

Status of Shortspine Thornyhead (*Sebastolobus alascanus*) along the US West coast in 2023

by

Joshua A. Zahner¹
Madison Heller-Shipley¹
Haley A. Oleynik²
Sabrina G. Beyer¹
Pierre-Yves Hernvann^{3,4}
Matthieu Véron^{1,5}
Andrea N. Odell⁶
Jane Y. Sullivan⁷
Adam L. Hayes¹
Kiva L. Oken⁴
Vladlena Gertseva⁴
Melissa A. Haltuch⁵
Owen S. Hamel⁴

¹School of Aquatic and Fishery Sciences, University of Washington, 1122 NE Boat Street,
Seattle, Washington 98195

²Institute for the Oceans and Fisheries, University of British Columbia, 2202 Main Mall,
Vancouver, British Columbia Canada V6T 1Z4

³Institute of Marine Sciences' Fisheries Collaborative Program, University of
California-Santa Cruz, 1156 High Street, Santa Cruz, California 95064

⁴Northwest Fisheries Science Center, U.S. Department of Commerce, National Oceanic and
Atmospheric Administration, National Marine Fisheries Service, 2725 Montlake Boulevard
East, Seattle, Washington 98112

⁵Alaska Fisheries Science Center, U.S. Department of Commerce, National Oceanic and
Atmospheric Administration, National Marine Fisheries Service, 7600 Sand Point Way N.E.,
Seattle, Washington 98115

⁶University of California Davis, One Shields Avenue, Davis, California 95616

⁷Alaska Fisheries Science Center, U.S. Department of Commerce, National Oceanic and
Atmospheric Administration, National Marine Fisheries Service, 17109 Point Lena Loop
Road, Juneau, Alaska 99801

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Executive summary

Stock

This assessment applies to shortspine thornyhead (*Sebastolobus alascanus*) off of the west coast of the United States from the U.S.-Canada border to the U.S.-Mexico border using data through 2022. Shortspine thornyhead are modeled in this assessment as a single stock. They have been reported as deep as 1,524 m, and this assessment applies to their full depth range although survey and fishery data are only available down to 1,280 m.

Catches

Historically, landings of shortspine thornyhead remained under 500 metric tons until the late 1960s when landings began to increase steadily, rising to a peak of 4,815 mt in 1989, followed by a sharp decline during a period when trip limits and other management measures were imposed in the 1990s. Since the institution of separate trip limits for shortspine and longspine thornyhead, the fishery has had more moderate removals of between 1,000 and 2,000 mt per year from 1995–1998. Landings fell below 1,000 mt per year from 1999–2006, then rose to 1,531 in 2009 and have declined since that time. Recreational fishery landings of thornyheads were negligible, so only commercial landings were included in the model.

Commercial landings are dominantly bottom trawl caught, and non-trawl landings include all other gear types, the majority of which is longline (Table i; Figure i). For this assessment, trawl landings were divided into northern (the waters off Washington and Oregon) and southern (the waters off California) fleets. Non-trawl landings represent one, coastwide, fleet. Discard rates (landings divided by total catch) for shortspine thornyhead have been estimated as high as 43% per year, but are more frequently below 20%. Discard rates in the trawl fleets, available from the West Coast Groundfish Observer Program (WCGOP), declined from 2003–2011 and have since increased from 2012–present, when under the catch shares system. Catches from the At-Sea Hake fishery were integrated into the North Trawl fleet.

Table i: Recent landings by fleet, total landings summed across fleets, and the total mortality including discards. Total dead fish is the combined landings and model estimated discards.

Year	North Trawl	South Trawl	Non-Trawl	Total Landings	Total Dead
2013	570.11	294.83	166.40	1,031.34	1,111.27
2014	456.13	254.05	147.81	858.00	928.12
2015	513.66	244.29	131.30	889.26	929.06
2016	587.71	185.73	168.94	942.38	992.09
2017	634.83	158.30	223.82	1,016.94	1,094.53
2018	595.89	105.07	184.48	885.44	948.28
2019	460.13	127.94	143.48	731.55	785.62
2020	258.09	87.99	85.17	431.26	477.36
2021	302.81	73.39	78.74	454.94	499.93

Table i: Recent landings by fleet, total landings summed across fleets, and the total mortality including discards. Total dead fish is the combined landings and model estimated discards.
(continued)

Year	North Trawl	South Trawl	Non-Trawl	Total Landings	Total Dead
2022	506.30	97.61	66.22	670.12	724.14

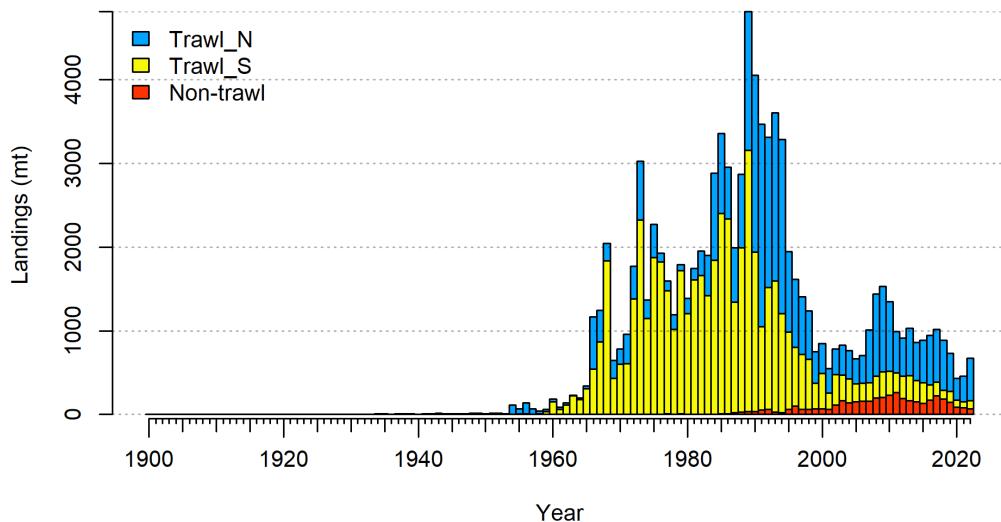


Figure i: Estimated landing history for shortspine thornyhead.

Data and assessment

The most recent assessment for shortspine thornyhead was conducted in 2013 (Taylor and Stephens 2013). Stock status was determined to be above the management target and catches did not attain the full management limits, so reassessment of thornyheads has not been a higher priority. This assessment uses Stock Synthesis (Methot and Wetzel 2013) Version 3.30.21, used in many other recent US West Coast assessments.

Data were divided into three fishery fleets: North trawl (the waters off Washington and Oregon including the At-Sea Hake fishery), South trawl (the waters off California), and coastwide Non-trawl, and three survey fleets: the AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) from 1980-2004, which was divided into early (pre-1995) and late period (post-1995) to account for a change in depth-sampling, and the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS), 2003-2022 (Figure ii).

Most data used in the 2013 assessment were newly pulled and processed for this assessment, including length compositions from all fishing and survey fleets, indices of abundance derived from new geostatistical analyses, discard rates from both a 1980s observer study (Pikitch et al. 1988) and the current WCGOP, historical catch data from Washington, Oregon, and California, and all reported catches from 1981-2022. The only data taken from the previous assessment without reanalysis were discard rates from the Enhanced Data Collection Project (EDCP) study in the 1990s.

New maturity analyses of samples collected by the WCGBTS in 2011, 2013, 2014, 2016 and 2018 were available for this assessment (Melissa Head, Northwest Fisheries Science Center (NWFSC), pers. comm.). The larger number and better spatial coverage of these samples allowed the use of statistical modeling to better understand the spatial variation in the proportion of females spawning. This assessment also assumes a new fecundity relationship, in which fecundity is modeled as a power function of length. New growth curves were estimated, using data from Butler (1995), which were similar to the curves assumed in the 2005 and 2013 assessments. In the previous assessment, a Beverton-Holt stock recruitment relationship was assumed and steepness (h) was fixed at 0.60. This assessment fixed steepness at 0.72, as recommended by Thorson et al. (2019). Natural mortality (M) was also updated, from 0.0505 in the 2013 assessment, to be fixed at 0.04.

This assessment estimated 197 parameters. The log of the unfished equilibrium recruitment, $\ln(R_0)$, controls the scale of the population and annual deviations around the stock-recruit curve (135 parameters) allow for more uncertainty in the population trajectory. In addition, 59 selectivity and retention parameters for the three fishery fleets and three surveys allowed for estimation of annual length compositions and discards rates. Two catchability parameters were analytically computed from the data, and one additional parameter, representing additional variability in the early Triennial survey, was directly estimated by the model.

Stock biomass and dynamics

Unfished equilibrium spawning output (B_0) is estimated to be 22.145 trillion eggs, with a 95% confidence interval of 18.166-26.124 trillion eggs. The B_0 estimate here is not comparable to previous assessment as the integration of new fecundity and maturity assumptions have changed the output units from traditional biomass to spawned eggs. Spawning output is estimated to have remained stable until the early-1970s before beginning to decline near linearly through the present day. The estimated spawning output in 2023 is 8.717 trillion eggs (5.545-11.889 trillion eggs), which represents a stock status or “depletion” (B_{2023}/B_0) of 39.4% (31.6%-47.1%; Table ii; Figure iii). The depletion in 2013 was estimated to be 43.5%, a large decrease from what was estimated by the 2013 assessment (~75%). The standard deviation of the log of spawning biomass in 2023 is 0.18, which is less than the 0.36 minimum assumed for use in p^* adjustments to overfishing limit (OFL) values.

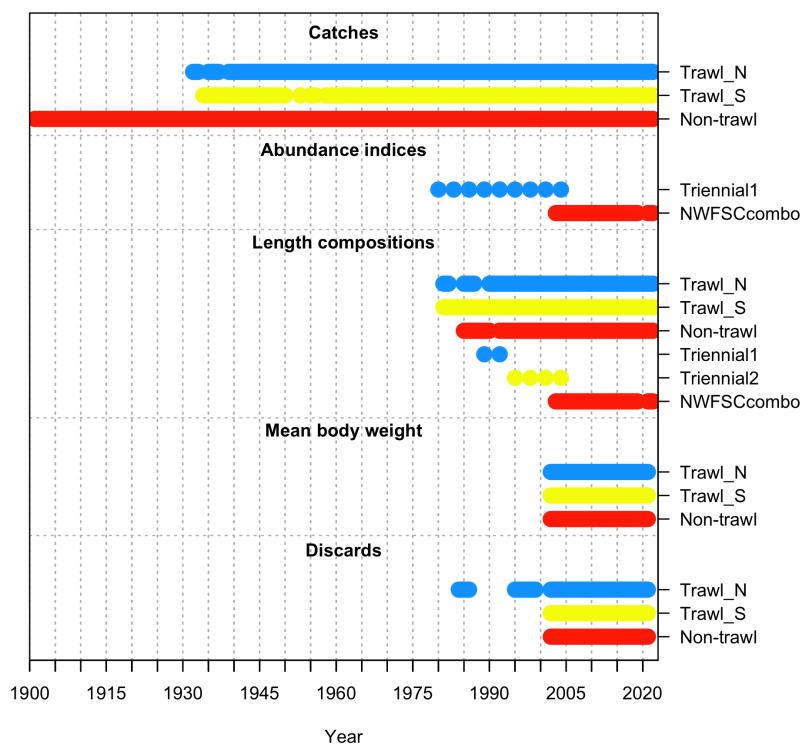


Figure ii: Summary of data sources used in the base model.

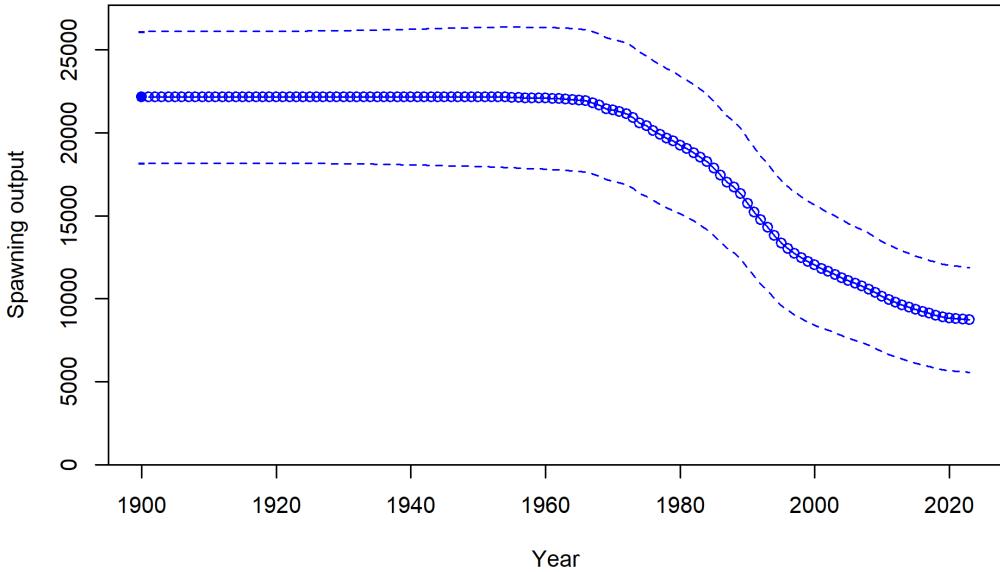


Figure iii: Estimated spawning output trajectory for shortspine thornyhead.

Table ii: Spawning output (millions of eggs) and fraction unfished with associated 95% confidence intervals (CI) from the base model.

Year	Spawning Output	Spawning Output 95% CI	Fraction Unfished	Fraction Unfished 95% CI
2013	9,626	6,360–12,892	0.435	0.360–0.509
2014	9,476	6,228–12,724	0.428	0.353–0.503
2015	9,348	6,116–12,579	0.422	0.347–0.497
2016	9,228	6,011–12,444	0.417	0.341–0.492
2017	9,112	5,908–12,315	0.411	0.336–0.487
2018	8,997	5,804–12,190	0.406	0.330–0.482
2019	8,902	5,718–12,086	0.402	0.325–0.478
2020	8,829	5,651–12,006	0.399	0.322–0.475
2021	8,787	5,614–11,960	0.397	0.320–0.474
2022	8,754	5,583–11,925	0.395	0.318–0.473
2023	8,717	5,545–11,889	0.394	0.316–0.471

Recruitment

This assessment assumed a Beverton-Holt stock recruitment relationship. Steepness (h , the fraction of expected equilibrium recruitment associated with 20% of equilibrium spawning biomass) was fixed at 0.72, slightly higher than what was assumed in previous assessments

($h = 0.60$). The scale of the population is largely determined by the log of unfished recruitment (R_0), which was estimated to be 9.439. This results in an unfished recruitment of 12,580,000 recruits (10,320,000–14,841,000). Recruitment variation (σ_R) was fixed at 0.50, as was done in the 2013 assessment. Recruitment deviations were estimated for the years 1901 through 2022, and ranged from -0.5 to 1.5 on the log scale. Estimated recruitments do not show high variability, and the uncertainty in each estimate is greater than the variability between estimates (Table iii; Figure iv).

Table iii: Estimated recent trend in recruitment and recruitment deviations and the 95% confidence intervals (CI) from the base model.

Year	Recruitment	95% CI	RecDevs	RecDev 95% CI
2013	9,622	4,001–23,138	-0.112	-1.004–0.781
2014	9,650	3,996–23,304	-0.105	-1.002–0.791
2015	9,783	4,016–23,832	-0.089	-0.996–0.818
2016	10,155	4,111–25,087	-0.049	-0.973–0.875
2017	9,995	4,024–24,828	-0.062	-0.992–0.868
2018	9,990	3,990–25,017	-0.060	-1.000–0.879
2019	10,354	4,097–26,165	-0.032	-0.989–0.926
2020	10,839	4,230–27,777	0.007	-0.968–0.981
2021	11,299	4,349–29,354	0.040	-0.951–1.031
2022	10,952	4,253–28,200	0.000	-0.980–0.980
2023	10,942	4,249–28,177	0.000	-0.980–0.980

Exploitation status

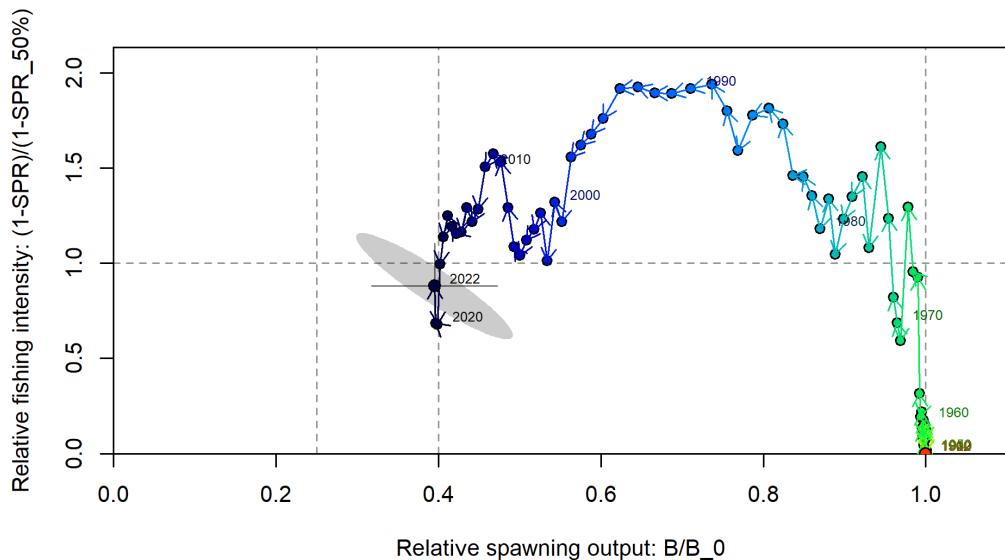
The summary harvest rate (total catch divided by age-1 and older biomass) closely follows the landings trajectory. The harvest rates are estimated to have never exceeded 5% and have remained below 2% in the past decade. Expressing exploitation rates in terms of spawning potential ratio (SPR) indicates that the exploitation consistently exceeded the $SPR_{50\%}$ reference point from 1980–2018. However, the stock status is estimated to have only fallen below the $B_{40\%}$ management target starting in 2020 (Table iv; Figures v–??).

Table iv: Estimated recent trend in relative fishing intensity, exploitation rate, and the 95 percent intervals. The spawning potential ratio (SPR) is utilized in the relative fishing intensity calculation as $(1 - SPR)/(1 - SPR_{40\%})$.

Year	$(1-SPR)/(1-SPR_{50\%})$	95% CI	Exploitation Rate	95% CI
2013	1.29	1.06–1.53	0.0120	0.0079–0.0160
2014	1.16	0.92–1.41	0.0100	0.0066–0.0134
2015	1.15	0.91–1.40	0.0100	0.0066–0.0135

Table iv: Estimated recent trend in relative fishing intensity, exploitation rate, and the 95 percent intervals. The spawning potential ratio (SPR) is utilized in the relative fishing intensity calculation as $(1 - SPR)/(1 - SPR_{40\%})$. (*continued*)

Year	$(1-SPR)/(1-SPR_{50\%})$	95% CI	Exploitation Rate	95% CI
2016	1.19	0.95–1.44	0.0107	0.0070–0.0144
2017	1.25	1.00–1.50	0.0118	0.0077–0.0159
2018	1.14	0.89–1.39	0.0103	0.0067–0.0138
2019	1.00	0.75–1.24	0.0085	0.0055–0.0114
2020	0.68	0.48–0.87	0.0051	0.0033–0.0069
2021	0.69	0.49–0.88	0.0053	0.0035–0.0072
2022	0.88	0.66–1.10	0.0076	0.0050–0.0103



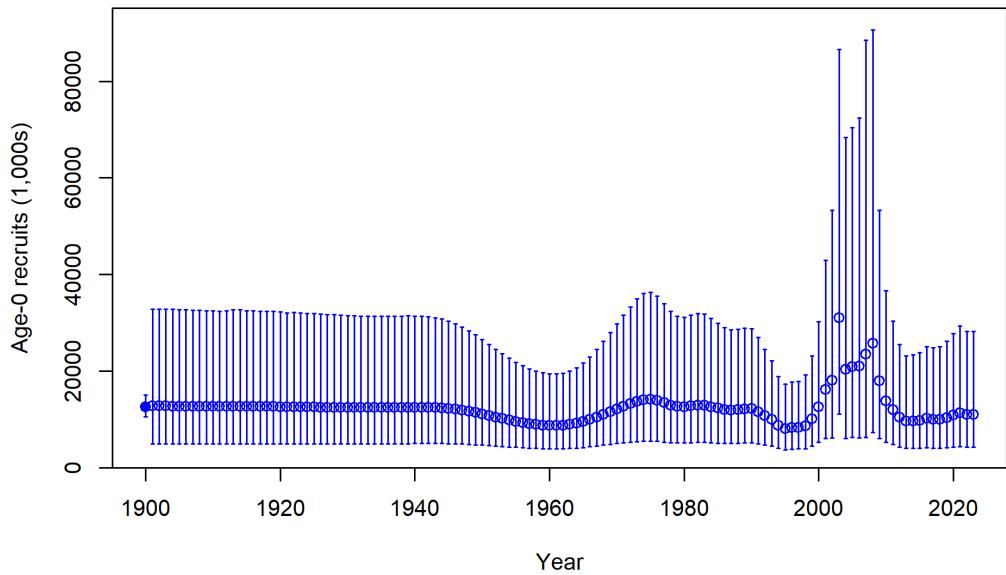


Figure iv: Estimated recruitment timeseries.

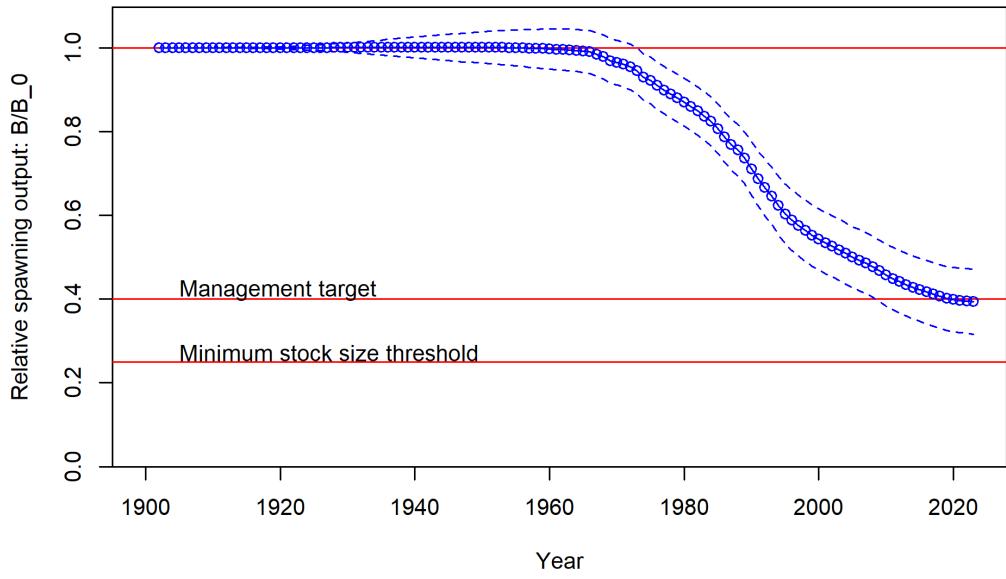


Figure v: Estimated spawning output relative to unfished equilibrium for shortspine thornyhead.

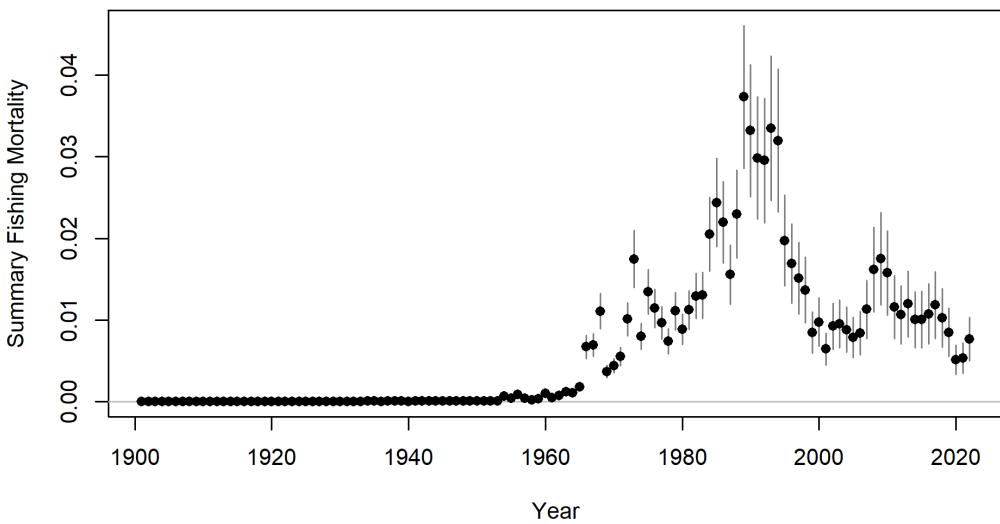


Figure vi: Summary fishing mortality rate (total landings / summary biomass).

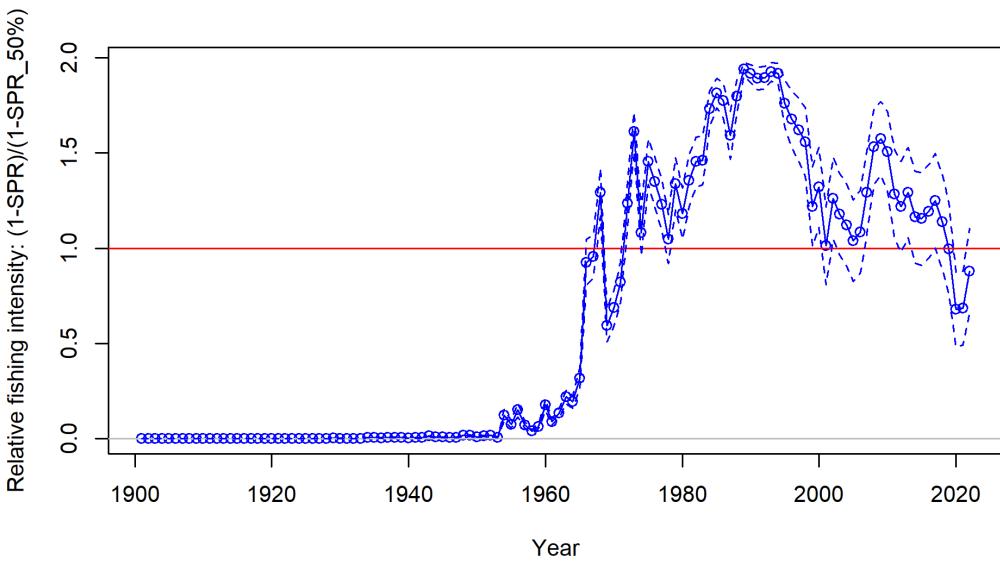


Figure vii: Estimated relative fishing intensity as a function of spawning potential ratio (SPR).

Ecosystem considerations

This stock assessment does not explicitly incorporate trophic interactions, habitat factors or environmental factors into the assessment model. More predation, diet, and habitat work, and mechanistic linkages to environmental conditions would be needed to incorporate these elements into the stock assessment.

Reference points

Reference points were calculated using the estimated catch distribution in the final year of the model (2023). In general, the population is on the boundary between “precautionary” ($B/B_0 = 0.40$) and “healthy” ($B/B_0 > 0.40$) status relative to the reference points (Figure viii). Sustainable total yield (landings plus discards) was estimated at 1,108 mt when using an $SPR_{50\%}$ reference harvest rate and ranged from 929–1,288 mt based on estimates of uncertainty (Table v). The spawning output equivalent to 40% of the unfished spawning output ($B_{40\%}$) was 8.858 trillion eggs. The most recent total mortality (landings plus discards) have been lower than the estimated long-term yields calculated using an $SPR_{50\%}$ reference point, but not as low as the lower bound of the 95% uncertainty interval. However, this is due to the fishery not fully attaining the full annual catch limit (ACL). The OFL and Acceptable Biological Catch (ABC) values over the past 6 years have been approximately 3100 mt and 2,500 mt, respectively.

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

Variable of Interest	Estimate	95% CI
Unfished Spawning Output	22,145	18,166–26,124
Unfished Age 1+ Biomass (mt)	216,864	177,897–255,831
Unfished Recruitment (R0)	12,580	10,320–14,841
Spawning Output (2023)	8,717	5,545–11,889
Fraction Unfished (2023)	0.39	0.32–0.47
Reference Points Based SB40%		
Proxy Spawning Output SB40%	8,858	7,266–10,450
SPR Resulting in SB40%	0.458	0.458–0.458
Exploitation Rate Resulting in SB40%	0.012	0.011–0.012
Yield with SPR Based On SB40% (mt)	1,160	971–1,348
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	9,880	8,105–11,656
SPR50	0.500	-
Exploitation Rate Corresponding to SPR50	0.010	0.010–0.011
Yield with SPR50 at SB SPR (mt)	1,108	929–1,288
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	6,155	5,057–7,253
SPR MSY	0.348	0.345–0.351
Exploitation Rate Corresponding to SPR MSY	0.017	0.016–0.017

Table v: Summary of reference points and management quantities, including estimates of the 95% intervals. (*continued*)

Variable of Interest	Estimate	95% CI
MSY (mt)	1,227	1,027–1,426

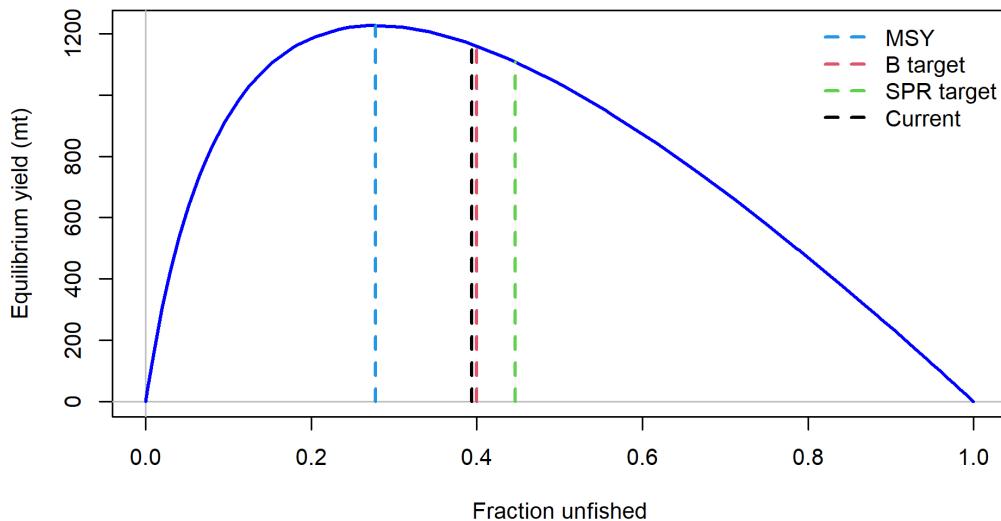


Figure viii: Estimated yield curve with reference points.

Management performance

Catches for shortspine thornyhead have not fully attained the catch limits in recent years. ACLs have hovered around 2500 mt since 2013, while total mortality has never exceeded 1085 mt, and is often smaller than that (Table vi). The fishery for shortspine thornyhead may be limited more by the ACLs on sablefish, with which they co-occur, and by the challenging economics of deep sea fishing, than by the management measures currently in place.

Table vi: Recent trend in the overfishing limits (OFLs), the acceptable biological catches (ABCs), the annual catch limits (ACLs), the total landings, and total mortality (mt). Total mortality is a function of both landings and model estimated discards.

Year	OFL	ABC	ACL	Landings	Total Mortality
2013	2333	2230	1937	1,031.34	1,111.27
2014	2310	2208	1918	858.00	928.12
2015	3203	2668	2668	889.26	929.06
2016	3169	2640	2639	942.38	992.09
2017	3144	2619	2619	1,016.94	1,094.53
2018	3116	2596	2596	885.44	948.28
2019	3089	2573	1983	731.55	785.62
2020	3063	2551	1669	431.26	477.36
2021	3211	2183	2183	454.94	499.93
2022	3194	2130	2130	670.12	724.14

Unresolved problems and major uncertainties

Major uncertainties in the model are centered around uncertainty in biological processes including growth, maturity, and mortality. The absence of reliable ageing methods for short-spine thornyhead, particularly, makes it difficult to estimate growth and natural mortality.

The assessment does not include age composition data; there is no production ageing of thornyheads for the U.S. West Coast (or Alaska). The assessment model used external estimates of a Von Bertalanffy growth curve based on the Butler research age dataset. The ages in these data were averaged from two age-readers. Nonetheless, there will still be ageing error in the averages. It was also not described how fish were selected for aging or whether they were representative of the overall stock. Age measurement errors and sampling methods are both sources of bias in Von Bertalanffy parameter estimates.

The WCGBTS model-based indices generally followed the design-based trends (Figure 9); however, the 2021 and 2022 model-based indices are substantially higher than the design-based indices. Confidence intervals for the model-based indices do not cover the 2021 design-based index, and barely cover the 2022 index. The assessment model could not fit the last two model-based indices which is a potential concern. It is a source of uncertainty why there is such a difference in design- and model-based indices in 2021 and 2022.

Shortspine thornyhead along the Pacific coast could be assessed as a single stock, but recognized that there is a lack of information of recruitment dynamics (e.g., larval transport) that may indicate functional substock structure. These fish do not move much and may be territorial which are attributes that can contribute to substock structure.

There is uncertainty in catch estimates, and more so for historic periods and when interpolations are used to fill in catches for some years. This uncertainty was not quantified and provided to the Panel. There is an important need for STATs to provide information on the quality of the annual catch estimates, and more specifically to quantify the uncertainty in these estimates. This technical deficiency is common to many assessments.

Decision table and projections

The calculated standard deviation of the log of spawning biomass in 2023 is $\sigma = 0.18$. This value is less than the standard , Category 2, sigma on OFL of 1.0, which is therefore used in the adjustment of quotas based on scientific uncertainty. The associated offset would therefore be a multiplication of the OFL by 76.2% in 2025 and decreasing in future years, which is the 40% quantile of a log-normal distribution with the associated σ . Twelve-year projections were conducted with a total catch assumed equal to the ACL calculated by applying this adjustment to the estimated OFL for each year. The selectivity and retention function and allocation of catch among fleets was assumed to match the values for the 2020-2022 timeblock. Catch for 2023 and 2024, the limits on which have already been set, were provided by the Pacific Fishery Management Council (PFMC), and correspond to a total catch of 756 mt.

This default harvest projection applied to the base model indicated that the stock status would slowly decline from 39.4% in 2023 to 39.2% in 2024, before beginning a slow rebound to 40.1% by 2034. The associated OFL values over the period 2025–2034 would average 1,022 mt and the average ACL would be 718 mt. These values are near recent annual catch levels.

Additional projections were conducted for the base model and low and high states of nature (columns) under two catch streams (rows) representing different levels of scientific uncertainty, and thus different values of P^* . The uncertainty in the OFL associated with the base model was broad ($\sigma = 0.18$), and states of nature were chosen based on values of natural mortality (M) that encapsulated the range of M seen in the literature. The low state of nature used $M = 0.03$ to fully encapsulate the low end of the range of M seen in assessments throughout the eastern Pacific. The high state of nature used $M=0.05$ to roughly encapsulate the value of M used by the 2013 assessment.

The catch streams chosen for the decision table were represented as total catch rather than landed catch, but discard rates were low under IFQs, so the difference in between total catch and landings is small, and represent catch under two distinct levels of P^* ($P^* = 0.40$ and $P^* = 0.45$). The most pessimistic forecast scenario, combining the low state of nature ($M=0.03$) with the high catch stream ($P^*=0.45$), resulted in a projected stock status of 38.7%, still very close to the target value, though there is a declining trend owing to a decline in productivity. All other projections led to a higher projected status, with a maximum of 54.7% for the combination of the high state of nature and low catch. Forecasts under the base case led to estimated depletion values of 39.1% in both catch scenarios, and increasing status at near the end of the projection period.

Table vii: Summary table of 12-year projections beginning in 2025 for alternate states of nature based on natural mortality. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.

Year	Catch	Low: M = 0.03		Base: 0.04		High: M = 0.05	
		SO	Dep	SO	Dep	SO	Dep
ACL P* = 0.4							

Table vii: Summary table of 12-year projections beginning in 2025 for alternate states of nature based on natural mortality. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels. (*continued*)

Year	Catch	SO	Dep	SO	Dep	SO	Dep
2023	756	13485	0.427	8717	0.394	9907	0.494
2024	756	13334	0.422	8687	0.392	9965	0.497
2025	711	13194	0.418	8666	0.391	10032	0.500
2026	713	13067	0.414	8659	0.391	10113	0.504
2027	716	12949	0.410	8660	0.391	10202	0.509
2028	718	12841	0.406	8670	0.392	10298	0.513
2029	720	12742	0.403	8688	0.392	10400	0.519
2030	721	12652	0.401	8712	0.393	10509	0.524
2031	722	12570	0.398	8744	0.395	10621	0.530
2032	721	12496	0.396	8782	0.397	10738	0.535
2033	720	12431	0.394	8826	0.399	10857	0.541
2034	719	12372	0.392	8874	0.401	10978	0.547
ACL P* = 0.45							
2023	756	13485	0.427	8717	0.394	9907	0.494
2024	756	13334	0.422	8687	0.392	9965	0.497
2025	815	13194	0.418	8666	0.391	10032	0.500
2026	825	13060	0.413	8652	0.391	10106	0.504
2027	834	12934	0.409	8645	0.390	10187	0.508
2028	843	12817	0.406	8647	0.390	10275	0.512
2029	851	12708	0.402	8655	0.391	10368	0.517
2030	859	12607	0.399	8670	0.392	10467	0.522
2031	866	12513	0.396	8691	0.392	10569	0.527
2032	872	12427	0.393	8717	0.394	10674	0.532
2033	877	12348	0.391	8747	0.395	10781	0.538
2034	883	12275	0.389	8782	0.397	10889	0.543

Scientific uncertainty

The model estimated uncertainty around the 2024 spawning biomass was $\sigma = 0.18$ and the uncertainty around the OFL was $\sigma = 0.17$. The category 2 default $\sigma = 1.0$ is used to apply scientific uncertainty in the projections.

Research and data needs

Research and data needs for future assessments include the following:

1. Research into aging methods and availability of reliable age data would be valuable for future stock assessments. Otoliths have been collected in good quantities from the WCGBTS, but there is currently no validated aging method for shortspine thornyhead.

2. Additional investigation into growth patterns would provide valuable information for future population projections. We acknowledge that additional work on aging shortspine thornyhead would be required to make such additional growth research possible. Use of an “Errors-as-Variables” approach (e.g. Dey et al. 2019) could be applied to the Butler growth dataset.
3. More investigation into maturity of shortspine thornyhead is necessary to understand the patterns in maturity observed in WCGBTS samples.
4. Information on possible migration of shortspine thornyhead would be valuable for understanding stock dynamics. Analysis of trace elements and stable isotopes in shortspine thornyhead otoliths may provide valuable information on the extent of potential migrations. Possible connections between migration and maturity could likewise be explored.
5. A greater understanding of the connection between thornyheads and bottom type could be used to refine the indices of abundance. Thornyheads are very well sampled in trawlable habitat, but the extrapolation of density to a survey stratum could be improved by accounting for the proportion of different bottom types within a stratum and the relative density of thornyheads within each bottom type.
6. Additional investigation into spatial stock structure could be valuable for determining whether future assessments should develop a spatial assessment model, or if shortspine thornyhead should be assessed at distinct spatial scales in the future.
7. Further research into the Dirichlet-Multinomial (DMN) data-weighting method for length-composition data is needed for integration with length-based data-moderate assessments like shortspine thornyhead. The DMN method has not, to date, been thoroughly simulation tested with length-composition data, and an attempted sensitivity analysis performed for the 2023 assessment failed to converge entirely. This is a general research need, and is widely applicable to many data-moderate or length-based assessments, not just shortspine thornyhead.

1 Introduction

1.1 Basic Information

This assessment reports the status of shortspine thornyhead (*Sebastolobus alascanus*) off the US West coast using data through 2022.

Shortspine thornyhead are found in the waters off the West Coast of the United States, from northern Baja California to the Bering Sea, at depths of 20 meters to over 1,500 meters. The majority of the spawning biomass occurs in the oxygen minimum zone between 600 and 1,400 meters. The distribution of the smallest shortspine thornyhead suggests that they tend to settle at 100–400 meters and are believed to exhibit ontogenetic migration down the slope, although large individuals are found across the depth range. Higher densities (kg/ha) of shortspine thornyhead occur in shallower areas (shallow than 400 meters) off Oregon and Washington, whereas in California, they occur in deeper areas (deeper than 400 meters; Figure 1).

Despite variation in density across the coast, survey data suggest that shortspine thornyheads are present in almost all trawlable areas below 500 meters, as they are caught in 91% of trawl survey hauls deeper than 500 m. Camera-tows show that thornyheads are spaced randomly across the sea floor, indicating a lack of schooling and territoriality (Wakefield 1990; Du Preez and Tunnicliffe 2011).

1.2 Stock Structure

Genetic studies of stock structure show few genetic differences among shortspine thornyhead along the Pacific coast, and thus do not suggest separate stocks (Siebenaller 1978; Stepien 1995). Stepien (1995) suggested that there may be a separate population of shortspine thornyhead in the isolated area around Cortes Bank off San Diego, California. Stepien (1995) also pointed out that juvenile dispersion might be limited in the area where the Alaska and California currents split, which occurs towards the northern boundary of the assessment area, near 48° N.

Stepien et al. (2000), using a more discerning genetic material (mtDNA), found evidence of a pattern of genetic divergence in shortspine thornyhead corresponding to geographic distance. However, this study, which included samples collected from southern California to Alaska, did not identify a clear difference between stocks even at the extremes of the range. No such pattern was seen in longspine thornyhead, which suggests that the shorter pelagic stage (~1 yr vs. ~2 yrs) of shortspine thornyhead may contribute to an increased genetic separation with distance.

Dorval et al. (2022) applied otolith microchemistry to immature fish to redefine population structure of shortspine thornyhead on the west coast. Their results indicate that the population of immature shortspines belongs to two distinct groups distributed north and south of Cape Mendocino, California.

1.3 Life History

Shortspine thornyheads along the West Coast spawn pelagic, gelatinous floating egg masses between December and May (Wakefield 1990; Erickson and Pikitch 1993; Pearson and Gunderson 2003). Cooper et al. (2005) and Pearson and Gunderson (2003) found no evidence for batch spawning in this species on the West Coast, but more recent histological examination of ovaries suggest that some shortspine thornyhead can be batch spawners with two to three batches developing simultaneously (Melissa Head, NWFSC, pers. comm.). Juveniles settle at around 1 year of age (22- 27 mm in length), likely in the range of 100-200 m (Vetter and Lynn 1997), and migrate down the slope with age and size, although large individuals are found across the depth range.

Shortspine thornyhead are notoriously challenging to age, and a recent age validation study using ^{14}C bomb radiocarbon was inconclusive (Kastelle et al. 2020). However, best available data suggests that the shortspine thornyhead life span may exceed 100 years (Butler 1995; Kline 1996). Estimates of natural mortality for shortspine thornyhead range from 0.013 (Pearson and Gunderson 2003) to 0.07 (Kline 1996). However, the Pearson and Gunderson estimate is based upon a regression model, using the gonadosomatic index as a proxy. Butler (1995) estimated M to be 0.05 based upon a maximum lifespan of 100 years. Butler (1995) also suggested that M may be lower for older, larger shortspine thornyhead residing in the oxygen minimum zone due to lack of predators. All estimates of M for thornyheads are highly uncertain.

Shortspine thornyhead grow very slowly and may continue growing throughout their lives, reaching maximum lengths of over 70 cm. Females grow to larger sizes than males. Maturity in females was previously estimated as occurring near 18 cm, with fish transitioning from immature to mature within a relatively narrow range of sizes between 15 and 20 cm (Pearson and Gunderson 2003). However, more recent histological data of gonads collected in the WCGBTS and analyzed using current best practices suggests that functional maturation, which accounts for abortive maturation and skip spawning, occurs over a broader spectrum of sizes between 10 and 55 cm (length-at-50% maturity, $L_{50} = 31.4$; personal communication, Melissa Head, NWFSC, pers. comm.).

1.4 Ecosystem Considerations

Shortspine thornyhead have historically been caught alongside longspine thornyhead in a dover sole, thornyhead, and trawl-caught sablefish complex (DTS). Other groundfishes that frequently co-occur in deep waters include a complex of slope rockfishes, Rex sole, longnose skate, roughtail skate, Pacific grenadier, giant grenadier, and Pacific flatnose. Non-groundfish species such as Pacific hagfish and a diverse complex of eelpouts also co-occur with shortspine thornyhead.

Shortspine thornyhead typically occur in shallower water than the shallowest longspine thornyhead, and migrate to deeper water as they age. The majority of spawning shortspine thornyheads occur between 600 and 1,400 meters, where longspine thornyhead are most abundant (Jacobson and Vetter 1996; Bradburn et al. 2011). When shortspine thornyhead

have reached a depth where they overlap with longspine thornyheads, they are typically larger than the largest longspine thornyhead.

Species distribution models developed by Liu et al. (in press) suggest that expected environmental changes over the next decades will lead to a decline in shortspine and increase in longspine abundance. Shortspine thornyhead are also projected to shift offshore, into deeper waters, potentially decreasing their availability in fisheries. To date, shortspine thornyhead have been observed by cameras below the 1280 meter limit of the current fishery and survey, but their distribution, abundance, and ecosystem interactions in these deep waters are relatively unknown. Thornyheads spawn gelatinous masses of eggs which float to the surface, which may represent a significant portion of the upward movement of organic carbon from the deep ocean (Wakefield 1990).

Shortspine thornyhead diet composition, as derived from stomach content collection in the 1980s and 1990s, varied by year (Bizzarro et al. 2023). In some years their diet consisted primarily of invertebrate species including pandalid shrimp, pink shrimp, and Tanner crab, while in others their stomach content was dominated by finfish species such as Pacific cod and Pacific Hake. As prey themselves, shortspine thornyheads were only found in the stomachs of other species in two years, 1991 and 1992 as recorded in the CA Current Trophic Database (CCTD), where shortspine thornyhead occurred in sablefish, Pacific hake, and other shortspine thornyhead stomachs (Bizzarro et al. 2023).

1.5 Historical and Current Fishery Information

Harvest of shortspine thornyhead has experienced fluctuations over time due to increased depth range of the fisheries, variable markets, and changes in fisheries management. In the early 1900's, landings were minimal because there were few markets for thornyheads and relatively little trawling at depths where the majority of thornyheads occur. Beginning in the 1930s, thornyhead landings increased as they were landed as incidental catch in the California sablefish fishery. The first significant market for thornyheads began in northern California in the early 1960s, when larger (30-35 cm) thornyhead were sold as "ocean catfish". By the early 1980s, the minimum marketable size decreased to 25 cm, and in the late 1980s a market for small thornyheads (~20 cm) developed due to the depletion of a related species (*Sebastolobus machrochir*) off the coast of Japan. The fishery moved into deeper waters with the demand for smaller thornyheads and began catching more longspine thornyheads. This is reflected in the changes in proportion of shortspine to total thornyheads through time, which decreased from around 90% in 1981 to 40% in 1994 (Figure 2).

Landings of shortspine thornyheads off the coast of California peaked around 3,500 mt in 1989, and have exceeded those from further north in most years (Figure 3). In the northern area off of Oregon and Washington, the fishery grew in the early 1980s, with landings peaking in 1991 at around 2200 mt.

Non-trawl landings of shortspine thornyhead were relatively low prior to the mid-1990s, at which point non-trawl landings, dominantly longline-caught from California, began to

increase steadily from less than 5 mt in 1994 to 237 mt in 2011. The increase in non-trawl landings was driven by the development of live-fish markets for thornyheads and the fact that ex-vessel prices associated with the non-trawl landings are much higher than those for the trawl fishery. Nominal prices for line-caught shortspine thornyhead have increased steadily through time, from \$0.49/lb in 1990 to \$4.71/lb in 2021. This steady increase is also evident when prices are adjusted for inflation, indicating a real price increase in line-caught shortspines that may help to explain the growth, based on landings, in the non-trawl fishery through time. Trawl prices, on the other hand, increased from \$0.32/lb in 1990 to a high of \$0.87/lb in 2002 and have since declined with prices in recent years hovering around \$0.30/lb.

The foreign fishery off of the West Coast is estimated to have caught approximately 7,400 mt of shortspine thornyhead during the 11 year period from 1966-1976 (Rogers 2003), which is similar to the estimated domestic catch (~8,600 mt) during that same period.

Management measures have contributed to a decline in coastwide landings from an estimated peak of 4,815 mt in 1989 to between 1,000 and 2,000 mt per year from 1995 through 1998. Landings fell below 1,000 mt per year from 1999 through 2006, then rose to 1,531 in 2009 and have declined since (Table 10).

In 2011, the west coast trawl fishery was rationalized, with the introduction of the Individual Fishing Quota (IFQ) Program. In order to provide more flexibility for fishers on the west coast, NOAA Fisheries implemented the West Coast Groundfish Trawl Fishery Catch Share Program, which allows for the division of catch allocated to the trawl fishery into shares controlled by individuals or cooperatives (West Coast Regional Office n.d.). All vessels that participate in the IFQ program are required to have 100% observer coverage at all times the vessels are at sea (West Coast Regional Office n.d.).

1.6 Summary of Management History and Performance

Beginning in 1989, both thornyhead species were managed as part of a DTS complex. In 1991, the PFMC adopted separate ABC levels for thornyheads and catch limits were imposed on the thornyhead complex, under the Pacific Coast Groundfish Fishery Management Plan (FMP). A Harvest guideline (HG) were instituted in 1992 along with an increase in the minimum mesh size for bottom trawl fisheries. In 1995 separate landing limits were placed on shortspine and longspine thornyhead and trip limits became more restrictive. Trip limits (predominantly 2-month limits on cumulative vessel landings) have often been adjusted during the year since 1995 in order to not exceed the HG or optimum yield (OY). At first, the HG for shortspine thornyhead was set higher than the ABC (1,500 vs. 1,000 mt in 1995-1997) in order to allow a greater catch of longspine thornyhead, which was considered relatively undepleted. In 1999 the OY was set at less than 1,000 mt and remained close to that level through 2006. As a result of the 2005 shortspine thornyhead assessment, catch limits increased to about 2,000 mt per year and have remained between 2,000 mt and 3,000 mt per year to present.

Since early 2011, trawl harvest of each thornyhead species has been managed under the PFMC's catch share, or individual fishing quota (IFQ), program. Whereas the trip limits

previously used to limit harvest restricted only the amount of fish each vessel could land, individual vessels fishing under the catch-share program are now held accountable for all of the quota-share species they catch.

Landings of shortspine thornyhead have been below the catch limits since 1999. The estimated total catch, including discards, has likewise remained below the limit during this period (Table 6).

1.7 Fisheries off Canada, Alaska and/or Mexico

Shortspine thornyhead are also caught, dominantly in mixed species trawl fisheries, in Canada and Alaska. Catches of shortspine thornyhead off the coast of Canada have exhibited a similar pattern to those on the U.S. West Coast, with catches increasing in the late 1990s and then decreasing to present. A stock assessment for the coastwide population of shortspine thornyhead in British Columbia was last conducted in 2015 and indicated that shortspine thornyhead stock status in Canada is well above reference points and not overfished (Starr and Haigh 2017).

In Alaska, total thornyhead (shortspine and longspine) catches averaged 1,090 tons between 1977 and 1983 in the Gulf of Alaska and then declined markedly in 1984 and 1985, primarily due to restrictions on foreign fisheries imposed by U.S. management policies. Starting in 1985, catches of thornyheads increased, reaching a peak in 1989 with a total removal of 2,616 mt. Catches averaged about 980 mt between 2003 and 2018, when annual catch began to decrease (Echave et al. 2022). The Alaska Fisheries Science Center (AFSC) conducts assessments of thornyheads as a mixed stock complex, including shortspine and longspine thornyheads. Similar to the British Columbia assessment, results of the 2022 Alaska Thornyhead complex assessment suggest that Thornyheads are not being subjected to overfishing (Echave et al. 2022).

While the range of shortspine thornyhead extends down into Mexico, there is little information about Mexican catch of shortspine thornyhead and no stock assessment conducted in Mexico.

2 Data

Data comprise the foundational components of stock assessment models. The decision to include or exclude particular data sources in an assessment model depends on many factors. These factors often include, but are not limited to, the way in which data were collected (e.g., measurement method and consistency); the spatial and temporal coverage of the data; the quantity of data available per desired sampling unit; the representativeness of the data to inform the modeled processes of importance; timing of when the data were provided; limitations imposed by the Terms of Reference; and the presence of an avenue for the inclusion of the data in the assessment model. Attributes associated with a data source can change through time, as can the applicability of the data source when different modeling approaches are explored (e.g., stock structure or time-varying processes). Therefore, the specific data sources included or excluded from this assessment should not necessarily

constrain the selection of data sources applicable to future stock assessments for shortspine thornyhead. Even if a data source is not directly used in the stock assessment they can provide valuable insights into biology, fishery behavior, or localized dynamics.

Data from a wide range of programs were available for possible inclusion in the current assessment model. Descriptions of each data source included in the model (Figure 4) and sources that were explored but not included in the base model are provided below. Data that were excluded from the base model were explicitly explored during the development of this stock assessment or have not changed since their past exploration in a previous shortspine thornyhead stock assessment. In some cases, the inclusion of excluded data sources were explored through sensitivity analyses.

2.1 Fishery-Dependent Data

2.1.1 Catch History

Data from the Pacific Fisheries Information Network (PacFIN) spanning 1981-present was used to estimate landings in the North (Oregon and Washington) and South (California) by gear type (Trawl and Non-Trawl) (Figure 3). One exception was Oregon data from 2017, which came from ODFW directly due to errors in the PacFIN data. All landings reported for the shortspine thornyhead and nominal shortspine thornyhead categories were considered shortspine thornyhead, whereas landings categorized as unidentified thornyheads were split between longspine thornyhead and shortspine thornyhead by the ratio of identified longspine and shortspine landings to total thornyhead landings for each year-state-gear combination (Figure 2).

Catches prior to 1981 are based on historical reconstructions provided by the respective states and a reconstruction of foreign fleet catch. Oregon landings for 1892-1986 are provided by Oregon Department of Fish and Wildlife (ODFW) and reconstruction methods are outlined in Karnowski et al. (2014). Shortspine thornyhead landings in Oregon are not available in the PacFIN data for the years 1981-1986, so the state reconstruction is used for this period instead. Washington landings for 1954-1980 are provided by Washington Department of Fish and Wildlife (WDFW). Landings prior to the beginning of this data are assumed to be zero. California landings are provided by California Department of Fish and Wildlife (CDFW) and Southwest Fisheries Science Center (SWFSC), and consist of California commercial data for 1969-1980, and a catch reconstruction documented by Ralston et al. (2010) for 1934-1968. As in the two previous assessments, catch data from Rogers (2003) is used to account for catches by foreign fleets during the years 1966-1976. Foreign catch in the Monterey and Eureka International North Pacific Fishery Commission (INPFC) areas is attributed to the South Trawl fleet, while foreign catch in Columbia and Vancouver areas is attributed to the North Trawl fleet, as was the case in the 2013 assessment.

For historical catches prior to 1981, all shortspine thornyhead, nominal shortspine, and unidentified thornyhead landings in the state catch reconstructions are considered shortspine thornyhead. Neither California reconstructions prior to 1978, nor the Karnowski et al. (2014)

reconstruction for Oregon, distinguish between shortspine and longspine thornyhead species. It is likely that assigning all thornyhead landings to shortspine overestimates total shortspine landings, however, the overwhelming majority of thornyhead landings were shortspine until the late 1980s when vessels began to move into deeper waters and a distinct fishery targeting longspine thornyhead developed (Hamel 2005; Karnowski et al. 2014).

This treatment of historical thornyhead landings differs from the 2005 and 2013 assessments. The 2005 assessment did not have access to the historical reconstructions used here, and instead imputed shortspine thornyhead landings as 30% of annual sablefish landings for the years 1901-1961. The 2013 assessment used the same imputed values as the 2005 assessment, but also conducted a sensitivity analysis in which all unassigned thornyheads in historical catch were considered shortspine thornyhead. Stock abundance estimates were found to be largely insensitive to which reconstructions were used (Taylor and Stephens 2013). The imputed historical values used for the 2005 and 2013 assessments will continue to be included as a sensitivity analysis here. Landings after 1961 from the state reconstructions remain very similar to the landings used in the 2013 assessment (Figure 3).

Unlike previous assessments, this assessment includes catches from the at-sea Pacific whiting fishery (data received from V. Tuttle, 5/15/2023). It includes both shortspine thornyhead catches, as well as unidentified thornyhead catches (the latter only available 1990 to present). Unidentified catches are apportioned based on the year-specific ratio of shortspine thornyhead to longspine thornyhead. There are only three years where Shortspine thornyheads represented less than 99% of thornyhead catches. The at-sea hake observer program does not collect length composition data on thornyheads, so these catches are added to the northern trawl fleet, considered the most similar gear to the midwater trawls used for Pacific whiting. Landings from this fishery usually constitute a very small percentage of total shortspine thornyhead catch, however, catches from this fishery in 2022 comprised nearly 30% of the total landings. It is believed that changes in behavior by the at-sea Pacific whiting fishery resulted in a substantial increase in the number of encounters with shortspine thornyhead, dramatically increasing total catches for this year.

2.1.2 Discards and retention

Predicted discards were based on estimated retention and selectivity for each fleet (Figure 5). Discards were informed by four data sources covering three different periods. Data sets included, 1) Pikitch et al. (1988) Discard and Mesh Studies, used to estimate both discard rates and length composition of the northern trawl fleet between 1985 and 1987 (John. R. Wallace, NWFSC pers. comm.), 2) the EDCP covering 1995-1999, which only informed discard rates of the northern trawl fleet, 3) the WCGOP, which provided discard rates, length composition, and individual average weight for years between 2002 and 2021 for all fleets, and 4) the Groundfish Expanded Mortality Multi-Year (GEMM) data set, covering the same period as the WCGOP with catch-share participation information and estimates of discard survival rates.

While the estimates from the first two data sets were directly integrated into the model, fleet discard rates after 2011 were available separately for catch-share and non-catch-share

programs. Final, fleet-specific, discard rates were thus computed as the average WCGOP discard rate weighted by the relative proportion of total landings belonging to the catch-share and non-catch-share, respectively (Figure 6). Regardless of the type of data, all estimates derived from these data sets had associated uncertainty accounting for the variability observed within the sample of hauls and fishing trips of each fleet. WCGOP-derived discard rates are an exception as, after the catch share program was initiated in 2011, 100% of hauls from catch share fleets were observed, while non-catch share vessels were only partially covered (West Coast Regional Office n.d.).

The discard data sources were the same as those used in the 2013 assessment. The main improvements are the increased representativeness of all 4 fleets (11 more years) and more accurate estimates of discard rates from EDCP that were not ready at the time of the previous assessment. Last, some errors in the previous assessment were corrected regarding the weight units considered for the average individual weight (WCGOP provides weight as pounds and not as kg).

2.1.3 Fishery Length Compositions

Commercial fishery length-composition data were obtained from PacFIN for 1978-2023. Due to variations in sampling effort and because the number of fish sampled by port samplers is not proportional to the amount of landed catch in each trip, the observed length data were expanded using the following algorithm using the `PacFIN.Utilities` package in R (Johnson and Stephens 2023):

1. Length data were acquired at the trip level by sex, year and state.
2. The raw numbers in each trip were scaled by a per-trip expansion factor calculated by dividing the total weight of trip landings by the total weight of the species sampled.
3. A per-year, per-state expansion factor was computed by dividing the total weight of state landings by the total weight of the species sampled for length in the state.
4. The per-trip expanded numbers were multiplied by the per-state expansion factor and summed to provide the coast-wide length-frequency distributions by year.

Only randomly collected samples were used. The sample sizes associated with the length compositions from the fishing fleets are shown in Table 14 (landings) and Table 15 (discards).

Input sample sizes, N_{input} , for fishery length frequency distributions by year were calculated as a function of the number of trips and number of fish via the Stewart Method (Ian Stewart, pers. comm.):

$$N_{input} = N_{trips} + 0.138N_{fish} \quad \text{when } \frac{N_{fish}}{N_{trips}} < 44 \quad (1)$$

$$N_{input} = 7.06N_{trips} \quad \text{when } \frac{N_{fish}}{N_{trips}} \geq 44 \quad (2)$$

The method is based on analysis of the input and model-derived effective sample sizes from west coast groundfish stock assessments. A piece-wise linear regression was used to estimate the increase in effective sample size per sample based on fish-per-sample and the maximum effective sample size for large numbers of individual fish.

All length data from commercial fisheries were included in the model with sexes combined. This avoids the possibility of bias due to difficulty in sex determination of thornyheads.

2.1.4 Age Compositions

No age composition data was used for this assessment because thornyheads are very difficult to age (Patrick MacDonald, NWFSC, pers. comm.). Even in directed studies such as those done by Kline (1996) and Butler (1995), there are large inter-reader differences, and a second reading by the same reader can produce a markedly different result. Kline (1996) reported only about 60% of the multiple reads were within 5 years of each other, and inter-reader differences were as large as 24 years for a sample of 50 otoliths. No production ageing of thornyheads is undertaken at this time for the west coast (or Alaska), although shortspine thornyhead otoliths are routinely collected in the NWFSC trawl survey.

2.2 Fishery-Independent Data

Four trawl surveys have been conducted on the U.S. west coast over the past four decades.

2.2.1 AFSC/NWFSC West Coast Triennial Shelf Survey

The AFSC conducted a triennial groundfish trawl survey (the Triennial Survey) on the continental shelf from 1977 to 2001, although the 1977 survey had incomplete coverage and is not believed to be comparable to the later years. A final survey was conducted in 2004 by the NWFSC using the same survey design. In 1995, the timing of the survey shifted from mid-July and late September to early June through mid-August. In 1980–1992 the survey had a maximum depth of 366 m, while from 1995 onward, the maximum depth was extended to 500 m. The shallow limit of the survey was 55 m in all years, but for purposes of computing indices, only tows deeper than 100 m were used as shortspine thornyhead are rarely seen at shallower depths.

For some species, the shift in timing between the 1992 and 1995 surveys would be expected to influence their catchability, availability, or distribution. However, thornyheads are believed to be sedentary enough that the change in timing would not be as influential. On the other hand, the increase in depth is expected to significantly increase the range of shortspine thornyhead habitat covered by the survey. In the 2013 assessment, the triennial survey was split into two timeseries, separated by the 366 m depth contour, in order to preserve a time series of maximum duration while eliminating the influence of the increased depth range. The first time series, “AFSC Triennial Shelf Survey 1”, consisted of 9 data points spanning the range 1980–2004 and covering the depths 100–366 m. The second, “AFSC Triennial Shelf Survey 2”, consisted of 4 data points spanning 1995–2004 and covering depths 366–500 m. This second time series is recognized as providing little information about stock status due

to the limited number of points and depth range, but there was no compelling reason to exclude it from the 2013 assessment. In contrast to the 2013 assessment, this assessment treated the Triennial Survey as a single time series for the geostatistical model-based indices, and used a different set of latitudinal and depth-based strata for survey length compositions (see Section 2.2.7).

2.2.2 AFSC and NWFSC Slope Surveys

Starting in the late 1990s, two slope surveys were conducted on the west coast. The AFSC Slope Survey (AFSC Slope Survey) was conducted during the years 1997 and 1999–2001 using the research vessel Miller Freeman. The NWFSC Slope Survey (NWFSC Slope Survey) was conducted from 1998–2002, and was conducted cooperatively using commercial fishing vessels. The AFSC Slope Survey was a source of valuable information on the depth distribution and overlap of shortspine and longspine thornyheads in the 1980s, but these early years had a very limited latitudinal range and will not be included. This survey also had a different net and larger roller gear than the NWFSC Slope Survey.

Neither of these surveys were included in the base model, as they represent relatively short temporal scales (4 years for the AFSC Slope Survey, and 5 years for the NWFSC Slope Survey) over a period for which survey data already exists (Triennial Survey covers this period, though at a sparser temporal resolution).

2.2.3 NWFSC West Coast Groundfish Bottom Trawl Survey

In 2003, the design of the NWFSC Slope Survey was modified, and the survey was expanded to cover the shelf and slope between 50 m and 1280 m. This combination shelf-slope survey, “NWFSC Combo Survey”, more recently known as the WCGBTS, has been conducted every year from 2003 to present with consistent design (note that the survey was not conducted in 2020 due to ongoing concerns about COVID-19). Data for the years 2003–2022 were available for this assessment. The WCGBTS represents the largest number of survey observations, the largest depth range, and the most consistent groundfish sampling program in the history of west coast fisheries. Continuing this time series in a consistent manner is vital for improving estimates of current stock status and detecting any future changes in size distribution or abundance of west coast groundfish.

2.2.4 Survey Stratification

Data from these four (nominally five for design-based indices) fishery-independent surveys were considered for use in this assessment (Figure 7) to estimate abundance. Two distinct survey abundance estimation methods were considered: design-based and geostatistical model-based indices. The 2013 assessment utilized delta-GLMMs, following the methods of Thorson and Ward (2013), to compute their indices of abundances, but these methods are no longer considered best practice within the field and were not considered in this assessment.

The five surveys were stratified based on depth and latitude, similar to how they were in 2013 (Table 16). The Triennial Survey was divided into two distinct survey time series, split

on the year 1995. The early-Triennial time series (1981-1992) was further stratified into four strata: north and south of 42° N, and shallower and deeper than 200m. The late-Triennial time series (1995-2004) was also further stratified into four strata: north and south of 40° N, and shallower and deeper than 200m. Note that this stratification scheme, as well as the two timeseries, applied to the Triennial Survey length composition data and design-based indices of abundance only. The geostatistical model-based indices that are used in the base model treat the Triennial Survey as a single timeseries of abundance. The AFSC Slope Survey was split into two coast-wide strata: shallow and deeper than 550m. The NWFSC Slope Survey was divided into 6 strata, with breaks dividing southern, central, and northern strata at 40.5° N and 43° N, each of which was further divided with a break at 550 m. The WCGBTS was divided into 7 strata, with two southern strata below 34.5° N, one covering 183–550 m and the other covering 550–1280 m. Two central strata, between 34.5° N and 40.5° N, had the same depth ranges. The latitudinal divide around 34.5° N is associated with changes in sampling intensity. North of 40.5° N, three strata were used, covering the ranges 100–183 m, 183–550 m, and the other covering 550–1280 m. The depth breaks at 183 m and 550 m are also associated with changes in the sampling intensity of the survey and are recommended to be used. South of 40.5° N, there are very few shortspine thornyhead shallower than 183 m, so no shallow stratum was used in these latitudes. The 2013 stratification was reused for the design-based indices as there was not sufficient evidence to support modifying the existing strata.

2.2.5 Design-based Indices of Abundance

Design-based indices of abundance were derived for all surveys (Figure 8). Note that for these indices of abundance, the Triennial Survey was split into two independent time series, separated by the year 1995. The construction of design-based indices mirrors a weighted average approach. For each survey year, an average CPUE is calculated across all tows within a stratum and expanded by area to determine the total estimated biomass. These values are then summed across all strata within the survey to create a time series of design-based indices of abundance. Design-based indices were computed using the official `nwfscSurvey` R package (Wetzel et al. 2023). Note that design-based indices were not used in the base model, and were only derived for the purposes of sensitivity testing.

2.2.6 Geostatistical Model-based Indices of Abundance

Model-based indices of abundance (Figure 9) for all surveys were derived using geostatistical models (Thorson et al. 2015) developed using the R package `sdmTMB` (Anderson et al. 2022). This approach utilizes geostatistical GLMMs with spatially and spatiotemporally correlated random effects, which can account for variables that cause correlations in the data across space and time. For this reason, the Triennial Survey can be, and was, treated as a single time series rather than split into two timeseries based on the introduction of additional sampling at greater depths. For the Triennial Survey, the geostatistical model included spatial and spatiotemporal random effects and depth and depth squared as a scaled covariate. Geostatistical models for the NWFSC Slope Survey, AFSC Slope Survey, and WCGBTS surveys were not run with depth as a covariate.

Abundance indices were obtained for models using both gamma and log-normal error structures. There is limited agreement on how best to go about model selection for these types of geostatistical models, and both error structures were tested as sensitivity analyses alongside the simple design-based indices described above. The abundance indices derived from the gamma model were most similar to the design-based indices for the Triennial and WCGBT surveys and were thus used for the base model (indices derived from the log-normal model displayed a similar trend to the gamma model-based indices, and the design-based indices, but were consistently larger in scale).

2.2.7 Length Composition Data

Length-composition data were available for each year of each survey including the AFSC Slope Survey, the NWFSC Slope Survey, the WCGBTS, and the Triennial Survey. For the Triennial survey, length compositions were divided into an early period (pre-1995), hereafter referred to as the “early-period Triennial” and late period (post-1995), hereafter referred to as the “late-period Triennial” survey, to account for the change in depth-sampling, and resulting selectivity, that occurred during the 1995 season. The early-period Triennial survey only uses data from 1989 and 1992 due to limited spatial coverage and sample sizes in other years. For all surveys, each haul consists of a set number of random samples regardless of the amount of catch, decoupling the sample and catch size. Therefore, the length compositions were calculated using an expansion factor to account for differences in the amount of catch that samples represent. An expansion factor (calculated as weight of caught fish divided by weight of fish sampled) is calculated for each haul, multiplied by the number of fish in each size bin, and then summed across hauls. This algorithm is repeated for each spatial stratum. Length composition data were compiled into 34, 2cm, length bins, ranging from 6 to 72 cm. Year-specific length frequency distributions generated for each survey are shown in Figure 11.

2.2.8 Frequency of Occurrence and Survey Information

The frequency of occurrence of shortspine and longspine thornyhead in trawl surveys remains extremely high. 91% of the tows in the WCGBTS below 500 m have at least one shortspine thornyhead in the catch (and 96% for longspine thornyhead), similar to the 2013 assessment. The number of survey hauls and shortspine thornyhead sampled available for this assessment is described in Table 17.

2.3 Biological Data

2.3.1 Natural Mortality

Butler (1995) estimated the lifespan of shortspine thornyhead to exceed 100 years and suggested that M was likely less than 0.05. M may decrease with age as shortspine migrate ontogenetically down the slope to the oxygen minimum zone, which is largely devoid of predators for fish of their body size. The 2005 assessment fixed the natural mortality parameter at 0.05, while the 2013 assessment used a prior on natural mortality based on a maximum age of 100 years. The prior had a mean of 0.0505 and a standard deviation on a log scale of 0.5361 (Owen Hamel, NWFSC, pers. comm.). For the 2023 base model,

natural mortality was fixed at 0.04, between the values used by the Alaska and British Columbia shortspine thornyhead assessments, and the values used in the most recent West Coast assessments. This implies an A_{max} of \sim 135 years following the mortality prior of Hamel and Cope (2022).

2.3.2 Maturation and Fecundity

2.3.2.1 Maturity Pearson and Gunderson (2003) estimated a length at 50% maturity of 18.2 cm on the West Coast, with most females maturing between 17 and 19 cm. This was represented in the 2005 and 2013 assessments by the logistic function,

$$M(L) = (1 + e^{-2.3(L-18.2)})^{-1} \quad (3)$$

where L is the length in cm.

The 2013 assessment considered new (at the time) maturity information from ovaries collected for maturity analysis on the 2011 and 2012 WCGBTS. Histological analysis of those samples (Melissa Head, NWFSC, pers. comm.) indicated puzzling patterns of spawning by female size and by latitude, with a higher fraction of fish spawning in the north than in the south and a higher fraction of spawning fish in the 20-30 cm range than in the 30-40 cm range. However, due to the complexity of these observed patterns and the known ontogenetic migrations of shortspine thornyhead, samples collected in 2011 and 2013 were not considered adequate for estimation of a new representative maturity curve for the entire shortspine thornyhead population in 2013. However, such a maturity curve was considered in a sensitivity analysis. On the basis of the sensitivity analysis, the 2013 assessment suggested that the slow but steady rate of growth for shortspine thornyhead, with growth still occurring at age 100, reduces the importance of assumptions about maturity because older individuals have significantly higher spawning output due to their much larger size, regardless of the fraction spawning.

New maturity analyses of samples collected on the WCGBTS in 2011, 2013, 2014, 2016 and 2018 were available for the 2023 assessment (Melissa Head, NWFSC, pers. comm.). The larger number ($N=397$) and better spatial coverage of these samples allowed the use of statistical modeling to better understand the spatial variation in the proportion of female spawning.

In the 2013 assessment, the exploration of maturity analyses from the WCGBTS samples highlighted maturity gradients along latitude and depth. To assess a potential relationship between fish location and the shape of the maturity curve, a Generalized Linear Model (GLM) was designed for estimating maturity curve parameters while integrating latitude and depth as covariates. This GLM consists of a logistic regression in which the functional maturity of samples, modeled with a Bernoulli distribution, is expressed as a linear combination of fish length, latitude, latitude squared, depth and depth squared. Once fitted, the GLM was used to predict the response of the probability of being mature along the range of individual shortspine thornyhead length considered in the model. For the 2023 assessment, this model

prediction was made while setting the latitude and depth at the values of the center of gravity (using number of fish as a weighing factor) of the population of shortspine thornyhead sampled by the WCGBTS to develop a single curve for the coastwide population assessment. Thus, this response of functional maturity to length was considered the mean maturity curve of the west coast shortspine thornyhead population. The parameters of the maturity curve L_{50} and k were arithmetically derived from this response to fish length. The new maturity curve is expressed as follows:

$$M(L) = (1 + e^{-2.3(L-31.42)})^{-1} \quad (4)$$

Figure 15 shows the fit of the maturity curve of the model per class of depth and latitude.

A sensitivity analysis assessed the impact of this change in the maturity curve on the model estimates by considering the newly estimated parameters, the Pearson and Gunderson relationship from 2013, and an intermediate option (Figure 14).

2.3.2.2 Fecundity The previous assessments assumed spawning biomass was equivalent to spawning output. The current assessment uses fecundity-at-length parameters reported in Cooper et al. (2005). Fecundity is modeled as a power function of length:

$$F = 0.0544L^{3.978} \quad (5)$$

where F is fecundity in the number of eggs per female and L is length in cm. Cooper et al. (2005) estimated the fecundity of 54 females collected from the West Coast and Alaska. They found no difference in the length-fecundity relationship by region and pooled the samples. That study suggested that fecundity increases at a faster rate with length than body weight with length for shortspine thornyhead, meaning that larger females have greater relative fecundity compared to small females. This assessment models a fecundity-at-length relationship using the fecundity parameters from Cooper et al. (2005) (Figure 16) and scaling the fecundity intercept by one million to report fecundity in billions of eggs.

Uncertainty remains in the spawning strategy of shortspine thornyhead. Cooper et al. (2005) and Pearson and Gunderson (2003) found no evidence of batch spawning in this species (i.e., a determinate, total spawning strategy). However, updated histological information suggests a possibility of batch spawning (Melissa Head, NWFSC, pers. comm.). Batch spawning could influence the fecundity-at-length relationship if not properly accounted for and should be a focus of future research.

2.3.3 Length-Weight Relationship

Fisheries-independent length and weight specimen data were available from the AFSC Slope Survey (1997, 1999-2001; $N=7,623$) and the WCGBTS (2003-2021, excluding 2020;

$N=20,142$). The WCGBTS data were used to estimate the length-weight relationship because it had the largest sample size and covered the greatest spatio-temporal resolution. Unsexed fish <16 cm in length, and obvious outliers were removed from the dataset prior to fitting the relationship. The allometric function models weight (W) as a power function of length (L), where:

$$W = \alpha L^\beta \quad (6)$$

This function can be linearized by taking the natural logarithm of both sides. The predicted weight-at-length values were bias-corrected using a multiplier of $\sigma^2/2$. The length-weight parameters were estimated for both sexes in R using the `lm()` function (R Core Team 2021).

The resulting parameters for 2023 (females: $\alpha = 4.86 * 10^{-6}$, $\beta = 3.26$; males: $\alpha = 4.69 * 10^{-6}$, $\beta = 3.25$; Figure 13) were very similar to the 2013 assessment values, which estimated a single length-weight relationship for males and females combined using WCGBTS data through 2012 (sexes combined: $\alpha = 4.77 * 10^{-6}$, $\beta = 3.26$). The available data suggested that length-weight is highly conserved in shortspine thornyhead; therefore, no sensitivity analysis was conducted for this set of parameters in the 2023 assessment.

2.3.4 Growth (Length-at-Age)

No validated ageing methods currently exist for shortspine thornyhead; therefore, this species is not aged by the NWFSC or SWFSC and length-at-age data were limited for this stock assessment. Two research age datasets exist for shortspine thornyhead in the West Coast region: (1) Kline (1996) includes 319 unsexed fish collected from Monterey Bay in central California in 1991, and (2) Butler (1995) includes 1,023 sexed fish collected in the waters off northern California and Oregon in 1978–1988 and 1990. The Kline specimens were aged by one age reader, and lengths were reported as total lengths, whereas the Butler specimens were aged independently by two separate age readers, and lengths were reported in fork length. The Butler data age data used in this assessment are the mean ages between the two age readers.

The length-at-age curve developed in the 2005 stock assessment and used again in 2013 was based on a Schnute parameterization of the Von-Bertalanffy growth function fit to the Kline data. The resulting parameter estimates for this growth function were as follows: growth rate k was 0.018 for both males and females, length at age-2 was 7 cm for both males and females, and length at age-100 was 67.5 cm for males and 75 cm for females based on the assumption that the asymptotic length for males should be 90% of the asymptotic length for females (Hamel 2005). The data and associated analysis from 2005 were lost; however, the original Kline and Butler datasets were obtained for use in this assessment (Donna Kline, pers. comm., March 2023). Using these newly obtained data, we could not reproduce the parameters used in the 2005 assessment.

Because the Butler data were sex-specific, had a higher sample size, were aged by two

readers instead of one, and were collected from a larger geographic area and over more years compared to the Kline data, we determined that Butler was the preferred dataset to estimate the length-at-age relationship for the 2023 stock assessment. We fit sex-specific Schnute growth functions to the Butler data:

$$\hat{L}_a = L_{a_1} + \frac{(L_{a_2} - L_{a_1})(1 - \exp(-k(a_2 - a_1)))}{(1 - \exp(-k(a_2 - a_1)))} \quad (7)$$

where: L_{a_1} and L_{a_2} are the lengths at reference ages a_1 and a_2 where $a_1 = 1$; $a_2 = 100$ and k is the growth rate. Growth curve estimation was conducted in R using the `optim()` function (R Core Team 2021). Errors were assumed to be lognormally distributed and predicted length-at-age was bias-corrected using a multiplier of $\sigma^2/2$. Updated growth parameters were fixed in the assessment at the following values using the reference ages and equation described above:

Females: $La_1 = 11.4$ cm; $La_2 = 73.6$ cm; $k = 0.0099$ per year

Males: $La_1 = 9.2$ cm; $La_2 = 66.1$ cm; $k = 0.0168$ per year

For reference, the equivalent von-Bertalanffy growth parameters are:

Females: $t_0 = -8.931$; $L_{inf} = 111.0$ cm; $k = 0.0099$ per year Males: $t_0 = -5.314$; $L_{inf} = 79.4$ cm; $k = 0.0168$ per year

Shortspine thornyhead are slow-growing fish that appear to continue to grow throughout their lifespan (i.e., the growth curve does not asymptote). The new growth curves estimated using the Butler dataset exhibited similar trends to those assumed in the 2005 and 2013 assessments (Figure 12). The male curves were almost identical, with the 2005/2013 curve exhibiting slightly lower length-at-age at young ages and slightly higher length-at-age at older ages. The 2005/2013 female curve was defined by a higher growth rate, leading to the higher length-at-age in the intermediate age range.

Two alternative sensitivity analyses were developed for the 2023 assessment. During the exploratory data analysis phase, we found that specimens collected in the Kline study exhibited higher size-at-age when compared to the Butler specimens (Figure 12). It is unknown if these differences should be attributed to spatial differences in growth between central California and northern California/Oregon, bias among age readers, or discrepancies between the total and fork length measurements (Donna Kline, pers. comm., March 2023). In order to account for this alternative growth pattern, we increased the lengths at ages 2 and 100 by 25% in the upper sensitivity analysis (Figure 12). The lower sensitivity analysis was defined by decreasing the lengths at ages 2 and 100 by 10% from the base model.

2.4 Environmental and Ecosystem Data

No ecological or environmental information was used in this assessment.

2.5 Changes in data from the 2013 assessment

Most of the data used in the previous assessment has been newly extracted and processed, including length compositions from each fishing fleet and survey, indices of abundance derived from new geostatistical models of survey data, discard rates from both the 1980s Pikitch study and the current WCGOP, and the time series of catch from 1900-2023.

New data or uses of data for this assessment include the geostatistical model-based indices of abundance for the four fisheries independent surveys, the histological maturity samples from the WCGBTS survey, and the historical state catch reconstructions. Previous assessments have treated the AFSC Triennial Shelf Survey as two separate indices of abundance separated by the 366m depth contour, but the transition to using geostatistical model-based indices have rendered this separation unnecessary by implicitly accounting for changes in depth sampling within the model. State-level historical reconstructions also replace previous analyses that imputed historical shortspine thornyhead catch as a fixed proportion of sablefish catch.

3 Assessment Model

3.1 Summary of Previous Assessments and Reviews

3.1.1 History of Modeling Approaches

Shortspine thornyhead was first assessed in 1990 by Jacobson (1990) and Jacobson (1991), and subsequently by Ianelli et al. (1994), Rogers et al. (1998), and Piner and Methot (2001). What would now be called a data-moderate assessment was conducted in 2005 (Hamel 2005) using Stock Synthesis (SS2). More recently, shortspine thornyhead were assessed by Taylor and Stephens (2013) using SS3. The 2013 model retained many of the assumptions made by Hamel (2005) including a four fisheries fleet structure, sex-specific growth, and no fecundity relationship. A catch-only projection was conducted in 2019 (Taylor 2019).

3.1.2 Most Recent STAR Panel Recommendations

The most recent assessment made a number of recommendations for data availability and modeling. Major recommendations included:

1. More investigation into maturity of shortspine thornyhead.

Progress: A new maturity curve was derived from new histological samples taken during the WCGBTS and processed by Melissa Head. The new maturity curve implies that maturation occurs at much larger lengths, and much more slowly, than what was assumed in 2013.

2. Information on possible migration of shortspine thornyhead would be valuable for understanding stock dynamics.

Progress: No additional progress has been made.

3. A greater understanding of catchability of shortspine thornyhead would help define the scale of the populations.

Progress: The degree of uncertainty in the scale of the population has substantially decreased since 2012, and the catchability coefficients in the current model are computed analytically by Stock Synthesis. Likelihood profiles over R_0 and M imply they have a much stronger relationship with overall population scale than the analytically derived catchability values.

4. Age data and additional research on ageing methods for thornyheads would be valuable.

Progress: Age data and aging methods remain limited for shortspine thornyhead.

5. A greater understanding of the connection between shortspine thornyhead and bottom type could be used to refine the indices of abundance.

Progress: No additional progress has been made.

6. A comprehensive catch reconstruction for shortspine and longspine thornyheads should be completed to estimate landings for each species prior to 1981 in each of the three states.

Progress: State-level catch reconstructions were integrated into the base model for 2023. They represented a minimal change in the catch timeseries as compared to the 2013 assessment.

7. Exploration of simpler assessment methods for shortspine thornyhead and evaluation of whether such methods would provide a more robust management strategy than the current approach.

Progress: While simpler methods were not tested for this assessment, the model structure was significantly reduced from four fleets and five surveys, to three fleets and two surveys. This significantly reduced the total number of parameters that needed to be estimated by the model.

8. More tows or visual surveys south of 34.5 deg. N. lat. including the large Cowcod Conservation Area (CCA). Because the southern Conception Area is a large potential habitat for shortspine thornyhead, more sampling effort would help refine the estimations of their abundance in this area.

Progress: No additional progress has been made.

3.2 Model Structure and Assumptions

3.2.1 Model Changes from the Last Assessment

The most notable changes from the previous assessment, conducted in 2013, include significant modifications to the fleet and survey structure, and major changes to the maturity and fecundity relationships that underlie the model’s biological assumptions.

The 2013 assessment consisted of four fisheries fleets, and used information from four (nominally five) scientific surveys, while the new assessment uses a condensed structure consisting of just three fisheries fleets and only two (nominally three) surveys (see Section 3.2.3 for more details).

This assessment assumes a new fecundity relationship, in which fecundity increases with body size, as well as a new maturity relationship, in which fish mature at much larger sizes and thus older ages, than were assumed in the 2013 assessment. Further details on the fecundity and maturity relationships can be found in Section 2.3.2. A sensitivity analysis was performed to determine the effect of different maturity assumptions on the final model output.

3.2.2 Modeling Platform and Bridging Analysis

This new assessment, including all exploratory models, profiles, and related analyses, was performed using Stock Synthesis Version 3.30.21 (Methot and Wetzel 2013; Methot et al. 2020). The majority of analyses were performed using multiple recent versions of R (R Core Team 2021), and relied heavily on the `r4ss` R package (Taylor et al. 2021) among others. The assessment model was developed and tested across multiple operating systems, including recent versions of Windows and macOS.

The process of bridging to a new model occurred in two steps. The initial bridging phase focused on the conversion from version SS-V3.24o to version SS-V3.30.21 using the same data and model assumptions used in the 2013 assessment. Two models were built during this first step: an initial model which fixed parameter values at the values estimated in the 2013 assessment (“2013 Model SS V3.30.21 Fixed Params”) and a second model which estimated all parameters as assumed in the 2013 assessment (“2013 Model SS V3.30.21”).

The subsequent bridging exercise involved updating the model (“2013 Model SS V3.30.21”) with the addition of new and reprocessed data through 2023 as well as updating biological parameters (growth, maturity, fecundity, and mortality parameters - see Section 2.3 for more details). Additional data include new catch, discard, survey indices, length-composition, and mean body weight (for discards only) data. The contribution of each data component and parameter update to the changes in the model outcome were analyzed by adding data and updating parameters in a linear piecewise fashion.

While there were no discernible changes between the 2013 assessment and the “2013 Model SS V3.30.21 Fixed Params” model, differences were observed in the estimated spawning

biomass, recruitment (age-0 fish), and fraction of unfished time series between these two models and the “2013 Model SS V3.30.21” model (marginally smaller spawning biomass and recruitment along with a smaller depletion level from the end 1970s onward; Figure 17). The source of these changes can be attributed to differences in the way of analytically computing survey catchability (“floatQ” approach, see Section 3.2.4.3) between the two versions of Stock Synthesis.

Inclusion of new data and updated parameters resulted in a series of changes to model outcomes (Figure 18, Figure 19). While the update of both growth and maturity parameters led to variation of spawning biomass in the range of the uncertainty previously observed (models “Updated Growth” and “Updated Maturity”, respectively), the one notable change in the estimates of spawning biomass occurs with the update of fecundity parameters (model “Updated Fecundity”) which resulted in a strong downward revision of the spawning biomass time series. This major change can be explained by the use of a new length-based fecundity relationship which was not considered in the previous assessment (see Section 1.1.1 for more information).

3.2.3 Model Structure

Similar to the 2013 assessment, the 2023 assessment model is a two-sex, length-based age-structured model that estimates population dynamics from 1901 onwards. The model assumes a steady equilibrium state with no fishing prior to the start year of the model (1901) and considers a spatially homogeneous unit stock in the waters off the U.S. West Coast.

Commercial fisheries landings were divided into three distinct fisheries fleets: a northern trawl fleet (hereinafter referred to as North Trawl) operating off the coasts of Oregon and Washington (including catch from the at-sea Pacific whiting fishery), a southern trawl fleet (hereinafter referred to as South Trawl) operating off the coast of California, and a coastwide non-trawl fleet (hereinafter referred to as Non-trawl).

Data from two fisheries-independent scientific surveys were used in this model: the Triennial Survey from 1980-2004, and the more recent WCGBTS from 2003-2022. The Triennial Survey length compositions were further divided into an early (pre-1995) and late period (post-1995) survey to account for changes in selectivity due to the change in depth-sampling that occurred during the 1995 season. These two periods for the Triennial Survey were treated as separate surveys in the model. The Triennial Survey abundance index timeseries is treated as a single timeseries spanning 1980-2004. The contribution of each new data component to the changes in the assessment outcome was analyzed by adding data in a linear piecewise way in order to understand how each change contributed to the model outcome.

3.2.4 Model Parameters

There are 197 estimated parameters in this assessment. The log of unfished recruitment, $\ln(R_0)$, controls the overall scale of the population, while annual deviations in recruitment about the assumed stock-recruit relationship (135 parameters) allow for additional uncertainty in the population trajectory and tracking of recent recruitment events. Selectivity and

retention parameters (59 parameters) for three fisheries fleets and three scientific surveys allow for estimation of annual length compositions and discards rates. Two catchability parameters are analytically computed from the data, and one additional parameter, representing additional variability in the early Triennial Survey, is directly estimated by the model. A variety of selectivity and retention blocks are utilized to improve fits to the length composition and discard rate information (Figure 23)

3.2.4.1 Growth, Maturity, Fecundity, Mortality, and Recruitment Growth, maturity, and fecundity parameters were fixed at values determined by external analyses (see Section 2.3 for more information). Due to a lack of aging data, growth could not be modeled internally by the assessment, though, like in the 2005 and 2013 models, there is no systematic misfit to the data suggesting that the externally derived growth curves were misspecified. Sensitivity analyses were performed to determine the overall effect of different assumptions regarding growth and maturity.

For this assessment, natural mortality (M) was fixed at a value of 0.04, as such a value provided better fits to the data and literature information implies that the maximum age of shortspine thornyhead could be well over 100 years. A likelihood profile exploring alternative natural mortality values was also conducted (Figure 56). In the 2013 assessment, M was fixed at 0.0505 Taylor and Stephens (2013), however, because shortspine thornyhead are difficult to age, aging error may bias age to be lower and they may live longer than those caught in surveys or fishing fleets, likely at deeper depths. Recent shortspine thornyhead assessments in Alaska and British Columbia used much lower M , as low as 0.03, in their models (Starr and Haigh 2017; Echave et al. 2022).

As in the previous shortspine thornyhead assessment, a Beverton-Holt stock recruitment relationship was assumed. Unlike the 2013 assessment, where steepness was fixed at a value of 0.60, this assessment fixed steepness at 0.72, as recommended by Thorson et al. (2019). A likelihood profile exploring alternative steepness parameters was conducted and the model results were found to be largely insensitive to the assumed value (Figure 55).

The overall scale of the population is estimated through the log of the initial recruitment parameter (R_0). Recruitment deviations were additionally estimated for the years 1901-2022. Recruitment bias adjustments were phased in beginning in 1950, and were adjusted by a factor of 0.30 in the years 1982-2018 (Taylor and Methot 2013). The σ_R parameter which controls the variability in recruitment deviations was fixed at 0.5 as in the previous assessment. Past assessments performed likelihood profiles over σ_R , finding the model results to be relatively insensitive to its value, and thus further profiles over the parameter were not conducted here.

3.2.4.2 Selectivity and Retention Gear selectivity parameters used in this assessment were specified as a function of size with the additional assumption that age 0 fish were not selected, regardless of their size. Separate size-based selectivity curves were fitted to each fishery fleet and survey.

The selectivity curves for all fisheries and surveys were allowed to be dome-shaped and modeled

with double-normal selectivity. The double-normal selectivity curve parameterization has six parameters, including: (1) peak, the length at which individuals are first fully selected, (2) width of the selectivity plateau, (3) width of the ascending part of the curve, (4) width of the descending part of the curve, (5) starting selectivity, and (6) final selectivity. Parameters 5 and 6 were not estimated and fixed at 0.0. The 2013 model allowed for all selectivity parameters to be estimated, regardless of whether one or more were estimated to be on the parameter bound. This model fixed parameter 2 (the plateau width) to the value of -15 for the North Trawl fleet to alleviate them hitting the lower parameter bound. Though exploratory models run with the plateau width on its lower bound still converged, fixing the parameter had negligible impact on the fits to the length composition data for this fleet. Sex-specific selectivity curves were fit to the WCGBTS and Triennial Survey length composition data.

As a new addition to this assessment, time-varying selectivity curves were estimated for the North and South trawl fleets. Three time blocks accounted for potential structural changes in these fisheries: (1) the historical period from 1901-2002, (2) 2003-2010, for the implementation of rockfish conservation areas, and (3) 2011 for the start of the IFQ program through the present (Figure 23; Figure 24).

Retention curves are defined as a logistic function of size. These are controlled by four parameters: (1) inflection, (2) slope, (3) asymptotic retention, and (4) male offset to inflection. Male offset to retention was fixed at 0 (i.e., no male offset was applied). The parameters for inflection and asymptotic retention (asymptotic retention was estimated for North Trawl and Non-Trawl, and fixed for South Trawl as the estimate was hitting the upper parameter bound) were modeled as time-varying quantities via the use of time blocks. Time blocks were expanded from the 2013 assessment. Both North Trawl and South Trawl fleets were broken into six time blocks, with slight variation between fleets: (1) 1901-1988, (2) 1989-2006, (3) 2007-2010, (4) 2011-2014 for North Trawl and 2011-2016 for South Trawl, (5) 2015-2019 for North Trawl and 2017-2019 for South Trawl, and finally (6) 2020-2022 for both trawl fleets (Figure 24; Figure 26). Notably, the sequence of shorter time blocks starting after 2006 noticeably improved fits to the lower discards rates seen in the mid-2010s; in a similar way, transition between the first and second time blocks improved the fit to discard rates from the Pikitch study. Additionally, a short, 3-year, time block for the years 2020 and 2022 was also included, as discard rates were noticeably higher in those years than in previous. After merging the two Non-Trawl fleets previously considered in the 2013, the reasons that justified the time blocks used in the 2013 assessment were not pertinent anymore and we decided not to represent time-varying retention for this fleet.

3.2.4.3 Catchability Catchability coefficients (q) were calculated for each of the two survey abundance time series. Like the 2013 model, catchability was analytically for each survey using the Stock Synthesis “floatQ” option, though the exact analytical computation has changed from what was used in 2013 (Methot et al. 2020).

This model depends on the assumptions that thornyheads are long-lived, slow-growing, and relatively sedentary groundfish. They are assumed to represent a single stock within the area

considered for this assessment. If the assumptions about growth, natural mortality, or stock structure turn out to be far from the true life history and ecology of shortspine thornyheads, this assessment will be highly inaccurate.

3.3 Base Model Results

3.3.1 Parameter Estimates

A complete set of parameter estimates are available in Table 20.

3.3.1.1 Recruitment The model estimated 135 annual recruitment deviations (1901-2034) as well as the log of unfished recruitment $\ln(R_0)$. Unfished recruitment was estimated to be ~12,580,000 annual age-0 recruits ($\ln(R_0) = 9.44$) while annual log deviations were generally estimated between -0.5 and 0.5 (Figure 20; Table 3). Recruitment in 2003 was estimated to be substantially larger than other years. As in the 2013 assessment, uncertainty in the scale of annual deviations was substantially larger than the variation between the deviations. Recruitment bias adjustments were performed following the advice of Methot et al. (2011).

3.3.1.2 Selectivity and Retention The 2023 assessment substantially extends the period over both length data of retained and discarded catch, and mean individual weight in discards and discard rates estimates are available. This data may reflect the dynamics of the thornyhead population but also structural, technical, or behavioral aspects affecting fishing fleets. Selectivity curves for all three fisheries fleets and the three scientific surveys were estimated as dome-shaped (Figure 22).

The early- and late-period Triennial Surveys had narrow dome-shapes, with peak selectivity occurring at relatively small length (~26 cm, and ~22 cm respectively). This shape is consistent with the design of the survey which focused its sampling on the relatively shallow shelf, where younger, smaller, shortspine thornyhead live before migrating to deeper waters as they age and mature. There was little difference in the estimated selectivity curves between male and female fish. Meanwhile, the WCGBTS was estimated to have a wide plateau (beginning at ~30cm) over which the species is fully selected for, including the lengths over which the species spends the bulk of its lifespan. This indicates that the WCGBTS is sampling a large proportion of the stock, and that annual length composition data from the survey is likely a good representation of the true distribution of lengths in the population.

Time blocks on selectivity and retention were specified for commercial fisheries. In particular, they explored changes to management and notable fleet behavior (Figure 23; Figure 24) for the North Trawl and South Trawl fleets. The North Trawl fleet was estimated to have a dome-shaped selectivity curve, where in early time periods (1901-2002) the peak is around 28 cm in length, and in later blocks moves incrementally to larger lengths (Figure 25). All time blocks have a long tail that spans nearly the entire range of observed lengths. The South trawl fleet was estimated to have a very large selectivity plateau, with early time periods (1901-2002) having the plateau ranging from 20-60cm and the later time periods (2006-2022)

ranging from 30-70cm (Figure 25). This pattern likely reflects important changes in the southern fisheries, notably matching the establishment of conservation areas, while fishing pressure in the northern part of the West Coast was historically less intense. All curves have steep ascending and descending limbs. Finally, the Non-Trawl fleet (no blocking) was estimated to have a relatively small plateau beginning at a much higher length than any other fleet or survey (~45 cm) (Figure 25). This can be explained by the fact that hook and line gear, the dominant gear type in the Non-Trawl fleet, selectively catches larger shortspine thornyhead.

Retention curves for all three fisheries were asymptotic in shape, with the two trawl fisheries asymptoting at a retention value of 1.0 and the non-trawl fishery asymptoting a value just below 1.0 (Figure 26), indicating that the Non-Trawl fishery still discards large fish in limited cases. Retention time blocks to allow for variation in retained sizes with fleet behavior and substantially improved fits to the discard rate data (Figure 26). The time-blocked fits to the North Trawl fleet show the fishery to have begun retaining smaller fish in more recent years than they have historically (although it is less clear after 2020). A similar pattern is observed for the South Trawl fleet, but to a smaller extent (Figure 26).

3.3.2 Fits to the Data

3.3.2.1 Abundance Indices The base model reasonably fit the available index data with the exception of the most recent two years of the WCGBTS. The fit to the Triennial Survey was relatively flat across the entire timeseries (1980-2004; Figure 27). An extra parameter was used to estimate additional variance beyond that estimated by the geostatistical model for this survey. The model fit to the WCGBTS indices appropriately captured the lack of trend in the early and middle portions of the timeseries, but struggled to fully capture the recent increase in abundance displayed by the indices (Figure 28). The model fit for this survey only just falls within the estimated confidence interval for the 2021 and 2022 indices. This could be, in part, due to the lack of index data from 2020 (surveys were not conducted due to the ongoing COVID-19 pandemic), which may have helped the model more accurately capture the increase, or could be due to changes in calculation of the abundance indices (the 2023 model moved to using model-based indices in lieu of design-based).

3.3.2.2 Fishery Discard Rates The model fit the discard rates for all three fisheries fleets quite well (Figure 29; Figure 30; Figure 31). The timeblocking scheme for retention that was inherited from the 2013 model was expanded to encompass a variety of additional changes in fishing behavior and observed patterns in the data. The final set of timeblocks are provided in Figure 23, and justification for their use is presented in Section 3.2.4.2.

3.3.2.3 Fishery Length Compositions The base model fit the fishery and discard length compositions reasonably well in aggregate (Figure 32), though there was significant annual variability in the quality of fit, often due to differences in effective sample sizes. The South trawl and Non-trawl fleets were exceptionally well fit by the model, while the model fit to the length compositions from the North trawl fleet underestimated the scale of the peak of the distribution. This type of misfit was similarly observed in the model fits on an

annual basis, with all years 2018-2022 displaying a similar underestimation of either the location or scale of the peak of the distribution (Figure 33; Figure 34). The exact causes of this under-estimation remain unknown at this time, but could be due to subtle changes in selectivity or availability. Time-varying selectivity in the form selectivity time-blocks slightly improved overall fit to the length composition data. The final set of timeblocks are provided in Figure 23, and justification for their use is presented in Section 3.2.4.2.

Trawl discards length compositions were well fit by the model in both the north and south regions, while the model struggled to adequately fit discard compositions from the Non-Trawl fleet (Figure 32). The Non-Trawl discards were of a larger size and were generally more dispersed than the discard compositions in the two trawl fleets, a feature the model did pick up on, but the model fit a wide plateau rather than narrow peak to these composition data. This is likely due to the wide variability in annual length compositions seen in this fleet, as well as the wide spatial coverage. An investigative model (not presented) identified the primary source of this misfit to discards from the South trawl fleet.

3.3.2.4 Survey Length Compositions Like the fishery derived length compositions, survey-derived length compositions were reasonably well fit in aggregate by the base model (Figure 32), though there was considerable annual variability in the quality of the model fit (Figure 41). The early-period Triennial Survey length composition data for both sexes were exceptionally well fit by the model. Length compositions from the late-period Triennial survey were slightly less well fit, with the model under-estimating the location of the peak for both sexes. For the WCGBTS length compositions, the male, female, and unsexed location of the compositional peaks were well estimated, though the overall scales were slightly underestimated. Pearson residuals did not demonstrate any obvious trends that would indicate systematic misfits to the data (Figure 43).

3.3.2.5 Mean Body Weight Mean body weight of discarded fish was well fit in the two trawl fleets, and no major trends were observed in either the data or the model estimates (Figure 44; Figure 45; Figure 46). Mean discard weight in the Non-Trawl fleet was observed to have increased in the last ten years, but this trend was not captured by the model. The model, instead, fit a declining trend in discard weight to the Non-Trawl fleet data (Figure 46). The reason for this disparity between the observed data and the model fit is unclear.

3.3.3 Population Trajectory

Unfished equilibrium spawning output (B_0) is estimated to be 22.145 trillion eggs (18.166-26.124 trillion eggs). The B_0 estimate is not directly comparable to estimates made in previous assessments, which assumed no fecundity relationship, and thus calculated B_0 in terms of biomass rather than egg production. Spawning output is estimated to have remained stable until the mid-1960s and then declined in the 1970s to about 80% in the mid-1980s, followed by a slower decline under the lower catch levels in the 2000s (Table 11; Figure 47). While the spawning output of the stock has declined near linearly since 1975, total biomass has stabilized in recent decades around ~85,000 mt. The estimated spawning output in 2023 is 8.717 trillion eggs (5.545-11.889 trillion eggs), which represents a stock status (depletion

level) of 39.4% (31.6%-47.1%; Table 7, Figure 48). The new depletion estimated for 2013 is 43.5%, which is significantly lower than the 74.2% estimated for 2013 in the previous assessment.

Twelve-year projections predict that the population is unlikely to experience a large increase in spawning output or spawning biomass in the near future, if the full ACL is taken each year.

3.4 Model Diagnostics

3.4.1 Convergence

The maximum likelihood parameter estimates found by AD Model Builder (ADMB) indicated a well-converged model. The base model had a small maximum gradient component (0.000102) and a positive definite Hessian matrix, both of which are associated with converged models.

Runs with 100 alternative sets of starting parameter values found no models with a better likelihood (Table 18). Of the 100 jittered model runs, 23 re-converged to the best estimates associated with the base model, while 62 converged to a likelihood value ~6% higher than that of the best estimate. No jittered model runs achieved a better likelihood than the base model. The proclivity of the model to converge to a nearby local minimum implies either a complex likelihood surface or very a flat likelihood around the minimum. Regardless, we are confident that the base model achieves the best possible fits to the model data.

3.4.2 Sensitivity Analyses

3.4.2.1 Sensitivity to growth parameters Growth parameters are uncertain for shortspine thornyhead due to difficulties in determining age from otoliths and subsequent lack of length-at-age information for this species, thus, sensitivities of length-at-age 25% higher and 10% lower was conducted to encompass the uncertainty in growth within and between data sets. Different assumptions about growth did not have much influence on relative spawning depletion. Depletion levels in the final year were slightly greater in a higher growth scenario and slightly lower in a lower growth scenario (Figure 63). Spawning output was more sensitive to assumptions about growth, with much higher spawning output when assuming a higher growth scenario (Figure 62). The high growth sensitivity had a slightly better overall fit to the data, including to the survey indices and length compositions (Table 19). Different assumptions about growth influence recruitment patterns and the timing of strong year classes. However, the influence of different growth assumptions is also sensitive to changes in other parameters, such as natural mortality.

3.4.2.2 Sensitivity to maturity The 2023 assessment used updated maturity-at-length information from the WCGBTS and port-sampling (Melissa Head, NWFSC, pers. comms.), which showed a larger length at 50% maturity ($L_{50\%} = 31.4$ cm) and slower rate of maturation (slope = -0.177) in the logistic curve compared to the smaller $L_{50\%}$ (18.1 cm) and faster rate of maturation (slope = -2.304) assumed in the 2013 assessment based on Pearson and Gunderson (2003). A sensitivity was conducted to maturity information from the two

datasets and to an intermediate maturity-at-length logistic curve (`mix_curve`, $L_{50\%} = 24.8$ cm and slope = -0.350). As in the 2013 assessment, estimates of population scale and status in the base model were not sensitive to different maturity assumptions (Figure 65; Figure 66). Differences in fits to the data were negligible. The slightly higher stock status in the final year with the Pearson and Gunderson (2003) maturity assumptions is likely due to females from strong cohorts in the 2000s assumed to mature at younger ages compared to the base model. As stated in the 2013 assessment, the slow growth rate of shortspine thornyhead, with growth still occurring at age 100, reduces the importance of assumptions about maturity because older individuals will have significantly higher spawning output due to their much larger size, regardless of the fraction spawning.

3.4.2.3 Sensitivity to Landings Two sensitivities were conducted to explore how changes in the historical landings timeseries effect modern-day estimates of stock status. One sensitivity replaces the historical landings reconstructions prior to 1962 with the imputed landings that were used in the 2005 and 2013 assessments. A second sensitivity replaces all landings information prior to 2013 with the values that were used in the 2013 assessment. There was little appreciable difference to base model fits across the two sensitivities (Figure 67; Figure 68). This is likely due to the fact that historical catches (pre-1962), and changes in catches due to state-level catch reconstruction updates, were relatively small and thus would have had minimal impact of the biomass timeseries.

3.4.2.4 Sensitivity to Abundance Index Methods The 2023 assessment uses model-based indices (MBIs) of abundance derived from geostatistical models, which differs from previously used design-based approaches (DBIs). There remains limited agreement on how best to approach model selection for such models. Therefore, two sensitivity analyses were conducted on the methods used to estimate indices of abundance: 1) using MBIs derived from a geostatistical model that assumed a lognormal error structure (compared to a gamma error structure in the base model); and 2) using newly calculated DBIs.

Estimates of population scale and status were not sensitive to changes in error structure used in the MBIs or changes in estimation methods (i.e. use of design-based indices). Small reductions in estimated spawning output were observed when lognormal error structures were used in MBIs as well as when design-based indices were used. No appreciable improvements to model fit were observed between model-based indices that used gamma or lognormal error structures. The use of DBIs reduced model fit compared to the base model (Figure 69-70).

3.4.3 Retrospective Analysis

Retrospective analysis indicates that removing the most recent years of data has minimal impact on the estimates of spawning output (Figure 59) and stock status (Figure 60). This is consistent with the results of the likelihood profile over R_0 (Figure 52) which showed that the data are moderately informative about stock scale. While the analysis does display some very minimal evidence of a retrospective pattern, all estimates of spawning output in the retrospective analysis fell within the 95% uncertainty interval around the base model spawning output time series (Figure 60).

As in the previous assessment, there is little evidence that such retrospective patterns are the result of additional years of survey abundance data (Figure 61), and thus, it is most likely that removal of informative length composition data is the source of such pattern.

3.4.4 Likelihood Profiles

Likelihood profiles were conducted over the log of unfished recruitment (R_0), the steepness of the stock recruit relationship (h), the value of natural mortality (M), and the growth curve.

A likelihood profile over $\ln(R_0)$ was performed to assess the influence of the various data sources on the unfished scale of the population. The profile shows most of the data sources to be in agreement regarding the best estimate of R_0 , with the exception of the indices of abundance, which are best fit by larger values of R_0 (Figure 52). Similarly, there is little inconsistency in likelihood contribution by fleet across the range of plausible R_0 values (Figure 52), though the Triennial survey does appear to be the source of the disagreement. This indicates that the data, together, are relatively informative about the overall scale of the population. The highest spawning output and lowest depletion levels were associated with higher R_0 values (Figure 53).

Likelihood values and model results were largely insensitive to changes in steepness (Figure 54). The change in negative log likelihood over the range of $h = 0.5\text{--}1.0$ was less than 10 units with the largest contribution coming from recruitment and abundance indices. No other likelihood component had a change of greater than 1 unit. The lowest B_0 and depletion values were associated with the most productive population, with $h = 1.0$, but there was no qualitative difference between any of these cases (total change in depletion values across the range of h tested was ~ 0.02 units; Figure 55). The apparent lack of influence of h on population dynamics for shortspine thornyhead is likely the result of the relatively high estimated stock status across the entire time series, which makes estimation of h difficult.

A likelihood profile over natural mortality (M) found the model results to be quite sensitive to the assumed value of M : with all values of M 0.025–0.055 resulting in likelihoods within 7 units of the base model (Figure 56). Meanwhile there was no support in the data for values of M above 0.06 or below 0.02. The profile over M does not indicate the existence of a “best” value over the range of values tested, which fully encompass the values seen in the literature. Length composition data, particularly from the south trawl fleet, was the major contributor to the changes in likelihood observed over the range of tested values for M (Figure 56). All plausible values of M resulted in similar levels of depletion (Figure 58), but a wide range of levels for unfished spawning output (Figure 57)

3.4.5 Unresolved Problems and Major Uncertainties

Few problems remain totally unresolved, though improvements to the model fit to the WCGBTS abundance indices and to the North Trawl fleet length compositions would be desirable. In addition, being able to freely estimate the width of the selectivity plateaus for many of the fleets and surveys would also improve the model.

The model fails, at this time, to fully capture the observed increase in abundance seen in the WCGBTS index time series, significantly underestimating the abundance in 2021 and 2022 (Figure 28). Better fits to WCGBTS length compositions in those years could possibly improve fits to the indices, but improvements to the length composition fits proved difficult without introducing time-blocked selectivity. As the WCGBTS is supposed to follow highly standardized survey methodologies, there seems to be minimal justification for introducing time-varying selectivity in the model at this time. The model also fails to fully capture the peak of the length compositions for the Northern Trawl fleet, underestimating the number of mid-sized fish that the fleet takes (Figure 32). This underestimation appears to be consistent, particularly in the last 10 years (Figure 34), implying a possible recent change in selectivity. While time-varying selectivity was not investigated here, if this trend persists, future assessments may wish to apply a selectivity time block to this fleet in order to better capture the peaks of the length compositions.

Major uncertainties in the model are centered around uncertainty in the biological parameters that govern growth, maturity, and natural mortality. Due to a lack of reliable aging methods, growth was estimated externally to data collected in the 1990s (see Section 2.3.4 for more information). Sensitivities conducted on length-at-age demonstrated that changes to the assumed growth function could have large effects on the estimated stock status (Figure 63). Due to inconsistent histological data, which suggest spatial variation in maturity-at-length for shortspine thornyhead, there remains some uncertainty about the shape of the species' maturity curve, though the model appears to be largely insensitive to variation in maturity (Figure 66). Finally, likelihood profiles over natural mortality demonstrate the model to be quite sensitive to its assumed value. There is insufficient information in the data to estimate natural mortality directly, constraining us to using meta-analyses or other natural mortality estimators, which frequently make use of aging information that is largely unavailable and highly uncertain for shortspine thornyhead.

4 Management

4.1 Reference Points

Reference points were calculated using the estimated catch distribution in the final year of the model (2023). In general, the population is on the boundary between “precautionary” ($B/B_0 = 0.40$) and “healthy” status relative to the reference points (Figure 48). Sustainable total yield (landings plus discards) was estimated at 1,108 mt when using an $SPR_{50\%}$ reference harvest rate and ranged from 929-1,288 mt based on estimates of uncertainty (Table 5). The spawning output equivalent to 40% of the unfished spawning output ($B_{40\%}$) was 8.858 trillion eggs. The most recent catches (landings plus discards) have been lower than the estimated long-term yields calculated using an $SPR_{50\%}$ reference point, but not as low as the lower bound of the 95% uncertainty interval. However, this is due to the fishery not fully attaining the full ACL. The OFL and ABC values over the past 6 years have been approximately 3100 mt and 2,500 mt, respectively. Both of those values are higher than the OFL and ACL values predicted in short-term forecasts, which are around 900 mt and 700 mt respectively for 2025–2026 (Table 7). This is reflected in the timeseries of low

harvest rates (Figure 49), high 1-SPR values (Figure 50), and the phase plot showing the history of being above the target biomass but also above the target fishing intensity reference points (Figure 51). The sharp decline in the OFL and ACL in coming years is the result of continued decline in the relative spawning output of the stock, which has placed it very near the “precautionary” zone for management.

4.2 Harvest Projections and Decision Tables

The standard deviation of the log of spawning biomass in 2023 is $\sigma = 0.18$. This value is in the adjustment of quotas based on scientific uncertainty (a process referred to by the notation “ P^* ”) when the value is greater than an assumed 0.36 minimum, as it is in this case. The associated offset would therefore be a multiplication of the OFL by 76.2%, which is the 40% quantile of a log-normal distribution with the associated σ . Twelve-year projections were conducted with a total catch assumed equal to the ACL calculated by applying this adjustment to the estimated OFL for each year. The selectivity and retention function and allocation of catch among fleets was assumed to match the values for the 2020-2022 timeblock. Catch for 2023 and 2024, the limits on which have already been set, were provided by the PFMC, and correspond to a total catch of 756 mt.

This default harvest projection applied to the base model indicated that the stock status would slowly decline from 39.4% in 2023 to 39.2% in 2024, before beginning a slow rebound to 40.1% by 2034. The associated OFL values over the period 2025–2034 would average 1,022 mt and the average ACL would be 718 mt. These values are near recent annual catch levels.

Additional projections were conducted for the base model and low and high states of nature (columns) under two catch streams (rows) representing different levels of scientific uncertainty, and thus different values of P^* . The uncertainty in the OFL associated with the base model was broad ($\sigma = 0.18$), and states of nature were chosen based on values of natural mortality (M) that encapsulated the range of M seen in the literature. The low state of nature used $M = 0.03$ to fully encapsulate the low end of the range of M seen in assessments throughout the eastern Pacific. The high state of nature used $M=0.05$ to roughly encapsulate the value of M used by the 2013 assessment.

The catch streams chosen for the decision table were represented as total catch rather than landed catch, but discard rates were low under IFQs, so the difference in between total catch and landings is small, and represent catch under two distinct levels of P^* ($P^* = 0.40$ and $P^* = 0.45$). The most pessimistic forecast scenario, combining the low state of nature ($M=0.03$) with the high catch stream ($P^*=0.45$), resulted in a projected stock status of 38.7%, very close to the target value. All other projections led to a higher projected status, with a maximum of 54.7% for the combination of the high state of nature and low catch. Forecasts under the base case led to estimated status ranging from 2024 spawning depletion values of 39.1% in both catch scenarios.

A decision table (Table 12) was assembled using projections associated with the high and low states of nature (columns) under two catch streams (rows).

4.3 Evaluation of Scientific Uncertainty

Scientific uncertainty was evaluated via several likelihood profiles and a wide range of sensitivity analyses, not all of which are reported on here. Likelihood profiles were performed over unfished recruitment (R_0), recruitment steepness (h), and natural mortality (M), as required by the Groundfish Terms of Reference. The profiles found the model results, particularly estimates of stock scale, to be relatively sensitive to changes to R_0 and M , as would be expected, but largely insensitive to changes in steepness. An additional likelihood profile was also run over growth, and found the model results to be quite sensitive to the assumed values of the growth curve. Sensitivities were performed using alternative growth and maturity curves, alternative time blocks for selectivity and retention, and alternative historical landings timeseries. Model results (particularly estimates of stock status) were largely insensitive to all changes except for growth.

The model estimated uncertainty around the 2023 spawning biomass was $\sigma = 0.18$ and the uncertainty around the OFL was $\sigma = 0.16$.

4.4 Research and Data Needs

Research and data needs for future assessments include the following:

1. Research into aging methods and availability of reliable age data would be valuable for future stock assessments. Otoliths have been collected in good quantities from the NWFSC survey, but there is currently no validated aging method for shortspine thornyhead.
2. Additional investigation into growth patterns would provide valuable information for future population projections. We acknowledge that additional work on aging shortspine thornyhead would be required to make such additional growth research possible.
3. More investigation into maturity of shortspine thornyhead is necessary to understand the patterns in maturity observed in WCGBTS samples.
4. Information on possible migration of shortspine thornyheads would be valuable for understanding stock dynamics. Analysis of trace elements and stable isotopes in short-spine otoliths may provide valuable information on the extent of potential migrations. Possible connections between migration and maturity could likewise be explored.
5. A greater understanding of the connection between thornyheads and bottom type could be used to refine the indices of abundance. Thornyheads are very well sampled in trawlable habitat, but the extrapolation of density to a survey stratum could be improved by accounting for the proportion of different bottom types within a stratum and the relative density of thornyheads within each bottom type.
6. Additional investigation into spatial stock structure could be valuable for determining whether future assessments should develop a spatial assessment model, or if shortspine thornyhead should be assessed at distinct spatial scales in the future.
7. Further research into the Dirichlet-Multinomial (DMN) data-weighting method for length-composition data is needed for integration with length-based data-moderate

assessments like shortspine thornyhead. The DMN method has not, to date, been thoroughly simulation tested with length-composition data, and an attempted sensitivity analysis performed for the 2023 assessment failed to converge entirely. This is a general research need, and is widely applicable to many data-moderate or length-based assessments, not just shortspine thornyhead.

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6 References

- Anderson, S.C., Ward, E.J., English, P.A., and Barnett, L.A.K. 2022. sdmTMB: An r package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields. *bioRxiv*. Cold Spring Harbor Laboratory. doi:10.1101/2022.03.24.485545.
- Bizzarro, J., Dewitt, L., Wells, B., Curtis, A., Santora, J., and Field, J. 2023. California current trophic database (CCTD). Marine Data Archive; NOAA Southwest Fisheries Science Center: United States.
- Bradburn, M.J., Keller, A.A., and Horness, B.H. 2011. The 2003 to 2008 US West Coast bottom trawl surveys of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, length, and age composition. US Department of Commerce, National Oceanic; Atmospheric Administration, National Marine Fisheries Service.
- Butler, C.K., J. L. 1995. Age determination of shortspine thornyhead, *sebastolobus alascanus*, using otolith sections and ^{210}Pb : ^{226}Ra ratio. Admin. Rep. No. LJ-95-12. National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, Calif.
- Cooper, D.W., Pearson, K.E., and Gunderson, D.R. 2005. Fecundity of shortspine thornyhead (*sebastolobus alascanus*) and longspine thornyhead (s. *Altivelis*) (scorpaenidae) from the northeastern pacific ocean, determined by stereological and gravimetric techniques*. Available from <http://hdl.handle.net/1834/26245>.
- Dorval, E., Methot, R., Taylor, I., and Piner, K. 2022. Otolith chemistry indicates age and region of settlement of immature shortspine thornyhead *sebastolobus alascanus* in the eastern pacific ocean. *Mar. Ecol. Prog. Ser.* **693**: 157–175. doi:10.3354/meps14092.
- Du Preez, C., and Tunnicliffe, V. 2011. Shortspine thornyhead and rockfish (scorpaenidae) distribution in response to substratum, biogenic structures and trawling. *Mar. Ecol. Prog. Ser.* **425**: 217–231. doi:10.3354/meps09005.
- Echave, K., Siwicke, K.A., Sullivan, J., Ferris, B., and Hulson, P.F. 2022. Assessment of the thornyhead stock complex in the gulf of alaska.
- Erickson, D.L., and Pikitch, E.K. 1993. A histological description of shortspine thornyhead, *sebastolobus alascanus*, ovaries: Structures associated with the production of gelatinous egg masses. *Environmental Biology of Fishes* **36**(3): 273–282. doi:10.1007/BF00001723.
- Hamel, O.S. 2005. Status and future prospects for the shortspine thornyhead resource in waters off washington, oregon, and california as assessed in 2005. Northwest Fisheries Science Center, US Department of Commerce, National Oceanic; Atmospheric Administration, National Marine Fisheries Service.

Hamel, O.S., and Cope, J.M. 2022. Development and considerations for application of a longevity-based prior for the natural mortality rate. *Fisheries Research* **256**: 106477. doi:10.1016/j.fishres.2022.106477.

Ianelli, J.N., Lauth, R., and Jacobson, L.D. 1994. Status of the thornyhead (*sebastolobus* sp.) resource in 1994. National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA,; Southwest Fisheries Science Center, La Jolla, CA.

Jacobson, L.D. 1990. Thornyheads—stock assessment for 1990. National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA.

Jacobson, L.D. 1991. Thornyheads—stock assessment for 1991. National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA.

Jacobson, L.D., and Vetter, R.D. 1996. Bathymetric demography and niche separation of thornyhead rockfish: *Sebastolobus alascanus* and *sebastolobus altivelis*. **53**.

Johnson, K.F., and Stephens, A. 2023. PacFIN.utilities: Generate fishery composition data from PacFIN data for the NWFSC.

Karnowski, M., Gertseva, V.V., and Stephens, A. 2014. Historical Reconstruction of Oregon's Commercial Fisheries Landings. Oregon Department of Fish; Wildlife, Salem, OR.

Kastelle, C., Helser, T., TenBrink, T., Hutchinson, C., Goetz, B., Gburski, C., and Benson, I. 2020. Age validation of four rockfishes (genera *sebastes* and *sebastolobus*) with bomb-produced radiocarbon. *Mar. Freshwater Res.* **71**(10): 1355–1366. Available from <https://doi.org/10.1071/MF19280>.

Kline, D.E. 1996. Radiochemical age verification for two deep-sea rockfishes, *sebastolobus altivelis* and *s. alascanus*. San Jose State University.

Liu, O., Ward, S., and Anderson, S. in pressin press. Species redistribution creates unequal outcomes for multispecies fisheries under projected climate change, PREPRINT (version 1).

Methot, R.D., 1953-, Wetzel, C.R., Taylor, I.G., 1974-, and Doering, K. 2020. Stock synthesis user manual : Version 3.30.15. doi:10.25923/5wpn-qt71.

Methot, R.D., Taylor, I.G., and Chen, Y. 2011. Adjusting for bias due to variability of estimated recruitments in fishery assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* **68**(10): 1744–1760. doi:10.1139/f2011-092.

Methot, R.D., and Wetzel, C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* **142**: 86–99. doi:10.1016/j.fishres.2012.10.012.

- Pearson, K.E., and Gunderson, D.R. 2003. Reproductive biology and ecology of shortspine thornyhead rockfish, *sebastolobus alascanus*, and longspine thornyhead rockfish, s. *Alutivelis*, from the northeastern pacific ocean. *Environmental Biology of Fishes* **67**(2): 117–136. doi:10.1023/A:1025623426858.
- Pikitch, E.K., Erickson, D.L., and Wallace, J.R. 1988. An evaluation of the effectiveness of trip limits as a management tool. Northwest; Alaska Fisheries Center, National Marine Fisheries Service NWAFC Processed Report. Available from <https://www.afsc.noaa.gov/Publications/ProcRpt/PR1988-27.pdf> [accessed 28 February 2017].
- Piner, K., and Methot, R. 2001. Stock status of shortspine thornyhead off the pacific west coast of the united states 2001. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.
- R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from <https://www.R-project.org/>.
- Ralston, S., Pearson, D.E., Field, J.C., and Key, M. 2010. Documentation of the California catch reconstruction project. US Department of Commerce, National Oceanic; Atmospheric Adminstration, National Marine.
- Rogers, B.R., Builder, T.L., Crone, P.R., Brodziak, J., Methot, R.D., and Conser, R.J. 1998. Status of the shortspine thornyhead (*sebastolobus alascanus*) resource in 1998. National Marine Fisheries Service, Northwest Fisheries Science Center, Newport, OR,; Alaska Fisheries Science Center, Seattle, WA.
- Rogers, J.B. 2003. Species allocation of *Sebastes* and *sebastolobus* species caught by foreign countries off Washington, Oregon, and California, U.S.A. In 1965-1976. Unpublished document.
- Siebenaller, J.F. 1978. Genetic variability in deep-sea fishes of the genus *sebastolobus* (scorpaenidae). In *Marine Organisms: Genetics, Ecology, and Evolution*. Edited by B. Battaglia and J. Beardmore. Plenum Press, New York. pp. 95–122.
- Starr, P.J., and Haigh, R. 2017. Stock assessment of the coastwide population of shortspine thornyhead (*sebastolobus alascanus*) in 2015 off the british columbia coast. DFO Canada Science Advisory Secretariat.
- Stepien, C.A. 1995. Population genetic divergence and geographic patterns from DNA sequences: Examples from marine and freshwater fishes. American Fisheries Society Symposium. pp. 263–287.
- Stepien, C.A., Dillon, A.K., and Patterson, A.K. 2000. Population genetics, phylogeography, and systematics of the thornyhead rockfishes (*sebastolobus*) along the deep continental

- slopes of the north pacific ocean. Canadian Journal of Fisheries and Aquatic Sciences **57**(8): 1701–1717. doi:10.1139/f00-095.
- Taylor, I.G. 2019. A 2019 catch-only projection from the 2013 stock assessment of shortspine thornyhead. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.
- Taylor, I.G., Doering, K.L., Johnson, K.F., Wetzel, C.R., and Stewart, I.J. 2021. Beyond visualizing catch-at-age models: Lessons learned from the r4ss package about software to support stock assessments. *Fisheries Research* **239**: 105924. Available from <https://doi.org/10.1016/j.fishres.2021.105924>.
- Taylor, I.G., and Methot, R.D. 2013. Hiding or dead? A computationally efficient model of selective fisheries mortality. *Fisheries Research* **142**: 75–85. doi:<https://doi.org/10.1016/j.fishres.2012.08.021>.
- Taylor, I.G., and Stephens, A. 2013. Stock assessment of shortspine thornyhead in 2013. Portland: Pacific Fishery Management Council.
- Thorson, J.T., Dorn, M.W., and Hamel, O.S. 2019. Steepness for West Coast rockfishes: Results from a twelve-year experiment in iterative regional meta-analysis. *Fisheries Research*. doi:10.1016/j.fishres.2018.03.014.
- Thorson, J.T., Shelton, A.O., Ward, E.J., and Skaug, H.J. 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES Journal of Marine Science* **72**(5): 1297–1310. doi:10.1093/icesjms/fsu243.
- Thorson, J.T., and Ward, E.J. 2013. Accounting for space–time interactions in index standardization models. *Fisheries Research* **147**: 426–433. doi:<https://doi.org/10.1016/j.fishres.2013.03.012>.
- Vetter, R.D., and Lynn, E.A. 1997. Bathymetric demography, enzyme activity patterns, and bioenergetics of deep-living scorpaenid fishes (*genera sebastes* and *sebastolobus*): Paradigms revisited. *Mar Ecol Prog Ser* **155**: 173–188. Available from <https://www.int-res.com/abstracts/meps/v155/p173-188/>.
- Wakefield, W.W., II. 1990. Patterns in the distribution of demersal fishes on the upper continental slope off central California with studies on the role of ontogenetic vertical migration in particle flux. PhD thesis, University of California, San Diego, United States – California. Available from <https://www.proquest.com/dissertations-theses/patterns-distribution-demersal-fishes-on-upper/docview/303821089/se-2?accountid=14784>.
- West Coast Regional Office. (n.d.). West coast groundfish trawl catch share program. NOAA. Available from <https://www.fisheries.noaa.gov/west-coast/sustainable-fisheries/west-coast-groundfish-trawl-catch-share-program>.

Wetzel, C.R., Johnson, K.F., and Hicks, A.C. 2023. nwfscSurvey: Northwest fisheries science center survey.

7 Tables

Table 1: Recent landings by fleet, total landings summed across fleets, and the total mortality including discards.

Year	North Trawl	South Trawl	Non-Trawl	Total Landings	Total Dead
2013	570.11	294.83	166.40	1,031.34	1,111.27
2014	456.13	254.05	147.81	858.00	928.12
2015	513.66	244.29	131.30	889.26	929.06
2016	587.71	185.73	168.94	942.38	992.09
2017	634.83	158.30	223.82	1,016.94	1,094.53
2018	595.89	105.07	184.48	885.44	948.28
2019	460.13	127.94	143.48	731.55	785.62
2020	258.09	87.99	85.17	431.26	477.36
2021	302.81	73.39	78.74	454.94	499.93
2022	506.30	97.61	66.22	670.12	724.14

Table 2: Spawning output (millions of eggs) and fraction unfished with associated 95% confidence intervals (CI) from the base model.

Year	Spawning Output	Spawning Output 95% CI	Fraction Unfished	Fraction Unfished 95% CI
2013	9,626	6,360–12,892	0.435	0.360–0.509
2014	9,476	6,228–12,724	0.428	0.353–0.503
2015	9,348	6,116–12,579	0.422	0.347–0.497
2016	9,228	6,011–12,444	0.417	0.341–0.492
2017	9,112	5,908–12,315	0.411	0.336–0.487
2018	8,997	5,804–12,190	0.406	0.330–0.482
2019	8,902	5,718–12,086	0.402	0.325–0.478
2020	8,829	5,651–12,006	0.399	0.322–0.475
2021	8,787	5,614–11,960	0.397	0.320–0.474
2022	8,754	5,583–11,925	0.395	0.318–0.473
2023	8,717	5,545–11,889	0.394	0.316–0.471

Table 3: Estimated recent trend in recruitment and recruitment deviations (RecDevs) and the 95% confidence intervals (CI) from the base model.

Year	Recruitment	95% CI	RecDevs	RecDev 95% CI
2013	9,622	4,001–23,138	-0.112	-1.004–0.781
2014	9,650	3,996–23,304	-0.105	-1.002–0.791
2015	9,783	4,016–23,832	-0.089	-0.996–0.818
2016	10,155	4,111–25,087	-0.049	-0.973–0.875
2017	9,995	4,024–24,828	-0.062	-0.992–0.868
2018	9,990	3,990–25,017	-0.060	-1.000–0.879
2019	10,354	4,097–26,165	-0.032	-0.989–0.926
2020	10,839	4,230–27,777	0.007	-0.968–0.981
2021	11,299	4,349–29,354	0.040	-0.951–1.031
2022	10,952	4,253–28,200	0.000	-0.980–0.980
2023	10,942	4,249–28,177	0.000	-0.980–0.980

Table 4: Estimated recent trend in relative fishing intensity, exploitation rate, and the 95% intervals. The spawning potential ratio (SPR) is utilized in the relative fishing intensity calculation as $(1 - SPR)/(1 - SPR_{50\%})$

Year	$(1-SPR)/(1-SPR_{50\%})$	95% CI	Exploitation Rate	95% CI
2013	1.29	1.06–1.53	0.0120	0.0079–0.0160
2014	1.16	0.92–1.41	0.0100	0.0066–0.0134
2015	1.15	0.91–1.40	0.0100	0.0066–0.0135
2016	1.19	0.95–1.44	0.0107	0.0070–0.0144
2017	1.25	1.00–1.50	0.0118	0.0077–0.0159
2018	1.14	0.89–1.39	0.0103	0.0067–0.0138
2019	1.00	0.75–1.24	0.0085	0.0055–0.0114
2020	0.68	0.48–0.87	0.0051	0.0033–0.0069
2021	0.69	0.49–0.88	0.0053	0.0035–0.0072
2022	0.88	0.66–1.10	0.0076	0.0050–0.0103

Table 5: Summary of reference points and management quantities, including estimates of the 95% intervals.

Variable of Interest	Estimate	95% CI
Unfished Spawning Output	22,145	18,166–26,124
Unfished Age 1+ Biomass (mt)	216,864	177,897–255,831
Unfished Recruitment (R0)	12,580	10,320–14,841
Spawning Output (2023)	8,717	5,545–11,889
Fraction Unfished (2023)	0.39	0.32–0.47
Reference Points Based SB40%		
Proxy Spawning Output SB40%	8,858	7,266–10,450
SPR Resulting in SB40%	0.458	0.458–0.458
Exploitation Rate Resulting in SB40%	0.012	0.011–0.012
Yield with SPR Based On SB40% (mt)	1,160	971–1,348
Reference Points Based on SPR Proxy for MSY		
Proxy Spawning Output (SPR50)	9,880	8,105–11,656
SPR50	0.500	-
Exploitation Rate Corresponding to SPR50	0.010	0.010–0.011
Yield with SPR50 at SB SPR (mt)	1,108	929–1,288
Reference Points Based on Estimated MSY Values		
Spawning Output at MSY (SB MSY)	6,155	5,057–7,253
SPR MSY	0.348	0.345–0.351
Exploitation Rate Corresponding to SPR MSY	0.017	0.016–0.017
MSY (mt)	1,227	1,027–1,426

Table 6: Recent trend in the overfishing limits (OFLs), the acceptable biological catches (ABCs), the annual catch limits (ACLs), the total landings, and total mortality (mt). Total mortality includes fishery catch and model estimated discards.

Year	OFL	ABC	ACL	Landings	Total Mortality
2013	2333	2230	1937	1,031.34	1,111.27
2014	2310	2208	1918	858.00	928.12
2015	3203	2668	2668	889.26	929.06
2016	3169	2640	2639	942.38	992.09
2017	3144	2619	2619	1,016.94	1,094.53
2018	3116	2596	2596	885.44	948.28
2019	3089	2573	2573	731.55	785.62
2020	3063	2551	2552	431.26	477.36
2021	3211	2183	2184	454.94	499.93
2022	3194	2130	2130	670.12	724.14

Table 7: Projections of potential OFLs (mt), ABCs (mt), estimated spawning output, and fraction unfished using $P^*=0.4$. The OFL and ABC for years 2023 and 2024 are fixed, while the OFL and ABC for years 2025 and on are estimated by the model.

Year	Adopted OFL (mt)	Adopted ABC (mt)	Assumed Catch (mt)	OFL (mt)	ACL (mt)	Buffer	Spawning Output	Fraction Unfished
2023	3177	2078	755	NA	NA	NA	8,716.84	0.394
2024	3162	2030	755	NA	NA	NA	8,686.69	0.392
2025	NA	NA	NA	939.75	710.84	0.762	8,666.24	0.391
2026	NA	NA	NA	962.46	713.47	0.747	8,658.74	0.391
2027	NA	NA	NA	984.52	716.19	0.733	8,660.12	0.391
2028	NA	NA	NA	1,005.90	718.04	0.719	8,669.87	0.391
2029	NA	NA	NA	1,026.58	720.05	0.706	8,687.53	0.392
2030	NA	NA	NA	1,046.56	721.25	0.693	8,712.50	0.393
2031	NA	NA	NA	1,065.88	721.67	0.680	8,744.22	0.395
2032	NA	NA	NA	1,084.54	721.32	0.667	8,782.10	0.397
2033	NA	NA	NA	1,102.57	720.20	0.654	8,825.59	0.399
2034	NA	NA	NA	1,119.95	719.01	0.642	8,874.11	0.401

Table 8: Projections of potential OFLs (mt), ABCs (mt), estimated spawning output, and fraction unfished using Pstar=0.45. The OFL and ABC for years 2023 and 2024 are fixed, while the OFL and ABC for years 2025 and on are estimated by the model.

Year	Adopted OFL (mt)	Adopted ABC (mt)	Assumed Catch (mt)	OFL (mt)	ACL (mt)	Buffer	Spawning Output	Fraction Unfished
2023	3177	2078	755	NA	NA	NA	8,716.84	0.394
2024	3162	2030	755	NA	NA	NA	8,686.69	0.392
2025	NA	NA	NA	939.75	815.32	0.874	8,666.24	0.391
2026	NA	NA	NA	961.08	824.77	0.865	8,651.73	0.391
2027	NA	NA	NA	981.63	834.40	0.857	8,645.37	0.390
2028	NA	NA	NA	1,001.34	843.25	0.849	8,646.64	0.390
2029	NA	NA	NA	1,020.21	851.33	0.841	8,655.00	0.391
2030	NA	NA	NA	1,038.26	858.65	0.833	8,669.87	0.391
2031	NA	NA	NA	1,055.52	866.29	0.826	8,690.66	0.392
2032	NA	NA	NA	1,071.99	872.17	0.818	8,716.67	0.394
2033	NA	NA	NA	1,087.70	877.35	0.810	8,747.37	0.395
2034	NA	NA	NA	1,102.67	882.91	0.803	8,782.19	0.397

Table 9: Summary of recent estimates and management quantities.

Quantity	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
OFL	2333	2310	3203	3169	3144	3116	3089	3063	3211	3194	3177
ACL	1937	1918	2668	2639	2619	2596	2573	2552	2184	2130	2078
Total Catch	1031	858	889	942	1017	885	732	431	455	670	NA
Total Dead	1111	928	929	992	1095	948	786	477	500	724	NA
(1-SPR)/(1-SPR_50%)	1.29	1.16	1.15	1.19	1.25	1.14	1.00	0.68	0.69	0.88	NA
Exploitation Rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	NA
Age 1+ Biomass (mt)	92,839	92,518	92,466	92,487	92,513	92,496	92,687	93,099	93,882	94,694	95,328
Spawning Output	9,626	9,476	9,348	9,228	9,112	8,997	8,902	8,829	8,787	8,754	8,717
Lower Interval	6,360	6,228	6,116	6,011	5,908	5,804	5,718	5,651	5,614	5,583	5,545
Upper Interval	12,892	12,724	12,579	12,444	12,315	12,190	12,086	12,006	11,960	11,925	11,889
Recruits	9,622	9,650	9,783	10,155	9,995	9,990	10,354	10,839	11,299	10,952	10,942
Lower Interval	4,001	3,996	4,016	4,111	4,024	3,990	4,097	4,230	4,349	4,253	4,249
Upper Interval	23,138	23,304	23,832	25,087	24,828	25,017	26,165	27,777	29,354	28,200	28,177
Fraction Unfished	0.435	0.428	0.422	0.417	0.411	0.406	0.402	0.399	0.397	0.395	0.394
Lower Interval	0.360	0.353	0.347	0.341	0.336	0.330	0.325	0.322	0.320	0.318	0.316
Upper Interval	0.509	0.503	0.497	0.492	0.487	0.482	0.478	0.475	0.474	0.473	0.471

Table 10: Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt) summed by year. Total dead includes fishery catch and model estimated discards.

Year	North Trawl	South Trawl	Non-Trawl	Total Landings	Total Dead
1901	0.00	0.00	0.09	0.09	0.11
1902	0.00	0.00	0.11	0.11	0.14
1903	0.00	0.00	0.13	0.13	0.16
1904	0.00	0.00	0.15	0.15	0.19
1905	0.00	0.00	0.17	0.17	0.21
1906	0.00	0.00	0.19	0.19	0.24
1907	0.00	0.00	0.21	0.21	0.27
1908	0.00	0.00	0.23	0.23	0.29
1909	0.00	0.00	0.26	0.26	0.32
1910	0.00	0.00	0.28	0.28	0.34
1911	0.00	0.00	0.30	0.30	0.37
1912	0.00	0.00	0.32	0.32	0.39
1913	0.00	0.00	0.34	0.34	0.42
1914	0.00	0.00	0.36	0.36	0.44
1915	0.00	0.00	0.38	0.38	0.47
1916	0.00	0.00	0.40	0.40	0.49
1917	0.00	0.00	0.42	0.42	0.52
1918	0.00	0.00	0.44	0.44	0.54
1919	0.00	0.00	0.46	0.46	0.57
1920	0.00	0.00	0.48	0.48	0.59
1921	0.00	0.00	0.50	0.50	0.62
1922	0.00	0.00	0.52	0.52	0.65
1923	0.00	0.00	0.54	0.54	0.67
1924	0.00	0.00	0.56	0.56	0.70
1925	0.00	0.00	0.58	0.58	0.72
1926	0.00	0.00	0.60	0.60	0.75
1927	0.00	0.00	0.63	0.63	0.77
1928	0.00	0.00	1.05	1.05	1.29
1929	0.00	0.00	1.66	1.66	2.05
1930	0.00	0.00	1.39	1.39	1.71
1931	0.00	0.00	1.13	1.13	1.40
1932	0.00	0.00	0.42	0.42	0.52
1933	0.00	0.00	0.62	0.62	0.77
1934	0.00	4.57	0.71	5.28	6.04
1935	0.00	6.33	0.67	6.99	7.98
1936	0.00	2.70	1.45	4.15	4.85
1937	0.01	5.42	1.44	6.87	7.92
1938	0.00	5.62	1.34	6.96	8.00
1939	0.01	5.81	0.42	6.24	7.09

Table 10: Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt) summed by year. Total dead includes fishery catch and model estimated discards.
(continued)

Year	North	South	Non-Trawl	Total	Total Dead
	Trawl	Trawl		Landings	
1940	0.19	0.95	1.60	2.74	3.30
1941	0.29	1.96	2.65	4.90	5.87
1942	0.69	1.03	3.77	5.49	6.74
1943	3.06	1.43	10.17	14.66	18.24
1944	5.34	0.21	1.82	7.38	9.59
1945	5.34	0.99	0.68	7.01	9.05
1946	4.07	0.61	0.99	5.68	7.32
1947	4.75	0.04	0.72	5.51	7.24
1948	13.38	0.02	1.02	14.42	19.03
1949	13.52	0.02	0.34	13.88	18.37
1950	6.93	0.01	0.82	7.75	10.20
1951	11.16	0.00	0.59	11.76	15.54
1952	13.85	0.00	0.28	14.13	18.70
1953	2.63	2.96	0.24	5.83	7.12
1954	112.45	0.00	0.38	112.83	149.50
1955	62.93	4.99	0.28	68.20	89.35
1956	133.04	6.82	0.48	140.34	184.48
1957	63.88	0.00	0.49	64.37	85.17
1958	27.80	9.51	0.14	37.45	47.67
1959	28.81	32.26	0.24	61.31	74.69
1960	31.09	149.61	0.10	180.80	209.37
1961	28.55	56.76	0.38	85.68	101.87
1962	22.47	113.69	0.45	136.60	157.67
1963	7.77	223.17	0.27	231.21	260.51
1964	25.19	173.49	0.78	199.45	228.07
1965	31.75	307.58	0.13	339.46	385.26
1966	623.08	542.10	0.13	1,165.31	1,419.32
1967	375.82	867.40	0.34	1,243.57	1,455.70
1968	207.45	1,834.26	0.26	2,041.97	2,307.78
1969	215.73	430.43	0.95	647.10	758.09
1970	179.79	599.25	0.26	779.30	896.52
1971	347.53	607.82	0.08	955.43	1,120.43
1972	390.43	1,380.65	0.11	1,771.19	2,028.48
1973	704.17	2,321.09	0.44	3,025.70	3,467.33
1974	219.17	1,146.08	1.32	1,366.58	1,548.21
1975	401.92	1,872.54	0.53	2,274.99	2,583.44
1976	105.65	1,824.32	0.51	1,930.48	2,155.09
1977	114.67	1,472.13	9.21	1,596.01	1,789.93
1978	176.78	1,013.53	2.96	1,193.27	1,354.92

Table 10: Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt) summed by year. Total dead includes fishery catch and model estimated discards.
(continued)

Year	North	South	Non-Trawl	Total	Total Dead
	Trawl	Trawl		Landings	
1979	69.69	1,715.69	6.56	1,791.94	2,009.80
1980	180.55	1,204.88	2.25	1,387.68	1,580.54
1981	133.01	1,608.49	2.74	1,744.24	1,979.58
1982	293.69	1,654.79	2.71	1,951.19	2,245.38
1983	480.91	1,416.64	2.76	1,900.31	2,225.99
1984	1,039.34	1,841.97	1.18	2,882.49	3,438.62
1985	957.63	2,397.97	6.00	3,361.60	3,989.88
1986	613.68	2,331.52	7.98	2,953.18	3,487.19
1987	646.13	1,322.44	22.19	1,990.76	2,401.12
1988	882.88	1,965.85	24.92	2,873.65	3,476.63
1989	1,655.68	3,123.78	35.74	4,815.20	5,491.29
1990	2,111.95	1,911.73	31.36	4,055.04	4,667.22
1991	2,417.55	995.94	53.54	3,467.03	4,030.93
1992	1,794.46	1,455.11	61.25	3,310.82	3,842.94
1993	2,010.72	1,571.84	26.59	3,609.15	4,201.69
1994	2,083.41	1,182.92	21.00	3,287.33	3,849.80
1995	960.14	929.27	57.01	1,946.42	2,281.71
1996	812.28	699.59	100.09	1,611.95	1,903.53
1997	690.20	654.17	62.74	1,407.11	1,666.52
1998	585.18	593.35	62.18	1,240.72	1,475.58
1999	373.93	309.07	64.39	747.39	895.69
2000	361.30	421.91	66.59	849.80	1,018.95
2001	292.26	197.49	57.98	547.73	663.05
2002	300.48	364.76	114.25	779.50	942.43
2003	361.85	302.40	166.56	830.80	960.59
2004	334.19	286.59	139.49	760.27	879.28
2005	299.68	214.11	149.69	663.48	775.07
2006	334.59	210.53	159.17	704.30	826.54
2007	628.77	222.56	158.80	1,010.12	1,103.22
2008	979.54	259.94	196.97	1,436.45	1,569.39
2009	1,023.19	308.38	200.62	1,532.20	1,673.89
2010	838.83	284.22	228.36	1,351.41	1,488.11
2011	496.88	232.99	260.52	990.39	1,083.82
2012	457.67	263.59	192.07	913.33	989.98
2013	570.11	294.83	166.40	1,031.34	1,111.27
2014	456.13	254.05	147.81	858.00	928.12
2015	513.66	244.29	131.30	889.26	929.06
2016	587.71	185.73	168.94	942.38	992.09
2017	634.83	158.30	223.82	1,016.94	1,094.53

Table 10: Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt) summed by year. Total dead includes fishery catch and model estimated discards.
(continued)

Year	North	South	Non-Trawl	Total	Total Dead
	Trawl	Trawl		Landings	
2018	595.89	105.07	184.48	885.44	948.28
2019	460.13	127.94	143.48	731.55	785.62
2020	258.09	87.99	85.17	431.26	477.36
2021	302.81	73.39	78.74	454.94	499.93
2022	506.30	97.61	66.22	670.12	724.14

Table 11: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Output	Age 1+ Biomass (mt)	% Unfished	Age 0 Recruits	Total Mortality	SPR Ratio	Expl Rate
1901	216,876	22,145	216,864	100.0	12,739	0.11	0.00	0.00
1902	216,877	22,145	216,866	100.0	12,742	0.14	0.00	0.00
1903	216,879	22,145	216,867	100.0	12,741	0.16	0.00	0.00
1904	216,882	22,145	216,870	100.0	12,724	0.19	0.00	0.00
1905	216,885	22,145	216,873	100.0	12,705	0.21	0.00	0.00
1906	216,888	22,145	216,876	100.0	12,698	0.24	0.00	0.00
1907	216,892	22,145	216,880	100.0	12,690	0.27	0.00	0.00
1908	216,897	22,145	216,885	100.0	12,673	0.29	0.00	0.00
1909	216,902	22,145	216,890	100.0	12,661	0.32	0.00	0.00
1910	216,908	22,145	216,896	100.0	12,636	0.34	0.00	0.00
1911	216,914	22,145	216,902	100.0	12,628	0.37	0.00	0.00
1912	216,921	22,145	216,909	100.0	12,660	0.39	0.00	0.00
1913	216,928	22,145	216,917	100.0	12,703	0.42	0.00	0.00
1914	216,937	22,146	216,925	100.0	12,714	0.44	0.00	0.00
1915	216,946	22,146	216,934	100.0	12,655	0.47	0.00	0.00
1916	216,956	22,146	216,944	100.0	12,640	0.49	0.00	0.00
1917	216,966	22,146	216,954	100.0	12,632	0.52	0.00	0.00
1918	216,977	22,146	216,965	100.0	12,617	0.54	0.00	0.00
1919	216,988	22,146	216,976	100.0	12,638	0.57	0.00	0.00
1920	216,999	22,147	216,988	100.0	12,599	0.59	0.00	0.00
1921	217,011	22,147	217,000	100.0	12,522	0.62	0.00	0.00
1922	217,023	22,148	217,012	100.0	12,551	0.65	0.00	0.00
1923	217,035	22,148	217,024	100.0	12,541	0.67	0.00	0.00
1924	217,047	22,149	217,035	100.0	12,522	0.70	0.00	0.00
1925	217,059	22,149	217,047	100.0	12,502	0.72	0.00	0.00
1926	217,070	22,150	217,059	100.0	12,482	0.75	0.00	0.00
1927	217,081	22,151	217,070	100.0	12,463	0.77	0.00	0.00
1928	217,092	22,152	217,080	100.0	12,444	1.29	0.00	0.00
1929	217,101	22,153	217,089	100.0	12,428	2.05	0.00	0.00

Table 11: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Output	Age 1+ Biomass (mt)	% Unfished	Age 0 Recruits	Total Mortality	SPR Ratio	Expl Rate
1930	217,108	22,154	217,097	100.0	12,414	1.71	0.00	0.00
1931	217,115	22,154	217,104	100.0	12,404	1.40	0.00	0.00
1932	217,121	22,156	217,110	100.0	12,399	0.52	0.00	0.00
1933	217,127	22,157	217,116	100.1	12,398	0.77	0.00	0.00
1934	217,131	22,158	217,120	100.1	12,402	6.04	0.00	0.00
1935	217,129	22,158	217,117	100.1	12,412	7.98	0.01	0.00
1936	217,122	22,159	217,111	100.1	12,426	4.85	0.00	0.00
1937	217,118	22,160	217,106	100.1	12,444	7.92	0.01	0.00
1938	217,108	22,160	217,097	100.1	12,462	8.00	0.01	0.00
1939	217,098	22,161	217,086	100.1	12,479	7.09	0.01	0.00
1940	217,086	22,162	217,075	100.1	12,490	3.30	0.00	0.00
1941	217,078	22,162	217,066	100.1	12,489	5.87	0.00	0.00
1942	217,065	22,163	217,054	100.1	12,470	6.74	0.00	0.00
1943	217,050	22,163	217,039	100.1	12,427	18.24	0.01	0.00
1944	217,021	22,162	217,010	100.1	12,352	9.59	0.01	0.00
1945	217,000	22,162	216,988	100.1	12,241	9.05	0.01	0.00
1946	216,976	22,162	216,965	100.1	12,089	7.32	0.01	0.00
1947	216,952	22,162	216,941	100.1	11,896	7.24	0.01	0.00
1948	216,924	22,161	216,913	100.1	11,663	19.03	0.02	0.00
1949	216,879	22,160	216,868	100.1	11,397	18.37	0.01	0.00
1950	216,829	22,158	216,819	100.1	11,104	10.20	0.01	0.00
1951	216,781	22,157	216,771	100.1	10,784	15.54	0.01	0.00
1952	216,719	22,155	216,710	100.0	10,459	18.70	0.02	0.00
1953	216,645	22,153	216,635	100.0	10,138	7.12	0.01	0.00
1954	216,571	22,151	216,562	100.0	9,832	149.50	0.12	0.00
1955	216,331	22,138	216,322	100.0	9,548	89.35	0.07	0.00
1956	216,140	22,129	216,132	99.9	9,294	184.48	0.15	0.00
1957	215,830	22,111	215,821	99.8	9,077	85.17	0.07	0.00
1958	215,608	22,101	215,599	99.8	8,903	47.67	0.04	0.00
1959	215,407	22,094	215,399	99.8	8,778	74.69	0.06	0.00
1960	215,157	22,084	215,149	99.7	8,708	209.37	0.18	0.00
1961	214,739	22,063	214,731	99.6	8,701	101.87	0.09	0.00
1962	214,414	22,049	214,406	99.6	8,767	157.67	0.13	0.00
1963	214,006	22,030	213,998	99.5	8,915	260.51	0.22	0.00
1964	213,462	22,002	213,454	99.4	9,156	228.07	0.19	0.00
1965	212,930	21,975	212,921	99.2	9,495	385.26	0.32	0.00
1966	212,202	21,933	212,193	99.0	9,931	1419.32	0.93	0.01
1967	210,327	21,803	210,318	98.5	10,445	1455.70	0.96	0.01
1968	208,376	21,666	208,366	97.8	11,011	2307.78	1.29	0.01
1969	205,459	21,453	205,448	96.9	11,587	758.09	0.59	0.00
1970	204,203	21,364	204,192	96.5	12,153	896.52	0.69	0.00
1971	202,782	21,261	202,770	96.0	12,698	1120.43	0.82	0.01
1972	201,106	21,136	201,093	95.4	13,226	2028.48	1.24	0.01
1973	198,423	20,929	198,410	94.5	13,702	3467.33	1.61	0.02

Table 11: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Output	Age 1+ Biomass (mt)	% Unfished	Age 0 Recruits	Total Mortality	SPR Ratio	Expl Rate
1974	194,148	20,594	194,134	93.0	14,028	1548.21	1.08	0.01
1975	191,947	20,414	191,934	92.2	14,103	2583.44	1.46	0.01
1976	188,609	20,141	188,596	91.0	13,860	2155.09	1.35	0.01
1977	185,727	19,899	185,714	89.9	13,406	1789.93	1.23	0.01
1978	183,244	19,683	183,232	88.9	12,934	1354.92	1.05	0.01
1979	181,244	19,500	181,232	88.1	12,626	2009.80	1.34	0.01
1980	178,530	19,257	178,518	87.0	12,572	1580.54	1.18	0.01
1981	176,296	19,047	176,284	86.0	12,729	1979.58	1.35	0.01
1982	173,634	18,800	173,622	84.9	12,882	2245.38	1.45	0.01
1983	170,693	18,526	170,681	83.7	12,838	2225.99	1.46	0.01
1984	167,788	18,250	167,776	82.4	12,602	3438.62	1.73	0.02
1985	163,566	17,865	163,554	80.7	12,301	3989.88	1.81	0.02
1986	158,728	17,429	158,717	78.7	12,030	3487.19	1.78	0.02
1987	154,430	17,031	154,419	76.9	11,888	2401.12	1.59	0.02
1988	151,336	16,722	151,325	75.5	11,967	3476.63	1.80	0.02
1989	147,071	16,320	147,059	73.7	12,126	5491.29	1.94	0.04
1990	140,583	15,741	140,572	71.1	12,179	4667.22	1.92	0.03
1991	134,998	15,223	134,987	68.7	11,560	4030.93	1.89	0.03
1992	130,121	14,754	130,111	66.6	10,746	3842.94	1.90	0.03
1993	125,437	14,300	125,428	64.6	9,979	4201.69	1.93	0.03
1994	120,357	13,814	120,349	62.4	8,733	3849.80	1.92	0.03
1995	115,663	13,355	115,656	60.3	8,004	2281.71	1.76	0.02
1996	112,686	13,030	112,678	58.8	8,224	1903.53	1.68	0.02
1997	110,145	12,739	110,137	57.5	8,321	1666.52	1.62	0.02
1998	107,895	12,471	107,886	56.3	8,645	1475.58	1.56	0.01
1999	105,886	12,223	105,877	55.2	10,113	895.69	1.22	0.01
2000	104,557	12,025	104,545	54.3	12,605	1018.95	1.32	0.01
2001	103,147	11,822	103,132	53.4	16,120	663.05	1.01	0.01
2002	102,195	11,651	102,178	52.6	18,032	942.43	1.26	0.01
2003	101,026	11,462	100,997	51.8	31,062	960.59	1.18	0.01
2004	99,935	11,267	99,916	50.9	20,287	879.28	1.12	0.01
2005	99,074	11,085	99,055	50.1	20,927	775.07	1.04	0.01
2006	98,399	10,918	98,380	49.3	21,018	826.54	1.09	0.01
2007	97,763	10,752	97,741	48.6	23,488	1103.22	1.29	0.01
2008	96,940	10,569	96,916	47.7	25,728	1569.39	1.53	0.02
2009	95,731	10,354	95,714	46.8	17,944	1673.89	1.58	0.02
2010	94,518	10,135	94,505	45.8	13,805	1488.11	1.51	0.02
2011	93,568	9,937	93,557	44.9	12,001	1083.82	1.28	0.01
2012	93,118	9,774	93,108	44.1	10,431	989.98	1.22	0.01
2013	92,847	9,626	92,838	43.5	9,622	1111.27	1.29	0.01
2014	92,527	9,476	92,518	42.8	9,650	928.12	1.16	0.01
2015	92,475	9,348	92,466	42.2	9,783	929.06	1.16	0.01
2016	92,496	9,228	92,487	41.7	10,155	992.09	1.19	0.01
2017	92,522	9,112	92,513	41.1	9,995	1094.53	1.25	0.01

Table 11: Time series of population estimates from the base model. (*continued*)

Year	Total Biomass (mt)	Spawning Output	Age 1+ Biomass (mt)	% Unfished	Age 0 Recruits	Total Mortality	SPR Ratio	Expl Rate
2018	92,505	8,997	92,496	40.6	9,990	948.28	1.14	0.01
2019	92,697	8,902	92,687	40.2	10,354	785.62	1.00	0.01
2020	93,109	8,829	93,099	39.9	10,839	477.36	0.68	0.01
2021	93,892	8,787	93,882	39.7	11,299	499.93	0.69	0.01
2022	94,704	8,754	94,694	39.5	10,952	724.14	0.88	0.01
2023	95,328	8,717	95,318	39.4	10,942	756.11	0.90	0.01
2024	95,952	8,687	95,942	39.2	10,933	756.11	0.88	0.01
2025	96,605	8,666	96,595	39.1	10,928	710.84	0.82	0.01
2026	97,328	8,659	97,318	39.1	10,926	713.47	0.81	0.01
2027	98,069	8,660	98,059	39.1	10,926	716.19	0.80	0.01
2028	98,824	8,670	98,813	39.1	10,929	718.04	0.79	0.01
2029	99,590	8,688	99,580	39.2	10,934	720.05	0.78	0.01
2030	100,366	8,712	100,356	39.3	10,940	721.25	0.76	0.01
2031	101,149	8,744	101,138	39.5	10,949	721.67	0.76	0.01
2032	101,937	8,782	101,927	39.7	10,959	721.32	0.74	0.01
2033	102,729	8,826	102,719	39.9	10,970	720.20	0.74	0.01
2034	103,525	8,874	103,514	40.1	10,983	719.01	0.72	0.01

Table 12: Summary table of 12-year projections beginning in 2025 for alternate states of nature based on natural mortality. Columns range over low, mid, and high state of nature, and rows range over different assumptions of catch levels.

Year	Catch	Low: M = 0.03		Base: 0.04		High: M = 0.05	
		SO	Dep	SO	Dep	SO	Dep
ACL P* = 0.4							
2023	756	13485	0.427	8717	0.394	9907	0.494
2024	756	13334	0.422	8687	0.392	9965	0.497
2025	711	13194	0.418	8666	0.391	10032	0.500
2026	713	13067	0.414	8659	0.391	10113	0.504
2027	716	12949	0.410	8660	0.391	10202	0.509
2028	718	12841	0.406	8670	0.392	10298	0.513
2029	720	12742	0.403	8688	0.392	10400	0.519
2030	721	12652	0.401	8712	0.393	10509	0.524
2031	722	12570	0.398	8744	0.395	10621	0.530
2032	721	12496	0.396	8782	0.397	10738	0.535
2033	720	12431	0.394	8826	0.399	10857	0.541
2034	719	12372	0.392	8874	0.401	10978	0.547
ACL P* = 0.45							
2023	756	13485	0.427	8717	0.394	9907	0.494
2024	756	13334	0.422	8687	0.392	9965	0.497
2025	815	13194	0.418	8666	0.391	10032	0.500
2026	825	13060	0.413	8652	0.391	10106	0.504
2027	834	12934	0.409	8645	0.390	10187	0.508
2028	843	12817	0.406	8647	0.390	10275	0.512
2029	851	12708	0.402	8655	0.391	10368	0.517
2030	859	12607	0.399	8670	0.392	10467	0.522
2031	866	12513	0.396	8691	0.392	10569	0.527
2032	872	12427	0.393	8717	0.394	10674	0.532
2033	877	12348	0.391	8747	0.395	10781	0.538
2034	883	12275	0.389	8782	0.397	10889	0.543

Table 13: Likelihood components by source for the base model.

Source	Likelihood Component
TOTAL	242.840
Catch	0.000
Equil catch	0.000
Survey	-53.277
Discard	100.666
Mean body wt	-78.582
Length comp	265.307
Recruitment	1.480
InitEQ Regime	0.000
Forecast Recruitment	0.005
Parm priors	7.241
Parm devs	0.000
F Ballpark	0.000
F Ballpark(info only) 1999 estF tgtF	0.016
Crash Pen	0.000

Table 14: Sample sizes of length composition samples for shortspine thornyhead landings.

Year	Samples North Trawl	Tows North Trawl	Samples South Trawl	Tows South Trawl	Samples Non-trawl	Tows Non-trawl
1981	30	1	737	42	NA	NA
1982	150	5	723	57	NA	NA
1983	NA	NA	1230	91	NA	NA
1984	NA	NA	2755	118	NA	NA
1985	NA	NA	3176	136	3	3
1986	NA	NA	978	42	9	9
1987	NA	NA	343	26	54	15
1988	NA	NA	140	15	8	7
1989	NA	NA	741	38	18	12
1990	390	33	517	32	24	14
1991	1059	47	532	41	NA	NA
1992	1227	52	448	36	75	4
1993	281	12	993	56	3	3
1994	40	1	1367	65	46	12
1995	24	2	2248	103	36	6
1996	497	15	2078	94	26	1
1997	2322	49	1720	92	36	2
1998	757	28	1130	57	130	7
1999	819	27	821	48	1852	73
2000	660	23	1027	63	447	20
2001	1632	45	1413	73	132	8
2002	2183	50	2320	108	1036	42
2003	2431	67	1909	80	834	29
2004	1509	53	1073	61	133	10
2005	1649	50	1393	75	620	34
2006	1573	53	3109	156	596	32
2007	2452	76	1893	98	393	17
2008	2660	90	2212	106	2037	80
2009	2854	85	2137	87	1298	60
2010	3130	91	1720	88	1346	75
2011	2381	67	2950	106	3276	163
2012	2262	67	2423	102	2419	137
2013	2519	84	2505	102	2010	115
2014	2036	73	1490	77	3283	149
2015	1915	65	1615	69	2971	152
2016	1495	59	2362	82	3087	147
2017	2158	75	1571	48	2504	139
2018	1828	78	1222	29	1333	91
2019	1539	68	740	29	1702	134

Table 14: Sample sizes of length composition samples for shortspine thornyhead landings.
(*continued*)

Year	Samples North Trawl	Tows North Trawl	Samples South Trawl	Tows South Trawl	Samples Non-trawl	Tows Non-trawl
2020	951	47	897	26	696	64
2021	1505	80	294	15	1067	108
2022	1103	57	273	13	863	75

Table 15: Sample sizes of length composition samples for discards.

Year	North Trawl	South Trawl	Non-trawl
2005	NA	NA	4
2006	148	56	102
2007	249	64	145
2008	354	79	102
2009	485	102	71
2010	271	43	98
2011	282	74	168
2012	378	126	224
2013	366	155	55
2014	311	126	120
2015	204	154	148
2016	216	108	189
2017	182	39	153
2018	211	47	148
2019	175	79	77
2020	163	99	43
2021	210	97	104

Table 16: Survey stratification information for each of the fishery independent surveys

Survey	Strata Definitions
Survey	Strata Definitions
AFSC Slope	2 strata: 32.0-49.0 degrees N: 150-500 m, 500-1280 m
NWFSC Combo (West Coast Groundfish Bottom Trawl Survey)	7 strata 32.0-34.5 degrees N: 183-550 m, 550-1280 m 34.5-40.5 degrees N: 183-550 m, 550-1280 m 40.5-49.0 degrees N: 100-183 m, 183-550 m, 550-1280 m The depth breaks at 183 m and 550 m are associated with changes in sampling intensity of the survey and are recommended to be used.
NWFSC Slope	6 strata 32.0-40.5 degrees N: 55-500m, 550-1280m 40.5-43.0 degrees N: 55-550m, 550-1280m 43.0-49.0 degrees N: 55-550m, 550-1280m
AFSC Triennial 1	1 stratum: <=366 m
AFSC Triennial 2	1 stratum: 366-500 m

Table 17: Survey samples and hauls for each of the fishery independent surveys for available years spanning from 1989 to 2022.

Year	Survey	Fish	Hauls
1989	Early Triennial	1770	51
1992	Early Triennial	1143	23
1995	Late Triennial	9984	128
1997	AFSC Slope	7454	171
1998	NWFSC Slope	8946	270
1998	Late Triennial	9871	147
1999	AFSC Slope	6752	188
1999	NWFSC Slope	10061	302
2000	AFSC Slope	7017	196
2000	NWFSC Slope	8057	295
2001	AFSC Slope	6072	196
2001	NWFSC Slope	8091	297
2001	Late Triennial	10147	190
2002	NWFSC Slope	11835	374
2003	WCGBTS	7693	293
2004	WCGBTS	6694	214
2004	Late Triennial	8508	137
2005	WCGBTS	8047	315
2006	WCGBTS	6198	332
2007	WCGBTS	5499	367
2008	WCGBTS	4697	362
2009	WCGBTS	4195	340
2010	WCGBTS	3859	360
2011	WCGBTS	4697	347
2012	WCGBTS	4678	349
2013	WCGBTS	3119	247
2014	WCGBTS	4617	346
2015	WCGBTS	4511	332
2016	WCGBTS	4604	355
2017	WCGBTS	4730	363
2018	WCGBTS	4996	368
2019	WCGBTS	2401	175
2021	WCGBTS	4690	345
2022	WCGBTS	4202	312

Table 18: Jitter results.

Total Likelihood	Change from Base	% Change	Frequency
242.840	0.000	0.00%	23
244.496	1.656	0.68%	4
253.348	10.508	4.33%	1
257.328	14.488	5.97%	62
260.141	17.301	7.12%	7
281.791	38.951	16.04%	1
285.383	42.543	17.52%	1
297.013	54.173	22.31%	1

Table 19: Comparison of likelihoods for all sensitivity analyses

Source	Base Model	Low Growth	High Growth	2013 Maturity	Inde-term. Maturity	Imputed Landings	2013 Landings
Total L	242.84	269.27	234.08	242.85	242.87	252.21	242.94
Survey L	-53.28	-50.23	-54.68	-53.28	-53.27	-50.93	-53.26
Length Comp L	265.31	257.70	275.24	265.33	265.32	272.18	265.52
Discards L	100.67	131.48	86.44	100.66	100.66	100.83	100.87
Mean Body Wt L	-78.58	-78.91	-78.82	-78.58	-78.58	-78.60	-78.59
Recruitment L	1.48	2.45	-1.08	1.49	1.50	1.53	1.11
Prior L	7.24	6.78	6.90	7.23	7.24	7.20	7.28
R0	12580.20	17129.40	8184.94	12580.20	12582.00	12593.10	13164.10
B0	8716.84	8183.13	13376.00	10015.90	9506.39	8275.08	8839.78
Depletion	0.39	0.43	0.40	0.42	0.41	0.37	0.38
Relative SPR	0.89	0.75	1.04	0.86	0.87	0.92	0.88

Table 20: All parameter estimates for the proposed base model

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
NatM_break_1_Fem_GP_1	0.0400000	-3	NA	0.040000	0.0400000
NatM_break_2_Fem_GP_1	0.0400000	-3	NA	NA	NA
L_at_Amin_Fem_GP_1	11.3832000	-2	NA	NA	NA
L_at_Amax_Fem_GP_1	73.6079000	-2	NA	NA	NA
VonBert_K_Fem_GP_1	0.0098986	-3	NA	NA	NA
CV_young_Fem_GP_1	0.1090340	-3	NA	NA	NA
CV_old_Fem_GP_1	0.1090340	-3	NA	NA	NA
Wtlen_1_Fem_GP_1	0.0000049	-3	NA	NA	NA
Wtlen_2_Fem_GP_1	3.2600000	-3	NA	NA	NA
Mat50%_Fem_GP_1	31.4247000	-3	NA	NA	NA
Mat_slope_Fem_GP_1	-0.1772910	-3	NA	NA	NA
Eggs_scalar_Fem_GP_1	0.0000001	-3	NA	NA	NA
Eggs_exp_len_Fem_GP_1	3.9780000	-3	NA	NA	NA
NatM_break_1_Mal_GP_1	0.0400000	-3	NA	NA	NA
NatM_break_2_Mal_GP_1	0.0400000	-3	NA	NA	NA
L_at_Amin_Mal_GP_1	9.1733000	-3	NA	NA	NA
L_at_Amax_Mal_GP_1	66.0728000	-2	NA	NA	NA
VonBert_K_Mal_GP_1	0.0167854	-3	NA	NA	NA
CV_young_Mal_GP_1	0.1090340	-3	NA	NA	NA
CV_old_Mal_GP_1	0.1090340	-3	NA	NA	NA
Wtlen_1_Mal_GP_1	0.0000050	-3	NA	NA	NA
Wtlen_2_Mal_GP_1	3.2500000	-3	NA	NA	NA
CohortGrowDev	1.0000000	-1	NA	NA	NA
FracFemale_GP_1	0.5000000	-99	NA	NA	NA
SR_LN(R0)	9.4398800	4	-0.0001186	NA	NA
SR_BH_stEEP	0.7200000	-2	NA	NA	NA
SR_sigmaR	0.5000000	-4	NA	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
SR_regime	0.0000000	-4	NA	NA	NA
SR_autocorr	0.0000000	-1	NA	NA	NA
Early_InitAge_1	0.0129677	6	-0.0000011	NA	NA
Main_RecrDev_1901	0.0125347	6	0.0000001	NA	NA
Main_RecrDev_1902	0.0128110	6	0.0000000	NA	NA
Main_RecrDev_1903	0.0127326	6	0.0000002	NA	NA
Main_RecrDev_1904	0.0113808	6	0.0000002	NA	NA
Main_RecrDev_1905	0.0098764	6	-0.0000002	NA	NA
Main_RecrDev_1906	0.0092902	6	-0.0000001	NA	NA
Main_RecrDev_1907	0.0087113	6	-0.0000002	NA	NA
Main_RecrDev_1908	0.0073379	6	-0.0000001	NA	NA
Main_RecrDev_1909	0.0063754	6	-0.0000005	NA	NA
Main_RecrDev_1910	0.0044196	6	-0.0000005	NA	NA
Main_RecrDev_1911	0.0037819	6	-0.0000003	NA	NA
Main_RecrDev_1912	0.0063118	6	-0.0000004	NA	NA
Main_RecrDev_1913	0.0097046	6	-0.0000007	NA	NA
Main_RecrDev_1914	0.0105388	6	-0.0000009	NA	NA
Main_RecrDev_1915	0.0058944	6	-0.0000008	NA	NA
Main_RecrDev_1916	0.0047044	6	-0.0000009	NA	NA
Main_RecrDev_1917	0.0041038	6	-0.0000008	NA	NA
Main_RecrDev_1918	0.0029072	6	-0.0000010	NA	NA
Main_RecrDev_1919	0.0045967	6	-0.0000011	NA	NA
Main_RecrDev_1920	0.0015146	6	-0.0000010	NA	NA
Main_RecrDev_1921	-0.0046215	6	-0.0000015	NA	NA
Main_RecrDev_1922	-0.0023083	6	-0.0000012	NA	NA
Main_RecrDev_1923	-0.0031058	6	-0.0000015	NA	NA
Main_RecrDev_1924	-0.0046543	6	-0.0000016	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Main_RecrDev_1925	-0.0062500	6	-0.0000015	NA	NA
Main_RecrDev_1926	-0.0078539	6	-0.0000021	NA	NA
Main_RecrDev_1927	-0.0094187	6	-0.0000020	NA	NA
Main_RecrDev_1928	-0.0108896	6	-0.0000017	NA	NA
Main_RecrDev_1929	-0.0122054	6	-0.0000022	NA	NA
Main_RecrDev_1930	-0.0133009	6	-0.0000016	NA	NA
Main_RecrDev_1931	-0.0141111	6	-0.0000022	NA	NA
Main_RecrDev_1932	-0.0145756	6	-0.0000031	NA	NA
Main_RecrDev_1933	-0.0146462	6	-0.0000022	NA	NA
Main_RecrDev_1934	-0.0142952	6	-0.0000028	NA	NA
Main_RecrDev_1935	-0.0135258	6	-0.0000028	NA	NA
Main_RecrDev_1936	-0.0123849	6	-0.0000028	NA	NA
Main_RecrDev_1937	-0.0109755	6	-0.0000032	NA	NA
Main_RecrDev_1938	-0.0094702	6	-0.0000031	NA	NA
Main_RecrDev_1939	-0.0081221	6	-0.0000034	NA	NA
Main_RecrDev_1940	-0.0072724	6	-0.0000034	NA	NA
Main_RecrDev_1941	-0.0073489	6	-0.0000035	NA	NA
Main_RecrDev_1942	-0.0088544	6	-0.0000033	NA	NA
Main_RecrDev_1943	-0.0123394	6	-0.0000034	NA	NA
Main_RecrDev_1944	-0.0183592	6	-0.0000033	NA	NA
Main_RecrDev_1945	-0.0274167	6	-0.0000035	NA	NA
Main_RecrDev_1946	-0.0398976	6	-0.0000034	NA	NA
Main_RecrDev_1947	-0.0560104	6	-0.0000032	NA	NA
Main_RecrDev_1948	-0.0757431	6	-0.0000030	NA	NA
Main_RecrDev_1949	-0.0988453	6	-0.0000021	NA	NA
Main_RecrDev_1950	-0.1248430	6	-0.0000021	NA	NA
Main_RecrDev_1951	-0.1529180	6	-0.0000018	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Main_RecrDev_1952	-0.1823700	6	-0.0000018	NA	NA
Main_RecrDev_1953	-0.2123130	6	-0.0000017	NA	NA
Main_RecrDev_1954	-0.2418060	6	-0.0000011	NA	NA
Main_RecrDev_1955	-0.2698840	6	-0.0000018	NA	NA
Main_RecrDev_1956	-0.2956010	6	-0.0000015	NA	NA
Main_RecrDev_1957	-0.3179980	6	-0.0000016	NA	NA
Main_RecrDev_1958	-0.3361610	6	-0.0000015	NA	NA
Main_RecrDev_1959	-0.3491480	6	-0.0000014	NA	NA
Main_RecrDev_1960	-0.3559300	6	-0.0000014	NA	NA
Main_RecrDev_1961	-0.3554410	6	-0.0000012	NA	NA
Main_RecrDev_1962	-0.3466700	6	-0.0000010	NA	NA
Main_RecrDev_1963	-0.3286130	6	-0.0000010	NA	NA
Main_RecrDev_1964	-0.3006630	6	-0.0000014	NA	NA
Main_RecrDev_1965	-0.2630010	6	-0.0000012	NA	NA
Main_RecrDev_1966	-0.2167930	6	-0.0000013	NA	NA
Main_RecrDev_1967	-0.1645850	6	-0.0000011	NA	NA
Main_RecrDev_1968	-0.1099880	6	-0.0000009	NA	NA
Main_RecrDev_1969	-0.0568378	6	-0.0000017	NA	NA
Main_RecrDev_1970	-0.0075609	6	-0.0000017	NA	NA
Main_RecrDev_1971	0.0379283	6	-0.0000021	NA	NA
Main_RecrDev_1972	0.0804411	6	-0.0000023	NA	NA
Main_RecrDev_1973	0.1179970	6	-0.0000024	NA	NA
Main_RecrDev_1974	0.1443140	6	-0.0000024	NA	NA
Main_RecrDev_1975	0.1517780	6	-0.0000011	NA	NA
Main_RecrDev_1976	0.1369450	6	-0.0000019	NA	NA
Main_RecrDev_1977	0.1061360	6	-0.0000016	NA	NA
Main_RecrDev_1978	0.0726112	6	-0.0000013	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Main_RecrDev_1979	0.0507453	6	-0.0000012	NA	NA
Main_RecrDev_1980	0.0489501	6	-0.0000012	NA	NA
Main_RecrDev_1981	0.0637665	6	-0.0000015	NA	NA
Main_RecrDev_1982	0.0783409	6	-0.0000011	NA	NA
Main_RecrDev_1983	0.0766034	6	-0.0000014	NA	NA
Main_RecrDev_1984	0.0597470	6	-0.0000019	NA	NA
Main_RecrDev_1985	0.0381035	6	-0.0000012	NA	NA
Main_RecrDev_1986	0.0187712	6	-0.0000010	NA	NA
Main_RecrDev_1987	0.0097229	6	-0.0000010	NA	NA
Main_RecrDev_1988	0.0185786	6	-0.0000008	NA	NA
Main_RecrDev_1989	0.0348546	6	-0.0000006	NA	NA
Main_RecrDev_1990	0.0439104	6	0.0000005	NA	NA
Main_RecrDev_1991	-0.0037715	6	0.0000015	NA	NA
Main_RecrDev_1992	-0.0725407	6	0.0000009	NA	NA
Main_RecrDev_1993	-0.1421580	6	0.0000017	NA	NA
Main_RecrDev_1994	-0.2705160	6	0.0000035	NA	NA
Main_RecrDev_1995	-0.3525910	6	0.0000037	NA	NA
Main_RecrDev_1996	-0.3218080	6	0.0000051	NA	NA
Main_RecrDev_1997	-0.3064720	6	0.0000045	NA	NA
Main_RecrDev_1998	-0.2649110	6	0.0000041	NA	NA
Main_RecrDev_1999	-0.1048200	6	0.0000077	NA	NA
Main_RecrDev_2000	0.1181320	6	0.0000083	NA	NA
Main_RecrDev_2001	0.3668890	6	0.0000087	NA	NA
Main_RecrDev_2002	0.4814550	6	0.0000099	NA	NA
Main_RecrDev_2003	1.0281000	6	0.0000146	NA	NA
Main_RecrDev_2004	0.6050550	6	0.0000091	NA	NA
Main_RecrDev_2005	0.6389970	6	0.0000078	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Main_RecrDev_2006	0.6460320	6	0.0000077	NA	NA
Main_RecrDev_2007	0.7599250	6	0.0000078	NA	NA
Main_RecrDev_2008	0.8541520	6	0.0000074	NA	NA
Main_RecrDev_2009	0.4976620	6	0.0000047	NA	NA
Main_RecrDev_2010	0.2394250	6	0.0000028	NA	NA
Main_RecrDev_2011	0.1032040	6	0.0000026	NA	NA
Main_RecrDev_2012	-0.0337970	6	0.0000023	NA	NA
Main_RecrDev_2013	-0.1115330	6	0.0000021	NA	NA
Main_RecrDev_2014	-0.1054800	6	0.0000020	NA	NA
Main_RecrDev_2015	-0.0890053	6	0.0000015	NA	NA
Main_RecrDev_2016	-0.0490248	6	0.0000017	NA	NA
Main_RecrDev_2017	-0.0623100	6	0.0000016	NA	NA
Main_RecrDev_2018	-0.0601378	6	0.0000015	NA	NA
Late_RecrDev_2019	-0.0315900	5	0.0000000	NA	NA
Late_RecrDev_2020	0.0066217	5	0.0000000	NA	NA
Late_RecrDev_2021	0.0397842	5	0.0000002	NA	NA
Late_RecrDev_2022	0.0000000	5	0.0000000	NA	NA
ForeRecr_2023	0.0000000	5	0.0000000	NA	NA
ForeRecr_2024	0.0000000	5	0.0000000	NA	NA
ForeRecr_2025	0.0000000	5	0.0000000	NA	NA
ForeRecr_2026	0.0000000	5	0.0000000	NA	NA
ForeRecr_2027	0.0000000	5	0.0000000	NA	NA
ForeRecr_2028	0.0000000	5	0.0000000	NA	NA
ForeRecr_2029	0.0000000	5	0.0000000	NA	NA
ForeRecr_2030	0.0000000	5	0.0000000	NA	NA
ForeRecr_2031	0.0000000	5	0.0000000	NA	NA
ForeRecr_2032	0.0000000	5	0.0000000	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
ForeRecr_2033	0.0000000	5	0.0000000	NA	NA
ForeRecr_2034	0.0000000	5	0.0000000	NA	NA
LnQ_base_Triennial1(4)	-0.4138250	-1	NA	NA	NA
Q_extraSD_Triennial1(4)	0.0866586	4	0.0000001	NA	NA
LnQ_base_NWFSCcombo(6)	0.2598070	-1	NA	NA	NA
Size_DblN_peak_Trawl_N(1)	25.3210000	1	-0.0000683	NA	NA
Size_DblN_top_logit_Trawl_N(1)	-15.0000000	-3	NA	NA	NA
Size_DblN_ascend_se_Trawl_N(1)	4.2979800	3	0.0000677	NA	NA
Size_DblN_descend_se_Trawl_N(1)	6.8307700	4	-0.0000678	NA	NA
Size_DblN_start_logit_Trawl_N(1)	-	-99	NA	NA	NA
	999.0000000				
99 Size_DblN_end_logit_Trawl_N(1)	-	-99	NA	NA	NA
	999.0000000				
Retain_L_infl_Trawl_N(1)	34.8080000	3	0.0001028	NA	NA
Retain_L_width_Trawl_N(1)	2.2890400	3	0.0000226	NA	NA
Retain_L_asymptote_logit_Trawl_N(1)	10.0000000	3	0.0000000	NA	NA
Retain_L_maleoffset_Trawl_N(1)	0.0000000	-4	NA	NA	NA
Size_DblN_peak_Trawl_S(2)	20.0179000	1	-0.0000626	NA	NA
Size_DblN_top_logit_Trawl_S(2)	-0.6019960	3	-0.0001331	NA	NA
Size_DblN_ascend_se_Trawl_S(2)	4.0047700	3	0.0000513	NA	NA
Size_DblN_descend_se_Trawl_S(2)	5.2208800	4	-0.0000578	NA	NA
Size_DblN_start_logit_Trawl_S(2)	-	-99	NA	NA	NA
	999.0000000				
Size_DblN_end_logit_Trawl_S(2)	-	-99	NA	NA	NA
	999.0000000				
Retain_L_infl_Trawl_S(2)	28.6998000	3	0.0001304	NA	NA
Retain_L_width_Trawl_S(2)	2.1096100	3	0.0000191	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Retain_L_asymptote_logit_Trawl_S(2)	10.0000000	3	0.0000000	NA	NA
Retain_L_maleoffset_Trawl_S(2)	0.0000000	-4	NA	NA	NA
Size_DblN_peak_Non-trawl(3)	44.8554000	2	-0.0000035	NA	NA
Size_DblN_top_logit_Non-trawl(3)	-3.3001600	3	-0.0000009	NA	NA
Size_DblN_ascend_se_Non-trawl(3)	5.0106300	3	0.0000039	NA	NA
Size_DblN_descend_se_Non-trawl(3)	4.6360400	4	-0.0000021	NA	NA
Size_DblN_start_logit_Non-trawl(3)	-	-99	NA	NA	NA
	999.0000000				
Size_DblN_end_logit_Non-trawl(3)	-	-99	NA	NA	NA
	999.0000000				
Retain_L_infl_Non-trawl(3)	25.4880000	3	-0.0000011	NA	NA
Retain_L_width_Non-trawl(3)	2.9771900	3	-0.0000003	NA	NA
Retain_L_asymptote_logit_Non-trawl(3)	1.5139700	3	0.0000013	NA	NA
Retain_L_maleoffset_Non-trawl(3)	0.0000000	-4	NA	NA	NA
Size_DblN_peak_Triennial1(4)	26.7371000	2	-0.0000022	NA	NA
Size_DblN_top_logit_Triennial1(4)	-7.0000000	-3	NA	NA	NA
Size_DblN_ascend_se_Triennial1(4)	4.1095800	3	0.0000018	NA	NA
Size_DblN_descend_se_Triennial1(4)	3.1637200	4	-0.0000005	NA	NA
Size_DblN_start_logit_Triennial1(4)	-	-99	NA	NA	NA
	999.0000000				
Size_DblN_end_logit_Triennial1(4)	-	-99	NA	NA	NA
	999.0000000				
SzSel_Male_Peak_Triennial1(4)	-1.9661900	3	-0.0000003	NA	NA
SzSel_Male_Ascend_Triennial1(4)	-0.1133280	3	0.0000022	NA	NA
SzSel_Male_Descend_Triennial1(4)	0.0000000	-3	NA	NA	NA
SzSel_Male_Final_Triennial1(4)	0.0000000	-3	NA	NA	NA
SzSel_Male_Scale_Triennial1(4)	1.0000000	-4	NA	NA	NA

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Size_DblN_peak_Triennial2(5)	23.7004000	2	-0.0000047	NA	NA
Size_DblN_top_logit_Triennial2(5)	-7.0000000	-3	NA	NA	NA
Size_DblN_ascend_se_Triennial2(5)	4.3701400	3	0.0000076	NA	NA
Size_DblN_descend_se_Triennial2(5)	4.0834600	4	0.0000009	NA	NA
Size_DblN_start_logit_Triennial2(5)	-	-99	NA	NA	NA
	999.0000000				
Size_DblN_end_logit_Triennial2(5)	-	-99	NA	NA	NA
	999.0000000				
SzSel_Male_Peak_Triennial2(5)	-1.9111400	3	-0.0000024	NA	NA
SzSel_Male_Ascend_Triennial2(5)	-0.3024540	3	0.0000134	NA	NA
SzSel_Male_Descend_Triennial2(5)	0.0000000	-3	NA	NA	NA
SzSel_Male_Final_Triennial2(5)	0.0000000	-3	NA	NA	NA
SzSel_Male_Scale_Triennial2(5)	1.0000000	-4	NA	NA	NA
Size_DblN_peak_NWFSCcombo(6)	31.4279000	2	-0.0000062	NA	NA
Size_DblN_top_logit_NWFSCcombo(6)	-0.9013760	3	-0.0000035	NA	NA
Size_DblN_ascend_se_NWFSCcombo(6)	4.9376900	3	0.0000119	NA	NA
Size_DblN_descend_se_NWFSCcombo(6)	4.4634300	4	-0.0000009	NA	NA
Size_DblN_start_logit_NWFSCcombo(6)	-	-99	NA	NA	NA
	999.0000000				
Size_DblN_end_logit_NWFSCcombo(6)	-	-99	NA	NA	NA
	999.0000000				
SzSel_Male_Peak_NWFSCcombo(6)	-4.3047300	3	-0.0000028	NA	NA
SzSel_Male_Ascend_NWFSCcombo(6)	-0.5187780	3	0.0000186	NA	NA
SzSel_Male_Descend_NWFSCcombo(6)	0.0000000	-3	NA	NA	NA
SzSel_Male_Final_NWFSCcombo(6)	0.0000000	-3	NA	NA	NA
SzSel_Male_Scale_NWFSCcombo(6)	1.0000000	-4	NA	NA	NA
Size_DblN_peak_Trawl_N(1)_BLK3delta_2003	2.0183700	2	-0.0000335	-0.473024	4.5097700

Table 20: All parameter estimates for the proposed base model (*continued*)

Source	Value	Phase	Gradient	Lower 95% CI	Upper 95% CI
Size_DblN_peak_Trawl_N(1)_BLK3delta_2011	1.4096700	2	-0.0000371	-0.505628	3.3249800
Retain_L_infl_Trawl_N(1)_BLK1delta_1989	-5.9890100	4	0.0000246	-10.000000	-0.4797730
Retain_L_infl_Trawl_N(1)_BLK1delta_2007	-5.0800500	4	0.0000256	-6.634900	-3.5252000
Retain_L_infl_Trawl_N(1)_BLK1delta_2011	-1.3376000	4	0.0000283	-2.884680	0.2094740
Retain_L_infl_Trawl_N(1)_BLK1delta_2015	-7.2102500	4	0.0000015	-8.339310	-6.0811900
Retain_L_infl_Trawl_N(1)_BLK1delta_2020	6.3364100	4	-0.0000008	5.322200	7.3506200
Retain_L_asymptote_logit_Trawl_N(1)_BLK1delta_1989	0.0005621	4	0.0000000	-0.391326	0.3924500
Retain_L_asymptote_logit_Trawl_N(1)_BLK1delta_2007	0.0006698	4	0.0000000	-0.391197	0.3925370
Retain_L_asymptote_logit_Trawl_N(1)_BLK1delta_2011	0.0005757	4	0.0000000	-0.391310	0.3924610
Retain_L_asymptote_logit_Trawl_N(1)_BLK1delta_2015	-0.0000345	4	0.0000000	-0.392039	0.3919700
Retain_L_asymptote_logit_Trawl_N(1)_BLK1delta_2020	-0.0000685	4	0.0000000	-0.392082	0.3919450
Size_DblN_peak_Trawl_S(2)_BLK3delta_2003	9.8182800	2	-0.0000265	5.005980	14.6306000
Size_DblN_peak_Trawl_S(2)_BLK3delta_2011	0.1307900	2	-0.0000347	-1.190200	1.4517800
Retain_L_infl_Trawl_S(2)_BLK2delta_1989	-2.1599500	4	0.0000394	-3.971210	-0.3486970
Retain_L_infl_Trawl_S(2)_BLK2delta_2007	-4.6270500	4	0.0000349	-6.212500	-3.0415900
Retain_L_infl_Trawl_S(2)_BLK2delta_2011	-3.8181100	4	0.0000340	-4.998410	-2.6378100
Retain_L_infl_Trawl_S(2)_BLK2delta_2017	7.9020900	4	0.0000222	7.059290	8.7448800
Retain_L_infl_Trawl_S(2)_BLK2delta_2020	-0.4405970	4	0.0000267	-0.786498	-0.0946961
Retain_L_asymptote_logit_Trawl_S(2)_BLK2delta_1989	0.0007199	4	-0.0000001	-0.391135	0.3925750
Retain_L_asymptote_logit_Trawl_S(2)_BLK2delta_2007	0.0010992	4	-0.0000001	-0.390682	0.3928800
Retain_L_asymptote_logit_Trawl_S(2)_BLK2delta_2011	0.0008178	4	0.0000000	-0.391018	0.3926540
Retain_L_asymptote_logit_Trawl_S(2)_BLK2delta_2017	-0.0002348	4	0.0000000	-0.392281	0.3918110
Retain_L_asymptote_logit_Trawl_S(2)_BLK2delta_2020	-0.0000802	4	0.0000001	-0.392096	0.3919350

8 Figures

8.1 Introduction and Data

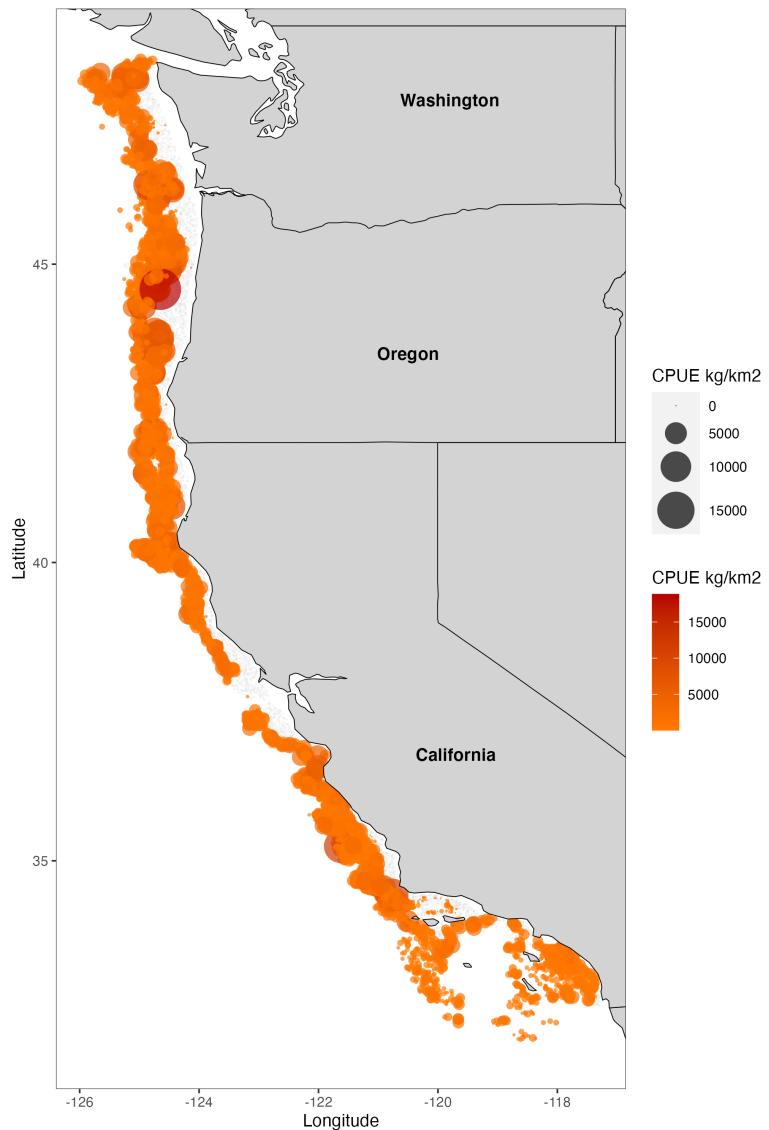


Figure 1: Biomass of shortspine thornyhead found in the NWFSC West Coast Groundfish Bottom Trawl Survey annual survey (2003-2022) coastwide.

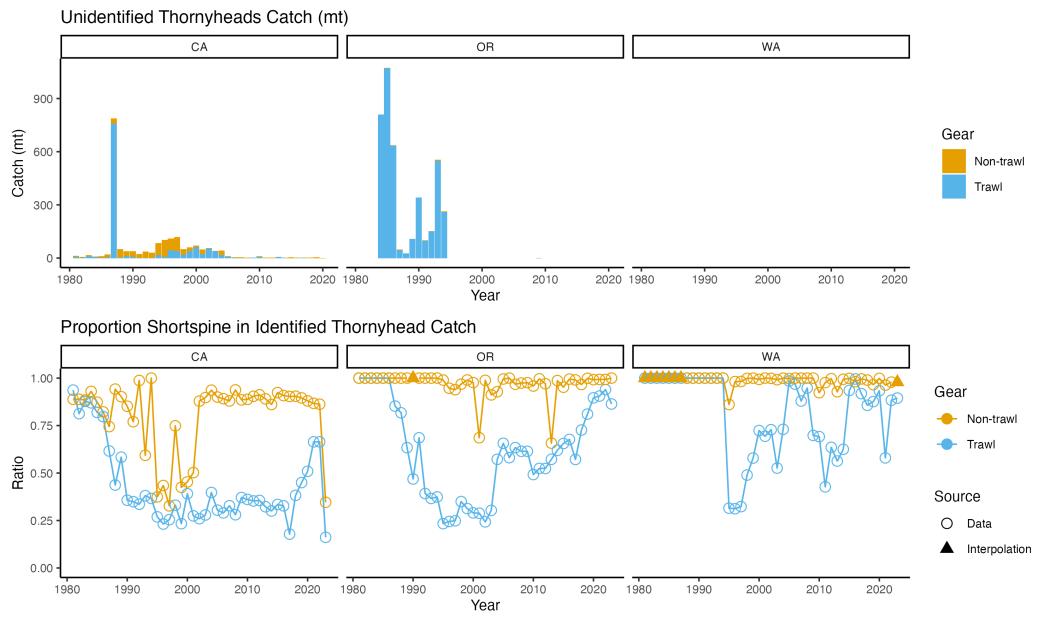


Figure 2: Unidentified thornyhead catches (mt) and the proportion identified as shortspines, calculated as the ratio of shortspine thornyhead catches to combined longspine and shortspine catches.

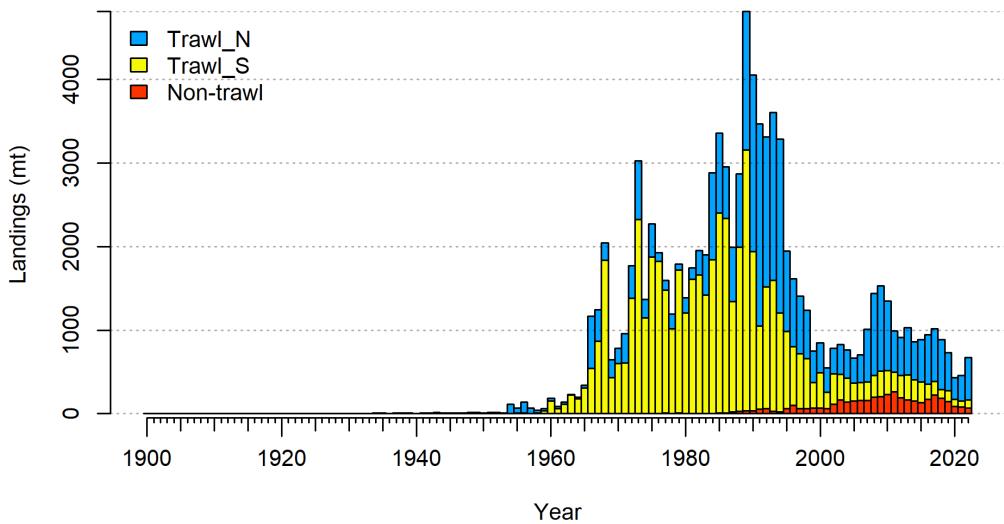


Figure 3: Landing history for shortspine thornyhead.

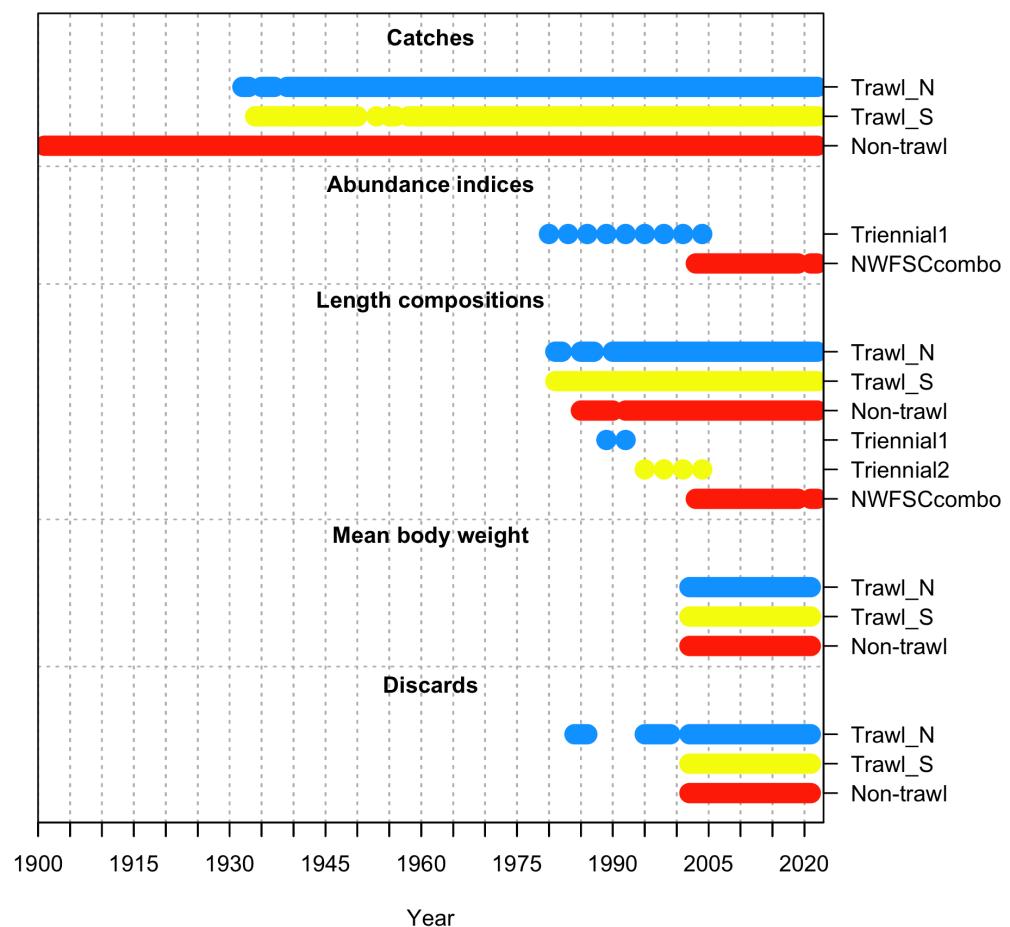


Figure 4: Summary of data sources used in the base model.

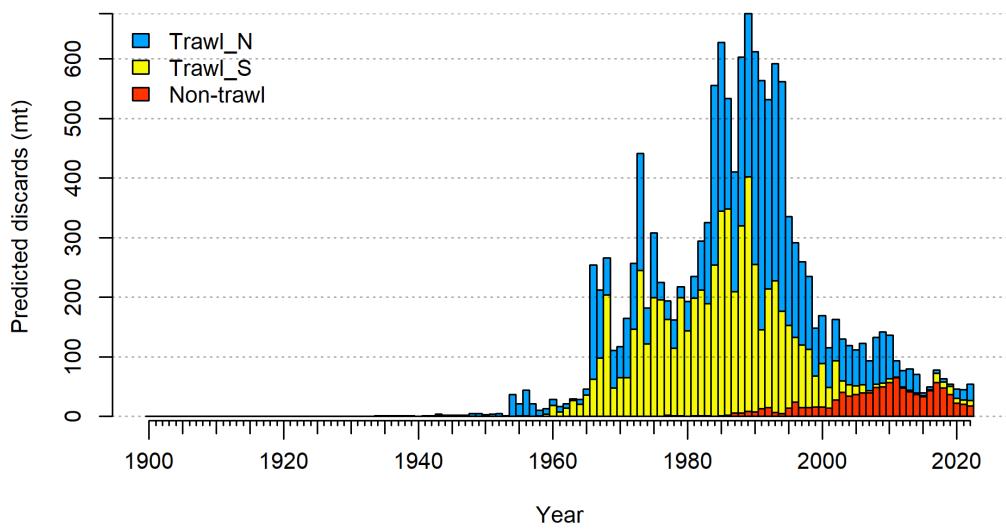


Figure 5: Predicted discards based estimated retention and selectivity for each fleet.

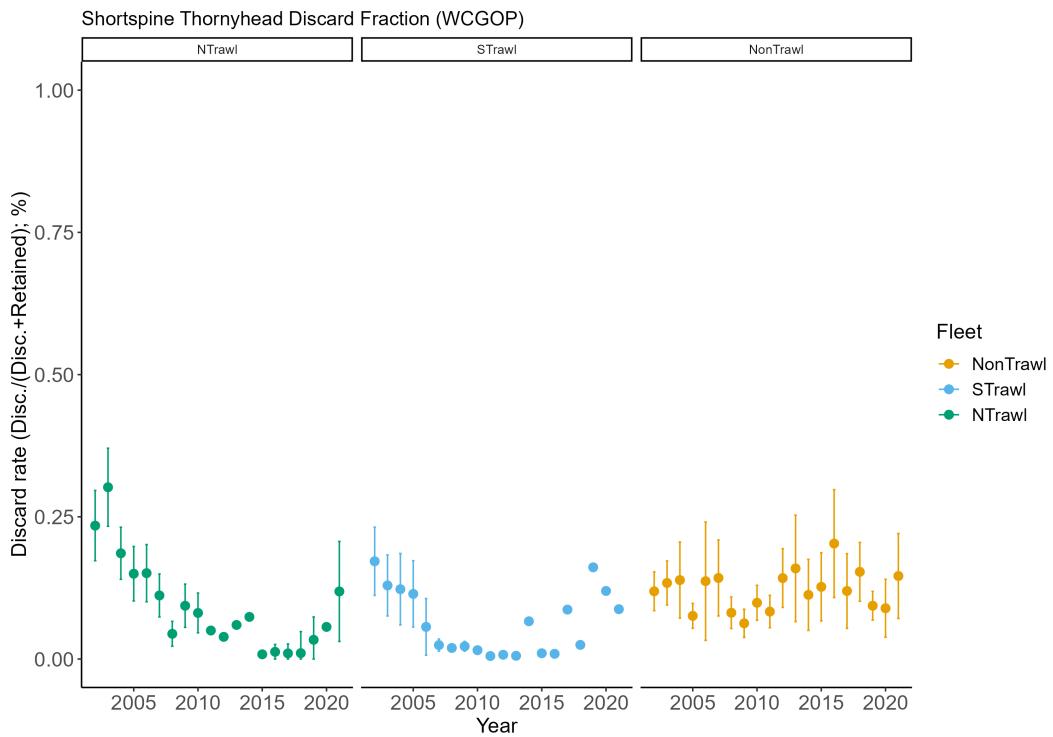


Figure 6: Discard rates from the WCGOP data set with catch share and non-catch share considerations from the GEMM dataset.

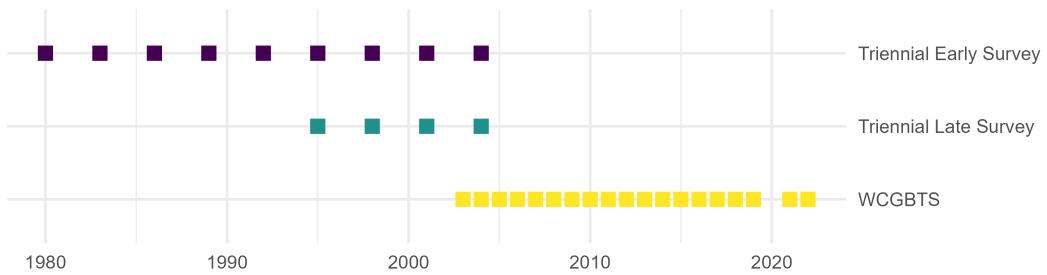


Figure 7: Summary of survey data sources used in the base model.

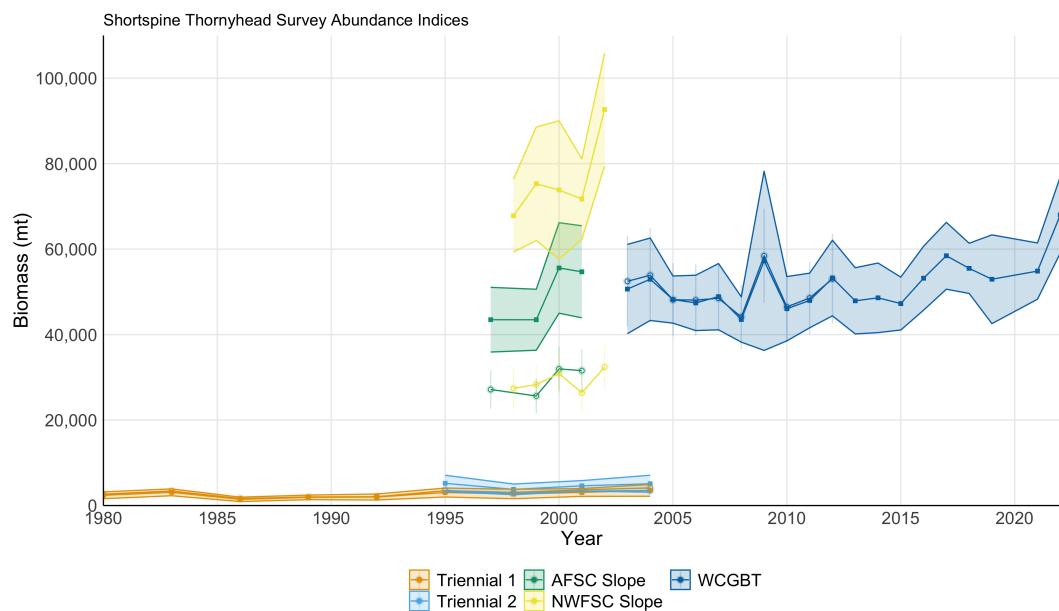


Figure 8: Abundance index timeseries. Points with shaded regions were calculated with survey data through 2023 using the `nwfscSurvey` R package, while points with errorbars are taken directly from the 2013 assessment which used GLMs.

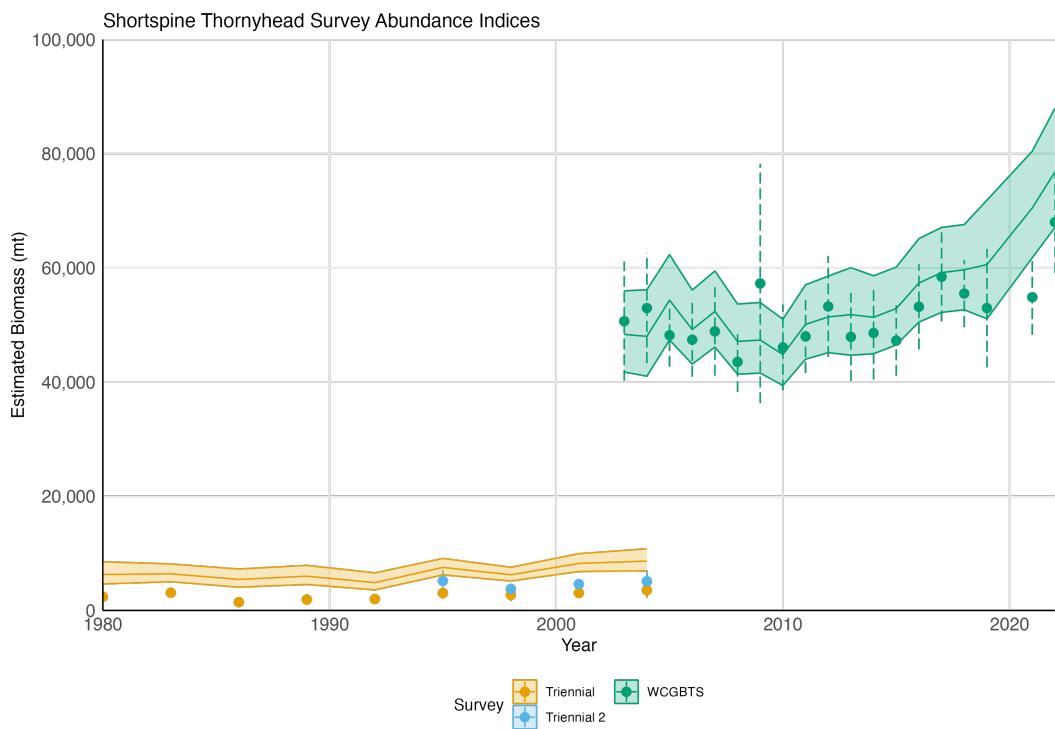


Figure 9: Abundance index timeseries. Points with shaded regions are the derived from geostatistical models, while points with errorbars are derived from design-based calculations.

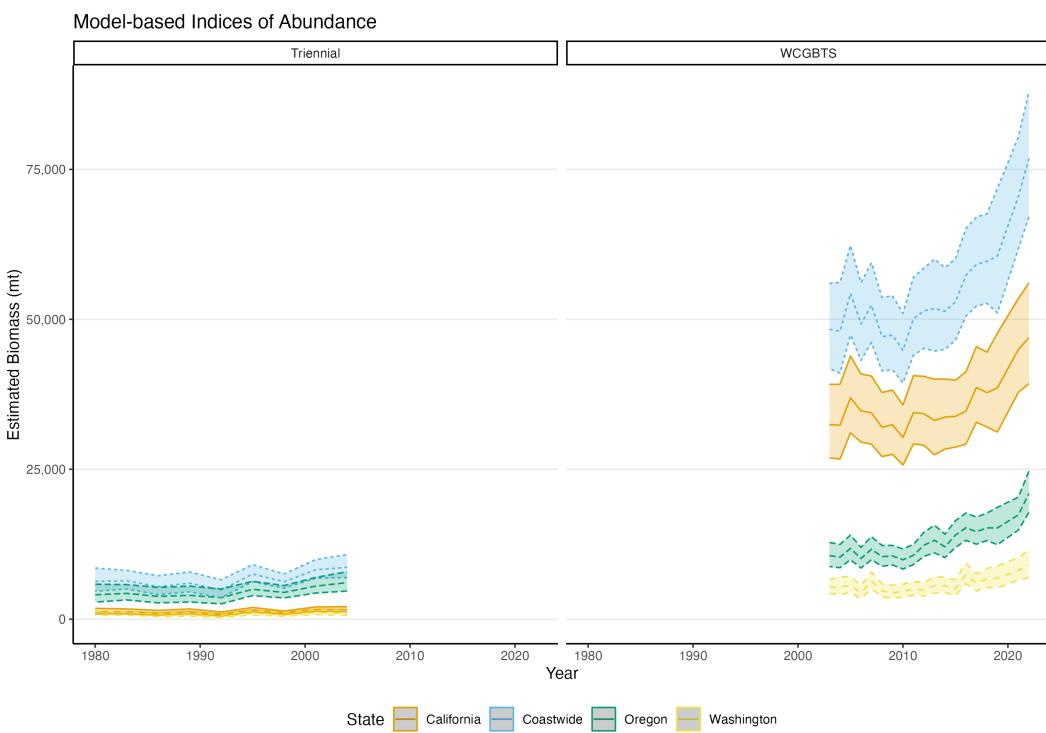


Figure 10: State level trends in abundance indices for the Triennial Surveys and WCGBTS. Coastwide indices were computed separately and should not be interpreted as the sum of the state-level indexes.

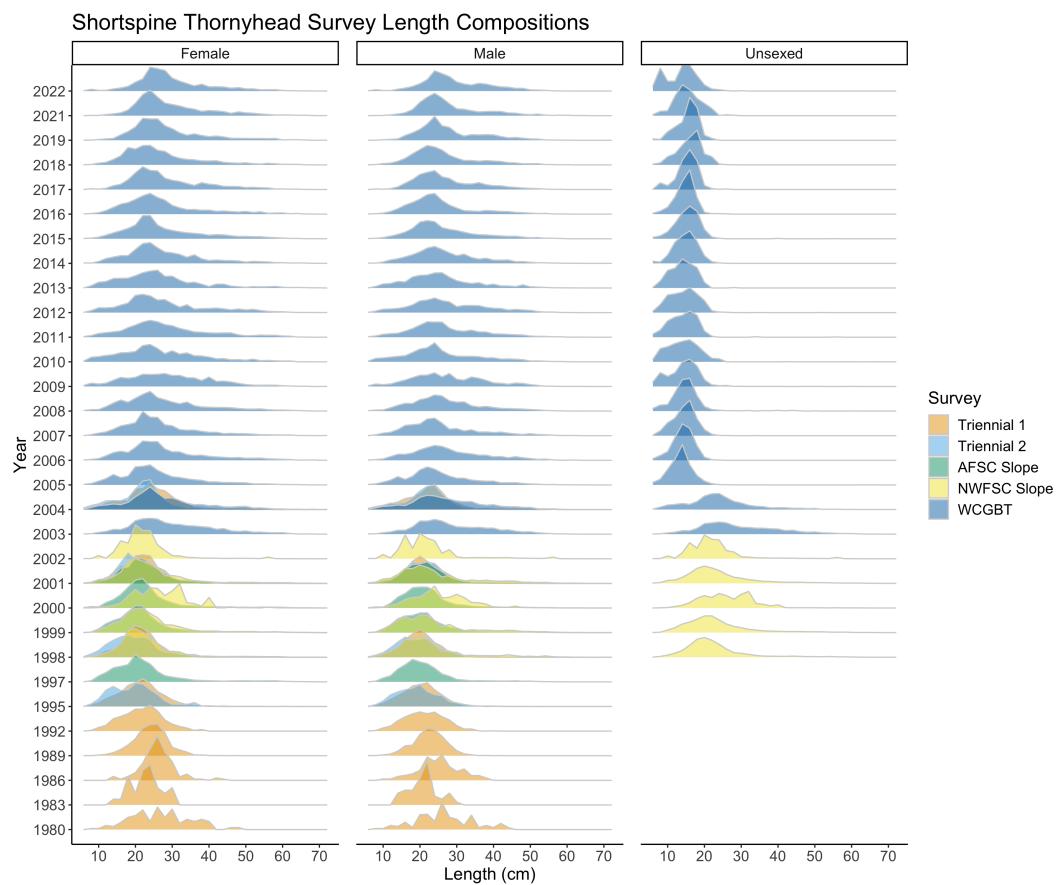


Figure 11: Summary of annual length composition data from available scientific surveys.

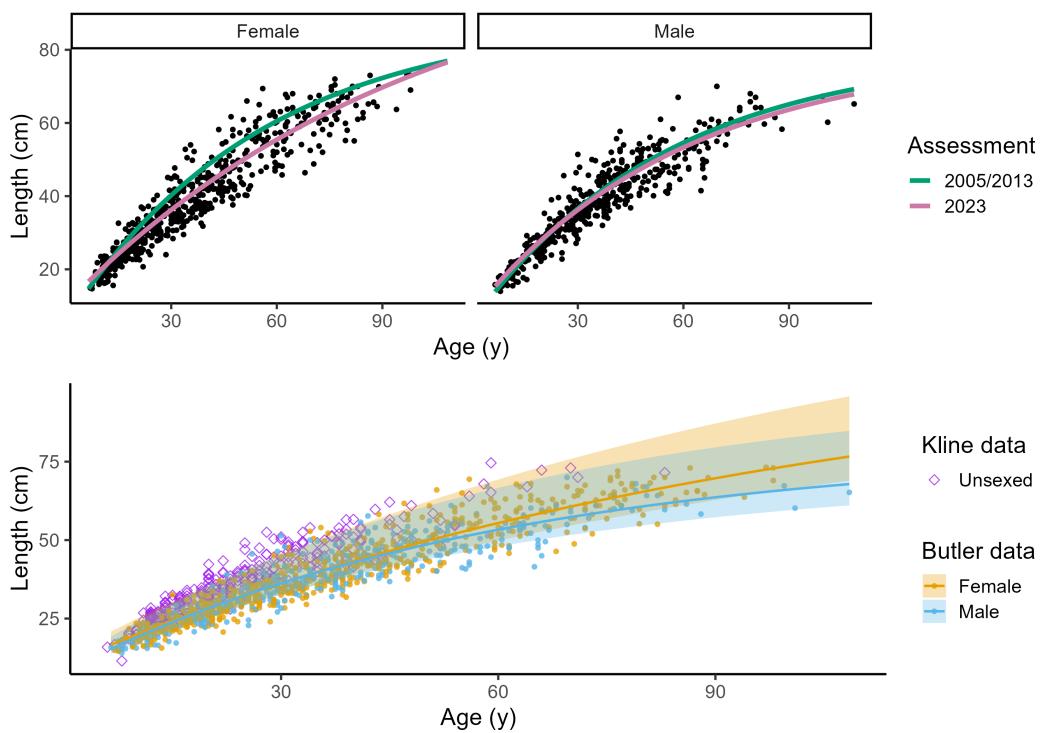


Figure 12: Comparison of growth curves used in the 2005/2013 assessment and the 2023 assessment, as well as high and low growth sensitivities.

Shortspine thornyhead length-weight relationship
NWFSC shelf/slope survey data, 2003-2021

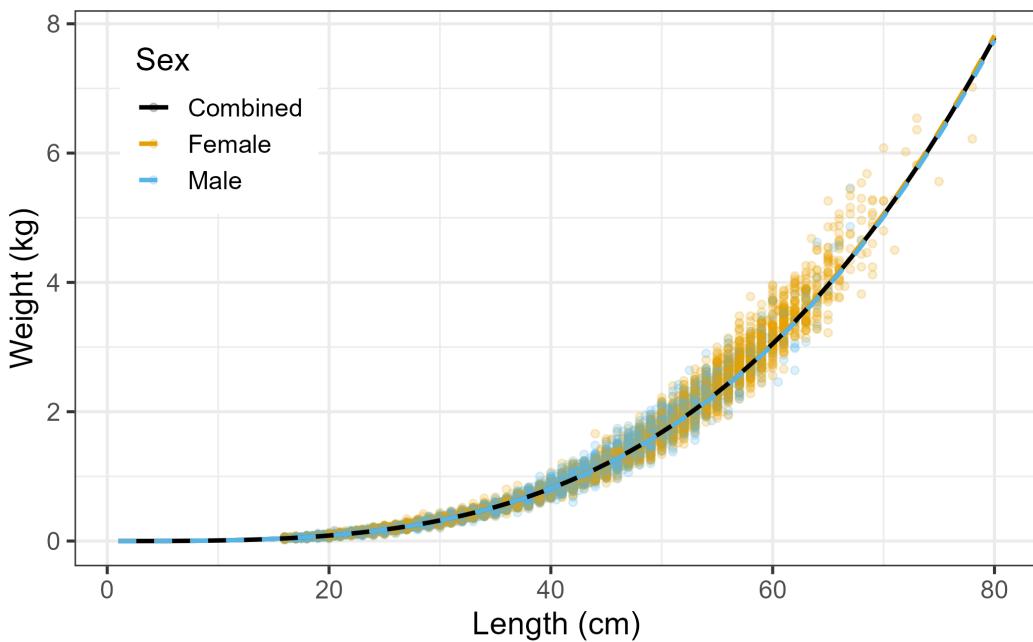


Figure 13: 2023 length-weight relationship and fits to WCGBTS weight-length data.

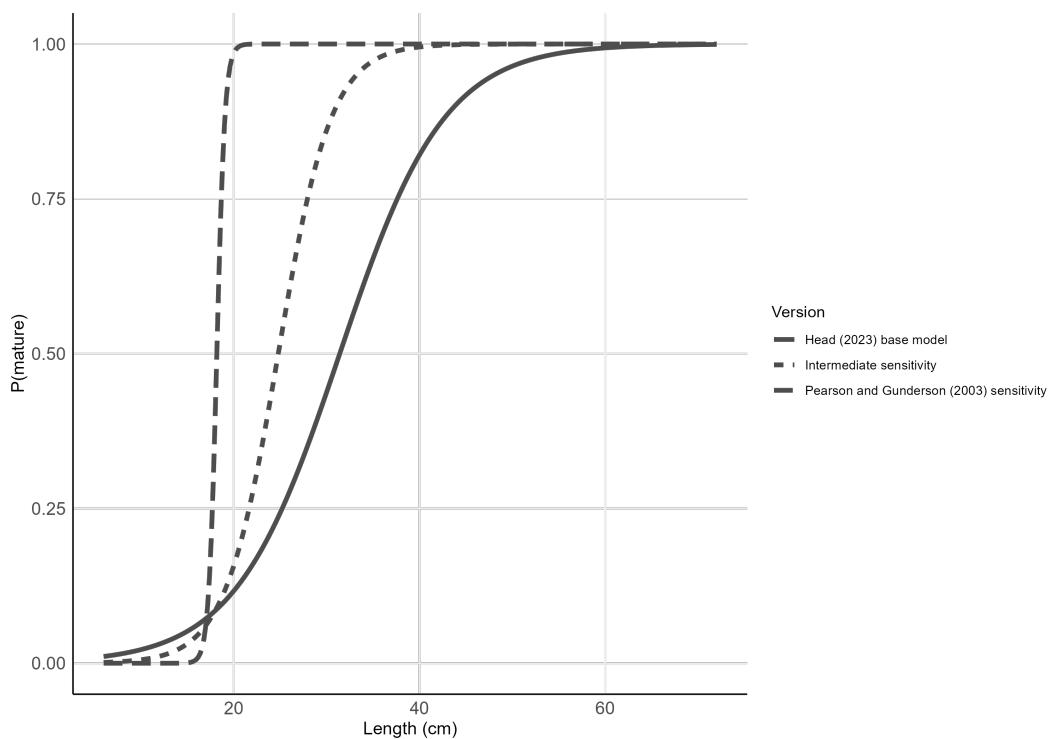


Figure 14: Maturity curves considered in the present assessment (Head (2023)) and alternative versions considered in the sensitivity analysis.

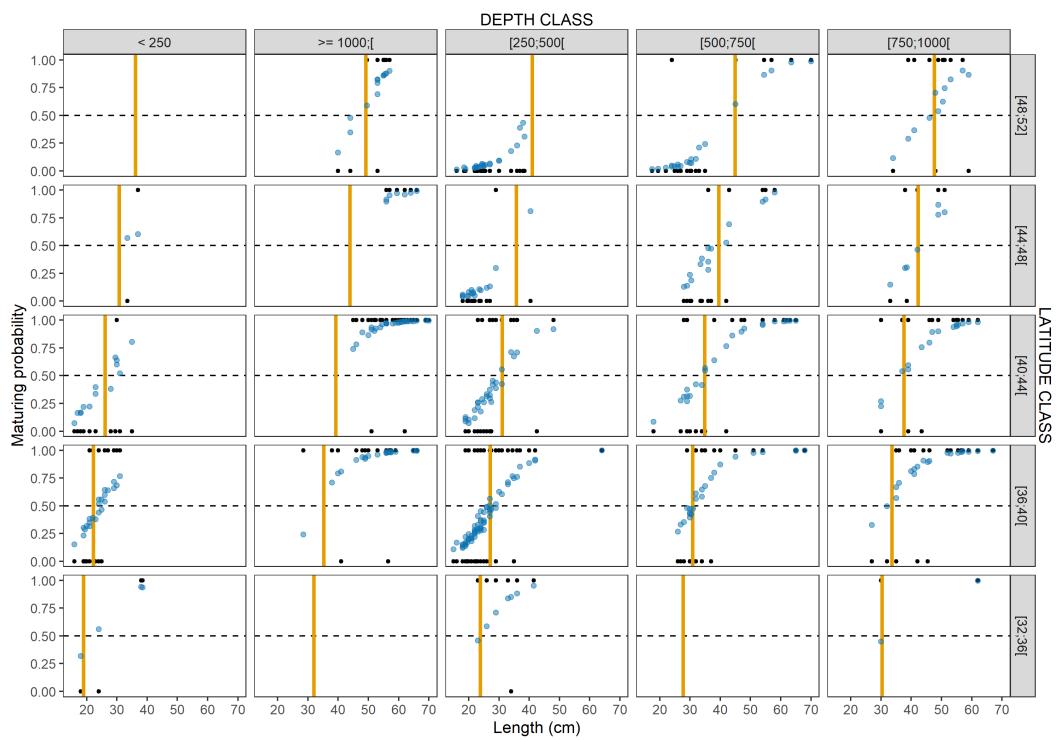


Figure 15: Fit of the maturity curves per size and depth classes. Classes are designed for visual check of the model predictions only since the model assumes continuous and not categorical response to these variables.

Shortspine thornyhead fecundity-at-length

Source: Cooper et al. 2005

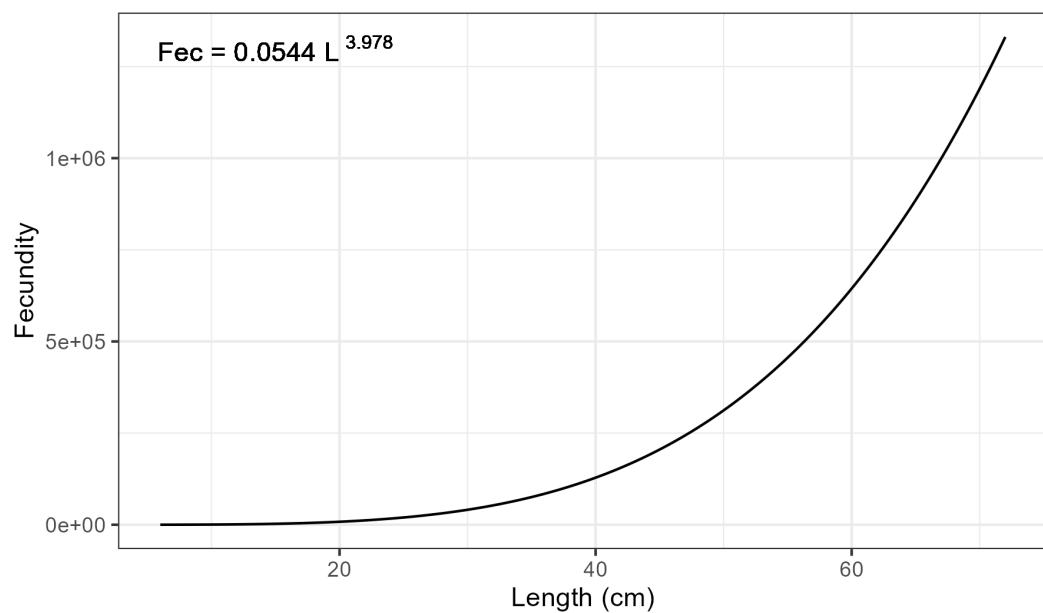


Figure 16: Fecundity-at-length relationship.

8.2 Bridging Analyses

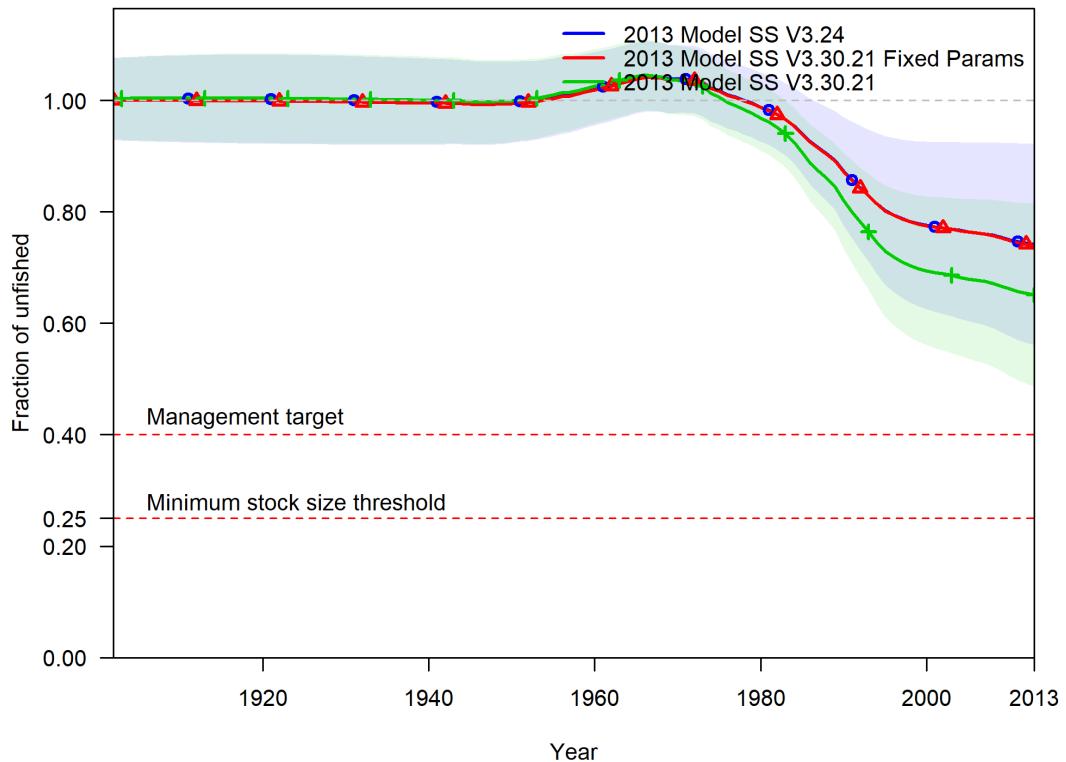


Figure 17: Relative spawning biomass timeseries for models run on updated Stock Synthesis versions.

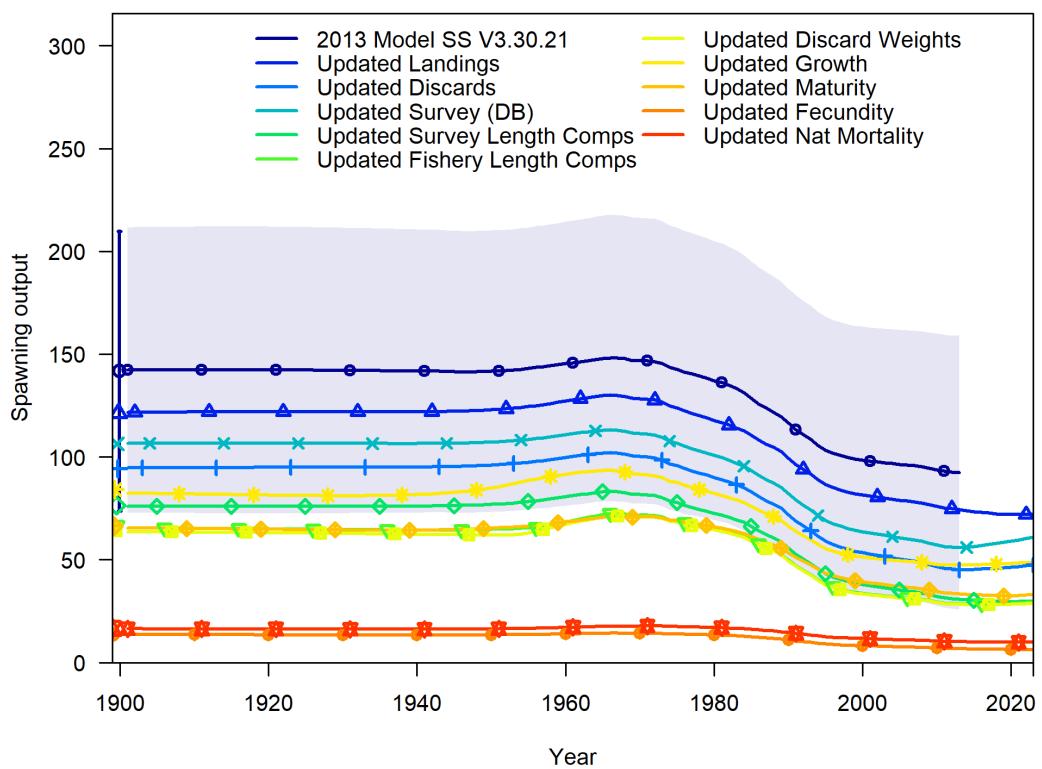


Figure 18: Spawning output timeseries for piecewise data updates.

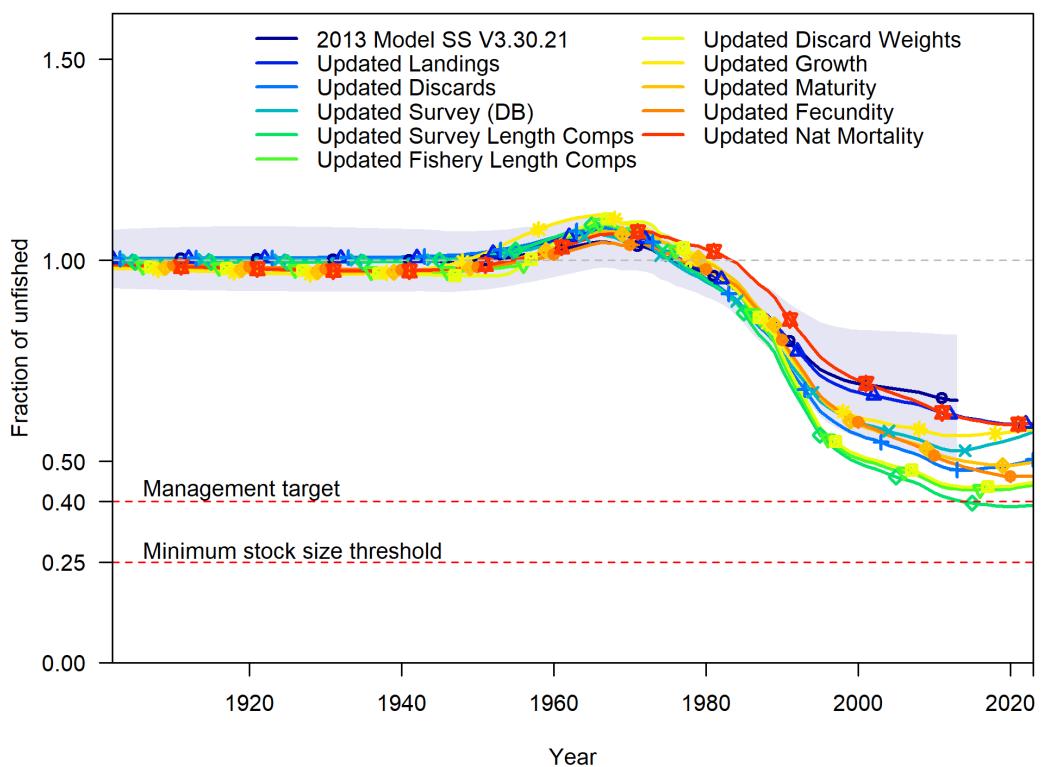


Figure 19: Relative spawning biomass timeseries for piecewise data updates.

8.3 Base Model Results and Fits

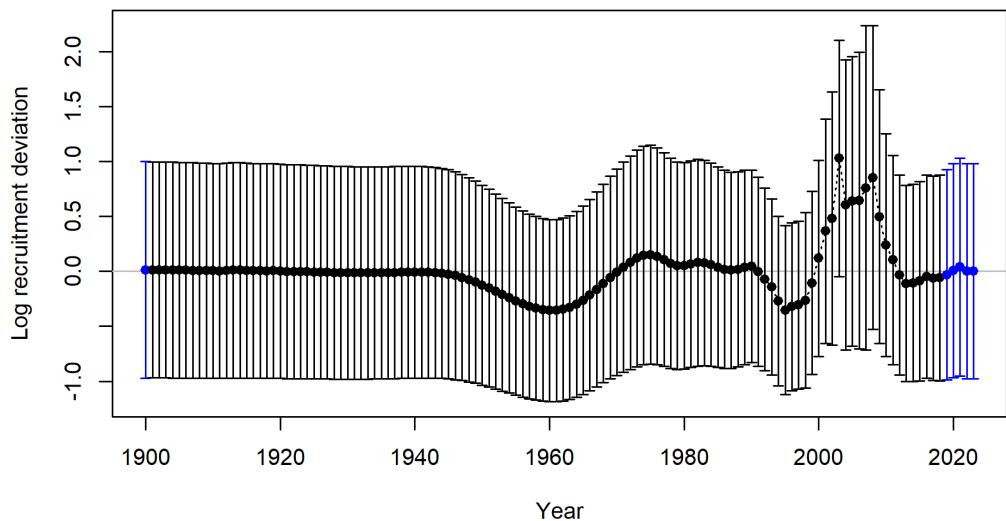


Figure 20: Annual recruitment deviations with 95% intervals.

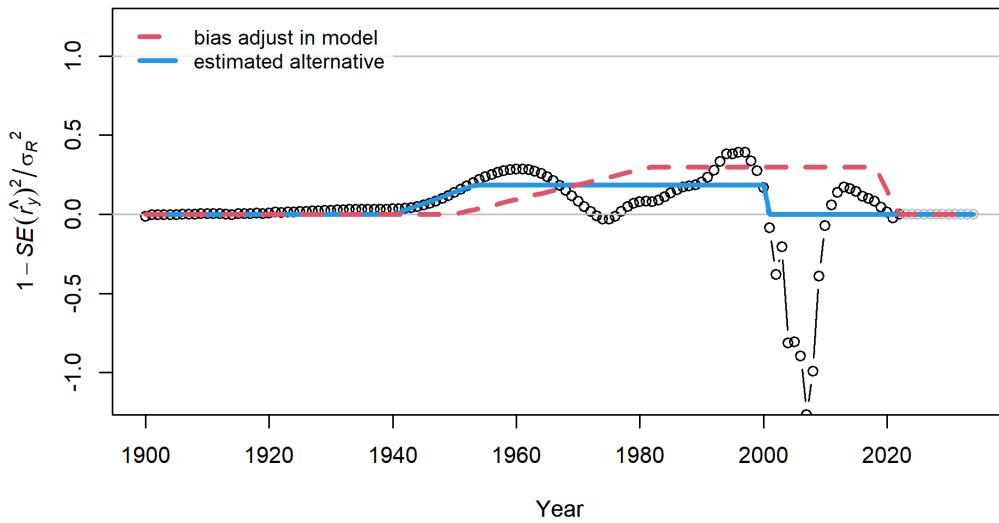


Figure 21: Recommended bias adjustment for recruitment deviations, from Hamel and Cope (2022).

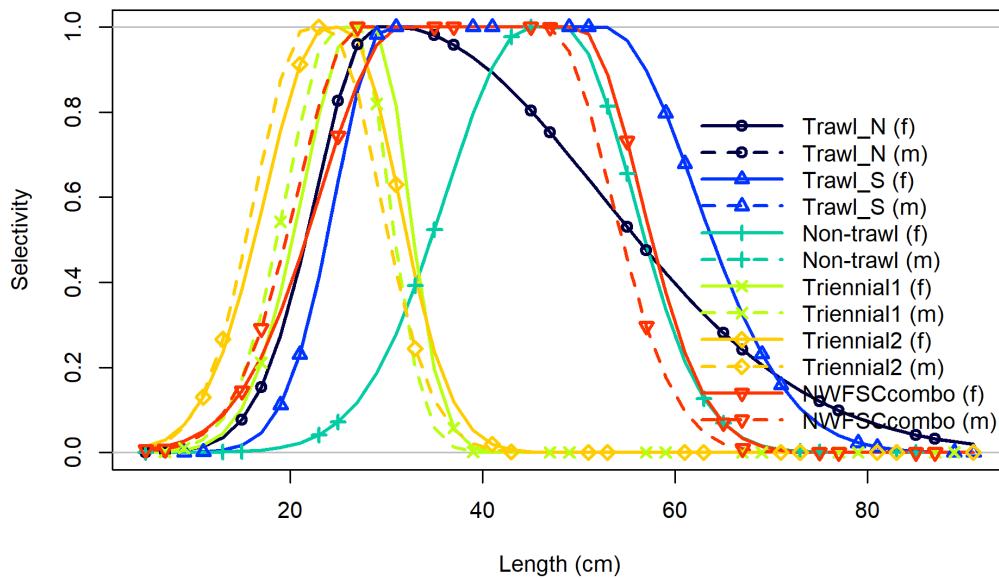


Figure 22: Selectivity at length for each combination of sex and fleet. Note that the three commercial fishery fleets were not modeled as having sex-specific selectivity.

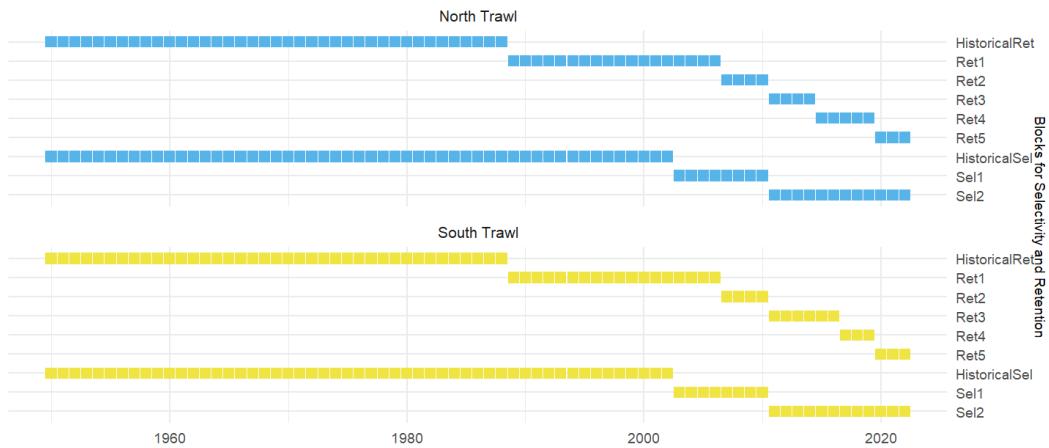


Figure 23: Time blocking for selectivity and retention for North and South trawl fleets.

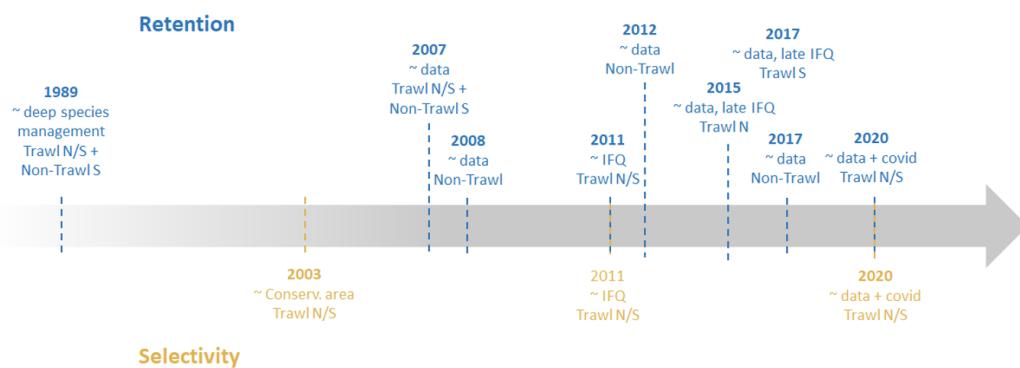


Figure 24: Timeline of management and fleet behavior changes associated with selectivity and retention blocks.

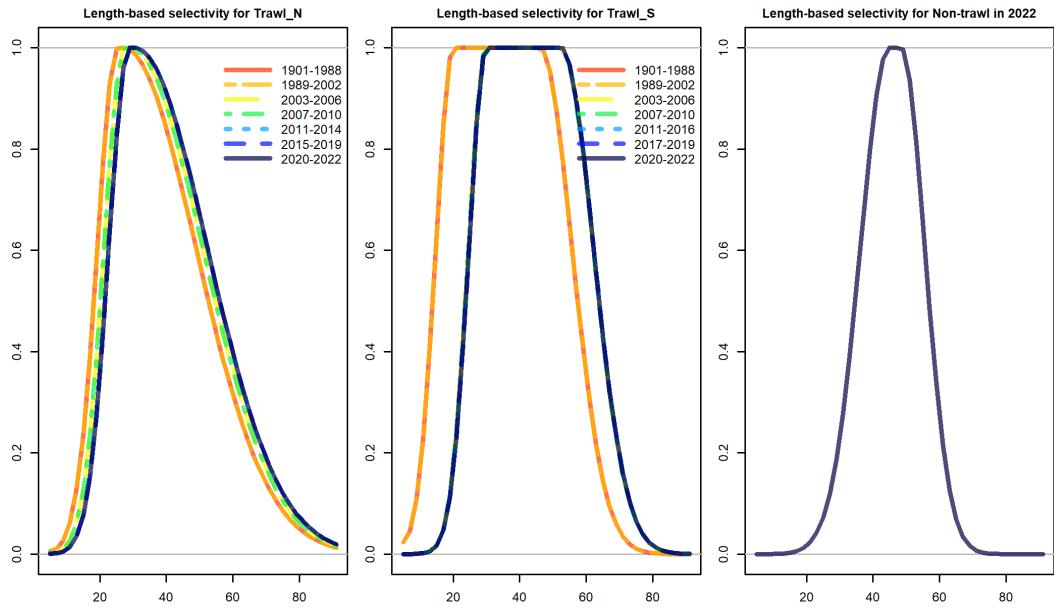


Figure 25: Selectivity curves for time blocks in the North Trawl, South Trawl, and Non-Trawl fleets.

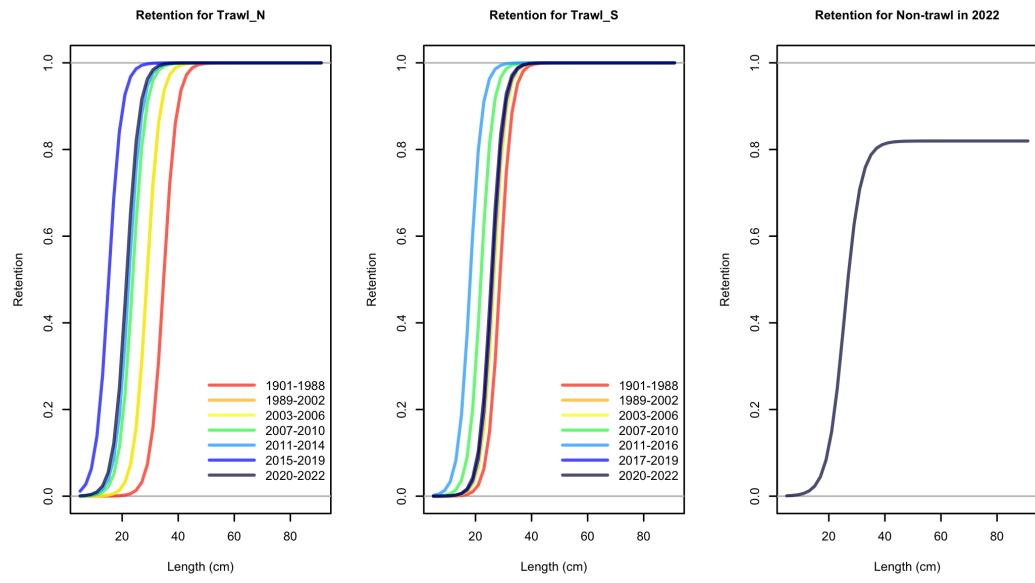


Figure 26: Retention curves for time blocks in the North Trawl, South Trawl, and Non-Trawl fleets.

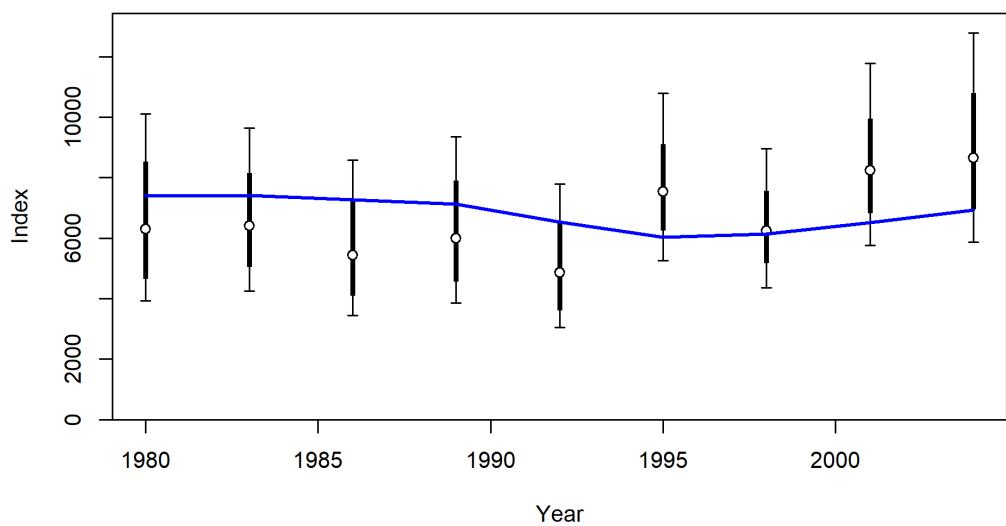


Figure 27: Fit to index of abundance data for the Triennial Survey. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty parameter.

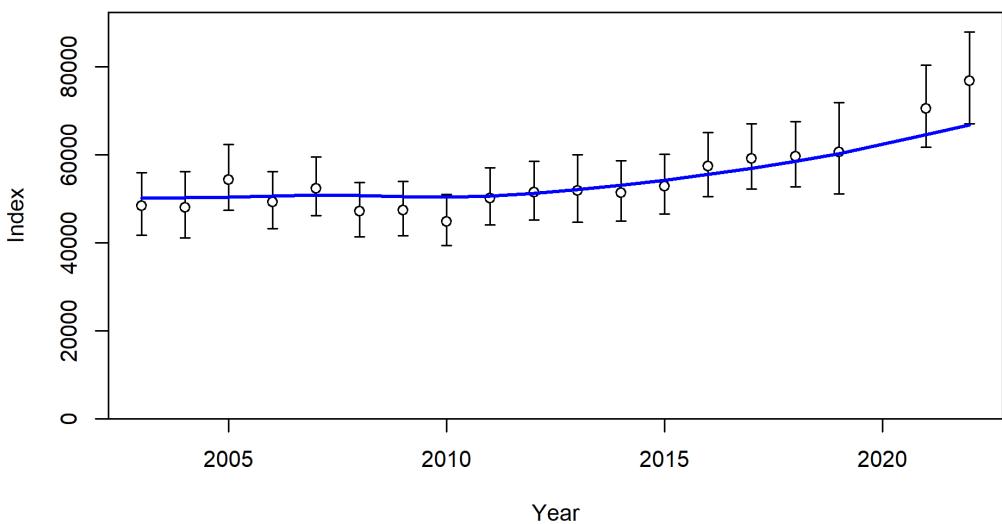


Figure 28: Fit to index of abundance data for the WCGBTS. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty parameter.

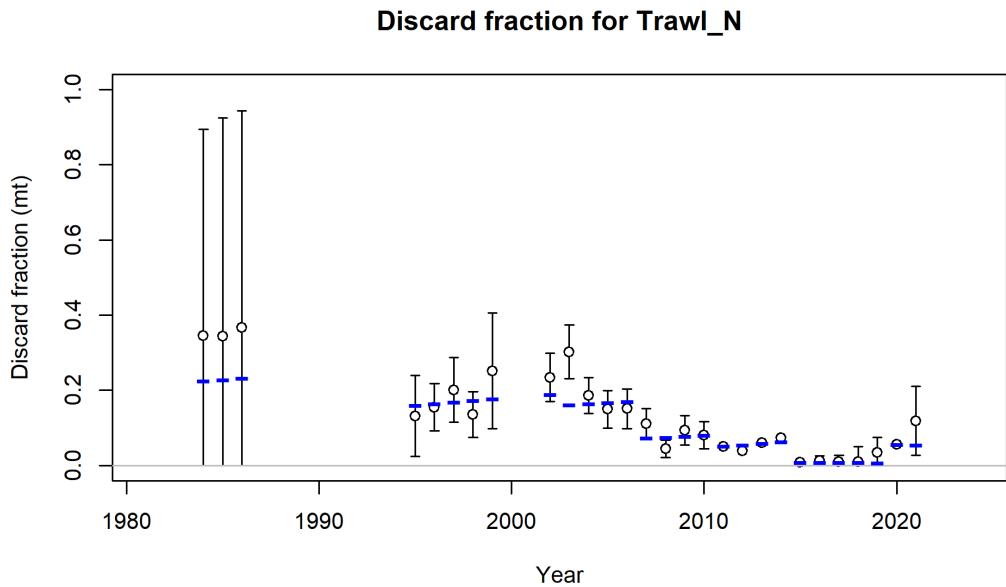


Figure 29: Discard fraction (percent of total catch that is not landed) for the North trawl fleet.

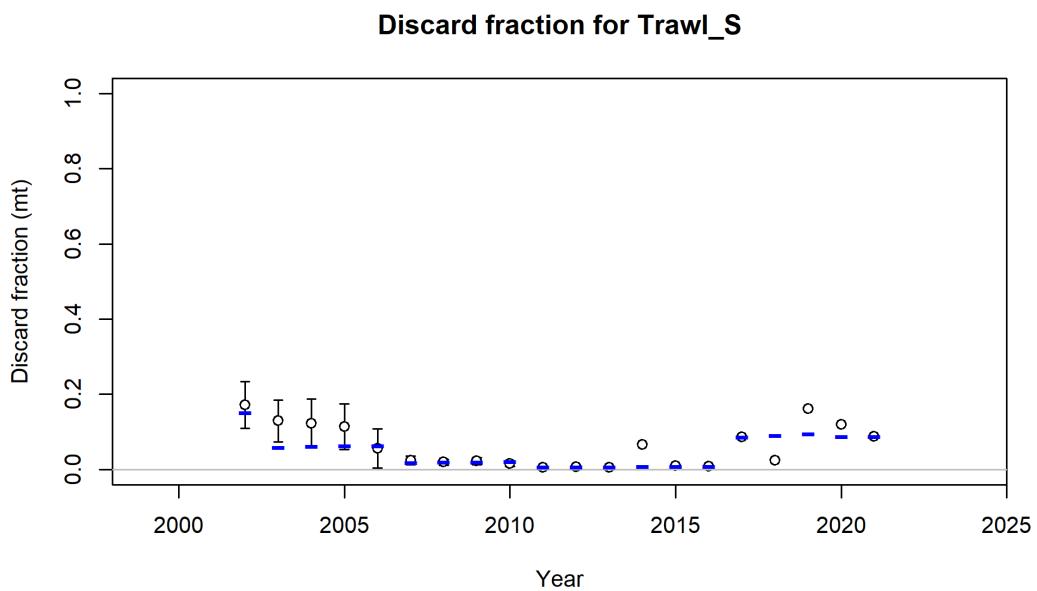


Figure 30: Discard fraction (percent of total catch that is not landed) for the South trawl fleet.

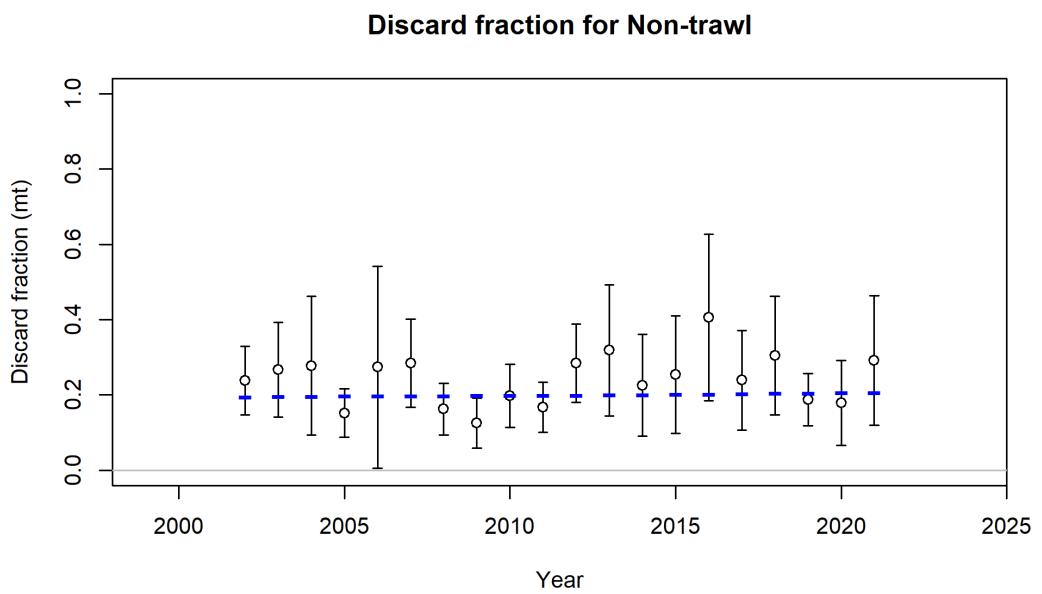


Figure 31: Discard fraction (percent of total catch that is not landed) for the Non-trawl fleet.

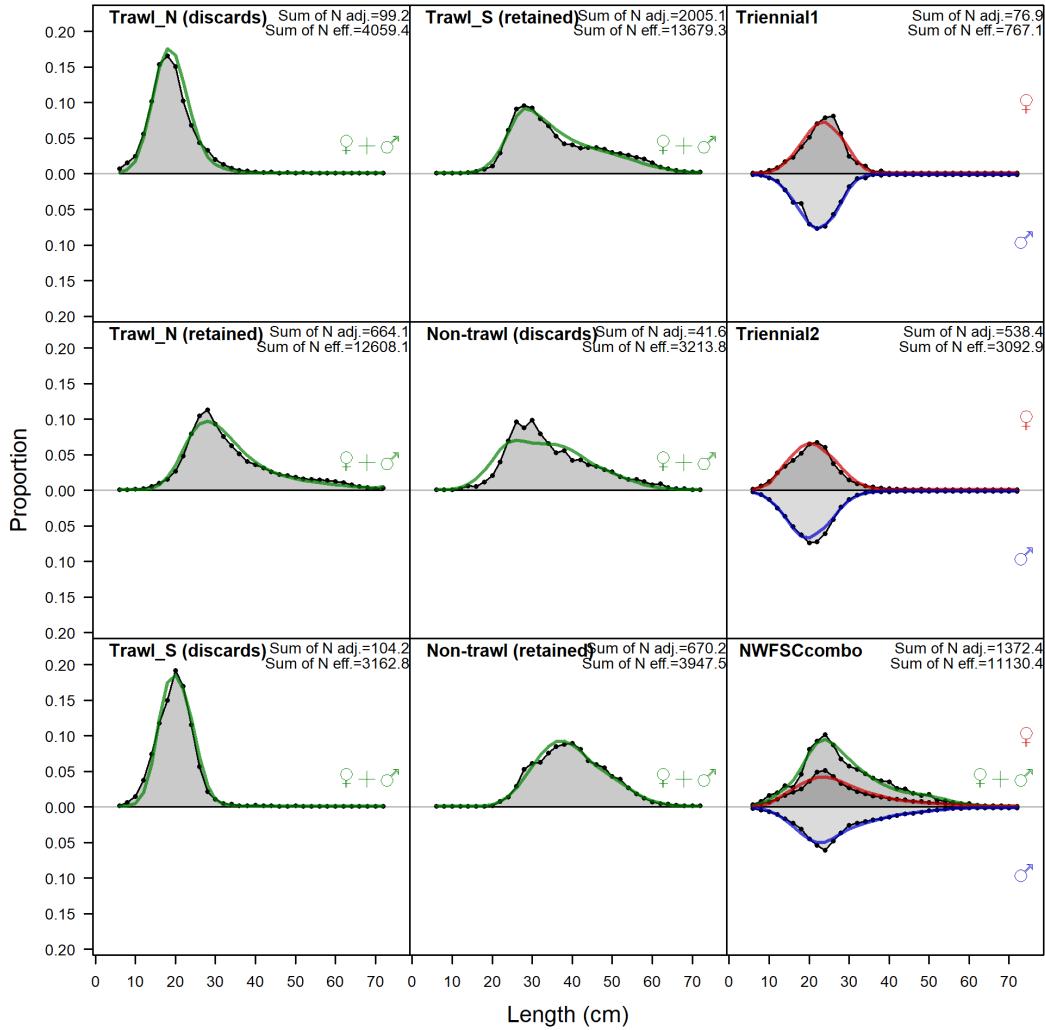


Figure 32: Length comps, aggregated across time by fleet. Labels ‘retained’ and ‘discard’ indicate discarded or retained samples for each fleet. Panels without this designation represent the whole catch.

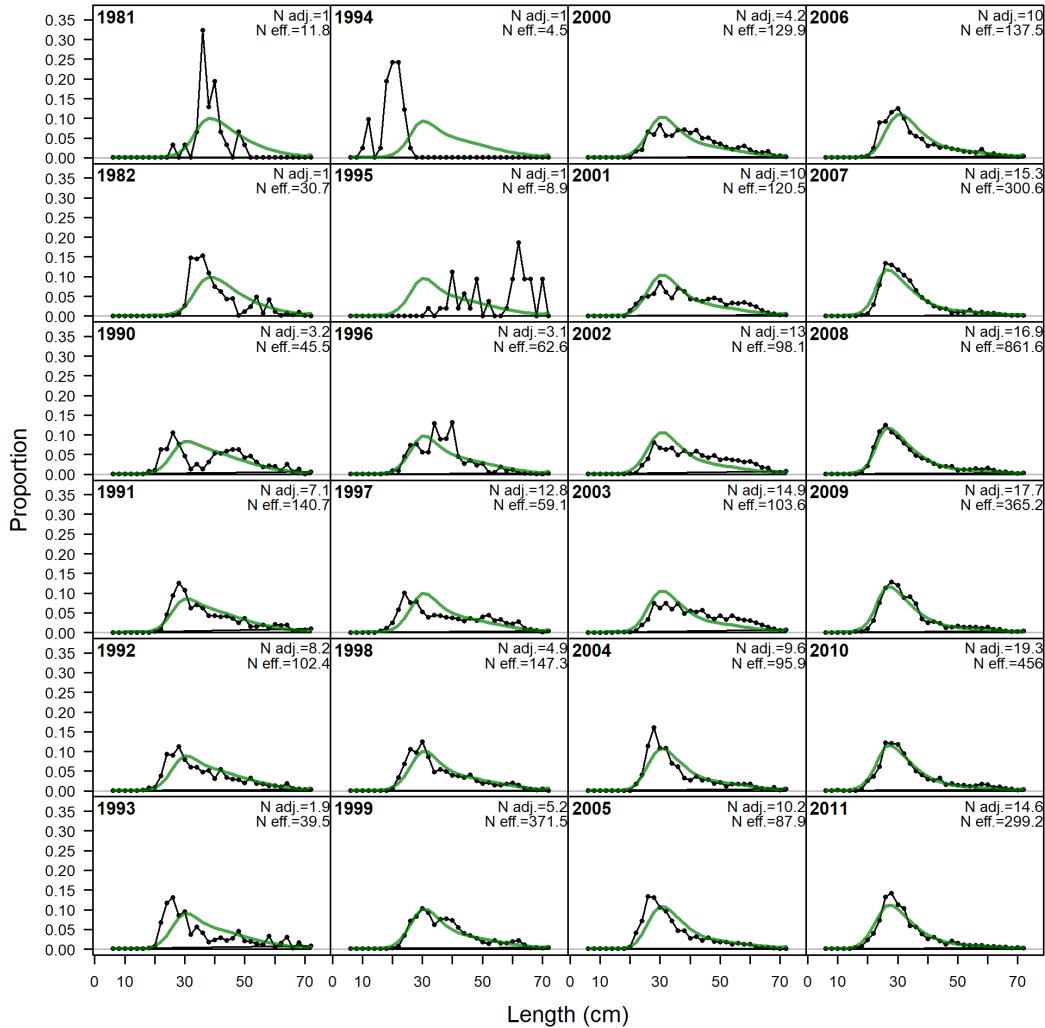


Figure 33: Annual length comps and model fit for North trawl retained catch. ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

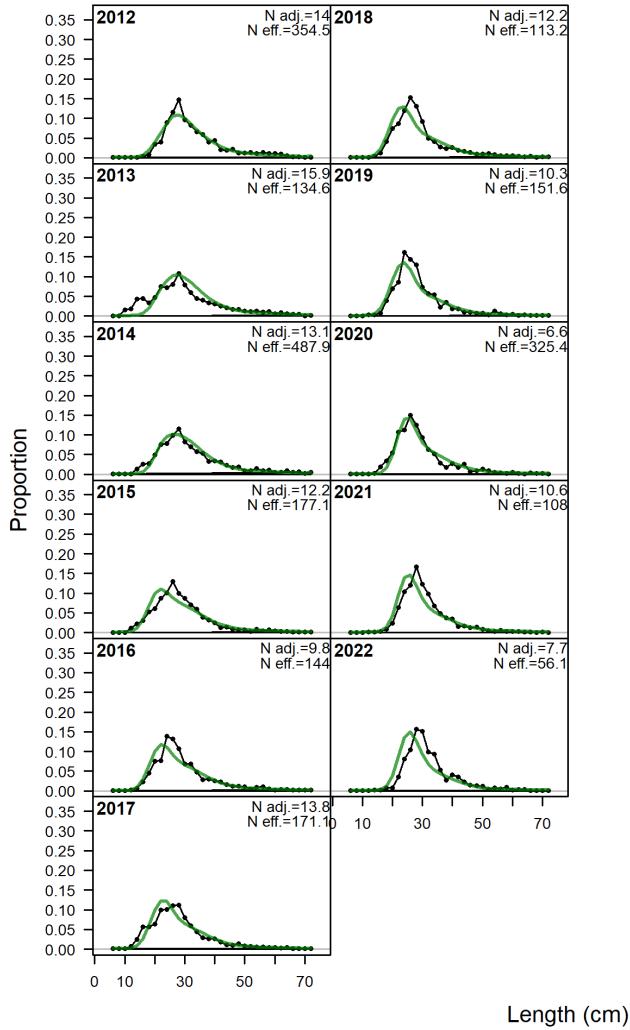


Figure 34: Annual length comps and model fit for North trawl retained catch. ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

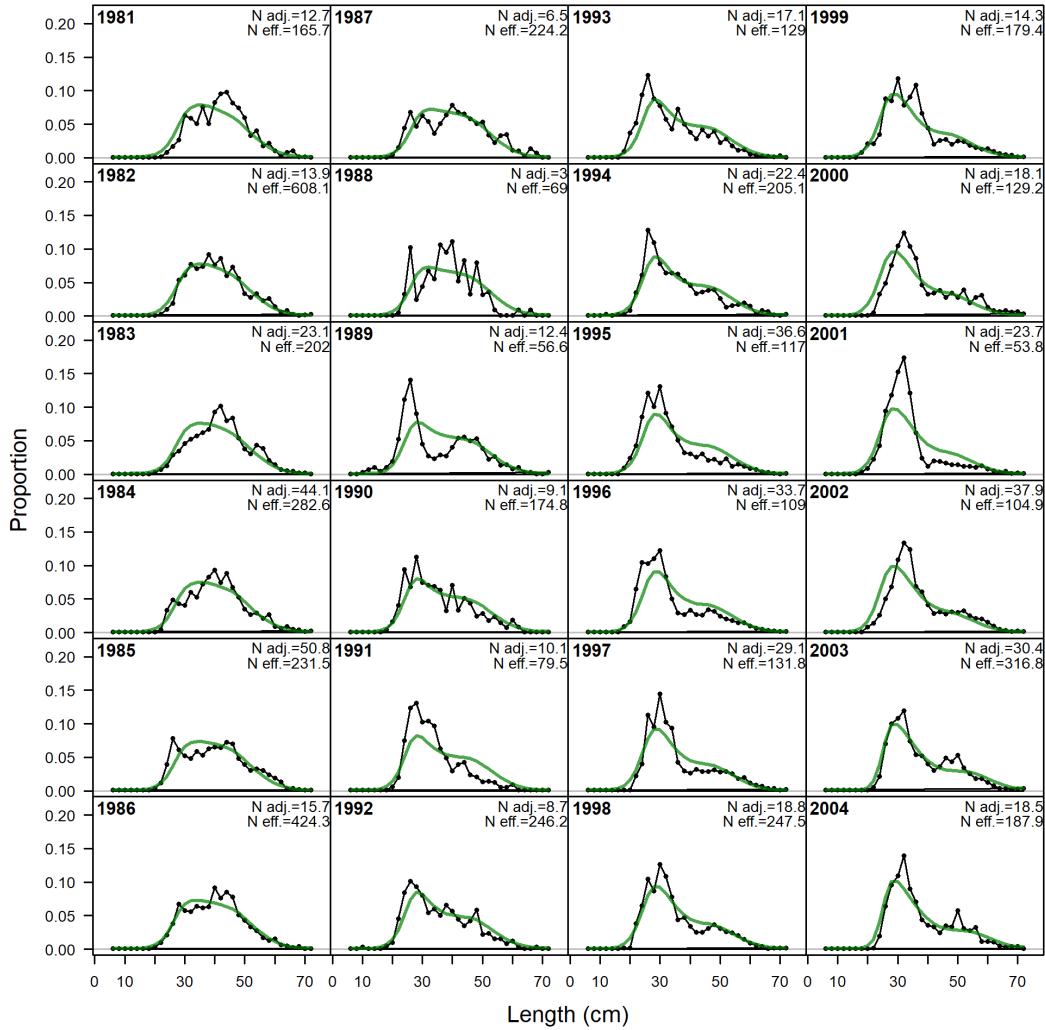


Figure 35: Annual length comps and model fit for South trawl retained catch. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

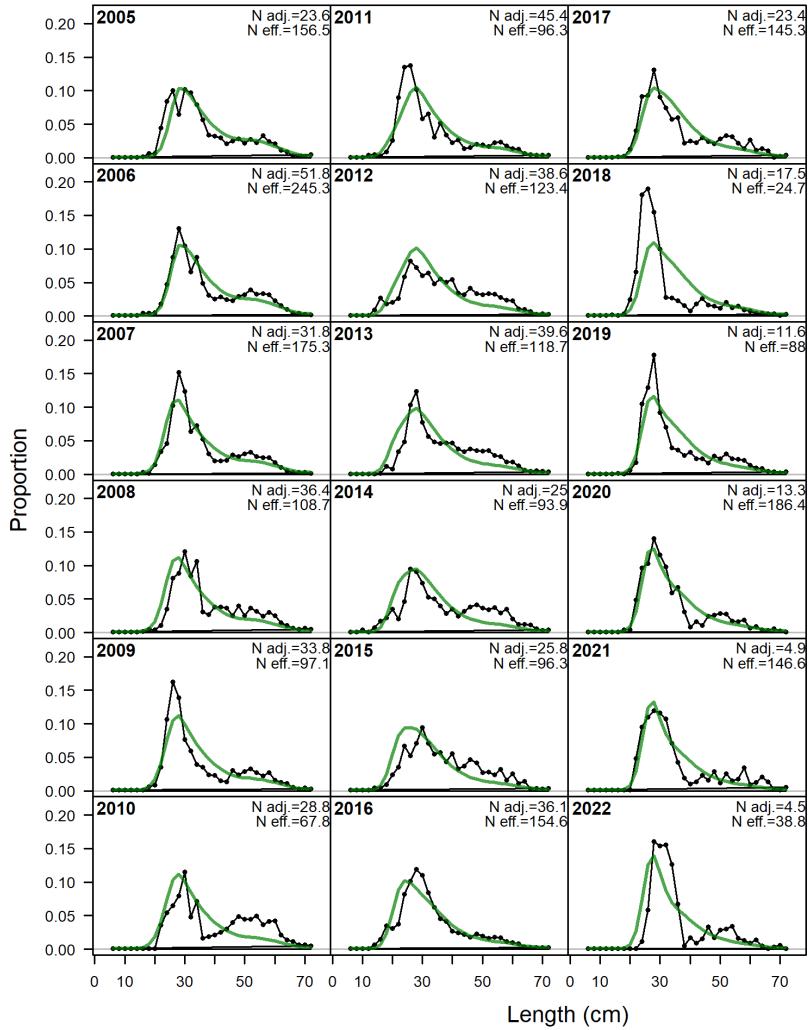


Figure 36: Annual length comps and model fit for South trawl retained catch. ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

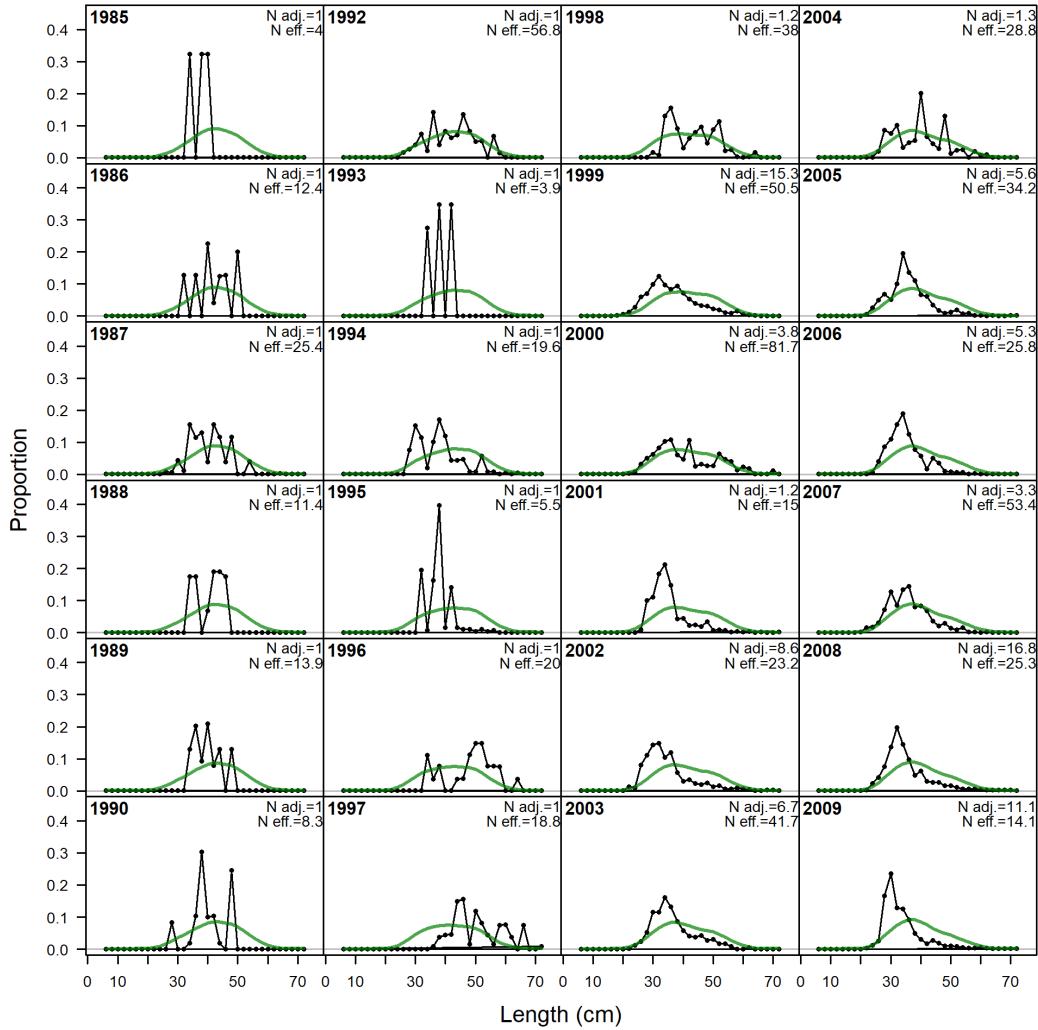


Figure 37: Annual length comps and model fit for Non-trawl retained catch. 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

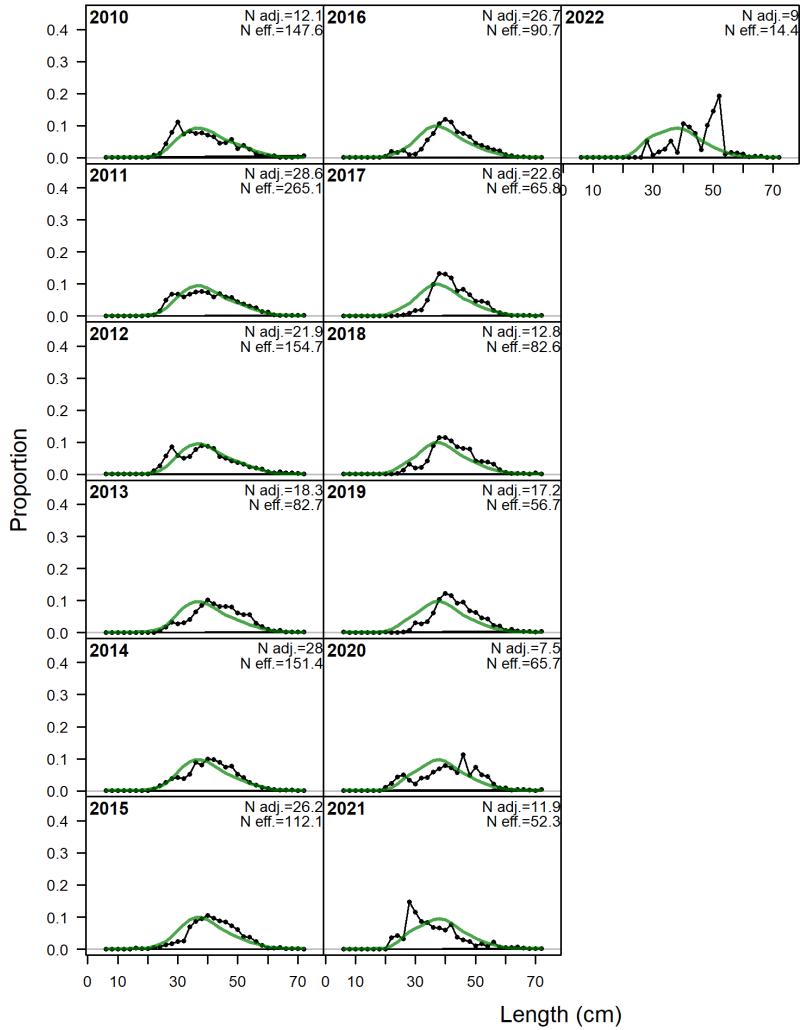


Figure 38: Annual length comps and model fit for Non-trawl retained catch. ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

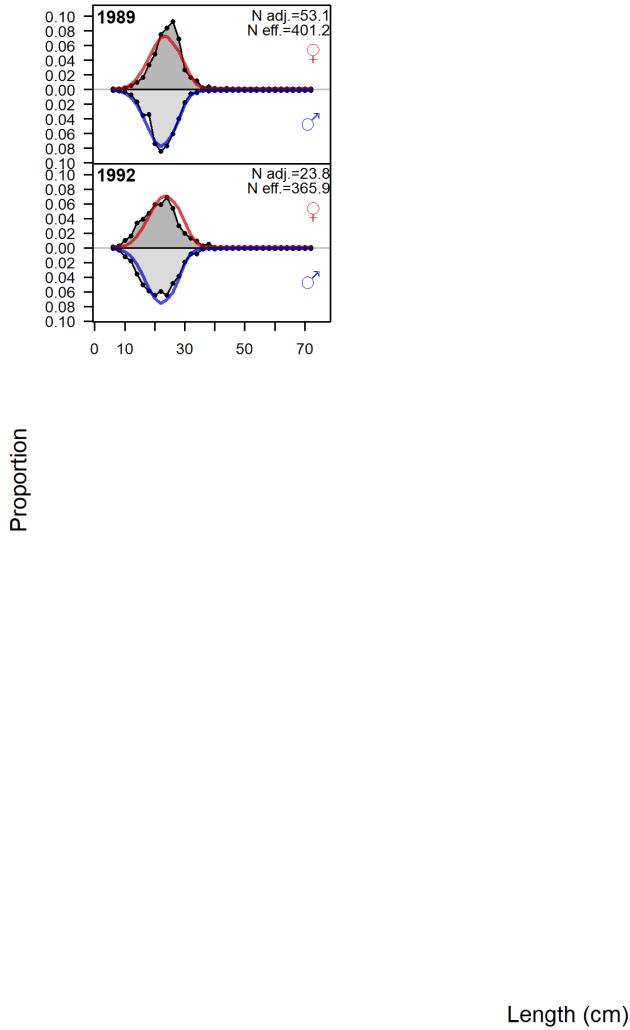


Figure 39: Length combs, whole catch, for the early-Triennial Survey (1980-1992). ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

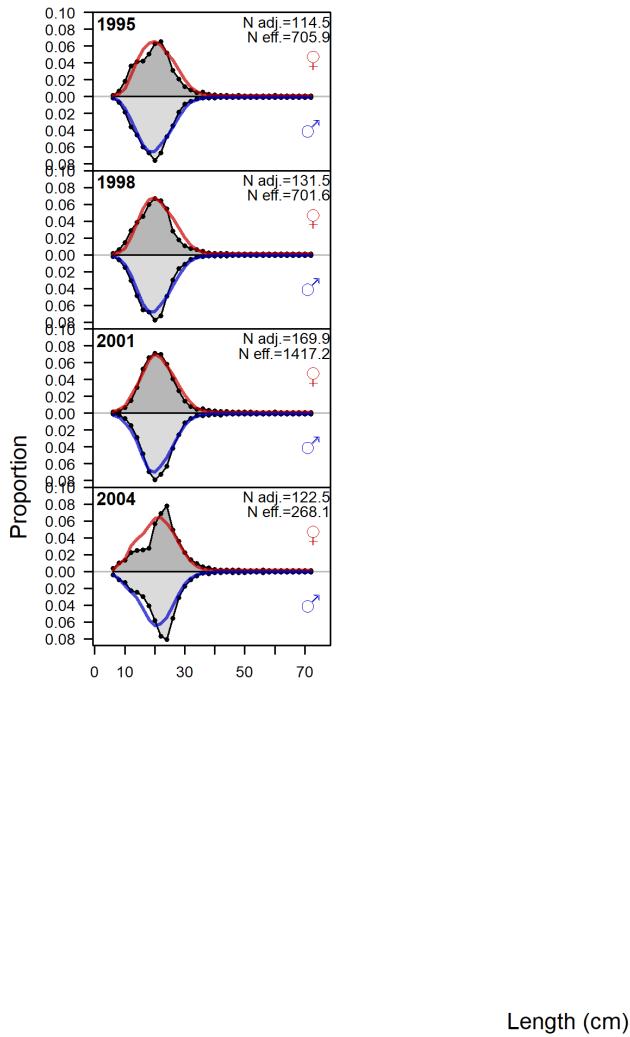


Figure 40: Length comps, whole catch, for the late-Triennial Survey (1995-2004). ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

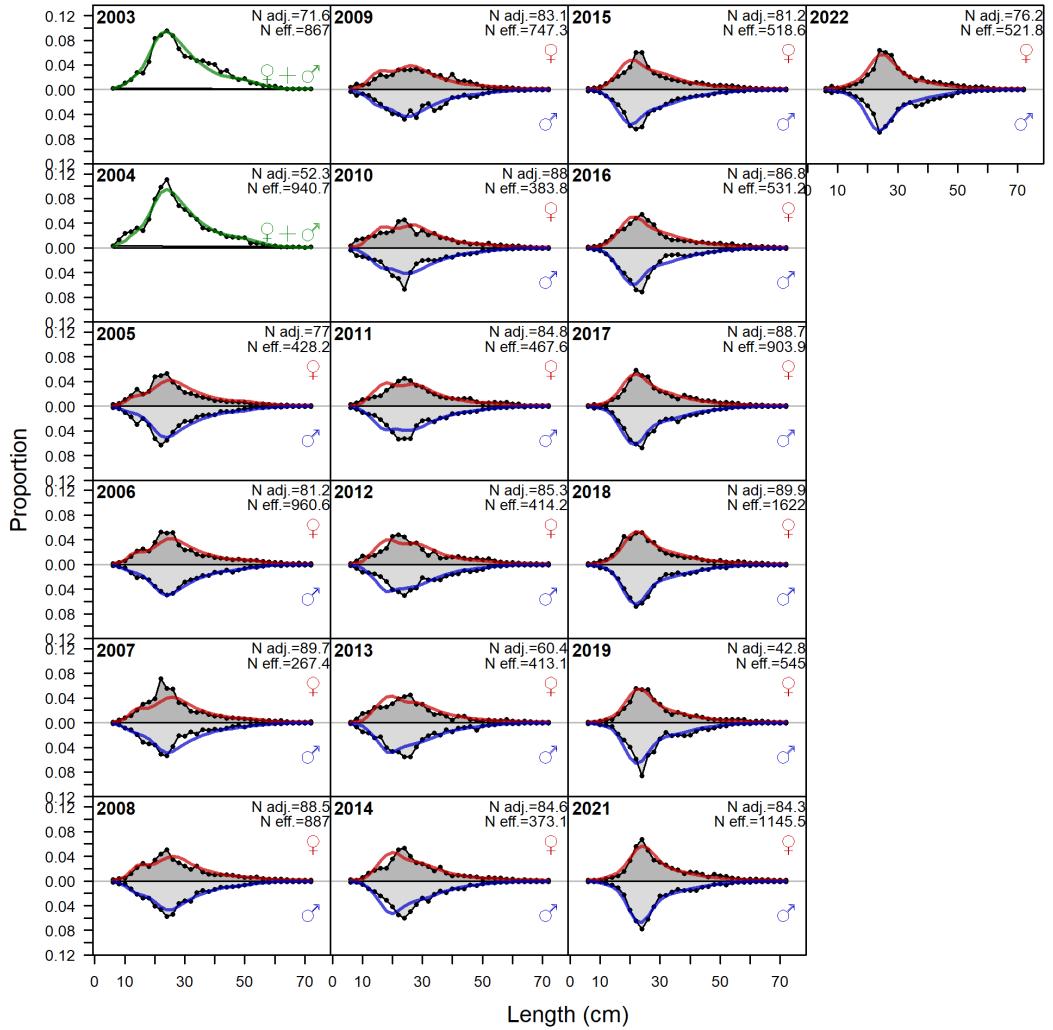


Figure 41: Length comps, whole catch, for the WCGBTS. ‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

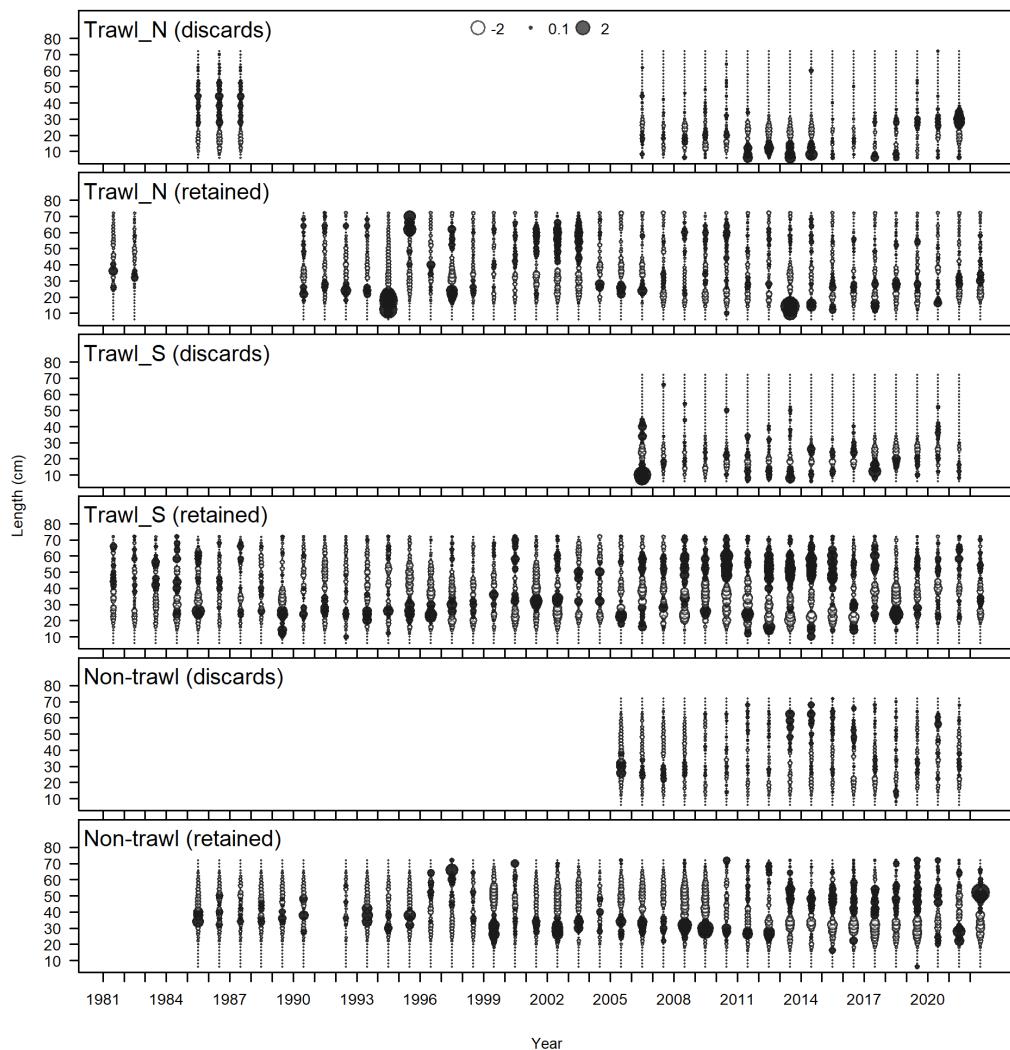


Figure 42: Pearson residuals, whole catch, for the three fisheries fleets. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

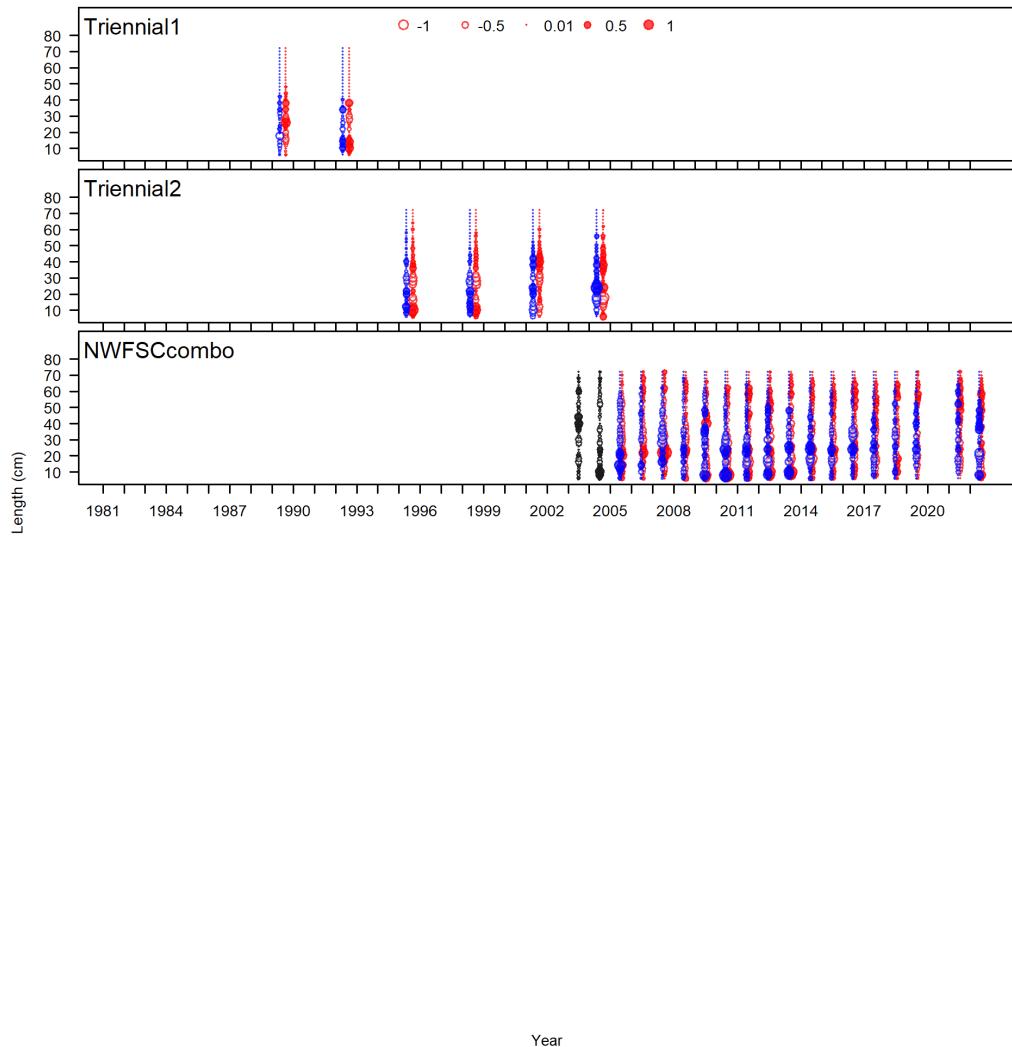


Figure 43: Pearson residuals, whole catch, for the three scientific surveys. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). Red bubbles are female, blue bubbles are male, and grey bubble are unsexed.

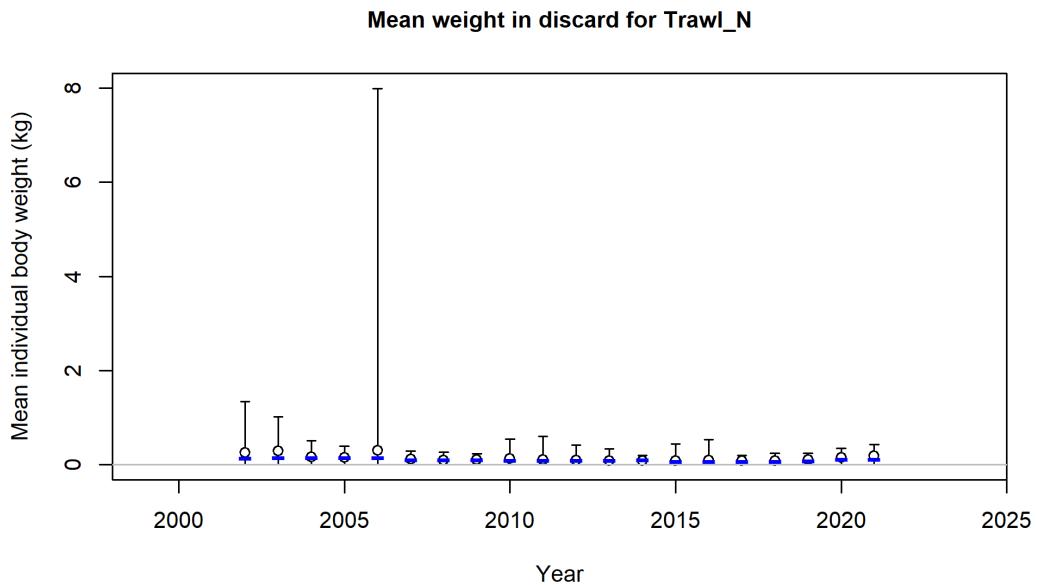


Figure 44: Mean individual body weight (kg) in discard for the North trawl fleet.

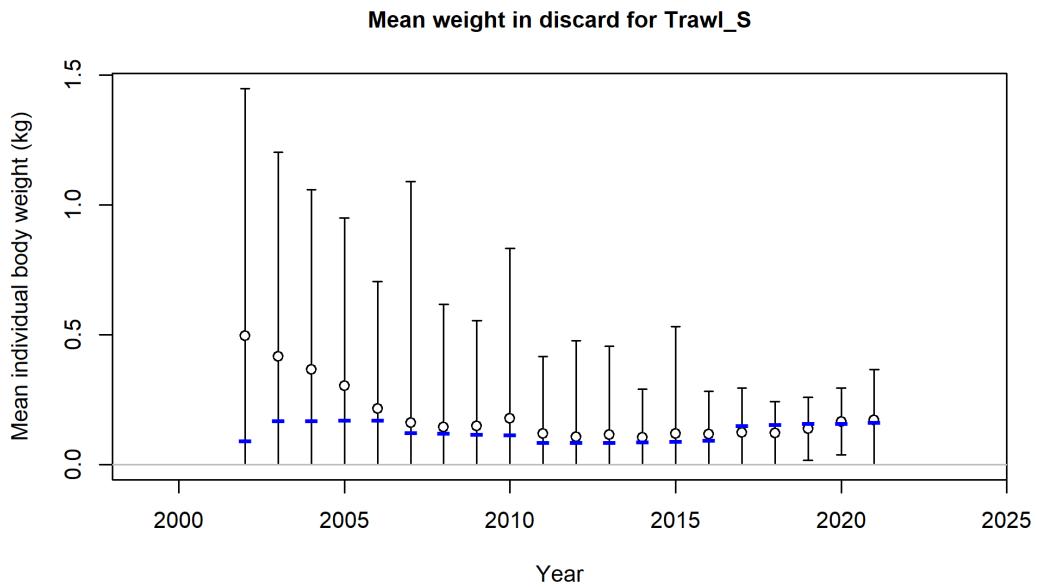


Figure 45: Mean individual body weight (kg) in discard for the South trawl fleet.

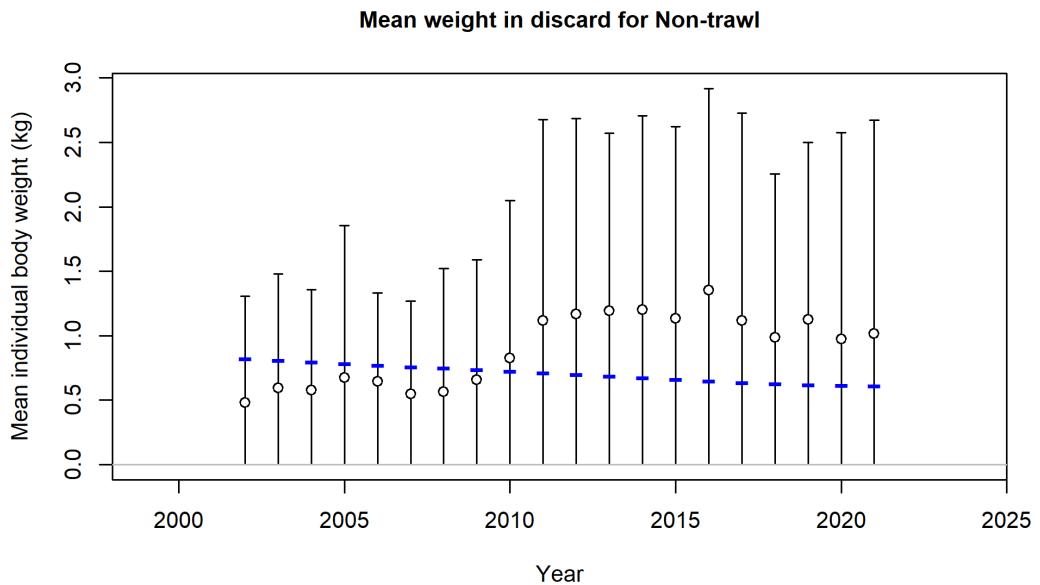


Figure 46: Mean individual body weight (kg) in discard for the Non-trawl fleet.

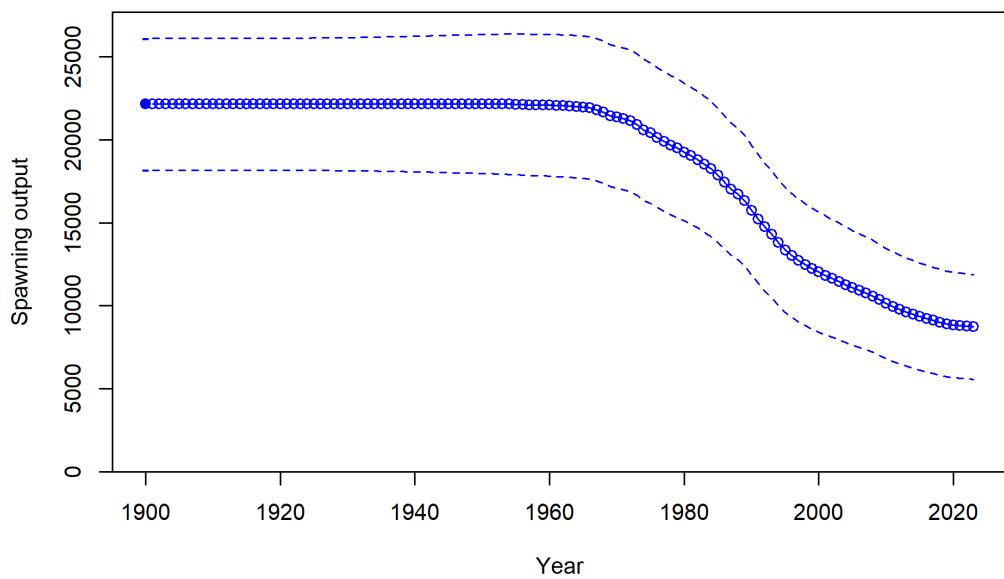


Figure 47: Spawning output (eggs) with 95% asymptotic intervals.

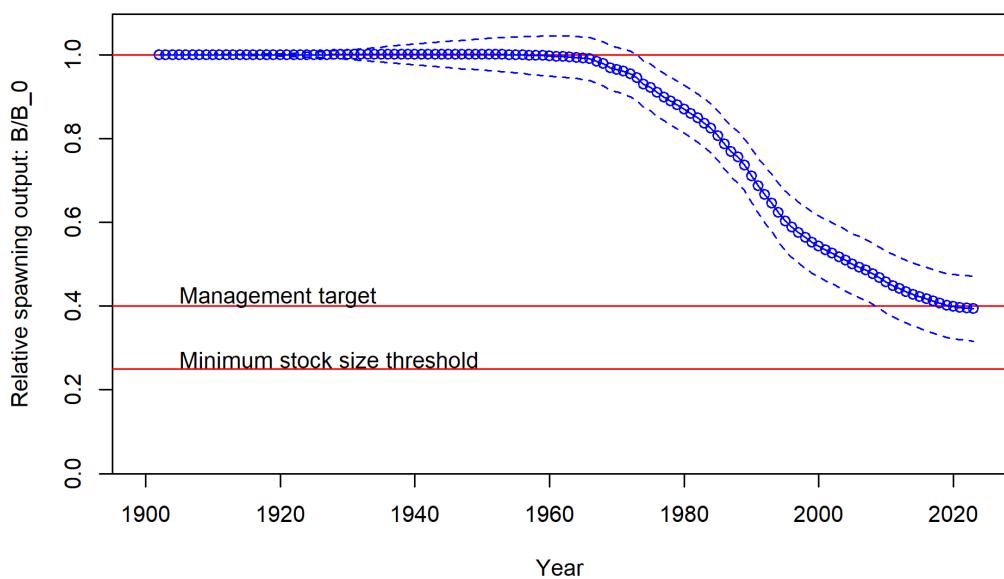


Figure 48: Relative spawning output: B/B_0 with 95% asymptotic intervals.

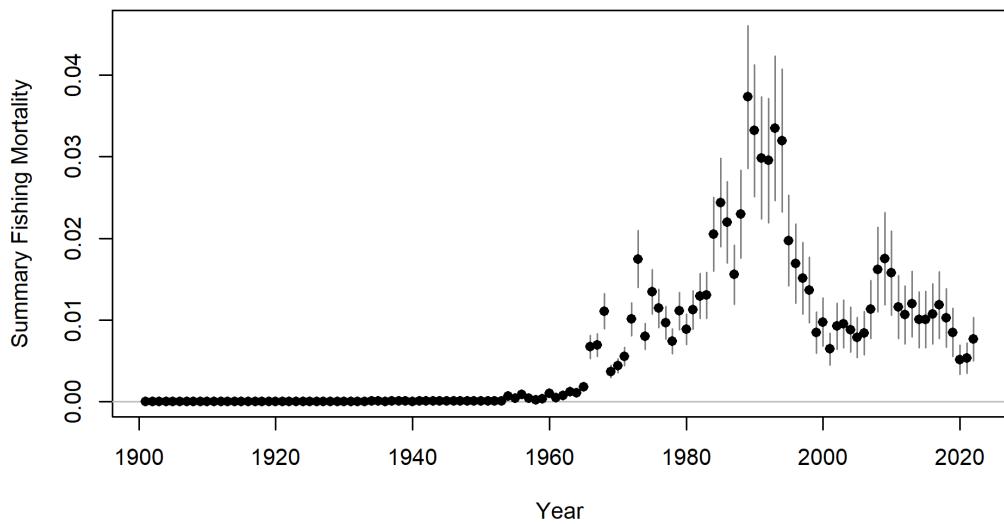


Figure 49: Summary fishing mortality rate (total landings / summary biomass).

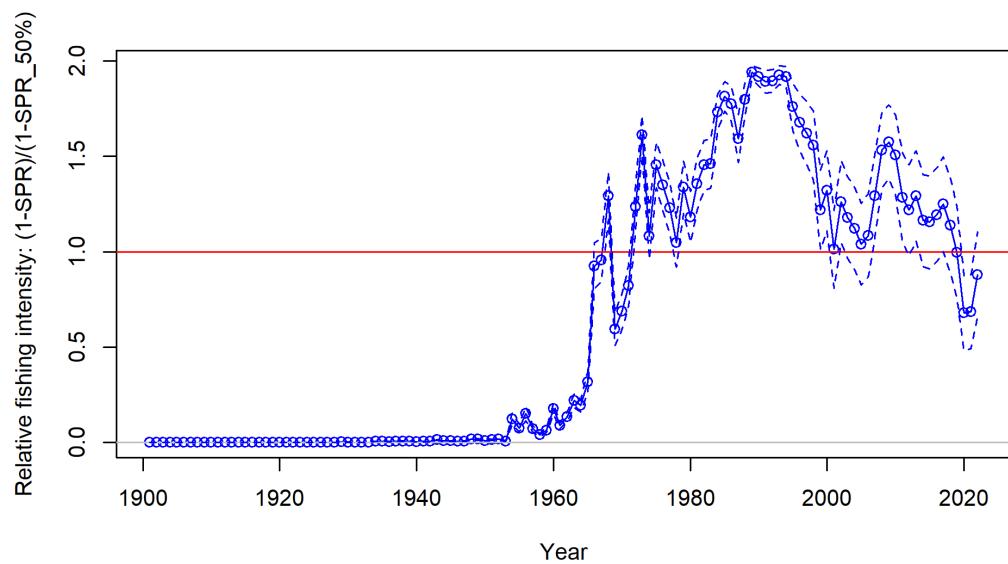


Figure 50: Estimated relative fishing intensity as a function of spawning potential ratio (SPR).

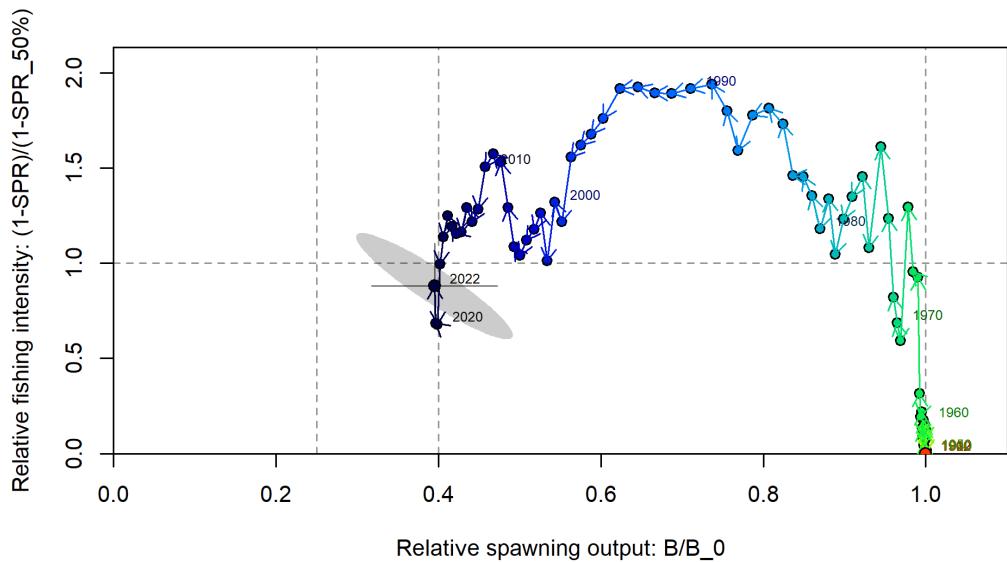


Figure 51: Phase plot of biomass ratio vs. spawning potential ratio (SPR) ratio. Points represent the annual biomass ratio and SPR ratio. Lines through the final point show 95% intervals based on the asymptotic uncertainty for each dimension, while the shaded ellipse is a 95% region accounting for estimated correlation between the two quantities.

8.4 Likelihood Profiles, Retrospectives, and Sensitivity Analyses

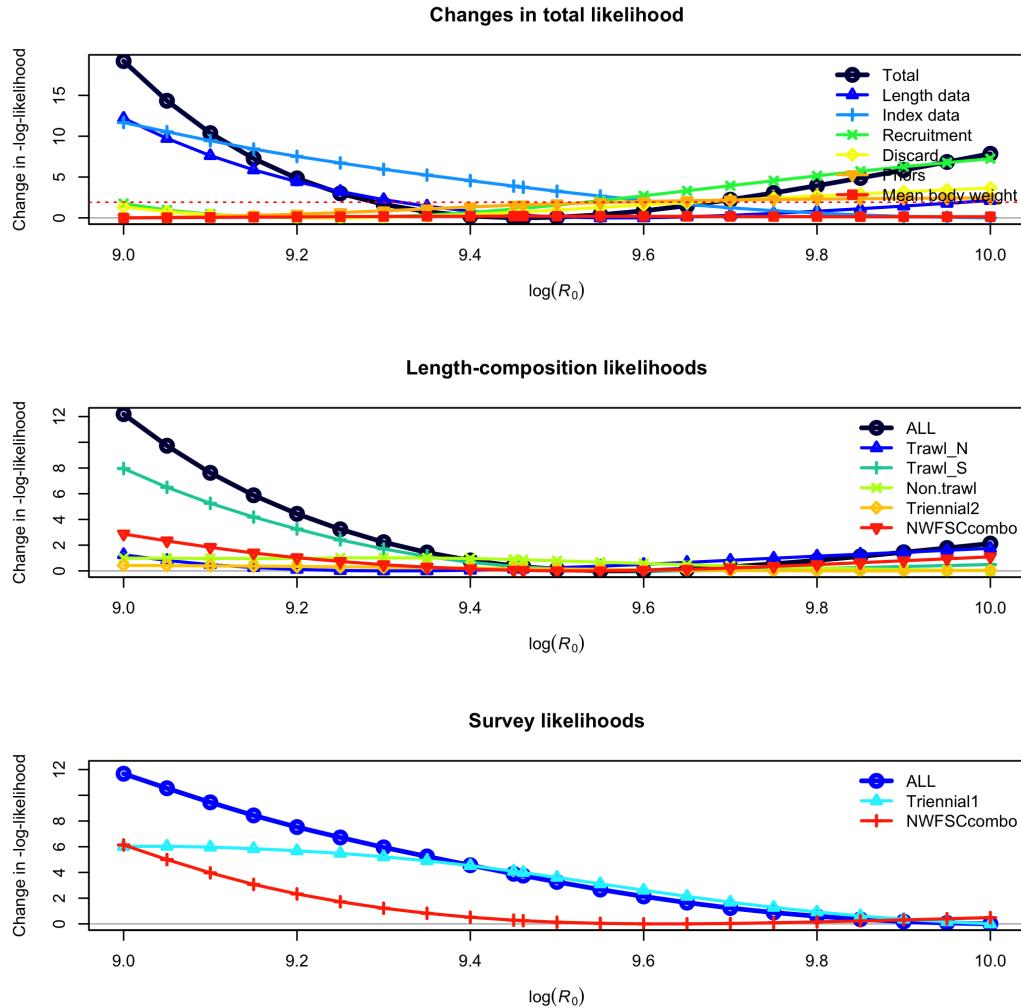


Figure 52: Piner panel plot showing the impact of changing R_0 on the overall (top), length composition (middle), and survy (bottom) likelihoods.

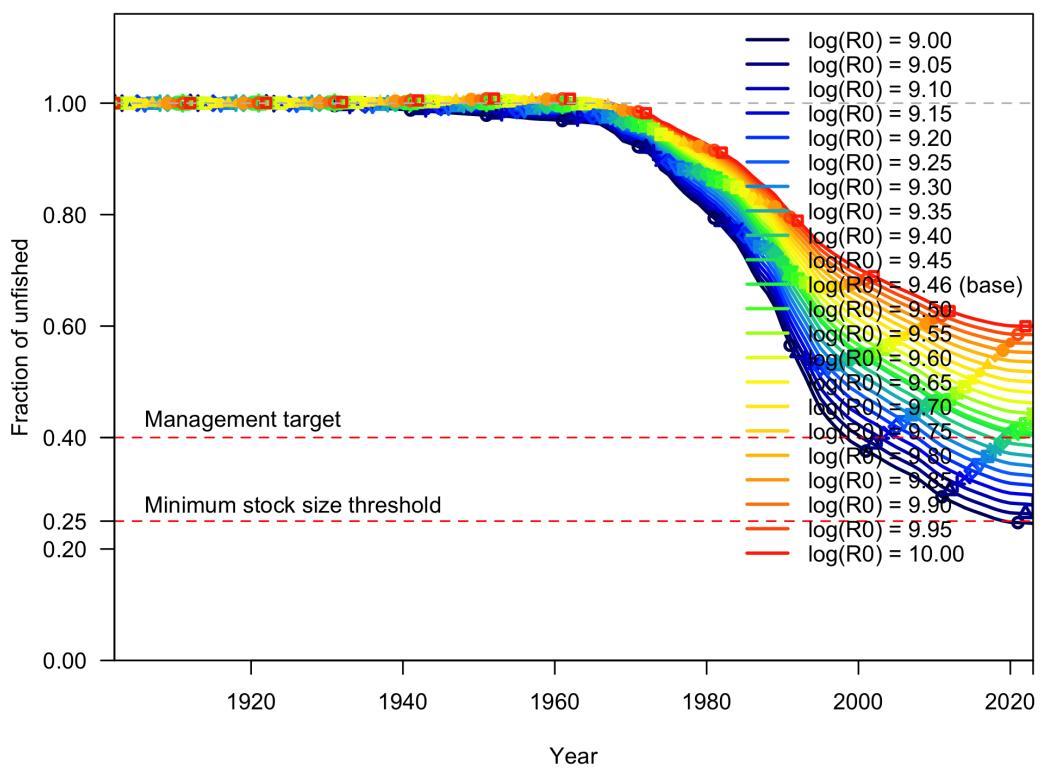


Figure 53: High to low values of R_0 and impact on spawning output.

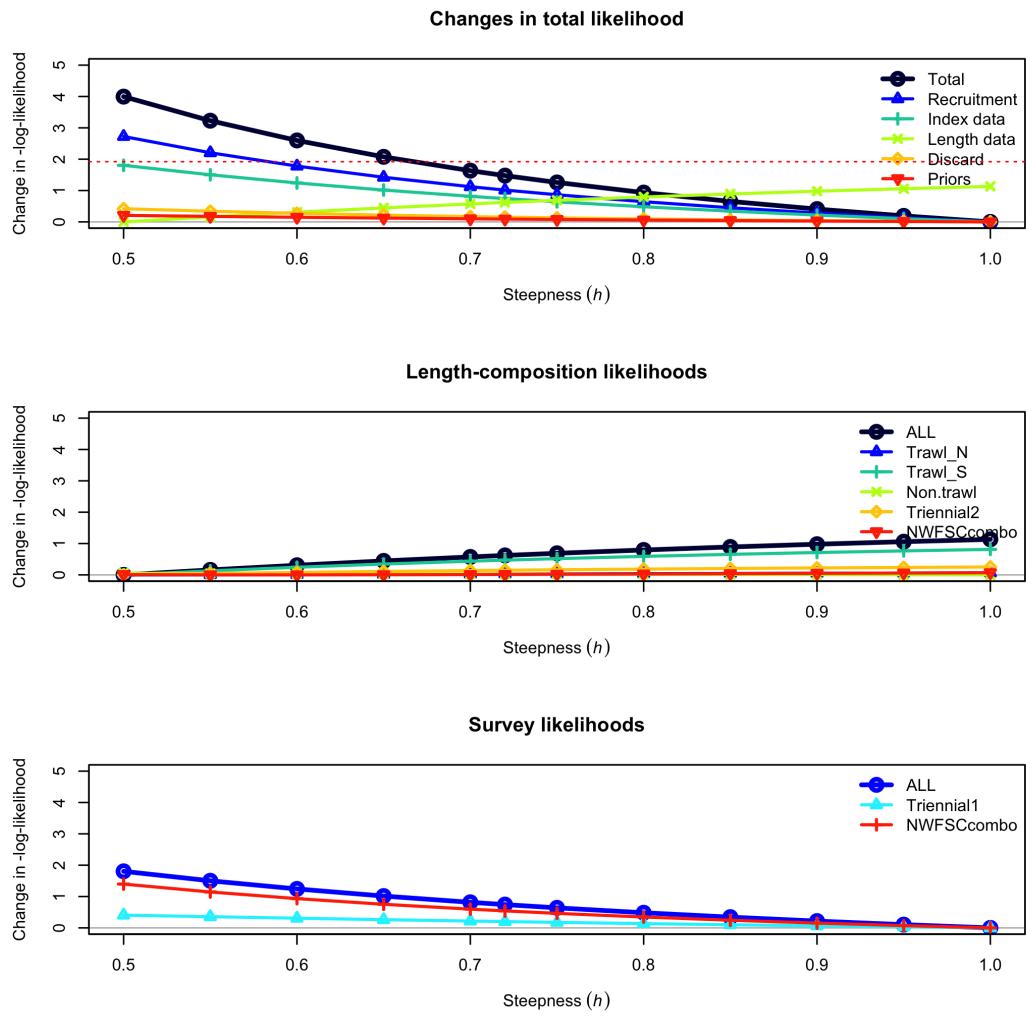


Figure 54: Piner panel plot showing the impact of changing h on the overall (top), length composition (middle), and survy (bottom) likeihoods.

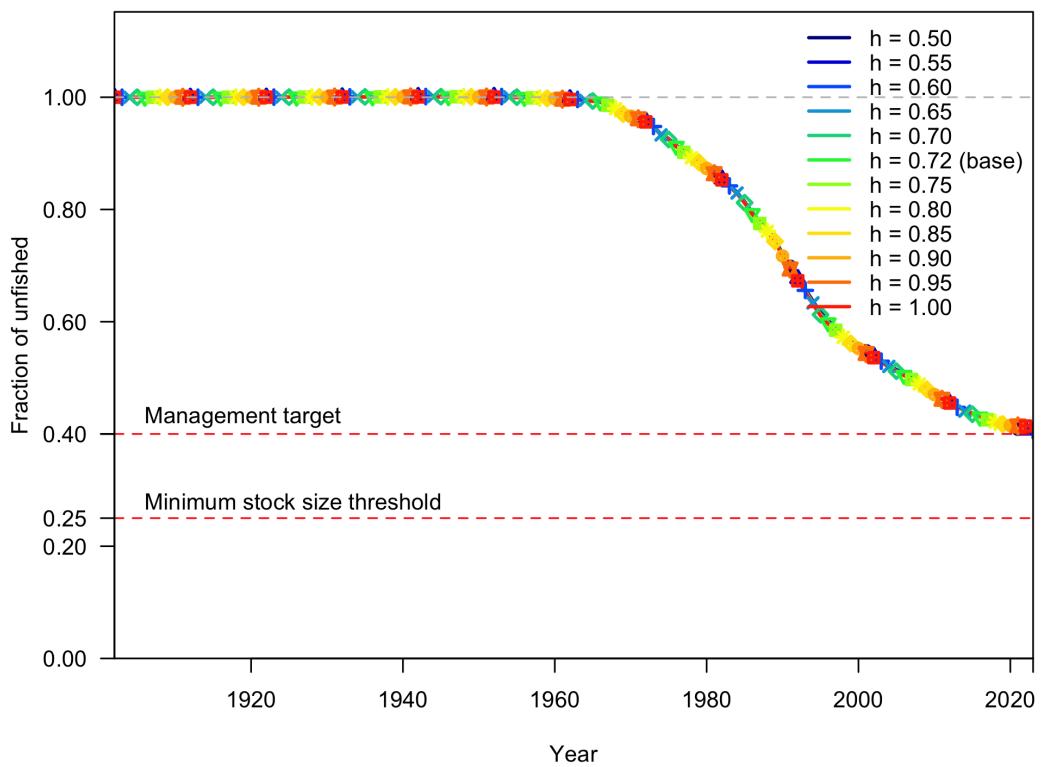


Figure 55: High to low values of h and impact on relative spawning output.

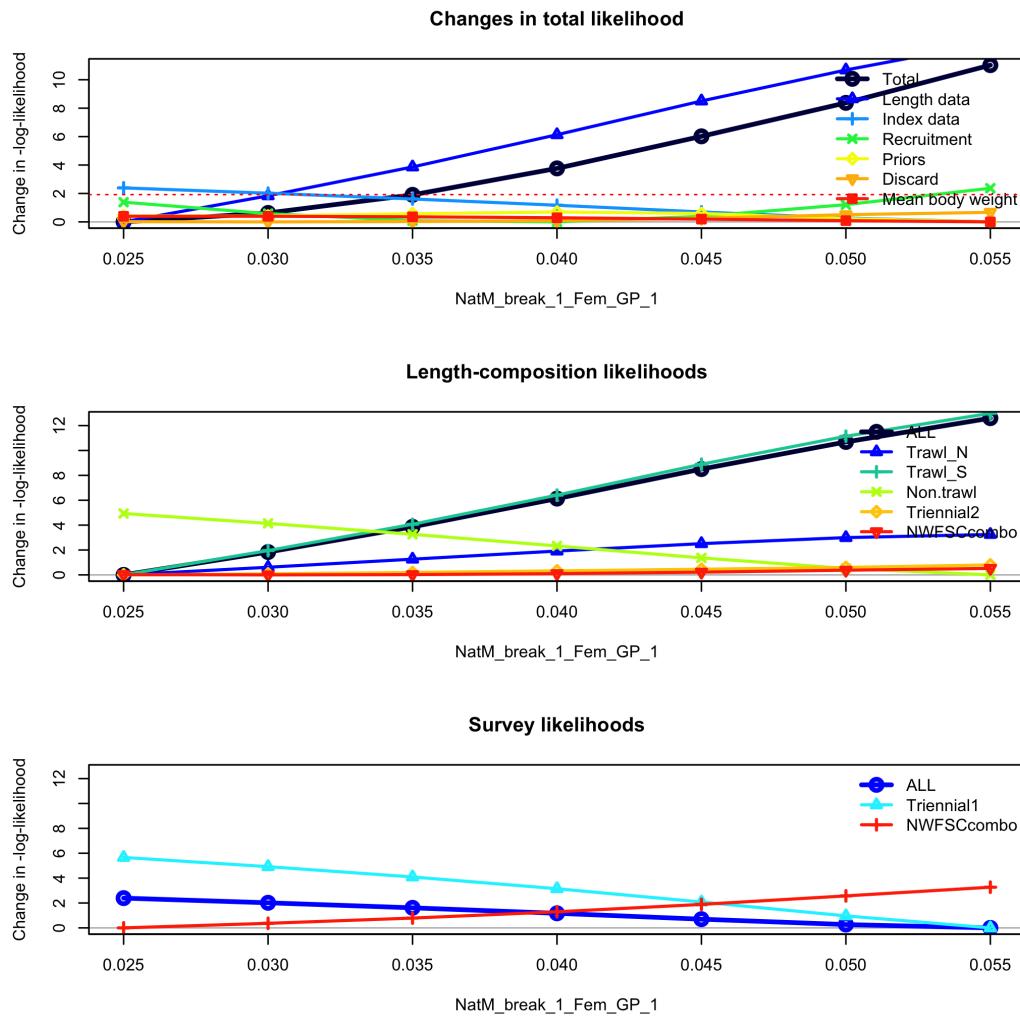


Figure 56: Piner panel plot showing the impact of changing natural mortality (M) on the overall (top), length composition (middle), and survey (bottom) likelihoods.

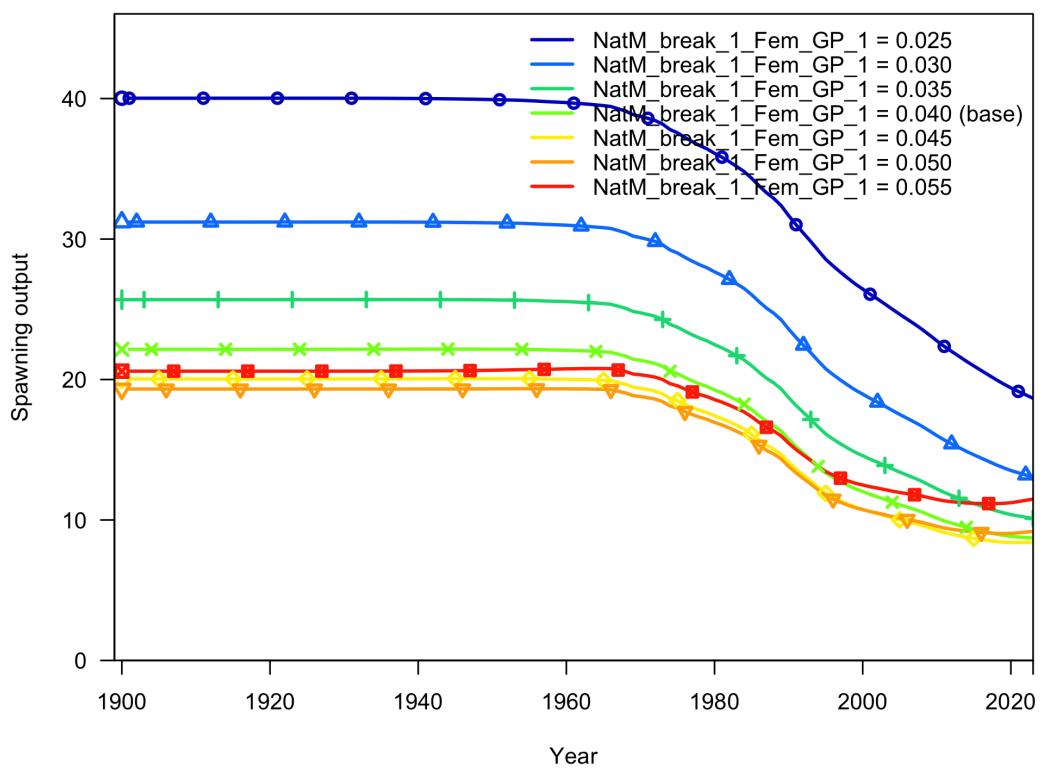


Figure 57: High to low values of M and impact on spawning output.

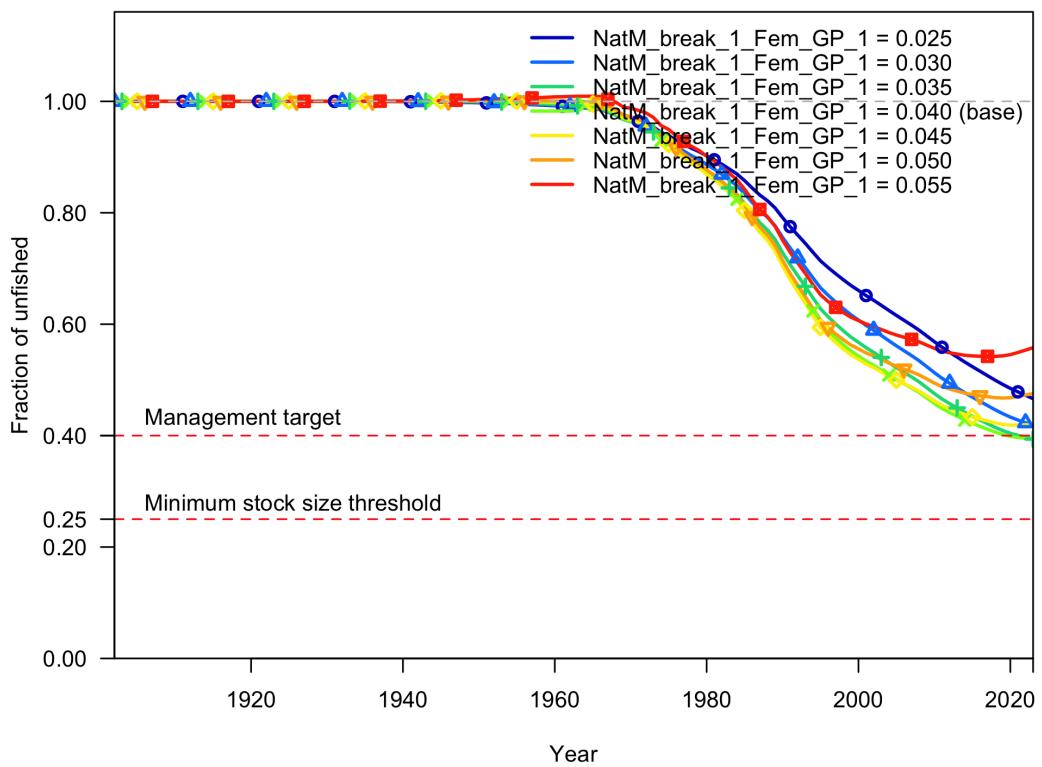


Figure 58: High to low values of M and impact on relative spawning output.

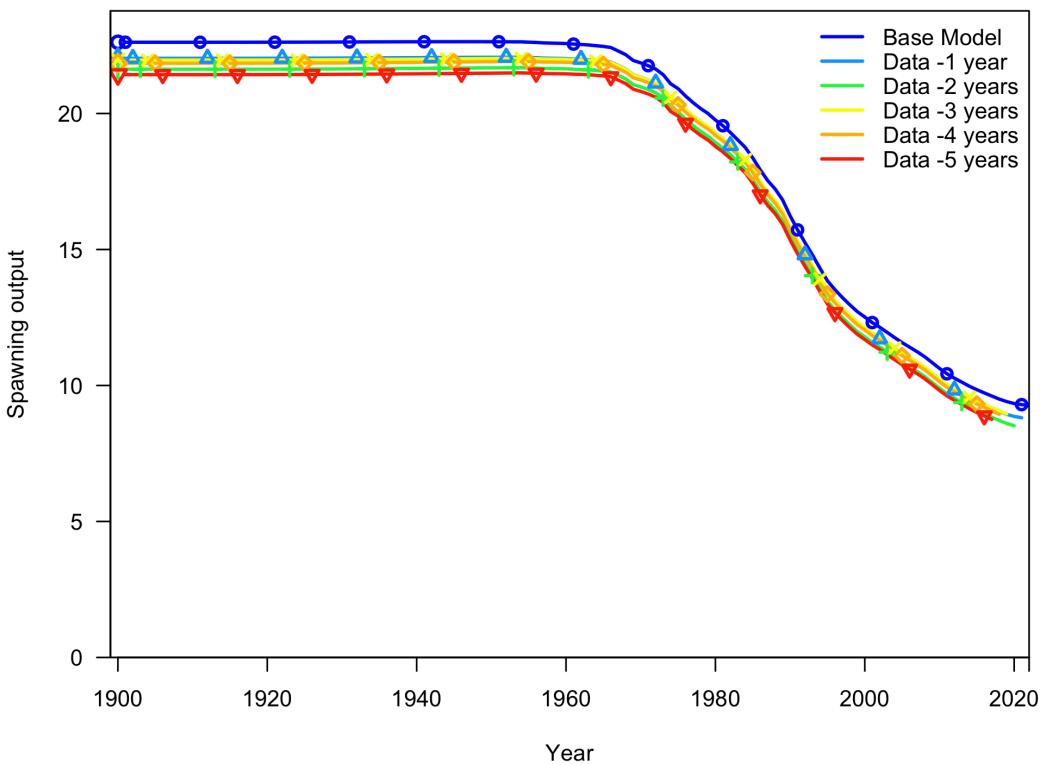


Figure 59: Impact of removing 1-5 years of data on estimated spawning output from retrospective analysis.

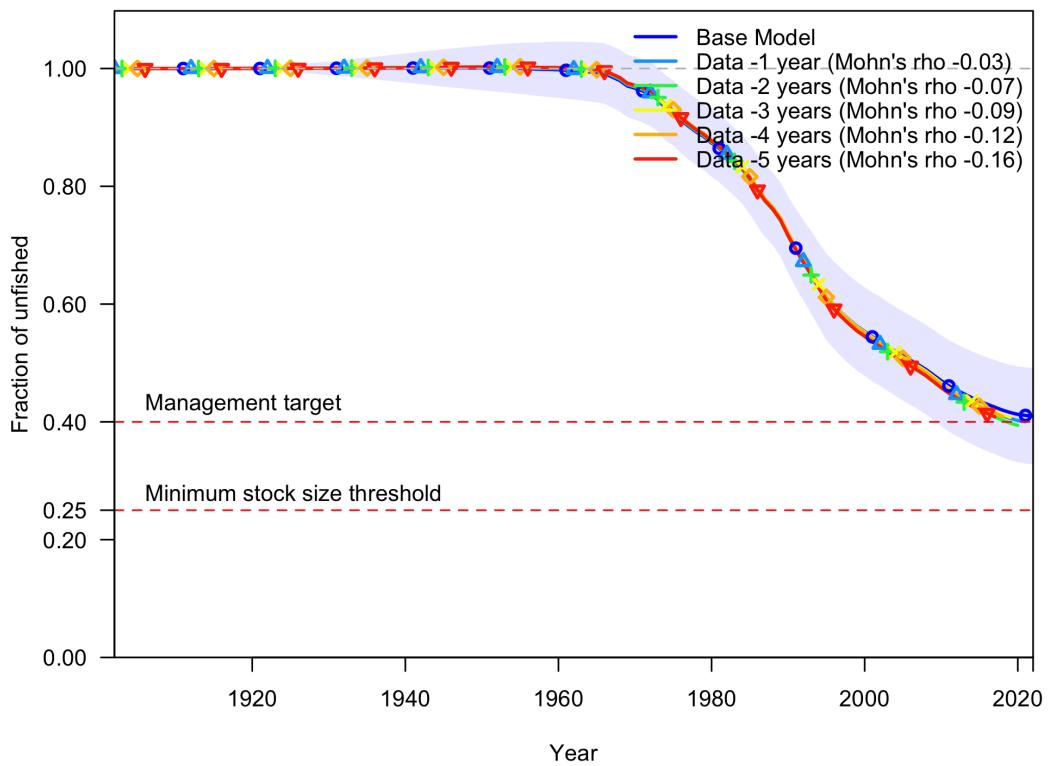


Figure 60: Impact of removing 1-5 years of data on estimated relative spawning output from retrospective analysis. Blue shaded region is the 95% confidence interval around the estimated timeseries from the 2023 base model.

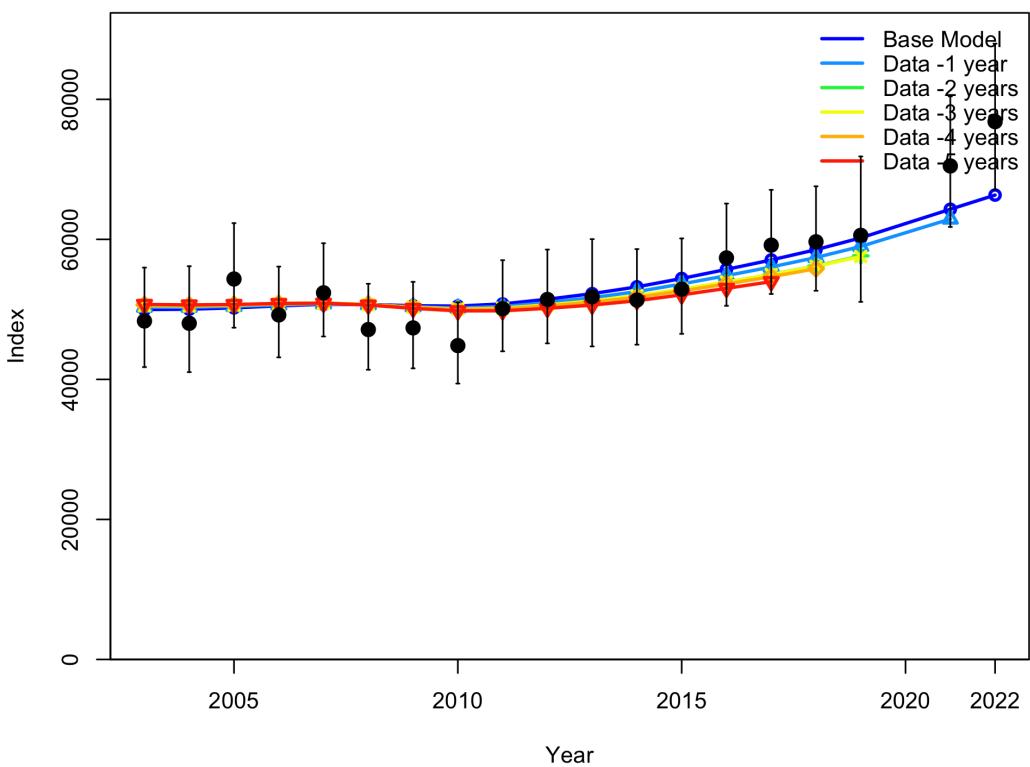


Figure 61: Impact of removing 1-5 years of data on model fit to the WCGBTS indices of abundance.

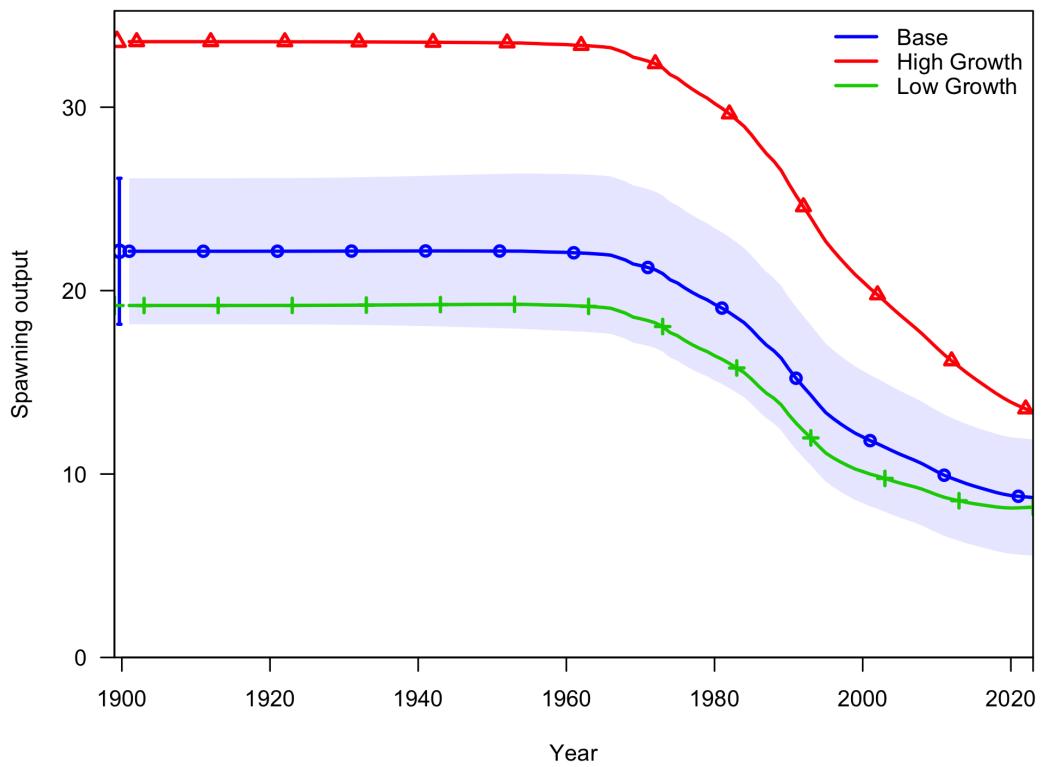


Figure 62: Spawning output comparisons of the base model and high growth and low growth assumptions.

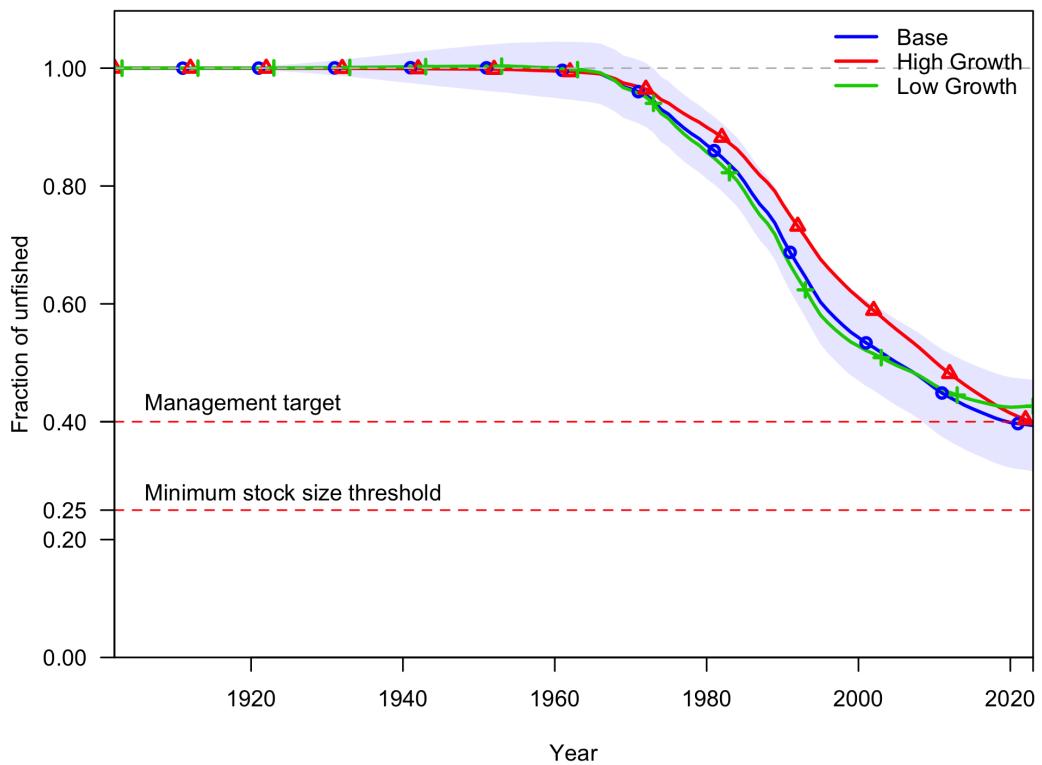


Figure 63: Relative spawning output comparisons of the base model and high growth and low growth assumptions.

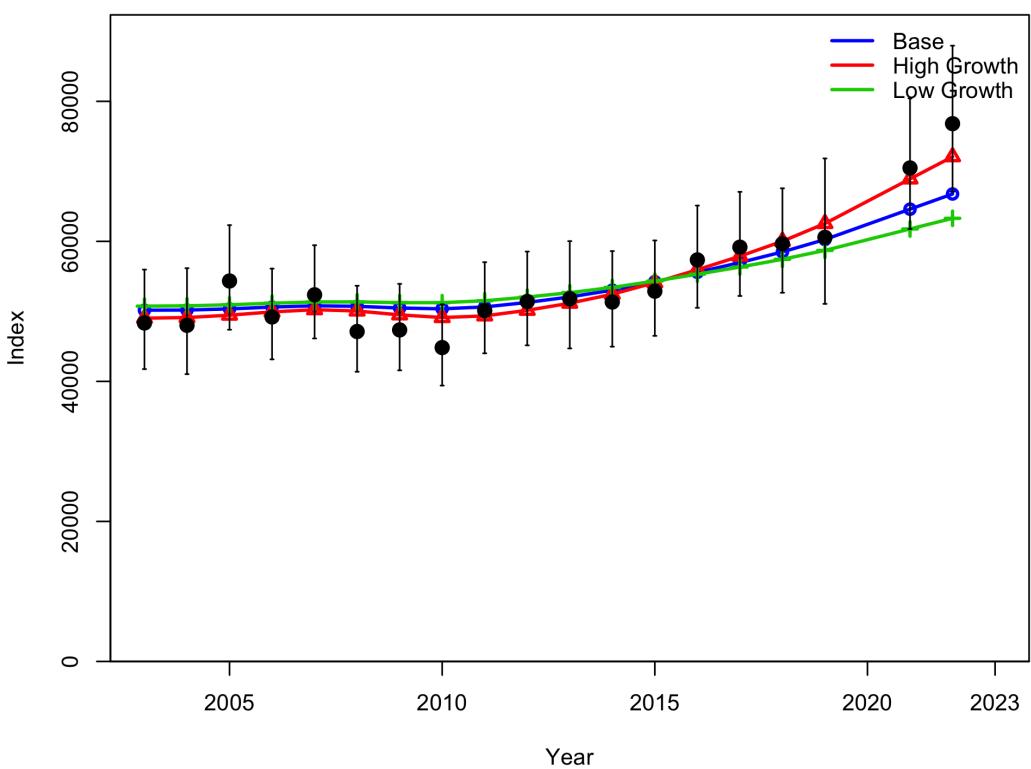


Figure 64: Comparison of fits to combo survey data between the base model and high growth and low growth sensitivities.

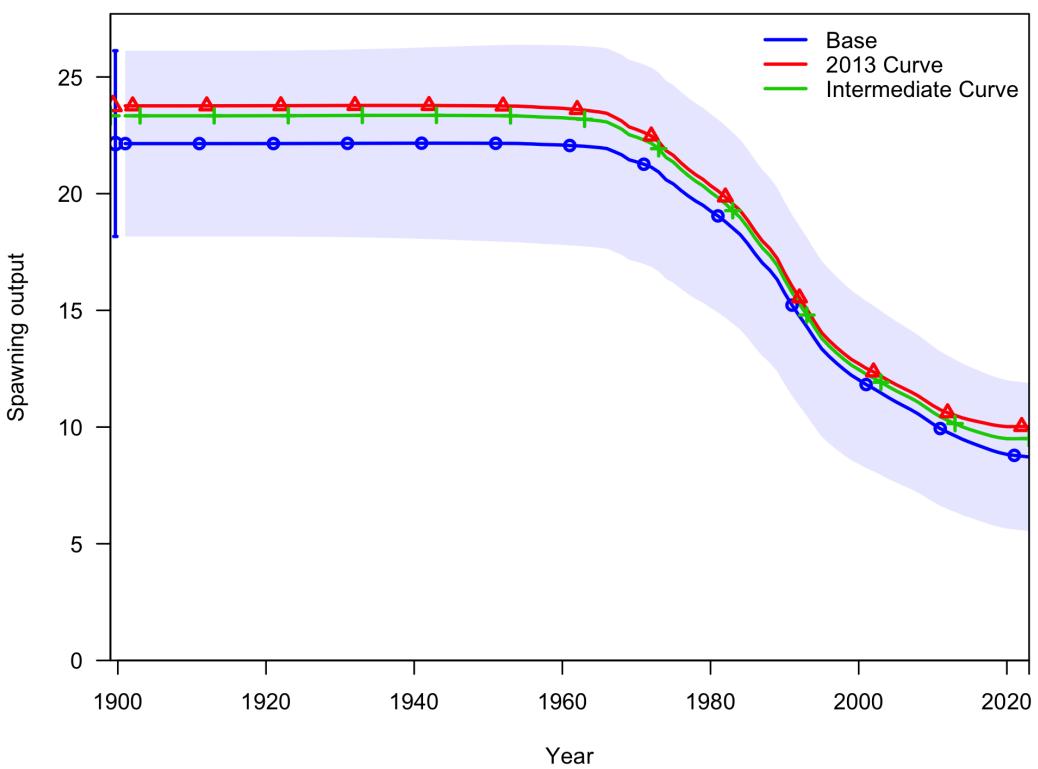


Figure 65: Spawning output comparisons of the base model and maturity sensitivities.

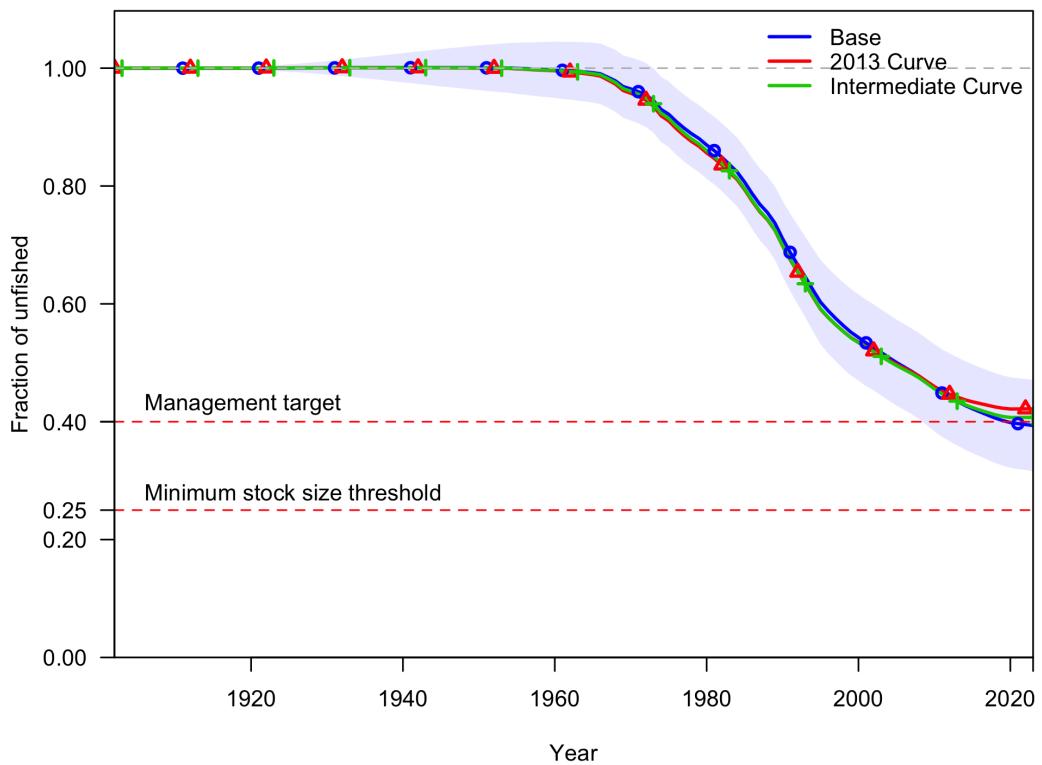


Figure 66: Relative spawning output comparisons of the base model and maturity sensitivities.

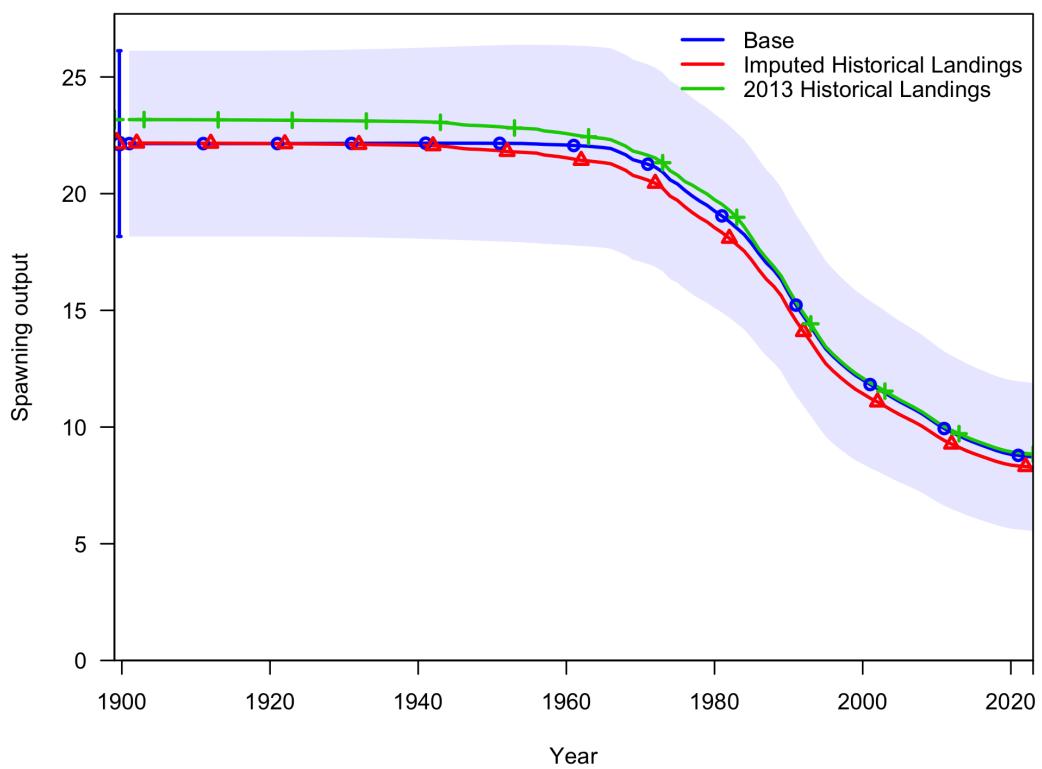


Figure 67: Spawning output comparisons of the base model and landing sensitivities.

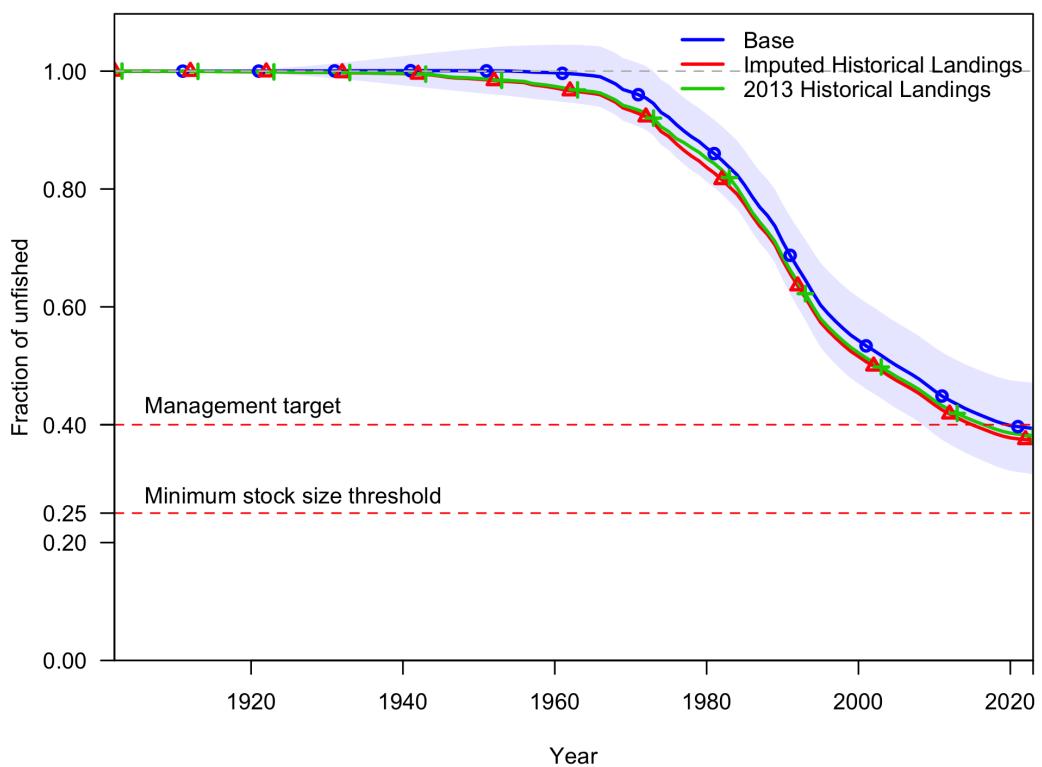


Figure 68: Relative spawning output comparisons of the base model and landing sensitivities.

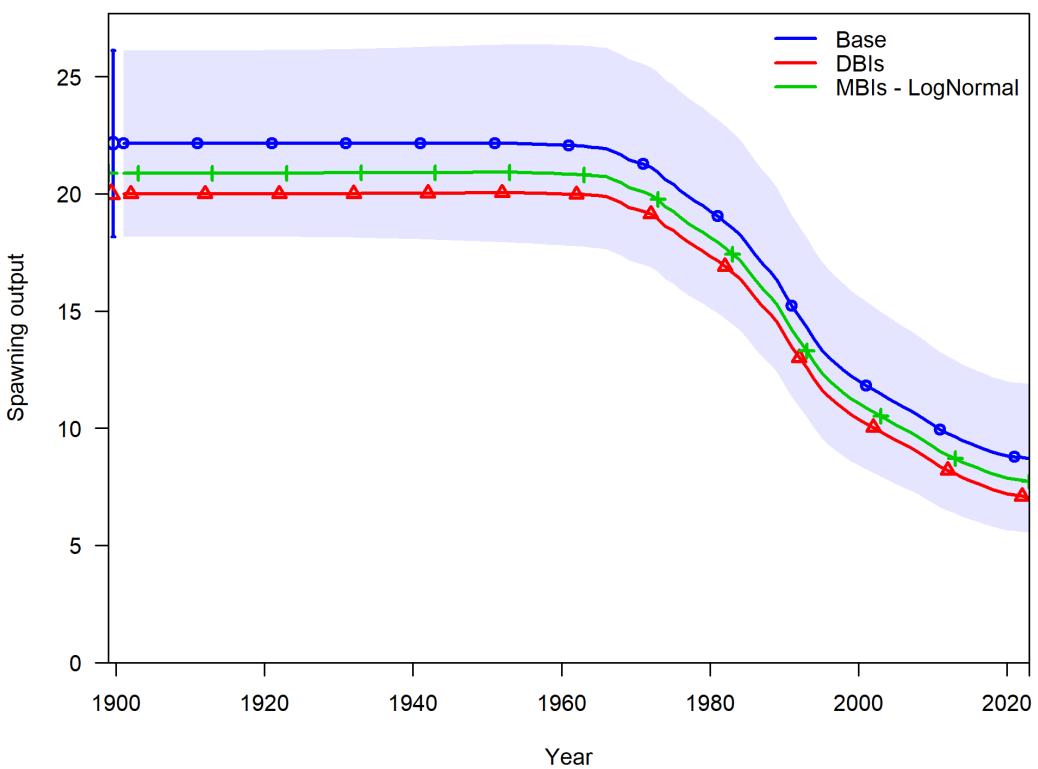


Figure 69: Spawning output comparisons of the base model and survey sensitivities.

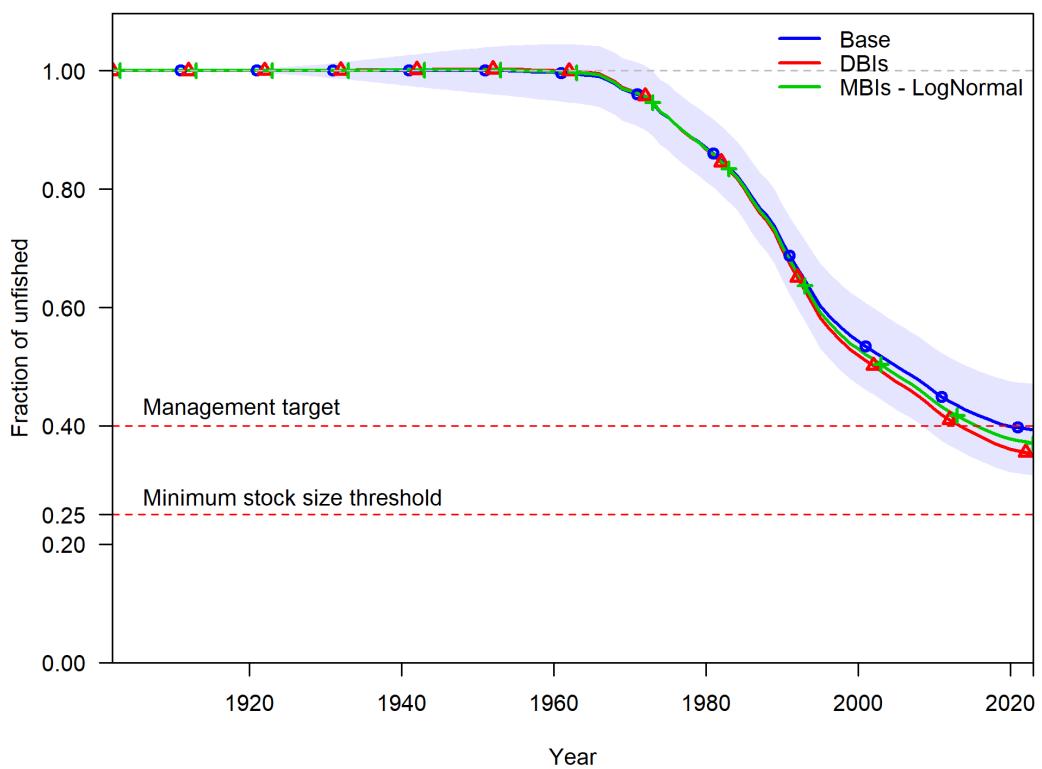


Figure 70: Relative spawning output comparisons of the base model and survey sensitivities.