most likely value when estimated.

Black rockfish spawning output in northern California was estimated to be 438 billion eggs in 2023 (~95% asymptotic intervals: 187-689; Table 38), which equates to a "depletion" level of 36% (~95% asymptotic intervals: 16%-57%; Table 38, Figure 123, Figure 124) in 2023. Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output. Spawning output in California (north of Point Arena) declined rapidly with wartime and post-war demand, recovered briefly, then declined to its lowest level in the late 1990s (Table 39, Figure 123). Reductions in catch since then, coupled with reasonably strong recruitments in the 1990s, result in increasing estimates of spawning output over the following two decades, slowing only in the past few years (Figure 124). Recruitments in the northern California model may be poorly estimated due to limited spatial and temporal coverage of age data, but the model picks up a reasonably strong 1999 year class, known to be a strong year-class for other *Sebastes* species (Figure 125). Relative exploitation rates [(1-SPR) / (1-SPR50%)] increased through time, peaking first with wartime catches, declining briefly, then peaking again in the late 1990s before falling to fluctuate around the 50% SPR harvest rate over the last two decades (Figure 126). The equilibrium yield curve is shifted left, as expected from the assumed Beverton-Holt steepness value (h=0.72) (Figure 127).

3.4.9 Evaluation of Uncertainty

3.4.9.1 Sensitivity to Assumptions, Data, and Weighting

We evaluated sensitivity of the northern California model to specific data sources using 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), after which parameter estimates and derived quantities were compared to the base model. Other sensitivity tests included:

- Comparison of model outputs using alternative weighting methods (Francis and McAllister-Ianelli); weights were capped at 1 for both methods (i.e. no up weighting of data)
- Assuming natural mortality was the same for both sexes
- Allowing all selectivity curves to assume a domed shape
- Estimation of all growth parameters
- Estimation of steepness and natural mortality (male and female)

The northern base model was stable with respect to population scale across most "drop-one" scenarios, with the exception of removing data associated with the trawl or non-trawl (dead landings) fleets (Table 40, Table 41, Figure 128). Removal of the non-trawl (dead landings) fleet resulted in spawning output trends that were just within the 95% confidence interval of the base model, whereas estimated unfished spawning output increased from 1205 billion eggs in the base model to 1756 billion eggs when trawl fleet ages and lengths were removed. In terms of relative spawning output (B / B_unfished), only removal of the trawl data resulted in a major change relative to the base model (Figure 129). Removal of the trawl fleet data caused the model to estimate lower recruitment over the modeled time period, and also changed patterns in early recruitment deviations (Figure 130, Figure 131).

The base model is weighted using method of Francis (2011), applied iteratively to all composition data sources (lengths and ages). Iterative application of McAllister-Ianelli weights (Table 31) to the base model gave less weight to the trawl fleet age data (0.33 with M-I weights, vs. 0.91 using Francis), the same weight to the trawl lengths (capped at 1) and resulted in a more depleted population, similar to what was seen in the drop-one analysis when trawl data were removed (Table 42, Figure 132, Figure 133). Recruitment was similarly lower with the M-I weights, and deviations were less variable in the early part of the time series (Figure 134, Figure 135).

A model run with natural mortality estimated using the same value for both sexes differed very little from the base model, apart from scaling up spawning output due to a slight decrease in female M. The minor effect is not surprising given the small value of the male offset in the base model (Table 42, Figure 132, Figure 133).

Assuming dome-shaped selectivity for fleets with asymptotic selectivity in the base model, resulted in a scaling up of spawning output, with little effect on relative spawning output. This rescaling is likely due to a decrease in the estimated value of M from 0.211 in the base model to 0.197 in the model with dome-shaped selectivity curves for all fleets model (Table 42, Figure 132, Figure 133).

When all growth parameters for both sexes were estimated, the length at age zero for males would hit the lower bound (-1 in offset space) and the CV of that length was unrealistically small (~0.01). Estimated female size at age zero was roughly 5 cm with a CV of 0.1 (Table 42, Figure 132, Figure 133). This is consistent with the typical size of YOY black rockfish in July, i.e. size at settlement in May-June is roughly 4-5 cm (T. Laidig, NMFS, pers. comm.), and also with the 95th percentile of size for pelagic juveniles observed in the SWFSC RREAS survey. Fixing the male offset at zero would average across the two sexes' data (reducing the female estimate), so it seemed reasonable to fix length at age zero at 5 cm for both sexes, and the CV(L(0)) at 0.1. 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. This choice was based on inspection of the relationship between CV(L(a)) and age, by sex, (Figure 73), and we note that the CV(L(a=0)) is roughly 0.1 near age zero and declines with age.

A model that estimates steepness (h=0.9) as well as natural mortality for both sexes reduces the total likelihood by over 40 points, with female natural mortality estimated closer to the prior median at 0.19 and male natural mortality slightly lower (Table 42). The stock is slightly less depleted relative to unfished spawning output in 2023, compared to the base model (Figure 132, Figure 133). Until longer time series of informative abundance indices become available, the STAT considers estimation of steepness to be asking too much of the available data, and chose to fix steepness at the prior mean of 0.72 in the base model.

3.4.9.2 Parameter Uncertainty

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.

Most data types in the model are best fit by higher steepness values (Figure 136). This is true for individual length data sources, with the exception of the commercial trawl lengths that seem to slightly favor lower steepness values, but the magnitude of the change in likelihood is small (Figure 137). Age compositions also favored high steepness values in the northern model (Figure 138). However, indices were inconsistent, with the PR index preferring lower steepness values, and the CCFRP and PC onboard indices preferring higher values (Figure 139). The absolute change in negative log likelihood across values of steepness was small for all indices. Profiling over steepness primarily affected the scale of spawning output, with little change in relative spawning output (Figure 140, Figure 141). Recruitment deviations across all values of steepness in the profile were within the range of uncertainty estimated by the base model (Figure 142). Steepness was negatively correlated with estimates of natural mortality and unfished recruitment (Table 43, Table 44).

A profile across log(R0) values from 6.5 to 8.5 in increments of 0.2 shows that both recruitment and age data favor values of R0 larger than about 7.3 (Figure 143). Length data sources, however, are fit by a variety of different R0 values, depending on the source (Figure 144). Commercial trawl, discard, and rec PR north seem to be better fit by lower values, while commercial non-trawl (dead landings), rec discard, and CCFRP seem to favor larger values. Age composition data are generally better fit by larger R0 values, but the Rec PR ages are best fit with values less than about 7.3 (Figure 145). The CCFRP and PC onboard indices are once again in agreement, with better fits associated with intermediate values from the range of profiled log(R0) values, unlike the PR index, which slightly favors large values at or beyond the range considered in this profile analysis (Figure 146). R0 has a large effect on the ending year spawning output (Figure 147), and similarly for relative spawning output (Figure 148).

The profile over female natural mortality (M) was conducted across a range of values slightly wider than the 2.5% and 97.5% percentiles of the lognormal prior on female M (0.08 – 0.30 yr^{-1}) while estimating male natural mortality as an exponential offset to female natural mortality (Table 45). Age and length data sources, overall, were fit poorly by low values of female natural mortality in the northern model (Figure 149). Length composition data had better fits using different values of M, depending on the data source, with the commercial trawl and non-trawl fleets strongly favoring values above ~0.16, and both rec fleets (PC and PR) favoring relatively lower values of M (Figure 150). Age data from the commercial trawl fleet appear to be least consistent with low female M values, whereas the other data sets are either uninformative or better fit by low M values (e.g. PR mode ages) (Figure 151). Index likelihoods once again had little information about M, based on the total change in negative log-likelihood (Figure 152), with CCFRP and the PC onboard index minima around 0.17 and the PR index minimum at the upper limit of the profile (M = 0.3).

3.4.9.3 Retrospective Analysis

A retrospective analysis was conducted by sequentially removing 1 through 5 years of data from the northern base model starting with 2022. Sequential removal of the data did not produce strong retrospective patterns, but all retro runs estimated slightly lower unfished spawning output and a slightly lower ending status, relative to the base model (Figure 153, Figure 154). Mohn's rho values based on a 5-year peel were -0.188 for spawning output, 0.086 for recruitment, and 0.246 for exploitation rate. This was calculated using the r4ss function "SSmohnsrho," dividing the reported cumulative value by the number of retrospective years (5). See STAR panel request 7 for additional details.

3.5 Central California Base Model Selection and Evaluation

3.5.1 Model Specifications

The assessment is structured as a single, sex-disaggregated population, spanning U.S. waters from the US/Mexico border to Point Arena. Black rockfish are rare south of Point Conception, so the central

California model focuses on the region between Point Conception and Point Arena. The assessment model operates on an annual time step covering the period 1875 to 2022 (not including forecast years) and assumes an unfished equilibrium population prior to 1875. Population dynamics are modeled for ages 0 through 50, with age-50 being the accumulator age. The maximum observed age was 33 for males and 35 for females. Population bins were set every 1 cm from 5 to 70 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 six fleets, and is informed by four time series of relative abundance (one fishery-independent survey, one CPUE index from a shore-based recreational sampling program, and two CPUE indices from onboard CPFV observer programs operating over different time periods). Size and age composition data include lengths from 1959-2022 and ages from 1980-2022, 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 50. All catch was 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 fishing type (CPFV or private boat) and catch type (retained or discarded). All recreational shore modes were combined with the private boat fleet due to their small contribution to overall catch. Discarded catch (CPFV and private boats combined) was modeled as separate fleet due to differences in size composition relative to retained catch, and a lack of sufficient data in an appropriate format to explicitly model retention. The commercial sector was represented by three fleets. A single "non-trawl" fleets representing primarily hook-and-line and longline gear types, but including other minor gears, included both 'live' and 'dead' conditions, as samples of live fish were too small to warrant a separate fleet. Other commercial fleets include a trawl fleet, and a fleet for discarded catch which represented discarded dead catch from both non-trawl and trawl fleets. Fleet selectivity was allowed to be domed for all commercial fleets. Sensitivity to these selectivity assumptions were explored during model development and relative to the base model.

The time-series of data used in the central California model are summarized in Figure 7. Sample sizes for age and length compositions used in the model are also summarized (Table 7, Table 5). For yearly, marginal composition data, initial sample sizes for recreational fleets were set at the number of sampled trips, or a proxy based on unique record identifiers in the data set. For the commercial fleets, the initial sample size was set to the number of cluster samples taken by port samplers (two 50-lb clusters per sample, typically). Age-at-length composition sample sizes were set at the number of aged fish in each 2-cm length data bin. 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, and variance adjustments were capped at a value of 1 for each iteration. The Francis method resulted in down-weighting of all fleet sample sizes, except for the commercial non-trawl fleet (Table 46).

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) particular 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. 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. Since most available age data is from north of Point Arena, natural mortality parameters in the central area base model are fixed at the values estimated in the northern area for both females and males (exponential offset from females). Beverton-Holt steepness is fixed at the prior mean of 0.72.

Likelihood components that were minimized in the overall fitting procedure include fleet-specific catch, length composition, and conditional age-at-length composition and also survey, recruitment deviate, parameter prior, and parameter soft-bound components.

This assessment used a recent version of Stock Synthesis 3 (version 3.30.21.00, optimized), which is available via GitHub (https://github.com/nmfs-stock-synthesis/stock-synthesis/releases). The basic population dynamic equations used in Stock Synthesis 3 can be found in Methot and Wetzel (2013). The relevant input files necessary to run the stock assessment are available on the Pacific Fisheries Management council website (https://www.pcouncil.org/stock-assessments-star-reports-stat-reports-rebuilding-analyses-terms-of-reference/groundfish-stock-assessment-documents/). The R package “r4ss” (Taylor et al. 2021) was used to visualize model output and greatly assisted with model development and evaluation.

3.5.2 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. A summary of all estimated and fixed parameter values in the central area base model, including associated properties, are listed in Table 47 and Table 48. A total of 118 parameters were estimated in the base model, including 68 recruitment deviations from 1955-2022, 20 ‘early’ recruitment deviation parameters from 1935-1954, and two forecast deviations (both equal to 0).

Natural mortality was fixed for females and for males at the values estimated in the northern model. 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 1955 – 2022 (the ‘main’ period) and 1935-1954 (the ‘early’ period). Recruitment variation about the stock recruitment curve was fixed at 0.6, a value tuned to the estimated recruitment deviation RMSE plus a slight adjustment upward to account for unmeasured process error.

Time-invariant growth parameters (Brody growth coefficient (*k*) and lengths at age 20,) were estimated using the Schnute parameterization (Schnute 1981) of the von Bertalanffy growth function for each gender, where males were estimated as an exponential offset of female parameters. The CV of length at age 20 was fixed at values estimated in the northern base model for both males and females. Estimated female size at age zero was roughly 5 cm with a CV of 0.1 in the northern model. This is consistent with the typical size of YOY black rockfish in July, i.e. size at settlement in May-June is roughly 4-5 cm (T. Laidig, NMFS, pers. comm.), and also with the 95^{th} percentile of size for pelagic juveniles observed in the SWFSC RREAS survey. Following the methods used in the northern model, we fix length at age zero at 5 cm for both sexes, and the CV(L(0)) at 0.1. 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. This choice was based on inspection of the relationship between CV(L(a)) and age, by sex, (Figure 73), and we note that the CV(L(a=0)) is roughly 0.1 near age zero and declines with age. Weight at length parameters were fixed at values externally estimated from private/rental boat observations.

Selectivity in the central area was allowed to be domed for all commercial fleets, using a double-normal functional form (see Methot and Wetzel 2013 for details). All selectivity parameters were assumed to be time-invariant in the central model. A time block was explored for the recreational fishery, similar to the northern model, but no significant changes in parameter estimates were observed and the time block was removed. Extra standard deviation parameters were estimated for the PR dockside abundance index, as the large sample sizes result in small input variances relative to other indices based on higher resolution catch and effort data, e.g. observed total catch by drift with location information in the onboard CPFV index vs. observed retained catch by trip with port of landing information in the PR index.

Parameters for fecundity at length were fixed at estimates following methods in Dick et al. (2017), and female maturity at length parameters were fixed at logistic "functional maturity" values provided by C. Rosemond and M. Head.

3.5.3 Key Assumptions and Structural Choices

Many of the key assumptions and structural choices made in the central area assessment were evaluated through sensitivity analysis (section 3.5.9). For consistency, model structural choices were made that were likely to result in the most parsimonious treatment of the available data, either a priori determined or through the evaluation of model goodness of fit. The major structural choices in this assessment were the use of two, independent population models to account for differences in exploitation history, size and age composition, and abundance trends.

Major structural assumptions included fixing the steepness stock recruitment parameter and fixing gender-specific natural mortality parameters at values estimated in the northern area model. As with the northern model, the central model assumes gender-invariant selectivity parameters. This favors the hypothesis that higher natural mortality for females explains the skewed sex ratio at older ages in the catch. An alternative hypothesis is that females become less available to the fishing gear, but continue to contribute to spawning output of the population. 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 bag limit 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 over the past 1-2 decades, and may contain information about recruitment.

3.5.4 Evaluation of Model Parameters

Model parameters were evaluated for stability and precision along likelihood profile gradients (section 3.5.9), and against the main assumptions in the base case model (section 3.5.1). Stability was examined by ensuring that model parameters were not up against a lower or upper bound and had sufficiently low gradients (Table 47, Table 48). Parameter precision was also monitored by looking at estimated standard deviations to assess the variability associated with point estimates.

3.5.5 Residual Analysis

Residuals to length composition and age composition fits to the model were explored during model development. The identification of residual patterns helped to sort out which set of a priori selectivity blocks were the most appropriate given the data. Alternative model configurations were also explored during model development in an attempt to minimize residual trends.

Fits to length composition data

Fits from the central base model to time-aggregated length compositions, by fleet, show that the recreational boat modes (PC and PR), commercial non-trawl (live landings), commercial non-trawl (unsexed dead landings), and CCFRP research lengths are best fit by the model (Figure 155). Predicted length distributions deviated more strongly from the sex-specific commercial composition data and the discard fleets, and the female component of the Abrams research data.

Pearson residuals for length composition data from commercial non-trawl fleet showed no obvious patterns and residuals were all <2. Since so few years of data are available from commercial fleet in the central area, it is difficult to draw any conclusions about trends in mean length over time (Figure 156), but the data appear to be sufficient to estimate selectivity for the commercial removals. The commercial discard fleet in the central model uses the same length composition data as the northern model's discard fleet, as too few observations were available to develop area-specific discard compositions. No clear patterns were visible in the discard residuals, but a few large residuals were present when very large (~50 cm) or very small (~10 cm) fish were observed (Figure 157).

Fits to length compositions for the recreational fleets (PC and PR) are able to capture the decline in mean length in 2010, but do not match the rate of decline in mean length observed in the 1980s PC data, which is not as apparent in the PR data (Figure 158, Figure 159). The earliest available length data for black rockfish in California (1959-60 & 1966) come from recreational boat modes in this area, and show similar mean lengths to what is observed in the recent fishery. Lengths of discarded fish are fit reasonably well, and do not show the shift to larger sizes observed in the northern area's recreational discard length data (Figure 160, compare to Figure 81).

Fits to length composition from the CCFRP survey in the central base model also show a decline in mean length around 2010, but the model predictions do not quite decrease as much as the means in the observed lengths and Pearson residuals did not show any strong patterns or contain any large values (Figure 161). The DWV onboard CPFV survey length data contained a larger proportion of fish above roughly 35 cm compared to the model predictions, but later years had few patterns and small residual values (Figure 162). Mean lengths from the DWV survey have a slightly declining trend while the model predicted lengths are flat if not slightly increasing over the same time period.

Fits to the length data from the Lea et al. research fleet are not good. These data are included in the model to inform growth, and following the recommendations of the accepted practices document, the STAT used constant selectivity for all ages and lengths in this 'fleet.' It is therefore not surprising to find residual patterns for this fleet (Figure 163).

Fits to age composition data

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. Marginal age compositions were entered into the model as observations without a likelihood component, having no effect on the model fit, but allowing for comparison of predicted marginal distributions to the data.

Age data from recreational fleets in the central model were limited to just five years, 1980-1982 for the PC fleet and 2021-2022 for the PR fleet (Figure 164, Figure 165). Predictions of mean length-at-age and mean age were consistent with the data, showing increases in mean age in both time periods.

Mean ages at lengths from the CCFRP survey were well-matched by the model (Figure 166). Mean age by year fluctuated between 4-5 years in the data, indicating that the survey is catching predominately immature fish. Mean ages in the Lea et al. research data were even younger in the first few years of available data, averaging between 3-4 years (Figure 167).

Fits to indices of abundance

Similar to other indices in the central area assessment, the recreational PR index of abundance shows an increase in 2013 that is reproduced by the model (Figure 168). Relative to the PR and CCFRP indices, this time series does not show as much of a decline in 2010, and the model's predicted abundance trend does not decline enough to match the observations in 2021 and 2022.

Fits to the CCFRP index for the central area are quite good, with the model tracking the low in 2010, but seeming to predict the high about a year earlier than the 2013 peak in the data (Figure 169). However, the more recent patterns in the index are followed fairly well, and the correlation between the observed index and model predictions is quite high.

The fit to the DWV onboard CPFV index is consistent with the direction of the data (declining), but the model cannot match the rate of decline, with positive residuals for the first five years (Figure 170). The CRFS PC onboard index shares characteristics of the previously described time series, in that it shows an increase in 2013, which is also consistent with the model trend, but it also declines faster than the model, similar to the PR index (Figure 171). The fit to this index ends with five years of negative residuals, after several years of relatively good fit.

3.5.6 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
- 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 = 0.6). 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

No parameters were hit the bounds (min or max), and the gradient of the central area base model was <0.0001. Across all jittered runs, the model found no minima lower than the base case likelihood (523.39). One run out of the 100 sets of starting values stopped at 1529, and one run stopped at 9687.

Results of the –hess_step run reported the following:

```
The 2 Hessian step(s) reduced maxgrad from 5.23125e-06 to 0 and NLL by 1.13687e-13.
All output files should be updated, but confirm as this is experimental still.
The fact this was successful gives strong evidence of convergence to a mode
with quadratic log-likelihood surface.
Iterations: 952
```

A comparison of likelihoods, parameter estimates, and derived quantities showed that results based on the –hess_step run were indistinguishable from the base.

3.5.7 Response to STAR Panel Recommendations

Request No. 1: Evaluate sensitivity of historical average weights by using a ten-year average of the earliest available MRFSS data rather than the specific estimates from publications.

Rationale: Changes in the estimate of early removals could impact the overall stock trajectory.

STAT Response: Average weights of retained fish in the historical recreational fishery were estimated using the mean weight from data collected 1980-1989 (MRFSS era) in central California. This increased the mean weights by roughly 0.2 kg in each mode relative to the pre- STAR base model (Figure 172). No change was made to the northern area estimate of 1.26 kg.

As noted in the assessment document, data from a study by Miller and Gotshall (1965) suggest that average fish weight in the late 1950s and early 1960s was roughly 0.72 kg for party/charter (PC) mode and 0.54 kg for private/rental (PR) mode (see Table 13 in the pre-STAR draft assessment document for sample sizes by mode and year). These estimates differ from those based on MRFSS data from 1980-1989 (shown in red, below), which suggest that the PC mode average weight was closer to 0.89 kg and the PR mode was near 0.71 kg. It's not clear which of these estimates is a better representation of average fish weight for the historical catch time series (Figure 173).

Average recreational weights [kg] in the pre-STAR base model:

Area	Mode	retained.avg.wgt
Central	PC	0.7193192
Central	PRplus	0.5356403
North	PC	1.2600000
North	PRplus	1.2600000

Average recreational weights based on 10-year average of most recent years in central area:

Area	Mode	retained.avg.wgt
Central	PC	0.8934083
Central	PRplus	0.7132623
North	PC	1.2600000
North	PRplus	1.260000

Time series of spawning output and relative spawning output were not strongly affected by the change to assumed average weight in the pre-1980 recreational catch (Figure 174). Since there was no change to catch in numbers, and discards were based on catch in numbers and discard average weights, there was no change to the time series of discarded catch.

Panel Conclusion: Using average recreational weights based on a 10-year average of most recent years in the central area, this slightly increases party/charter (PC) and private/rental (PR) catches in the central area, but has small impacts on the estimation of spawning output and exploitation rate. Considering the reasonably large sample sizes in Miller and Gotshall (1965), the Panel supports the use of the historical average weight for the PC and PR catch estimation for the reference model. More research may be needed to better quantify the historical catch data.

Request No. 2: Generate pairwise plots (and calculate correlation coefficients) for all the abundance indices, for years which overlap.

Rationale: The consistency of various abundance indices are evaluated graphically in the report. Pairwise comparison of all abundance indices can provide a more quantitative evaluation of consistency of abundance indices.

STAT Response: Index combinations were separated into fishery-dependent, combined fishery-dependent and -independent, and young of the year (YOY) survey categories because insufficient overlap among years prohibited all possible combinations (see Figure 7 of the stock assessment document for the temporal extent of each index). There were significant, positive correlations between CRFS_PR and CRFS_PCO, CRFS_PR and CCFRP, CRFS_PR and PISCO, and CRFS_PCO and CCFRP (Figure 175). CRFS_PCO and PISCO and CCFRP and PISCO showed weak or no correlation ($p > 0.1$). The relationship between MRFSS and Onboard_CPFV is unclear (negative but nonsignificant, $p > 0.1$). The YOY surveys (RREAS and SWFSC_YOY) showed weak or no correlation ($p > 0.1$). The PISCO survey was not included in the pre-STAR base model.

Panel Conclusion: The generally positive correlations between abundance indices suggest that there are consistent temporal patterns in the fishery-dependent and fishery-independent abundance indices for this stock. This result supports inclusion of these indices in the assessment.

Request No. 3: Estimate and plot natural mortality (M) as a function of steepness (h), given the potential interactions, for females and males.

Rationale: M and h tend to be highly correlated. An examination of LL (log likelihood) values under a varying M and h (over a reasonable range) would help us understand how they interact and how they may influence the assessment of population dynamics.

STAT Response: Profiles were initially approximated from the bivariate profile over M and h, by minimizing the NLL value with regard to M for each h. Subsequently, a profile over steepness was completed with female M estimated in each run. As expected, these produce similar results, and each demonstrates a negative relationship between h and M, so that as h increases M decreases (Figure 176, Figure 177, and Table 49).

Panel Conclusion: Natural mortality M and steepness h are negatively correlated as expected. Surprisingly the maximum likelihood estimates (MLE) of steepness and M are relatively close to the fixed values used in the reference assessment model. The bivariate profile plots may be useful to inform the determination of the states of nature.

Request No. 4: Update the ageing error data to include the errors before 2015 since only those after 2015 were applied and plot results relative to the reference base model.

Rationale: Ageing error matrices were developed for two time periods, but only the errors from after 2015 were included. This will better reflect the ageing errors in each period.

STAT Response: Correcting the ageing error matrix for the pre-2015 data had little effect on spawning output or relative spawning output, relative to the pre-STAR base model (Figure 178).

Panel Conclusion: The Panel supports the use of the corrected ageing error matrix for the pre- 2015 data in the post-STAR base model. Additional data on aging error represents an informational improvement that should be included in the assessment. The net difference in model spawning output is small. Nevertheless, the new data on aging error should be implemented into an updated base model.

Request No. 5: Provide a sensitivity analysis fitting functional maturity with a spline in addition to the logistic curve applied in the assessment.

Rationale: A spline was fit to data in the Oregon and Washington assessments and the Panel would like the STAT to provide comparable results for California.

STAT Response: Updating the functional maturity relationship from the logistic model in the pre-STAR base to the spline model increased the scale of spawning output, but did not significantly change the time series of relative spawning output (Figure 178), estimated parameters, or fits to the data. This is likely due to the fact that the functional maturity logistic model was already in the pre-STAR base model, and few fish in the central model get large enough to be affected by the descending limb of the spline model.
Panel Conclusion: The Panel supports the use of spline functional maturity in the post-STAR reference model. Panel encourages the development of functional maturity estimates for the central assessment area. As shown in the study in Oregon, interannual variation is present in the functional maturity. The panel supports additional research into functional maturity and variation with time/environmental drivers in the central California assessment area. The spline model should be used in an updated reference model so that a consistent approach is applied across all assessments.

Request No. 6: Provide the Mohn's rho values from the retrospective analysis. Provide a plot to show relative error in spawning output as suggested in the best practice guideline outlined in Legault (2009). In addition, provide relative error plots for exploitation rate, and recruitment.

Rationale: The values will be useful in assessing the retrospective pattern. There are multiple options for calculating Mohn's rho in r4ss and thus it is important to understand the mechanism being used. Retrospective error is a particular type of uncertainty and it is important to understand any bias.

STAT Response: Mohn's rho values based on a 5-year peel were -0.036 for spawning output, 0.311 for recruitment, and 0.062 for exploitation rate. This was calculated using the r4ss function "SSmohnsrho," dividing the reported cumulative value by the number of retrospective years (5).

Plots were provided for the time series of spawning output, recruitment, and exploitation rate (Figure 179) and percent change relative to the base model (Figure 180). Removal of the last 1- 5 years of data tends to lead to lower estimates of spawning output (back to ~1980, generally not exceeding 20%), higher exploitation rates, and higher recent recruitments. Differences in recent recruitment predictions occur primarily because predictions revert back to the mean of the stock- recruit curve as data are removed.

Panel Conclusion: Retrospective patterns do not appear to be an issue for spawning output and the exploitation estimates in this assessment. The retrospective pattern for recruitment is large but it is unclear if this represents a systematic bias since it may just reflect the lack of information on recruitment in the ending year of the stock assessment. Generally, the Panel had no further recommendations, but noted that this exploration should be considered in the future.

Request No. 7: Conduct a sensitivity run with dome-shaped selectivities being replaced with asymptotic selectivities (except for CCFRP that was mainly in shallow water and Lea et al. data) while having M estimated.

Rationale: It is hypothesized that the lack of large/old individuals in this stock resulted from large/old fishes moving out to the northern area. This hypothesis is supported by tagging study, although more data are probably still needed to continue testing this hypothesis. It is less likely that the lack of large/old fish resulted from poor selectivity for the large/old black rockfish. Thus, selectivities are more likely to follow logistic functions. The loss of large/old fish due to movement may be captured by having M estimated. Thus, M would be representing natural mortality and emigration.

STAT Response: All fleets were set to asymptotic except for the discard fleets and CCFRP survey (Figure 181). Female natural mortality was allowed to be estimated with a fixed male offset. Female natural mortality was estimated much higher than the prior and female Lmax increased dramatically (Figure 182). Spawning output was decreased substantially across the time series. Ending stock status is just below the minimum threshold (Figure 183). Early recruitment deviations became more positive, resulting in a shift toward more negative deviations in later years, possibly due to the sum-to-zero constraint on deviations (Figure 184).

Panel Conclusion: Changing selectivity has large impacts on the estimation of M (much higher) and other parameters (e.g., Lmax which becomes biologically unrealistic). It is not plausible to use logistical selectivity in the current assessment, but logistic selectivity may be considered in a future assessment when a spatially explicit model (e.g., 2-box model) linking the northern and central assessment areas through migration rates from CCFRP or other tagging data sources is developed for future stock assessment.

Request No. 8: Provide squid plots showing the age at which recruitment is first detected in the fishery and fishery-dependent studies, using the base model and a model including the RREAS and SCUBA young of year surveys.

Rationale: To identify how long it takes for recruitment to be detected in the data from the fisheries or non-young of year surveys. This will help inform how much potential benefit there is for early indications of recent recruitments from the inclusion of the RREAS and SCUBA survey young of year surveys in the assessment.

STAT Response: The STAT was unable to complete the request, as the number of possible combinations of YOY index configurations and run times made it impossible to fully analyze the impact of including these data sets in a base model. However, we present preliminary results for the central area, with and without inclusion of the YOY indices (RREAS and SWFSC SCUBA), estimating an additive variance parameter for the SCUBA survey.

As noted during earlier discussions with the panel, black rockfish are infrequently encountered by the RREAS survey, and the majority of encounters have occurred off central California. Since the adult population is larger in the northern part of the state, further research is needed to understand dispersal patterns, timing of parturition and settlement, and other factors that may influence spatiotemporal patterns of abundance for black rockfish pelagic juveniles.

Preliminary figures were generated using the r4ss function “SSplotRetroRecruits.” The analysis uses retrospective runs (12 runs were completed for the figures below, based on the typical forecast length for PFMC assessments), and the figures illustrate how estimates of recruitment deviations stabilize over time with the addition of new data each year. Since recent recruitments are often not well informed by composition data, the number of years it takes for deviations to stabilize can be interpreted as the lag between each model's ending year and a stable estimate of recruitment, given the data. For the central California model, the lag appears to be in the range of 4-6 years, roughly (Figure 185, Figure 186). The deviation for 2011 is unique in that it does not begin at zero (Figure 185), and the STAT needs to investigate this further.

A model that included the YOY abundance indices, as described above, appears to provide information sooner about the strength of recruitment in some years (e.g. 2014, 2015, 2016, and 2018; Figure 187 and Figure 188). However, in other years (2010 and 2011) the initial estimates are slightly negative with inclusion of the indices, but ultimately stabilize at positive values as information improves over time.

Panel Conclusion: This analysis shows that the RREAS and SCUBA young of year surveys may have potential to inform future recruitment in the projection. However, the STAT did not have time to fully explore incorporation of these data sets in the reference model, including evaluating model diagnostics to ensure the appropriate use of the information. These data should be considered in future stock assessments.

Request No. 9: Incorporate the ageing error prior to 2015 and spline fit to the functional maturity to provide a revised base model.

Rationale: To implement the conclusions of Request No. 4 (the ageing error prior to 2015) and Request No. 5 (functional maturity fit with a flexible spline), which improved the base model.

STAT Response: The corrected ageing error matrix and spline model for functional maturity were included in the model, and Francis weights updated (little change in weights). As noted in the request to revise the maturity relationship, spawning output was slightly scaled upwards, but relative spawning output remained very similar over time (Figure 189 and Figure 190).

Model likelihoods, parameter estimates, and derived quantities are similar between the pre- STAR base and the updated model in Request No. 9 (Table 51). Further details of the updated model were presented using the r4ss html output.

Panel Conclusion: The Panel supports the use of the corrected ageing error matrix and spline model for functional maturity in the post-STAR base model with the Francis weights being updated.

Request No. 10: For the bivariate steepness and natural mortality plot (see Request No. 3), provide the 75% confidence region for both the northern and central California models.

Rationale: To provide a potential basis for selecting a combination of steepness and natural mortality for a decision table.

STAT Response: The STAT completed the request, which shows that the base model with fixed M and h is close to the minimum and falls within the 75% chi-squared interval (Figure 191). A figure with 95% chi-square intervals was also produced for comparison (Figure 192)

Panel Conclusion: The Panel requested that the bivariate steepness and natural mortality plot be modified to provide the 75% confidence region for both the northern and central models, which may provide a basis for selecting a combination of steepness and natural mortality for a decision table. However, the contrast in the M and h values within the 75% confidence region was not sufficiently broad to provide a suitable set of alternatives. Instead, the Panel suggests to use the uncertainty in the prior for natural mortality only to obtain possible upper and lower states of nature (see Request No. 11).

Request No. 11: Use the uncertainty in the prior for natural mortality to obtain possible upper and lower states of nature. Center this uncertainty on the point estimate of the base model and use the M at the 12.5 and 87.5 percentile of the distribution for lower and upper states of nature.

Rationale: To provide a potential basis for selecting natural mortality values for a decision table.

STAT Response: The central area model has female natural mortality fixed at the value estimated in the northern area model (0.2103 yr-1) and also fixes the offset for male natural mortality at the estimate of the northern area model (male M=0.1998 yr-1). The log-scale standard deviation of the prior for M is 0.31. The point estimates of M for the high and low states of nature were calculated as $\exp\{\log_e(0.2103) +/- 0.31*1.15\}$, where 1.15 is the z-score corresponding to a two-tailed 75% interval in log space (i.e. plus or minus 1.15 standard deviations from the point estimate). The resulting values of M in arithmetic space for the high and low states of nature are 0.300 and 0.147, respectively.

Estimated time series of spawning output are scaled upward under the assumption that M = 0.147 (the 'low' state of nature), and downward with M = 0.300 (the 'high' state of nature). Estimated unfished spawning output varies more than recent estimates (Figure 193), and on a relative scale the low state is well within the base model's range of uncertainty while the high state is at the upper edge of that range in recent years (Figure 194). The pattern of scaling relative to the base model holds for the early recruitment deviations, while more recent estimates are less affected (Figure 195). Parameter estimates and derived quantities associated with each state of nature are provided as Table 51.

Panel Conclusion: The states of nature identified by this approach (M = 0.147, 0.300) provide a sufficient contrast to capture the uncertainty in the assessment.

3.5.8 Central California Base-Model Results

The central California base model produced reasonable values for the subset of growth parameters that were estimated (k and length at age 20 for females and males; Table 47, Figure 196). Male growth was faster than females and females grew larger, consistent with the northern model. Length at age 20 was estimated to be 54.7 cm for females (versus 54.5 cm in the north) and 49.4 for males (versus 47.0 cm in the north.

Fits to abundance indices in the central model are, on the whole, significantly better than fits to indices in the northern model. The three indices that span the period 2010-2015, namely rec PR, CCFRP, and PC onboard, all show a similar pattern of a spike in 2013 abundance (Figure 168, Figure 169, Figure 171). This increase is also observed in the catch, however two of the indices are not independent from the catch estimates (PC and PR, as catch rates from the boat mode surveys are used to estimate catch). However, the CCFRP index is a fishery-independent validation of the pattern in 2013, and, the PISCO SCUBA survey observed a similar peak in black rockfish abundance in 2013 (see "UCSC index" in section 0). The synchrony among recreational dockside and onboard surveys and two fishery-independent surveys is noteworthy in the central area, particularly because it is not apparent in any of the northern area indices.

Another shared pattern among central area data sources is a decline in mean length in 2010. This is likely the reason for the model's estimated large recruitment in 2008 (Figure 197). The 'dip' in mean length is present in the length compositions for the recreational PC, PR, and discard fleets, and the CCFRP survey (Figure 157, Figure 158, Figure 159, Figure 160, Figure 161) but not in the two largest fleets in the northern area (Figure 79, Figure 80). This recruitment could also be the source of the increased central area abundances observed in 2013, as the cohort becomes increasingly available to the fishery.

Prior to 2000, the onboard CPFV observer index (the "DWV" index) shows a declining trend that the model fits reasonably well, (Figure 170). In recent years, there is a negative residual pattern shared by the PC and PR indices, i.e. both indices show declines in recent abundance that the model does not fit (Figure 168, Figure 171). The CCFRP index does not show this decline, and in fact has positive residuals in the past three year (Figure 169).

Estimates of year-class strength in the central model are largest, in absolute terms, in 2008, 2010, and 1976 (Figure 198). The data likely informing the 2008 year class have already been discussed, and it along with 2010 were also the two highest years of black rockfish and yellowtail rockfish YOY abundances observed during SCUBA surveys around Monterey bay (T. Laidig, pers. comm.). Black and yellowtail rockfishes are difficult to distinguish from each other using visual SCUBA surveys.

All selectivity curves in the central area model were double-normal and dome-shaped (Figure 199). The one exception was the Lea et al. research 'fleet' that assumed flat selectivity across lengths and ages, as per the accepted practices guide for data included only for purposes of estimating growth. Preliminary investigations of time blocks for recreational fleets showed little response to depth restrictions in this area, as opposed to the northern area data that were better fit by asymptotic shapes prior to 2004 and domed shapes in later years.

Black rockfish spawning output in central California was estimated to be 145 billion eggs at the start of 2023 (~95% asymptotic intervals: 36-253 billion eggs; Table 52), which equates to a "depletion" level of 42% (~95% asymptotic intervals: 14%-70%; Table 52, Figure 200, Figure 201) in 2023. Depletion is a ratio of the estimated spawning output in a particular year relative to estimated unfished, equilibrium spawning output. Spawning output in California (south of Point Arena) declined slowly prior to WWII, reaching about 70% of unfished biomass by the early 1920s (Table 53). Spawning output remained relatively stable until the 1960s, after which increases in recreational catch and a period of below-average recruitment in the 1980s and 1990s led to declines in spawning output through the early 2000s (Figure 202, Figure 11, Figure 200). Recent large recruitments were estimated to occur in 2008 and 2010, with average to below-average recruitment estimated over the past few years, but recent recruitments are typically not well estimated (Figure 203). Relative exploitation rates [(1-SPR) / (1-SPR50%)] increased to a stable period of low exploitation prior to WWII, then climbed after 1950 and remained high until the 2000s (Figure 204). The equilibrium yield curve for the central area is shifted left, as expected from the assumed Beverton-Holt steepness value (h=0.72) (Figure 205).

3.5.9 Evaluation of Uncertainty

3.5.9.1 Sensitivity to Assumptions, Data, and Weighting

We evaluated sensitivity of the central California model to specific data sources using 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), after which parameter estimates and derived quantities were compared to the base model. Other sensitivity tests included:

- Comparison of model outputs using alternative weighting methods (Francis and McAllister-Ianelli); weights were capped at 1 for both methods (i.e. no up weighting of data)

- Assuming natural mortality was the same for both sexes
- Forcing commercial fleets to have asymptotic selectivity
- Estimation of all growth parameters
- Estimation of natural mortality (male and female); steepness fixed at 0.72

The central base model was stable with respect to population scale across most “drop-one” scenarios, with the exception of removing data associated with the CCFRP survey, and to a lesser extent, the DWV onboard survey (Figure 206, Figure 207, Figure 208, Figure 209). The change associated with removing the CCFRP index can be explained by improved fits to the PR and PC onboard indices, which previously had larger negative residuals in recent years (Figure 210, Figure 211). The improvement in fit is also illustrated by a smaller “extraSD” parameter value for the PR index when CCFRP is removed (Table 54, Table 55).

Changes associated with other sensitivity analyses only slight deviations in M when it was estimated as the same for both sexes or sex-specific (Table 56). Forcing commercial selectivity to be asymptotic had little effect on the result, but note that M was fixed as in the base model for this run. Estimation of all growth parameters had little effect on the outcome (Figure 212), but estimated length at age 0 for females hit the lower bound and CVs of length at age 20 seemed small (0.05 for females and 0.03 for males), so the values estimated from the northern model were fixed in the central model. The use of McAllister-Ianelli weights had the largest effect among this set of sensitivities on ending relative stock size, but even that was well within the uncertainty estimated by the base model (Figure 213, Figure 214, Figure 215).

3.5.9.2 Parameter Uncertainty

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.

Most data types in the model are best fit by higher steepness values with the exception of the index data (Figure 216). Among individual length data sources, only the PR data have enough contrast in the likelihood across steepness values to provide information, and that only excludes very small values (Figure 217). Age compositions also favored high steepness values in the central model (Figure 218), while the improved fit of indices for small steepness values was limited to the PR and PC length comps (Figure 219). Profiling over steepness primarily affected the scale of spawning output, with little change in relative spawning output other than to ‘smooth out’ the trends when steepness was small (Figure 220, Figure 221). Recruitment deviations varied little across all values of steepness in the profile (Figure 125). Steepness was negatively correlated with estimates of unfished recruitment (Table 57, Table 58).

Profiling over R0 (Table 59, Table 60) in the central model is less informative than other profiles because steepness and natural mortality are already fixed. For any fixed value of R0, the only parameters left to adjust are those related to recruitment deviations, growth, selectivity, and nuisance parameters (e.g. additive variances). A profile across log(R0) values from 5.8 to 7.2 in increments of 0.2 shows that as unfished recruitment declines, recruitment deviations must compensate by growing large relative to the assumed log-scale variance of 0.6, resulting in large negative log-likelihood values (Figure 223, Figure 224, Figure 225, Figure 226, Figure 227, Figure 228).

The profile over female natural mortality (M) was conducted across a range of values slightly wider than the 2.5% and 97.5% percentiles of the lognormal prior on female M (0.08 – 0.30 yr-1) while estimating male natural mortality as an exponential offset to female natural mortality (Table 61, Table 62). Age, length, and index data sources, overall, were fit poorly by low values of female natural mortality in the central model (Figure 229). Length composition data sources were mainly consistent in this respect, with the exception of the Lea et al. data, which was better fit by lower female M values (Figure 230). Age data from the recreational PC fleet seemed most influential, and were best fit by M values between 0.15 and 0.27, based on this univariate likelihood profile (Figure 231). Index likelihoods were either multi-modal, favoring the extremes of the profile over M, or minimized at high parameter values (Figure 232), with CCFRP and the PC onboard index minima around 0.17 and the PR index minimum at the upper limit of the profile (M = 0.3).

3.5.9.3 Retrospective Analysis

A retrospective analysis was conducted by sequentially removing 1 through 5 years of data from the central base model starting with 2022. Sequential removal of the data did not produce strong retrospective patterns (Figure 233, Figure 234). Mohn's rho values based on a 5-year peel were -0.036 for spawning output, 0.311 for recruitment, and 0.062 for exploitation rate. This was calculated using the r4ss function "SSmohnsrho," dividing the reported cumulative value by the number of retrospective years (5). See STAR panel request 6 for additional details.

3.6 Historical Analysis

Comparisons of spawning output and relative spawning output from the 2015 assessment and the combined spawning output from the northern and central area models are shown in Figure 235 and Figure 236. Spawning output in the 2023 model is scaled higher than the 2015 assessment, but relative spawning output (combined, as described below) is very similar, particularly towards the end of the time series for the 2015 model.

4 Reference Points

Reference points for the area-specific models are discussed in the results section for each model. The STAT combined a subset of the model outputs to estimate statewide spawning output and other quantities of interest to management. (Table 63, Figure 237, Figure 238). The combined status of the stock in California is estimated to be at 37.7% of unfished biomass, when calculated this way.

5 Harvest Projections and Decision Tables

Alternative states of nature identified during the STAR panel were used to forecast population dynamics for the California stock assuming low, medium, and high catch projections (Table 64). Catch projections for 2023-2024 and fleet allocations for 2025-2034 were provided for each area and fleet by state representatives on the GMT. Harvest control rules were applied iteratively, at the state level, based on output from both models. An allocation of the ACL based on the proportion of the OFL from each area was requested by the GMT, and is provided as Table 65.

For the northern area model, the reported 'sigma' (log-space uncertainty around the OFL value for the first forecast year, i.e. 2023) is 0.274. For the central California model, the reported 'sigma' is 0.254.

6 Regional Management Considerations

Given the differences in exploitation history, average size, and abundance trends, it seems reasonable to use the area specific models as a guideline for harvest allocation, whether formal or informal. In order to fully understand the implications of regional management decisions for this stock, further research is needed with respect to movement patterns, differences in life history, and genetic differentiation within U.S. waters off California.

7 Research and Data Needs

There is conflicting evidence or limited information with which to evaluate black rockfish stock structure, especially off California. Future research on larval dispersal, life history traits, adult movement, and genetics south of the California-Oregon border would improve inputs for stock assessments and provide support for the spatiotemporal scale that is most appropriate for modeling black rockfish. Specifically, information about growth, maturity, and mortality north and south of Point Arena would further justify the separation of black rockfish at this location. Further genetic evaluation regarding the extent to which Point Arena may serve as a barrier to gene flow would also be valuable for this stock. Much of what we know about black rockfish life history in California also comes from research that was conducted in the 1980s (e.g., Echeverria 1987). Updating these estimates would be a worthwhile area of future study, given observed changes for other species over similar time scales (e.g., blue rockfish; Schmidt 2014). California-specific estimates of larval dispersal and movement rates at various life stages would further our understanding about connectivity among the three West Coast stocks of black rockfish. Although most black rockfish show moderate to high site fidelity and some degree of homing, a notable proportion of fish appear to cross stock boundaries. Additional research on the directions and distances that black rockfish move in northern California and southern Oregon would help elucidate the degree of intergenerational exchange across this particular stock boundary. Finally, much of what we know about the habitat associations and ecological role of black rockfish come from Oregon, Washington, and Alaska. Research that is specific to central and northern California is needed to fully understand variation in black rockfish life history, population structure, and trophic positioning.

Exploration of multiple-area models for the stock is recommended when sufficient data are available to parameterize movement within the model. Directional movement between areas (south to north, as observed in the CCFRP movement data) may partially explain sustained differences in size and age composition throughout the state.

Attempts to investigate recruitment indices (RREAS, SWFSC SCUBA) for the fleets-as-areas model configuration were not successful, and there was not enough time to evaluate area-specific indices prior to the STAR panel document deadline (although they have been developed). Future assessments may benefit from an analysis of these recruitment indices representing sub-areas defined in this assessment.

Further research is also needed to explain skewed sex ratios among older individuals in the population. This assessment assumes that size-dependent selectivity is equal for both sexes, and does not consider alternative hypotheses such as sex- or age-specific selectivity or age-dependent natural mortality, both of which could also explain, in whole or in part, the reduced fraction of older females in the data.

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10 Auxiliary Files

Files archived with the California assessment, northern area model

black_rockfish_Northern_CA_2023_control.ss
black_rockfish_Northern_CA_2023_data.ss
forecast.ss
Report.sso
starter.ss
[r4ss html output and associated figures in 'plots' folder]

Files archived with the California assessment, central area model

black_rockfish_Central_CA_2023_control.ss
black_rockfish_Central_CA_2023_data.ss
forecast.ss
Report.sso
starter.ss
[r4ss html output and associated figures in 'plots' folder]

11 Tables

Table 1: Evaluation of Management Performance for Black Rockfish. Total Mortality estimates are based on the Groundfish Expanded Mortality Multiyear (GEMM) report. Catch values prior to 2017 are not reported here because black rockfish catch limits were defined across state lines and are not comparable to the California-only estimates used in this assessment. The GEMM report estimate for 2022 was not yet released when this assessment was prepared.

Year	Assessed Area	Overfishing Limit	Acceptable Biological Catch	Annual Catch Limit	Total Mortality
2013	OR - CA	1159	1108	1000	--
2014	OR - CA	1166	1115	1000	--
2015	OR - CA	1176	1124	1000	--
2016	OR - CA	1183	1131	1000	--
2017	CA	349	334	334	171
2018	CA	347	332	332	142
2019	CA	344	329	329	159
2020	CA	341	326	326	117
2021	CA	379	348	348	236
2022	CA	373	341	341	--

Table 2: Commercial catches for the northern area by fleet and year

Year	Comm. Non-Trawl Dead	Comm. Non-Trawl Alive	Comm. Trawl	Comm. Discard	Grand Total
1875	0.048			0.001	0.049
1876	0.095			0.002	0.097
1877	0.143			0.003	0.146
1878	0.19			0.004	0.194
1879	0.238			0.005	0.243
1880	0.285			0.005	0.29
1881	0.333			0.006	0.339
1882	0.38			0.007	0.387
1883	0.428			0.008	0.436
1884	0.476			0.009	0.485
1885	0.523			0.01	0.533
1886	0.571			0.011	0.582
1887	0.618			0.012	0.63
1888	0.666			0.013	0.679
1889	0.713			0.014	0.727
1890	0.761			0.014	0.775
1891	0.808			0.015	0.823
1892	0.856			0.016	0.872
1893	0.903			0.017	0.92
1894	0.951			0.018	0.969
1895	0.999			0.019	1.018
1896	1.046			0.02	1.066
1897	1.094			0.021	1.115
1898	1.141			0.022	1.163
1899	1.189			0.023	1.212
1900	1.236			0.023	1.259
1901	1.284			0.024	1.308
1902	1.331			0.025	1.356
1903	1.379			0.026	1.405
1904	1.427			0.027	1.454
1905	1.474			0.028	1.502
1906	1.522			0.029	1.551
1907	1.569			0.03	1.599
1908	1.617			0.031	1.648
1909	1.664			0.032	1.696
1910	1.712			0.033	1.745
1911	1.759			0.033	1.792
1912	1.807			0.034	1.841
1913	1.855			0.035	1.89
1914	1.902			0.036	1.938
1915	1.95			0.037	1.987
1916	1.997			0.038	2.035
1917	3.93			0.075	4.005
1918	9.175			0.174	9.349
1919	2.109			0.04	2.149
1920	2.864			0.054	2.918
1921	4.295			0.082	4.377
1922	3.201			0.061	3.262
1923	1.049			0.02	1.069
1924	2.869			0.055	2.924
1925	9.301			0.177	9.478
1926	9.175			0.174	9.349

Year	Comm. Non-Trawl Dead	Comm. Non-Trawl Alive	Comm. Trawl	Comm. Discard	Grand Total
1927	17.412			0.331	17.743
1928	15.02			0.285	15.305
1929	14.602		3.521	0.344	18.467
1930	22.486		2.356	0.472	25.314
1931	31.527		6.803	0.728	39.058
1932	22.212		4.96	0.516	27.688
1933	16.663		8.943	0.487	26.093
1934	17.805		6.294	0.458	24.557
1935	28.87		6.207	0.666	35.743
1936	27.794		2.913	0.583	31.29
1937	20.745		7.579	0.538	28.862
1938	31.869		7.951	0.757	40.577
1939	32.346		15.874	0.916	49.136
1940	21.864		8.512	0.577	30.953
1941	24.704		7.888	0.619	33.211
1942	30.793		10.403	0.783	41.979
1943	37.166		12.599	0.946	50.711
1944	115.374		64.704	3.421	183.499
1945	273.435		120.257	7.48	401.172
1946	322.788		264.276	11.154	598.218
1947	156.059		397.61	10.52	564.189
1948	133.002		58.596	3.64	195.238
1949	52.071		66.462	2.252	120.785
1950	51.813		349.186	7.619	408.618
1951	51.743		185.75	4.512	242.005
1952	30.243		41.844	1.37	73.457
1953	26.527		135.62	3.081	165.228
1954	65.129		235.749	5.717	306.595
1955	2.659		160.781	3.105	166.545
1956	12		37.92	0.948	50.868
1957	19.079		76.4	1.814	97.293
1958	14.61		57.314	1.367	73.291
1959	6.385		37.058	0.825	44.268
1960	3.52		66.612	1.333	71.465
1961	4.489		64.556	1.312	70.357
1962	5.139		58.532	1.21	64.881
1963	11.592		75.825	1.661	89.078
1964	7.369		45.179	0.998	53.546
1965	12.29		24.653	0.702	37.645
1966	9.574		17.482	0.514	27.57
1967	9.406		15.906	0.481	25.793
1968	10.276		17.592	0.529	28.397
1969	27.997		11.43	0.749	40.176
1970	5.734		15.823	0.41	21.967
1971	3.943		23.934	0.53	28.407
1972	7.136		39.132	0.879	47.147
1973	8.229		46.702	1.044	55.975
1974	16.213		82.702	1.879	100.794
1975	12.783		41.154	1.025	54.962
1976	35.764		52.405	1.675	89.844
1977	16.986		52.417	1.319	70.722
1978	6.486		105.387	2.126	113.999
1979	2.868		0.088	0.056	3.012
1980	2.785		48.955	0.983	52.723

Year	Comm. Non-Trawl Dead	Comm. Non-Trawl Alive	Comm. Trawl	Comm. Discard	Grand Total
1981	19.076		50.385	1.32	70.781
1982	85.998		62.455	2.821	151.274
1983	143.038		99.039	4.599	246.676
1984	162.233		35.016	3.748	200.997
1985	124.145		80.961	3.897	209.003
1986	9.258		0.745	0.19	10.193
1987	14.435		65.604	1.521	81.56
1988	25.385		48.972	1.413	75.77
1989	103.236		25.372	2.444	131.052
1990	132.417		0.149	2.519	135.085
1991	117.68		21.117	2.637	141.434
1992	195.355		49.684	4.656	249.695
1993	115.363		2.082	2.231	119.676
1994	115.09	0.684	0.272	2.205	118.251
1995	160.017	0.054	2.063	3.081	165.215
1996	77.588	0.624	10.369	1.683	90.264
1997	95.325	2.129	11.63	2.073	111.157
1998	58.315	1.799	5.216	1.241	66.571
1999	48.563	3.753	0.231	0.998	53.545
2000	28.726	12.893	0.318	0.797	42.734
2001	64.161	27.702	0.981	1.764	94.608
2002	41.698	48.462	0.571	1.724	92.455
2003	16.456	39.096	0.093	1.057	56.702
2004	17.771	46.046	1.126	1.234	66.177
2005	17.91	53.322	0.005	1.354	72.591
2006	13.244	46.517		1.135	60.896
2007	23.528	58.018		1.549	83.095
2008	9.371	73.311		1.571	84.253
2009	24.115	65.425	0.056	1.702	91.298
2010	10.617	39.773		0.957	51.347
2011	7.612	16.814		0.464	24.89
2012	7.766	11.095		0.358	19.219
2013	10.582	19.563	0.003	0.573	30.721
2014	14.972	21.823		0.699	37.494
2015	35.405	62.838	0.025	1.867	100.135
2016	29.425	31.909	0.274	1.171	62.779
2017	20.423	33.99		1.034	55.447
2018	17.555	26.616	0.012	0.839	45.022
2019	19.274	29.12	0.015	0.92	49.329
2020	19.958	20.282	0.216	0.769	41.225
2021	20.482	16.879		0.71	38.071
2022	25.017	29.915	0.052	1.045	56.029
Grand Total	4356.87	840.45	3883.91	172.54	9253.768

Table 3: Commercial catches for the central area by fleet and year

Year	Comm. Non-Trawl	Comm. Trawl	Comm. Discard	Grand Total
1875	1.004		0.019	1.023
1876	2.007		0.038	2.045
1877	3.011		0.057	3.068
1878	4.015		0.076	4.091
1879	5.018		0.095	5.113
1880	6.022		0.114	6.136
1881	7.026		0.133	7.159
1882	8.029		0.153	8.182
1883	9.033		0.172	9.205
1884	10.037		0.191	10.228
1885	11.041		0.21	11.251
1886	12.044		0.229	12.273
1887	13.048		0.248	13.296
1888	14.052		0.267	14.319
1889	15.055		0.286	15.341
1890	16.059		0.305	16.364
1891	17.063		0.324	17.387
1892	18.066		0.343	18.409
1893	19.07		0.362	19.432
1894	20.074		0.381	20.455
1895	21.077		0.4	21.477
1896	22.081		0.42	22.501
1897	23.085		0.439	23.524
1898	24.088		0.458	24.546
1899	25.092		0.477	25.569
1900	26.096		0.496	26.592
1901	27.099		0.515	27.614
1902	28.103		0.534	28.637
1903	29.107		0.553	29.66
1904	30.11		0.572	30.682
1905	31.114		0.591	31.705
1906	32.118		0.61	32.728
1907	33.122		0.629	33.751
1908	34.125		0.648	34.773
1909	35.129		0.667	35.796
1910	36.133		0.687	36.82
1911	37.136		0.706	37.842
1912	38.14		0.725	38.865
1913	39.144		0.744	39.888
1914	40.147		0.763	40.91
1915	41.151		0.782	41.933
1916	42.155		0.801	42.956
1917	65.51		1.245	66.755
1918	76.465		1.453	77.918
1919	53.131		1.009	54.14
1920	54.204		1.03	55.234
1921	44.771		0.851	45.622
1922	38.55		0.732	39.282
1923	41.756		0.793	42.549
1924	24.431		0.464	24.895
1925	30.446		0.578	31.024
1926	48.973		0.93	49.903

Year	Comm. Non-Trawl	Comm. Trawl	Comm. Discard	Grand Total
1927	41.583		0.79	42.373
1928	50.041		0.951	50.992
1929	41.501		0.789	42.29
1930	57.942	0.669	1.114	59.725
1931	51.048		0.97	52.018
1932	37.877		0.72	38.597
1933	24.875		0.473	25.348
1934	24.947		0.474	25.421
1935	38.539		0.732	39.271
1936	37.596		0.714	38.31
1937	44.687	0.136	0.852	45.675
1938	30.426	0.102	0.58	31.108
1939	14.402		0.274	14.676
1940	24.303		0.462	24.765
1941	31.498		0.598	32.096
1942	8.24	0.176	0.16	8.576
1943	19.187	1.063	0.385	20.635
1944	4.164	0.382	0.086	4.632
1945	8.831	0.899	0.185	9.915
1946	10.395	0.869	0.214	11.478
1947	14.942	1.547	0.313	16.802
1948	13.211	0.854	0.267	14.332
1949	19.66	2.337	0.418	22.415
1950	16.002	3.524	0.371	19.897
1951	23.655	8.075	0.603	32.333
1952	20.357	31.303	0.982	52.642
1953	14.538	22.899	0.711	38.148
1954	20.547	8.896	0.559	30.002
1955	24.899	13.378	0.727	39.004
1956	19.502	1.779	0.404	21.685
1957	22.164	0.674	0.434	23.272
1958	55.981	1.046	1.084	58.111
1959	75.761	1.217	1.463	78.441
1960	27.01	0.183	0.517	27.71
1961	22.929	1.227	0.459	24.615
1962	30.918	3.399	0.652	34.969
1963	20.204	4.169	0.463	24.836
1964	13.516	3.005	0.314	16.835
1965	17.22	3.489	0.393	21.102
1966	12.711	0.903	0.259	13.873
1967	31.509	0.283	0.604	32.396
1968	37.416	0.085	0.713	38.214
1969	32.239	0.037	0.613	32.889
1970	32.294	3.557	0.681	36.532
1971	29.329	0.002	0.557	29.888
1972	73.64	3.282	1.462	78.384
1973	16.488	3.875	0.387	20.75
1974	49.324	0.137	0.94	50.401
1975	33.261	0.213	0.636	34.11
1976	20.9	0.217	0.401	21.518
1977	38.338	0.103	0.73	39.171
1978	22.789	0.081	0.435	23.305
1979	41.594	21.849	1.205	64.648
1980	2.893	10.738	0.259	13.89
1981	5.325	2.115	0.141	7.581

Year	Comm. Non-Trawl	Comm. Trawl	Comm. Discard	Grand Total
1982	6.968	0.145	0.135	7.248
1983	3.962	0.428	0.083	4.473
1984	6.267	0.882	0.136	7.285
1985	21.755		0.413	22.168
1986	13.793		0.262	14.055
1987	6.527		0.124	6.651
1988	6.362		0.121	6.483
1989	3.77		0.072	3.842
1990	1.983	0.181	0.041	2.205
1991	7.792		0.148	7.94
1992	16.711	0.003	0.318	17.032
1993	23.942	0.909	0.472	25.323
1994	19.776	0.045	0.377	20.198
1995	6.891	0.211	0.135	7.237
1996	29.269	0.002	0.556	29.827
1997	16.671	0.039	0.317	17.027
1998	21.427	0.16	0.41	21.997
1999	6.161	0.347	0.124	6.632
2000	3.576	0.983	0.087	4.646
2001	6.667	0.239	0.131	7.037
2002	2.26	1.463	0.071	3.794
2003	1.662	0.416	0.039	2.117
2004	3.149	0.018	0.06	3.227
2005	2.512		0.048	2.56
2006	1.864		0.035	1.899
2007	2.064	0.034	0.04	2.138
2008	1.15		0.022	1.172
2009	1.597		0.03	1.627
2010	0.9		0.017	0.917
2011	2.004		0.038	2.042
2012	2.755	0.001	0.052	2.808
2013	4.975		0.095	5.07
2014	3.803	0.002	0.072	3.877
2015	4.395		0.084	4.479
2016	1.919	0.01	0.037	1.966
2017	0.983	0.002	0.019	1.004
2018	1.082		0.021	1.103
2019	0.638		0.012	0.65
2020	1.185		0.023	1.208
2021	1.311		0.025	1.336
2022	1.198		0.023	1.221
Grand Total	3213.387	171.294	64.31	3448.991

Table 4: Length composition sample sizes available for the northern model.

	Commercial Non-Trawl Dead		Commercial Non-Trawl Live		Commercial Trawl		WCGOP Discard		Rec CPFV MRFSS/CRFS		Rec Private MRFSS/CRFS		Rec CPFV Obs. Discard		CCFRP Research		Abrams Research	
Year	Samp	Lengths	Samp	Lengths	Samp	Lengths	Hauls	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Drifts	Lengths	Drifts	Lengths
1978	-	-	-	-	2	36	-	-	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1980	-	-	-	-	8	93	-	-	2	2	131	462	-	-	-	-	-	-
1981	-	-	-	-	8	103	-	-	8	33	141	549	-	-	-	-	-	-
1982	3	75	-	-	13	252	-	-	16	55	165	610	-	-	-	-	-	-
1983	3	71	-	-	11	195	-	-	1	1	102	408	-	-	-	-	-	-
1984	2	57	-	-	6	156	-	-	12	40	143	540	-	-	-	-	-	-
1985	1	31	-	-	6	151	-	-	6	38	205	836	-	-	-	-	-	-
1986	-	-	-	-	1	22	-	-	1	3	204	887	-	-	-	-	-	-
1987	-	-	-	-	7	178	-	-	1	10	50	140	-	-	-	-	-	-
1988	-	-	-	-	3	63	-	-	4	49	48	126	-	-	-	-	-	-
1989	-	-	-	-	3	65	-	-	-	-	62	480	-	-	-	-	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	1	32	-	-	-	-	-	-	-	-	-	-	-	-
1992	24	700	-	-	2	64	-	-	-	-	-	-	-	-	-	-	-	-
1993	68	2119	-	-	-	-	-	-	-	-	219	700	-	-	-	-	-	-
1994	67	2494	-	-	-	-	-	-	-	-	188	808	-	-	-	-	-	-
1995	56	2096	-	-	-	-	-	-	35	162	104	372	-	-	-	-	-	-
1996	52	1851	-	-	1	25	-	-	59	379	159	815	-	-	-	-	-	-
1997	31	903	-	-	3	82	-	-	-	-	29	173	-	-	-	-	-	-
1998	8	256	-	-	-	-	-	-	7	535	148	594	-	-	-	-	-	-
1999	57	2166	3	120	1	25	-	-	15	36	232	830	-	-	-	-	-	-
2000	19	480	5	67	1	25	-	-	-	-	182	517	-	-	-	-	-	-
2001	21	634	10	230	4	47	-	-	10	52	52	175	-	-	-	-	-	-
2002	10	253	12	295	-	-	-	-	1	1	39	224	-	-	-	-	-	-
2003	1	48	3	70	1	19	-	-	45	210	153	637	-	-	-	-	-	-
2004	2	50	5	177	-	-	47	185	22	97	178	518	-	-	-	-	-	-
2005	4	88	5	123	-	-	38	197	22	179	240	2381	-	-	-	-	-	-
2006	1	41	24	583	-	-	35	171	28	270	226	1705	-	-	-	-	-	-
2007	3	87	18	422	-	-	31	94	63	834	233	3308	-	-	-	-	-	-
2008	2	54	10	207	-	-	26	85	86	1225	248	4195	8	25	-	-	-	-
2009	14	312	11	245	1	33	31	181	125	2243	284	5844	9	65	-	-	-	-
2010	2	36	4	107	-	-	26	105	96	1428	178	2580	10	60	-	-	145	1134
2011	9	274	2	36	-	-	60	185	49	597	244	2244	3	20	-	-	142	1218
2012	21	626	-	-	-	-	49	177	80	1486	291	1980	10	29	-	-	-	-
2013	15	495	1	12	-	-	42	157	119	1836	356	3436	8	17	-	-	-	-
2014	27	1157	2	20	-	-	39	195	129	2009	308	2869	10	60	-	-	-	-
2015	41	1665	-	-	1	12	89	351	113	1239	398	4989	6	21	-	-	-	-
2016	21	808	-	-	1	27	37	113	72	484	336	4333	11	111	-	-	-	-
2017	12	462	-	-	-	-	29	92	66	390	380	4126	3	101	44	203	-	-
2018	14	545	1	12	-	-	36	119	76	474	429	3658	7	262	52	174	-	-
2019	3	75	2	103	-	-	18	44	43	197	342	2741	-	-	47	167	-	-
2020	18	489	-	-	-	-	18	53	-	-	3	12	-	-	57	282	-	-
2021	21	592	-	-	-	-	17	44	36	307	214	1744	2	5	74	399	-	-
2022	10	293	-	-	1	24	-	-	50	792	322	2111	8	154	68	340	-	-

Table 5: Length composition sample sizes available for the central model.

	Commercial Non-Trawl*		WCGOP Discard**		Rec CPFV MRFSS/CRFS^		Rec Private MRFSS/CRFS^		Rec CPFV Obs. Discard		CCFRP Research		CPFV Onboard CDFW (DWV)		CDFW (Lea) Research	
Year	Samp	Lengths	Hauls	Lengths	Trips	Lengths	Trips	Lengths	Trips	Lengths	Drifts	Lengths	Trips	Lengths	Trips	Lengths
1959	-	-	-	-	4	86	24	860	-	-	-	-	-	-	-	-
1960	-	-	-	-	19	366	13	201	-	-	-	-	-	-	-	-
1961	-	-	-	-	2	27	-	-	-	-	-	-	-	-	-	-
1966	-	-	-	-	5	111	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67
1980	-	-	-	-	23	92	64	166	-	-	-	-	-	-	-	42
1981	-	-	-	-	15	24	25	64	-	-	-	-	-	-	-	30
1982	-	-	-	-	3	7	18	32	-	-	-	-	-	-	-	39
1983	-	-	-	-	12	27	6	25	-	-	-	-	-	-	-	-
1984	-	-	-	-	34	119	78	256	-	-	-	-	-	-	-	-
1985	-	-	-	-	100	365	112	388	-	-	-	-	-	-	-	-
1986	-	-	-	-	40	86	58	142	-	-	-	-	-	-	-	-
1987	-	-	-	-	37	151	63	240	-	-	-	-	-	-	-	-
1988	2	62	-	-	21	56	50	196	-	-	-	-	21	888	-	-
1989	-	-	-	-	24	148	33	352	-	-	-	-	22	948	-	-
1990	-	-	-	-	-	-	-	-	-	-	-	-	7	261	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-	17	521	-	-
1992	6	150	-	-	-	-	-	-	-	-	-	-	24	384	-	-
1993	7	100	-	-	10	21	176	570	-	-	-	-	32	698	-	-
1994	11	176	-	-	1	2	56	140	-	-	-	-	38	1024	-	-
1995	-	-	-	-	5	12	72	172	-	-	-	-	25	773	-	-
1996	1	23	-	-	85	232	64	143	-	-	-	-	36	1086	-	-
1997	2	23	-	-	(47)	(1647)	53	130	-	-	-	-	54	1794	-	-
1998	-	-	-	-	(22)	(705)	29	71	-	-	-	-	34	450	-	-
1999	-	-	-	-	95	436	116	371	-	-	-	-	-	-	-	-
2000	1	24	-	-	76	304	66	228	-	-	-	-	-	-	-	-
2001	-	-	-	-	147	628	65	232	-	-	-	-	-	-	-	-
2002	2	23	-	-	192	706	114	350	-	-	-	-	-	-	-	-
2003	-	-	-	-	330	1134	153	435	-	-	-	-	-	-	-	-
2004	-	-	47	185	263	1094	563	1754	-	-	-	-	-	-	-	-
2005	-	-	38	197	44	538	249	2311	2	13	-	-	-	-	-	-
2006	-	-	35	171	74	717	342	2646	-	-	-	-	-	-	-	-
2007	-	-	31	94	37	517	303	2239	-	-	223	754	-	-	-	-
2008	-	-	26	85	55	800	290	2117	-	-	237	899	-	-	-	-
2009	1	31	31	181	55	728	309	2567	-	-	132	615	-	-	-	-
2010	1	17	26	105	40	486	198	1216	2	9	102	614	-	-	-	-
2011	1	15	60	185	115	2129	286	2785	21	150	137	812	-	-	-	-
2012	-	-	49	177	89	2255	430	4126	4	18	182	1466	-	-	-	-
2013	2	43	42	157	118	4428	560	7868	6	16	220	2674	-	-	-	-
2014	1	10	39	195	111	2423	526	4710	3	6	234	2182	-	-	-	-
2015	-	-	89	351	73	663	604	4544	3	7	129	1089	-	-	-	-
2016	-	-	37	113	93	1131	481	2864	5	23	194	1368	-	-	-	-
2017	-	-	29	92	43	295	296	784	4	9	142	604	-	-	-	-
2018	-	-	36	119	26	187	278	743	7	18	158	747	-	-	-	-
2019	-	-	18	44	26	271	185	371	3	17	154	812	-	-	-	-
2020	-	-	18	53	-	-	-	-	-	-	153	599	-	-	-	-
2021	1	22	17	44	28	295	189	611	5	15	163	1070	-	-	-	-
2022	-	-	-	-	38	370	236	712	4	13	91	655	-	-	-	-

* combines live and dead landings; ** commercial discard lengths assumed same as north; ^ includes Miller and Gotshall (1965), 1959-1966

Table 6: Number of ages by data source, year, and sex in the northern area model (n = 3,963 total).

Source	Year	Female	Male	Unsexed
Commercial (California Cooperative Groundfish Survey)	1980	13	15	
	1981	75	54	
	1982	0	16	
	1984	100	126	
	1985	66	78	
	2001	22	10	
	2002	12	1	
	2003	15	4	
	2004	5	4	
	2007	10	17	
	2009	58	38	
	2011	22	18	
	2012	28	16	
	2020	266	200	
	2021	219	248	
	2022	111	130	
Commercial (CDFW Pilot)	2019	144	160	
Recreational (Pearson)	1982	8	8	
Recreational (CDFW)	2022	214	185	64
Abrams research	2010	296	242	10
	2011	304	294	6
CCFRP	2022	16	10	5

Table 7: Number of ages by data source, year, and sex in the central area model (n = 755 total).

Source	Year	Female	Male	Unsexed
Recreational	1980	34	30	3
	1981	19	34	11
	1982	65	55	27
	2021	5	2	1
	2022	59	39	8
Lea et al. Research	1979	22	45	0
	1980	27	12	3
	1981	12	8	10
	1982	16	11	12
CCFRP	2017	33	27	9
	2018	6	5	12
	2019	16	15	1
	2020	16	11	0
	2021	5	5	2
	2022	8	13	1

Table 8: Recreational catches (mt) by area, mode, disposition, and year.

	North				Central				
	PC		PRplus		PC		PRplus		
Year	Retained	Discarded Dead	Retained	Discarded Dead	Retained	Discarded Dead	Retained	Discarded Dead	Grand Total
1928	0.190	0.002	0.308	0.003	0.437	0.006	0.527	0.010	1.482
1929	0.381	0.003	0.616	0.005	0.874	0.012	1.054	0.019	2.964
1930	0.437	0.004	0.709	0.006	1.004	0.014	1.212	0.022	3.408
1931	0.583	0.005	0.945	0.008	1.339	0.018	1.616	0.030	4.544
1932	0.729	0.006	1.181	0.010	1.674	0.023	2.020	0.037	5.681
1933	0.875	0.007	1.417	0.012	2.009	0.028	2.424	0.045	6.817
1934	1.020	0.009	1.654	0.014	2.343	0.032	2.828	0.052	7.953
1935	1.166	0.010	1.890	0.016	2.678	0.037	3.232	0.060	9.089
1936	1.312	0.011	2.125	0.018	3.013	0.041	3.635	0.067	10.223
1937	1.555	0.013	2.521	0.022	3.571	0.049	4.312	0.080	12.123
1938	1.530	0.013	2.479	0.021	3.513	0.048	4.240	0.078	11.922
1939	1.338	0.011	2.168	0.019	3.072	0.042	3.707	0.069	10.425
1940	1.926	0.017	3.118	0.027	4.424	0.061	5.331	0.099	15.002
1941	1.780	0.015	2.881	0.025	4.089	0.056	4.927	0.091	13.865
1942	0.946	0.008	1.530	0.013	2.172	0.030	2.617	0.048	7.365
1943	0.904	0.008	1.464	0.013	2.077	0.029	2.503	0.046	7.044
1944	0.743	0.006	1.202	0.010	1.705	0.023	2.055	0.038	5.783
1945	0.990	0.008	1.602	0.014	2.274	0.031	2.740	0.051	7.711
1946	1.704	0.015	2.758	0.024	3.914	0.054	4.717	0.087	13.272
1947	1.348	0.012	2.194	0.019	3.096	0.043	3.752	0.069	10.533
1948	2.691	0.023	4.385	0.038	6.180	0.085	7.498	0.139	21.039
1949	3.488	0.030	5.681	0.049	8.010	0.110	9.715	0.180	27.262
1950	4.251	0.036	6.923	0.059	9.762	0.134	11.839	0.219	33.222
1951	4.854	0.042	10.284	0.088	11.147	0.153	17.587	0.325	44.480
1952	4.224	0.036	8.967	0.077	9.701	0.134	15.334	0.283	38.757
1953	3.598	0.031	7.656	0.066	8.262	0.114	13.093	0.242	33.061
1954	4.473	0.038	9.590	0.082	10.274	0.141	16.401	0.303	41.303
1955	5.339	0.046	11.525	0.099	12.262	0.169	19.710	0.364	49.515
1956	5.959	0.051	12.883	0.110	13.685	0.188	22.032	0.407	55.316
1957	5.510	0.047	12.438	0.107	12.655	0.174	21.271	0.393	52.596
1958	10.489	0.090	20.233	0.173	24.089	0.332	34.601	0.640	90.647
1959	7.476	0.064	16.880	0.145	17.170	0.236	28.867	0.534	71.371
1960	6.669	0.057	13.090	0.112	15.316	0.211	22.386	0.414	58.256
1961	5.248	0.045	11.362	0.097	10.145	0.140	16.356	0.302	43.697
1962	5.721	0.049	20.073	0.172	9.448	0.130	24.684	0.456	60.733
1963	9.456	0.081	28.857	0.247	13.491	0.186	30.658	0.567	83.543
1964	6.461	0.055	34.074	0.292	8.032	0.111	31.546	0.583	81.155
1965	12.860	0.110	53.289	0.457	14.026	0.193	43.281	0.800	125.015
1966	14.584	0.125	68.173	0.584	14.027	0.193	48.824	0.902	147.412
1967	16.257	0.139	82.201	0.705	13.841	0.190	52.116	0.963	166.413
1968	14.977	0.128	99.424	0.852	11.321	0.156	55.964	1.034	183.857
1969	16.346	0.140	117.699	1.009	10.991	0.151	58.932	1.089	206.357
1970	27.294	0.234	146.570	1.256	16.343	0.225	65.354	1.208	258.484
1971	21.080	0.181	154.099	1.321	11.244	0.155	61.208	1.131	250.419
1972	35.750	0.306	191.600	1.642	16.979	0.234	67.762	1.252	315.526
1973	35.983	0.308	231.945	1.988	15.198	0.209	72.949	1.348	359.930
1974	41.298	0.354	263.215	2.256	15.479	0.213	73.464	1.358	397.637
1975	38.668	0.331	285.323	2.446	12.823	0.176	70.456	1.302	411.525
1976	44.902	0.385	321.596	2.757	13.120	0.181	69.970	1.293	454.203
1977	49.697	0.426	336.630	2.885	12.725	0.175	64.185	1.186	467.911
1978	41.687	0.357	352.815	3.024	9.289	0.128	58.542	1.082	466.924
1979	41.957	0.360	397.042	3.403	8.063	0.111	56.817	1.050	508.802
1980	58.005	0.420	312.481	3.668	16.316	0.110	77.554	0.965	469.519
1981	28.665	0.207	465.991	4.594	1.437	0.018	26.188	0.409	527.509
1982	61.824	0.486	411.705	3.630	4.566	0.040	22.496	0.297	505.043
1983	13.607	0.119	135.077	1.234	8.575	0.075	83.897	0.779	243.364
1984	17.176	0.176	430.451	4.406	4.123	0.043	44.042	1.078	501.495
1985	47.161	0.433	423.706	4.269	13.339	0.192	105.210	1.890	596.198
1986	16.199	0.148	423.939	4.281	1.693	0.021	44.723	0.595	491.598
1987	45.281	0.473	154.839	2.037	8.451	0.124	48.253	0.535	259.993
1988	64.971	0.872	191.065	2.352	19.849	0.244	45.856	0.658	325.865
1989	13.406	0.286	214.475	2.586	4.282	0.085	46.847	0.769	282.735

	North				Central				
	PC		PRplus		PC		PRplus		
Year	Retained	Discarded Dead	Retained	Discarded Dead	Retained	Discarded Dead	Retained	Discarded Dead	Grand Total
1990	46.281	0.527	198.483	2.260	9.134	0.166	39.172	0.713	296.736
1991	40.646	0.457	208.396	2.345	8.013	0.153	41.084	0.783	301.879
1992	36.509	0.390	227.341	2.427	10.662	0.138	66.394	0.857	344.718
1993	28.587	0.324	278.976	3.161	5.825	0.121	56.841	1.179	375.014
1994	19.821	0.260	172.878	2.267	5.736	0.102	50.024	0.892	251.981
1995	16.727	0.198	139.648	1.652	4.416	0.082	36.864	0.685	200.271
1996	27.513	0.280	104.070	1.159	7.881	0.122	29.377	0.506	170.909
1997	22.779	0.270	69.880	0.829	6.233	0.124	17.886	0.381	118.382
1998	1.578	0.028	82.670	1.117	0.778	0.014	27.705	0.539	114.428
1999	15.742	0.237	89.729	1.732	6.101	0.120	54.063	0.877	168.600
2000	26.225	0.491	57.897	1.083	14.241	0.261	37.646	0.576	138.419
2001	96.239	0.844	138.487	1.481	28.527	0.471	51.708	0.826	318.583
2002	20.586	0.296	95.809	0.941	9.843	0.173	36.380	0.550	164.578
2003	59.588	0.581	159.967	1.506	17.967	0.355	50.707	0.922	291.593
2004	33.207	0.353	65.087	0.702	11.637	0.227	27.629	0.450	139.292
2005	31.397	0.635	92.212	1.527	18.618	0.102	28.260	0.362	173.113
2006	26.632	0.807	80.533	1.304	31.518	0.331	31.564	0.553	173.243
2007	26.926	0.346	80.794	1.473	7.502	0.028	26.018	0.208	143.296
2008	14.178	0.126	98.953	1.584	19.673	0.166	19.945	0.234	154.859
2009	36.054	0.619	154.619	3.309	19.235	0.109	29.328	0.345	243.618
2010	51.004	0.631	91.473	1.211	24.185	0.307	31.784	0.158	200.754
2011	18.286	0.333	101.623	0.734	26.880	0.622	25.637	0.195	174.310
2012	33.560	0.188	86.801	0.514	50.748	0.511	37.829	0.185	210.337
2013	46.648	0.405	94.976	0.541	114.118	1.428	103.802	0.956	362.874
2014	45.212	0.366	133.602	1.355	48.531	0.676	51.113	1.444	282.299
2015	35.258	1.194	119.113	3.941	26.061	0.247	37.719	1.729	225.262
2016	23.900	1.086	76.039	2.541	35.026	0.564	24.841	1.048	165.044
2017	11.458	1.185	57.511	4.171	12.600	0.569	9.392	0.997	97.883
2018	14.719	1.447	55.674	3.492	9.826	0.767	8.908	0.850	95.682
2019	21.516	1.263	64.707	3.853	12.302	0.405	5.490	0.702	110.239
2020	19.747	0.238	53.550	0.820	12.500	0.247	15.092	0.729	102.925
2021	63.564	0.389	93.939	4.219	18.823	0.374	16.909	0.955	199.173
2022	53.263	2.034	120.896	4.293	10.539	0.088	20.425	0.602	212.141
Grand Total	2002.35	27.34	10281.35	127.50	1172.69	17.24	3015.46	55.41	16699.3

Table 9: Filters applied to the PR dockside index data

Filter	Description	Samples	Prop_Positive_Samples
All data	All data	169911	0.272
Year	Remove 2015-2020 due to bag limits and COVID	123259	0.266
Areas fished	Retain nearshore trips only	110836	0.285
Gear	Retain trips with primary gear of hook-and-line	60977	0.426
Months fished	Remove Nov-Apr; seasonal closures and small sample sizes	55443	0.439
Target species	Retain trips based primary and secondary targets; see text	38922	0.542

Table 10: Sample sizes by year and area for the PR dockside index

Year	Region	n	Year	Region	n
2004	C	1271	2004	N	998
2005	C	1686	2005	N	1498
2006	C	2412	2006	N	1869
2007	C	1651	2007	N	1445
2008	C	1910	2008	N	1157
2009	C	2079	2009	N	1438
2010	C	1364	2010	N	849
2011	C	1478	2011	N	965
2012	C	1559	2012	N	1099
2013	C	2213	2013	N	986
2014	C	2581	2014	N	1479
2021	C	1586	2021	N	782
2022	C	1483	2022	N	1084

Table 11: Model selection for the PR dockside index

Model (all catch models include a log(effort) offset)	WAIC	Δ WAIC
catch ~ year + district + wave + prim1Common	172306.7	7946.4
catch ~ year + district + wave + prim1Common + year:district	170767.2	6406.9
catch ~ year + district + wave + prim1Common + year:district + district:wave	170527.1	6166.8
catch ~ year + district + wave + prim1Common + year:district + district:wave zi ~ 1	170267.6	5907.3
catch ~ year + district + wave + prim1Common + year:district + district:wave zi ~ district	165404.5	1044.2
catch ~ year + district + wave + prim1Common + year:district + district:wave zi ~ year + district + wave + prim1Common	165092.1	731.8
catch ~ year + district + wave + prim1Common + year:district + district:wave zi ~ year + district + wave + prim1Common + year:district	164396.6	36.3
catch ~ year + district + wave + prim1Common + year:district + district:wave zi ~ year + district + wave + prim1Common + year:district + district:wave	164360.3	0

Table 12: Data filters applied to the DWV CPFV onboard index

Filter	Description	Samples	Proportion_Positive
All	None	7569	0.0843
Year	Remove 1987 (sampled Monterey only)	7223	0.0881
Effort	Remove fishing time < 5 min	7128	0.0880
Target	Retain trips with at least 90% groundfish catch	6465	0.0945
Districts	Remove Districts 5-6 due to limited sampling	6294	0.0895
Depth	Remove depths >= 40fm	4084	0.1379

Table 13: Samples sizes for the DWV CPFV onboard index

	CRFS District 3		CRFS District 4	
Year	0-20 fm	20-40 fm	0-20 fm	20-40 fm
1988	14	117	37	37
1989	15	104	33	84
1990	1	24	11	21
1991	20	29	4	11
1992	42	52	15	43
1993	47	121	32	56
1994	66	141	43	73
1995	117	215	59	116
1996	186	255	136	131
1997	208	184	229	230
1998	181	152	212	180

Table 14: Model selection for the DWV CPFV onboard index. All models contained year and an offset term for effort.

(Intercept)	DEPTH_BIN	DISTRICT	WAVE	DEPTH_BIN:YEAR	DISTRICT:YEAR	df	logLik	BIC	delta
-2.218	+	+	+	NA	NA	19	-2778	5713	0
-3.464	+	+	+	+	NA	29	-2746	5733	19
-3.089	+	+	+	NA	+	29	-2754	5750	36
-0.880	+	+	NA	NA	NA	14	-2823	5763	49
-1.870	+	+	NA	+	NA	24	-2789	5777	63
-3.122	+	+	+	+	+	39	-2727	5778	64
-1.399	+	+	NA	NA	+	24	-2803	5806	93
-2.537	+	+	NA	+	+	34	-2774	5831	118

Table 15: Standardized DWV CPFV onboard index for central California

year	index	lower95	upper95	log.se
1988	5.6500	3.0362	9.3465	0.2804
1989	3.1962	1.6387	5.4576	0.2986
1990	3.2223	0.9250	7.7812	0.5004
1991	5.5411	1.9986	11.6985	0.4232
1992	3.5720	1.6193	6.4408	0.3391
1993	1.0974	0.5899	1.7904	0.2735
1994	3.7495	2.1390	5.8506	0.2473
1995	1.1396	0.7128	1.6429	0.2086
1996	1.0230	0.6930	1.4014	0.1763
1997	2.0335	1.4744	2.7043	0.1556
1998	0.5778	0.4081	0.7904	0.1685

Table 16: Data filters applied to the CRFS PC onboard index

Filter	Description	Samples	Percent_positive
All data	All data	30595	13.3%
Zero effort	Remove drifts with effort=0	30303	13.3%
Depth	Impute missing depths with GIS and remove NAs	30264	13.3%
Errors, Missing Data, >5 hrs fished	Remove missing data, errors, and drifts 5+ hours	29981	13.4%
Area fished	Remove drifts in bays & NAs from Bay Area	29422	13.6%
Months fished	Remove Jan-March; recreational rockfish fishery closed	28463	14.0%
Depth fished	Keep drifts <300 ft in districts 3-4, and <150 ft in districts 5-6	27617	14.4%
Observed anglers	Remove drifts <2 or >15 observed anglers	27196	14.5%
Distance from reef	Remove drifts 100+ meters from reef	24883	15.0%

Table 17: Model selection for the CRFS PC onboard index based on WAIC.

Model (all catch models include a log(effort) offset)	WAIC	Δ WAIC
catch ~ year + district + depth_bin + month	22498.5	1997.3
catch ~ year + district + depth_bin + month + year:district	21653.6	1152.4
catch ~ year + district + depth_bin + month + year:district zi ~ 1	21657.5	1156.3
catch ~ year + district + depth_bin + month zi ~ district	21396.7	895.5
catch ~ year + district + depth_bin + month + year:district zi ~ year + district + depth_bin + month	20677	175.8
catch ~ year + district + depth_bin + month + year:district zi ~ year + district + depth_bin + month + year:district	20686.8	185.6
catch ~ year + district + depth_bin + month + (1|year:district) zi ~ year + district + depth_bin + month + (1|year:district)	20636.7	135.5
catch ~ year + district + depth_bin + month + year:district + month:district zi ~ year + district + depth_bin + month + year:district + month:district	20563.3	62.1
catch ~ year + district + depth_bin + month + (1|year:district) + (1|month:district) zi ~ year + district + depth_bin + month + (1|year:district) + (1|month:district)	20501.2	0

Table 18: Sample sizes by year and region for the CRFS PC onboard index.

Year	Region	n	Year	Region	n
2001	C	302			
2002	C	317			
2003	C	1043			
2004	C	1475			
2005	C	1006			
2006	C	1357			
2007	C	1405			
2008	C	1005	2008	N	228
2009	C	922	2009	N	313
2010	C	1471	2010	N	226
2011	C	1541	2011	N	106
2012	C	1282	2012	N	130
2013	C	1347	2013	N	60
2014	C	1214	2014	N	138
2015	C	1134	2015	N	42
2016	C	1476	2016	N	111
2017	C	1042	2017	N	71
2018	C	799	2018	N	98
2019	C	1116			
2021	C	594	2021	N	40
2022	C	827	2022	N	153

Table 19: Data filters applied to the California Collaborative Fisheries Research Program (CCFRP) index.

Filter	Description	No. Drifts Remaining	Percent of total
All data	central California (2007 to 2022) statewide (2017 to 2022)	10571	100.0
Exclude grid cells	Outside bounds, too deep, or < 2 min duration	9229	87.3
Southern California	All drifts south of Point Conception	7789	73.7
Missing data	No geographic location	7775	73.6

Table 20:. Sample size (number of drifts) by year and California Recreational Fisheries Survey (CRFS) district for the California Collaborative Fisheries Research Program (CCFRP) index. CFRS districts were assigned by county. Districts 5 and 6 were not sampled prior to 2017.

	CRFS District				
Year	3	4	5	6	Subtotal
2007	303	254			557
2008	361	201			562
2009	244	126			370
2010	257	159			416
2011	258	117			375
2012	274	127			401
2013	294	132			426
2014	304	146			450
2015	149	75			224
2016	303	125			428
2017	253	170	61	51	535
2018	206	263	71	67	607
2019	218	278	74	74	644
2020	215	263	71	70	619
2021	220	233	72	79	604
2022	220	221	61	55	557
Subtotal	4079	2890	410	396	7775

Table 21: Normalized weights based on the proportion of rocky reef habitat in each California Recreational Fisheries Survey (CRFS) district, showing assignment of CCFRP Areas to CRFS Districts

CCFRP Area	CRFS District	Weight
Cape Mendocino	6	0.1943
Ten Mile	5	0.1620
Stewart's Point	4	0.3210
Bodega Head	4	0.3210
Año Nuevo	4	0.3210
Point Lobos	3	0.3227
Piedras Blancas	3	0.3227
Point Buchon	3	0.3227

Table 22: Proportion of drifts that caught black rockfish by year and California Recreational Fisheries Survey (CRFS) district for the California Collaborative Fisheries Research Program (CCFRP) index. CFRS districts were assigned by county. Districts 5 and 6 were not sampled prior to 2017.

	CRFS District				
Year	3	4	5	6	Marginal
2007	0.290	0.531			0.400
2008	0.277	0.687			0.423
2009	0.152	0.754			0.357
2010	0.062	0.541			0.245
2011	0.209	0.709			0.365
2012	0.296	0.795			0.454
2013	0.347	0.894			0.516
2014	0.375	0.822			0.520
2015	0.430	0.867			0.576
2016	0.294	0.840			0.453
2017	0.158	0.600	0.246	0.569	0.348
2018	0.136	0.494	0.282	0.478	0.346
2019	0.041	0.522	0.230	0.405	0.312
2020	0.037	0.551	0.394	0.414	0.339
2021	0.041	0.661	0.431	0.544	0.392
2022	0.045	0.367	0.492	0.691	0.285
Marginal	0.208	0.624	0.344	0.508	0.385

Table 23: Results from Tweedie and negative binomial generalized additive models used to quantify covariate effects on unweighted black rockfish catch for the California Collaborative Fisheries Research Program (CCFRP) index.

	adj. R^2	Deviance Explained	REML	Scale est.	ΔAIC
Tweedie	0.542	58.5%	11011	3.0021	0
Negative Binomial	0.516	55.3%	11096	1.0000	174.84

Table 24: Alternative models (truncated to exclude models with extremely low AIC weights) for district-weighted black rockfish catch based on California Collaborative Fisheries Research Program (CCFRP) data. Model covariates and selection criteria are shown. Results are from generalized additive models using a Tweedie distribution and log link.

Intercept	Region	Year	Lon, Lat	Lon, Lat, Year	Depth (ft)	offset (log effort, hr)	df	logLik	ΔAIC	wt
-2.05	NA	+	+	+	+	+	51	-7341.6	0.0	0.602
-2.14	+	+	+	+	+	+	52	-7341.2	0.8	0.398
-2.04	NA	+	NA	+	+	+	50	-7396.6	108.2	0.000
-2.11	+	+	NA	+	+	+	51	-7396.1	108.9	0.000
-1.91	NA	+	+	+	NA	+	28	-7537.1	346.3	0.000
-2.04	+	+	+	+	NA	+	29	-7536.4	346.6	0.000
-1.96	NA	NA	+	+	+	+	59	-7541.9	416.8	0.000
-4.72	+	NA	+	+	+	+	58	-7568.4	467.2	0.000
-1.76	NA	NA	NA	+	+	+	58	-7594.9	521.3	0.000
-4.47	+	NA	NA	+	+	+	57	-7621.8	572.7	0.000

Table 25: Tweedie model results for California Collaborative Fisheries Research Program (CCFRP) index of district-weighted black rockfish catch.

	edf	Ref. df	F	p
Year	8.46	8.74	19.09	< 0.001
Long, Lat	11.38	24.00	91.95	< 0.001
Long, Lat, Year	21.01	64.00	5.36	< 0.001
Depth (m)	4.73	5.00	163.06	< 0.001

	Est.	SE	t	p
Intercept	- 2.05	0.07	- 29.23	< 0.001

Dev. explained	adj-R^2	REML	Scale est.
58.4%	0.55	7477	1.29

Table 26: Relative abundance estimates for black rockfish using California Collaborative Fisheries Research Program (CCFRP) data. Mean predicted catch per unit effort (CPUE) and log-scale standard errors are shown by a) year (statewide) or by b) year and region. The index represents the sum of area-specific CPUE in a given year (a) or year and region (b) and was standardized by dividing year-specific values by the mean for the time series.

a)

Year	Mean CPUE	log SE CPUE	Index	Std. Index
2007	0.408	0.115	1.224	0.585
2008	0.299	0.169	1.197	0.572
2009	0.265	0.148	1.061	0.507
2010	0.218	0.151	0.870	0.416
2011	0.321	0.142	1.283	0.614
2012	0.644	0.118	2.578	1.233
2013	0.879	0.093	3.516	1.682
2014	0.838	0.097	3.353	1.603
2015	0.826	0.092	2.479	1.186
2016	0.427	0.112	1.708	0.817
2017	0.259	0.182	2.075	0.992
2018	0.200	0.154	1.597	0.764
2019	0.241	0.158	1.931	0.924
2020	0.392	0.153	3.139	1.501
2021	0.409	0.170	3.273	1.565
2022	0.271	0.215	2.171	1.038

b)

	Central California				Northern California			
Year	Mean CPUE	log SE CPUE	Index	Std. Index	Mean CPUE	log SE CPUE	Index	Std. Index
2007	0.408	0.115	1.224	0.645				
2008	0.299	0.169	1.197	0.631				
2009	0.265	0.148	1.061	0.559				
2010	0.218	0.151	0.870	0.459				
2011	0.321	0.142	1.283	0.676				
2012	0.644	0.118	2.578	1.358				
2013	0.879	0.093	3.516	1.853				
2014	0.838	0.097	3.353	1.766				
2015	0.826	0.092	2.479	1.306				
2016	0.427	0.112	1.708	0.900				
2017	0.267	0.167	1.602	0.844	0.236	0.228	0.473	0.919
2018	0.215	0.150	1.291	0.680	0.153	0.164	0.306	0.594
2019	0.263	0.155	1.575	0.830	0.178	0.167	0.356	0.693
2020	0.418	0.157	2.506	1.320	0.317	0.141	0.633	1.231
2021	0.419	0.182	2.514	1.324	0.380	0.134	0.760	1.477
2022	0.269	0.228	1.613	0.850	0.174	0.242	0.559	1.086

Table 27: Model selection tables for ageing error models.

Read year	Bias	Precision	AIC	AICc	dAIC	dAICc
2023	None	Constant CV	5331.9	5340.1	34.8	31
	None	Curvilinear SD	5510.9	5520.3	213.9	211.2
	None	Curvilinear CV	5299.7	5309.1	2.7	0
	Linear	Constant CV	5335.4	5344.7	38.3	35.6
	Linear	Curvilinear SD	5514.3	5525.0	217.3	215.8
	Linear	Curvilinear CV	5303.7	5314.3	6.6	5.2
	Curvilinear	Constant CV	5323.9	5335.9	26.8	26.8
	Curvilinear	Curvilinear SD	5303.5	5317.1	6.5	8
	Curvilinear	Curvilinear CV	5297.0	5310.6	0	1.5
2015-2017	None	Constant CV	7510.3	7516.2	53.1	50.9
	None	Curvilinear SD	7503.3	7510.1	46.1	44.7
	None	Curvilinear CV	7513.3	7520.2	56.2	54.8
	Linear	Constant CV	7498.6	7505.0	41.5	39.6
	Linear	Curvilinear SD	7486.0	7493.3	28.9	28
	Linear	Curvilinear CV	7502.5	7509.8	45.3	44.4
	Curvilinear	Constant CV	7462.2	7469.5	5.1	4.1
	Curvilinear	Curvilinear SD	7457.5	7465.7	0.3	0.3
	Curvilinear	Curvilinear CV	7457.1	7465.4	0	0

Table 28: Likelihoods generated by successive versions of the Stock Synthesis model. The 2015 assessment used version 3.24. Results were nearly identical using version 3.30.20.

	Stock Synthesis Version	
Likelihood Component	3.24	3.30.20.00
TOTAL	1213.0	1213.1
Equil_catch	0	0
Survey	-14.137	-14.109
Length_comp	353.05	353.16
Age_comp	876.04	876.04
Recruitment	-2.7368	-2.7433
InitEQ_Regime	NA	6.21E-31
Forecast_Recruitment	0	0
Parm_priors	0.72663	0.72590
Parm_softbounds	0.00469	0.00469

Table 29: Effects of changing F estimation method and weighting approach, and updating catch histories, on absolute (top panel) and relative (bottom panel) spawning output, starting from the 2015 assessment.

Quantity	2015 Assessment	Hybrid F method	2015 Francis weights (FW)	2015 fleets with 2023 catches (FW)
N.Parms	88	88	88	88
TOTAL	1213.1	1213.0	838.9	822.6
Survey	-14.1	-14.2	-13.6	-13.4
Length_comp	353.2	353.1	364.3	363.6
Age_comp	876.0	876.1	491.7	476.3
Recruitment	-2.7	-2.8	-4.1	-4.5
Parm_priors	0.7	0.7	0.5	0.6
NatM_uniform_Fem_GP_1	0.181	0.182	0.167	0.175
L_at_Amin_Fem_GP_1	23.390	23.378	24.455	24.477
L_at_Amax_Fem_GP_1	54.539	54.532	53.069	52.925
VonBert_K_Fem_GP_1	0.152	0.152	0.148	0.150
CV_young_Fem_GP_1	0.094	0.094	0.109	0.110
CV_old_Fem_GP_1	0.073	0.072	0.074	0.074
NatM_uniform_Mal_GP_1	-0.343	-0.346	-0.314	-0.287
L_at_Amin_Mal_GP_1	0.075	0.075	0.040	0.034
L_at_Amax_Mal_GP_1	-0.170	-0.170	-0.152	-0.148
VonBert_K_Mal_GP_1	0.341	0.340	0.333	0.328
CV_young_Mal_GP_1	0.009	0.009	-0.113	-0.118
CV_old_Mal_GP_1	-0.028	-0.028	0.009	0.003
SR_LN(R0)	7.61	7.61	7.56	7.70
Size_DblN_peak_Trawl(1)	49.34	49.33	49.53	49.44
Size_DblN_top_logit_Trawl(1)	0.32	0.32	0.29	0.25
Size_DblN_ascend_se_Trawl(1)	3.47	3.47	3.55	3.56
Size_DblN_peak_nonTrawldead(2)	41.71	41.69	42.15	42.07
Size_DblN_top_logit_nonTrawldead(2)	-1.82	-1.84	-1.84	-1.85
Size_DblN_ascend_se_nonTrawldead(2)	4.28	4.27	4.31	4.30
Size_DblN_peak_nonTrawllive(3)	34.58	34.59	34.87	34.87
Size_DblN_top_logit_nonTrawllive(3)	-0.98	-0.97	-0.34	-0.33
Size_DblN_ascend_se_nonTrawllive(3)	2.79	2.79	2.87	2.86
Size_DblN_descend_se_nonTrawllive(3)	4.15	4.14	2.11	2.03
Size_DblN_end_logit_nonTrawllive(3)	-3.16	-3.14	-0.81	-0.75
Size_DblN_peak_Rec(4)	31.24	31.25	31.22	31.25
Size_DblN_top_logit_Rec(4)	-3.05	-3.07	-3.37	-3.43
Size_DblN_ascend_se_Rec(4)	3.35	3.35	3.36	3.36
Size_DblN_peak_OnboardCPUE(5)	26.89	26.92	26.70	26.72
Size_DblN_top_logit_OnboardCPUE(5)	-2.12	-2.13	-2.09	-2.09
Size_DblN_ascend_se_OnboardCPUE(5)	2.28	2.29	2.15	2.16
Size_DblN_peak_RecResearch(7)	26.33	26.35	26.71	26.72
Size_DblN_top_logit_RecResearch(7)	-1.44	-1.44	-1.52	-1.53
Size_DblN_ascend_se_RecResearch(7)	2.89	2.90	3.06	3.05
Bratio_2015	0.33	0.33	0.28	0.33
SSB_unfished	1061.86	1047.36	1130.41	1125.88
Totbio_unfished	9539.32	9492.7	10052.4	10314.3
Recr_unfished	2008.74	2011.48	1919	2215.61
MSY_proxy_F(SPR50)	319.075	318.797	318.406	340.727
OFLCatch_2015	343.825	343.438	302.048	360.513

Table 30: Updates to the weight-length, maturity, and fecundity relationships, relative to the model with revised catches, weights, and F estimation method.

	Model Run			
Quantity	2015 fleets with 2023 catches (FW)	Update W-L	Update maturity	Update fecundity
N.Parms	88	88	88	88
TOTAL	822.6	822.6	821.6	821.8
Survey	-13.4	-13.5	-13.3	-13.3
Length_comp	363.6	363.6	362.8	362.9
Age_comp	476.3	476.3	476.6	476.6
Recruitment	-4.5	-4.5	-5.1	-5.0
Parm_priors	0.6	0.7	0.6	0.6
NatM_uniform_Fem_GP_1	0.175	0.176	0.170	0.171
L_at_Amin_Fem_GP_1	24.477	24.471	24.530	24.520
L_at_Amax_Fem_GP_1	52.925	52.917	52.943	52.934
VonBert_K_Fem_GP_1	0.150	0.150	0.149	0.150
CV_young_Fem_GP_1	0.110	0.110	0.110	0.110
CV_old_Fem_GP_1	0.074	0.074	0.073	0.073
Wtlen_1_Fem_GP_1	0.000	0.000	0.000	0.000
Wtlen_2_Fem_GP_1	2.942	3.012	3.012	3.012
Mat50%_Fem_GP_1	43.690	43.690	40.360	40.360
Mat_slope_Fem_GP_1	-0.660	-0.660	-0.381	-0.381
Eggs/kg_inter_Fem_GP_1	0.275	0.275	0.275	NA
Eggs/kg_slope_wt_Fem_GP_1	0.094	0.094	0.094	NA
NatM_uniform_Mal_GP_1	-0.29	-0.29	-0.29	-0.29
L_at_Amin_Mal_GP_1	0.03	0.03	0.03	0.03
L_at_Amax_Mal_GP_1	-0.15	-0.15	-0.15	-0.15
VonBert_K_Mal_GP_1	0.33	0.33	0.34	0.34
CV_young_Mal_GP_1	-0.12	-0.12	-0.12	-0.12
CV_old_Mal_GP_1	0.00	0.00	0.01	0.01
Wtlen_1_Mal_GP_1	0.00	0.00	0.00	0.00
Wtlen_2_Mal_GP_1	2.96	3.01	3.01	3.01
SR_LN(R0)	7.70	7.63	7.55	7.56
Size_DblN_peak_Trawl(1)	49.44	49.44	49.42	49.43
Size_DblN_top_logit_Trawl(1)	0.25	0.25	0.22	0.23
Size_DblN_ascend_se_Trawl(1)	3.56	3.56	3.56	3.56
Size_DblN_peak_nonTrawldead(2)	42.07	42.07	42.13	42.12
Size_DblN_top_logit_nonTrawldead(2)	-1.85	-1.85	-1.81	-1.82
Size_DblN_ascend_se_nonTrawldead(2)	4.30	4.30	4.30	4.30
Size_DblN_peak_nonTrawllive(3)	34.87	34.87	34.88	34.88
Size_DblN_top_logit_nonTrawllive(3)	-0.33	-0.33	-0.32	-0.32
Size_DblN_ascend_se_nonTrawllive(3)	2.86	2.86	2.86	2.86
Size_DblN_descend_se_nonTrawllive(3)	2.03	2.03	1.99	1.99
Size_DblN_end_logit_nonTrawllive(3)	-0.75	-0.75	-0.72	-0.73
Size_DblN_peak_Rec(4)	31.25	31.25	31.25	31.25
Size_DblN_top_logit_Rec(4)	-3.43	-3.44	-3.46	-3.46
Size_DblN_ascend_se_Rec(4)	3.36	3.36	3.36	3.36
Size_DblN_peak_OnboardCPUE(5)	26.72	26.73	26.72	26.73
Size_DblN_top_logit_OnboardCPUE(5)	-2.09	-2.09	-2.09	-2.09
Size_DblN_ascend_se_OnboardCPUE(5)	2.16	2.16	2.16	2.16
Size_DblN_peak_RecResearch(7)	26.72	26.73	26.65	26.67
Size_DblN_top_logit_RecResearch(7)	-1.53	-1.53	-1.51	-1.52
Size_DblN_ascend_se_RecResearch(7)	3.05	3.05	3.03	3.04
Eggs_scalar_Fem_GP_1	NA	NA	NA	1.41E-08
Eggs_exp_len_Fem_GP_1	NA	NA	NA	4.69
Bratio_2015	0.33	0.33	0.39	0.38
SSB_unfished	1125.88	1235.19	1404.79	1634.76
Totbio_unfished	10314.3	10323.3	10064.5	10112
Recr_unfished	2215.61	2068.88	1898.47	1928.28
MSY_proxy_F(SPR50)	340.73	340.43	343.45	342.36
OFLCatch_2015	360.51	359.26	374.44	370.11

Table 31: Data weights by fleet and data type in the northern base model and using an alternative data weighting method (McAllister-Ianelli).

Fleet name	Data Type	Base (Francis Weights)	McAllister-Ianelli weights
Comm_nonTwl_dead	length	0.694059	1
Comm_nonTwl_live	length	1	1
Comm_Trawl	length	1	1
Comm_Discard	length	0.290534	0.731417
Rec_PC_North	length	0.468295	0.574223
Rec_PR_North	length	0.171834	0.436339
Rec_Disc_North	length	0.359958	1
CCFRP	length	0.712134	1
Abrams_Research	length	0.372812	1
Comm_nonTwl_dead	age	0.04474	0.174288
Comm_Trawl	age	0.907791	0.332602
Rec_PC_North	age	0.478482	0.538038
Rec_PR_North	age	0.225143	0.23098
CCFRP	age	0.097806	0.10544
Abrams_Research	age	0.385793	0.06488

Table 32: Parameters used in the northern California base case assessment model. See separate table for selectivity parameters.

Parameter	Number Estimated	Bounds (low, high)	Prior (Mean, SD) - Type	Value	Transformed Value	SE	gradient
General Biology							
Natural mortality (M) - female	1	(0.01, 0.5)	(-1.869, 0.31) - Lognormal	0.211		0.016	-6E-05
Nat. mortality (M) - male (offset)	1	(-0.5, 0.5)	-	-0.053	0.200	0.031	-1E-05
Ln (R_0)	1	(6, 10)	-	7.728	2271.7	0.173	6E-05
Steepness (h)	0	(0.201, 0.999)	(0.72, 0.16) - Full Beta	0.720		-	-
Growth							
Length at age 0 - female	0	(3, 30)	-	5.000		-	-
Length at age 20 - female	1	(45, 60)	-	54.494		0.782	2E-05
von Bertalnaffy k - female	1	(0.05, 0.3)	-	0.148		0.006	3E-05
CV(L(age 0)) - female	0	(0.01, 0.4)	-	0.100		-	-
CV(L(age 20)) - female	1	(0.01, 0.2)	-	0.082		0.008	3E-06
Length at age 0 - male (offset)	0	(-1, 1)	-	0.000	5.000	-	-
Length at age 20 - male (offset)	1	(-0.5, 0.5)	-	-0.147	47.040	0.015	3E-05
von Bertalnaffy k - male (offset)	1	(-1, 1)	-	0.312	0.202	0.044	1E-05
CV(L(age 0)) - male (offset)	0	(-1, 1)	-	0.000	0.100	-	-
CV(L(age 20)) - male (offset)	1	(-2, 2)	-	-0.319	0.059	0.140	9E-07
Indices							
Extra SD - CRFS private dockside	1	(0, 0.4)	-	0.088		0.027	7E-09
Recruitment Deviations (sum=0)							
SD of log-scale rec devs (sigma-R)	0	(0, 2)		0.60		-	-
Main Recruitment Deviation Parameters				Min	Max	maxSE	maxGrad
1963-2022	60	(-5, 5)	-	-0.744	1.279	0.564	1E-05
Summary of model parameters (see separate table for selectivity parameters)							
Number of parameters in model	144						
Estimated parameters	98	(including 2 forecast devs)					
Number within 1% of bound	0						

Table 33: Selectivity parameters used in the northern California base case assessment model.

Parameter	Number Estimated	Bounds (low, high)	Value	Transformed Value	SE	gradient
Selectivity						
Commercial Non-Trawl, landed dead						
Logistic inflection point	1	(25, 45)	35.928		0.550	7E-06
Logistic width, 50th to 95th percentile	1	(0, 12)	5.859		0.534	-3E-06
Commercial Non-Trawl, landed alive						
Double-Normal Peak	1	(25, 50)	36.232		1.424	2E-06
Double-Normal Top (logit)	0	(-10, 10)	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(0.5, 6)	3.093		0.456	-6E-07
Double-Normal Descending SE	1	(1, 10)	5.684		0.991	7E-07
Double-Normal Initial (logit)	0	(-11, -9)	-10.000	0.000	_	_
Double-Normal Final (logit)	0	(-12, 12)	-10.000	0.000	_	_
Commercial Trawl						
Logistic inflection point	1	(35, 55)	45.427		1.123	-4E-07
Logistic width, 50th to 95th percentile	1	(0.1, 10)	5.688		0.887	1E-07
Commercial Discard						
Double-Normal Peak	1	(20, 35)	27.109		0.715	-3E-07
Double-Normal Top (logit)	0	(-10, 10)	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(1, 6)	3.422		0.231	1E-07
Double-Normal Descending SE	1	(1, 6)	3.909		0.232	-1E-06
Double-Normal Initial (logit)	0	(-11, -9)	-10.000	0.000	_	_
Double-Normal Final (logit)	0	(-11, -9)	-10.000	0.000	_	_
Recreational CPFV, 2004-present						
Double-Normal Peak	1	(30, 55)	40.807		0.724	-2E-06
Double-Normal Top (logit)	0	(-10, 10)	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(2, 6)	4.210		0.108	-1E-06
Double-Normal Descending SE	1	(0.1, 10)	4.755		0.490	-8E-07
Double-Normal Initial (logit)	0	(-11, -9)	-10.000	0.000	_	_
Double-Normal Final (logit)	1	(-15, 15)	-2.695	0.063	2.849	2E-07
D-N Peak, 1875-2003	1	(25, 45)	34.214		0.937	3E-06
D-N Ascending SE, 1875-2003	1	(1, 7)	3.863		0.195	-5E-07
D-N Descending SE, 1875-2003	0	(0.1, 10)	6.000		_	_
D-N Final (logit), 1875-2003	0	(-15, 15)	10.000	1.000	_	_
Recreational Private Boat (mirrors CPFV)						
Recreational Discard						
Double-Normal Peak	1	(15, 45)	28.386		2.582	5E-07
Double-Normal Top (logit)	0	(-10, 0)	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(1, 7)	4.204		0.570	-3E-07
Double-Normal Descending SE	1	(1, 8)	4.511		0.617	1E-07
Double-Normal Initial (logit)	0	(-11, -9)	-10.000	0.000	_	_
Double-Normal Final (logit)	0	(-11, -9)	-10.000	0.000	_	_
CCFRP						
Double-Normal Peak	1	(30, 55)	42.166		1.099	2E-07
Double-Normal Top (logit)	0	(-10, 10)	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(2, 7)	4.595		0.169	3E-06
Double-Normal Descending SE	1	(0.05, 8)	2.805		0.691	8E-07
Double-Normal Initial (logit)	0	(-11, -9)	-10.000	0.000	_	_
Double-Normal Final (logit)	1	(-15, 15)	-3.178	0.040	1.591	2E-06
CRFS CPFV Onboard (PCO; mirrors CPFV)						
Abrams Thesis Research						
Double-Normal Peak	1	(20, 60)	39.881		2.311	2E-06
Double-Normal Top (logit)	0	(-10, 10)	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(2, 7)	4.529		0.325	-4E-06
Double-Normal Descending SE	1	(0.1, 10)	4.552		0.826	3E-07
Double-Normal Initial (logit)	0	(-11, -9)	-10.000	0.000	_	_
Double-Normal Final (logit)	0	(-15, 10)	-5.000	0.007	_	_

Table 34: Number of estimated parameters, likelihood values, and parameter estimates for the northern California models evaluated in STAR panel request 3.

Quantity	Pre-STAR base	Add early ageing error matrix
N.Parms	98	98
TOTAL	1106.27	1105.25
Survey	-29.9739	-29.9719
Length_comp	366.71	367.543
Age_comp	773.604	771.501
Recruitment	-4.58365	-4.3299
Parm_priors	0.517137	0.505673
NatM_uniform_Fem_GP_1	0.211457	0.210716
L_at_Amax_Fem_GP_1	54.4938	54.4408
VonBert_K_Fem_GP_1	0.147691	0.148211
CV_old_Fem_GP_1	0.0816563	0.0836846
NatM_uniform_Mal_GP_1	-0.0533557	-0.052892
L_at_Amax_Mal_GP_1	-0.147081	-0.146587
VonBert_K_Mal_GP_1	0.311759	0.311706
CV_old_Mal_GP_1	-0.319049	-0.334481
SR_LN(R0)	7.72829	7.72042
Q_extraSD_Rec_PR_North(6)	0.0878346	0.0878631

Table 35: Mean CPUE, number of trips landing black rockfish (tripsWithTarget), number of trips that did not land a black rockfish (tripsWOTarget), total number of trips, and percentage of total trips that landed a black rockfish (percentpos), by angler-reported primary target (prim1Common) and CRFS district number (districts 5 & 6 represent northern California.

prim1Common	district	MeanCPUE	tripsWithTarget	tripsWOTarget	totalTrips	percentpos
bottomfish (groundfish)	3	0.016	1	30	31	3%
bottomfish (groundfish)	4	3.017	11	5	16	69%
bottomfish (groundfish)	5	1.804	793	498	1291	61%
bottomfish (groundfish)	6	3.909	7380	1401	8781	84%
lingcod	3	0.277	196	672	868	23%
lingcod	4	0.665	87	162	249	35%
lingcod	5	1.196	58	47	105	55%
lingcod	6	2.192	325	168	493	66%
rockfish genus	3	0.434	3930	11357	15287	26%
rockfish genus	4	1.346	5138	4271	9409	55%
rockfish genus	5	1.367	1156	843	1999	58%
rockfish genus	6	4.311	3783	417	4200	90%

Table 36: Number of estimated parameters, likelihood values, parameter estimates, and derived quantities for the pre- and post-STAR northern California base models.

Label	Pre-STAR base model	Proposed final base, updated ageing error and maturity
N.Parms	98	98
TOTAL	1106.27	1080.47
Survey	-29.9739	-30.0399
Length_comp	366.71	365.653
Age_comp	773.604	748.844
Recruitment	-4.58365	-4.48439
Parm_priors	0.517137	0.498684
NatM_uniform_Fem_GP_1	0.211457	0.21026
L_at_Amax_Fem_GP_1	54.4938	54.3987
VonBert_K_Fem_GP_1	0.147691	0.148452
CV_old_Fem_GP_1	0.0816563	0.0834932
NatM_uniform_Mal_GP_1	-0.0533557	-0.050796
L_at_Amax_Mal_GP_1	-0.147081	-0.145894
VonBert_K_Mal_GP_1	0.311759	0.309366
CV_old_Mal_GP_1	-0.319049	-0.329013
SR_LN(R0)	7.72829	7.7183
Q_extraSD_Rec_PR_North(6)	0.0878346	0.0877788
Size_inflection_Comm_nonTwl_dead(1)	35.9278	35.9117
Size_95%width_Comm_nonTwl_dead(1)	5.85885	5.85588
Size_DblN_peak_Comm_nonTwl_live(2)	36.2324	36.2334
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.09347	3.09416
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.68353	5.67865
Size_inflection_Comm_Trawl(3)	45.4269	45.3946
Size_95%width_Comm_Trawl(3)	5.68759	5.67484
Size_DblN_peak_Comm_Discard(4)	27.1087	27.1041
Size_DblN_ascend_se_Comm_Discard(4)	3.42201	3.42218
Size_DblN_descend_se_Comm_Discard(4)	3.90851	3.90775
Size_DblN_peak_Rec_PC_North(5)	40.8067	40.7959
Size_DblN_ascend_se_Rec_PC_North(5)	4.20983	4.2097
Size_DblN_descend_se_Rec_PC_North(5)	4.75464	4.75971
Size_DblN_end_logit_Rec_PC_North(5)	-2.69513	-2.73716
Size_DblN_peak_Rec_Disc_North(7)	28.3864	28.3708
Size_DblN_ascend_se_Rec_Disc_North(7)	4.20435	4.2038
Size_DblN_descend_se_Rec_Disc_North(7)	4.51076	4.51057
Size_DblN_peak_CCFRP(8)	42.1655	42.1661
Size_DblN_ascend_se_CCFRP(8)	4.59475	4.59644
Size_DblN_descend_se_CCFRP(8)	2.80511	2.80592
Size_DblN_end_logit_CCFRP(8)	-3.17849	-3.18391
Size_DblN_peak_Abrams_Research(11)	39.8806	39.8553
Size_DblN_ascend_se_Abrams_Research(11)	4.52931	4.5296
Size_DblN_descend_se_Abrams_Research(11)	4.55167	4.5564
Size_DblN_peak_Rec_PC_North(5)_BLK1repl_1875	34.2142	34.1981
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1repl_1875	3.86314	3.86098
Bratio_2023	0.36359	0.364302
SSB_unfished	1205.06	1126.05
Totbio_unfished	6573.23	6569.59
Recr_unfished	2271.71	2249.13
Dead_Catch_SPR	265.141	265.453
OFLCatch_2023	203.162	203.852

Table 37: Number of estimated parameters, likelihood values, parameter estimates, and derived quantities for the three alternative states of nature described in STAR panel request 11 for the northern model.

Label	Northern, base	North, M=0.300	North, M=0.147
N.Parms	98	97	97
TOTAL	1080.5	1090.9	1096.2
Survey	-30.0	-29.3	-30.3
Length_comp	365.7	369.2	366.7
Age_comp	748.8	752.5	757.1
Recruitment	-4.5	-3.7	2.8
Parm_priors	0.5	2.3	0.0
NatM_uniform_Fem_GP_1	0.210	0.300	0.147
L_at_Amax_Fem_GP_1	54.399	54.249	54.142
VonBert_K_Fem_GP_1	0.148	0.148	0.151
CV_old_Fem_GP_1	0.083	0.083	0.087
NatM_uniform_Mal_GP_1	-0.051	-0.062	-0.003
L_at_Amax_Mal_GP_1	-0.146	-0.143	-0.142
VonBert_K_Mal_GP_1	0.309	0.294	0.307
CV_old_Mal_GP_1	-0.329	-0.314	-0.365
SR_LN(R0)	7.718	8.768	7.151
Q_extraSD_Rec_PR_North(6)	0.088	0.083	0.086
Size_inflection_Comm_nonTwl_dead(1)	35.91	36.31	35.50
Size_95%width_Comm_nonTwl_dead(1)	5.86	5.89	5.75
Size_DblN_peak_Comm_nonTwl_live(2)	36.23	36.54	36.02
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.09	3.12	3.07
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.68	5.80	5.76
Size_inflection_Comm_Trawl(3)	45.39	45.67	44.69
Size_95%width_Comm_Trawl(3)	5.67	5.66	5.52
Size_DblN_peak_Comm_Discard(4)	27.10	27.42	26.90
Size_DblN_ascend_se_Comm_Discard(4)	3.42	3.42	3.43
Size_DblN_descend_se_Comm_Discard(4)	3.91	3.95	3.89
Size_DblN_peak_Rec_PC_North(5)	40.80	41.52	40.63
Size_DblN_ascend_se_Rec_PC_North(5)	4.21	4.23	4.23
Size_DblN_descend_se_Rec_PC_North(5)	4.76	4.82	4.70
Size_DblN_end_logit_Rec_PC_North(5)	-2.74	-2.21	-3.00
Size_DblN_peak_Rec_Disc_North(7)	28.37	29.06	27.89
Size_DblN_ascend_se_Rec_Disc_North(7)	4.20	4.21	4.21
Size_DblN_descend_se_Rec_Disc_North(7)	4.51	4.55	4.53
Size_DblN_peak_CCFRP(8)	42.17	42.78	41.95
Size_DblN_ascend_se_CCFRP(8)	4.60	4.57	4.64
Size_DblN_descend_se_CCFRP(8)	2.81	2.59	2.87
Size_DblN_end_logit_CCFRP(8)	-3.18	-2.74	-3.43
Size_DblN_peak_Abrams_Research(11)	39.86	40.56	39.65
Size_DblN_ascend_se_Abrams_Research(11)	4.53	4.52	4.55
Size_DblN_descend_se_Abrams_Research(11)	4.56	4.59	4.51
Size_DblN_peak_Rec_PC_North(5)_BLK1repl_1875	34.20	34.73	33.79
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1repl_1875	3.86	3.87	3.86
Bratio_2023	0.364	0.760	0.176
SSB_unfished	1126	997	1671
Totbio_unfished	6570	8656	7299
Recr_unfished	2249	6423	1276
Dead_Catch_SPR	265	419	234
OFLCatch_2023	204	557	105

Table 38: Reference points for the northern California base model.

Reference Point	Estimate	Interval
Unfished Spawning Output (billions of eggs)	1,126	926 - 1,326
Unfished Age 8+ Biomass (mt)	4,219	3,651 - 4,787
Unfished Recruitment (R0, 1000s)	2,249	1,493 - 3,005
Spawning Output (2023, billions of eggs)	410	175 - 645
Fraction Unfished (2023)	0.36	0.16 - 0.57
Reference Points Based SB40%		
Proxy Spawning Output SB40%	450	370 - 531
SPR Resulting in SB40%	0.458	0.458 - 0.458
Exploitation Rate Resulting in SB40%	0.16	0.131 - 0.190
Yield with SPR Based On SB40% (mt)	280	239 - 321
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	502	413 - 592
SPR50	0.5	-
Exploitation Rate Corresponding to SPR50	0.137	0.112 - 0.162
Yield with SPR50 at SB SPR (mt)	265	227 - 304
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	276	223 - 330
SPR MSY	0.319	0.313 - 0.325
Exploitation Rate Corresponding to SPR MSY	0.281	0.220 - 0.342
MSY (mt)	307	261 - 353

Table 39: Time series of biomass and mortality estimates (mt), spawning output (billions of eggs), recruits (1000s), and exploitation rate (catch / age 8+ biomass) for the northern California base model.

Year	Total Biomass	Spawning Output	Biomass age 8+	Fraction Unfished	Age-0 Recruits	Total Mortality	(1-SPR) / (1-SPR_50%)	Exploitation Rate
1875	6,573	1,205	4,214	100	2,272	0.05	0	0.000
1876	6,573	1,205	4,214	100	2,272	0.10	0	0.000
1877	6,573	1,205	4,214	100	2,272	0.15	0	0.000
1878	6,573	1,205	4,214	100	2,272	0.19	0.001	0.000
1879	6,573	1,205	4,214	100	2,272	0.24	0.001	0.000
1880	6,573	1,205	4,214	100	2,272	0.29	0.001	0.000
1881	6,572	1,205	4,214	100	2,272	0.34	0.001	0.000
1882	6,572	1,205	4,213	100	2,272	0.39	0.001	0.000
1883	6,572	1,205	4,213	100	2,272	0.44	0.001	0.000
1884	6,572	1,205	4,213	100	2,272	0.49	0.002	0.000
1885	6,572	1,205	4,213	100	2,272	0.53	0.002	0.000
1886	6,571	1,204	4,213	100	2,272	0.58	0.002	0.000
1887	6,571	1,204	4,212	99.9	2,272	0.63	0.002	0.000
1888	6,571	1,204	4,212	99.9	2,272	0.68	0.002	0.000
1889	6,570	1,204	4,212	99.9	2,272	0.73	0.002	0.000
1890	6,570	1,204	4,211	99.9	2,272	0.78	0.003	0.000
1891	6,570	1,204	4,211	99.9	2,272	0.82	0.003	0.000
1892	6,569	1,204	4,211	99.9	2,272	0.87	0.003	0.000
1893	6,569	1,204	4,211	99.9	2,272	0.92	0.003	0.000
1894	6,569	1,204	4,210	99.9	2,271	0.97	0.003	0.000
1895	6,568	1,204	4,210	99.9	2,271	1.02	0.003	0.000
1896	6,568	1,204	4,210	99.9	2,271	1.07	0.004	0.000
1897	6,568	1,203	4,209	99.9	2,271	1.12	0.004	0.000
1898	6,567	1,203	4,209	99.9	2,271	1.16	0.004	0.000
1899	6,567	1,203	4,209	99.8	2,271	1.21	0.004	0.000
1900	6,567	1,203	4,208	99.8	2,271	1.26	0.004	0.000
1901	6,566	1,203	4,208	99.8	2,271	1.31	0.004	0.000
1902	6,566	1,203	4,208	99.8	2,271	1.36	0.005	0.000
1903	6,566	1,203	4,207	99.8	2,271	1.41	0.005	0.000
1904	6,565	1,203	4,207	99.8	2,271	1.45	0.005	0.000
1905	6,565	1,203	4,207	99.8	2,271	1.50	0.005	0.000
1906	6,565	1,202	4,206	99.8	2,271	1.55	0.005	0.000
1907	6,564	1,202	4,206	99.8	2,271	1.60	0.005	0.000
1908	6,564	1,202	4,206	99.8	2,271	1.65	0.006	0.000
1909	6,564	1,202	4,205	99.8	2,271	1.70	0.006	0.000
1910	6,563	1,202	4,205	99.8	2,271	1.75	0.006	0.000
1911	6,563	1,202	4,205	99.7	2,271	1.79	0.006	0.000
1912	6,562	1,202	4,204	99.7	2,271	1.84	0.006	0.000
1913	6,562	1,202	4,204	99.7	2,271	1.89	0.006	0.000
1914	6,562	1,202	4,204	99.7	2,271	1.94	0.007	0.000
1915	6,561	1,202	4,203	99.7	2,271	1.99	0.007	0.000
1916	6,561	1,201	4,203	99.7	2,271	2.04	0.007	0.000
1917	6,561	1,201	4,203	99.7	2,271	4.01	0.013	0.001
1918	6,559	1,201	4,201	99.6	2,271	9.35	0.031	0.002
1919	6,552	1,199	4,195	99.5	2,271	2.15	0.007	0.001
1920	6,552	1,199	4,195	99.5	2,271	2.92	0.01	0.001
1921	6,552	1,199	4,195	99.5	2,271	4.38	0.015	0.001
1922	6,551	1,198	4,194	99.4	2,270	3.26	0.011	0.001
1923	6,551	1,198	4,193	99.4	2,270	1.07	0.004	0.000
1924	6,552	1,199	4,195	99.5	2,271	2.92	0.01	0.001
1925	6,552	1,199	4,195	99.5	2,271	9.48	0.032	0.002
1926	6,546	1,197	4,190	99.3	2,270	9.35	0.031	0.002
1927	6,541	1,196	4,185	99.2	2,270	17.74	0.059	0.004
1928	6,529	1,192	4,174	98.9	2,269	15.81	0.053	0.004
1929	6,520	1,190	4,165	98.7	2,269	19.47	0.066	0.005
1930	6,508	1,186	4,154	98.4	2,268	26.47	0.088	0.006
1931	6,492	1,181	4,139	98	2,267	40.60	0.135	0.010
1932	6,465	1,173	4,115	97.4	2,266	29.61	0.1	0.007
1933	6,452	1,169	4,101	97	2,265	28.41	0.098	0.007
1934	6,441	1,165	4,091	96.6	2,264	27.25	0.093	0.007
1935	6,433	1,162	4,083	96.4	2,264	38.83	0.13	0.010
1936	6,415	1,156	4,068	96	2,262	34.76	0.117	0.009
1937	6,403	1,153	4,057	95.7	2,262	32.97	0.113	0.008
1938	6,394	1,150	4,049	95.4	2,261	44.62	0.15	0.011

Year	Total Biomass	Spawning Output	Biomass age 8+	Fraction Unfished	Age-0 Recruits	Total Mortality	(1-SPR) / (1-SPR_50%)	Exploitation Rate
1939	6,376	1,144	4,033	95	2,260	52.67	0.178	0.013
1940	6,353	1,137	4,011	94.4	2,259	36.04	0.124	0.009
1941	6,347	1,135	4,006	94.2	2,258	37.91	0.13	0.009
1942	6,341	1,133	4,000	94	2,258	44.48	0.152	0.011
1943	6,329	1,129	3,990	93.7	2,257	53.10	0.18	0.013
1944	6,311	1,124	3,973	93.2	2,256	185.46	0.535	0.047
1945	6,179	1,084	3,852	89.9	2,247	403.79	0.938	0.105
1946	5,868	993	3,568	82.4	2,226	602.72	1.196	0.169
1947	5,423	856	3,151	71	2,185	567.76	1.201	0.180
1948	5,078	732	2,806	60.7	2,137	202.38	0.719	0.072
1949	5,083	728	2,808	60.4	2,136	130.03	0.531	0.046
1950	5,153	742	2,873	61.6	2,142	419.89	1.095	0.146
1951	4,973	679	2,711	56.3	2,113	257.27	0.883	0.095
1952	4,946	670	2,707	55.6	2,108	86.76	0.4	0.032
1953	5,061	708	2,840	58.7	2,127	176.58	0.684	0.062
1954	5,085	719	2,884	59.6	2,132	320.78	0.97	0.111
1955	4,980	693	2,800	57.5	2,119	183.55	0.715	0.066
1956	5,003	700	2,821	58	2,123	69.87	0.327	0.025
1957	5,114	737	2,932	61.2	2,140	115.40	0.485	0.039
1958	5,173	760	2,994	63	2,149	104.28	0.435	0.035
1959	5,232	783	3,051	65	2,159	68.83	0.301	0.023
1960	5,314	812	3,124	67.3	2,169	91.39	0.382	0.029
1961	5,368	830	3,172	68.9	2,176	87.11	0.362	0.027
1962	5,421	846	3,218	70.2	2,182	90.90	0.367	0.028
1963	5,465	861	3,253	71.4	2,173	127.72	0.477	0.039
1964	5,471	865	3,255	71.8	2,004	94.43	0.369	0.029
1965	5,502	877	3,284	72.8	1,660	104.36	0.39	0.032
1966	5,505	888	3,304	73.7	1,416	111.04	0.407	0.034
1967	5,468	896	3,315	74.4	1,378	125.10	0.448	0.038
1968	5,375	900	3,313	74.7	1,677	143.78	0.507	0.043
1969	5,230	899	3,293	74.6	2,601	175.37	0.602	0.053
1970	5,046	887	3,247	73.6	1,656	197.32	0.683	0.061
1971	4,870	866	3,180	71.9	1,152	205.09	0.729	0.064
1972	4,709	835	3,068	69.3	1,654	276.45	0.924	0.090
1973	4,488	780	2,838	64.8	4,085	326.20	1.053	0.115
1974	4,265	715	2,544	59.3	5,597	407.92	1.225	0.160
1975	4,102	636	2,216	52.8	1,856	381.73	1.25	0.172
1976	4,154	576	2,001	47.8	4,329	459.48	1.401	0.230
1977	4,241	507	1,911	42.1	3,077	460.36	1.404	0.241
1978	4,408	452	1,692	37.5	1,029	511.88	1.435	0.303
1979	4,530	408	1,416	33.9	1,118	445.77	1.301	0.315
1980	4,600	424	1,347	35.2	1,314	427.30	1.275	0.317
1981	4,548	454	1,665	37.7	1,198	570.24	1.426	0.343
1982	4,230	474	2,114	39.3	1,106	628.92	1.51	0.298
1983	3,769	473	1,857	39.2	1,338	396.71	1.294	0.214
1984	3,498	480	2,092	39.8	2,112	653.21	1.625	0.312
1985	2,969	426	1,912	35.3	2,041	684.57	1.728	0.358
1986	2,474	337	1,385	28	1,981	454.76	1.673	0.328
1987	2,264	285	1,095	23.6	1,129	284.19	1.459	0.260
1988	2,280	251	955	20.8	1,270	335.03	1.567	0.351
1989	2,255	217	815	18	1,392	361.81	1.617	0.444
1990	2,190	192	688	15.9	948	382.64	1.649	0.556
1991	2,084	180	624	14.9	1,151	393.28	1.679	0.631
1992	1,941	170	655	14.1	1,391	516.36	1.808	0.788
1993	1,673	140	581	11.6	944	430.72	1.811	0.741
1994	1,483	122	536	10.1	2,223	313.48	1.745	0.585
1995	1,422	111	447	9.2	3,694	323.44	1.785	0.723
1996	1,417	96	375	7.9	1,135	223.29	1.666	0.596
1997	1,602	94	382	7.8	773	204.92	1.615	0.537
1998	1,833	96	364	8	742	151.96	1.374	0.418
1999	2,072	111	424	9.2	2,026	160.98	1.226	0.380
2000	2,236	138	542	11.5	1,348	128.43	0.944	0.237
2001	2,391	185	613	15.3	1,950	331.66	1.484	0.541
2002	2,328	216	819	17.9	1,450	210.09	1.214	0.257
2003	2,386	248	1,254	20.6	1,857	278.34	1.405	0.222
2004	2,382	257	1,160	21.3	1,271	165.53	1.04	0.143
2005	2,497	269	1,065	22.4	1,463	198.36	1.132	0.186
2006	2,569	278	964	23.1	721	170.17	1	0.177

Year	Total Biomass	Spawning Output	Biomass age 8+	Fraction Unfished	Age-0 Recruits	Total Mortality	(1-SPR) / (1-SPR_50%)	Exploitation Rate
2007	2,649	294	1,116	24.4	2,057	192.64	1.049	0.173
2008	2,676	310	1,138	25.8	2,510	199.09	1.039	0.175
2009	2,702	327	1,269	27.2	1,451	285.90	1.282	0.225
2010	2,681	328	1,232	27.2	1,967	195.67	1.051	0.159
2011	2,769	337	1,313	27.9	1,228	145.87	0.867	0.111
2012	2,913	348	1,315	28.9	1,326	140.28	0.817	0.107
2013	3,042	361	1,365	30	1,218	173.29	0.9	0.127
2014	3,103	376	1,258	31.2	1,427	218.03	1.011	0.173
2015	3,084	391	1,397	32.5	1,090	259.64	1.118	0.186
2016	2,998	400	1,573	33.2	2,023	166.35	0.847	0.106
2017	2,986	419	1,581	34.7	1,352	129.77	0.708	0.082
2018	3,015	437	1,711	36.3	1,076	120.35	0.67	0.070
2019	3,053	450	1,693	37.4	2,033	140.67	0.756	0.083
2020	3,067	455	1,679	37.7	1,775	115.58	0.653	0.069
2021	3,121	460	1,658	38.2	2,097	200.18	0.964	0.121
2022	3,118	451	1,621	37.5	1,851	236.52	1.085	0.146

Table 40: Comparison of northern base model outputs for 'drop-one' analyses (part 1)

Label	Base	Drop Non-Trawl Dead	Drop Non-Trawl Live	Drop Trawl	Drop Comm Discard	Drop Rec PC
N.Parms	98	96	95	96	95	98
TOTAL	1106.27	962.91	1093.78	549.77	1058.70	997.34
Survey	-29.97	-32.36	-30.07	-31.77	-30.16	-30.13
Length_comp	366.71	277.30	354.37	321.59	320.34	306.06
Age_comp	773.60	721.63	773.54	269.62	772.33	725.75
Recruitment	-4.58	-4.10	-4.58	-9.69	-4.32	-4.88
Parm_priors	0.52	0.43	0.53	0.02	0.51	0.54
NatM_uniform_Fem_GP_1	0.211	0.206	0.212	0.144	0.211	0.213
L_at_Amax_Fem_GP_1	54.494	55.970	54.519	51.240	54.411	54.254
VonBert_K_Fem_GP_1	0.148	0.139	0.147	0.168	0.149	0.149
CV_old_Fem_GP_1	0.082	0.082	0.082	0.066	0.082	0.084
NatM_uniform_Mal_GP_1	-0.053	-0.029	-0.053	0.006	-0.054	-0.056
L_at_Amax_Mal_GP_1	-0.147	-0.164	-0.148	-0.116	-0.146	-0.143
VonBert_K_Mal_GP_1	0.312	0.356	0.313	0.225	0.310	0.305
CV_old_Mal_GP_1	-0.319	-0.313	-0.317	-0.270	-0.321	-0.330
SR_LN(R0)	7.728	7.735	7.741	7.334	7.716	7.733
Q_extraSD_Rec_PR_North(6)	0.088	0.083	0.086	0.091	0.086	0.087
Size_inflection_Comm_nonTwl_dead(1)	35.93	35.93	35.93	36.33	35.92	36.05
Size_95%width_Comm_nonTwl_dead(1)	5.86	5.86	5.85	6.36	5.86	5.92
Size_DblN_peak_Comm_nonTwl_live(2)	36.23	36.20	36.23	35.92	36.22	36.37
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.09	3.10	3.09	3.05	3.09	3.12
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.68	5.24	5.68	9.49	5.69	5.84
Size_inflection_Comm_Trawl(3)	45.43	44.53	45.42	45.43	45.47	45.59
Size_95%width_Comm_Trawl(3)	5.69	5.41	5.68	5.69	5.71	5.70
Size_DblN_peak_Comm_Discard(4)	27.11	27.13	27.11	26.84	27.11	27.10
Size_DblN_ascend_se_Comm_Discard(4)	3.42	3.42	3.42	3.42	3.42	3.41
Size_DblN_descend_se_Comm_Discard(4)	3.91	3.89	3.91	3.91	3.91	3.92
Size_DblN_peak_Rec_PC_North(5)	40.81	40.21	40.78	41.21	40.79	40.77
Size_DblN_ascend_se_Rec_PC_North(5)	4.21	4.14	4.21	4.29	4.21	4.22
Size_DblN_descend_se_Rec_PC_North(5)	4.75	4.61	4.75	4.85	4.76	4.74
Size_DblN_end_logit_Rec_PC_North(5)	-2.70	-3.52	-2.71	0.84	-2.65	-2.08
Size_DblN_peak_Rec_Disc_North(7)	28.39	28.38	28.39	27.79	28.35	28.40
Size_DblN_ascend_se_Rec_Disc_North(7)	4.20	4.20	4.20	4.20	4.20	4.21
Size_DblN_descend_se_Rec_Disc_North(7)	4.51	4.46	4.51	4.56	4.51	4.53
Size_DblN_peak_CCFRP(8)	42.17	41.96	42.16	42.66	42.21	42.22
Size_DblN_ascend_se_CCFRP(8)	4.59	4.56	4.59	4.68	4.61	4.59
Size_DblN_descend_se_CCFRP(8)	2.81	2.83	2.81	2.63	2.79	2.80
Size_DblN_end_logit_CCFRP(8)	-3.18	-3.64	-3.19	-2.20	-3.15	-3.10
Size_DblN_peak_Abrams_Research(11)	39.88	39.30	39.91	41.16	39.65	39.97
Size_DblN_ascend_se_Abrams_Research(11)	4.53	4.48	4.53	4.72	4.51	4.56
Size_DblN_descend_se_Abrams_Research(11)	4.55	4.41	4.54	4.97	4.61	4.63
Size_DblN_peak_Rec_PC_North(5)_BLK1 repl_1875	34.21	33.59	34.26	33.26	34.21	34.73
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1 repl_1875	3.86	3.78	3.87	3.79	3.87	3.98
Bratio_2023	0.364	0.440	0.371	0.121	0.367	0.342
SSB_unfished	1205.1	1445.8	1209.3	1755.8	1198.3	1160.5
Totbio_unfished	6573.2	7015.2	6605.6	8242.9	6546.1	6474.8
Recr_unfished	2271.7	2287.5	2301.5	1531.3	2244.3	2281.7
Dead_Catch_SPR	265.1	275.8	266.9	266.9	263.7	262.5
OFLCatch_2023	203.2	251.1	207.4	90.0	201.9	193.5

Table 41: Comparison of northern base model outputs for 'drop-one' analyses (part 2)

Label	Base	Drop Rec PR	Drop Rec Discard	Drop CCFRP	Drop PC Onboard	Drop Abrams
N.Parms	98	97	95	94	98	95
TOTAL	1106.27	969.82	1087.05	1079.62	1118.61	972.18
Survey	-29.97	-12.03	-30.22	-31.27	-16.59	-29.11
Length_comp	366.71	270.54	347.52	349.77	366.41	357.21
Age_comp	773.60	717.43	773.81	764.80	772.79	648.21
Recruitment	-4.58	-6.90	-4.57	-4.26	-4.53	-4.70
Parm_priors	0.52	0.79	0.52	0.58	0.53	0.57
NatM_uniform_Fem_GP_1	0.211	0.228	0.211	0.215	0.212	0.215
L_at_Amax_Fem_GP_1	54.494	54.049	54.479	54.513	54.526	54.311
VonBert_K_Fem_GP_1	0.148	0.151	0.148	0.148	0.147	0.151
CV_old_Fem_GP_1	0.082	0.078	0.082	0.080	0.082	0.082
NatM_uniform_Mal_GP_1	-0.053	-0.075	-0.054	-0.050	-0.052	-0.106
L_at_Amax_Mal_GP_1	-0.147	-0.139	-0.147	-0.146	-0.147	-0.148
VonBert_K_Mal_GP_1	0.312	0.297	0.312	0.308	0.312	0.326
CV_old_Mal_GP_1	-0.319	-0.391	-0.321	-0.309	-0.317	-0.380
SR_LN(R0)	7.728	7.855	7.729	7.761	7.738	7.688
Q_extraSD_Rec_PR_North(6)	0.088	NA	0.088	0.090	0.090	0.092
Size_inflection_Comm_nonTwl_dead(1)	35.93	36.34	35.93	35.86	35.93	35.85
Size_95%width_Comm_nonTwl_dead(1)	5.86	6.04	5.86	5.82	5.86	5.86
Size_DblN_peak_Comm_nonTwl_live(2)	36.23	36.32	36.23	36.22	36.24	36.06
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.09	3.10	3.09	3.09	3.09	3.07
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.68	5.97	5.70	5.63	5.66	5.67
Size_inflection_Comm_Trawl(3)	45.43	46.19	45.44	45.43	45.41	45.72
Size_95%width_Comm_Trawl(3)	5.69	5.82	5.69	5.70	5.68	5.85
Size_DblN_peak_Comm_Discard(4)	27.11	27.22	27.11	27.09	27.10	27.06
Size_DblN_ascend_se_Comm_Discard(4)	3.42	3.44	3.42	3.43	3.42	3.42
Size_DblN_descend_se_Comm_Discard(4)	3.91	3.94	3.91	3.91	3.91	3.89
Size_DblN_peak_Rec_PC_North(5)	40.81	41.50	40.81	40.70	40.81	40.50
Size_DblN_ascend_se_Rec_PC_North(5)	4.21	4.24	4.21	4.20	4.21	4.19
Size_DblN_descend_se_Rec_PC_North(5)	4.75	5.13	4.76	4.73	4.75	4.94
Size_DblN_end_logit_Rec_PC_North(5)	-2.70	-7.81	-2.70	-2.55	-2.70	-2.93
Size_DblN_peak_Rec_Disc_North(7)	28.39	28.58	28.39	28.29	28.40	28.32
Size_DblN_ascend_se_Rec_Disc_North(7)	4.20	4.22	4.20	4.19	4.20	4.20
Size_DblN_descend_se_Rec_Disc_North(7)	4.51	4.54	4.51	4.51	4.51	4.50
Size_DblN_peak_CCFRP(8)	42.17	42.60	42.18	42.17	42.08	41.98
Size_DblN_ascend_se_CCFRP(8)	4.59	4.58	4.59	4.59	4.60	4.60
Size_DblN_descend_se_CCFRP(8)	2.81	2.66	2.80	2.81	2.84	2.88
Size_DblN_end_logit_CCFRP(8)	-3.18	-2.74	-3.17	-3.18	-3.20	-3.09
Size_DblN_peak_Abrams_Research(11)	39.88	39.96	39.85	39.76	39.95	39.88
Size_DblN_ascend_se_Abrams_Research(11)	4.53	4.53	4.52	4.51	4.53	4.53
Size_DblN_descend_se_Abrams_Research(11)	4.55	4.79	4.56	4.55	4.53	4.55
Size_DblN_peak_Rec_PC_North(5)_BLK1 repl_1875	34.21	32.95	34.21	34.20	34.22	34.00
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1 repl_1875	3.86	3.35	3.86	3.86	3.86	3.84
Bratio_2023	0.364	0.379	0.357	0.405	0.374	0.378
SSB_unfished	1205.1	1059.9	1206.9	1180.5	1205.6	1109.2
Totbio_unfished	6573.2	6501.5	6588.0	6523.7	6579.7	6501.8
Recr_unfished	2271.7	2577.6	2273.9	2347.3	2293.1	2182.6
Dead_Catch_SPR	265.1	275.4	265.7	265.9	265.8	266.3
OFLCatch_2023	203.2	233.4	201.7	207.6	204.6	208.6

Table 42: Comparison of northern base model sensitivity analyses.

Label	Base (Francis)	M-I weights	share M	All domed	Est. all growth	Est. steep
N.Parms	98	98	97	102	102	99
TOTAL	1106.27	1130.80	1078.45	1121.88	1101.32	1064.90
Survey	-29.97	-28.27	-29.75	-29.98	-29.81	-29.94
Length_comp	366.71	643.56	373.87	366.92	363.86	371.12
Age_comp	773.60	519.17	738.53	788.57	771.11	728.85
Recruitment	-4.58	-3.84	-4.64	-3.95	-4.38	-5.40
Parm_priors	0.52	0.18	0.43	0.31	0.53	0.27
NatM_uniform_Fem_GP_1	0.211	0.186	0.206	0.197	0.212	0.191
L_at_Amin_Fem_GP_1	5.000	5.000	5.000	5.000	5.160	5.000
L_at_Amax_Fem_GP_1	54.494	53.189	54.522	56.597	54.565	54.513
VonBert_K_Fem_GP_1	0.148	0.157	0.147	0.135	0.146	0.148
CV_young_Fem_GP_1	0.100	0.100	0.100	0.100	0.109	0.100
CV_old_Fem_GP_1	0.082	0.079	0.083	0.086	0.072	0.080
NatM_uniform_Mal_GP_1	-0.053	-0.065	0.000	-0.010	-0.050	-0.046
L_at_Amin_Mal_GP_1	0.000	0.000	0.000	0.000	-1.000	0.000
L_at_Amax_Mal_GP_1	-0.147	-0.134	-0.145	-0.178	-0.154	-0.147
VonBert_K_Mal_GP_1	0.312	0.257	0.312	0.391	0.396	0.312
CV_young_Mal_GP_1	0.000	0.000	0.000	0.000	0.012	0.000
CV_old_Mal_GP_1	-0.319	-0.255	-0.336	-0.313	-0.329	-0.298
SR_LN(R0)	7.728	7.523	7.744	7.691	7.747	7.369
SR_BH_steep	0.720	0.720	0.720	0.720	0.720	0.896
Q_extraSD_Rec_PR_North(6)	0.088	0.097	0.088	0.086	0.089	0.091
Size_inflection_Comm_nonTwl_dead(1)	35.93	35.96	35.84	NA	35.78	35.89
Size_95%width_Comm_nonTwl_dead(1)	5.86	5.96	5.80	NA	5.81	5.85
Size_DblN_peak_Comm_nonTwl_live(2)	36.23	36.01	36.22	36.21	36.11	36.17
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.09	3.05	3.09	3.10	3.07	3.09
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.68	5.97	5.61	5.19	5.64	5.65
Size_inflection_Comm_Trawl(3)	45.43	45.30	45.18	NA	45.64	45.42
Size_95%width_Comm_Trawl(3)	5.69	5.97	5.62	NA	5.85	5.70
Size_DblN_peak_Comm_Discard(4)	27.11	26.95	27.11	27.09	27.09	27.04
Size_DblN_ascend_se_Comm_Discard(4)	3.42	3.41	3.42	3.42	3.42	3.42
Size_DblN_descend_se_Comm_Discard(4)	3.91	3.90	3.91	3.89	3.90	3.90
Size_DblN_peak_Rec_PC_North(5)	40.81	40.70	40.74	40.29	40.50	40.54
Size_DblN_ascend_se_Rec_PC_North(5)	4.21	4.23	4.20	4.16	4.18	4.19
Size_DblN_descend_se_Rec_PC_North(5)	4.75	4.78	4.67	4.57	4.78	4.71
Size_DblN_end_logit_Rec_PC_North(5)	-2.70	-1.73	-2.75	-4.12	-2.50	-2.74
Size_DblN_peak_Rec_Disc_North(7)	28.39	28.12	28.40	28.32	28.34	28.21
Size_DblN_ascend_se_Rec_Disc_North(7)	4.20	4.22	4.20	4.20	4.20	4.20
Size_DblN_descend_se_Rec_Disc_North(7)	4.51	4.54	4.50	4.47	4.49	4.50
Size_DblN_peak_CCFRP(8)	42.17	41.99	42.09	41.78	41.95	41.95
Size_DblN_ascend_se_CCFRP(8)	4.59	4.61	4.59	4.57	4.59	4.60
Size_DblN_descend_se_CCFRP(8)	2.81	2.86	2.82	2.90	2.87	2.86
Size_DblN_end_logit_CCFRP(8)	-3.18	-3.03	-3.31	-3.87	-3.18	-3.33
Size_DblN_peak_Abrams_Research(11)	39.88	40.97	39.82	39.39	39.40	39.62
Size_DblN_ascend_se_Abrams_Research(11)	4.53	4.66	4.52	4.48	4.48	4.52
Size_DblN_descend_se_Abrams_Research(11)	4.55	4.40	4.49	4.37	4.62	4.54
Size_DblN_peak_Rec_PC_North(5)_BLK1repl_1875	34.21	33.89	34.20	33.85	34.04	34.19
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1repl_1875	3.86	3.87	3.86	3.82	3.84	3.87
Size_DblN_peak_Comm_nonTwl_dead(1)	NA	NA	NA	42.49	NA	NA
Size_DblN_top_logit_Comm_nonTwl_dead(1)	NA	NA	NA	-6.00	NA	NA
Size_DblN_ascend_se_Comm_nonTwl_dead(1)	NA	NA	NA	3.97	NA	NA
Size_DblN_descend_se_Comm_nonTwl_dead(1)	NA	NA	NA	4.31	NA	NA
Size_DblN_start_logit_Comm_nonTwl_dead(1)	NA	NA	NA	-10.00	NA	NA
Size_DblN_end_logit_Comm_nonTwl_dead(1)	NA	NA	NA	-10.28	NA	NA
Size_DblN_peak_Comm_Trawl(3)	NA	NA	NA	50.63	NA	NA
Size_DblN_top_logit_Comm_Trawl(3)	NA	NA	NA	-6.00	NA	NA
Size_DblN_ascend_se_Comm_Trawl(3)	NA	NA	NA	3.81	NA	NA
Size_DblN_descend_se_Comm_Trawl(3)	NA	NA	NA	3.55	NA	NA
Size_DblN_start_logit_Comm_Trawl(3)	NA	NA	NA	-10.00	NA	NA
Size_DblN_end_logit_Comm_Trawl(3)	NA	NA	NA	-8.88	NA	NA
Bratio_2023	0.36	0.28	0.37	0.43	0.37	0.39
SSB_unfished	1205.1	1300.1	1325.5	1629.0	1207.4	1137.1
Totbio_unfished	6573.2	6829.6	6731.7	7236.6	6538.7	5638.1
Recr_unfished	2271.7	1850.8	2307.1	2187.9	2314.8	1586.2
Dead_Catch_SPR	265.1	255.8	267.4	276.3	267.6	231.7
OFLCatch_2023	203.2	160.6	208.0	238.4	208.9	183.1

Table 43: Steepness profile for the northern California base model (part 1, values 0.25 – 0.6). Note that steepness values of 0.25 and 0.3 are inconsistent with a proxy MSY harvest rate of F(SPR_50%).

Beverton-Holt steepness	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
TOTAL	1134.6	1128.0	1123.0	1119.0	1115.9	1113.3	1111.2	1109.4
Survey	-28.3	-29.0	-29.4	-29.7	-29.8	-29.9	-30.0	-30.0
Length_comp	373.8	371.6	370.1	369.0	368.2	367.7	367.2	367.0
Age_comp	780.7	779.3	778.2	777.3	776.5	775.9	775.3	774.7
Recruitment	1.5	1.0	0.2	-0.7	-1.5	-2.2	-2.9	-3.4
Parm_priors	6.9	5.1	3.9	3.1	2.4	1.9	1.5	1.1
NatM_uniform_Fem_GP_1	0.320	0.299	0.283	0.269	0.257	0.246	0.237	0.229
L_at_Amax_Fem_GP_1	54.10	54.12	54.16	54.20	54.25	54.29	54.34	54.39
VonBert_K_Fem_GP_1	0.149	0.149	0.149	0.149	0.149	0.149	0.148	0.148
CV_old_Fem_GP_1	0.085	0.084	0.084	0.084	0.083	0.083	0.083	0.082
NatM_uniform_Mal_GP_1	-0.050	-0.052	-0.053	-0.054	-0.054	-0.054	-0.054	-0.054
L_at_Amax_Mal_GP_1	-0.141	-0.142	-0.142	-0.143	-0.144	-0.144	-0.145	-0.146
VonBert_K_Mal_GP_1	0.293	0.294	0.296	0.298	0.300	0.302	0.305	0.307
CV_old_Mal_GP_1	-0.345	-0.341	-0.338	-0.335	-0.332	-0.330	-0.327	-0.325
SR_LN(R0)	9.90	9.39	9.04	8.77	8.54	8.35	8.18	8.03
Q_extraSD_Rec_PR_North(6)	0.087	0.084	0.083	0.083	0.083	0.084	0.085	0.085
Size_inflection_Comm_nonTwl_dead(1)	35.753	35.816	35.856	35.884	35.903	35.916	35.925	35.930
Size_95%width_Comm_nonTwl_dead(1)	5.665	5.721	5.760	5.789	5.811	5.828	5.840	5.849
Size_DblN_peak_Comm_nonTwl_live(2)	36.505	36.456	36.415	36.379	36.348	36.322	36.298	36.277
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.113	3.109	3.106	3.104	3.102	3.100	3.098	3.097
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.558	5.603	5.633	5.654	5.669	5.680	5.686	5.689
Size_inflection_Comm_Trawl(3)	45.235	45.308	45.353	45.382	45.401	45.414	45.422	45.426
Size_95%width_Comm_Trawl(3)	5.605	5.635	5.653	5.665	5.674	5.679	5.683	5.685
Size_DblN_peak_Comm_Discard(4)	27.495	27.418	27.358	27.310	27.268	27.232	27.199	27.170
Size_DblN_ascend_se_Comm_Discard(4)	3.426	3.425	3.424	3.423	3.423	3.423	3.422	3.422
Size_DblN_descend_se_Comm_Discard(4)	3.956	3.950	3.943	3.937	3.932	3.927	3.922	3.918
Size_DblN_peak_Rec_PC_North(5)	41.612	41.522	41.421	41.326	41.237	41.152	41.071	40.992
Size_DblN_ascend_se_Rec_PC_North(5)	4.230	4.232	4.232	4.230	4.228	4.225	4.222	4.219
Size_DblN_descend_se_Rec_PC_North(5)	4.803	4.803	4.800	4.796	4.791	4.785	4.778	4.772
Size_DblN_end_logit_Rec_PC_North(5)	-2.246	-2.274	-2.318	-2.366	-2.418	-2.470	-2.522	-2.574
Size_DblN_peak_Rec_Disc_North(7)	29.184	29.043	28.928	28.830	28.745	28.671	28.604	28.543
Size_DblN_ascend_se_Rec_Disc_North(7)	4.218	4.217	4.215	4.214	4.213	4.212	4.211	4.210
Size_DblN_descend_se_Rec_Disc_North(7)	4.559	4.552	4.545	4.538	4.532	4.527	4.522	4.517
Size_DblN_peak_CCFRP(8)	42.910	42.814	42.718	42.630	42.548	42.472	42.399	42.328
Size_DblN_ascend_se_CCFRP(8)	4.565	4.573	4.578	4.582	4.585	4.587	4.590	4.591
Size_DblN_descend_se_CCFRP(8)	2.543	2.581	2.618	2.651	2.681	2.707	2.731	2.755
Size_DblN_end_logit_CCFRP(8)	-2.681	-2.737	-2.796	-2.853	-2.908	-2.960	-3.011	-3.062
Size_DblN_peak_Abrams_Research(11)	40.689	40.585	40.479	40.381	40.293	40.212	40.135	40.059
Size_DblN_ascend_se_Abrams_Research(11)	4.521	4.526	4.529	4.531	4.532	4.532	4.533	4.532
Size_DblN_descend_se_Abrams_Research(11)	4.568	4.573	4.575	4.575	4.572	4.569	4.565	4.562
Size_DblN_peak_Rec_PC_North(5)_BLK1repl_1875	33.939	34.029	34.087	34.127	34.154	34.174	34.189	34.200
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1repl_1875	3.784	3.806	3.820	3.831	3.839	3.846	3.851	3.856
Bratio_2023	0.416	0.370	0.354	0.347	0.345	0.346	0.348	0.351
SSB_unfished	2590	1988	1719	1560	1455	1379	1323	1279
Totbio_unfished	22824	16038	12898	11017	9744	8819	8113	7552
Recr_unfished	19923	11968	8434	6422	5130	4235	3581	3084
Equil. Yield at SPR50% proxy for MSY	0.0	0.0	91.1	227.9	275.7	290.6	291.5	286.3
OFLCatch_2023	783.7	500.3	389.7	329.0	290.1	263.1	243.2	228.0

Table 44: Steepness profile for the northern California base model (part 2, values 0.65 – 0.95), including the assumed value of 0.72 in the base model.

Beverton-Holt steepness	0.65	0.7	0.72	0.75	0.8	0.85	0.9	0.95
TOTAL	1107.9	1106.7	1106.3	1105.7	1105.0	1104.6	1104.4	1104.7
Survey	-30.0	-30.0	-30.0	-30.0	-29.9	-29.9	-29.9	-29.8
Length_comp	366.8	366.7	366.7	366.7	366.8	367.0	367.2	367.5
Age_comp	774.2	773.8	773.6	773.4	772.9	772.6	772.2	771.9
Recruitment	-4.0	-4.4	-4.6	-4.8	-5.1	-5.3	-5.4	-5.4
Parm_priors	0.8	0.6	0.5	0.4	0.3	0.2	0.3	0.6
NatM_uniform_Fem_GP_1	0.221	0.214	0.211	0.208	0.202	0.197	0.192	0.189
L_at_Amax_Fem_GP_1	54.43	54.48	54.49	54.52	54.56	54.60	54.63	54.64
VonBert_K_Fem_GP_1	0.148	0.148	0.148	0.148	0.147	0.147	0.147	0.147
CV_old_Fem_GP_1	0.082	0.082	0.082	0.082	0.081	0.081	0.081	0.081
NatM_uniform_Mal_GP_1	-0.054	-0.054	-0.053	-0.053	-0.053	-0.052	-0.051	-0.051
L_at_Amax_Mal_GP_1	-0.146	-0.147	-0.147	-0.147	-0.148	-0.149	-0.149	-0.149
VonBert_K_Mal_GP_1	0.309	0.311	0.312	0.313	0.315	0.316	0.318	0.318
CV_old_Mal_GP_1	-0.322	-0.320	-0.319	-0.318	-0.316	-0.313	-0.312	-0.310
SR_LN(R0)	7.90	7.78	7.73	7.66	7.56	7.46	7.37	7.30
Q_extraSD_Rec_PR_North(6)	0.086	0.087	0.088	0.088	0.089	0.090	0.091	0.091
Size_inflection_Comm_nonTwl_dead(1)	35.931	35.929	35.928	35.925	35.917	35.905	35.887	35.859
Size_95%width_Comm_nonTwl_dead(1)	5.855	5.858	5.859	5.859	5.857	5.852	5.844	5.830
Size_DblN_peak_Comm_nonTwl_live(2)	36.257	36.239	36.232	36.223	36.207	36.191	36.176	36.160
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.095	3.094	3.093	3.093	3.092	3.090	3.089	3.087
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.689	5.686	5.684	5.680	5.671	5.659	5.643	5.622
Size_inflection_Comm_Trawl(3)	45.427	45.427	45.427	45.426	45.425	45.425	45.428	45.437
Size_95%width_Comm_Trawl(3)	5.687	5.687	5.688	5.688	5.688	5.690	5.693	5.699
Size_DblN_peak_Comm_Discard(4)	27.143	27.118	27.109	27.095	27.074	27.055	27.038	27.025
Size_DblN_ascend_se_Comm_Discard(4)	3.422	3.422	3.422	3.422	3.422	3.422	3.422	3.422
Size_DblN_descend_se_Comm_Discard(4)	3.914	3.910	3.909	3.906	3.903	3.899	3.895	3.891
Size_DblN_peak_Rec_PC_North(5)	40.914	40.837	40.807	40.761	40.684	40.607	40.527	40.438
Size_DblN_ascend_se_Rec_PC_North(5)	4.215	4.211	4.210	4.207	4.203	4.198	4.193	4.186
Size_DblN_descend_se_Rec_PC_North(5)	4.765	4.758	4.755	4.750	4.743	4.735	4.727	4.722
Size_DblN_end_logit_Rec_PC_North(5)	-2.625	-2.675	-2.695	-2.724	-2.770	-2.812	-2.846	-2.872
Size_DblN_peak_Rec_Disc_North(7)	28.480	28.411	28.386	28.353	28.303	28.257	28.214	28.179
Size_DblN_ascend_se_Rec_Disc_North(7)	4.209	4.205	4.204	4.203	4.202	4.202	4.201	4.200
Size_DblN_descend_se_Rec_Disc_North(7)	4.513	4.512	4.511	4.509	4.505	4.501	4.498	4.494
Size_DblN_peak_CCFRP(8)	42.259	42.192	42.166	42.126	42.062	41.999	41.937	41.875
Size_DblN_ascend_se_CCFRP(8)	4.593	4.594	4.595	4.596	4.597	4.598	4.599	4.599
Size_DblN_descend_se_CCFRP(8)	2.777	2.797	2.805	2.817	2.835	2.852	2.869	2.884
Size_DblN_end_logit_CCFRP(8)	-3.111	-3.159	-3.178	-3.207	-3.253	-3.299	-3.341	-3.380
Size_DblN_peak_Abrams_Research(11)	39.985	39.910	39.881	39.836	39.760	39.683	39.601	39.511
Size_DblN_ascend_se_Abrams_Research(11)	4.531	4.530	4.529	4.528	4.526	4.523	4.520	4.515
Size_DblN_descend_se_Abrams_Research(11)	4.557	4.553	4.552	4.549	4.545	4.541	4.539	4.537
Size_DblN_peak_Rec_PC_North(5)_BLK1repl_1875	34.208	34.213	34.214	34.216	34.215	34.211	34.201	34.182
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1repl_1875	3.859	3.862	3.863	3.864	3.866	3.867	3.867	3.865
Bratio_2023	0.356	0.361	0.364	0.368	0.375	0.385	0.398	0.417
SSB_unfished	1244	1215	1205	1191	1169	1149	1128	1104
Totbio_unfished	7094	6710	6573	6382	6096	5844	5618	5421
Recr_unfished	2694	2380	2272	2123	1910	1733	1590	1483
Equil. Yield at SPR50% proxy for MSY	278.2	269.0	265.1	259.3	249.7	240.5	231.9	224.8
OFLCatch_2023	216.1	206.5	203.2	198.7	192.4	187.6	184.6	184.5

Table 45: Female natural mortality profile for the northern California base model.

Quantity	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.22	0.24	0.26	0.28	0.3
N.Parms	97	97	97	97	97	97	97	97	97	97	97	97
TOTAL	1237	1184	1150	1128	1115	1109	1107	1106	1108	1110	1113	1116
Survey	-28.1	-29.0	-29.8	-30.2	-30.4	-30.3	-30.1	-29.9	-29.7	-29.5	-29.4	-29.3
Length_comp	386	379	372	368	367	366	366	367	367	368	369	370
Age_comp	828	808	794	785	779	775	774	774	774	775	776	777
Recruitment	49.0	25.5	12.4	5.0	0.4	-2.4	-4.0	-4.8	-5.1	-4.9	-4.5	-3.9
Parm_priors	2.2	1.0	0.3	0.0	0.0	0.1	0.4	0.7	1.0	1.4	1.8	2.3
L_at_Amax_Fem_GP_1	52.5	53.4	53.8	54.1	54.3	54.4	54.5	54.5	54.5	54.5	54.4	54.4
VonBert_K_Fem_GP_1	0.17	0.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
CV_old_Fem_GP_1	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
NatM_uniform_Mal_GP_1	0.19	0.12	0.05	0.01	-0.02	-0.04	-0.05	-0.05	-0.06	-0.06	-0.06	-0.06
L_at_Amax_Mal_GP_1	-0.11	-0.13	-0.14	-0.14	-0.14	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.14
VonBert_K_Mal_GP_1	0.24	0.28	0.29	0.30	0.31	0.31	0.31	0.31	0.31	0.30	0.30	0.30
CV_old_Mal_GP_1	-0.46	-0.39	-0.37	-0.36	-0.35	-0.33	-0.32	-0.32	-0.31	-0.31	-0.31	-0.30
SR_LN(R0)	6.34	6.65	6.89	7.09	7.26	7.43	7.62	7.82	8.03	8.26	8.50	8.76
Q_extraSD_Rec_PR_North(6)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08
Size_inflection_Comm_nonTwl_dead(1)	34.6	34.8	35.1	35.4	35.6	35.8	35.9	36.0	36.0	36.1	36.2	36.3
Size_95%width_Comm_nonTwl_dead(1)	5.35	5.45	5.58	5.71	5.81	5.85	5.86	5.85	5.85	5.86	5.87	5.89
Size_DblN_peak_Comm_nonTwl_live(2)	35.6	35.7	35.9	36.0	36.1	36.1	36.2	36.3	36.3	36.4	36.5	36.5
Size_DblN_ascend_se_Comm_nonTwl_live(2)	3.01	3.03	3.05	3.06	3.08	3.08	3.09	3.10	3.10	3.10	3.11	3.12
Size_DblN_descend_se_Comm_nonTwl_live(2)	5.79	5.70	5.72	5.76	5.77	5.75	5.71	5.67	5.66	5.69	5.74	5.81
Size_inflection_Comm_Trawl(3)	43.7	43.8	44.2	44.6	45.0	45.2	45.4	45.5	45.5	45.6	45.6	45.7
Size_95%width_Comm_Trawl(3)	5.29	5.29	5.39	5.51	5.59	5.65	5.68	5.69	5.69	5.69	5.68	5.67
Size_DblN_peak_Comm_Discard(4)	26.6	26.7	26.8	26.9	26.9	27.0	27.1	27.1	27.2	27.3	27.3	27.4
Size_DblN_ascend_se_Comm_Discard(4)	3.45	3.44	3.44	3.43	3.43	3.43	3.42	3.42	3.42	3.42	3.42	3.42
Size_DblN_descend_se_Comm_Discard(4)	3.85	3.86	3.88	3.89	3.90	3.90	3.91	3.91	3.92	3.92	3.94	3.95
Size_DblN_peak_Rec_PC_North(5)	39.6	40.0	40.3	40.6	40.7	40.8	40.8	40.8	40.9	41.0	41.3	41.5
Size_DblN_ascend_se_Rec_PC_North(5)	4.16	4.19	4.21	4.22	4.23	4.23	4.22	4.21	4.20	4.21	4.22	4.23
Size_DblN_descend_se_Rec_PC_North(5)	4.63	4.60	4.64	4.68	4.72	4.75	4.75	4.76	4.76	4.77	4.79	4.82
Size_DblN_end_logit_Rec_PC_North(5)	-2.86	-2.99	-2.97	-2.93	-2.89	-2.84	-2.75	-2.65	-2.53	-2.41	-2.29	-2.17
Size_DblN_peak_Rec_Disc_North(7)	27.2	27.4	27.6	27.8	28.0	28.2	28.3	28.5	28.6	28.7	28.9	29.1
Size_DblN_ascend_se_Rec_Disc_North(7)	4.20	4.20	4.20	4.21	4.21	4.21	4.20	4.21	4.21	4.21	4.21	4.22
Size_DblN_descend_se_Rec_Disc_North(7)	4.57	4.56	4.55	4.54	4.53	4.52	4.51	4.51	4.51	4.52	4.53	4.55
Size_DblN_peak_CCFRP(8)	41.1	41.4	41.7	41.9	42.0	42.1	42.1	42.2	42.3	42.4	42.6	42.8
Size_DblN_ascend_se_CCFRP(8)	4.71	4.69	4.67	4.65	4.63	4.62	4.60	4.59	4.58	4.58	4.57	4.57
Size_DblN_descend_se_CCFRP(8)	3.06	2.98	2.93	2.89	2.85	2.83	2.81	2.80	2.77	2.72	2.66	2.59
Size_DblN_end_logit_CCFRP(8)	-3.86	-3.79	-3.63	-3.47	-3.34	-3.26	-3.21	-3.15	-3.08	-2.98	-2.87	-2.74
Size_DblN_peak_Abrams_Research(11)	38.53	38.93	39.27	39.56	39.77	39.88	39.89	39.88	39.94	40.09	40.30	40.57
Size_DblN_ascend_se_Abrams_Research(11)	4.51	4.52	4.54	4.55	4.55	4.55	4.54	4.52	4.52	4.51	4.52	4.52
Size_DblN_descend_se_Abrams_Research(11)	4.48	4.45	4.47	4.50	4.52	4.53	4.55	4.56	4.57	4.57	4.58	4.59
Size_DblN_peak_Rec_PC_North(5)_BLK1 repl_1875	33.2	33.3	33.5	33.7	33.9	34.0	34.2	34.3	34.4	34.5	34.6	34.8
Size_DblN_ascend_se_Rec_PC_North(5)_BLK1 repl_1875	3.86	3.86	3.86	3.87	3.87	3.87	3.87	3.86	3.86	3.86	3.87	3.88
Bratio_2023	0.12	0.13	0.14	0.16	0.20	0.24	0.31	0.40	0.50	0.59	0.68	0.75
SSB_unfished	2705	2539	2227	1909	1638	1424	1269	1167	1103	1066	1050	1057
Totbio_unfished	8039	8096	7838	7450	7064	6753	6584	6608	6821	7206	7773	8579
Recr_unfished	568	775	985	1197	1427	1694	2031	2480	3081	3875	4928	6360
Dead_Catch_SPR	166	196	216	229	238	246	257	273	296	326	365	415
OFLCatch_2023	58.9	71.9	84.0	97.6	115.5	140.6	176.6	225.8	287.3	359.6	444.1	546.5

Table 46: Data weights by fleet and data type in the central base model and using an alternative data weighting method (McAllister-Ianelli).

Fleet name	Data Type	Base (Francis Weights)	McAllister-Ianelli weights
Comm_nonTwl	length	1	1
Comm_Discard	length	0.234979	0.553307
Rec_PC_Central	length	0.163105	0.276469
Rec_PR_Central	length	0.209161	0.180067
Rec_Disc_Central	length	0.406678	1
CCFRP	length	0.083533	0.422884
DWV_Onboard_CPFV	length	0.160869	1
CDFG_Lea_Research	length	0.20309	0.166601
Rec_PC_Central	age	0.439739	0.411451
Rec_PR_Central	age	0.283349	0.187136
CCFRP	age	0.174282	0.435953
CDFG_Lea_Research	age	0.130598	0.343527

Table 47: Parameters used in the central California base case assessment model. See separate table for selectivity parameters.

Parameter	Number Estimated	Bounds (low, high)	Prior (Mean, SD) - Type	Value	Transformed Value	SE	gradient
General Biology							
Natural mortality (M) - female	0	(0.01, 0.6)	(-1.869, 0.31) - Lognormal	0.211		_	_
Nat. mortality (M) - male (offset)	0	(-1, 1)	-	-0.053	0.200	_	_
Ln (R_0)	1	(4, 9)	-	6.479	651.0	0.050	5E-06
Steepness (h)	0	(0.201, 0.999)	(0.72, 0.16) - Full Beta	0.720		-	-
Growth							
Length at age 0 - female	0	(3, 30)	-	5.000		-	-
Length at age 20 - female	1	(45, 65)	-	54.651		2.001	9E-07
von Bertalnaffy k - female	1	(0.05, 0.25)	-	0.145		0.012	1E-06
CV(L(age 0)) - female	0	(0.01, 0.2)	-	0.100		-	-
CV(L(age 20)) - female	0	(0.01, 0.2)	-	0.082		_	_
Length at age 0 - male (offset)	0	(-1, 1)	-	0.000	5.000	-	-
Length at age 20 - male (offset)	1	(-1, 1)	-	-0.100	49.438	0.042	1E-06
von Bertalnaffy k - male (offset)	1	(-1, 1)	-	0.246	0.185	0.101	7E-07
CV(L(age 0)) - male (offset)	0	(-1, 1)	-	0.000	0.100	-	-
CV(L(age 20)) - male (offset)	0	(-1, 1)	-	-0.319	0.060	_	_
Indices							
Extra SD - CRFS private dockside	1	(-5, 5)	-	-0.471		0.380	-4E-07
Recruitment Deviations (sum=0)							
SD of log-scale rec devs (sigma-R)	0	(0, 1)		0.60		-	-
Early Recruitment Deviation Parameters				Min	Max	maxSE	maxGrad
1935-1954	20	(-5, 5)	-	0.004	0.055	0.604	4E-07
Main Recruitment Deviation Parameters				Min	Max	maxSE	maxGrad
1955-2022	68	(-5, 5)	-	-1.068	1.689	0.618	3E-06
Selectivity (see separate table)							
Summary of model parameters (see separate table for selectivity parameters)							
Number of parameters in model	166						
Estimated parameters	118	(including 2 forecast devs)					
Number within 1% of bound	0						

Table 48: Selectivity parameters used in the central California base case assessment model.

Parameter	Number Estimated	Bounds (low, high)	Prior (Mean, SD) - Type	Value	Transformed Value	SE	gradient
Selectivity							
<u>Commercial Non-Trawl</u>							
Double-Normal Peak	1	(15, 45)	-	29.956		3.142	4E-07
Double-Normal Top (logit)	0	(-10, 10)	-	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(0.5, 7)	-	2.815		1.117	-2E-07
Double-Normal Descending SE	1	(0.5, 10)	-	4.502		1.651	-1E-07
Double-Normal Initial (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
Double-Normal Final (logit)	1	(-15, 15)	-	-1.320	0.211	1.634	-1E-07
<u>Commercial Trawl (mirrors Non-Trawl)</u>							
<u>Commercial Discard</u>							
Double-Normal Peak	1	(15, 40)	-	27.498		0.848	4E-07
Double-Normal Top (logit)	0	(-10, 10)	-	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(1, 7)	-	3.432		0.255	-2E-07
Double-Normal Descending SE	1	(1, 7)	-	3.975		0.278	2E-07
Double-Normal Initial (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
Double-Normal Final (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
<u>Recreational CPFV, 2004-present</u>							
Double-Normal Peak	1	(28, 38)	-	32.994		0.309	1E-06
Double-Normal Top (logit)	0	(-10, 10)	-	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(2, 5)	-	3.516		0.066	-1E-06
Double-Normal Descending SE	1	(0.1, 5)	-	2.057		0.245	-3E-07
Double-Normal Initial (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
Double-Normal Final (logit)	1	(-5, 5)	-	-2.046	0.114	0.206	2E-06
<u>Recreational Private Boat (mirrors CPFV)</u>							
<u>Recreational Discard</u>							
Double-Normal Peak	1	(10, 40)	-	24.278		2.408	5E-08
Double-Normal Top (logit)	0	(-10, 0)	-	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(1, 8)	-	3.588		0.676	2E-08
Double-Normal Descending SE	1	(1, 8)	-	4.234		0.679	1E-07
Double-Normal Initial (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
Double-Normal Final (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
<u>CCFRP</u>							
Double-Normal Peak	1	(15, 45)	-	32.809		0.742	2E-06
Double-Normal Top (logit)	0	(-10, 10)	-	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(0.05, 8)	-	4.005		0.149	3E-07
Double-Normal Descending SE	1	(0.05, 10)	-	2.169		0.492	1E-06
Double-Normal Initial (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
Double-Normal Final (logit)	1	(-20, 20)	-	-4.667	0.009	1.232	1E-07
<u>CRFS CPFV Onboard (PCO; mirrors CPFV)</u>							
<u>DWV CPFV Onboard</u>							
Double-Normal Peak	1	(20, 40)	-	29.382		1.676	-6E-07
Double-Normal Top (logit)	0	(-10, 10)	-	-6.000	0.002	_	_
Double-Normal Ascending SE	1	(0.1, 7)	-	2.720		0.552	7E-08
Double-Normal Descending SE	1	(0.1, 8)	-	3.081		1.189	-2E-07
Double-Normal Initial (logit)	0	(-11, -9)	-	-10.000	0.000	_	_
Double-Normal Final (logit)	1	(-6, 6)	-	-1.249	0.223	0.666	-4E-08

Table 49: Estimates of female natural mortality conditioned on alternative fixed values of steepness in the central California model.

h	M|h from 2-D profile	M|h (M estimated)	NLL
0.25	0.28	0.275	533.813
0.3	0.26	0.269	531.044
0.35	0.26	0.262	529.009
0.4	0.26	0.256	527.487
0.45	0.26	0.250	526.34
0.5	0.24	0.245	525.328
0.55	0.24	0.239	524.912
0.6	0.24	0.234	524.021
0.65	0.22	0.229	523.659
0.7	0.22	0.223	523.357
0.75	0.22	0.218	523.273
0.8	0.22	0.213	523.417
0.85	0.20	0.208	523.752
0.90	0.2	0.206	524.303
0.95	0.2	0.208	525.221

Table 50: Number of estimated parameters, likelihood values, parameter estimates, and derived quantities for the three alternative states of nature in the central California model, as described in request 11.

Label	**Central, base**	**Central, M=0.300**	**Central, M=0.147**
N.Parms	118	118	118
TOTAL	520.484	524.917	527.597
Survey	20.6343	17.5095	22.1225
Length_comp	319.157	319.714	322.546
Age_comp	178.095	181.866	179.565
Recruitment	2.09745	3.52576	3.35007
Parm_priors	0.498516	2.3007	0.0121744
NatM_uniform_Fem_GP_1	0.21026	0.3	0.147
L_at_Amax_Fem_GP_1	54.6712	55.9329	53.4577
VonBert_K_Fem_GP_1	0.144782	0.137387	0.152801
L_at_Amax_Mal_GP_1	-0.10082	-0.116921	-0.0893332
VonBert_K_Mal_GP_1	0.24799	0.278353	0.225275
SR_LN(R0)	6.47327	7.02112	6.11101
Q_extraSD_Rec_PR_Central(5)	0.377881	0.362366	0.377306
Size_DblN_peak_Comm_nonTwl(1)	29.9412	30.056	29.5288
Size_DblN_ascend_se_Comm_nonTwl(1)	2.81086	2.81972	2.71577
Size_DblN_descend_se_Comm_nonTwl(1)	4.52856	4.79617	4.34205
Size_DblN_end_logit_Comm_nonTwl(1)	-1.33925	-1.61883	-1.37348
Size_DblN_peak_Comm_Discard(3)	27.4959	27.7505	27.2327
Size_DblN_ascend_se_Comm_Discard(3)	3.4325	3.42739	3.4279
Size_DblN_descend_se_Comm_Discard(3)	3.97451	4.0256	3.90991
Size_DblN_peak_Rec_PC_Central(4)	32.993	33.2072	32.7007
Size_DblN_ascend_se_Rec_PC_Central(4)	3.51636	3.51827	3.50563
Size_DblN_descend_se_Rec_PC_Central(4)	2.05918	1.85688	2.2639
Size_DblN_end_logit_Rec_PC_Central(4)	-2.04922	-1.74457	-2.44505
Size_DblN_peak_Rec_Disc_Central(6)	24.2756	24.6617	23.9039
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.58767	3.59827	3.5665
Size_DblN_descend_se_Rec_Disc_Central(6)	4.2343	4.27171	4.19077
Size_DblN_peak_CCFRP(7)	32.8079	33.027	32.5214
Size_DblN_ascend_se_CCFRP(7)	4.00553	3.99054	4.01249
Size_DblN_descend_se_CCFRP(7)	2.16916	2.09659	2.25166
Size_DblN_end_logit_CCFRP(7)	-4.67126	-4.32086	-5.08348
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.3786	29.5837	28.967
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.71895	2.76686	2.61836
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.08284	2.82761	3.39622
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.2525	-0.863897	-1.85692
Bratio_2023	0.420579	0.608575	0.361595
SSB_unfished	324.133	187.23	553.927
Totbio_unfished	1959.46	1554.2	2733.35
Recr_unfished	647.6	1120.04	450.793
Dead_Catch_SPR	64.8502	70.0031	63.827
OFLCatch_2023	48.4745	62.1215	46.0443

Table 51: Number of estimated parameters, likelihood values, parameter estimates, and derived quantities from the pre-STAR and revised (post-STAR) models.

Label	**Pre-STAR central base model**	**Proposed final base, updated ageing error and maturity**
N.Parms	118	118
TOTAL	523.4	520.5
Survey	20.6	20.6
Length_comp	319.3	319.2
Age_comp	180.8	178.1
Recruitment	2.1	2.1
Parm_priors	0.5	0.5
NatM_uniform_Fem_GP_1	0.211	0.210
L_at_Amax_Fem_GP_1	54.651	54.671
VonBert_K_Fem_GP_1	0.145	0.145
NatM_uniform_Mal_GP_1	-0.053	-0.051
L_at_Amax_Mal_GP_1	-0.100	-0.101
VonBert_K_Mal_GP_1	0.246	0.248
SR_LN(R0)	6.479	6.473
Q_extraSD_Rec_PR_Central(5)	0.378	0.378
Size_DblN_peak_Comm_nonTwl(1)	29.96	29.94
Size_DblN_ascend_se_Comm_nonTwl(1)	2.81	2.81
Size_DblN_descend_se_Comm_nonTwl(1)	4.50	4.53
Size_DblN_end_logit_Comm_nonTwl(1)	-1.32	-1.34
Size_DblN_peak_Comm_Discard(3)	27.50	27.50
Size_DblN_ascend_se_Comm_Discard(3)	3.43	3.43
Size_DblN_descend_se_Comm_Discard(3)	3.97	3.97
Size_DblN_peak_Rec_PC_Central(4)	32.99	32.99
Size_DblN_ascend_se_Rec_PC_Central(4)	3.52	3.52
Size_DblN_descend_se_Rec_PC_Central(4)	2.06	2.06
Size_DblN_end_logit_Rec_PC_Central(4)	-2.05	-2.05
Size_DblN_peak_Rec_Disc_Central(6)	24.28	24.28
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.59	3.59
Size_DblN_descend_se_Rec_Disc_Central(6)	4.23	4.23
Size_DblN_peak_CCFRP(7)	32.81	32.81
Size_DblN_ascend_se_CCFRP(7)	4.01	4.01
Size_DblN_descend_se_CCFRP(7)	2.17	2.17
Size_DblN_end_logit_CCFRP(7)	-4.67	-4.67
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.38	29.38
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.72	2.72
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.08	3.08
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.25	-1.25
Bratio_2023	0.420	0.421
SSB_unfished	344.5	324.1
Totbio_unfished	1952.2	1959.5
Recr_unfished	651.0	647.6
Dead_Catch_SPR	64.8	64.9
OFLCatch_2023	48.5	48.5

Table 52: Reference points for the central California base model.

Reference Point	Estimate	Interval
Unfished Spawning Output (billions of eggs)	324	292 - 356
Unfished Age 8+ Biomass (mt)	1,280	1,133 - 1,428
Unfished Recruitment (R0, 1000s)	648	584 - 712
Spawning Output (2023, billions of eggs)	136	35 - 238
Fraction Unfished (2023)	0.42	0.14 - 0.70
Reference Points Based SB40%		
Proxy Spawning Output SB40%	130	117 - 142
SPR Resulting in SB40%	0.458	0.458 - 0.458
Exploitation Rate Resulting in SB40%	0.135	0.127 - 0.142
Yield with SPR Based On SB40% (mt)	68	62 - 75
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	145	130 - 159
SPR50	0.5	-
Exploitation Rate Corresponding to SPR50	0.114	0.108 - 0.120
Yield with SPR50 at SB SPR (mt)	65	59 - 71
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	80	72 - 88
SPR MSY	0.32	0.316 - 0.325
Exploitation Rate Corresponding to SPR MSY	0.24	0.225 - 0.254
MSY (mt)	75	68 - 82

Table 53: Time series of biomass and mortality estimates (mt), spawning output (billions of eggs), recruits (1000s), and exploitation rate (catch / age 8+ biomass) for the central California base model.

Year	Total Biomass	Spawning Output	Biomass age 8+	Fraction Unfished	Age-0 Recruits	Total Mortality	(1-SPR)/ (1-SPR_50%)	Exploitation Rate
1875	1,952	345	1,272	100	651	1.02	0.013	0.001
1876	1,951	344	1,272	100	651	2.05	0.026	0.002
1877	1,949	344	1,271	99.9	651	3.07	0.039	0.002
1878	1,946	344	1,269	99.7	651	4.09	0.051	0.003
1879	1,942	343	1,266	99.6	651	5.11	0.064	0.004
1880	1,937	342	1,262	99.3	651	6.14	0.077	0.005
1881	1,932	341	1,258	99	650	7.16	0.09	0.006
1882	1,926	340	1,253	98.7	650	8.18	0.103	0.007
1883	1,919	339	1,248	98.3	650	9.21	0.115	0.007
1884	1,912	337	1,242	97.9	650	10.23	0.128	0.008
1885	1,904	336	1,235	97.4	649	11.25	0.141	0.009
1886	1,896	334	1,229	96.9	649	12.27	0.154	0.010
1887	1,888	332	1,222	96.4	649	13.30	0.167	0.011
1888	1,879	330	1,215	95.8	648	14.32	0.18	0.012
1889	1,870	328	1,207	95.3	648	15.34	0.192	0.013
1890	1,861	326	1,200	94.7	648	16.36	0.205	0.014
1891	1,852	324	1,192	94.1	647	17.39	0.218	0.015
1892	1,842	322	1,184	93.5	647	18.41	0.231	0.016
1893	1,833	320	1,176	92.9	646	19.43	0.244	0.017
1894	1,823	318	1,167	92.2	646	20.46	0.257	0.018
1895	1,813	315	1,159	91.6	645	21.48	0.27	0.019
1896	1,802	313	1,151	90.9	645	22.50	0.284	0.020
1897	1,792	311	1,142	90.2	644	23.52	0.297	0.021
1898	1,782	309	1,133	89.6	644	24.55	0.31	0.022
1899	1,771	306	1,125	88.9	643	25.57	0.323	0.023
1900	1,761	304	1,116	88.2	643	26.59	0.336	0.024
1901	1,750	301	1,107	87.5	642	27.61	0.35	0.025
1902	1,740	299	1,098	86.8	642	28.64	0.363	0.026
1903	1,729	297	1,089	86.1	641	29.66	0.376	0.027
1904	1,718	294	1,080	85.4	640	30.68	0.39	0.028
1905	1,707	292	1,071	84.7	640	31.71	0.403	0.030
1906	1,696	289	1,062	84	639	32.73	0.417	0.031
1907	1,685	287	1,053	83.3	639	33.75	0.43	0.032
1908	1,674	284	1,044	82.5	638	34.77	0.444	0.033
1909	1,663	282	1,035	81.8	637	35.80	0.457	0.035
1910	1,652	279	1,025	81.1	637	36.82	0.471	0.036
1911	1,640	277	1,016	80.4	636	37.84	0.484	0.037
1912	1,629	274	1,007	79.6	635	38.87	0.498	0.039
1913	1,617	272	997	78.9	635	39.89	0.512	0.040
1914	1,606	269	988	78.2	634	40.91	0.526	0.041
1915	1,595	267	979	77.4	633	41.93	0.54	0.043
1916	1,583	264	969	76.7	632	42.96	0.553	0.044
1917	1,571	262	960	75.9	632	66.76	0.796	0.070
1918	1,536	256	938	74.3	630	77.92	0.911	0.083
1919	1,491	249	910	72.2	628	54.14	0.705	0.060
1920	1,473	244	891	70.9	626	55.23	0.72	0.062
1921	1,456	240	871	69.6	624	45.62	0.619	0.052
1922	1,451	237	859	68.7	623	39.28	0.544	0.046
1923	1,454	235	855	68.2	623	42.55	0.578	0.050
1924	1,454	234	854	67.9	622	24.90	0.36	0.029
1925	1,474	235	864	68.3	623	31.02	0.433	0.036
1926	1,486	237	875	68.8	624	49.90	0.646	0.057
1927	1,479	237	876	68.7	623	42.37	0.568	0.048
1928	1,479	237	880	68.8	624	51.97	0.675	0.059
1929	1,468	236	877	68.6	623	44.25	0.596	0.050
1930	1,465	236	874	68.5	623	61.98	0.784	0.071
1931	1,444	233	861	67.7	622	55.02	0.723	0.064
1932	1,431	231	851	67.1	621	42.35	0.588	0.050
1933	1,432	230	847	66.8	621	29.85	0.433	0.035
1934	1,447	231	850	67.1	621	30.68	0.438	0.036
1935	1,461	233	856	67.5	624	45.28	0.606	0.053
1936	1,459	233	859	67.5	625	45.07	0.606	0.052

Year	Total Biomass	Spawning Output	Biomass age 8+	Fraction Unfished	Age-0 Recruits	Total Mortality	(1-SPR)/ (1-SPR_50%)	Exploitation Rate
1937	1,458	233	863	67.6	625	53.69	0.702	0.062
1938	1,447	232	860	67.3	625	38.99	0.544	0.045
1939	1,451	232	861	67.5	625	21.57	0.32	0.025
1940	1,474	235	870	68.2	627	34.68	0.482	0.040
1941	1,483	237	875	68.7	627	41.26	0.557	0.047
1942	1,484	237	880	68.9	628	13.44	0.202	0.015
1943	1,514	241	898	70.1	630	25.29	0.355	0.028
1944	1,530	244	910	71	631	8.45	0.126	0.009
1945	1,563	250	932	72.5	634	15.01	0.213	0.016
1946	1,588	255	952	73.9	636	20.25	0.281	0.021
1947	1,605	259	971	75.1	638	23.76	0.323	0.024
1948	1,616	262	985	76.2	641	28.23	0.38	0.029
1949	1,621	265	995	77	645	40.43	0.522	0.041
1950	1,613	266	995	77.2	648	41.85	0.544	0.042
1951	1,602	266	990	77.1	651	61.55	0.753	0.062
1952	1,571	262	972	76.1	648	78.09	0.914	0.080
1953	1,525	256	941	74.2	641	59.86	0.764	0.064
1954	1,500	250	916	72.7	663	57.12	0.744	0.062
1955	1,481	246	892	71.3	736	71.51	0.886	0.080
1956	1,451	239	865	69.4	744	58.00	0.767	0.067
1957	1,441	235	849	68.1	729	57.77	0.766	0.068
1958	1,440	231	835	66.9	705	117.77	1.256	0.141
1959	1,382	220	797	63.9	680	125.25	1.324	0.157
1960	1,321	208	751	60.5	660	66.04	0.882	0.088
1961	1,324	203	727	59	658	51.56	0.708	0.071
1962	1,342	201	714	58.5	638	69.69	0.875	0.098
1963	1,341	200	714	58	592	69.74	0.88	0.098
1964	1,337	199	727	57.9	594	57.11	0.764	0.079
1965	1,340	201	745	58.4	585	79.40	0.985	0.107
1966	1,315	201	749	58.3	577	77.82	0.997	0.104
1967	1,287	200	746	58.1	580	99.51	1.204	0.133
1968	1,234	196	725	56.8	624	106.69	1.301	0.147
1969	1,172	189	694	54.7	759	104.05	1.328	0.150
1970	1,119	180	656	52.3	751	119.66	1.47	0.182
1971	1,060	169	606	49.1	513	103.63	1.403	0.171
1972	1,028	159	561	46.1	406	164.61	1.715	0.293
1973	936	142	495	41.3	422	110.45	1.476	0.223
1974	892	132	454	38.4	504	140.92	1.634	0.311
1975	809	121	408	35	563	118.87	1.598	0.292
1976	744	112	373	32.4	1,175	106.08	1.622	0.284
1977	702	103	355	30	478	117.44	1.748	0.331
1978	676	93	329	27	342	92.35	1.632	0.281
1979	688	85	297	24.7	151	130.69	1.756	0.439
1980	655	76	255	22	393	108.84	1.534	0.426
1981	622	72	234	20.8	469	35.63	0.742	0.153
1982	643	75	235	21.6	223	34.65	0.765	0.147
1983	660	81	254	23.4	232	97.80	1.628	0.386
1984	601	81	336	23.6	667	56.57	1.358	0.168
1985	583	83	341	24	614	142.80	1.902	0.419
1986	487	74	288	21.4	371	61.09	1.624	0.212
1987	488	69	244	20.1	316	64.01	1.654	0.262
1988	497	64	219	18.5	275	73.09	1.577	0.334
1989	496	59	203	17.2	339	55.82	1.248	0.275
1990	502	58	185	16.7	490	51.39	1.167	0.278
1991	507	58	174	16.9	264	57.97	1.332	0.333
1992	504	60	209	17.3	207	95.08	1.755	0.455
1993	458	57	224	16.6	268	89.29	1.785	0.398
1994	412	53	205	15.5	201	76.95	1.721	0.375
1995	374	50	184	14.5	160	49.28	1.487	0.268
1996	357	49	167	14.1	745	67.71	1.755	0.405
1997	323	45	150	12.9	278	41.65	1.531	0.278
1998	330	42	152	12.3	210	51.03	1.697	0.335
1999	339	39	138	11.4	699	67.79	1.819	0.491
2000	338	35	121	10.3	446	57.37	1.566	0.474
2001	357	34	115	9.7	504	88.57	1.805	0.773
2002	352	31	100	9	523	50.74	1.539	0.505
2003	392	31	91	8.9	318	72.07	1.607	0.796
2004	416	31	116	9	352	43.17	1.132	0.374

Year	Total Biomass	Spawning Output	Biomass age 8+	Fraction Unfished	Age-0 Recruits	Total Mortality	(1-SPR)/ (1-SPR_50%)	Exploitation Rate
2005	462	34	117	9.8	156	49.90	1.143	0.425
2006	492	38	118	11.1	165	65.86	1.316	0.558
2007	488	44	170	12.6	428	35.89	0.925	0.211
2008	503	51	201	14.8	1,980	41.19	1.073	0.205
2009	524	58	237	16.9	636	50.64	1.355	0.213
2010	590	63	268	18.2	1,117	57.35	1.552	0.214
2011	692	64	261	18.6	568	55.38	1.25	0.212
2012	826	65	260	18.9	403	92.08	1.171	0.355
2013	918	67	238	19.5	418	225.37	1.696	0.948
2014	838	68	209	19.7	258	105.64	1.25	0.506
2015	835	75	216	21.8	264	70.24	1.005	0.326
2016	838	87	371	25.1	810	63.44	1.025	0.171
2017	828	99	390	28.7	393	24.56	0.551	0.063
2018	858	113	491	32.8	243	21.45	0.529	0.044
2019	891	125	525	36.2	301	19.55	0.489	0.037
2020	917	133	535	38.7	578	29.78	0.614	0.056
2021	924	138	547	40.2	562	38.40	0.725	0.070
2022	921	142	524	41.1	572	32.88	0.697	0.063

Table 54: Comparison of central area base model outputs for 'drop-one' analyses (part 1).

Quantity	Base	Drop Non-Trawl	Drop Comm Discard	Drop Rec PC	Drop Rec PR	Drop Rec Discard
N.Parms	118	114	115	118	118	112
TOTAL	523.4	517.1	480.4	352.7	382.8	505.2
Survey	20.6	20.6	20.7	18.0	9.9	20.2
Length_comp	319.3	313.1	275.7	249.5	213.6	301.5
Age_comp	180.8	180.7	180.2	82.7	158.2	180.8
Recruitment	2.1	2.1	3.2	2.0	0.7	2.3
Parm_priors	0.5	0.5	0.5	0.5	0.5	0.5
L_at_Amax_Fem_GP_1	54.65	54.71	54.42	52.46	57.82	54.60
VonBert_K_Fem_GP_1	0.14	0.14	0.15	0.16	0.13	0.15
L_at_Amax_Mal_GP_1	-0.10	-0.10	-0.10	-0.05	-0.15	-0.10
VonBert_K_Mal_GP_1	0.25	0.25	0.24	0.16	0.35	0.24
SR_LN(R0)	6.48	6.48	6.47	6.51	6.48	6.48
Q_extraSD_Rec_PR_Central(5)	0.38	0.38	0.38	0.36	0.38	0.38
Size_DblN_peak_Comm_nonTwl(1)	29.96	29.96	29.96	29.56	28.88	29.93
Size_DblN_ascend_se_Comm_nonTwl(1)	2.81	2.81	2.82	2.71	2.51	2.81
Size_DblN_descend_se_Comm_nonTwl(1)	4.50	4.50	4.50	4.67	4.75	4.51
Size_DblN_end_logit_Comm_nonTwl(1)	-1.32	-1.32	-1.29	-1.71	-1.74	-1.33
Size_DblN_peak_Comm_Discard(3)	27.50	27.52	27.50	27.40	27.64	27.50
Size_DblN_ascend_se_Comm_Discard(3)	3.43	3.43	3.43	3.42	3.44	3.43
Size_DblN_descend_se_Comm_Discard(3)	3.97	3.98	3.97	3.95	3.97	3.97
Size_DblN_peak_Rec_PC_Central(4)	32.99	33.02	32.98	32.87	32.83	32.98
Size_DblN_ascend_se_Rec_PC_Central(4)	3.52	3.52	3.51	3.49	3.52	3.52
Size_DblN_descend_se_Rec_PC_Central(4)	2.06	2.04	2.06	2.15	1.96	2.06
Size_DblN_end_logit_Rec_PC_Central(4)	-2.05	-2.02	-2.04	-2.23	-1.95	-2.06
Size_DblN_peak_Rec_Disc_Central(6)	24.28	24.30	24.35	24.20	24.75	24.28
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.59	3.59	3.60	3.58	3.63	3.59
Size_DblN_descend_se_Rec_Disc_Central(6)	4.23	4.24	4.22	4.21	4.16	4.23
Size_DblN_peak_CCFRP(7)	32.81	32.84	32.81	32.66	32.73	32.79
Size_DblN_ascend_se_CCFRP(7)	4.01	4.01	4.01	4.00	3.98	4.01
Size_DblN_descend_se_CCFRP(7)	2.17	2.16	2.17	2.21	2.23	2.18
Size_DblN_end_logit_CCFRP(7)	-4.67	-4.65	-4.65	-4.74	-4.65	-4.68
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.38	29.38	29.38	29.39	29.41	29.37
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.72	2.71	2.72	2.71	2.73	2.72
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.08	3.03	3.08	3.12	3.10	3.09
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.25	-1.21	-1.24	-1.43	-1.65	-1.27
Bratio_2023	0.420	0.403	0.425	0.508	0.404	0.432
SSB_unfished	344.5	345.8	337.5	300.1	421.2	343.2
Totbio_unfished	1952.2	1953.5	1932.8	1966.3	2021.5	1949.5
Recr_unfished	651.0	651.6	646.4	672.4	654.4	650.0
Dead_Catch_SPR	64.8	64.9	64.3	64.8	65.7	64.6
OFLCatch_2023	48.5	47.2	47.6	53.9	55.0	48.6

Table 55: Comparison of central area base model outputs for 'drop-one' analyses (part 2).

Quantity	Base	Drop CCFRP	Drop DWV Onboard	Drop PC Onboard	Drop Lea Research
N.Parms	118	118	114	118	118
TOTAL	523.4	453.3	492.8	496.2	455.9
Survey	20.6	18.9	4.1	-1.1	20.8
Length_comp	319.3	291.0	306.9	314.3	275.5
Age_comp	180.8	138.1	180.7	180.6	158.4
Recruitment	2.1	4.9	0.6	1.9	0.6
Parm_priors	0.5	0.5	0.5	0.5	0.5
L_at_Amax_Fem_GP_1	54.65	53.90	54.78	54.54	56.34
VonBert_K_Fem_GP_1	0.14	0.15	0.14	0.15	0.13
L_at_Amax_Mal_GP_1	-0.10	-0.09	-0.10	-0.10	-0.12
VonBert_K_Mal_GP_1	0.25	0.24	0.25	0.24	0.27
SR_LN(R0)	6.48	6.43	6.55	6.50	6.51
Q_extraSD_Rec_PR_Central(5)	0.38	0.18	0.36	0.43	0.39
Size_DblN_peak_Comm_nonTwl(1)	29.96	30.55	30.66	30.18	30.07
Size_DblN_ascend_se_Comm_nonTwl(1)	2.81	2.96	2.97	2.87	2.83
Size_DblN_descend_se_Comm_nonTwl(1)	4.50	4.45	5.08	4.48	4.62
Size_DblN_end_logit_Comm_nonTwl(1)	-1.32	-1.25	-1.15	-1.28	-1.52
Size_DblN_peak_Comm_Discard(3)	27.50	27.96	27.34	27.61	27.65
Size_DblN_ascend_se_Comm_Discard(3)	3.43	3.52	3.41	3.44	3.45
Size_DblN_descend_se_Comm_Discard(3)	3.97	4.15	3.93	4.01	4.00
Size_DblN_peak_Rec_PC_Central(4)	32.99	33.66	32.76	33.16	33.14
Size_DblN_ascend_se_Rec_PC_Central(4)	3.52	3.58	3.51	3.53	3.52
Size_DblN_descend_se_Rec_PC_Central(4)	2.06	1.64	2.17	1.96	2.00
Size_DblN_end_logit_Rec_PC_Central(4)	-2.05	-1.59	-2.23	-1.89	-1.95
Size_DblN_peak_Rec_Disc_Central(6)	24.28	24.22	24.14	24.32	24.47
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.59	3.60	3.57	3.59	3.62
Size_DblN_descend_se_Rec_Disc_Central(6)	4.23	4.50	4.20	4.29	4.25
Size_DblN_peak_CCFRP(7)	32.81	30.00	32.55	32.81	32.98
Size_DblN_ascend_se_CCFRP(7)	4.01	4.03	4.00	4.01	4.00
Size_DblN_descend_se_CCFRP(7)	2.17	5.02	2.25	2.17	2.12
Size_DblN_end_logit_CCFRP(7)	-4.67	0.00	-4.89	-4.61	-4.59
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.38	29.57	29.38	29.49	29.57
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.72	2.76	2.72	2.74	2.76
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.08	2.92	3.08	3.01	3.04
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.25	-0.76	-1.25	-1.08	-1.11
Bratio_2023	0.420	0.065	0.597	0.366	0.339
SSB_unfished	344.5	320.3	373.7	348.6	386.1
Totbio_unfished	1952.2	1872.6	2102.3	1986.2	2018.1
Recr_unfished	651.0	621.8	698.8	665.6	670.2
Dead_Catch_SPR	64.8	65.0	68.9	66.6	66.2
OFLCatch_2023	48.5	10.6	64.4	50.3	43.7

Table 56: Comparison of central base model sensitivity analyses.

Quantity	Base (Francis)	M-I weights	share M	Logistic Commercial	Est. all growth	Est. M (f+m)
N.Parms	118	118	118	116	124	120
TOTAL	523.4	814.1	519.2	501.1	520.0	523.2
Survey	20.6	34.8	20.6	21.2	19.7	20.3
Length_comp	319.3	518.5	319.7	314.3	318.7	319.0
Age_comp	180.8	258.6	176.3	162.9	178.7	181.0
Recruitment	2.1	1.6	2.1	2.2	2.4	2.2
Parm_priors	0.5	0.5	0.4	0.5	0.5	0.7
NatM_uniform_Fem_GP_1	0.211	0.211	0.206	0.211	0.211	0.224
L_at_Amin_Fem_GP_1	5	5	5	5	3	5
L_at_Amax_Fem_GP_1	54.7	53.9	54.3	54.3	55.0	55.0
VonBert_K_Fem_GP_1	0.145	0.145	0.147	0.147	0.154	0.143
CV_young_Fem_GP_1	0.1	0.1	0.1	0.1	0.110	0.1
CV_old_Fem_GP_1	0.082	0.082	0.082	0.082	0.048	0.082
NatM_uniform_Mal_GP_1	-0.053	-0.053	0.000	-0.053	-0.053	-0.086
L_at_Amin_Mal_GP_1	0	0	0	0	0.544	0
L_at_Amax_Mal_GP_1	-0.100	-0.097	-0.091	-0.096	-0.107	-0.106
VonBert_K_Mal_GP_1	0.246	0.241	0.226	0.237	0.184	0.259
CV_young_Mal_GP_1	0	0	0	0	0.0230264	0
CV_old_Mal_GP_1	-0.319	-0.319	-0.319	-0.319	-0.368	-0.319
SR_LN(R0)	6.479	6.520	6.484	6.474	6.458	6.525
Q_extraSD_Rec_PR_Central(5)	0.378	0.390	0.377	0.379	0.379	0.377
Size_DblN_peak_Comm_nonTwl(1)	29.956	29.886	29.964	NA	29.872	29.975
Size_DblN_top_logit_Comm_nonTwl(1)	-6	-6	-6	NA	-6	-6
Size_DblN_ascend_se_Comm_nonTwl(1)	2.815	2.742	2.818	NA	2.792	2.816
Size_DblN_descend_se_Comm_nonTwl(1)	4.502	4.526	4.489	NA	4.505	4.544
Size_DblN_start_logit_Comm_nonTwl(1)	-10	-10	-10	NA	-10	-10
Size_DblN_end_logit_Comm_nonTwl(1)	-1.32	-1.20	-1.29	NA	-1.28	-1.35
Size_DblN_peak_Comm_Discard(3)	27.50	27.62	27.50	27.52	27.49	27.53
Size_DblN_ascend_se_Comm_Discard(3)	3.43	3.45	3.43	3.44	3.43	3.43
Size_DblN_descend_se_Comm_Discard(3)	3.97	4.02	3.98	3.98	3.96	3.98
Size_DblN_peak_Rec_PC_Central(4)	32.99	33.21	33.00	33.02	32.95	33.02
Size_DblN_ascend_se_Rec_PC_Central(4)	3.52	3.55	3.52	3.52	3.51	3.52
Size_DblN_descend_se_Rec_PC_Central(4)	2.06	1.85	2.06	2.02	2.10	2.03
Size_DblN_end_logit_Rec_PC_Central(4)	-2.05	-1.76	-2.04	-1.99	-2.11	-2.01
Size_DblN_peak_Rec_Disc_Central(6)	24.28	24.31	24.27	24.30	24.31	24.32
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.59	3.63	3.59	3.59	3.60	3.59
Size_DblN_descend_se_Rec_Disc_Central(6)	4.23	4.30	4.24	4.24	4.21	4.24
Size_DblN_peak_CCFRP(7)	32.81	32.39	32.81	32.85	32.79	32.84
Size_DblN_ascend_se_CCFRP(7)	4.01	4.05	4.01	4.01	4.01	4.00
Size_DblN_descend_se_CCFRP(7)	2.17	2.41	2.17	2.15	2.18	2.16
Size_DblN_end_logit_CCFRP(7)	-4.67	-4.55	-4.67	-4.61	-4.73	-4.62
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.38	30.37	29.38	29.27	29.41	29.42
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.72	3.08	2.72	2.69	2.72	2.73
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.08	2.86	3.08	2.93	3.08	3.05
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.25	-0.75	-1.25	-1.16	-1.32	-1.19
Size_inflection_Comm_nonTwl(1)	NA	NA	NA	25.41	NA	NA
Size_95%width_Comm_nonTwl(1)	NA	NA	NA	2.57	NA	NA
Bratio_2023	0.420	0.329	0.415	0.394	0.439	0.436
SSB_unfished	344.5	331.1	364.6	333.0	349.2	309.7
Totbio_unfished	1952	1964	1959	1925	1918	1881
Recr_unfished	651.0	678.5	654.3	647.8	638.0	681.7
Dead_Catch_SPR	64.8	66.5	64.7	64.4	65.1	65.0
OFLCatch_2023	48.5	44.3	48.1	46.3	49.8	49.4

Table 57: Steepness profile for the central California base model (part 1, values 0.25 – 0.6). Note that steepness values of 0.25 and 0.3 are inconsistent with a proxy MSY harvest rate of F(SPR_50%).

	Beverton-Holt Steepness							
Quantity	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
N.Parms	118	118	118	118	118	118	118	118
TOTAL	537.2	533.8	531.3	529.3	527.7	526.4	525.3	524.5
Survey	16.7	17.1	17.5	17.9	18.3	18.8	19.2	19.6
Length_comp	326.9	325.2	323.7	322.6	321.6	320.9	320.4	319.9
Age_comp	183.9	183.3	182.8	182.4	182.0	181.7	181.5	181.2
Recruitment	5.0	5.0	4.8	4.5	4.1	3.7	3.3	2.9
Parm_priors	4.7	3.3	2.5	2.0	1.6	1.3	1.0	0.8
L_at_Amax_Fem_GP_1	54.4	54.4	54.4	54.4	54.5	54.5	54.5	54.5
VonBert_K_Fem_GP_1	0.149	0.149	0.148	0.148	0.147	0.147	0.147	0.146
L_at_Amax_Mal_GP_1	-0.106	-0.106	-0.105	-0.104	-0.103	-0.102	-0.101	-0.101
VonBert_K_Mal_GP_1	0.259	0.257	0.255	0.253	0.251	0.249	0.248	0.247
SR_LN(R0)	7.881	7.515	7.282	7.111	6.975	6.860	6.760	6.670
Q_extraSD_Rec_PR_Central(5)	0.316	0.324	0.331	0.339	0.346	0.352	0.359	0.364
Size_DblN_peak_Comm_nonTwl(1)	28.24	28.44	28.63	28.83	29.01	29.17	29.33	29.48
Size_DblN_ascend_se_Comm_nonTwl(1)	2.36	2.41	2.46	2.52	2.57	2.61	2.65	2.69
Size_DblN_descend_se_Comm_nonTwl(1)	4.46	4.48	4.49	4.50	4.51	4.52	4.52	4.53
Size_DblN_end_logit_Comm_nonTwl(1)	-2.14	-2.12	-2.06	-1.98	-1.89	-1.78	-1.68	-1.57
Size_DblN_peak_Comm_Discard(3)	27.02	27.09	27.16	27.22	27.27	27.31	27.36	27.40
Size_DblN_ascend_se_Comm_Discard(3)	3.38	3.39	3.39	3.40	3.40	3.41	3.41	3.42
Size_DblN_descend_se_Comm_Discard(3)	3.83	3.85	3.87	3.89	3.91	3.92	3.93	3.95
Size_DblN_peak_Rec_PC_Central(4)	32.20	32.33	32.43	32.53	32.62	32.69	32.77	32.84
Size_DblN_ascend_se_Rec_PC_Central(4)	3.48	3.48	3.48	3.49	3.49	3.50	3.50	3.51
Size_DblN_descend_se_Rec_PC_Central(4)	2.42	2.38	2.34	2.30	2.26	2.22	2.18	2.15
Size_DblN_end_logit_Rec_PC_Central(4)	-2.76	-2.66	-2.56	-2.47	-2.39	-2.32	-2.25	-2.19
Size_DblN_peak_Rec_Disc_Central(6)	23.80	23.89	23.96	24.02	24.07	24.11	24.16	24.20
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.51	3.53	3.54	3.55	3.56	3.56	3.57	3.57
Size_DblN_descend_se_Rec_Disc_Central(6)	4.14	4.15	4.17	4.18	4.19	4.20	4.21	4.22
Size_DblN_peak_CCFRP(7)	32.10	32.22	32.32	32.40	32.48	32.55	32.61	32.67
Size_DblN_ascend_se_CCFRP(7)	3.99	3.99	3.99	3.99	4.00	4.00	4.00	4.00
Size_DblN_descend_se_CCFRP(7)	2.37	2.34	2.31	2.29	2.27	2.25	2.23	2.21
Size_DblN_end_logit_CCFRP(7)	-5.32	-5.21	-5.12	-5.04	-4.97	-4.90	-4.84	-4.79
Size_DblN_peak_DWV_Onboard_CPFV(8)	28.40	28.53	28.64	28.75	28.86	28.96	29.06	29.15
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.56	2.58	2.59	2.61	2.63	2.64	2.66	2.68
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.29	3.28	3.27	3.26	3.24	3.22	3.19	3.17
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-2.45	-2.30	-2.17	-2.04	-1.91	-1.79	-1.66	-1.54
Bratio_2023	0.55	0.50	0.47	0.46	0.45	0.44	0.43	0.43
SSB_unfished	1404	972	769	647	564	502	454	415
Totbio_unfished	7976	5521	4370	3680	3209	2860	2587	2364
Recr_unfished	2648	1835	1454	1225	1069	954	863	789
Dead_Catch_SPR	0	0	21	54	66	70	71	70
OFLCatch_2023	168	113	91	78	69	63	59	55

Table 58: Steepness profile for the central California base model (part 2, values 0.65 – 0.95). Note that steepness values of 0.25 and 0.3 are inconsistent with a proxy MSY harvest rate of F(SPR_50%).

	Beverton-Holt Steepness						
Quantity	0.65	0.7	0.75	0.8	0.85	0.9	0.95
N.Parms	118	118	118	118	118	118	118
TOTAL	523.9	523.5	523.3	523.4	523.7	524.305	525.2
Survey	20.0	20.4	20.8	21.1	21.2	21.0655	20.6
Length_comp	319.6	319.4	319.3	319.2	319.3	319.431	319.8
Age_comp	181.0	180.9	180.7	180.7	180.7	180.725	180.9
Recruitment	2.5	2.2	2.0	2.0	2.1	2.52053	3.1
Parm_priors	0.7	0.6	0.5	0.4	0.5	0.56246	0.9
L_at_Amax_Fem_GP_1	54.6	54.6	54.7	54.8	54.8	54.7951	54.7
VonBert_K_Fem_GP_1	0.146	0.145	0.145	0.144	0.144	0.143931	0.145
L_at_Amax_Mal_GP_1	-0.100	-0.100	-0.100	-0.101	-0.101	-0.100728	-0.100
VonBert_K_Mal_GP_1	0.246	0.246	0.246	0.247	0.248	0.247427	0.246
SR_LN(R0)	6.587	6.509	6.434	6.363	6.299	6.25022	6.231
Q_extraSD_Rec_PR_Central(5)	0.370	0.376	0.381	0.385	0.387	0.386193	0.381
Size_DblN_peak_Comm_nonTwl(1)	29.69	29.89	30.05	30.19	30.28	30.26	30.10
Size_DblN_ascend_se_Comm_nonTwl(1)	2.75	2.80	2.84	2.87	2.89	2.88667	2.85
Size_DblN_descend_se_Comm_nonTwl(1)	4.51	4.50	4.50	4.51	4.52	4.53655	4.55
Size_DblN_end_logit_Comm_nonTwl(1)	-1.46	-1.36	-1.27	-1.19	-1.16	-1.19975	-1.35
Size_DblN_peak_Comm_Discard(3)	27.44	27.48	27.52	27.54	27.55	27.531	27.48
Size_DblN_ascend_se_Comm_Discard(3)	3.43	3.43	3.44	3.44	3.44	3.43728	3.43
Size_DblN_descend_se_Comm_Discard(3)	3.96	3.97	3.98	3.99	3.99	3.9851	3.97
Size_DblN_peak_Rec_PC_Central(4)	32.91	32.97	33.03	33.07	33.09	33.0642	32.99
Size_DblN_ascend_se_Rec_PC_Central(4)	3.51	3.51	3.52	3.52	3.52	3.52205	3.52
Size_DblN_descend_se_Rec_PC_Central(4)	2.11	2.07	2.04	2.01	1.99	2.01092	2.06
Size_DblN_end_logit_Rec_PC_Central(4)	-2.13	-2.07	-2.02	-1.98	-1.96	-1.97943	-2.04
Size_DblN_peak_Rec_Disc_Central(6)	24.23	24.27	24.29	24.31	24.32	24.2897	24.24
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.58	3.59	3.59	3.59	3.59	3.59218	3.59
Size_DblN_descend_se_Rec_Disc_Central(6)	4.22	4.23	4.24	4.24	4.24	4.23701	4.22
Size_DblN_peak_CCFRP(7)	32.73	32.79	32.84	32.87	32.88	32.8389	32.76
Size_DblN_ascend_se_CCFRP(7)	4.00	4.00	4.01	4.01	4.01	4.00647	4.00
Size_DblN_descend_se_CCFRP(7)	2.19	2.18	2.16	2.15	2.15	2.15994	2.19
Size_DblN_end_logit_CCFRP(7)	-4.73	-4.69	-4.64	-4.61	-4.60	-4.62538	-4.69
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.25	29.34	29.44	29.52	29.58	29.586	29.51
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.70	2.71	2.73	2.75	2.76	2.75706	2.74
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.13	3.10	3.06	3.02	3.00	3.01757	3.07
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.42	-1.30	-1.18	-1.08	-1.01	-1.03032	-1.16
Bratio_2023	0.42	0.42	0.42	0.43	0.46	0.51	0.58
SSB_unfished	383	355	330	309	290	276	270
Totbio_unfished	2175	2012	1868	1742	1634	1557	1526
Recr_unfished	726	671	623	580	544	518	508
Dead_Catch_SPR	68	66	63	61	58	56	56
OFLCatch_2023	52	49	47	46	46	47	50

Table 59: Profile over unfished recruitment (log(R0)) for the central California base model (part 1).

	log(R0)							
Quantity	5.8	5.9	6	6.1	6.2	6.3	6.4	6.5
N.Parms	117	117	117	117	117	117	117	117
TOTAL	586.7	573.6	561.7	550.8	540.0	530.4	524.7	523.5
Survey	19.2	19.2	19.2	19.2	19.2	19.4	20.0	20.7
Length_comp	331.5	328.7	326.2	323.7	321.5	320.1	319.2	319.6
Age_comp	183.6	182.9	182.5	183.3	183.4	181.3	181.0	180.8
Recruitment	52.0	42.3	33.3	24.1	15.5	9.1	4.1	1.9
Parm_priors	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
L_at_Amax_Fem_GP_1	59.5	58.5	57.8	57.3	56.9	56.0	55.2	54.5
VonBert_K_Fem_GP_1	0.123	0.127	0.131	0.133	0.135	0.139	0.143	0.146
L_at_Amax_Mal_GP_1	-0.200	-0.181	-0.167	-0.158	-0.149	-0.130	-0.113	-0.097
VonBert_K_Mal_GP_1	0.465	0.423	0.390	0.368	0.349	0.307	0.272	0.240
Q_extraSD_Rec_PR_Central(5)	0.329	0.333	0.337	0.340	0.343	0.351	0.365	0.380
Size_DblN_peak_Comm_nonTwl(1)	30.532	30.466	30.423	30.388	30.362	30.339	30.179	29.856
Size_DblN_ascend_se_Comm_nonTwl(1)	2.95	2.93	2.92	2.91	2.91	2.90	2.87	2.79
Size_DblN_descend_se_Comm_nonTwl(1)	4.77	4.75	4.77	4.92	4.96	4.73	4.56	4.50
Size_DblN_end_logit_Comm_nonTwl(1)	-0.54	-0.68	-0.85	-1.16	-1.30	-1.22	-1.21	-1.37
Size_DblN_peak_Comm_Discard(3)	27.72	27.69	27.67	27.65	27.63	27.60	27.56	27.47
Size_DblN_ascend_se_Comm_Discard(3)	3.45	3.45	3.45	3.45	3.45	3.44	3.44	3.43
Size_DblN_descend_se_Comm_Discard(3)	4.04	4.03	4.03	4.02	4.01	4.00	3.99	3.97
Size_DblN_peak_Rec_PC_Central(4)	33.21	33.19	33.16	33.14	33.12	33.09	33.06	32.96
Size_DblN_ascend_se_Rec_PC_Central(4)	3.52	3.52	3.52	3.52	3.52	3.52	3.52	3.51
Size_DblN_descend_se_Rec_PC_Central(4)	2.01	2.01	2.01	2.02	2.03	2.03	2.04	2.07
Size_DblN_end_logit_Rec_PC_Central(4)	-1.96	-1.96	-1.97	-1.99	-2.01	-2.02	-2.02	-2.07
Size_DblN_peak_Rec_Disc_Central(6)	24.45	24.44	24.43	24.42	24.42	24.39	24.34	24.25
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.62	3.62	3.62	3.62	3.62	3.61	3.60	3.58
Size_DblN_descend_se_Rec_Disc_Central(6)	4.41	4.38	4.36	4.34	4.32	4.30	4.26	4.22
Size_DblN_peak_CCFRP(7)	33.49	33.42	33.35	33.28	33.21	33.11	32.97	32.75
Size_DblN_ascend_se_CCFRP(7)	4.04	4.04	4.04	4.03	4.03	4.02	4.01	4.00
Size_DblN_descend_se_CCFRP(7)	1.91	1.94	1.97	2.00	2.02	2.06	2.11	2.19
Size_DblN_end_logit_CCFRP(7)	-4.40	-4.42	-4.45	-4.48	-4.51	-4.54	-4.59	-4.70
Size_DblN_peak_DWV_Onboard_CPFV(8)	28.90	28.98	29.04	29.07	29.09	29.17	29.30	29.38
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.58	2.60	2.62	2.63	2.64	2.66	2.70	2.72
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.28	3.24	3.21	3.20	3.20	3.16	3.11	3.08
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.33	-1.34	-1.34	-1.35	-1.36	-1.33	-1.28	-1.27
Bratio_2023	0.38	0.37	0.36	0.35	0.33	0.34	0.36	0.45
SSB_unfished	240.48	251.37	265.68	285.69	308.37	320.40	333.59	348.23
Totbio_unfished	1055	1153	1263	1390	1531	1672	1823	1990
Recr_unfished	330	365	403	446	493	545	602	665
Dead_Catch_SPR	35	38	42	46	51	56	61	66
OFLCatch_2023	24	25	27	28	30	33	40	52

Table 60: Profile over unfished recruitment (log(R0)) for the central California base model (part 2).

	log(R0)						
Quantity	6.6	6.7	6.8	6.9	7	7.1	7.2
N.Parms	117	117	117	117	117	117	117
TOTAL	525.0	526.3	527.4	528.2	528.9	529.5	529.9
Survey	19.5	18.6	18.0	17.5	17.2	17.0	16.8
Length_comp	321.1	322.5	323.6	324.4	325.1	325.7	326.2
Age_comp	181.3	181.9	182.3	182.6	182.8	183.0	183.2
Recruitment	2.5	2.9	3.1	3.2	3.2	3.2	3.3
Parm_priors	0.5	0.5	0.5	0.5	0.5	0.5	0.5
L_at_Amax_Fem_GP_1	54.3	54.3	54.3	54.3	54.3	54.3	54.3
VonBert_K_Fem_GP_1	0.147	0.148	0.148	0.149	0.149	0.149	0.149
L_at_Amax_Mal_GP_1	-0.095	-0.097	-0.099	-0.100	-0.101	-0.102	-0.102
VonBert_K_Mal_GP_1	0.236	0.241	0.244	0.246	0.248	0.249	0.250
Q_extraSD_Rec_PR_Central(5)	0.365	0.352	0.344	0.338	0.334	0.331	0.328
Size_DblN_peak_Comm_nonTwl(1)	29.180	28.876	28.691	28.557	28.464	28.398	28.341
Size_DblN_ascend_se_Comm_nonTwl(1)	2.61	2.53	2.48	2.44	2.42	2.40	2.38
Size_DblN_descend_se_Comm_nonTwl(1)	4.50	4.48	4.47	4.46	4.45	4.45	4.44
Size_DblN_end_logit_Comm_nonTwl(1)	-1.78	-1.95	-2.02	-2.07	-2.09	-2.11	-2.12
Size_DblN_peak_Comm_Discard(3)	27.28	27.20	27.15	27.12	27.09	27.06	27.04
Size_DblN_ascend_se_Comm_Discard(3)	3.41	3.40	3.39	3.39	3.39	3.39	3.38
Size_DblN_descend_se_Comm_Discard(3)	3.91	3.89	3.87	3.86	3.85	3.85	3.84
Size_DblN_peak_Rec_PC_Central(4)	32.68	32.54	32.45	32.39	32.34	32.30	32.27
Size_DblN_ascend_se_Rec_PC_Central(4)	3.50	3.49	3.49	3.49	3.48	3.48	3.48
Size_DblN_descend_se_Rec_PC_Central(4)	2.21	2.28	2.32	2.34	2.36	2.38	2.39
Size_DblN_end_logit_Rec_PC_Central(4)	-2.30	-2.43	-2.51	-2.57	-2.61	-2.65	-2.68
Size_DblN_peak_Rec_Disc_Central(6)	24.06	23.98	23.93	23.89	23.86	23.84	23.82
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.56	3.55	3.54	3.53	3.53	3.52	3.52
Size_DblN_descend_se_Rec_Disc_Central(6)	4.18	4.16	4.15	4.15	4.14	4.14	4.13
Size_DblN_peak_CCFRP(7)	32.44	32.33	32.27	32.22	32.18	32.14	32.11
Size_DblN_ascend_se_CCFRP(7)	3.99	3.99	3.99	3.99	3.99	3.99	3.99
Size_DblN_descend_se_CCFRP(7)	2.28	2.31	2.33	2.34	2.35	2.36	2.37
Size_DblN_end_logit_CCFRP(7)	-4.93	-5.04	-5.11	-5.16	-5.20	-5.23	-5.26
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.08	28.87	28.75	28.67	28.61	28.56	28.52
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.67	2.63	2.61	2.60	2.59	2.58	2.58
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.19	3.23	3.25	3.26	3.27	3.27	3.28
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.70	-1.96	-2.10	-2.20	-2.27	-2.33	-2.37
Bratio_2023	0.70	0.84	0.92	0.97	1.02	1.06	1.09
SSB_unfished	380.58	423.10	469.42	520.21	576.09	637.70	705.71
Totbio_unfished	2198	2435	2695	2981	3297	3646	4031
Recr_unfished	735	812	898	992	1097	1212	1339
Dead_Catch_SPR	72	79	87	96	106	117	130
OFLCatch_2023	76	92	106	120	135	152	169

Table 61: Female natural mortality profile for the central California base model (part 1).

	Female Natural Mortality (M, 1/yr)					
Quantity	0.08	0.1	0.12	0.14	0.16	0.18
N.Parms	118	118	118	118	118	118
TOTAL	564.5	549.3	539.1	532.3	527.9	525.2
Survey	22.9	22.7	22.5	22.2	21.8	21.4
Length_comp	336.2	330.1	326.2	323.5	321.6	320.4
Age_comp	195.2	189.2	185.3	182.9	181.5	180.9
Recruitment	8.0	6.3	4.8	3.7	2.9	2.4
Parm_priors	2.2	1.0	0.3	0.0	0.0	0.1
L_at_Amax_Fem_GP_1	52.0	52.4	52.8	53.3	53.7	54.1
VonBert_K_Fem_GP_1	0.164	0.160	0.157	0.154	0.151	0.149
L_at_Amax_Mal_GP_1	-0.085	-0.084	-0.085	-0.087	-0.091	-0.094
VonBert_K_Mal_GP_1	0.222	0.216	0.217	0.221	0.227	0.234
SR_LN(R0)	5.685	5.817	5.946	6.069	6.187	6.302
Q_extraSD_Rec_PR_Central(5)	0.354	0.365	0.372	0.376	0.378	0.379
Size_DblN_peak_Comm_nonTwl(1)	28.80	29.08	29.31	29.47	29.65	29.79
Size_DblN_ascend_se_Comm_nonTwl(1)	2.51	2.60	2.66	2.70	2.75	2.78
Size_DblN_descend_se_Comm_nonTwl(1)	4.51	4.44	4.36	4.34	4.35	4.39
Size_DblN_end_logit_Comm_nonTwl(1)	-2.97	-2.15	-1.69	-1.45	-1.33	-1.28
Size_DblN_peak_Comm_Discard(3)	26.87	26.99	27.10	27.20	27.29	27.37
Size_DblN_ascend_se_Comm_Discard(3)	3.42	3.42	3.43	3.43	3.43	3.43
Size_DblN_descend_se_Comm_Discard(3)	3.80	3.84	3.87	3.90	3.93	3.95
Size_DblN_peak_Rec_PC_Central(4)	32.17	32.36	32.52	32.66	32.77	32.87
Size_DblN_ascend_se_Rec_PC_Central(4)	3.48	3.49	3.50	3.50	3.51	3.51
Size_DblN_descend_se_Rec_PC_Central(4)	2.56	2.46	2.37	2.29	2.22	2.15
Size_DblN_end_logit_Rec_PC_Central(4)	-3.25	-2.93	-2.69	-2.51	-2.35	-2.22
Size_DblN_peak_Rec_Disc_Central(6)	23.38	23.56	23.71	23.85	23.98	24.11
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.52	3.54	3.55	3.56	3.57	3.58
Size_DblN_descend_se_Rec_Disc_Central(6)	4.13	4.15	4.17	4.18	4.20	4.21
Size_DblN_peak_CCFRP(7)	32.07	32.22	32.36	32.48	32.59	32.68
Size_DblN_ascend_se_CCFRP(7)	4.02	4.02	4.01	4.01	4.01	4.01
Size_DblN_descend_se_CCFRP(7)	2.36	2.32	2.29	2.26	2.23	2.21
Size_DblN_end_logit_CCFRP(7)	-5.84	-5.55	-5.33	-5.14	-4.98	-4.85
Size_DblN_peak_DWV_Onboard_CPFV(8)	27.95	28.36	28.67	28.90	29.07	29.21
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.32	2.45	2.54	2.60	2.65	2.68
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	4.03	3.80	3.60	3.44	3.32	3.22
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-3.27	-2.66	-2.25	-1.95	-1.71	-1.51
Bratio_2023	0.353	0.348	0.349	0.355	0.367	0.383
SSB_unfished	1303	987	782	636	527	442
Totbio_unfished	4852	3928	3312	2865	2525	2260
Recr_unfished	294	336	382	432	486	545
Dead_Catch_SPR	60	61	63	64	64	64
OFLCatch_2023	47	47	46	46	46	47

Table 62: Female natural mortality profile for the central California base model (part 2).

	Female Natural Mortality (M, 1/yr)					
Quantity	0.2	0.22	0.24	0.26	0.28	0.3
N.Parms	118	118	118	118	118	118
TOTAL	523.8	523.3	523.6	524.5	525.9	527.6
Survey	20.9	20.3	19.7	19.0	18.3	17.5
Length_comp	319.6	319.2	319.1	319.2	319.4	319.9
Age_comp	180.7	180.9	181.5	182.2	183.2	184.3
Recruitment	2.2	2.2	2.4	2.7	3.1	3.6
Parm_priors	0.4	0.7	1.0	1.4	1.8	2.3
L_at_Amax_Fem_GP_1	54.4	54.8	55.1	55.4	55.7	55.9
VonBert_K_Fem_GP_1	0.146	0.144	0.142	0.140	0.139	0.137
L_at_Amax_Mal_GP_1	-0.098	-0.102	-0.106	-0.110	-0.113	-0.116
VonBert_K_Mal_GP_1	0.242	0.249	0.257	0.264	0.271	0.276
SR_LN(R0)	6.414	6.527	6.641	6.759	6.884	7.018
Q_extraSD_Rec_PR_Central(5)	0.378	0.377	0.375	0.371	0.367	0.362
Size_DblN_peak_Comm_nonTwl(1)	29.90	29.99	30.05	30.09	30.10	30.07
Size_DblN_ascend_se_Comm_nonTwl(1)	2.80	2.82	2.83	2.84	2.83	2.82
Size_DblN_descend_se_Comm_nonTwl(1)	4.46	4.53	4.61	4.67	4.72	4.75
Size_DblN_end_logit_Comm_nonTwl(1)	-1.30	-1.34	-1.41	-1.47	-1.51	-1.53
Size_DblN_peak_Comm_Discard(3)	27.45	27.53	27.59	27.65	27.70	27.75
Size_DblN_ascend_se_Comm_Discard(3)	3.43	3.43	3.43	3.43	3.43	3.43
Size_DblN_descend_se_Comm_Discard(3)	3.97	3.98	4.00	4.01	4.02	4.03
Size_DblN_peak_Rec_PC_Central(4)	32.95	33.02	33.09	33.14	33.18	33.21
Size_DblN_ascend_se_Rec_PC_Central(4)	3.52	3.52	3.52	3.52	3.52	3.52
Size_DblN_descend_se_Rec_PC_Central(4)	2.09	2.03	1.98	1.93	1.89	1.86
Size_DblN_end_logit_Rec_PC_Central(4)	-2.10	-2.01	-1.92	-1.85	-1.79	-1.75
Size_DblN_peak_Rec_Disc_Central(6)	24.22	24.32	24.42	24.51	24.59	24.66
Size_DblN_ascend_se_Rec_Disc_Central(6)	3.58	3.59	3.59	3.60	3.60	3.60
Size_DblN_descend_se_Rec_Disc_Central(6)	4.23	4.24	4.25	4.26	4.26	4.27
Size_DblN_peak_CCFRP(7)	32.77	32.84	32.90	32.95	32.99	33.03
Size_DblN_ascend_se_CCFRP(7)	4.01	4.00	4.00	4.00	3.99	3.99
Size_DblN_descend_se_CCFRP(7)	2.18	2.16	2.14	2.12	2.11	2.10
Size_DblN_end_logit_CCFRP(7)	-4.73	-4.62	-4.53	-4.45	-4.38	-4.32
Size_DblN_peak_DWV_Onboard_CPFV(8)	29.33	29.42	29.49	29.54	29.57	29.58
Size_DblN_ascend_se_DWV_Onboard_CPFV(8)	2.71	2.73	2.74	2.76	2.76	2.77
Size_DblN_descend_se_DWV_Onboard_CPFV(8)	3.13	3.05	2.98	2.92	2.87	2.83
Size_DblN_end_logit_DWV_Onboard_CPFV(8)	-1.34	-1.19	-1.07	-0.97	-0.90	-0.87
Bratio_2023	0.405	0.432	0.466	0.505	0.551	0.606
SSB_unfished	376	323	281	248	221	201
Totbio_unfished	2051	1886	1757	1659	1592	1555
Recr_unfished	611	683	766	862	976	1117
Dead_Catch_SPR	65	65	65	66	68	70
OFLCatch_2023	48	49	51	54	57	62

Table 63: Select reference points for the combined northern and central area models (point estimates only). Each is calculated as the sum of values in the area-specific models, with the exception of Fraction Unfished (2023), which is the ratio of Spawning Output (2023) to Unfished Spawning Output.

Reference Point	Estimate
Unfished Spawning Output (billions of eggs)	1,471
Unfished Age 8+ Biomass (mt)	5,491
Unfished Recruitment (R0, 1000s)	2,900
Spawning Output (2023, billions of eggs)	555
Fraction Unfished (2023)	0.377
Reference Points Based SB40%	
Proxy Spawning Output SB40%	588
Yield with SPR Based On SB40% (mt)	348
Reference Points Based on SPR Proxy for MSY	
Proxy Spawning Output (SPR50)	656
Yield with SPR50 at SB SPR (mt)	330
Reference Points Based on Estimated MSY Values	
Spawning Output at MSY (SB MSY)	361
MSY (mt)	382

Table 64: 12-year projections (2023 – 2034) for California black rockfish (statewide) according to three alternative states of nature based on the annual rate of natural mortality. Columns represent low, medium (base case), and high states of nature, and rows range over different assumed catch levels corresponding to the forecast catches from each state of nature. Spawning output units are billions of eggs. Catches in 2023-2024 assume full attainment of the ACL as forecast by the 2015 assessment.

P* = 0.45, sigma = 0.5			State of nature: Low		State of nature: Base case		State of nature: High	
			Female M = 0.147		Female M = 0.210		Female M = 0.300	
Management decision	Year	Catch (mt)	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished	Spawning Output	Fraction Unfished
Low Catch	2023	334	494	0.222	547	0.377	872	0.736
	2024	329	477	0.215	530	0.365	847	0.716
	2025	86	457	0.205	513	0.354	824	0.696
	2026	96	471	0.212	532	0.367	837	0.707
	2027	109	487	0.219	558	0.384	858	0.725
	2028	122	506	0.227	590	0.407	885	0.748
	2029	135	528	0.237	627	0.432	912	0.770
	2030	148	555	0.249	664	0.458	933	0.788
	2031	160	586	0.263	700	0.483	948	0.801
	2032	171	618	0.278	731	0.504	957	0.808
	2033	181	651	0.293	758	0.523	960	0.811
	2034	189	683	0.307	781	0.539	960	0.811
Base Catch	2023	334	494	0.222	547	0.377	872	0.736
	2024	329	477	0.215	530	0.365	847	0.716
	2025	224	457	0.205	513	0.354	824	0.696
	2026	236	447	0.201	511	0.353	819	0.692
	2027	249	437	0.196	516	0.356	822	0.694
	2028	261	428	0.192	526	0.363	832	0.702
	2029	270	421	0.189	539	0.372	841	0.711
	2030	277	420	0.189	554	0.382	848	0.716
	2031	282	423	0.190	569	0.392	851	0.719
	2032	285	428	0.193	583	0.402	850	0.718
	2033	286	436	0.196	595	0.410	848	0.716
	2034	287	443	0.199	606	0.418	844	0.713
High Catch	2023	334	494	0.222	547	0.377	872	0.736
	2024	329	477	0.215	530	0.365	847	0.716
	2025	580	457	0.205	513	0.354	824	0.696
	2026	566	384	0.173	458	0.316	771	0.652
	2027	555	313	0.141	412	0.284	732	0.618
	2028	543	249	0.112	374	0.258	704	0.594
	2029	529	204	0.092	344	0.237	682	0.576
	2030	518	181	0.081	321	0.221	664	0.561
	2031	507	174	0.078	303	0.209	649	0.548
	2032	498	172	0.077	290	0.200	637	0.538
	2033	491	173	0.078	278	0.192	627	0.530
	2034	485	174	0.078	268	0.185	619	0.523

Table 65: Base model estimates of the OFL (mt), ABC (mt), ACL (mt), buffer, spawning output in billions of eggs across California, and relative spawning output by year along with the sub-area allocations of the ACL for the northern and central regions. Buffers are based on the default category 1 uncertainty level (sigma=0.5) and a P-star of 0.45.

Year	OFL (mt)	ABC (mt)	ACL (mt)	Buffer	Spawning Output	Fraction Unfished	Sub-ACL North	Sub-ACL Central
2025	250.1	233.8	223.6	0.935	513.0	0.354	182.0	41.6
2026	265.3	246.8	235.7	0.93	511.5	0.353	190.3	45.5
2027	280.6	259.9	249.1	0.926	516.0	0.356	199.4	49.7
2028	293.2	270.3	261.0	0.922	526.0	0.363	208.1	53.0
2029	302.2	277.1	270.2	0.917	539.4	0.372	215.2	55.0
2030	308.4	281.6	277.2	0.913	554.2	0.382	221.1	56.1
2031	312.6	284.2	282.3	0.909	569.0	0.392	225.6	56.7
2032	315.6	285.3	285.3	0.904	582.8	0.402	228.4	56.9
2033	318.1	286.3	286.3	0.9	595.1	0.410	229.5	56.8
2034	320.5	287.2	287.2	0.896	606.1	0.418	230.5	56.7

12 Figures

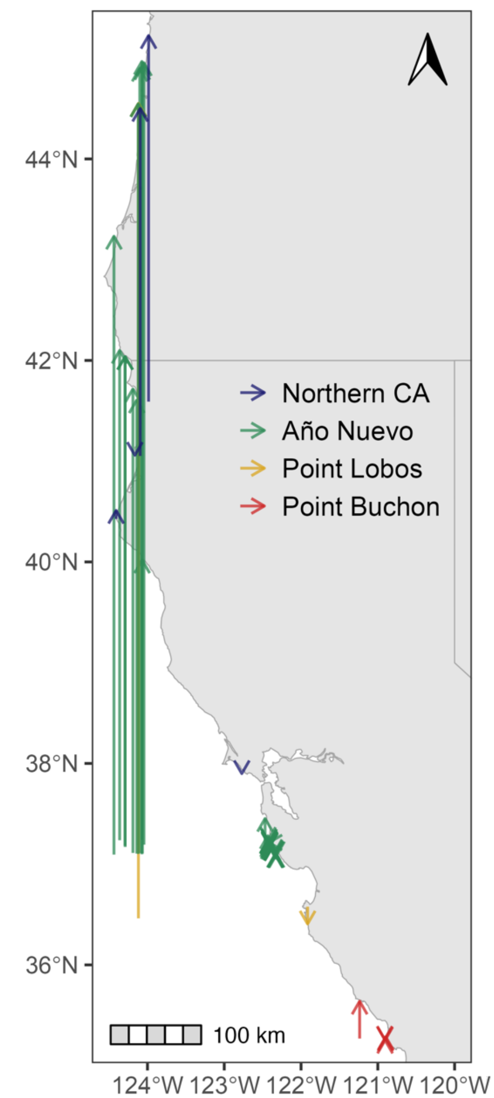


Figure 1: Map of recaptured black rockfish (n = 65) tagged as part of the California Collaborative Fisheries Research Program (CCFRP, 2007 to 2022). Colors represent different release locations and arrows denote recapture locations. Euclidean distances (km) were estimated for net movements (see text for further details). Arrows were jittered for visualization.

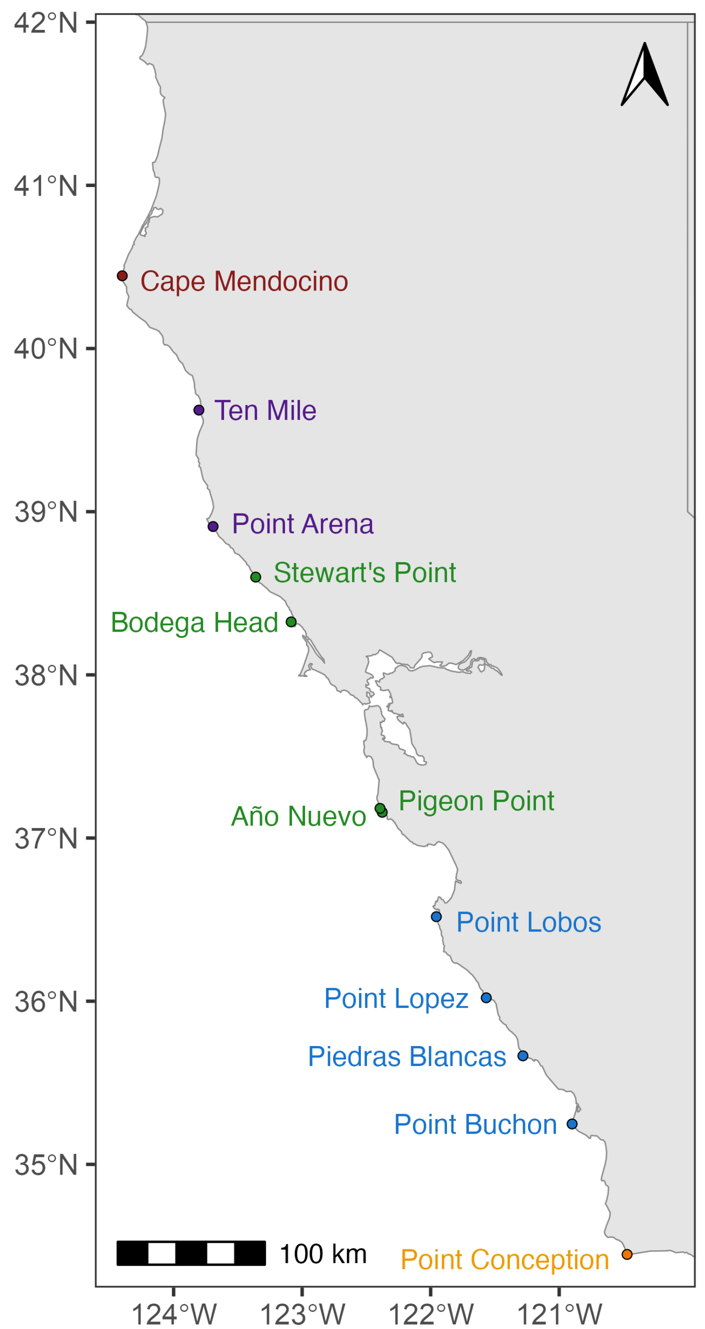


Figure 2: Map of selected coastal features in the 2023 California stock assessment for black rockfish. The assessed area covers U.S. waters between the California/Oregon border (42° N. latitude) and Point Conception (34° 27′ N. lat.). Features are color-coded by California Recreational Fisheries Survey (CRFS) district (red = district 6, purple = district 5, green = district 4, blue = district 3, orange = district 2).

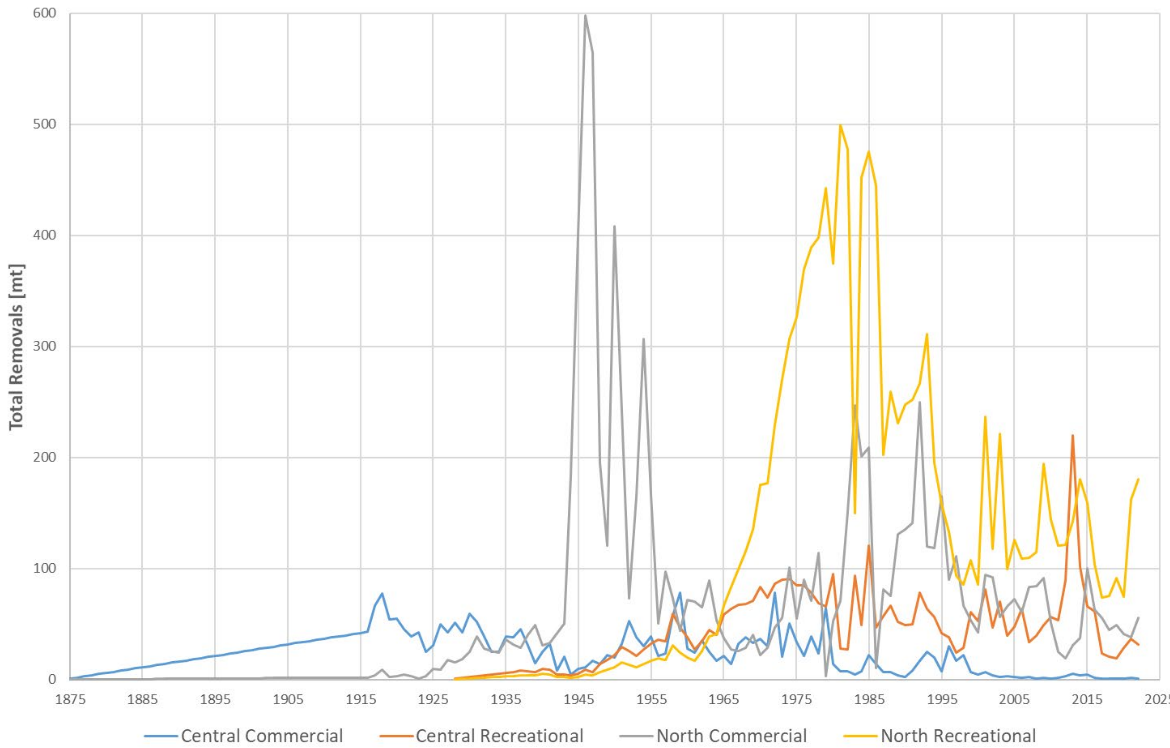


Figure 3: Summary of black rockfish total removals (catch + discard) in California by area and sector, 1875-2022. The northern area includes U.S. waters from the CA/OR border to Point Arena. The central area includes U.S. waters off California south of Point Arena.

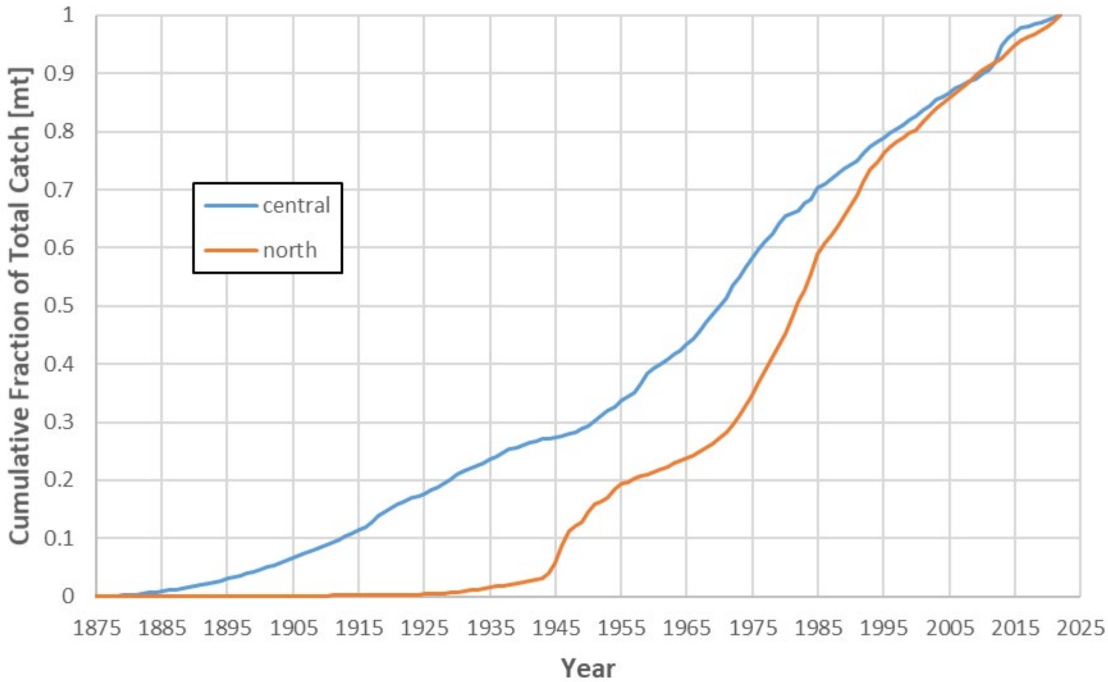


Figure 4: Cumulative fraction of black rockfish total removals (catch + discard) in California by area, 1875-2022. The northern area includes U.S. waters from the CA/OR border to Point Arena. The central area includes U.S. waters off California south of Point Arena.

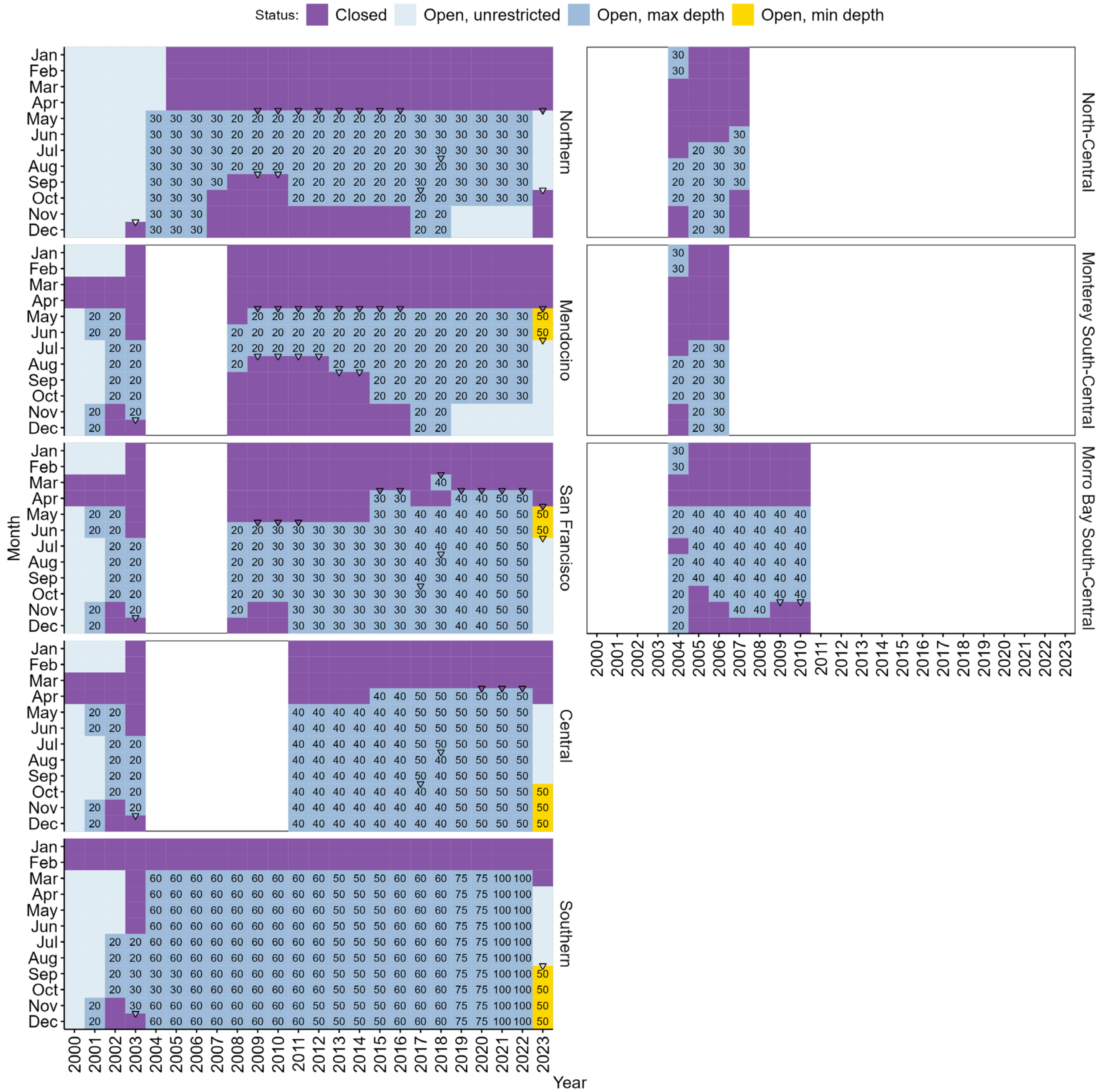


Figure 5: The CDFW recreational season length and depth restriction for nearshore rockfish by month from 2000 to 2023. A triangle indicates a regulation change mid-month. The regions defined base on the following latitudes: Northern (42°00´ N. lat. to 40°10´ N. lat.), Mendocino (40°10´ N. lat. to 38°57´ N. lat.), San Francisco (38°57´ N. lat. to 37°11´ N. lat.), Central (37°11´ N. lat. to 34°27´ N. lat.), Southern (34°27´ N. lat. to the U.S./Mexico border). Not all management areas have been consistently defined over time. The northern and southern management areas have remained the same. From 2001-2003 the Central management area was defined as 40°10´ N. lat. to 34°27´ N. lat. In 2004, the Central area was split into a North-Central and South-Central areas at 36°00´ N. lat. In 2005, the regions from 40°10´ N. lat. to 34°27´ N. lat. were redefined. The North-Central encompasses 40°10´ N. lat. to 37°11´ N. lat., Monterey South-Central from 37°11´ N. lat. to 36°00´ N. lat., and Morro Bay South-Central from 36°00´ N. lat. to 34°27´ N. lat.

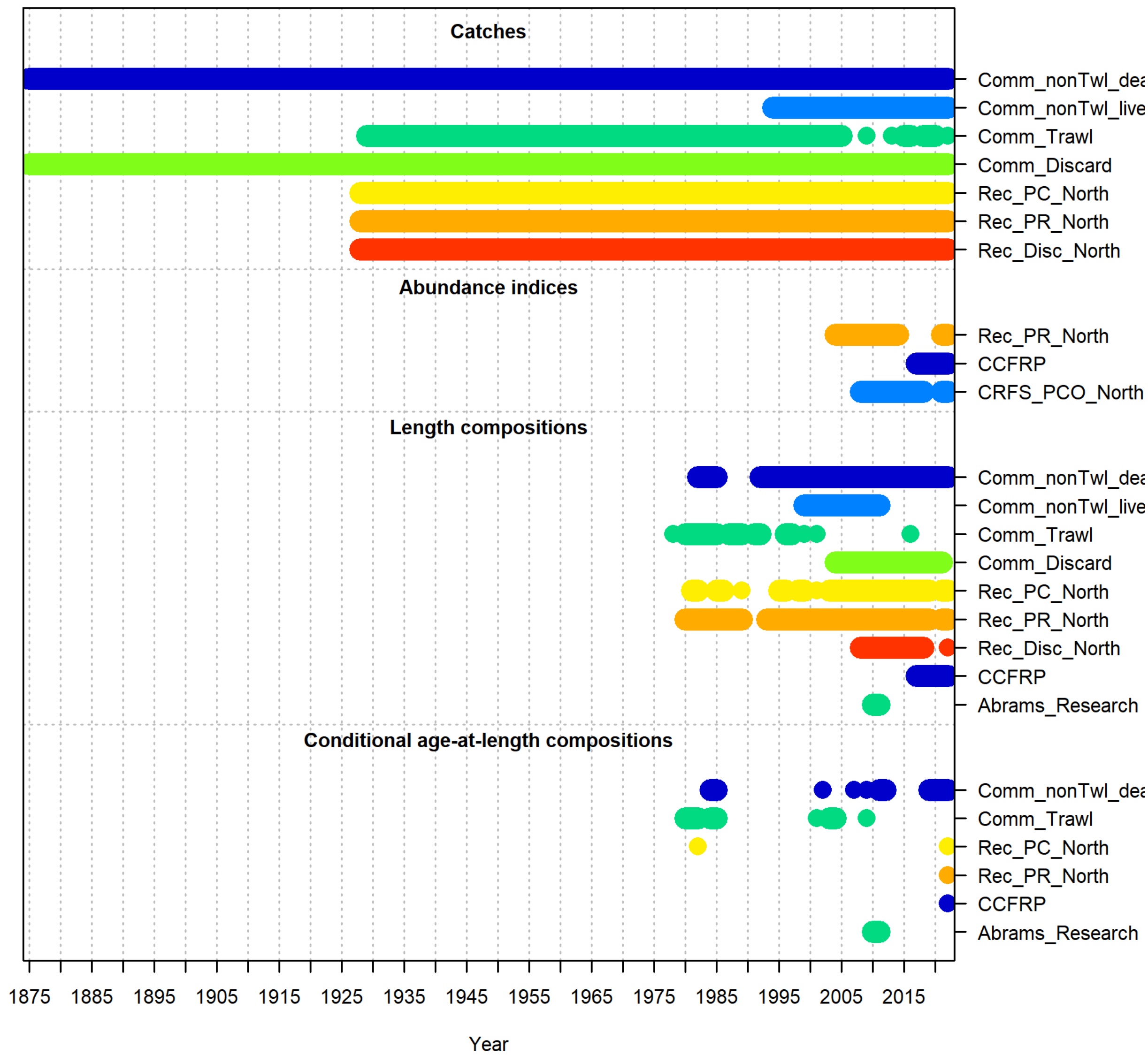


Figure 6: Summary of data sources in the northern base model.

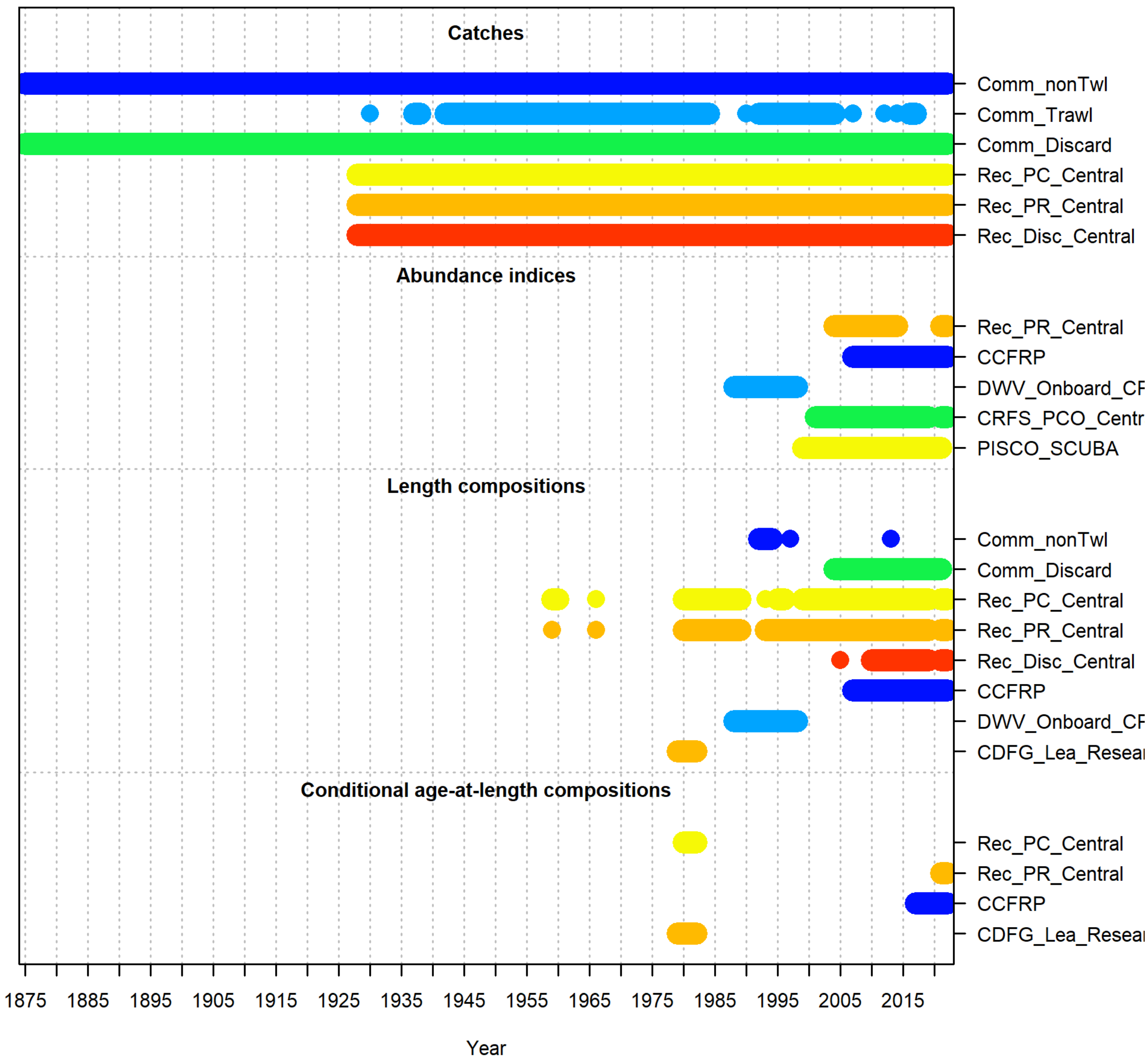


Figure 7: Summary of data sources in the central base model. The "PISCO SCUBA" index was included for comparison only, and not included in the likelihood function.

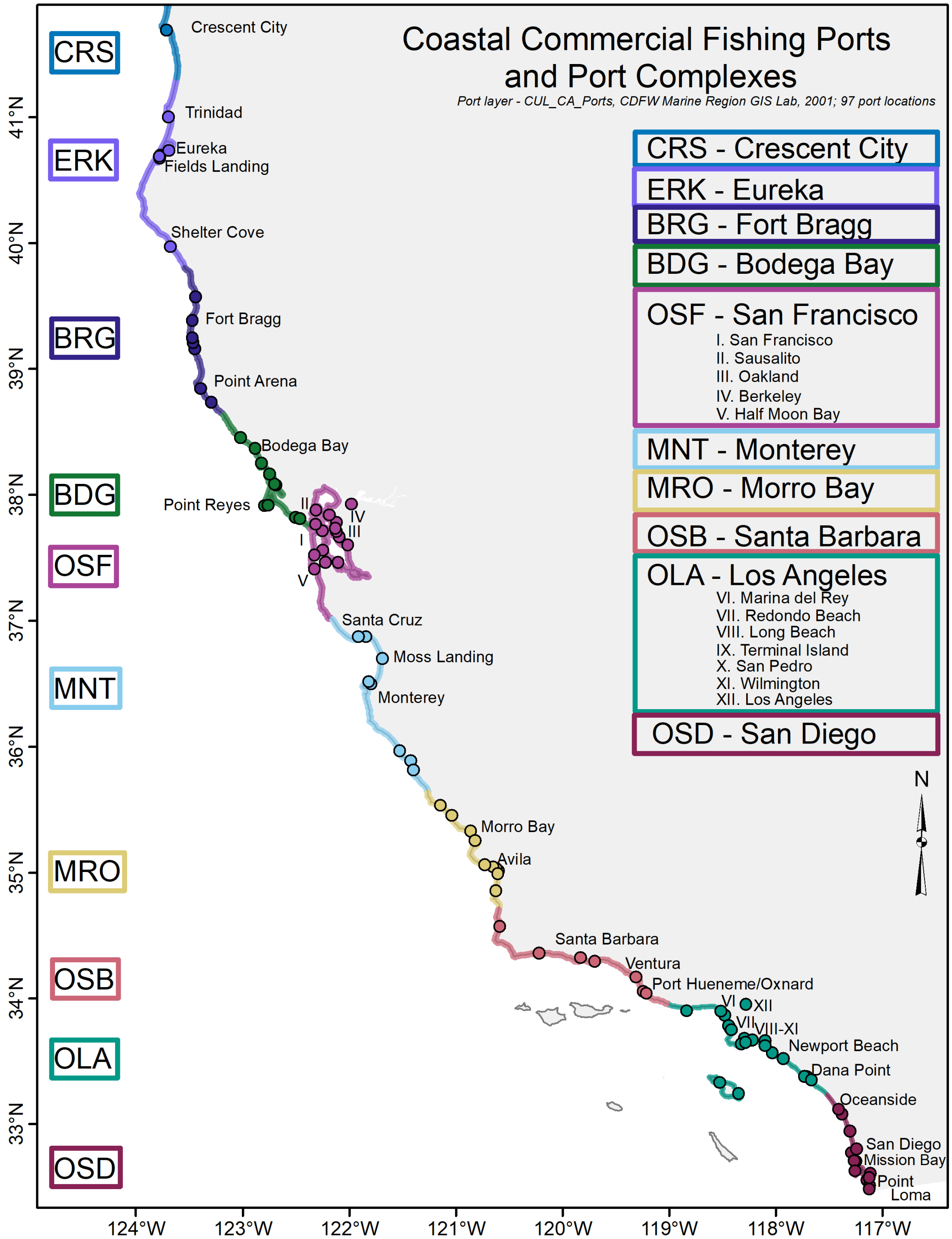


Figure 8: California commercial fishing ports and port complexes sampled by the CCGS.

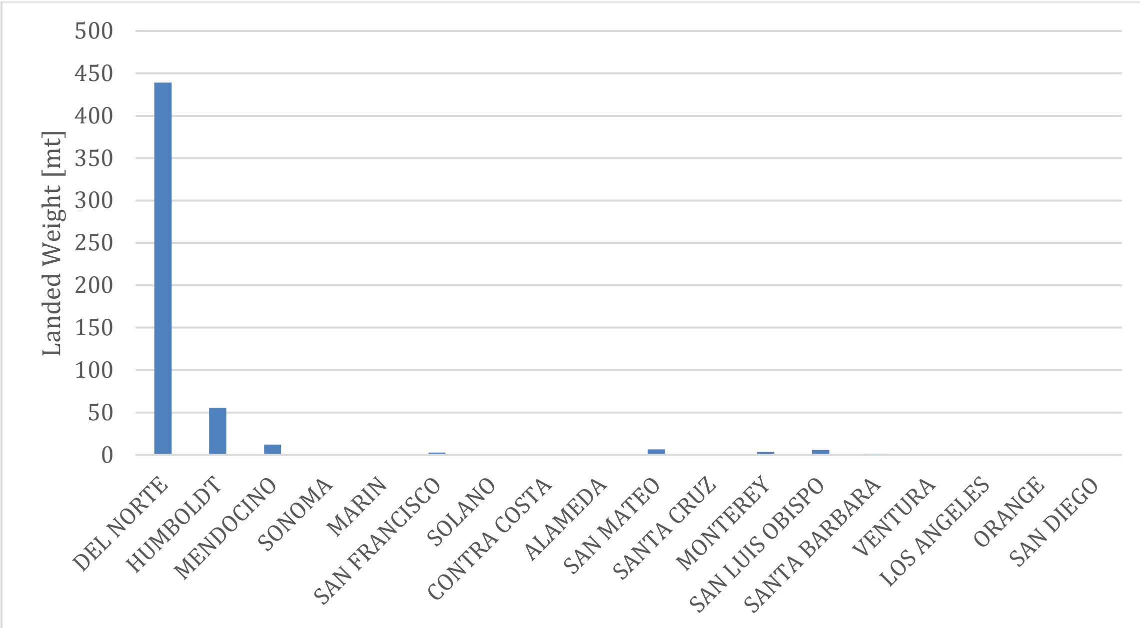


Figure 9: Recent commercial landings of black rockfish in California, .2013-2022 by coastal county and arranged north to south (left to right). Source: PacFIN.

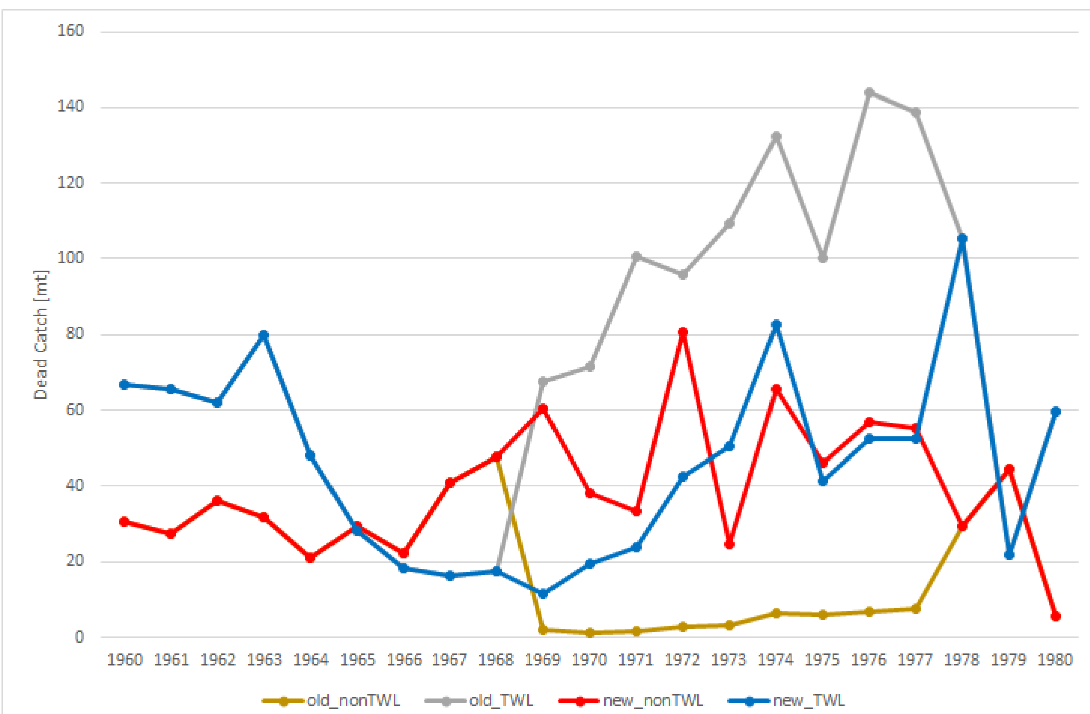


Figure 10: Revision to commercial landings estimates (red and blue lines) for the years 1969-1977, relative to estimates provided for the 2015 assessment (yellow and gray).

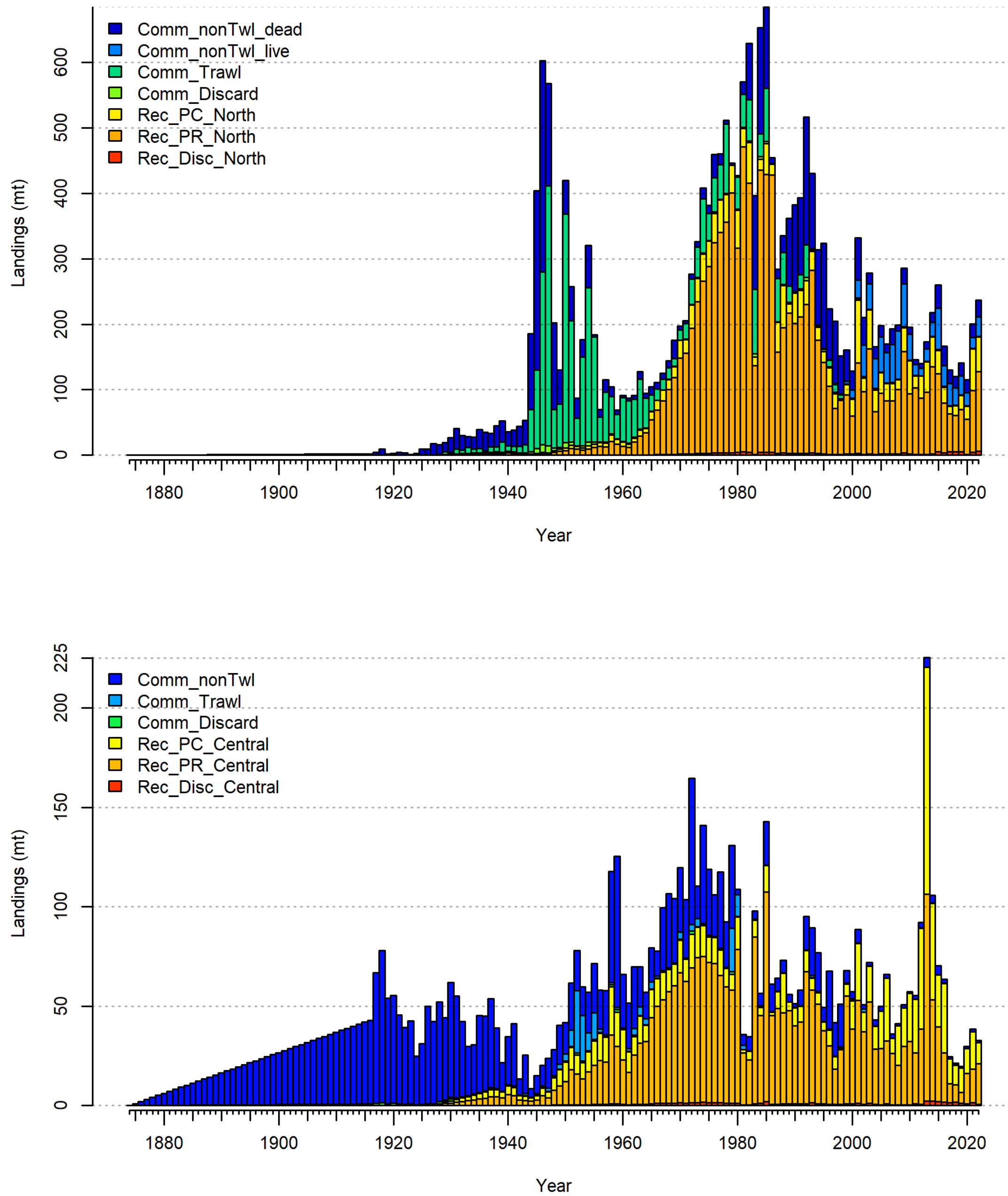


Figure 11: Landings by fleet and year in the northern assessment area (upper panel) and central assessment area (lower panel).

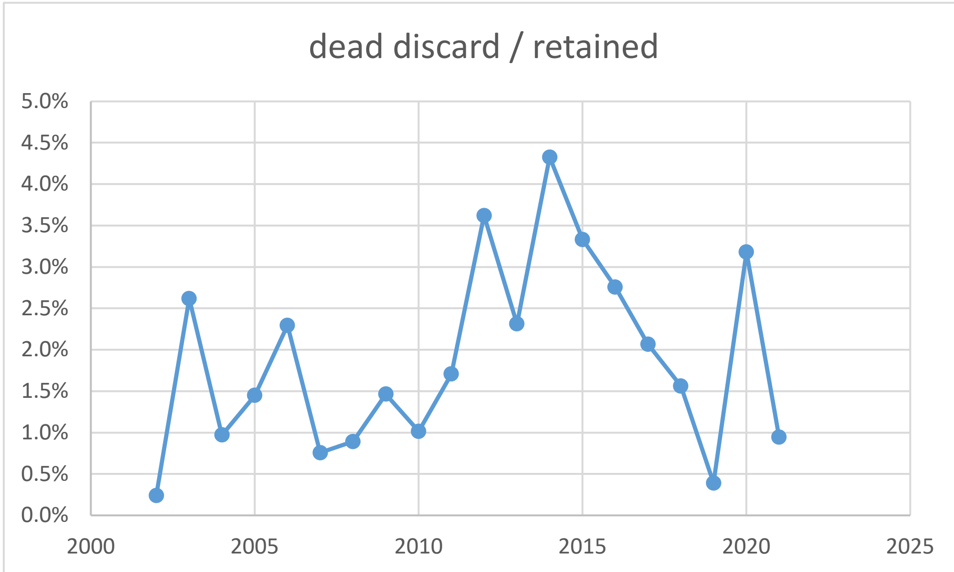


Figure 12: Ratio of dead discard to retained catch for commercially caught black rockfish, 2002-2021. Source: WCGOP.

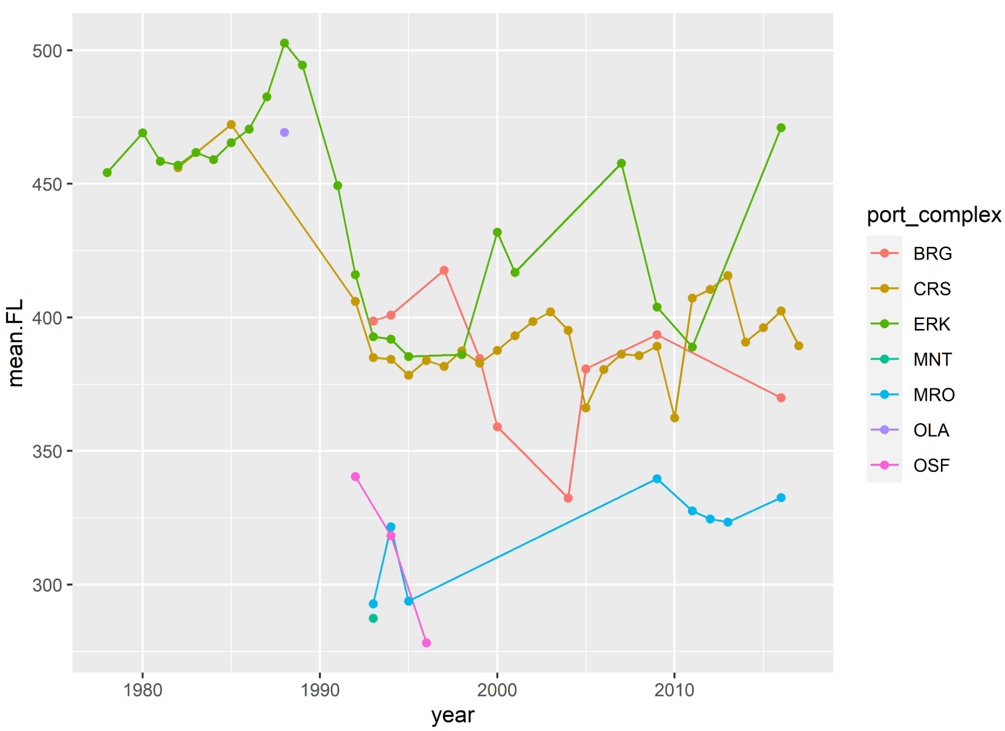


Figure 13: Mean fork lengths from commercial sources by port complex and year. Northern area ports (CRS, ERK, BRG) have consistently higher average length than areas south of Point Arena.

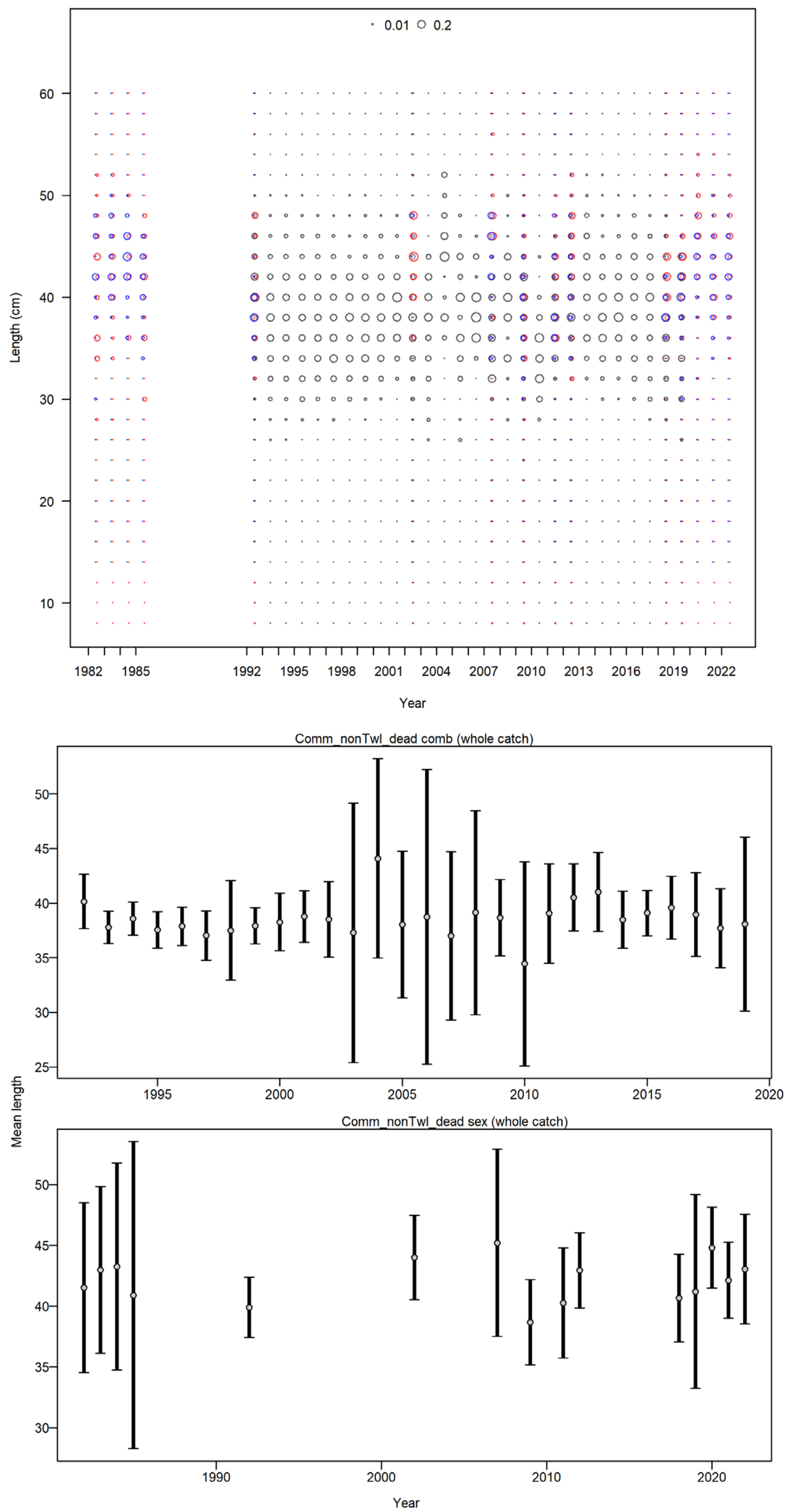


Figure 14: Length composition data (upper panel) and mean lengths for combined sex data (middle panel) and sex-specific data (lower panel) from the northern, non-trawl commercial fleet (dead landings).

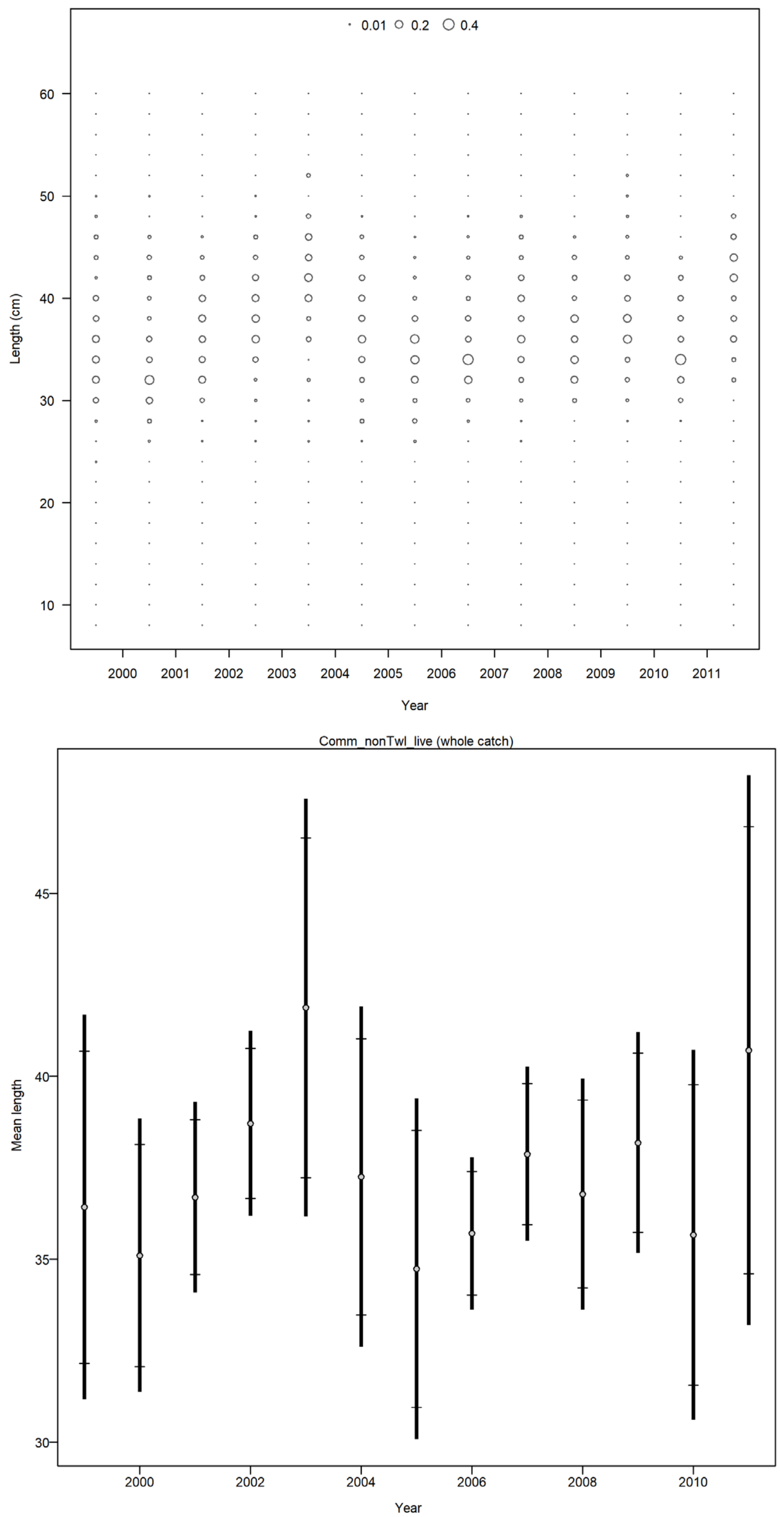


Figure 15: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the northern, non-trawl commercial fleet (live landings).

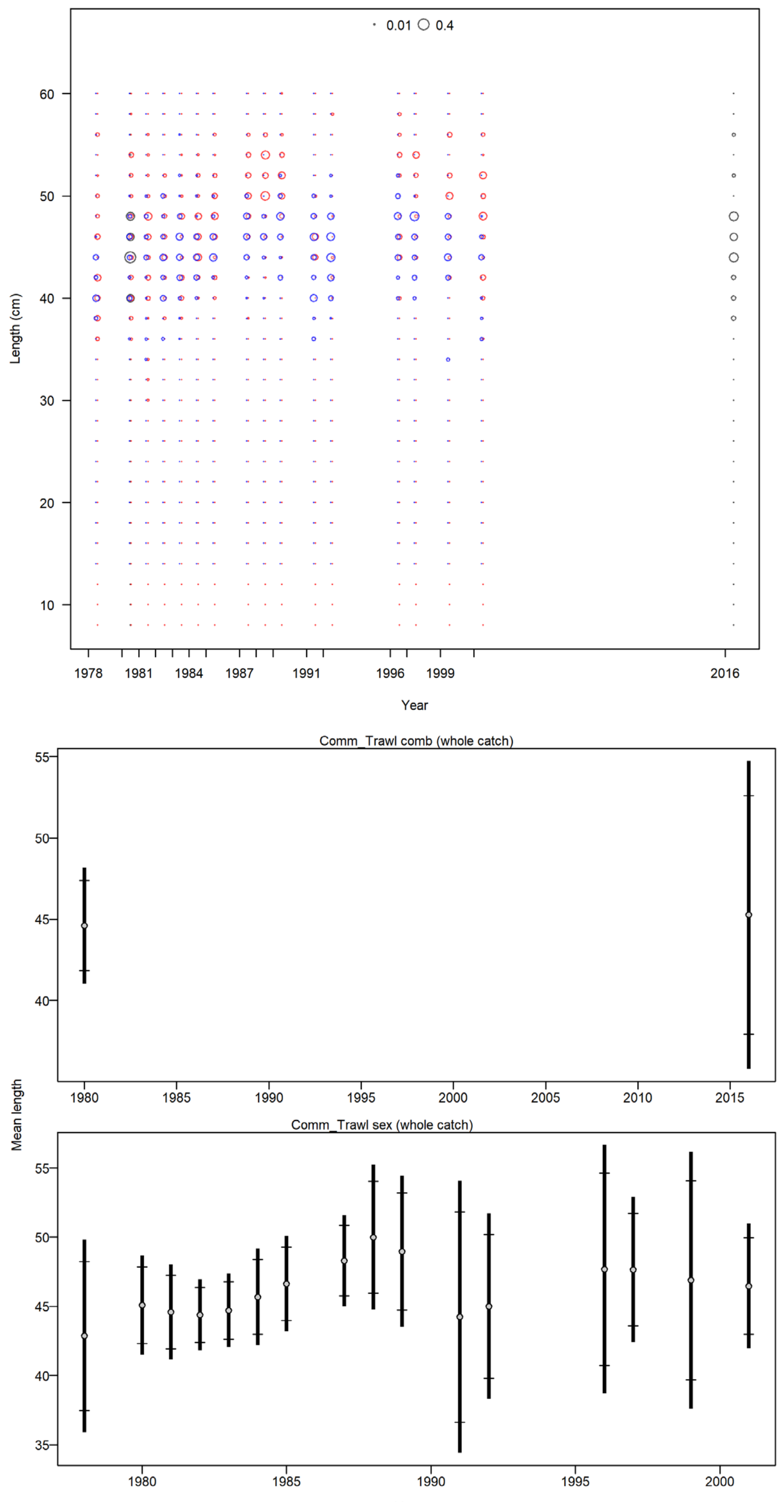


Figure 16: Length composition data (upper panel) and mean lengths for combined sex data (middle panel) and sex-specific data (lower panel) from the northern trawl commercial fleet.

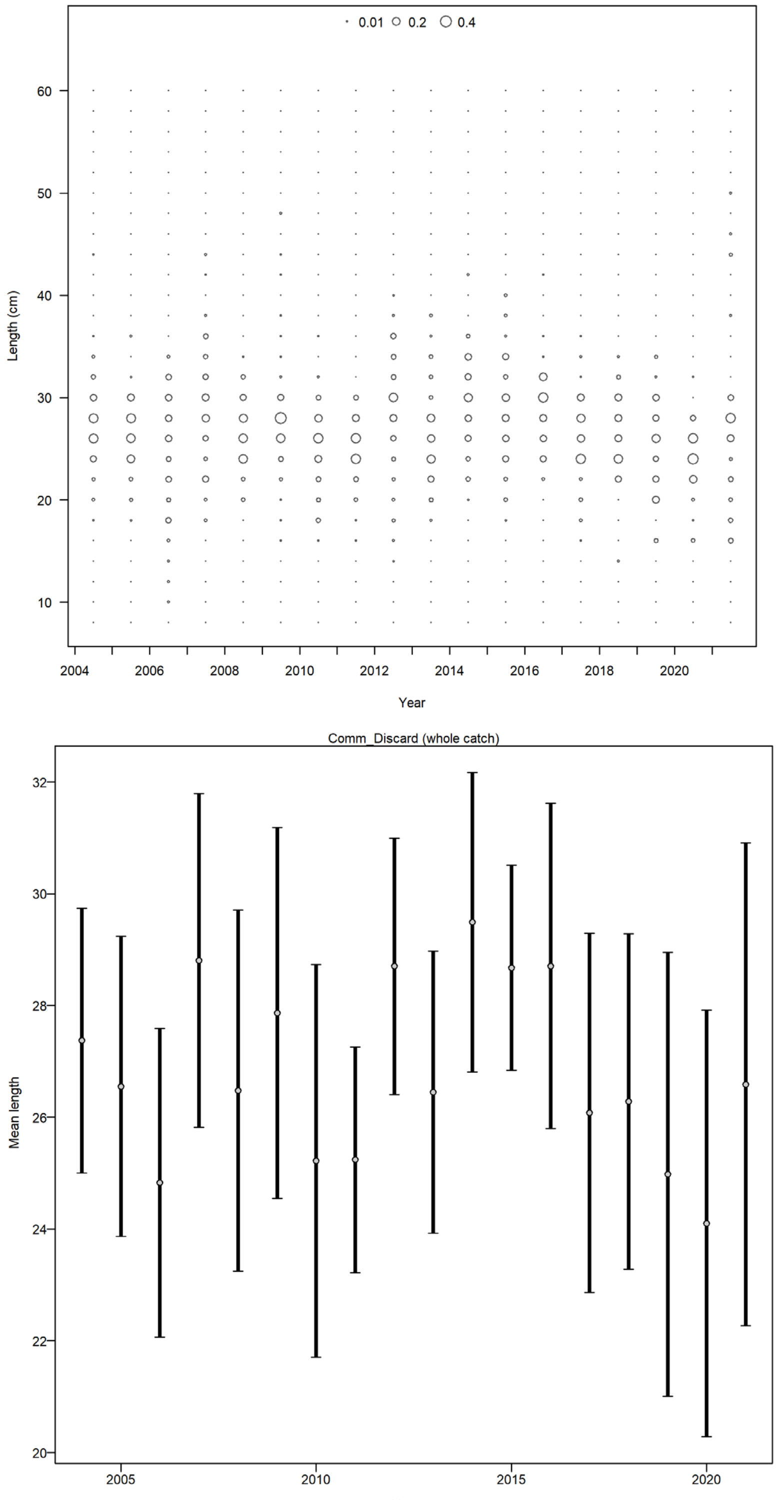


Figure 17: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the northern commercial discard fleet (and assumed to be the same for the central area).

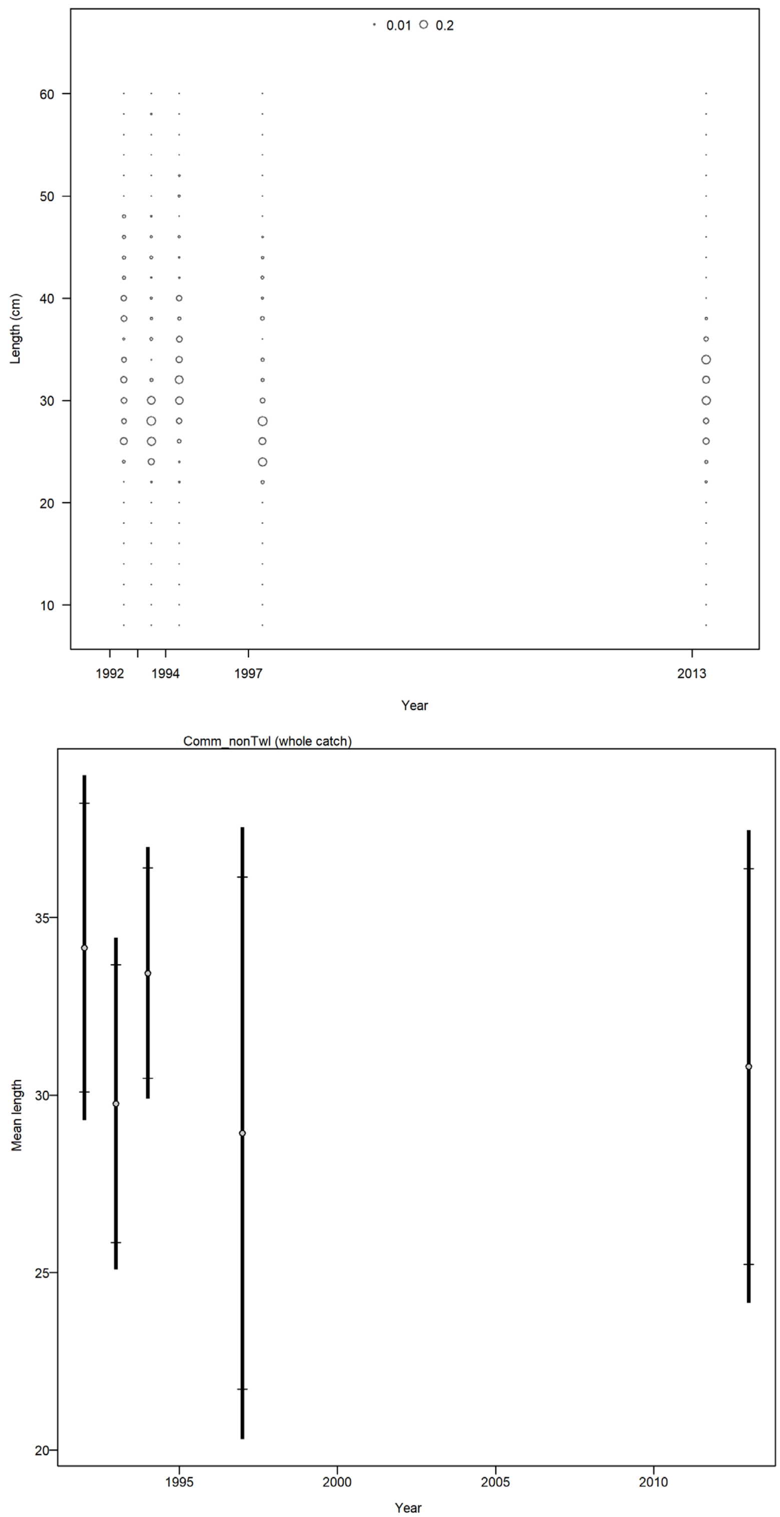


Figure 18: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the central commercial non-trawl fleet

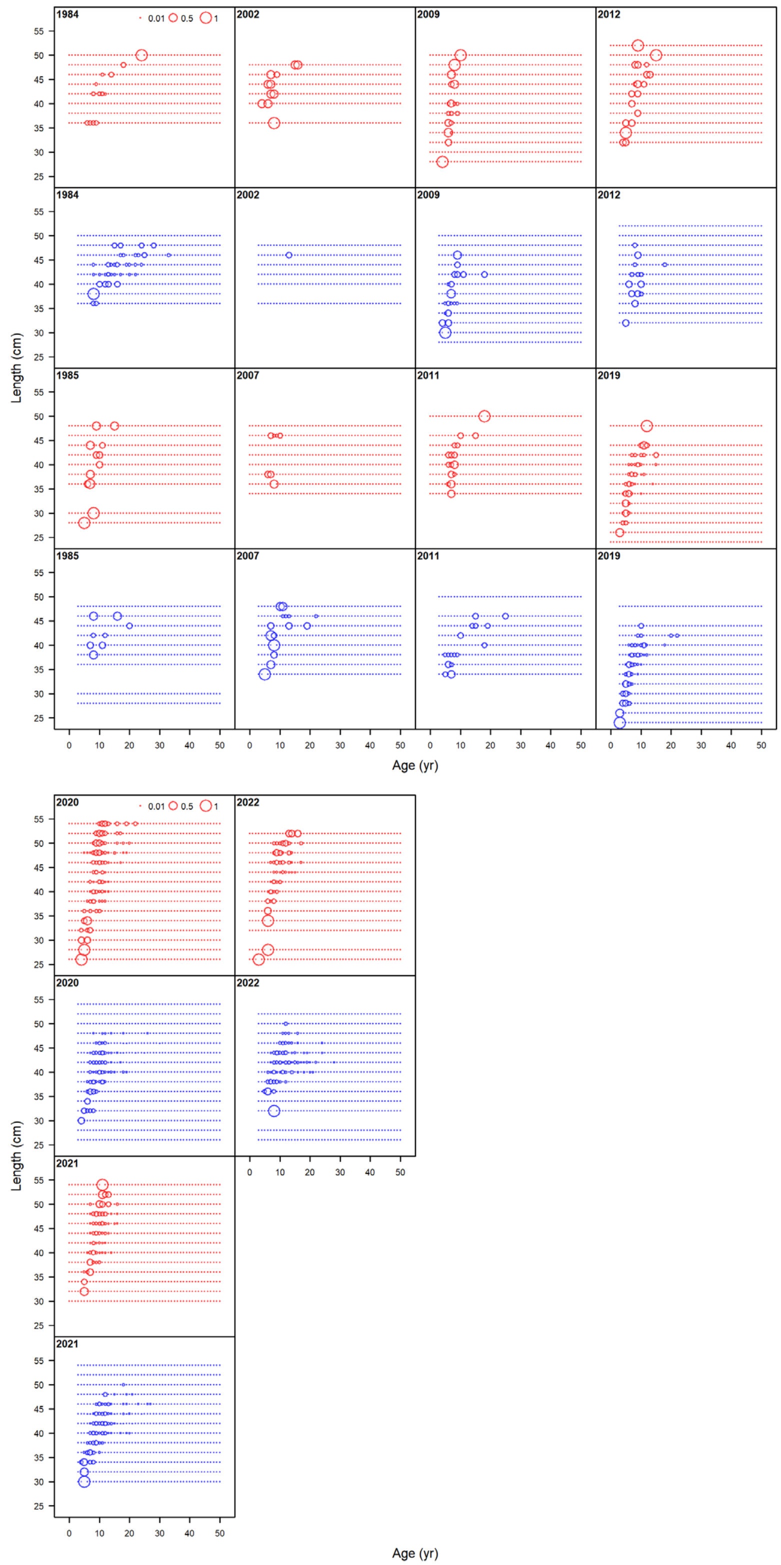


Figure 19: Conditional age-at-length data, northern commercial non-trawl fleet. Red panels are female, blue panels are male.

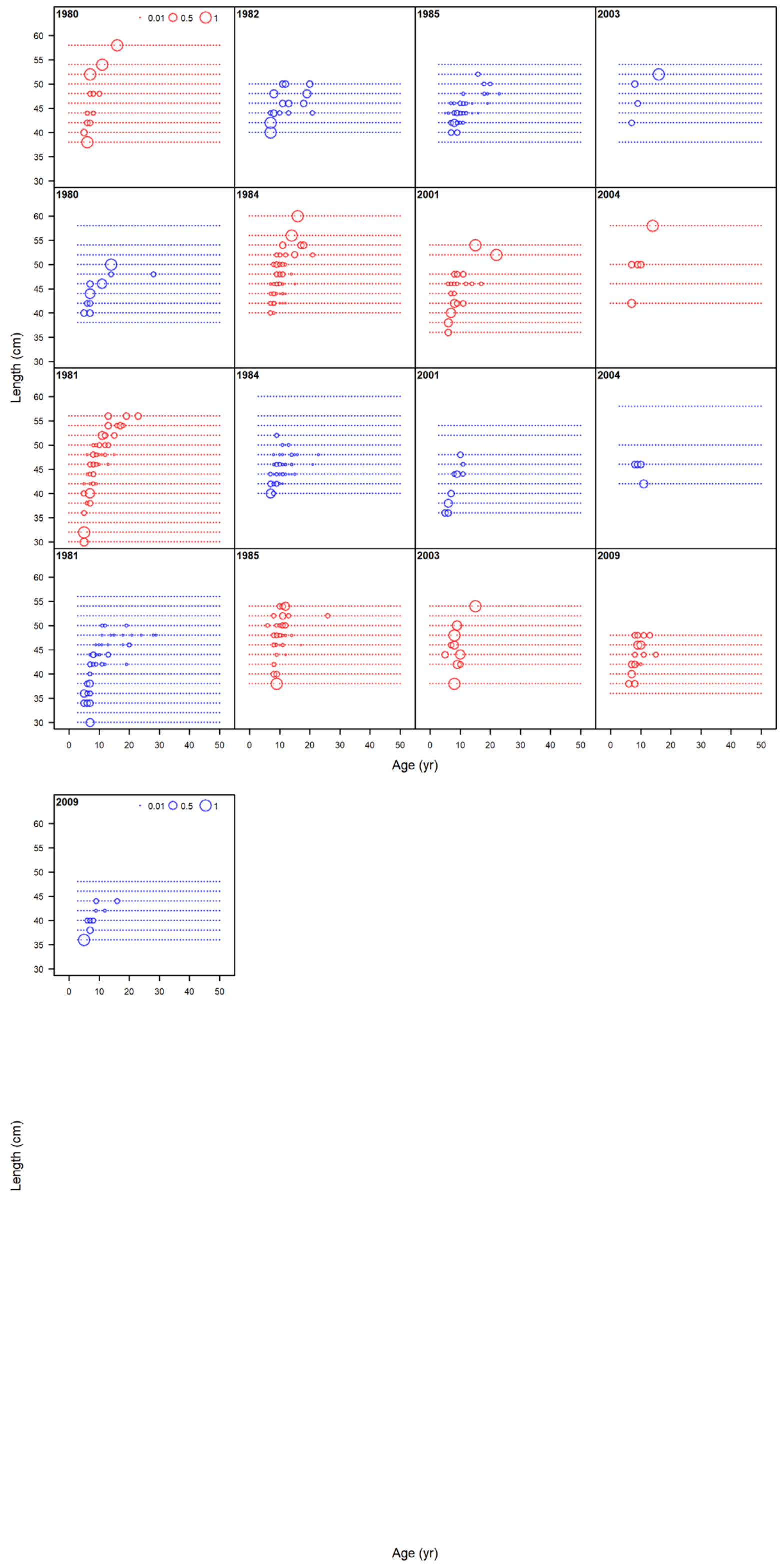


Figure 20: Conditional age-at-length data, northern commercial trawl fleet. Red panels are female, blue panels are male.

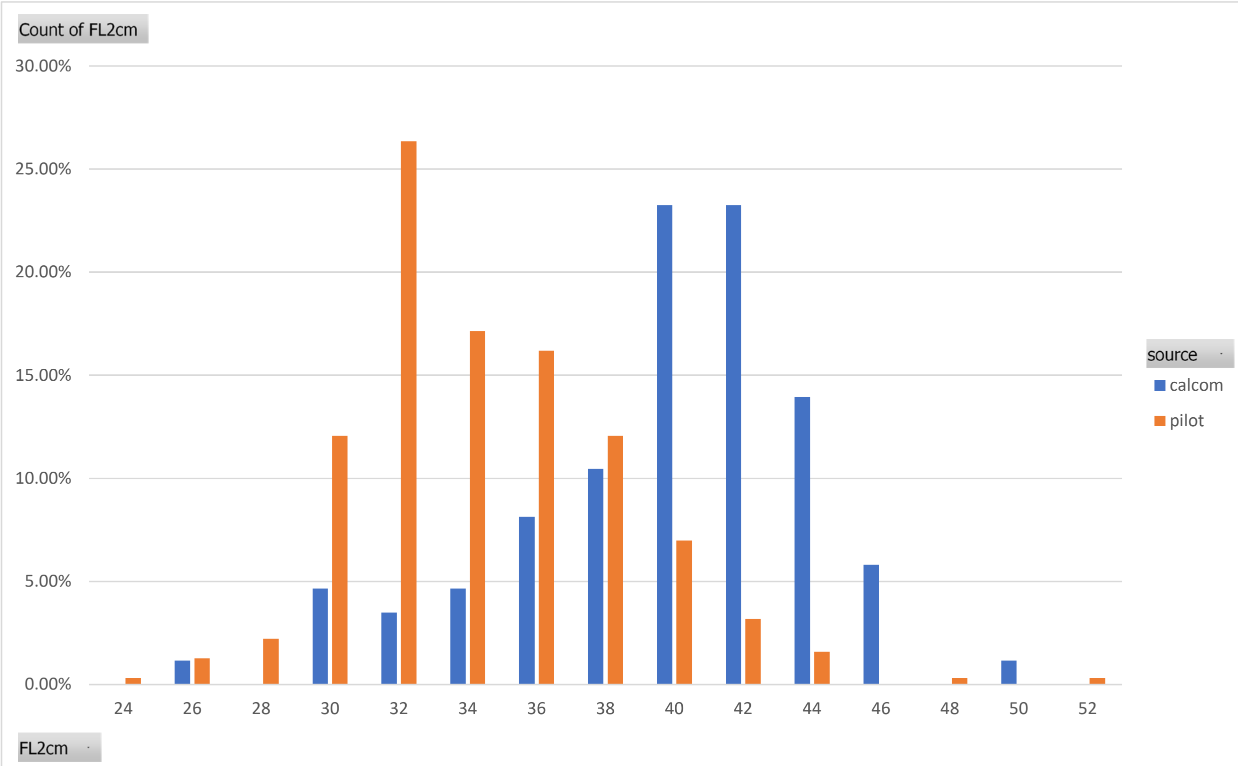


Figure 21: Comparison of length distributions between fish sampled by CCGS (blue, “CALCOM”) and a commercial pilot sampling project conducted in 2019 by CDFW (orange, “pilot”).

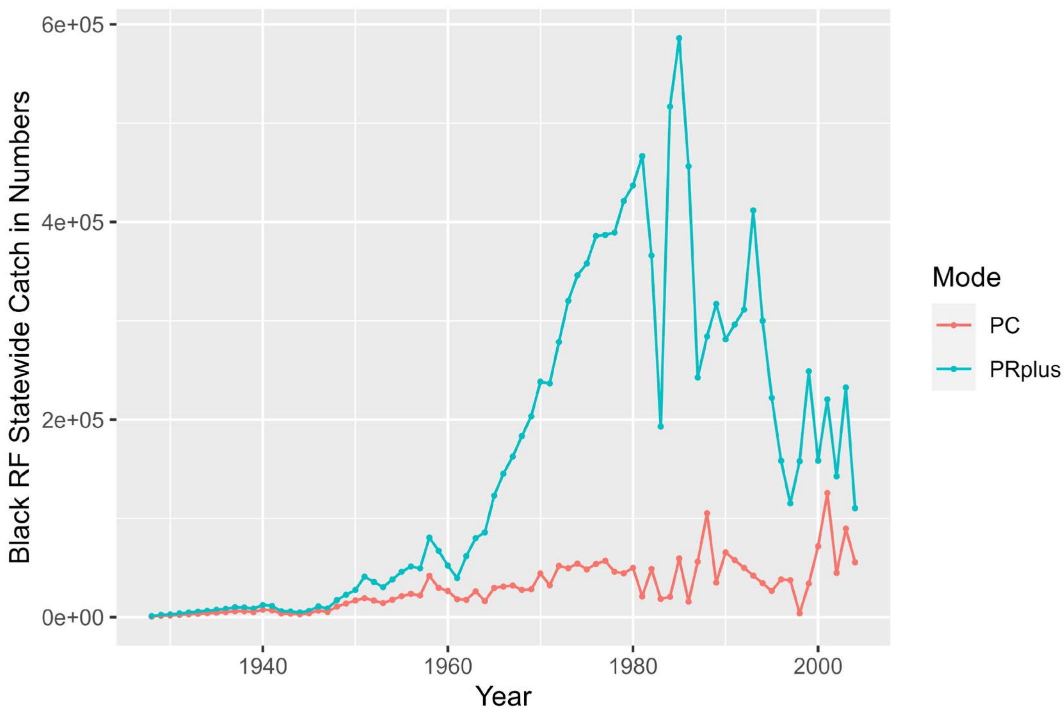


Figure 22: Estimates of statewide recreational catch in numbers by year and mode.

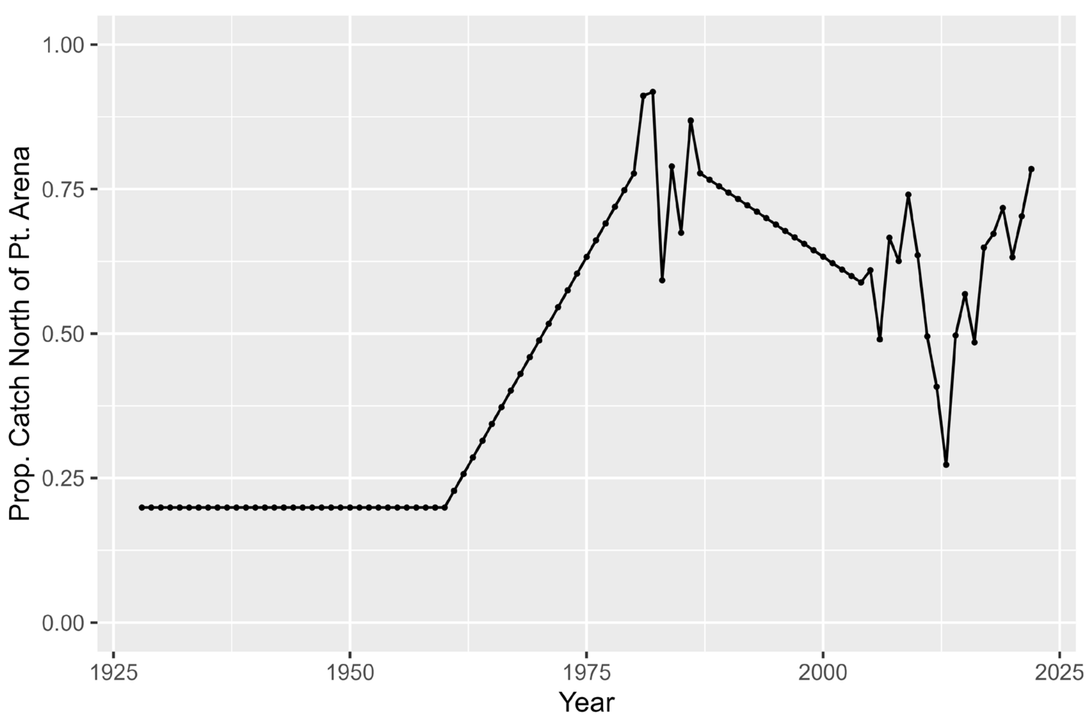


Figure 23: Proportion of statewide catch allocated to the area north of Point Arena. Information from 1981-1986 from Albin et al. (1993). Estimates from CRFS, 2005-2022 are shown for reference.

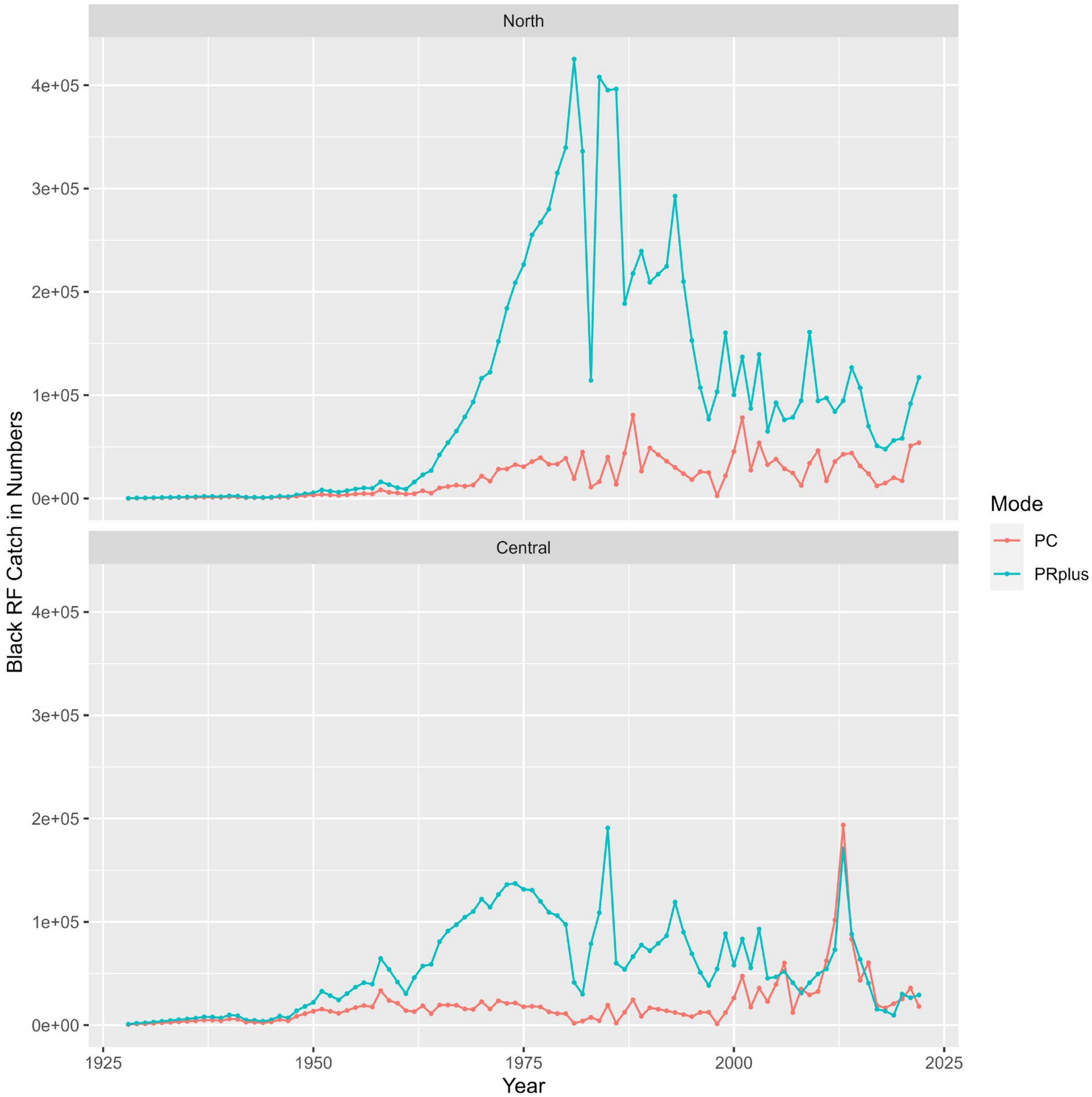


Figure 24: Result of allocating statewide catch in numbers to areas north and south of Point Arena.

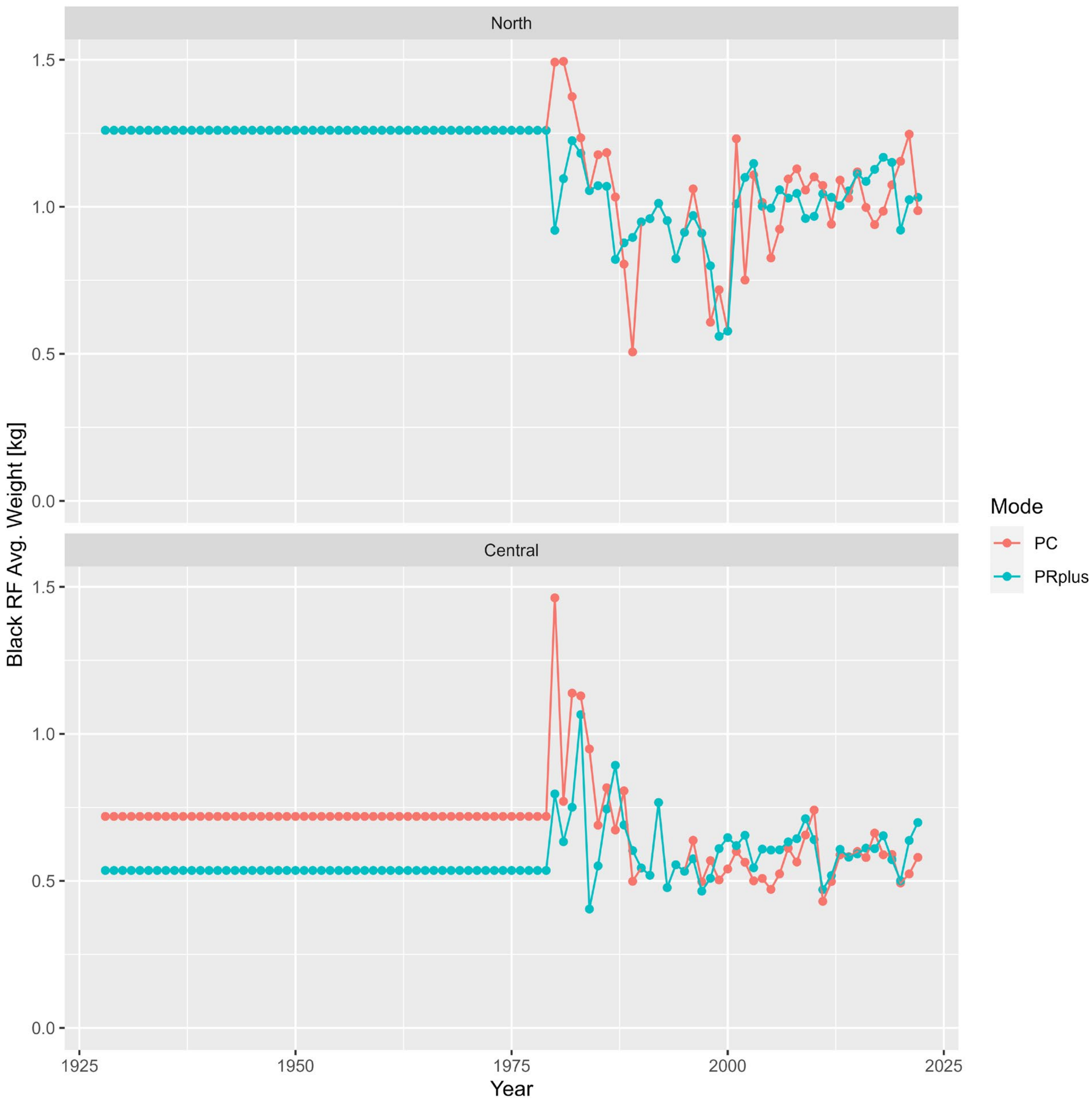


Figure 25: Estimates of average fish weight by year, area, and mode. Source: MRFSS and CRFS. Estimates of average weight prior to 1980 are taken from Karpov et al. in the northern area and fleet-specific estimates from Miller and Gotshall (1965) data in the central area.

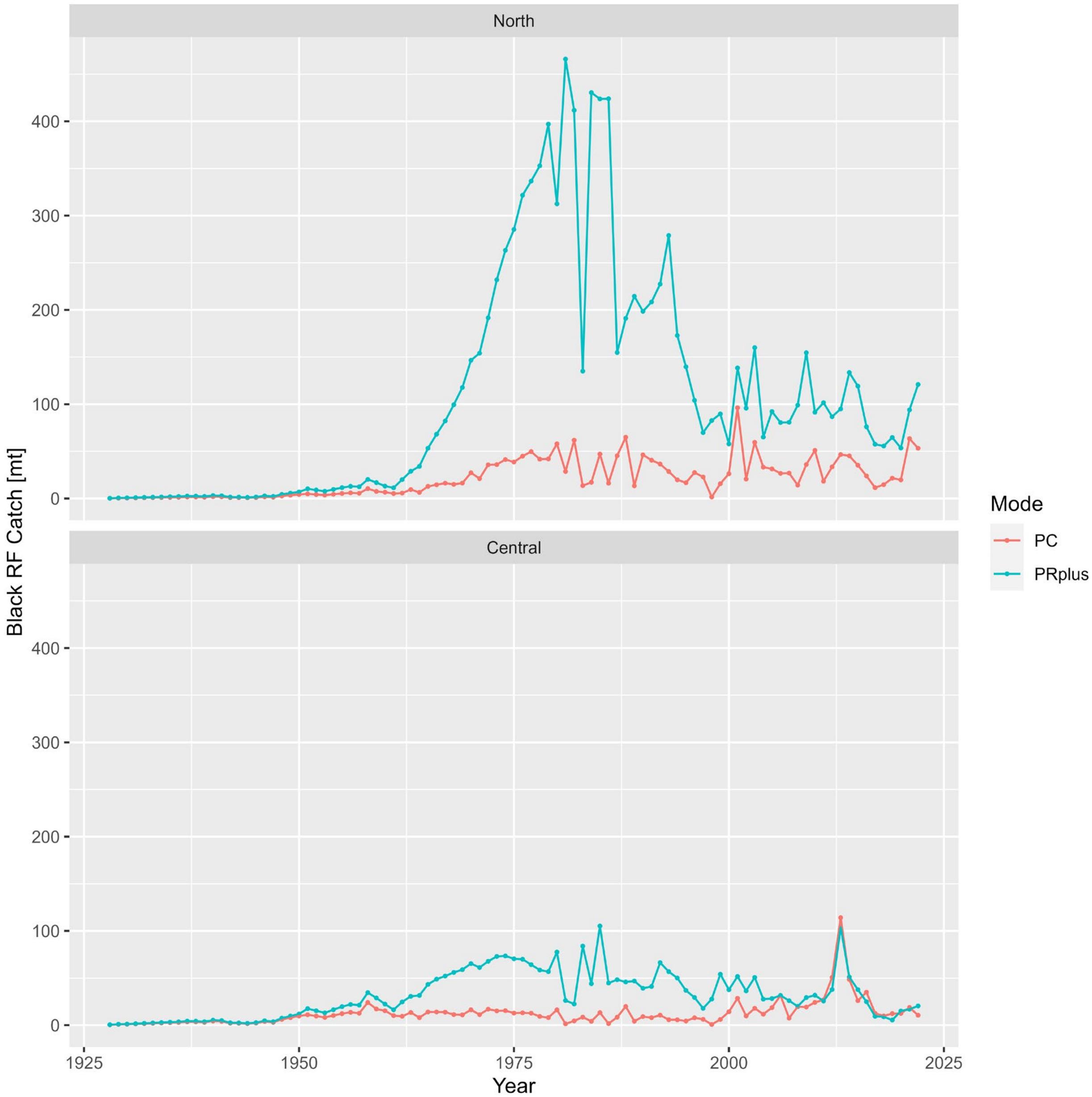


Figure 26: Estimated catch in metric tons by year, area, and mode. This was calculated as the product of average weight per fish and catch in numbers.

California Recreational Fisheries Survey (CRFS) Districts

Figure 27: Map of CRFS districts in California. Source: CDFW website.

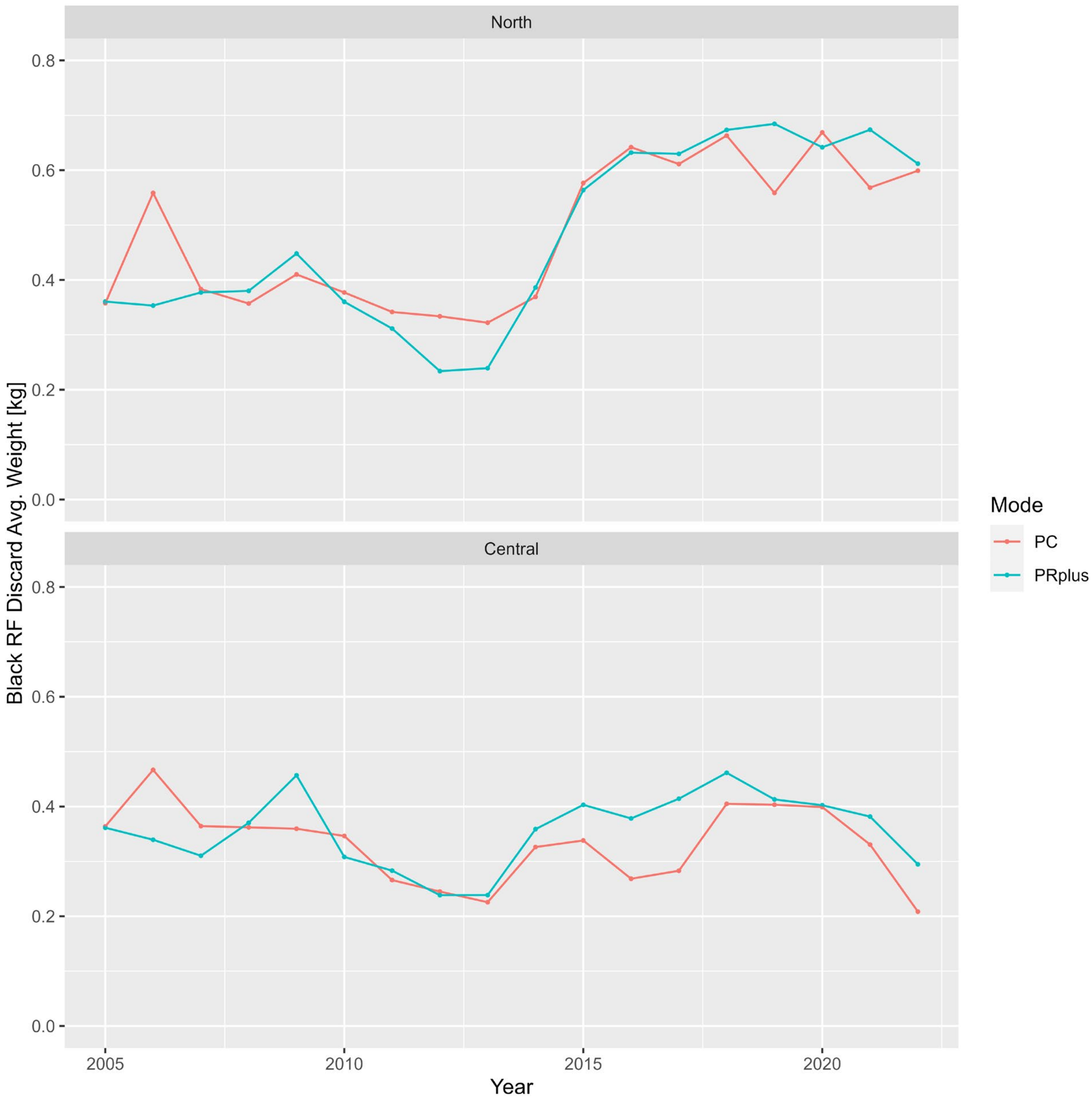


Figure 28: Average weights of discarded fish by year, area, and mode. The increase in average weight of discarded fish in the northern area is consistent with bag limits put in place in 2015. Source: CRFS.

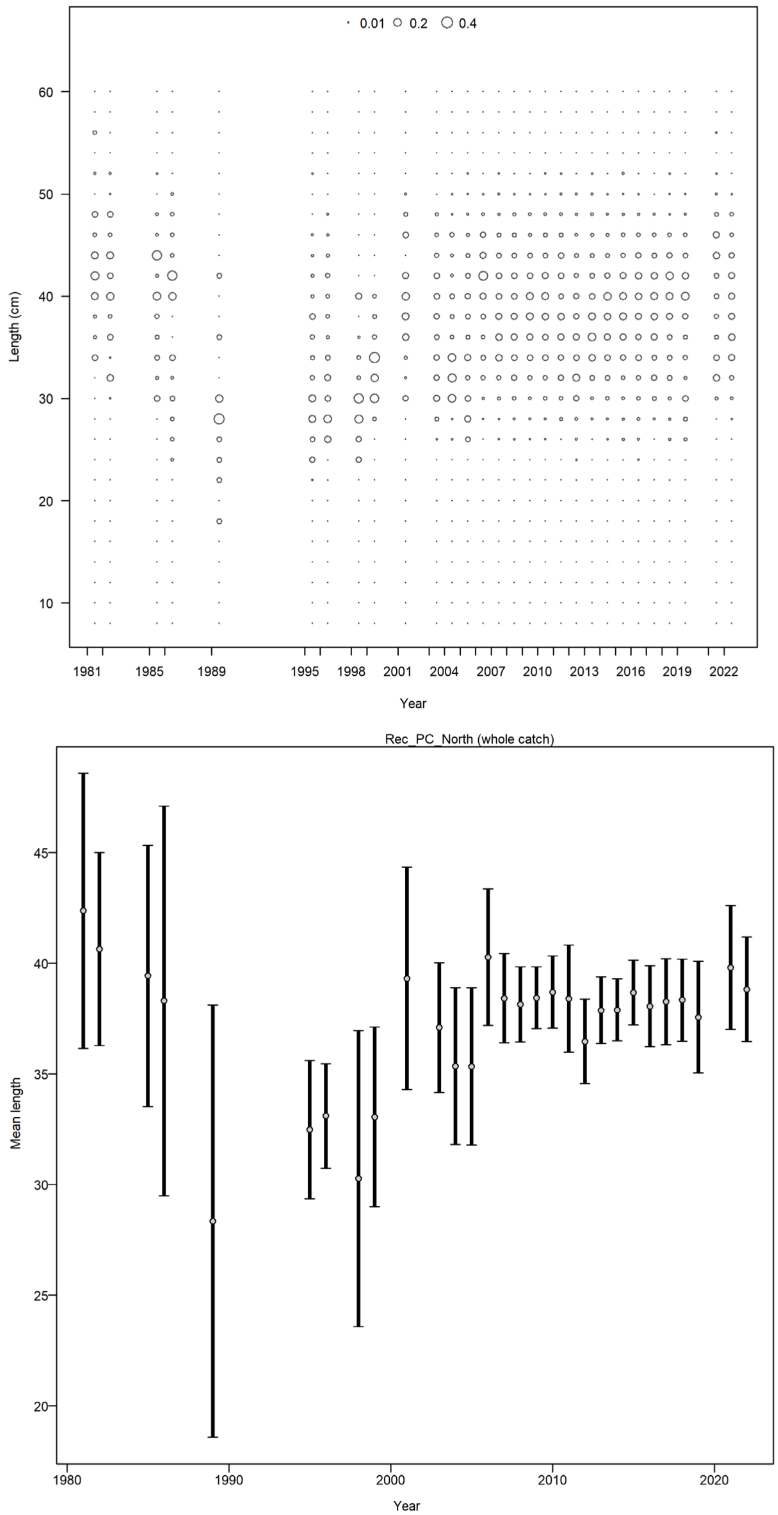


Figure 29: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the northern recreational PC fleet

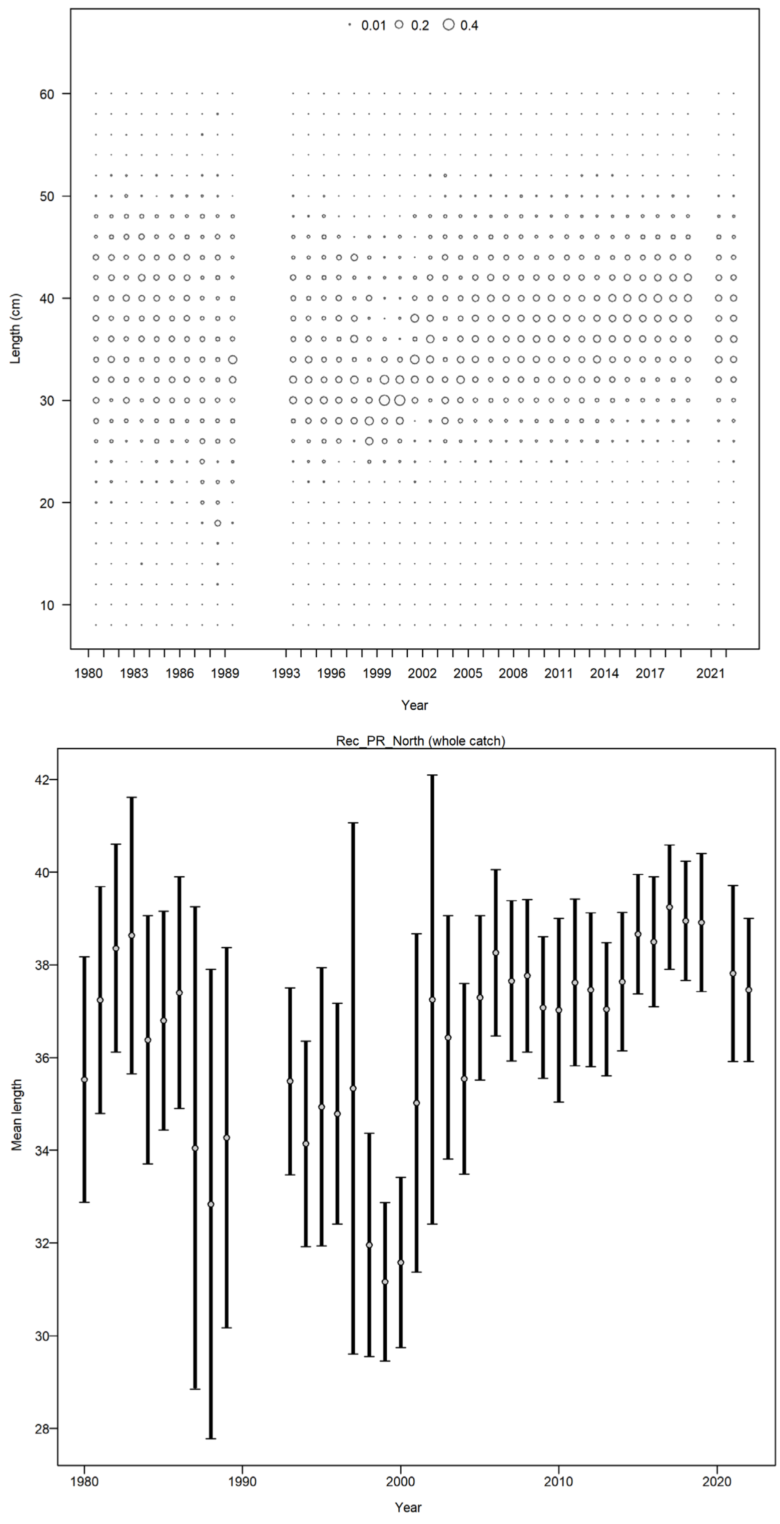
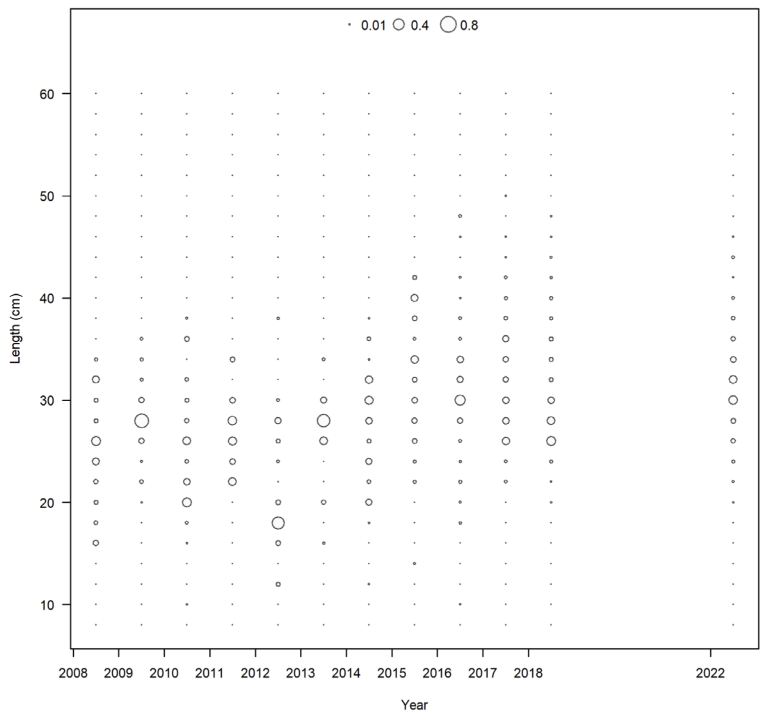


Figure 30: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the northern recreational PR fleet



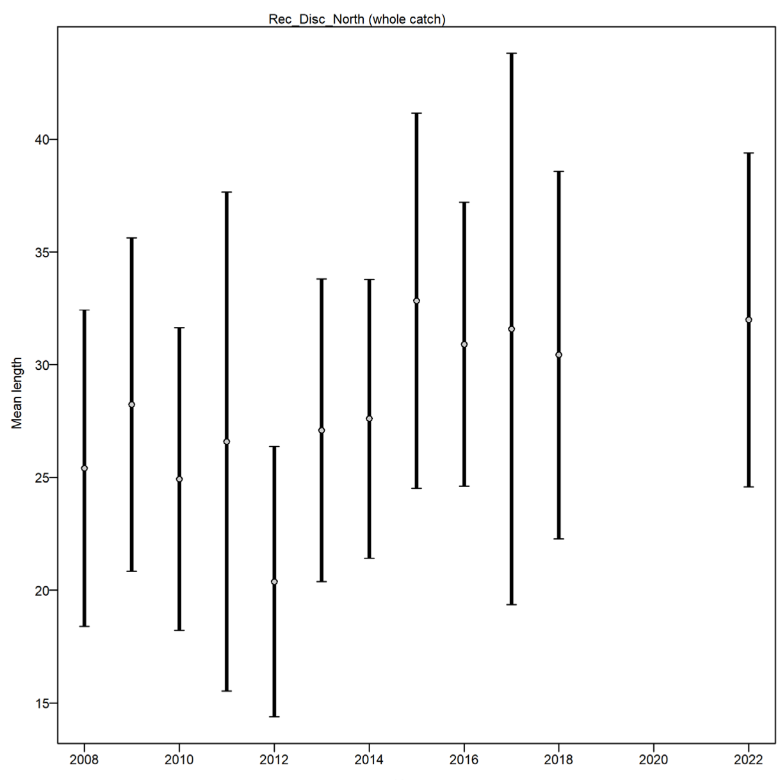
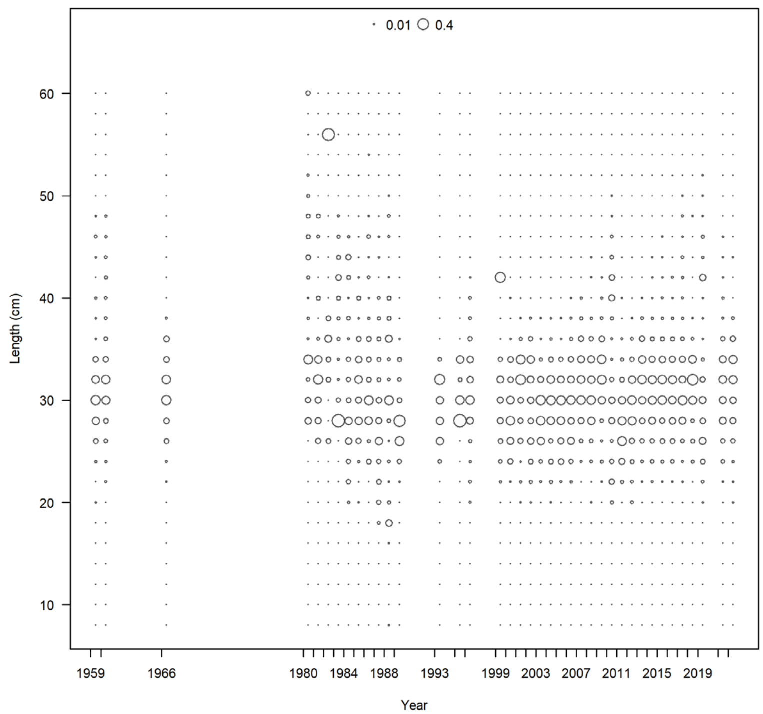


Figure 31: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the northern recreational discard fleet



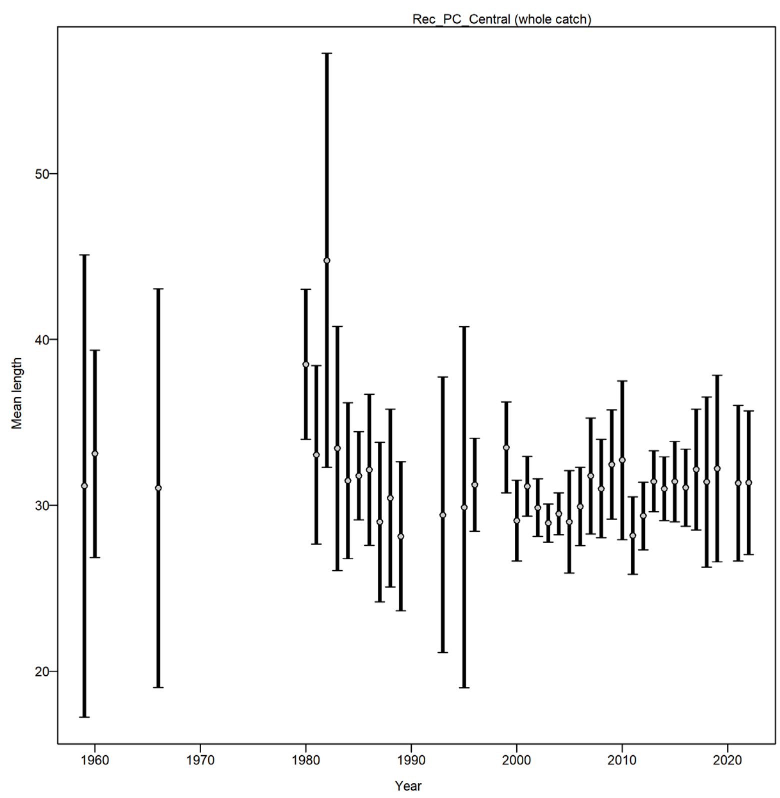
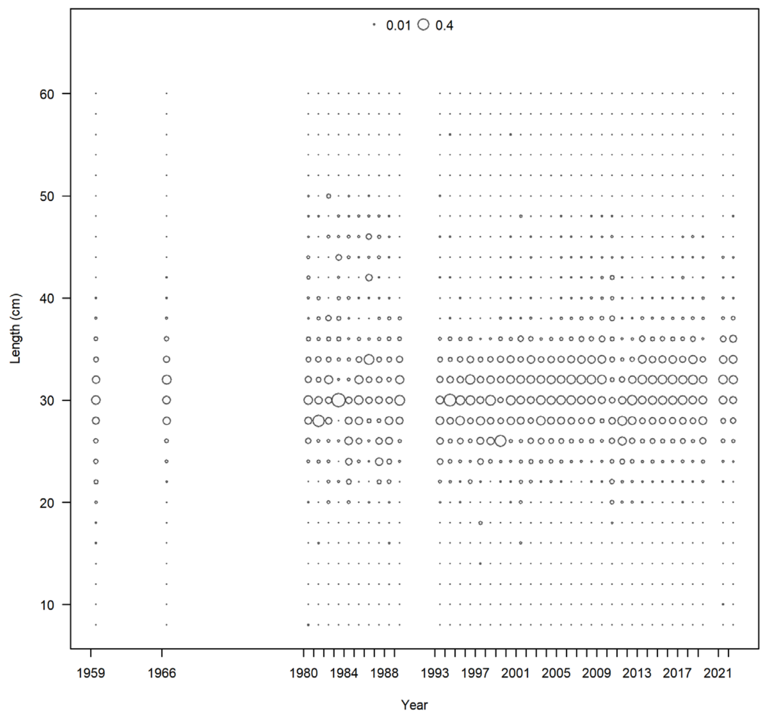


Figure 32: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the central recreational PC fleet



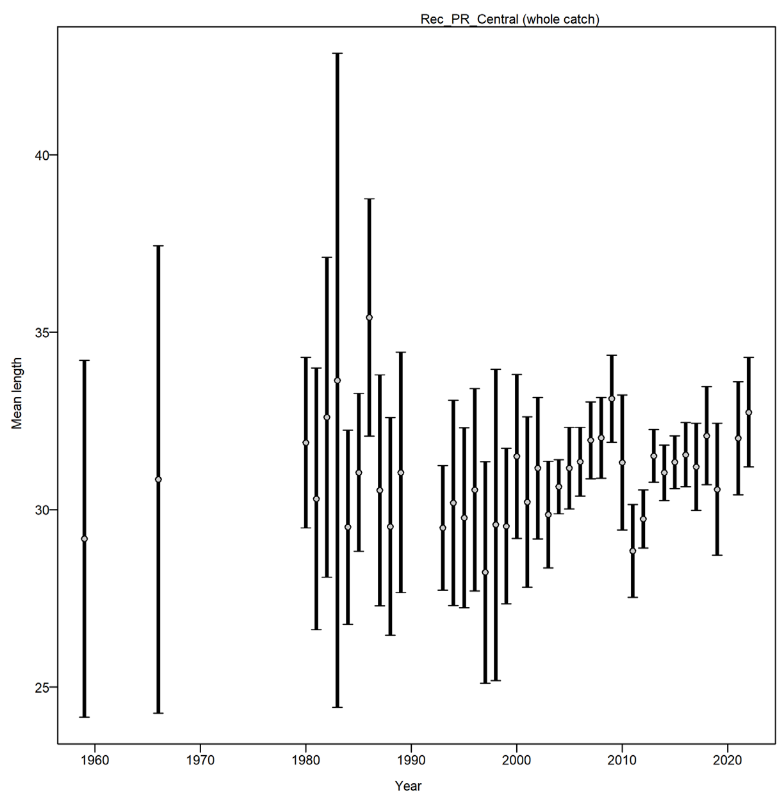


Figure 33: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the central recreational PR fleet

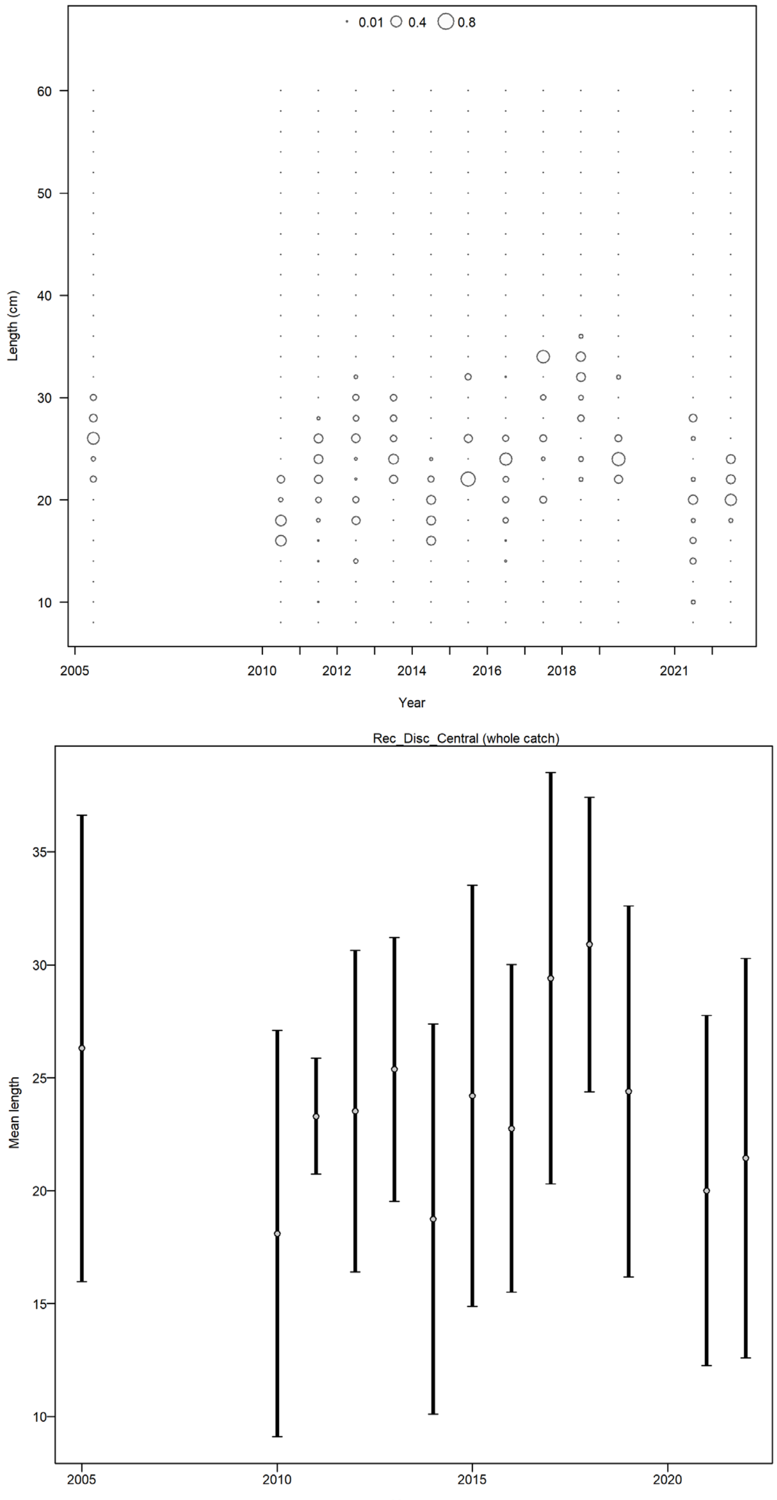


Figure 34: Length composition data (upper panel) and mean lengths for combined sex data (lower panel) from the central recreational discard fleet

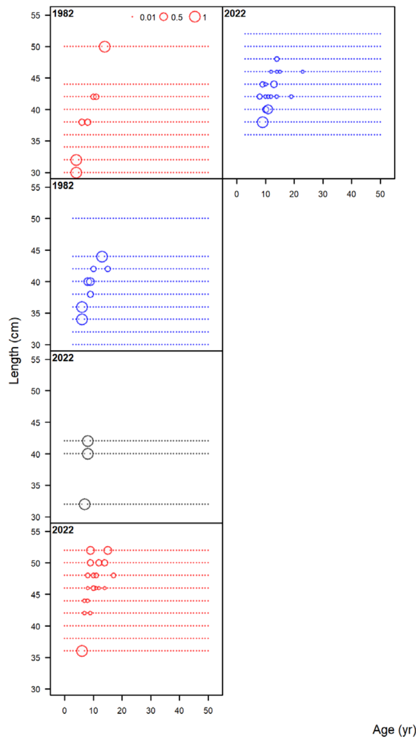


Figure 35: Conditional age-at-length composition data from the northern recreational PC fleet

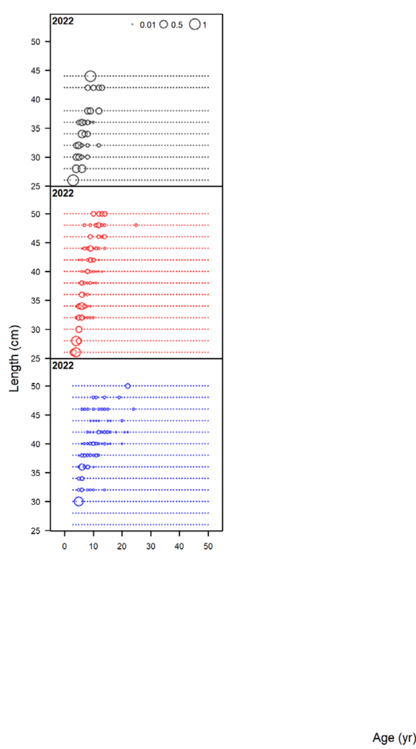


Figure 36: Conditional age-at-length composition data from the northern recreational PR fleet

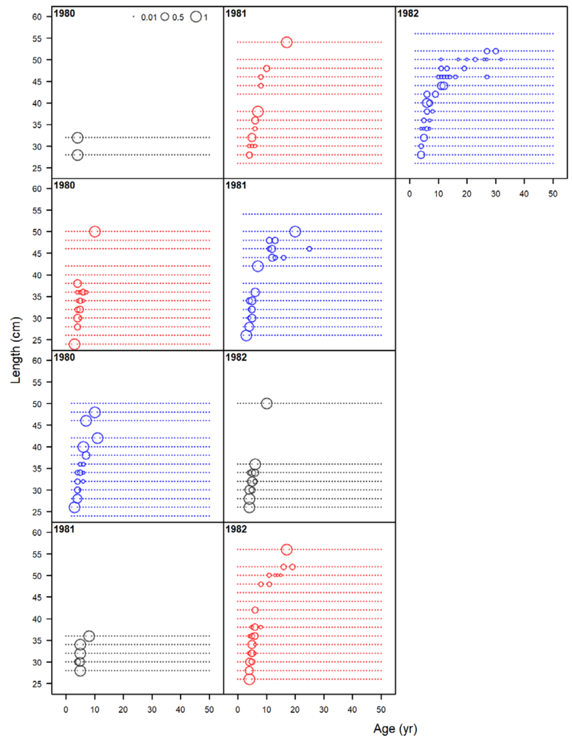


Figure 37: Conditional age-at-length composition data from the central recreational PC fleet

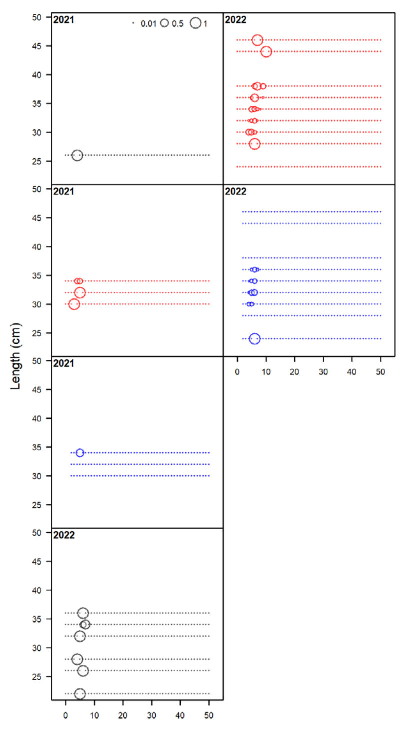


Figure 38: Conditional age-at-length composition data from the northern recreational PR fleet

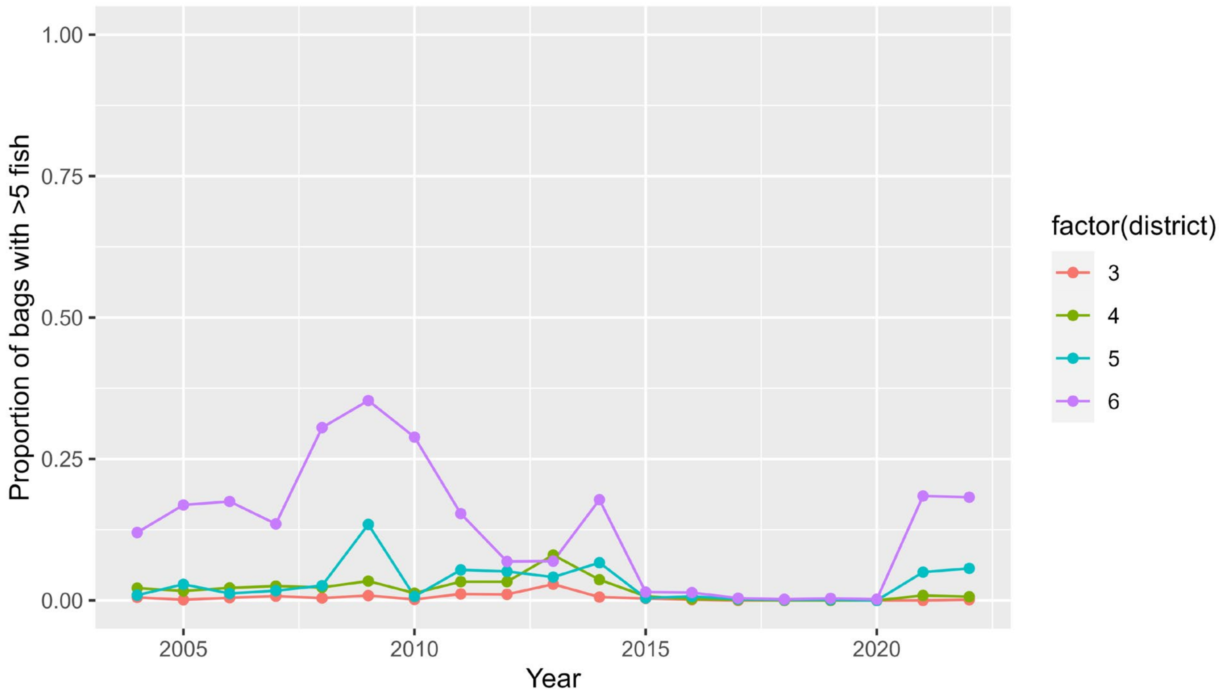


Figure 39: Effect of sub-bag limits, 2015-2020, on the proportion of “bags” (fish per angler trip) with 5+ black rockfish, by CRFS district.

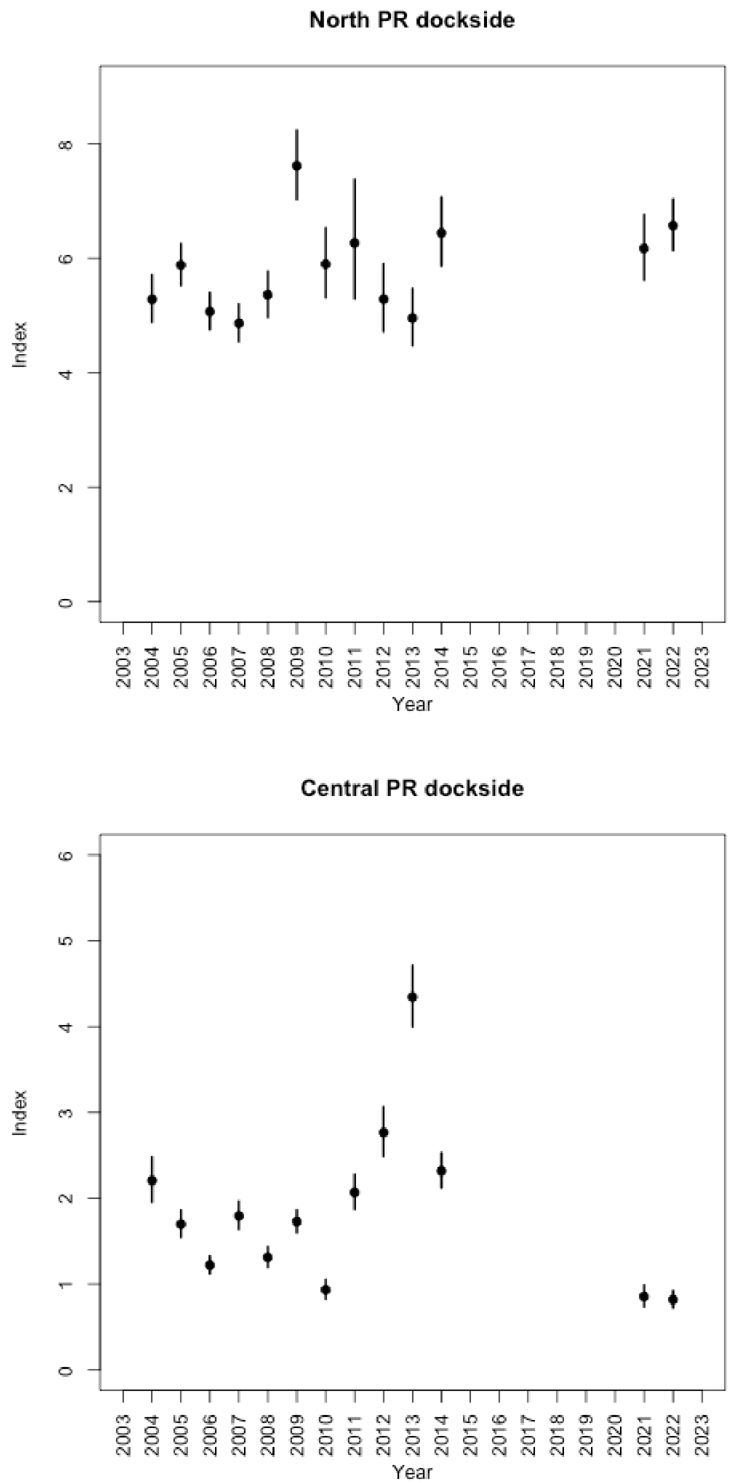


Figure 40: PR dockside indices for the northern and central areas with 95% highest posterior density intervals.

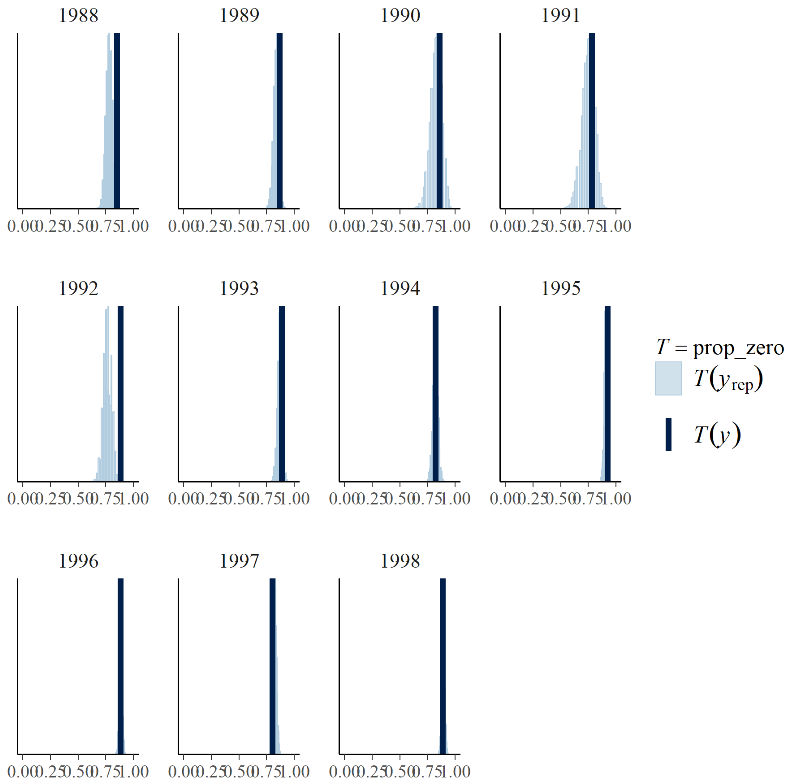


Figure 41: Posterior predictive distributions of the proportion of zero observations, by year, in the DWV CPFV onboard observer index for central California.

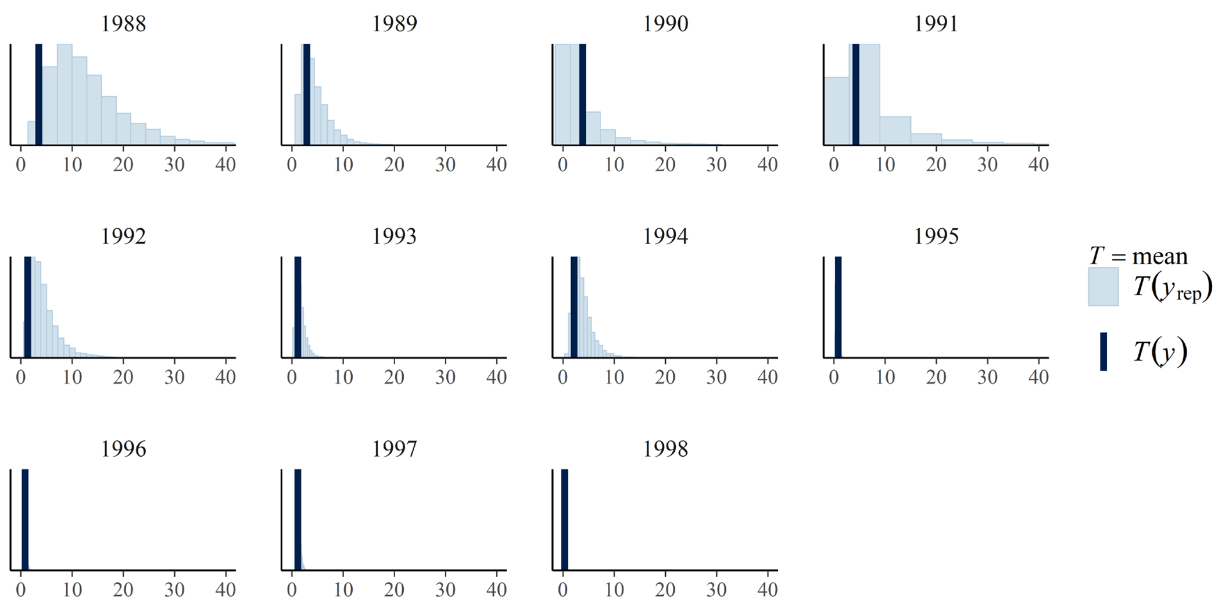


Figure 42: Posterior predictive distributions of the mean catch (number of fish), by year, in the DWV CPFV onboard observer index for central California.

Figure 43: DWV CPFV onboard observer index for central California with 95% highest posterior density intervals.

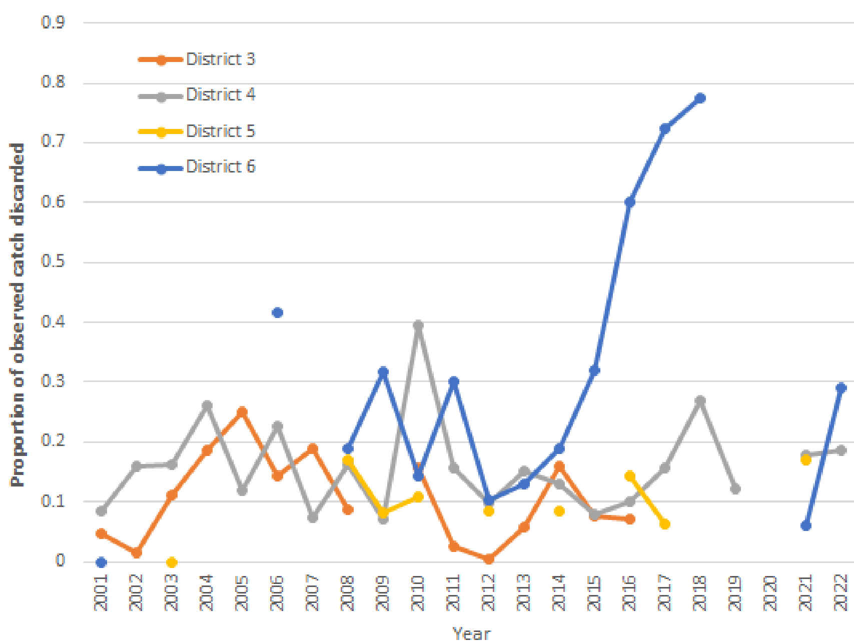


Figure 44: The proportion of black rockfish discarded by observed CPFV anglers, by year and district. Sub-bag limits for black rockfish were introduced in 2015 and continued until 2020.

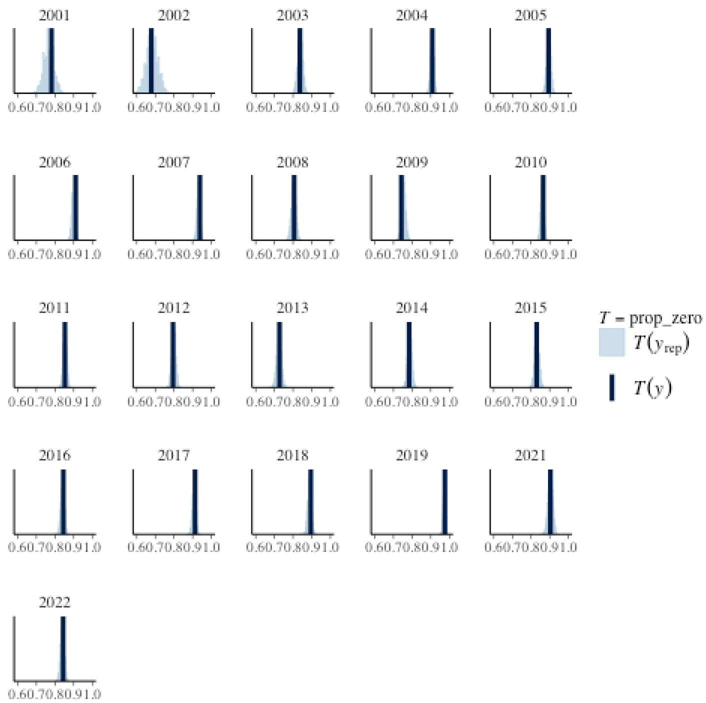


Figure 45: Posterior predictive distributions of the proportion of zero observations, by year, in the CRFS PC onboard observer index

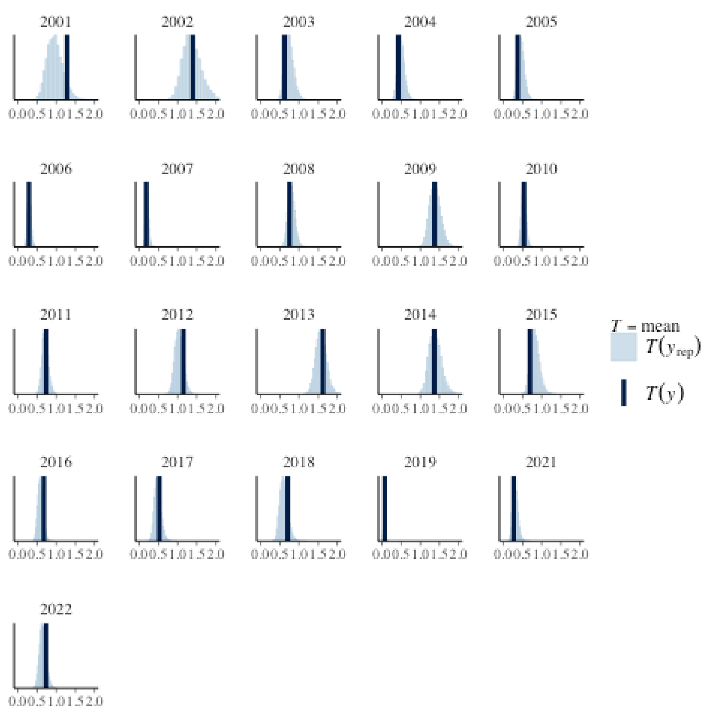


Figure 46: Posterior predictive distributions of the mean catch, by year, in the CRFS PC onboard observer index.

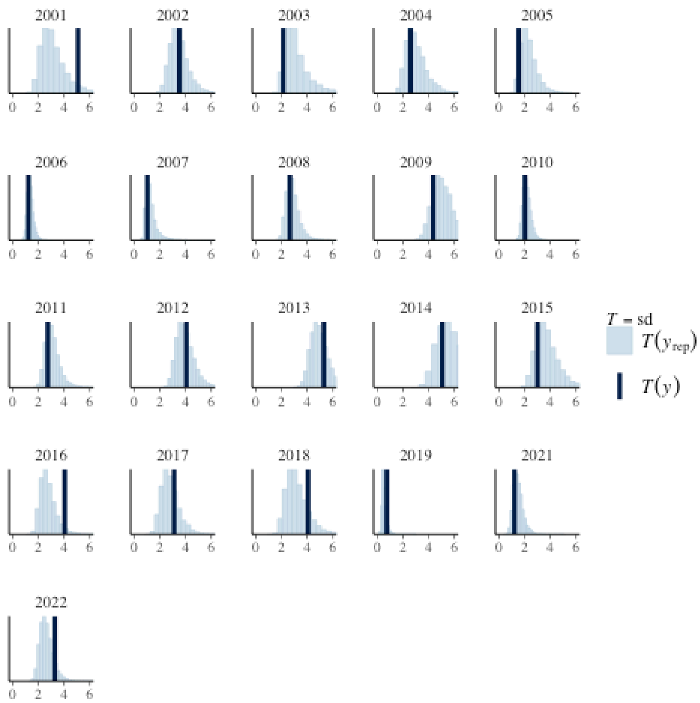


Figure 47: Posterior predictive distributions of the standard deviation of catch, by year, in the CRFS PC onboard observer index.

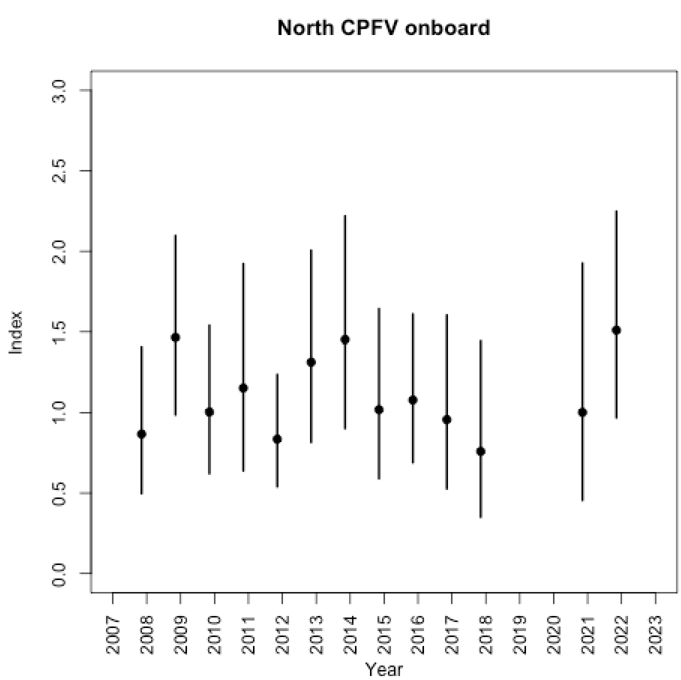


Figure 48: Posterior medians with 95% highest posterior density intervals of the northern region abundance trend from CRFS PC onboard observer index.

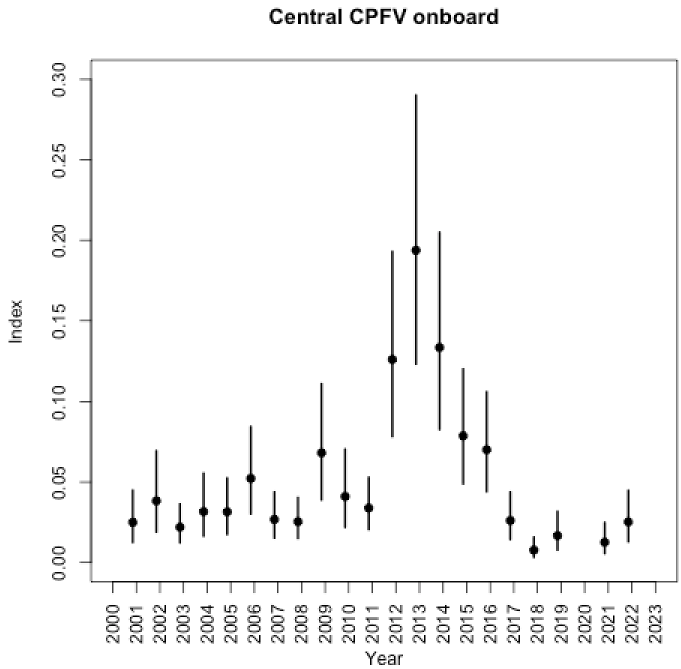


Figure 49: Posterior medians with 95% highest posterior density intervals of the central region abundance trend from CRFS PC onboard observer index.

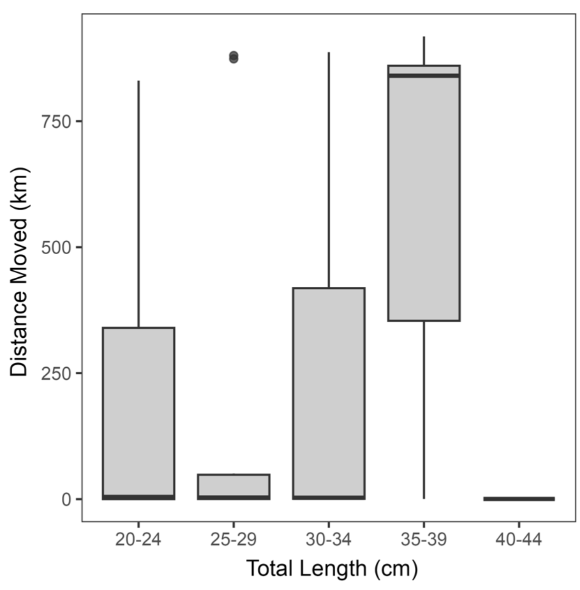


Figure 50: Length-based (cm) distances moved (km) by black rockfish that were tagged and recaptured as part of the California Collaborative Fisheries Research Program (CCFRP). Boxes represent the first and third quartiles (i.e., 25th and 75th percentiles), dark lines denote the median, whiskers illustrate values that fall within 1.5 times the interquartile range (i.e., distance between first and third quartiles) of the hinge, and points represent outliers.

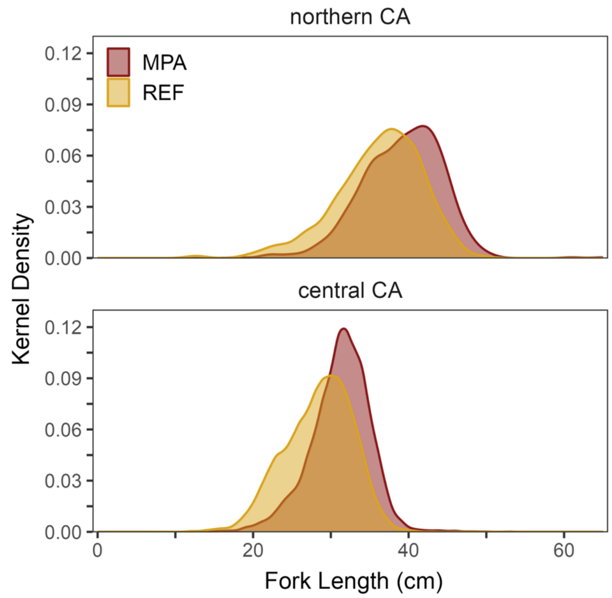


Figure 51: Kernel densities for fork lengths (cm) of black rockfish measured during California Collaborative Fisheries Research Program (CCFRP) sampling trips. Fish caught inside marine protected areas (MPS; red) and associated reference sites exposed to fishing (REF; orange) are shown by region and year.

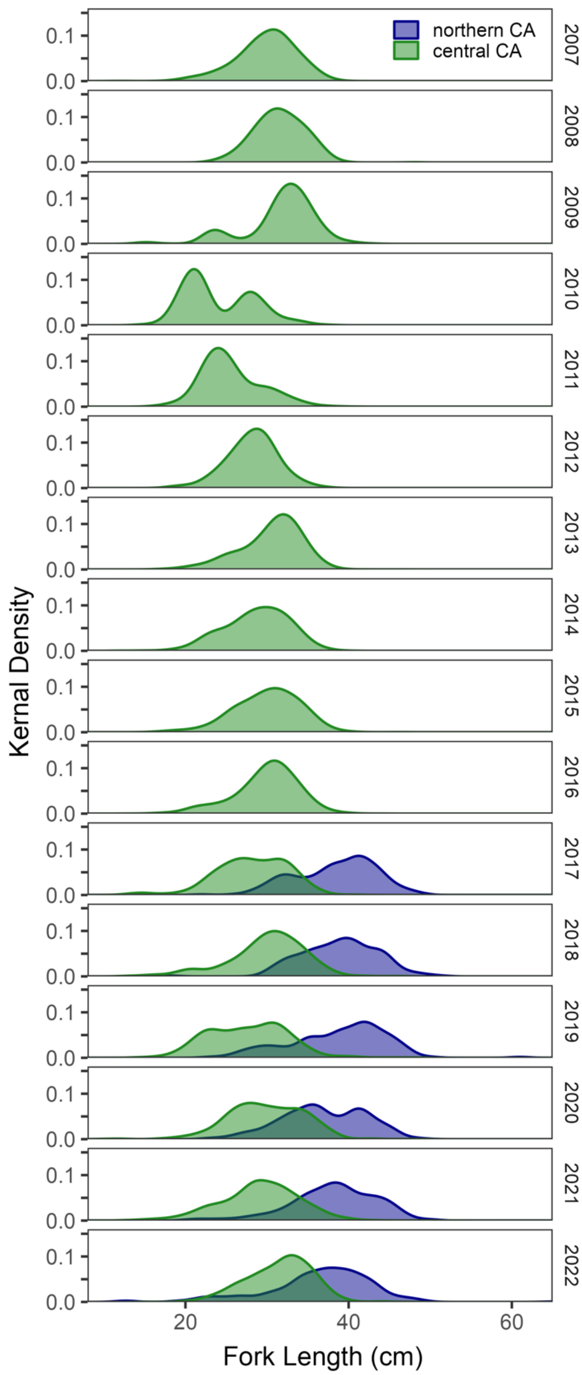


Figure 52: Kernel densities for fork lengths (cm) of black rockfish measured during California Collaborative Fisheries Research Program (CCFRP) sampling trips. Fish caught in northern (blue) and central (green) California are shown by year

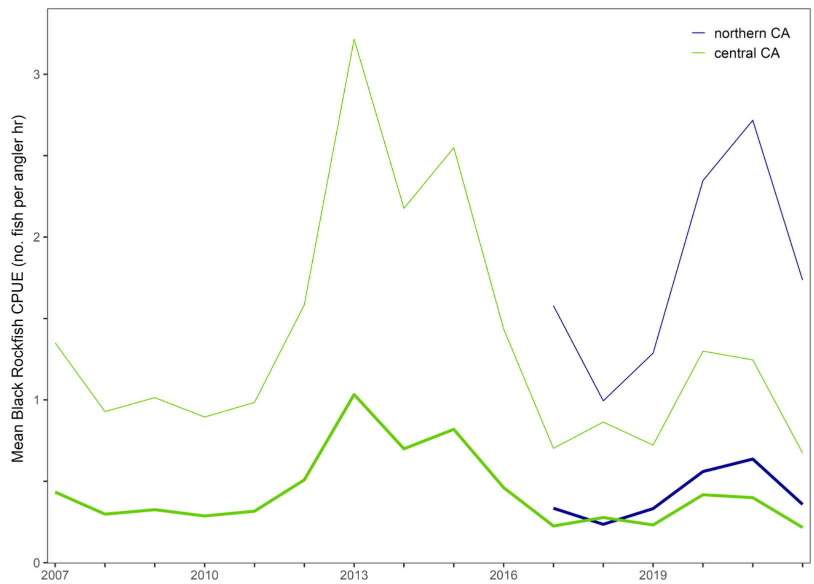


Figure 53: Mean catch per unit effort (CPUE; number of black rockfish per angler hr) by year and region. Thin lines represent unweighted catch. Thick lines denote district-weighted catch. Errors were excluded for illustrative purposes. Data source: California Collaborative Fisheries Research Program (CCFRP).

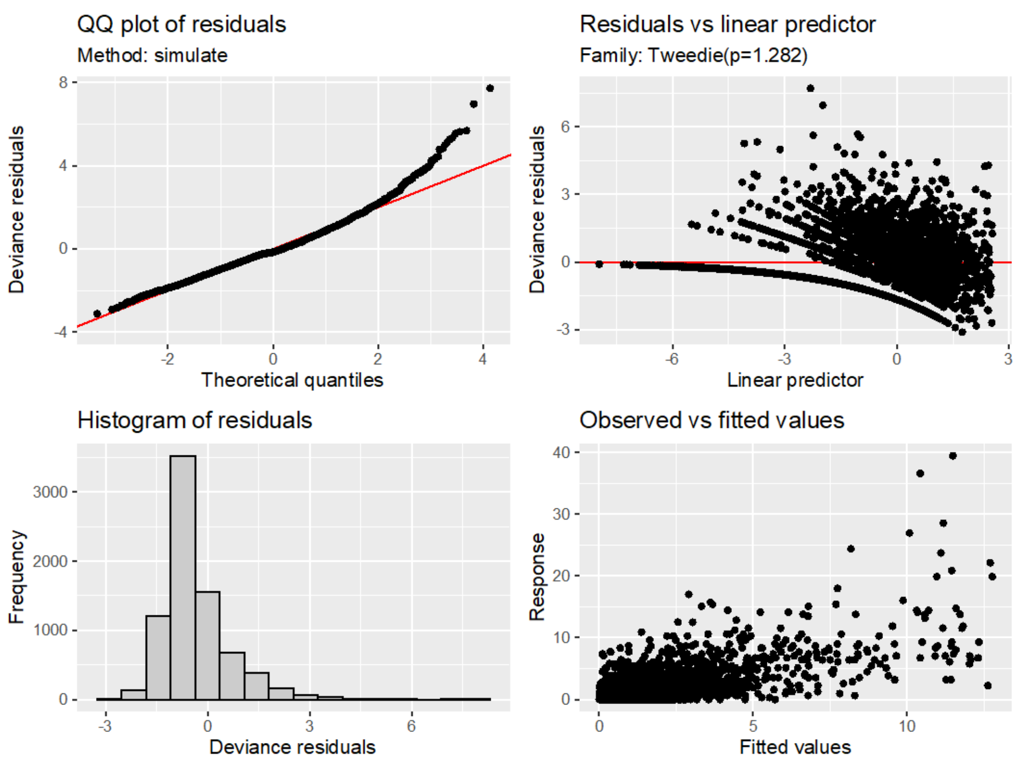


Figure 54: Tweedie model diagnostics for California Collaborative Fisheries Research Program (CCFRP) index of district-weighted black rockfish catch

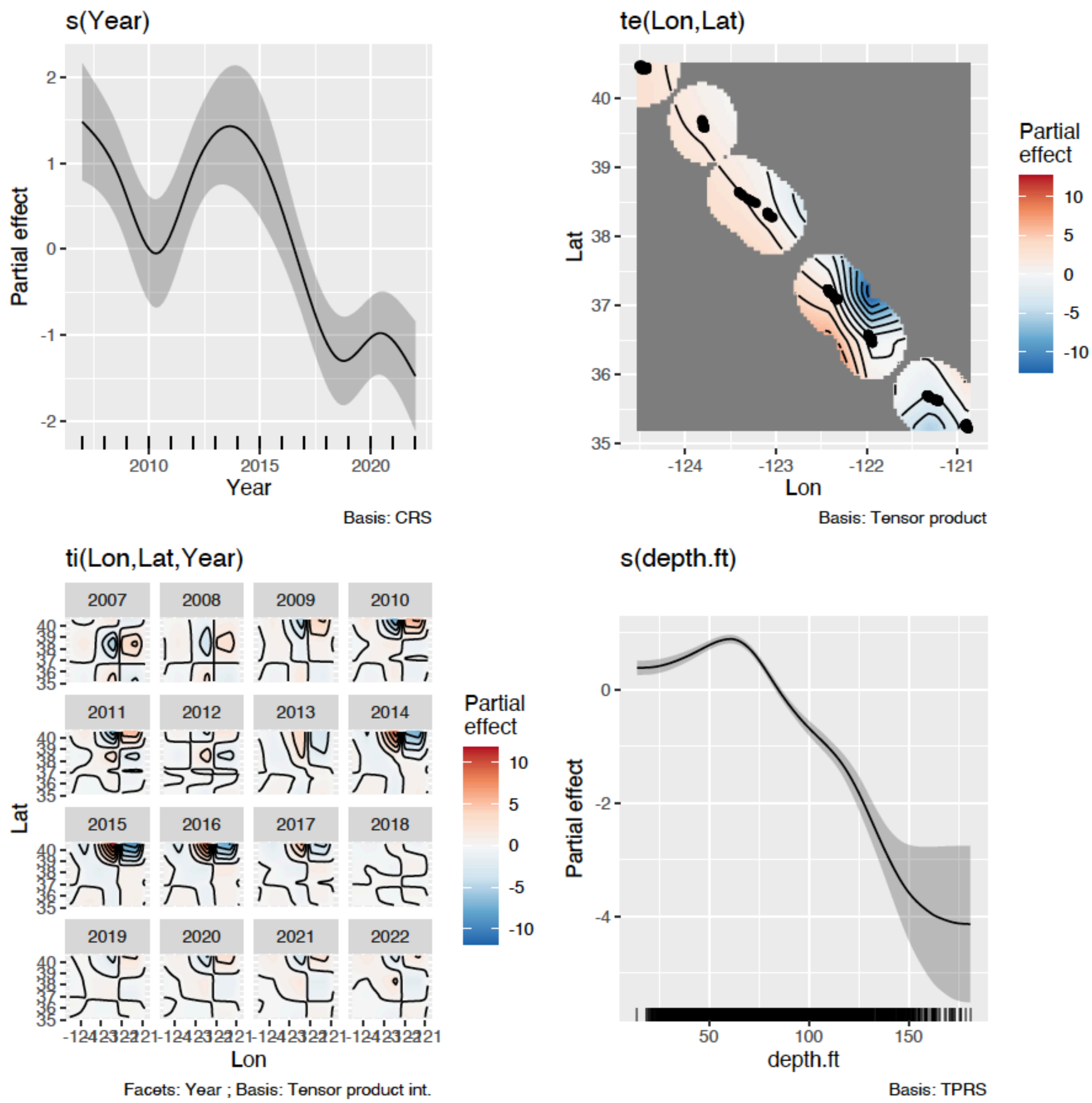


Figure 55: Partial covariate effects on district-weighted black rockfish catch for the California Collaborative Fisheries Research Program (CCFRP) index

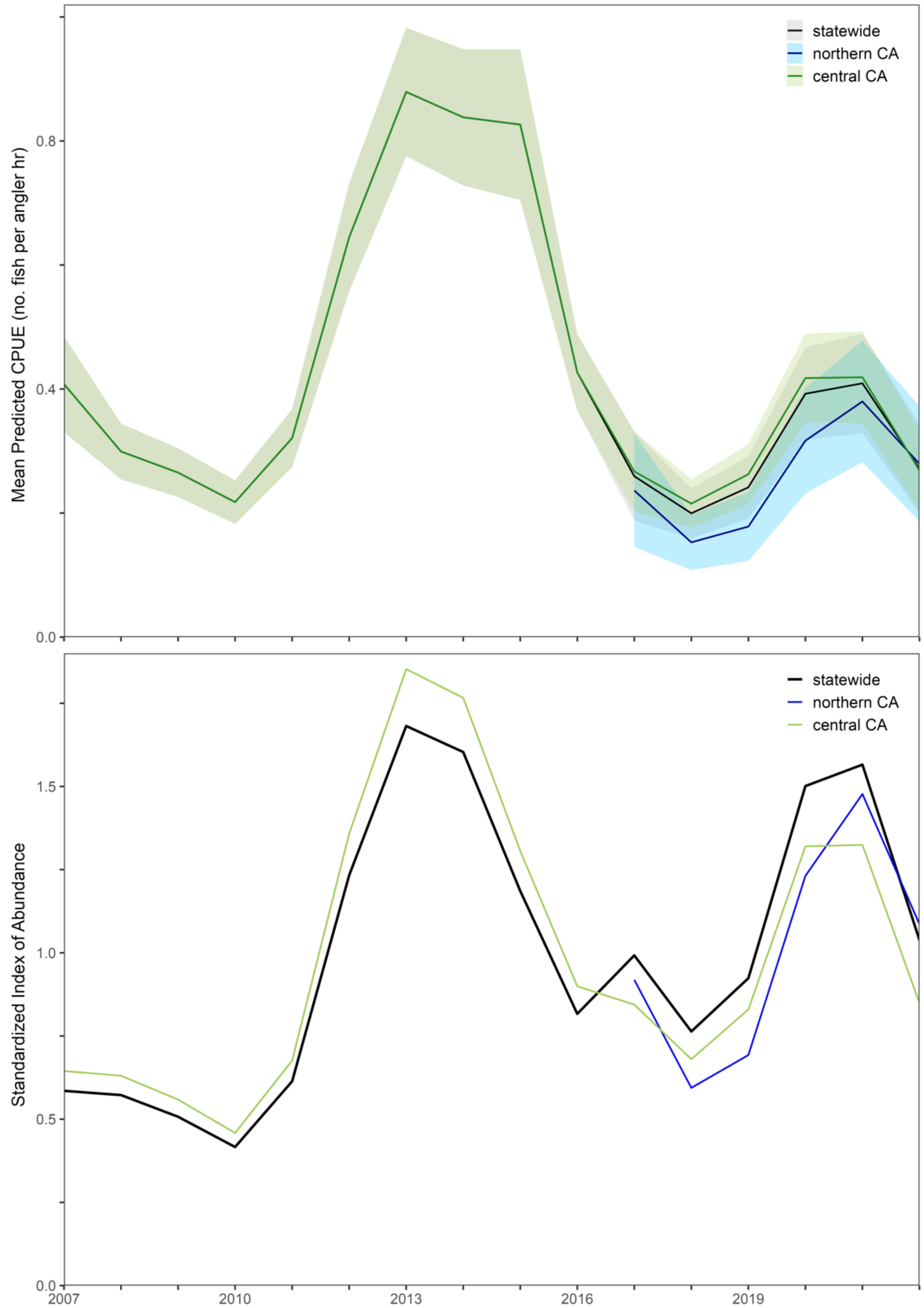


Figure 56: Model-based estimates of black rockfish abundance by region (black: statewide; blue: northern California; green: central California) and year. Mean predicted catch per unit effort (CPUE; no. fish per angler hr) is shown above. Standardized indices of abundance are shown below. Data source: California Collaborative Fisheries Research Program (CCFRP).

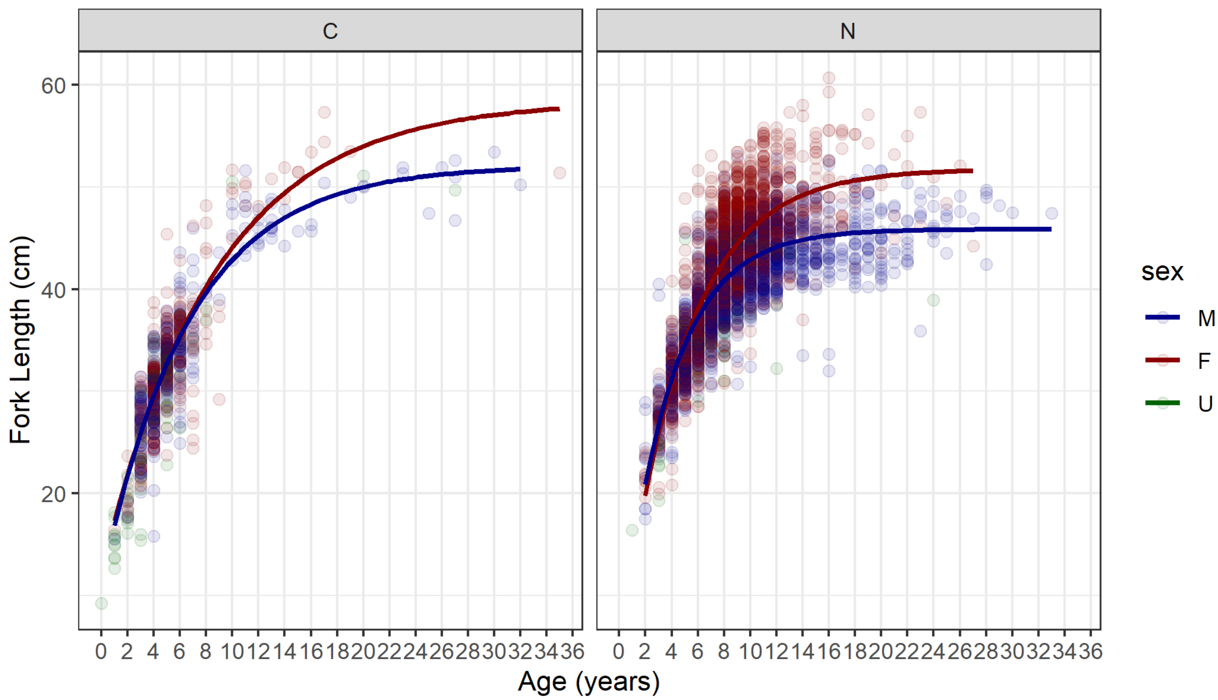


Figure 57: External von Bertallanfy growth curve fits to length-at-age data, by sex (M=male, F=female, U=unknown sex), and area (N=north of Point Arena; C=central, i.e. south of Point Arena).

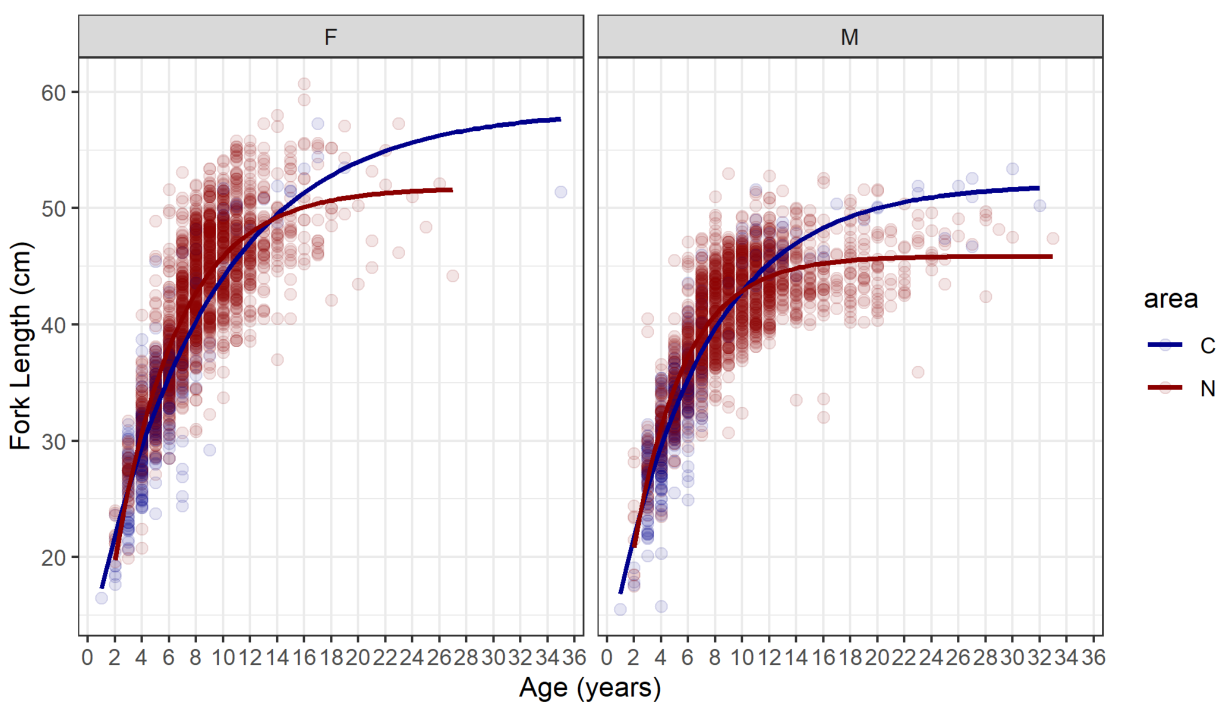


Figure 58: External von Bertallanfy growth curve fits to length-at-age data, by area (N=north of Point Arena; C=central, i.e. south of Point Arena) and sex (M=male, F=female).

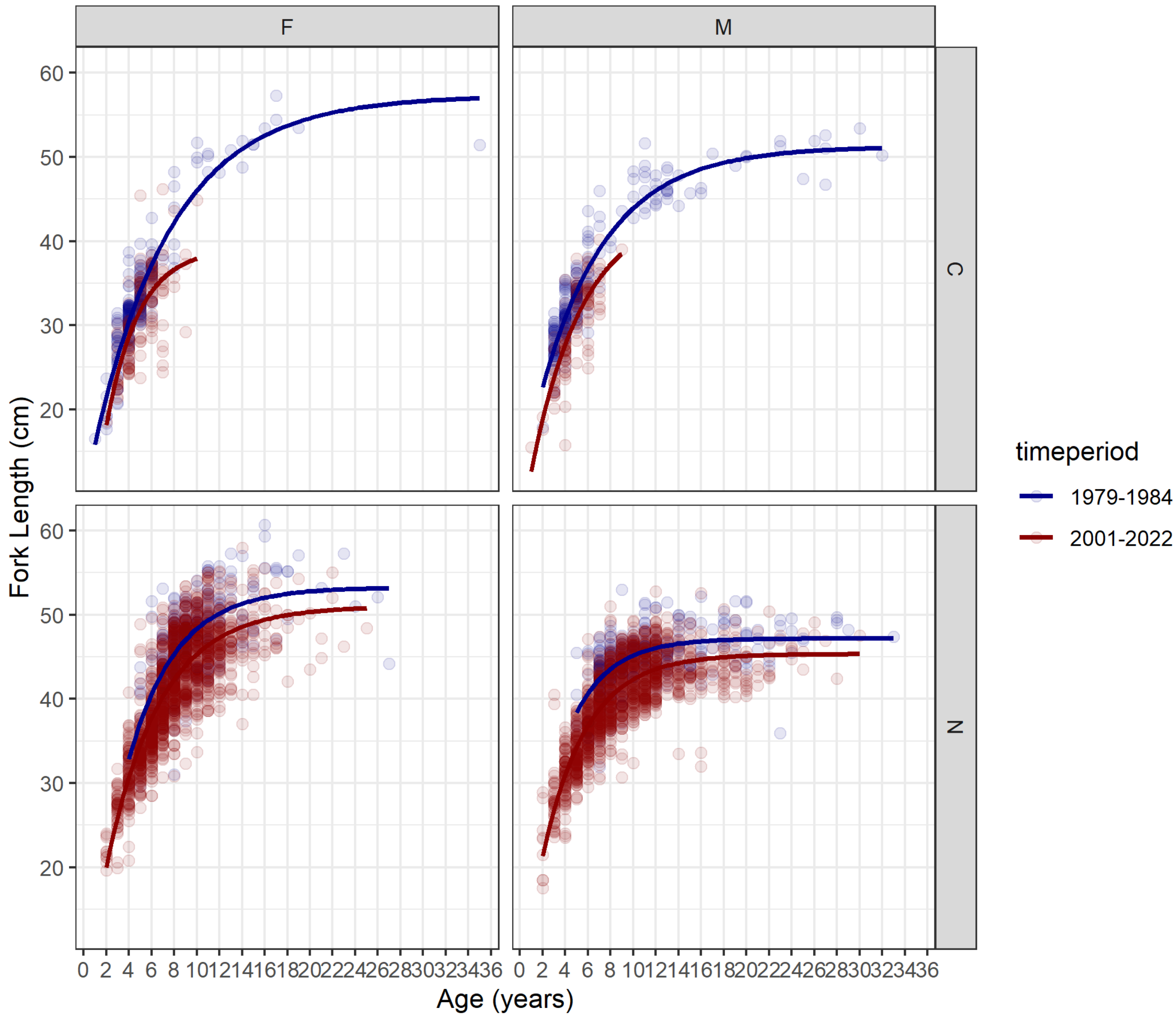


Figure 59: External von Bertallanfy growth curve fits to length-at-age data, by area (N=north of Point Arena; C=central, i.e. south of Point Arena), sex (M=male, F=female), and time period (1979-1984 and 2001-2022).

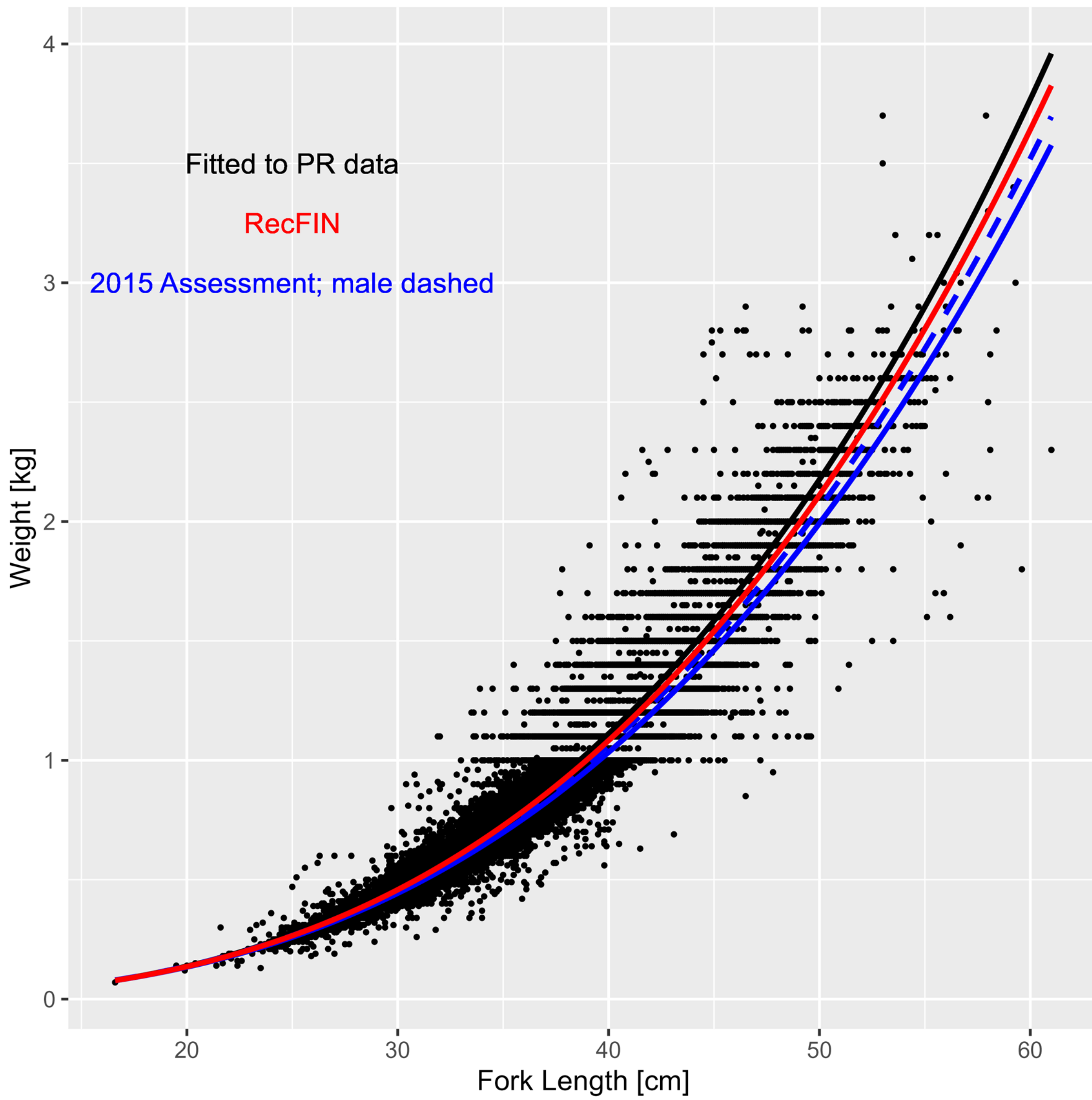


Figure 60: Weight at length (sexes combined) data for black rockfish from private/rental boat sampling (Source: CDFW). Scales used to weigh fish less than 1 kg have an accuracy of 10 grams, and scales for fish less than 5 kg have an accuracy of 100 grams. The fitted mean relationship from a back-transformed and bias corrected log-log regression (black) is compared to reported weight-length relationships from RecFIN (red) and the 2015 stock assessment (blue; females = solid line, males = dashed line).

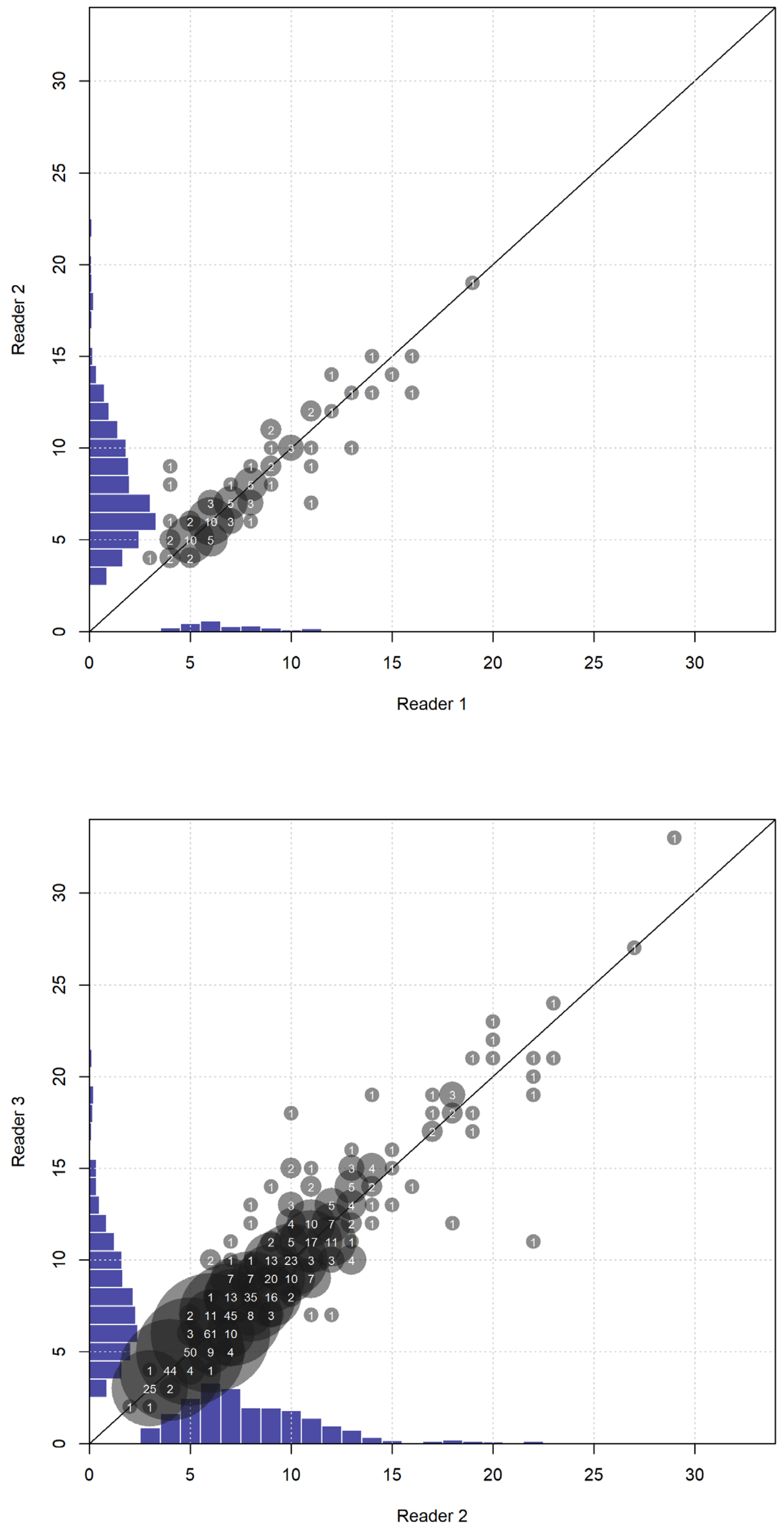


Figure 61: Comparison of age estimates produced by reader 1 (P. McDonald) and reader 2 (L. Ortiz), and the reader 2 and reader 3 (J. Hale).

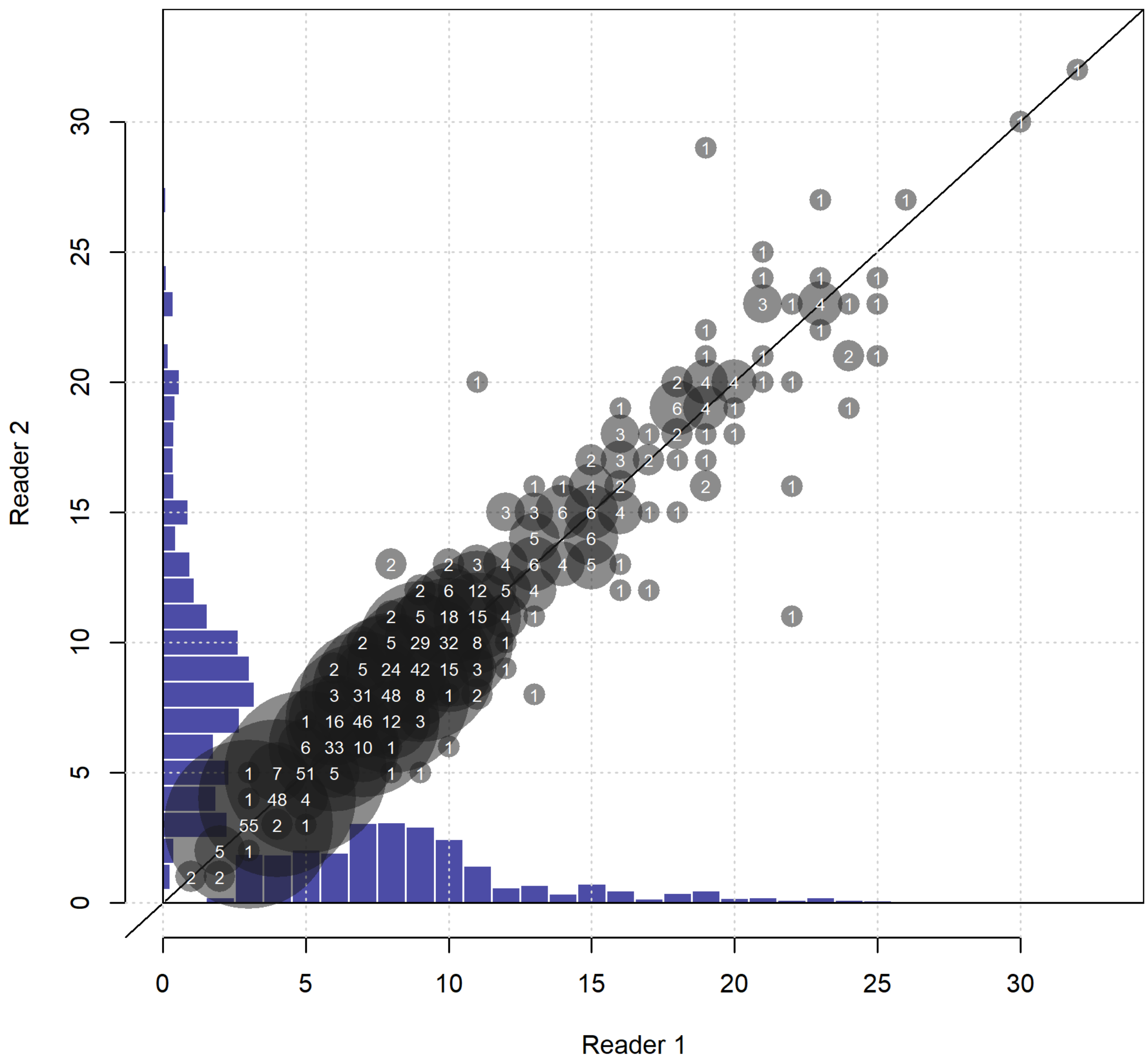


Figure 62: Comparison of age estimates produced by T. Johnson (reader 1 in figure, reader 4 in text) and N. Atkins (reader 2 in figure, reader 5 in text) for the 2015 assessment.

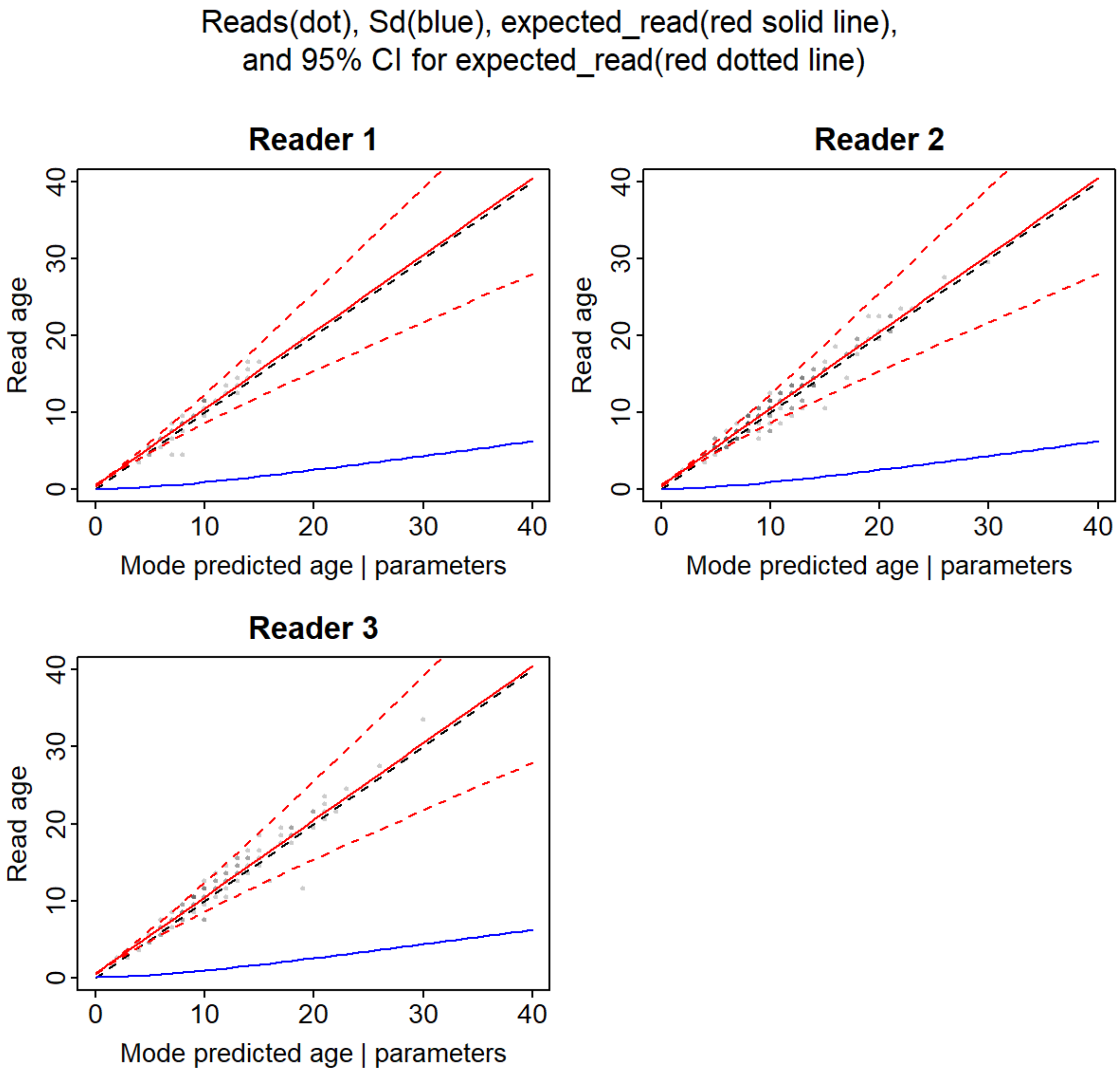


Figure 63: Fits to ageing error model based on readers 1-3 based on the AICc best-fit model (unbiased across all readers with a curvilinear CV).

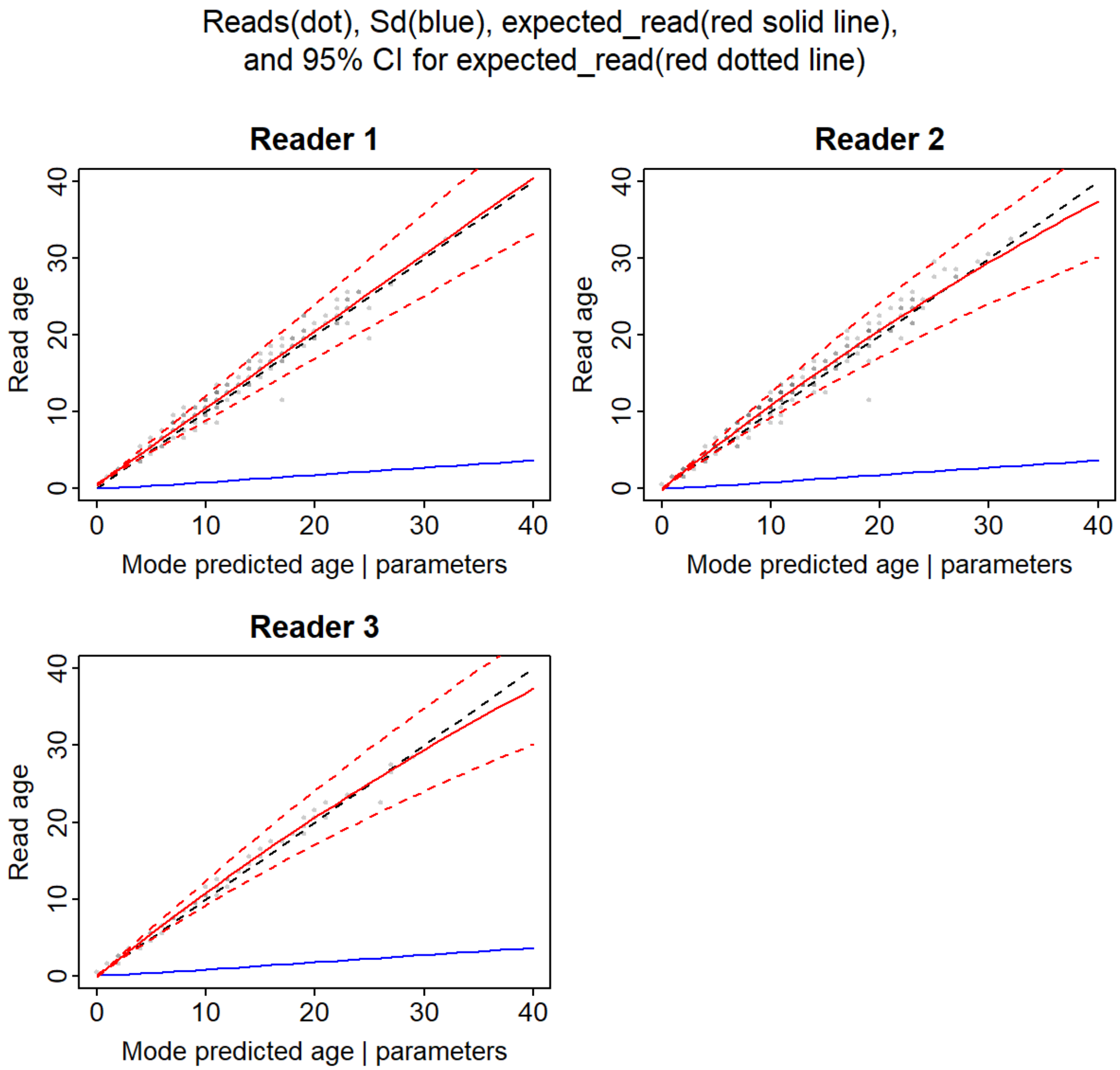


Figure 64: Fits to ageing error model (Reader 1 = Reader 4 in text, Reader 2 = Reader 5 in text, Reader 3 = duplicate reads by Reader 5 in text) from the AICc best-fit model.

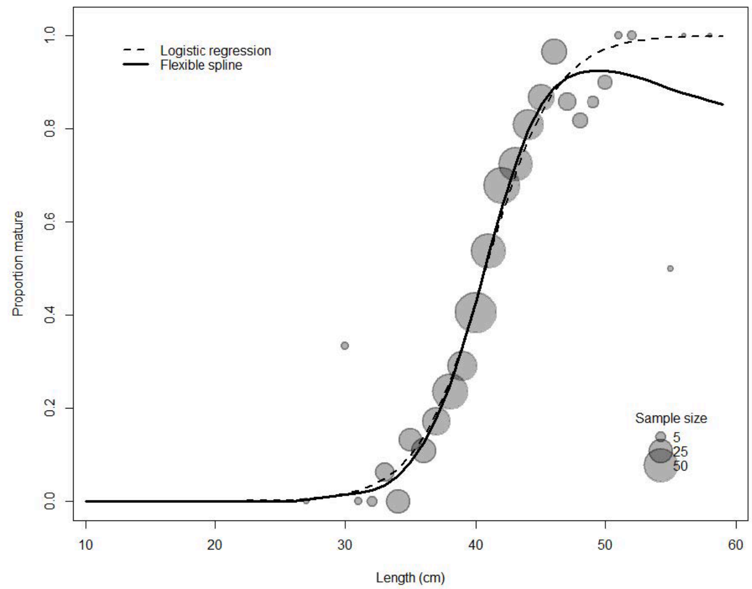


Figure 65: Functional maturity of female black rockfish. Logistic regression model is the dashed line, spline model is the solid line. Sample size is denoted by the size of the bubbles. Source: Claire Rosemond and Melissa Head.

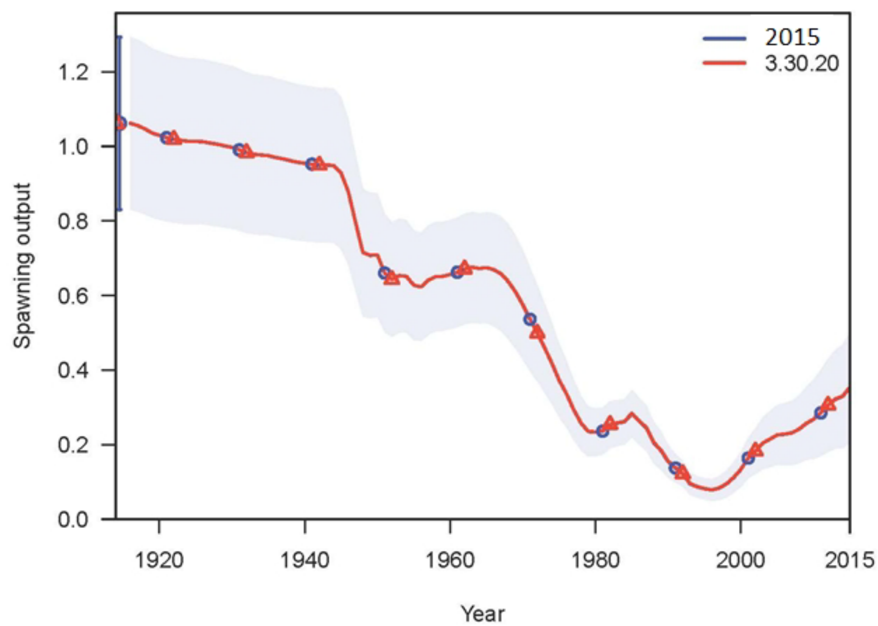


Figure 66: Update from Stock Synthesis v3.24 (used in the 2015 assessment) to version 3.30.20 produced nearly identical results.

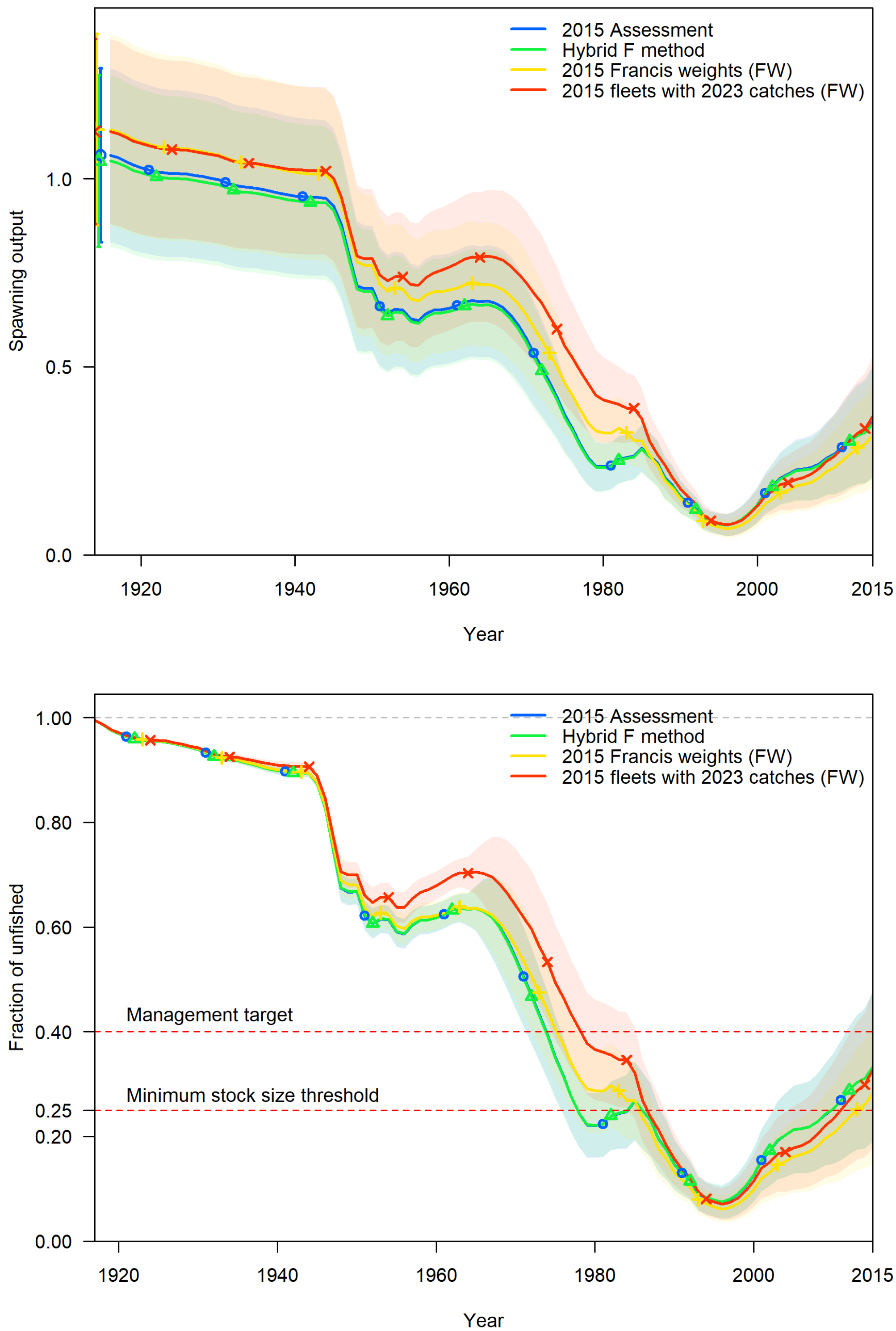


Figure 67: Effects of changing F estimation method and weighting approach, and updating catch histories, on absolute (top panel) and relative (bottom panel) spawning output, starting from the 2015 assessment.

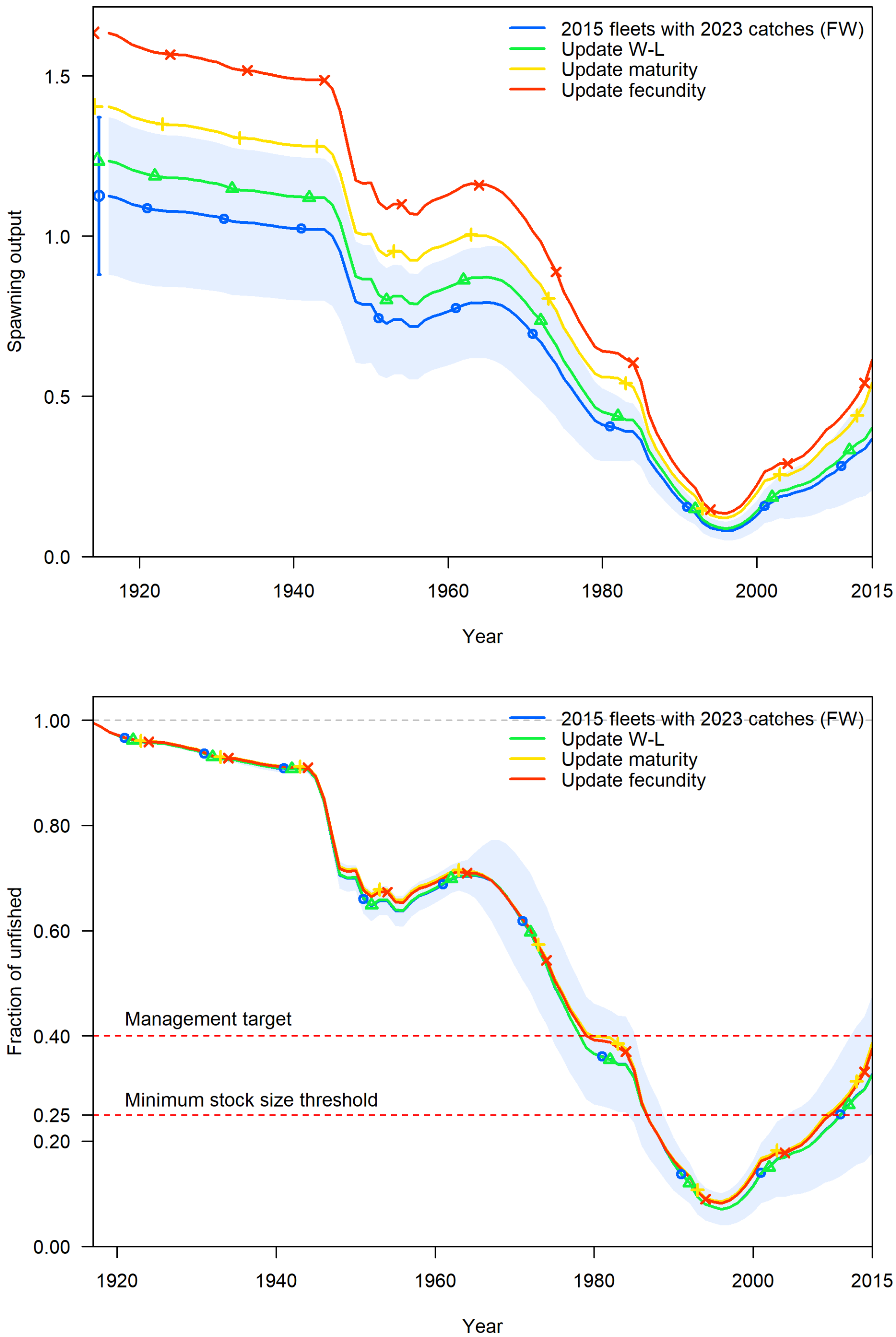


Figure 68: Updates to the weight-length, maturity, and fecundity relationships, relative to the model with revised catches, weights, and F estimation method.

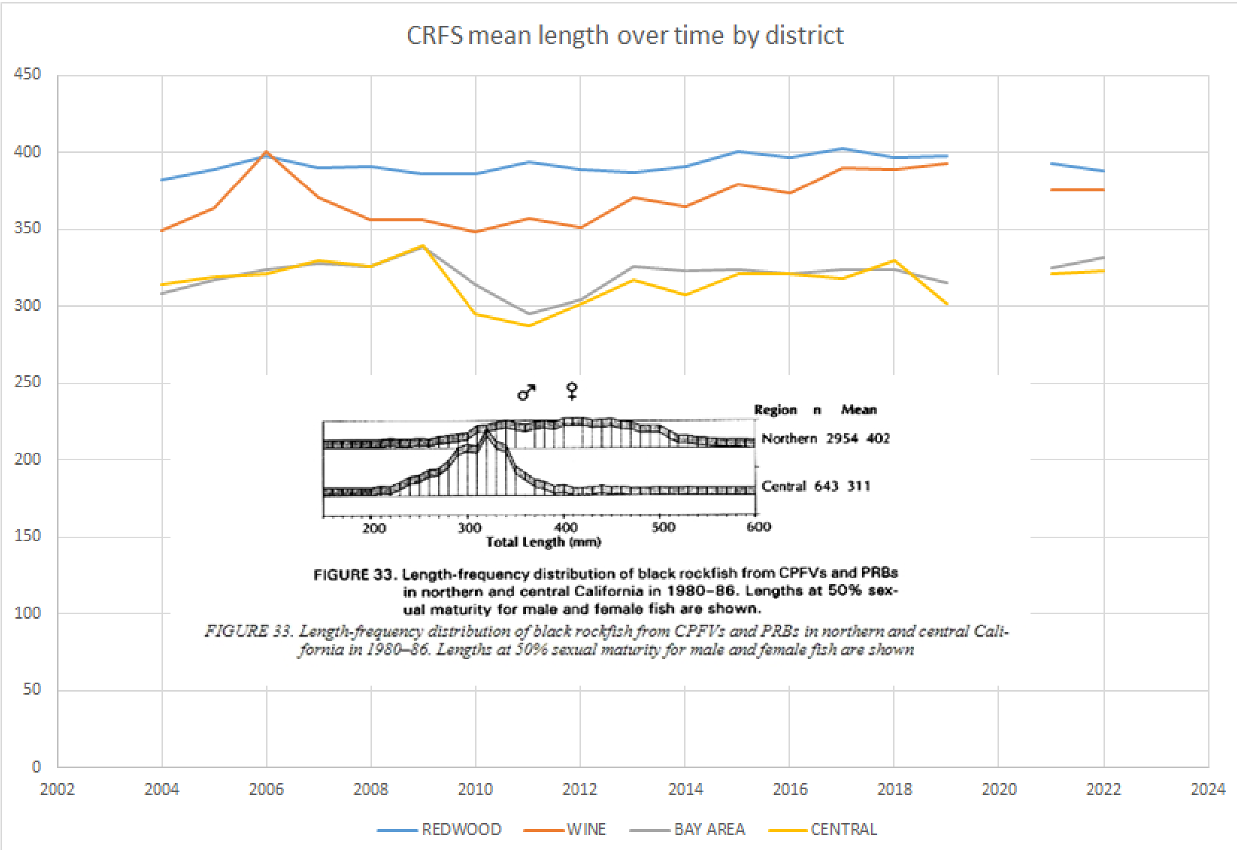


Figure 69: Mean length by CRFS district and year. Inset is from Karpov et al. 1995, comparing aggregated length comps (1980-1986) in their central (south of Sonoma Cty.) and northern areas.

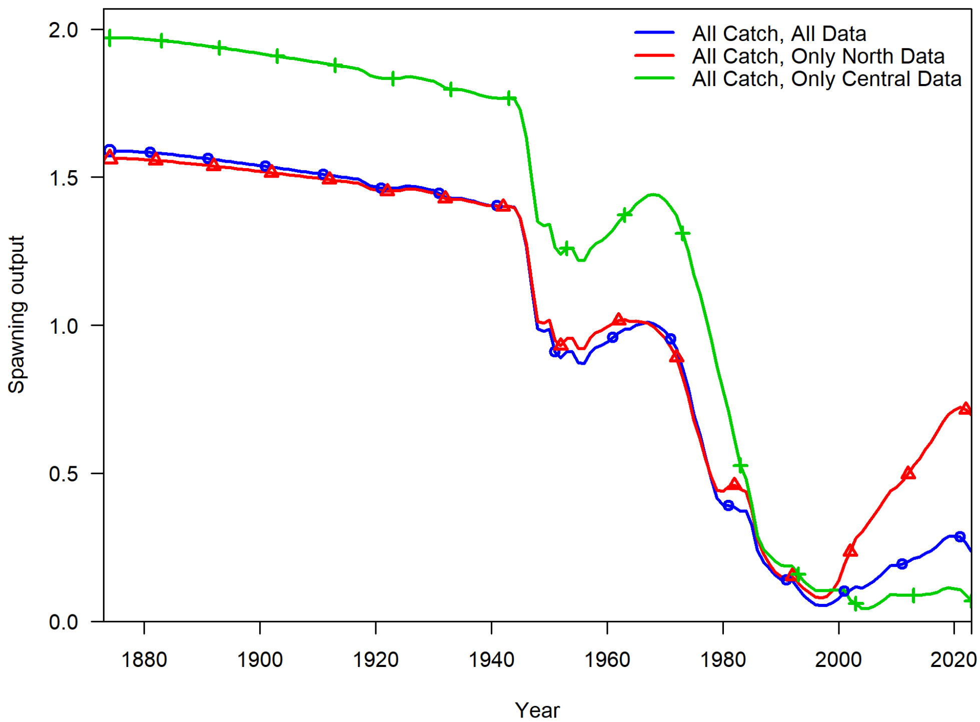


Figure 70: Spawning output by year estimated by an exploratory fleets-as-areas model for black rockfish. Catches represented statewide removals in all models, which were fit to trend and composition data from all areas (blue), data from the central region only (green), and data from the northern area only (red).

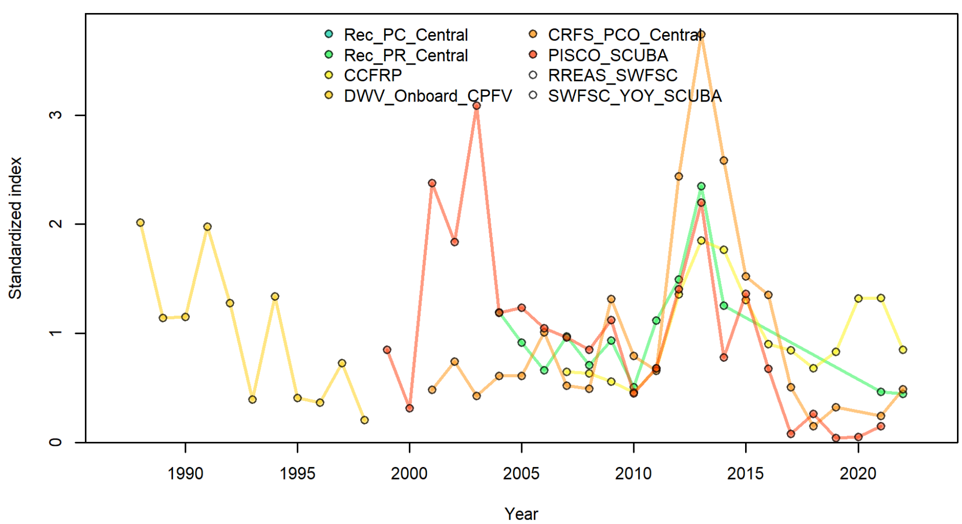


Figure 71: Indices from central California (south of Point Arena) scaled to have means of 1 for comparison. The PISCO SCUBA index was ultimately exluded from the pre-STAR base model.

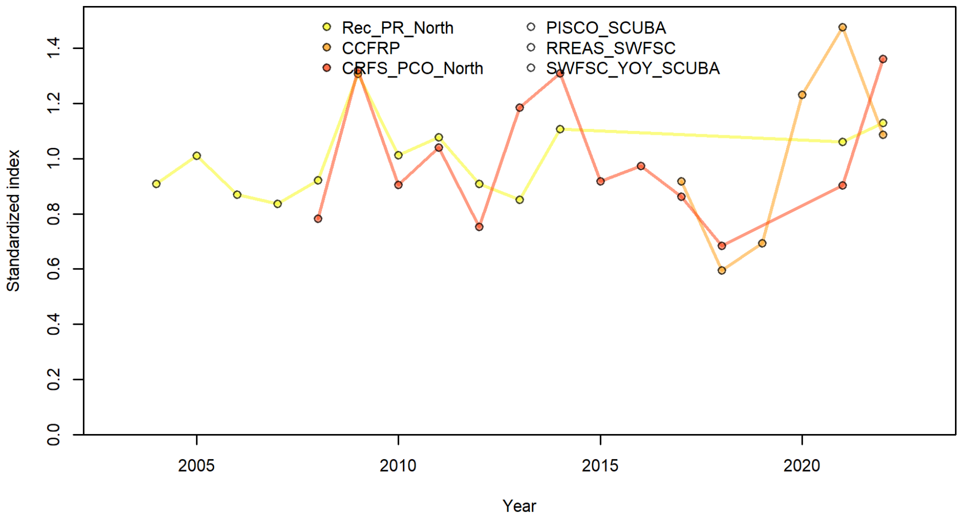


Figure 72: Indices from northern California (north of Point Arena) scaled to have means of 1 for comparison.

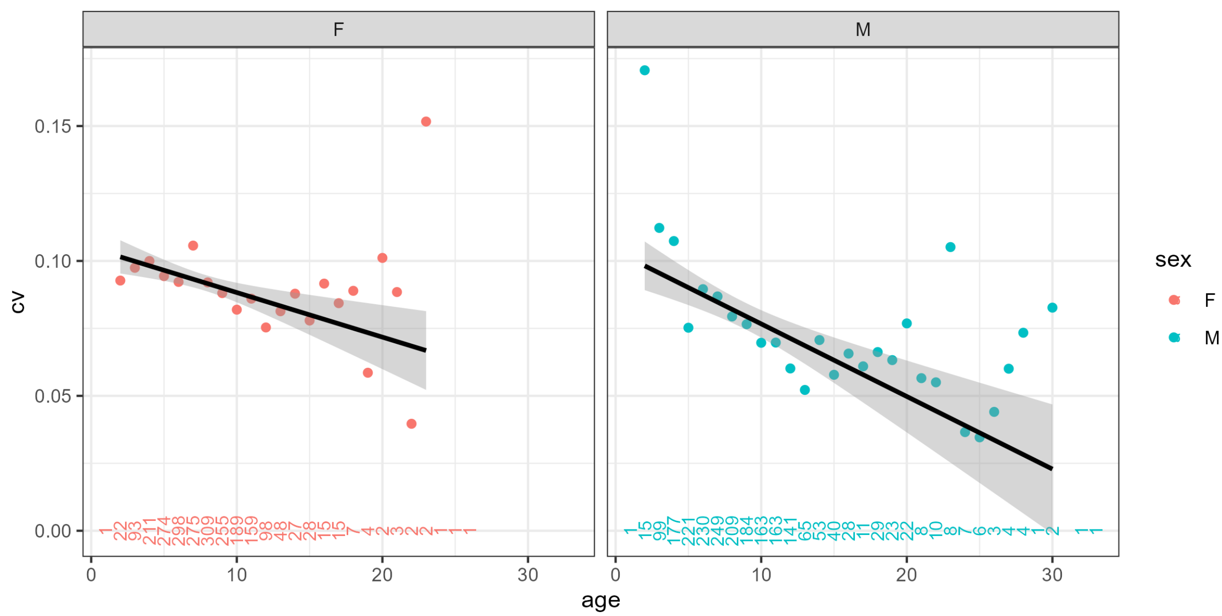


Figure 73: Coefficient of variation (CV) of length at age. Sample sizes are noted along the x-axis, and a fitted linear regression with 95% confidence intervals (shaded area) is shown for reference.

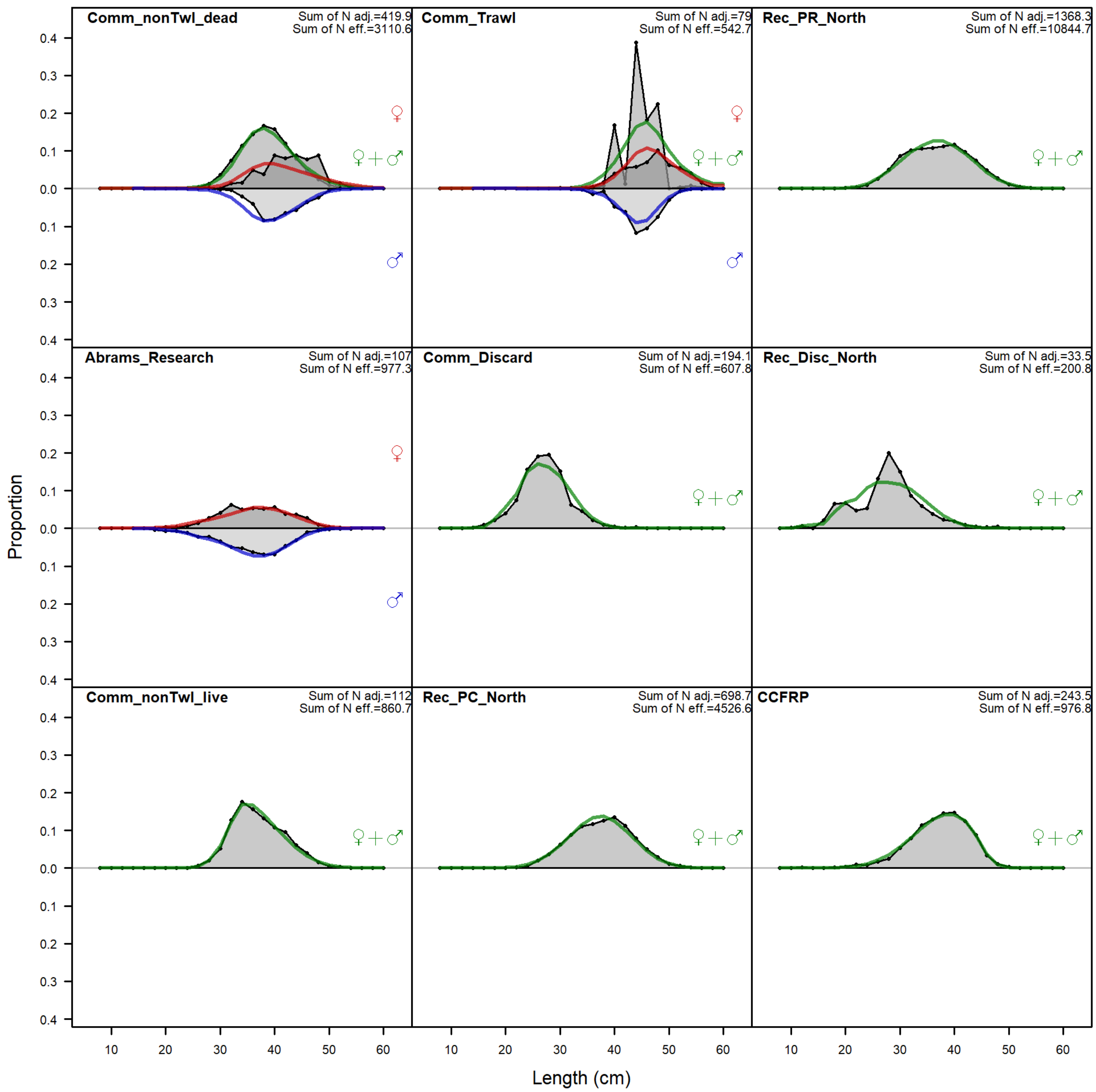


Figure 74: Northern base model fit to time-aggregated length composition, by fleet.

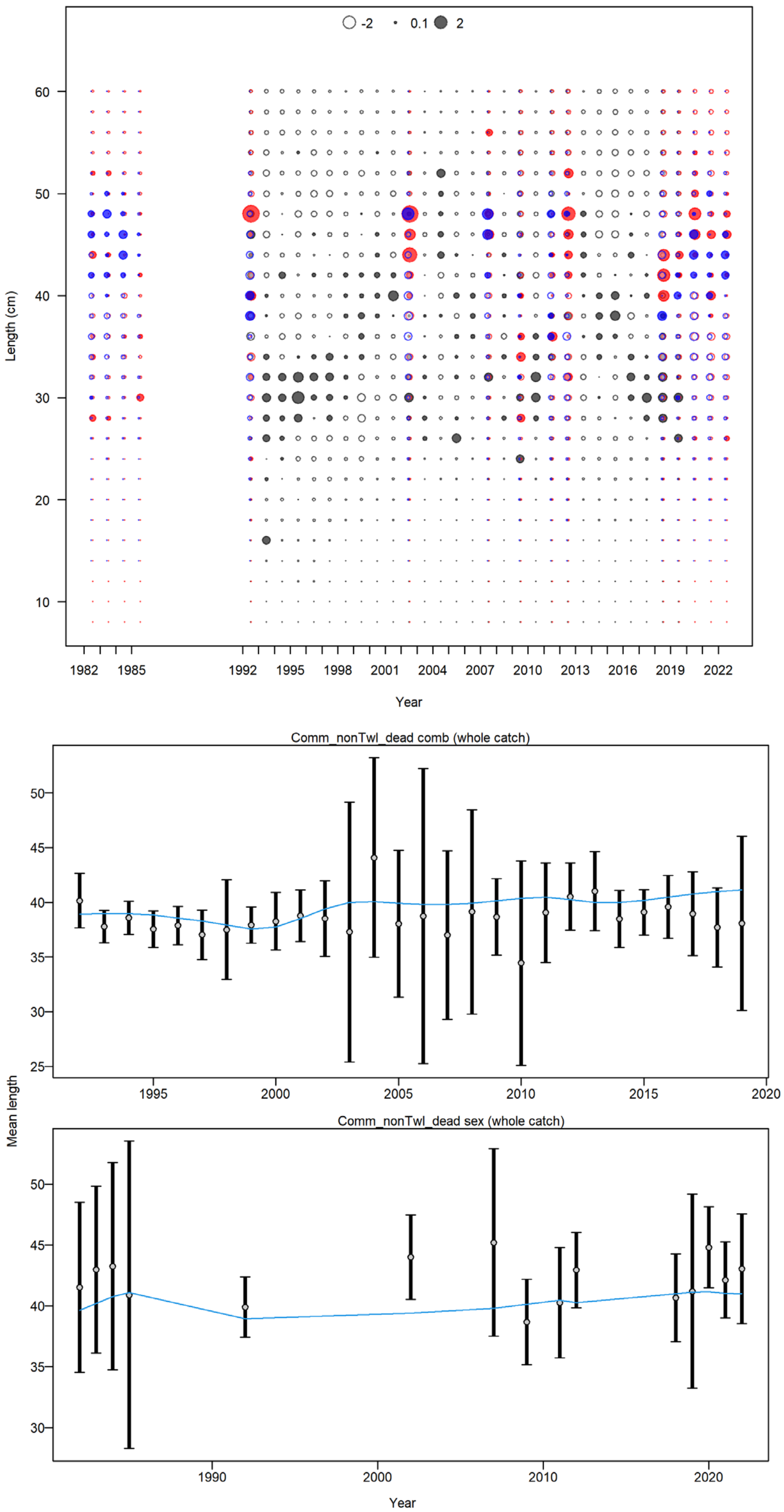
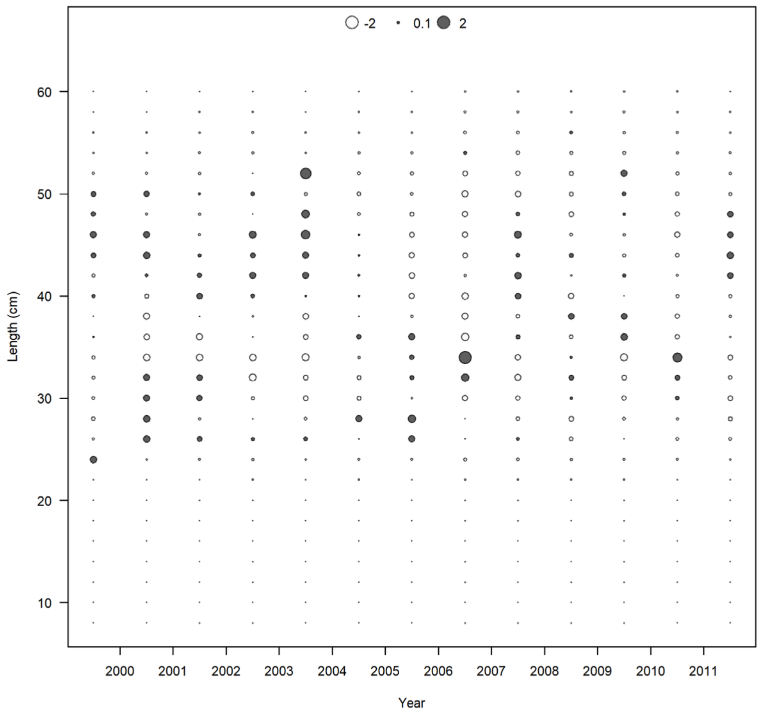


Figure 75: Length composition Pearson residuals (top panel) and fits to mean lengths (combined sex data, middle panel; separate sex data, bottom panel) for the northern commercial non-trawl fleet (dead landings).



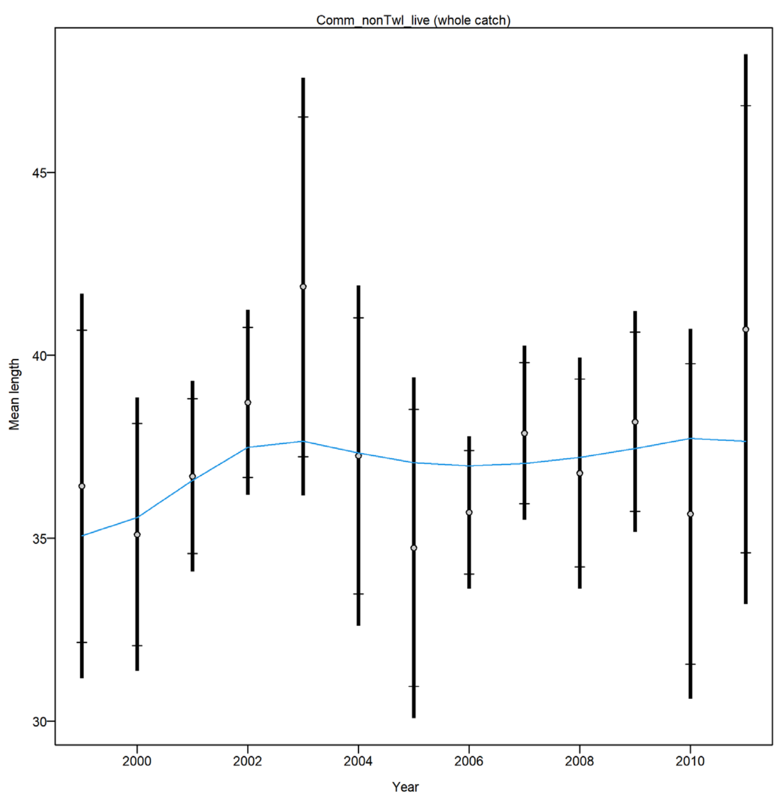


Figure 76: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the northern commercial non-trawl fleet (live landings).

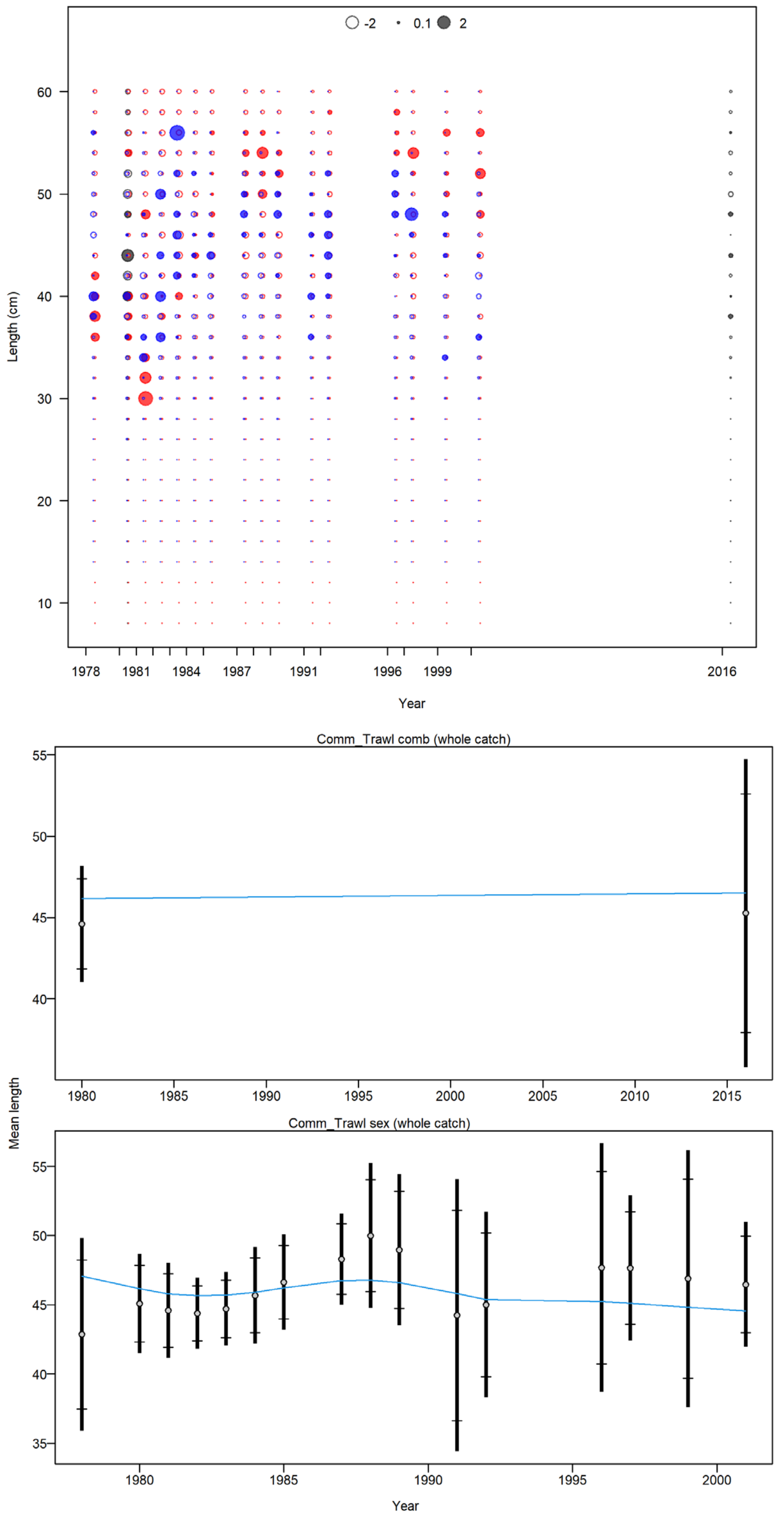


Figure 77: Length composition Pearson residuals (top panel) and fits to mean lengths (combined sex data, middle panel; separate sex data, bottom panel) for the northern commercial trawl fleet.

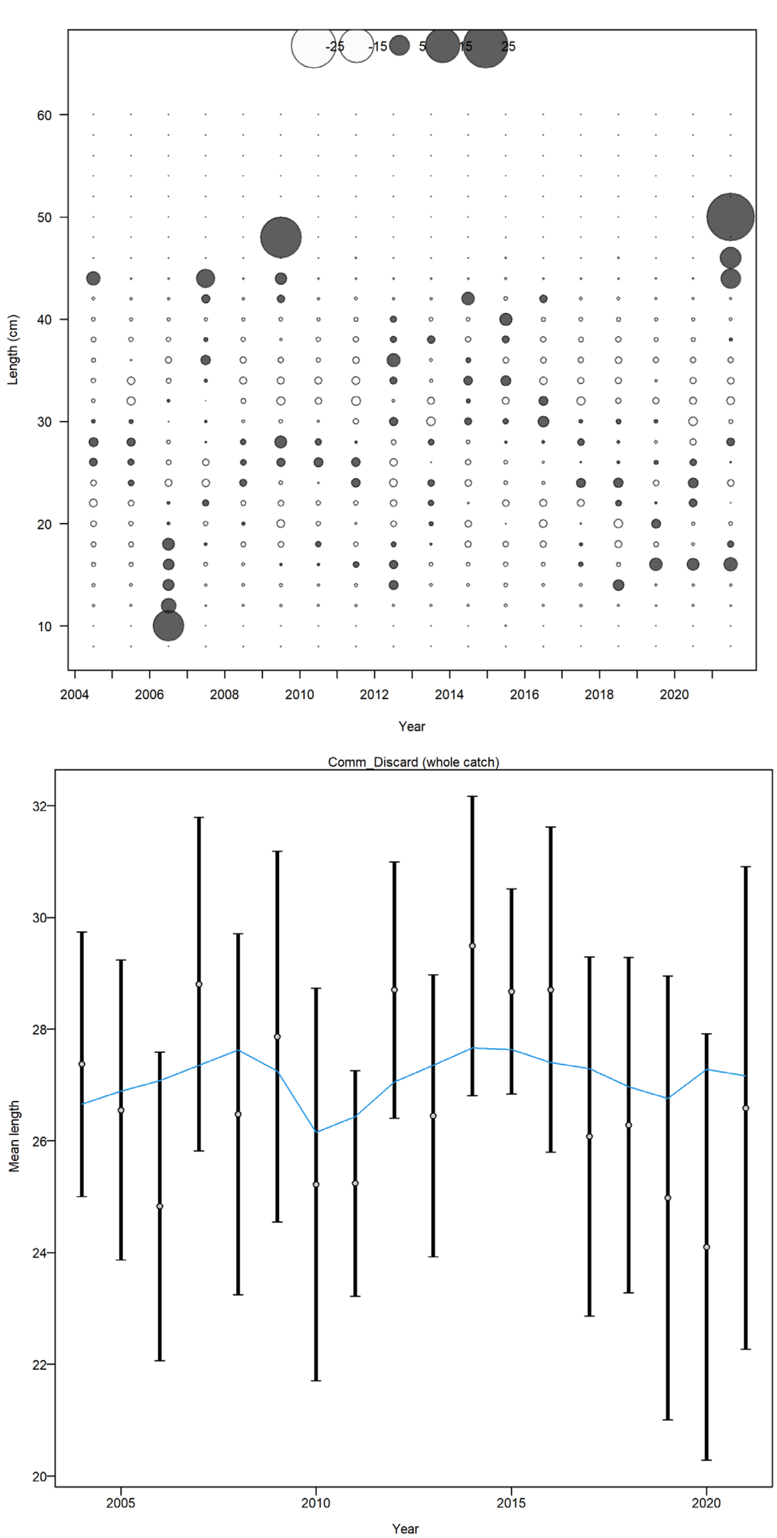


Figure 78: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the northern commercial discard fleet.

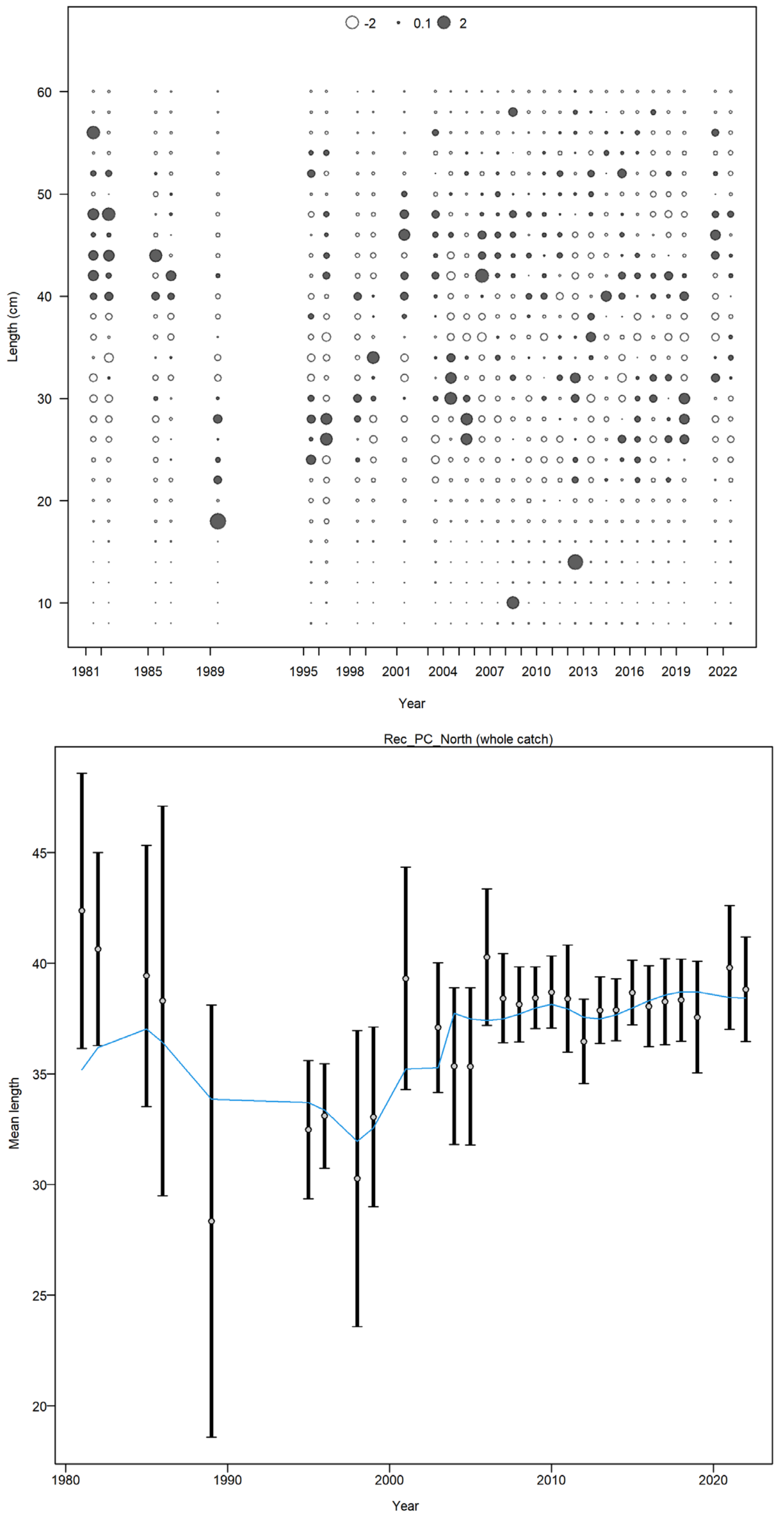


Figure 79: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the northern recreational CPFV fleet.

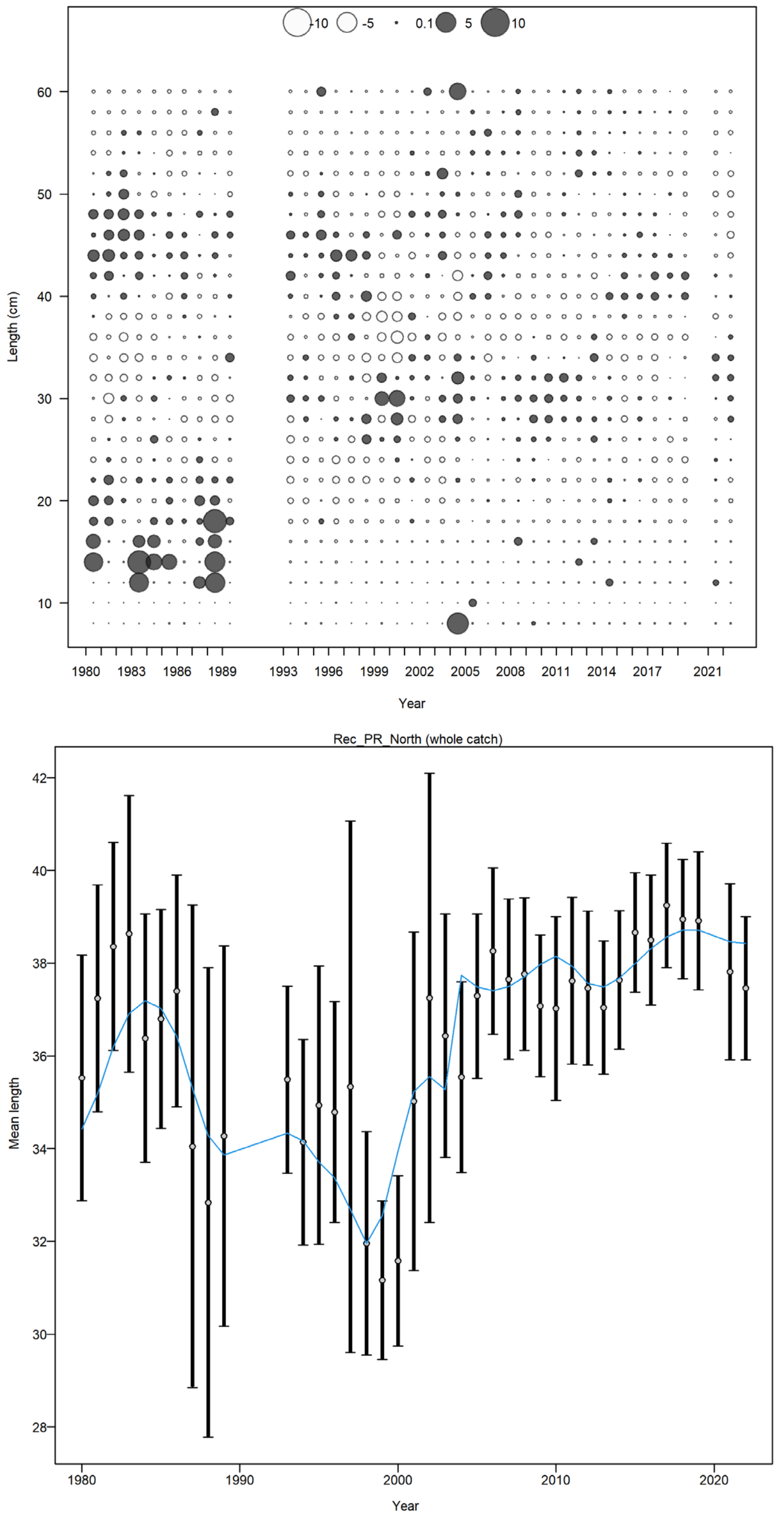
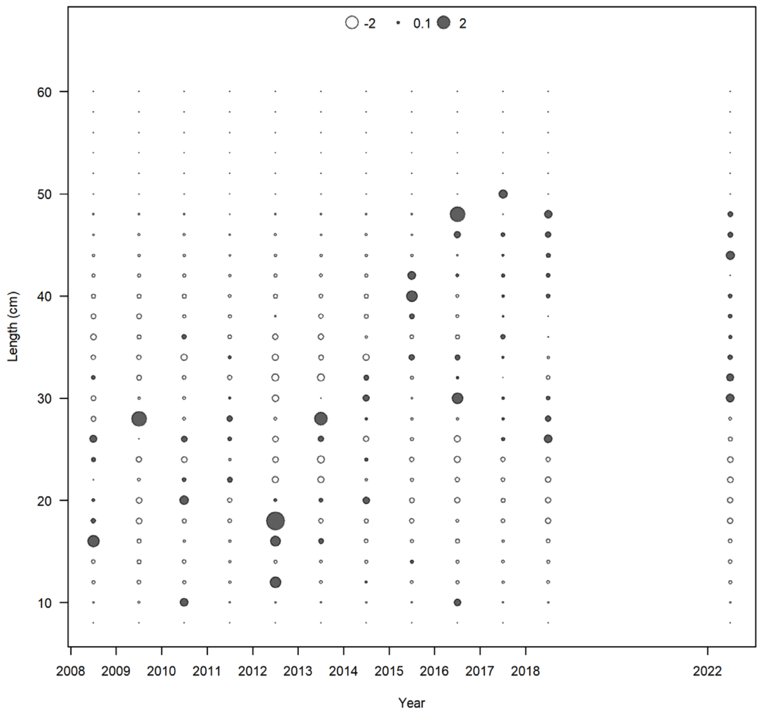


Figure 80: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the northern recreational private/rental boat fleet.



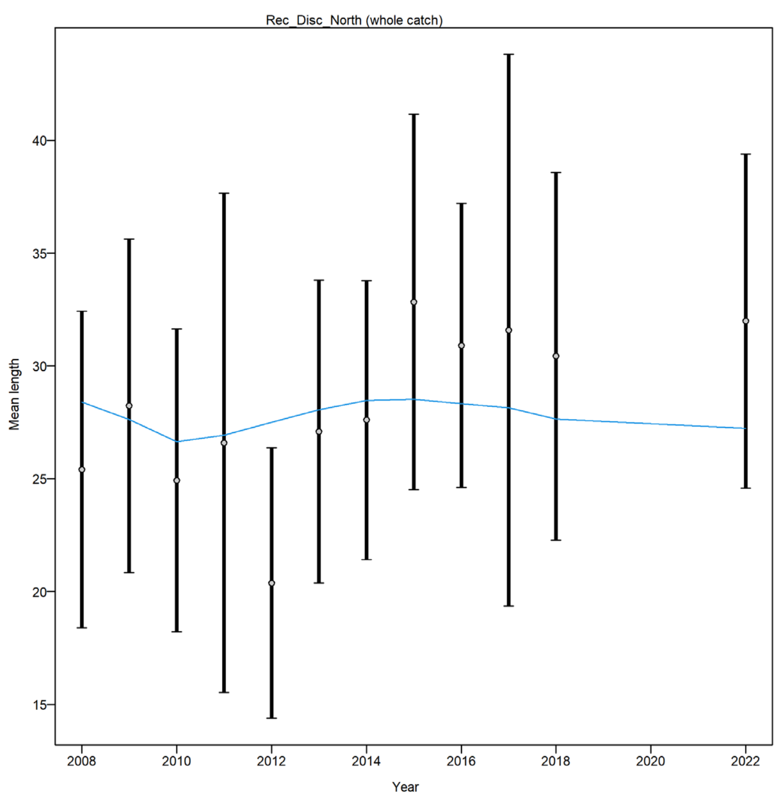
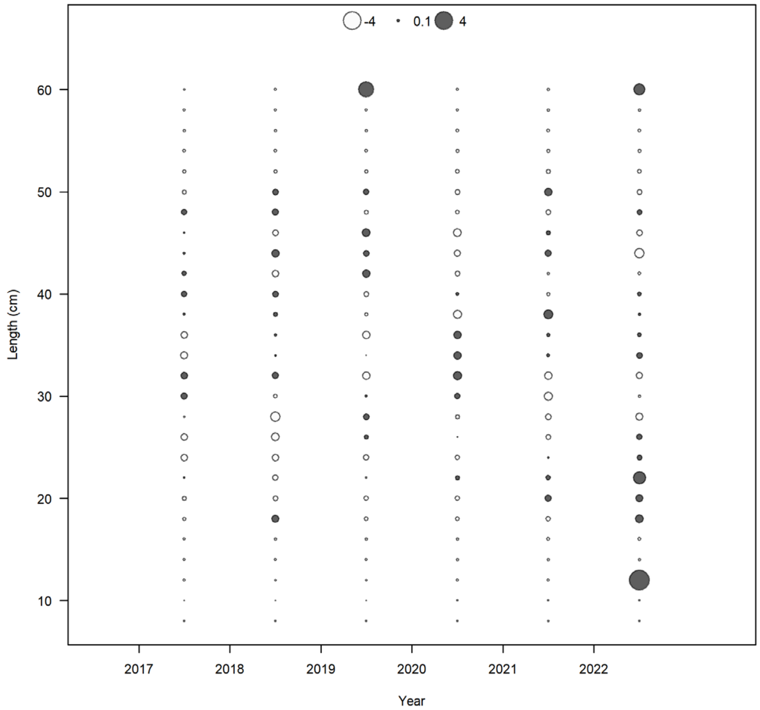


Figure 81: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the northern recreational discard fleet.



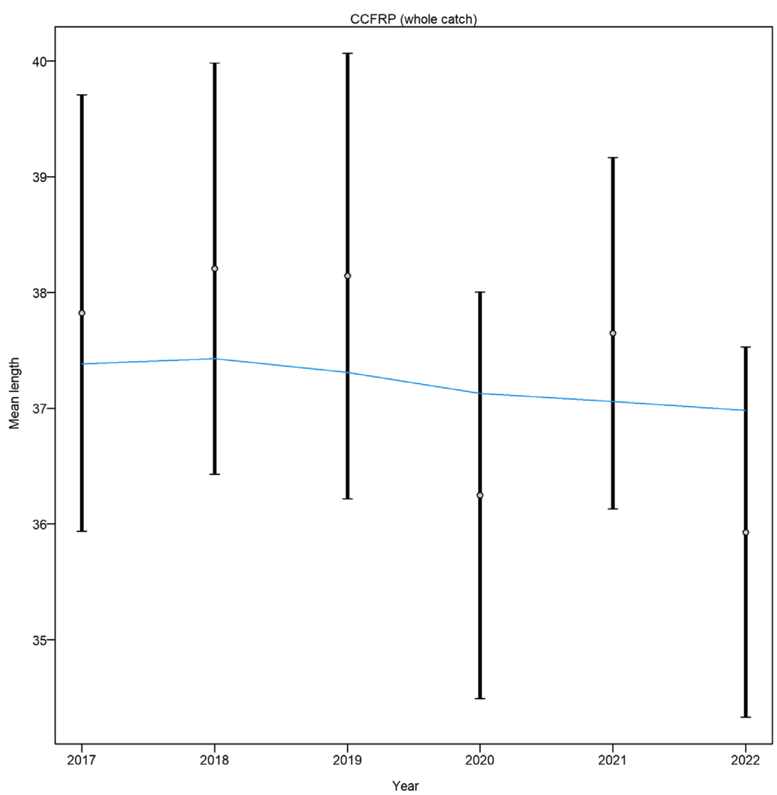


Figure 82: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the CCFRP survey.

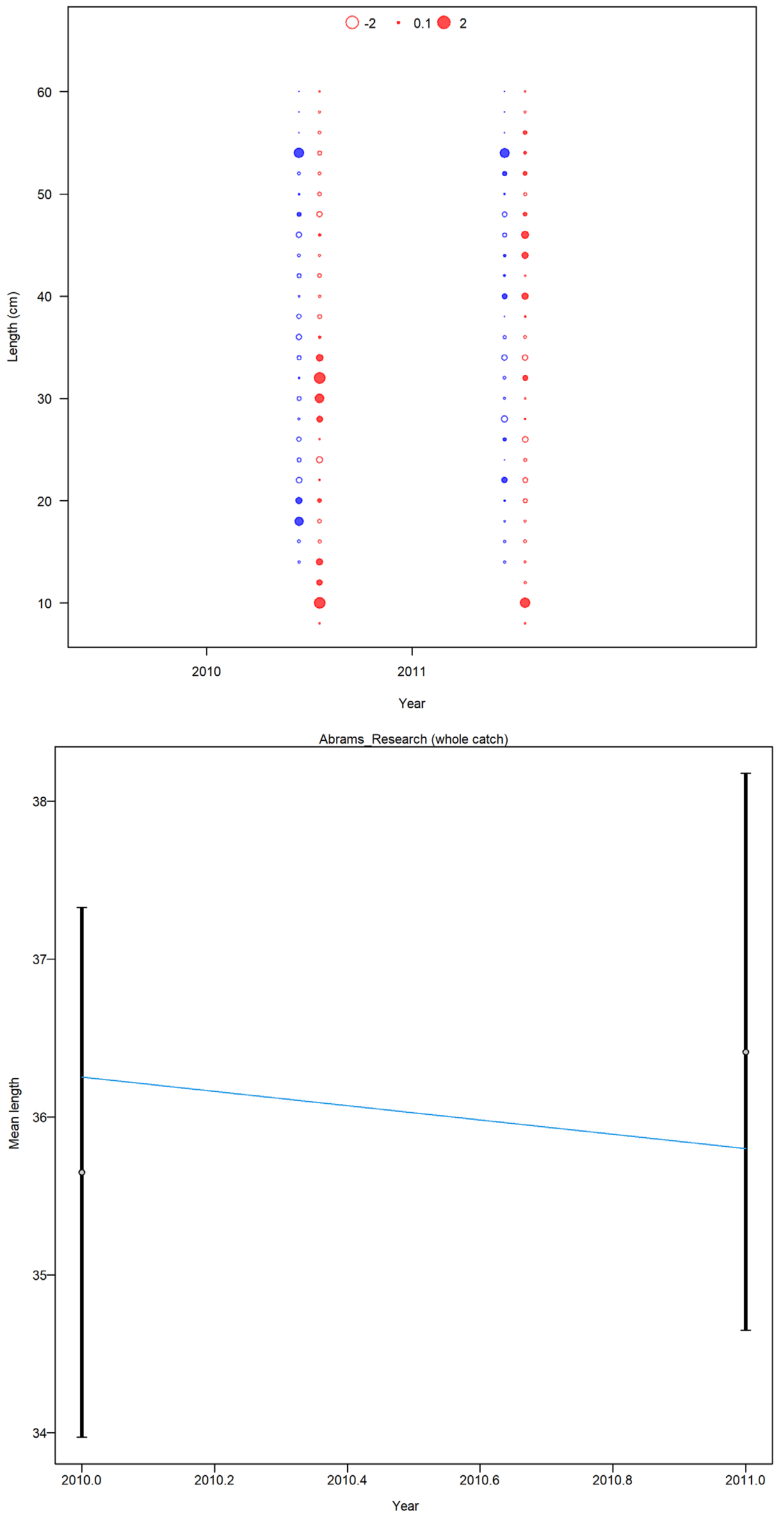


Figure 83: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the Abrams Research survey.

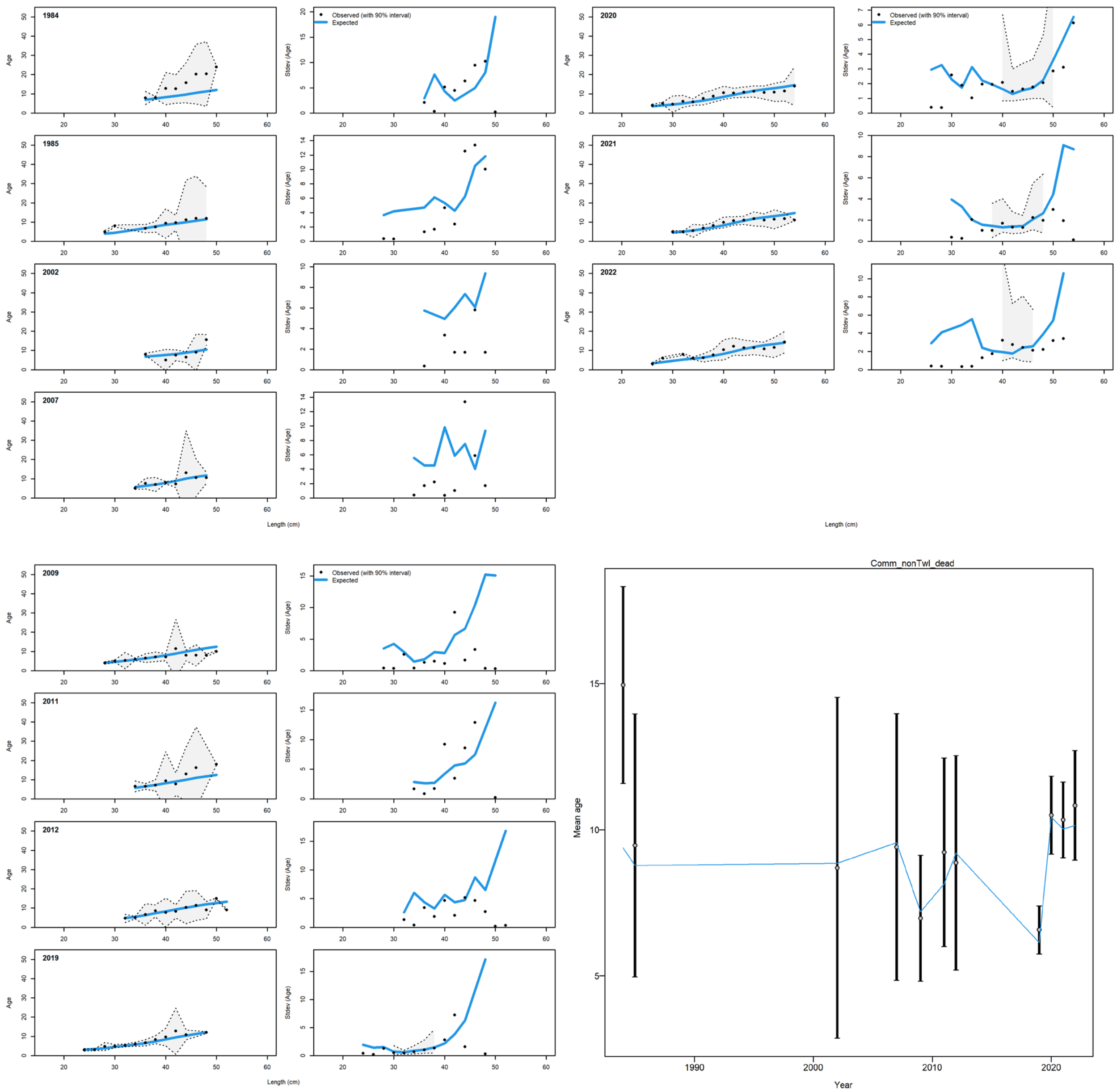


Figure 84: Northern base model fits to conditional age-at-length data and mean age data from the commercial non-trawl fleet (dead landings)

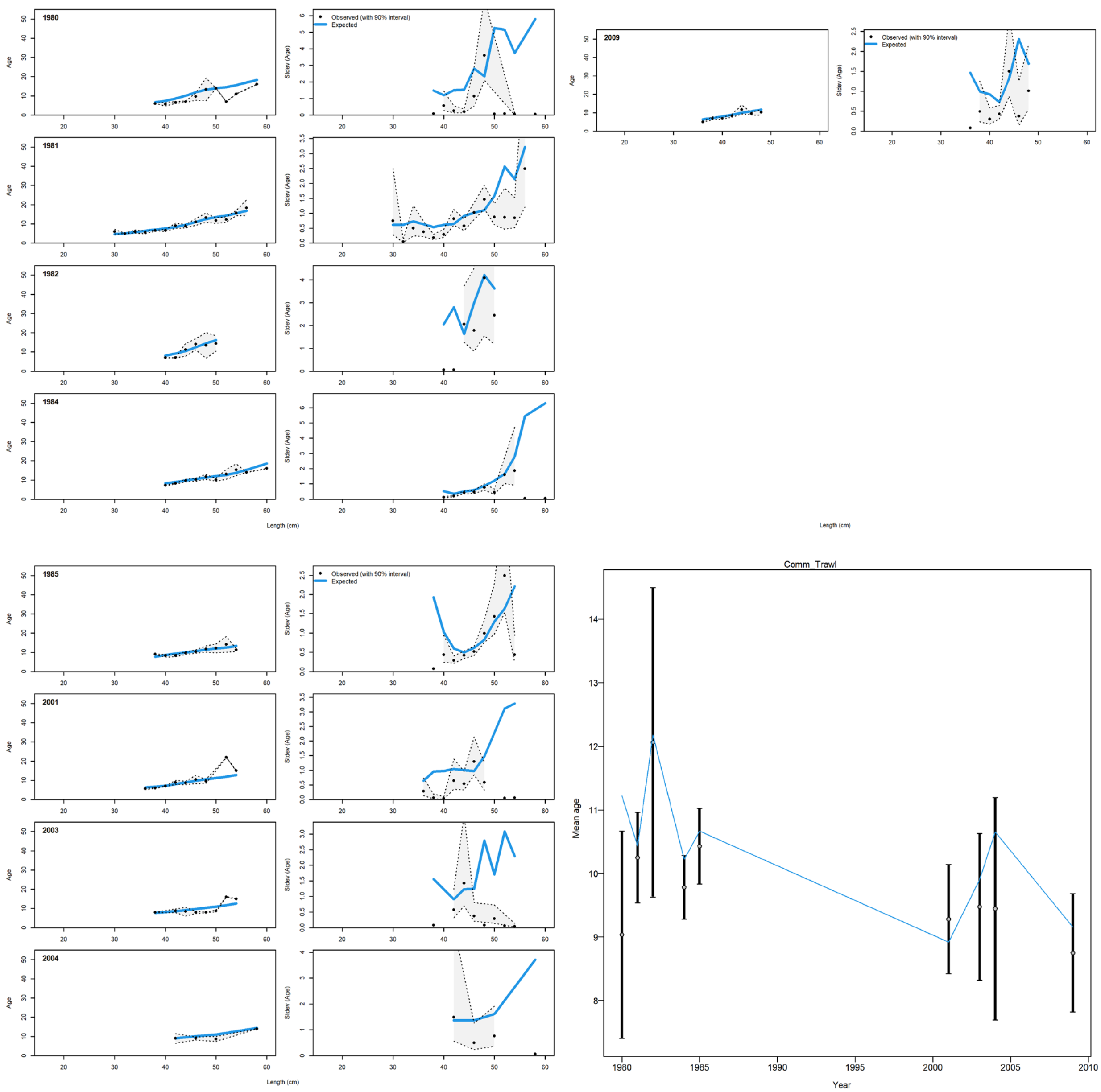


Figure 85: Northern base model fits to conditional age-at-length data and mean age data from the commercial trawl fleet.

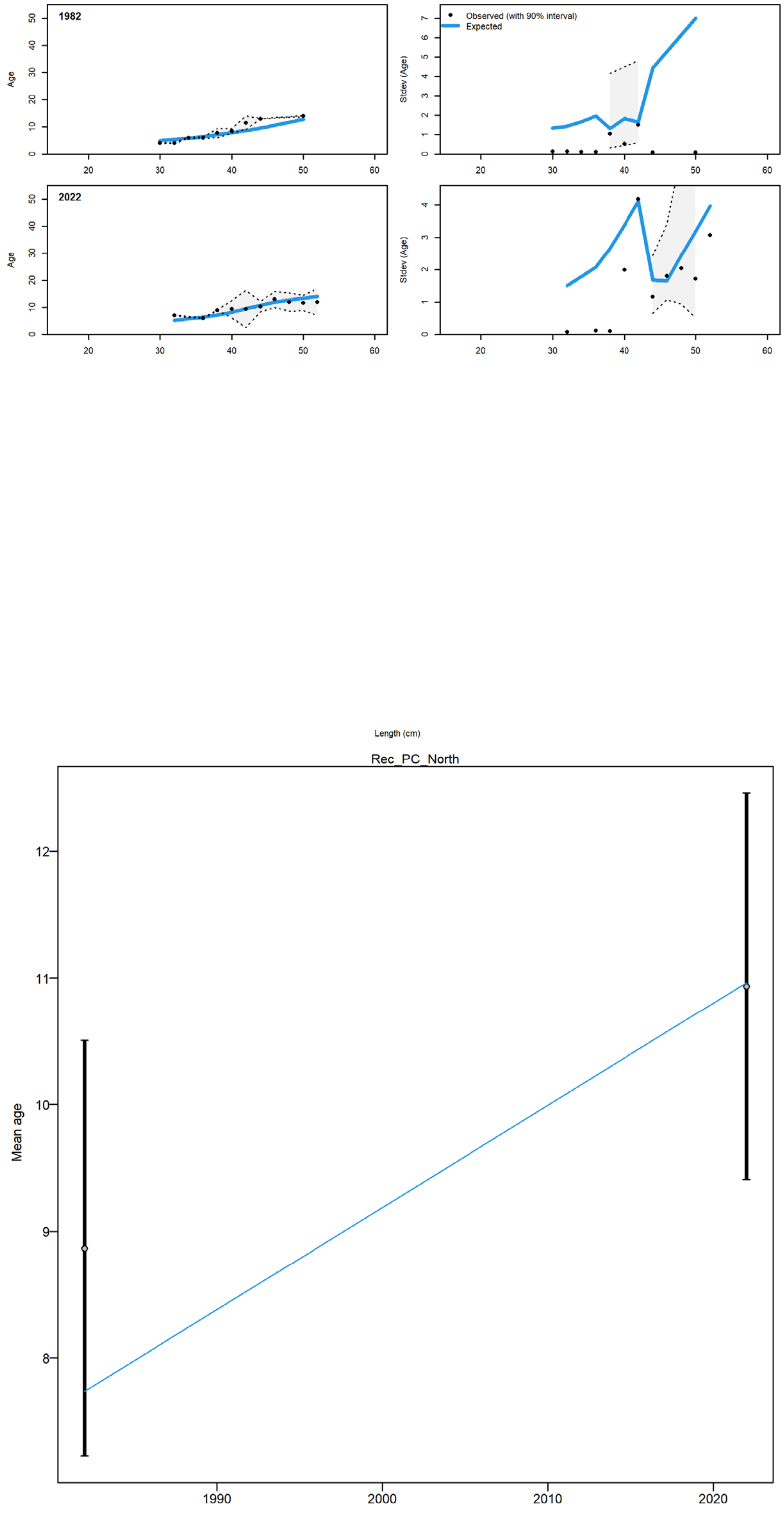


Figure 86: Northern base model fits to conditional age-at-length data and mean age data from the recreational CPFV fleet.

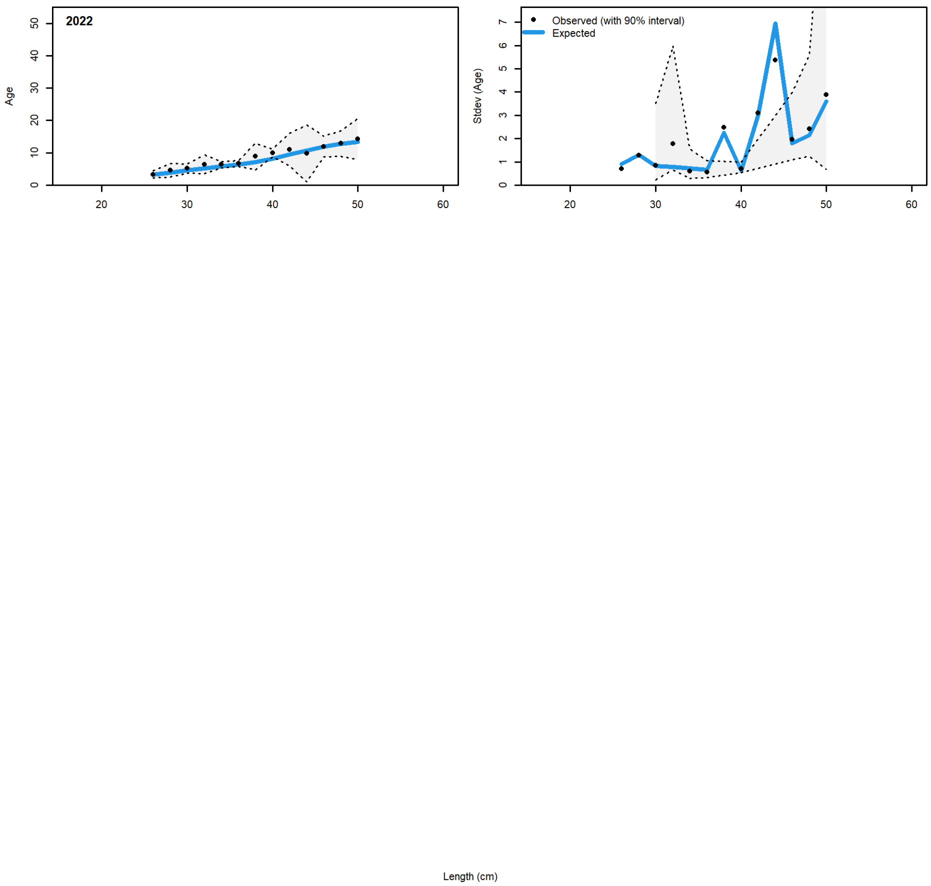


Figure 87: Northern base model fits to conditional age-at-length data from the recreational PR fleet. There were too few points (only 1 year of observations) to calculate adjustments for the Francis data weighting method (TA1.8) in this fleet.

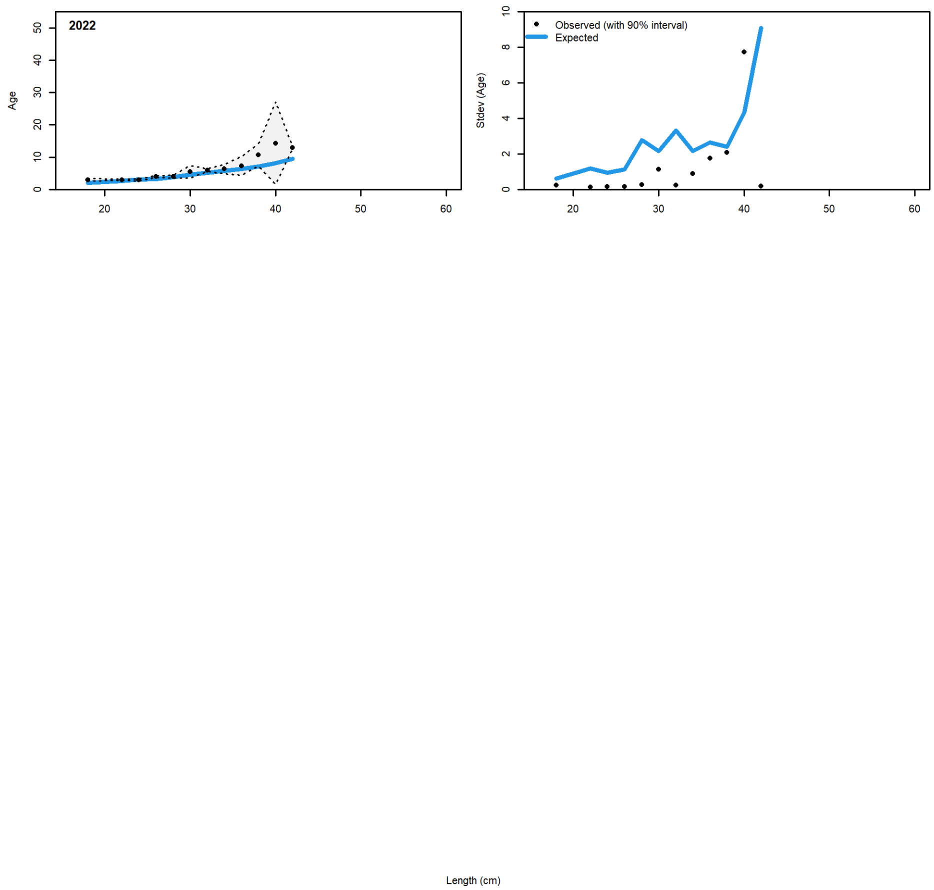
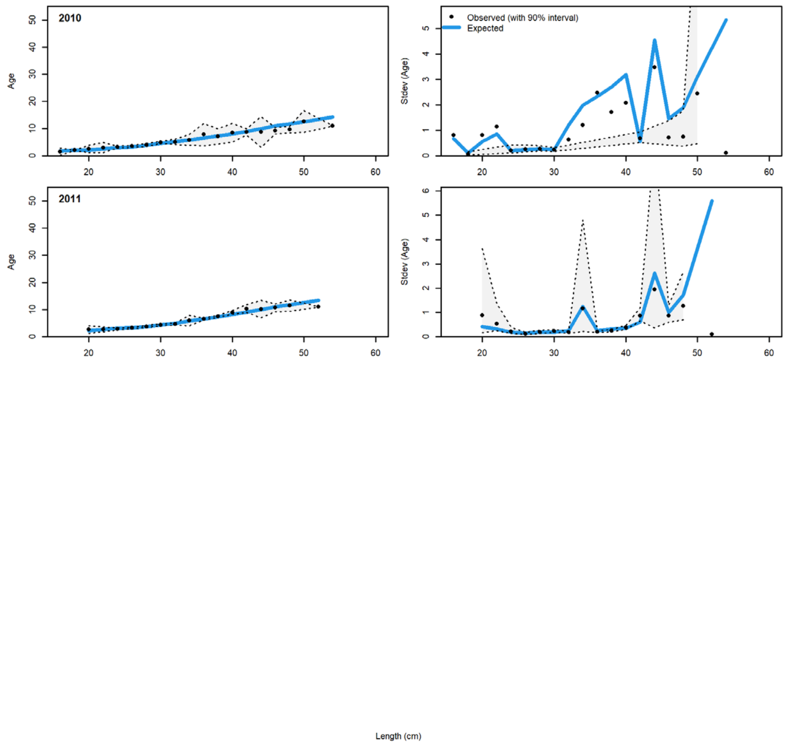


Figure 88: Northern base model fits to conditional age-at-length data from the CCFRP survey. There were too few points (only 1 year of observations) to calculate adjustments for the Francis data weighting method (TA1.8) in this fleet.



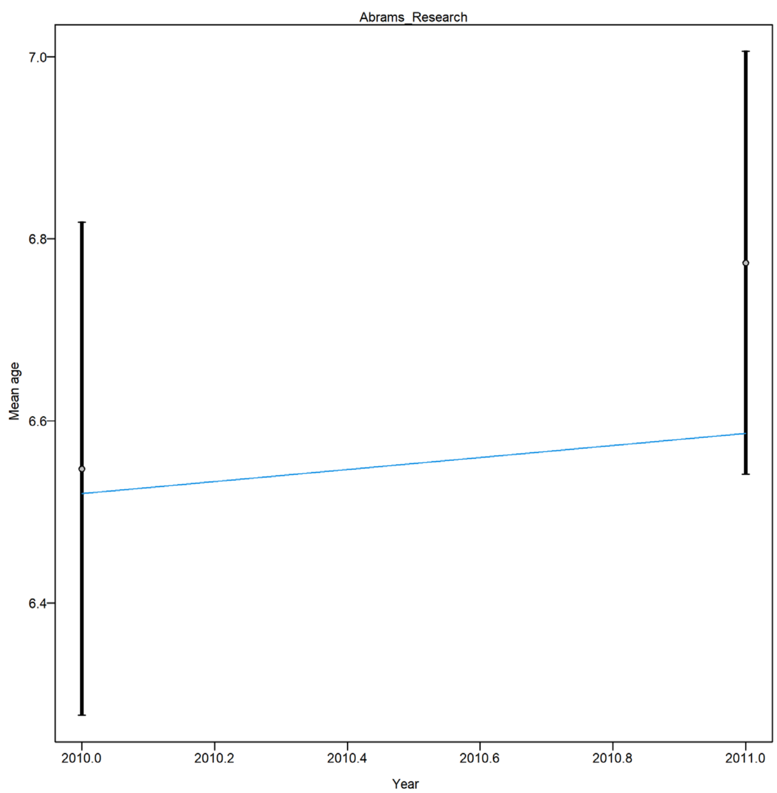


Figure 89: Northern base model fits to conditional age-at-length data and mean age data from the Abrams Research fleet.

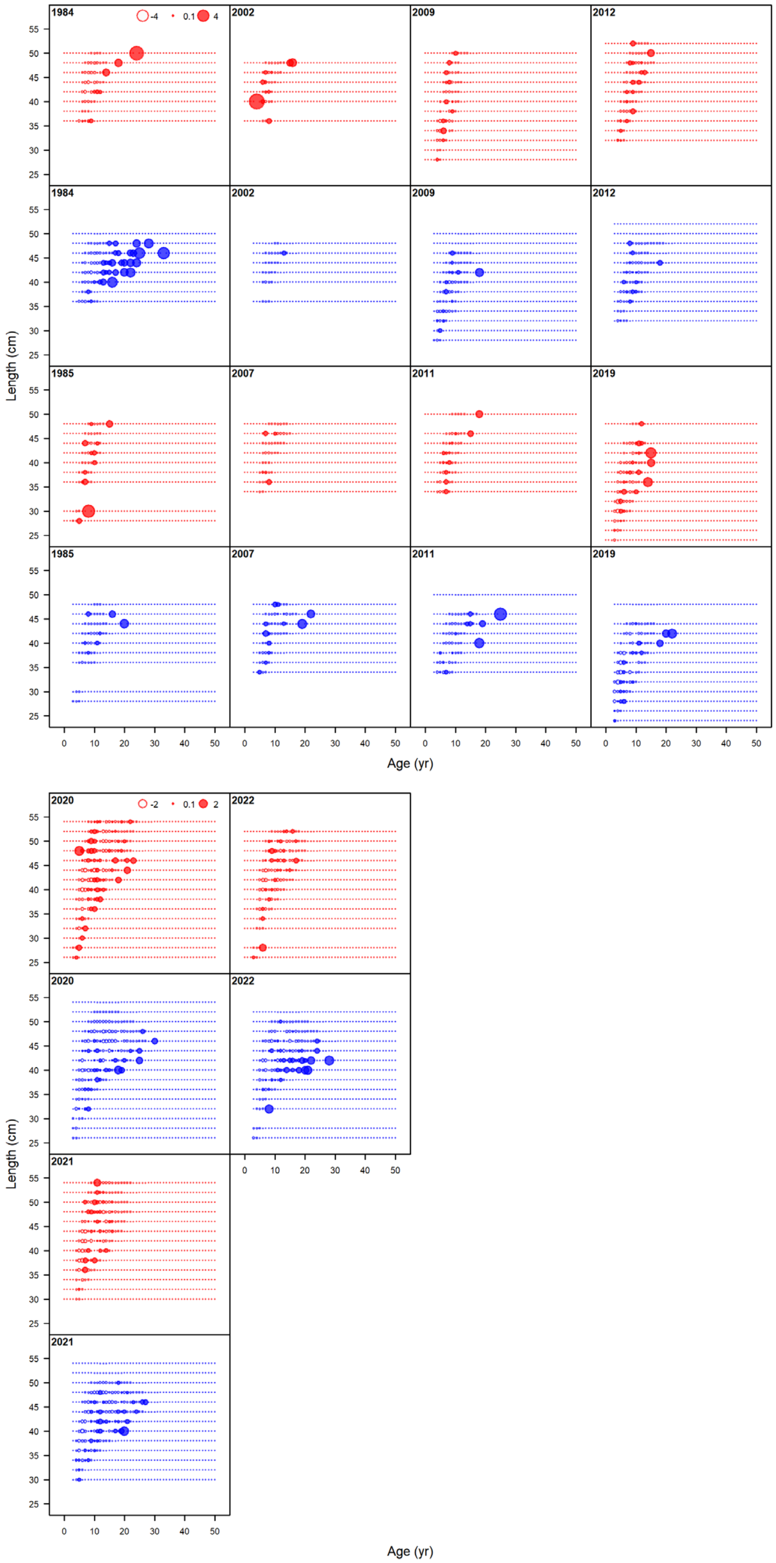


Figure 90: Northern model Pearson residuals for conditional age-at-length data in the commercial non-trawl (landed dead) fleet.

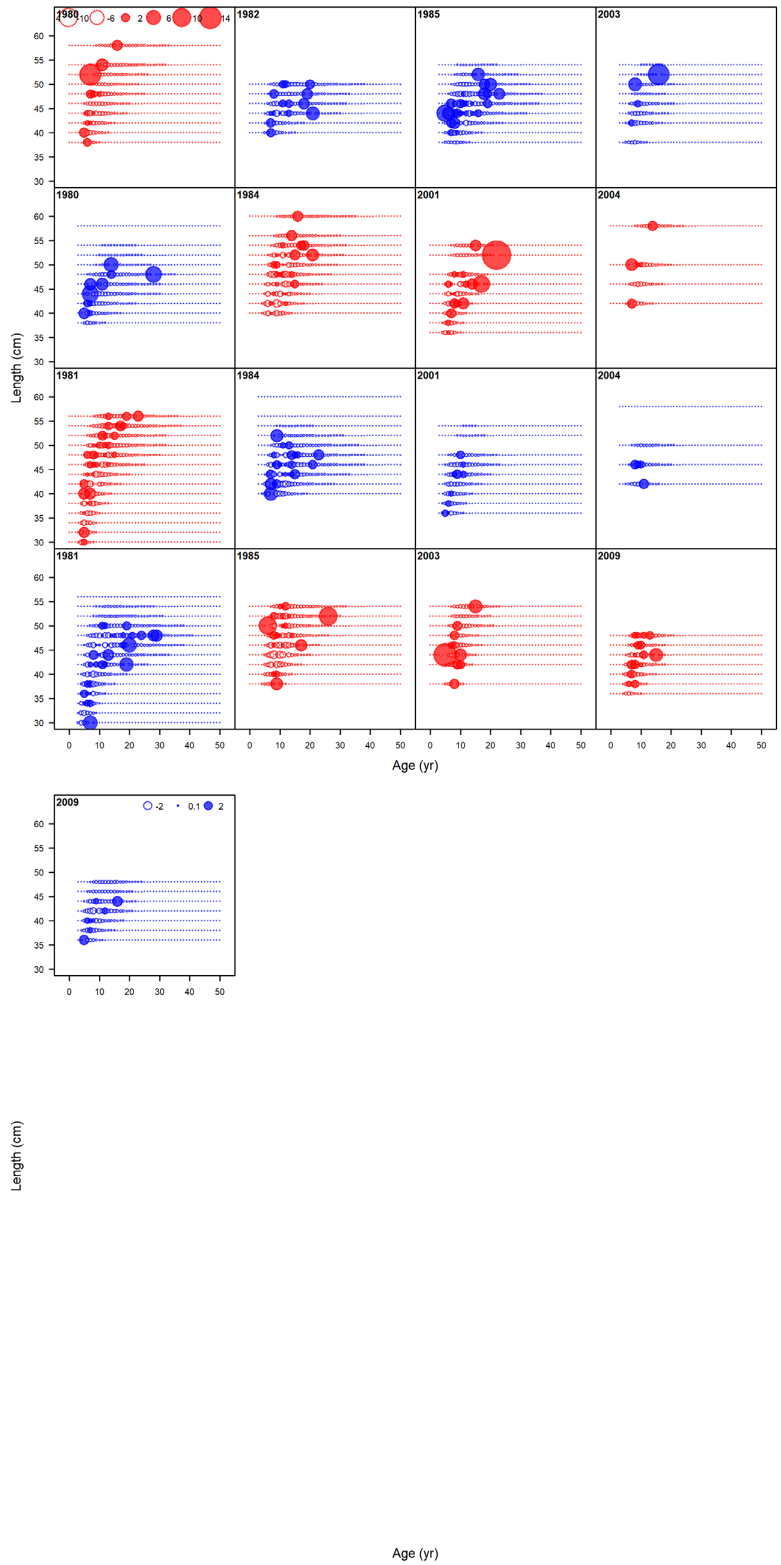


Figure 91: Northern model Pearson residuals for conditional age-at-length data in the commercial trawl fleet.

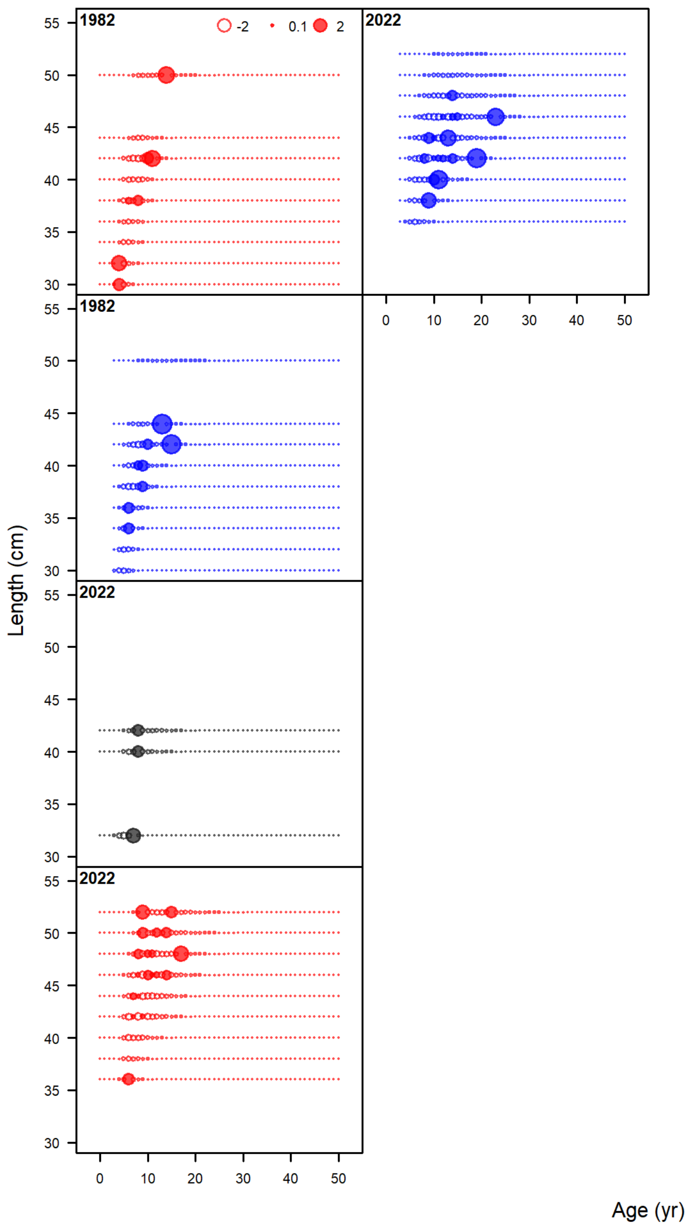


Figure 92: Northern model Pearson residuals for conditional age-at-length data in the recreational CPFV fleet.

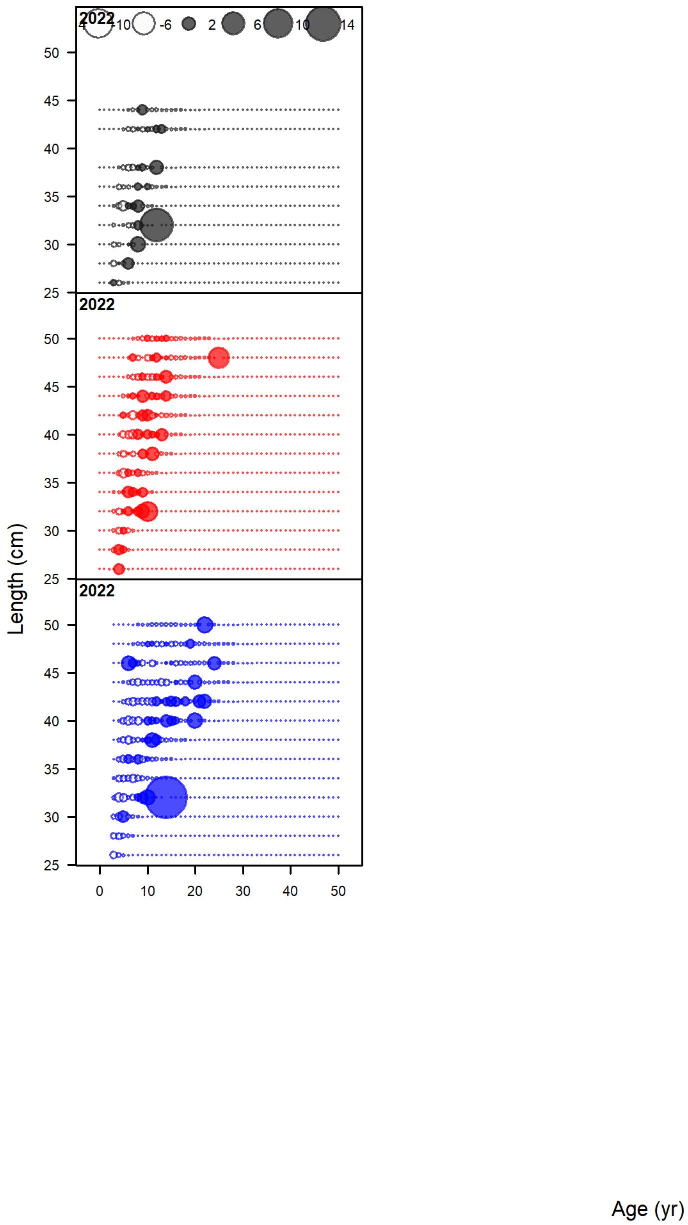


Figure 93: Northern model Pearson residuals for conditional age-at-length data in the recreational PR fleet.

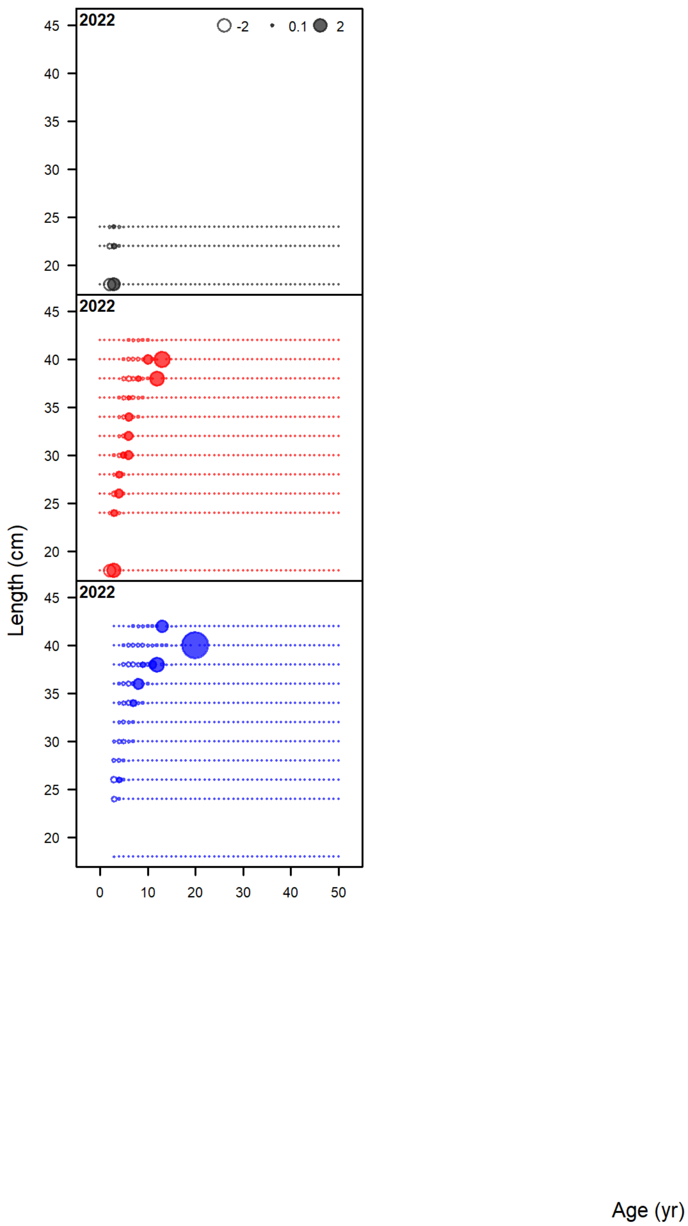


Figure 94: Northern model Pearson residuals for conditional age-at-length data in the CCFRP survey.

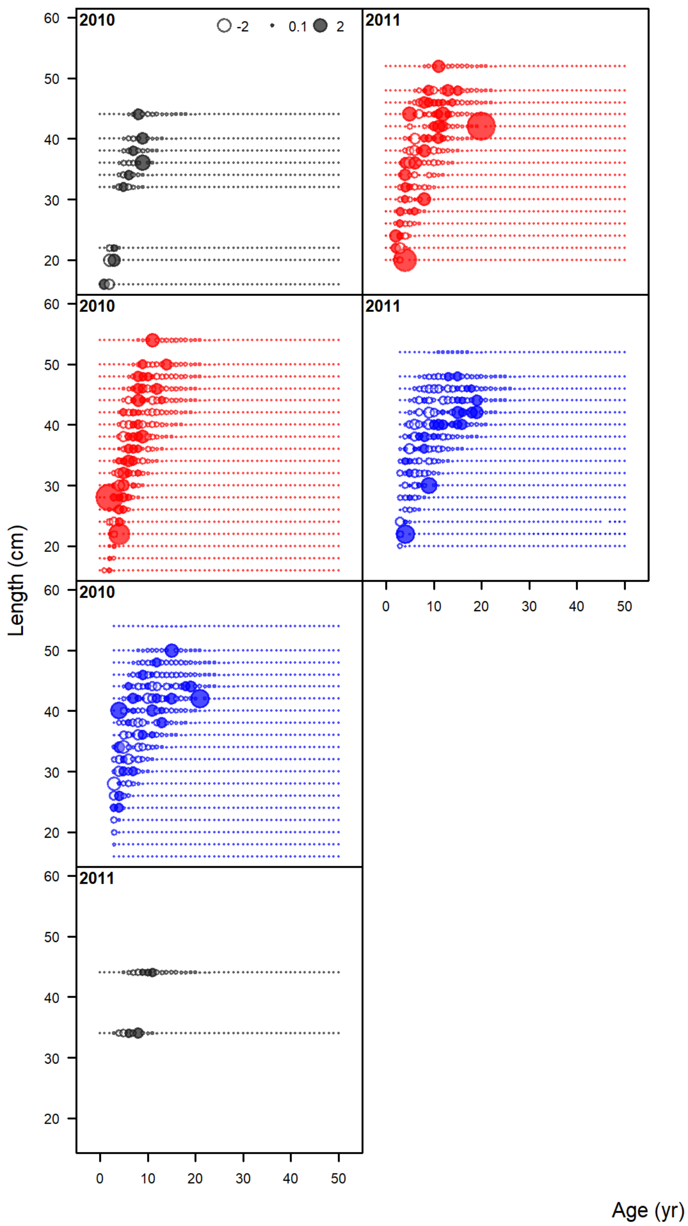


Figure 95: Northern model Pearson residuals for conditional age-at-length data in the Abrams Research survey.

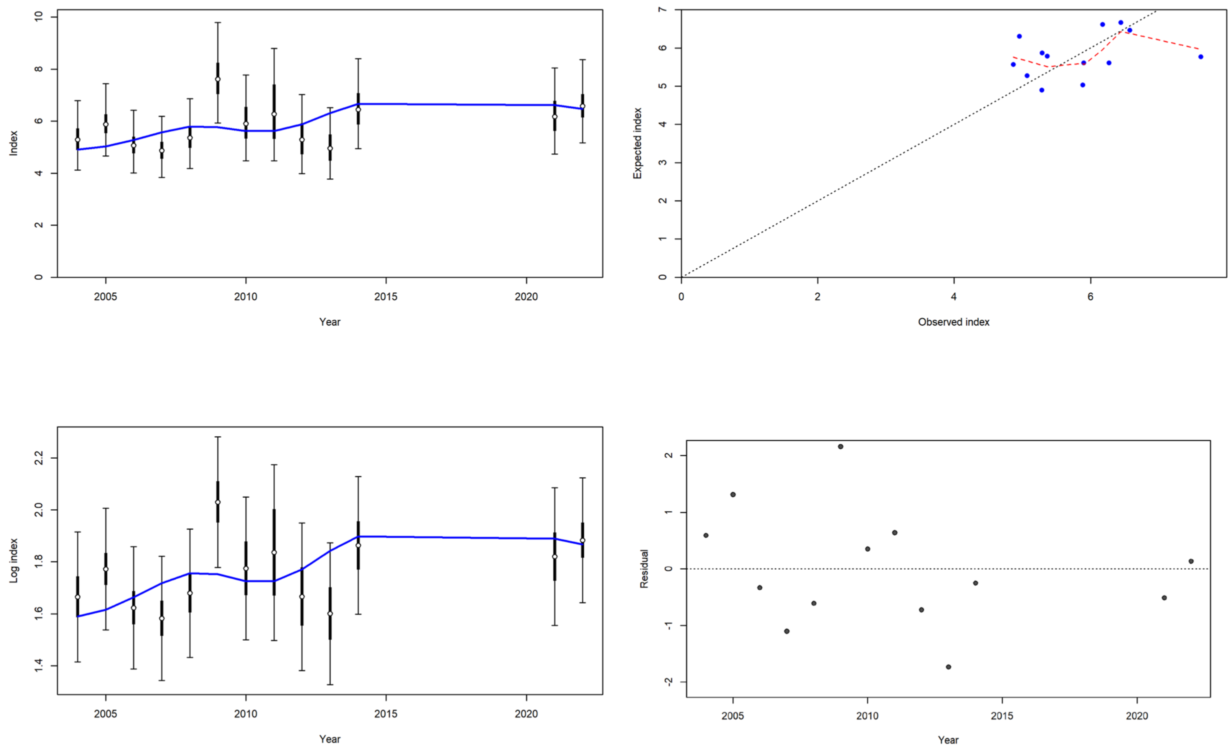


Figure 96: Northern model fit to the recreational PR index. Top row: arithmetic scale fit and 1:1 plot. Bottom Row: log-scale fit and log-scale standardized residual plot.

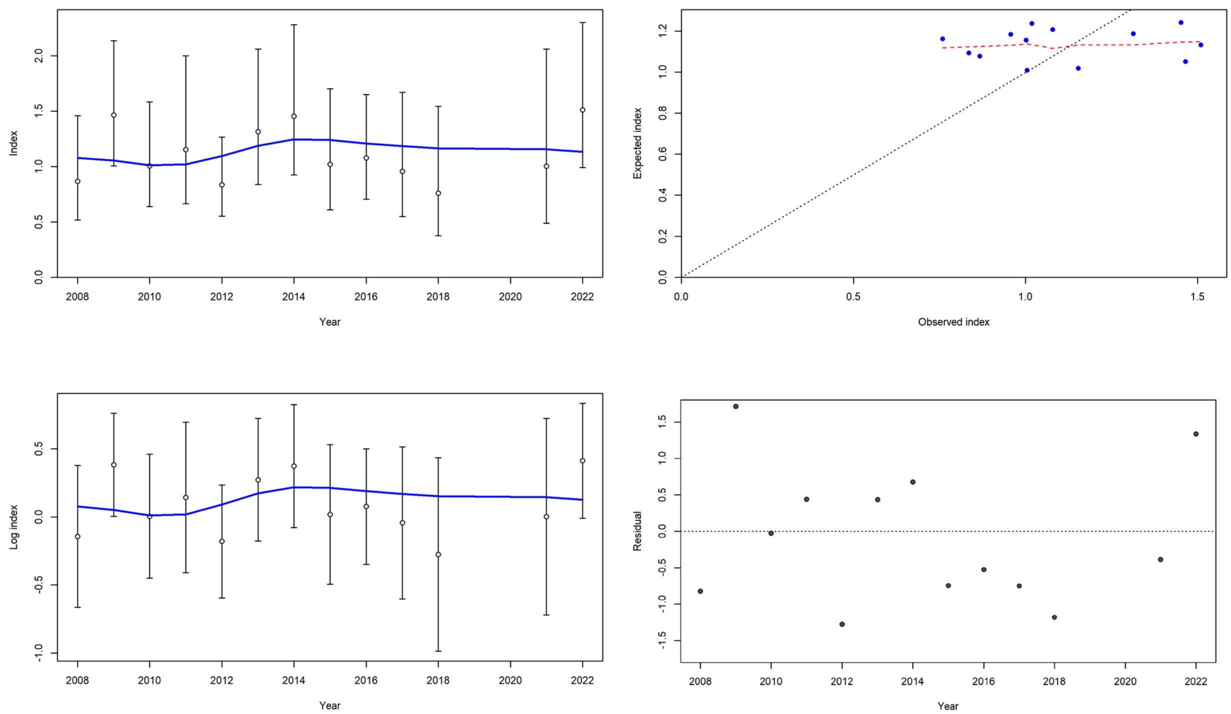


Figure 97: Northern model fit to the Recreational CPFV Onboard Index. Top row: arithmetic scale fit and 1:1 plot. Bottom Row: log-scale fit and log-scale standardized residual plot.

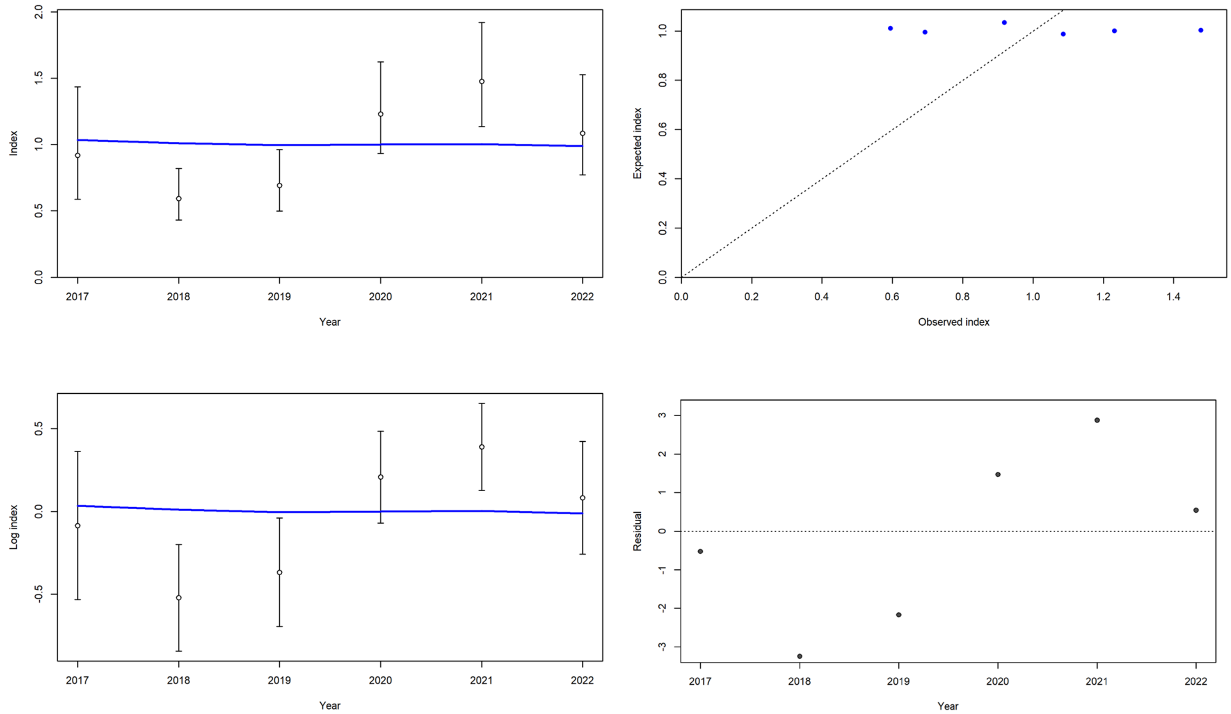


Figure 98: Northern model fit to the CCFRP index. Top row: arithmetic scale fit and 1:1 plot.
Bottom Row: log-scale fit and log-scale standardized residual plot.

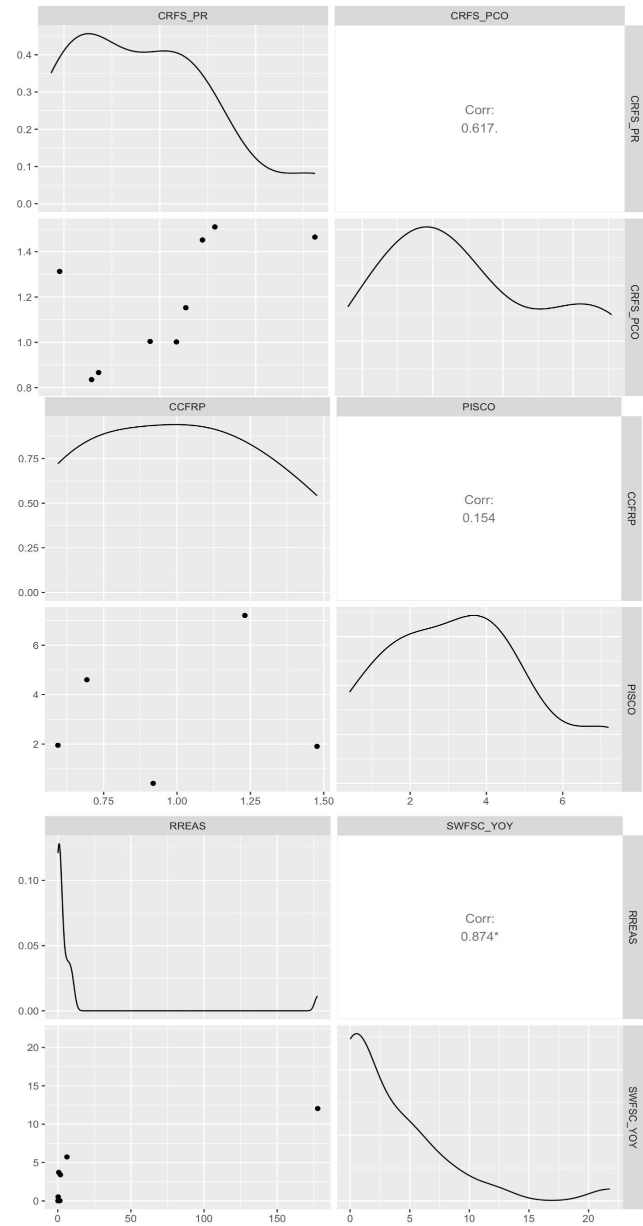


Figure 99: Pairwise comparisons of abundance indices considered for the northern California assessment. Correlation coefficients (numbers) and p values (*** < 0.001, ** < 0.01, * < 0.05, and . < 0.10) are shown in the upper right quadrants, data points are shown in the lower left quadrants, and kernel densities are shown along the diagonals. A minimum of five overlapping years was required for inclusion. CRFS_PR: dockside private/rental recreational fishing boats; CRFS PCO: party/charter onboard observers; CCFRP: California Collaborative Fisheries Research Program; PISCO: Partnership for the Interdisciplinary Study of Coastal Oceans; RREAS: NMFS SWFSC's Rockfish Recruitment and Ecosystem Assessment Survey; SWFSC_YOY: NMFS SWFSC's young of the year SCUBA survey.

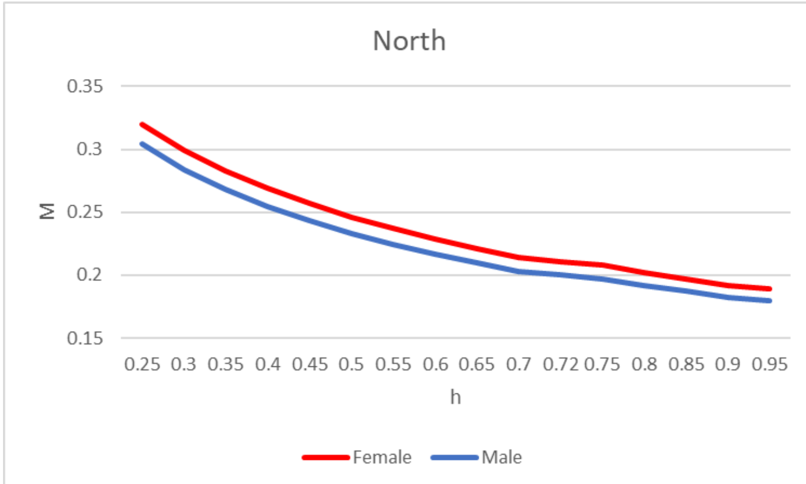


Figure 100: Estimated values of female and male natural mortality (M) as a function of the Beverton-Holt steepness parameter (h), northern model.

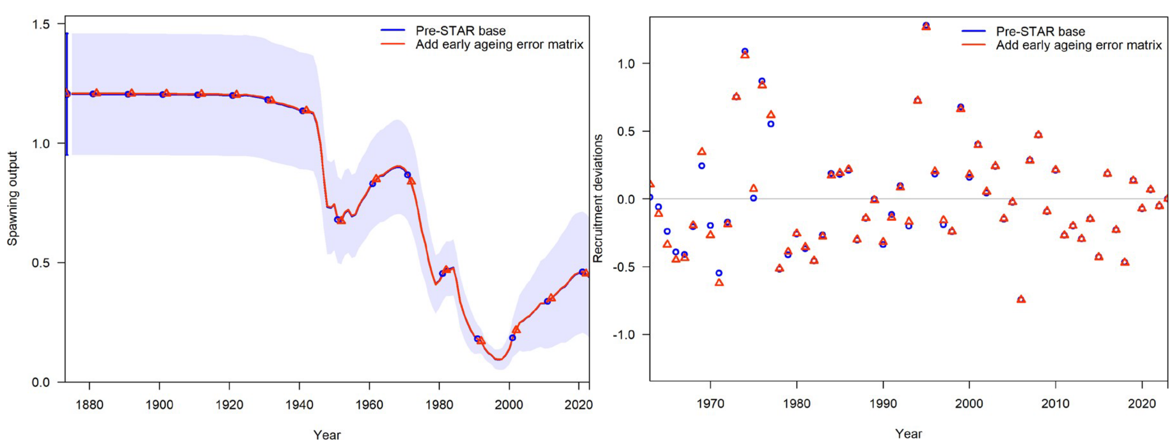


Figure 101: Comparison of estimated time series of spawning output (billions of eggs) and recruitment deviations from the pre-STAR base model and a revised model using the correct pre- 2015 ageing error matrix.

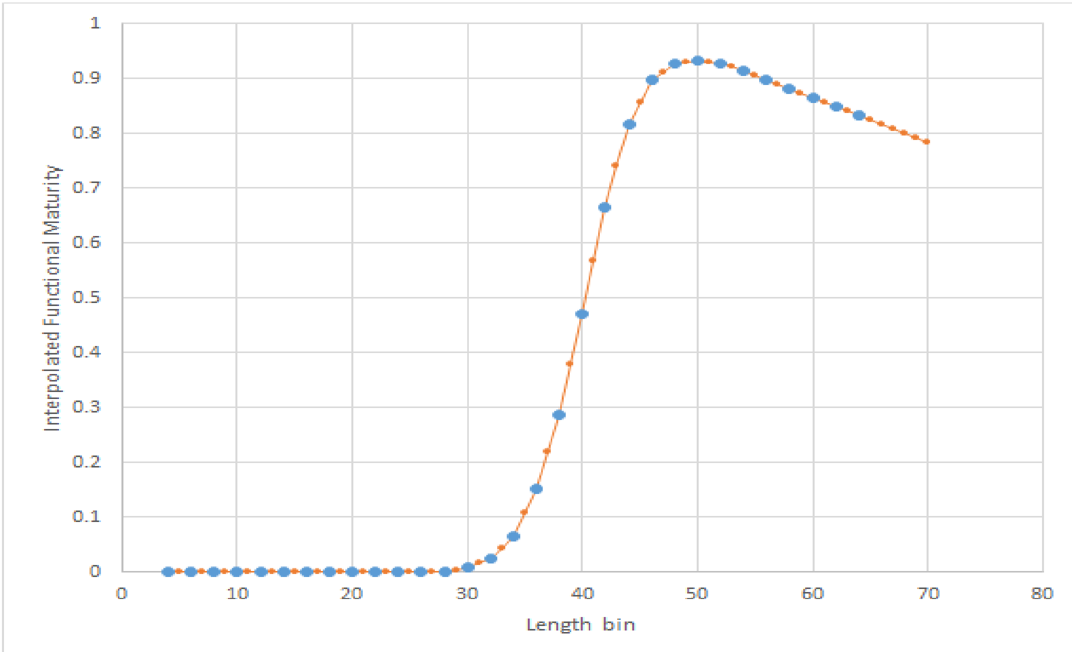


Figure 102: Spline model for functional maturity used in request number 4 (northern model). Blue points are the estimates used in the Washington/Oregon models, and the orange line and points are the interpolated and extrapolated values used in the sensitivity run

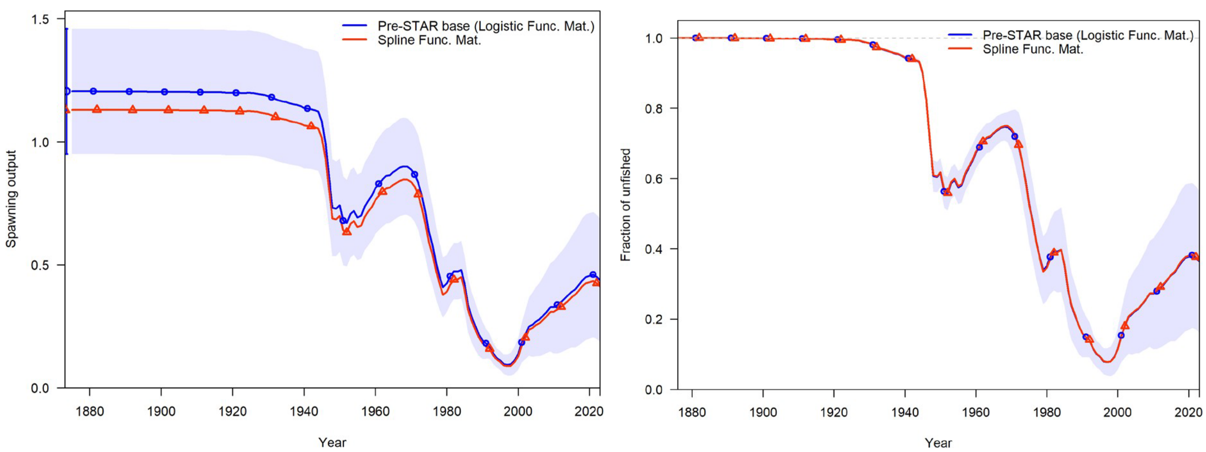


Figure 103: Effect of changing the functional maturity relationship (from a logistic model to a spline model) on time series of spawning output (billions of eggs) and spawning output relative to unfished spawning output

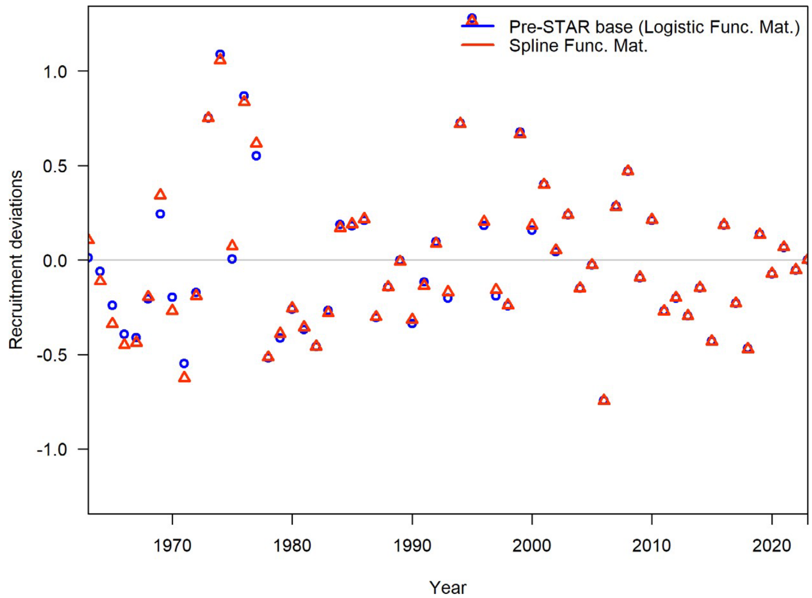


Figure 104: Effect of changing the functional maturity relationship (from a logistic model to a spline model) on estimated annual recruitment deviations.

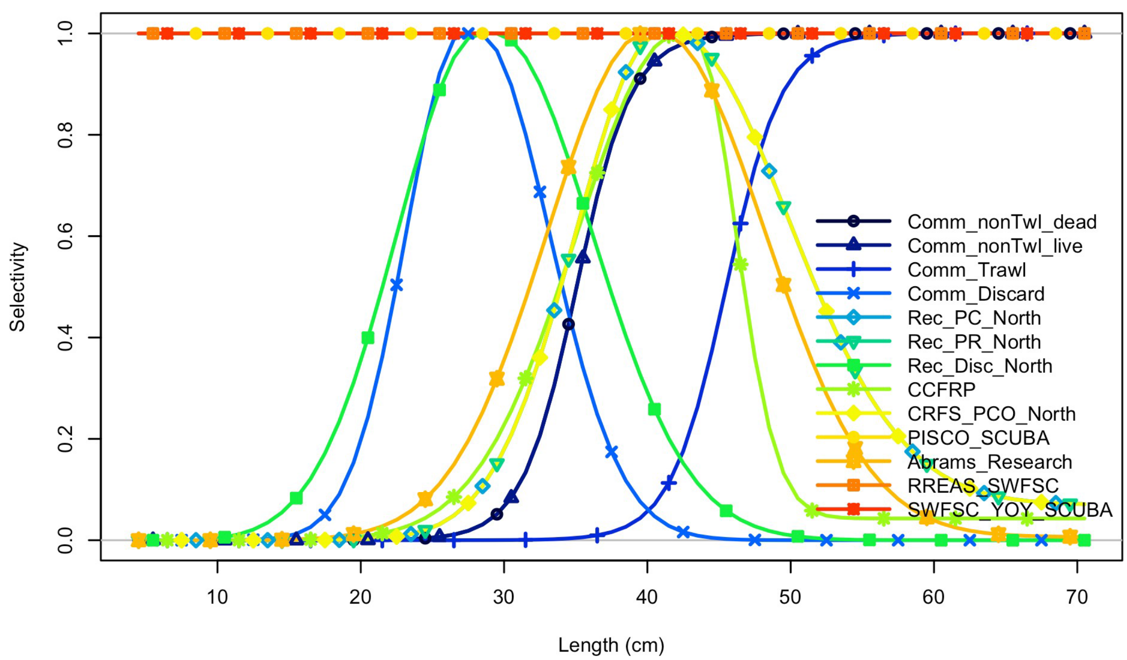


Figure 105: Length-based selectivity curves from the STAR panel request 5 (northern model), with “mirrored” (equivalent) functional forms for the commercial non-trawl dead (Comm_nonTwl_dead) and live fisheries (Comm_nonTwl_live).

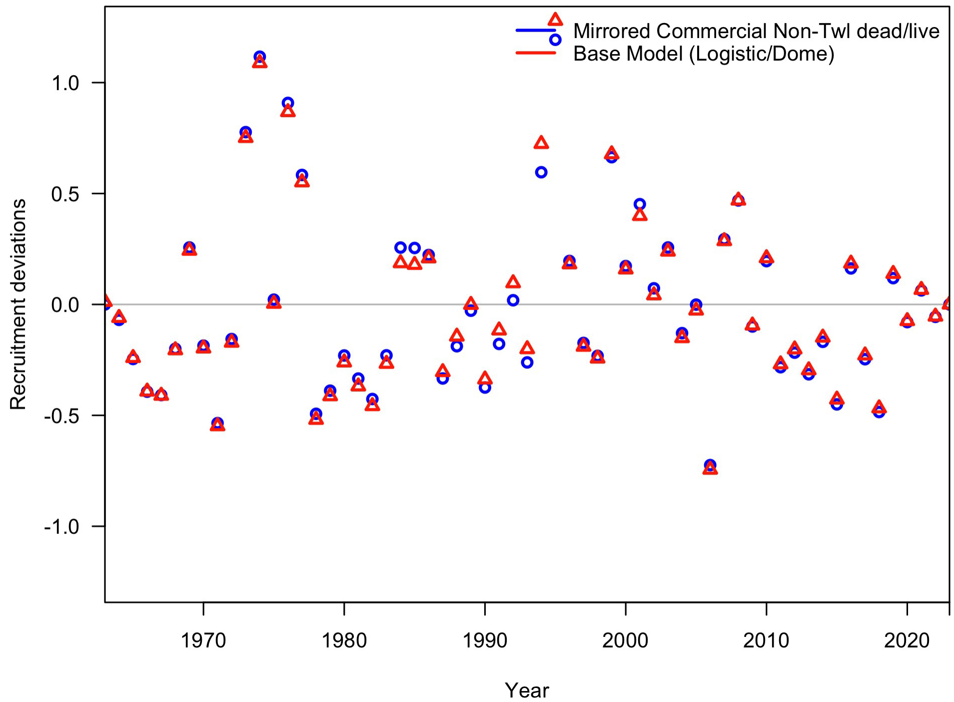


Figure 106: Changes in estimated recruitment deviations resulting from "mirrored" (equivalent) functional forms for the commercial non-trawl dead (Comm_nonTwl_dead) and live fisheries (Comm_nonTwl_live).

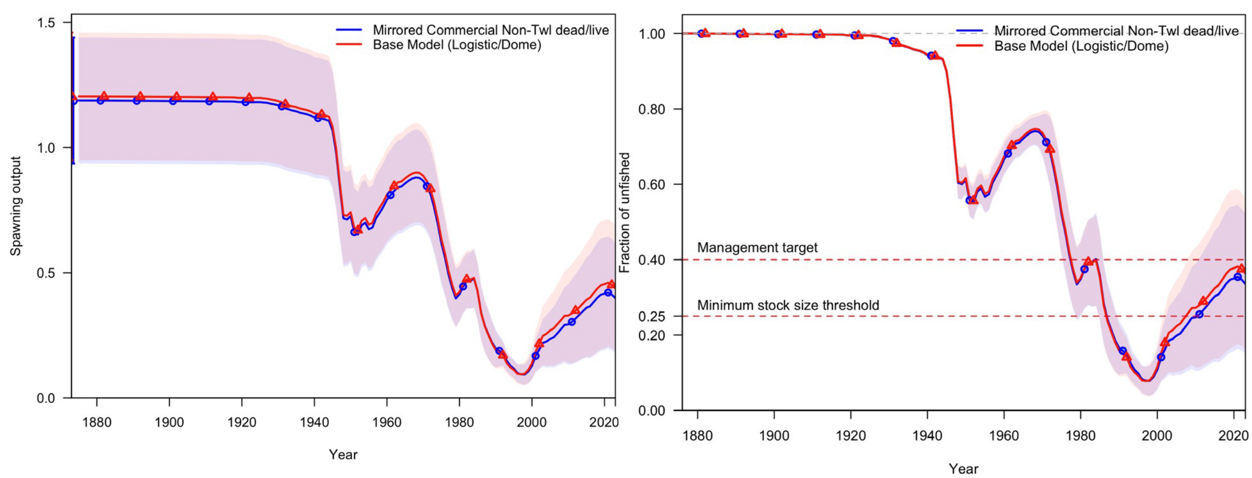


Figure 107: Comparison of time series of spawning output (billions of eggs) and relative spawning output from the pre-STAR northern base model and a revised model with mirrored selectivity for the live and dead non-trawl fleets.

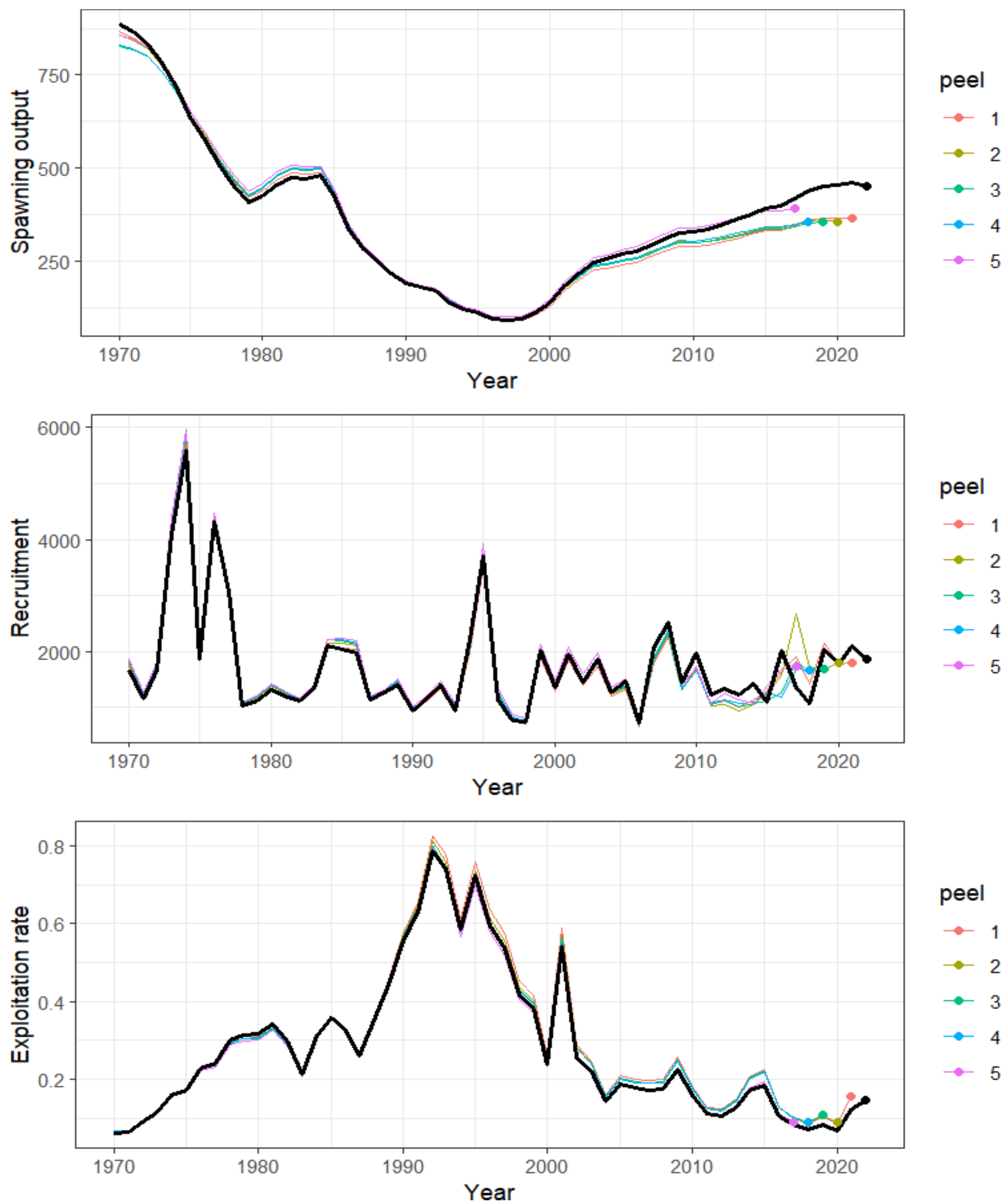


Figure 108: Time series of spawning output (billions of eggs; top panel), recruitment (1000s of age-0 fish; middle panel), and exploitation rate (catch divided by age 8+ biomass; bottom panel) for retrospective runs removing 1-5 years of data from the northern California black rockfish model. Black line shows results from the pre-STAR base model, for reference.

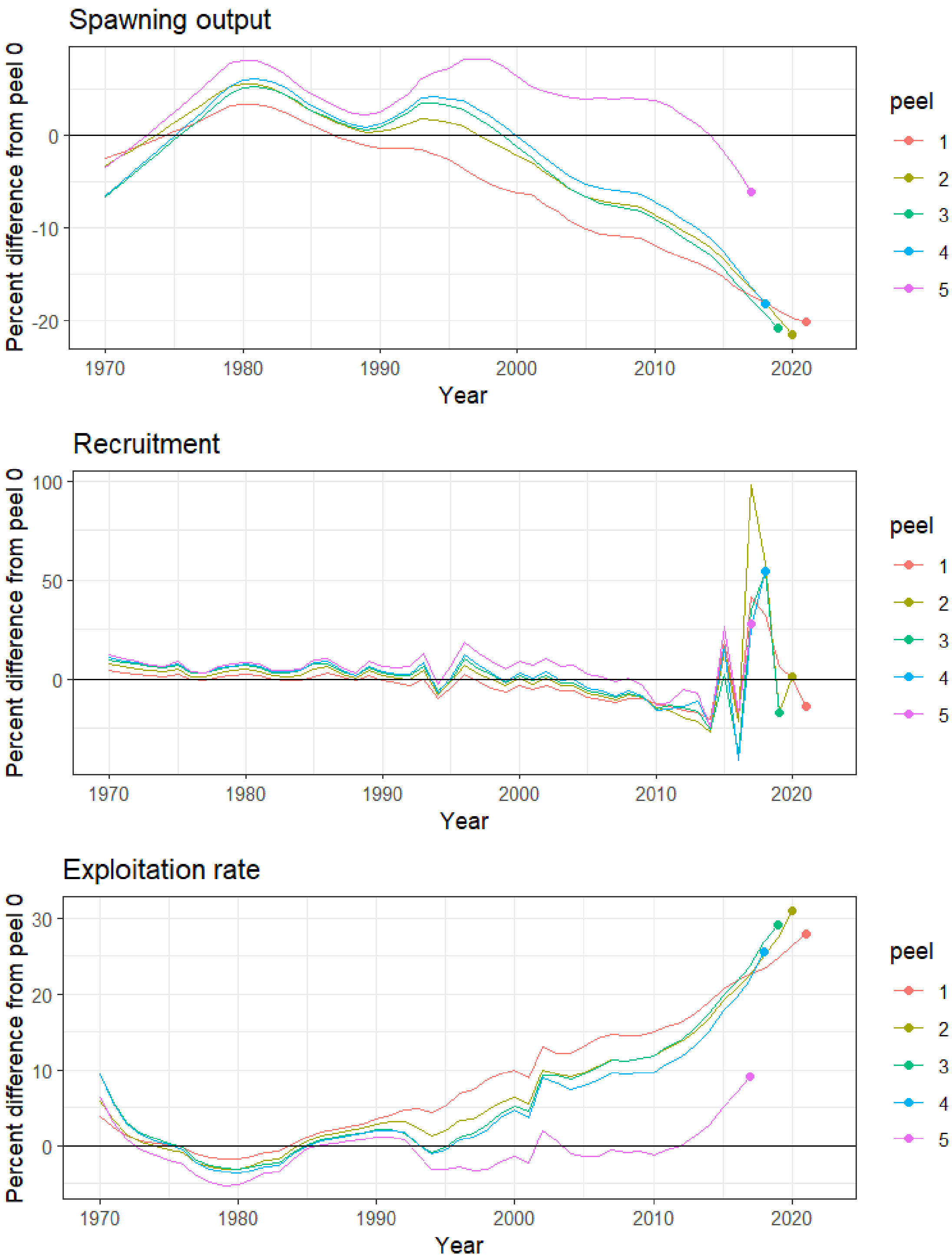


Figure 109: Time series of change in spawning output (billions of eggs; top panel), recruitment (1000s of age-0 fish; middle panel), and exploitation rate (catch divided by age 8+ biomass; bottom panel) for retrospective runs removing 1-5 years of data, relative to the northern California pre-STAR black rockfish model.

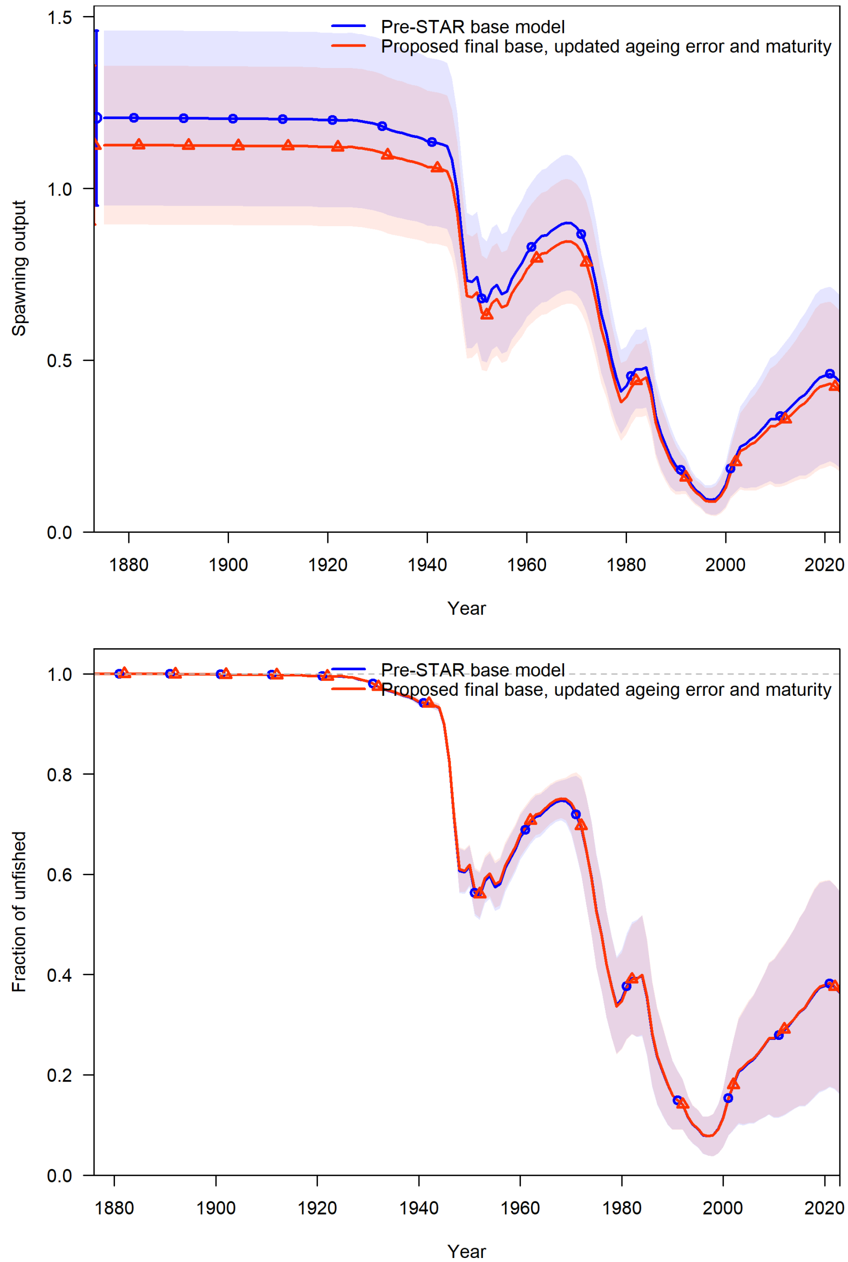


Figure 110: Comparison of the pre- and post-STAR base models' estimated time series of spawning output (billions of eggs; top panel) and relative spawning output (spawning output / unfished spawning output; bottom panel).

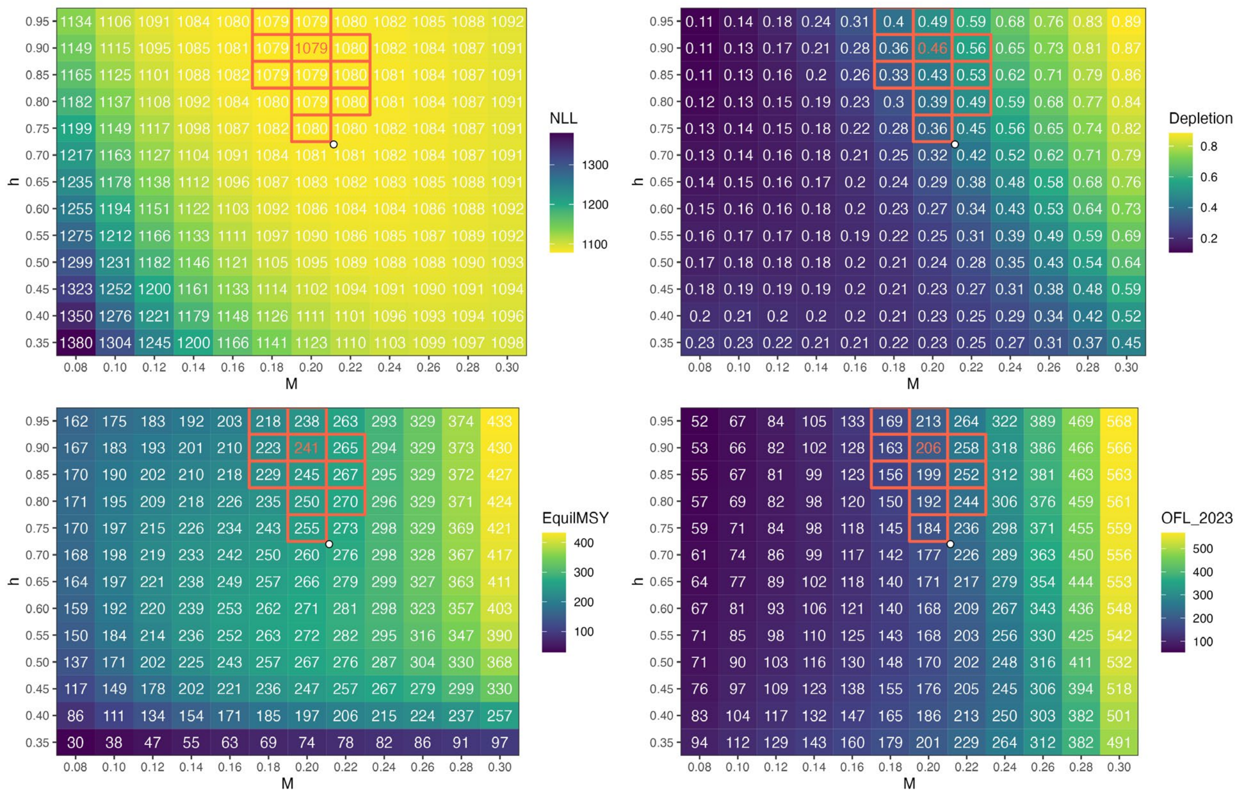


Figure 111: Bivariate profile over steepness and female natural mortality, plotting NLL, Depletion, Equilibrium proxy MSY, and OFL in 2023. The white point is the base model. Numbers in red are values at the NLL minimum. Parameter combinations outlined in red are within the bivariate 75% chi-squared interval of the NLL minimum. Numbers within the plots are rounded for readability. Steepness values of 0.25 and 0.30 were not consistent with the SPR50% proxy harvest rate (equilibrium MSY = 0), and were removed from the figure.

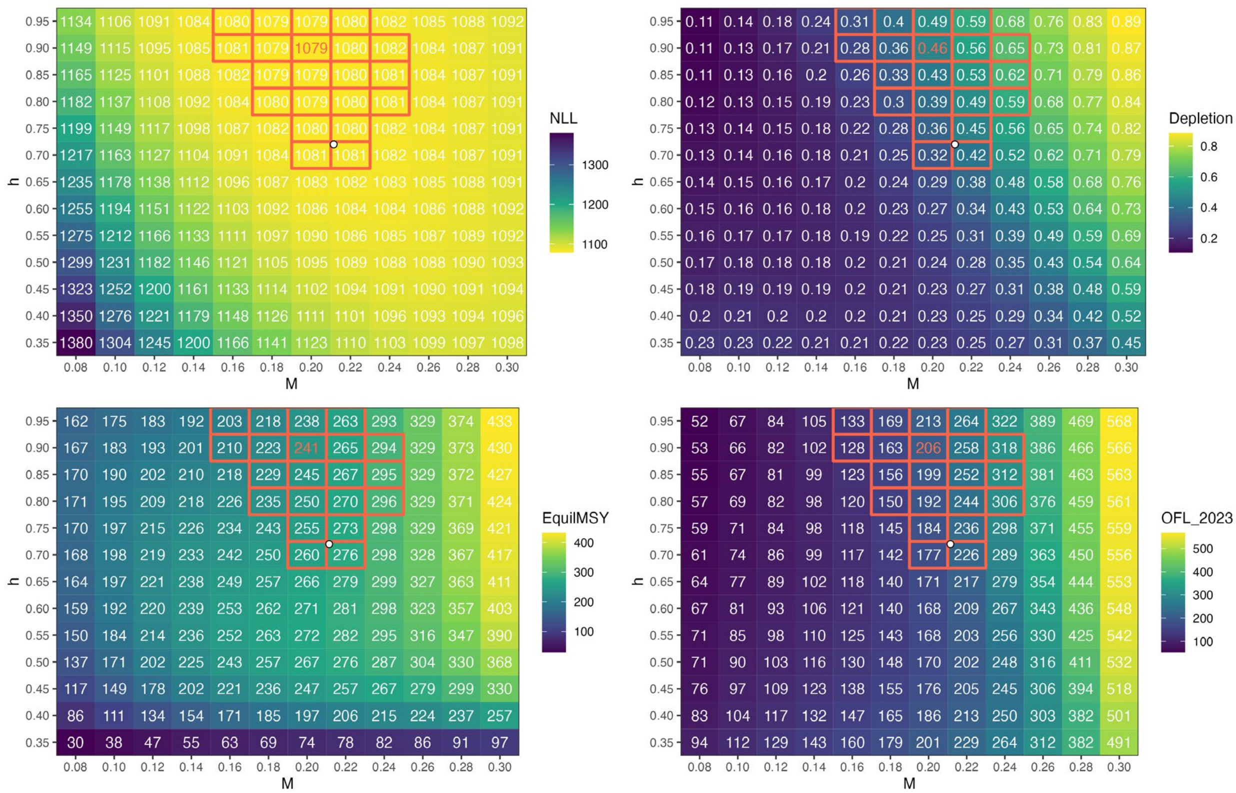


Figure 112: Bivariate profile over steepness and female natural mortality, plotting NLL, Depletion, Equilibrium MSY, and OFL. The white point is the base model. Parameter combinations outlined in red are within the bivariate 95% chi-squared interval of the NLL minimum. Steepness values of 0.25 and 0.30 were not consistent with the SPR50% proxy harvest rate (equilibrium MSY = 0), and were removed from the figure.

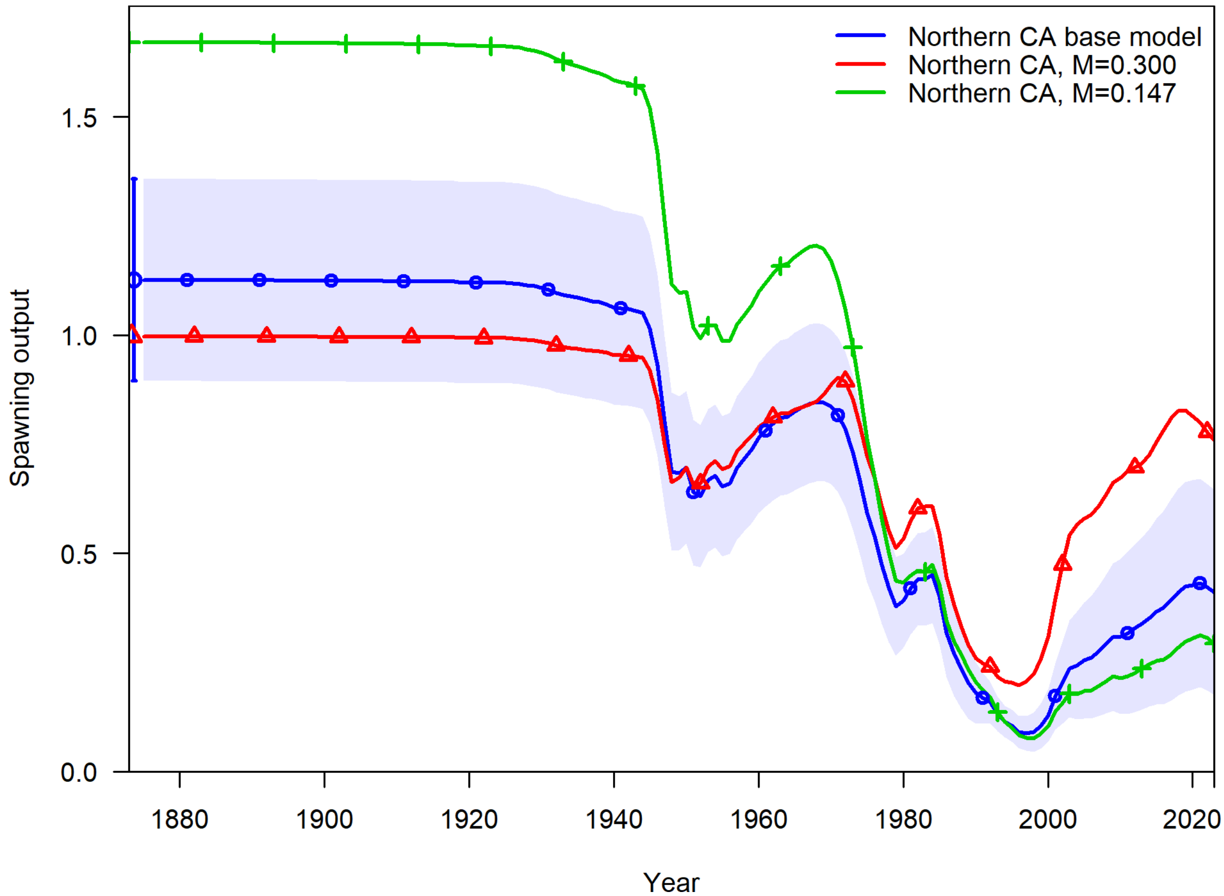


Figure 113: Comparison of spawning output time series (billions of eggs) for alternative states of nature described under request 11.

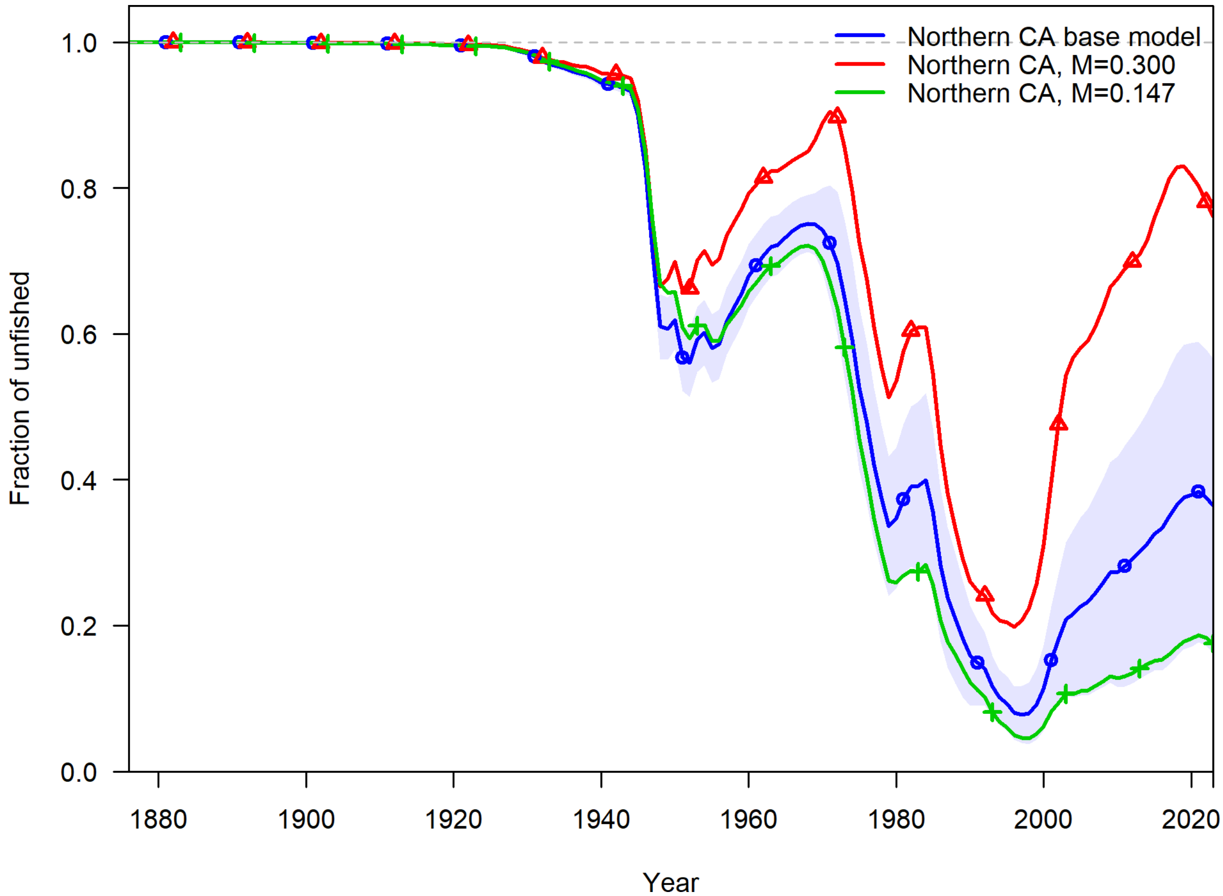


Figure 114: Comparison of relative spawning output time series (scaled relative to unfished spawning output) for alternative states of nature described under request 11.

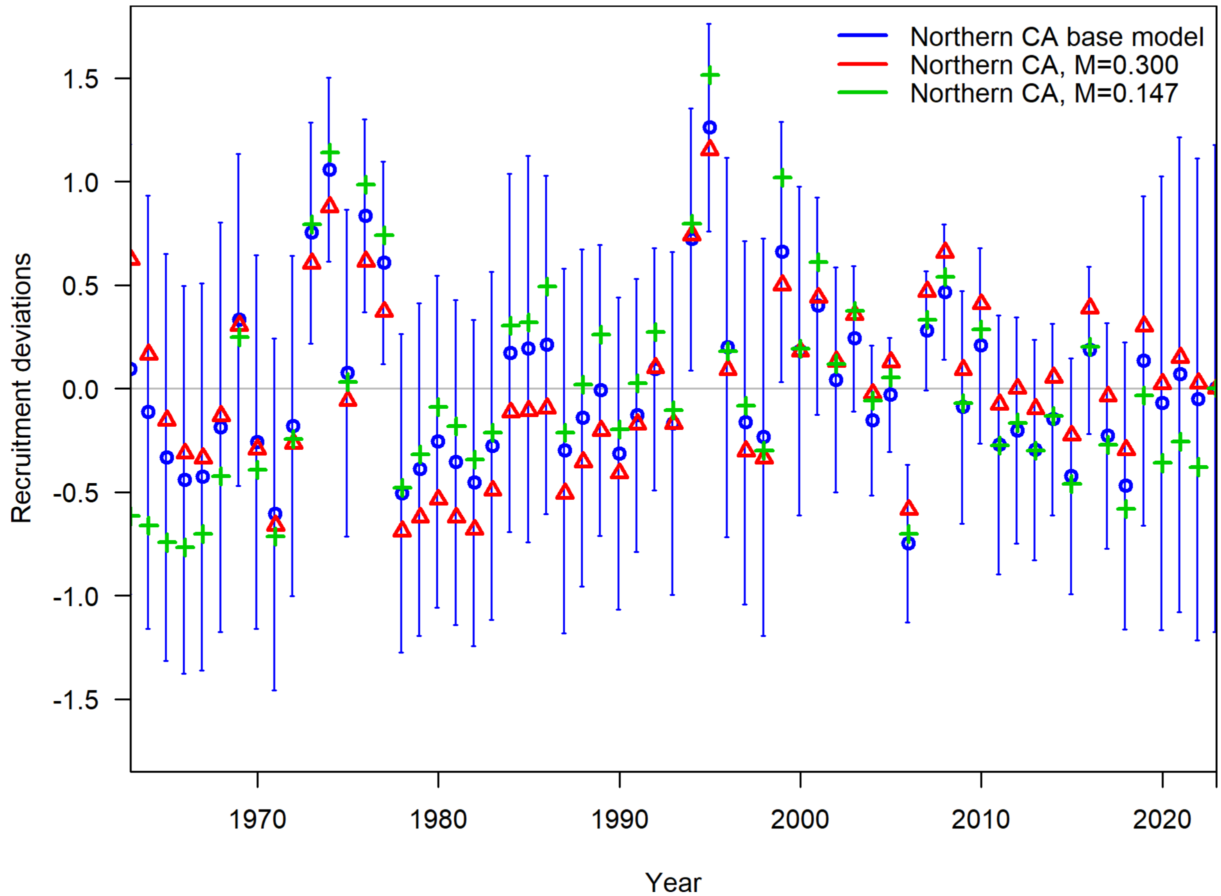


Figure 115: Comparison of recruitment deviations over time for alternative states of nature described under request 11.

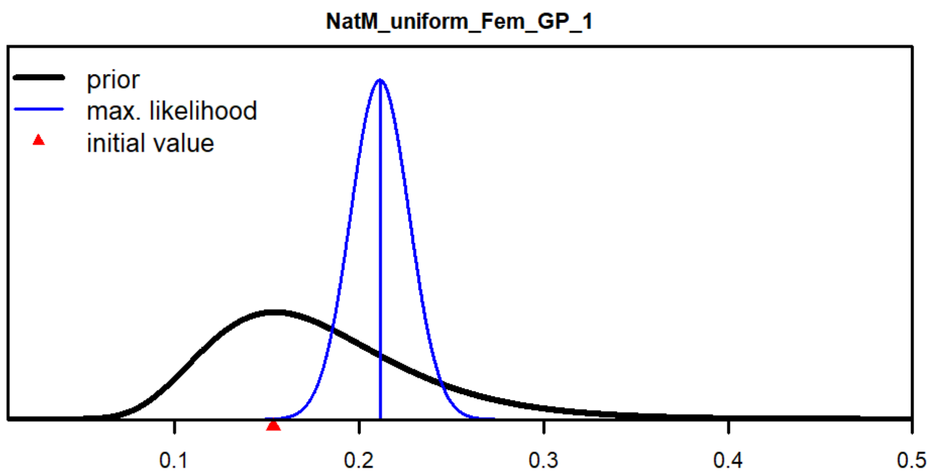


Figure 116: Female natural mortality prior distribution (black) and estimated value (0.21; blue, with assumed normal distribution based on estimated asymptotic standard error) from the northern California base model. Male natural mortality was estimated at 0.20.

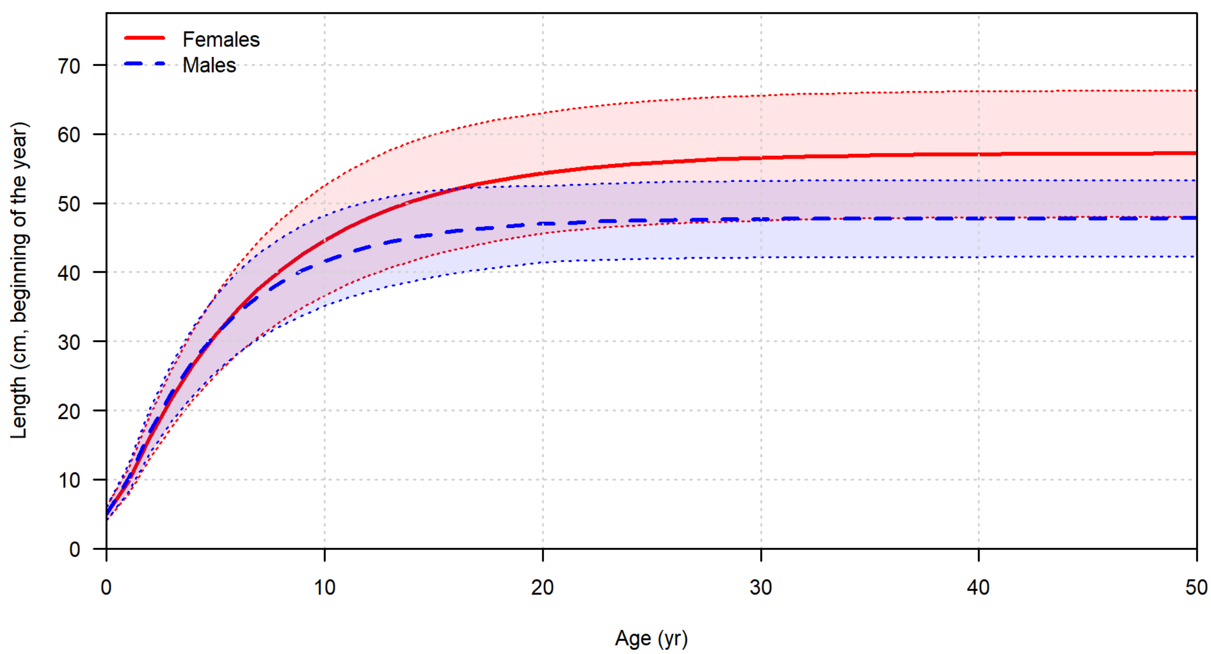


Figure 117: Length at age estimated by the northern base model. Shaded area indicates 95% distribution of length at age around the estimated growth curve.

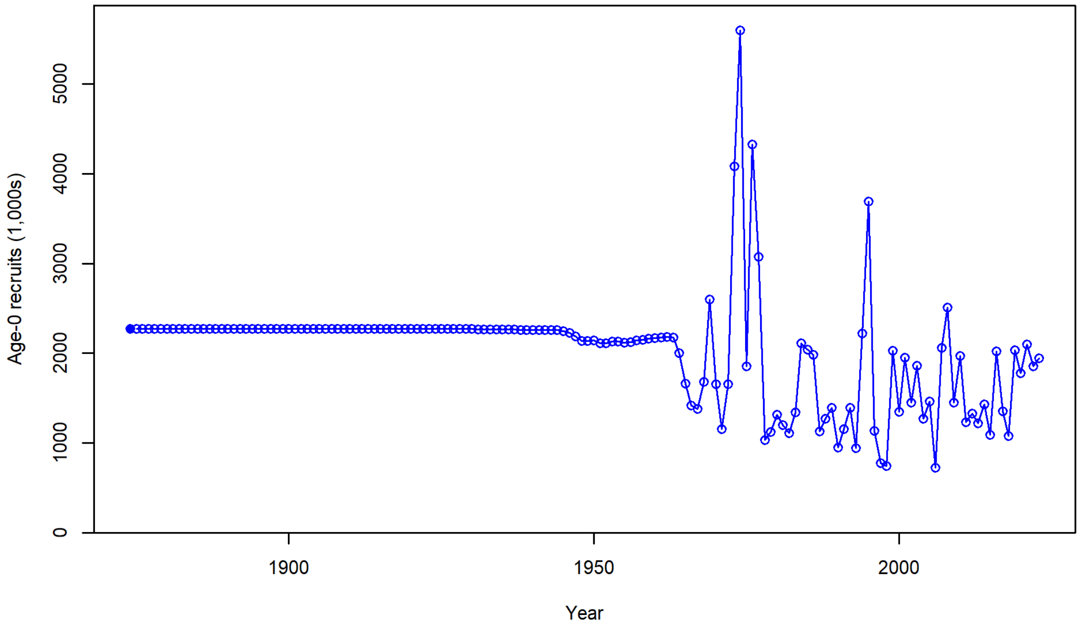


Figure 118: Number of age-0 recruits (1000s) in the northern base model.

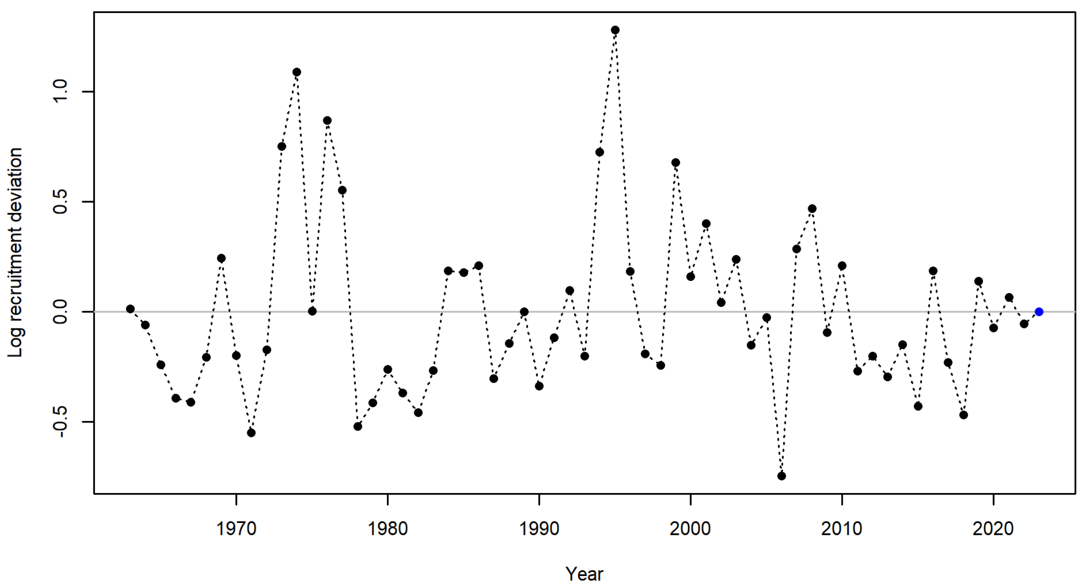


Figure 119: Estimated log-scale recruitment deviations in the northern base model.

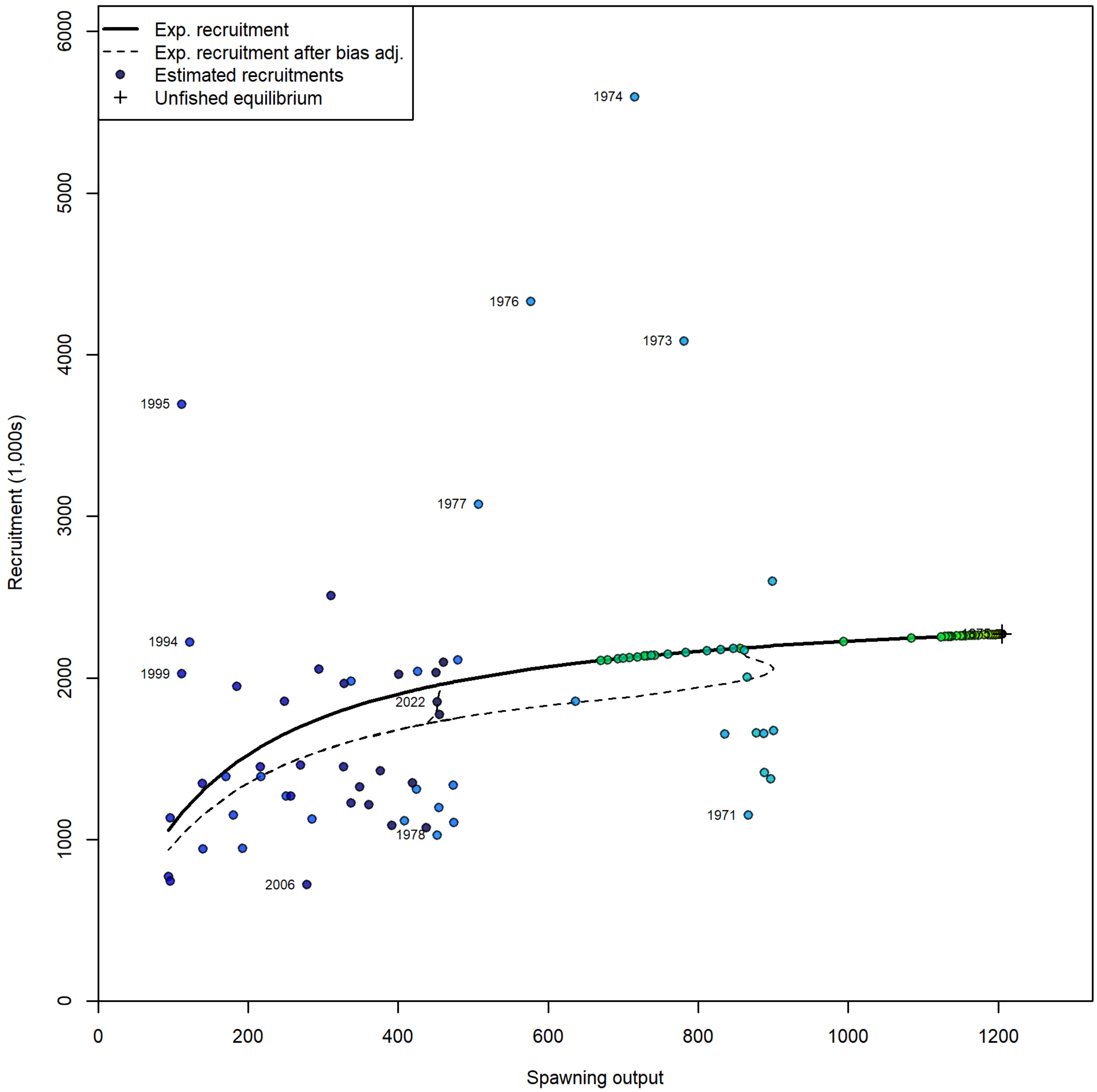


Figure 120: Stock-recruit curve for the northern base model with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years. Steepness was fixed at the prior mean of 0.72.

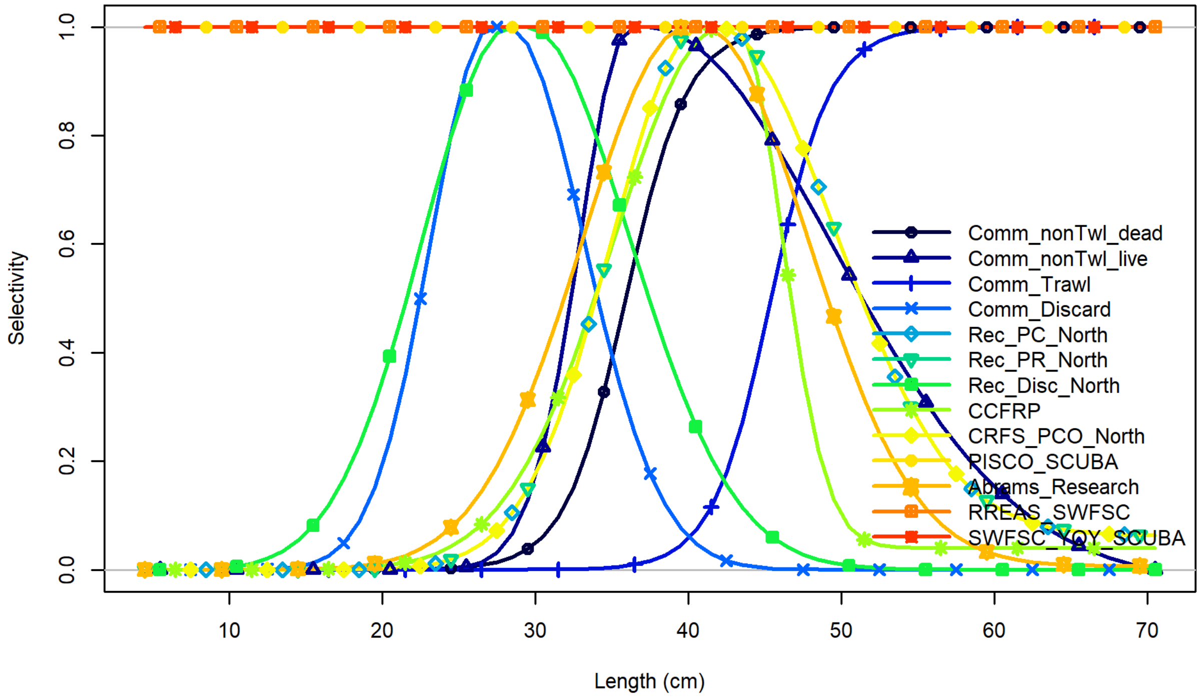


Figure 121: Length-based selectivity curves estimated for the northern California model. Fleets retained in the model file for implied fits, but not included in the likelihood: PISCO SCUBA, RREAS SWFSC, and SWFSC YOY SCUBA.

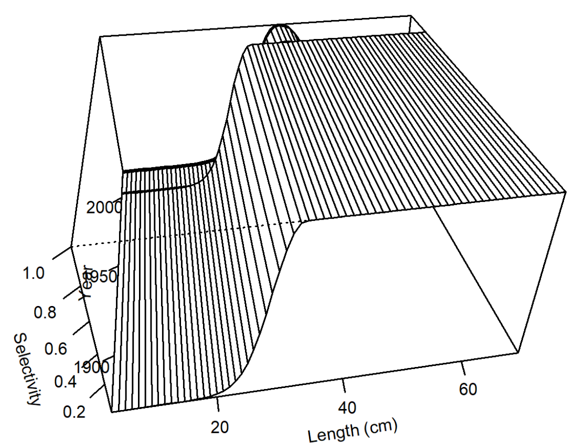


Figure 122: Time-varying selectivity for the recreational PC and PR modes, reflecting a change in depth restrictions from 2004-present that constrained fishing to shallow waters.

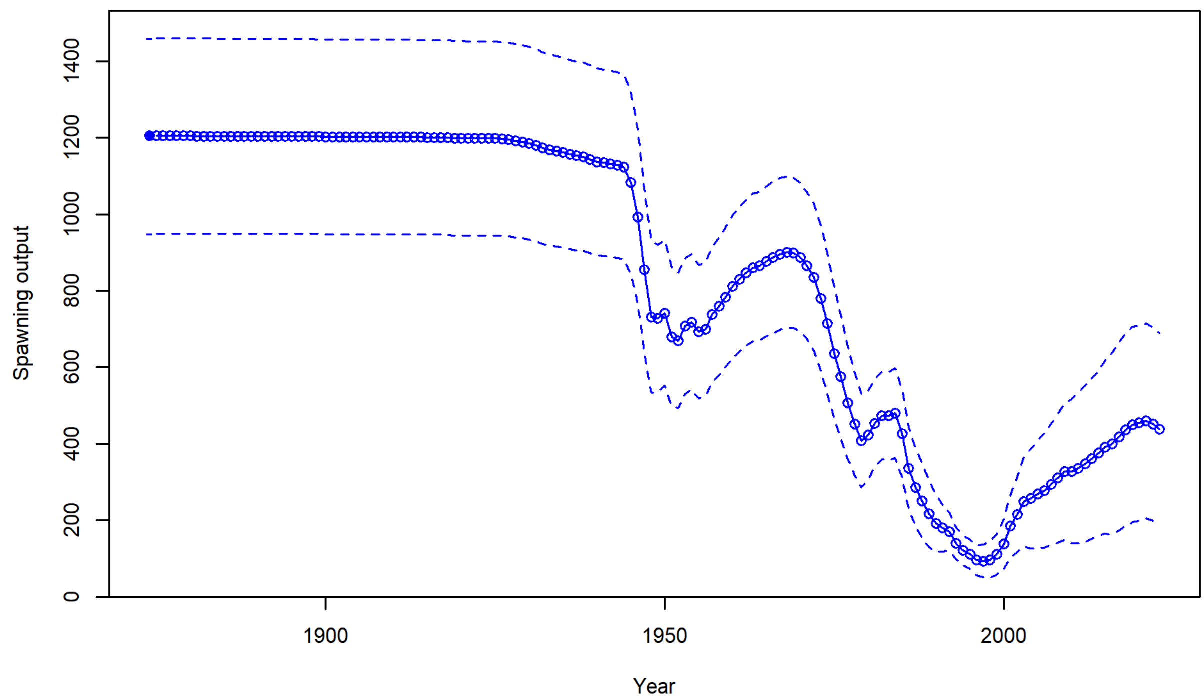


Figure 123: Northern California spawning output (billions of eggs) with ~95% asymptotic intervals.

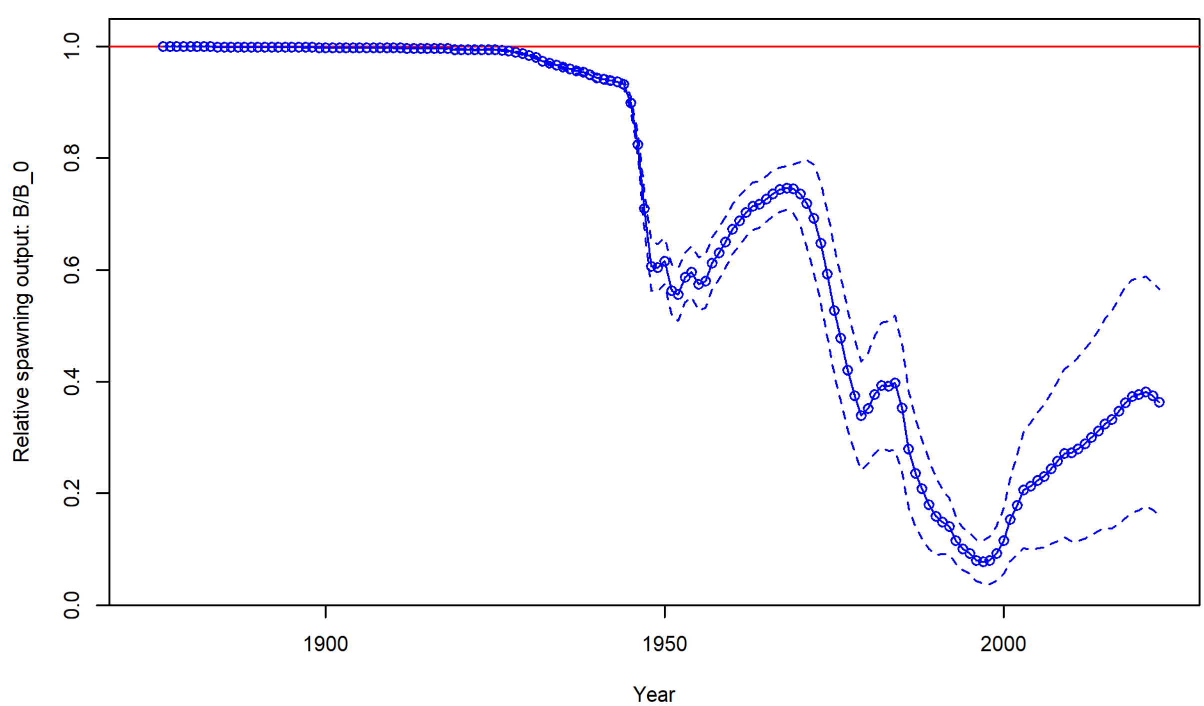


Figure 124: Relative spawning output in northern California: B/B_0 with ~95% asymptotic intervals

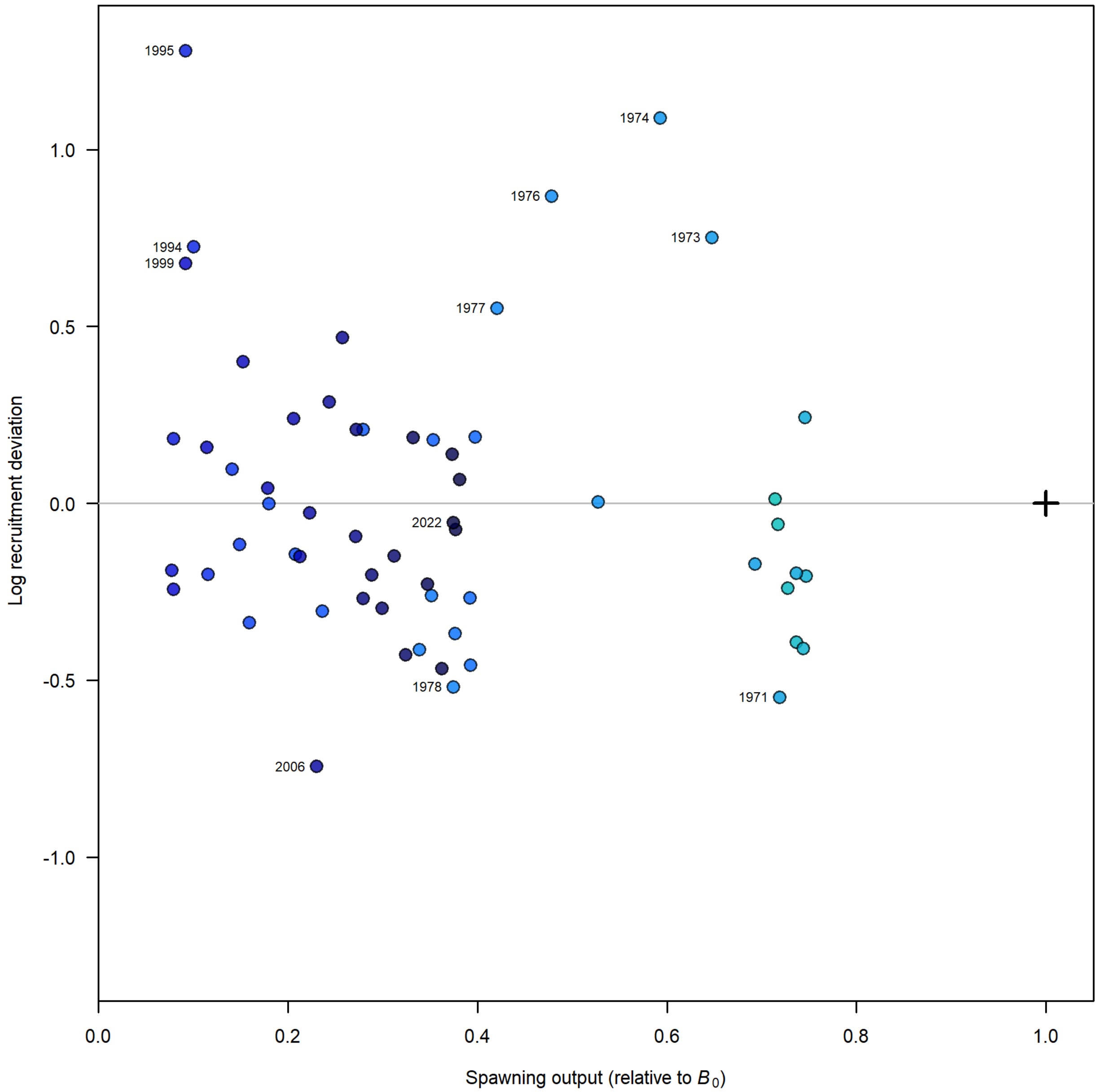


Figure 125: Deviations around the stock-recruit curve for the northern California model. Labels are on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

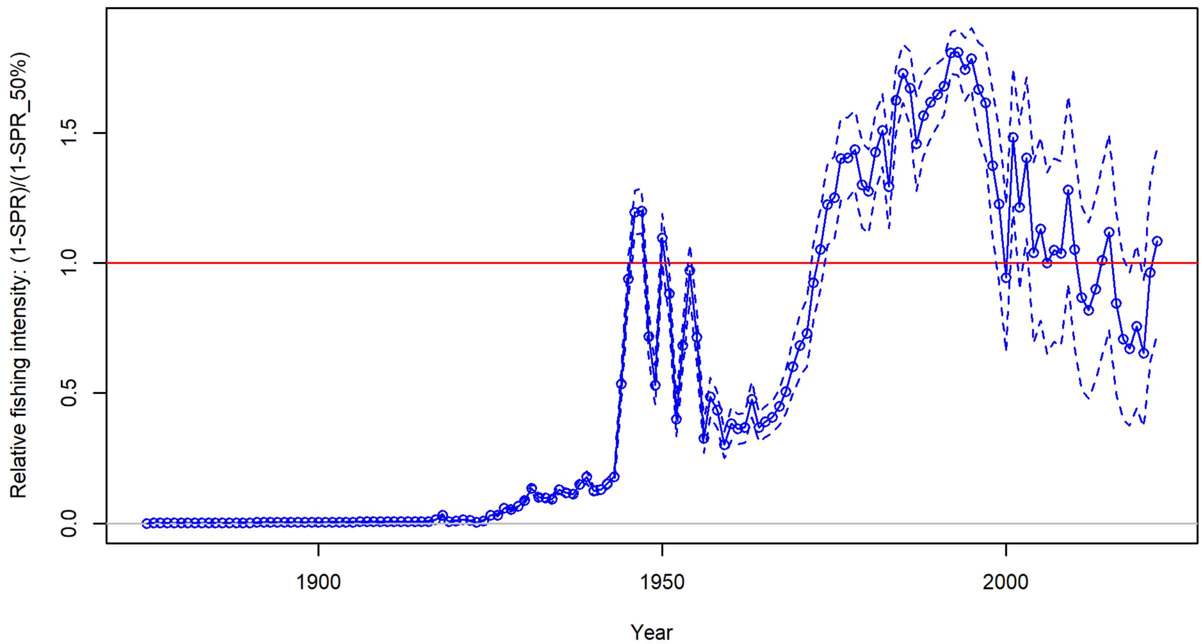


Figure 126: Equilibrium estimates of relative fishing intensity, (1-SPR) / (1-SPR50%) for the northern California base model.

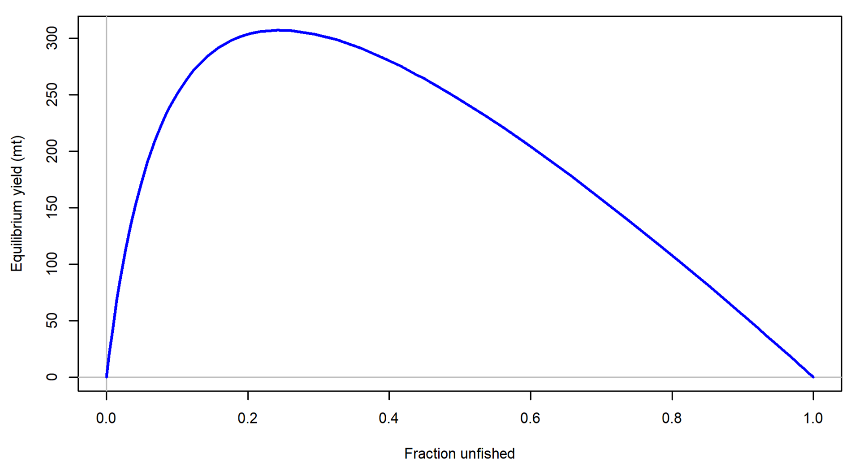


Figure 127: Yield curve for the northern California base model.

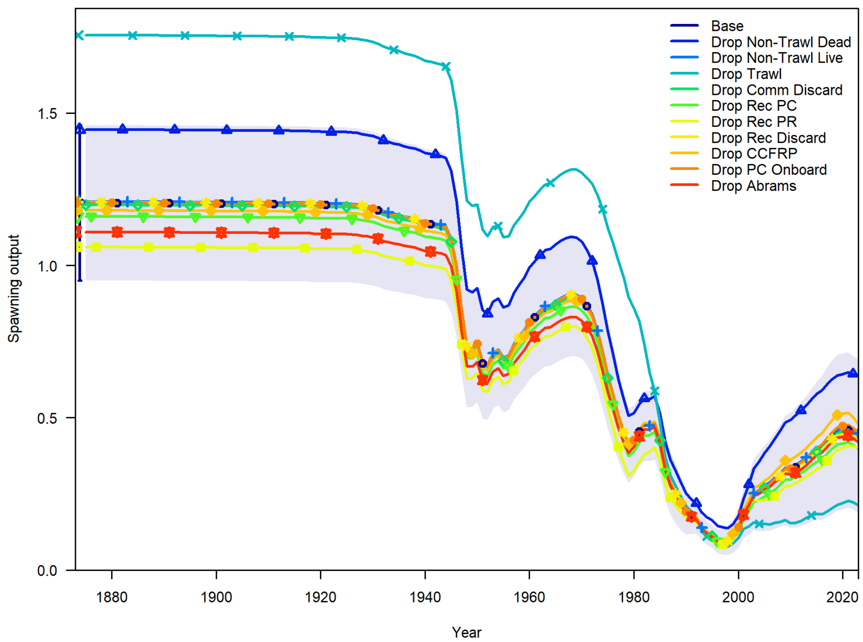


Figure 128: Changes in spawning output (billions of eggs) resulting from removal of individual fleets' data sources in the northern California model.

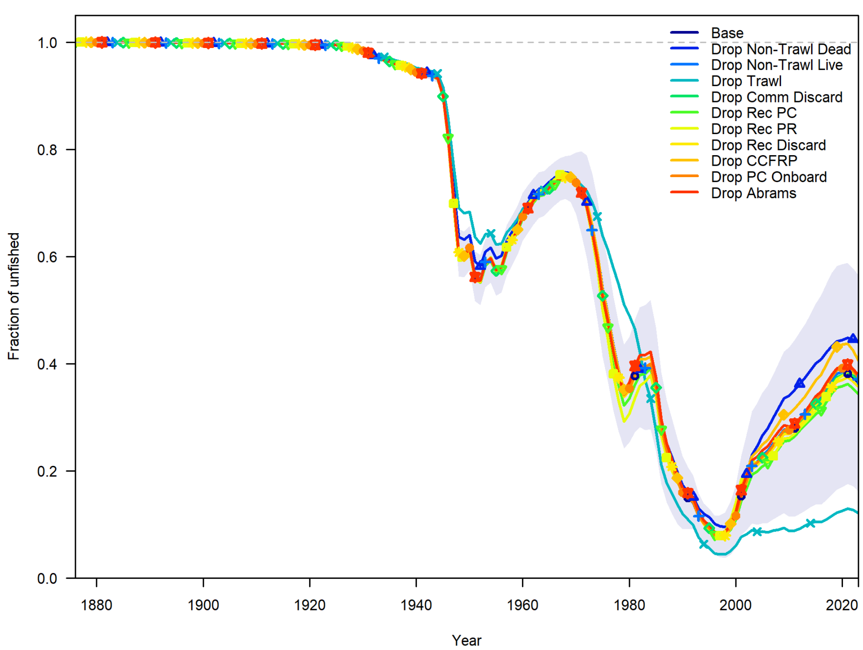


Figure 129: Changes in relative spawning output (B / B_unfished) resulting from removal of individual fleets' data sources in the northern California model.

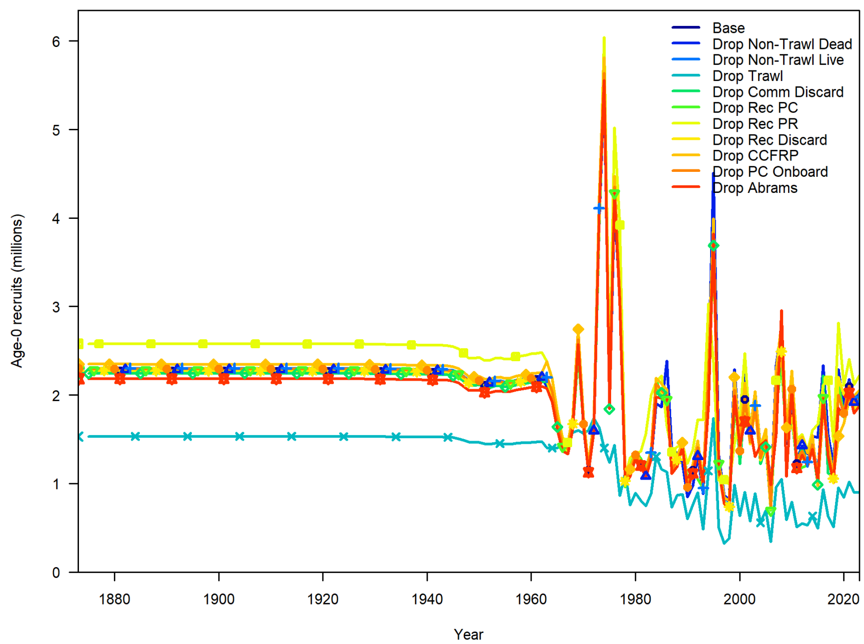


Figure 130: Changes in estimated recruitment of age-zero fish resulting from removal of individual fleets' data sources in the northern California model.

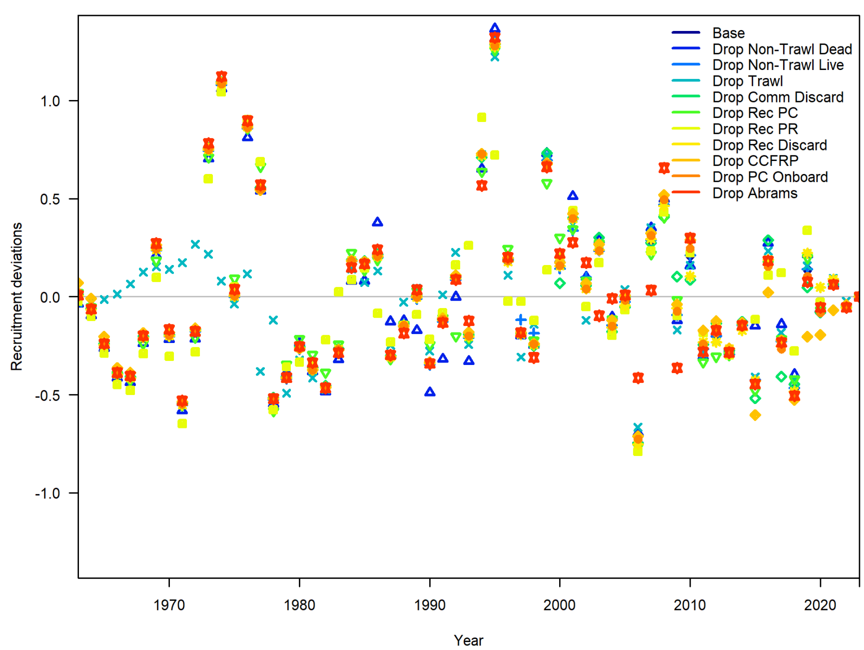


Figure 131: Changes in estimated log-scale recruitment deviations resulting from removal of individual fleets' data sources in the northern California model.

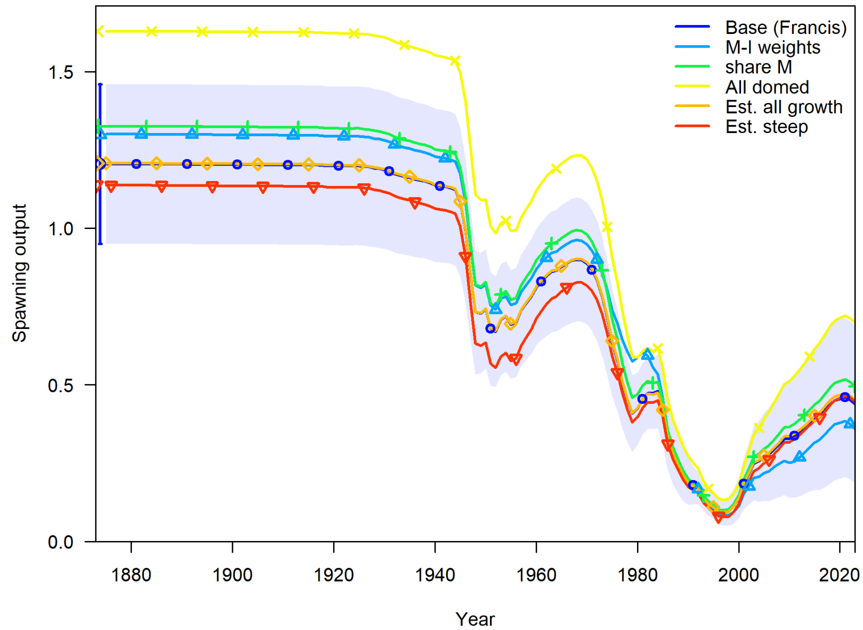


Figure 132: Trends in spawning output (billions of eggs) associated with sensitivity analyses for the northern California base model.

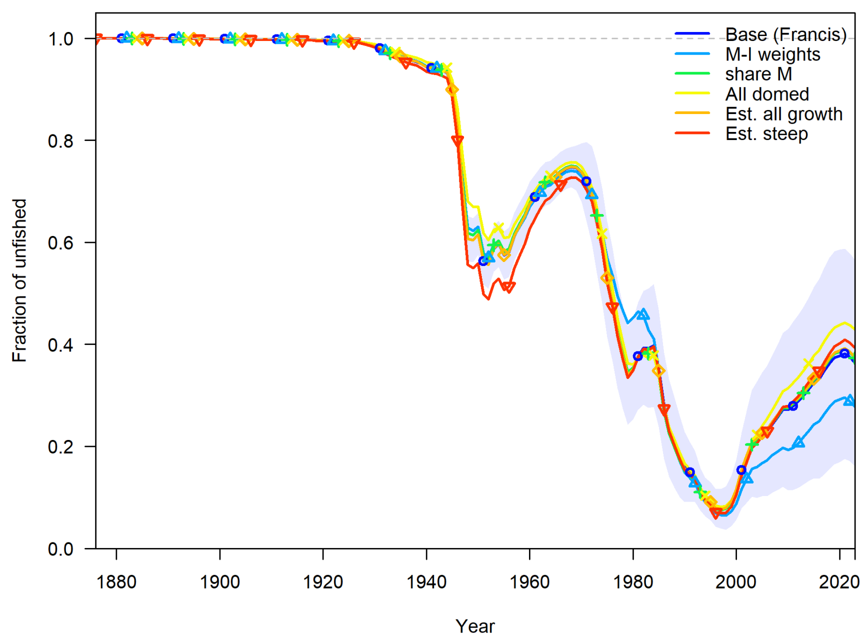


Figure 133: Trends in relative spawning output (B / B_unfished) associated with sensitivity analyses for the northern California base model.

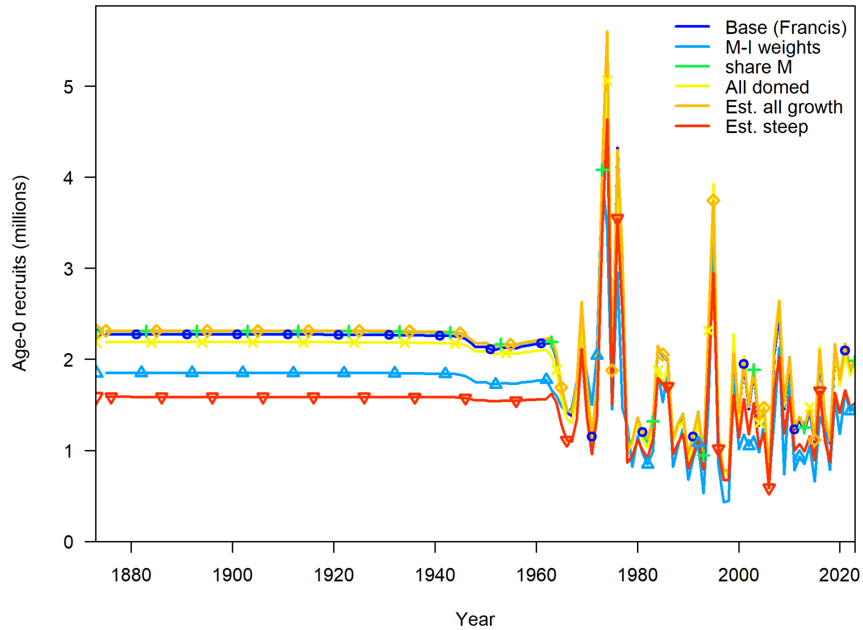


Figure 134: Trends in recruitment of age-0 fish (1000s) associated with sensitivity analyses for the northern California base model.

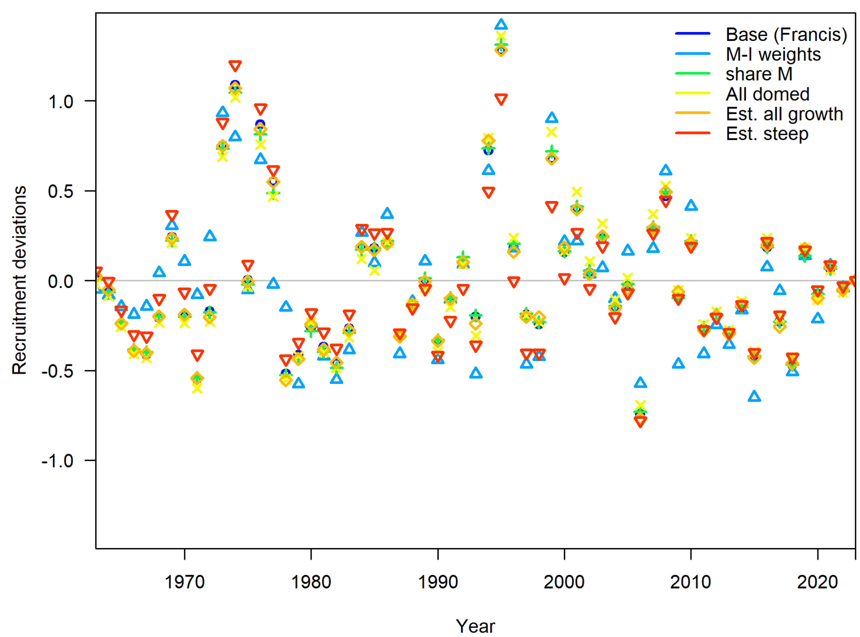


Figure 135: Trends in log-scale deviations from the stock-recruitment relationship associated with sensitivity analyses for the northern California base model.

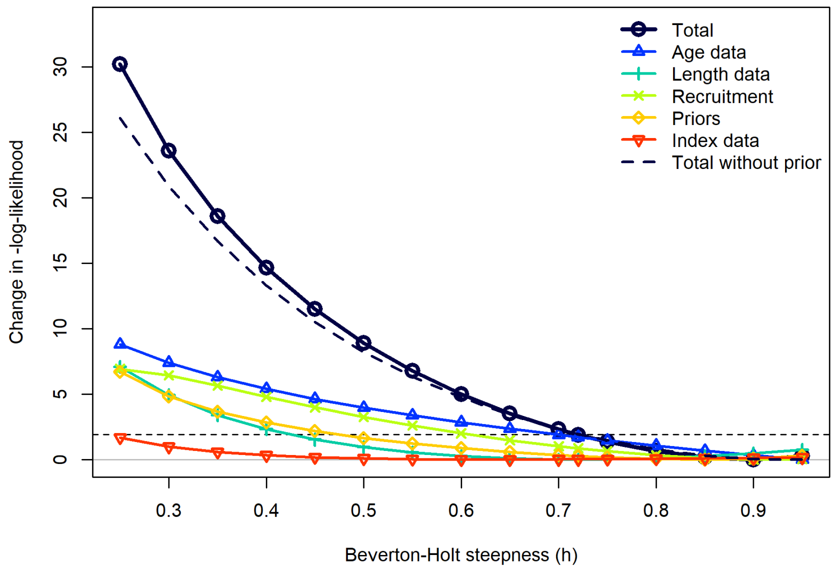


Figure 136: Likelihood profile over steepness for the northern California model, by data type.

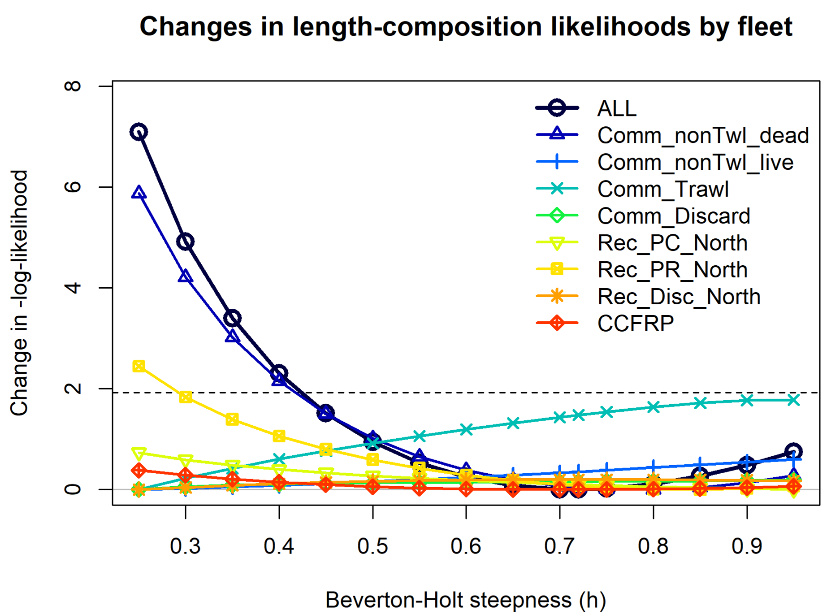


Figure 137: Likelihood profile over steepness for the northern California model, by length data source.

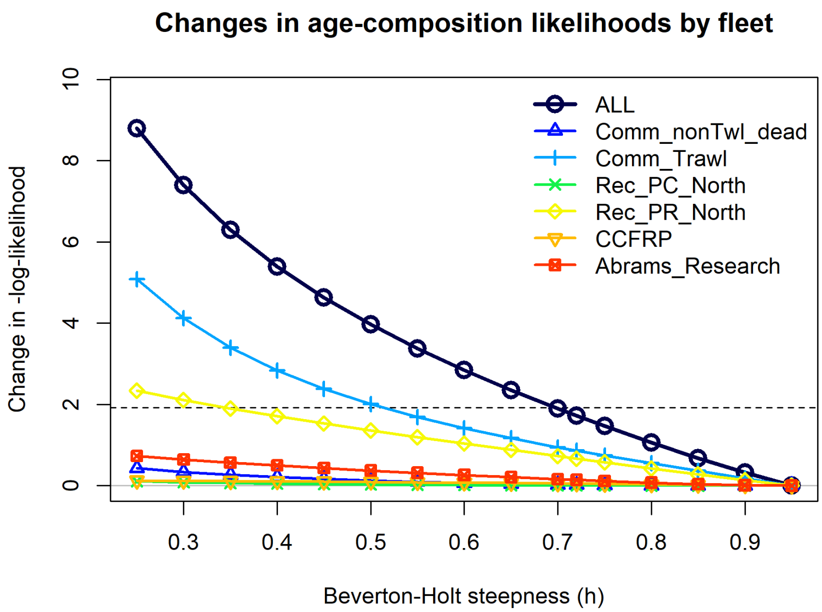


Figure 138: Likelihood profile over steepness for the northern California model, by age data source.

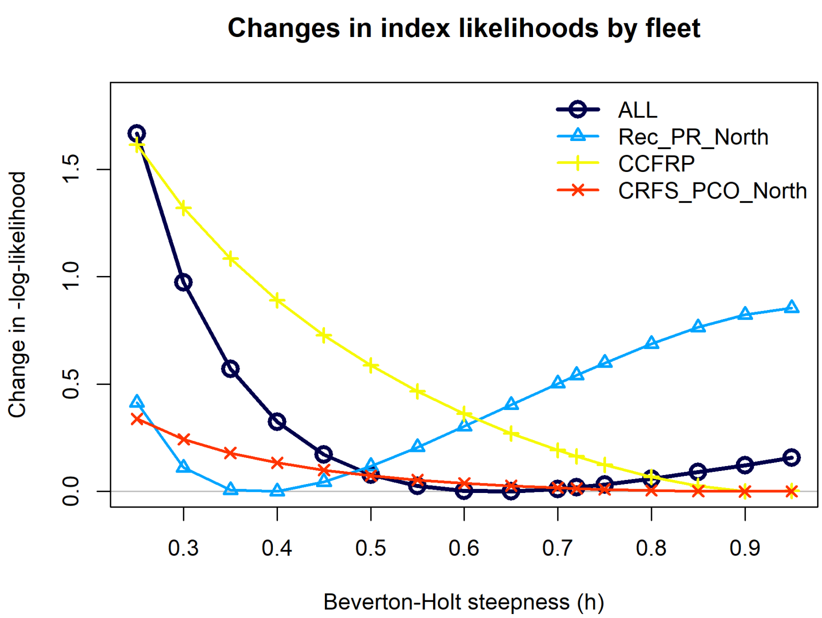


Figure 139: Likelihood profile over steepness for the northern California model, by index data source..

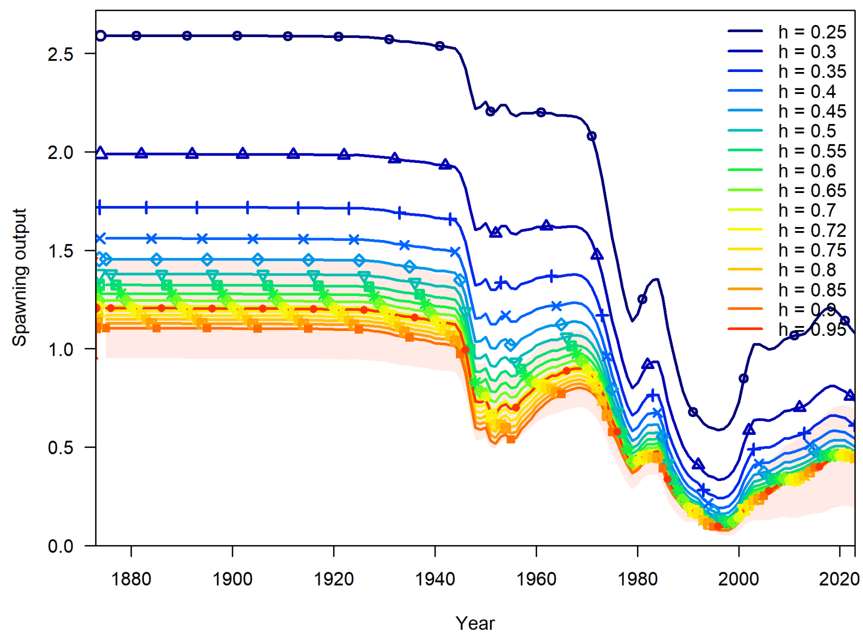


Figure 140: Spawning output time series from a steepness profile for the northern California base model (h=0.72).

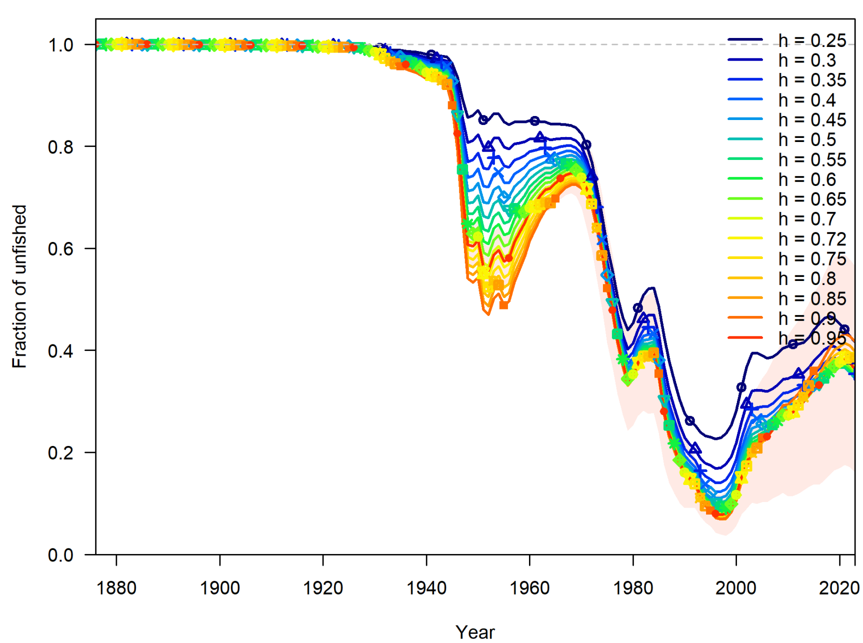


Figure 141: Relative spawning output time series from a steepness profile for the northern California base model (h=0.72).

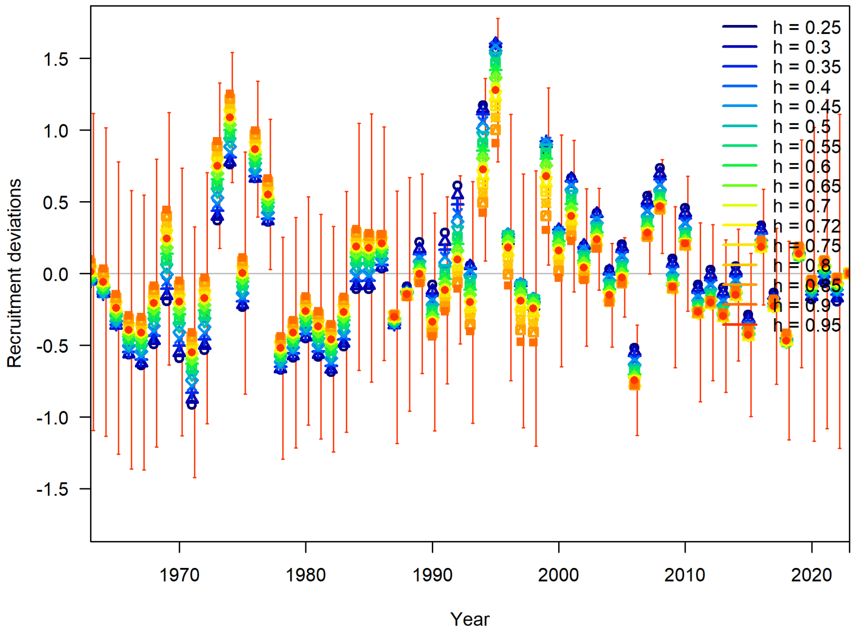


Figure 142: Log-scale recruitment deviations from a steepness profile for the northern California base model (h=0.72). Vertical bars are 95% asymptotic confidence intervals from the base model.

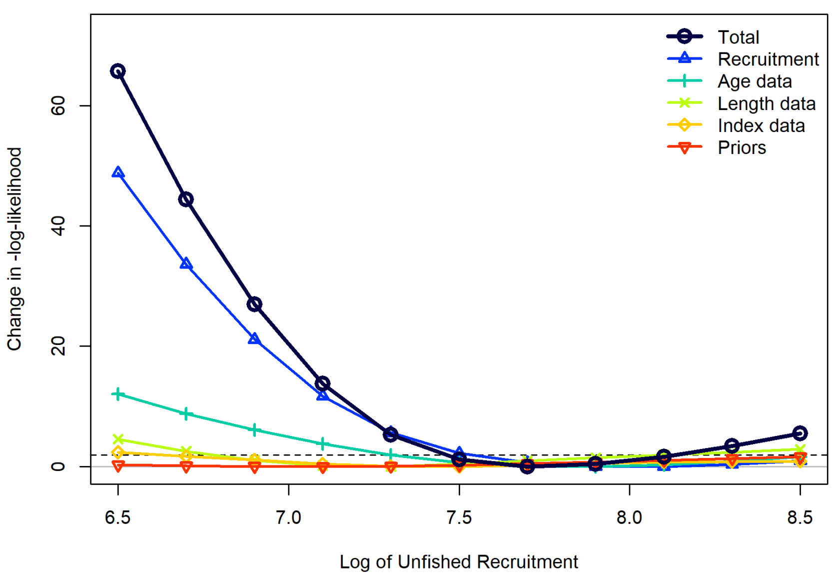


Figure 143: Likelihood profile over the log of unfished recruitment for the northern California model, by data type.

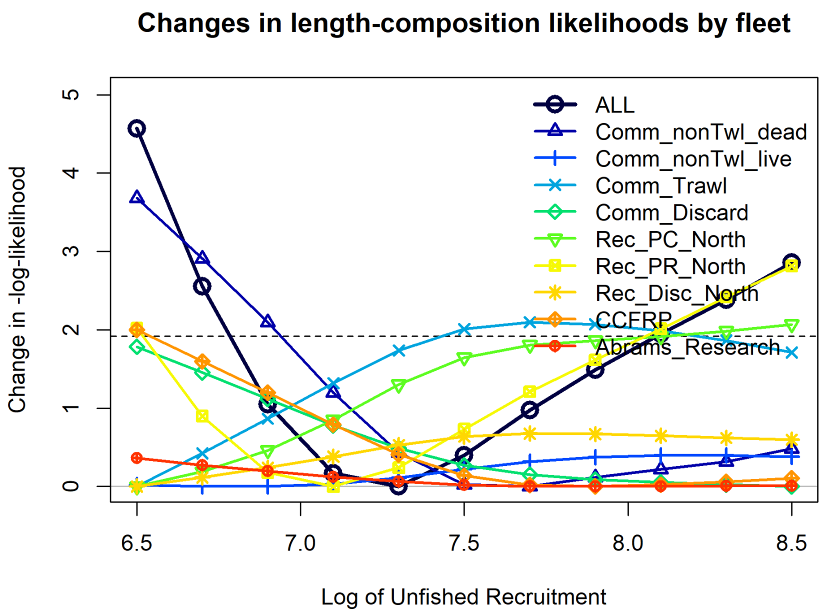


Figure 144: Likelihood profile over the log of unfished recruitment for the northern California model, by length data source.

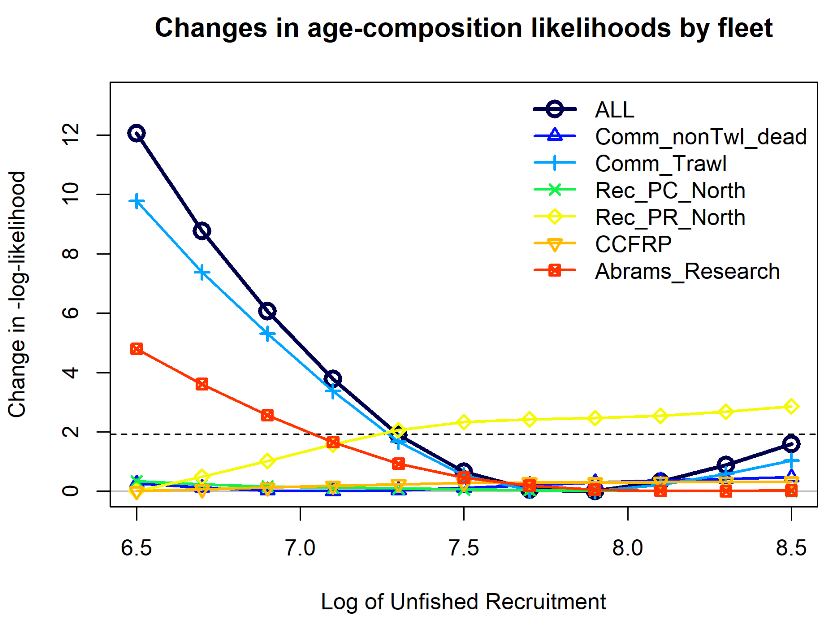


Figure 145: Likelihood profile over the log of unfished recruitment for the northern California model, by age data source.

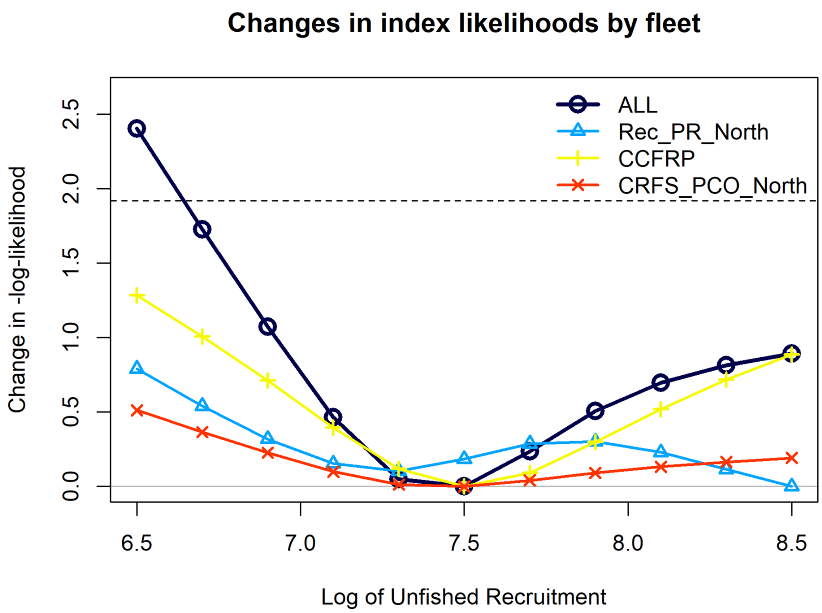


Figure 146: Likelihood profile over the log of unfished recruitment for the northern California model, by index data source.

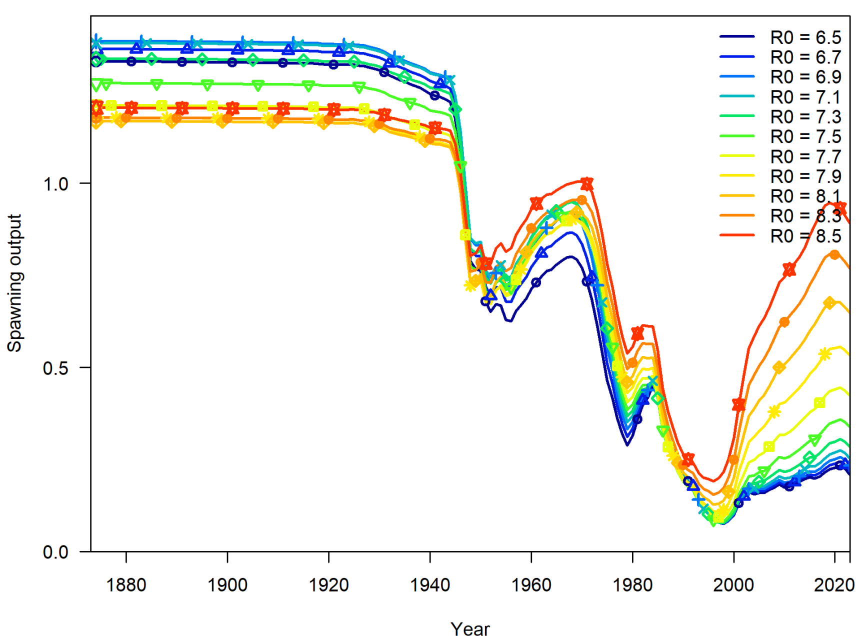


Figure 147: Spawning output time series from a log(R0) profile for the northern California base model.

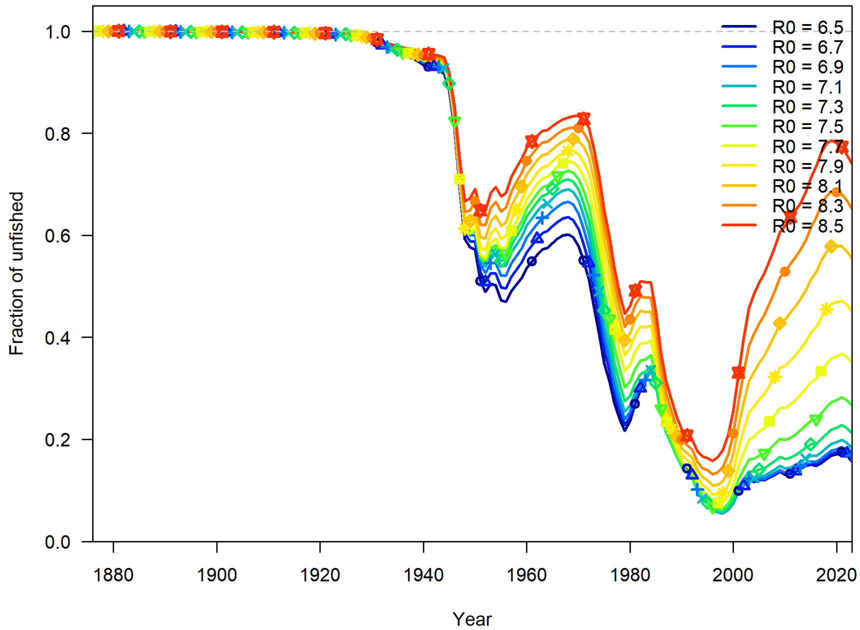


Figure 148: Relative spawning output time series from a log(R0) profile for the northern California base model.

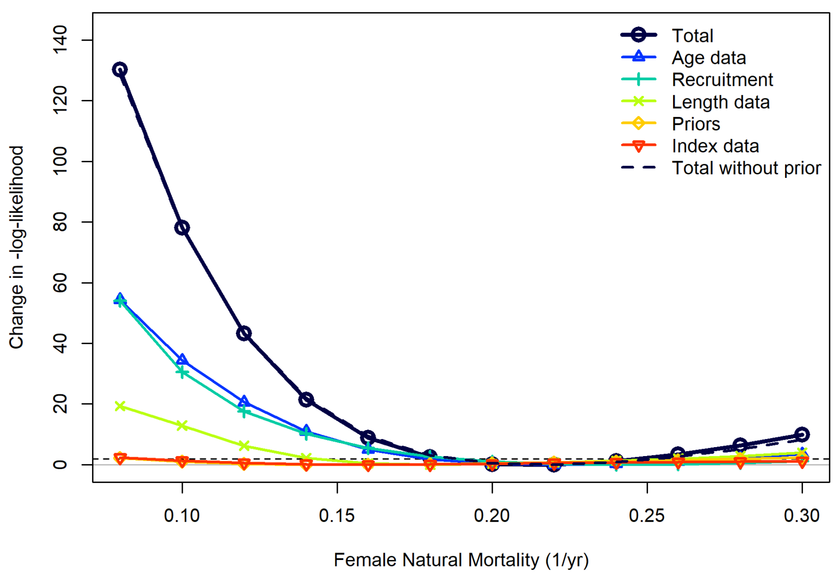


Figure 149: Likelihood profile over the female natural mortality rate for the northern California model, by data type.

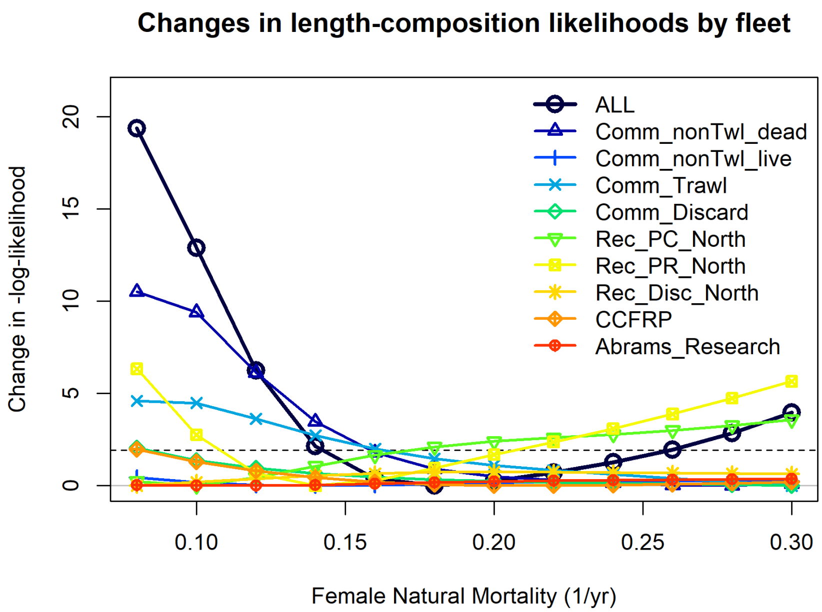


Figure 150: Likelihood profile over the female natural mortality rate for the northern California model, by length data source.

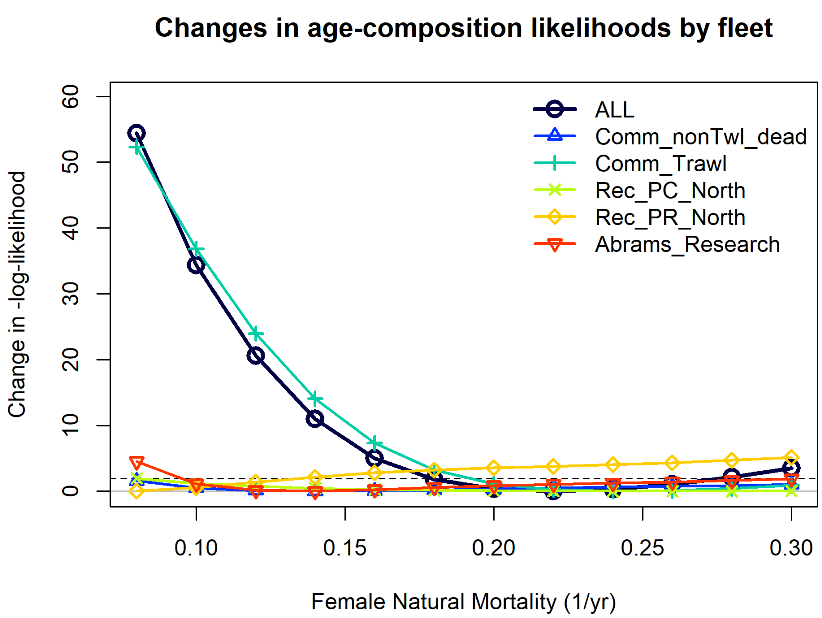


Figure 151: Likelihood profile over the female natural mortality rate for the northern California model, by age data source.

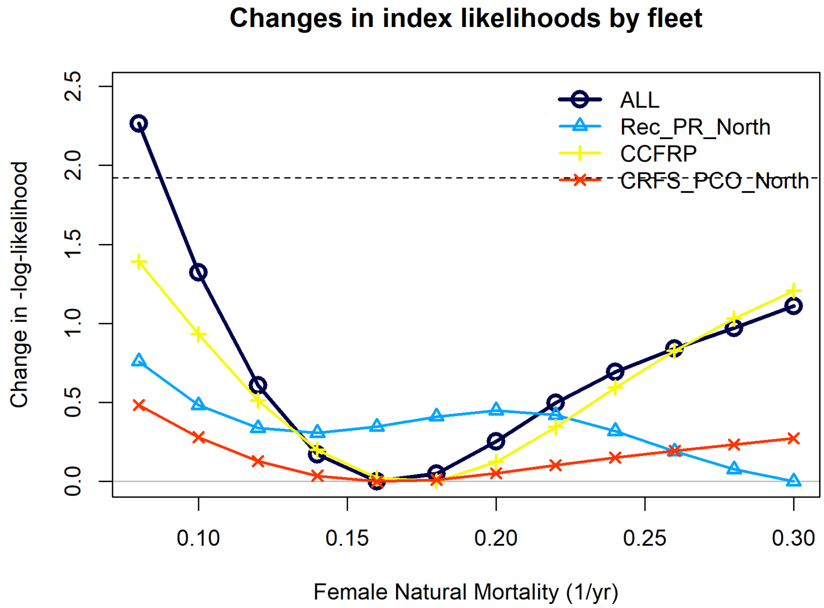


Figure 152: Likelihood profile over the female natural mortality rate for the northern California model, by index data source.

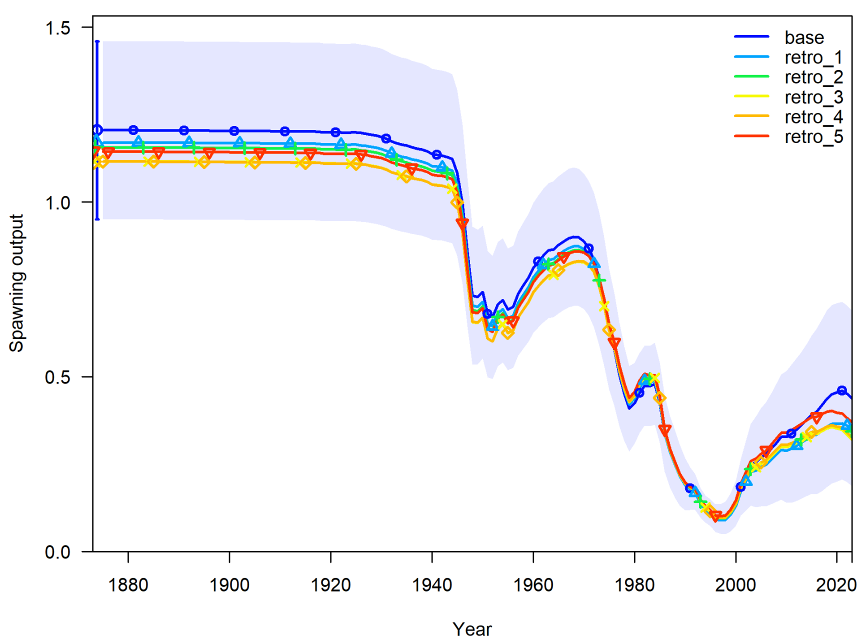


Figure 153: Retrospective analysis, showing the effect of removing individual years' data on estimated times series of spawning output (billions of eggs) from the northern model.

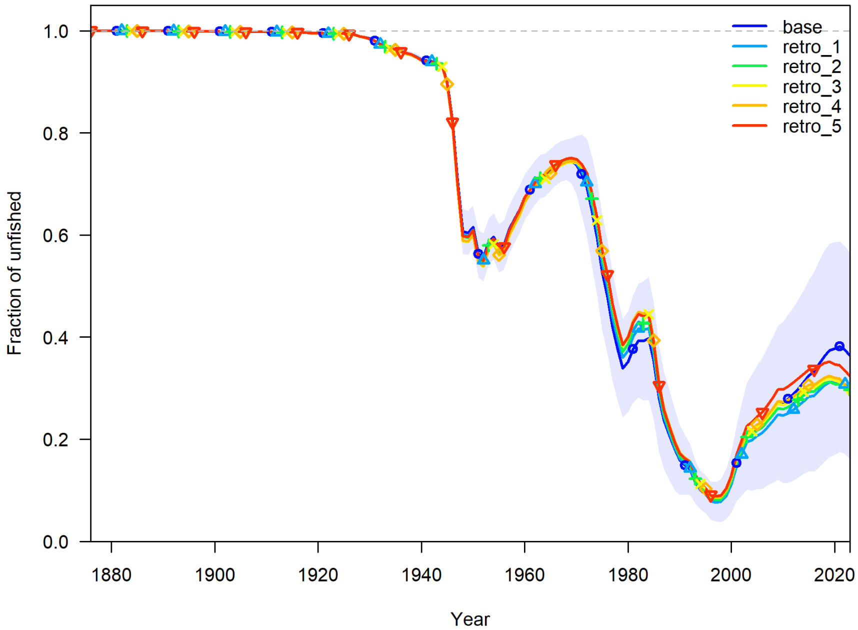


Figure 154: Retrospective analysis, showing the effect of removing individual years' data on estimated times series of relative spawning output (B / Bunfished) from the northern model.

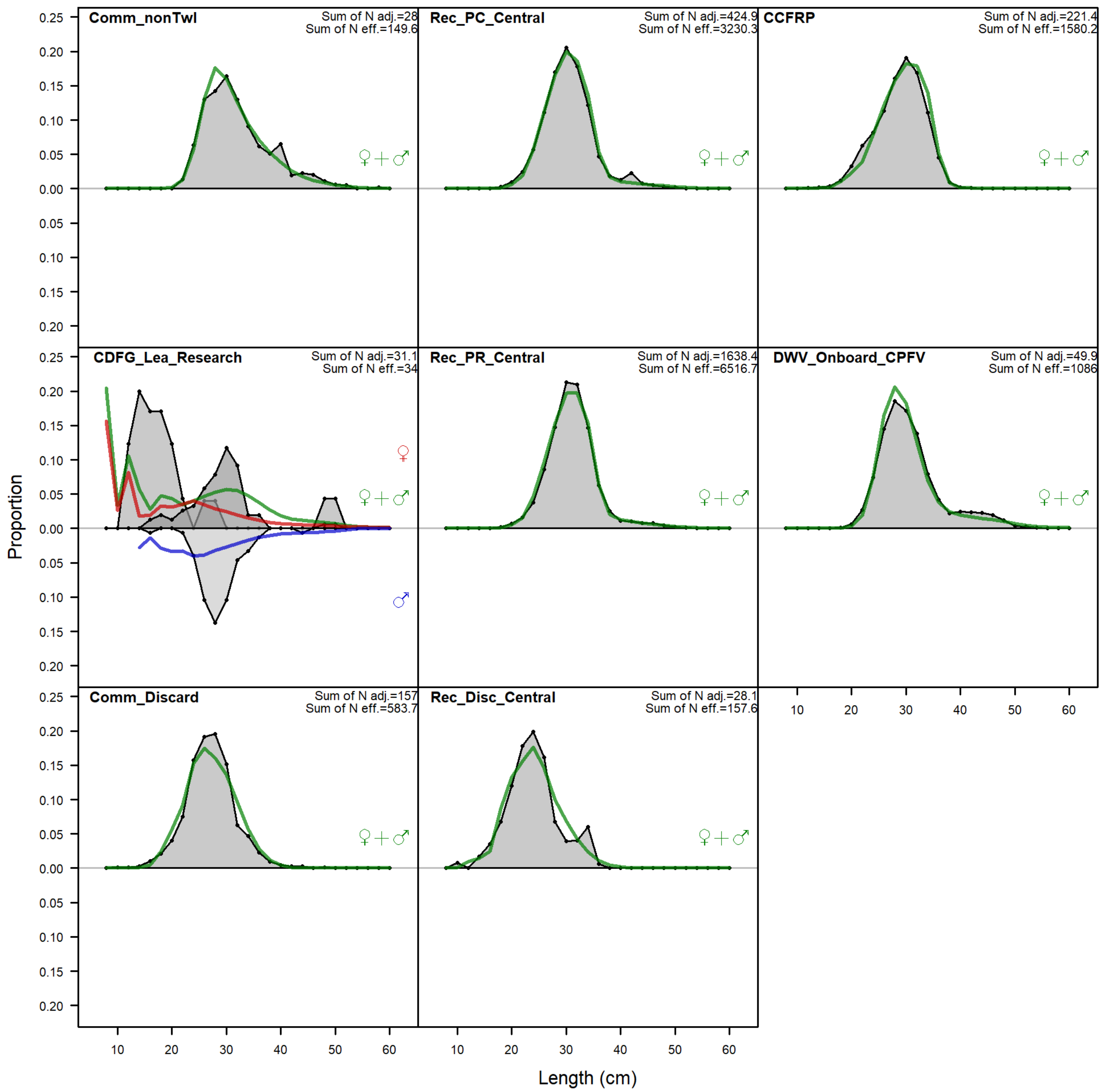


Figure 155: Central base model fit to time-aggregated length composition, by fleet.

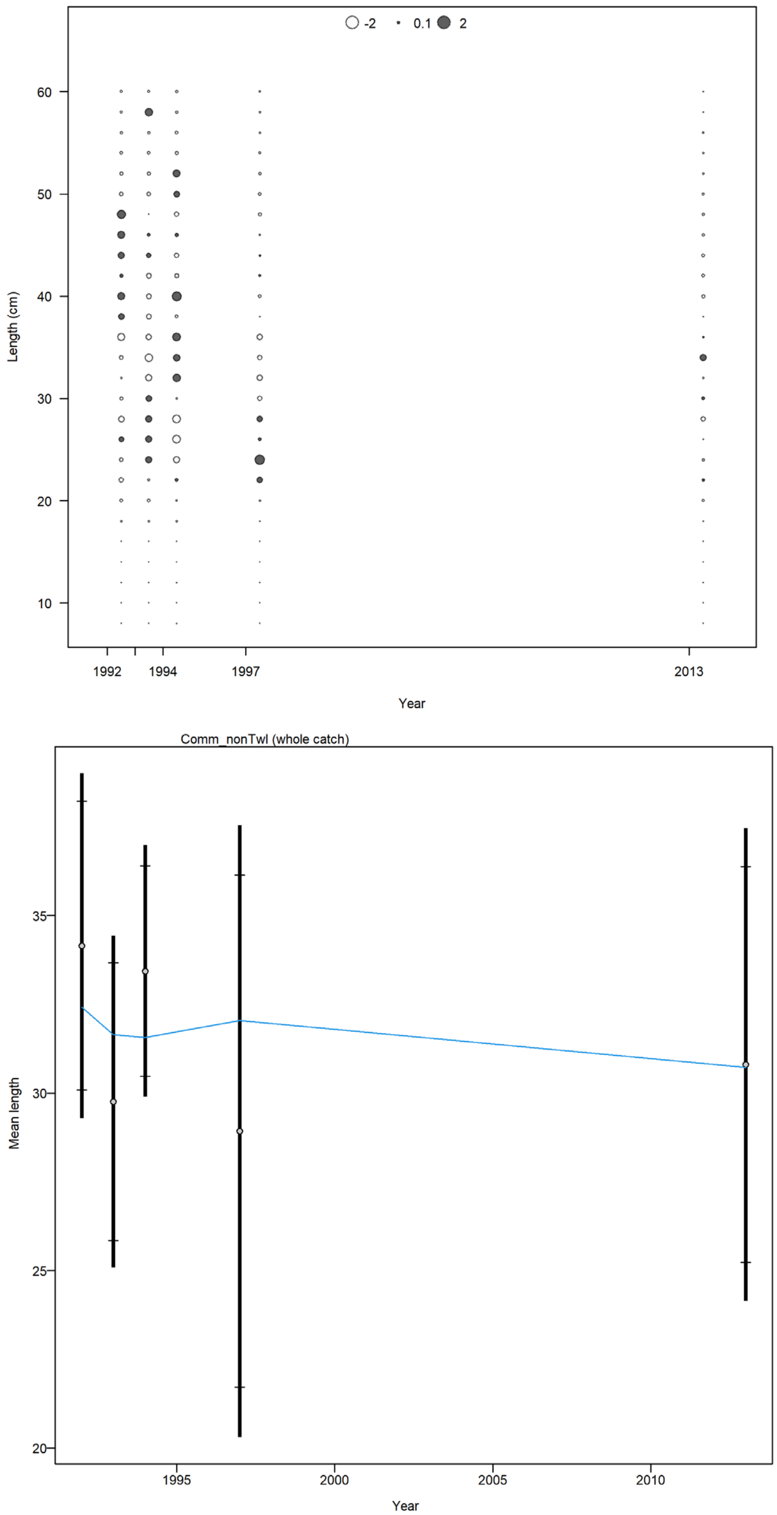


Figure 156: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the central commercial non-trawl fleet.

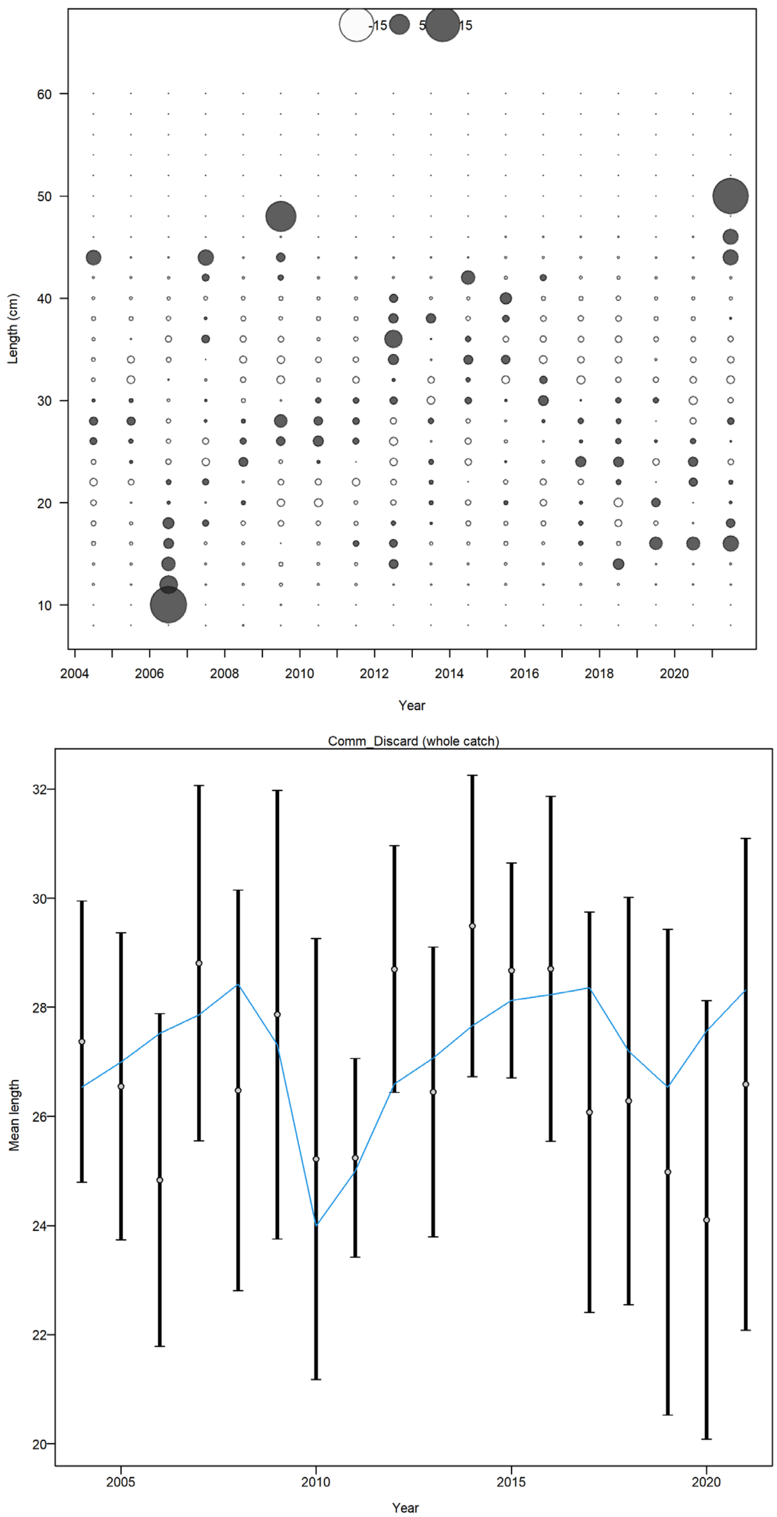


Figure 157: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the central commercial discard fleet.

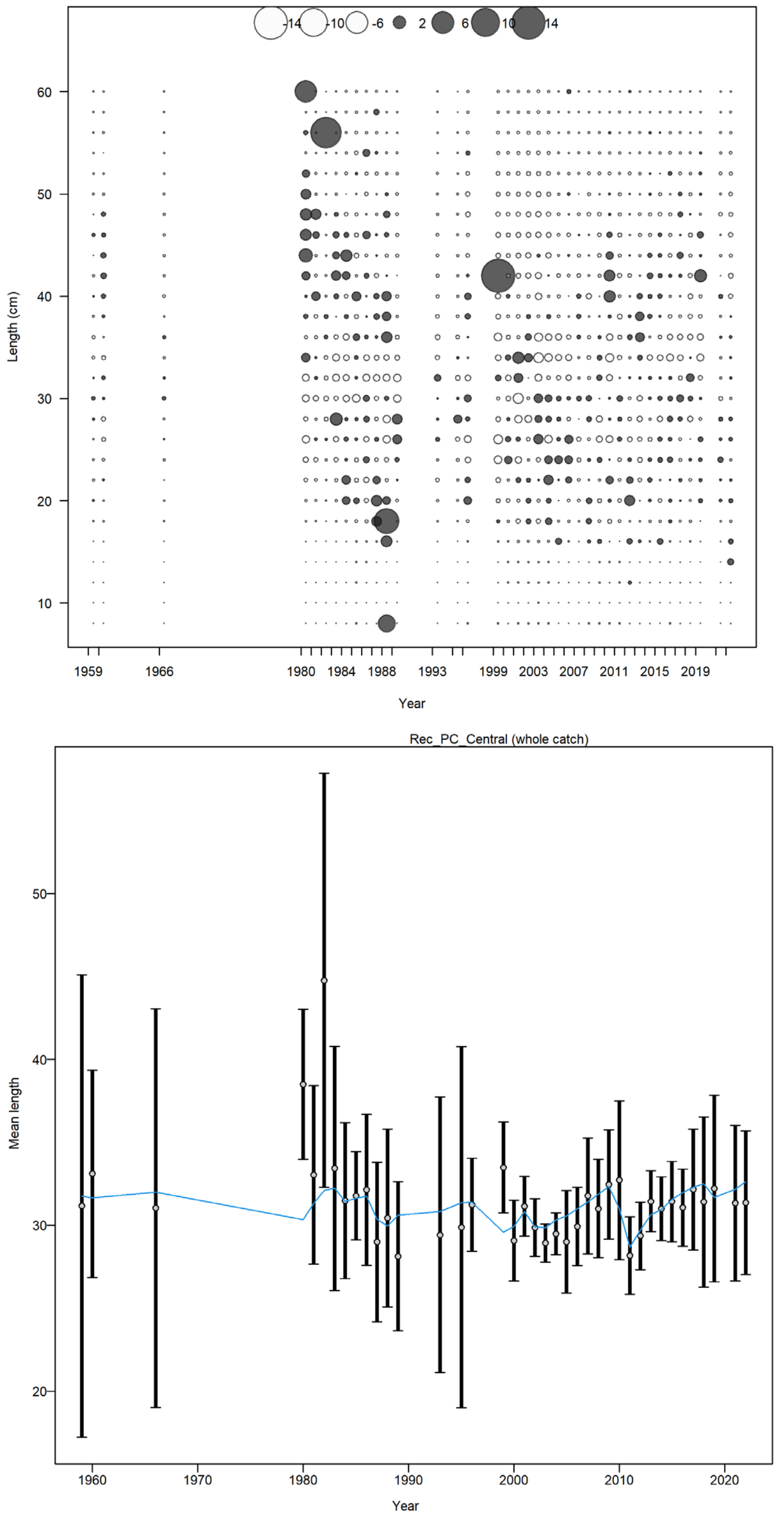
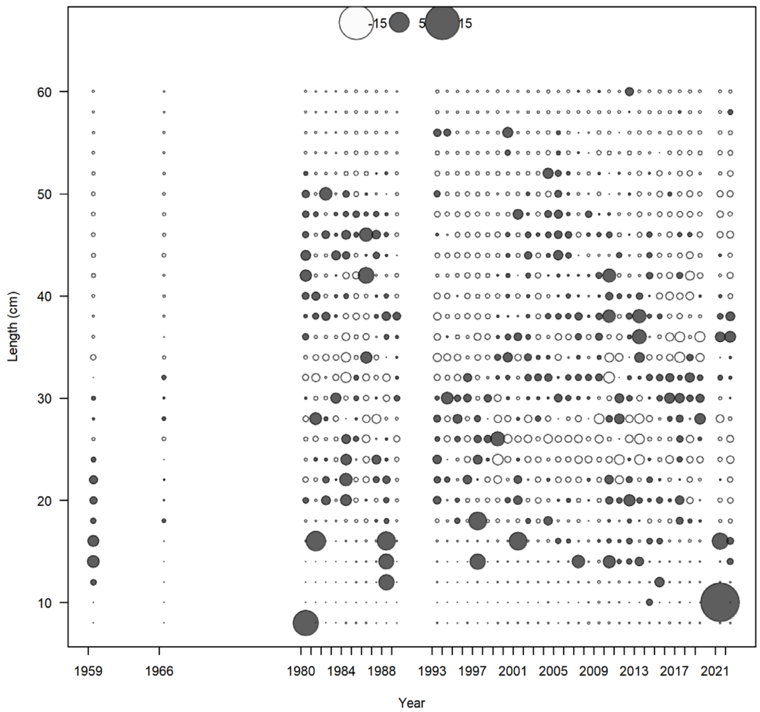


Figure 158: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the central recreational PC fleet.



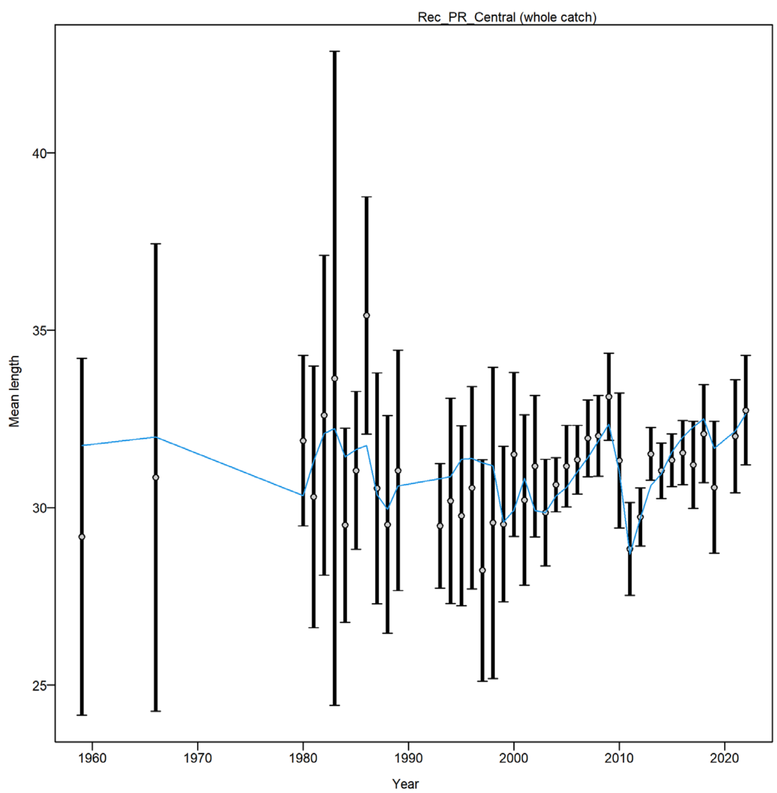


Figure 159: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the central recreational PR fleet.

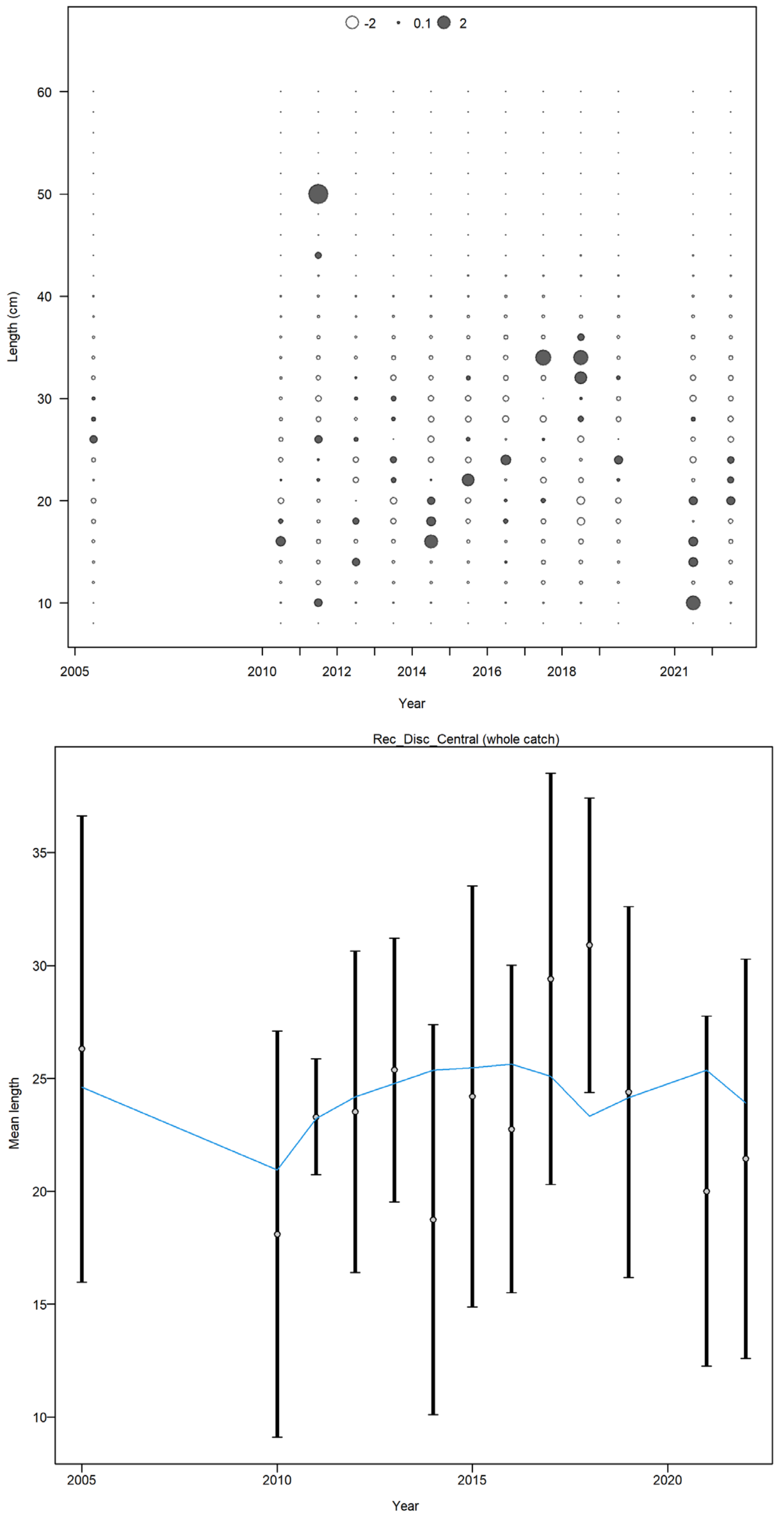


Figure 160 Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the central recreational discard fleet.

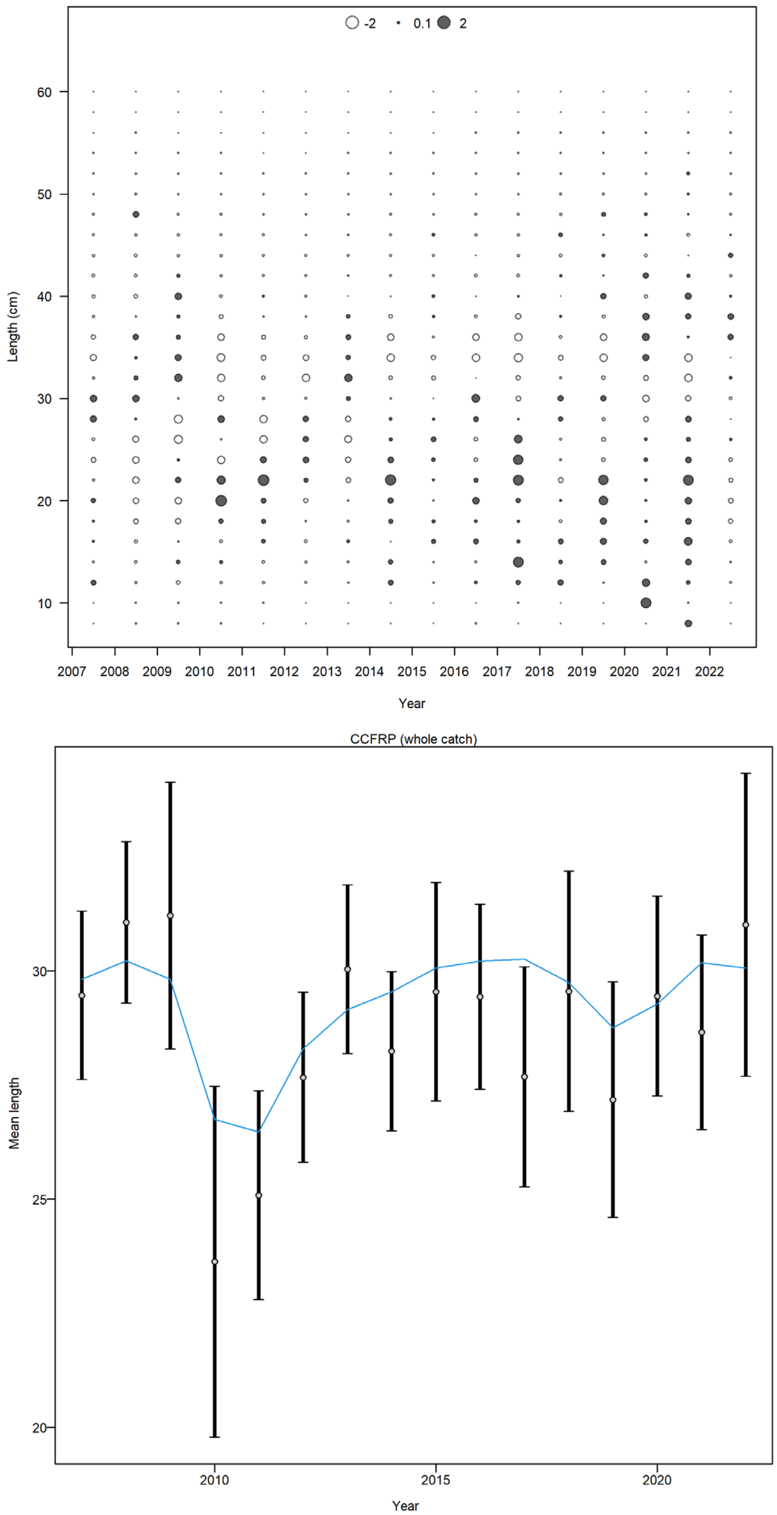


Figure 161: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the CCFRP survey

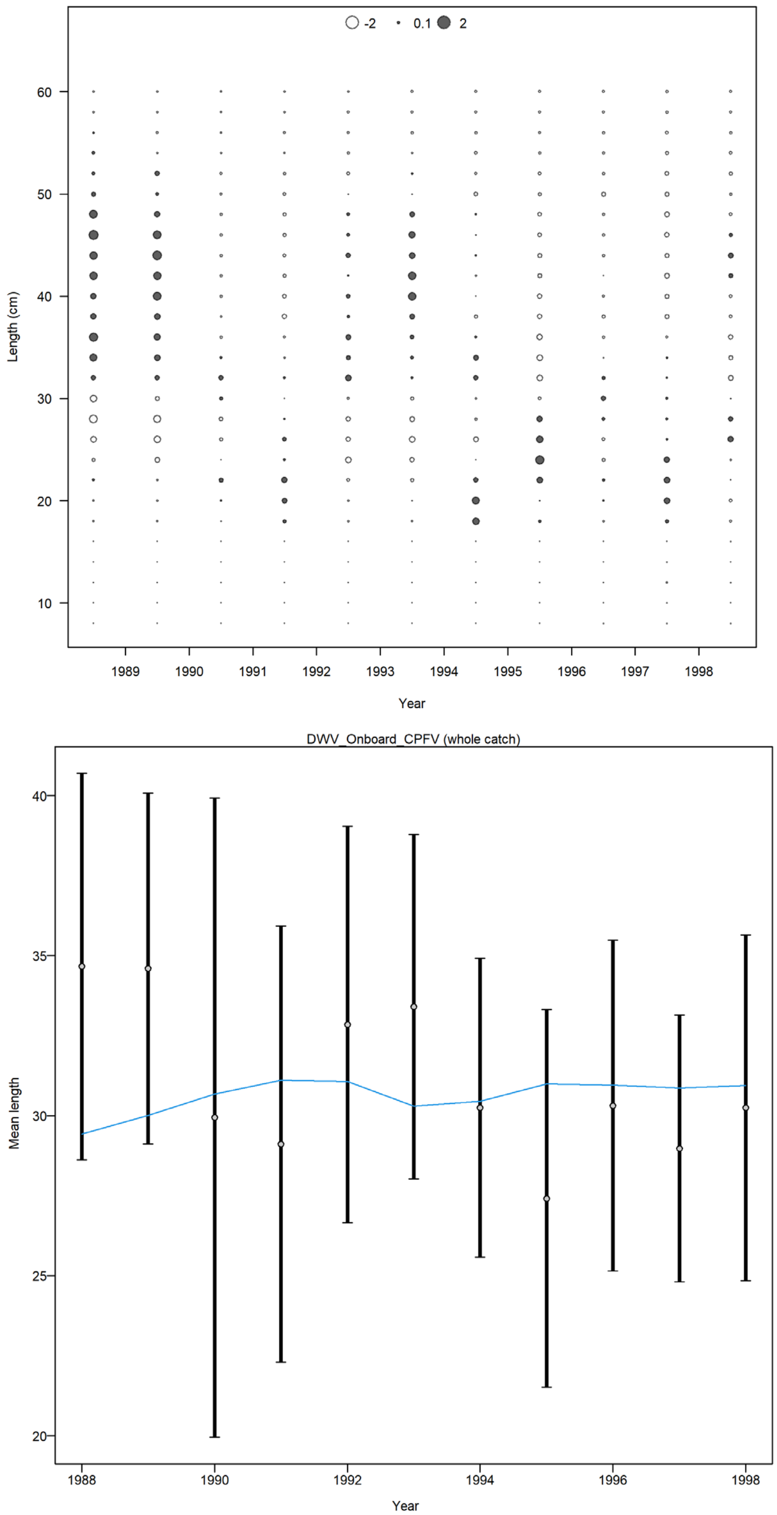


Figure 162: Length composition Pearson residuals (top panel) and fits to mean lengths (bottom panel) for the DWV onboard CPFV survey.

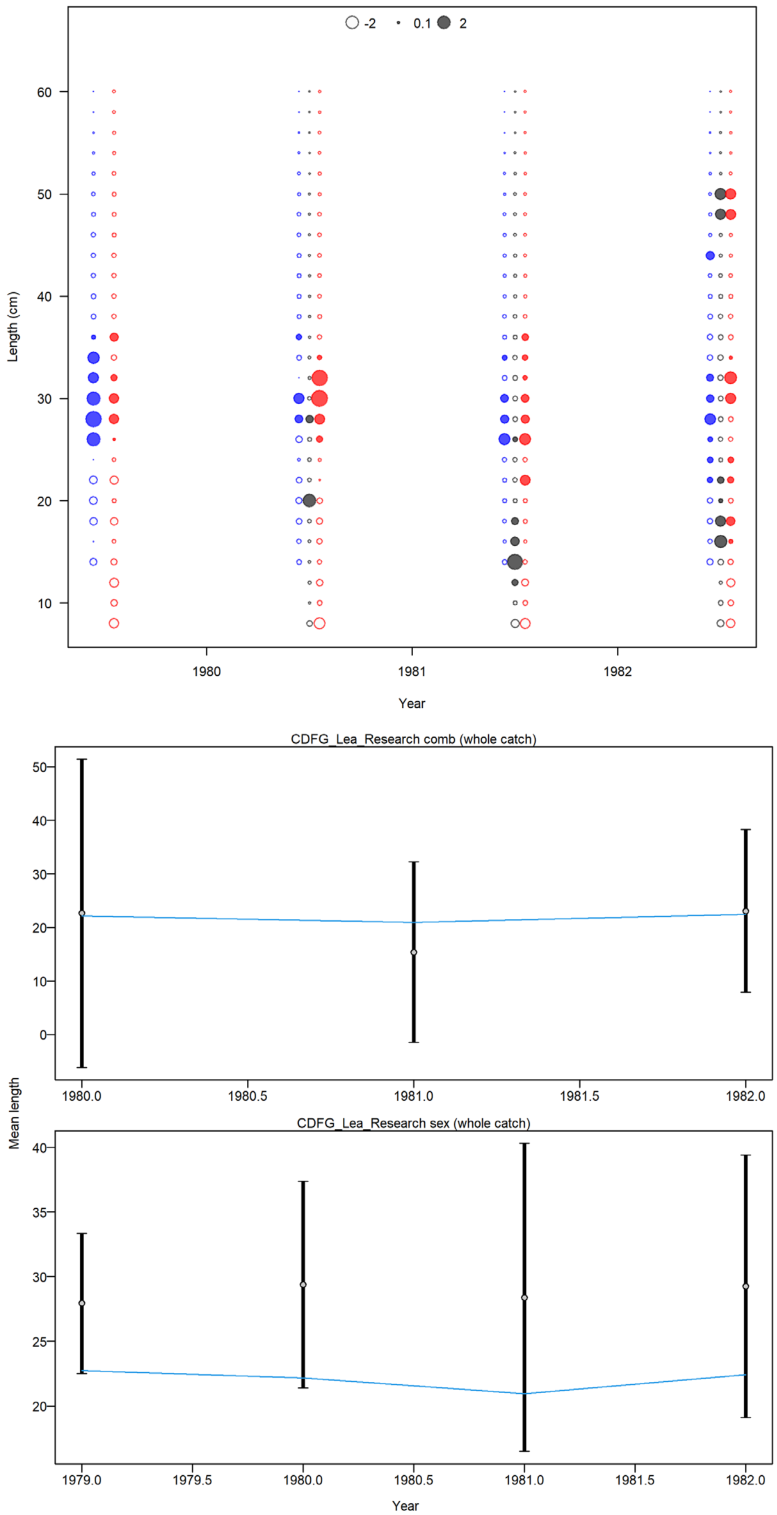
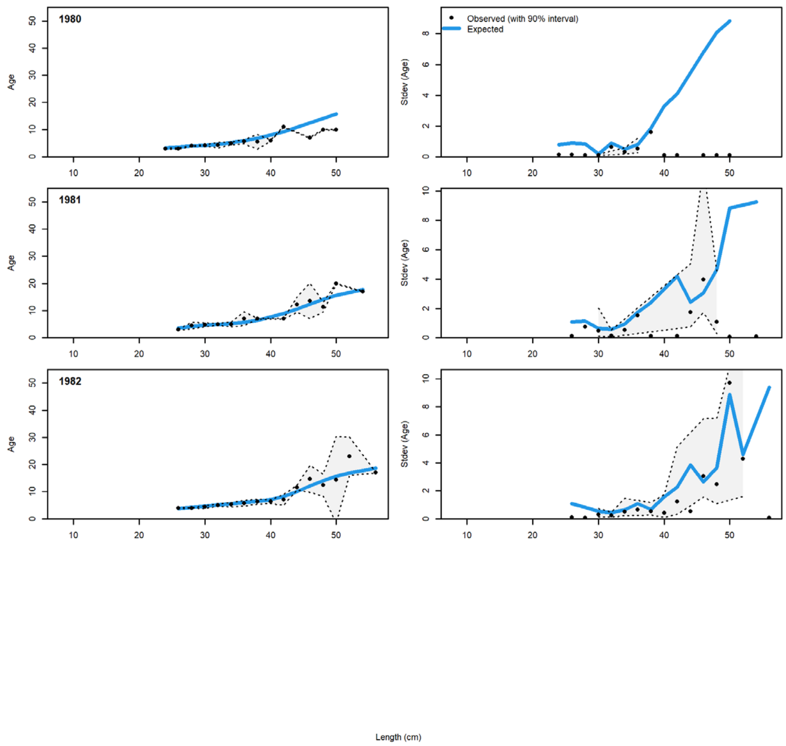


Figure 163: Length composition Pearson residuals (top panel) and fits to mean lengths (combined sex data, middle panel; separate sex data, bottom panel) for the Lea et al. research fleet.



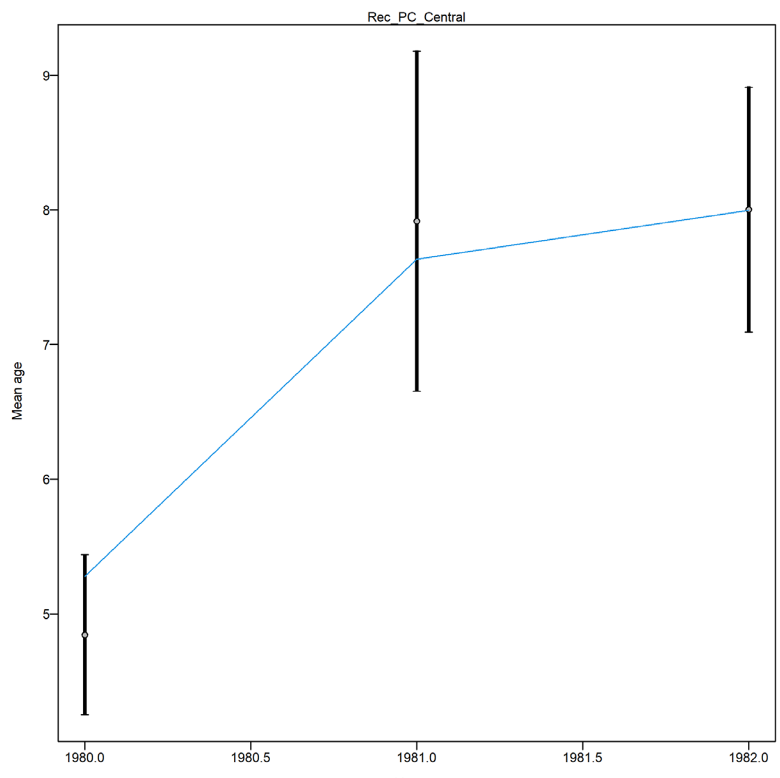


Figure 164: Central base model fits to conditional age-at-length data and mean age data from the rec PC central.

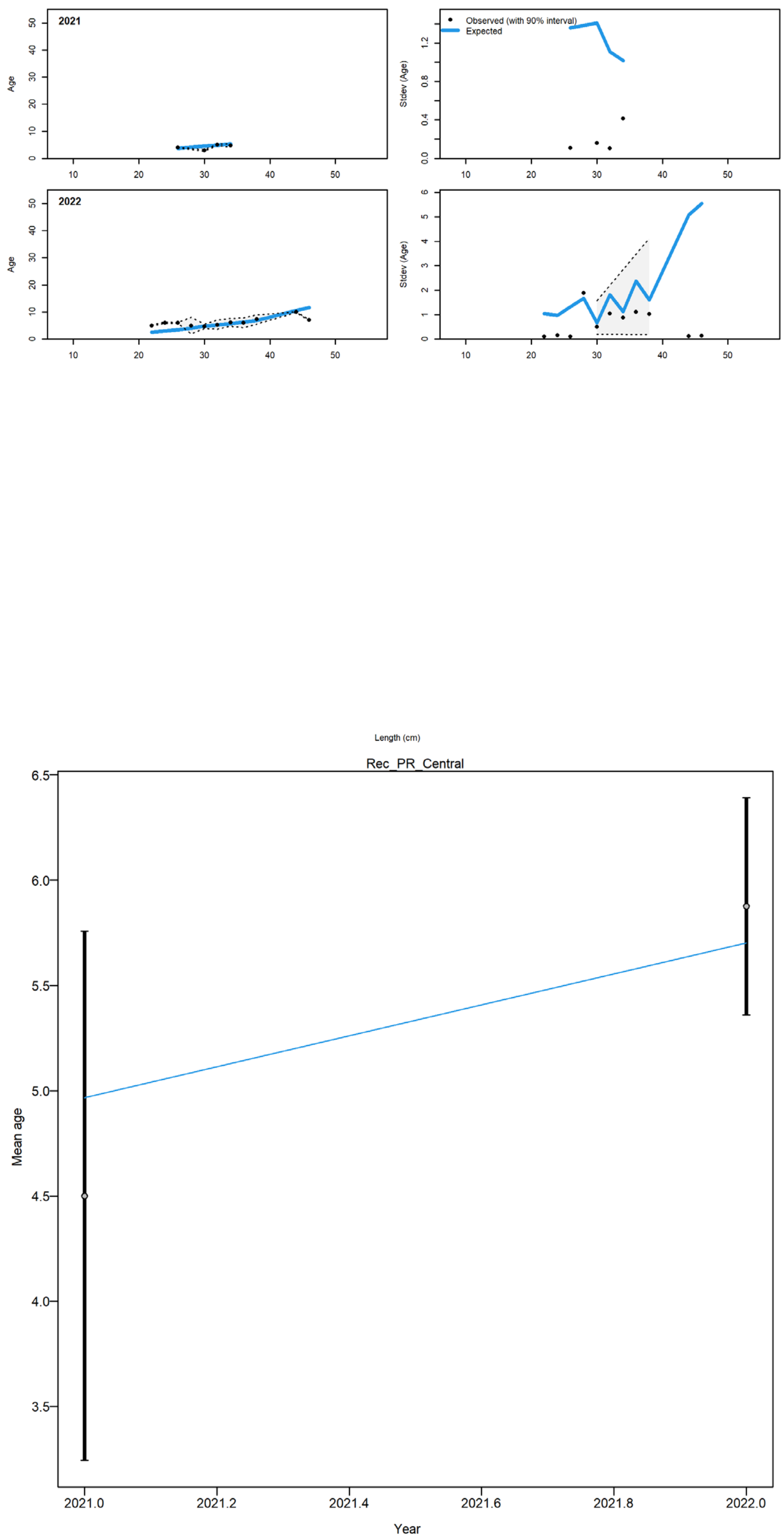


Figure 165: Central base model fits to conditional age-at-length data and mean age data from the rec PR central fleet.

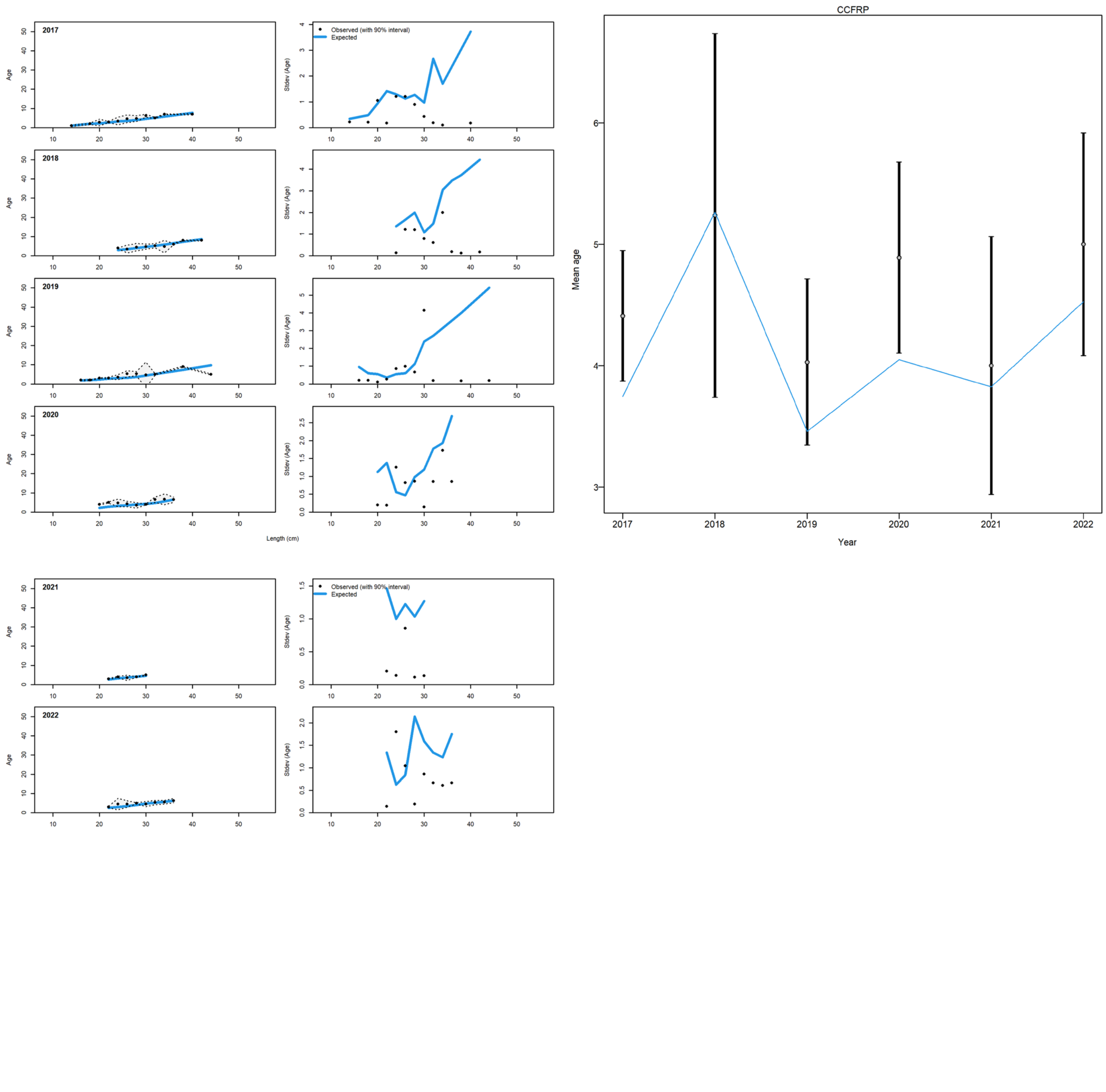


Figure 166: Central base model fits to conditional age-at-length data and mean age data from the CCFRP survey.

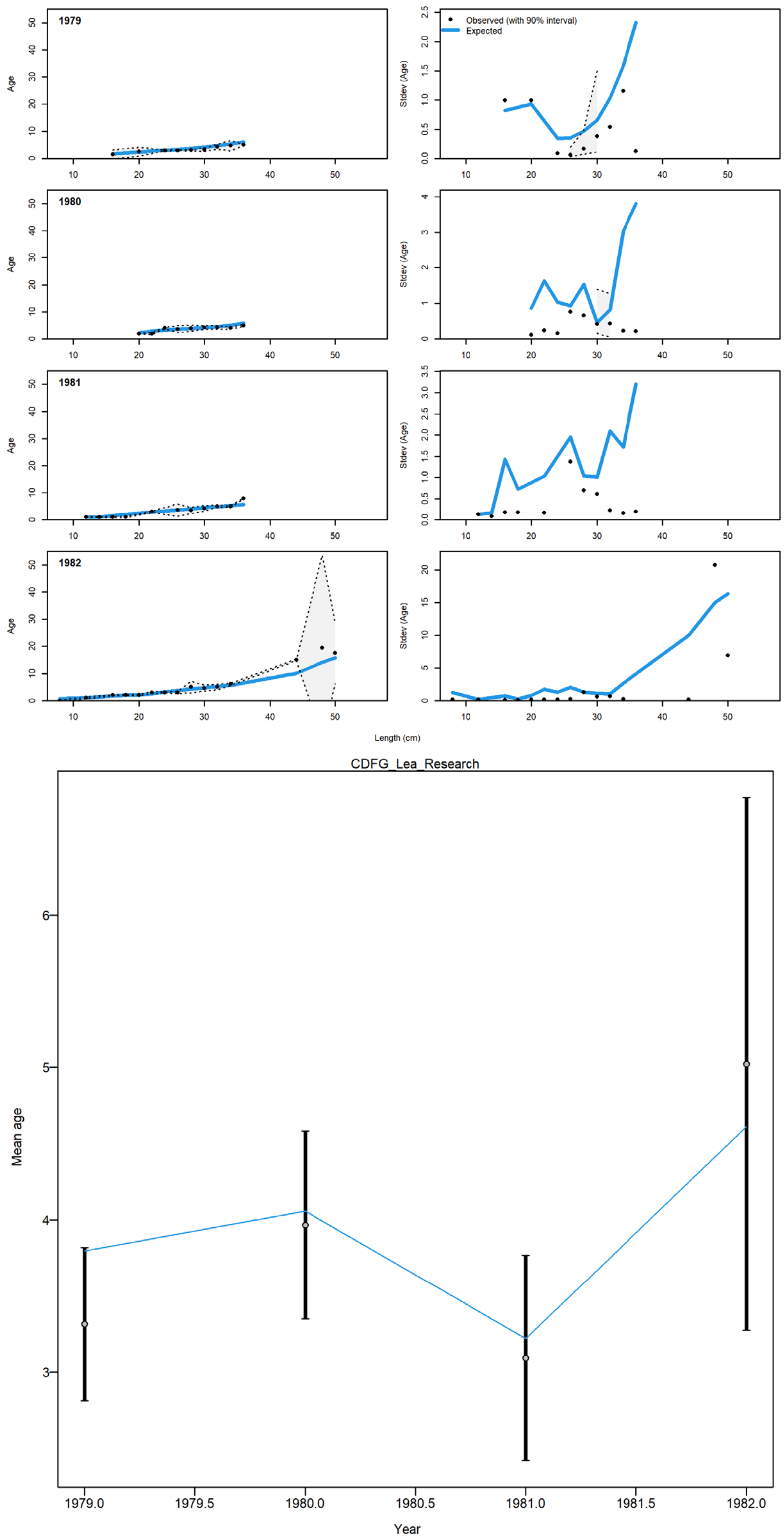


Figure 167: Central base model fits to conditional age-at-length data and mean age data from the Lea et al. research fleet.

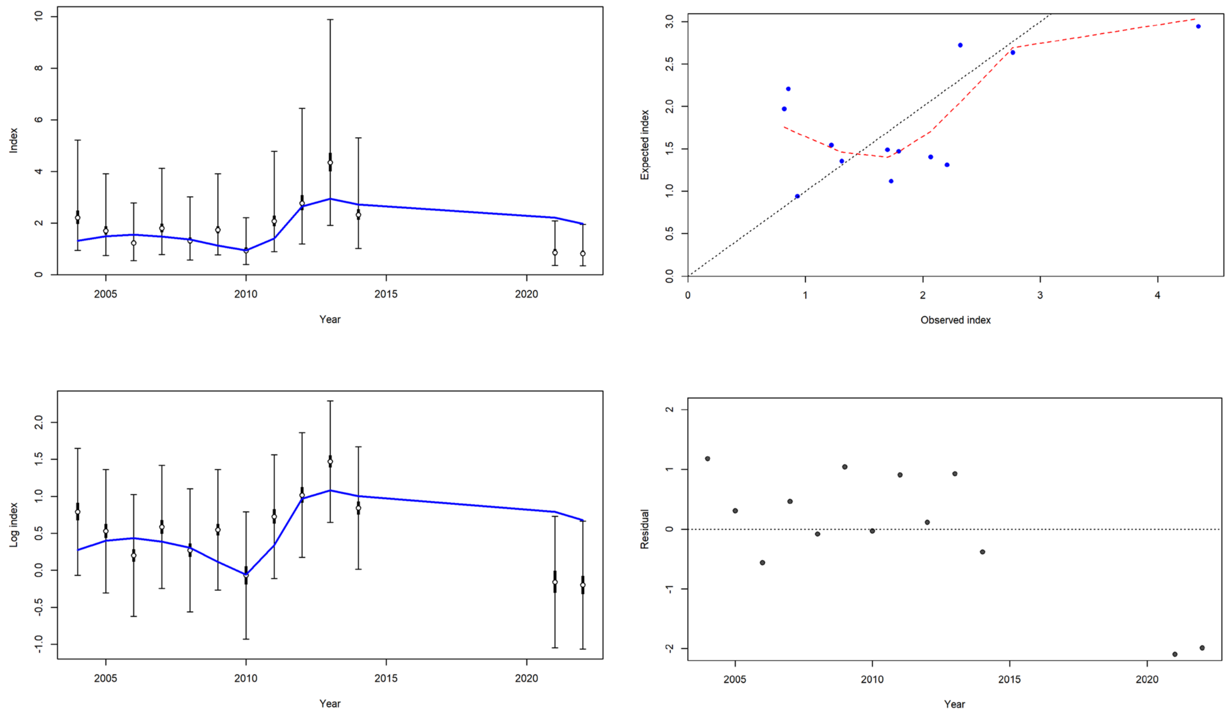


Figure 168: Central model fit to the recreational PR index. Top row: arithmetic scale fit and 1:1 plot.
Bottom Row: log-scale fit and log-scale standardized residual plot.

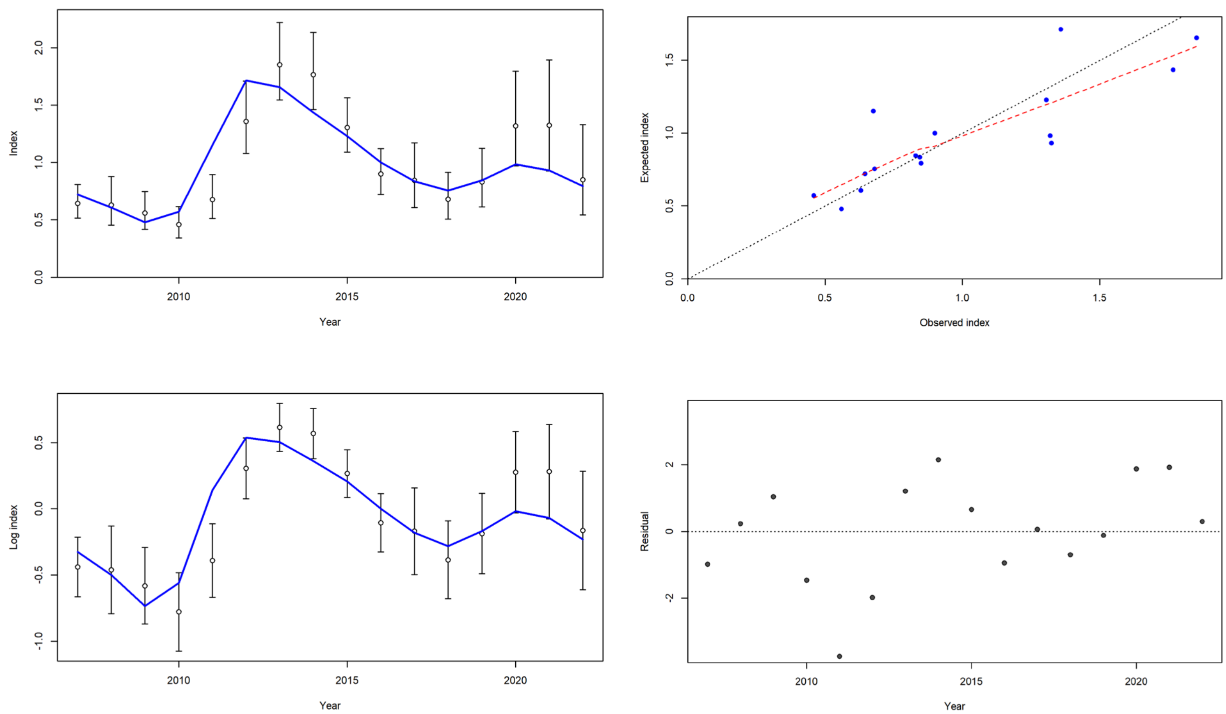


Figure 169: Central model fit to the CCFRP index. Top row: arithmetic scale fit and 1:1 plot. Bottom Row: log-scale fit and log-scale standardized residual plot.

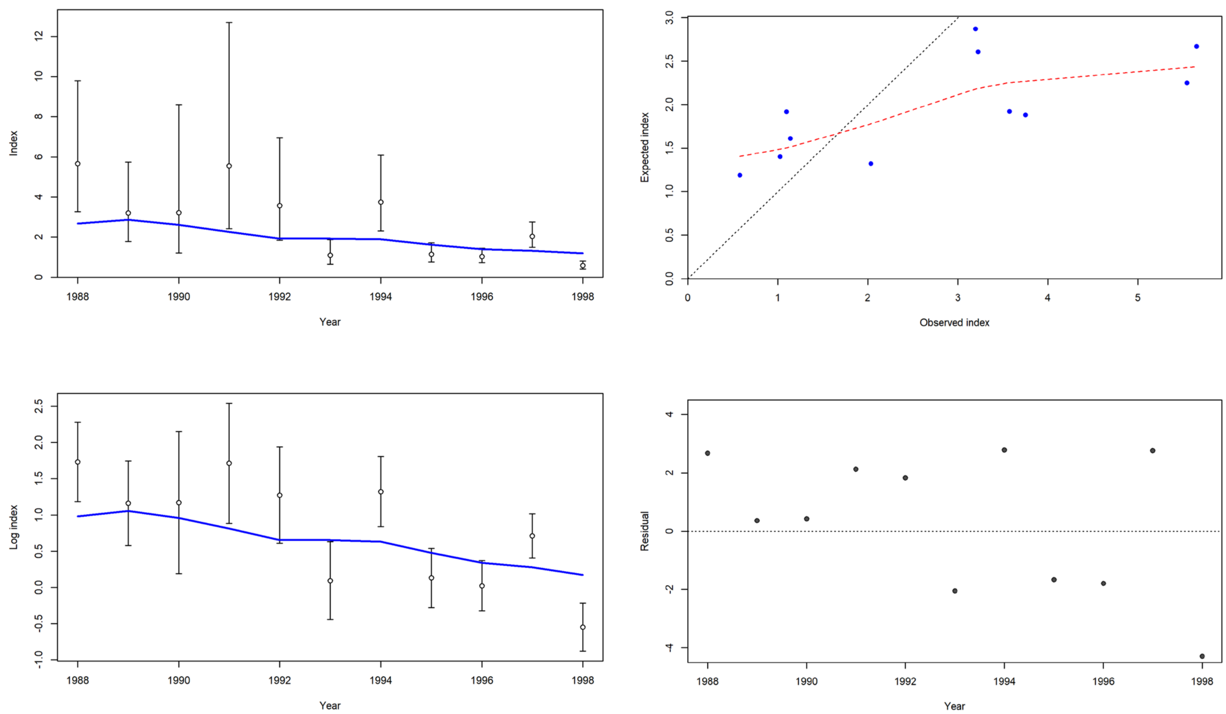


Figure 170: Central model fit to the DWV onboard CPFV index. Top row: arithmetic scale fit and 1:1 plot. Bottom Row: log-scale fit and log-scale standardized residual plot.

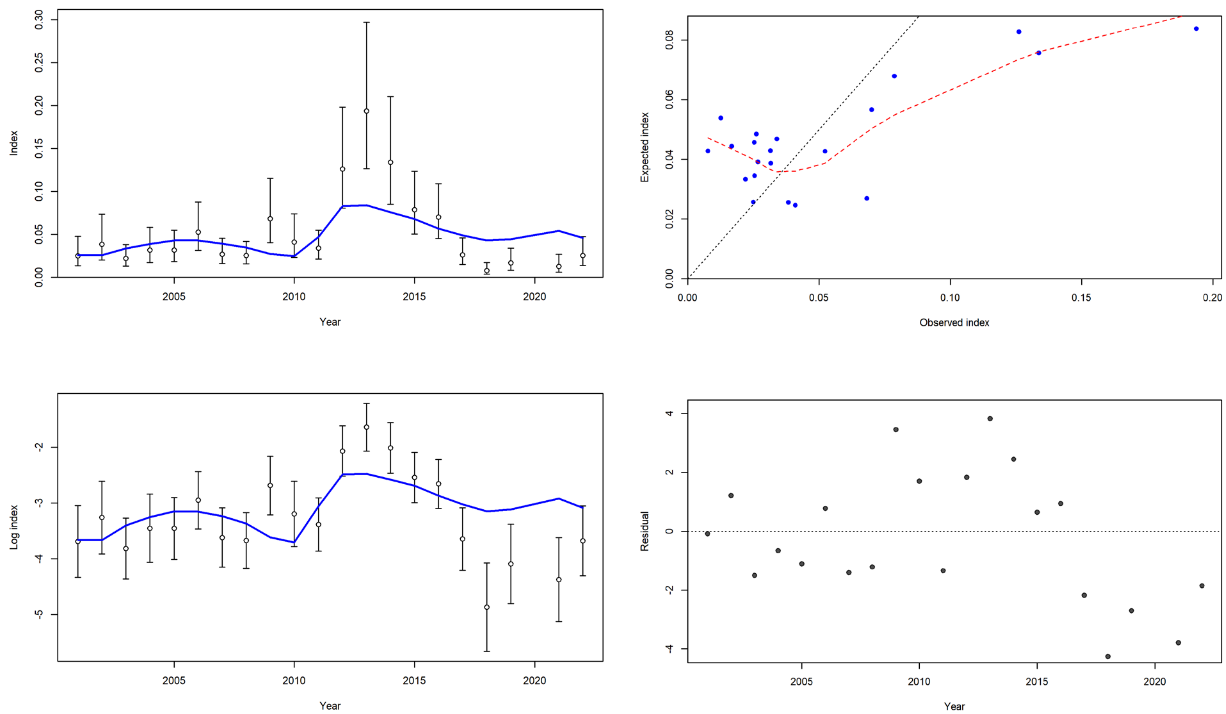


Figure 171: Central model fit to the CRFS PC onboard index. Top row: arithmetic scale fit and 1:1 plot. Bottom Row: log-scale fit and log-scale standardized residual plot.

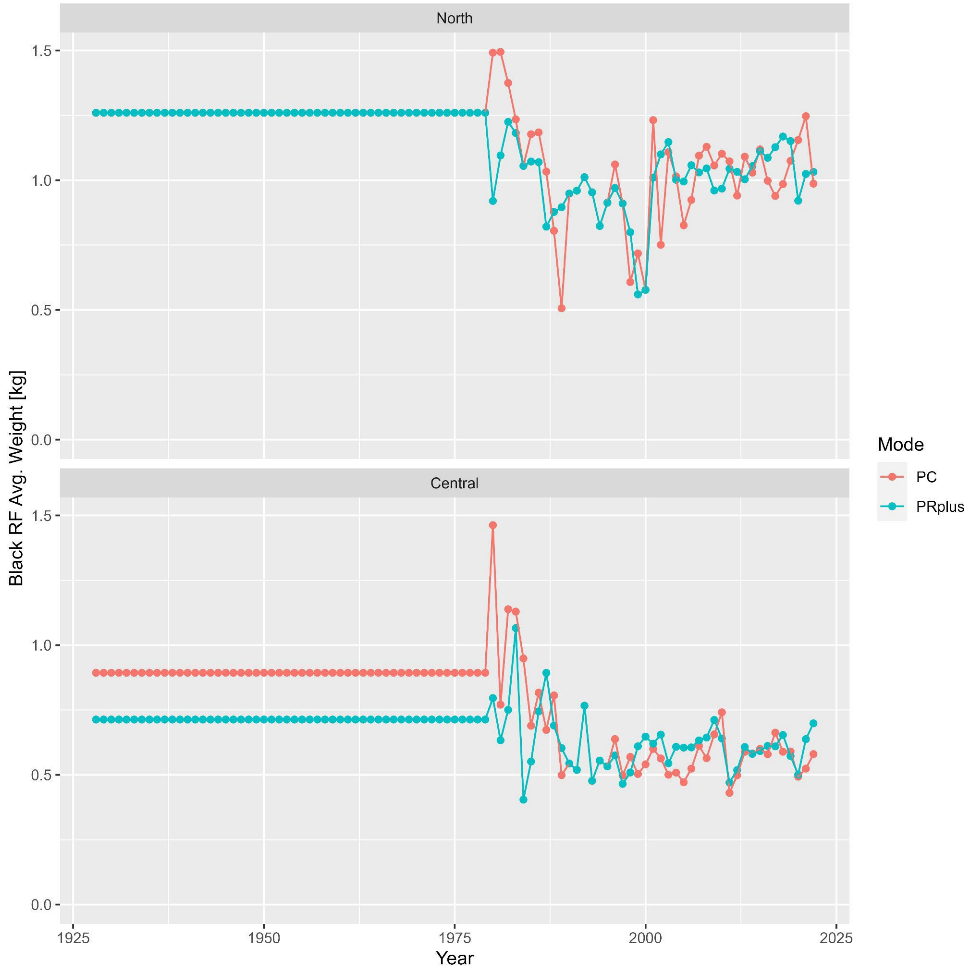


Figure 172: Mean weight (kg) of black rockfish by area, year, and mode. Modifications to the assumed mean weight in years prior to 1980 are illustrated in the lower panel.

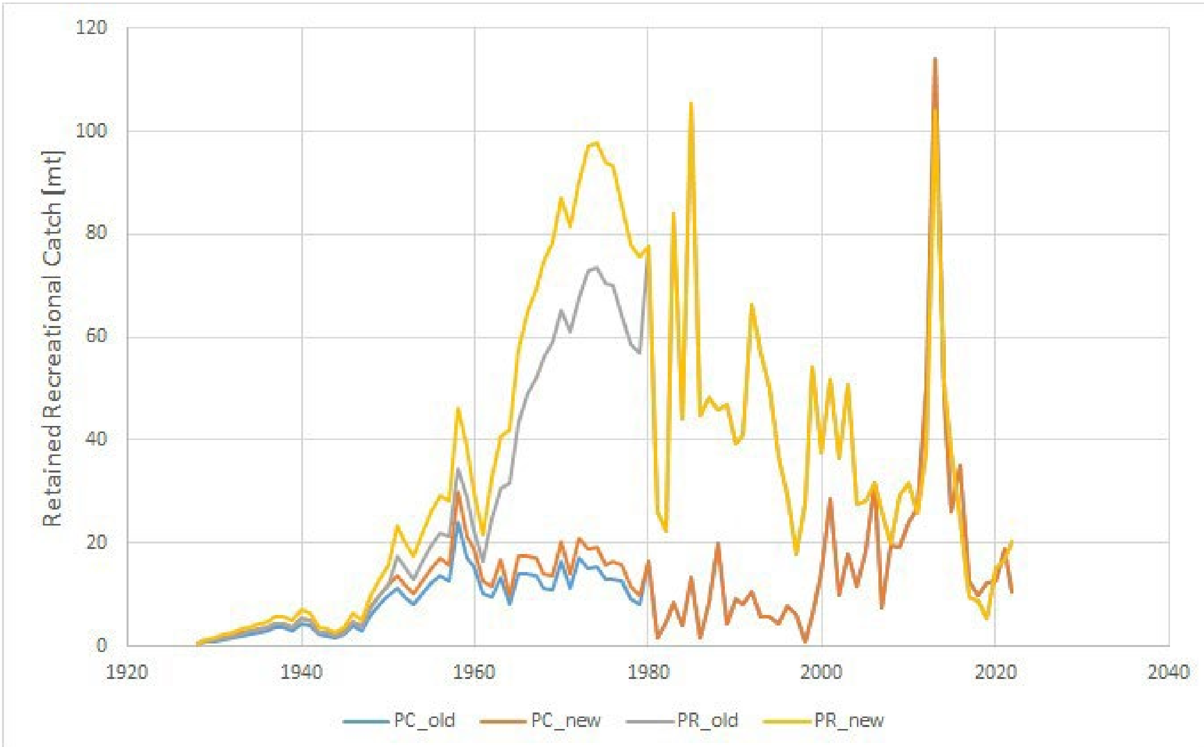


Figure 173: Time series of retained recreational catch (metric tons) using alternative average weight estimates. “PC_old” refers to the pre-STAR base model catch estimate for the PC mode, and “PC_new” refers to the catches based on the MRFSS average weights (with similar labels for the PR mode).

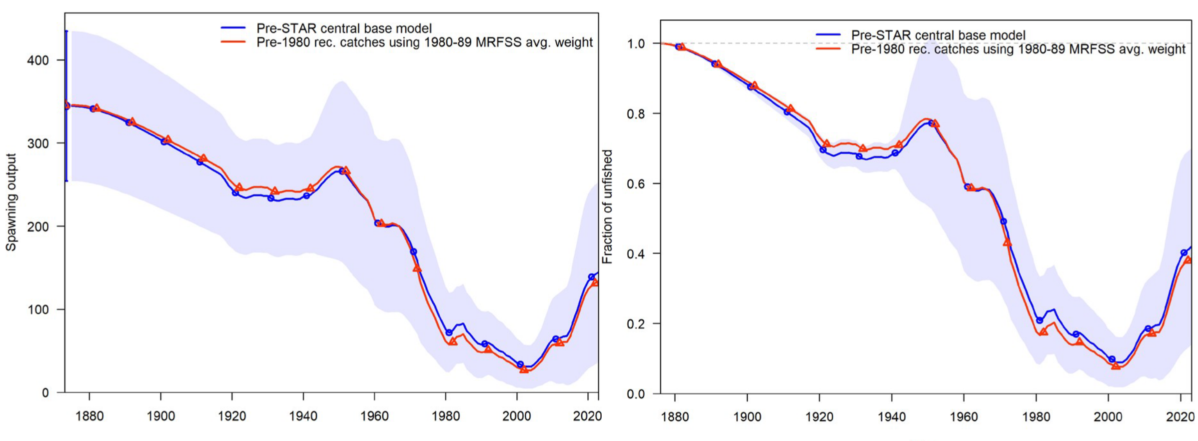


Figure 174: Time series of spawning output (billions of eggs) and spawning output relative to unfished levels, shown for the pre-STAR base model and a model with historical recreational catches derived from average weights over the period 1980-1989.

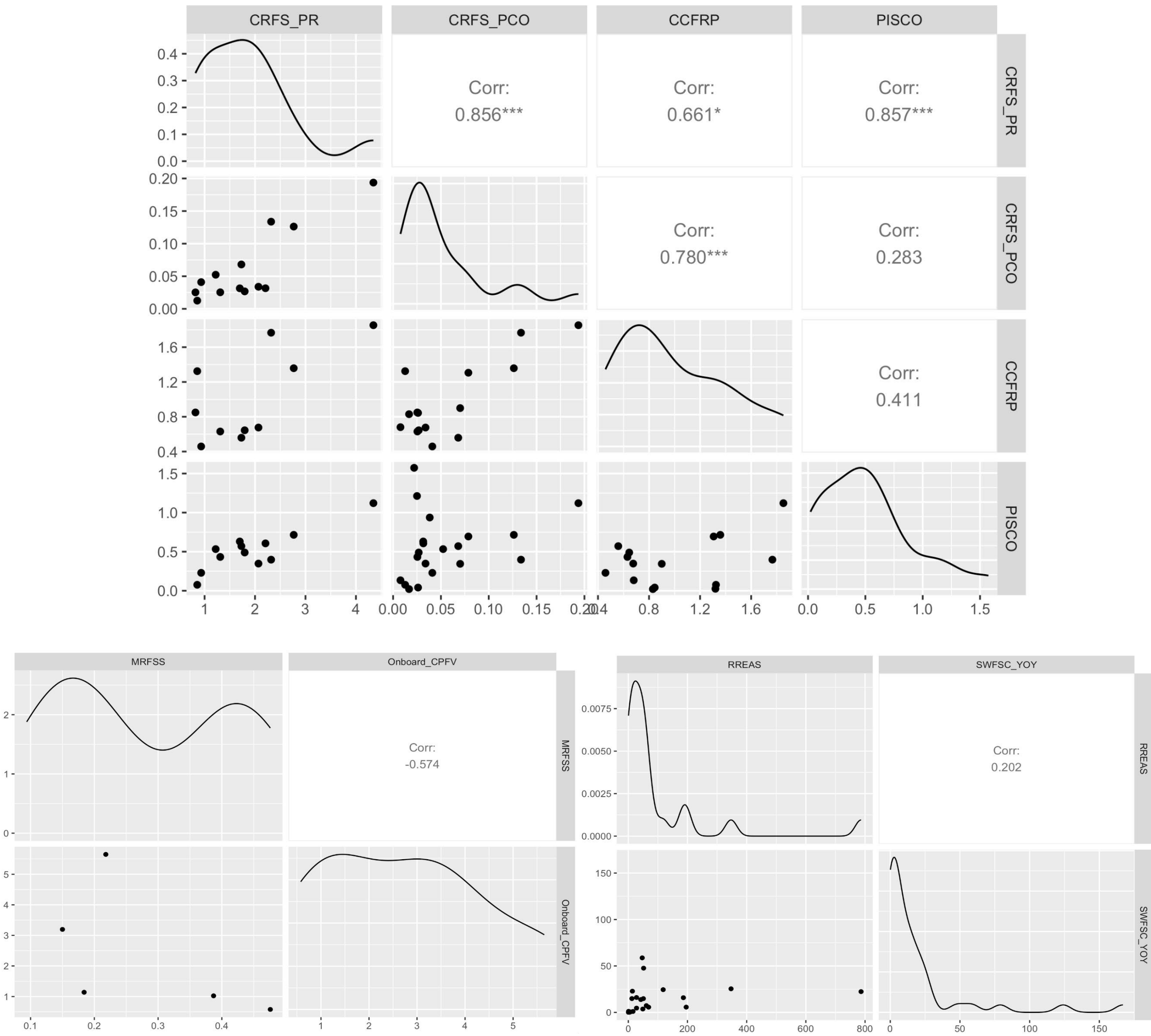


Figure 175: Pairwise comparisons of abundance indices, central California (CRFS Districts 3 and 4). Correlation coefficients (numbers) and p values (*** < 0.001, ** < 0.01, * < 0.05, and . < 0.10) are shown in the upper right quadrants, data points are shown in the lower left quadrants, and kernel densities are shown along the diagonals. A minimum of five overlapping years was required for inclusion. CRFS_PR: private/rental recreational fishing boats; CRFS PCO: party/charter operations; CCFRP: California Collaborative Fisheries Research Program; PISCO: Partnership for the Interdisciplinary Study of Coastal Oceans; MRFSS: Marine Recreational Fisheries Statistics Survey; Onboard_CPFV: Commercial Passenger Fishing Vessel Observer Program; RREAS: NMFS SWFSC's Rockfish Recruitment and Ecosystem Assessment Survey; SWFSC_YOY: NMFS SWFSC's young of the year SCUBA survey.

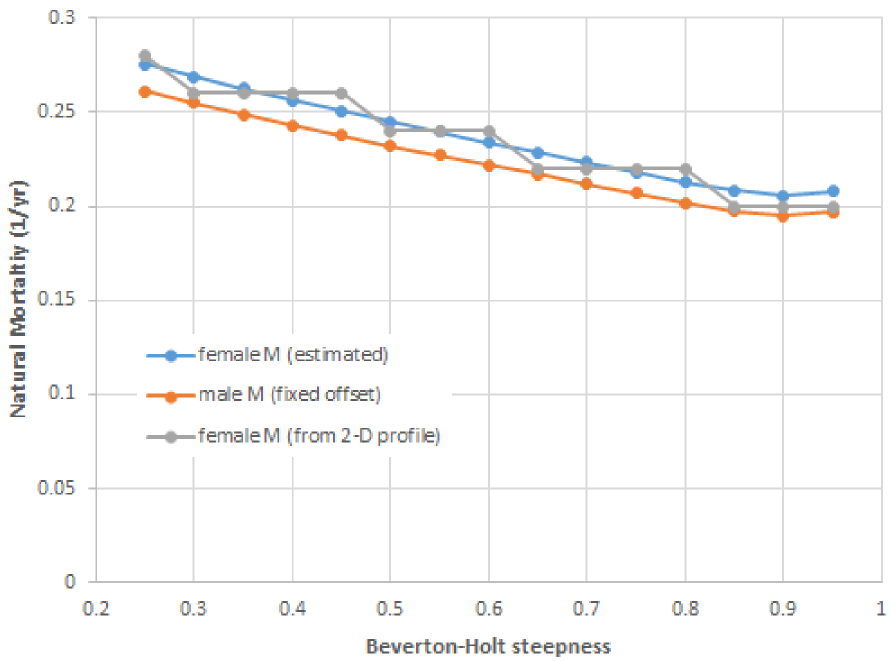


Figure 176: Natural mortality for females and males as a function of steepness in the central California model. The male offset was fixed at the value estimated in the northern model.

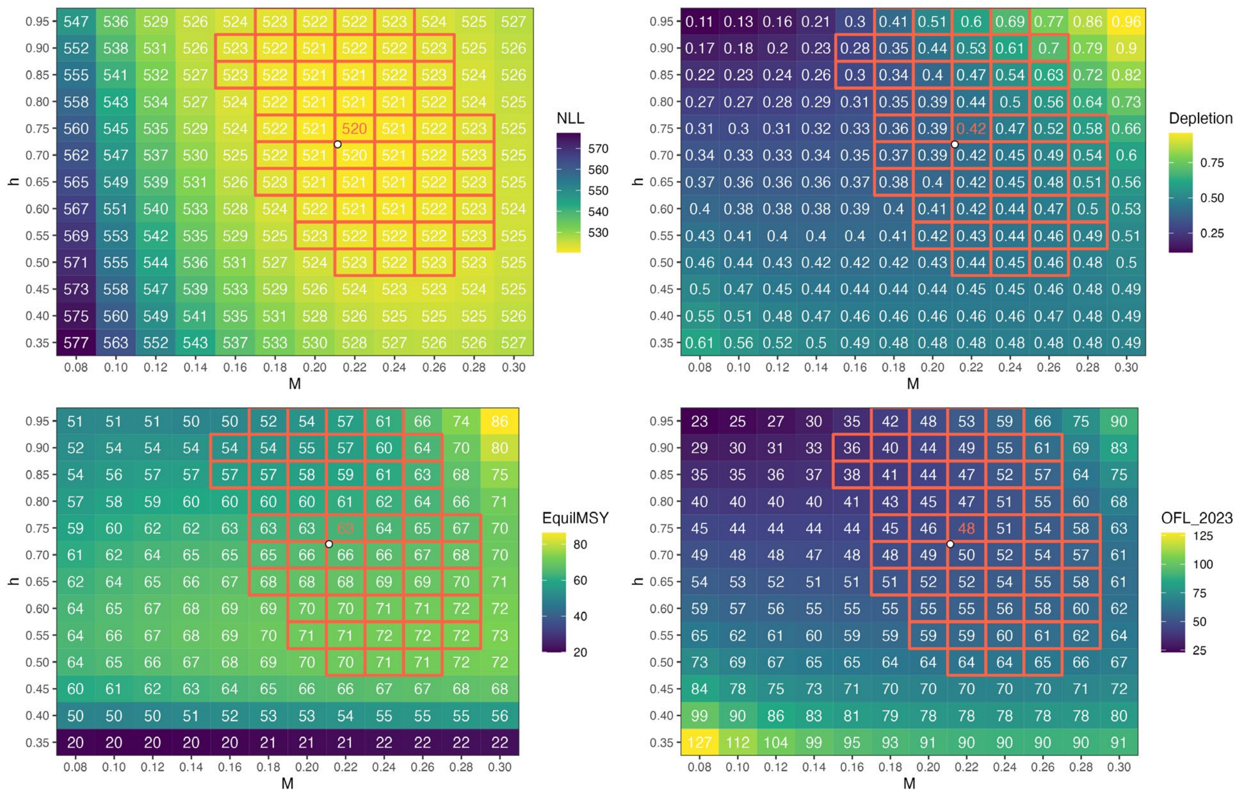


Figure 177: Bivariate profile over steepness and female natural mortality, plotting NLL, Depletion, Equilibrium proxy MSY, and OFL. The white point is the base model. Numbers in red are values at the NLL minimum. Parameter combinations outlined in red are within the bivariate 95% chi-squared interval of the NLL minimum. The base model is close to the minimum and falls within the 95% chi-squared interval. Numbers within the plots are rounded for readability. Steepness values of 0.25 and 0.3 were excluded as they are inconsistent with the proxy SPR50% harvest rate (equilibrium MSY = 0).

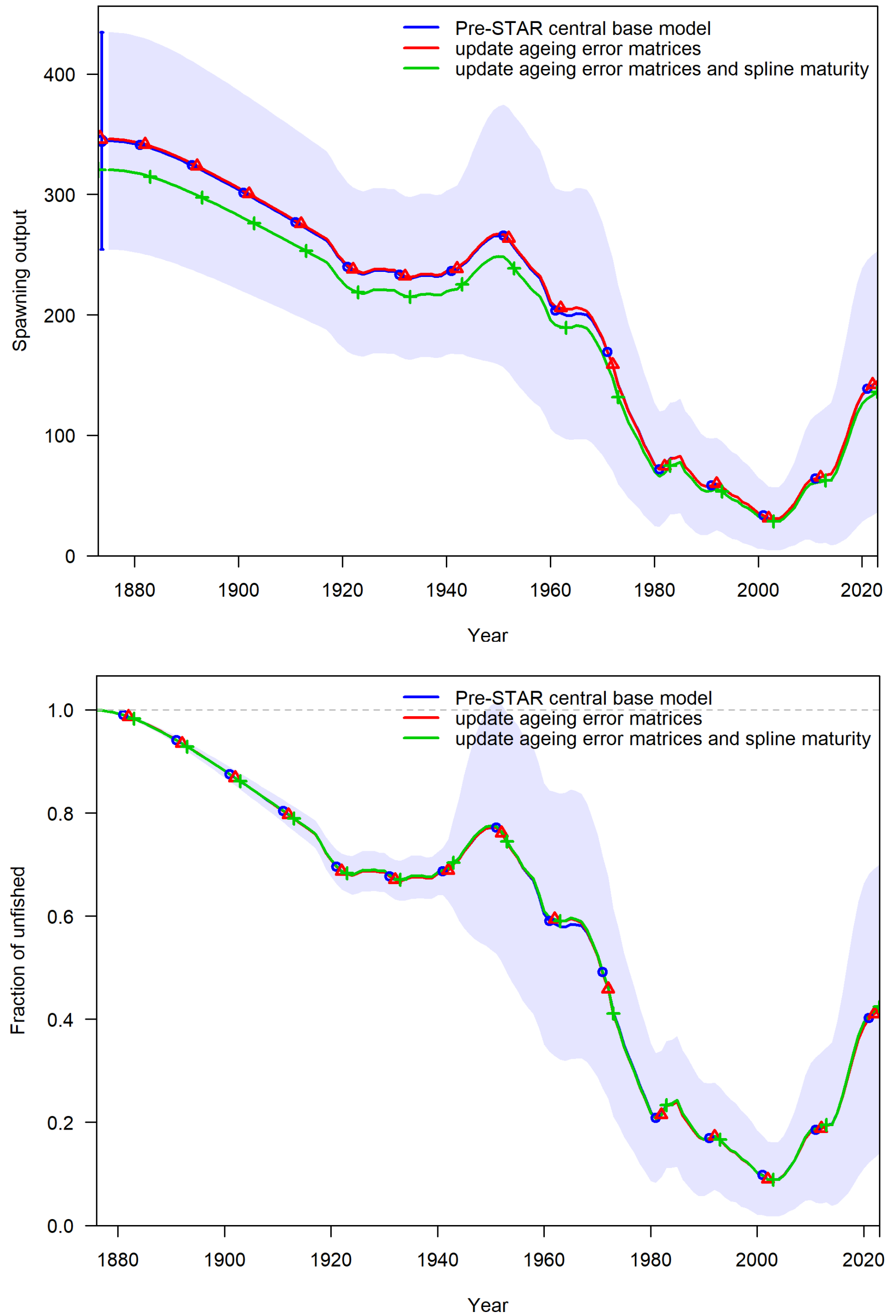


Figure 178: Comparison of spawning output (billions of eggs, upper panel) and relative spawning output (lower panel) time series from the pre-STAR base model and models with updated ageing error matrices and a spline model for the maturity at length relationship.

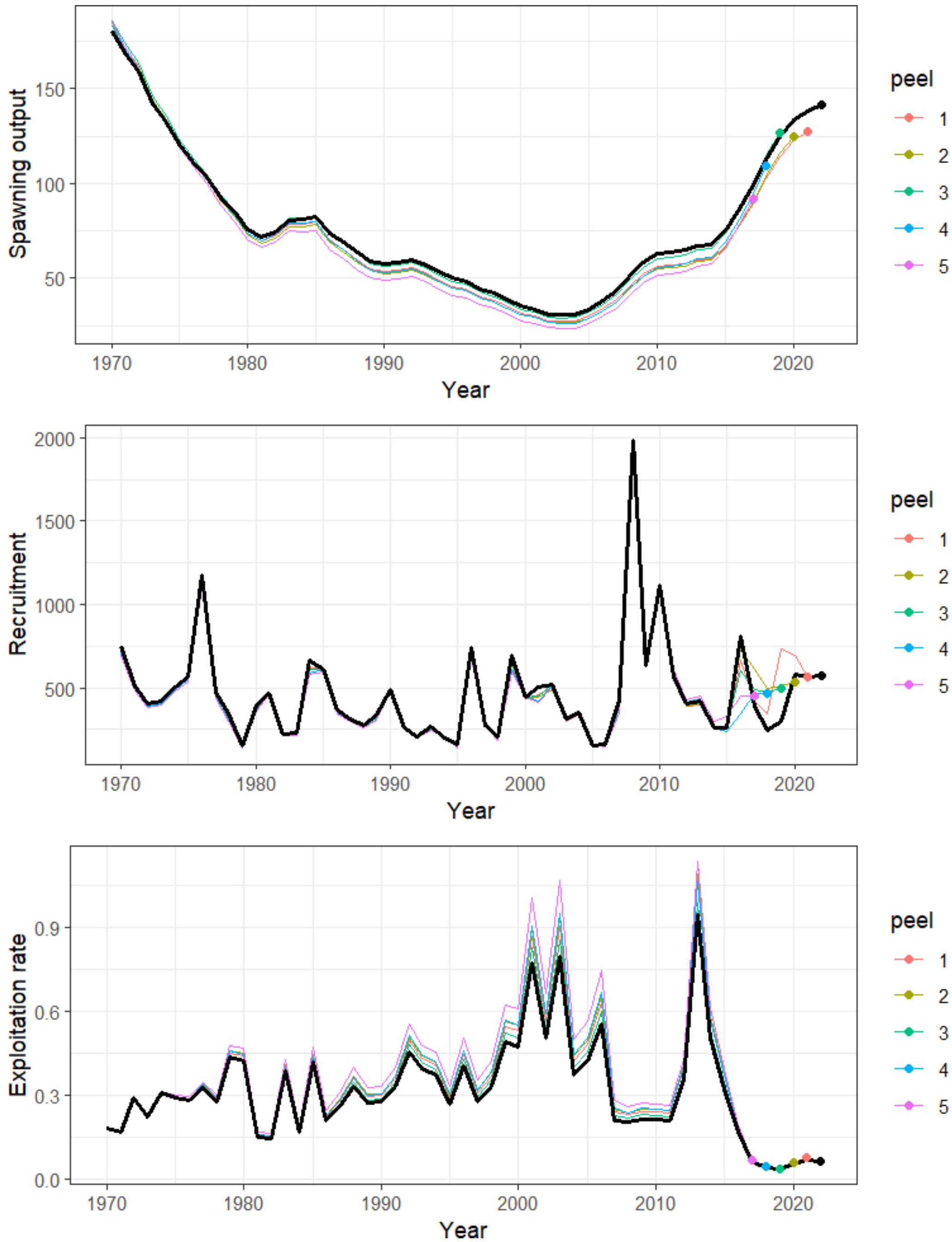


Figure 179: Time series of spawning output (billions of eggs; top panel), recruitment (1000s of age-0 fish; middle panel), and exploitation rate (catch divided by age 8+ biomass; bottom panel) for retrospective runs removing 1-5 years of data from the central California black rockfish model. Black line shows results from the pre-STAR base model, for reference.

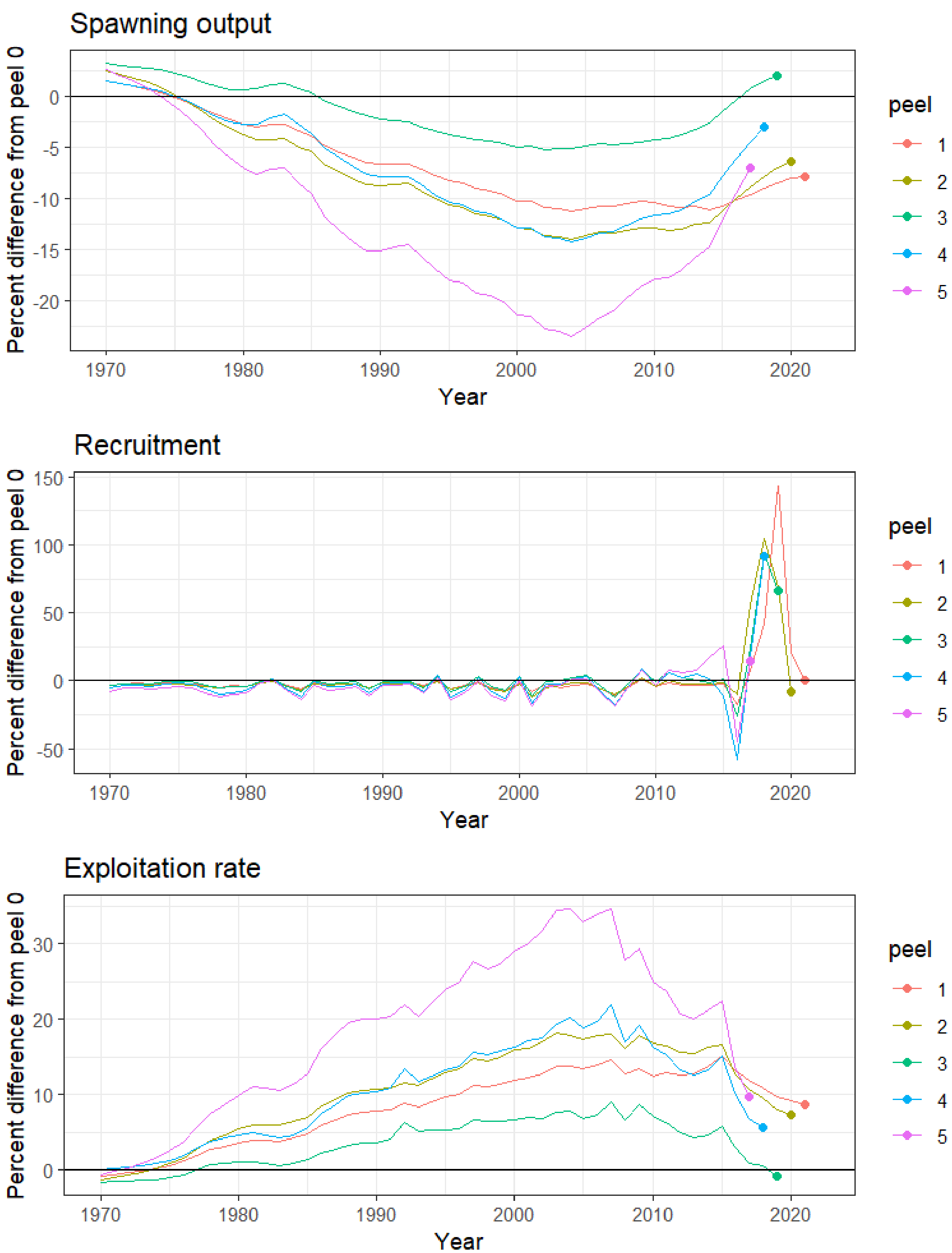


Figure 180: Time series of change in spawning output (billions of eggs; top panel), recruitment (1000s of age-0 fish; middle panel), and exploitation rate (catch divided by age 8+ biomass; bottom panel) for retrospective runs removing 1-5 years of data, relative to the central California pre-STAR black rockfish model.

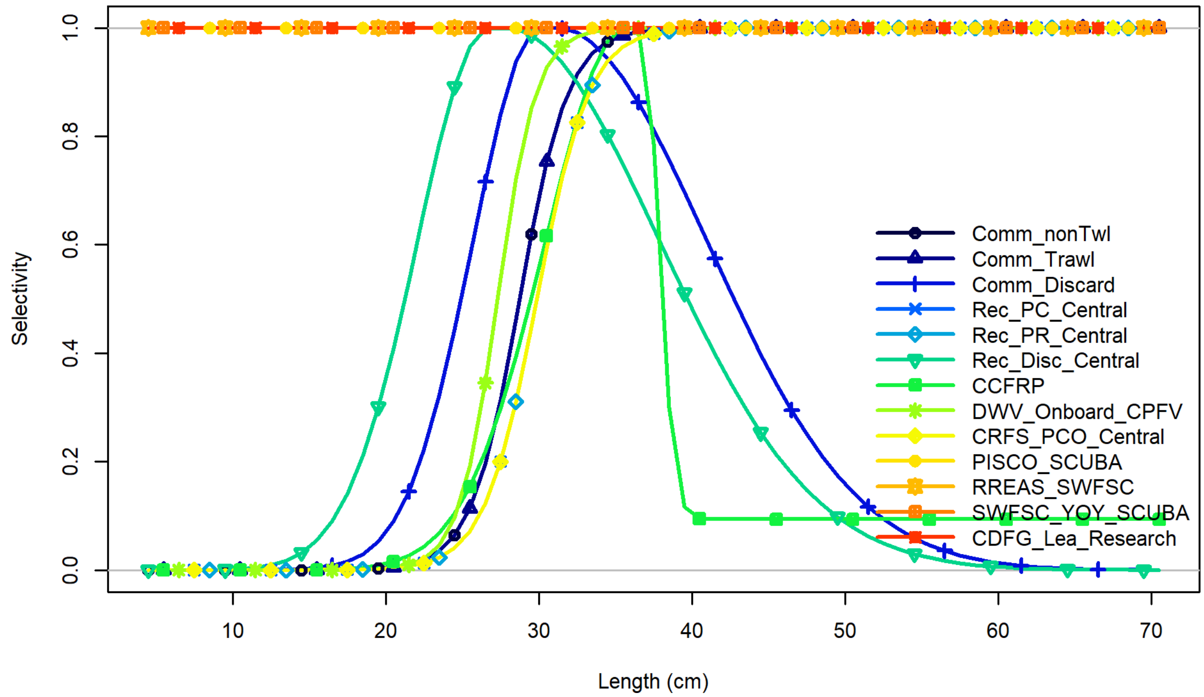


Figure 181: Selectivity at length for fleets in the central California model, forcing asymptotic relationships for all fleets except the discard fleets and the CCFRP survey, per STAR panel request 7.

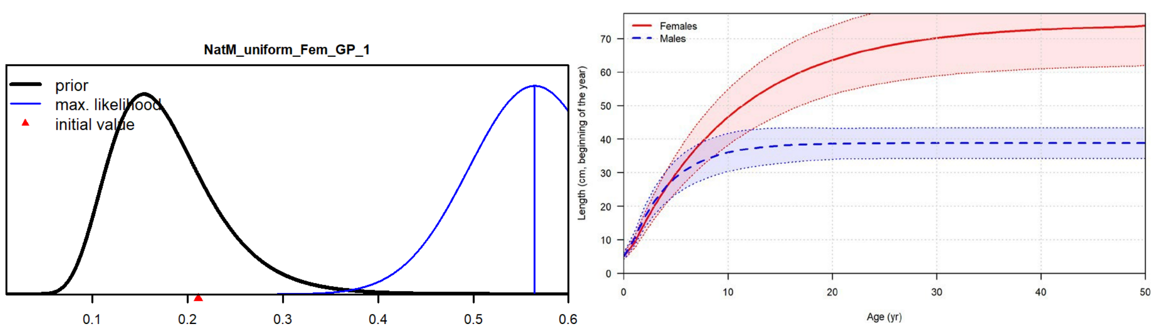


Figure 182: Comparison of prior for natural mortality and estimated value when forcing asymptotic selectivity curves as described in request 8 (left panel). Estimates of length at age for females and males under the same assumption (right panel).

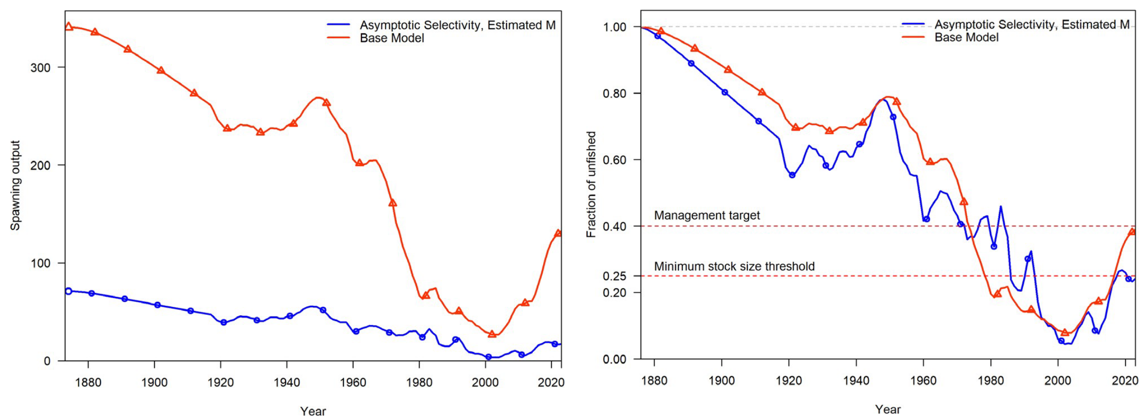


Figure 183: Comparison of a model forcing asymptotic selectivity at length relationships for all fleets except the discard fleets and the CCFRP survey, per request 7, and the pre-STAR base model..

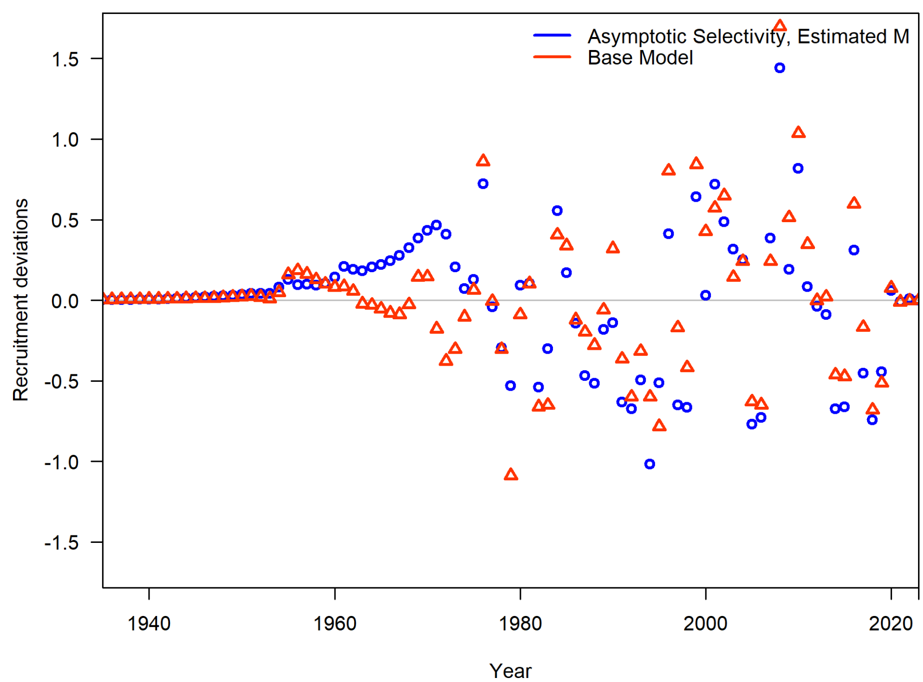


Figure 184: Estimated recruitment deviations in the central California model, forcing asymptotic relationships for all fleets except the discard fleets and the CCFRP survey, per request 7, and allowing dome-shaped selectivity, as in the pre-STAR base model.

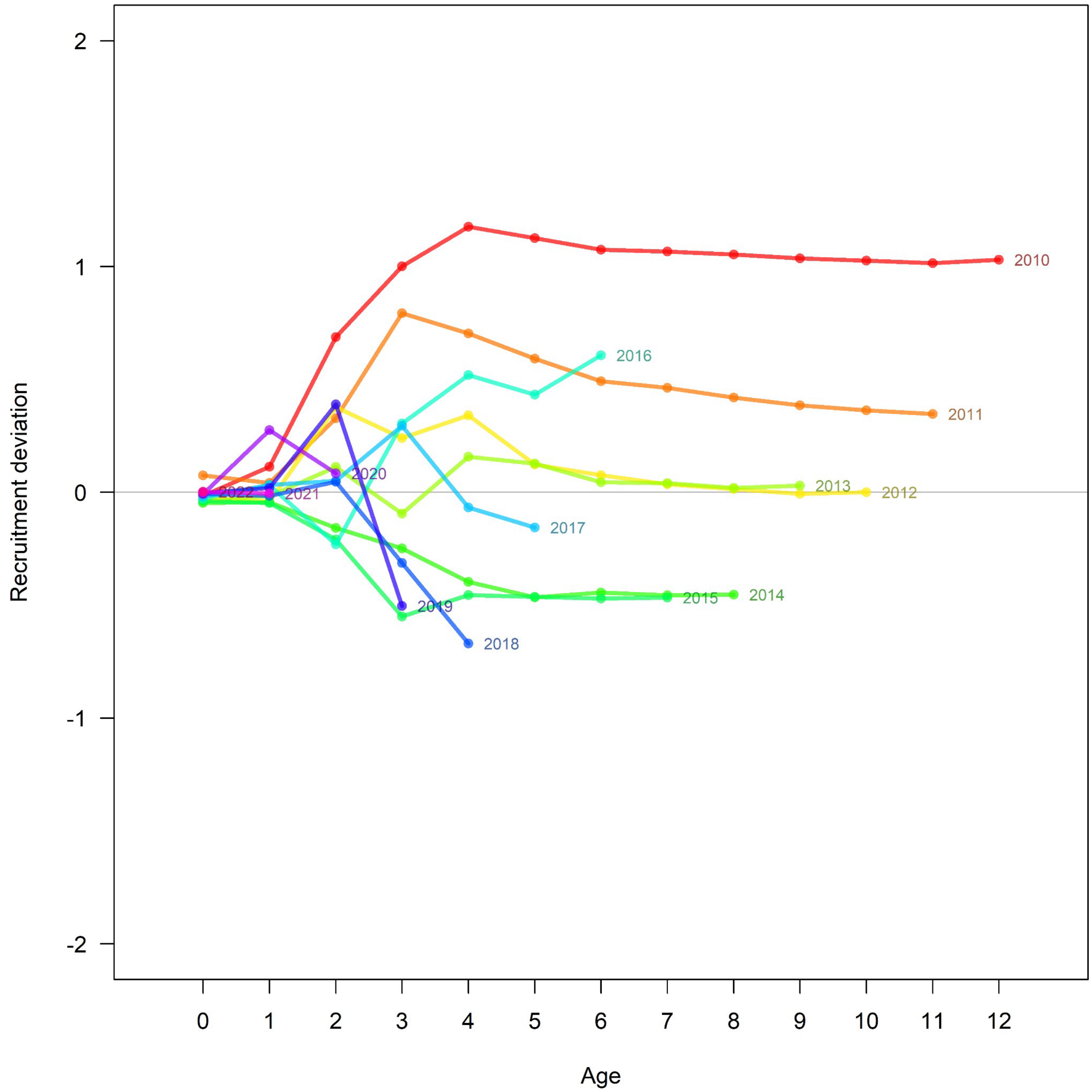


Figure 185: Retrospective analysis of recruitment deviations ('squid plot') for the central California model. 'Age' is the end year of each retrospective peel minus the year of the estimated deviation, e.g. the base model ends in 2022, so the maximum 'age' of the 2010 deviation in the retrospective analysis is 12.

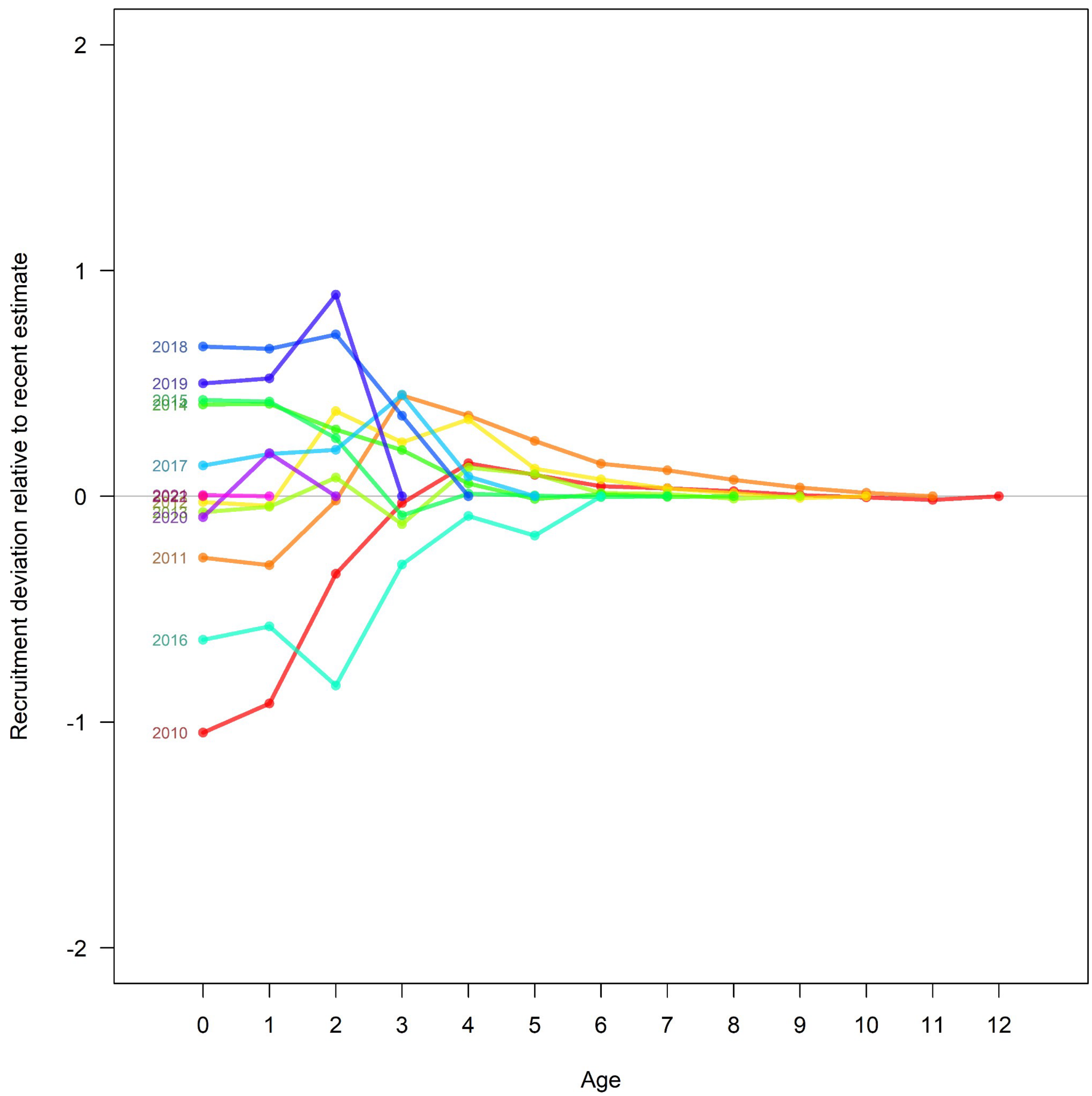


Figure 186: Retrospective analysis of recruitment deviations for the central California model, scaled relative to the most recent recruitment estimate. Convergence of the deviations is represented by the values approaching zero along the vertical axis.

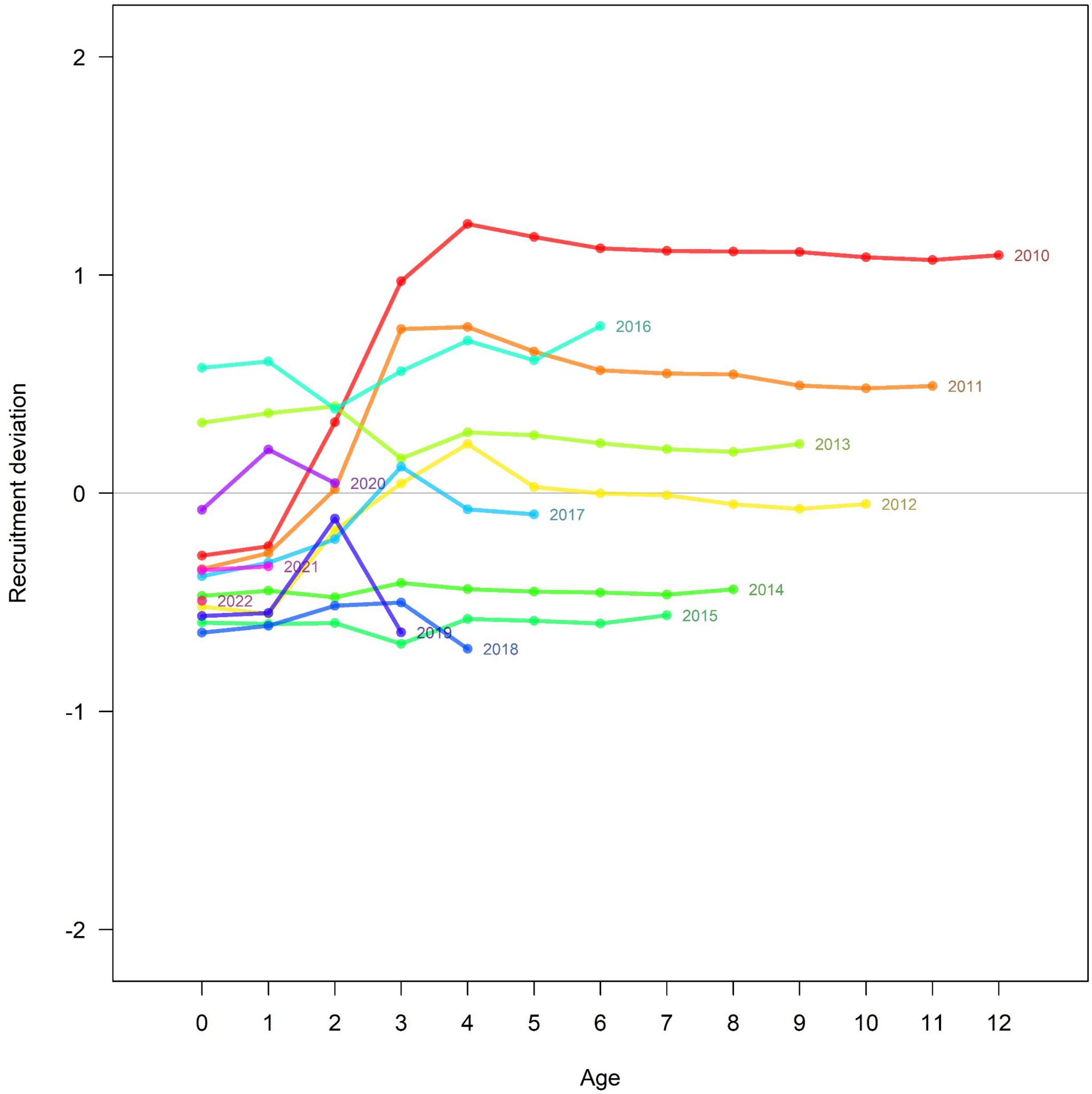


Figure 187: Effect of adding YOY abundance indices to a retrospective analysis of recruitment deviations (‘squid plot’) for the central California model. ‘Age’ is the end year of each retrospective peel minus the year of the estimated deviation, e.g. the base model ends in 2022, so the maximum ‘age’ of the 2010 deviation in the retrospective analysis is 12.

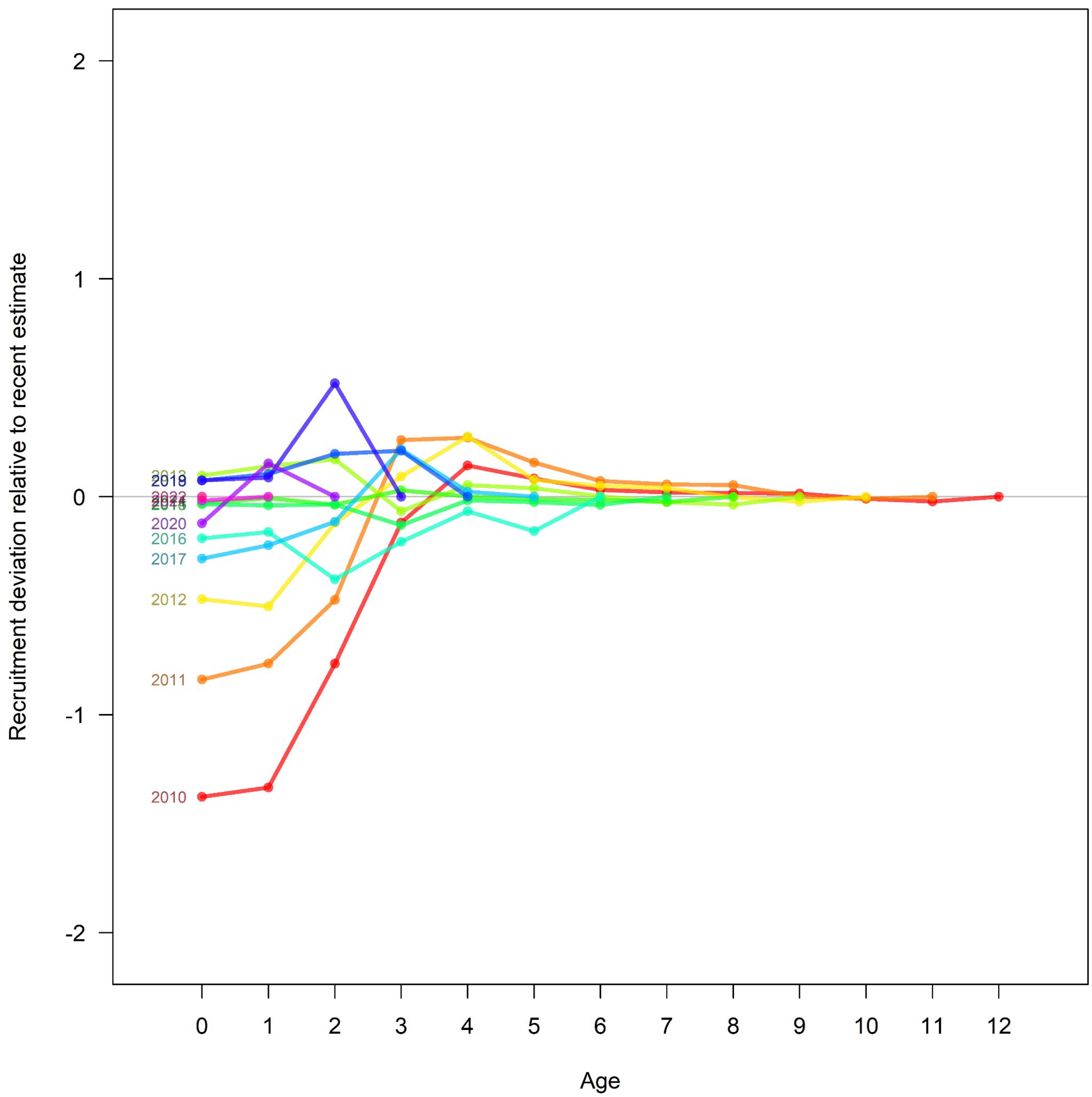


Figure 188: Retrospective analysis of recruitment deviations for the central California model fit with YOY abundance indices, scaled relative to the most recent recruitment estimate. Convergence of the deviations is represented by the values approaching zero along the vertical axis.

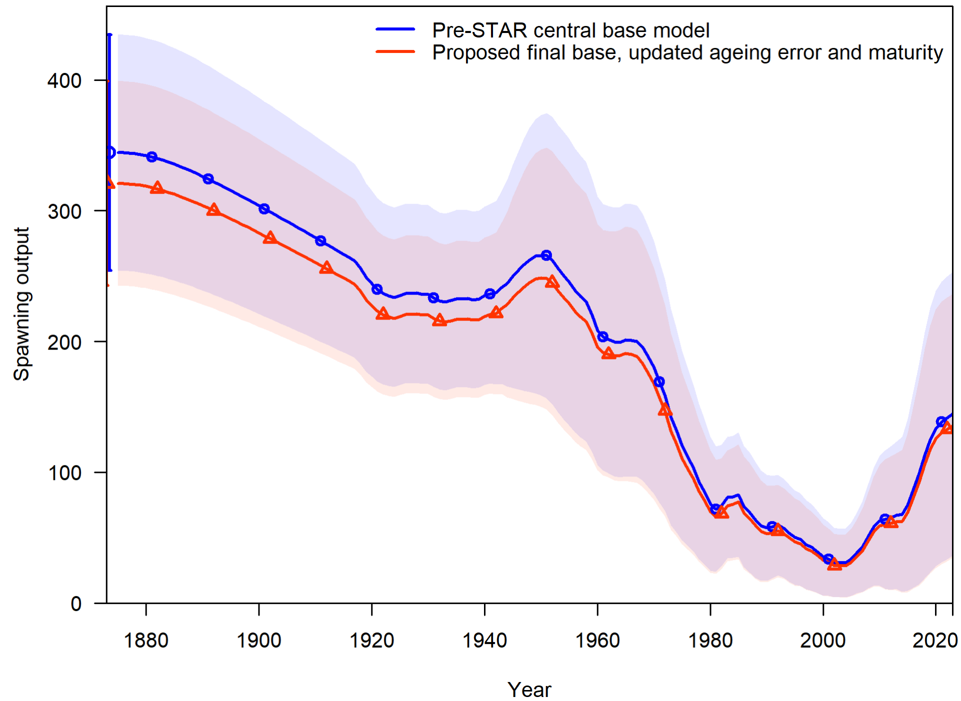


Figure 189: Time series of spawning output (billions of eggs) comparing the pre-STAR base model to a revised model with updated ageing error matrices and a spline function for maturity at length.

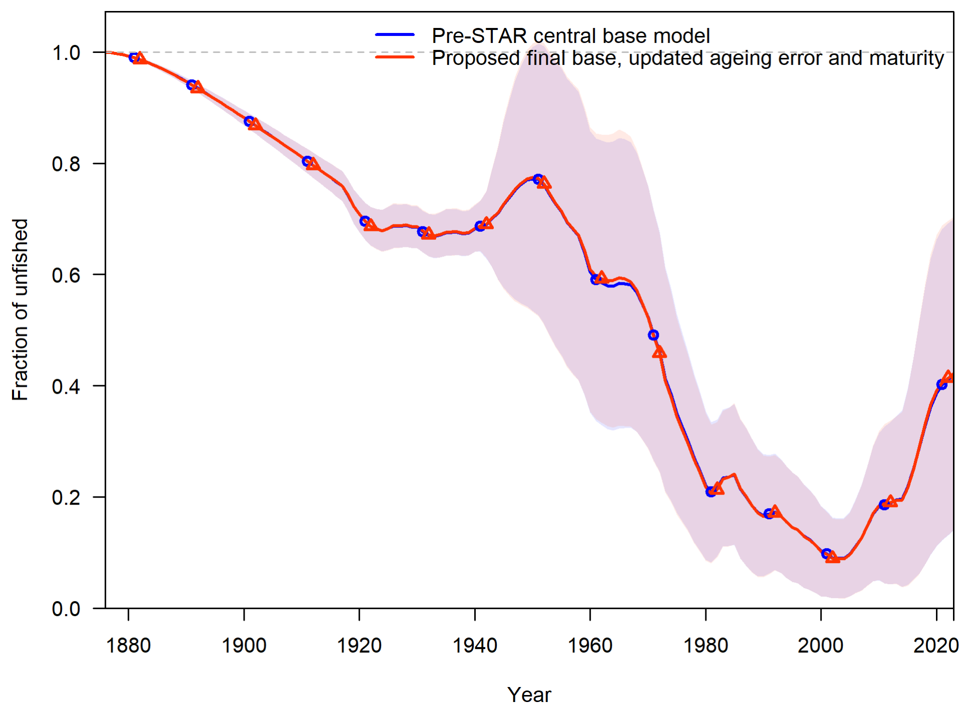


Figure 190: Time series of relative spawning output comparing the pre-STAR base model to a revised model with updated ageing error matrices and a spline function for maturity at length.

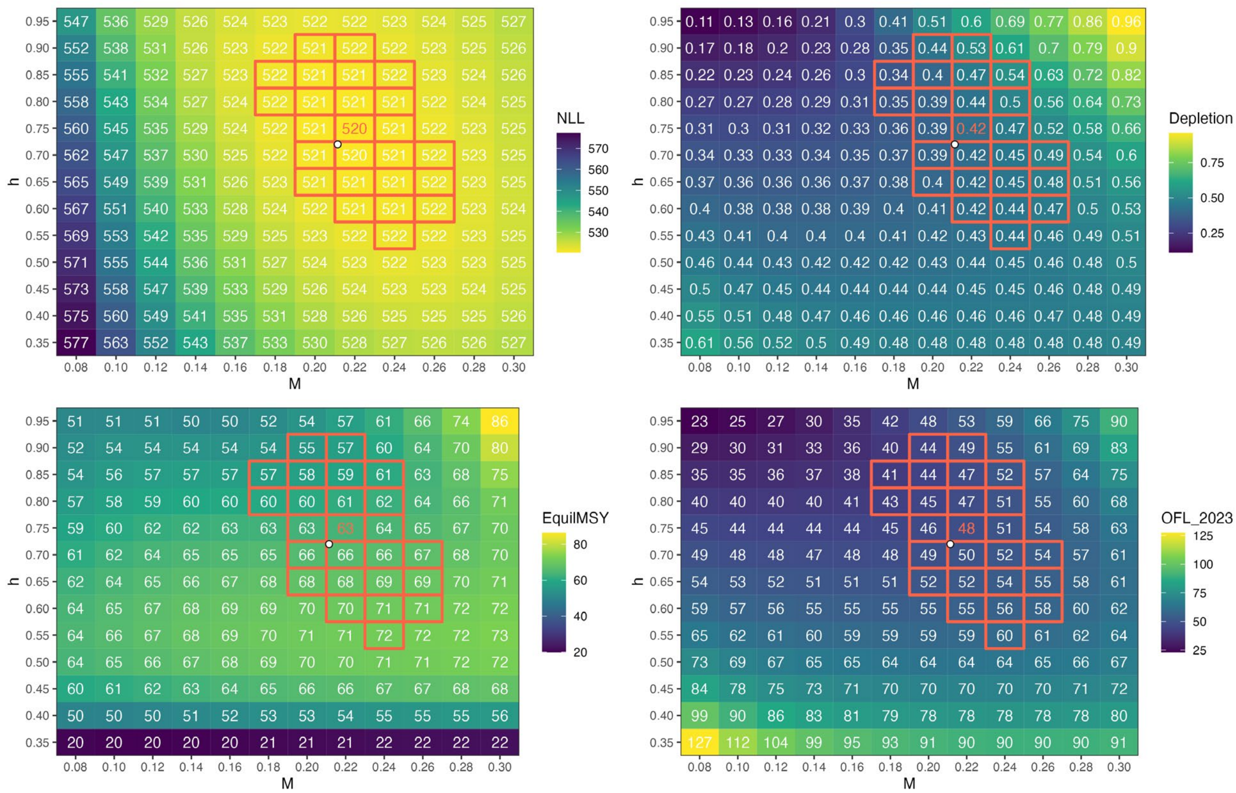


Figure 191: Bivariate profile over steepness and female natural mortality, plotting NLL (top left), Depletion (top right), Equilibrium MSY (bottom left), and OFL (bottom right). The white point is the base model. Numbers in red are values at the NLL minimum. Parameter combinations outlined in red are within the bivariate 75% chi-squared interval of the NLL minimum. Numbers within the plots are rounded for readability.

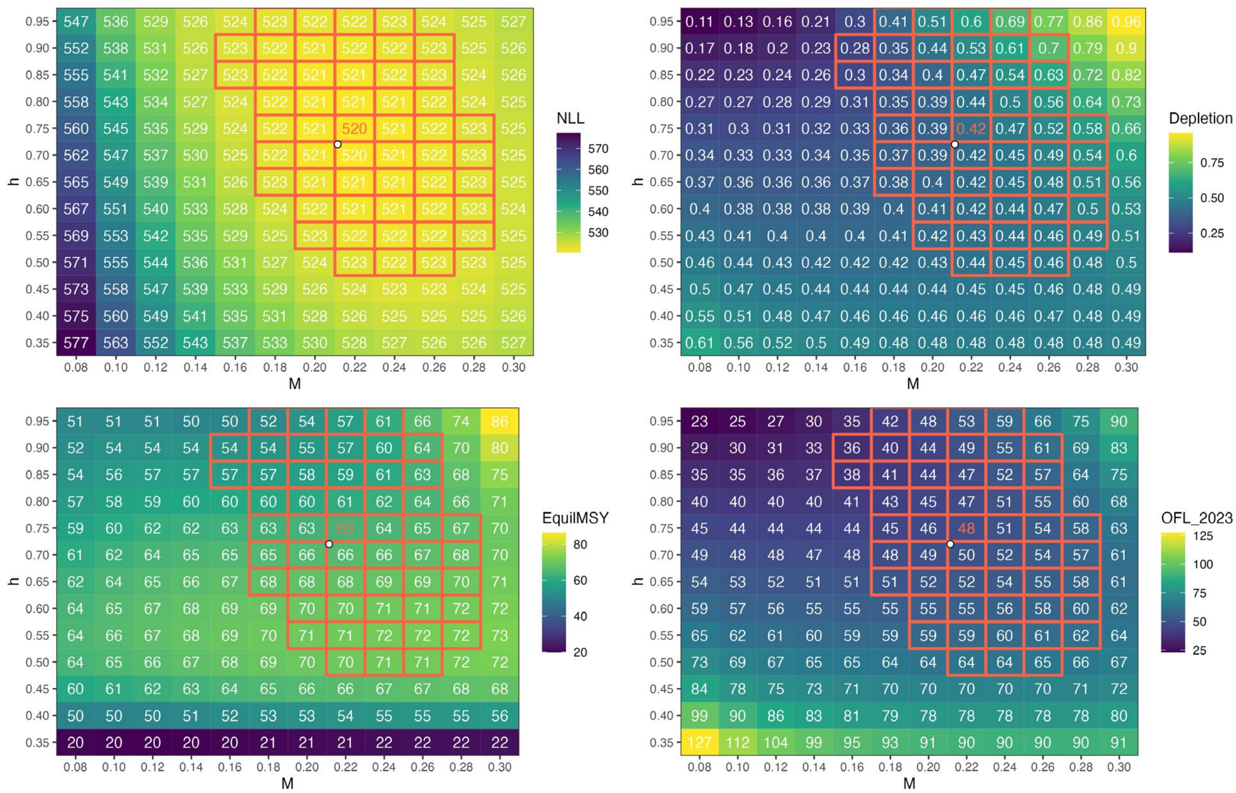


Figure 192: Bivariate profile over steepness and female natural mortality, plotting NLL (top left), Depletion (top right), Equilibrium MSY (bottom left), and OFL (bottom right). The white point is the base model. Numbers in red are values at the NLL minimum. Parameter combinations outlined in red are within the bivariate 95% chi-squared interval of the NLL minimum. Numbers within the plots are rounded for readability.

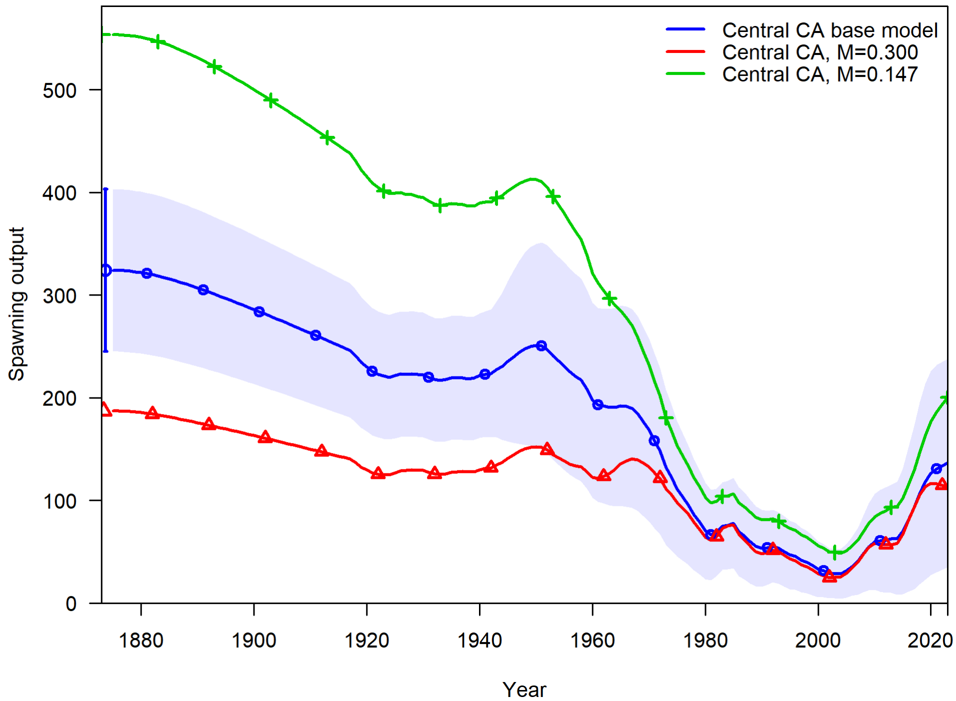


Figure 193: Comparison of spawning output time series (billions of eggs) for alternative M values (states of nature) for the central California post-STAR base model.

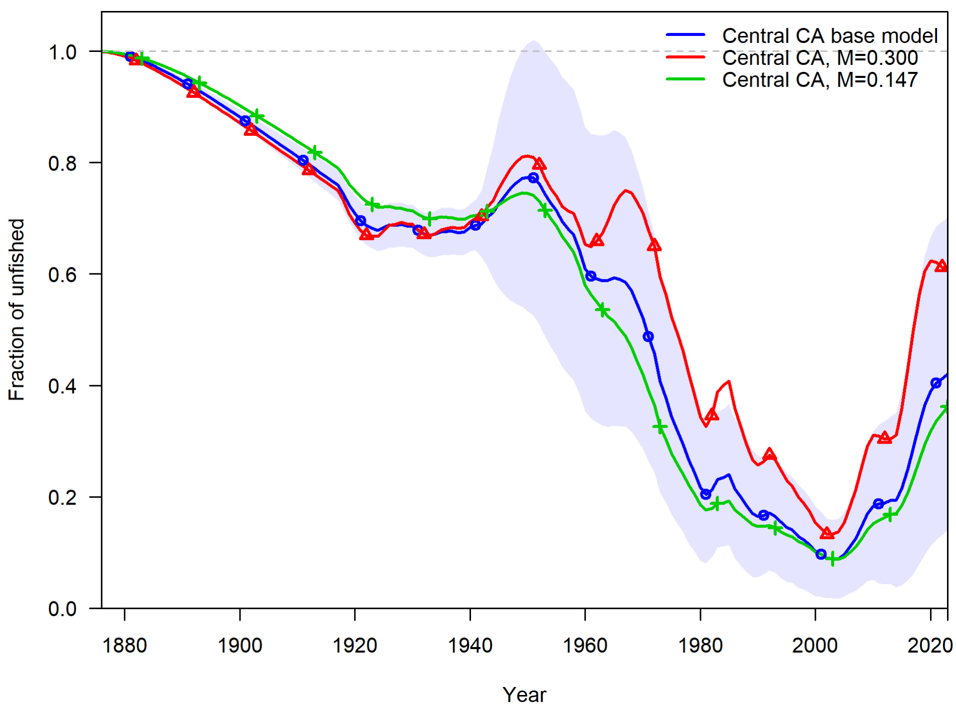


Figure 194: Comparison of relative spawning output time series (relative to unfished spawning output) for alternative M values (states of nature) for the central California post-STAR base model.

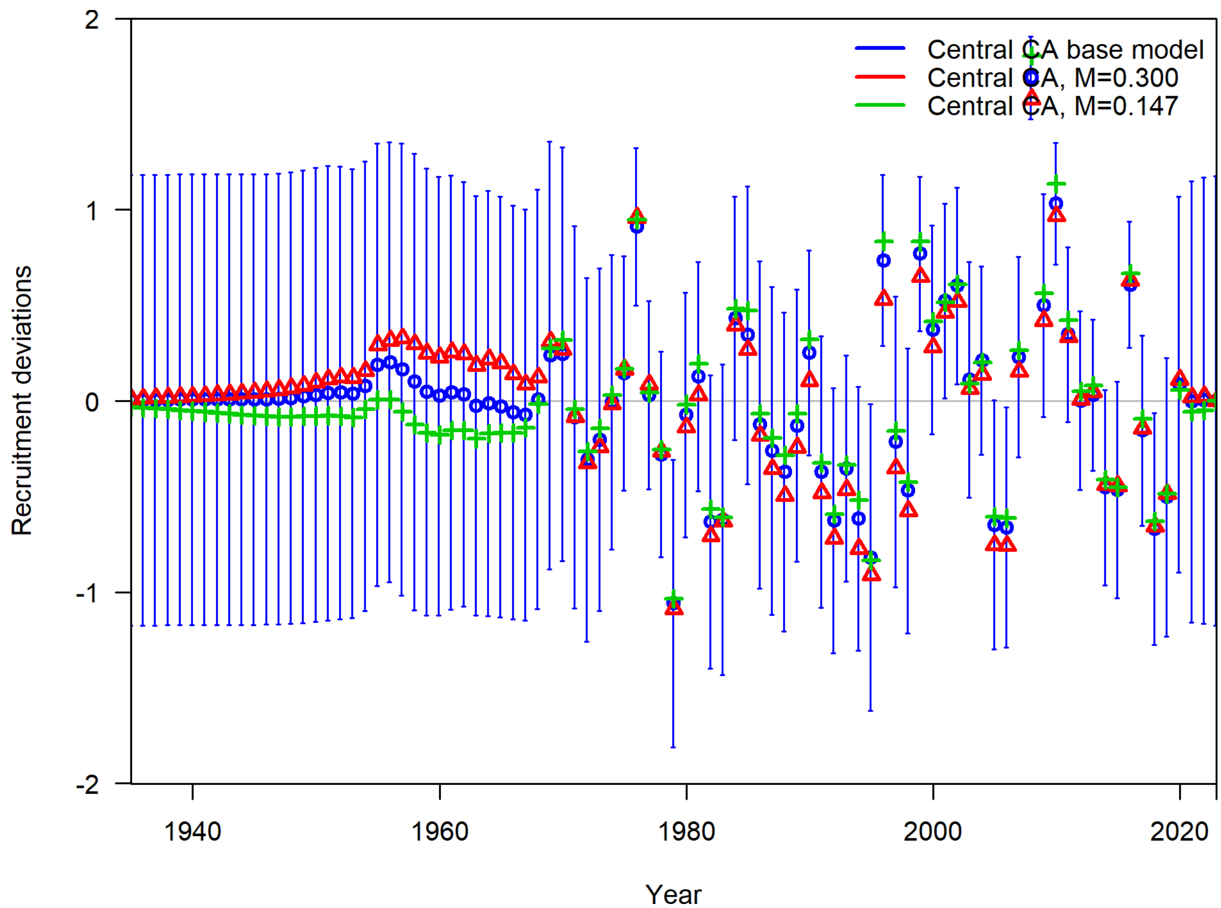


Figure 195: Comparison of estimated recruitment deviations given alternative M values (states of nature) for the central California post-STAR base model.

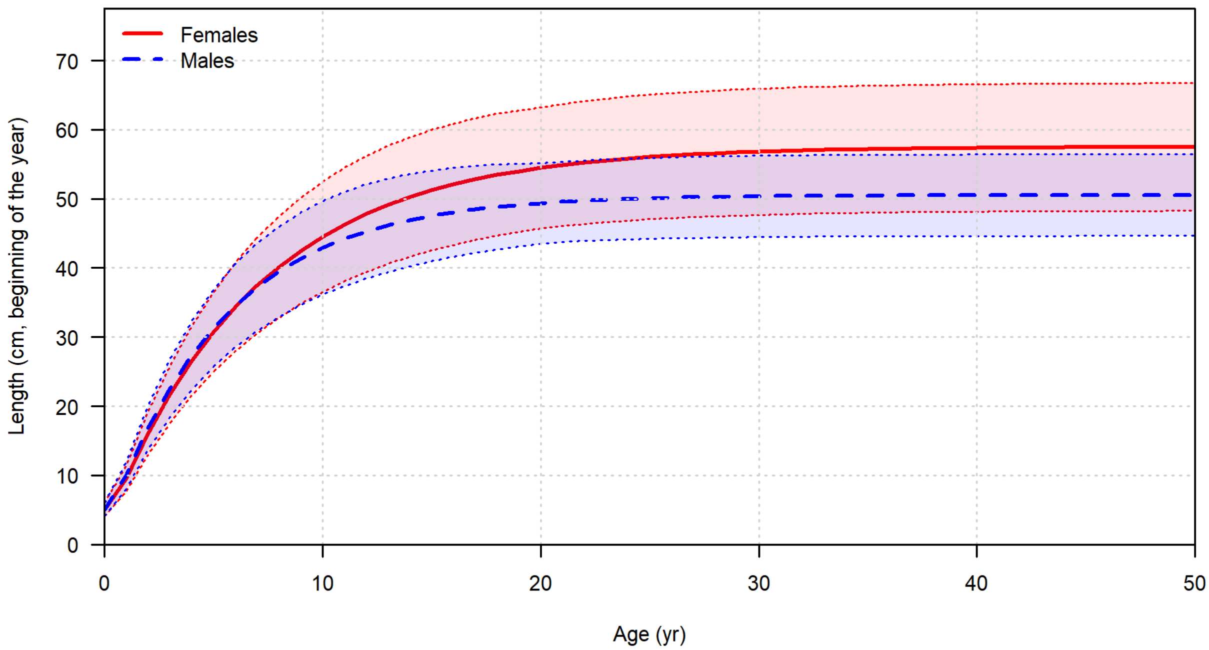


Figure 196: Length at age in the central area model. Shaded area indicates 95% distribution of length at age around estimated growth curve.

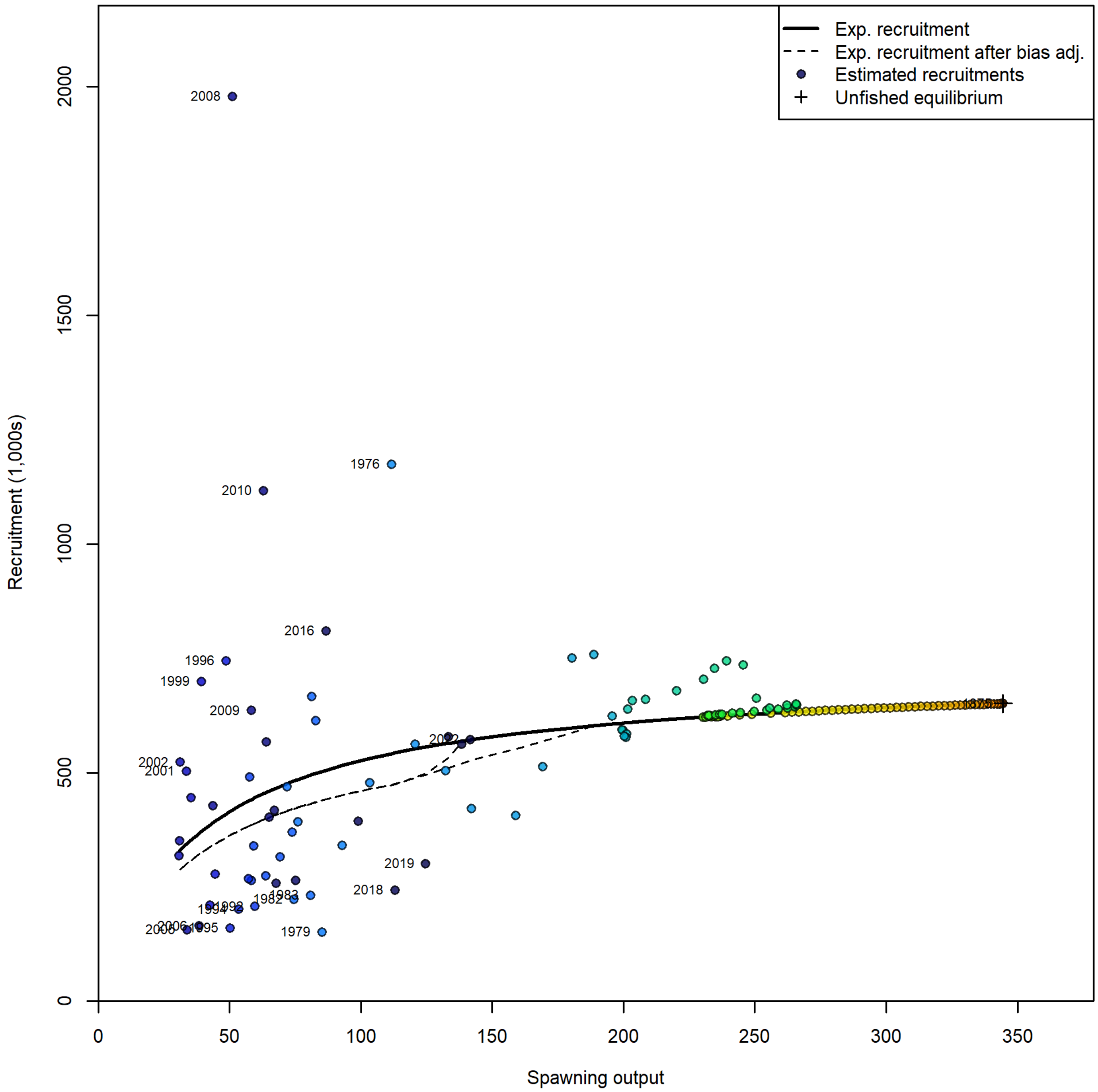


Figure 197: Stock-recruit curve for the central base model with labels on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years. Steepness was fixed at the prior mean of 0.72.

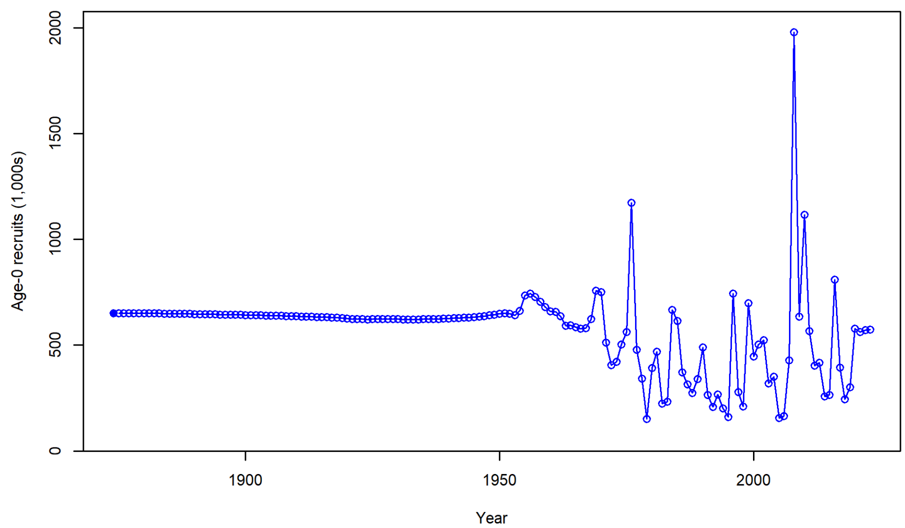


Figure 198: Number of age-0 recruits (1000s) in the central base model.

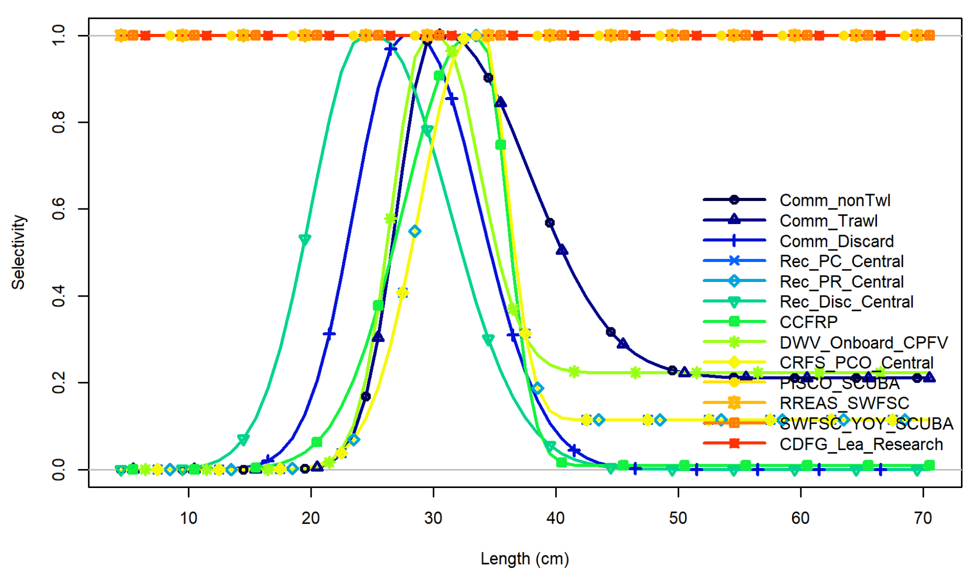


Figure 199: Length-based selectivity curves estimated for the central California model. Fleets retained in the model file for implied fits, but not included in the likelihood: PISCO SCUBA, RREAS SWFSC, and SWFSC YOY SCUBA.

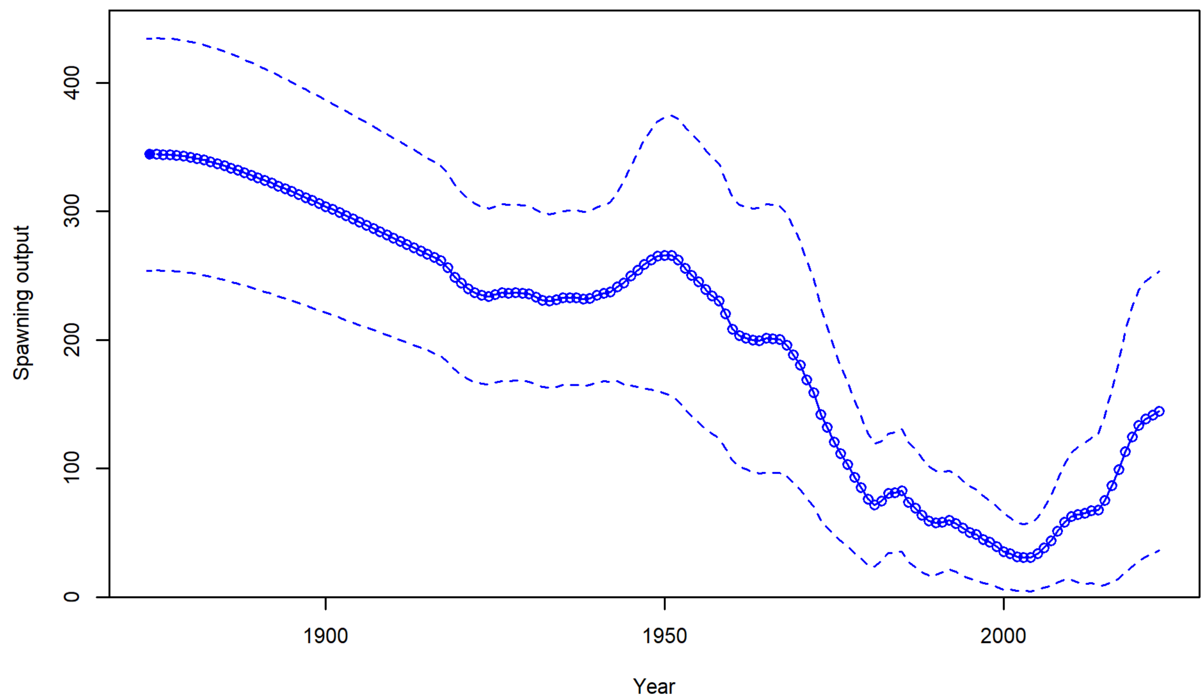


Figure 200: Central California spawning output (billions of eggs) with ~95% asymptotic intervals.

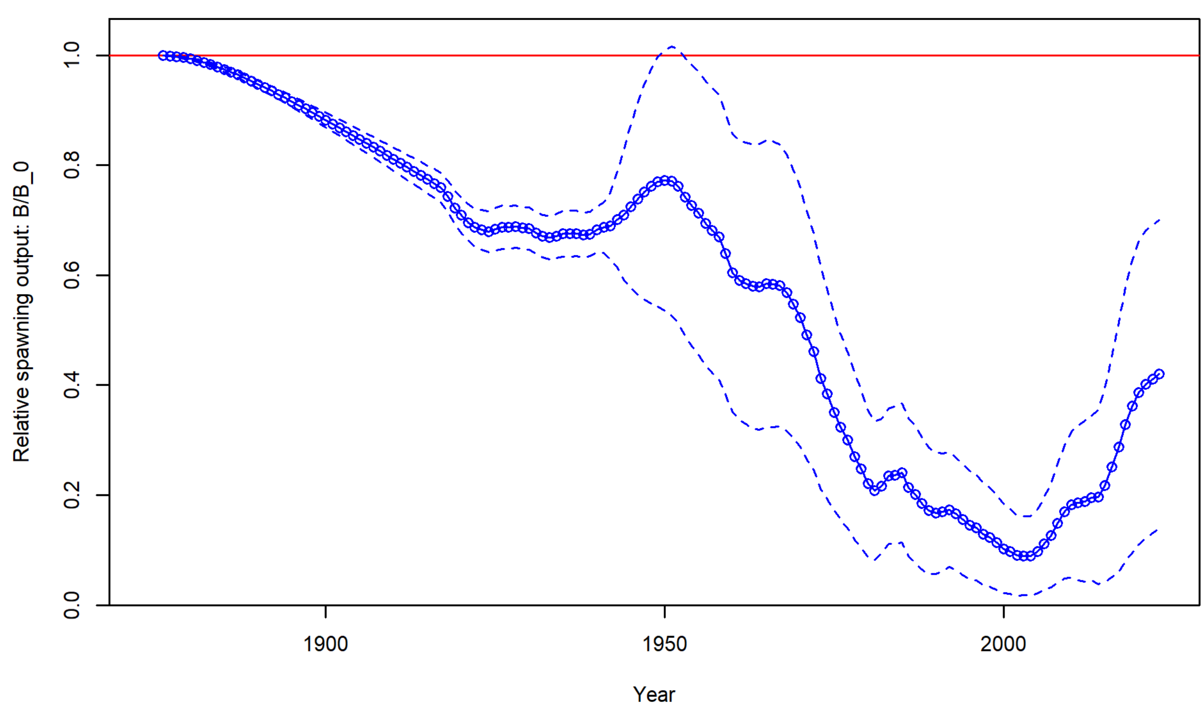


Figure 201: Relative spawning output in central California: B/B_0 with ~95% asymptotic intervals

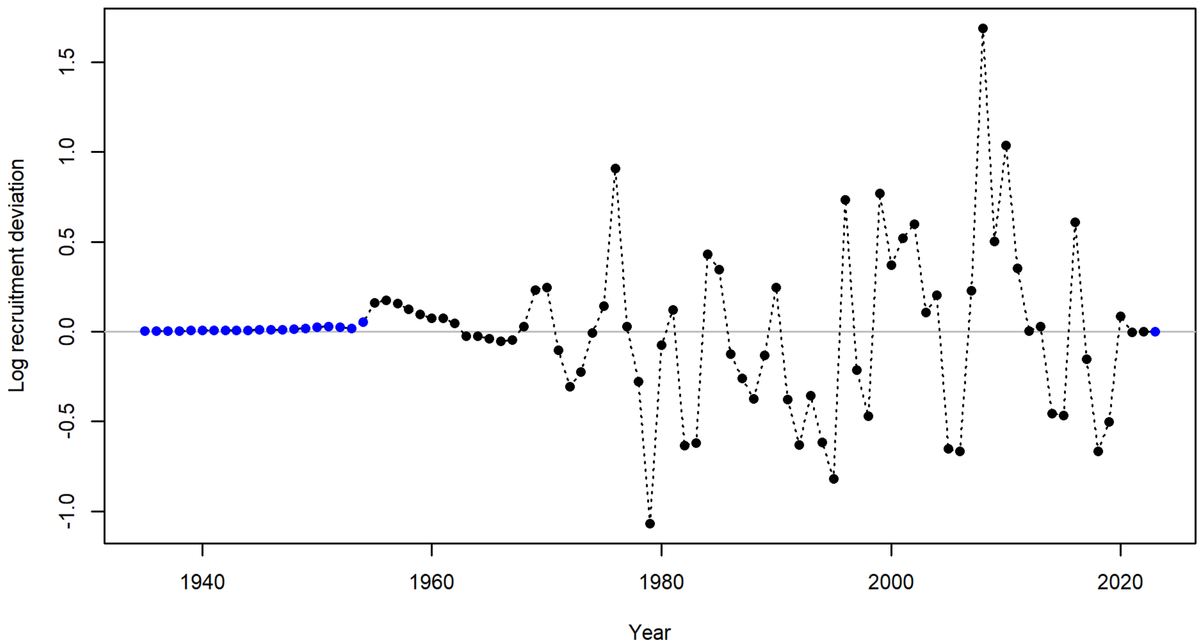


Figure 202: Estimated log-scale recruitment deviations in the central base model.

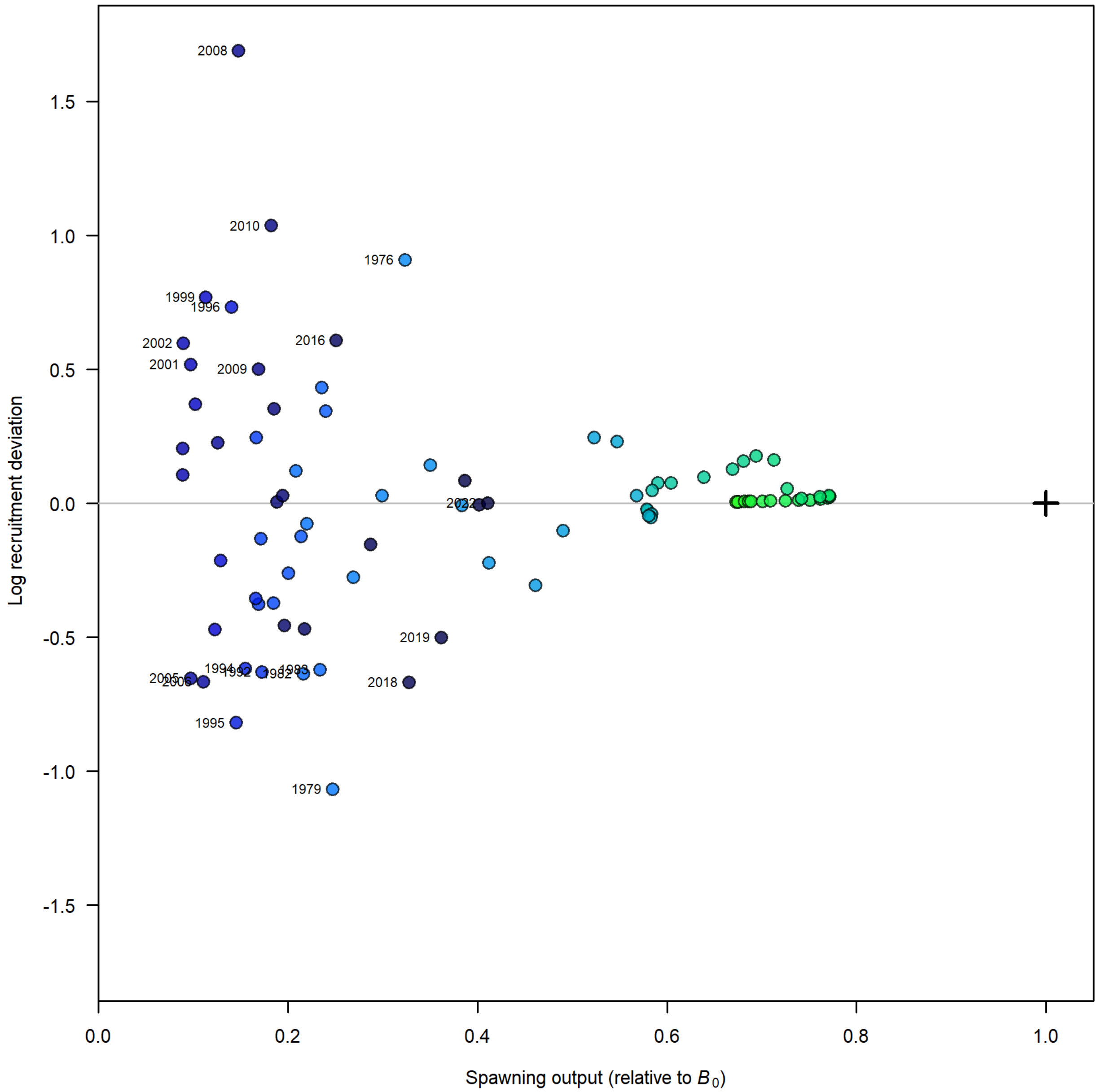


Figure 203: Deviations around the stock-recruit curve for the central California model. Labels are on first, last, and years with (log) deviations > 0.5. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

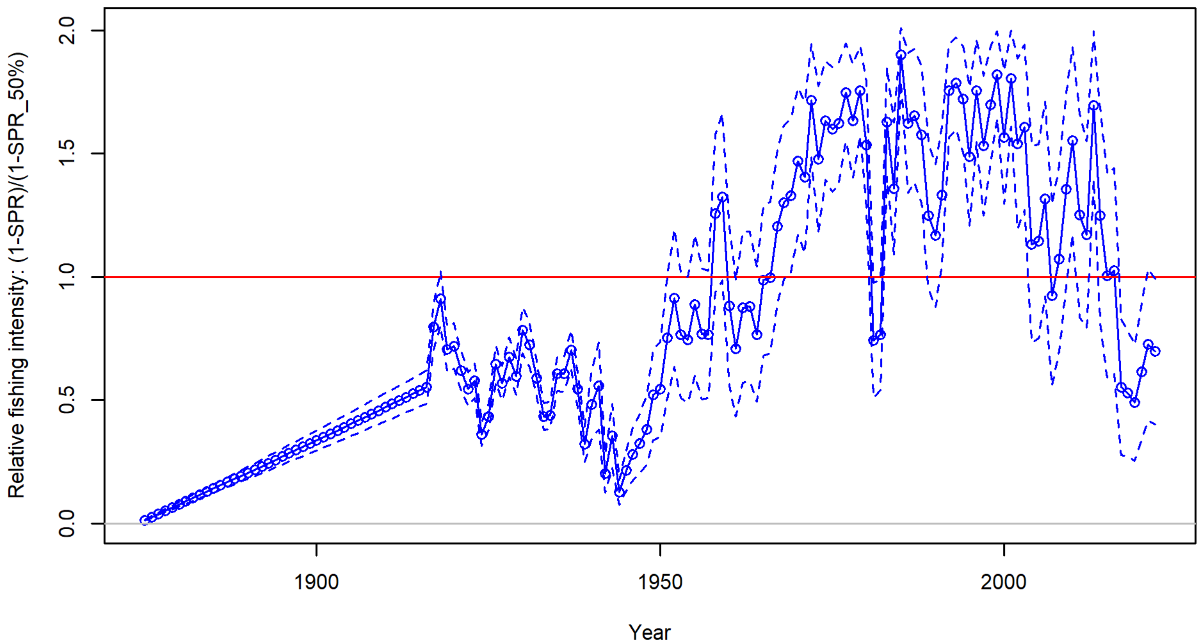


Figure 204: Equilibrium estimates of relative fishing intensity, (1-SPR) / (1-SPR50%) for the central California base model.

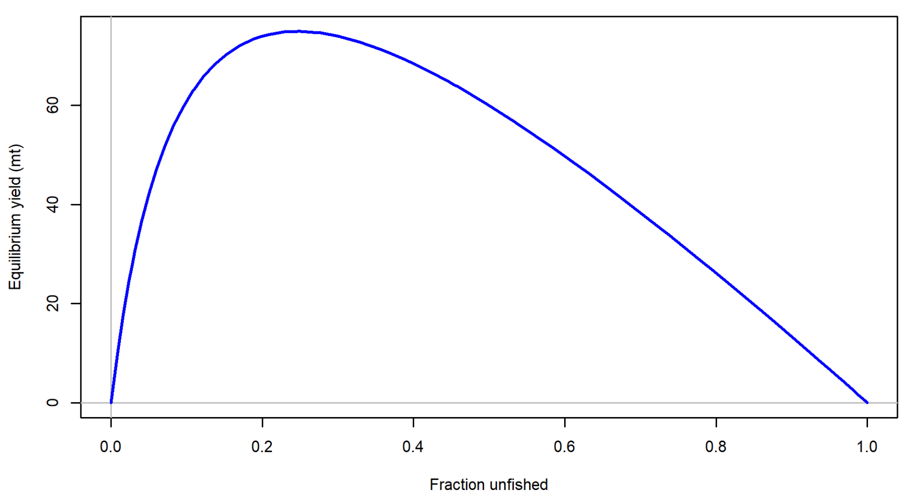


Figure 205: Yield curve for the central California base model.

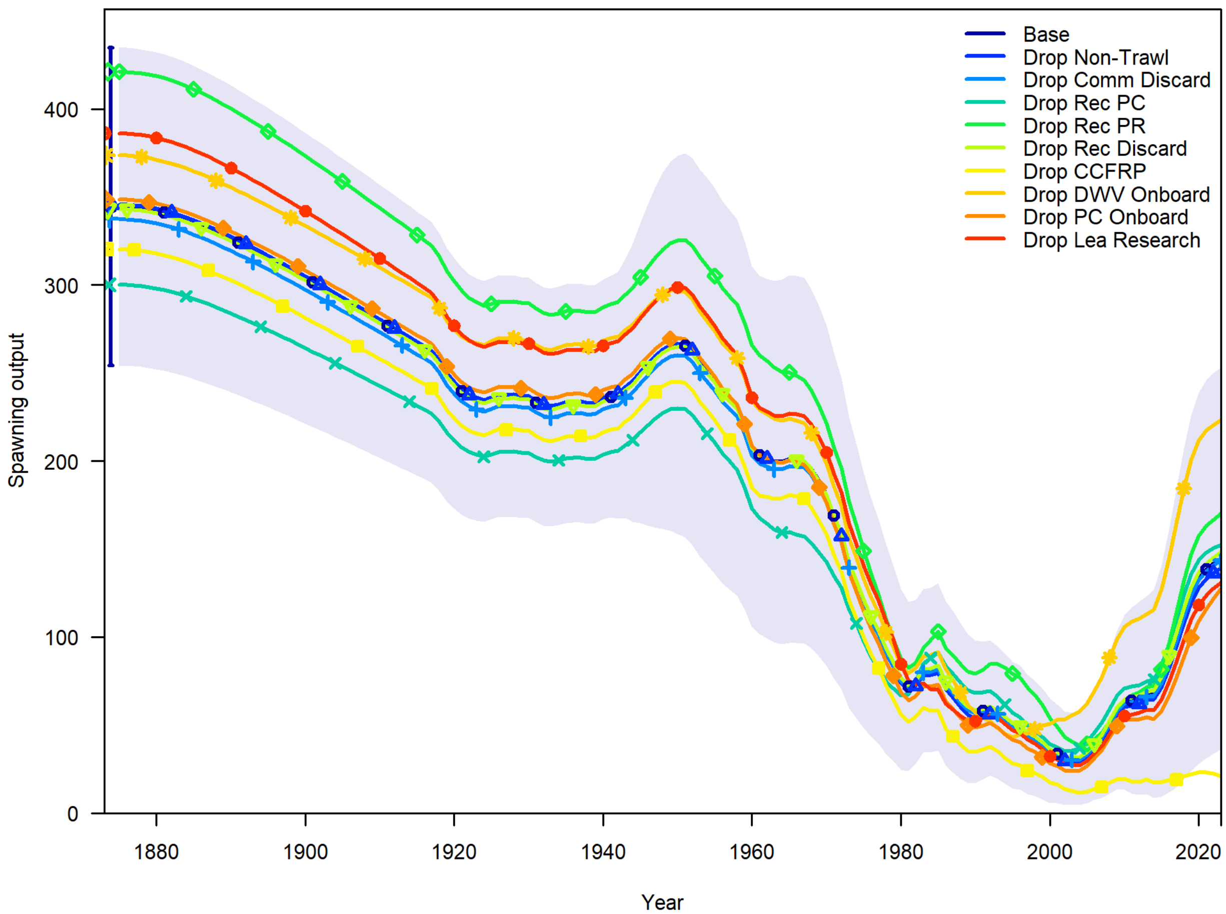


Figure 206: Changes in spawning output (billions of eggs) resulting from removal of individual fleets' data sources in the central California model.

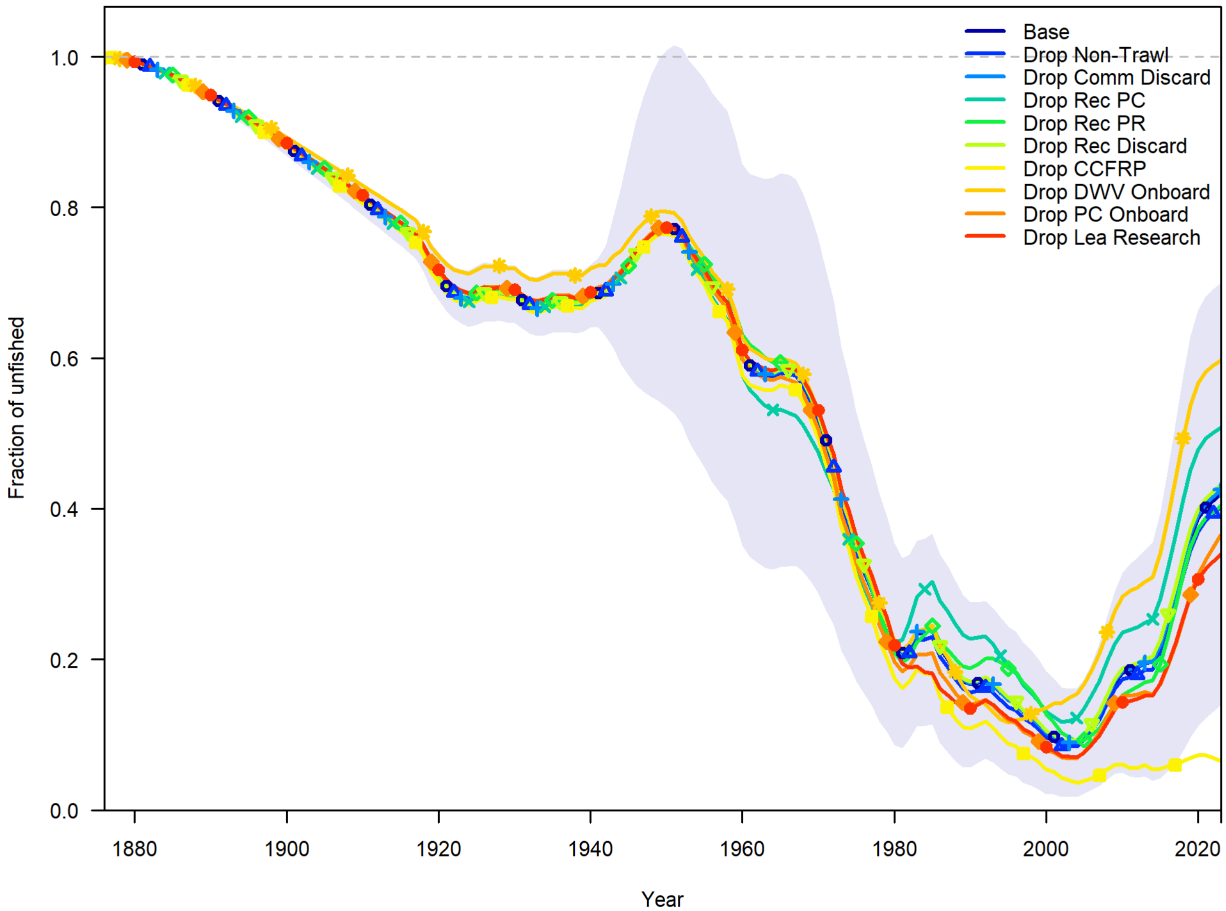


Figure 207: Changes in relative spawning output (B / B_unfished) resulting from removal of individual fleets' data sources in the central California model.

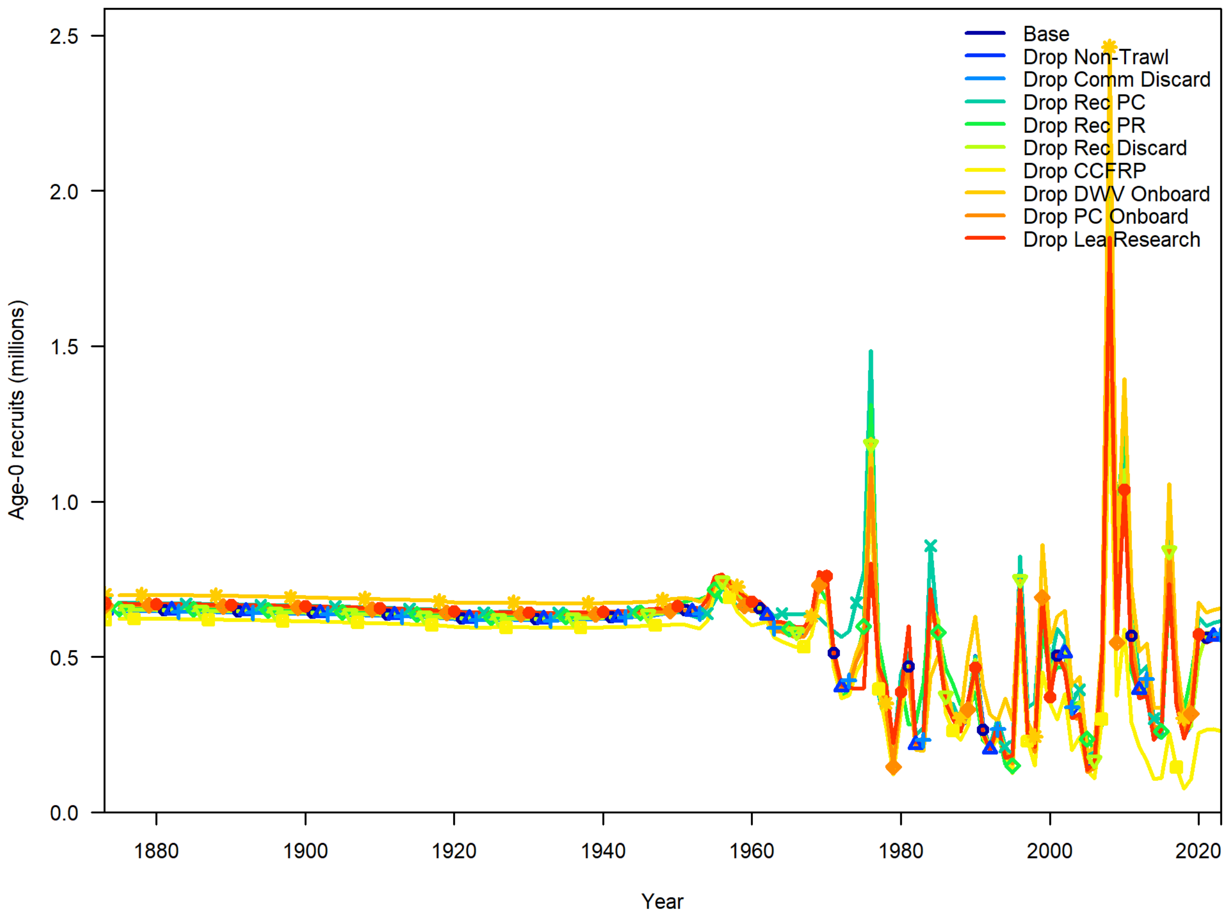


Figure 208: Changes in estimated recruitment of age-zero fish resulting from removal of individual fleets' data sources in the central California model.

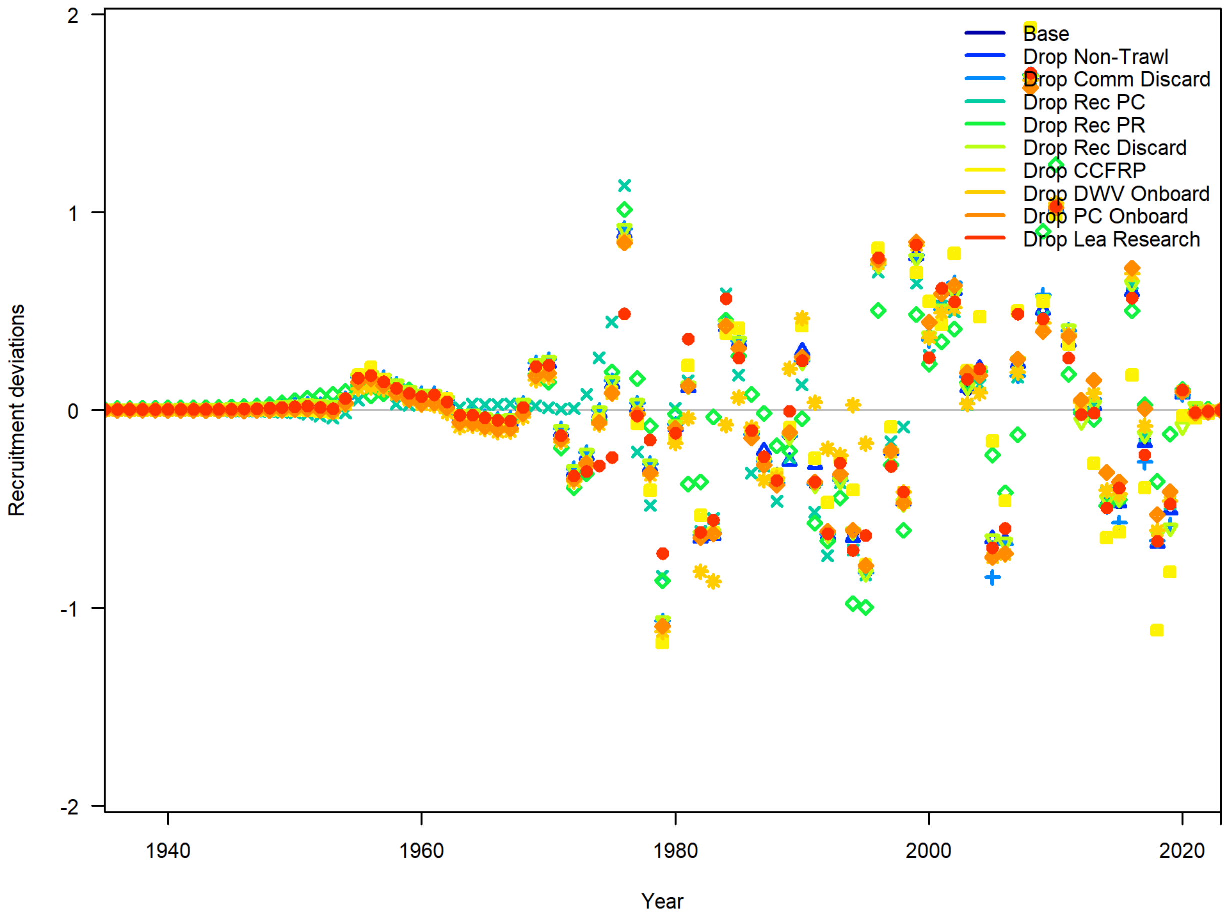


Figure 209: Changes in estimated log-scale recruitment deviations resulting from removal of individual fleets' data sources in the central California model.

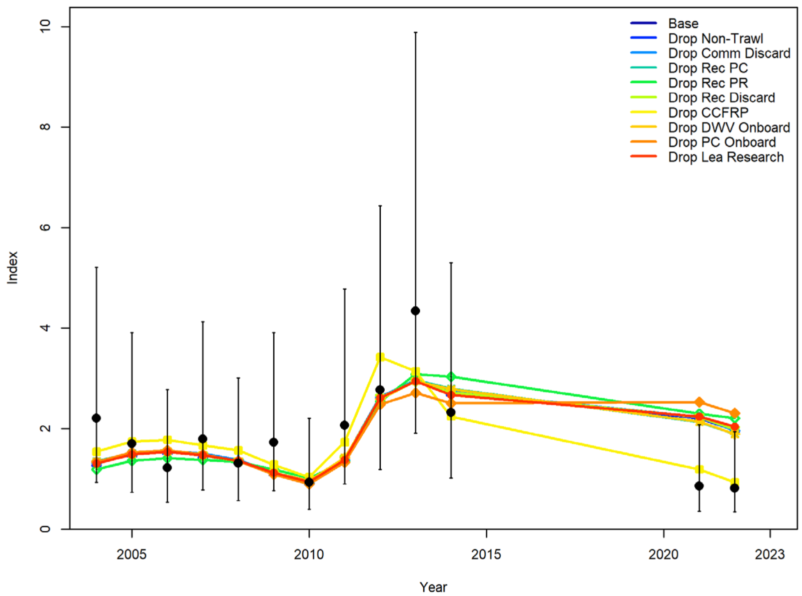


Figure 210: Fits to the central area recreational PR index when removing data one fleet at a time.

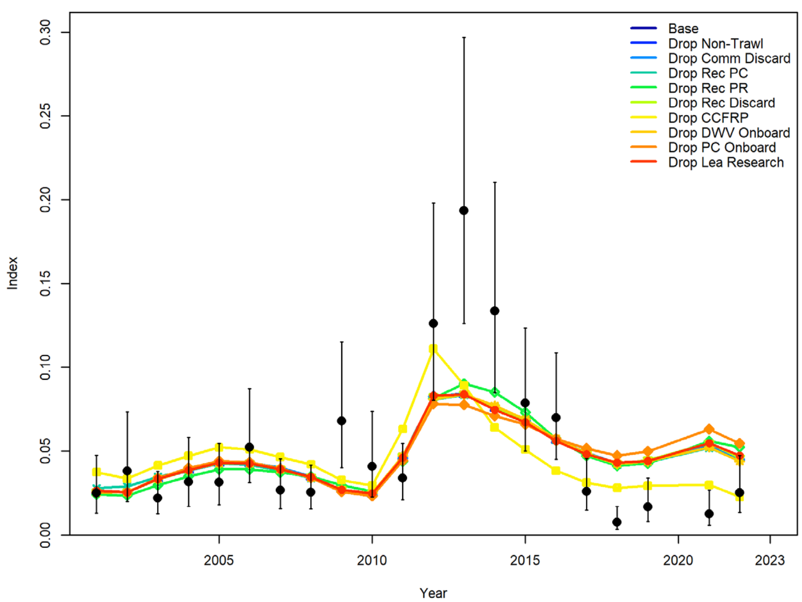


Figure 211: Fits to the central area CRFS PC onboard index when removing data one fleet at a time.

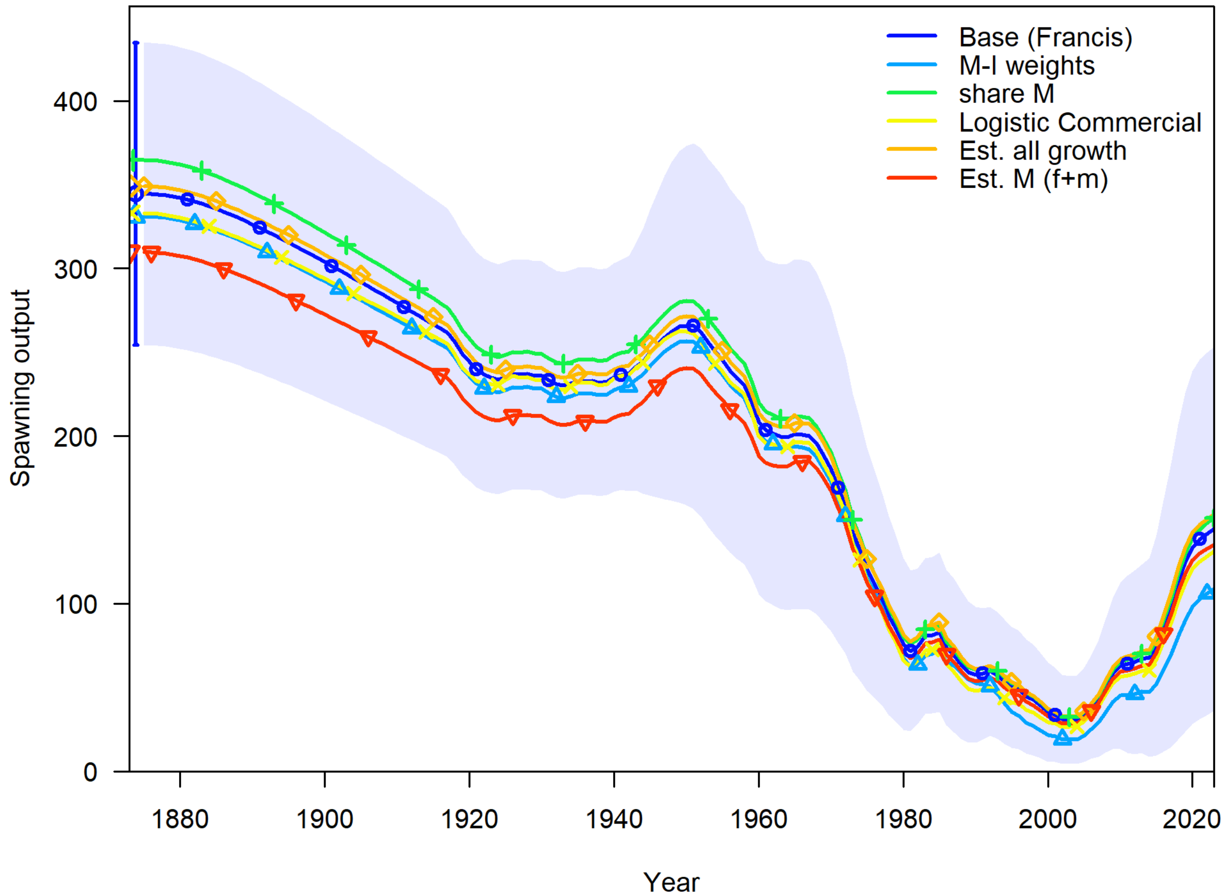


Figure 212: Trends in spawning output (billions of eggs) associated with sensitivity analyses for the central California base model.

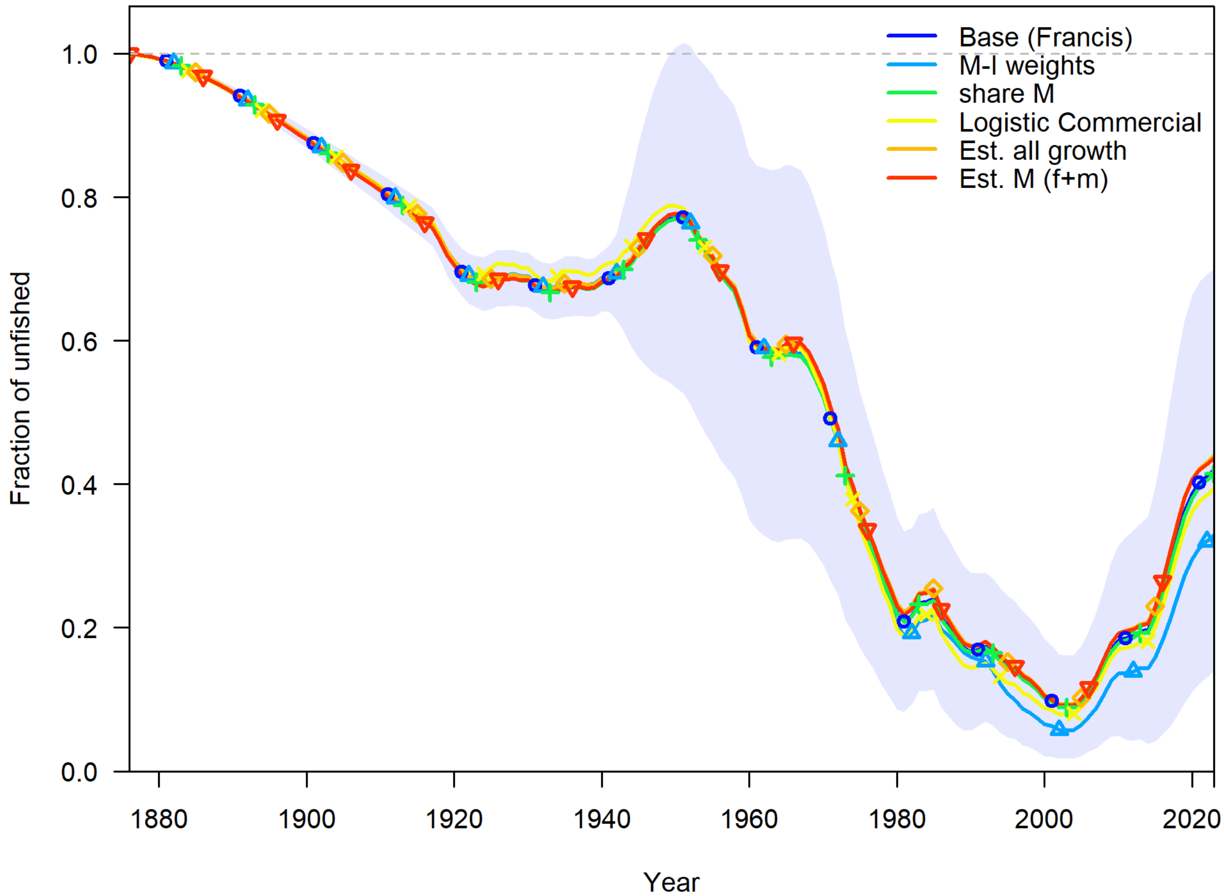


Figure 213: Trends in relative spawning output (B / B_unfished) associated with sensitivity analyses for the central California base model.

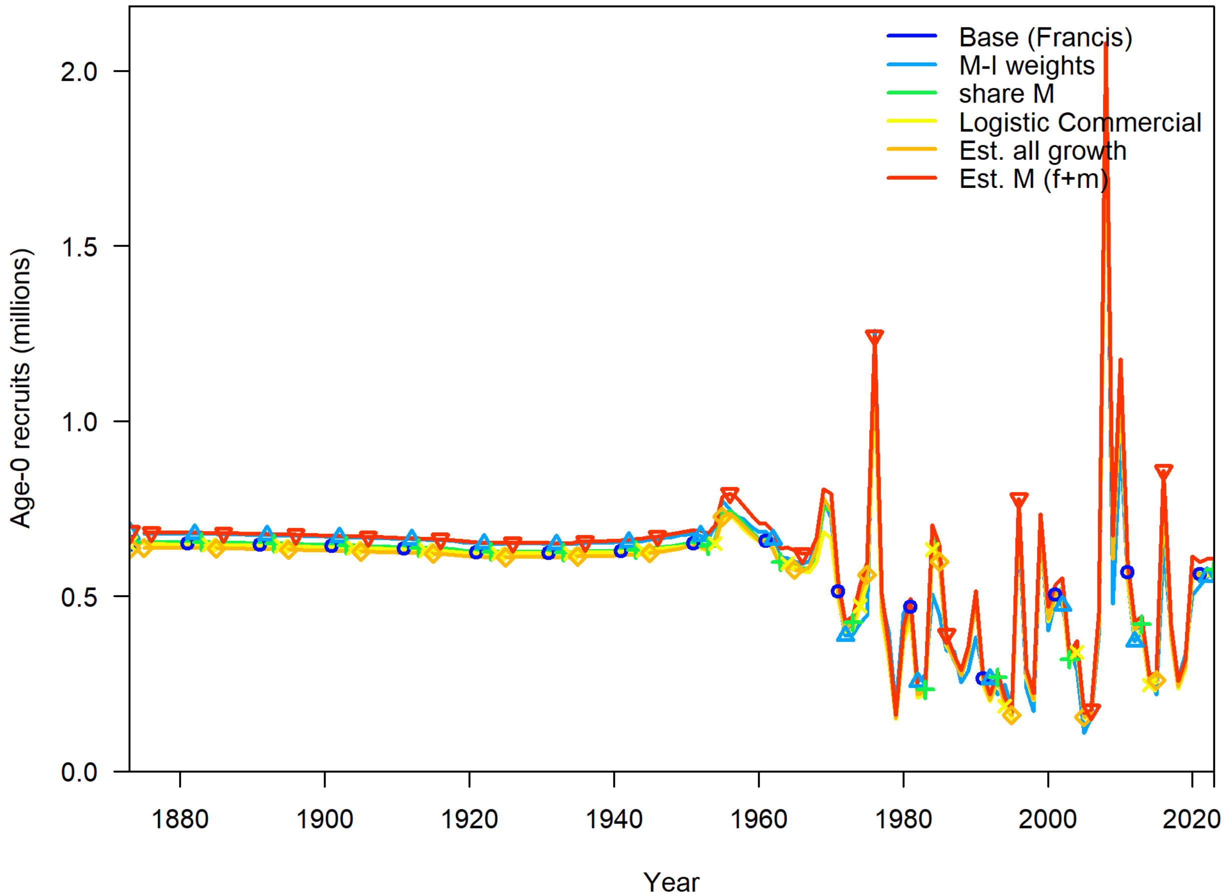


Figure 214: Trends in recruitment of age-0 fish (1000s) associated with sensitivity analyses for the central California base model.

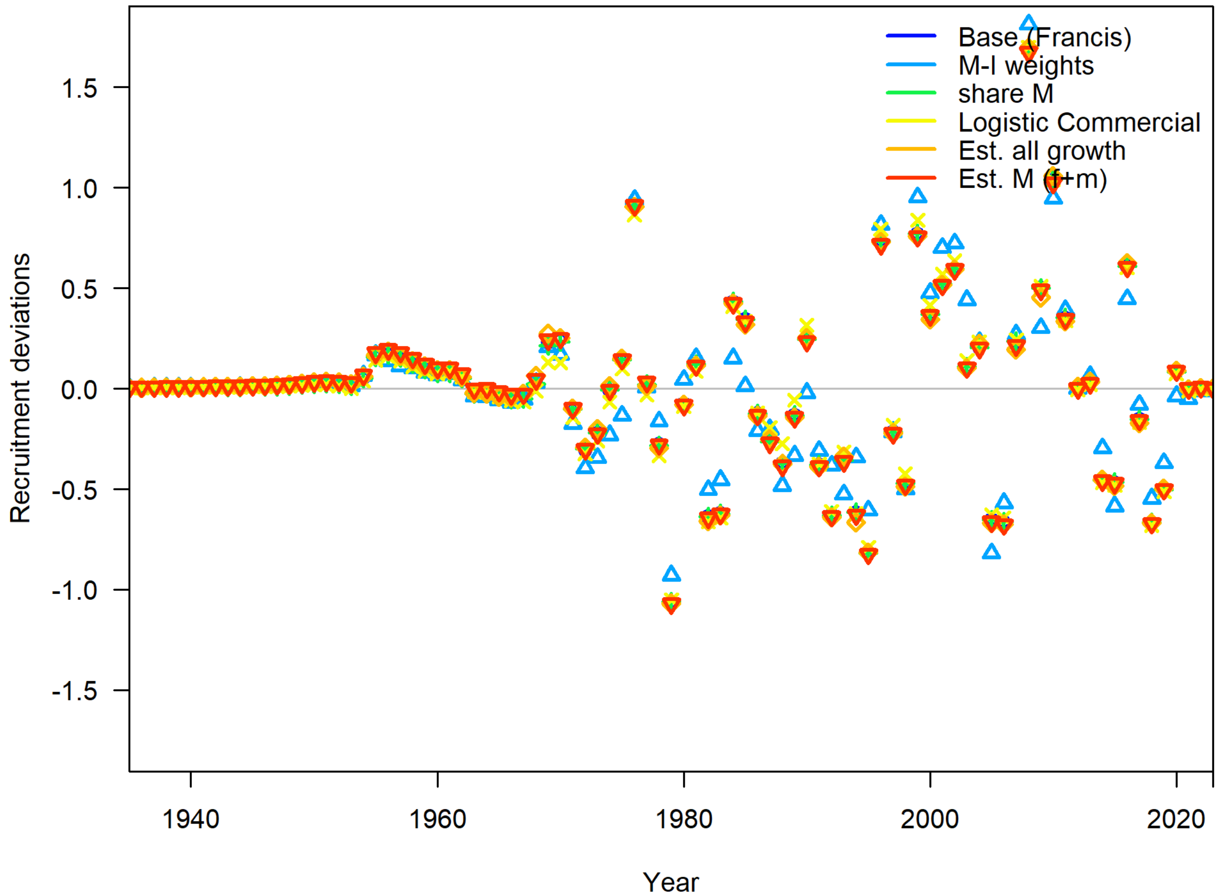


Figure 215: Trends in log-scale deviations from the stock-recruitment relationship associated with sensitivity analyses for the central California base model.

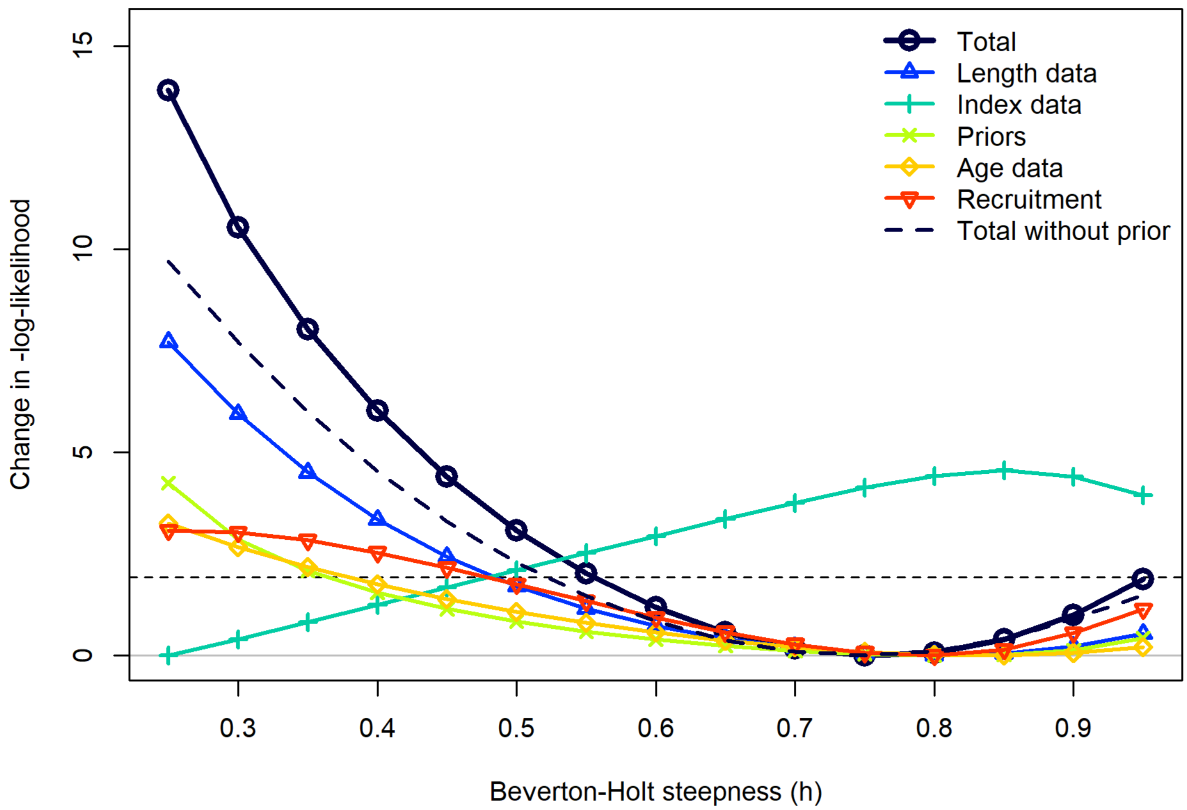


Figure 216: Likelihood profile over steepness for the central California model, by data type.

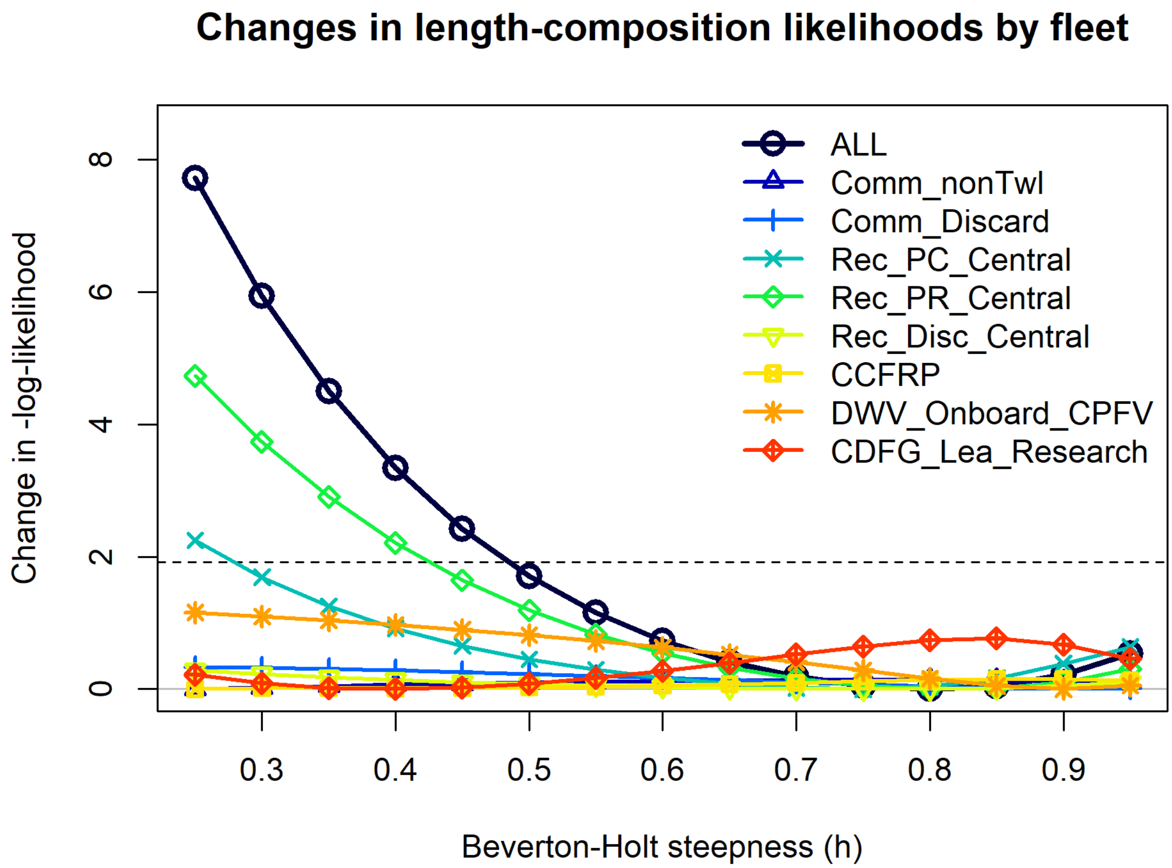


Figure 217: Likelihood profile over steepness for the central California model, by length data source.

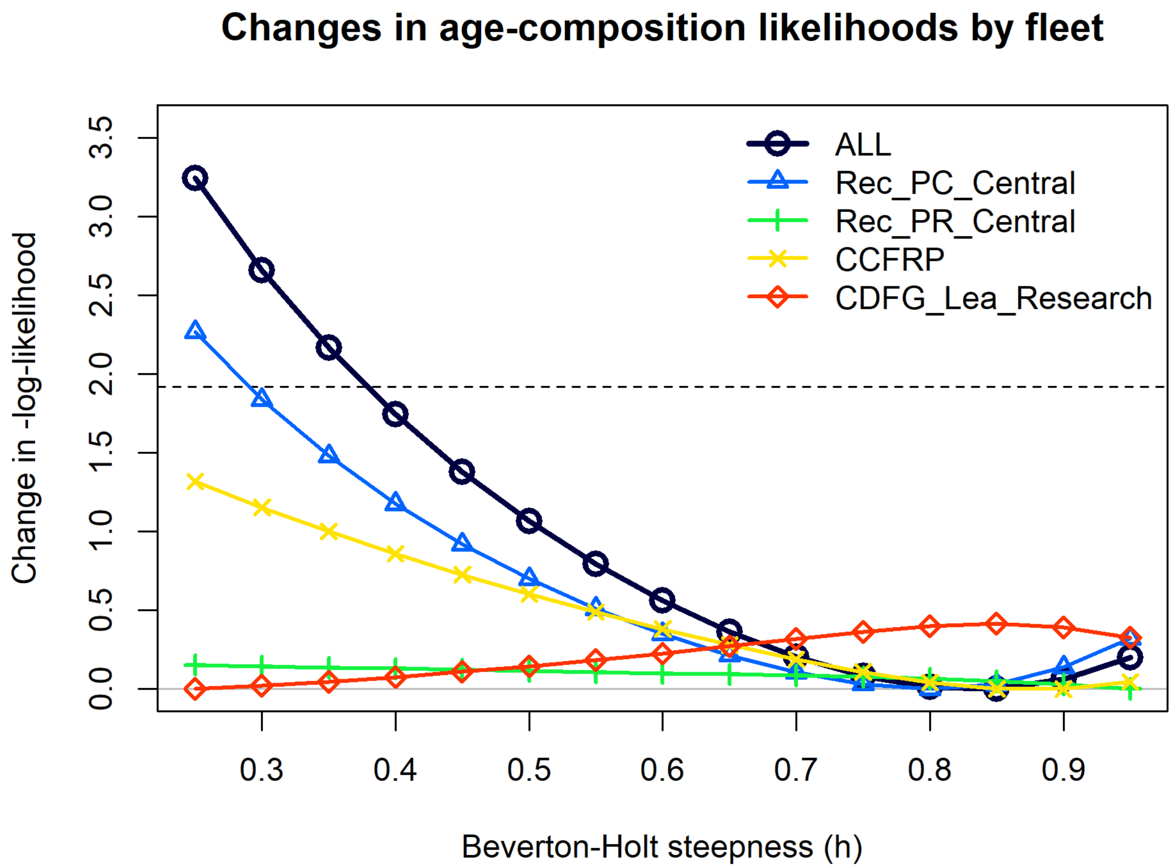


Figure 218: Likelihood profile over steepness for the central California model, by age data source.

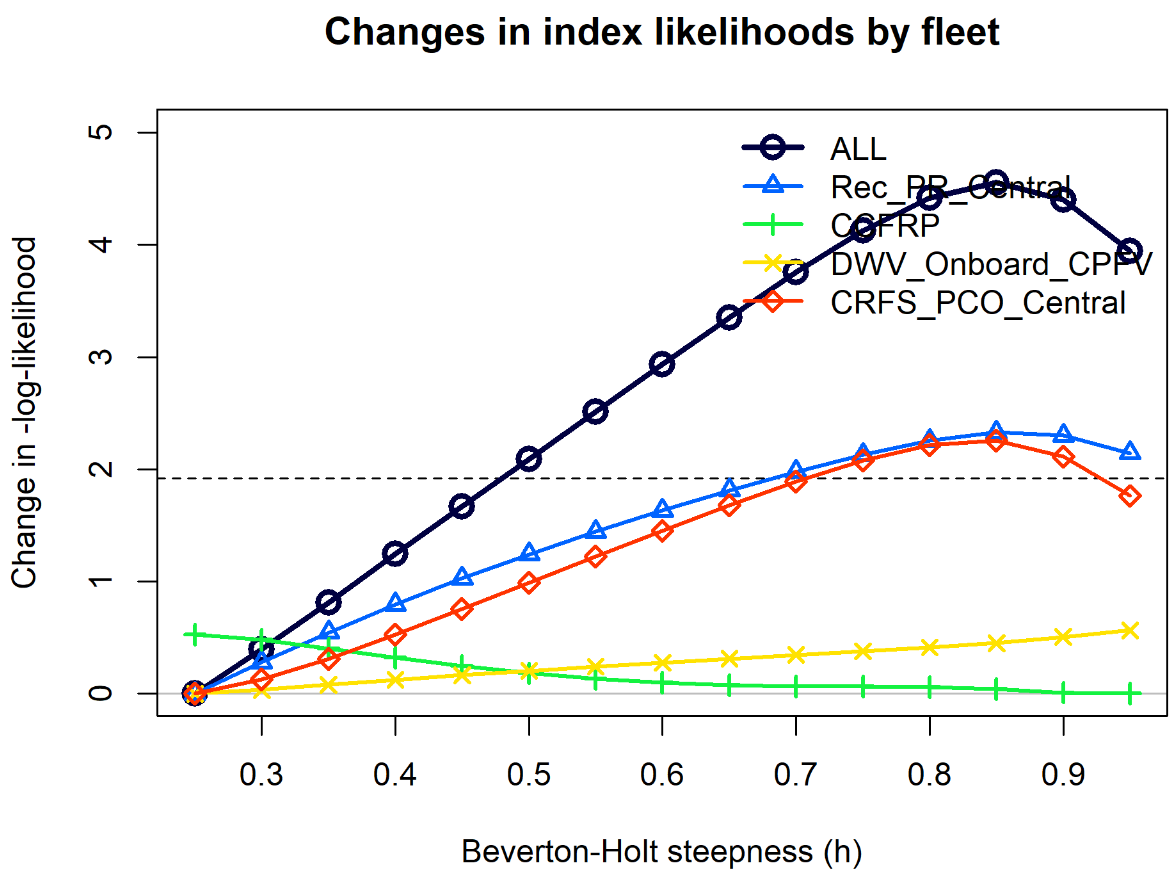


Figure 219: Likelihood profile over steepness for the central California model, by index data source..

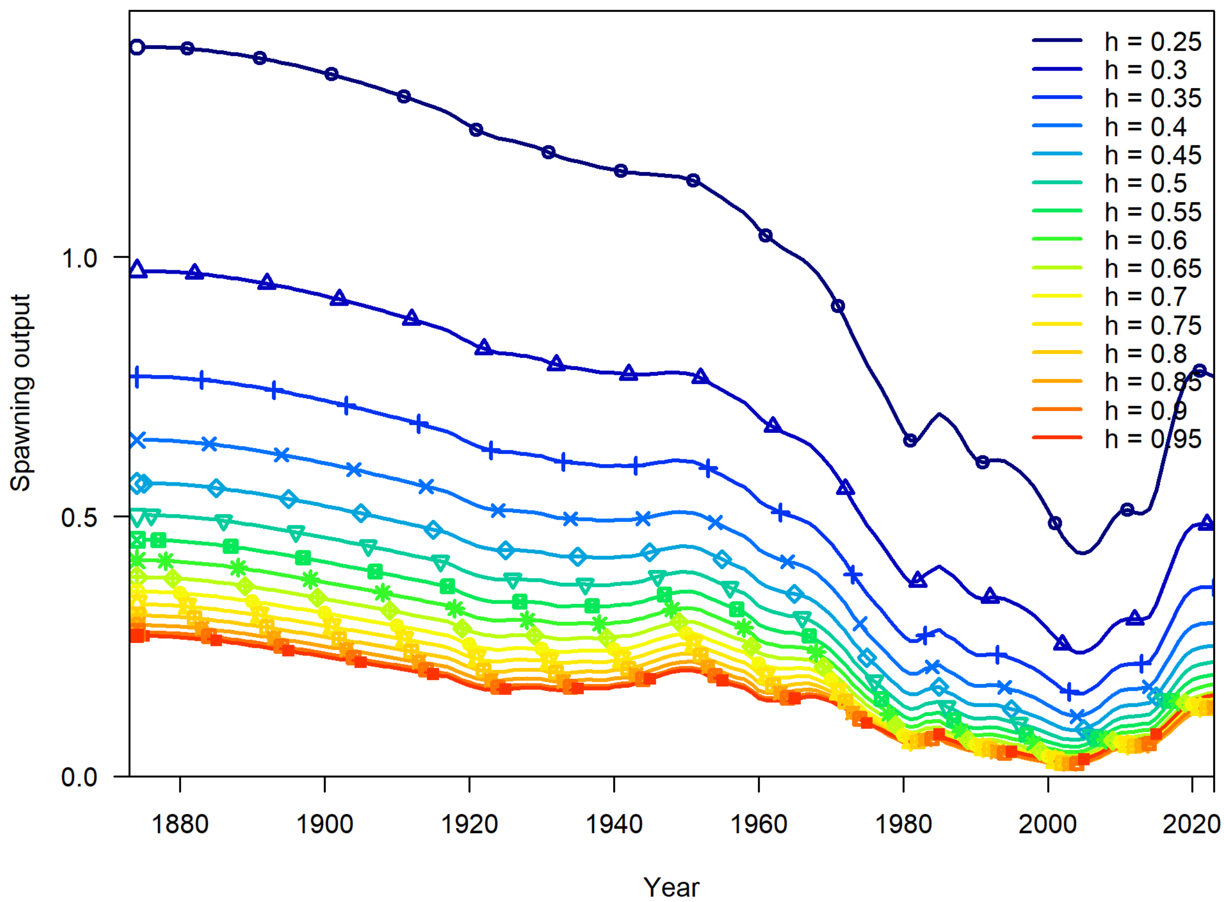


Figure 220: Spawning output time series from a steepness profile for the central California base model (h=0.72).

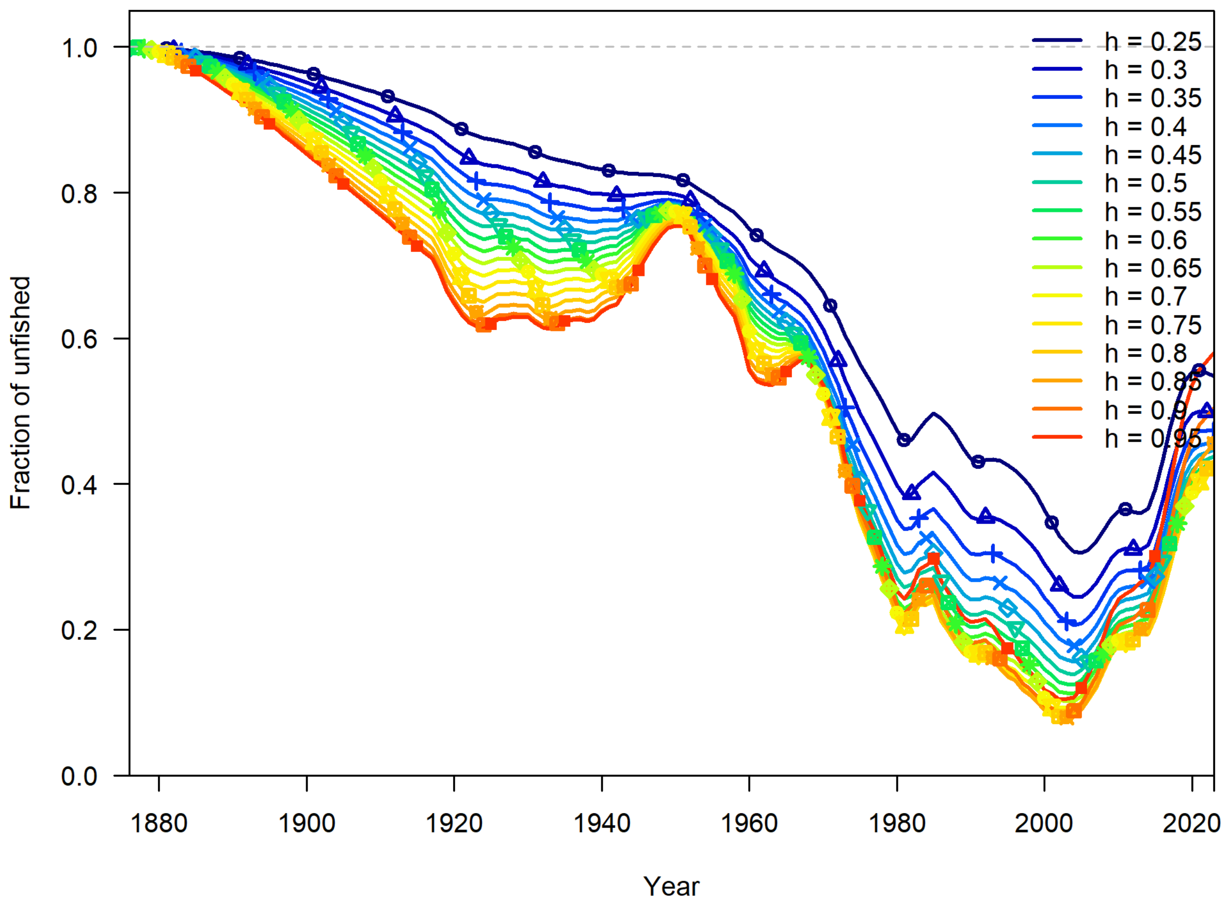


Figure 221: Relative spawning output time series from a steepness profile for the central California base model (h=0.72).

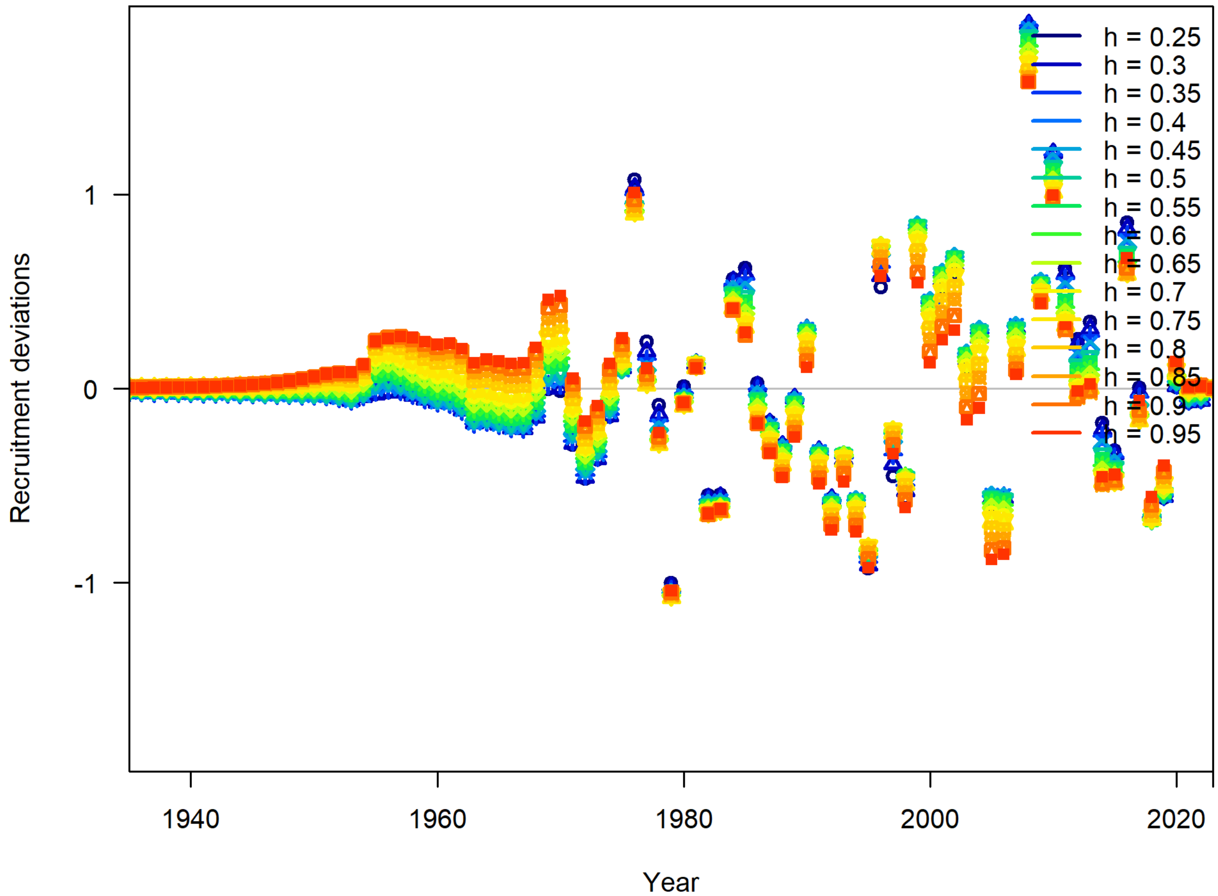


Figure 222: Log-scale recruitment deviations from a steepness profile for the central California base model (h=0.72). Vertical bars are 95% asymptotic confidence intervals from the base model.

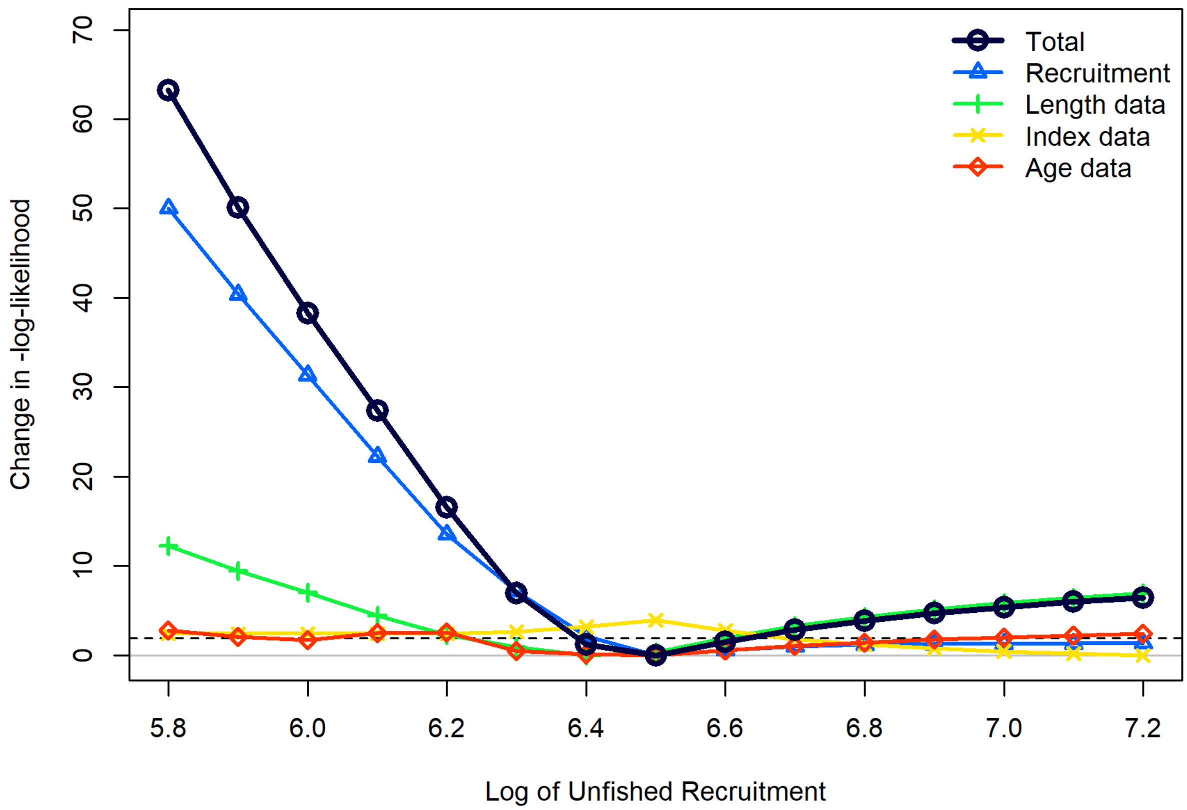


Figure 223: Likelihood profile over the log of unfished recruitment for the central California model, by data type.

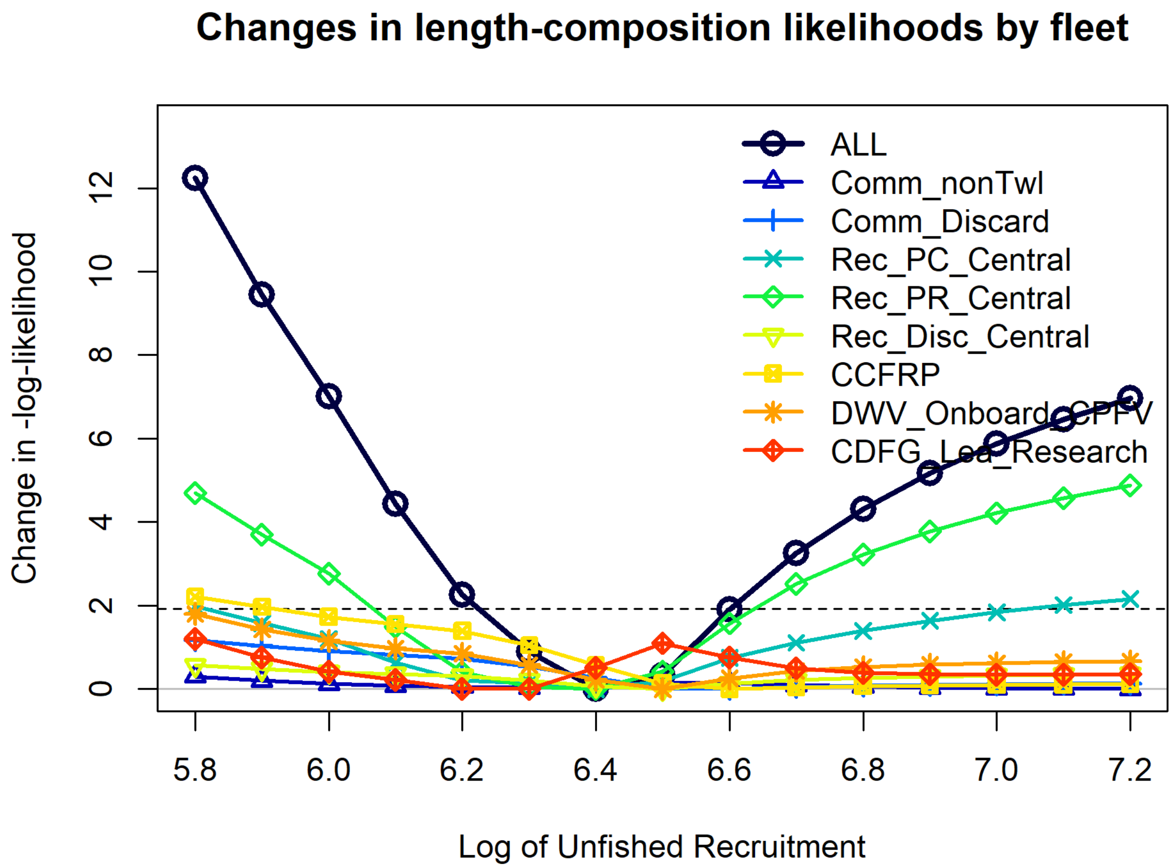


Figure 224: Likelihood profile over the log of unfished recruitment for the central California model, by length data source.

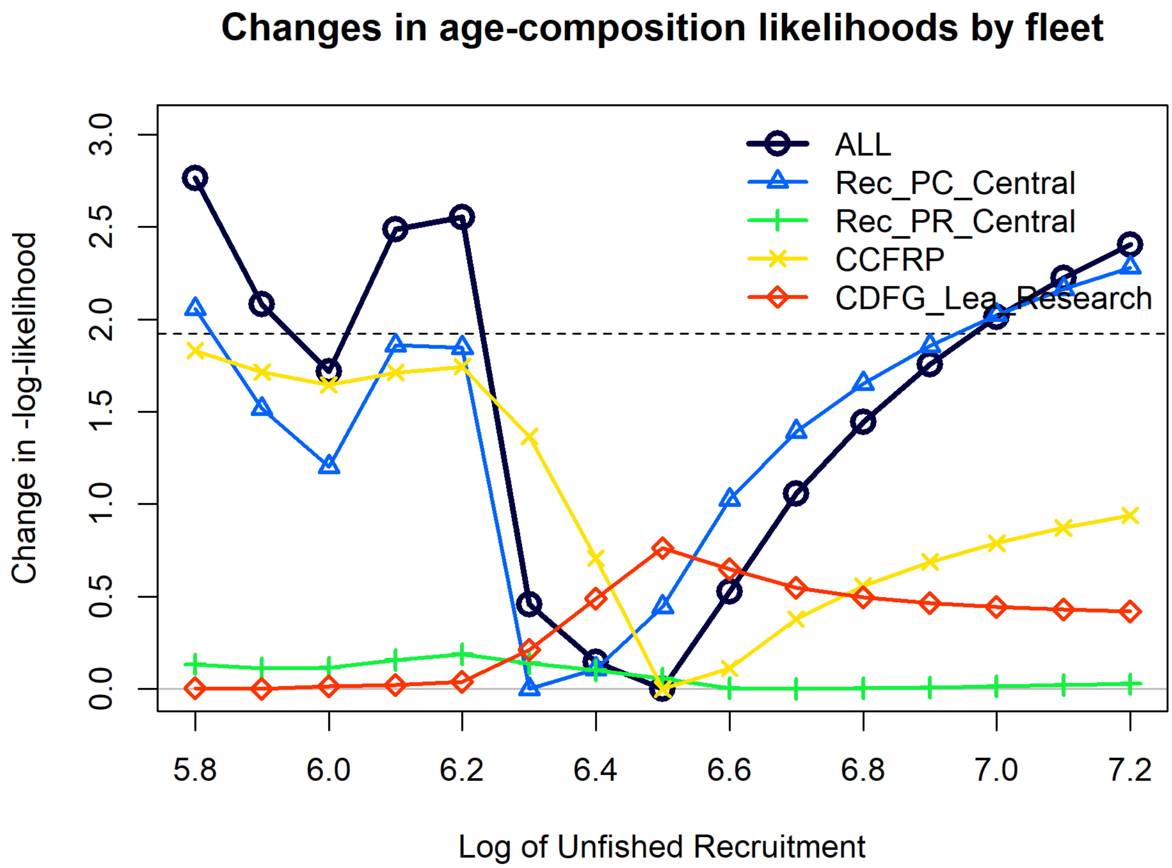


Figure 225: Likelihood profile over the log of unfished recruitment for the central California model, by age data source.

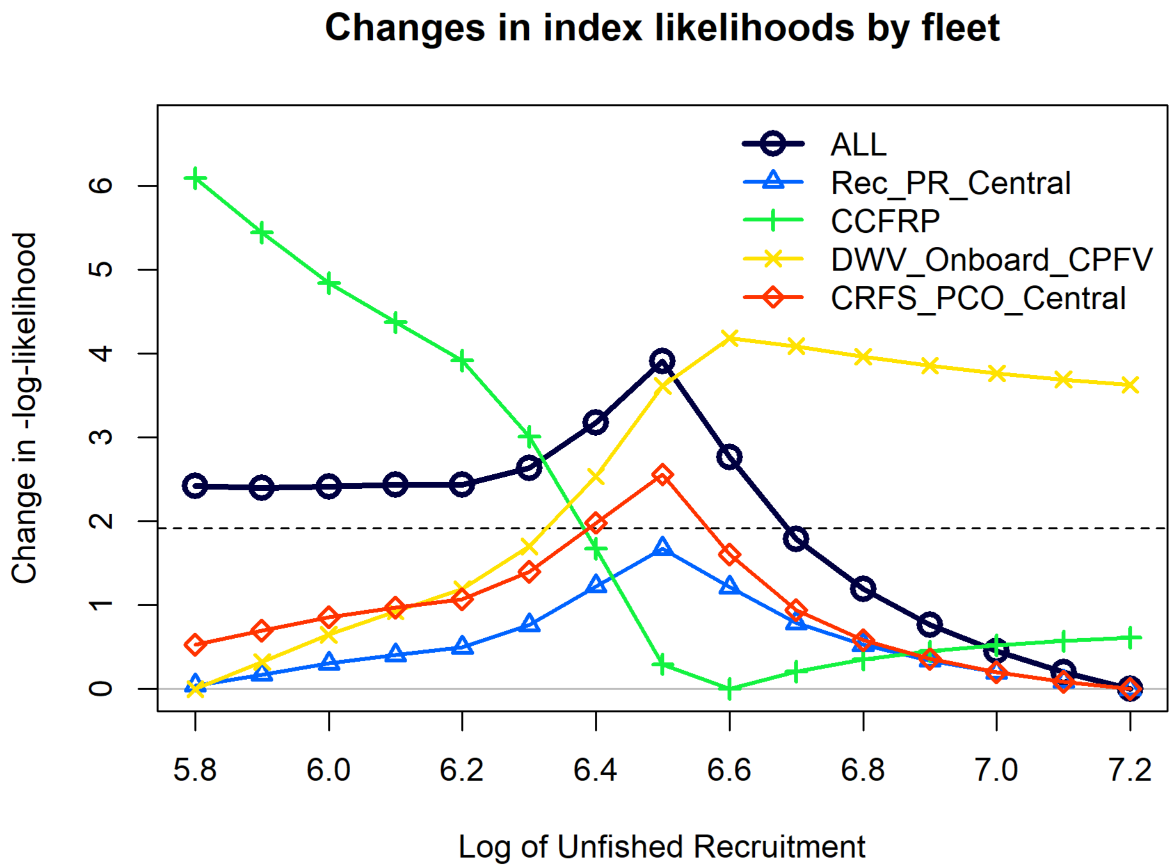


Figure 226: Likelihood profile over the log of unfished recruitment for the central California model, by index data source.

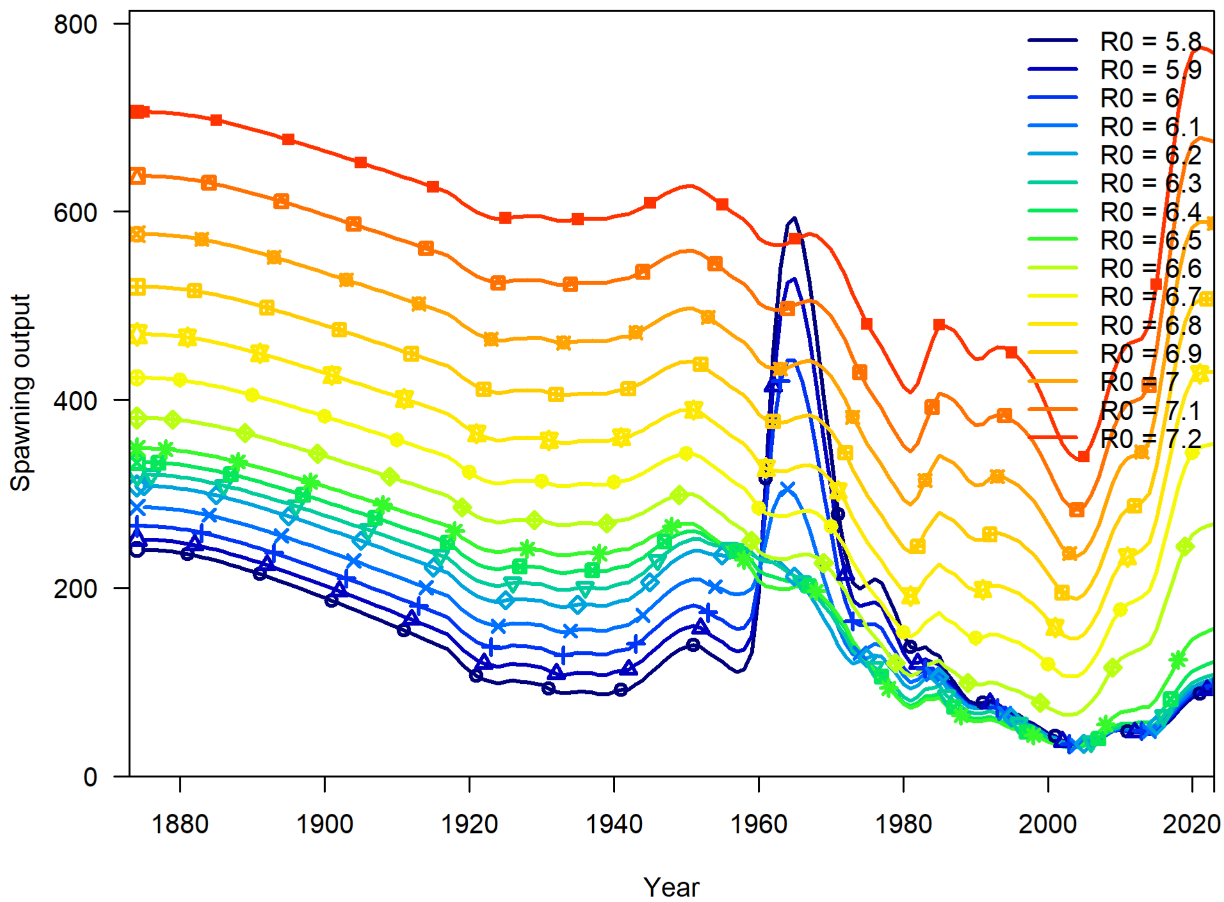


Figure 227: Spawning output time series from a log(R0) profile for the central California base model.

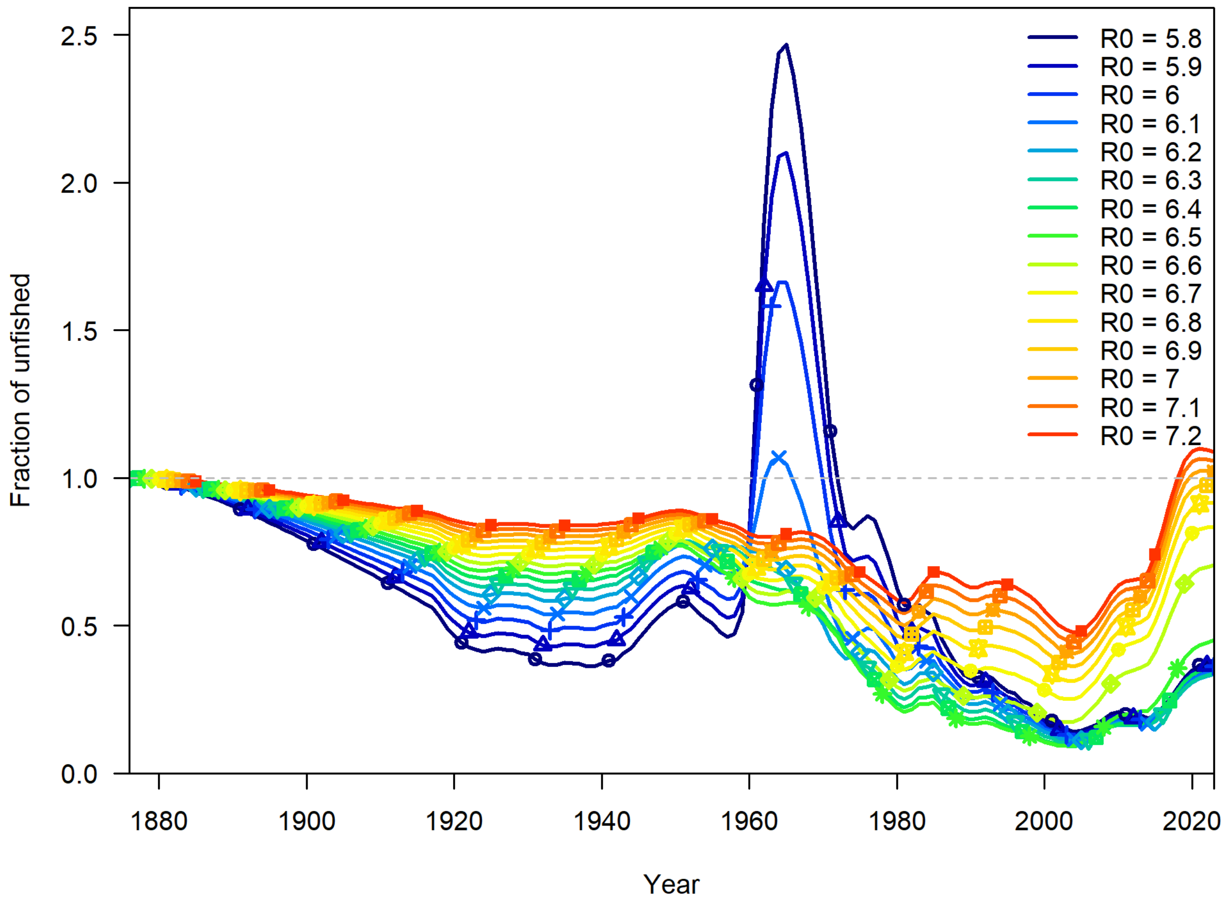


Figure 228: Relative spawning output time series from a log(R0) profile for the central California base model.

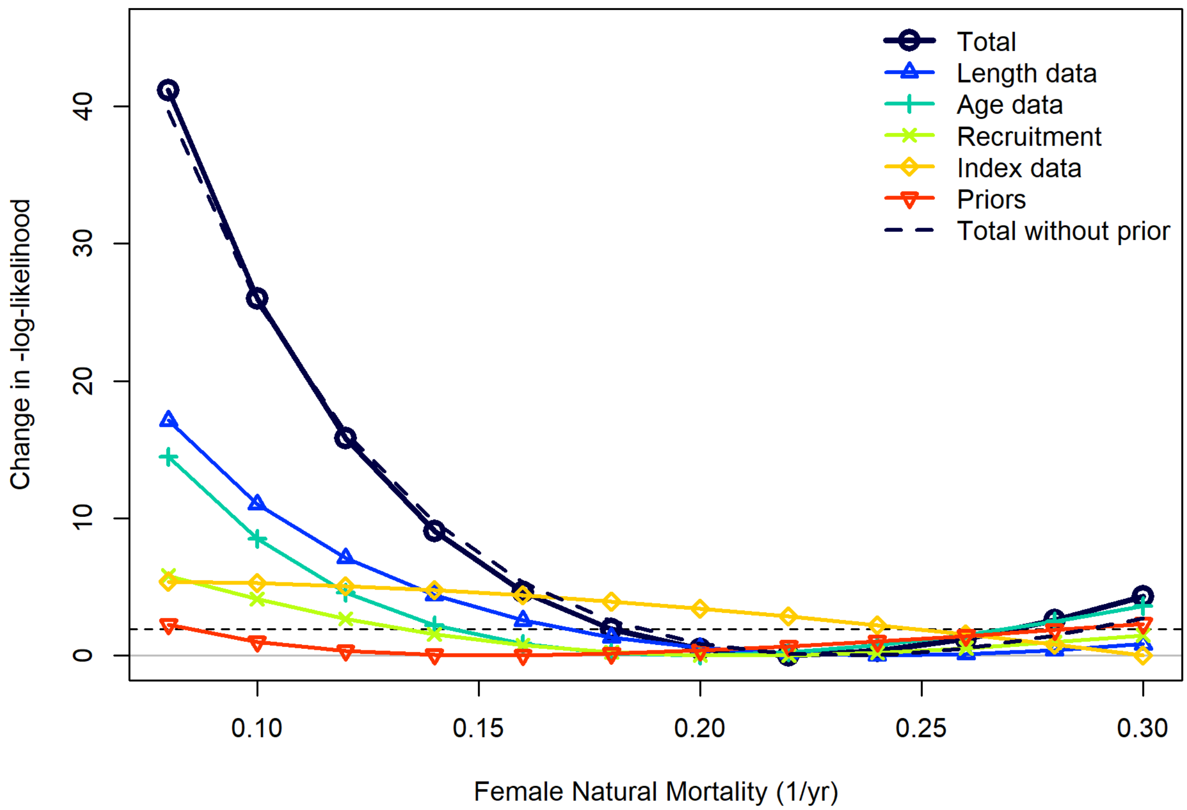


Figure 229: Likelihood profile over the female natural mortality rate for the central California model, by data type.

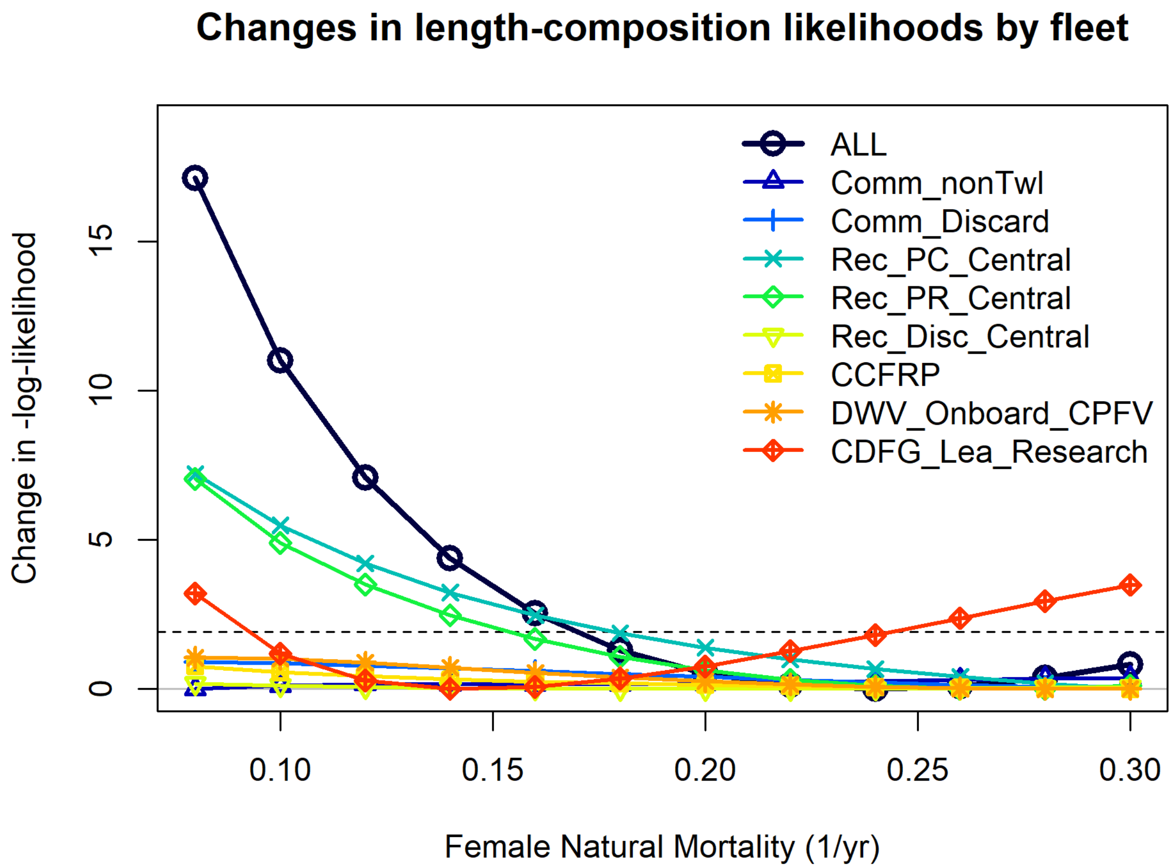


Figure 230: Likelihood profile over the female natural mortality rate for the central California model, by length data source.

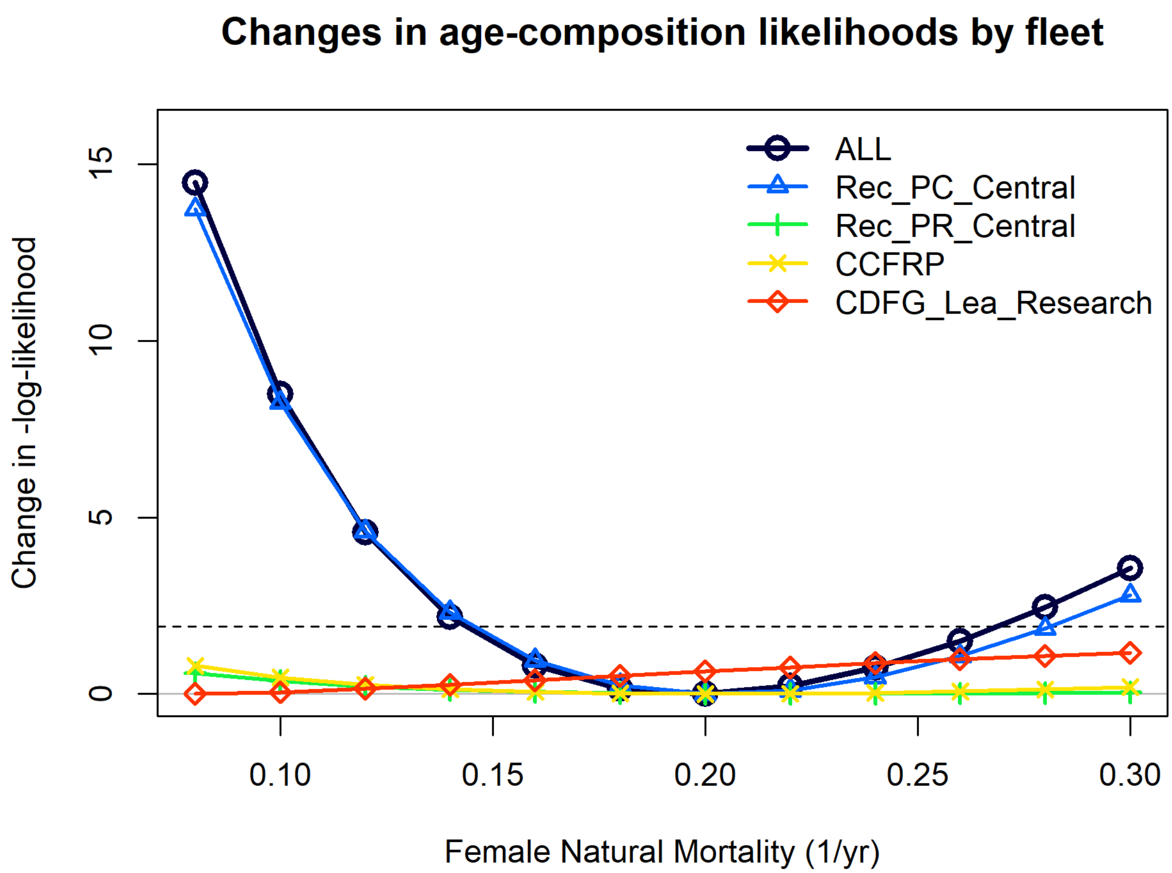


Figure 231: Likelihood profile over the female natural mortality rate for the central California model, by age data source.

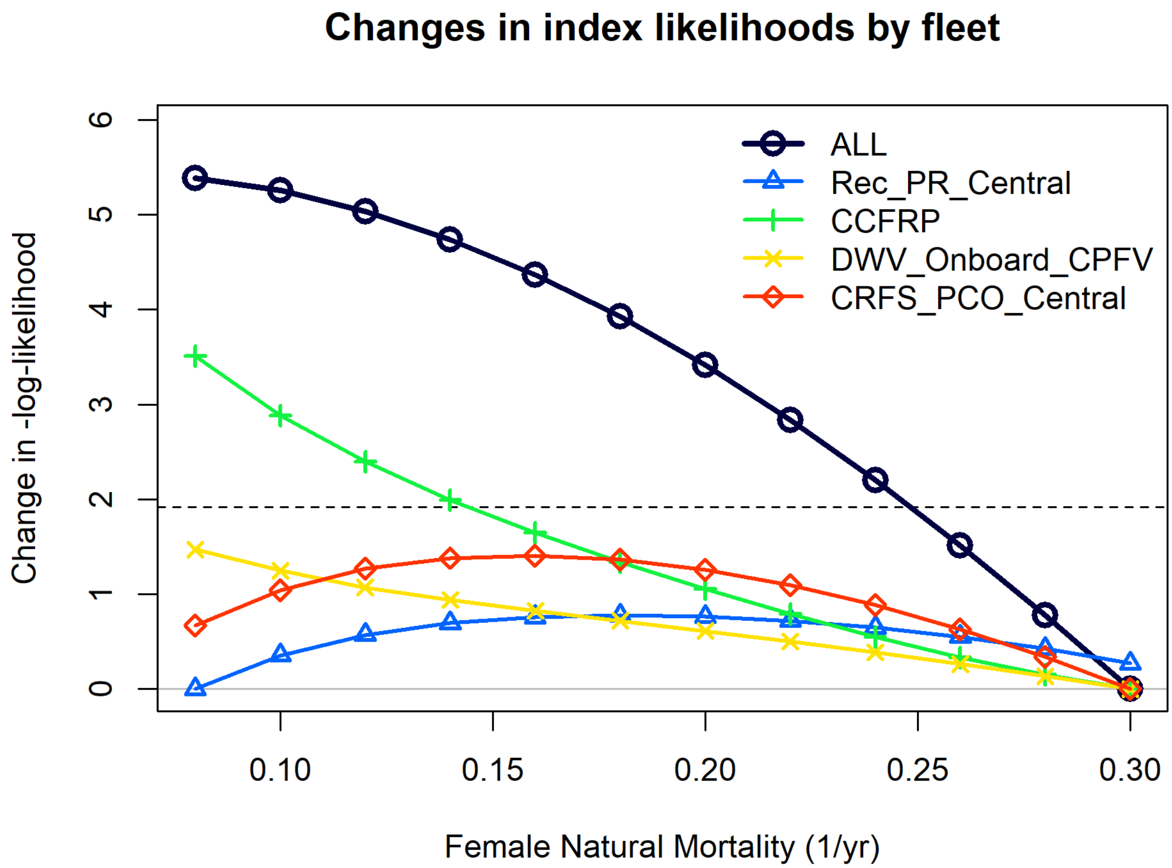


Figure 232: Likelihood profile over the female natural mortality rate for the central California model, by index data source.

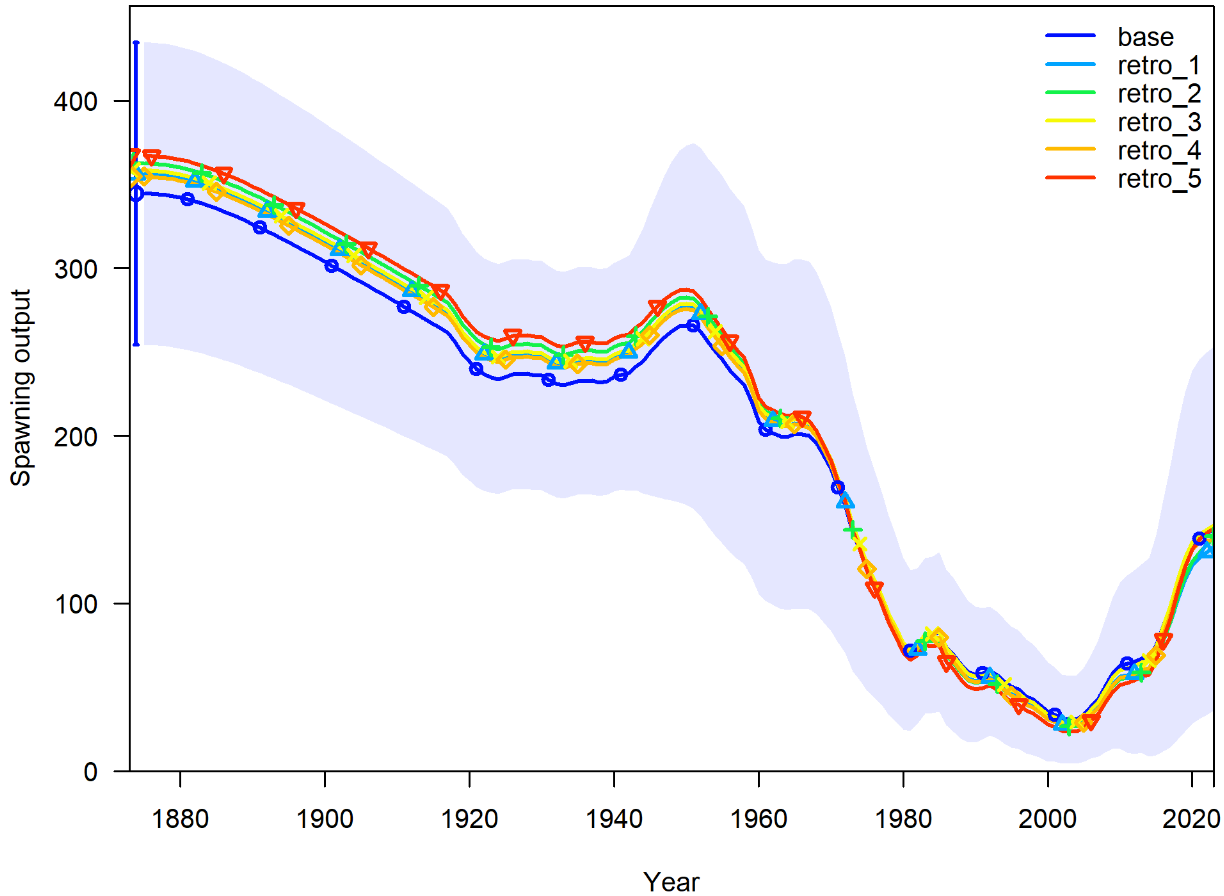


Figure 233: Retrospective analysis, showing the effect of removing individual years' data on estimated times series of spawning output (billions of eggs) from the central model.

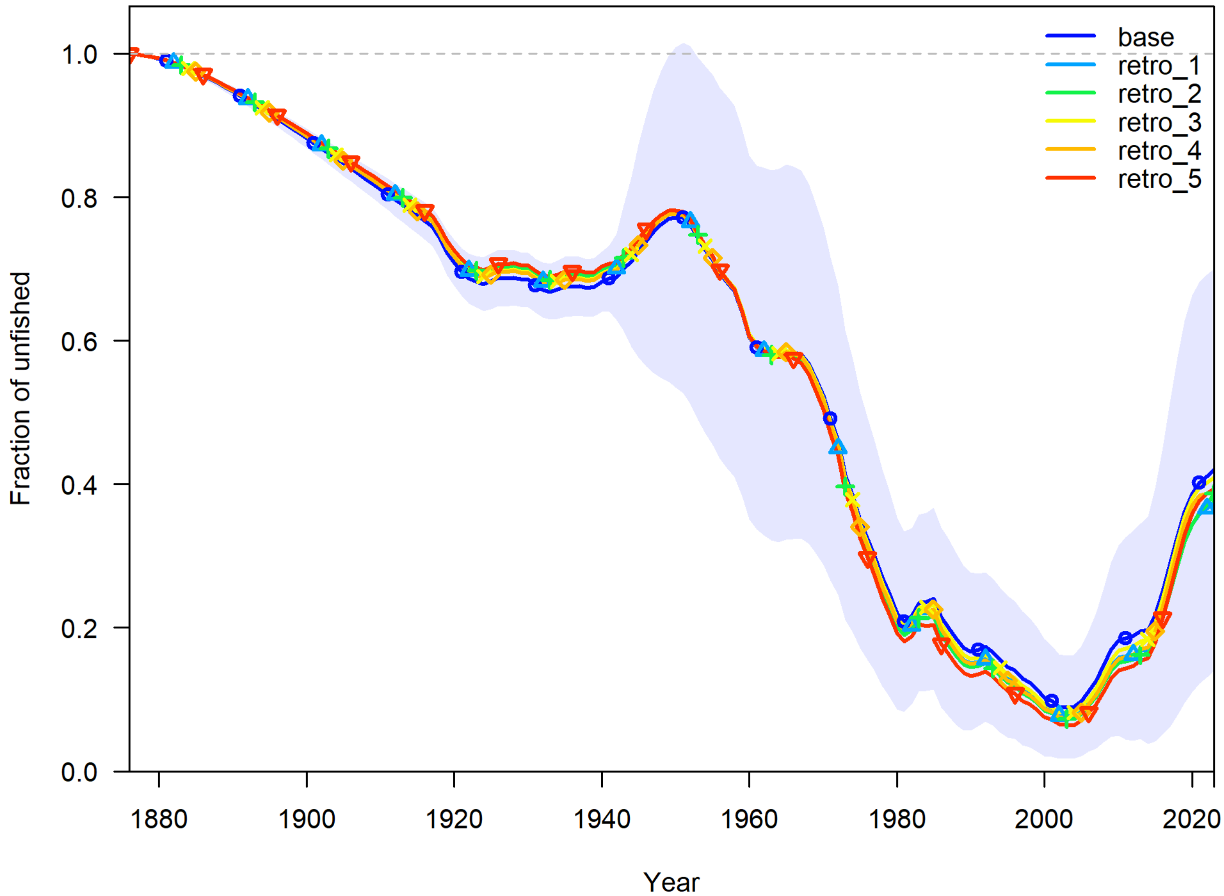


Figure 234: Retrospective analysis, showing the effect of removing individual years' data on estimated times series of relative spawning output (B / Bunfished) from the central model.

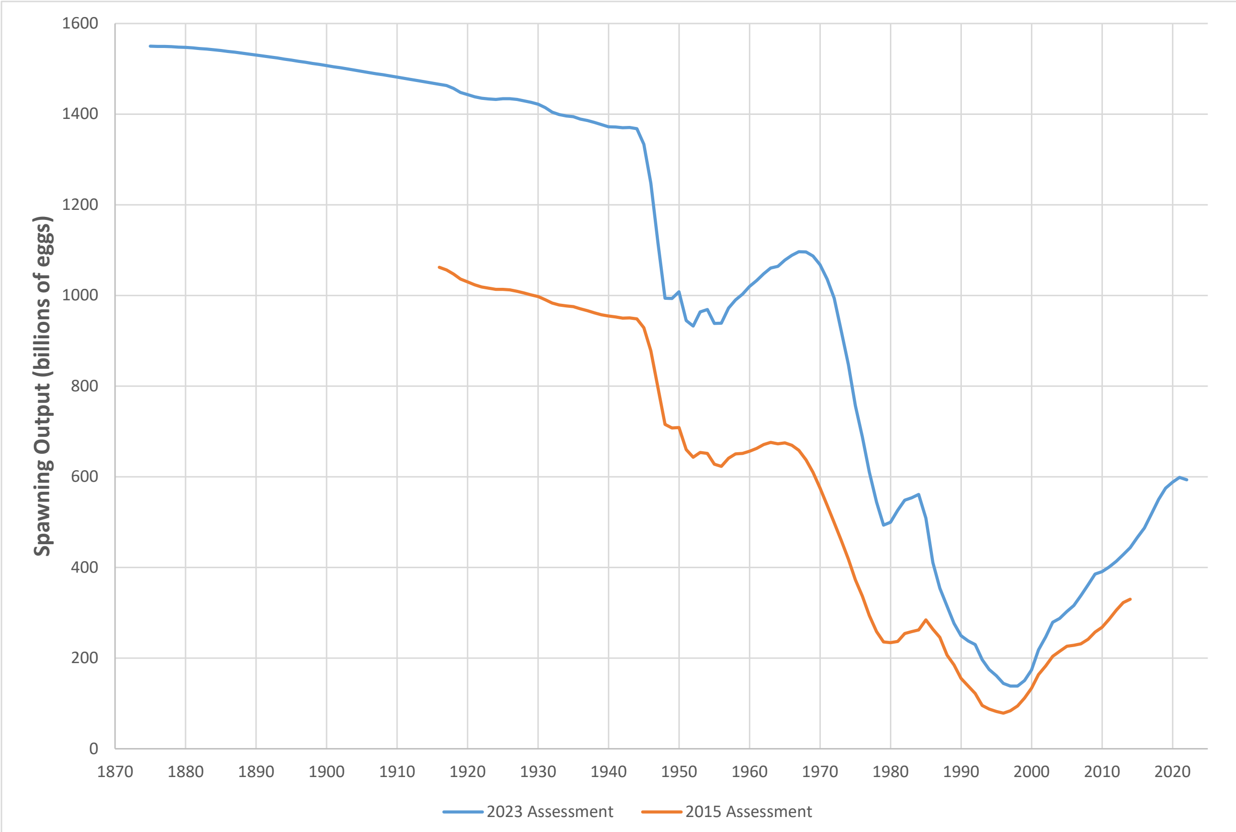


Figure 235: Comparison of spawning output (summed across areas) from the 2023 assessment and the 2015 assessment.

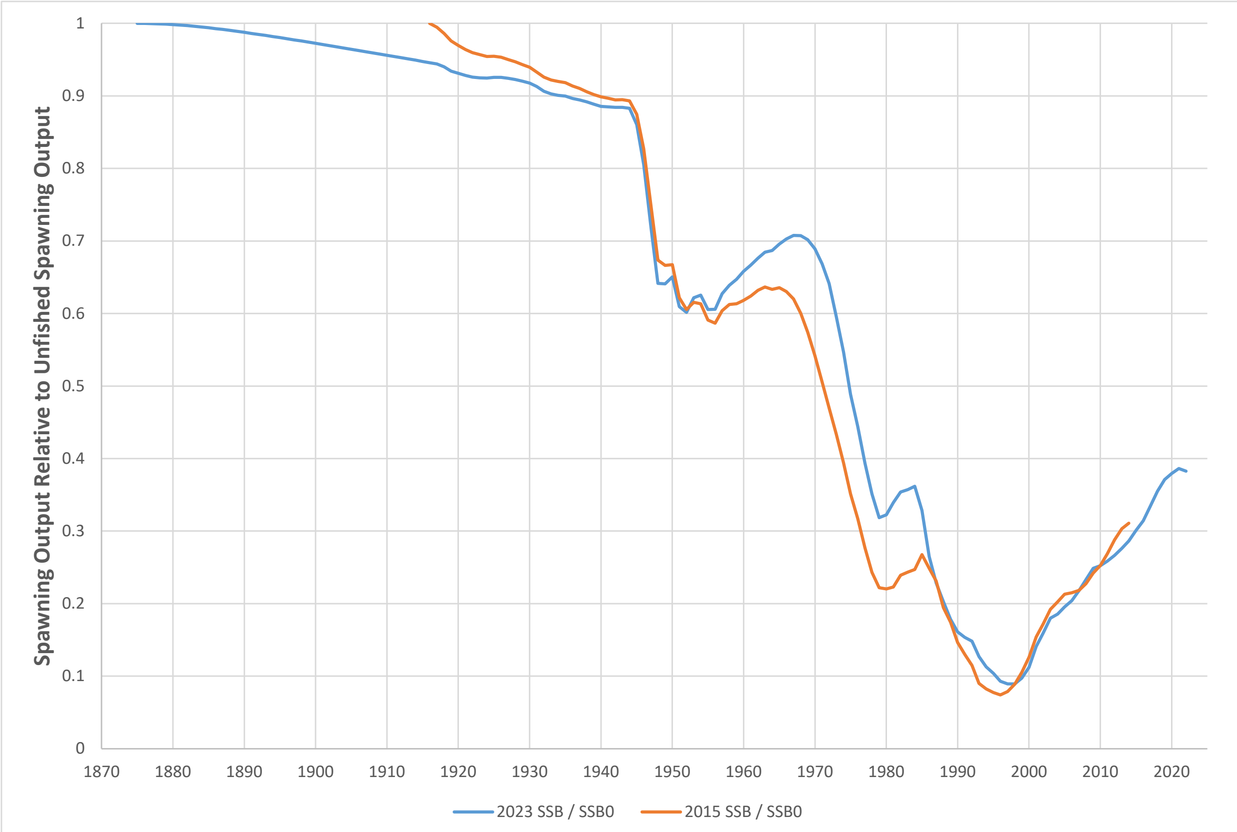


Figure 236: Comparison of relative spawning output (summed across areas) from the 2023 assessment and the 2015 assessment.

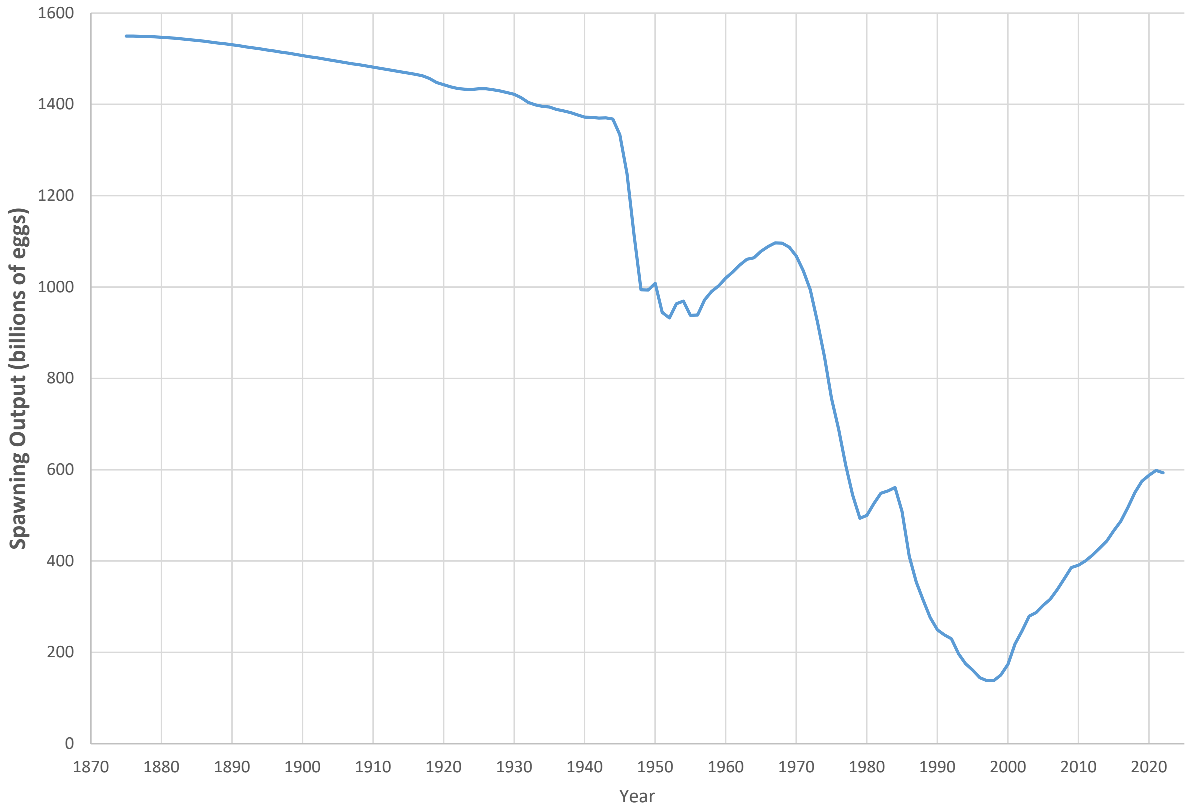


Figure 237: Time series of combined spawning output (billions of eggs) for the combined northern and central base models.

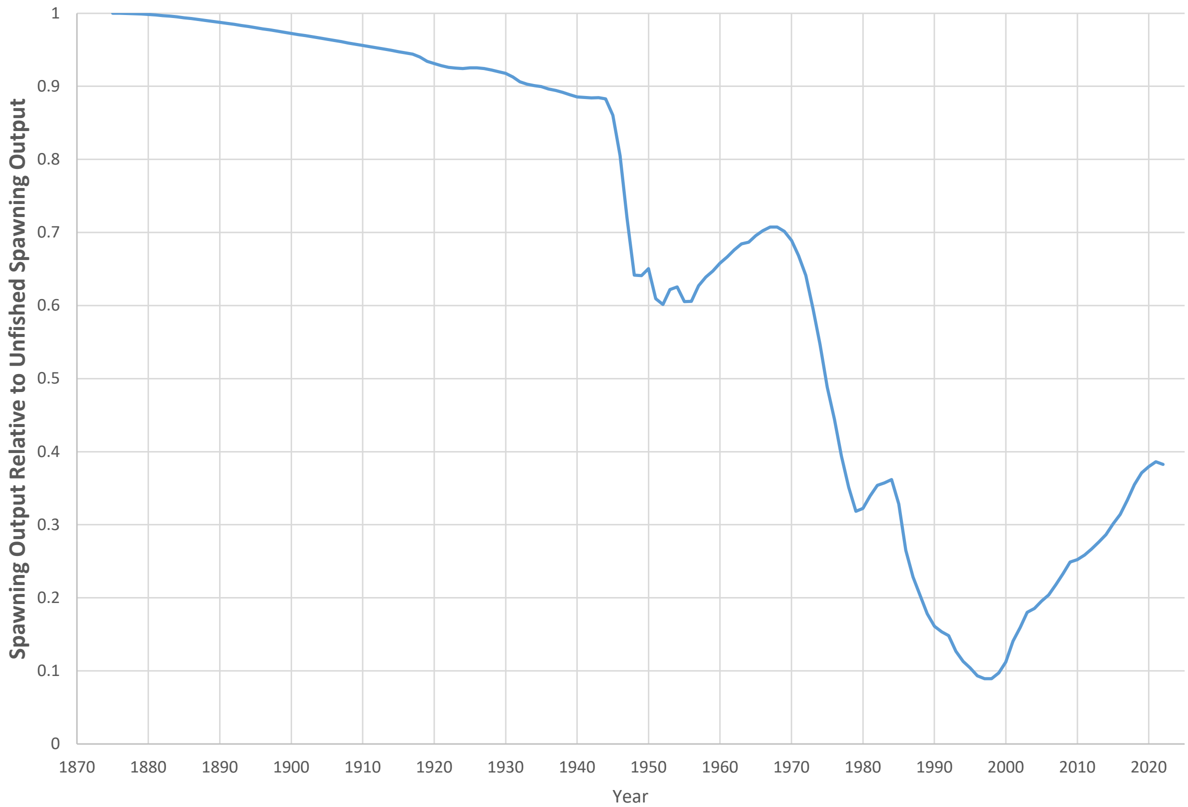


Figure 238: Time series of relative spawning output (B / B_unfished) for the northern and central base models.

Appendix A. Notes on black rockfish habitat associations and fishing behavior, attributed to Kenyon Hensel

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Kenyon's background

I have been a commercial fishermen, fishing with rod and reel and focusing on black rockfish, out of the Crescent City Harbor, since 1982. I have primarily fished in the nearshore waters from the Lake Earl estuary to the Klamath rivermouth, from the nearshore to about 6 miles offshore. I have typically landed around 30,000 pounds per year, and I still fish many of the same rocks and rocky structures that I fished in my early years.

I have also spent time from the 1990s through the 2000s representing Northern California open access fixed gear fishermen to the Pacific Fishery Management Council. At 64 years of age I have slowed my fishing efforts, but did manage to land over twenty thousand pounds of fish last year. I now fish in deeper waters, mostly for rockfish other than black rockfish. However, I often but run through the same reefs where I previously fished for black rockfish, and often enjoy seeing the schools working the surface around the shallow rocks.

Over the years I have seen reductions in effort lead to increase in the stock sizes, from a period low of abundance in the 1990s to robust and rebuilt populations currently. In my view, there is currently not enough fishing pressure to have any more than a minimal effect on stock sizes. Forty years ago there were over 1500 boats fishing in any given August day, but now the boats number in the hundreds on the busiest holidays. A lot has changed as I have fished across the decades.

Perspective on black rockfish habitat associations

Along this part of the Northern California coastline, there is little kelp in rough open waters. The coastline is rocky, but open to strong currents and winter swells that can exceed 25 feet at times during the winter. Bull Kelp can and does grow here, but not in large, thick light cutting mats that I have observed in Southern California waters. There are years in which the kelp will be thicker and more noticeable, these are mostly warm water years.

It seems that the limited availability of kelp habitat leads young black rockfish to grow out over benthic habitats very close to shore. Humboldt State University (HSU) has done juvenile studies and found Young-of-the-Year (YOY) black rockfish living out their first summers in tide pools and rock jetties. The black rockfish component of these YOY in tide pools can be very high, and my personal experience with YOY black rockfish is consistent with recruitment into shallow water.

I wondered for many years why our catches of older fish consisted primarily of adult fish over 3 pounds, with few or no subadults. The schools of fish found locally were huge, but did not include younger, smaller individuals. By contrast, schools of blue rockfish that coexisted in close proximity to black rockfish did include many smaller individuals, including fish only a few inches in length. Many of the blue rockfish schools could not be fished due to the bycatch of unmarketable juveniles. By contrast, it seems to me that when the black rockfish reach about 12 inches they begin to integrate into the larger offshore schools, where fish aggregate in areas that have enough food is available to support them.

After years of fishing, I was able to find midsize fish in the substrates off the sides of rock structures, usually out of the way and under the schools of larger adults. Apparently they find ways to minimize competition with adults during this stage of their growth. During the 1990s this seemed to happen more frequently, when back to back warm water seasons resulted in lower forage availability and smaller fish were more frequently found in the offshore schools. This was really the first time that I saw and caught many fish in the 1.5 to 2lb range (approximately twelve to fourteen inches). Since the warm water events came to an end around 2000, the schools have grown and reestablished themselves as primarily composed of 3 to 5 pound adults again.

There was high abundance of YOY black rockfish shortly after cool conditions returned around 2000. During that time, I often observed 2 inch black rockfish being regurgitated by adults in my live tank, only to be eaten again by other adults. In my view, these fish are indiscriminately eating juveniles of their own species, and those of any other species, whenever possible. Over my decades of fishing experiences, the philosophy of rockfish survival to me is that if it fits in your mouth, eat it. In the race to get big, and thus reduce the predators who can eat you, rapid growth is essential.

Movement patterns

The available food supplies play a strong role in growth potential. I constantly see areas where water bourn forage is supporting huge, dispersed populations of large black rockfish that seem to hold, at least during periods of abundant food, in large open areas. These fish are prone to aggregate around fishing activities as if they were chasing bait. I have had them follow my boat while biting for as far as a half mile. Some conditions will promote movement as the fish compete for food, at such times there can be schools of black rockfish near the surface, in a show of synchronized swimming, picking off bait fish as the baitfish form dense balls in trying to escape. Other times, the fish seem stuck to a rock and will not follow our boat very far over flat bottom, although they may pick up any lures that get close to them. You can even anchor over them and pick off one fish at a time for hours, until they get tired of biting, or you get tired of catching.

So, at times adult fish are ready to leave rocky habitat and chase bait, other times they are much less prone to travel. Some of the fish seem to be homebodies, who stay associated with structure, and are often available to us trip after trip. Other groups of active feeders will split off of the structure to chase large bait schools as they pass through. These chasing schools will redistribute themselves after feeding, and might not necessarily end up at the same habitat that they started on. I have definitely seen fish be scattered after heavy periods of abundant bait, and not regather in the same area, after days of strong weather and currents, particularly at depths of 20 fathoms and greater. I have even left good bites due to time constraints, only to have to relocate the fish in different areas the next day.

Year after year, I have fished the same rocks and caught hundreds of fish each day, and have yet to see any of these rocks become fishless. That in itself lends to the dynamic of these fish both traveling afar, as well as moving back and forth among the structures of our reefs, where local abundance can be actively replenished. Most of the major changes or movements of black rockfish schools comes during winter weather events and during the spawning season. Some of the best fishing weather comes to California during the fall. As we move into November, the storms begin to line up and move across the North Pacific, bringing large swells and stronger currents. I have always fished throughout the year for rockfish, and found that to be successful I had to adapt to these winter conditions.

Spawning and fish condition

As I have always cut and cleaned my fish to increase the value, I have observed the seasonal changes inside of the fish, and noted many interesting patterns in feed and spawning behavior. For example, in the fall of a good feed year, in which bait is plentiful throughout the summer, I will see fish fully fattened out, with large amounts of interstitial fat lining their body cavities. During such times, female fish of smaller sizes will have bright yellow egg masses already highly visible when cut. This show of eggs is prominent in 12 to 14 inch long fish, and these fish were mixed in with the general population, although it may be false spawning activity as I have otherwise never seen any gravid fish under 4 lbs.

Larger spawning females are typically observed later in December, when I have to fish the sides of the rocks because fish are no longer gathering on top of them. There I catch a few much larger black rockfish that seem to be stationary breeders, as these 4+ pound fish will would be full of larvae ready to drop. These fish are spread out to the point that I would only be able to catch a few at each rock, since they would not follow or gather as they do during summer months. At this time of year, Dungeness Crab fishing would open, and crabbers would often report finding these large fish heavy with eggs in their traps on the river delta, in habitats surrounded by miles of sand and no rocky structure.

This scattering of black rockfish would usually lead me to concentrate on the nearby schools of blue rockfish at this time of year, as those schools seem to feed heavily all year long. By mid January, the black rockfish breeding activity tapers off and black rockfish body cavities are empty as the fish began to gather again for the monumental spring bite.

To the question of what happens to the breeding females, I would often see a few spent females returning back into the spring schools, but I would also see some spent females scattered throughout the year. I would even catch a few spring females with unspent larvae, so it is not clear whether all of them drop their young every year. I think it is entirely possible that some of these large females do not return back into the mixed schools. They may be large enough to be past their most productive ages, or the physical requirements of spawning forced them into a slow recovery, or state of weakness that might leave them easy prey. Perhaps all of their energy is best used in producing a large batch of eggs, and the females may die after birth (parturition).

The amount of young produced by a single female is incredible. I have heard testimony by University of Oregon scientists that based on genetic analysis, a single female black rockfish can repopulates an entire reef. This would support the idea that you don't need many spawners surviving each year to have a viable population. What I am sure of is that gravid females do not, or cannot compete for feed as well as the other black rockfish do. We never see them high up in the bite chasing bait as we do younger and smaller fish. They go off to have their young and may not all return, or they may live a life free of the schooling dynamic, in order to fully focus their energy to produce young. From my years of cutting rockfish, I have found that for the midwater species that I have encountered, the immature females and males seem to outnumber the gravid females.

Appendix B. Data sources evaluated, but not used in the California assessment

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 on 5/22/2023. 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). The methodology for aggregating the data to the trip level was reviewed and approved by the PFMC Scientific and Statistical Committee in March of 2013 (PFMC, 2013). The database contains information on catch by species (number of retained fish), effort (angler hours), sample location (county and interview site), date, and distance from shore (inside/outside of 3nm from shore).

MRFSS CPUE Index: Data Preparation, Filtering, and Sample Sizes

In order to define effective fishing effort (i.e. identify trips that were likely to catch black rockfish), we used the method of Stephens and MacCall (2004) to predict the probability of catching a black rockfish given the occurrence of other species in the catch. The unfiltered data set contained 2923 trips. Species that are rarely encountered will provide little information about the likelihood of catching a black rockfish, so we identified "indicator" species that were caught in at least 30 trips. One of these was "rockfish genus," a catch-all category for rockfish that was excluded from the set of indicator species because the species composition of this category changes by area within the state. Catch of these commonly-encountered species in a given trip was coded as presence/absence (1/0) and treated as a categorical variable in the Stephens-MacCall logistic regression analysis. Next, we flagged commonly-caught species that never co-occurred with black rockfish ("extreme counter-indicators"). In the MRFSS data set, sablefish and albacore tuna were the only species that were caught in at least 30 trips and never co-occurred with black rockfish. This would produce an undefined ($-\infty$) coefficient in the binomial GLM, i.e. a predicted probability of exactly zero, so we removed 142 trips that caught sablefish or albacore tuna from the data set.

The Stephens-MacCall logistic regression was fit to the remaining set of 39 indicator species (Figure 239). The top five species with high probability of co-occurrence with black rockfish include three other rockfishes (black-and-yellow, brown, and china), as well as kelp greenling and cabezon. The co-occuring species identified by the analysis are likely skewed towards the species composition of catch in central California, simply because a greater number of samples were taken in that area. The species with the lowest probability of co-occurrence were albacore tuna and sablefish (which never co-occurred but appeared in >30 trips, as noted above), chilipepper rockfish, rock sole, and chinook salmon. These species are not commonly caught during the same trip as black rockfish, presumably due to different habitat associations and fishing techniques. Other species had large negative coefficients (squarespot rockfish and Pacific whiting), but the estimates were highly imprecise. The Area Under the Characteristic curve (AUC) for this model is 0.89, a significant improvement over a random classifier (AUC = 0.5). AUC represents the probability that a randomly chosen positive trip would be assigned a higher ranked prediction by the GLM than a randomly chosen trip that did not catch a black rockfish (Figure 240).

Stephens and MacCall (2004) proposed ignoring trips below a threshold probability, based on a criterion of balancing the number of false positives and false negatives. False positives (FP) are trips that are predicted to catch a black rockfish based on the species composition of the catch, but did not. False negatives (FN) are trips that were not predicted to catch a black rockfish, given the catch composition, but caught at least one. For the MRFSS data set, the threshold probability (0.319) that balances FP and FN excluded almost 2,000 trips that did not catch a black rockfish, and 155 trips that caught a black rockfish. Given the low prevalence of black rockfish in the original data (16%), we chose the same threshold for excluding trips, which removed slightly fewer (1789) trips. We also retained the false negative trips, assuming that catching a black rockfish indicates that a non-negligible fraction of the fishing effort occurred in appropriate habitat. Only "true negatives" based on the baseline threshold (the 1789 trips that neither caught black rockfish, nor were predicted to catch them by the model) were excluded from the index standardization.

No MRFSS CPUE data are available for the years 1990-1992, due to a hiatus in sampling related to funding issues. When the program resumed, sampling of California CPFVs north of Point Conception was further delayed, and CPFV samples in 1993 and 1994 are limited to San Luis Obispo County. These years were removed from the index due to insufficient spatial coverage. We also removed 1997 due to an apparent anomaly in effort calculations, as first noted by Key et al. (2008). A plot of catch per angler vs. catch per angler hour by year shows that the average reported hours fished is generally consistent over time, with the exception of data in 1997 (Figure 241). The exact reason for the difference remains unknown, but similar to Key et al., we excluded data from 1997. Unlike Key et al.'s observations for blue rockfish, there was no apparent difference in 1998 for black rockfish, and data for that year were retained in our analysis.

Finally, although MRFSS CPUE data are available through 2003, years after 1999 were excluded from the black rockfish index due to regulatory changes that may affect catch rates. In 2000, anglers targeting rockfish were limited to one line with three hooks and the bag limit for the rockfish/cabezon/greenling group was reduced from 15 to 10 fish. The number of hooks per line was further reduced in 2001, to two hooks per line. Depth restrictions were introduced in 2001 (Figure 5), potentially changing catch rates relative to data from 1980-1999, when there were no gear or depth restrictions in place. The bag limit remained unchanged (15 fish) from 1980-1999. The final, filtered data set consisted of 558 trips (**Table 66**).

MRFSS CPUE Index: Model Development, Selection, and Diagnostics

Data at the county level were sparse, so we assigned trips to equivalent CRFS districts based on county (Table 67). The number of CPFV samples from northern counties has consistently been smaller than in central and southern California, which is problematic when assessing trends for species like black rockfish that have a more northerly distribution. This is due in part to the statewide distribution of recreational effort and fleet size, particularly during the years when the MRFSS dockside sampling program was operating. Even in recent years, the CRFS program has lower CPFV sample sizes, as smaller vessel sizes ("6-packs") in the northern counties are less likely to have room for an onboard observer. We combined districts 3-4 and 5-6 into 'central' and 'north' areas, respectively, for index standardization. The proportion of positive trips varied by year and district, with 47% of all trips encountering a black rockfish (Table 68). Apart from differences in catch rate among district and year, we also considered changes associated with season (2-month "waves") and a course measure of distance from shore ("Area_X" in the MRFSS data, labeled "water_area" in our results). This distance variable is a categorical variable indicating whether most of the fishing took place inside or outside 3 nautical miles from shore, as reported by anglers during each interview. Estimates of mean catch rates (catch per angler hour) by year and area are highly variable in the north, likely due to small sample sizes (Figure 242).

The counts of black rockfish per trip in the filtered data set were heavily skewed with a large proportion of zeros (Figure 243). To model the counts, we used a Bayesian negative binomial regression model implemented with the 'rstanarm' package in R (Goodrich et al. 2023). Due to small sample size relative to the potential number of model parameters, we based model selection on the Akaike Information Criterion with small-sample bias correction (AICc; Burnham and Anderson, 2002). The “glm.nb” function (from the “MASS” library) was used for model selection to reduce run times, and final inference and diagnostics were based on the ‘best-AICc’ model fit using rstanarm. We included a model with an interaction between year and area in the set of candidate models, but AICc was minimized by a simpler model with main effects for year, area, and wave (**Table 69**). Adding the variable describing distance from shore increased the AICc score by ~2, so it was left out, but the 2-month “wave” was retained because removing it increased the AICc score by more than 14 points. Predictive distributions, by year, from the best-AIC model were consistent with the observed annual means (Figure 244) and standard deviations (Figure 245).

To further evaluate the model, we compared the predicted distributions of the proportion of zeros by year in replicate data sets from the model to the observed proportion of zeros. The negative binomial model is able to reproduce the observed proportion of zeros in the data (although the predictive distributions cover a wide range of values; Figure 246), similar to the delta-GLM approach (Lo et al., 1992; Stefánsson 1996) but requires fewer parameters. Strata with all positive observations are easily handled by the NB model, whereas the binomial portion of a delta-GLM model will produce an undefined coefficient (estimate goes to infinity). In this data set, some strata have all positive observations (Table 68), which would complicate the estimation of uncertainty using the delta-GLM approach.

Catch rates in the north are estimated by the standardization model to be larger than the central area, with peak catch rates occurring in the summer months, i.e. waves 3-4, or May-August (Figure 247).The final standardized time series of relative abundance is provided as Table 70 and illustrated in Figure 248.

MRFSS CPUE Index: Summary of changes relative to the 2015 assessment

The index presented in this assessment is derived from the same data set used in the 2015 assessment (Cope et al. 2015). Similar to the previous index, we removed data from 1993-94 due to limited sampling. We decided to remove data from 1997 after repeating the analysis of Key et al. (2008) and identifying years with anomalous effort patterns. The previous assessment included MRFSS data after 1999, but broke the time series into two separate indices to account for regulatory changes. In this assessment, trends in abundance after 1999 are informed by the ongoing onboard CPFV sampling program (Section 2.2.3.3) and a new dockside private boat index (Section 2.2.3.1). The 2015 assessment also used a delta-GLM model to standardize the index. To illustrate how each of these changes affected the index, we first fit the same data set used in 2015 with a negative binomial model. This produced a very similar result to the 2015 index fit using the delta-GLM (Figure 249). Then, we dropped data from 1997 and 2000-2003, which removed the large spike in 1997 and increased the index in most years. Finally, we compared the best-fit model described above, which had little effect relative to dropping the years. We feel that the reasons given above for removing the years 1997 and 2000-2003 justify the changes, and that changes in the index are largely driven by these decisions rather than the specific choice of statistical model.

Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)

Subtidal SCUBA Survey

The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) is an academic consortium conducting monitoring of coastal ecosystems in California as well as research to support marine protected area design. Their work includes SCUBA surveys within rocky reef habitats at a suite of sites across the state using standardized protocols so that multiple participating universities collect compatible data. These protocols are described in great detail by Gillett et al. (2012). We examined fish transect data collected by participating PISCO researchers at the University of California Santa Cruz (UCSC), University of California Santa Barbara (UCSB), and Humboldt State University (HSU) where sites align with the black rockfish stock. Below we outline the structure of PISCO fish transect data, the procedure we used to filter the data to include black rockfish habitat, and methods for development of a fishery-independent abundance index.

Each fish transect location is surveyed by divers who count fish within a 30 x 2 x 2-m volume on the bottom, mid-way up the water column, and near the surface just below the kelp canopy. Three replicate transects are performed within inner, inner-mid, outer-mid, and deep zones of the reef corresponding to depths between 5 and 20 m. This results in 12 transect locations per reef site and 36 transect swims incorporating the three levels. Divers count fish by species and estimate sizes. Survey sites are typically grouped within a geographic area, i.e., there are three sites on Naples reef near Santa Barbara (Naples Central, Naples East, and Naples West). We grouped these sites such that they represent one survey location with up to three times as many replicate transects.

The full dataset was filtered for quality and habitat appropriate for black rockfish (**Table 71**, **Table 72**). We eliminated sites that were sampled in less than 80% of the survey years for each campus. Black rockfish were observed on bottom and mid-water but not canopy transects. Canopy transects were removed, and bottom and mid-water were combined to represent a single unit of effort. Transects within the "mid" and "deep" zone categories were removed due to infrequent use at sites where black rockfish were observed. Divers noted approximate water visibility and transects with visibility less than 3 m were removed. We also retained only fish greater than or equal to 16 cm in length to construct an adult index. The months of May, June and November were removed due to infrequent detection of black rockfish. Following these filters, only one site monitored by the UCSB campus in the northern Channel Islands remained. Therefore, all UCSB campus monitored sites were removed due to general unrepresentativeness of the region. Five out of seven UCSC sites are within MPAs while two out of four HSU sites are within MPAs. We did not filter sites based on MPA status. Remaining UCSC sites were concentrated on the Monterey peninsula and HSU sites in the Mendocino region. We separated the UCSC and HSU data to produce separate indices representative of central and northern California. The UCSC time series extends from 1999 to 2021 while HSU monitoring occurred from 2014 to 2021.

The index was modeled as a negative binomial regression. Models incorporating temporal (year, month) and geographic (site, zone) factors were evaluated. Based on AIC values from maximum likelihood fits (**Table 73**), a main effects model including all factors (year, month, site and zone) was fit in the "rstanarm" R package (version 2.21.3) for both campuses. The proportion of samples with zero observations of black rockfish observed in the data were consistent with replicate data sets generated by the model (Figure 250).

The final index for the UCSC campus peaks in 2003 then declines before increasing again to a secondary peak in 2013 and ends with low values for the final five years. The peak in 2013 is consistent with other abundance indices in the assessment (i.e. CCFRP, PR dockside, and CPFV onboard). The peak in 2003 was not observed in the CPFV onboard index (which includes both retained and discarded fish), which is the only other index that includes 2003. The model was also unable to match the declines in abundance implied by the index after 2016, a pattern also seen in the CPFV onboard index. The final index for the HSU campus is relatively flat with high uncertainty but peaks in 2020. (Figure 251).

The PISCO dive survey was excluded from the final base model because the estimated additive (log-scale) standard deviation parameter (i.e. variance added to the input variances) for this index was large (0.74), suggesting that the index was not consistent with structural assumptions of the model and/or other data sources.

Recruitment Survey

The PISCO program monitors young-of-the-year fish recruitment by sampling artificial settlement substrates called Standard Monitoring Units for Recruitment of Fishes (SMURFs). Similar to the SCUBA surveys, SMURF surveys are conducted by multiple universities using standardized protocols. Methods are described by Steele et al. (2002). We examined data collected by the UCSC campus and ultimately determined that the data were not sufficiently representative of Black Rockfish recruitment to be used as an index in the assessment. Surveys by UCSC were conducted between 1999 and 2016. Only two sites regularly observed Black Rockfish. These were Hopkins and Stillwater Cove on the Monterey Peninsula. Juvenile Black Rockfish are difficult to distinguish from juvenile Olive (*Sebastes serranoides*) and Yellowtail Rockfish (*S. flavidus*). We examined the frequency of detections of Black, Olive and Yellowtail rockfish combined and found that several years of the time series had zero detections of the species combination. Resulting negative binomial model explorations produced imprecise estimates.

NMFS Fishery-Independent Trawl Surveys

Black rockfish are poorly sampled by fishery-independent bottom trawl surveys, with a reported catch of 21 individuals from 13 hauls over the period 2001-2022 from the West Coast Groundfish Bottom Trawl Survey. An additional 264 individuals were collected by the Triennial Survey over a period spanning the early 1980s to the early 2000s, occurring in <0.25% of hauls conducted.

NWFSC Southern California Shelf Rockfish Hook and Line Survey

According to the FRAM Data Warehouse, Black Rockfish were not encountered by this survey, which has operated exclusively in the Southern California Bight.

SWFSC 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) 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). Past assessments have used data from this survey to provide indices of year-class strength (as relative age 0 abundance), including assessments for Blue/Deacon Rockfish (Dick et al. 2017), Widow Rockfish (Adams et al. 2019), Bocaccio (He et al. 2015), Shortbelly Rockfish (Field et al. 2007) and Chilipepper Rockfish (Field 2015).

Historically, 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), but starting in 2004 the spatial coverage 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 (2001-2009) and the Northwest Fisheries Science Center "Pre-recruit" survey (2011-2022) for waters off of 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: The near absence of fish in the core survey area during the 2005-2007 period, which saw two of the lowest abundance levels of juvenile rockfish ever observed in the core area time series, was associated with an apparent redistribution of fish, both to the north and the south (Ralston and Stewart, 2013). 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. We used data from 2001 to 2022, 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, so this year is excluded. In the years 2010, 2012, and 2022, sampling did not span the entire coastwide spatial domain, with data lacking from northern CA and OR (Figure 252). These years were included in the model, but sensitivity of the stock assessment to exclusion of the index for these years could be explored.

As pelagic juveniles, black rockfish can be identified to species (Figure 253); however, black and yellowtail rockfish are difficult to differentiate: the distinction is primarily based on pectoral fin ray counts (yellowtail: 17-18, black: 19), however the meristics are variable (yellowtail can occasionally have 19, and black can occasionally have 18), so some misclassification undoubtedly occurs. Yellowtail rockfish are closely related to black rockfish, have similar life histories, and are more abundant and frequently encountered in the survey than black rockfish (Figure 254). Thoughout the survey, approximately 6x more yellowtail have been caught than black rockfish. Yellowtail tend to co-occur with black rockfish (and also blue and widow rockfish), such that their CPUE co-varies (Figure 255). As previously mentioned, high synchrony has been observed among many rockfishes in the survey. For all of these reasons, we produced one index with black rockfish alone, and another with pooled black and yellowtail rockfish.

Catch per tow was adjusted to a common age of 100 days to account for interannual differences in age structure, as has been done for prior assessment indices using this dataset.

Model

For the index model, we used data from 35–43°N latitude (just north of Point Conception to southern OR). Black and yellowtail rockfish were rarely caught south of 35°N, and samples from southern OR were included in the model training data to improve estimation of spatial fields near the CA-OR border. Model predictions upon which the index was based were restricted to 35–42°N (just north of Point Conception to the CA-OR border). In years 2006, 2012, 2017, and 2021, no black rockfish were caught. At least one yellowtail was caught every year.

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 year along with Julian date (GAM smoother with k=4) to account for seasonality, a spatial random field, and IID spatiotemporal random fields.

In sdmTMB index models, year effects are typically modeled as fixed factors, however this approach is unable to estimate an index and associated uncertainty for years in which there are no positive catches. For black rockfish only, there were several years with extensive sampling but where no black rockfish were caught. In order to not have to exclude these years, which are informative about abundance being relatively low, year effects were instead modeled using time-varying (random walk) intercepts. In years with positive catches (all years for black+yellowtail, and most years for black only), the resulting indices and uncertainties were nearly identical to those using fixed year effects, and in years with no positive catches, the model appropriately produced an index with a low value and relatively high (but not infinite) uncertainty, which is usable in the assessment. For consistency, we used this time-varying intercept structure for both black+yellowtail and black only.

We fit the model using 3 different error structures: tweedie, delta-lognormal, and delta-gamma. Dharma quantile residuals from model simulations suggested that tweedie distribution was the best (Figure 256), 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 (black+yellowtail: observed: 0.83, tweedie: 0.84, delta-lognormal: 0.72, delta-gamma: 0.72. CA black: observed: 0.94, tweedie: 0.95). As expected, 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 (Figure 257).

Predictions from the model were made for all active sample stations from 35–42°N (just north of Point Conception to the CA-OR border), for the mean Julian date (143.7), for each year. Predictions were added together for each year to produce the index. Active stations are those regularly and consistently sampled, and are located on a semi-regular grid spanning the sampling region. Interpolating to a finer spatial grid had little impact on the resulting index.

If the spatio-temporal field is excluded from the model, the indices show the same general trend, with some differences in the relative magnitude of values, mostly in years with high abundance. Since areas of high recruitment are variable over both space and time, we suspect the spatio-temporal model is better able to capture this variation from year to year, and is thus more accurate.

The indices for black only and black+yellowtail were highly correlated (log index: 0.77, index: 0.92) (Figure 258), even with yellowtail accounting for the majority of fish caught. The two indices deviated mainly in the years 2021 and 2022: black alone rockfish were low, but yellowtail were relatively abundant. Sensitivity of the stock assessment to the use of each index should be explored.

SWFSC SCUBA survey

Data

The Fishery Ecology Division of the Southwest Fishery Science Center has conducted standardized surveys for settled juvenile young-of-the-year (age-0) rockfishes in California kelp beds, which is the habitat to which black rockfish recruit. These surveys are conducted annually between 1 July and 30 September. Several nearby sites were surveyed in the vicinity of Albino, CA (Mendocino County), for the years 1983-2007, and in the vicinity of Monterey for the years 1984, 1996, 1997, and 2001-2022. Kelp beds consisted of high-relief bedrock interspersed with low-relief cobble and sand areas. Researchers surveyed strip transects using SCUBA. Researchers swam 2 m above the seafloor at Mendocino sites and 1 m above the seafloor at Monterey sites because of differing topographies (Mendocino has more pinnacles and required swimming farther off the seafloor; Monterey is flatter and researchers could be consistently closer to the seafloor). Researchers swam in one direction and counted all juvenile rockfishes within 3 m in any direction for 1 minute (with the exception of years 1983-1984, where transect duration ranged from 1-30 minutes). At the end of each one minute survey, the numbers of each species were recorded. The researcher would then haphazardly choose another direction to swim and conduct rockfish counts for another minute. Surveys were made throughout the kelp bed from the surface to 20 m depth. Young-of-the-year rockfishes were distinguished from older conspecifics by their size (less than 80 mm standard length in August) and from other rockfish species by body shape and pigment patterns (Anderson, 1983; Love et al., 2002). To standardize survey conditions, surveys were only conducted between the hours of 0900 and 1700, when underwater visibility was greater than 4 m, and when swell height was less than 2 m.

For consistency with the analysis of the RREAS pelagic juvenile data, and because (as with the RREAS data) yellowtail rockfish were observed more frequently than black rockfish, we produced one index with black rockfish alone, and another with pooled black and yellowtail rockfish.

Model

For the index model, we used a negative binomial GLM with the number of fish observed as the response variable, and the log number of minutes surveyed as an offset. Poisson GLM models were also tried, but the residuals were strongly overdispersed; the negative binomial model produced acceptable diagnostic plots. For pooled black+yellowtail, fixed effects were included for year and area (Mendocino, Monterey). For just black rockfish, there were some years with no fish observed, so time-varying (random walk) intercepts were used rather than fixed effects in order to obtain estimates for those years. The area effect had to be dropped for this model because the time-varying intercept approach does not work with categorical covariates that are not sampled in all years. We reasoned that not accounting for area effects (which were relatively weak) would be less undesirable than having to exclude years with no fish caught that are indicative of low recruitment. Models were fit with the package sdmTMB with spatial fields turned off (Anderson et al. 2022).

Correlations between the log indices for the pelagic juvenile survey and the SCUBA (settled juvenile) survey were 0.58 for black rockfish and 0.73 for black+yellowtail rockfish (Figure 259, Figure 260).

California Remotely Operated Vehicle Survey Data

The California Department of Fish and Wildlife (CDFW) in collaboration with Marine Applied Research and Exploration (MARE) have been conducting remotely operated vehicle (ROV) surveys along the California coast in Marine Protected Areas (MPAs) and reference sites adjacent to them since 2007 for the purposed of long-term monitoring of changes in size, density (fish/sq meter) and length of fish and invertebrate species along the California coast. Surveys of the entire coast have been undertaken twice, taking three years to complete each resulting in super years of 2015 (2014-2016) and 2020 (2019-2021) available for analysis. The 500 m strip survey transects in each rocky reef sample site were selected by first randomly selecting the deepest transect at a given site, then selecting transects on a constant interval into shallower depths. Transects were designed to be oriented parallel to general depth contours, though they were carried out using a fixed bearing that crossed depths in some cases. Species encountered by the ROV along the transect were identified to species or lowest taxonomic grouping possible and stereo cameras along with analytical software were used to determine the length of individuals in a suitable orientation for estimation. Seafloor was characterized along the course of the transect in 1 second micro blocks assembled into classifications of rock, mixed and soft bottom habitat. The transects were then broken into 10 m segments to allow evaluation of density of fish with variables such as depth, habitat type and terrain attributes derived from the California Seafloor mapping project. The terrain attributes were only available for a subset of the ROV transects due to limitations on the availability of 2x2 m resolution depth data from which the terrain attributes calculated across 3x3 or 5x5 grids such as slope, depth range and rugosity that were georeferenced to the centroid of each segment. While the habitat type is available from ROV observations, the terrain attributes provide a measure of relief in the seafloor, though only for a subset of transects. A larger number of segments are available for analysis without the limitations on terrain attributed derivation. Length data from the stereo-camera estimates provide composition data representing the observed fish sampled among MPAs and reference sites that can be paired with the indices or abundance estimates as a research fleet. In addition, they provide the basis for average weight expansions for estimates of abundance.

The use of this data in stock assessments was approved by the SSC for use in stock assessments after a methodology review conducted in 2019 for use as an index of abundance or absolute abundance estimate using seafloor mapping as the basis for expansion to rocky reef habitat. Additional details on sampling methods, data processing, index derivation and absolute abundance estimation principles and method can be found in the report from the methodology review.

The ROV survey reported observations of 902 black rockfish in northern and central California from 2014-2016 and 2019-2021. Documentation provided to the STAT states, "Schooling rockfish species such as blue, black or yellowtail rockfish were unavailable to the ROV in mid-water making the ROV based methods poorly suited to estimating their abundance without supplemental acoustic data and potential changes to the sampling methodology." The report from the methodological review stated, "Black, blue/deacon and canary rockfish may be candidates for developing indices if ROV data is coupled with other observational data given the tendency of these species to be found in midwater or off-bottom schools." (PFMC, 2020) Data from the survey were not included in the current assessment, but may provide useful information to future assessments with additional analysis and/or coupling with other data sets.

Appendix B Tables

Table 66: Data filters applied to the California MRFSS dockside CPFV index. See Section 0 for details regarding specific filter steps.

Filter	Description	Samples	Percent_Positive
All data	California data north of Point Conception	2923	15.4%
Remove suspect years	Only sampled SLO County in 1993-94; Effort issue in 1997	2695	14.9%
Extreme counter-indicators	Remove trips encountering sablefish and albacore	2553	15.7%
Stephens-MacCall	Remove predicted false negatives	764	52.6%
Remove 2000-2003	Change in bag limit after 1999; remove 1 extreme catch rate	558	47.3%

Table 67: Sample size (number of trips) by year and CRFS district for the California MRFSS dockside CPFV index. Data were assigned to CRFS District by county.

	CRFS District				
Year	3	4	5	6	Subtotal
1980	14	14	7	0	35
1981	5	17	5	1	28
1982	2	7	10	1	20
1983	7	9	5	0	21
1984	20	13	2	0	35
1985	22	41	8	2	73
1986	12	16	5	0	33
1987	11	32	2	1	46
1988	22	16	1	2	41
1989	7	12	3	1	23
1995	7	8	6	6	27
1996	24	28	6	10	68
1998	33	27	1	2	63
1999	18	21	5	1	45
Subtotal	204	261	66	27	558

Table 68: Proportion of trips that caught black rockfish by year and CRFS district for the California MRFSS dockside CPFV index. Data were assigned to CRFS District by county.

	CRFS District				
Year	3	4	5	6	Marginal
1980	0.214	0.429	0.143		0.286
1981	0.600	0.294	0.6	1	0.429
1982	0.500	0.286	0.8	1	0.600
1983	0.143	0.667	0.2		0.381
1984	0.150	0.692	0		0.343
1985	0.318	0.659	0.5	1	0.548
1986	0.250	0.500	0.8		0.455
1987	0.182	0.531	0	1	0.435
1988	0.182	0.563	0	0.5	0.341
1989	0.143	0.333	1	0	0.348
1995	0.143	0.375	0.833	1	0.556
1996	0.333	0.571	0.833	0.9	0.559
1998	0.455	0.630	1	1	0.556
1999	0.500	0.571	0.6	1	0.556
Marginal	0.299	0.540	0.576	0.889	0.473

Table 69: Akaike Information Criteria for alternative negative binomial regression models of catch-per-unit-effort based on California MRFSS dockside CPFV data. All candidate models include an intercept, effort offset term (log of angler hours), and an additive year effect.

Covariates ("+" = included)								
year	area	wave	water_area	area:year	df	logLik	AICc	delta
+	+	+	NA	NA	21	-1215.74	2475.2	0.0
+	+	+	+	NA	22	-1215.66	2477.2	2.0
+	+	+	NA	+	34	-1205.53	2483.6	8.4
+	NA	+	NA	NA	20	-1221.25	2484.1	8.9
+	+	+	+	+	35	-1205.29	2485.4	10.2
+	NA	+	+	NA	21	-1221.15	2486.0	10.8
+	+	NA	NA	NA	16	-1228.21	2489.4	14.2
+	+	NA	+	NA	17	-1228.20	2491.5	16.3
+	+	NA	NA	+	29	-1217.81	2496.9	21.7
+	+	NA	+	+	30	-1217.81	2499.2	23.9
+	NA	NA	NA	NA	15	-1237.83	2506.5	31.3
+	NA	NA	+	NA	16	-1236.94	2506.9	31.7

Table 70: California MRFSS dockside CPFV Index, with log-scale standard errors and 95% highest posterior density (HPD) intervals.

year	index	lower HPD interval	upper HPD interval	log.SE
1980	0.141	0.057	0.292	0.401
1981	0.094	0.032	0.223	0.479
1982	0.235	0.054	0.650	0.578
1983	0.125	0.033	0.336	0.545
1984	0.441	0.161	0.994	0.451
1985	0.427	0.211	0.766	0.320
1986	0.180	0.060	0.396	0.438
1987	0.411	0.154	0.820	0.402
1988	0.218	0.079	0.447	0.417
1989	0.150	0.045	0.384	0.512
1995	0.184	0.057	0.446	0.495
1996	0.387	0.171	0.705	0.346
1998	0.476	0.243	0.822	0.295
1999	0.419	0.170	0.842	0.389

Table 71: Data filtering steps for the PISCO SCUBA survey

Process	**Transects**	**# Black Rockfish**	**% Positive**
Original	61322	13855	7%
Group Sites	44918	13855	9%
Regularly sampled sites, saw black rockfish >= once	10721	4979	13%
Remove low visibility transects & canopy transects	10089	4842	14%
Group mid and bottom transects	5296	4842	20%
Filter to age 1+ fish (<=16cm)	5296	3711	18%
Remove mid & deep zones, May, June & Nov, UCSB sites with few detections	2948	3596	31%

Table 72: Number of transects remaining in the filtered data set by campus and year

Campus	Year	# Transects
HSU	2014	113
HSU	2015	107
HSU	2017	59
HSU	2018	111
HSU	2019	110
HSU	2020	78
HSU	2021	54
UCSC	1999	40
UCSC	2000	40
UCSC	2001	48
UCSC	2002	72
UCSC	2003	72
UCSC	2004	84
UCSC	2005	85
UCSC	2006	84
UCSC	2007	84
UCSC	2008	84
UCSC	2009	84
UCSC	2010	114
UCSC	2011	132
UCSC	2012	108
UCSC	2013	148
UCSC	2014	120
UCSC	2015	111
UCSC	2016	108
UCSC	2017	132
UCSC	2018	153
UCSC	2019	138
UCSC	2020	155
UCSC	2021	120

Table 73: Model selection for the PISCO SCUBA survey data by campus

	UCSC		HSU	
Model	**AIC**	**df**	**AIC**	**df**
Year	2863.994	24	1123.802	8
Year, Month	2856.65	27	1127.235	11
Year, Month, Site	2757.558	33	1131.597	14
Year, Month, Site, Zone	2661.45	36	1111.957	17

Appendix B Figures

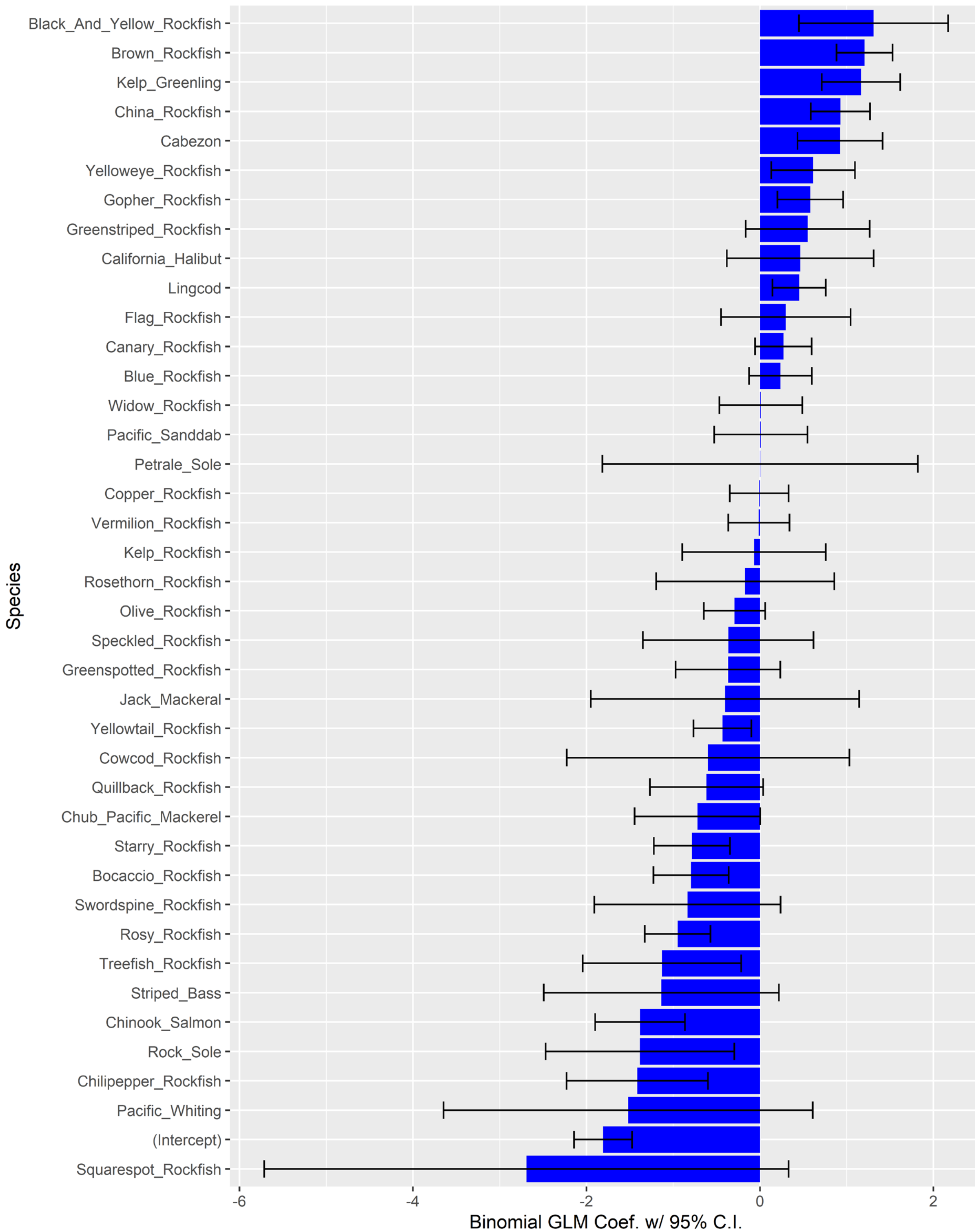

Figure 239: Species coefficients (blue bars) from the binomial GLM for presence/absence of black rockfish in the MRFSS data for California north of 34°27′ N. latitude. Horizontal black bars are 95% confidence intervals.

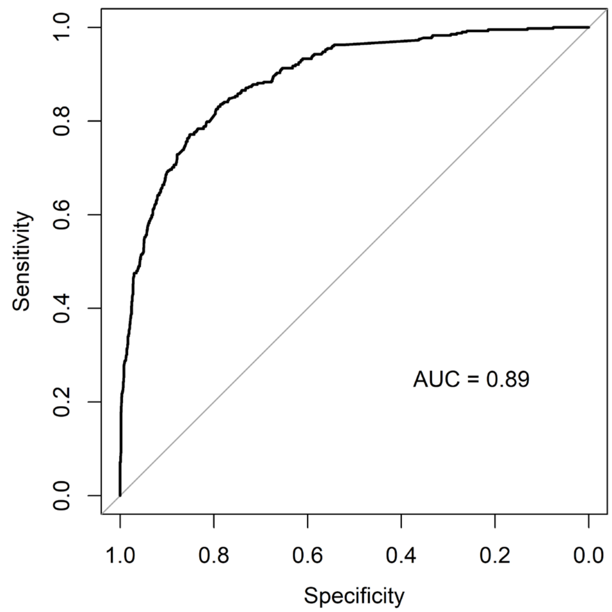

Figure 240: MRFSS Receiver Operating Characteristic (ROC) curve for Stephens-MacCall logistic regression model. AUC is the probability that a randomly chosen observation of presence would be assigned a higher ranked prediction than a randomly chosen observation of absence.

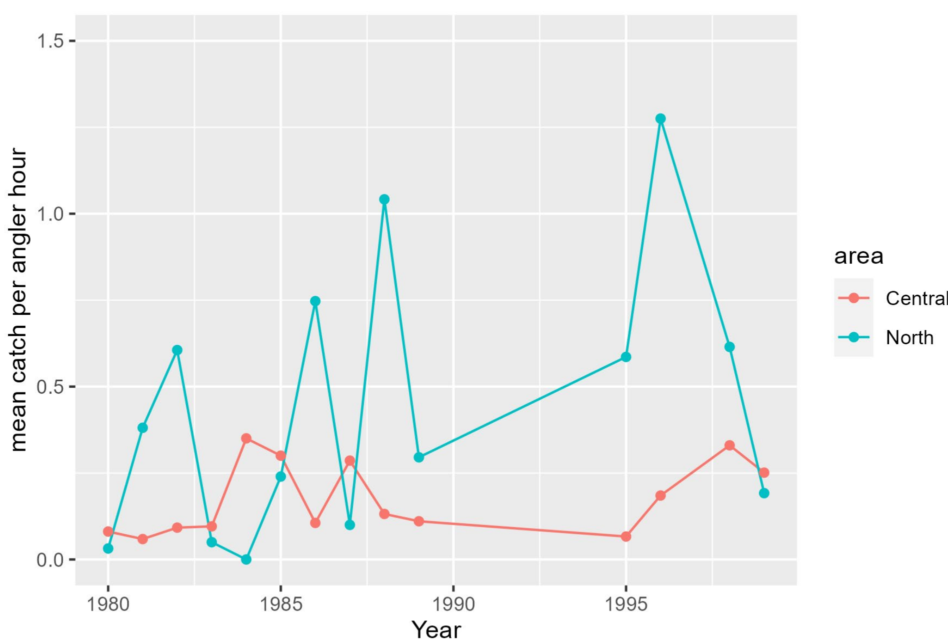

Figure 241: Average catch per angler hour (filtered data) by year and area for the MRFSS dockside CPFV data.

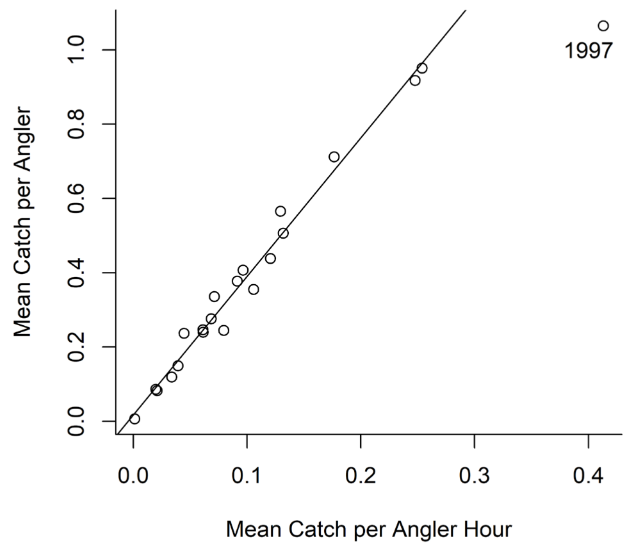

Figure 242: MRFSS Northern California CPFV effort anomaly in 1997, as noted by Key et al. 2008.

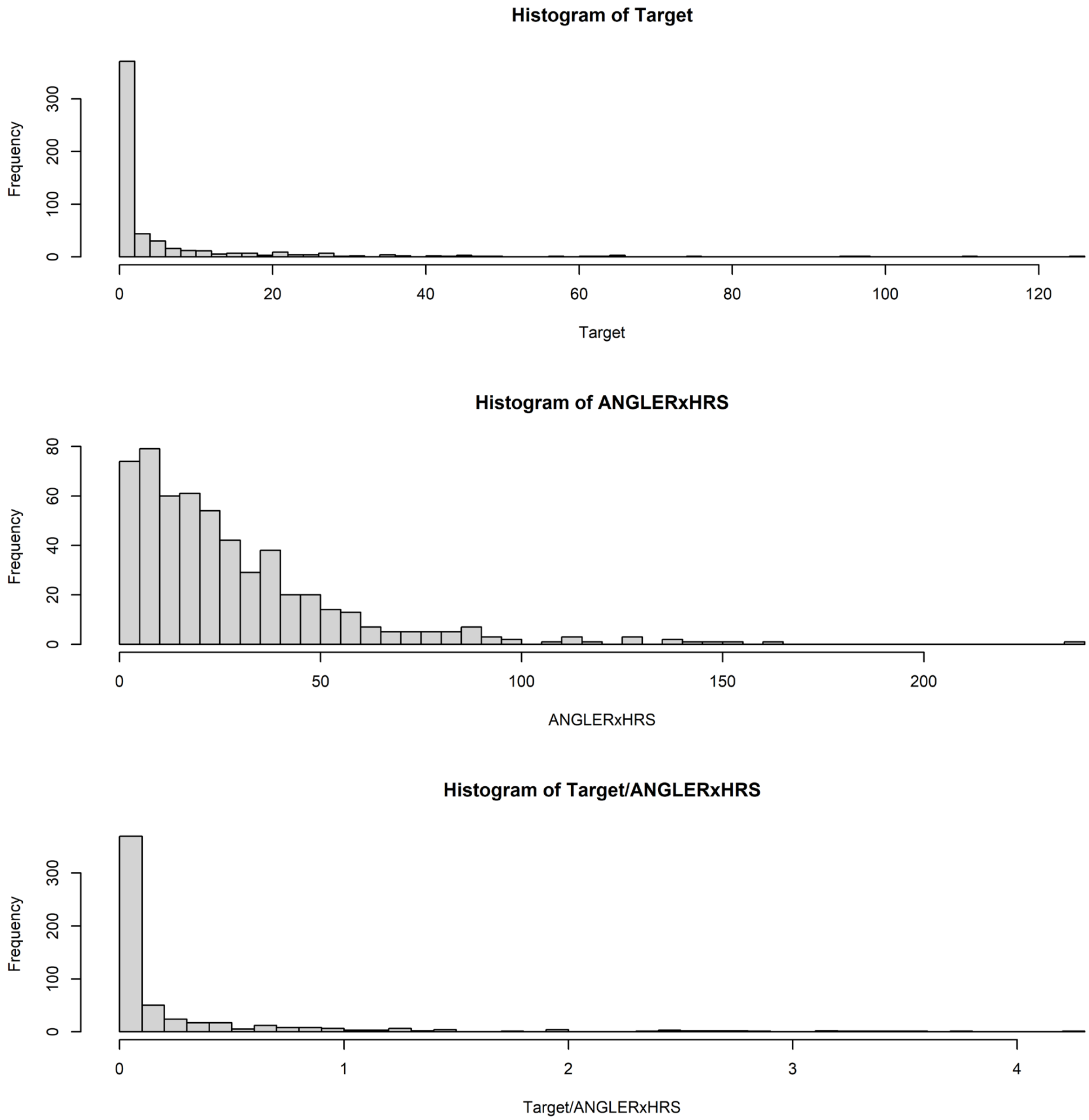

Figure 243: Distributions of the count of black rockfish ("Target"), the product of reported anglers and hours fished (ANGLERxHRS), and catch rates (fish per angler hour), by trip, in the MRFSS dockside CPFV data.

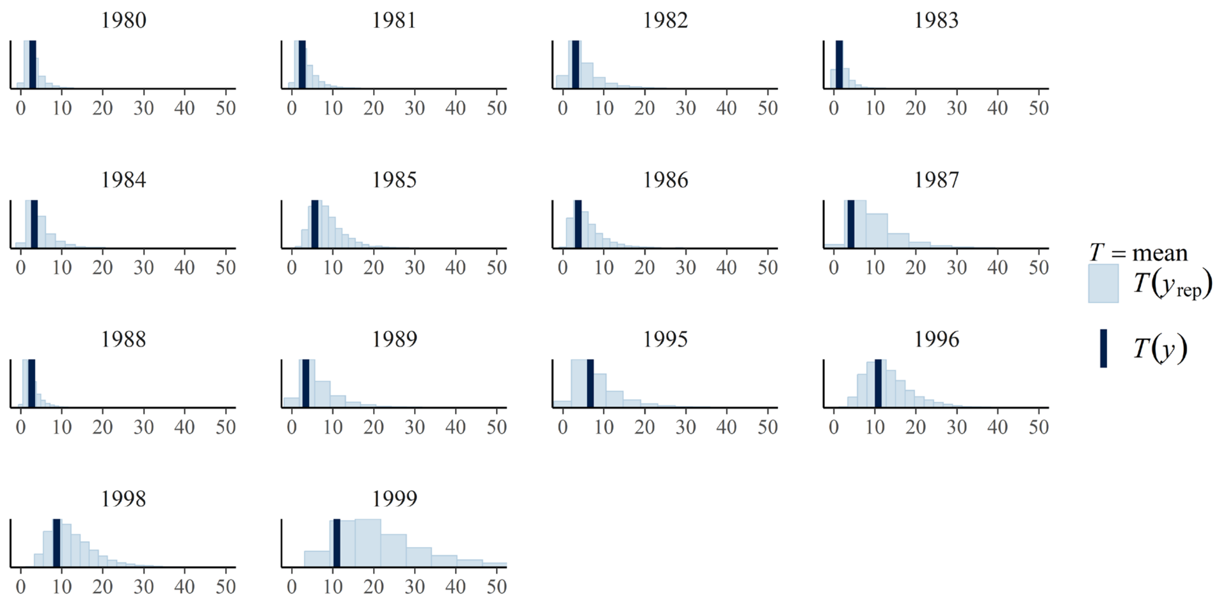

Figure 244: Posterior predictive distributions of the mean catch by year from the negative binomial model (histograms), compared to the observed mean number of black rockfish in the MRFSS CPFV data.

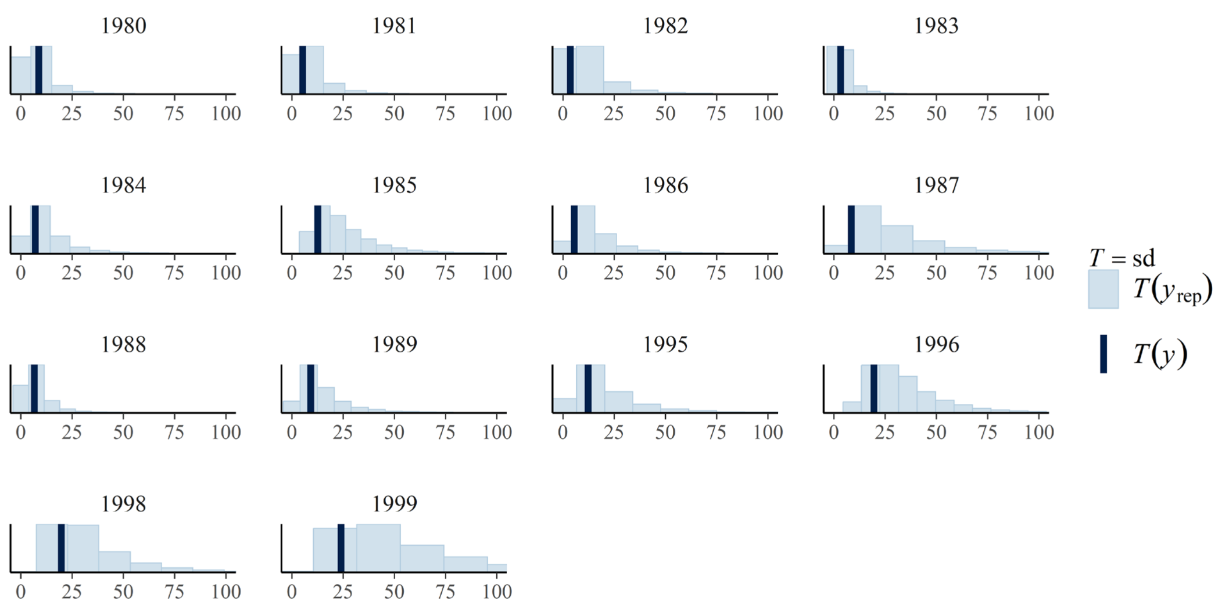

Figure 245: Posterior predictive distributions of the standard deviation of catch by year from the negative binomial model (histograms), compared to the observed standard deviation of black rockfish in the MRFSS CPFV data.

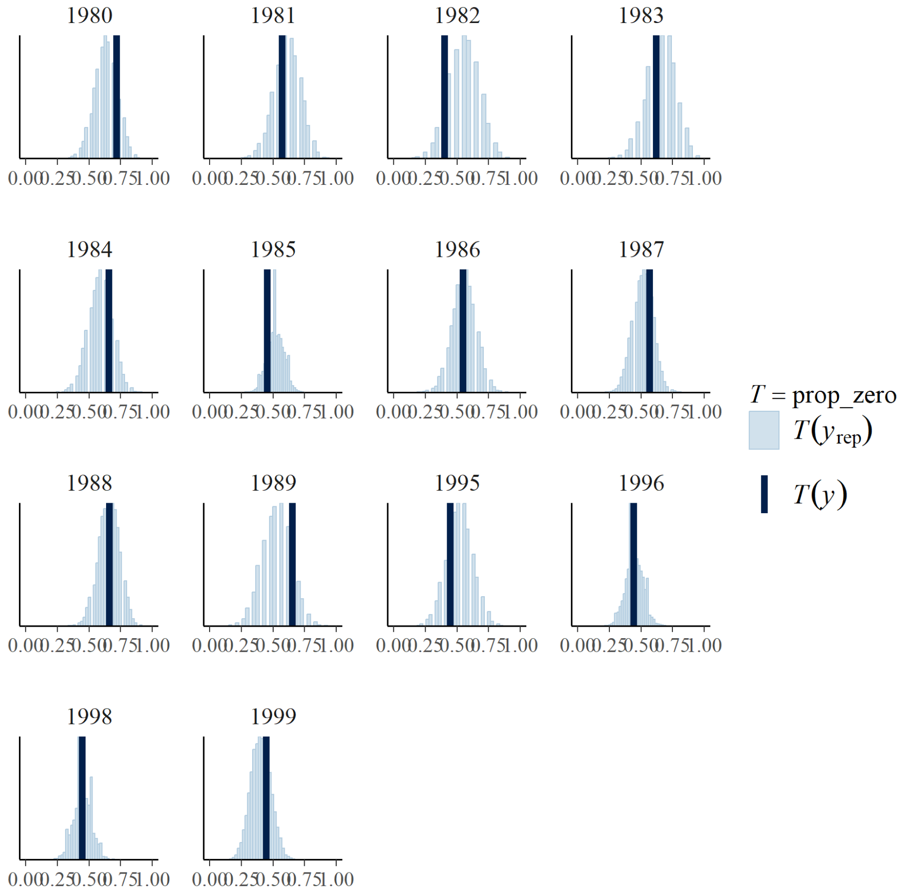

Figure 246: Posterior predictive distribution of the proportion of zero observations in replicate data sets, by year, generated by the negative binomial model for MRFSS CPFV data.

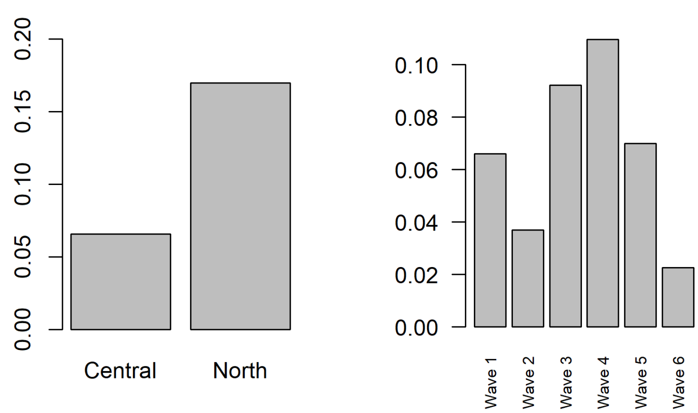

Figure 247: Relative area and wave effects estimated from the MRFSS CPFV data.

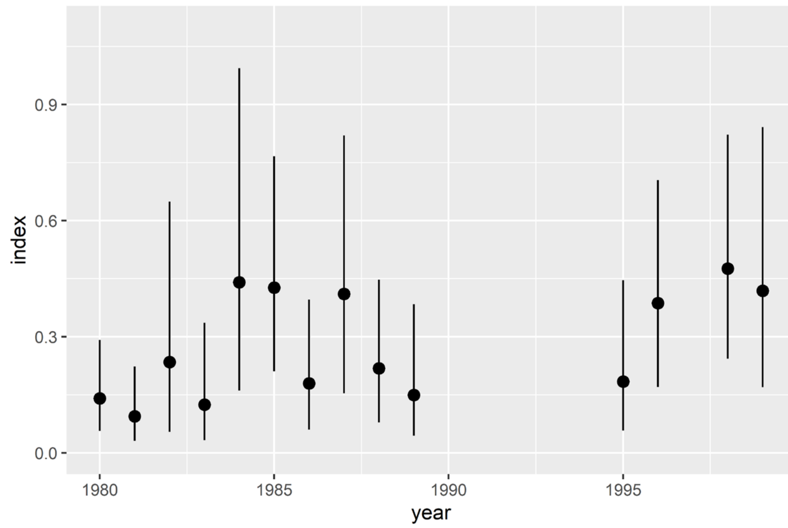

Figure 248: Standardized index of abundance for black rockfish based on the MRFSS CPFV data. Medians (points) of the back-transformed posterior distributions are shown with 95% highest posterior density intervals (line segments).

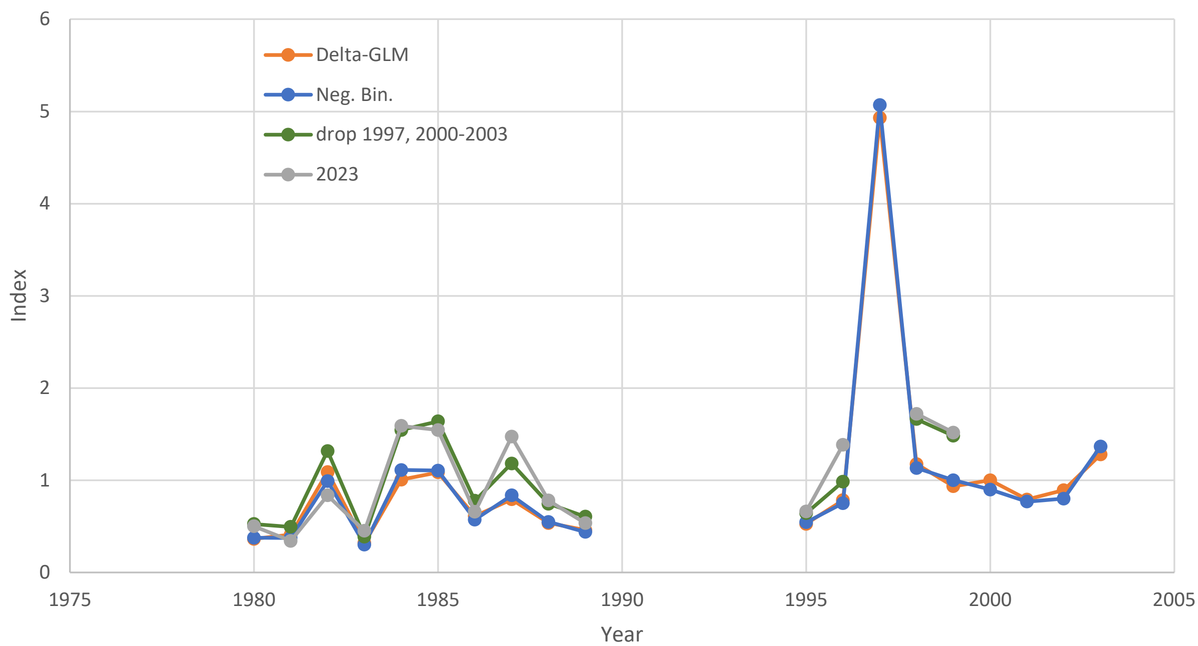

Figure 249: Comparison of the 2015 MRFSS CPFV index and the 2023 index, illustrating incremental changes as described in Section 0.

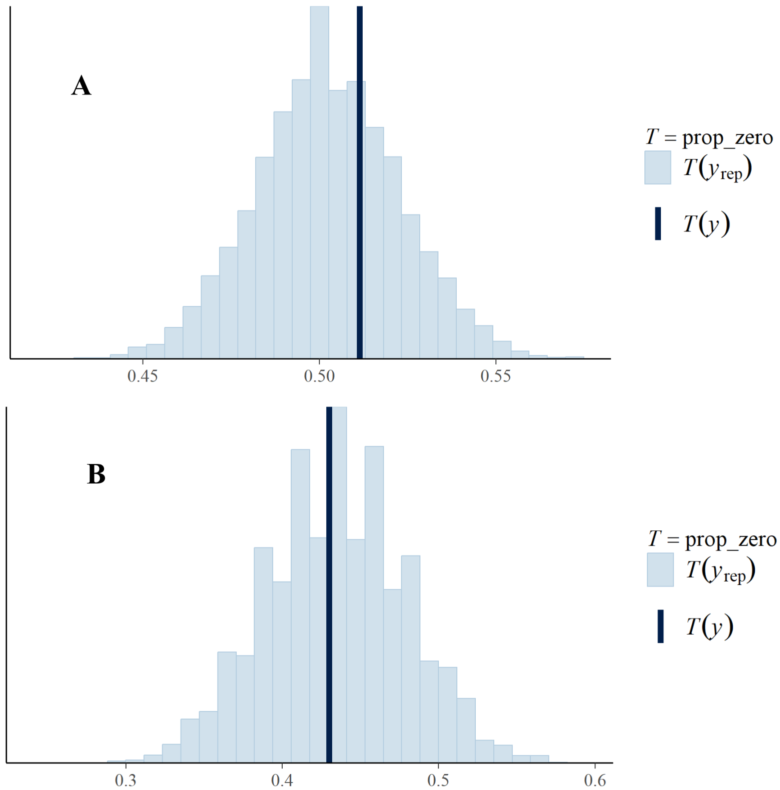

Figure 250: Posterior predictive distribution of the proportion of zero observations in replicate data sets generated by the negative binomial model for the PISCO kelp forest fish survey. A) UCSC, B) HSU.

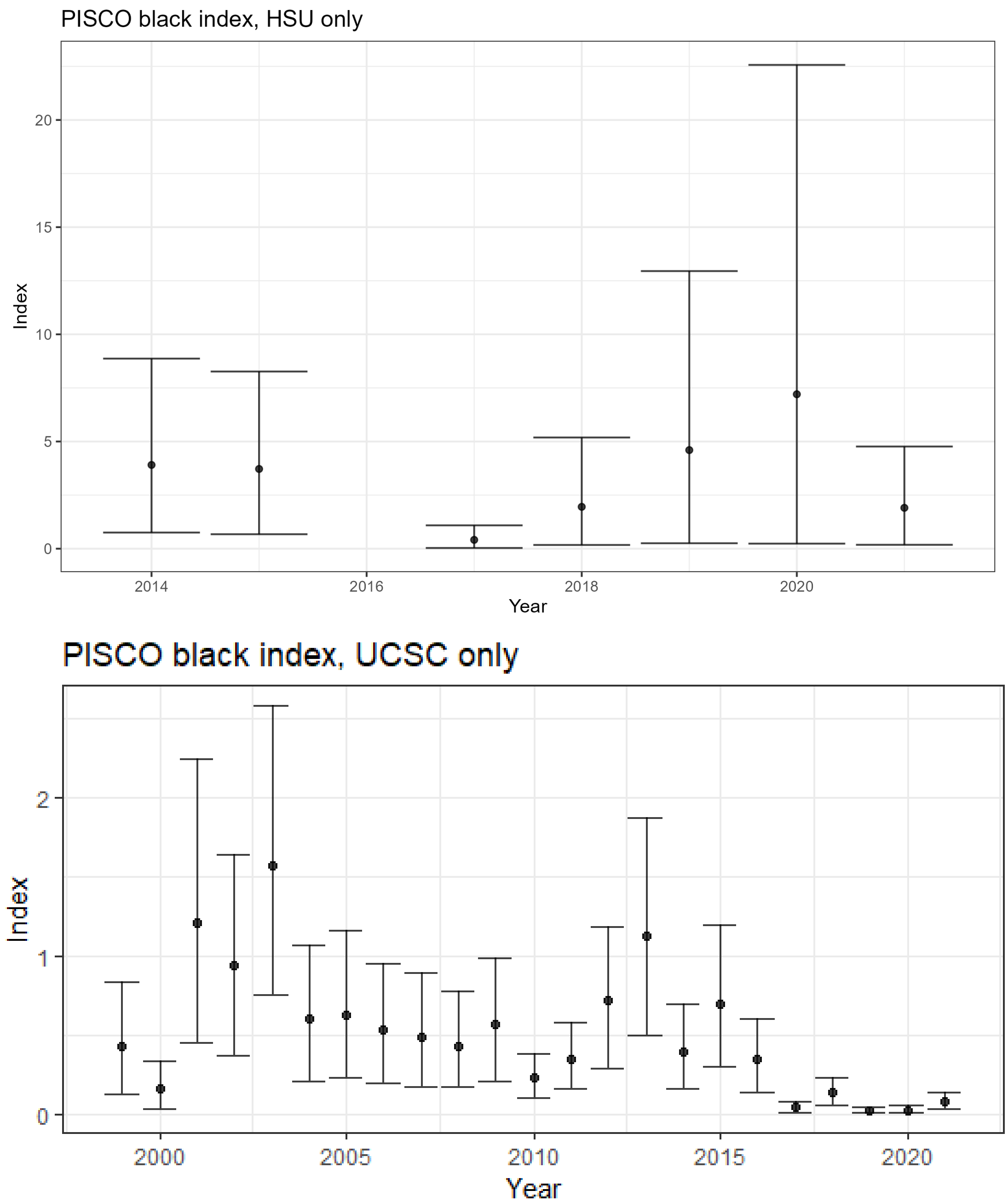

Figure 251: PISCO SCUBA survey indices of relative abundance developed from data collected by Humboldt State University (HSU, top panel) and the University of California, Santa Cruz (UCSC, bottom panel).

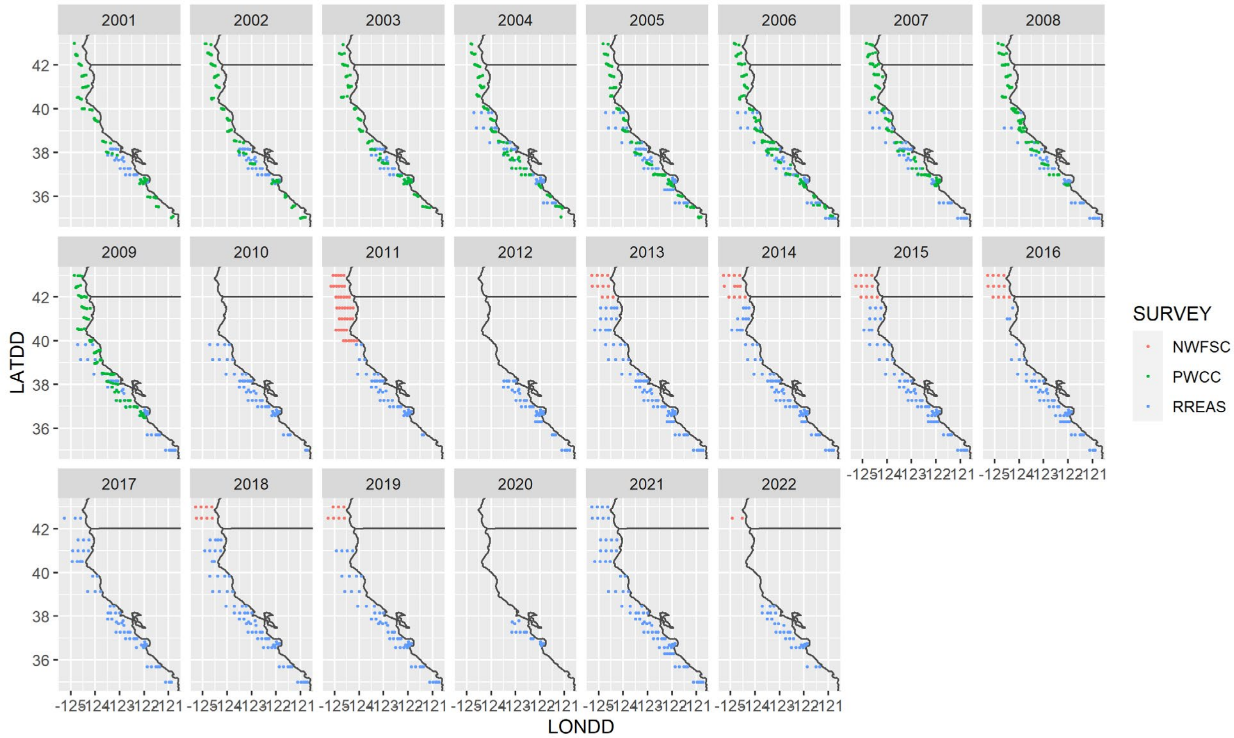

Figure 252: Location of samples by year and survey for CA and OR.

Figure 253: Pelagic juvenile black rockfish, approx. 40 mm standard length.

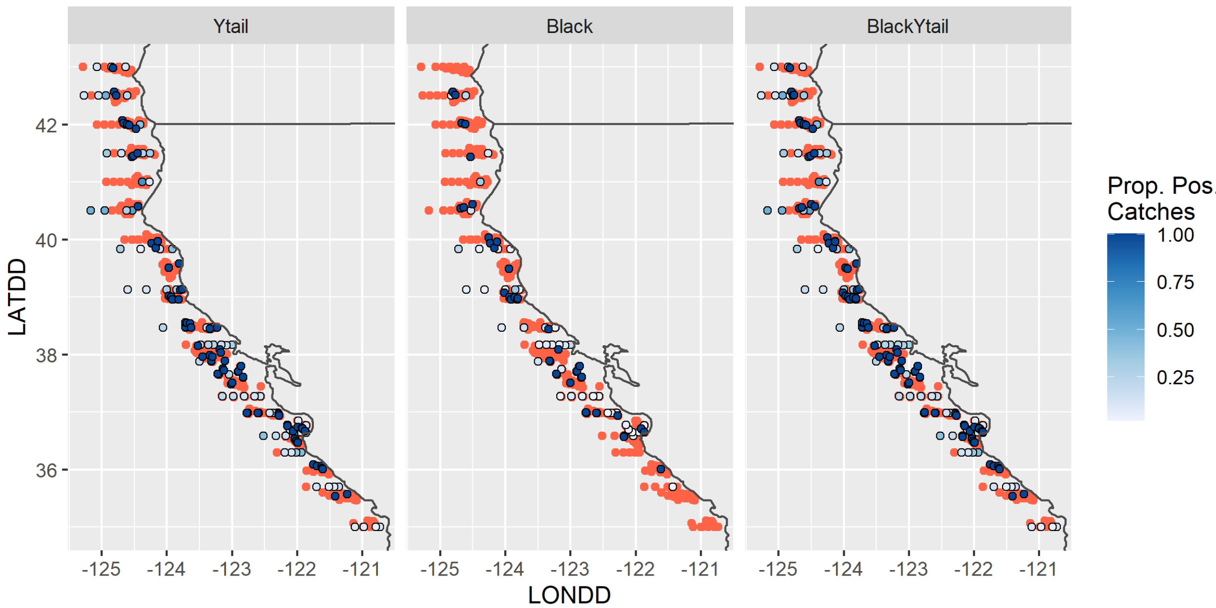

Figure 254: Proportion positive catches of black, yellowtail, and black+yellowtail at each station across all years. Red points are zeros (species never caught at this station).

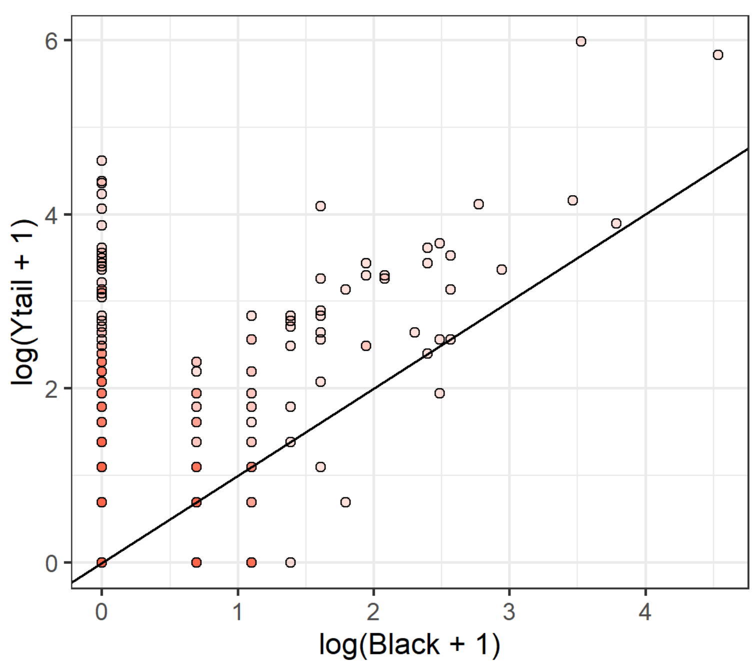

Figure 255: Correlation between black and yellowtail rockfish raw CPUE.

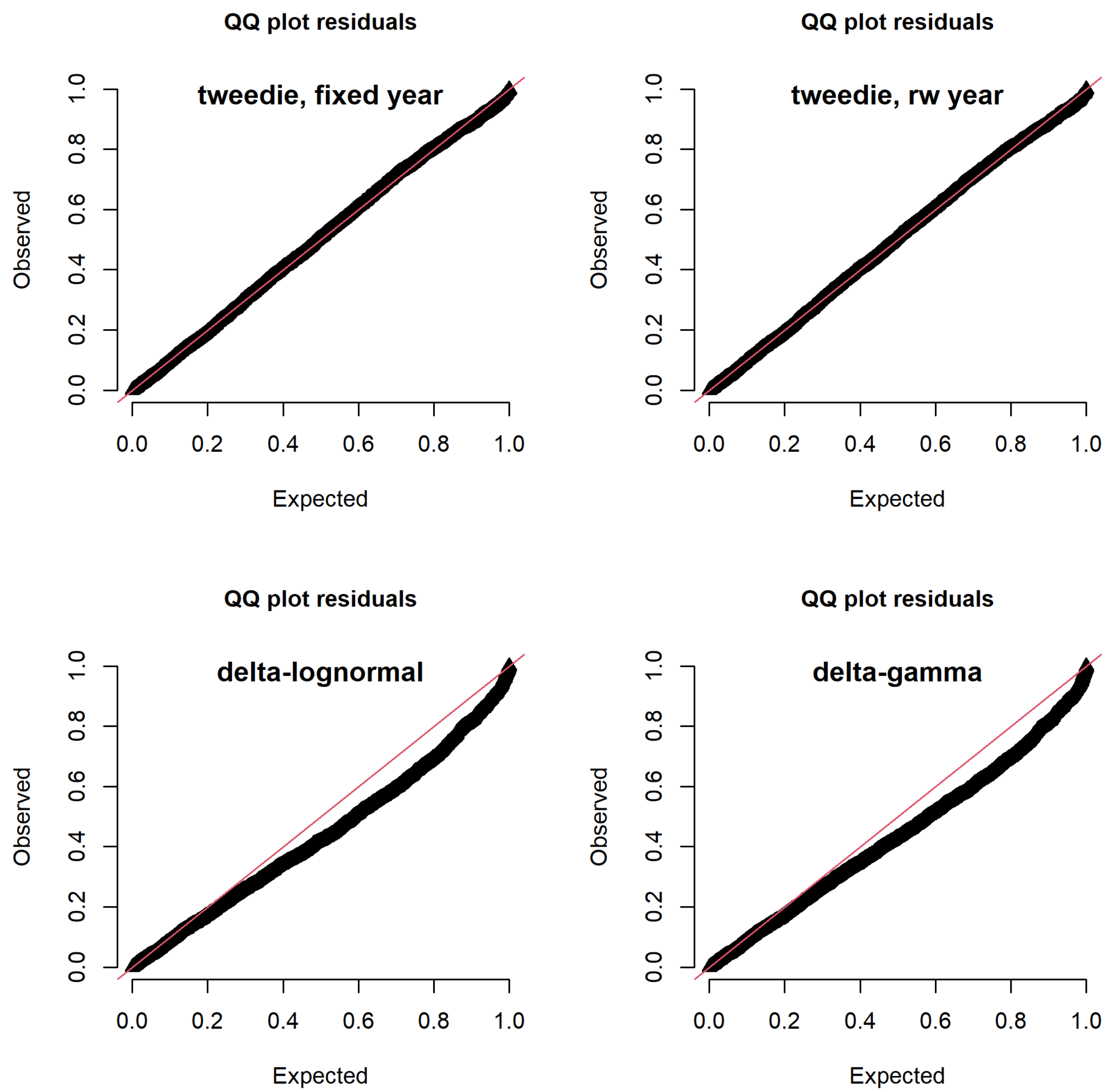

Figure 256: QQ plots using simulation-based quantile residuals for models with three different error distributions. These are for the CA black+yellowtail model. Delta models were fit using fixed year effects since the delta models had difficulty converging with time-varying intercepts. Tweedie models were fit using both year effect structures and had similar fit diagnostics.

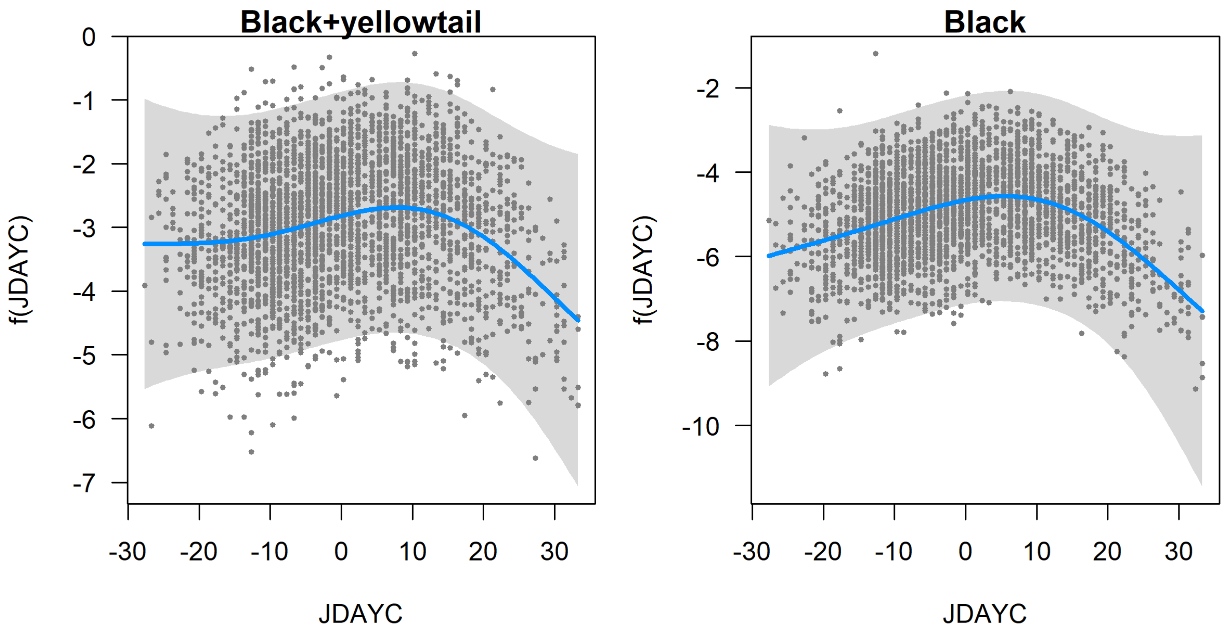

Figure 257: Conditional effect of Julian date (centered on the mean, 143.7) on log CPUE. Points are partial randomized quantile residuals..

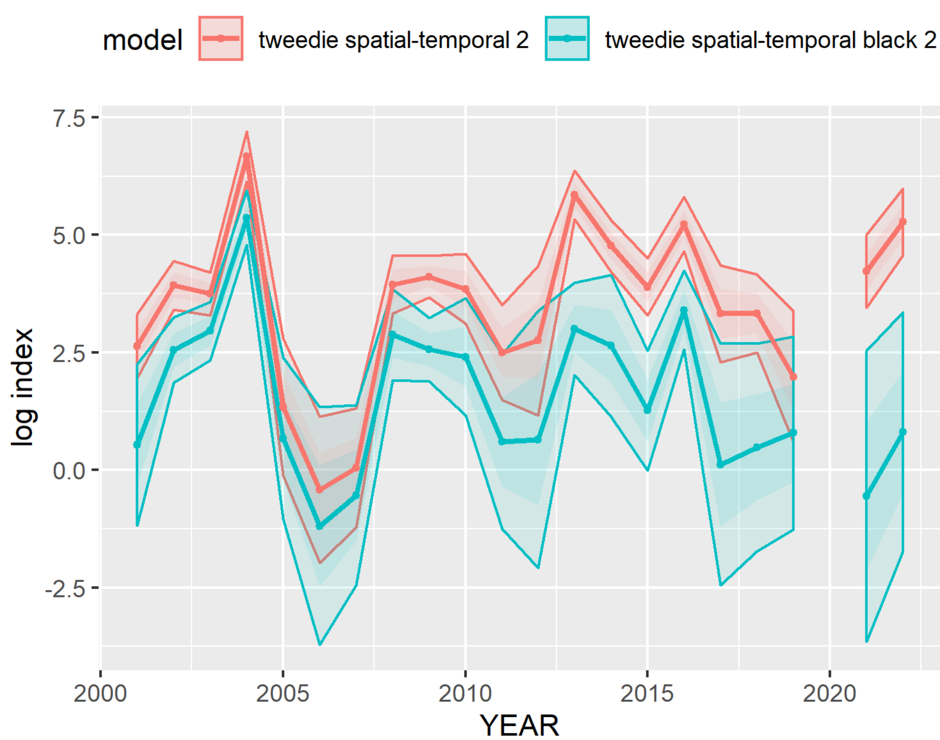

Figure 258: Comparison of log indices for black+yellowtail and black rockfish alone.

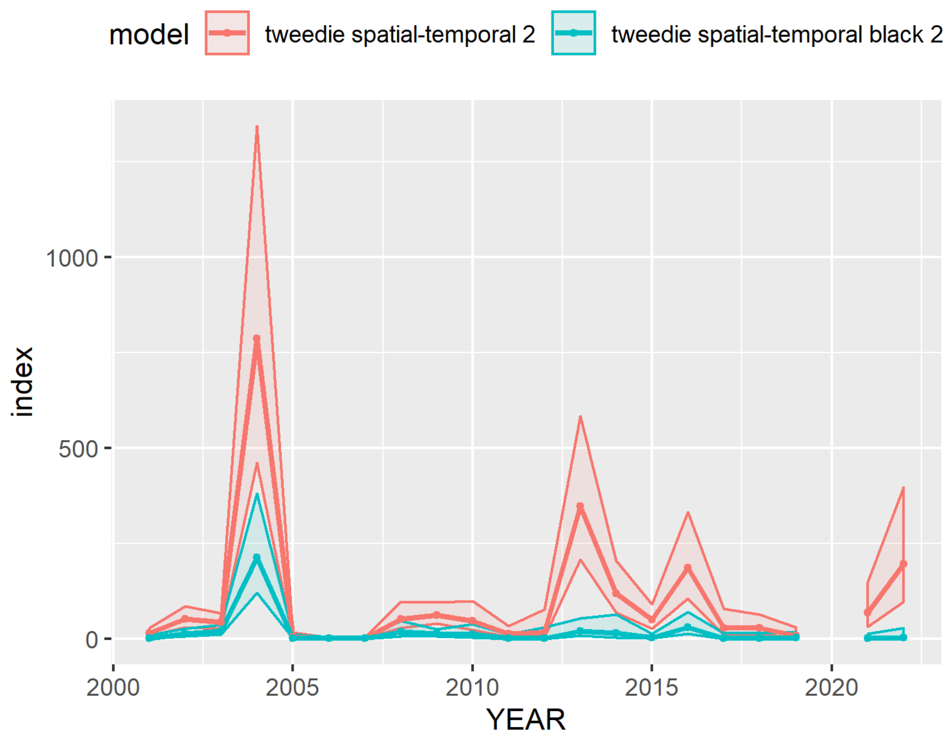

Figure 259: Comparison of indices for black+yellowtail rockfish and black rockfish alone.

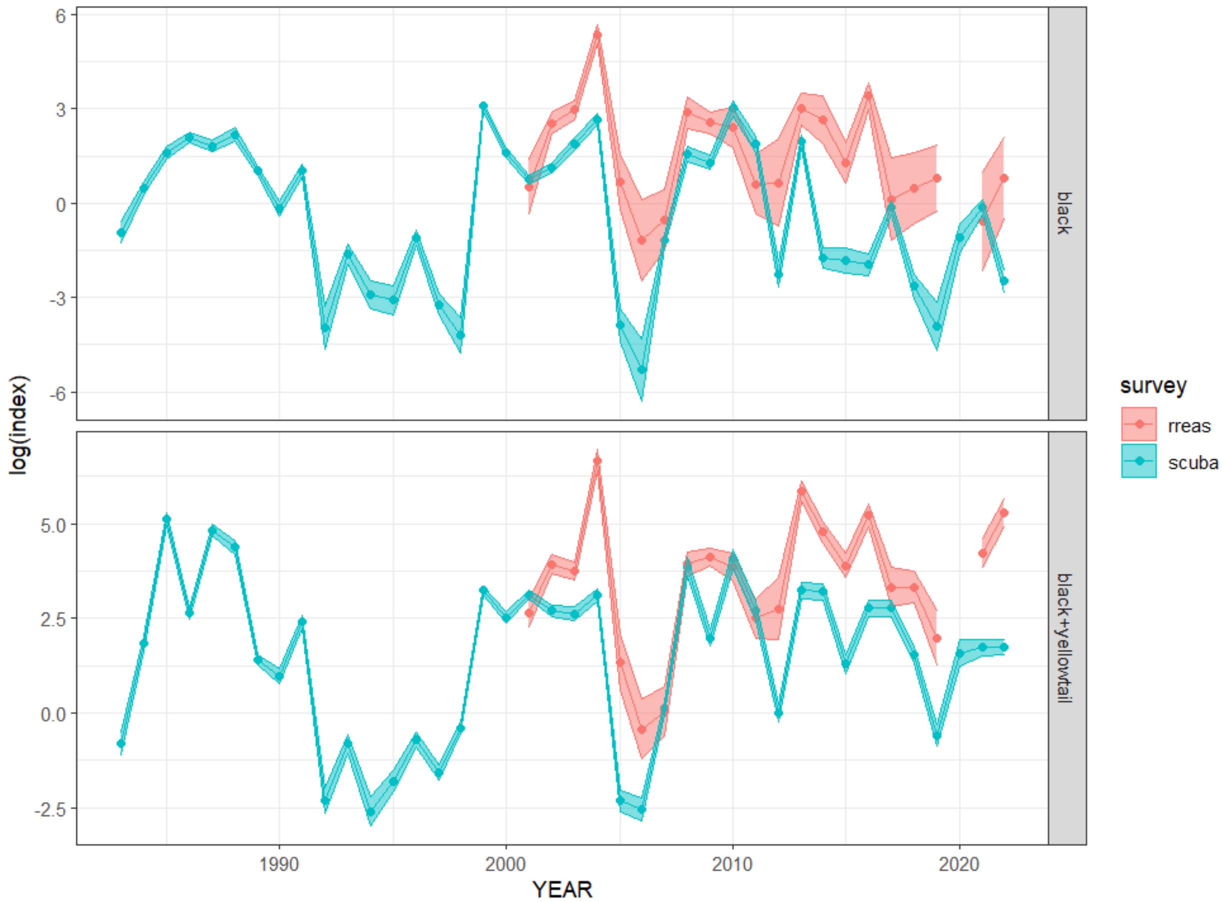

Figure 260: Comparison of RREAS and SWFSC SCUBA recruitment indices