Status of Sablefish (*Anoplopoma fimbria*) along the US West coast in 2021

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Stock

This update assessment reports the status of sablefish (*Anoplopoma fimbria*) off the US West coast using data through 2020. The resource is modeled as a single stock; however, sablefish disperse to and from offshore seamounts, along the coastal waters of the US West Coast, Canada, and Alaska, and across the Aleutian Islands to the western Pacific. Their movement is not explicitly accounted for in this analysis.

Catches

For the 2019 benchmark assessment, a variety of sources were used to reconstruct state-specific historical sablefish landings (i.e., fish brought to market), creating a series of landings from 1890 to present. In general, these reconstructions are more reliable than those for many other groundfish species because of the consistent identification of sablefish to the species level. Historical-landings reconstructions for sablefish have been completed for California, Oregon, and Washington, extending landings to the beginning of the US West Coast sablefish fishery (Figures 1 and 2). Fishery discard rates and weights were fit within the assessment model, i.e., simultaneous estimation of total catches and other model parameters. This internal estimation can result in model estimates of total mortality that differ between stock assessments, even when the input landings remain unchanged, due to changes in fixed and estimated parameter values, priors, or parameterizations. Model estimates of fishery discards in this update assessment resulted in model estimated total dead catches that were an average of 1.84% larger than the landings input into the stock assessment model over the last decade.

Historically, sablefish landings were just below recent landings (<4,000 mt) until the end of the 1960s and were primarily harvested by fixed gear (Figure 1). Large catches (24,395 mt) by foreign vessels fishing pot gear in 1976 resulted in the largest landings reported in a single year. A rapid rise in domestic pot and trawl landings followed this peak removal, such that, on average, nearly 8,400 mt of sablefish were landed per year between 1976 and 1990. Subsequently, annual landings have remained below 9,000 mt and, during the most recent decade, have been divided approximately 67%/33% between fixed and trawl gears, respectively. An Individual Fishing Quota (IFQ) program, referred to as "catch shares", was implemented for the U.S. West Coast trawl fleet beginning in 2011. Gear switching is allowed within the program such that fixed gear can be used to catch sablefish under trawl IFQ. This has resulted in changes in fleet behavior, the distribution of fishing effort, and discarding rates for both fisheries. Complete observer coverage on all vessels fishing IFQ quota became mandatory at the start of the program, while coverage in the other sectors remained stratified by port. The lack of historical observer coverage, and consequently information on total catch and age and length compositions, contributes to uncertainty regarding selectivity and retention during the historical period.

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

Year	Fixed-gear	Trawl	Total Landings	Model-Estimated Total Dead Catch
2011	4,420.85	1,728.40	6,149.25	6,253.97
2012	3,670.22	1,514.58	5,184.80	5,283.60
2013	2,585.07	1,402.13	3,987.20	4,050.48
2014	2,924.26	1,292.20	4,216.46	4,294.90
2015	3,554.94	1,470.29	5,025.23	5,105.52
2016	3,829.86	1,475.95	5,305.81	5,401.39
2017	3,680.67	1,669.97	5,350.64	5,465.76
2018	3,648.68	1,478.26	5,126.94	5,220.22
2019	3,568.27	1,625.44	5,193.71	5,372.81
2020	2,660.03	1,102.72	3,762.75	3,882.69

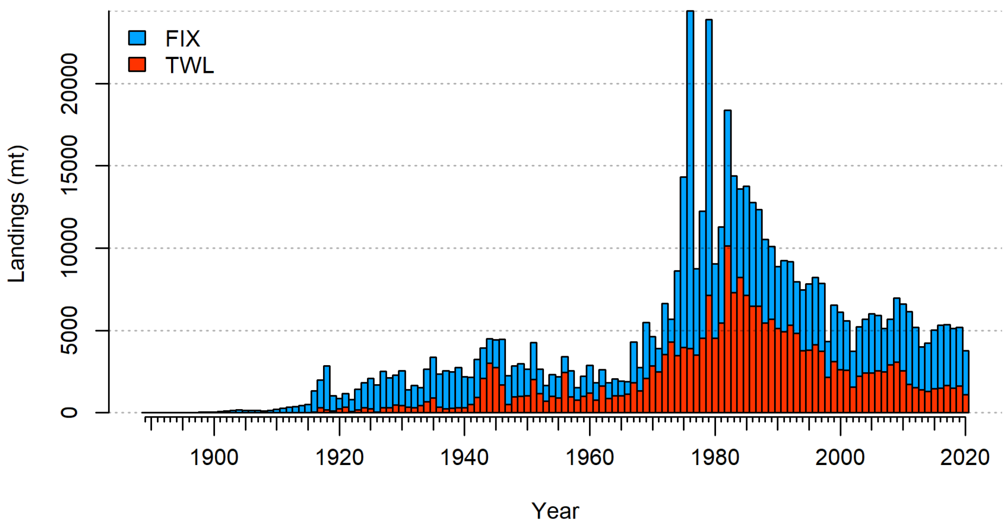


Figure i: Sablefish landings from 1890–2020 summarized by the gear types included in the base model, fixed-gear and trawl. Landings include those from foreign fleets, which are largely responsible for the peaks in 1976 and 1979.

Data and Assessment

The last benchmark stock assessment for sablefish took place during 2019 (Haltuch et al. (2019)), preceded by an update assessment during 2015 (Johnson et al. (2016)). The present (2021) update assessment used the most recent version of the Stock Synthesis modeling platform (3.30), and bridged between the sub-version used in the benchmark (v3.30.09, released 2019-03-09) and the latest release (v3.30.16, released 2020-09-03). Primary data sources include landings and age-composition data from the retained catch (Figure 3). For recent years, data on the discarded portion of commercial catch are available, including discard lengths, rates, and mean observed individual body weight of the discarded catch. The relative index of abundance estimated from the National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center (NWFSC) West Coast Groundfish Bottom Trawl (WCGBT) Survey, which includes depths from 55 - 1,280 m, represents the primary source of information on the stock's trend and was updated and re-analyzed to include the most recent data, covering the period 2003-2019 (Figure 4); the updated index was consistent with the previous (Figures 5 and 12). Note that the WCGBT Survey does not access the closed Cowcod Conservation areas in southern California, and was not performed in 2020 due to the global SARS-CoV-2 pandemic. Other, discontinued, survey indices contribute information on trend and sablefish demographics: (a) NWFSC Slope Survey conducted from 1998-2002, (b) Alaska Fisheries Science Center (AFSC) Slope Survey (1997-2001), and (c) AFSC/NWFSC Triennial Shelf Survey (1980-2004). Additionally, an environmental time-series of sea level was used as a survey index of recruitment in the base model; this time-series was updated and re-analyzed using the latest tide gauge data (Figures 13 and 14).

All externally estimated model parameters, (a) weight-length relationship, (b) maturity schedule, and (c) fecundity relationships remained unchanged from the 2019 benchmark assessment. As in previous assessments, growth and natural mortality were estimated using sex-specific relationships. Uncertainty in recruitment was included by estimating a full time-series of deviations from the stock-recruitment curve. The 'one-way-trip' nature of the time-series does not facilitate estimation of the steepness parameter (h) of the stock-recruitment relationship. Therefore, h was fixed at 0.7, similar to values used on other groundfish stock assessments, and was explored via sensitivity analysis in 2019; we explore information regarding h via likelihood profiles. During the 2019 assessment, a vast number of historical management actions were evaluated and condensed to a subset that were most likely to have had a direct influence on fishery behavior (either sorting and retention, selectivity, or both). These time periods were used to define time blocks to reduce the complexity of selectivity and retention parameterizations. The 2019 benchmark assessment utilized the same general structure as the 2011 assessment, with the addition of full retention for the trawl fishery after the implementation of the IFQ program in 2011.

During the exploration of recent data for this update assessment, modelers identified increased discarding in the trawl fleet, for which the discard ratio nearly quadrupled between 2018 and 2019 (Figure 64). In the first iteration of this update model, retention curve parameters were fixed, as discard length compositions were not included due to conflicts between the age and length data found in the 2019 benchmark assessment. Absent the data or structural flexibility to account for increased discarding, a model that conformed to the Terms of Reference (TOR) for an update assessment was unable to satisfactorily fit to the age composition data from the trawl fleets (Figure 17) nor the WCGBT survey length composition data (Figure 18), and greatly overestimated the 2019 index (Figure 19). Because the TOR model estimates retention for both fisheries in a single timeblock from 2011 onward, the discard data forced the model to generate many small fish, thus overestimating the model-expected index of abundance, the frequency of young and/or small individuals, and distorting the recruitment pattern (Figure 20).

We rectify the lack of fit to the data found in the TOR model by re-introducing the discard length compositions and time-blocking the retention curve to include a new block for the final two years of the model period (2019-2020; the benchmark model's terminal period for retention selectivity ran from 2011-2017). This adjustment resolved the aforementioned model fit issues (Figures 21-28), and is herein presented as the "base model".

Aging error, both precision and accuracy, was extensively investigated during the 2011 assessment but remains unresolved given the lack of an age validation study for sablefish. The age error analysis for this assessment used the same software and methods as the 2019 assessment, and the 2015 update and 2011 assessment before it. The larger number of between-lab reads from the AFSC and the NWFSC available for the 2019 assessment showed a small amount of variability between laboratories. Therefore, the analysis used the between-lab reads as well as the double reads from the NWFSC, treating them both as unbiased but potentially non-linearly variable. The age imprecision was such that by age 50 observed ages could differ from true ages by up to 16-17 years. The potential for underestimating or overestimating the age of the oldest fish still remains, and thus, the potential for aging bias remains a source of uncertainty.

Stock Biomass and Dynamics

During the first half of the 20th century it is estimated that sablefish were exploited at relatively modest levels. Modest catches continued until the 1960s, along with a higher frequency of above average, but uncertain, estimates of recruitment through the 1970s. The spawning stock biomass increased during the mid-1950s to mid-1970s. Subsequently, biomass is estimated to have declined between the mid-1970s and the early 2010s, with the largest harvests occurring during the 1970s followed by harvests that were, on average, higher than pre-1970s harvest through the 2000s. Despite estimates of harvest rates that were right around the target in the 1980s and 1990s and largely below overfishing rates from the 1990s forward coupled with a few high recruitments from the 1980s forward, the spawning biomass has only recently begun to increase. A period of low recruitment from 2001-2012 corresponds to with the decrease in harvest rates, restricting the rate of recovery. This stock assessment does suggest spawner per recruitment rates higher than the target during some years from the 1990s (as well as back to the 1970s) forward for two reasons. First, there have been many years with lower than expected recruitment. Second, stock assessment estimates of unfished spawning biomass have been steadily declining in each subsequent assessment prior to this update since 2007. Estimates of unfished biomass scale catch advice.

Although the relative trend in spawning biomass is robust to uncertainty in the leading model parameters, the productivity of the stock is uncertain due to confounding of natural mortality, absolute stock size, and productivity. The estimates of uncertainty around the point estimate of unfished stock size are large, suggesting that the unfished spawning biomass could range from just under 108,000 mt to 230,000 mt. The point estimate of 2021 spawning biomass from the base model is 97,801.9, however, the 95% interval ranges broadly from 40,802–154,801 mt. The point estimate of 2021 spawning biomass relative to an unfished state (i.e., depletion) from the base model is 57.9% of unexploited levels (95% interval: 38.4%-77.5%).

Table ii: Estimated recent trend in spawning biomass and the fraction unfished and the 95 percent intervals.

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2011	80,351.5	32,648.1	128,054.9	0.48	0.32	0.63
2012	79,223.0	31,838.5	126,607.5	0.47	0.31	0.63
2013	79,605.1	32,059.9	127,150.3	0.47	0.31	0.63
2014	80,187.9	32,563.5	127,812.3	0.47	0.31	0.64
2015	79,676.1	32,447.4	126,904.8	0.47	0.31	0.63
2016	78,633.2	31,824.6	125,441.8	0.47	0.31	0.62
2017	79,326.7	31,973.0	126,680.6	0.47	0.31	0.63
2018	80,687.2	32,503.6	128,870.8	0.48	0.31	0.64
2019	83,925.1	33,936.0	133,914.2	0.50	0.33	0.67
2020	90,756.5	37,136.0	144,377.0	0.54	0.35	0.72
2021	97,801.9	40,802.4	154,801.4	0.58	0.38	0.77

Recruitment

Sablefish recruitment is estimated to be quite variable with large amounts of uncertainty in individual recruitment events. A period with generally higher frequencies of strong recruitments spans from the early 1950s through the 1970s, followed by a lower frequency of large recruitments during 1980 forward, contributing to stock declines, with some recent larger recuritments pushing the population higher in the past few years. The period with a higher frequency of high recruitments contributed to a large increase in stock biomass that subsequently declined throughout much of the 1970s forward. Less frequent large recruitments during the mid-1980s through 1990 slowed the rate of stock decline, with another series of large recruitments during 1999 and 2000 leading to a leveling off in the stock decline. The above-average cohorts from 2008, 2010, 2013, and 2016 are contributing to an increasing spawning stock size.

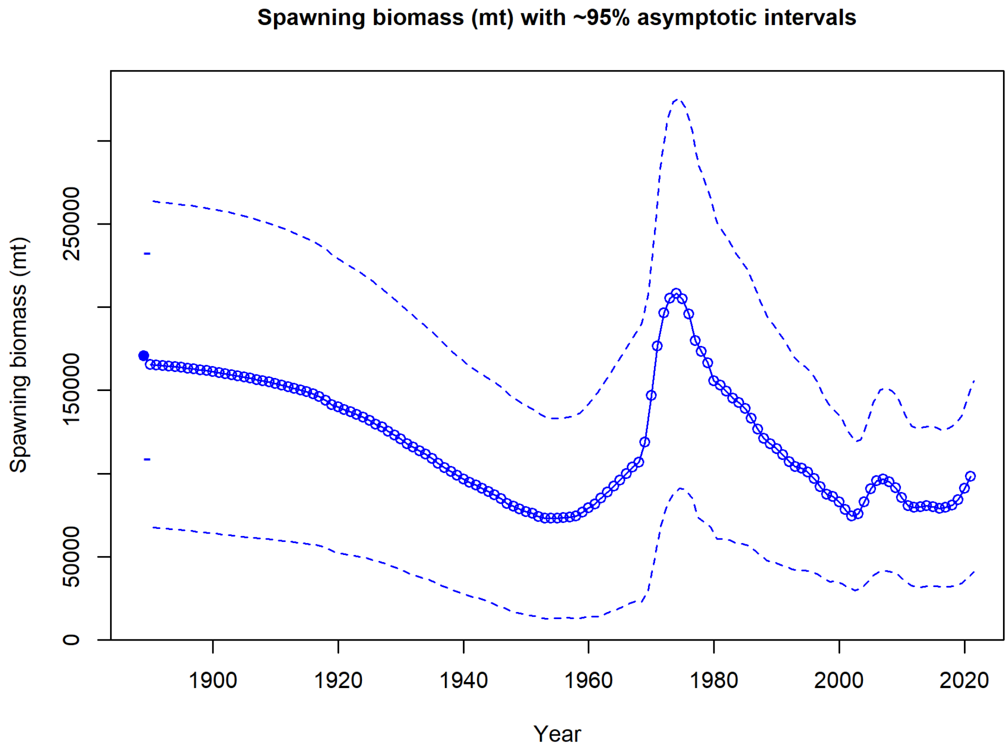
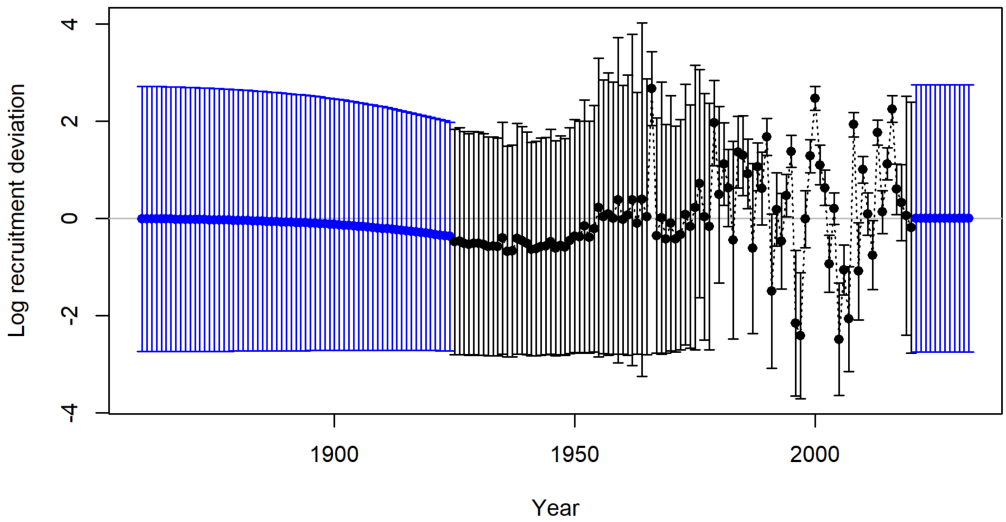


Figure ii: Time series of estimated sablefish spawning biomass (mt) from the base model (circles) with 95% intervals (dashedlines).



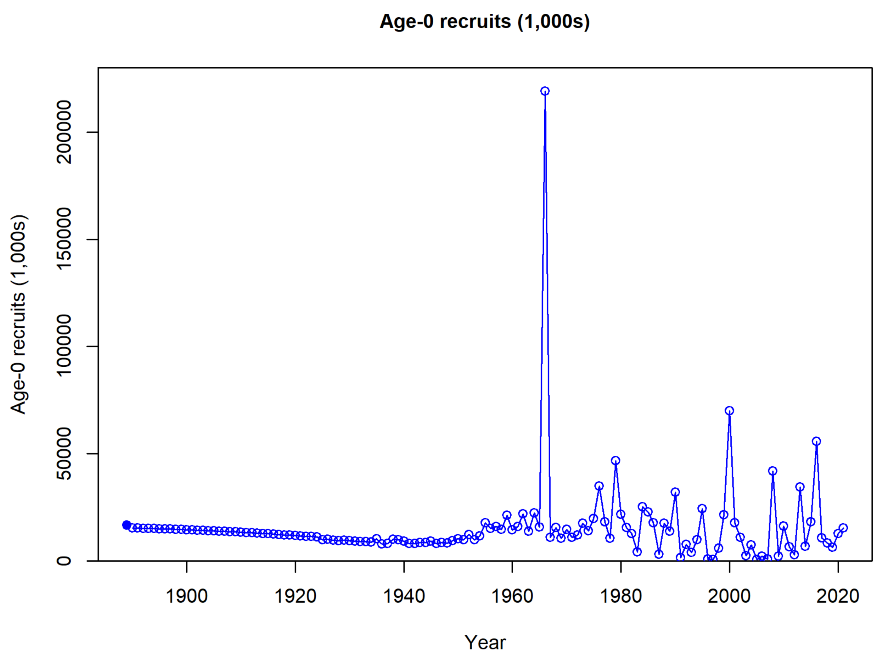


Figure iii: Time series of estimated recruitment deviations from the base model (solid line) with 95% intervals (vertical lines; upper panel) and recruitment without intervals (lower panel).

Exploitation Status

Although the estimated productivity and absolute scale of the stock are poorly informed by the available data and are, therefore, sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a declining trend in biomass since the 1970s followed by a recent increase in biomass (Figures 33 and 34). The spawner potential ratio (SPR) relative to the fishing mortality target or overfishing level ($SPR_{45\%}$) that stabilizes the stock at the target (reported as $(1 - SPR)/[1 - SPR_{45\%}]$), was greater than 1 (thus exceeding the target rate) during nearly half of the years from 1976 through 2000, has been below the target since, and was between 0.62 and 0.76 from 2015-2019, descending to 0.40 in 2020. 'Relative 1-SPR' in Table 4 refers to $(1-SPR)/[1-SPR_{45\%}]$; where 1 is the target exploitation rate, and values over 1 indicate overexploitation relative to this proxy. While highly uncertain, the absolute equilibrium yield at the estimated fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 9,024 mt (4,242-13,807, ~95% interval), while the proxy SPR rate of 0.45 leads to a proxy MSY of 8,350 mt (3,924 - 12,777, 95% interval).

Table iii: Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-SPRTarget=0.45%), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Model-Estimated Total Dead Catch	Rel 1-SPR	Interval	Exploitation Rate	Interval
2011	6,253.97	0.97	0.60–1.34	0.0316	0.0138–0.0494
2012	5,283.60	0.75	0.41–1.09	0.0240	0.0106–0.0375
2013	4,050.48	0.61	0.31–0.92	0.0192	0.0084–0.0300
2014	4,294.90	0.61	0.30–0.92	0.0200	0.0088–0.0311
2015	5,105.52	0.71	0.37–1.05	0.0243	0.0108–0.0379
2016	5,401.39	0.76	0.41–1.10	0.0270	0.0119–0.0421
2017	5,465.76	0.68	0.36–1.01	0.0250	0.0110–0.0389
2018	5,220.22	0.66	0.34–0.98	0.0243	0.0107–0.0379
2019	5,372.81	0.62	0.31–0.92	0.0244	0.0107–0.0381
2020	3,882.69	0.40	0.18–0.63	0.0149	0.0066–0.0231

Ecosystem Considerations

The National Oceanic and Atmospheric Administration (NOAA) document titled 'Implementing a Next Generation Stock Assessment Enterprise, An update to the NOAA Fisheries Stock Assessment Improvement Plan' (Lynch, Methot, and Link (2018)) calls for bringing an ecosystem perspective into the assessment process. Moreover, introducing this perspective to the assessment process is a key component of the NOAA Fisheries Ecosystem-Based Fisheries Management (EBFM) Policy (NOAA National Oceanic and Atmospheric Administration (2016)), which calls for incorporation of ecosystem considerations into the management of living marine resources. Uptake of EBFM principles and tools into the assessment process can be accomplished through including ecosystem information in assessments, harvest control rules, and management decisions that are coordinated across species-specific

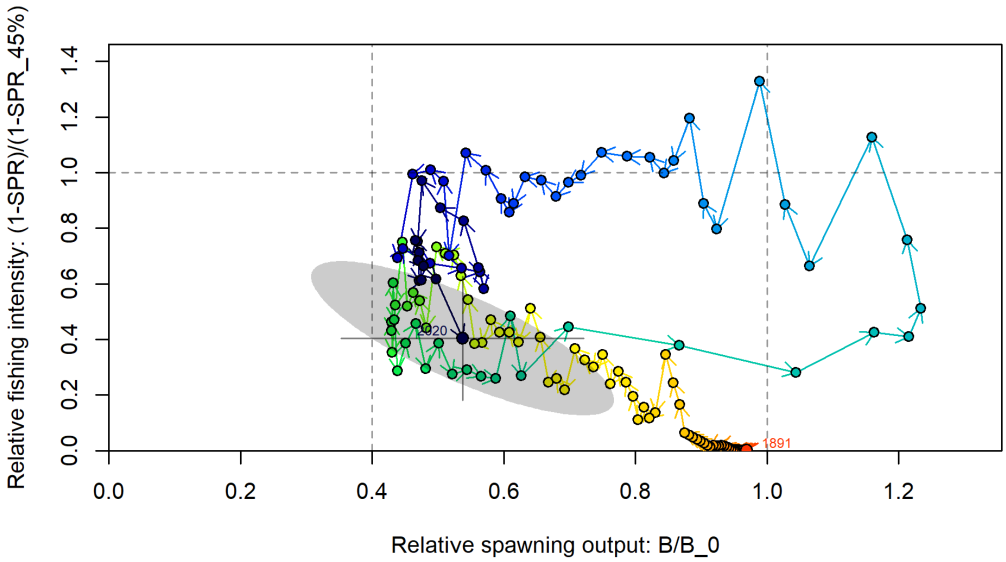


Figure iv: Estimated relative spawning potential ratio $(1 - SPR/1 - SPR_{Target=0.45\%})$ vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The dark blue circle indicates the last year of available data, 2020, and the grey lines indicate the 95% confidence interval. Plot is based on maximum likelihood estimation results.

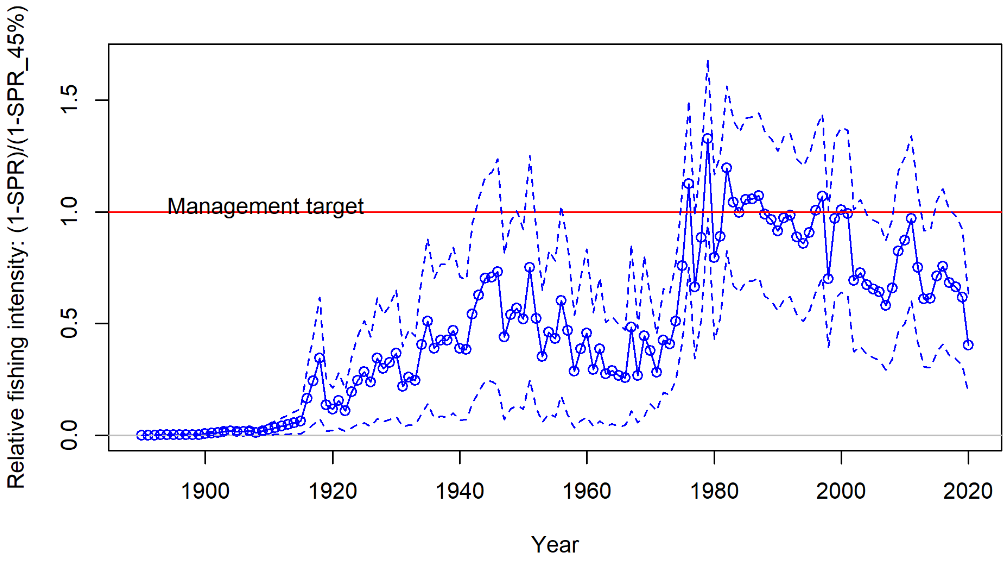


Figure v: Time series of estimated relative spawning potential ratio (1-SPR/1-SPRTarget=0.45%) from the base model (points) with 95% intervals (dashed lines). Values above 1.0 (red, horizontal line) reflect harvest rates in excess of the current overfishing proxy.

management plans and account for diverse trade-offs (NOAA National Oceanic and Atmospheric Administration (2016), Lynch, Methot, and Link (2018)). Guidelines for incorporating ecosystem considerations into fisheries management advice form the core of Guiding Principle 5 for implementing the NOAA EBFM Policy.

This assessment includes ecological factors based on the idea that research focused on the linkages within a social-ecological system (SES) and how they increase or decrease sustainability can help inform the management of natural resources (Ostrom (2009)). The SES framework requires consideration of extractive goals and human activities at a level that allows for ecological sustainability while also considering human well-being. Thus, the SES framework facilitates the consideration of environmental and human impacts on sablefish as well as sablefish impacts on the ecosystem and humans (e.g., Levin et al. (2016)).

The sablefish CVA McClure and Haltuch (n.d.)} suggests that processes affecting recruitment are sensitive to climatic and, therefore, oceanic drivers. Given high climate vulnerability, changes in the abundance, productivity, and spatial distribution of sablefish are likely, and these changes are likely to impact fishing fleets and communities because of the high value of this fishery. The CVA also suggests that sablefish are likely to shift their distribution in response to climate variability. Strong coast-wide recruitment appears to be associated with good recruitment north of Cape Mendocino ($\sim$ 40°N). Modeling work shows that strong recruitment is correlated with transport and temperature in the northern portion (40° − 48°N) of the U.S. West Coast, specifically with the northern transport of yolk-sac larvae (Tolimieri et al. (2018)). A re-analysis of the relationship between sea level and recruitment found that variation around the stock-recruitment curve was negatively correlated with sea level north of Cape Mendocino. Reliable sea-level data are available back to 1925; the ability to produce an environment-recruitment index with this time series may allow for both hindcasting to better represent stock dynamics during data-poor time periods and nowcasting of recruitment with robust estimates of uncertainty.

The sablefish stock has experienced latitudinal shifts in the center of the distribution of stock biomass along the US West Coast, which has affected fishing opportunities to individual ports (Selden et al. (n.d.)). The population centroid shifted to the north from 1980 to 1992 then south by 2013. More recently, the distribution of stock biomass shifted north, illustrated by an increase in trawl survey biomass in the north, but not as far north as in the 1990s.

Whale entanglements with pot gear has the potential to limit effort in the pot-gear sectors due to protections for marine mammals. The estimated fleet-wide entanglements were consistently above the 5-year running average threshold during 2002 to 2017 in the combined Limited Entry sablefish and Open Access Fixed Gear pot sectors (Hanson et al. (2019)). This result was largely due to the Open Access Fixed Gear pot sector, which had entanglements consistently above the 5-year running average threshold, while entanglements in the Limited Entry sablefish pot sector were consistently below the threshold.

A detailed description of social-ecological system (SES) analyses, the Climate Vulnerability Assessment, and environmental drivers of sablefish recruitment is available in the 2019 Benchmark Assessment report (Haltuch et al. (2019)), and truncated from this update document.

Reference Points

Unfished spawning biomass was estimated to be 168,875 mt (107,749–230,001 ~95% interval). The abundance of sablefish was estimated to have declined to near the target during the period 1980-2000. The estimate of the target spawning biomass was 67,550 (43,099-92,001, ~95% interval). The stock was estimated to be above the target stock size in the beginning of 2021 at 97,802 mt (40,801-154,802, ~95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield (0.4) (Figures 31 and 32). The estimate of the stock's current 2021 level of depletion was 0.579.

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

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	168,875	107,749	230,001

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

	Estimate	Lower Interval	Upper Interval
Unfished Age 4+ Biomass (mt)	393,647	242,084	545,210
Unfished Recruitment (R0)	16,392	6,586	26,198
Spawning Biomass (mt) (2021)	97,802	40,802	154,801
Fraction Unfished (2021)	0.579	0.384	0.775
Proxy Spawning Biomass (mt) SB40 Percent	67,550	43,100	92,000
SPR Resulting in SB40 Percent	0.464		
Exploitation Rate Resulting in SB40 Percent	0.043	0.035	0.051
Yield with SPR Based On SB40 Percent (mt)	8,209	3,857	12,562
Proxy Spawning Biomass (mt) (SPR45)	64,848	41,376	88,320
Exploitation Rate Corresponding to SPR45	0.045	0.037	0.053
Yield with SPR45 at SB SPR (mt)	8,350	3,924	12,777
Spawning Biomass (mt) at MSY (SB MSY)	41,702	26,527	56,876
SPR MSY	0.328	0.324	0.331
Exploitation Rate Corresponding to SPR MSY	0.070	0.057	0.083
MSY (mt)	9,024	4,242	13,807

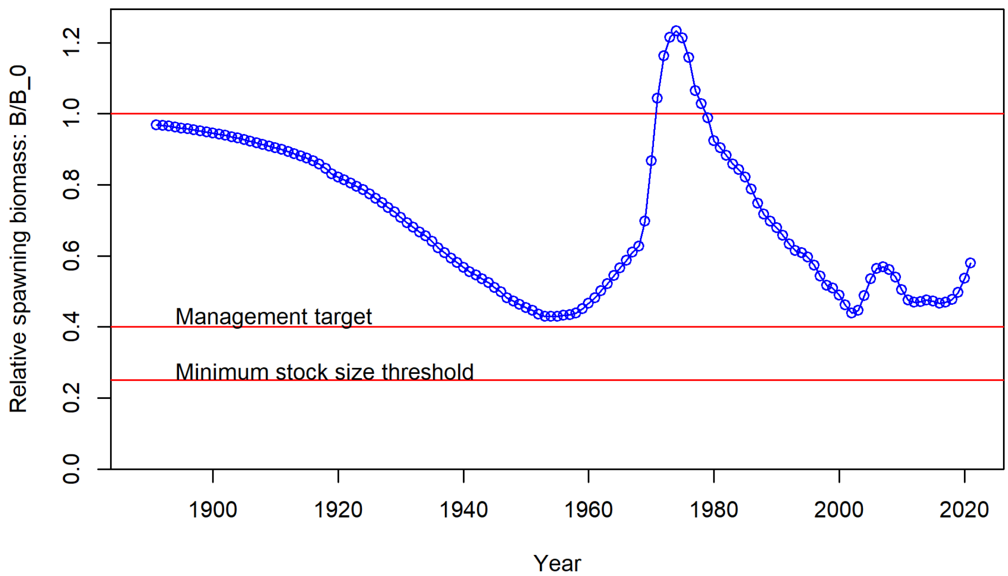


Figure vi: Time series of estimated depletion (i.e., spawning biomass relative to unfished spawning biomass) from the base model (circles) with 95% intervals (dashed lines).

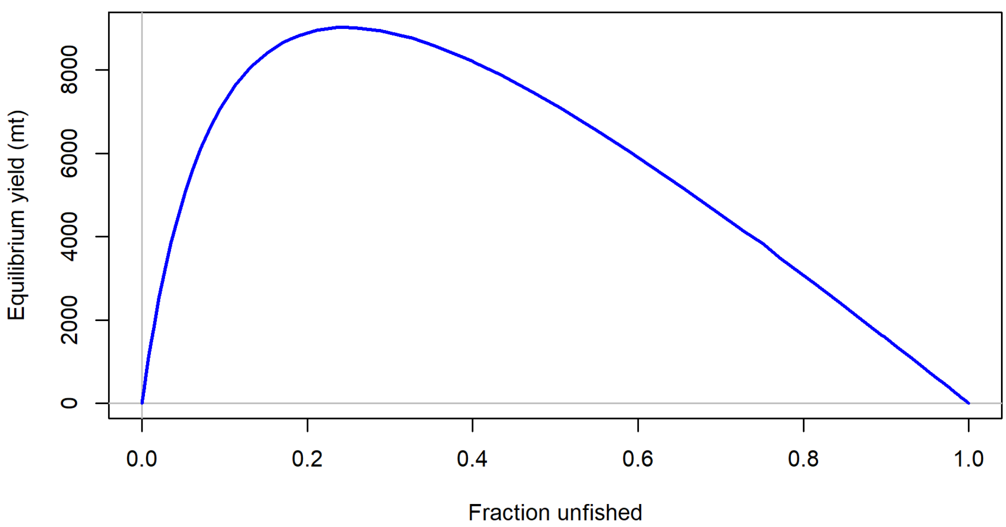


Figure vii: Equilibrium yield curve (total dead catch) for the base model.

Management Performance

Sablefish management includes a rich history of seasons, size-limits, trip-limits, and a complex permit system. Managers divide coast-wide yield targets among the fleets, fishery sectors (including both limited entry and open access), as well as north and south of 36°N latitude. Peak catches occurred during the late 1970s just prior to the imposition of the first catch limits. Over the last decade, the total estimated dead catch has been 55% of the sum of the overfishing limits and 65% of the annual catch limits.

Table v: Recent trend in the overfishing limits (OFL), the annual catch limits (ACLs), the total landings, and model-estimated total dead catch (”total mortality”, mt). Note that the Acceptable Biological Catches (ABCs) and ACLs are equal because the stock is estimated to be above 40% of the unfished spawning biomass, and the PFMC has not seen fit to lower the ACLs for other reasons.

Year	OFL	ACL	Landings	Total Mortality
2011	8,808	6,813	6,149.25	6,253.97
2012	8,623	6,605	5,184.80	5,283.59
2013	6,621	5,451	3,987.20	4,050.48
2014	7,158	5,909	4,216.46	4,294.90
2015	7,857	6,512	5,025.23	5,105.53
2016	8,526	7,121	5,305.81	5,401.39
2017	8,050	7,117	5,350.64	5,465.75
2018	8,239	7,419	5,126.94	5,220.23
2019	8,489	7,750	5,193.71	5,372.81
2020	8,648	7,896	3,762.75	3,882.70
2021	9,402	8,791	-	-
2022	9,005	8,375	-	-

Unresolved Problems and Major Uncertainties

The data available for sablefish off the U.S. West Coast are not informative with respect to absolute stock size and productivity. This is, in part, due to the one-way-trip nature of the historical series (i.e., a slow and steady decline in spawning biomass), which can be consistent with a larger less productive stock, a smaller more productive stock, or many combinations in between. While the historical catches provide some information about the minimum stock size necessary to remove the catches from the population, there is limited information in the data regarding the upper limit of the stock size. The above factors are also confounded by movement of sablefish between the region included in this assessment and regions to the north primarily, which is ignored in the stock assessment. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in any of a suite of parameters can result in different management reference points. However, because leading model parameters, such as natural mortality, selectivity, and historical recruitments, are estimated within the stock assessment model, the uncertainty about these estimates remains large and uncertainty intervals typically overlapped among the investigated models. The uncertainty will remain high until a more informative time-series, better quality demographic and biological information are accumulated, or a range-wide analysis is completed for sablefish.

There is no age validation for sablefish. Validation is complicated by the fact that most known-age fish from Alaska are aged at less than 20 years while there are very few ages from the US West Coast, particularly in recent decades. Uncertainty in the current aging methods (both bias and imprecision), as well as relatively sparse fishery sampling, result in age data that potentially variable. Furthermore, because sablefish grow rapidly, nearing asymptotic length in their first decade of life, length data is not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that the stock trajectory (via shifts in recruitment strength) is closely linked to productivity regimes in the US West Coast. Uncertainty in future environmental conditions, changes in the timing, dynamics, and productivity of the California Current ecosystem via climate change or cycles similar to the historical period should be considered a significant source of uncertainty in all projections of stock status. The ongoing WCGBT Survey is a fairly precise relative index of abundance over a broad demo- graphic component of the stock, but it does not survey the entire stock as sablefish reside in waters deeper than 1280 m, the survey depth limit, and to the north of the Washington/British Columbia border. To the modelers' knowledge there is no information from the Pacific coast of Mexico. Therefore, a portion of the stock is unobserved. This index has the potential to inform future stock assessments about the scale of the population relative to catches being removed, however such information will require contrast in the observed survey trend.

Decision Table and Harvest Projections

Decision Table

The decision table reports 12-year projections for alternate states of nature (columns) and management options (rows). The results of this table are conditioned on the Groundfish Management Team specified catches for 2021 and 2022, which are below the already-specified annual catch limits approved by the Pacific Fisheries Management Council.

Uncertainty in management quantities for the decision table was characterized using the asymptotic standard deviation for the 2021 spawning biomass from the base model. Specifically, the 2021 spawning biomass for the high and low states of nature are given by the base model mean $\pm 1.15 \cdot$ standard deviation (i.e., the 12.5th and 87.5th percentiles). A search across fixed values of R_0 was used to attain the 2021 spawning biomass values for the high and low states of nature. The base catch streams were based on the 40-10 harvest control rule and a $P^* = 0.45$ buffer vector. This is presented as the bottom row of the decision table as it represents the highest exploitation level among the three catch streams. To replicate a request of the Groundfish Management Team representative at the 2019 STAR panel, the additional catch streams were set using the Category 1 values of $P^* = 0.35$ and $P^* = 0.40$; these are presented as the first and second rows of the decision table, respectively.

Spawning stock biomass in 2021 ranges across the three states of nature from 64,916 to 131,513 mt, with corresponding stock status ranging from 51% to 63% of the unfished stock size. The decision table suggests that all catch scenarios under across all states of nature result in decreases in stock size. Under both the base and high states of nature and across all catch scenarios, the stock remains either at or above the target stock size at the end of the projection period. The reason that depletion does not decline as substaintally as suspected in the base case at the 12-year time horizon is the emergence of recent, large recruitment events into the fishery; this is reflected in a disproportionate increase in summary biomass (Figure 68). However, all catch scenarios under the low state of nature drive the stock into the precautionary zone by 2030, where it remains in 2032.

Table vi: Decision table of 12-year projections of spawning stock biomass (SSB) and % unfished (depletion) for alternative states of nature (columns) and management options (rows) beginning in 2021. Low and high states of nature are based on the 2021 SSB ± 1.15·base model SSB standard deviation and the resulting unfished recruitment was used for the projections. Results are conditioned on the 2021 and 2022 catches, provided by the Pacific Fisheries Management Council Groundfish Management Team (GMT), being achieved exactly. The alternative catch streams are based on the GMT's requested P* values of 0.35 and 0.40. Note that values for the agreed-upon buffer level of P* = 0.45 is presented as the third row of the decision table as it represents the highest exploitation level among the three catch streams. Catches are total dead biomass, i.e., dead discard plus catch.

	Year	Total	Low state (0.25)		Base (0.5)		High state (0.25)	
scenario		catch	SSB	Depletion	SSB	Depletion	SSB	Depletion
P*=0.35	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	9,412	65,396	0.51	99,450	0.59	134,266	0.64
	2024	8,608	62,150	0.49	96,661	0.57	131,626	0.63
	2025	8,101	59,177	0.46	94,436	0.56	129,680	0.62
	2026	7,796	56,750	0.44	92,909	0.55	128,548	0.62
	2027	7,649	54,732	0.43	91,867	0.54	127,974	0.61
	2028	7,570	52,951	0.41	91,099	0.54	127,714	0.61
	2029	7,504	51,310	0.40	90,483	0.54	127,626	0.61
	2030	7,437	49,770	0.39	89,967	0.53	127,646	0.61
	2031	7,342	48,316	0.38	89,530	0.53	127,742	0.61
	2032	7,247	46,956	0.37	89,175	0.53	127,911	0.61
P*=0.40	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	10,107	65,396	0.51	99,450	0.59	134,266	0.64
	2024	9,252	61,794	0.48	96,308	0.57	131,273	0.63
	2025	8,722	58,494	0.46	93,761	0.56	129,004	0.62
	2026	8,421	55,765	0.44	91,935	0.54	127,568	0.61
	2027	8,282	53,451	0.42	90,602	0.54	126,699	0.61
	2028	8,218	51,380	0.40	89,546	0.53	126,149	0.60
	2029	8,168	49,449	0.39	88,643	0.52	125,774	0.60
	2030	8,117	47,616	0.37	87,840	0.52	125,509	0.60
	2031	8,039	45,869	0.36	87,117	0.52	125,324	0.60
	2032	7,950	44,214	0.35	86,479	0.51	125,215	0.60
P*=0.45	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	10,825	65,396	0.51	99,450	0.59	134,266	0.64
	2024	9,923	61,426	0.48	95,935	0.57	130,908	0.63
	2025	9,372	57,787	0.45	93,014	0.55	128,302	0.62
	2026	9,070	54,742	0.43	90,821	0.54	126,550	0.61
	2027	8,934	52,126	0.41	89,130	0.53	125,375	0.60
	2028	8,888	49,760	0.39	87,727	0.52	124,528	0.60
	2029	8,860	47,532	0.37	86,483	0.51	123,858	0.59
	2030	8,810	45,402	0.36	85,346	0.51	123,298	0.59
	2031	8,753	43,364	0.34	84,304	0.50	122,829	0.59
	2032	8,684	41,415	0.32	83,351	0.49	122,438	0.59

Harvest Projections

Previous sablefish stock assessments have been designated as Category 1 stock assessments. Projections and decision tables are based on P^*=0.45, the adopted value for the most recent management cycle, and the values of σ adopted by the Pacific Fisheries Management Council for stock projections. The time series of multiplicative buffer fractions that are a function of P^* and the time series of σs provide the multipliers on the overfishing limit; these values are all less than 1 for category 1 stocks. σ for sablefish is the time-varying category 1 value, which starts at 0.5 in the year after the (update) assessment and increases throughout the projection period. The uncertainty around the OFL value for the first forecast year (2022) is 0.319; the uncertainty around spawning output in that same year is 0.298, both less than 0.5. The multipliers are combined with OFLs to calculate the ABC values. The Council sets ACL values which cannot exceed (with limited exceptions) the ABCs as modified by the 40-10 rule. The total catches in 2021 and 2022 were set at the Pacific Fisheries Management Council Groundfish Management Team requested values, below the Pacific Fisheries Management Council annual catch limits for sablefish. The average ratio between GMT-specified 2021-2022 catches were used to distribute catches among the fisheries for forecasted years.

Projections are provided through 2032 (Table 7). Current medium-term projections from the base model under the Pacific Fisheries Management Council 40-10 harvest control rule estimate that the stock will remain above the target stock size of 40% of the estimated unfished spawning biomass during the projection period. Forecasts from the 2019 benchmark assessment projected the spawning biomass to increase by 28% from 2017 to 2021 given specified harvests, whereas the current assessment estimated the increase at 23%. The estimate of unexploited spawning biomass (in the year of each assessment) is 13% higher than that estimated in 2019 and 19% lower than the 2011 estimate. Relative unfished biomass in 2021 was estimated at 0.58, while the 2019 benchmark assessment forecasted it to be 0.46.

Table vii: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and fraction unfished. The total catches in 2021 and 2022 were set at the PFMC Groundfish Management Team requested values of 7,405 mt for 2021 and 7,055 mt for 2022 which are about 20% lower than the ACL = ABC for those years; see Table 6 for GMT-defined ACLs and OFLs in 2021 and 2022.

Year	Predicted OFL (mt)	*Catches* (2021-22) or ABCs (2023+) (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	-	*7,405.00*	265,655	97,801.9	0.58
2022	-	*7,055.00*	261,481	99,956.5	0.59
2023	11,577.1	10,824.6	253540	99,449.9	0.59
2024	10,669.8	9,922.9	246090	95,943.8	0.57
2025	10,120.6	9,371.7	241976	93,063.3	0.55
2026	9,837.4	9,070.1	238823	90,925.0	0.54
2027	9,742.3	8,933.7	236280	89,290.8	0.53
2028	9,735.2	8,888.3	234037	87,941.5	0.52
2029	9,747.2	8,860.2	231955	86,743.8	0.51

Table vii: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and fraction unfished. *(continued)*

Year	Predicted OFL (mt)	*Catches* (2021-22) or ABCs (2023+) (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2030	9,746.0	8,810.4	229993	85,644.5	0.51
2031	9,725.9	8,753.3	228162	84,634.2	0.50
2032	9,691.9	8,684.0	226462	83,707.8	0.50

Scientific Uncertainty

The time series of multiplicative buffer fractions that are a function of P^* and the time series of σs provide the multipliers on the overfishing limit; these values are all less than 1 for category 1 stocks. σ for sablefish is the time-varying category 1 value, which starts at 0.5 in the year after the (update) assessment and increases throughout the projection period. The uncertainty around the OFL value for the first forecast year (2022) is 0.319; the uncertainty around spawning output in that same year is 0.298, both less than 0.5.

Research and Data Needs

Most of the research needs listed below entail investigations that need to take place outside of the routine assessment cycle and require additional resources to be completed.

1. Not all of the available sablefish otoliths were aged for this stock assessment update because of time constraints resulting from Covid-19, exacerbated by the the federal government furlough in 2019, and, in some cases, the sample sizes of aged fish are lower than what would be ideal. Resources should be provided to age otolith samples from years with missing age data or small sample sizes.

2. A transboundary stock assessment and the management framework to support such assessments would be beneficial given the migratory nature and broad distribution of sablefish along the Pacific Rim. A transboundary assessment would likely improve the ability to estimate the scale of the population, particularly during the early modeled period.

3. Investigation of environmental covariates for recruitment on a stock-wide, northeast Pacific scale.

4. Continuation of the annual WCGBT Survey will provide information on stock trends and incoming recruitments. A longer survey time series may improve the precision of estimates of absolute stock size and productivity into the future.

5. Age validation is needed to verify the level of age bias present in the data, if any.

6. Investigate aging methods that could prove more precise and/or rapid than current break-and-burn methods. More accurate age data would facilitate tracking cohorts to older ages, improving estimates of historical year-class strengths.

7. Research on understanding the interactions between spatial patterns in sablefish growth, fishery size selectivity, and movement across the Northeast Pacific began during 2019 and are ongoing. The results of this research should be considered in future benchmark stock assessments.

8. Anecdotal information, such as the large 1947 recruitment reported by central California sport fisherman, along with historical records could be investigated to provide additional information on historical patterns of recruitment.

1 Introduction

1.1 Basic Information

Sablefish (*Anoplopoma fimbria*, or 'black cod') are distributed in the northeastern Pacific Ocean from the southern tip of Baja California northward to the north-central Bering Sea and in the northwestern Pacific Ocean from Kamchatka southward to the northeastern coast of Japan Hart (1973), Eschmeyer and Herald (1983). U.S. West Coast sablefish are modeled as a single stock. Thus, this stock assessment does not explicitly account for movement between offshore sea mounts {Shaw and Parks (1997), Morita, Morita, and Nishimura (2012), Hanselman et al. (2015), Rogers et al. (n.d.), regions to the north of the U.S. west coast, or to the western Pacific (Fujioka et al. (1988), Heifetz and Fujioka (1991), Hanselman et al. (2015), Rogers et al. (n.d.)). To the modelers' knowledge there is no information from the Pacific coast of Mexico. While previous analyses suggest the existence of several stocks of sablefish in the eastern Pacific Ocean that are largely delineated by management boundaries (Schirripa (2007)); and earlier assessments), more recent genetic analyses found that sablefish in the northeastern Pacific Ocean are a single panmictic population Jasonowicz et al. (2017)). Additional support for a panmictic population stems from tag recoveries that show sablefish move between the regions currently used for management (Hanselman et al. (2015), Sogard and Berkeley (2017), Rogers et al. (n.d.)). Analyses of length-at-age data has found spatial variation in von Bertalanffy growth parameters across the northeastern Pacific Ocean (McDevitt (1987), Echave et al. (2012), Head, Keller, and Bradburn (2014), Gertseva, Matson, and Cope (2017), Kapur et al. (2020)).

While geographic break points at approximately (1) 36°N between Point Conception and Monterey, California at the start of the southern California Bight and (2) 50°N where the North Pacific Current bifurcates suggest zones of growth variation, generally with increasing maximum body size and decreasing growth rates with increasing latitude, they do not indicate regions with separate populations.

Smaller sablefish are generally found in shallower waters, but the demographics appears to be fully mixed (adult and juvenile) near the shelf-slope break (i.e., 100-300 m). Beyond the shelf-slope break, the adult population is dominated by older individuals (Methot (1994)) and younger fish become increasingly rare. Fish in the deepest areas sampled tend to be the oldest individuals, but not the largest individuals, suggesting that age rather than size dictates depth distribution. However, the interaction between environmental conditions and seasonal movements that produce an increase in age with depth are largely unknown. The stock is distributed beyond the greatest depth sampled by any of the surveys and beyond the deepest commercial fishing areas. Research in these deeper habitats occupied by sablefish is potentially difficult because they extend across the boundary of the exclusive economic zone and sea mounts and ridges around the Pacific. There are relatively fewer sablefish in the

Puget Sound and the Strait of Georgia than in coastal U.S. waters. Therefore, connectivity among these areas and the open coast is likely of less importance to this stock assessment than movement along the coast.

1.2 Life History

Tolimieri et al. (2018) provide a thorough review of the literature on spawning and early life history of sablefish in the US West Coast. Briefly, sablefish off the U.S. West Coast exhibit a protracted spawning period from December through March, with peak in February Guzmán et al. (2017). This winter-time spawning may result in reduced availability to the commercial fishery during the winter months. Spawning occurs along the continental shelf-slope break in waters deeper than 300 m. Eggs ($\sim$ 2.1 mm in diameter) are buoyant and rise in the water column before hatching and sinking to deeper waters. Pelagic juveniles are present in off-shore surface waters and settle to the benthos as age-0 recruits during the late summer to fall, with most newly settled fish at depths of less than 250 m. sablefish reach full size and maturity in their first decade of life, reaching nearly asymptotic size and beginning to mature after 5-7 years. Female sablefish generally reach larger sizes than males. However, the sex-ratio tends to be skewed toward males at the oldest ages implying a lower natural mortality rate for males relative to females. The oldest sablefish on record was captured in 2006 off Washington and aged (with observation error) at 102 years. This female was only 68 cm long, nowhere near the longest individual (117 cm).

Adult sablefish are fast-swimming and capable of feeding on a diverse array of prey species including fishes, cephalopods, and crustaceans Low, Tanonaka, and Shippen (1976). The co-habitation of adult and juvenile sablefish may result in some cannibalism, and large changes in predator biomass (such as the recent rebuilding of lingcod, *Ophiodon elongatus*) could have a feedback on juvenile survival and, therefore, stock productivity.

Range-wide investigations of sablefish growth suggest that growth varies across the north-eastern Pacific, with a generally increasing cline in length-at-age with latitude (Echave et al. (2012), Gertseva, Matson, and Cope (2017), McDevitt (1987), Kapur et al. (2020)). Break points in growth have been identified at around 50°N (approximately the northern end of Vancouver Island, Canada), where north of this breakpoint female asymptotic-length estimates were consistently over 70 cm and south of this breakpoint female asymptotic-length estimates were below 66 cm (Kapur et al. 2020). A second break point was identified by Kapur et al. (2020) at 36°N (approximately Monterey, California), where asymptotic size for females and males to the south were 60.43 cm and 55 cm, respectively. Note that this information was not included in the 2019 benchmark assessment nor this update, as the data to construct a spatially-structured model and account for movement between areas north and south of 36°N are not available. Instead, coast-wide sex-specific growth parameters were estimated for females and males, as it was done in 2019 benchmark assessment.

1.3 Ecosystem Considerations

A detailed summary of social-ecological system (SES) analyses, the Climate Vulnerability Assessment, and environmental drivers of sablefish recruitment is available in the 2019 Benchmark Assessment report (Haltuch et al. (2019)), and truncated for this update document.

1.4 Historical and Current Fishery Information

Historical sablefish landings, beginning in 1890, have been reconstructed by the states (Washington, Oregon, and California) using a variety of sources. Generally, historical sablefish landings were more reliable than those for many other groundfish species because of their consistent species-level identification. While sablefish landings were recorded back to the beginning of the 20th century, appreciable quantities were not landed until 1916-1919, with landings remaining below 5,000 mt through the late 1960s (Table 1; Figure 1).

Landings prior to 1960 were primarily harvested by hook-and-line gear. The peak around World War II was likely due to a relaxed degree of species sorting rather than a dramatic increase in fishing effort (grey literature notes a decrease in manpower with the onset of the war), where increases in demand were fueled by the need for domestic sources of protein (Browning (1980)).

The sablefish fishery increased dramatically during the 1970s, first from a combination of foreign vessels (Lynde (1986), McDevitt (1987)), followed by an increase in the domestic fleet. Increases correspond to the introduction of a pot fishery followed by an increase in the catch coming from the trawl sector, with only minor increases in the hook-and-line sector until the mid-1980s, after the peak removals from the other sectors. Large catches by foreign vessels, fishing pot gear, in 1976 resulted in the largest single-year removal of over 25,000 mt from U.S. West Coast waters. A rapid rise in domestic pot and trawl landings followed this peak removal, such that on average, nearly 14,000 mt of sablefish were landed per year between 1976 and 1990. During the most recent decade, annual landings have remained below 10,000 mt, composed of approximately 3,454 from fixed gear and 1,476 from trawl gear during the most recent decade. The decline in domestic landings through the 1980s was likely due to a combination of declining stock size, many years with below average recruitment, reduced Asian-market strength, and increasing fishery regulations.

1.5 Foreign Fisheries (Canada and Alaska)

Similarly to the U.S. West Coast, sablefish fisheries in Alaska and British Columbia waters began in the late 1800s, with generally low catches until after World War II. Foreign fisheries began exploiting sablefish in the northeastern Pacific Ocean during the late 1950s in the Bering Sea leading to rapidly increasing catches in the region through the 1980s. Historically, Alaskan landings were much larger than those off the U.S. West Coast, rising to over 20,000 mt during the early 1960s, with many years above this level until the mid 1990s. In the most recent decade, Alaskan landings, including those taken from inside waters under the management of the Alaska Department of Fish and Game, have averaged just over 12,000 mt.

The sablefish fishery in British Columbian waters has a similar history to those in U.S. waters. The fishery primarily uses pots, with a lesser amount landed using long lines and trawls. Landings ranged up to just over 7,000 mt during the mid-1970s, followed by a variable but generally declining trend through the present (Kronlund (2010); pers. comm., B. Connors). In the most recent decade, average landings have been just over 2,100 mt, with the 2014 landings representing the lowest since the the mid 1960s (pers. comm., B. Connors).

1.6 Summary of Management History and Performance

Between 2003 and 2010 the trawl logbook and WCGOP observer data show the fishery was distributed widely across the continental shelf from approximately 40°N to the U.S. Canadian border, with fishing effort distributed towards deeper waters south of the 40° line and limited effort south of the 36° management line (Figure 35). With the beginning of the catch shares program in 2011, the trawl logbook and WCGOP data show the fishery shifted its distribution towards deeper waters with greatly decreased effort in California.

During 2003 through 2017 WCGOP observer program data show the non-catch shares fixed-gear fishery had a more patchy distribution compared to the trawl fishery (data from logbooks), with hook-and-line fishing effort extending into waters south of Point Conception while pot fishing effort was largely concentrated off of the coasts of Washington and Oregon (Figures 36 and 37). Since the inception of the catch shares program in 2011, the WCGOP observer program data show that catch shares vessel fishing with hook-and-line gears are distributed to the north and focused on limited spatial regions with little effort in waters south of 40°N, while catch shares vessels fishing with pots have expanded into waters south of 36°N. Note that the catch shares sectors, and the pre-catch shares bottom trawl sectors are the only ones which have data near completion. Maps for the hook-and-line and pot gears, show catch shares (right panel) and non-catch shares (left panel) sectors separately. Non-catch shares trips continue into the more recent period, but in contrast to catch shares, the non-catch shares trips are not all observed. The West Coast Groundfish Observer Program data, 2003-2019, was downloaded on 2/26/2021. Coverage rates of all sectors can be found at https://www.nwfsc.noaa.gov/research/divisions/fram/observation/data/_products/sector/_products.cfm.

From the early 1900s to the early 1980s, management of the sablefish fishery was the responsibility of the individual coastal states (California, Oregon, and Washington). Since the adoption of the Groundfish Fishery Management Plan by the Pacific Fisheries Management Council in 1982, responsibility has rested with the federal government and the Council. From 1977 to the mid-1980s, U.S. commercial fishermen took advantage of their newly protected fishing grounds (i.e., the enactment of the 'Fishery Conservation and Management Act', which occurred in in 1976, later to be renamed 'Magnuson Stevens Fishery Conservation and Management Act') recording high catches of sablefish to meet the demands of flourishing export (primarily Asian countries) and domestic markets. The first coast-wide regulations off the U.S. Pacific Coast for the sablefish fishery were implemented as trip limits in October 1982, followed by a rich history of management via seasons, size-limits, trip-limits, and a complex permit system; see Appendix 10 of Haltuch et al. (2019) for a comprehensive list of management actions. Beginning in 1983, additional trip limits were imposed on landings of sablefish less than 22 in in length, considered incidental catch. In 1987, allocations between the trawl and non-trawl fleets were implemented.

Beginning in the late-1980s, the fixed-gear sablefish fishery was managed as a 'derby' fishery, characterized by successive reductions in season lengths. In 1991, the fully open season lasted seven weeks, from April 1 through May 23. In 1992, approximately 1,300 mt were landed under early season trip limits of up to 1,500 lb/day, and the fully open season lasted from May 12 through May 26. In 1993, there was a 250 lb/day trip limit prior to the open season which extended from May 12 through June 1. In 1994, the fully open season was shortened to May 15 through June 3. In 1995, the open season lasted ten days, from August 3 to August 13. The open season spanned only six days in 1996, from September 1 to September 6. In 1997, ten days (August 25 to September 3) were set aside for the open season, with a mop-up period from October 1-15. In the more recent period, the Limited Entry Fixed Gear sector has been managed primarily through the use of tiered cumulative limits (allocated on the basis of historical landings) which can be landed throughout the 7-month season. The remaining open-access fishery and some limited-entry non-trawl vessels are allowed to make smaller landings that are subject to daily/weekly limits and two-month cumulative caps.

Additionally, sablefish are harvested by the trawl fishery in association with a variety of other species that are distributed to domestic and foreign markets. Prior to 2011, the trawl fishery was managed primarily through the use of trip limits. These evolved from simple per-trip limits in the 1980s to cumulative periodic (monthly or bi-monthly) limits by the mid-1990s. In addition to sablefish-specific limits, various limits were in place for the overall landings of deep-water complex species (Stewart, Thorson, and Wetzel (2011)). Coast-wide yield-targets are divided among the different gears, fishery sectors (including both limited entry and open access) as well as north and south of 36° latitude. The overfishing level (OFL, formerly the allowable biological catch, i.e., ABC) for sablefish has ranged from 6621 to 8623 during the last decade (Table 6). Catch targets (ACLs, formerly OYs) ranged from 5451 to 7896 mt over the same period. Landings were estimated to be below the ACLs in all years. Total mortality (including discards predicted to not survive) in the context of management limits and targets is discussed in Section 4 below.

2 Data

A brief description of each data source (Figure 3) is provided below. The following sources of data were used in building this assessment, and the data preparation approach was unchanged from the 2019 benchmark, with the exception of implementing the latest version of the PacFinUtilities R package (version 0.0.2.0002), and including the commercial discard lengths.

1. Fishery-independent data, including relative abundance indices and length and age data from the Northwest Fisheries Science Center (NWFSC) West Coast Groundfish Bottom Trawl (WCGBT) Survey 2003-2019, and relative abundance indices and age data from the NWFSC slope survey 1998-2002, the Alaska Fisheries Science Center (AFSC) Slope Survey 1997-2001, and the Triennial Shelf Survey 1980-2004. Input sample sizes were based on the number of tows for length and marginal age compositions, whereas conditional age-at-length (CAAL) input sample sizes were based on the number of fish sampled.
2. Estimates of fecundity, maturity, weight-length relationships, and ageing imprecision. There were no changes to these parameters in this update assessment.
3. Informative sex-specific priors on natural mortality based upon meta-analytical relationships with other life-history parameters derived from data across a number of fish stocks (Figure 41). This update assessment used the same prior as was implemented in the 2019 benchmark assessment.
4. Reported commercial and reconstructed landings 1889-2020 (Figures 1 and 2).
5. Biological data (ages) from the commercial port sampling programs 1983-2020. Input sample sizes for the composition data were based on the number of port samples.

6. Estimates of commercial discard length and mean weight and fraction discarded in the fishery obtained from the West Coast Groundfish Observer Program (WCGOP; 2005-2019 for the fixed gear fishery, 2004-2019 for the trawl fishery, and 1986-1988 from Pikitch, Erickson, and Wallace (1988). Input sample sizes for discard length compositions were based on the number of observed trips.
7. Environmental index of age-0 recruitment derived from tide-gauge measurements of sea level, for which we re-ran the analysis using tide guage data through 2020 (Figure 13).

2.1 Fishery-Independent data

2.1.1 Northwest Fisheries Science Center West Coast Groundfish Bottom Trawl Survey

The WCGBT Survey has maintained a consistent stratified random-grid survey design over the period 2003-2019, including depths from 55-1,280 m (Bradburn, Keller, and Horness 2011). WCGBT data are used to estimate a relative index of abundance for several groundfish species including sablefish, which are captured in a high proportion of survey hauls over most of the west coast shelf and slope depths. The survey design divides the U.S. West Coast into $\sim$ 13,000 adjacent cells of equal area. Typically, four chartered industry vessels conduct tows in randomly selected grid cells as they travel from north to south during one of two passes from late-May to mid-October. The design therefore incorporates both vessel-to-vessel differences in catchability and variability associated with selecting a relatively small number ($\sim$ 700) of cells from the large population of possible cells. The WCGBT Survey encounters sablefish in a high percentage of tows, which leads to confidence intervals which are relatively small and consistent year-to-year; this is the case for other highly-encountered species such as Petrale Sole. Note that the WCGBT Survey is not permitted to access the Cowcod Conservation areas in southern California. Additionally, there were only two vessels used in 2019 and three in 2013, with one of the three that year unable to complete its survey pass due to a government shutdown. No survey occurred in 2020 due to the Covid-19 pandemic.

The data were analyzed using the Vector-Autoregressive spatiotemporal Model (VAST; Thorson and Barnett (2017), Thorson (2019)) available within the https://github.com/James-Thorson-NOAA/VAST R package following the same procedure as was done in 2019 (Figure 12).

VAST Model convergence and fit were evaluated using the matrix of second-order partial derivatives ('Hessian matrix') and quantile-quantile ('Q-Q') plots of the predicted distribution versus the expectation under a null model (i.e., uniform distribution). Positive definite Hessian matrices were indicative of a model that had reached a local minimum and, thus, converged. Q-Q plots that largely followed a 1:1 relationship suggested that the distributional form used to fit the positive catch-rate data captured the shape of the dispersion present in the data (Figure 5). Histograms of the quantiles were also used to inspect for over- and under-estimated probability of encounter rates, which can suggest a lack of fit. Finally, plots of Pearson residuals across space and time were investigated for spatial and spatiotemporal patterns suggesting model misspecification. Additional tables and a comparison with the design based index are available in Appendix 1 of the 2019 benchmark assessment (Haltuch et al. 2019).

The estimated index shows relatively precise indices with a strong declining trend from 2004-2008, stabilization with a slight increase from 2008 through 2016, an increase between 2016 and 2017 and finally a flat trend through 2019 (Figure 4). The increase in the mid-2010s is largely due to increases in densities off of the coast of Washington. We utilized a gamma distribution, as Q-Q plots in the 2019 benchmark suggested that the gamma distribution fit the data better than a log-normal distribution (see Haltuch et al. (2019)). The lowest densities per year were predicted off of the southern coast of California (Figure 6). No spatial or spatiotemporal patterns were found in the Pearson residuals (Figure 9).

Sampled lengths were binned into 37 2cm-wide bins from 18 (cm) to $\geq$ 90 (cm) to summarize the sex- and year-specific length data.

Large cohorts are visible beginning in 2008, 2010 and 2013 showing clear progressions in the length-composition data over time (Figure 21).

Conditional age-at-length (CAAL) data from the WCGBT Survey are used in the base model because this survey is the most representative source of sablefish age and length data from the U.S. West Coast. Age distributions included 51 bins from age 0 to age 50 and older. Approximately one-quarter as many fish were aged as were measured for length, but these fish were collected from a similar number of tows. CAAL compositions confirm cohorts seen in the length compositions, although signals are dominated largely by age-1 fish (Figures 53-56). An appreciable number of fish are also observed in age classes above age 10. Data confirm the the rapid growth trajectory over the first several years of life, with growth slowing rapidly after 10 years old. Dimorphic growth is also pronounced, with virtually all sablefish above 70 cm being female (Figure 40).

2.1.2 Northwest Fisheries Science Center Slope Survey

The NWFSC Slope survey preceded the WCGBT Survey, starting in 1998 and ending in 2002.

The survey covered depths ranging from 183 - 1,280 m and used small (i.e. 65-86 foot) chartered commercial fishing vessels. This survey consists of fewer tows than the WCGBT Survey and the fraction of tows that sampled ages is much lower. VAST was used in a similar fashion to that specified for fitting the WCGBT Survey data to estimate a relative index of abundance for the 2019 benchmark assessment, which we did not change for this update. We also did not change the biological data associated with this historical survey.

2.1.3 Alaska Fisheries Science Center Slope Survey

The AFSC Slope Survey (Slope Survey) operated during the months of October to November aboard the R/V *Miller Freeman*. Partial survey coverage of the US west coast occurred during the years 1988-1996 and complete coverage (north of 34°30'S) during the years 1997 and 1999-2001. Typically, only these four years that are considered complete surveys are included in assessments. Limited sampling in earlier years covered only relatively small and inconsistent portions of the coast and are therefore insufficient to provide an index of abundance. This survey had a very high degree of both positive tows and biological sampling. A relative index of abundance was estimated using VAST for the 2019 benchmark assessment; it was unchanged in this update. We also did not change the biological data associated with this historical survey.

2.1.4 Triennial Shelf Survey

The AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) was first conducted by the Alaska Fisheries Science Center (AFSC) in 1977, and the survey continued until 2004 (Weinberg et al. 2002). Its basic design was a series of equally-spaced east-to-west transects across the continential shelf from which searches for tows in a specific depth range were initiated. The survey design changed slightly over time.In general, all of the surveys were conducted in the mid summer through early fall. The 1977 survey was conducted from early July through late September. The surveys from 1980 through 1989 were conducted from mid-July to late September. The 1992 survey was conducted from mid July through early October. The 1995 survey was conducted from early June through late August. The 1998 survey was conducted from early June through early August. Finally, the 2001 and 2004 surveys were conducted from May to July. Haul depths ranged from 91-457 m during the 1977 survey with no hauls shallower than 91 m. Due to haul performance issues and truncated sampling with respect to depth, the data from 1977 were omitted from this analysis. The surveys in 1980, 1983, and 1986 covered the US West Coast south to 36.8°N latitude and a depth range of 55-366 m. The surveys in 1989 and 1992 covered the same depth range but extended the southern range to 34.5°N (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 m and surveyed south to 34.5°N. In 2004, the final year of the Triennial Survey series, the Northwest Fisheries Science Center (NWFSC) Fishery Resource and Monitoring division (FRAM) conducted the survey following similar protocols to earlier years. Values for this survey remained unchanged from the 2019 benchmark for this update. We also did not change the biological data associated with this historical survey.

2.1.5 Environmental indices

Research and assessments during recent decades have examined the relationship between sea level, measured via tide gauges, and sablefish recruitment (Schirripa and Methot (2001), Schirripa and Colbert (2005), Schirripa and Colbert (2006), Schirripa (2007), Schirripa, Goodyear, and Methot (2009), Stewart, Thorson, and Wetzel (2011), Johnson et al. (2016)). Changes in sea level serve as a proxy for large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport. A re-analysis of the sea level-recruitment relationship was conducted for this assessment that included all available tide-gauge data available for the U.S. West Coast through 2020, using the same approach as in the 2019 benchmark assessment. The resultant values are nearly identical to those used in that assessment (Figure 13 and Table 13).

2.2 Fishery-Dependent data

2.2.1 Historical commercial landings

Historical commercial landings remained unchanged from the 2019 Benchmark Assessment. Landings data were extracted for the period 1982-2020 and are generally the same as those used in the benchmark assessment, with the addition of the last two years of data. (Figure 2).

2.2.2 Fishery biological data

Data for all states were extracted from PacFIN's Biological Data System (BDS). Broadly, the weighting of commercial biological samples was conducted via the following method using the R package PacFIN.Utilities `https://github.com/nwfsc-assess/PacFIN.Utilities`. This approach did not change between the 2019 benchmark assessment and the present update.

1. Expand the sample weight of lengths (or ages) from the state recorded subsample, consisting of one or more baskets of fish, to the estimated total catch in that market category (or trip for ungraded samples). This step accounts for differences in the fraction of each landing (or market category) that was actually sampled and is important during periods where there are some differences in the number of baskets or fish that comprise a 'sample'. When sample weights were unavailable, as is always the case for fish landed in Washington, gender-specific weight-length relationships were used to approximate the weight of the sample.
2. Sum the trip-expanded values within gear and state combinations. Data sampled from larger landings thus account for more weight in the sum to better reflect the total catch.
3. Expand the values to the reconstructed gear-specific landings, ensuring that if one state sampled landings very heavily but is responsible for only a small fraction of the total landings it will not be weighted too heavily.
4. Sum the number of port-side samples included in the compositions by year and gear for the input sample size.

2.2.3 Discard ratio estimates

The WCGOP estimates commercial fishery discard ratios for the period from 2002 to 2019 using data collected by gear type, fishery (e.g., open access, limited entry), and species/management units. The discard ratios were computed as the total estimated discarded weight (lbs) on observed trips divided by the estimated total catch (discarded and retained). To aggregate these ratios into the gear types modeled in this assessment, each state, fishery, and gear combination was weighted by the total estimated catch (discarded and retained weight). Thus, the discard rates represent weighted estimates from each contributing segment within each gear type. Uncertainty in these values was quantified via bootstrapping the individual observations and then aggregating to the total estimate, providing a distribution of the discard rate. From this distribution, a standard error associated with year specific discard ratio estimate was also estimated. Note that these methods are different than those used by WCGOP to estimate total discards but explicitly consider differences in catch by sector, state, and gear.

Additional years of data were available for the trawl fleet from the 'Pikitch study' conducted from 1985-1987 Pikitch, Erickson, and Wallace (1988) and the Enhanced Data Collection Program (EDCP; Sampson (2002)) conducted from 1996-2000. Discard rates and their corresponding standard errors for 1986-1988 were taken from a re-analysis completed by the NWFSC during 2017 (pers comm., John Wallace). Discard rates ranged from 6%-22% for the fixed gear fishery over the period 2002-2019 (Figure 64). The early estimates of discard rates for the trawl fishery from the 1980s averaged 36.33%. More recent trawl estimates peaked in 2002 at 58.64%. After the implementation of the catch share program in 2011, discard rate estimates for the trawl fleet have dropped as low as 0.50% in 2012, with the highest recent observed rate of 6.62% in 2019. There was a near quadrupling of discard rates in the trawl fishery between 2018 and 2019, from 1.74% to 6.62% (Figure 64).

2.2.4 Discard mortality estimates

Discard mortality rates have been the subject of numerous research studies. sablefish, lacking a swim-bladder (and therefore the propensity for severe barotrauma), may survive after capture, depending on the specific conditions that they experience during the process. Warmer water results in higher mortality because the physiological stress of transitioning from very cold bottom temperatures to warmer surface water and air temperatures can be great (Davis, Olla, and Schreck 2001). Furthermore, fixed gears are less physically damaging to sablefish compared to spending an extended period in a trawl cod-end with a large catch volume. Treatment and handling of captured fish, including time-on-deck, are also likely to be important for subsequent survival. Analysis of discard mortality is hampered by the lack of available temperature information. Substantial efforts as part of the 2005 assessment resulted in a detailed model-based approach that used seasonal average water temperatures to predict variable annual discard mortality rates over the historical time-series, corrected for estimated differences among gear types (Schirripa and Colbert 2005). Ultimately the approach was too complex to be supported by the available data with which to assign temperature and other individual fishing trip variables. In 2011, discard mortality estimates were corrected to be consistent with those used by the Pacific Fisheries Management Council's Groundfish Management Team (GMT) in predicting in-season total mortality and the National Oceanic and Atmospheric Administration's annual calculation of total mortality for comparison with harvest regulations. These values are 20% discard mortality for sablefish captured with fixed gear and 50% discard mortality for sablefish captured with trawls. An exception to this is for age-0 fish for which discard mortality is assumed to be 100%. These rates were used in this assessment.

2.3 Biological Parameters

A number of biological parameters were estimated outside the 2019 assessment model (weight-length relationship, the maturity schedule, and fecundity relationships). These values are treated as fixed in that model and the present update (Table 12), and therefore, uncertainty reported for the stock assessment results does not include any uncertainty associated with these quantities.

3 Assessment Model

3.1 General model specifications

The 2019 update stock assessment model was transitioned into SS version 3.30.13-safe, released 2019/03/09. Our transitioned model matched the time series of spawning biomass and stock depletion estimated in the 2019 stock assessment (light grey and dark grey lines, Figure 38). The likelihoods between models were identical only when the natural mortality parameter for both sexes, and the descending standard error for both AKSLP and NWSLP survey age-based selectivities, were fixed to the values in the 2019 benchmark assessment (Table 9). The base model presented here estimates parameters in the manner done in 2019, with the same priors. SS has a broad suite of structural options available for each application. There are no true 'default' settings for most of these options; each application must be customized to best represent the life-history, dynamics, data-complexity, and estimation approach (Bayesian or maximum likelihood) most appropriate. After sequentially adding all new data, we freed the aforementioned parameters to produce a model which conformed to the Terms of Reference. The uncertainty in this model (which otherwise matches the structure of the 2019 benchmark assessment) was larger than the benchmark, which was not the case when the values for natural mortality were fixed. Importantly, this model was unable to satisfactorily fit to the composition data from the trawl fleet nor the WCGBT Survey (Figures 16, 17, and 18), greatly overestimated the 2019 index, and distorted the recruitment patterns to suggest two large recruitment events since 2016 (Figure 20).

During the exploration of recent data for this update assessment, modelers identified increased discarding in the trawl fleet, for which the discard ratio nearly quadrupled between 2018 and 2019 (Figure 64). Absent the data or structural flexibility to account for increased discarding, a model that conformed to the Terms of Reference (TOR) for an update assessment was unable to satisfactorily fit to the age composition data from the trawl fleets (Figure 17) nor the WCGBT survey length composition data (Figure 18), and greatly overestimated the 2019 index (Figure 19). We rectify the lack of fit to the data found in the TOR model by re-introducing the discard length compositions and time-blocking the retention curve to include a new block for the final two years of the model period (2019-2020; the benchmark model's terminal period for retention selectivity ran from 2011-2017). This adjustment resolved the aforementioned model fit issues (Figures 21-28). The proposed base model presented here otherwise estimates parameters in the manner done in 2019, with the same priors.

This stock assessment encompasses the U.S. West Coast and assumes a closed population. The first modeled year is 1890, the start of sablefish landings in Washington. The population is assumed to be at equilibrium at the start of the modeling period because data from a full catch reconstruction for sablefish back to the inception of the fishery is used to fit the model. Fishery removals were divided among two fleets, (1) fixed gears and (2) trawl gears. Selectivity schedules are treated separately for each fleet. In the base model, retention parameters were fixed at values estimated from earlier exploratory model runs. Each trawl survey is treated as a separate survey with independently estimated selectivity parameters reflecting differences in depth and latitudinal coverage, survey design, methods, and equipment.

This assessment specifies sex with growth curves for males and females and tracks the total and summary biomass for both sexes combined, but the spawning biomass only of females, for calculating management quantities. Growth parameters describing the von Bertalanffy growth equation, as well as the spread of lengths for a given age, were estimated for each sex. The parameterization used for the estimation of growth by SS allows the user to specify the age for the two growth parameters (rather than the length at age zero and the implied length at infinite age). Ages 0.5 and 30 were selected to be close to the ranges found in the observed data. Sex-specific M was estimated, with the informative priors based on the maximum aged fish in the composition data (102 years old for females from the fishery in 2006 and 91 years old for males from the survey in 2016).

Age bins for the internal population dynamics range from 0-70 years, with the accumulator age of 70 specifying the plus group. This age was necessary to ensure that the plus group did not have a large number of fish.

Recruitment dynamics are governed by a Beverton-Holt stock-recruitment function. This relationship is parameterized to include two estimated quantities, the log of unexploited equilibrium recruitment (R_0) and steepness (relative recruitment at 20% of unfished spawning output; h). A full time-series of recruitment deviations, including the initial age-structure at the start of the model are estimated to adequately propagate uncertainty in the historical period and avoid imparting the perception of information through overly rigid conditions prior to the most recent time-period informed by length- and age-composition data.

The model calculates quantities using an annual time step. Thus, data collection is assumed to be relatively continuous throughout the year. Fishery removals occur instantaneously at the mid-point of each year and recruitment occurs on the 1st of January. The sex-ratio at birth is fixed at 1:1. Sex-specific M and selectivity can result in significant departures from equality for older ages due to differential M and F over age and sex. Model files including the SS executable, data, control, starter, and forecast files are archived with the Pacific Fisheries Management Council.

3.1.1 Priors

Uniform (non-informative) priors were applied to all estimated parameters in the base model with the exception of male and female M. Parameter bounds were identical to those used in 2019, which were selected to be sufficiently wide to avoid truncating the search procedure during maximum likelihood estimation. The base model fixed h at 0.7. As with many assessments, this assessment is unable to estimate h, likely due to the largely one-way trip nature of the time-series during the period with good data collections and the high degree of confounding between population scale (via equilibrium recruitment), M, and h. Likelihood profiles for h in past sablefish assessments suggest that there is little information in the data to determine h. The use of a fixed value underestimates the uncertainty in MSY and equilibrium yield. However, the importance of this reduced uncertainty is somewhat reduced because both and F and SB_{proxy} are used for management rather than MSY.

3.1.2 Data weighting

Sample weighting was used to achieve consistency between the degree of uncertainty in each data set and the fit of model estimates to those data. Variances and sample sizes were first derived from the raw data sources and then re-weighted using the Francis method ensure consistency between the input sample sizes (or standard errors) and the effective sample sizes (root mean square error, RMSE) based on model fit. This approach reduces the potential for particular data sources to have a disproportionate effect on total model fit, while creating estimates of uncertainty that are commensurate with the uncertainty inherent in the data.

In 2019, added variances for discard rates and mean body weights were set using values calculated iteratively using the RMSE of differences between input and estimated values derived from SS. Variances were parameterized in terms of standard deviation and coefficient of variation, respectively. We did not adjust nor re-calculate these values for the update assessment.

Indices of relative abundance all had variance estimates generated as part of the analysis of raw catch data. These variances were converted to standard deviations in log space for use in the model; additional variances for the indices of abundance were estimated inside the model, except for the WCGBT Survey, for which the estimated added variance was near zero, so it was fixed at zero.

Additional variances were added to mean body weight of the fishery discard data as well as to the discard rates in a manner identical to those used in the 2019 assessment. The weighting of age- and length-composition data attempted to reduce the potential for particular data sources to have a disproportionate effect on total model fit, while creating estimates of uncertainty that were commensurate with the uncertainty inherent in the input data.

Input age- and length-composition data were weighted via the Francis method (Table 15). Sensitivity to the iterative re-weighting approaches for developing consistency between the input composition sample sizes (or standard errors) and the effective sample sizes based on model fit using the Harmonic Mean (McAllister and Ianelli (1997)) and (Francis (2011)) methods was completed. The Harmonic Mean method consisted of comparing the mean input sample size for compositional data with the mean effective sample size based on model fit. The Francis method considers the influence of compositional weights on fits to average lengths or average lengths-at-age. Generally, the Harmonic method suggested similar weights for the commercial length composition data, but placed more weight on the survey length data. It also indicated a downweighting of commercial age composition data compared to the 2019 benchmark, but to a lesser degree than the Francis approach (Figure 39).

During the Francis weighting process, several distinctions between this update and the weights used in the 2019 benchmark became apparent. Firstly, the 2019 benchmark assessment iteratively re-weighted both commercial fleet age composition weights to a maximum of one, whereas in this update (in the presence of commercial discard length compositions) they were downweighted by 90% and 81% (for fixed gear and trawl fleets, respectively, Table 15) . In addition, the WCGBT Survey length compositions were downweighted in the update by a factor of about 10 (from 0.29 in the benchmark to 0.033 in the present model), whereas the Triennial age compositions were upweighted by a factor of 10 (from 0.10 in the benchmark to a cap at 1.0 in the present model). We performed a sensitivity run where the Francis weights were fixed to the values used in 2019 and found the model to fit more poorly (Figure 39 and Table 16).

3.1.3 Recruitment variation

The value of the parameter controlling recruitment variability was determined in 2019 using an iterative procedure with the aim of ensuring that the value assumed by the assessment model and the empirical variance in recruitment were self-consistent. This involved setting to an initial value, fitting the model and calculating the variance of the recruitment deviations for the years for which recruitments are estimated, then replacing the assumed value of by the calculated value. The recruitment variability was tuned up to and capped at a value of 1.4, the maximum value at which the bias correction was expected to provide reliable results. This value was unchanged in this update assessment.

3.1.4 Estimated and fixed parameters

A total of 313 parameters were specified in the base model and 235 of them were estimated (Tables 12 and 14). Female and male M were estimated, as is commonly done for groundfish stocks that exhibit dimorphic growth such as sablefish. Time-invariant, sex-specific growth was also estimated.

3.1.4.1 Natural mortality

From 1992 to 2007 a single fixed value for natural mortality (M) of 0.07 was assumed in all sablefish stock assessments (Schirripa 2007). Improvements in the understanding of the importance of M estimates on stock assessment model uncertainty, and the growing number of assessments identifying differences in M among male and female groundfish, make a fixed value approach undesirable. Furthermore, the maximum aged sablefish on record is over 100 years. This assessment uses a prior probability distribution for males and females based maximum observed age (Then et al. (2015)). Results of the analysis led to log-normal priors as follows: $ln(M)$ = ⟨-2.94,0.44⟩ for females (Hamel (2015)) and $ln(M)$ = ⟨-2.9,0.44⟩ for males (Figure 41).

Both priors resulted in a substantial probability density over the range 0.02 to 0.12. The upper bound is higher than might be expected given that sablefish are long-lived fish, but they also grow rapidly relative to most other long-lived fish.

3.1.4.2 Growth

This assessment specifies sex with growth curves for males and females but tracks only the spawning biomass of females for calculating management quantities. Growth parameters describing the von Bertalanffy growth equation, as well as the spread of lengths for a given age, were estimated for each sex. The parameterization used for the estimation of growth by SS allows the user to specify the age for the two growth parameters (rather than the length at age zero and the implied length at infinite age). Ages 0.5 and 30 were selected to be close to the ranges found in the observed data.

3.1.4.3 Unexploited Recruitment R_0

The log of the unexploited recruitment level, $ln(R_0)$, for the Beverton-Holt stock-recruitment function was estimated, as were annual recruitment deviations beginning at the model start, 1890. The main period of recruitment deviation estimation was chosen based on the first year of available sea-level data (i.e., 1925. The years in which mean bias was corrected for was based on methods developed by Methot and Taylor (2011) that estimate the residual variability in the recruitment deviations for years in which data are available to inform the stock-recruitment curve. Survey catchability parameters were calculated analytically (set as scaling factors) such that the estimate is median unbiased, which is how q is treated in most groundfish assessments approved by the Pacific Fisheries Management Council. Age selectivities were estimated using a double normal parameterization (SS pattern 24) for all fleets and surveys. The double normal allows for either dome-shaped or logistic selectivity, allowing for easy exploration of alternative selectivity assumptions. Sex-specific age selectivity was estimated for the fixed-gear fishery and the Triennial Shelf Survey because females are more selected to the gear than males. A single set of age selectivity parameters was estimated for females and males for the trawl fleet and all other surveys.

3.1.4.4 Selectivity and Retention

Initially, parameters for the width at the peak (P2) and initial selectivity (P5) were fixed at values that fit the data to allow for the estimation of dome-shaped selectivity. Dome-shaped selectivity was estimated by estimating the final selectivity parameters (P6) for all patterns except for the selectivities associated with the fixed-gear fleet and the WCGBT Survey, which was fixed based on a likelihood profile. The width of the descending limb parameters (P4) were estimated for all fleets except for the trawl fleet, which was fixed at the 2019 value. Surveys covering the shelf depths (WCGBT Survey and Triennial Shelf Survey) captured a large fraction of age-0 and age-1 sablefish, with peak ages of the catch less at young ages ($\sim<2$ years). Selectivity was lower for older individuals.

Time blocks for fishery selectivity and retention schedules were based on previous research with respect to influential management 'milestones' and the recent introduction of catch shares within the trawl fishery (Table 11). Milestones include:

1. Full retention of age-1^{+} sablefish during WWII, rapid post-war fishery development, and introduction of trip-limit induced discarding (not just size-sorting) for the trawl fleet in 1982 and for fixed-gear fleets in 1997;
2. A change in selectivity during the post-war groundfish fishery development in 2003 resulting from large scale movements of all fleets in response to large spatial closures (Rockfish Conservation Areas; RCAs); and
3. Full retention all sablefish within the trawl fishery with the implementation of the 2011 catch share program.

4. *New to this update assessment*: a time block in commercial retention for the final two years of the model (2019-2020) reflecting a change in discarding rates, responsive to a large influx of small recruits (particularly in the trawl fishery).

Length-based retention is defined for the commercial fishing fleets via a length-based logistic curve defined by an inflection, slope, and asymptote. The main retention curve parameters in the base model were fixed at values estimated in using models that fit to the discard length data. Ultimately, time-varying retention was implemented for the inflection and asymptote parameters for the fisheries to enable fitting of the discard-rate data. Full retention of small fish during World War II was assumed by fixing the inflection at 25 cm, implying retention of all fish greater than age-0. This inflection parameter was then permitted to vary through time. Full fishery retention was assumed prior to the institution of fishery trip limits (by fixing the asymptote parameter), then was permitted to vary until the most recent time period in the trawl fishery. Full retention in the time period from 2011-2018 was assumed in the trawl fishery due to the requirement of full catch accounting with the implementation of the catch shares program. The inflection point and asymptote for both the trawl and fixed-gear fishery retention curves were estimated in a final time block (2019-2020) to allow for increased discarding in those years. Peak fishery selectivity and the ascending limb of selectivity were permitted to vary among the time blocks for the fixed-gear fleet. The width of the descending limb of the trawl fleet was permitted to vary among the time blocks. Finally, time-varying selectivity was estimated using the descending limb of the Triennial Shelf Survey from 1995 forward to allow for changes in survey design.

3.2 Changes made from 2019 Assessment

During the exploration of recent data for this update assessment, modelers identified increased discarding in the trawl fleet, for which the discard ratio nearly quadrupled between 2018 and 2019 (Figure 64). In the first iteration of this update model, retention curve parameters were fixed, as discard length compositions were not included due to conflicts between the age and length data found in the 2019 benchmark assessment. Absent the data or structural flexibility to account for increased discarding, a model that conformed to the Terms of Reference (TOR) for an update assessment was unable to satisfactorily fit to the age composition data from the trawl fleets (Figure 17) nor the WCGBT survey length composition data (Figure 18), and greatly overestimated the 2019 index (Figure 19). Because the TOR model estimates retention for both fisheries in a single timeblock from 2011 onward, the discard data forced the model to generate many small fish, thus overestimating the model-expected index of abundance, the frequency of young and/or small individuals, and distorting the recruitment pattern (Figure 20).

We rectify the lack of fit to the data found in the TOR model by re-introducing the discard length compositions and time-blocking the retention curve to include a new block for the final two years of the model period (2019-2020; the benchmark model's terminal period for retention selectivity ran from 2011-2017). This adjustment resolved the aforementioned model fit issues (Figures 21-28), and is herein presented as the ”base model”.

The salient changes to this update assessment versus the 2019 benchmark are as follows. Stopping at step 1 below produced the model that conformed to the Terms of Reference described in the executive summary, which failed to satisfactorily fit the data. To generate the base case model presented here, all three steps were taken.

1. Addition of recent information for all data sources which were included in 2019. Of these, we performed re-analyses for the WCGBT Survey (with data through 2019, see Section 2.1.1) and the environmental index of sea surface height (using tide-gauge information through 2020, see Section 2.1.5).
2. Introduction of commercial discard length compositions from the West Coast Groundfish Observer Program (WCGOP) for 2005-2019 and 2004-2019 for the fixed gear and trawl fleets, respectively. Input sample sizes for discard length compositions were based on the number of observed trips.
3. Addition of a terminal time block for the two commercial fishery fleets from 2019-2020. Both the asymptote and inflection point are estimated for this time block for both fisheries; otherwise, the estimation structure for retention and selectivity parameters remains the same.

3.3 Base model selection and evaluation

All structural choices for stock assessment models are likely to be important under some circumstances. Therefore, these choices are generally made to be as objective as possible and follow generally accepted methods of approaching similar models and data. Sources of structural uncertainty in this assessment include:

1. the fixed value used for h,
2. the fixed parameter values for the descending limb of dome shaped age selectivity in the fixed gear fleet (fixed by using likelihood profiles),
3. the assumption of a closed stock within the US West Coast, and
4. the use of a time- and age-invariant (but sex-specific) M.
5. the assumption that the stock-recruit relationship follows a Beverton-Holt parameterization.

In reality, unmodeled spatiotemporal variation in M, growth, and movement may impact sablefish and the perception of the stock size and status. Predation, availability of food resources, or environmental factors may have directional instead of random effects on survival, growth, or movement during the modeled period. However, this degree of complexity is beyond the information content of the available data. Residual patterns in the length data could be due to unmodeled time-varying processes or reflect different growth trajectories among cohorts. Sablefish along the US West Coast do not exist independently of the population that occurs in British Columbia, Mexico to the south, and Alaskan waters to the north. The degree to which recruitment linkages and adult movement may be contributing to the observed dynamics of the U.S. West Coast stock is unknown. Potential shifts in spatial distribution in response to changes in density outside our waters or climate impacts could substantially reduce our ability to model and predict current and future trends. Efforts to synthesize existing data for northeast Pacific sablefish with the aim of stock-wide modeling are underway.

3.4 Base Model Results

3.5 Convergence status

To test for convergence, 100 trials of the base model were ran using randomly generated alternative initial values for each estimated parameter. A value of 0.1 was used to define the uniform distribution that is transformed into cumulative normal space and subsequently used to calculate these initial values based on the parameter bounds. Thus, each trial perturbs the initial values used for minimization with the intention of causing the search to traverse a broader region of the likelihood surface (Methot and Wetzel (2013)). The 100 iterations of the jitter test for the base model resulted in 18 model runs that failed to converge, 24 model runs that converged at or close to the total likelihood estimate value of the base case model run, and 58 model runs with total likelihood values higher than the base. This demonstrates that the jittered model was sensitive to the initial values of the parameters. The specification of both bounds and priors on individual parameters, together with penalties, weights on associated likelihoods, and high correlations among parameters can all affect jitter convergence. None of the trial runs were used to replace the base model.

The biological parameters (growth and M) estimated using the base model and alternate models were reasonable. Growth parameters were consistent with those from previous sablefish stock assessments and commensurate with the raw data (Table 12). Female and male sablefish showed similar rapid growth trajectories; with females growing to a slightly larger size at age 30 (62.46 cm) than males (56.62 cm) and showing a broader distribution of length at a given age (Figure 40). M for females (0.073) and males (0.60) were similar to values estimated in previous assessments (2011: 0.080 and 0.065 respectively; 2015: 0.076 and 0.062, 2019: 0.065 and 0.059, respectively; Figure 41).

Estimated selectivity curves for the trawl surveys varied, with the surveys that sample the continental slope sampling the broadest demographic of the sablefish population and the Triennial Shelf Survey the most limited (Tables 12 and 14; Figure 42).

The fixed gear fisheries showed males were less selected than females, and that individuals of approximately age 20 and older were much less available to the fishery on a relative basis (Figure 44). The trawl fishery selected younger fish than the fixed gear fleet and showed little difference between males and females (Figure 44). Retention schedules (Table 14) showed rapidly increasing retention of age-1 fish for the fixed gear fishery but less than full retention of the largest individuals, likely due to some trip-limit based discarding or depredation of large fish during gear retrieval (Figure 43). Full retention of the largest individuals was assumed since the beginning of the 2011 catch-shares program for the trawl fishery, with an increase in the minimum retention size for both sexes in the final two modeled years (Figure 45).

The base model fit the trend (decline, then stabilization, and increase) in the WCGBT Survey well (Figure 46), such that the added variance parameter was set to zero as was done in 2019. Fits to the NWFSC Slope Survey were generally flat (Figure 47), as might be expected for such short time-series. Fits to the AFSC Slope Survey suggest a decreasing trend during the late 1990s followed by and increase into the early 2000s (Figure 48). Estimates of added variance were 0.16 and 0.04, respectively (Table 14). Given the time change in the estimate of q for the Triennial Shelf Survey beginning in 1995, predicted survey values were also relatively flat over this period until the last two years of the survey (Figure 49), although the estimated extra variance of 0.18 suggested a relatively poor fit to these data compared to other surveys.

The fit to the sea-level index of recruitment was noisy, as expected, due to the relatively weak but persistent sea-level recruitment relationship, showing periods where the model was able to fit the data well, as well as periods with a lack of fit (Figure 50). The estimated added standard deviation was 0.41, thus the sea-level index provided limited information regarding historical recruitment during model periods without other data.

The base model fit the length distributions from the WCGBT Survey well given that selectivity was modeled as age based, with residual patterns (Figures 18 and 52) primarily generated through small mismatches in the model structure, likely due differences in growth, environmental conditions, or timing rather than misspecification of year-classes. The fits to the WCGBT Survey conditional-age-at-length distributions were good (Figures 53-56). The slope survey fits to the marginal-age distributions also showed no glaring residual patterns in the age data (Figures 58- 60). The selection of younger sablefish was evident for the Triennial Shelf Survey, with a larger residuals from 1995 forward (Figure 62).

Fits to the marginal age compositions for the fisheries were good (Figure 57). All fisheries show relatively small residuals, with patterns of large cohorts moving through the population at some point (Figures 58 and 59). Residual patterns might partially be the result of spatial differences in fishing, growth or movement.

The model was able to fit the mean body weights of the fishery discards and discard fractions well (Figures 63 and 64).

Deviations about the estimated stock-recruitment function generally had high uncertainty prior to the mid-1970s, when the age-composition data first become informative about cohort strengths (Figure 65). This stock assessment update was able to estimate cohort strengths further back in time due to the increased plus group, extended to 50 years (note that the data plus group is 70 years, whereas the modeled plus group is 50). The NWFSC and AFSC Slope Surveys, as well as the WCGBT Survey, all catch older fish that provided some information with respect to recruitment prior to the mid-1970s (the informative period for recruitment in past assessments). Including the sea level as a survey index of recruitment strength informs recruitment estimates in a limited fashion prior to the mid-1970s. The recruitment bias adjustment was set as recommended by Methot and Taylor (2011).

Sablefish recruitment was estimated to be highly variable with large amounts of uncertainty in individual recruitment events. Within this variability, there were sets of years with recruitment estimated consistently higher or lower than the long term mean (Figure 29), with both the lowest and highest estimates occurring during the past 20 years. Given a relatively high degree of recruitment variability, the estimated stock-recruitment function predicted a wide range of cohort sizes over the observed range of spawning biomass (Figure 66).

Catches were input from the beginning of the time series (Table 17). The estimates of uncertainty around the point estimate of unfished biomass are large across the range of models explored within this assessment, suggesting that the unfished spawning biomass could range from just under 100,000 mt to over 200,000 mt. This uncertainty is largely due to the confounding of natural mortality, absolute stock size, and productivity. The point estimate of 2020 spawning biomass from the base model is 97,802 mt; however, the $\sim$ 95% interval ranges broadly from 40,801 to 154,802 mt. The relative trend in spawning biomass is robust to uncertainty in the leading model parameters. The 2021 point estimate of spawning stock biomass is 58% of the unfished state (approximate 95% interval: 38% to 77%). Estimates indicate that the spawning biomass was near the target (Figure 30). The estimated time-series of total, age-4+ (Figure 68), and spawning biomass (Figure 69) track one another closely (Table 18).

3.6 Uncertainty and Sensitivity Analyses

Sensitivity analyses were performed to determine the sensitivity of the model results to a range of alternative assumptions. While the recent stock trend and estimates of stock depletion were similar among model sensitivities, a common theme is that the size of the unfished spawning biomass was highly uncertain. The available data for sablefish were largely uninformative about the absolute stock size and productivity. This stock assessment model, given the data, was unable to discriminate between a larger, less productive stock and a smaller more productive stock, or many combinations in between. This could be due to the largely 'one-way-trip' during the period with the most informative data or the fact that northeast Pacific sablefish are a single stock that exhibit movement throughout their range. In addition, the inclusion of new data from the same sources as the 2019 benchmark resulted in greater uncertainty around the derived quantities, a pattern which emerged as soon as natural mortality was freed and most pronounced in the slighly increased uncertainty around growth parameters.

Historical catches provide some information about the minimum stock size needed to have supported the observed time-series but there is less information about the upper bound on stock size. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in many parameters can result in differing point estimates for management reference points, however the uncertainty about these estimates remains large unless leading model parameters, such as M and h, are fixed. This uncertainty will remain until a more informative time-series and better quality demographic and biological information are accumulated for the stock, and potentially until a range wide northeast Pacific sablefish analysis is available.

Uncertainty in the properties of current aging methods (both potential bias and imprecision), as well as relatively sparse fishery sampling, result in potentially noisy age data. Similarly, because sablefish grow very rapidly and reach near-asymptotic length in their first decade of life, length-composition data were not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that the stock trajectory (via shifts in recruitment strength) was linked to productivity regimes in the California Current. Uncertainty in future environmental conditions, changes in the timing, dynamics, and productivity of the California Current ecosystem, via climate change or cycles similar to the historical period, should be considered as a significant source of uncertainty in projections of stock status.

The WCGBT Survey was an excellent relative index of abundance over a broad demographic component of the sablefish stock (although not the entire stock, as some of it occurs in deep water and was therefore unobserved). This index, as well as stock assessments that better capture the dynamics of sablefish across the NE Pacific, may inform future stock assessments about the scale of the sablefish population relative to the catches being removed. The reduced survey effort (by 50%) in 2019 and lack of survey at all in 2020 certainly reduced recent information available for this assessment. Having a complete survey in future years is of great importance for future iterations of this assessment.

A small set of sensitivity analyses were chosen to provide more information about potential information in the data, and potentially conflicting signals among data sources.

The results are by no means meant to be a comprehensive comparison of all possible aspects of model uncertainty, nor do they reflect even the full range of models considered in developing the base model.

1. Use of the McAllister-Ianelli (Harmonic Mean) data weighting method as an alternative to the Francis method (described above in Section 3.1.2 on Data Weighting).
2. Use of the 2019 Francis data weights in lieu of the tuned Francis weights (described above in Section 3.1.2 on Data Weighting).
3. Inclusion of the At-Sea Hake Observer Program data (landings and length compositions). Adding information about sablefish abundance gained from the Pacific hake (*Merluccius productus*) fishery did not lead to significant changes relative to the base model; this model used the same weights as was done for the sensitivity in the 2019 benchmark analysis (Figure 70). A sensitivity run with the Francis weight for the At-Sea Hake length compositions set to 1 did not converge (results not shown).
4. Inclusion of the commercially-landed length compositions for the fixed-gear and trawl fleets, using the same Francis data weights as in the base model. The time series of spawning biomass and depletion for this sensitivity were similar to the base model, though there were small changes in the magnitude of recruitment events in the 1970s (Figure 71). While we did not retune the Francis weights after the inclusion of this data, the tuning algorithm suggested to downweight the fixed-gear compositions by about half, and to upweight the trawl-gear lengths by a factor of about two. This is consistent with the trawl fishery, which samples more of the population, containing more information about incoming recruits.
5. Estimating a single parameter for natural mortality (M). In the base model, M was estimated at 0.0726 for females and 0.0605 for males; the single-parameter model estimated it to be lower at 0.052. The estimated unfished spawning biomass, while within the uncertainty bounds of the base model, was below the base model value. The sensitivity model reduced the size of large recruitment events and suggested the stock to be just barely above $B_{40\%}$ in 2020 (Figure 72).
6. Implementing asymptotic age-based selectivity for the WCGBT Survey. This reduced overall model uncertainty (principally through reducing the standard deviation of R_0) and also reduced the size of large recruitment events. This model had a higher overall log-likelihood than the base model, and did a poorer job of fitting the length compositions from that survey, particularly in the last year of data (Figure 73).
7. Removing the index of sea surface height. A model run with the SSH data removed was identical to the base model in terms of depletion from the late 1970s onward, and shifted the large recruitment event backward by 3 years. (Figure 74).
8. We also explored various parameter phasings, which had little impact on the base model.

3.7 Retrospective analysis

A retrospective analysis was conducted by running the base model with data removed for the past 5 years. All retrospective model runs fall within the uncertainty estimates from the base model. There was limited evidence of a retrospective pattern in estimates of spawning biomass and stock status, such that the view of the stock becomes more pessimistic as data are removed (Figures 75 and 76). The retrospective pattern in stock status is largely driven by the relative amount of data available to inform the estimates of some of the largest recruitments observed for sablefish during 2013 and 2016 (Figure 77).

3.8 Historical analysis

Estimates of the current stock size and relative depletion were highly consistent with prior stock assessments, particularly from the 1970s forward, the period of time with good data for sablefish (Figure 80). Estimates of stock size prior to the mid-1970s are greater in the 2005 and 2007 assessments, however there were limited data to inform the pre-1970 model period. Notably, depletion estimates for retrospective runs which truncate the series to 2019 or earlier are within the narrower uncertainty bounds from the 2019 benchmark, while the perception of the stock as increasing is consistent across all models which include the new data and timeblocking structure (Figures 78 and 79).

3.9 Likelihood profiles

Likelihood profiles were used to elucidate conflicting information among various data sources, to determine how asymmetric the likelihood surfaces surrounding point estimates may be, and to provide an additional evaluation of how precisely parameters are being estimated. Likelihood profiles were completed for three key model parameters: female M, unexploited equilibrium recruitment (R_0), and h. For a single parameter (loosely interpreting an iteratively re-weighted stock assessment objective function in terms of true likelihood) an increase in negative log-likelihood of more than two units indicates a statistically significant degradation in fit.

Female M (male natural mortality rate estimates are highly correlated with female mortality, so it is not included in this discussion) was found to be moderately informed across a relatively wide range of values. Data from the discard appears to be the most influential for this parameter. Differences in total negative log likelihood was less than two across approximately 0.060-0.095 for female sablefish M Figures 81). However, this is not a trivial parameter range and the assessment results vary considerably among these values in absolute scale (Figure 83).

Unexploited equilibrium recruitment (R_0) was found to have similar likelihoods over 9.2-10.4, values which led to a broad range of stock sizes (Figures 84-85). The range of values explored led to little differences in the current level of depletion the stock is facing but large differences in depletion from 1935 to 1970 where there is little information during a period with fishing (Figure 86).

In the base model, h is fixed at 0.7, making it an important profile to evaluate as its uncertainty is not explicitly included in the base-model results. In 2011, the maximum likelihood estimate for h was 0.2, which implies zero surplus production, which is biologically implausible. This assessment found essentially equal support in the data over a broad range of explored values (Figure 87). Most of the values included in the profile led to similar trajectories of spawning biomass (Figure 88).

In aggregate, these profiles explain why the asymptotic uncertainty about historical and current stock size is so broad and underscore the lack of information in the data regarding scale for this stock assessment.

4 Reference points

Unfished spawning biomass was estimated to be 168,875 mt (107,749–230,001 ~95% interval). The abundance of sablefish was estimated to have declined to near the target during the period 1980-2000. The estimate of the target spawning biomass was 67,550 (43,099-92,001, ~95% interval). The stock was estimated to be above the target stock size in the beginning of 2021 at 97,802 mt (40,801-154,802, ~95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield (0.4) (Figures 31 and 32). The estimate of the stock's current 2021 level of depletion was 0.579.

Although the estimated productivity and absolute scale of the stock are poorly informed by the available data and are, therefore, sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a declining trend in biomass since the 1970s followed by a recent increase in biomass (Figures 33 and 34). The spawner potential ratio (SPR) relative to the fishing mortality target or overfishing level ($SPR_{45\%}$) that stabilizes the stock at the target (reported as $(1 - SPR)/[1 - SPR_{45\%}]$), was greater than 1 (thus exceeding the target rate) during nearly half of the years from 1976 through

2000, has been below the target since, and was between 0.62 and 0.76 from 2015-2019, descending to 0.40 in 2020. 'Relative 1-SPR' in Table 4 refers to $(1-SPR)/[1-SPR_{45\%}]$; where 1 is the target exploitation rate, and values over 1 indicate overexploitation relative to this proxy. While highly uncertain, the absolute equilibrium yield at the estimated fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 9,024 mt (4,242-13,807, ~95% interval), while the proxy SPR rate of 0.45 leads to a proxy MSY of 8,350 mt (3,924 - 12,777, 95% interval).

The phase plot shows the interaction of fishing intensity and biomass targets (Figure 32).

5 Harvest projections and decision tables

Previous sablefish stock assessments have been designated as Category 1 stock assessments. Projections and decision tables are based on P^*=0.45, the adopted value for the most recent management cycle, and the values of σ adopted by the Pacific Fisheries Management Council for stock projections. The time series of multiplicative buffer fractions that are a function of P^* and the time series of σs provide the multipliers on the overfishing limit; these values are all less than 1 for category 1 stocks. σ for sablefish is the time-varying category 1 value, which starts at 0.5 in the year after the (update) assessment and increases throughout the projection period. The uncertainty around the OFL value for the first forecast year (2022) is 0.319; the uncertainty around spawning output in that same year is 0.298, both less than 0.5. The multipliers are combined with OFLs to calculate the ABC values. The Council sets ACL values which cannot exceed (with limited exceptions) the ABCs as modified by the 40-10 rule. The total catches in 2021 and 2022 were set at the Pacific Fisheries Management Council Groundfish Management Team requested values, below the Pacific Fisheries Management Council annual catch limits for sablefish. The average ratio between GMT-specified 2021-2022 catches were used to distribute catches among the fisheries for forecasted years.

Projections are provided through 2032 (Table 7). Current medium-term projections from the base model under the Pacific Fisheries Management Council 40-10 harvest control rule estimate that the stock will remain above the target stock size of 40% of the estimated unfished spawning biomass during the projection period. Forecasts from the 2019 benchmark assessment projected the spawning biomass to increase by 28% from 2017 to 2021 given specified harvests, whereas the current assessment estimated the increase at 23%. The estimate of unexploited spawning biomass (in the year of each assessment) is 13% higher than that estimated in 2019 and 19% lower than the 2011 estimate. Relative unfished biomass in 2021 was estimated at 0.58, while the 2019 benchmark assessment forecasted it to be 0.46.

6 Regional management considerations

Recent sablefish management has relied upon apportionment of the ACL north and south of 36° N latitude using the average estimated differences in biomass from the WCGBT Survey. This historical management line corresponds with a recent data-driven analysis of sablefish growth that suggests a difference in growth rates north and south of 36° N latitude (Kapur et al. (2020)). The estimates represent the relative distribution of the sablefish population observed by the survey, not the entire population. Additionally, it is likely that fish from more northerly regions are migrating into U.S. West Coast waters (pers. comm., L. Rogers), which may bias the survey estimates of the distribution of fish in each region. Thus, these results should be interpreted with caution.

The average survey biomass, from 2003 to 2019, that has been distributed south of 36°N, is 24%. The average survey biomass, from 2003 to 2019, that has been distributed north of 36°N, is 76%. The 2015 and 2019 assessments estimated that 26.2% and 26.3% of the biomass was found south of Point Conception and 73.8% and 73.7% of the biomass was found to the north, respectively. The estimates from the WCGBT Survey show that the spatial distribution of sablefish along the U.S. West Coast appears to be relatively stable, particularly from 2008 to 2014 (Figure 4).

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9 Figures

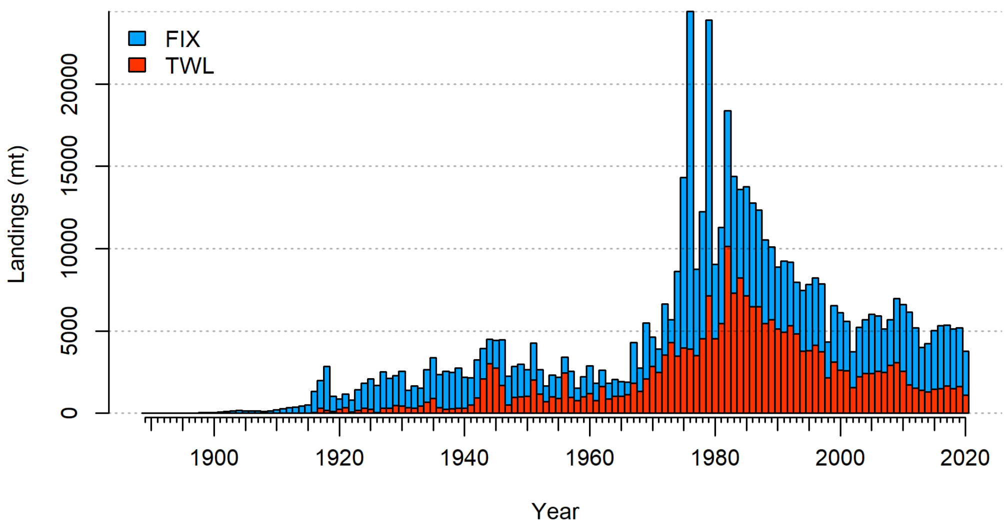


Figure 1: Sablefish landings from 1890–2020 summarized by the gear types included in the base model, fixed-gear and trawl. Landings include those from foreign fleets, which are largely responsible for the peaks in 1976 and 1979.

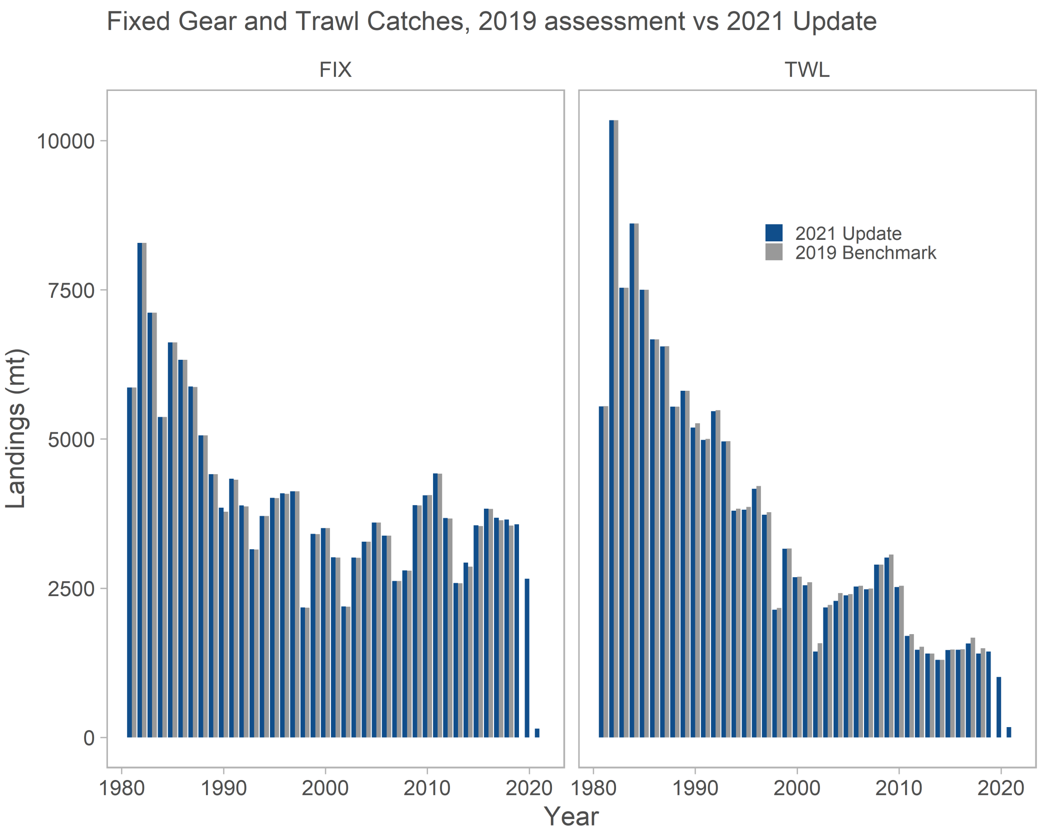


Figure 2: Comparison of landings by fleet used in 2019 benchmark Assessment (grey bars) and in present update (blue bars), 1982-2020. Historically reconstructed landings remain unchanged.

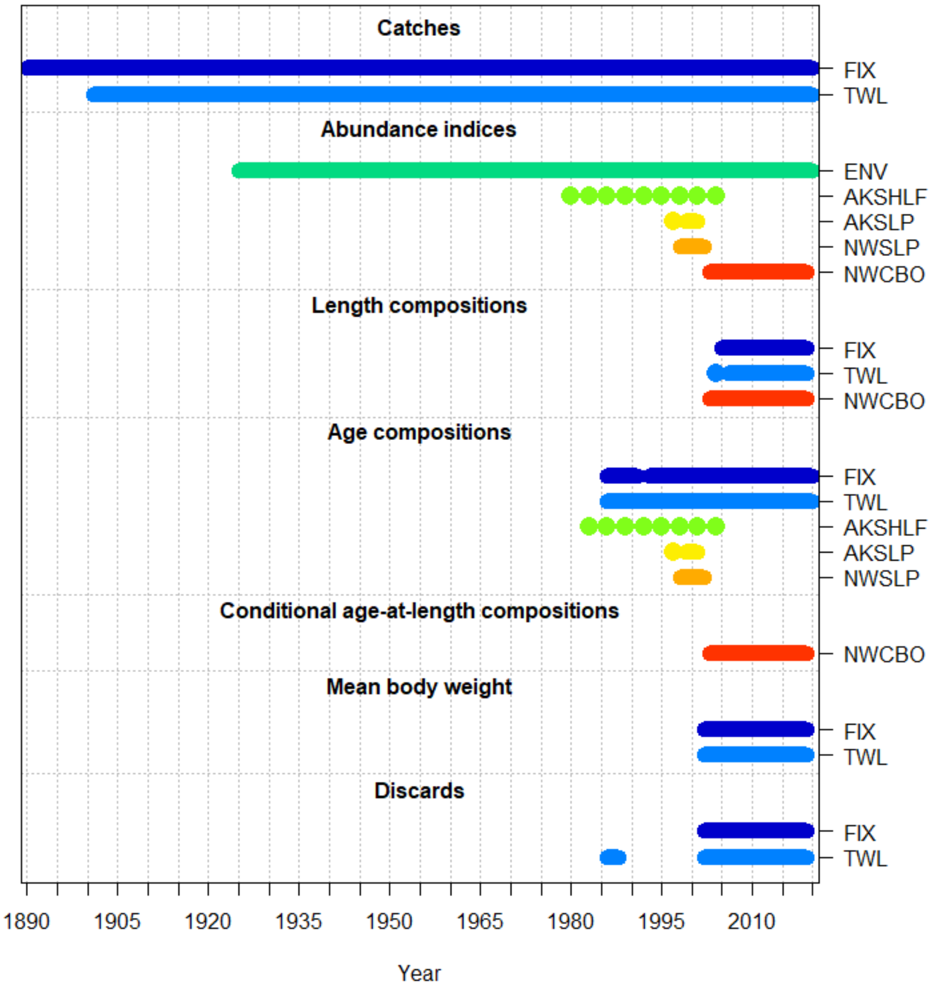


Figure 3: Summary of data sources used in the base model.

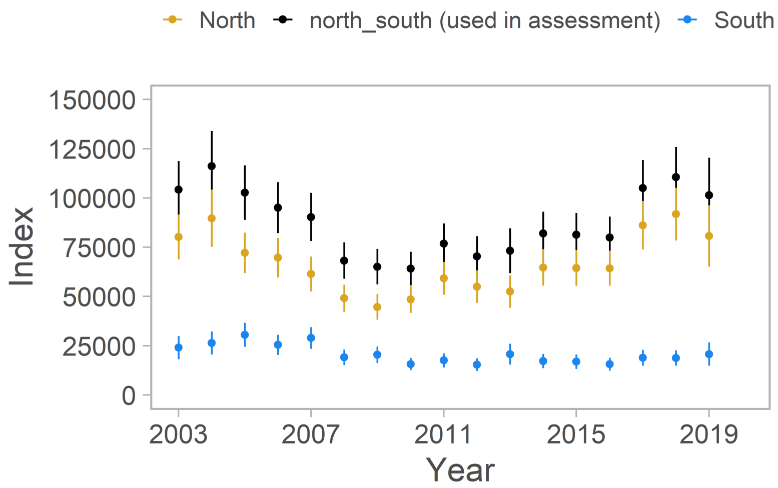


Figure 4: Estimated index of relative abundance (mt) for the West Coast Groundfish Bottom Trawl Survey, with 5% and 95% intervals. Region-specific estimates are included for north and south of 36 degrees N ('north' and 'south', respectively), as well as the coast-wide estimate ('north-south').

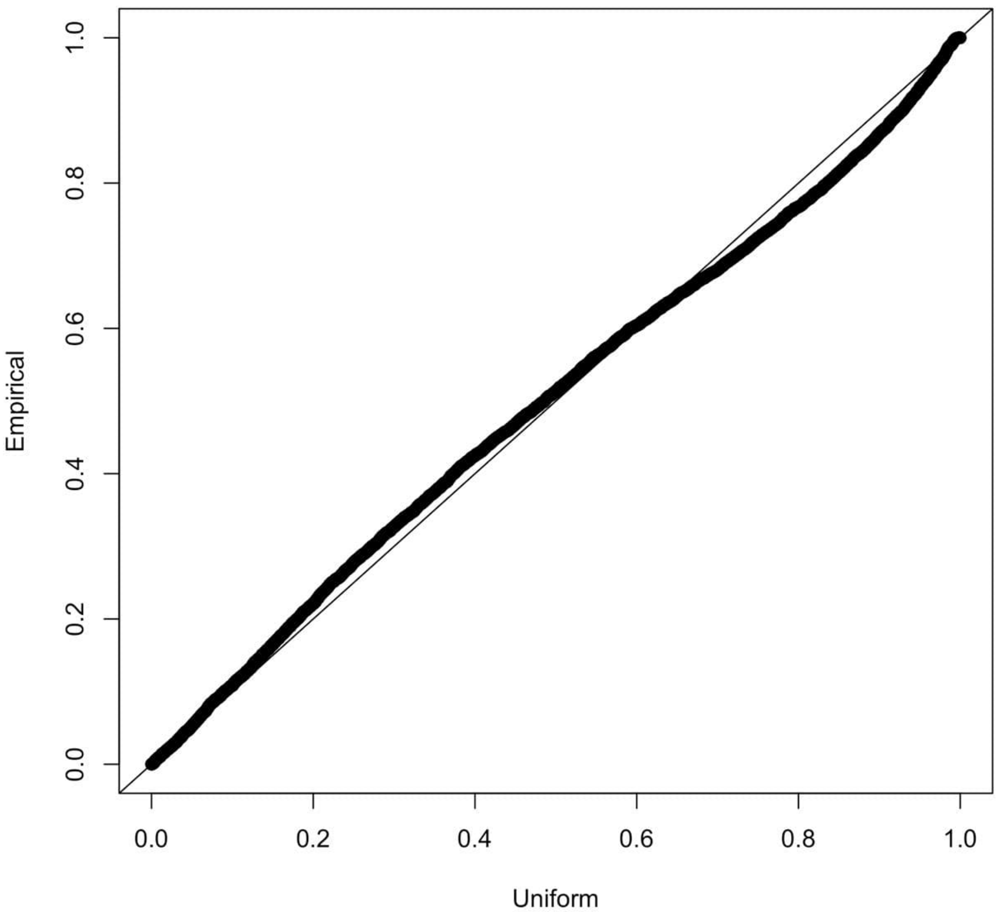


Figure 5: Observed (black points) vs. predicted (red polygon) quantiles from a gamma distribution for encounter probability when fitting a vector-autoregressive spatiotemporal model to data from the West Coast Groundfish Bottom Trawl Survey.

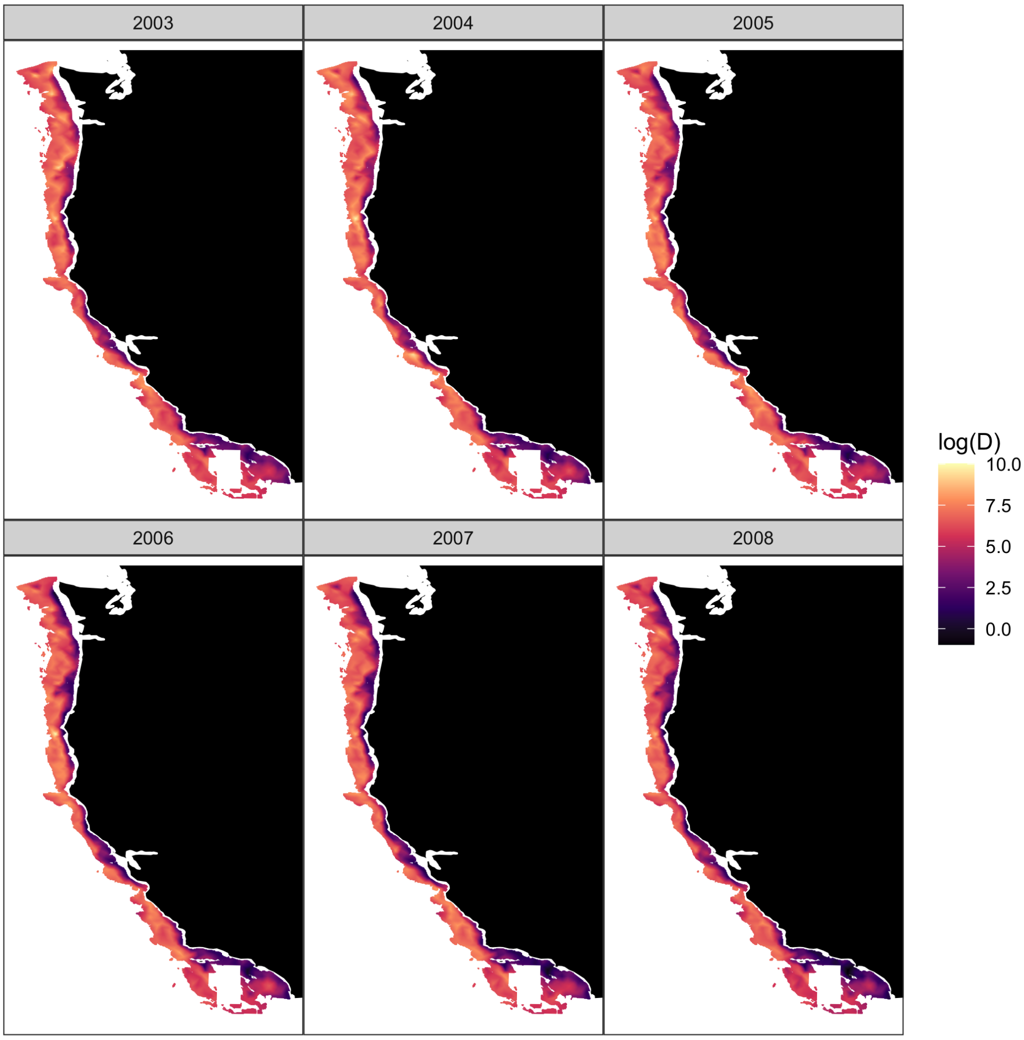


Figure 6: Estimated log-densities across space and time (panels) following VAST standardization for the West Coast Groundfish Bottom Trawl Survey.

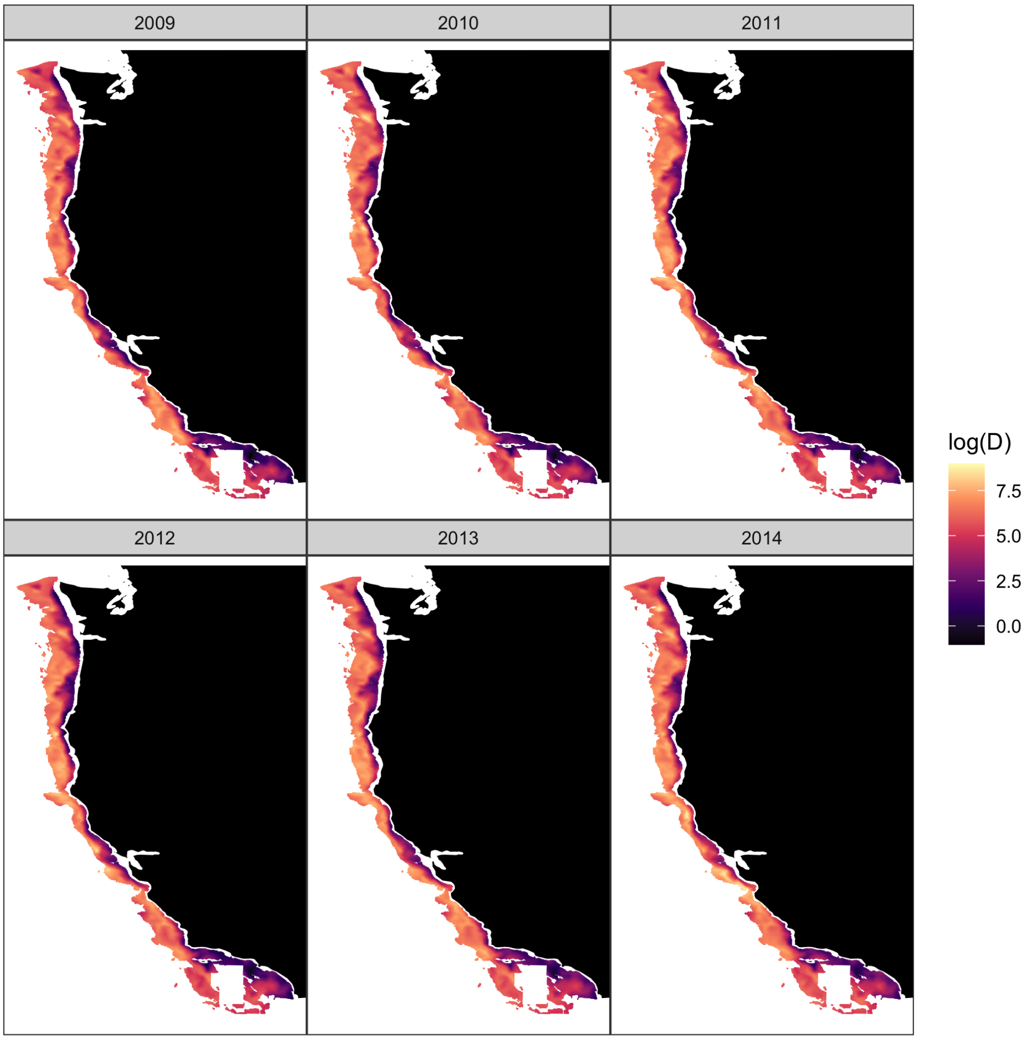


Figure 7: Figure 6 (contd).

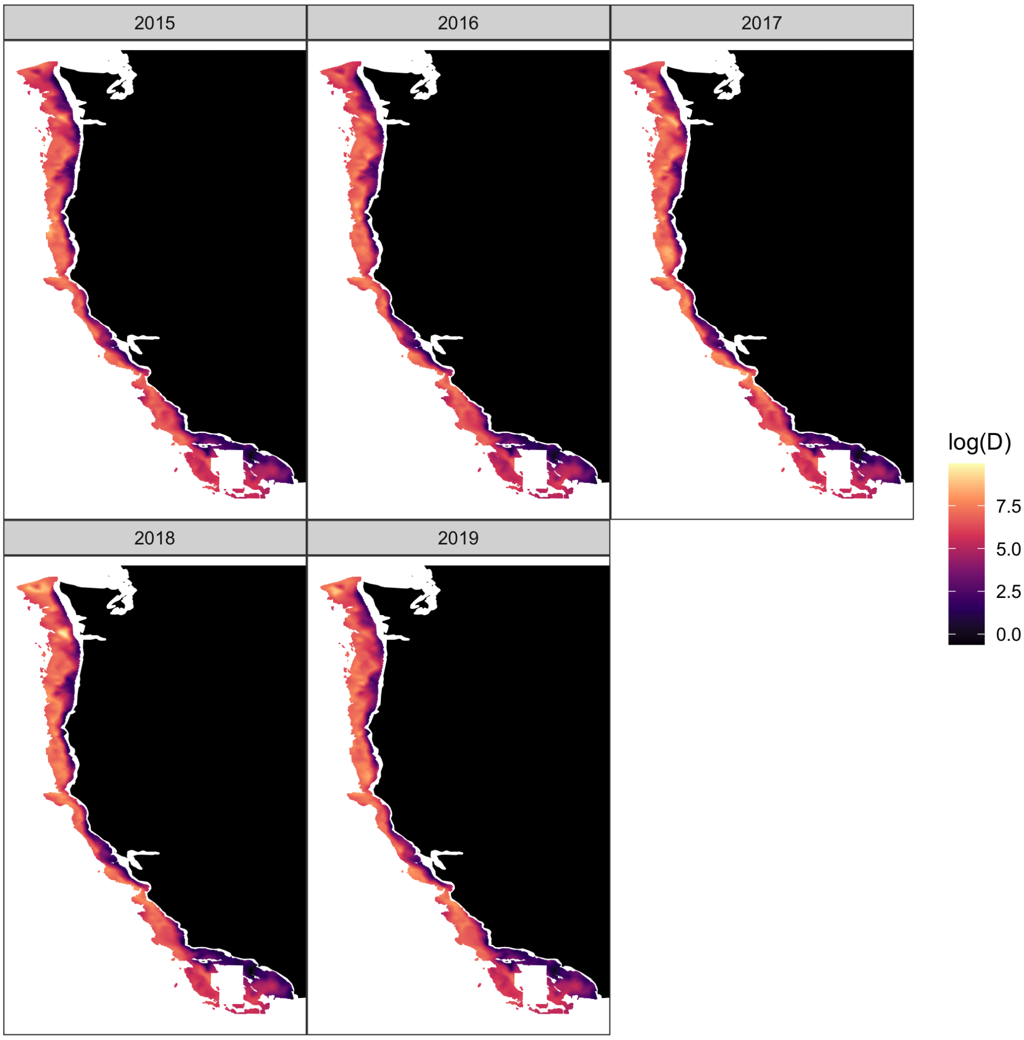


Figure 8: Figure 6 (contd).

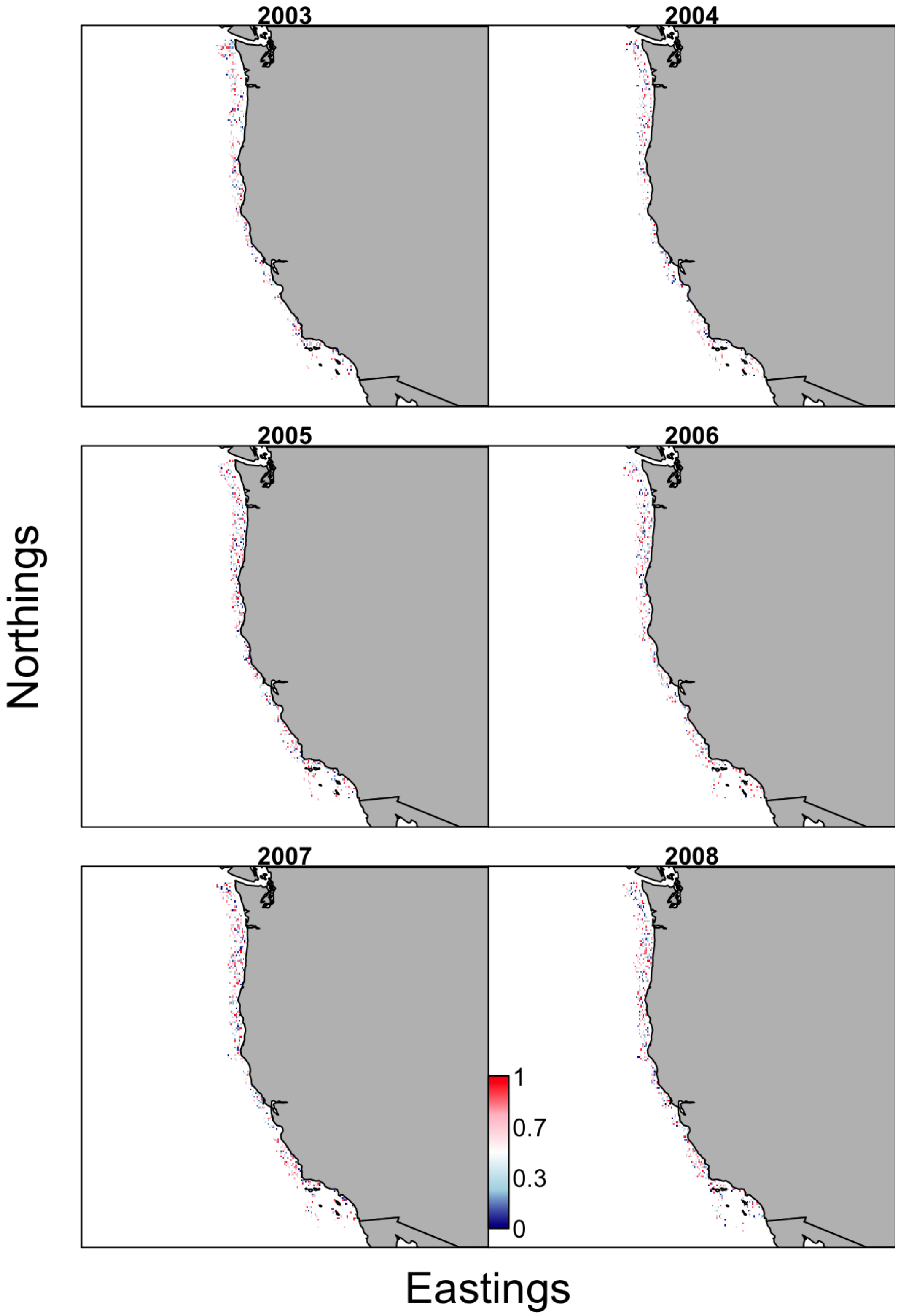


Figure 9: Pearson residuals across space and time (panels) for predicted catch rates for the West Coast Groundfish Bottom Trawl Survey.

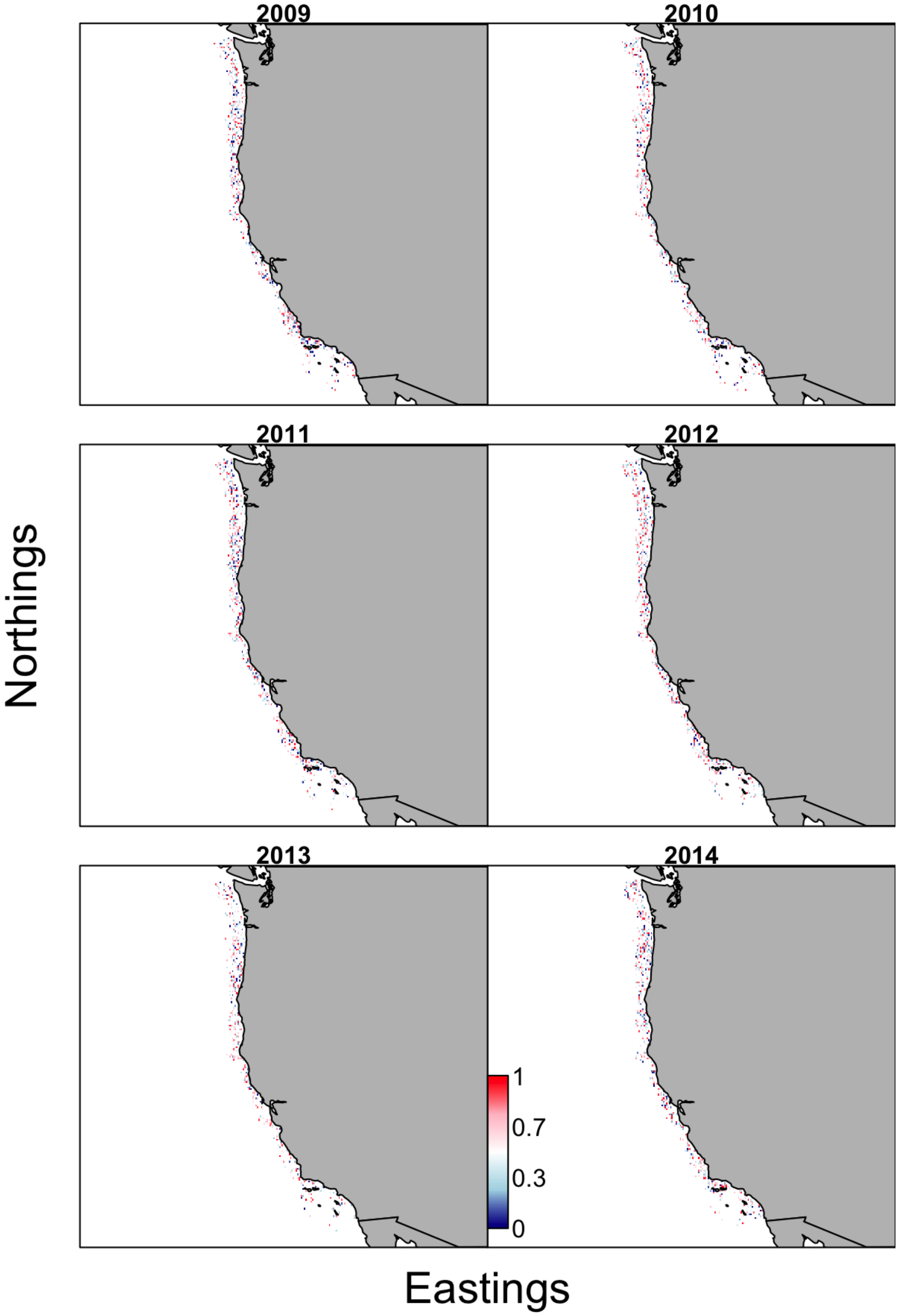


Figure 10: Figure 9 (contd).

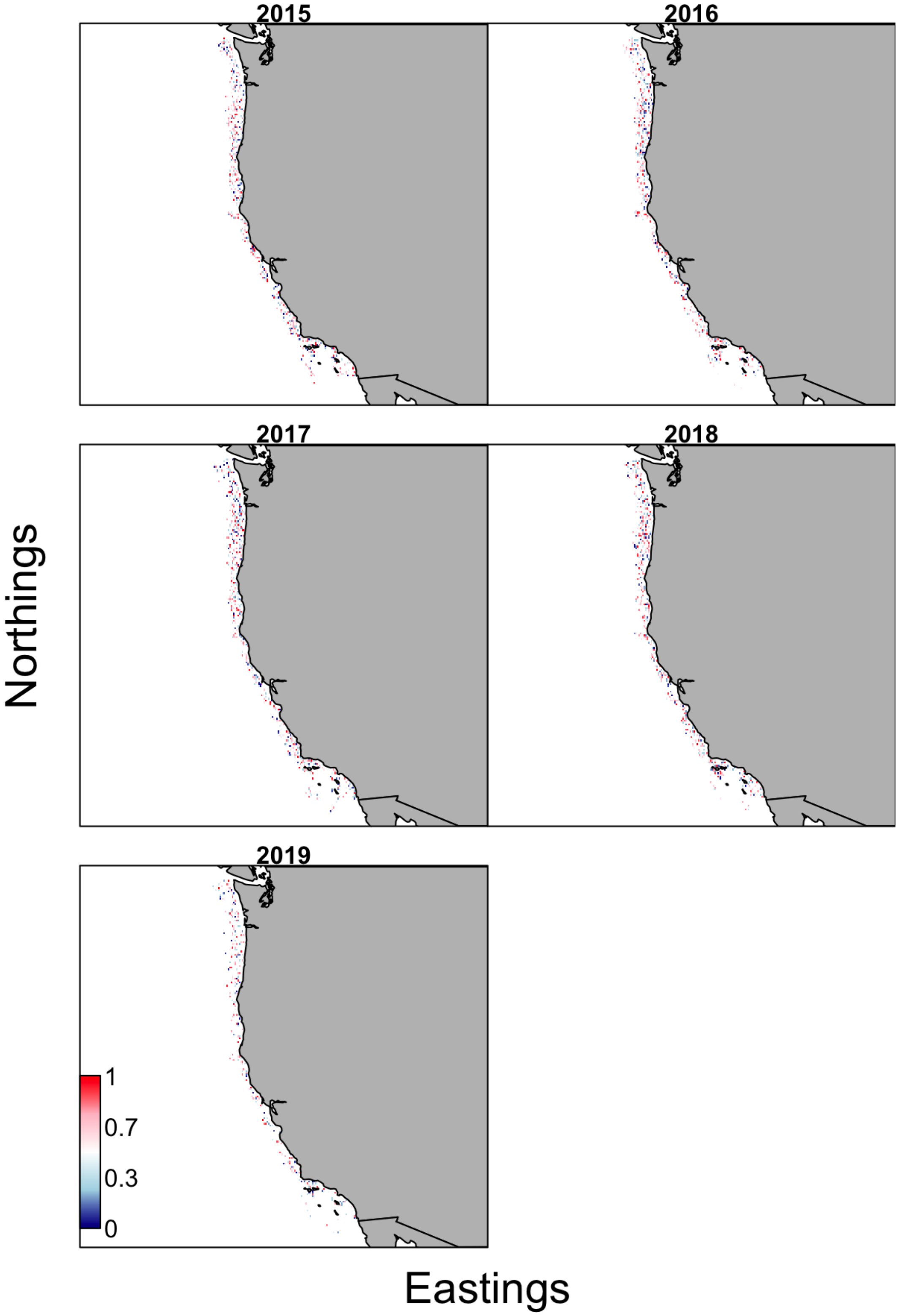


Figure 11: Figure 9 (contd).

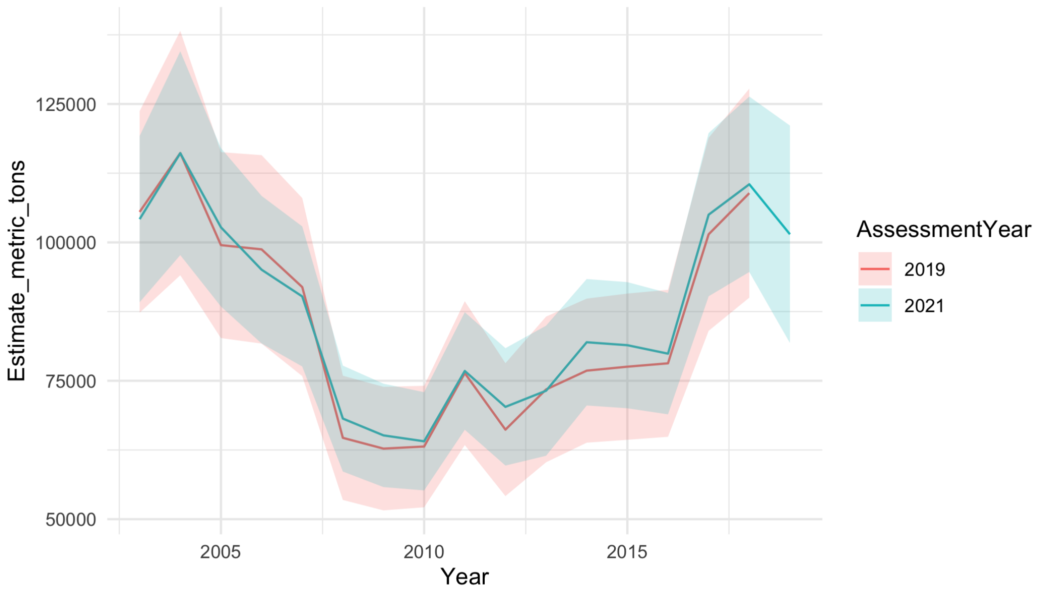


Figure 12: Comparison between WCGBTS index of abundance standardized using VAST in the 2019 benchmark (red lines) and the re-standardization using one more year of data for the present update (blue lines). Shaded area reflects 95% confidence interval.

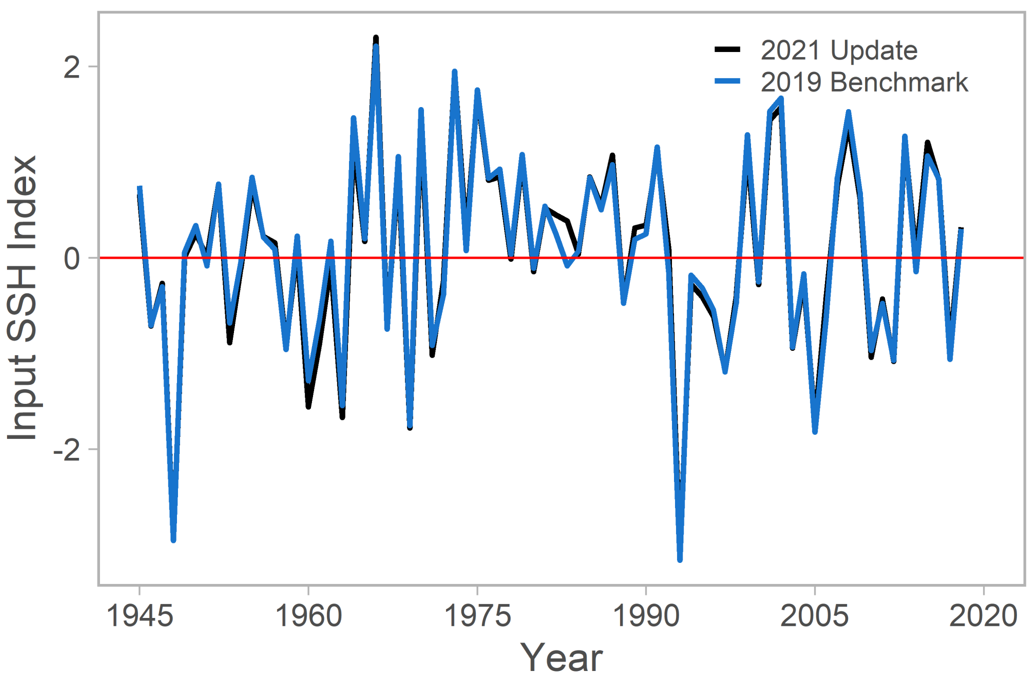


Figure 13: Comparison of sea level index input data between 2019 benchmark assessment and 2021 update using new tide-gauge records and re-running the analysis.

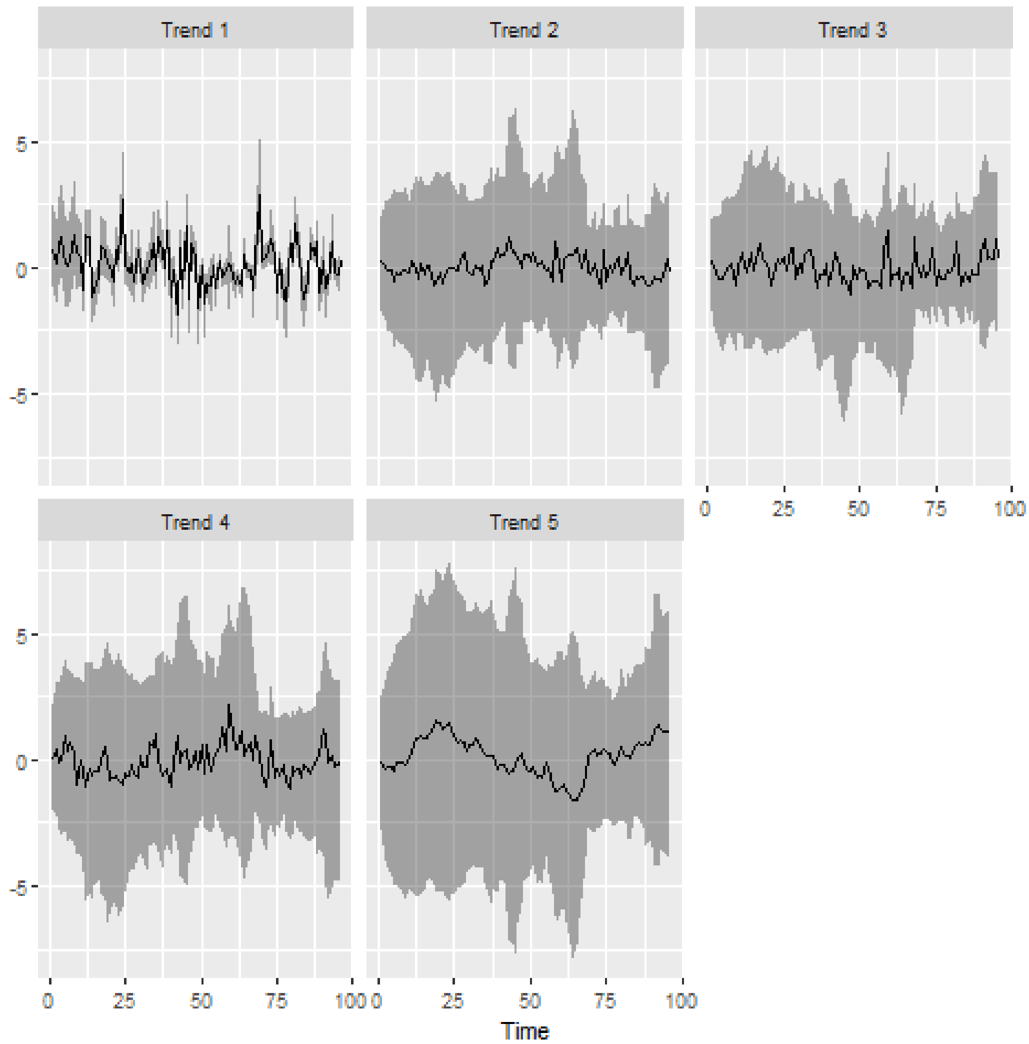


Figure 14: Time series of dynamic factors from the SSH analysis that explained significant variation in sablefish recruitment. Grey envelopes are the 95% confidence interval.

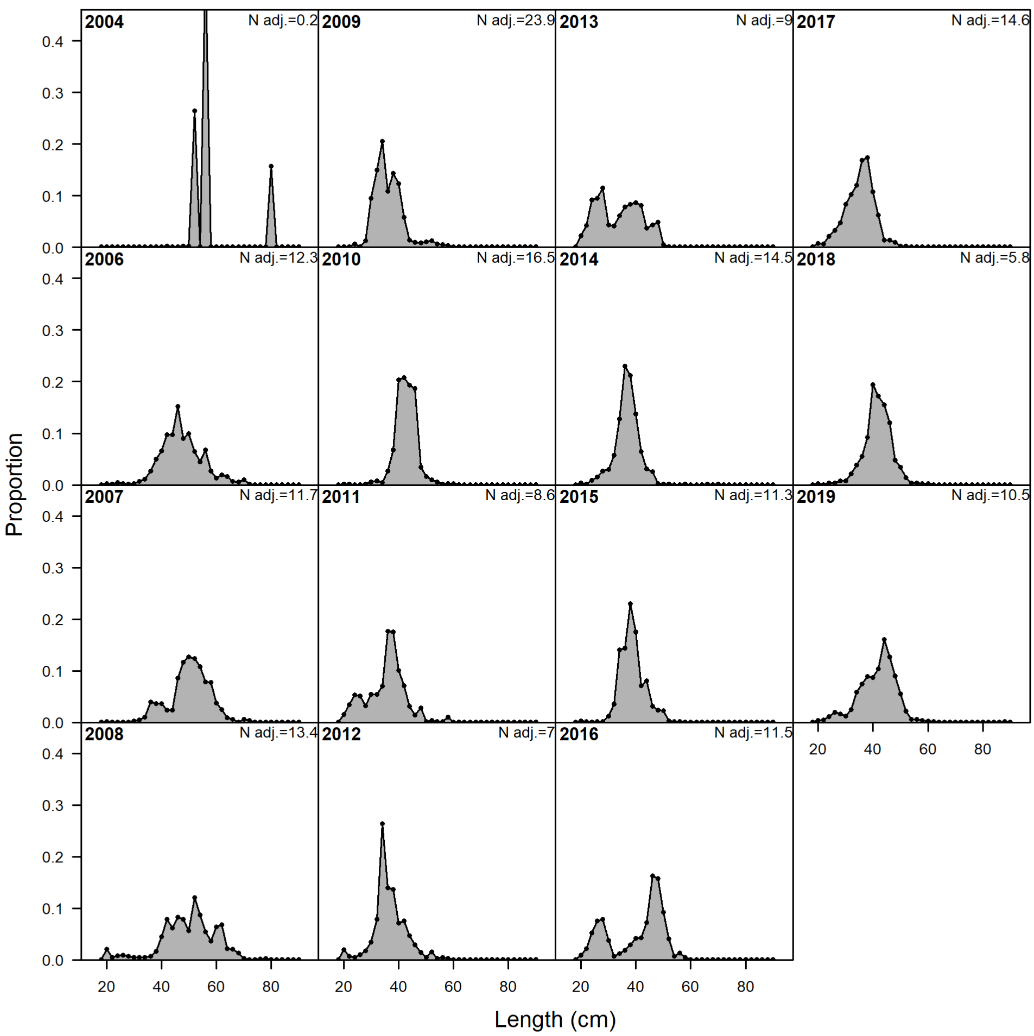


Figure 15: Recent length compositions (2004-2019) of discarded sablefish from the trawl gear fishery, aggregated across sexes.

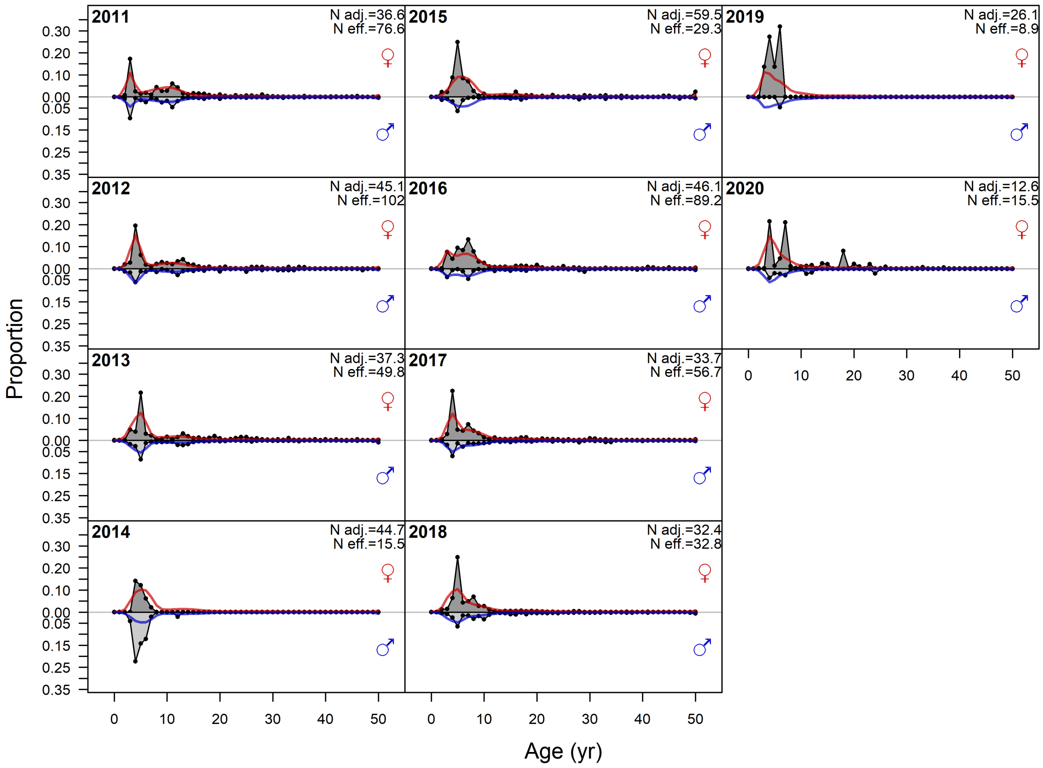


Figure 16: Age compositions for female and male sablefish from the retained catch in the fixed gear fishery in recent years, from a model that conforms to the Terms of Reference. Fits are shown with solid lines.

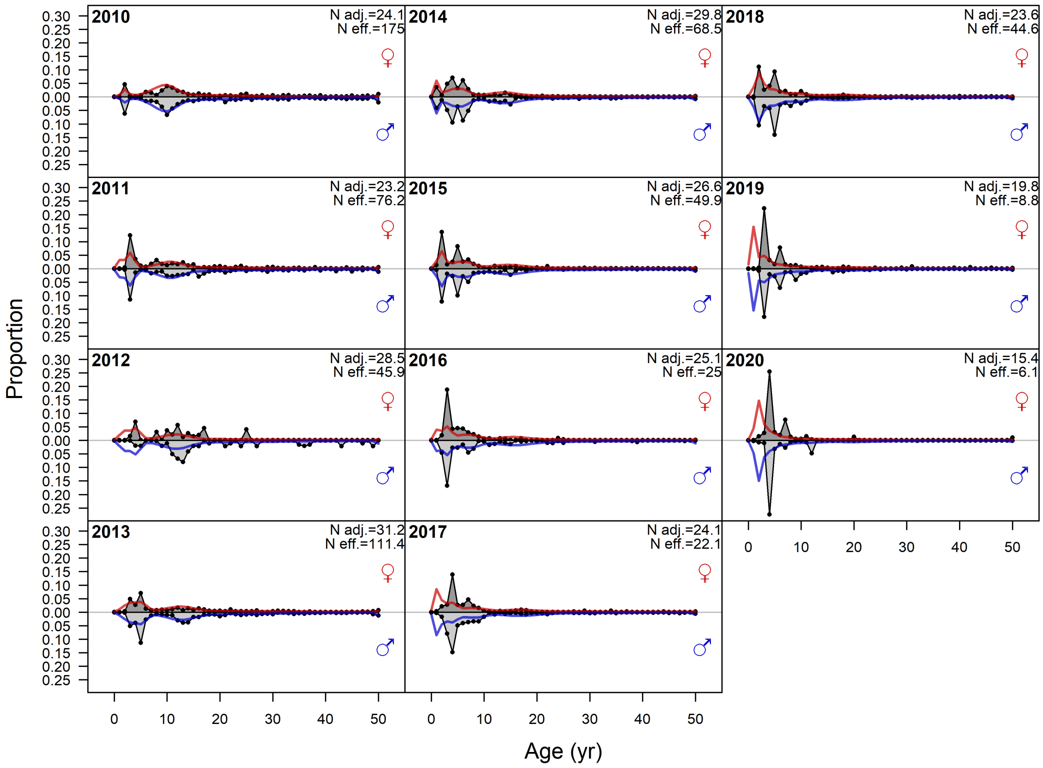


Figure 17: Age compositions for female and male sablefish from the retained catch in the trawl fishery in recent years, from a model that conforms to the Terms of Reference. Fits are shown with solid lines.

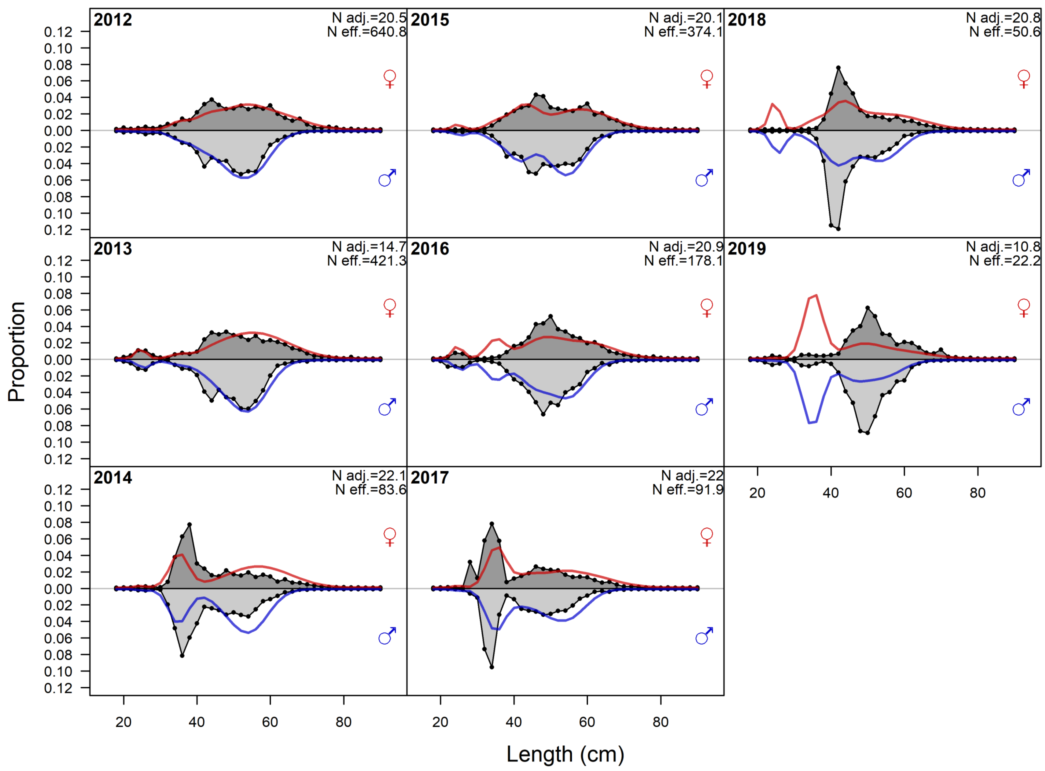


Figure 18: Length compositions for female and male sablefish from the WCGBT survey in recent years, from a model that conforms to the Terms of Reference. Fits are shown with solid lines.

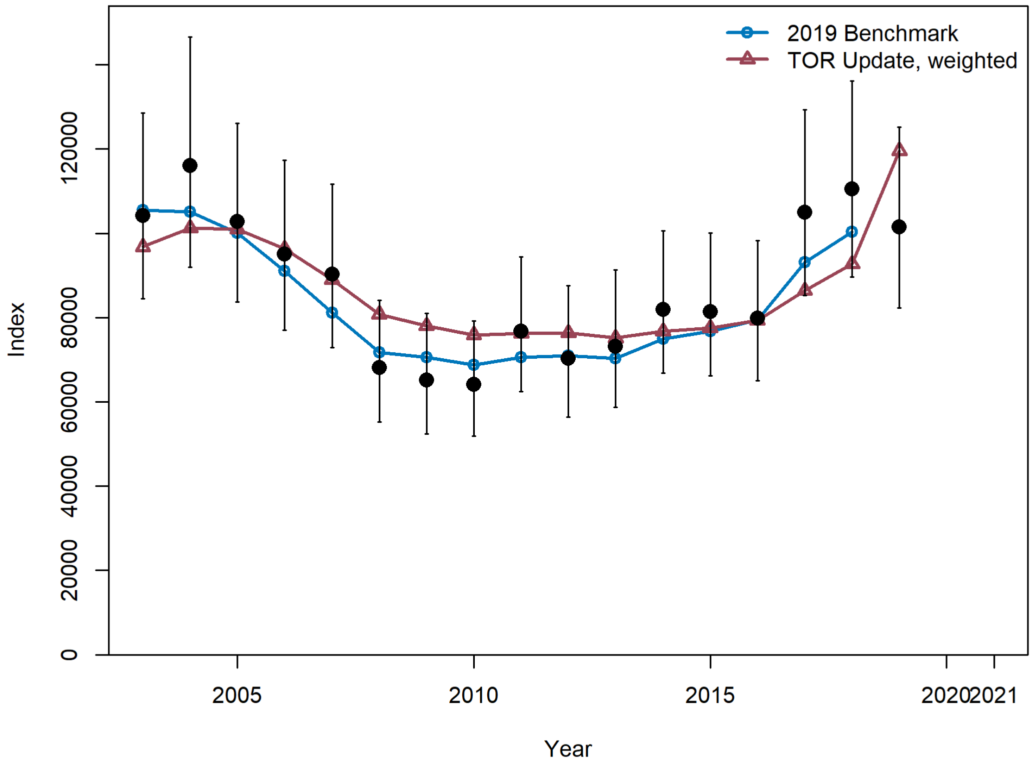


Figure 19: Comparison of fits to the WCGBTS Index of abundance between the 2019 benchmark assessment (blue lines), and an update assessment which conforms to the Terms of Reference (red lines).

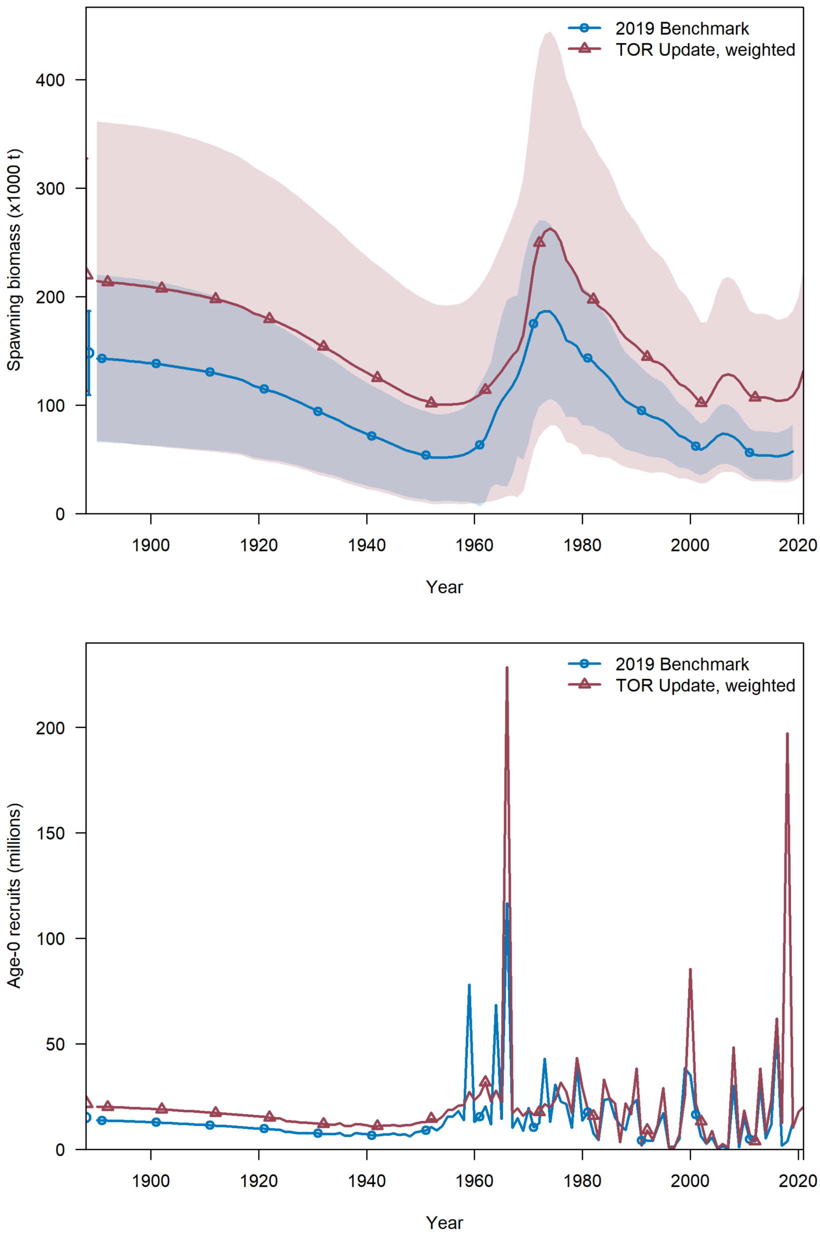


Figure 20: Comparison of derived quantities between the 2019 benchmark assessment (blue lines), and an update assessment which conforms to the Terms of Reference (red lines). Top to bottom: spawning biomass, age-0 recruits, and fits to the WCGBTS Index of abundance.

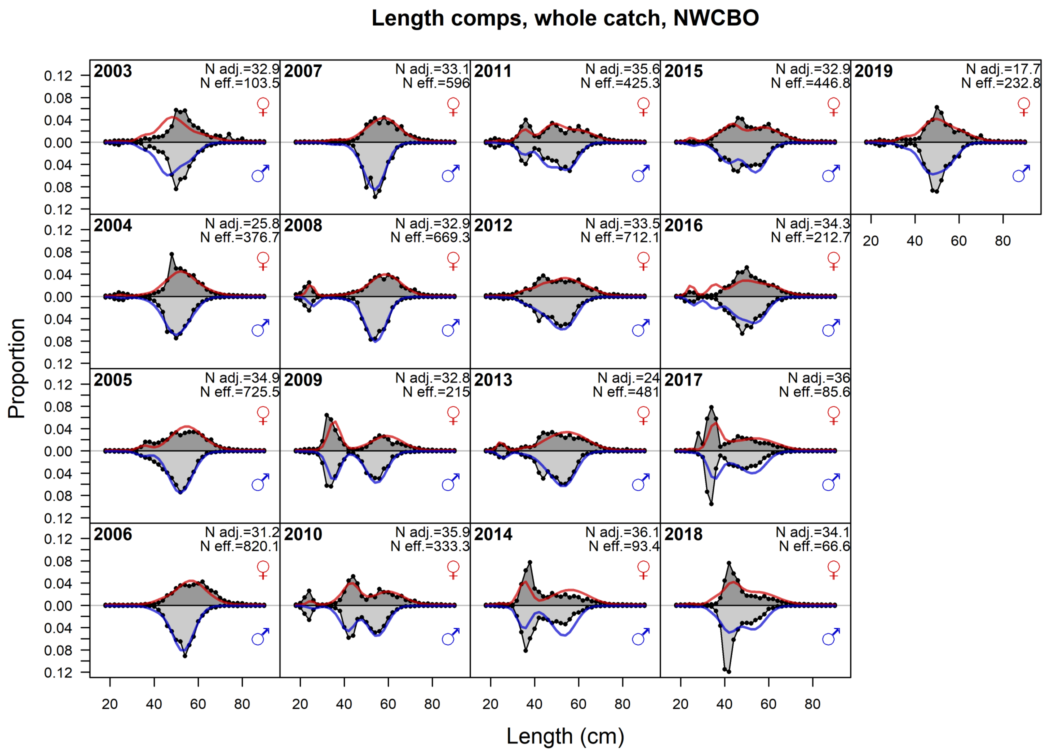


Figure 21: Length compositions for female and male sablefish from the WCGBT Survey in recent years, from the base model. Fits are shown with solid lines.

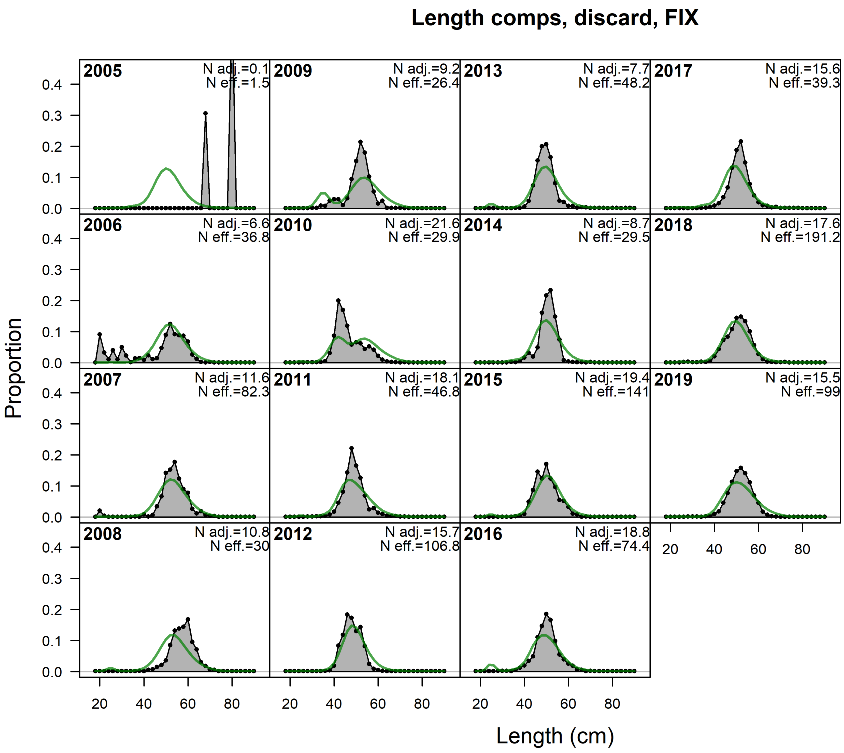


Figure 22: Length compositions for female and male sablefish discarded in the fixed gear fishery, from the base model. Fits are shown with solid lines.

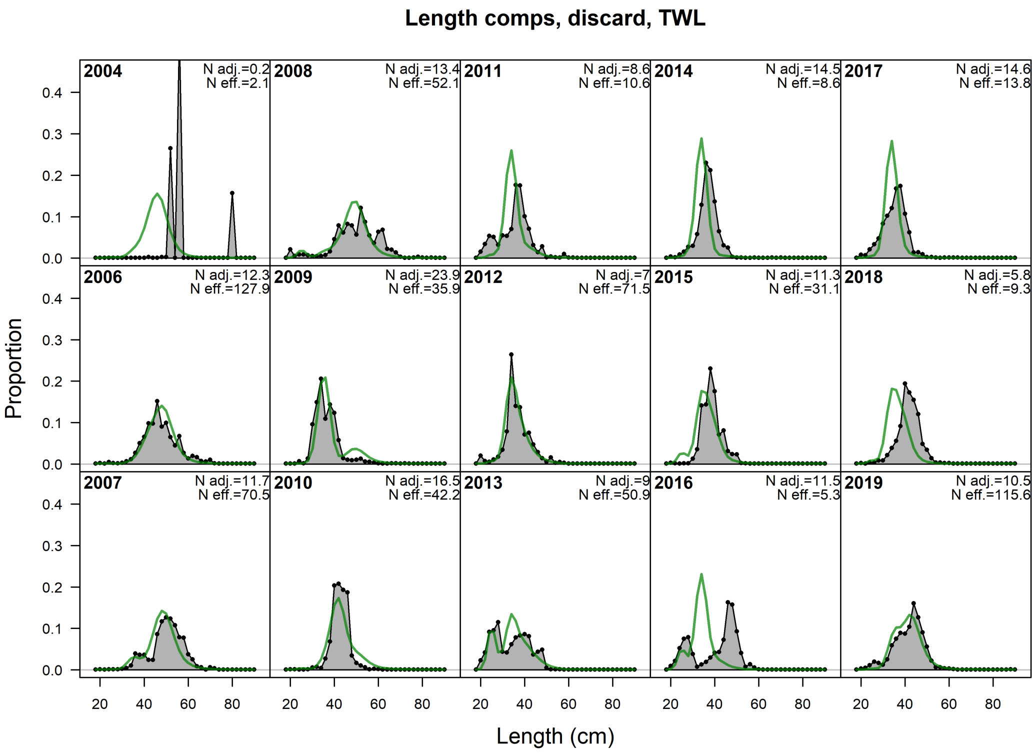


Figure 23: Length compositions for female and male sablefish discarded in the trawl gear fishery, from the base model. Fits are shown with solid lines.

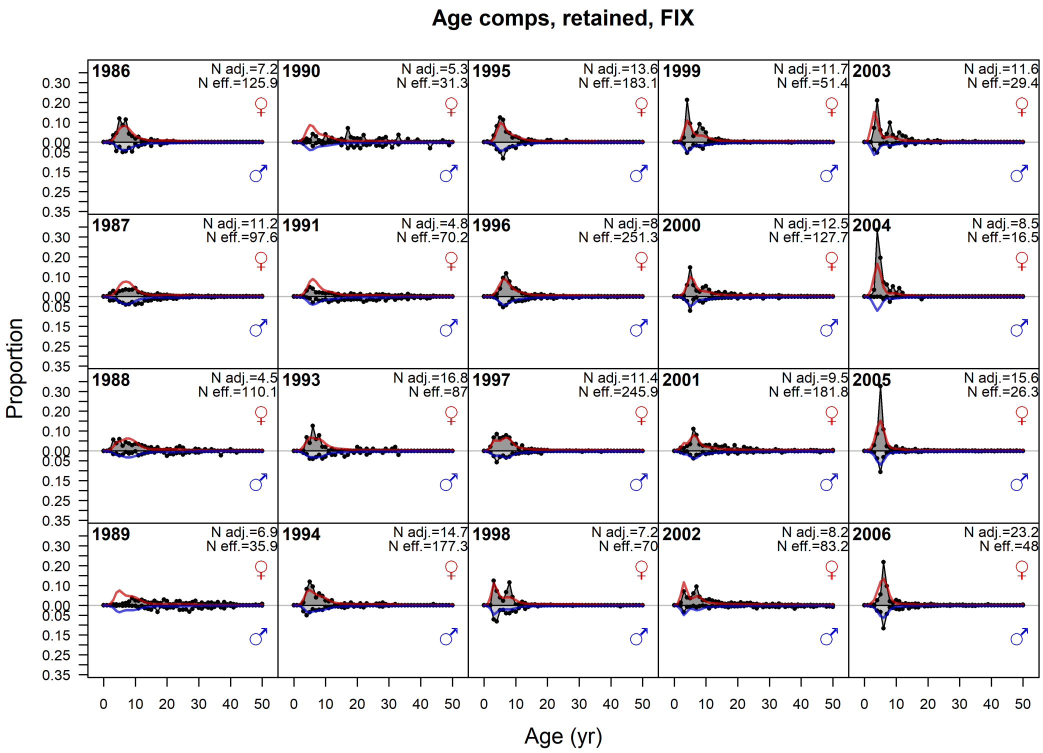


Figure 24: Age compositions for female and male sablefish from the retained catch in the fixed gear fishery in recent years from the base model. Fits are shown with solid lines.

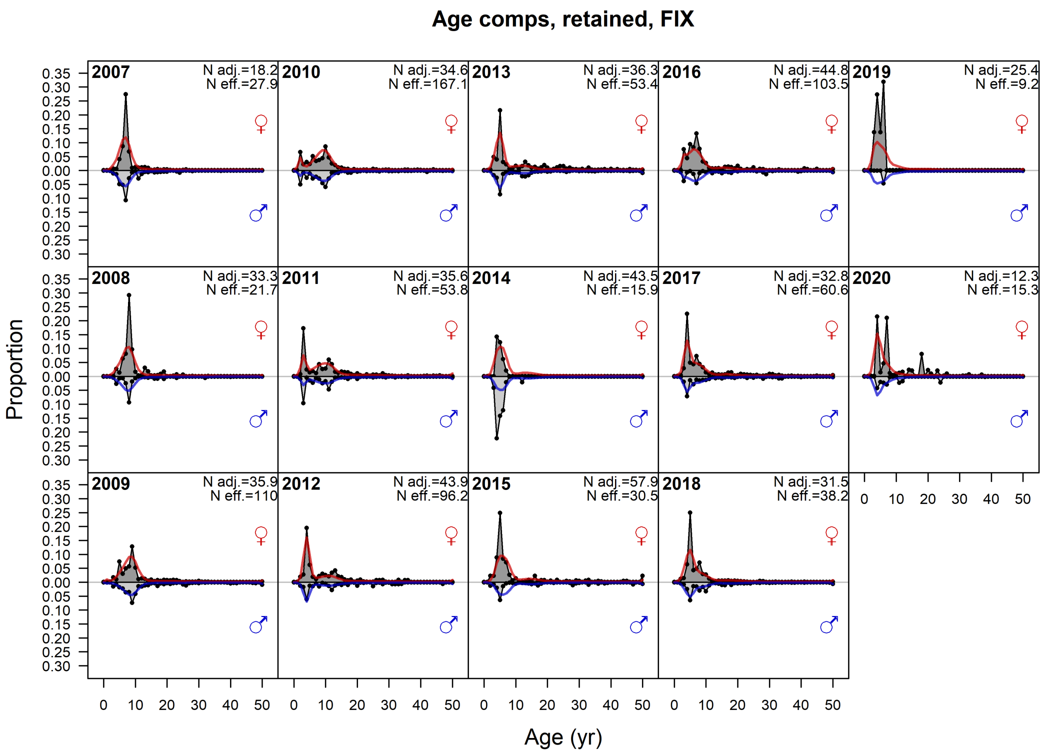


Figure 25: Figure 24 (contd).

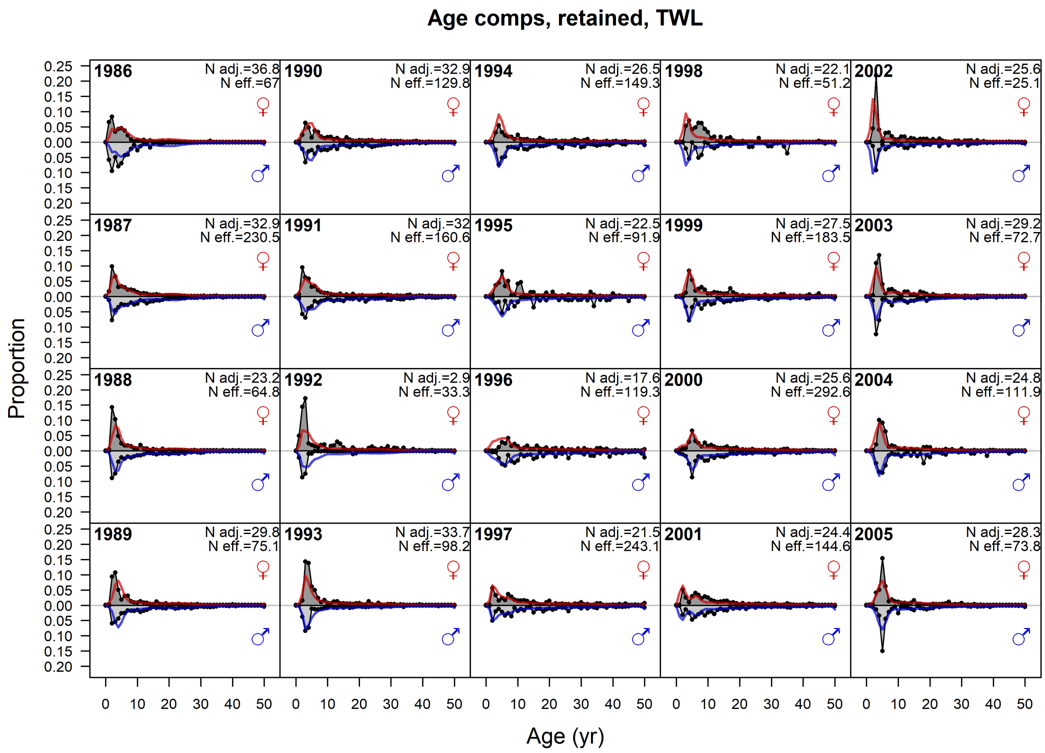


Figure 26: Age compositions for female and male sablefish from the retained catch in the trawl fishery in recent years from the base model. Fits are shown with solid lines.

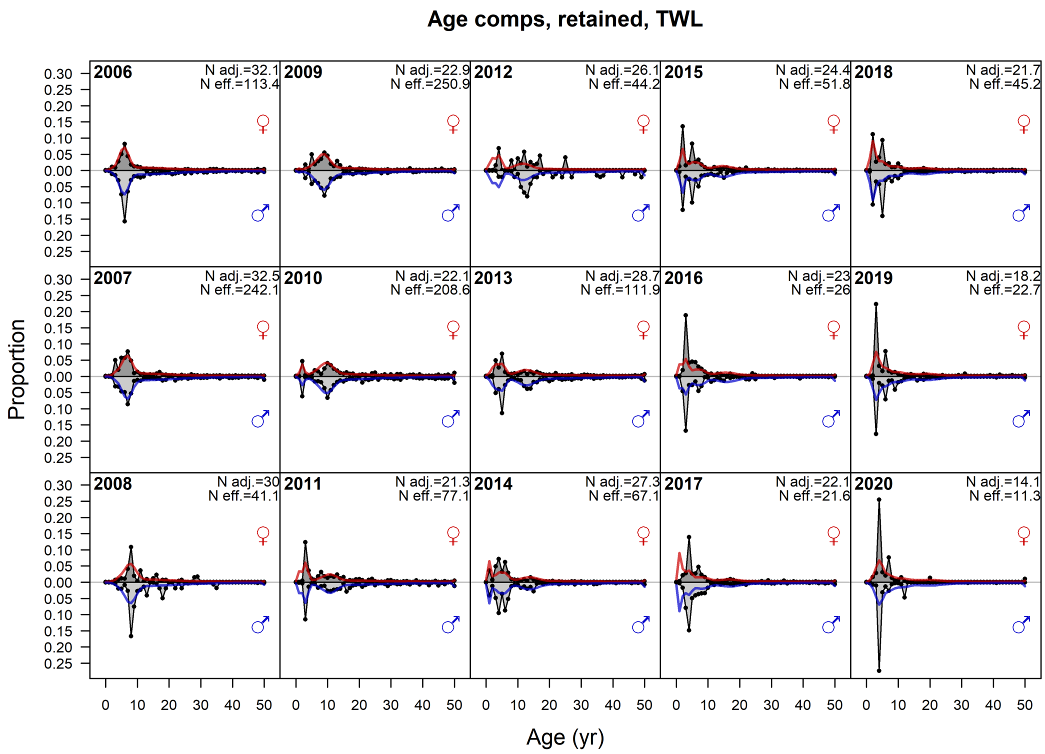


Figure 27: Figure 26 (contd.)

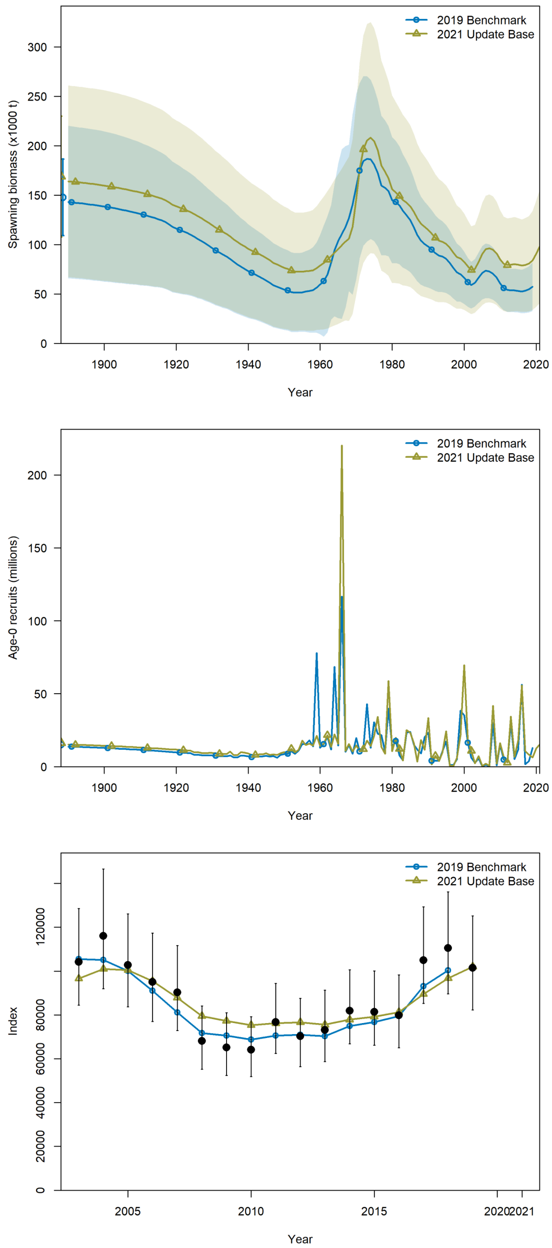
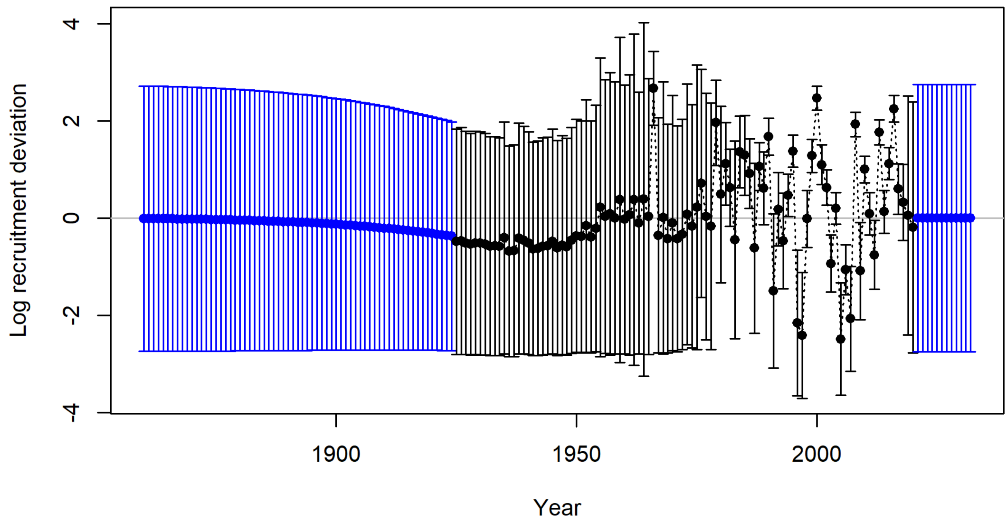


Figure 28: Comparison of selected derived quantities between the 2019 benchmark assessment (blue lines) and update base model (green lines). Top to bottom: spawning biomass, age-0 recruits, and fits to the WCGBTS Index of abundance.



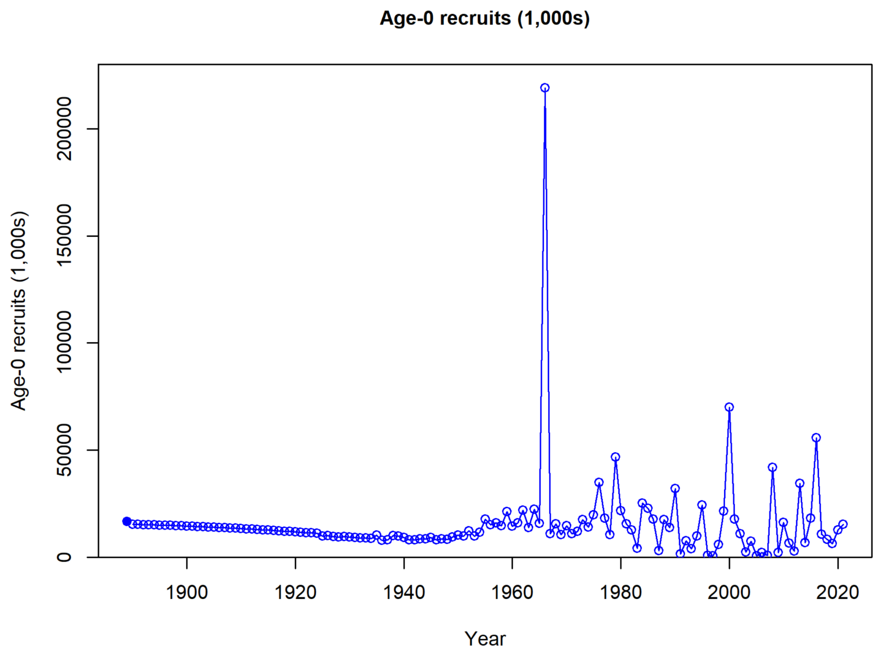


Figure 29: Time series of estimated recruitment deviations from the base model (solid line) with 95% intervals (vertical lines; upper panel) and recruitment without intervals (lower panel).

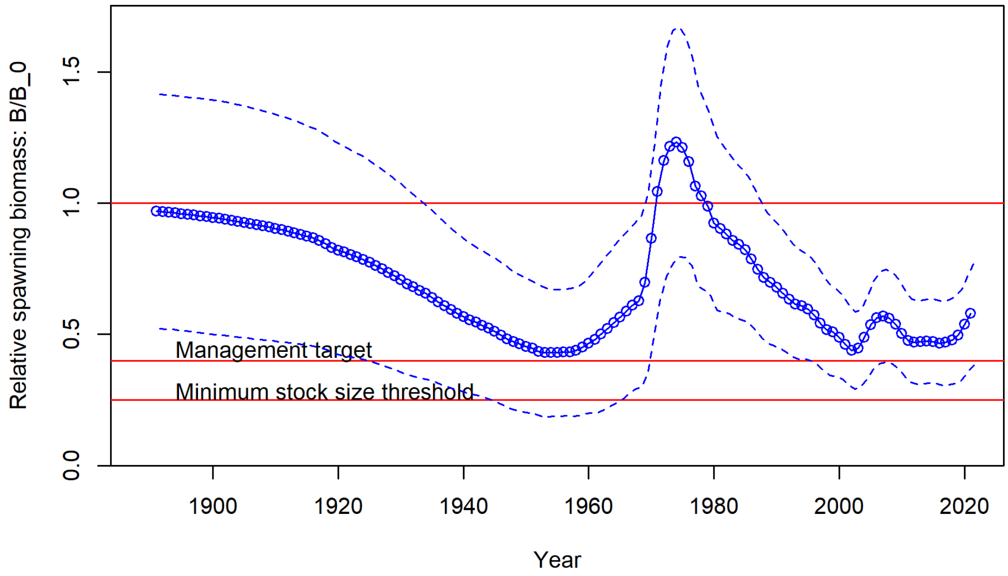


Figure 30: Time series of estimated depletion (i.e., spawning biomass relative to unfished spawning biomass) from the base model (circles) with 95% intervals (dashed lines).

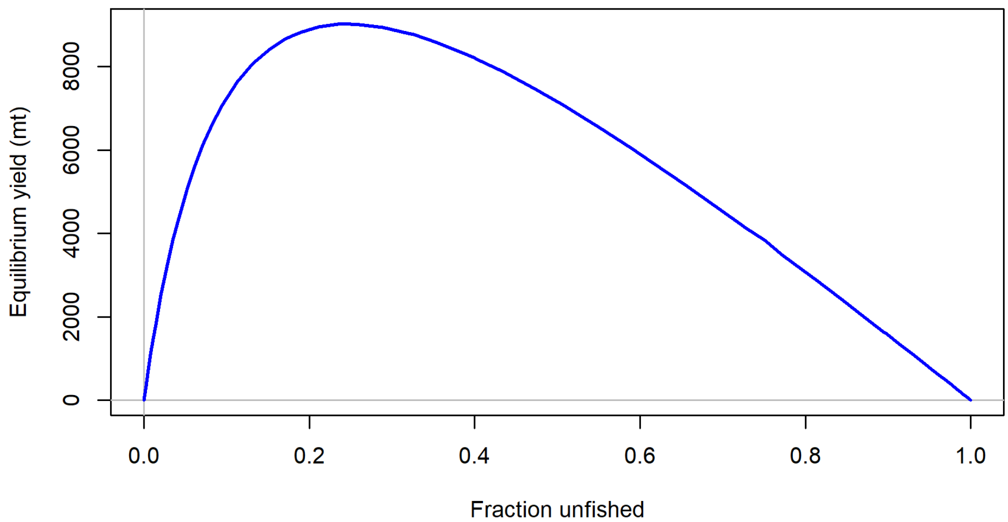


Figure 31: Equilibrium yield curve (total dead catch) for the base model.

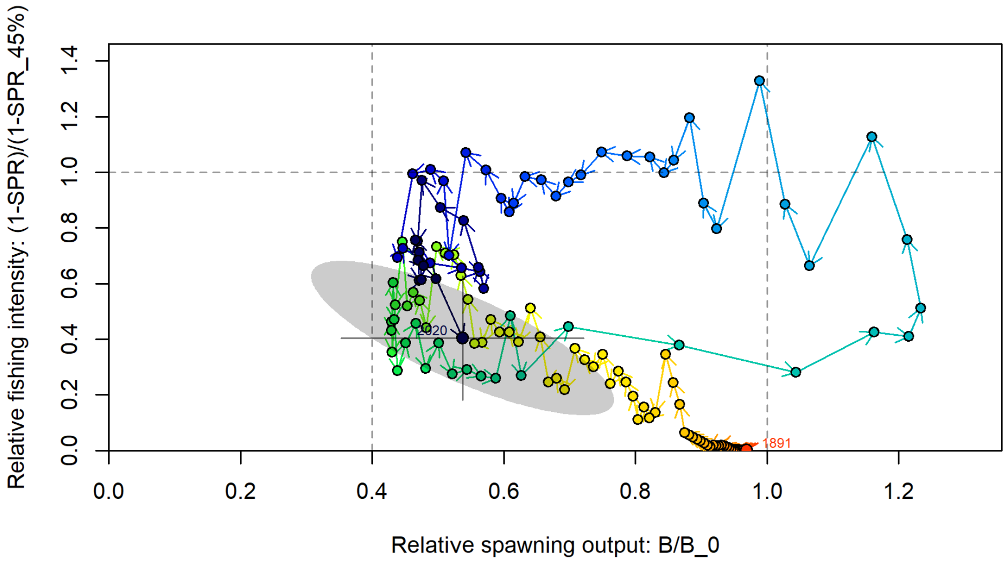


Figure 32: Estimated relative spawning potential ratio relative to the proxy target/limit of 45% vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The dark blue circle indicates the last year of available data, 2020, and the grey lines indicate the 95% confidence interval. Plot is based on maximum likelihood estimation results.

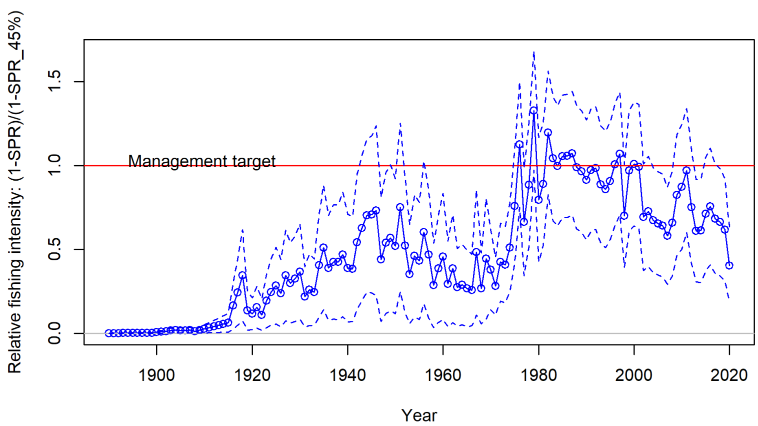


Figure 33: Time series of estimated relative 1-spawning potential ratio ($1 - SPR/1 - SPR_{Target=0.45\%}$) for the base model (round points) with ~95% intervals (dashed lines). Values of relative 1-SPR above 1.0 reflect harvest rates in excess of the current overfishing proxy.

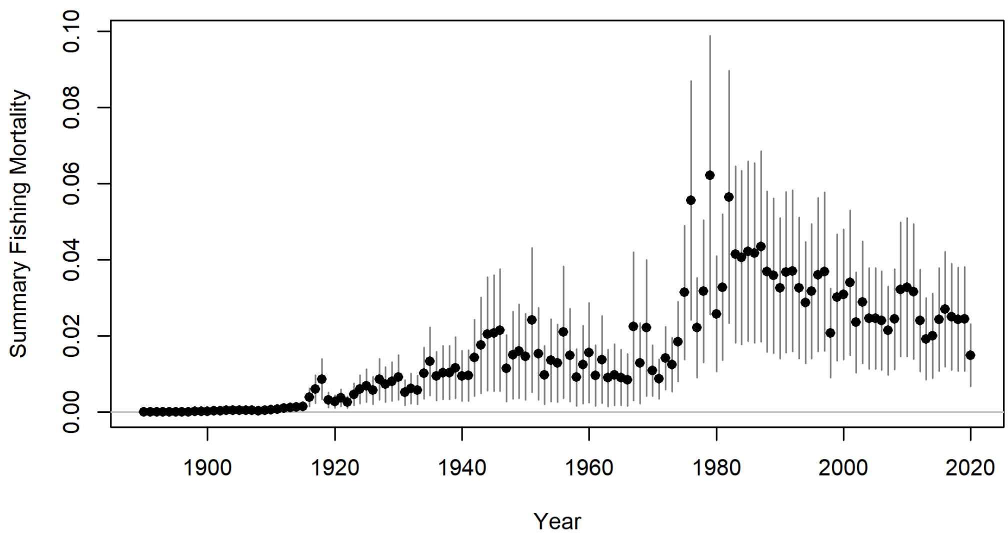


Figure 34: Time series of estimated exploitation fraction (catch/age 4 and older biomass) and their associated uncertainty (vertical lines) for the base model.

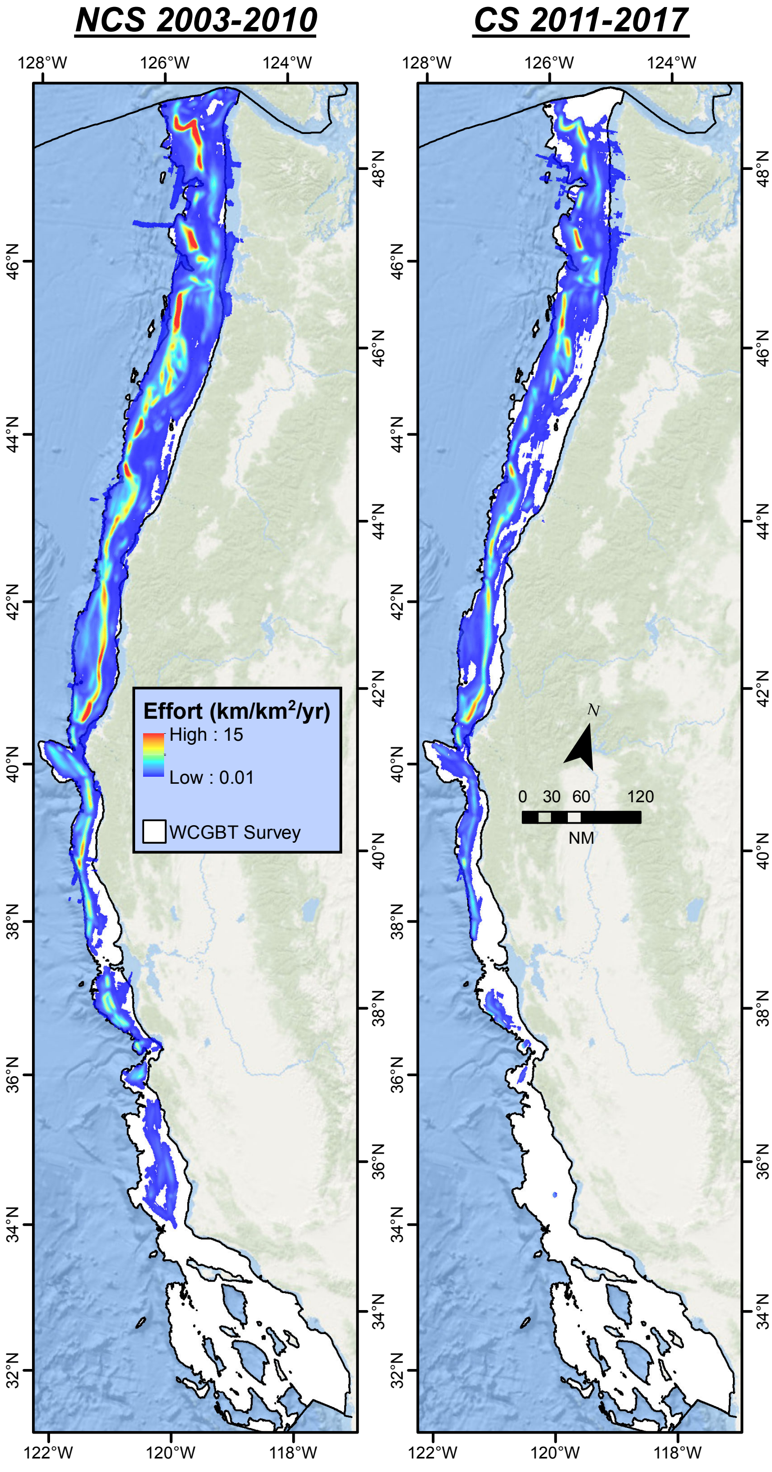


Figure 35: Spatial footprint of effort using trawl gear (km/km^2/yr) in the sablefish fishery before catch shares (2003–2010; left) and post catch shares (2011–2017; right) in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white). Fishery data are from Pacific Fisheries Information Network logbooks and the West Coast Groundfish Observer Program.

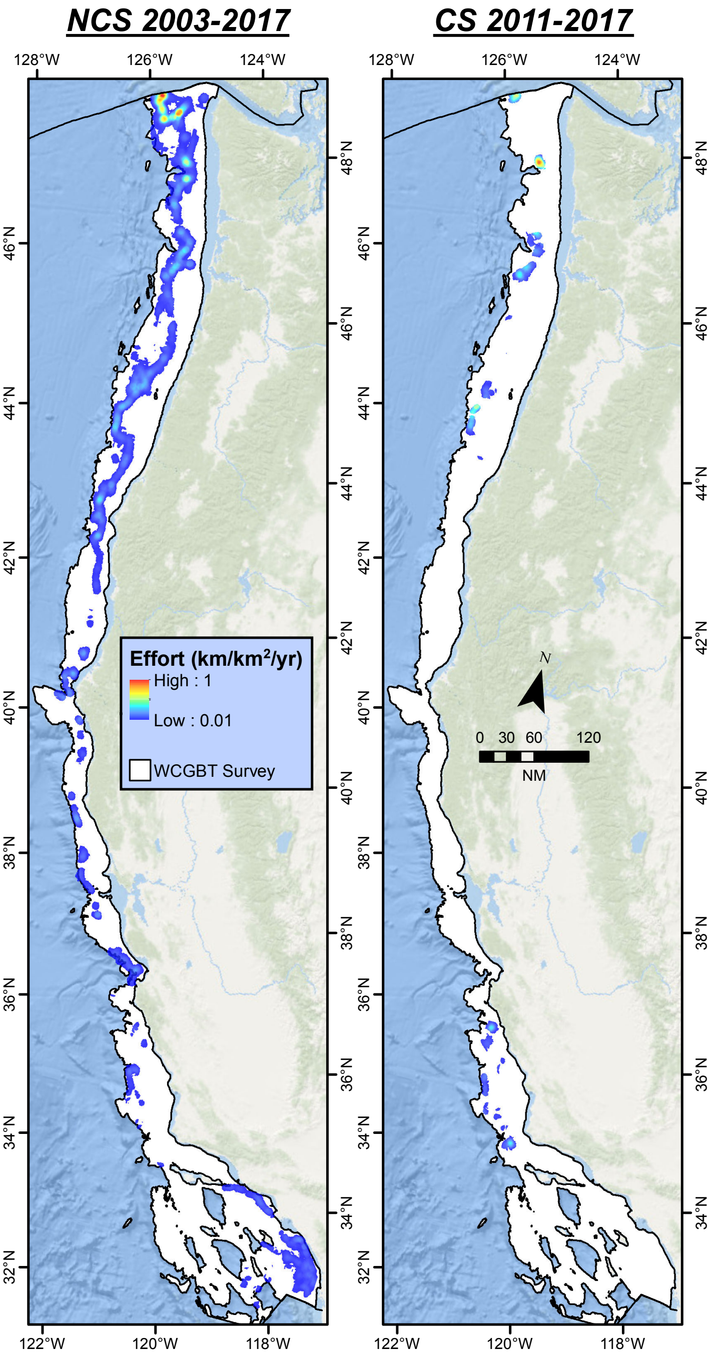


Figure 36: Spatial footprint of effort using hook-and-line gear (km/km^2/yr) in the sablefish fishery with non catch-share vessels since 2003 (2003–2017; left) and with catch-share vessels since 2011 (2011–2017; right) as observed by the West Coast Groundfish Observer Program in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white).

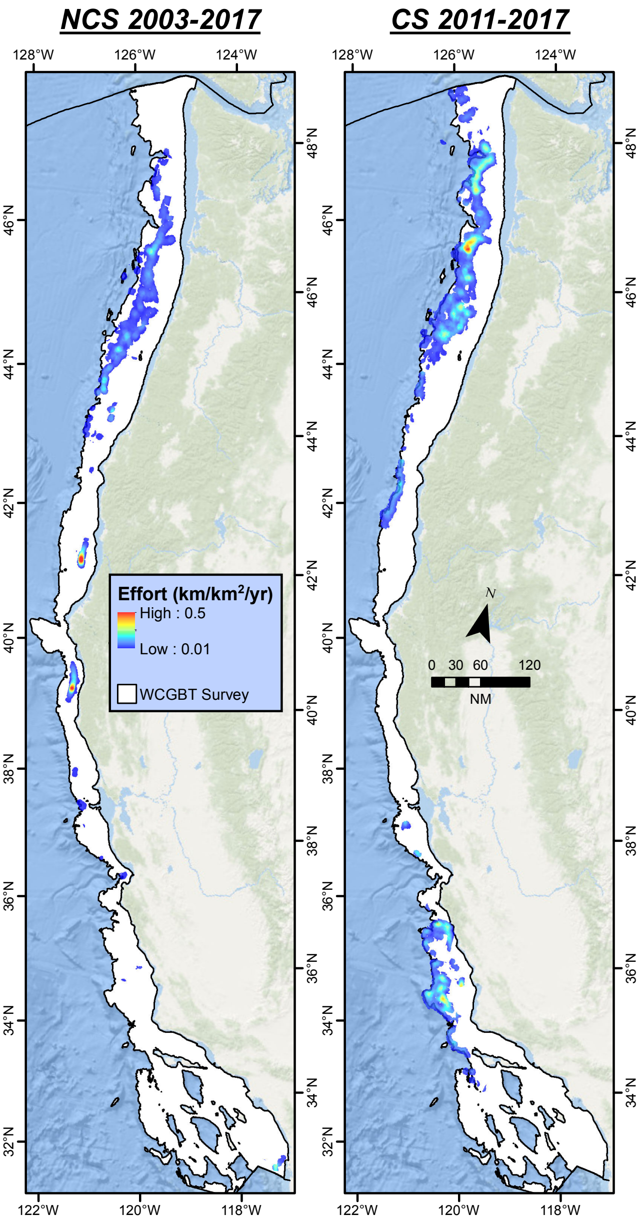


Figure 37: Spatial footprint of effort using pot gear (km/km^2/yr) in the sablefish fishery with non catch-share vessels since 2003 (2003–2017; left) and with catch-share vessels since 2011 (2011–2017; right) in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white)

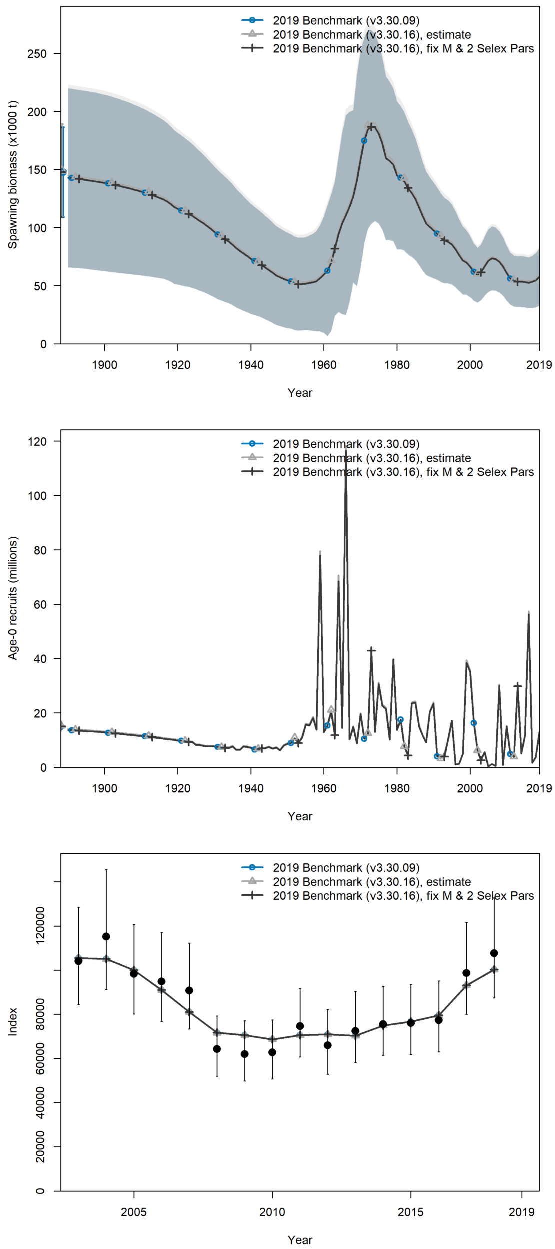


Figure 38: Comparison of derived quantities between the 2019 benchmark assessment (blue lines), a bridged model that matches the estimation structure of the benchmark in Stock Synthesis v3.30.16 (light grey lines) and a model that fixes natural mortality and the descending limb standard error for the NWSLP and AKSLP surveys in Stock Synthesis v3.30.16 (dark grey lines). Top to bottom: spawning biomass, age-0 recruits, and fits to the WCGBTS Index of abundance.

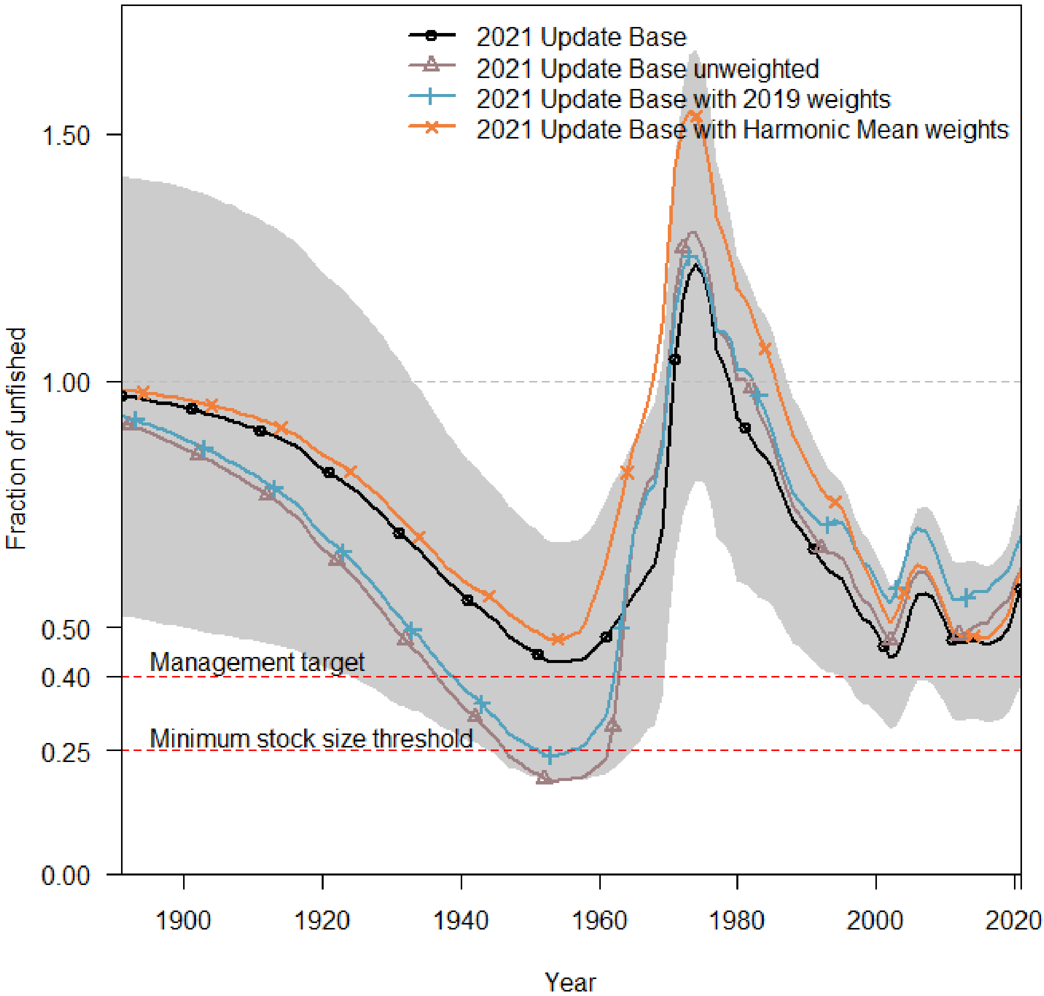


Figure 39: Changes in spawning stock biomass and depletion for alternative data-weighting methods used to downweight the compositional data.

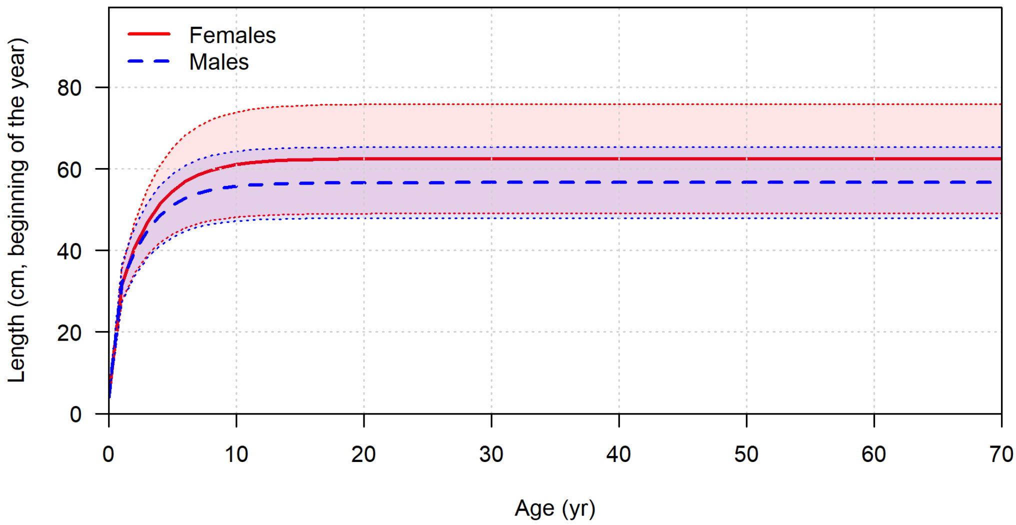


Figure 40: Growth curve for females and males with 95% intervals (dashed lines) indicating the expectation and individual variability of length-at-age for the base model.

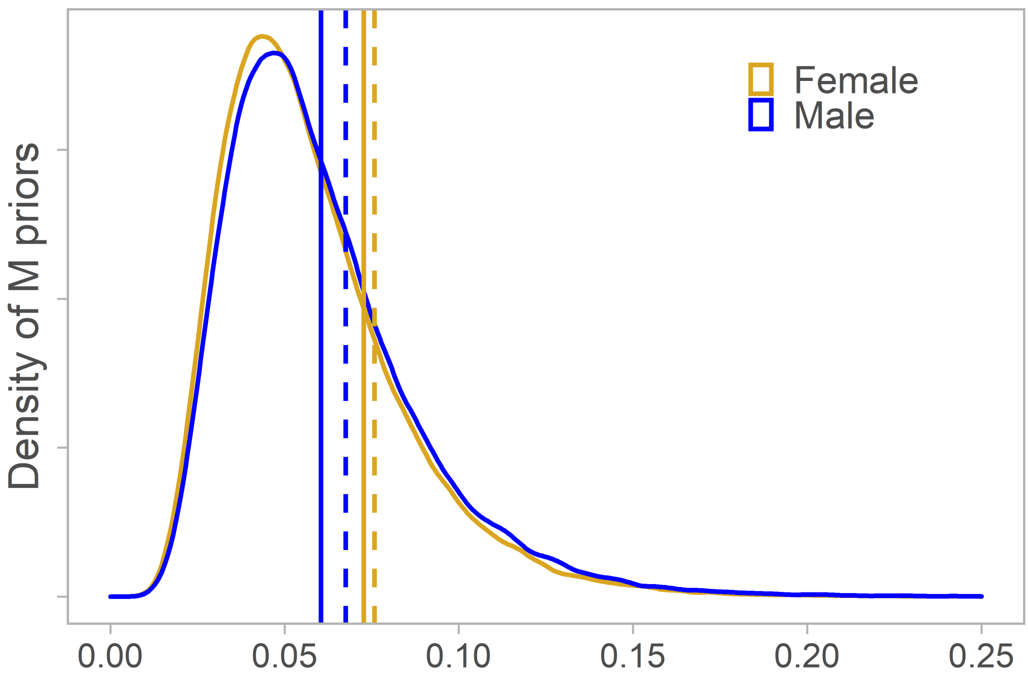


Figure 41: Prior for female (gold) and male (blue) natural mortality (M). Vertical lines delineate estimates from the current base models (solid lines) and 2019 benchmark assessment (dashed line).

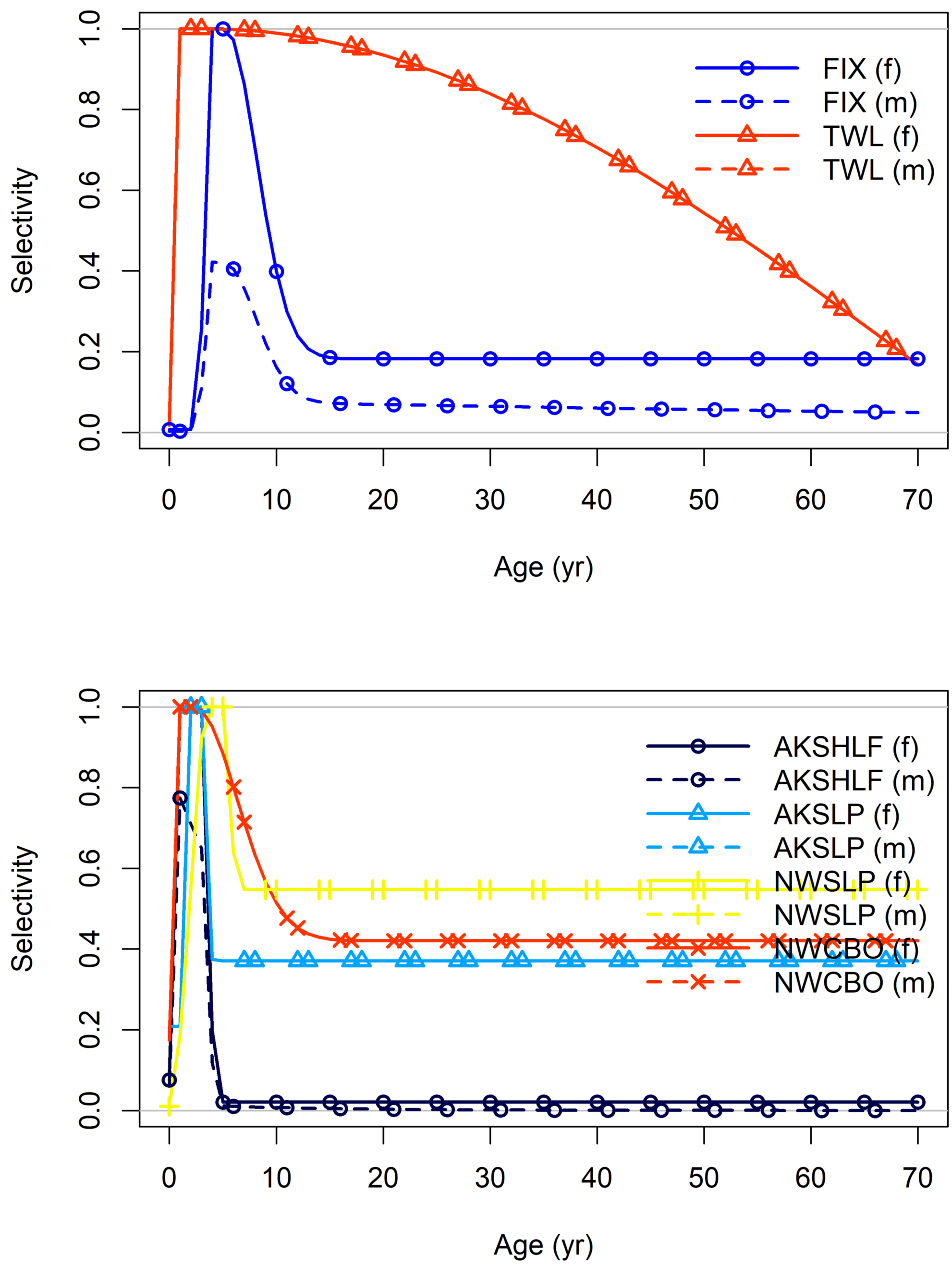


Figure 42: Fleet-specific selectivity at age in the terminal year of the model for fishery fleets (upper) and survey fleets (lower). Solid lines are female-specific and dashed lines are male-specific selectivities.

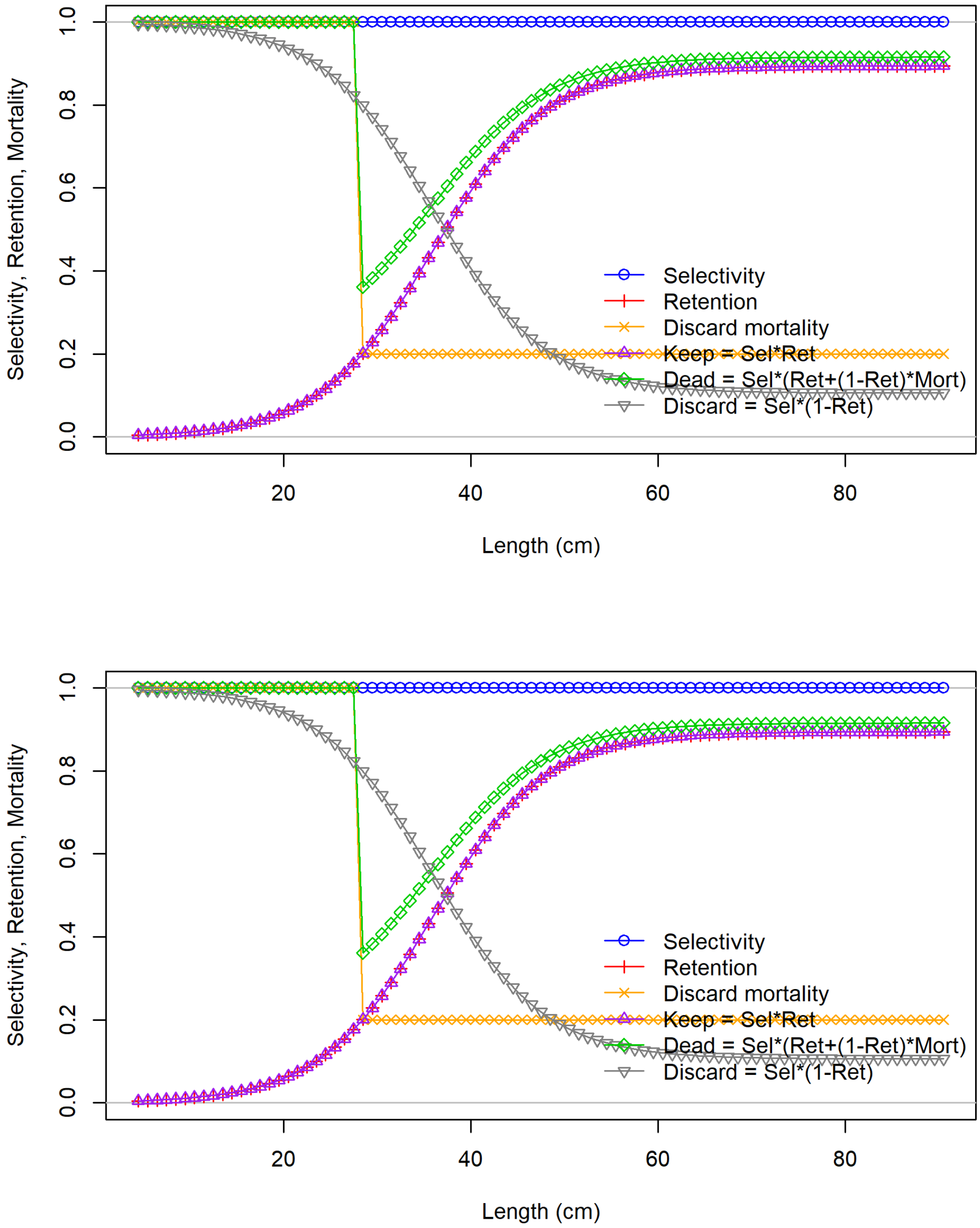


Figure 43: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the fixed-gear fishery.

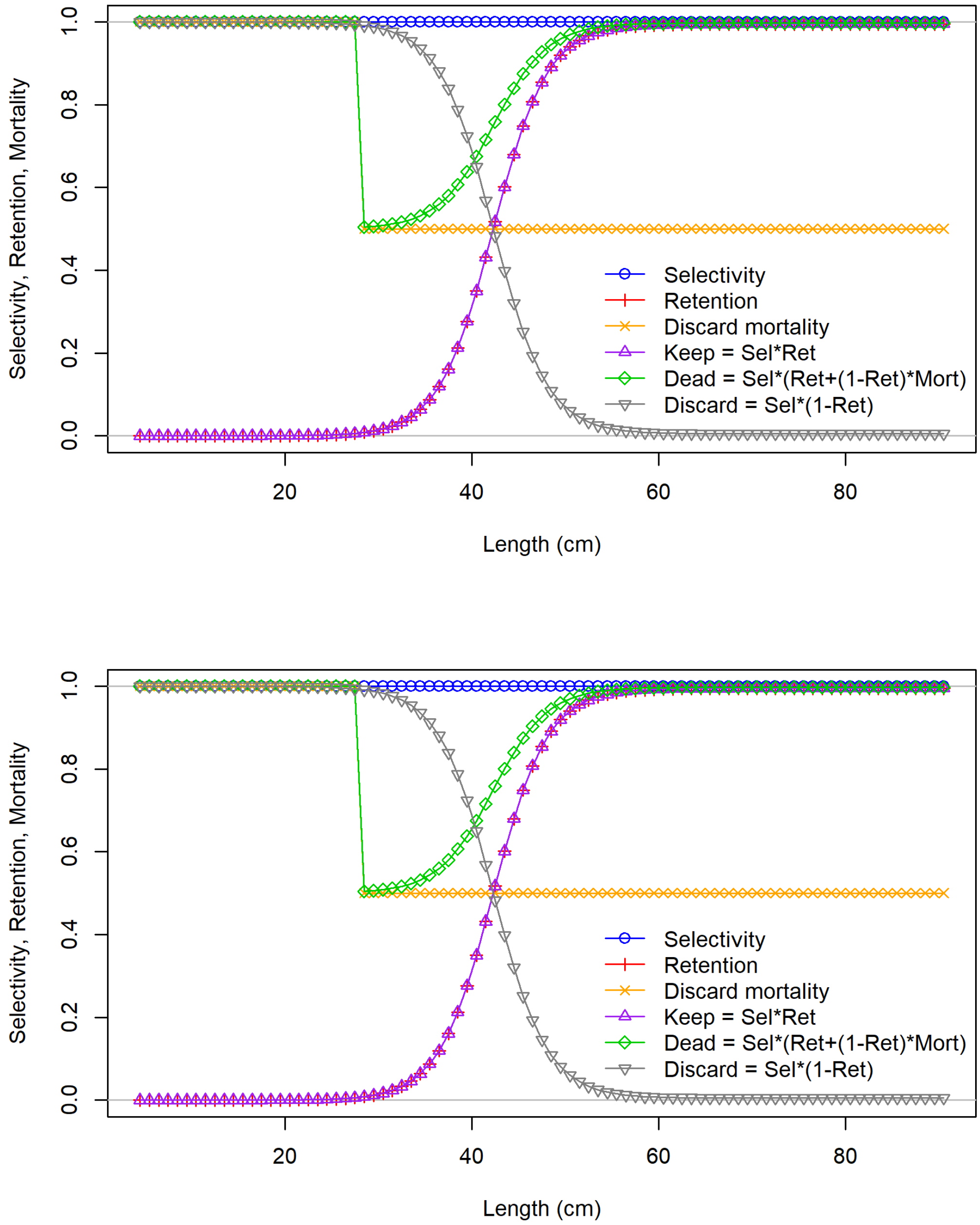


Figure 44: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the fixed-gear fishery.

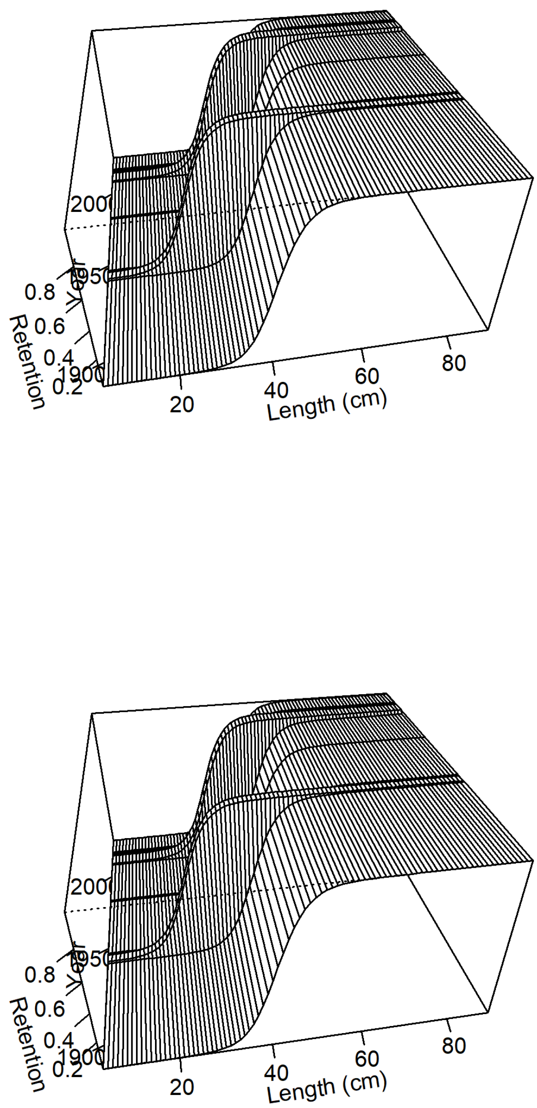


Figure 45: Estimated time-varying retention and discard mortality for females (upper panel) and males (lower panel) for the trawl fishery.

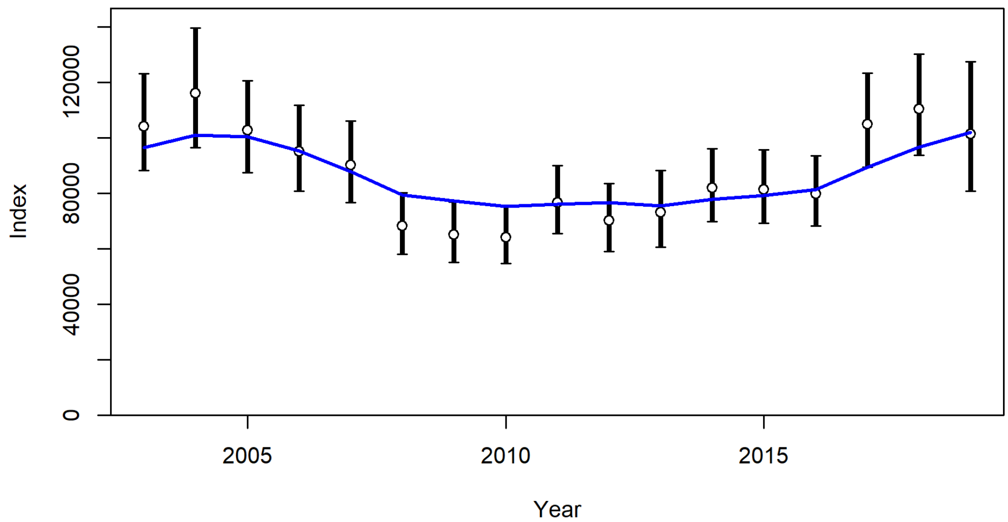


Figure 46: Fit to the West Coast Groundfish Bottom Trawl Survey.

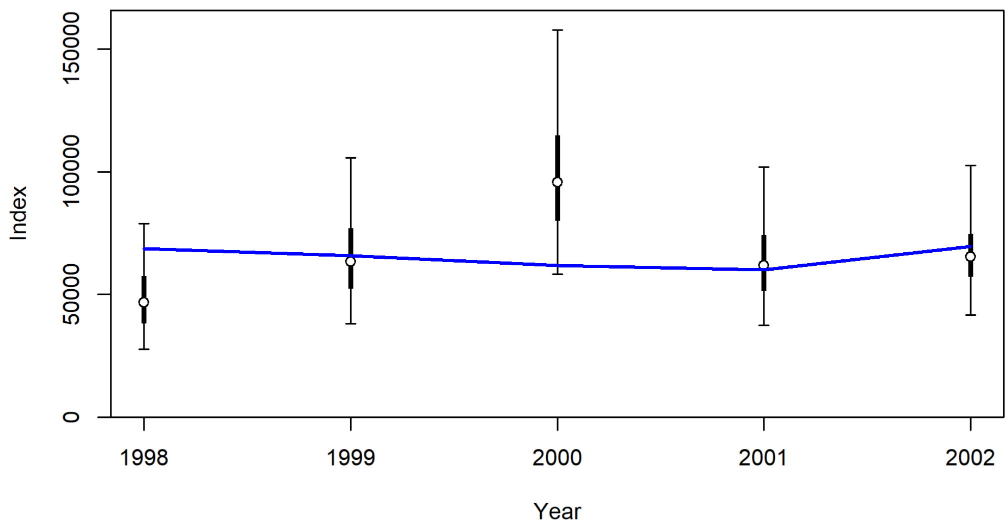


Figure 47: Fit to the Northwest Fisheries Science Center Slope Survey.

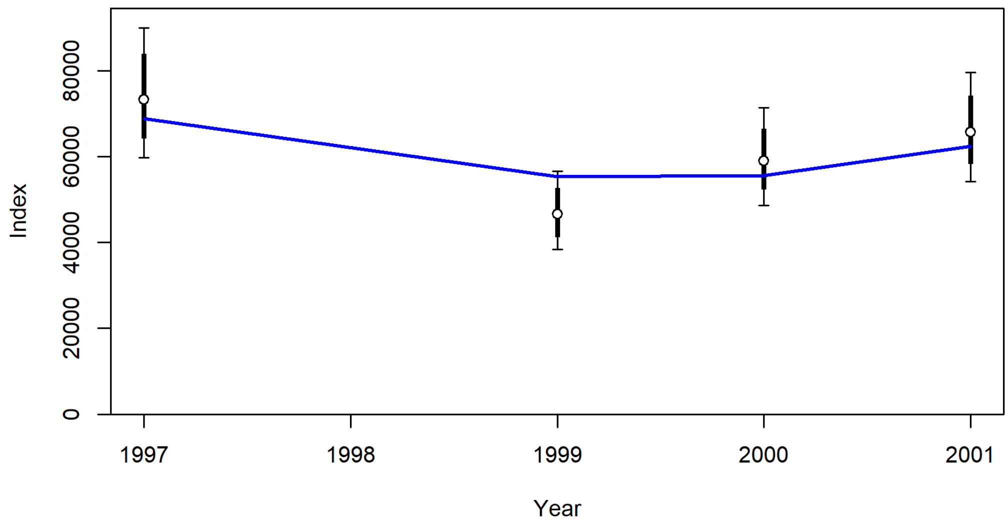


Figure 48: Fit to the Alaska Fisheries Science Center Slope Survey.

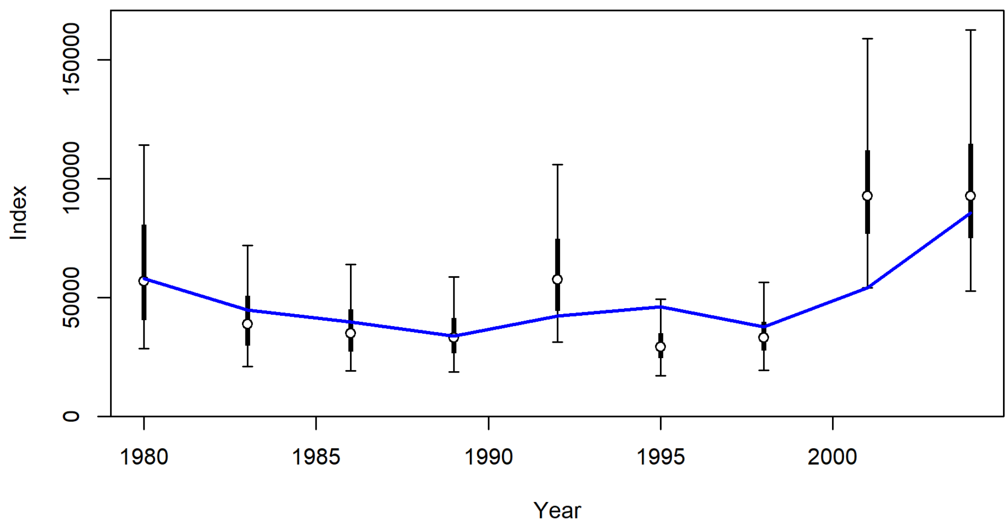


Figure 49: Fit to the Triennial Shelf Survey.

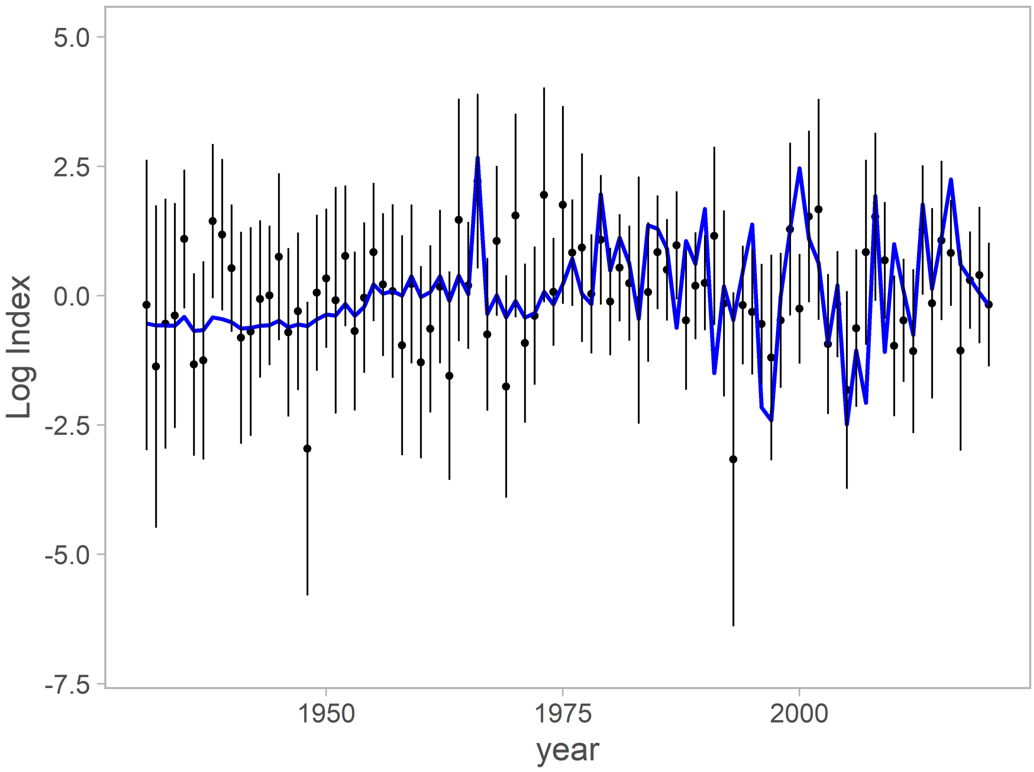


Figure 50: Fit to the sea-level index of recruitment; blue line is model-estimated recruitment deviations. The environmental index of sea-level was modeled as exp(recruitment deviation).

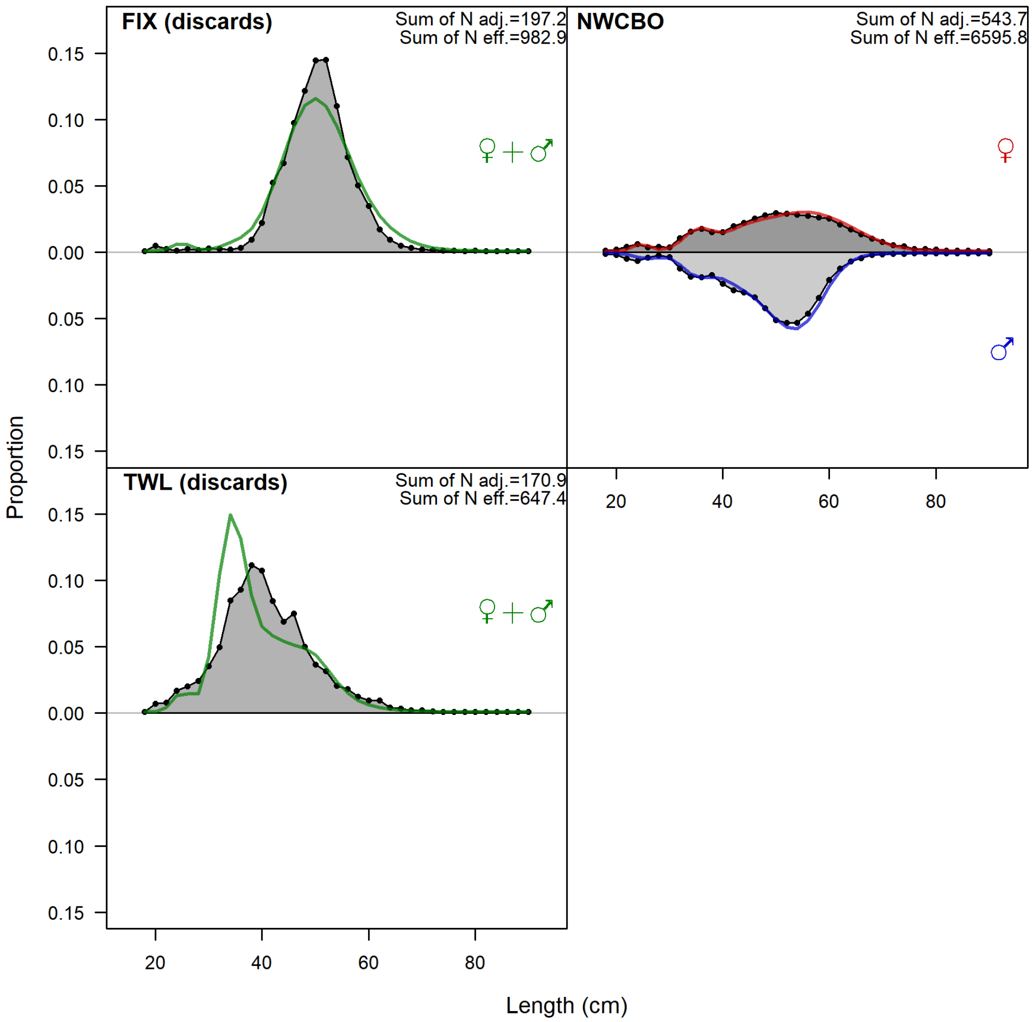


Figure 51: Length compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportions for sex-specific data. Fits are shown using solid lines.

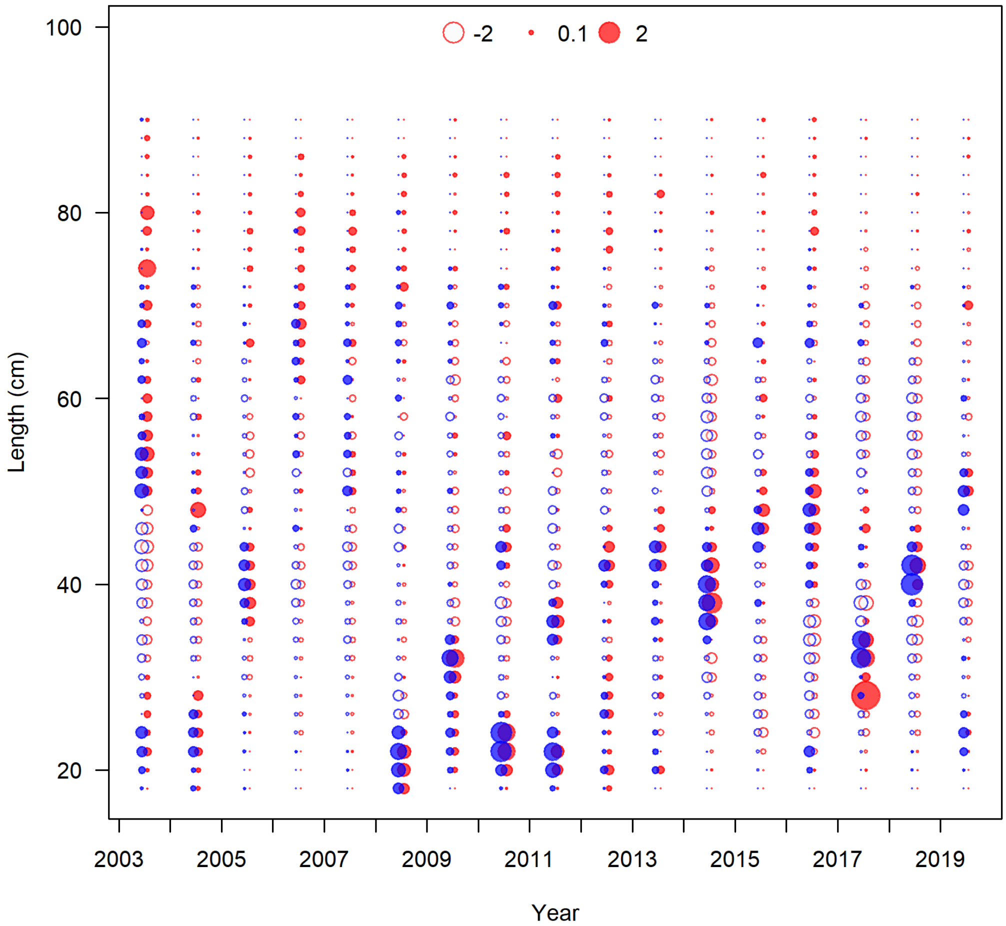


Figure 52: Pearson residuals for the fits to West Coast Groundfish Bottom Trawl length compositions. Filled circles represent positive residuals(observed-expected) and red and blue indicate females and males, respectively.

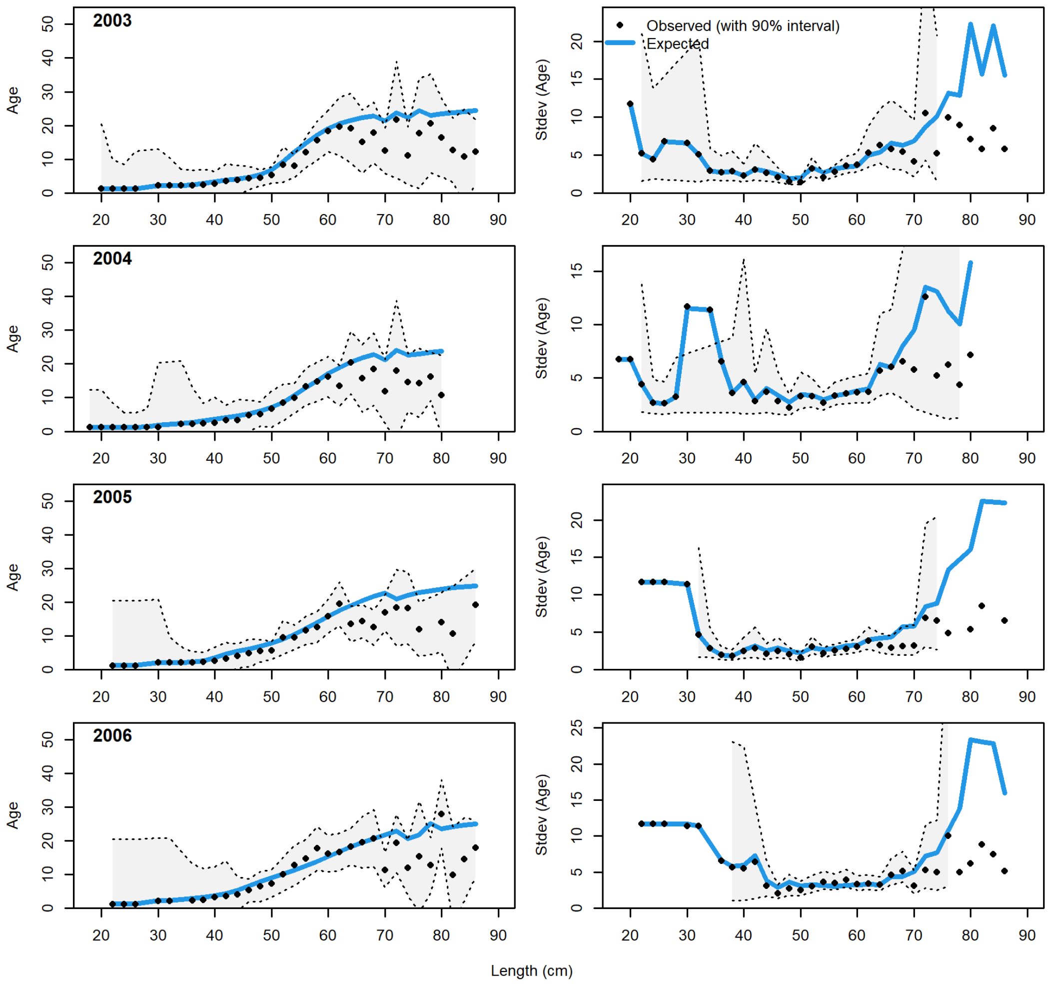


Figure 53: Year-specific conditional age-at-length data (left) and standard deviation (stdev) at age (right) from the West Coast Groundfish Bottom Trawl Survey. Shaded areas are confidence intervals based on adding 1.64 standard errors of the mean to the mean age and 90% intervals from a chi-square distribution for the stdev of mean age.

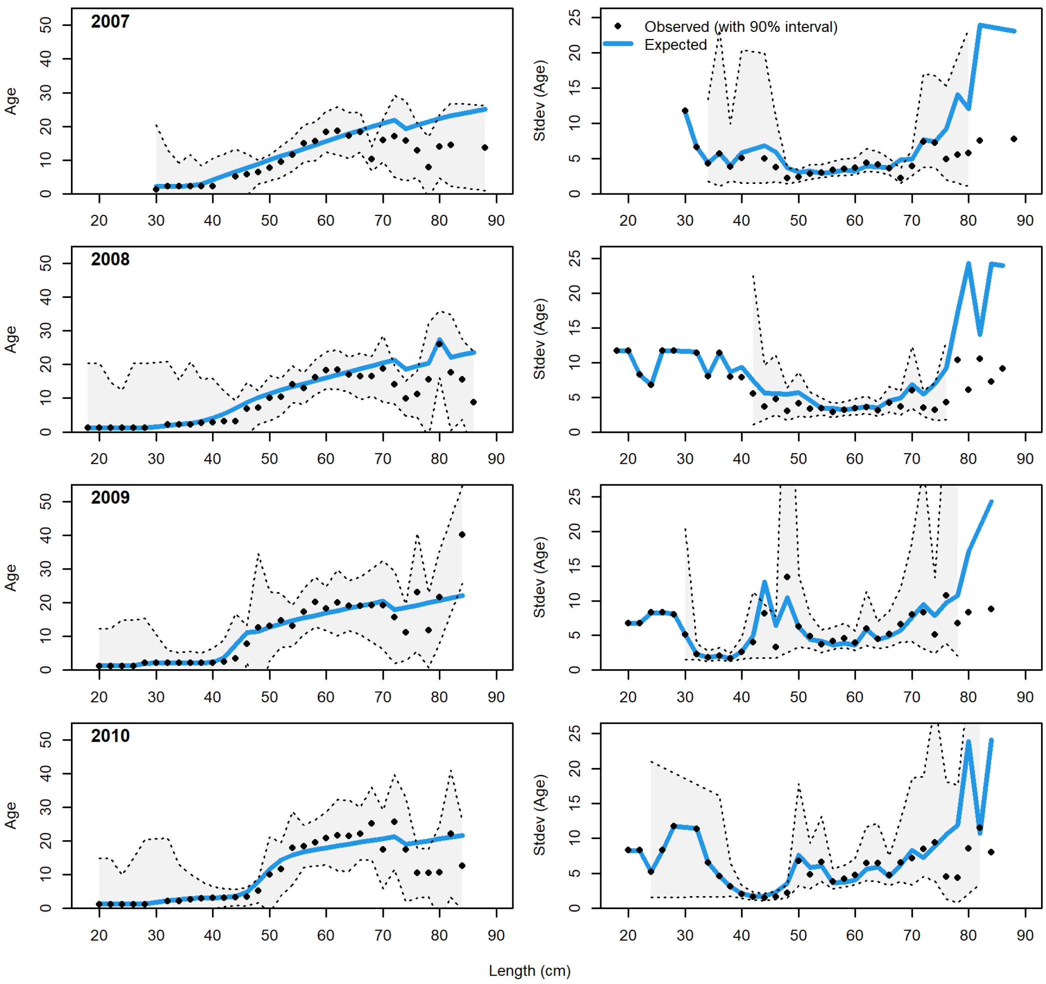


Figure 54: Figure 44 (cont.)

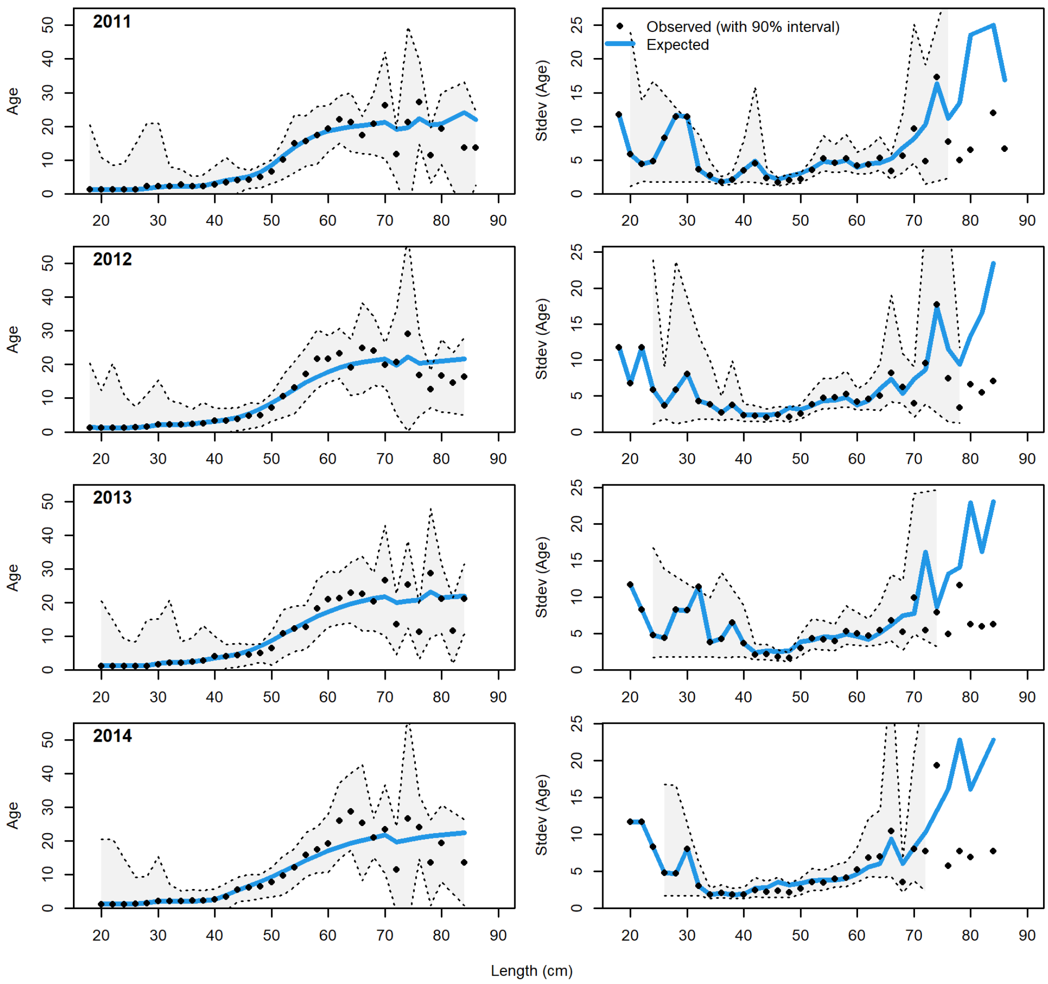


Figure 55: Figure 44 (cont.)

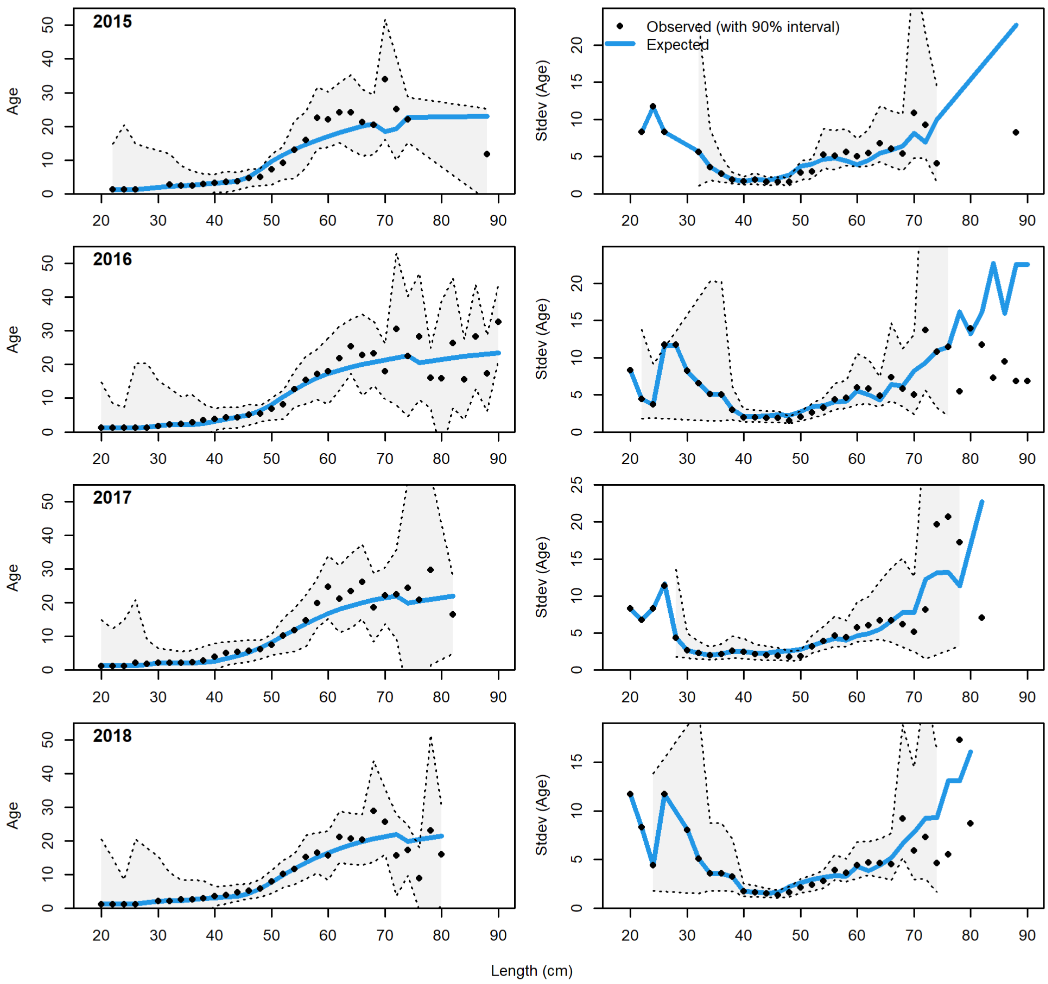


Figure 56: Figure 44 (cont.)

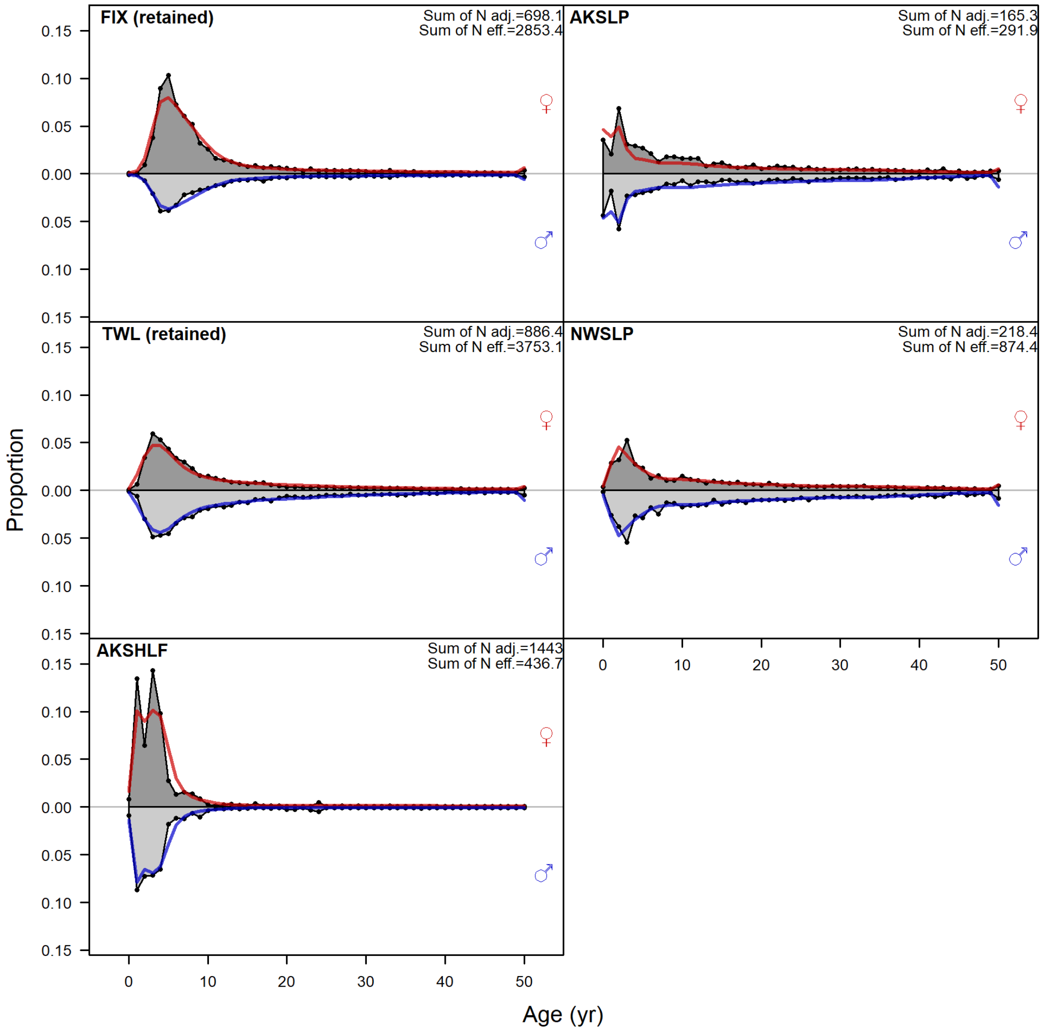


Figure 57: Age compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportionsfor sex-specific data. Fits are shown using solid lines.

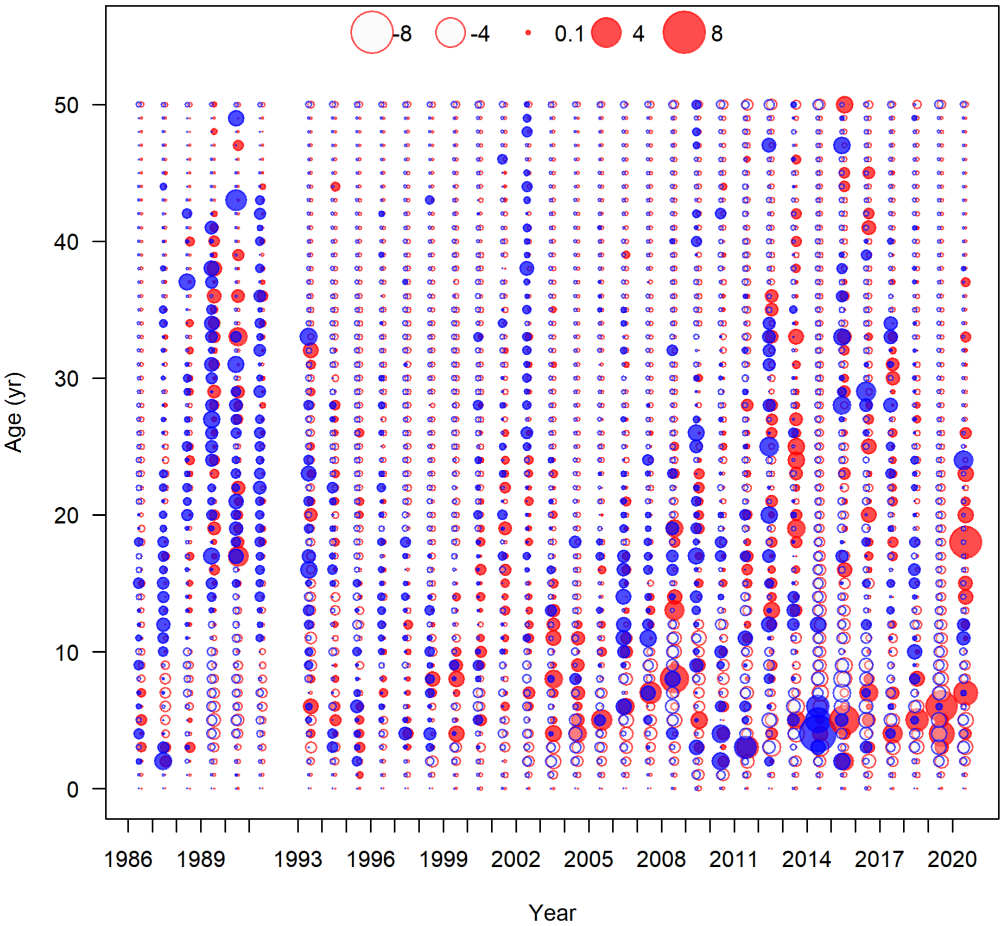


Figure 58: Pearson residuals for the fits to the fixed gear retained age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

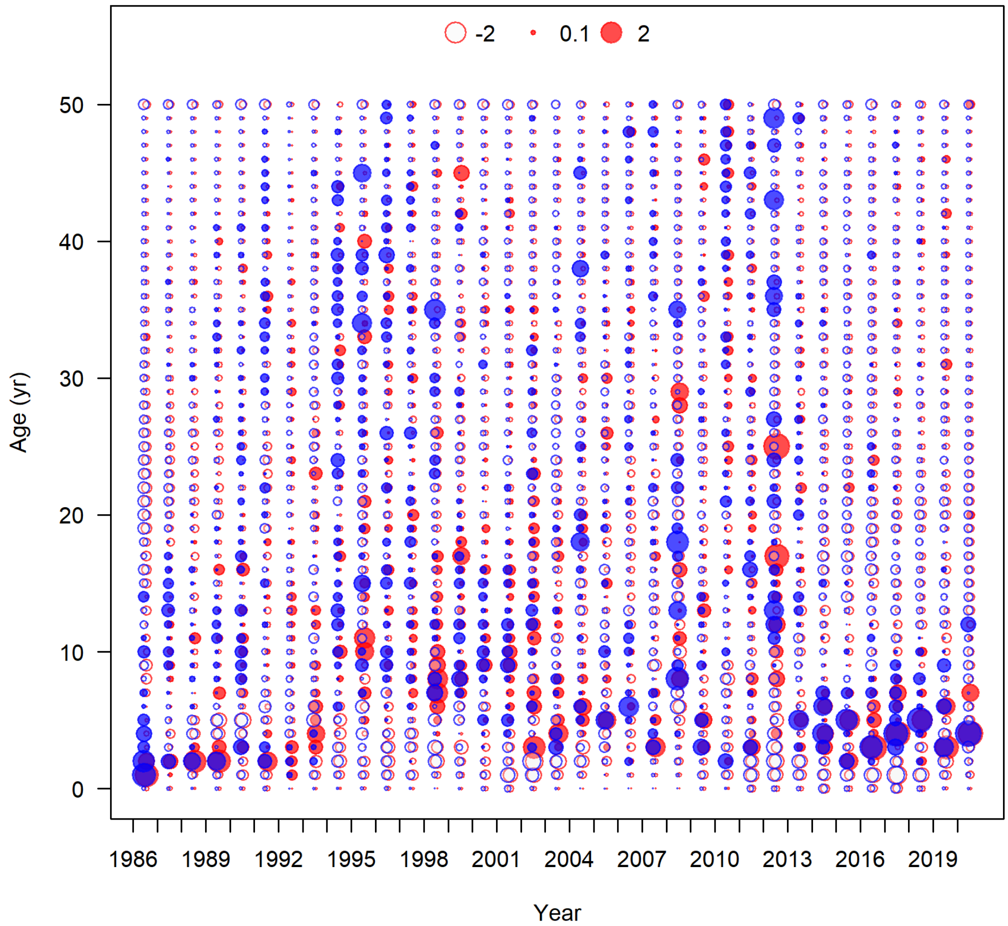


Figure 59: Pearson residuals for the fits to the trawl gear retained age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

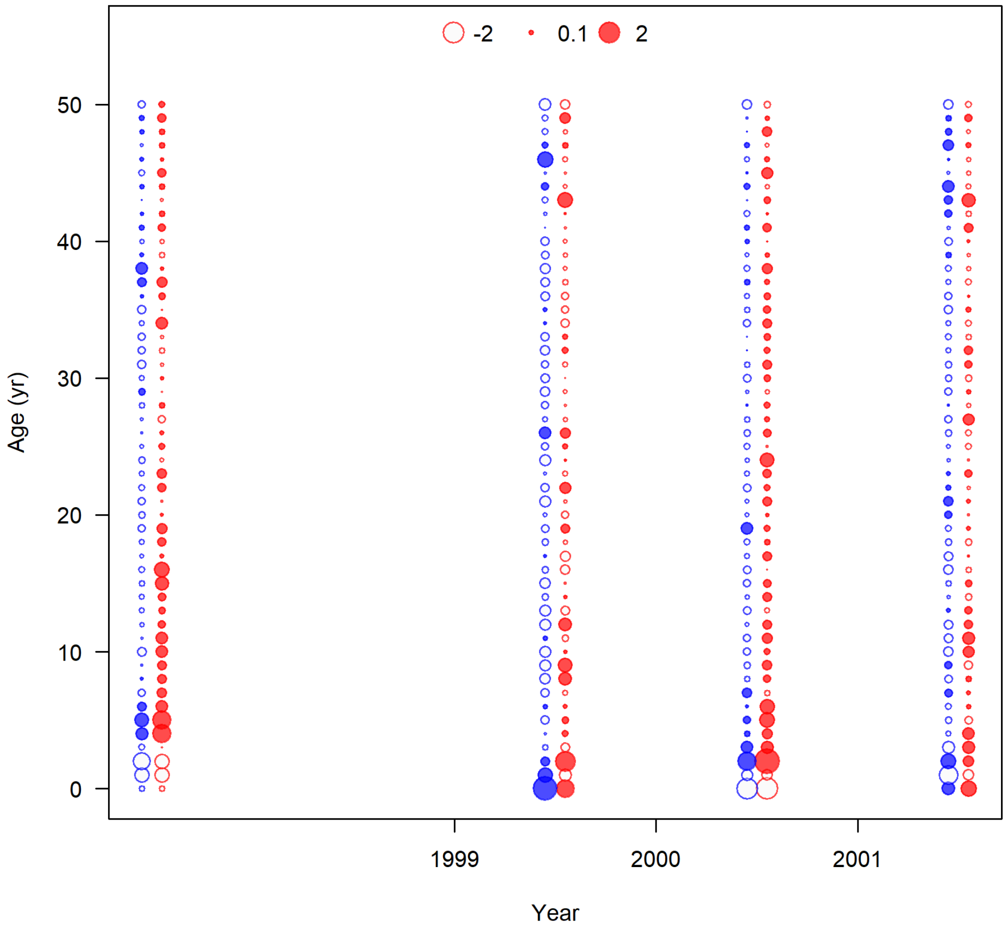


Figure 60: Pearson residuals for the fits to the Alaska Fisheries Science Center Slope Survey age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

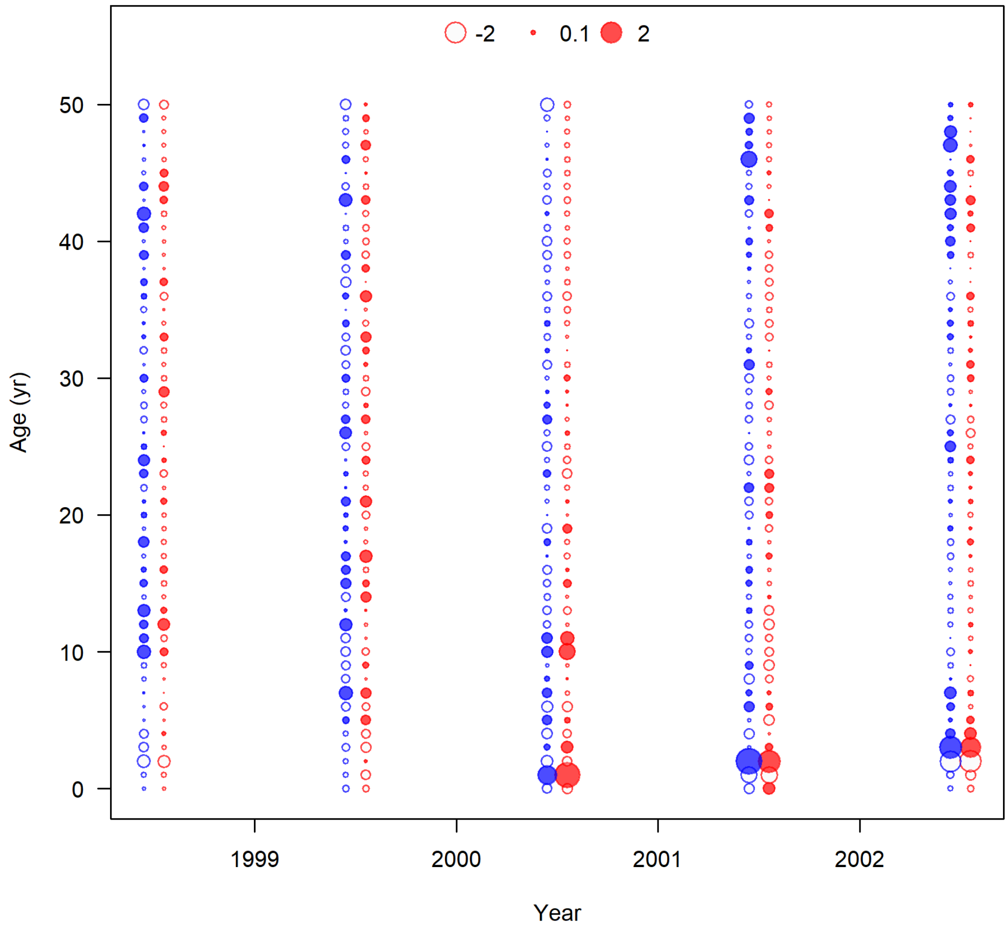


Figure 61: Pearson residuals for the fits to the Northwest Fisheries Science Center Slope Survey age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

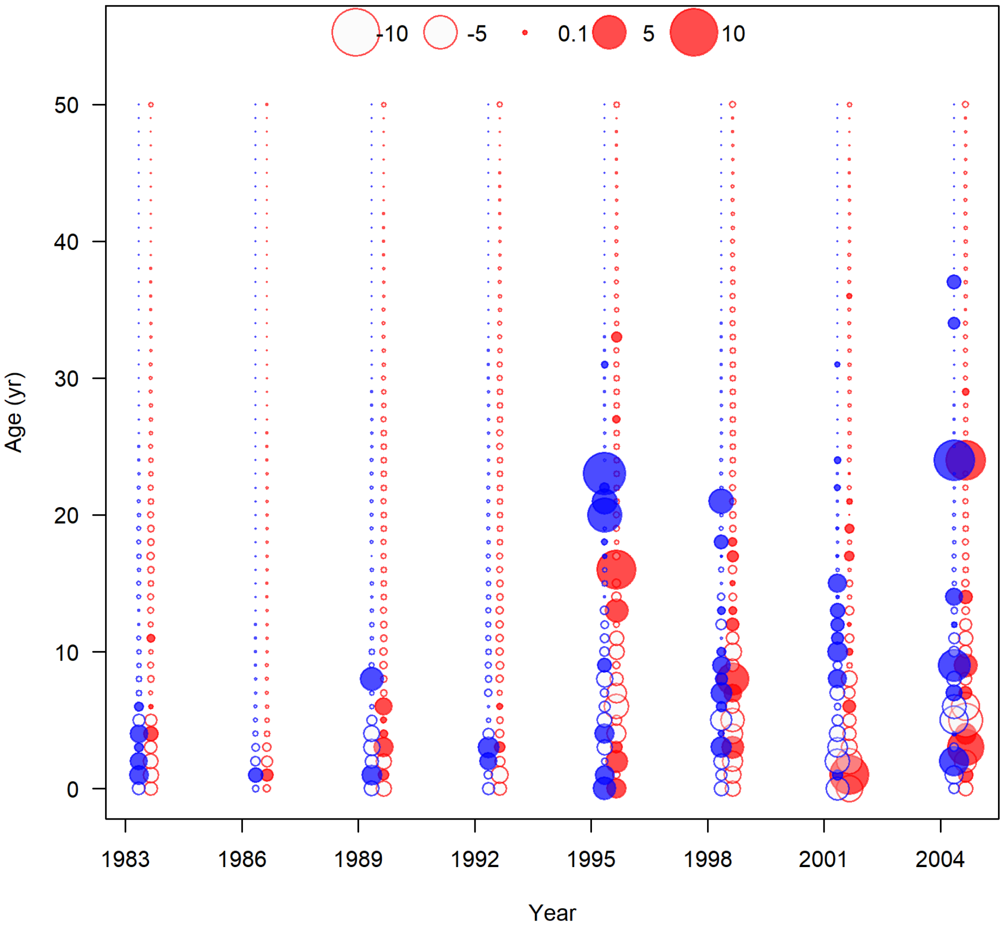
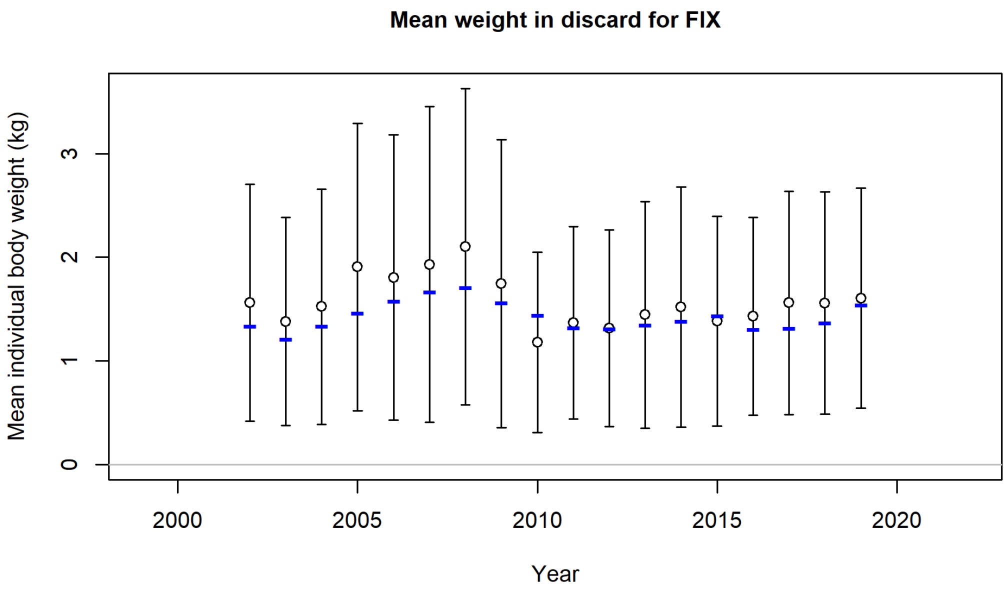


Figure 62: Pearson residuals for the fits to the Triennial Shelf Survey age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.



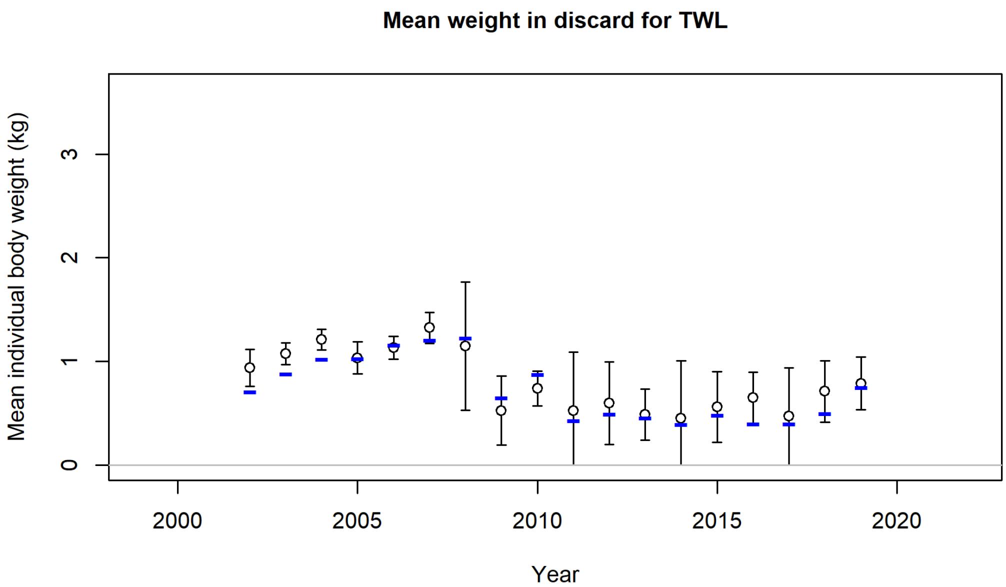


Figure 63: Fit to the fishery discard mean body weight data.

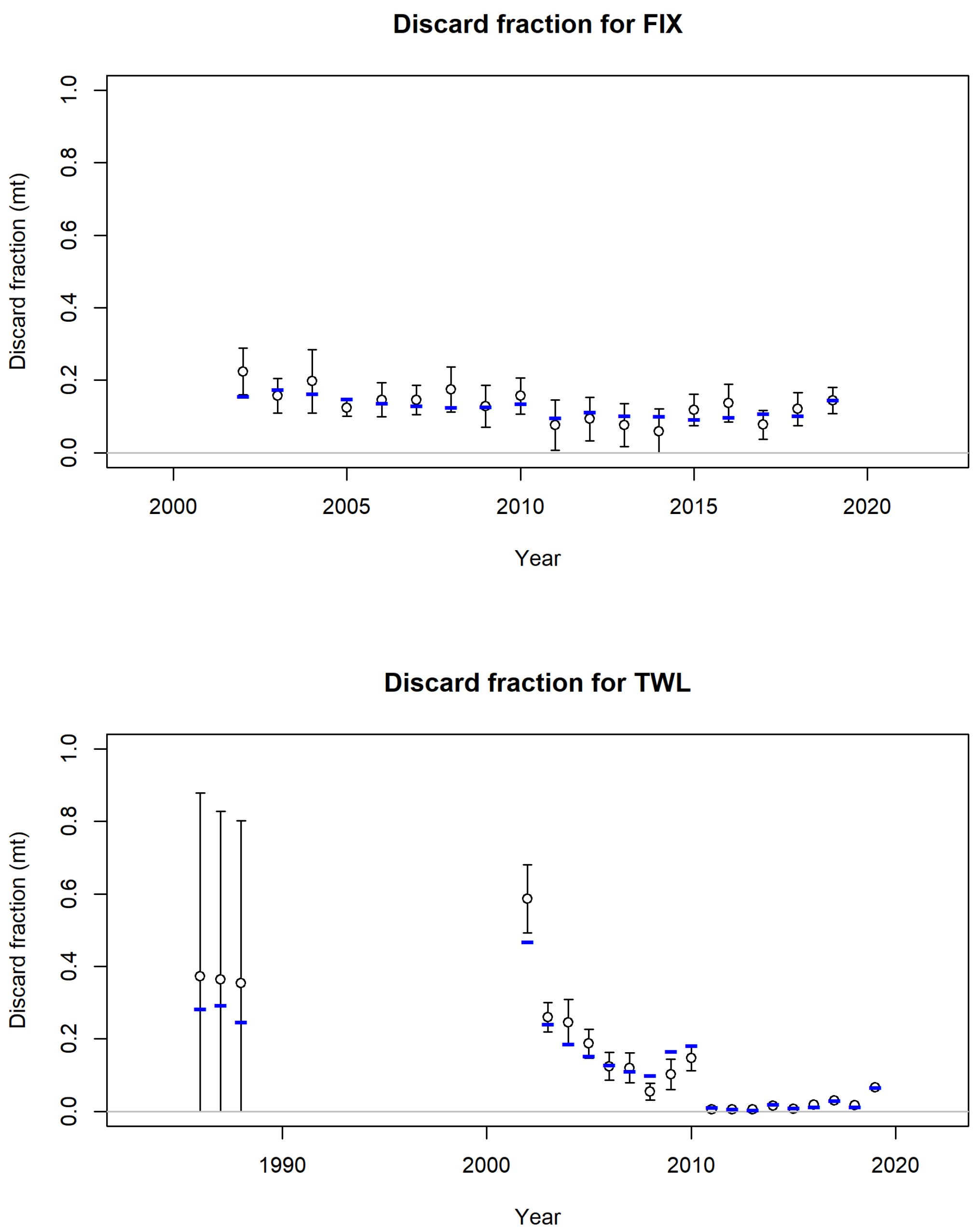


Figure 64: Fit to the fishery discard fraction data.

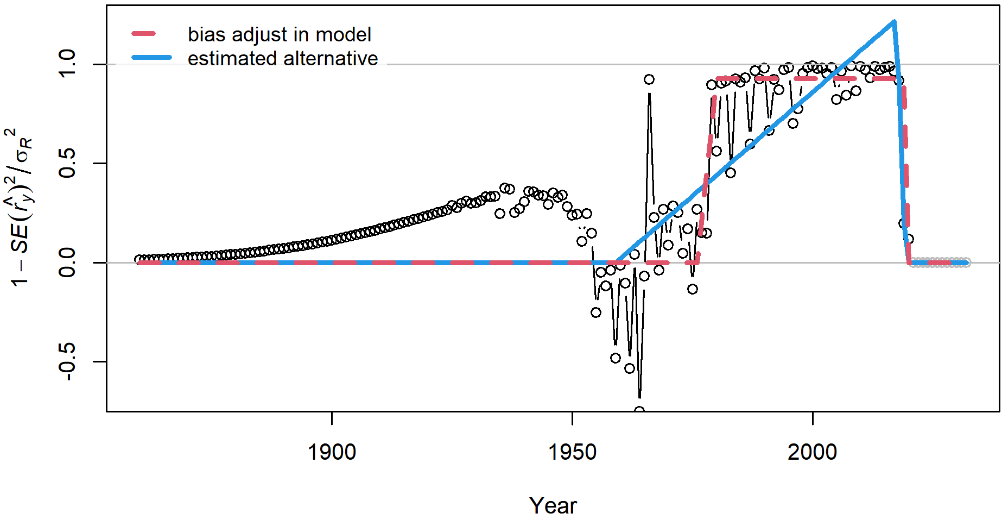


Figure 65: Estimated recruitment deviation time-series (upper panel) and bias adjustment relative to the ratio of recruitment estimation uncertainty and σ_r (lower panel).

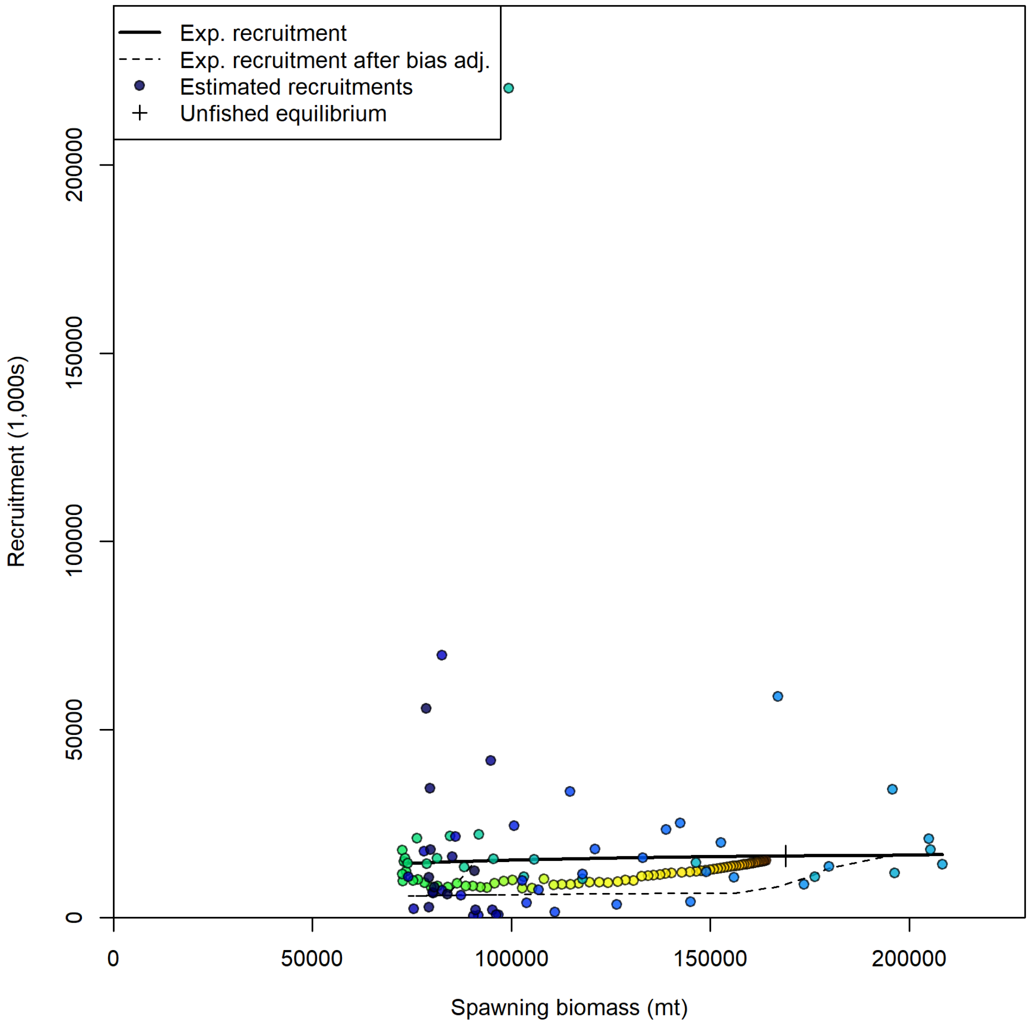


Figure 66: Estimated stock-recruitment function for the base model.

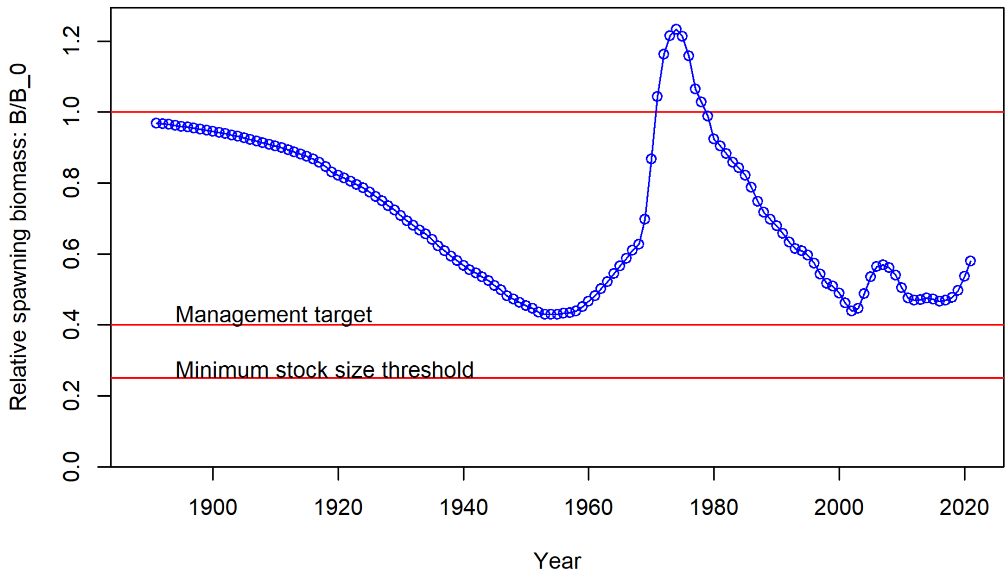


Figure 67: Estimated spawning biomass time-series for the base model (solid line) with 95% interval (dashed lines).

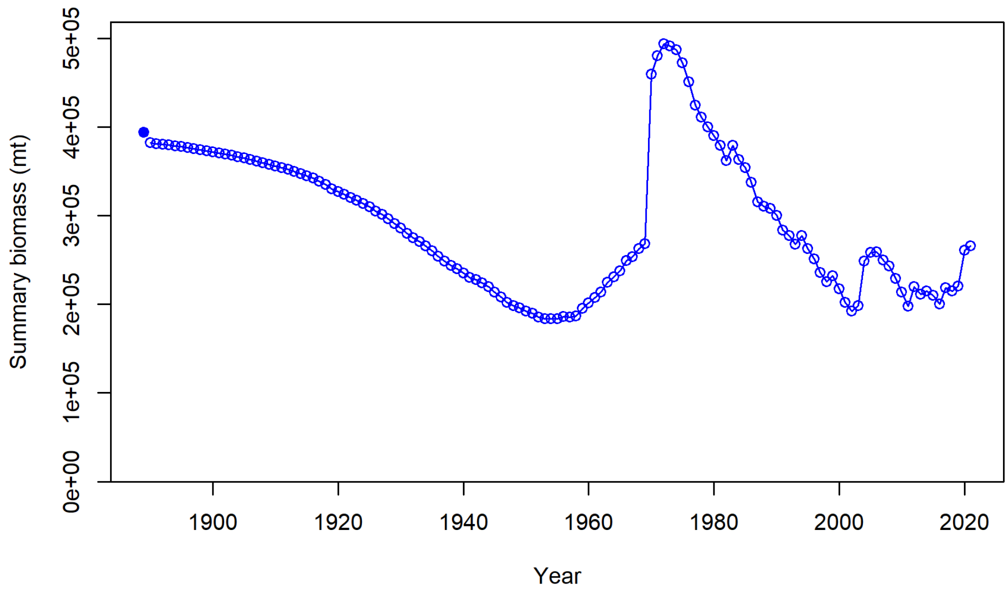


Figure 68: Estimated summary biomass time-series for the base model (solid line) with 95% interval (dashed lines).

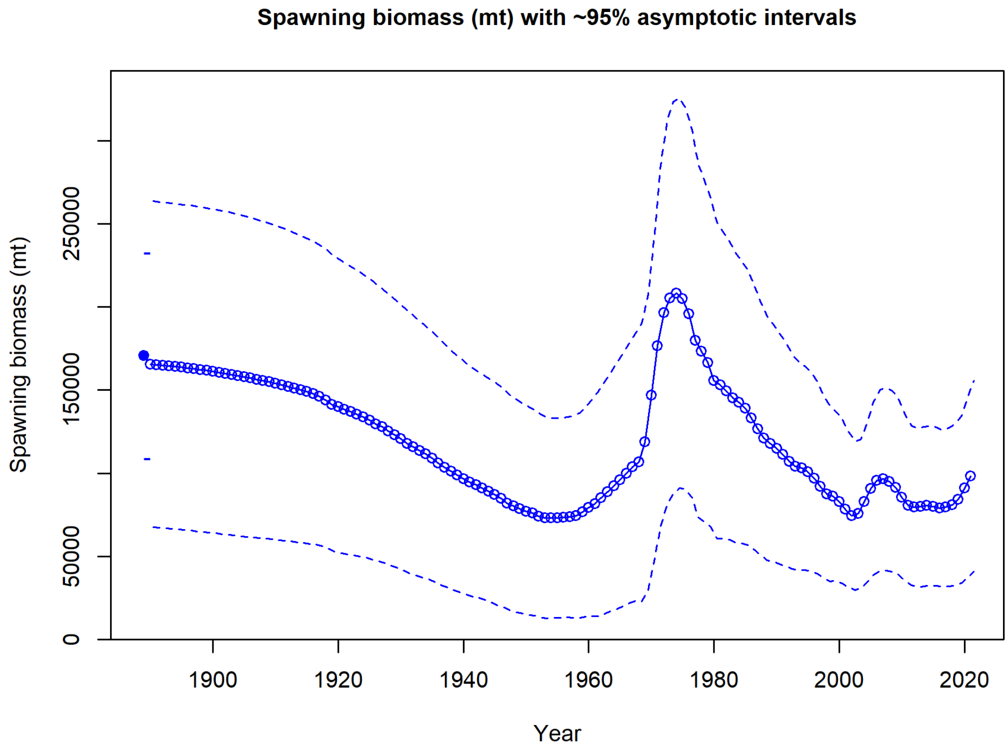


Figure 69: Estimated spawning biomass time-series for the base model (solid line) with 95% interval (dashed lines).

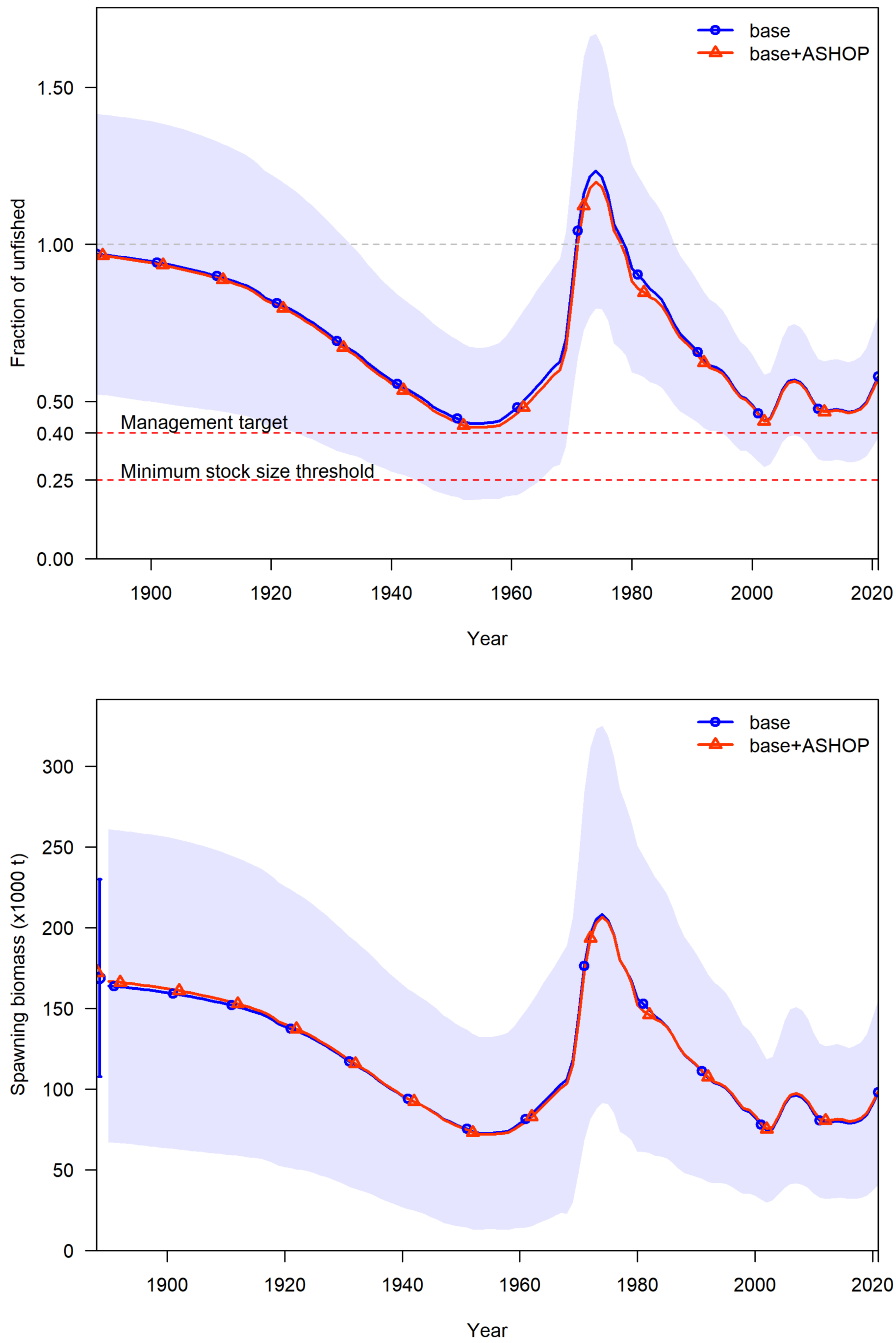


Figure 70: Comparison of depletion (upper panel) and spawning biomass (lower panel) between base model and model run with inclusion of At Sea Hake landings and length compositions. The Francis data weights for these data were left at the same value used in a similar sensitivity run for the 2019 benchmark.

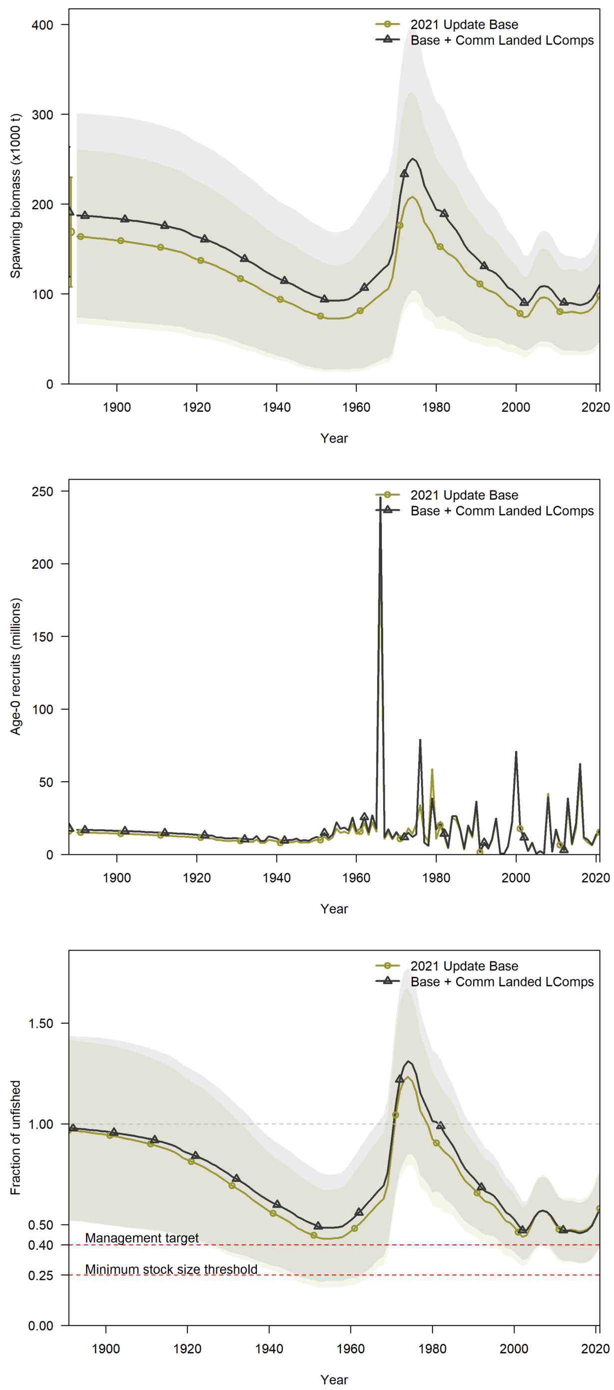


Figure 71: Comparison figures for spawning biomass (top row) age-0 recruits (middle row) and depletion (bottom row) between the base model and a sensitivity model run run with inclusion of commercially-landed length compositions. The Francis data weights for these data were left at the same value used in the base.

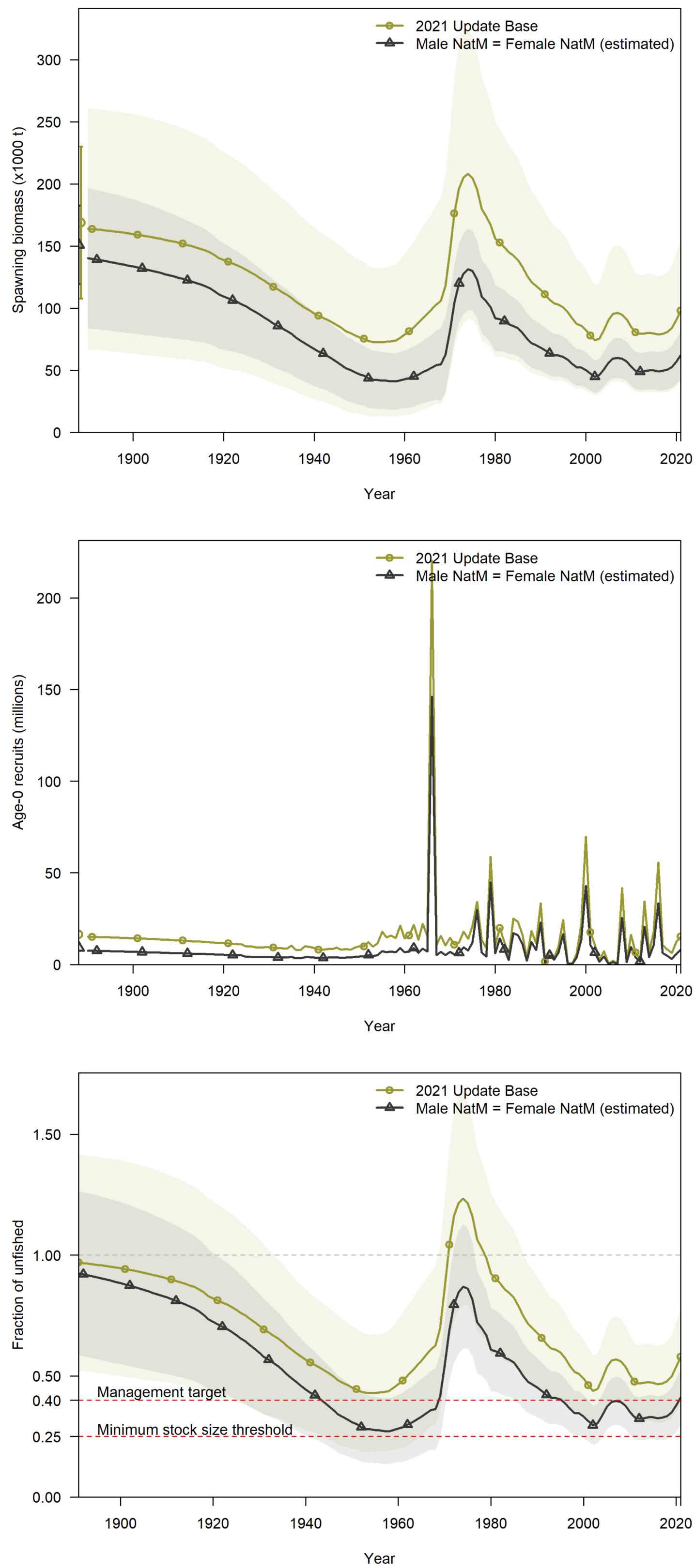


Figure 72: Comparison figures for spawning biomass (top row) age-0 recruits (middle row) and depletion (bottom row) between the base model and a sensitivity model run with a single value estimated for female and male natural mortality.

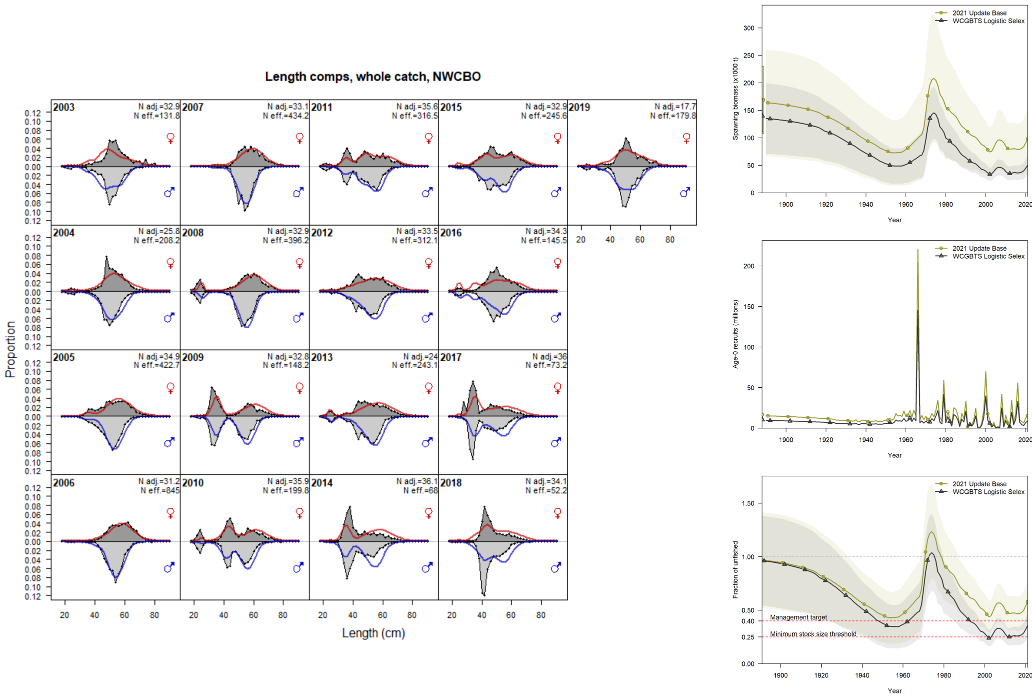


Figure 73: Comparison figures for a sensitivity run with the WCBGT Survey selectivity forced to be asymptotic. Clockwise from left: fits to length composition data from the WCGBT Survey (fits are shown with solid lines), estimated stock spawning biomass, recruitment and depletion.

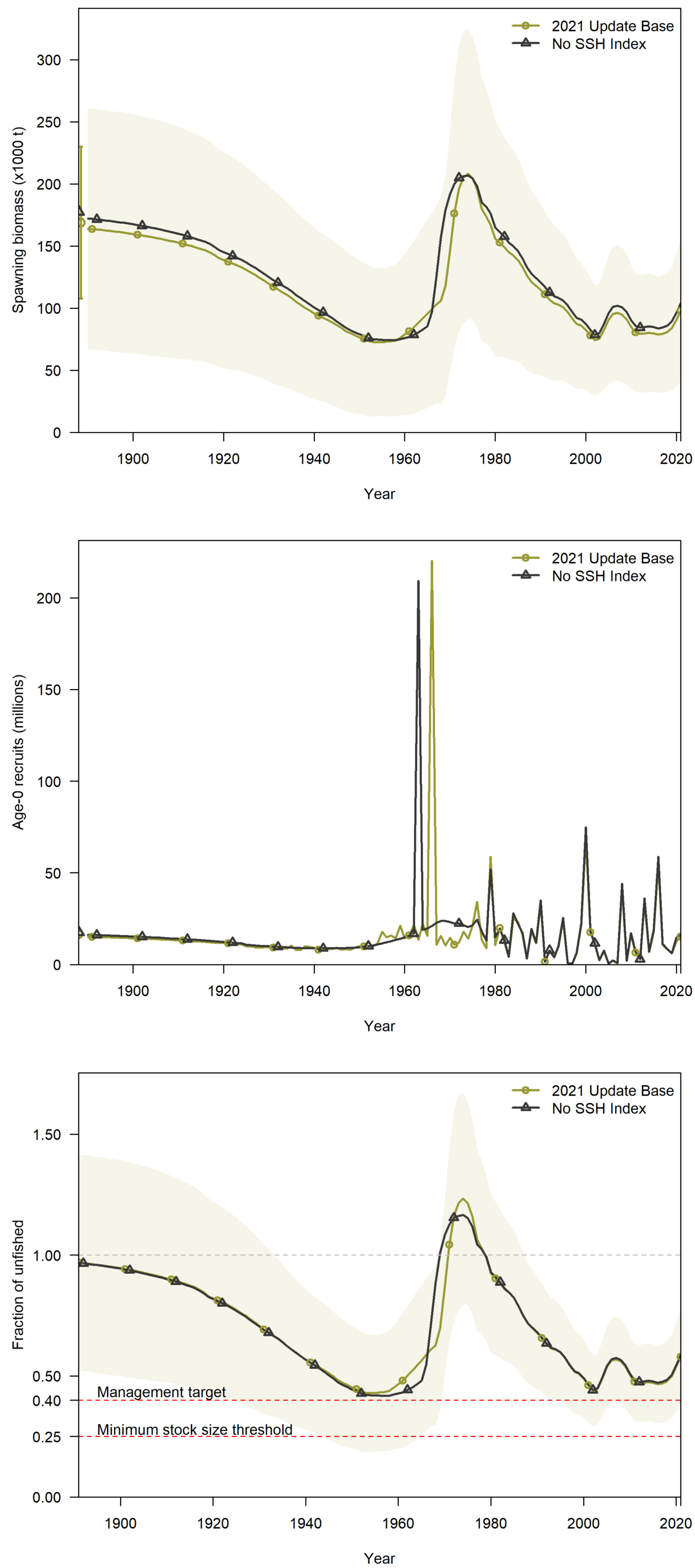


Figure 74: Comparison figures for spawning biomass (top row) age-0 recruits (middle row) and depletion (bottom row) between the base model and a sensitivity run with the sea surface height index removed from the model.

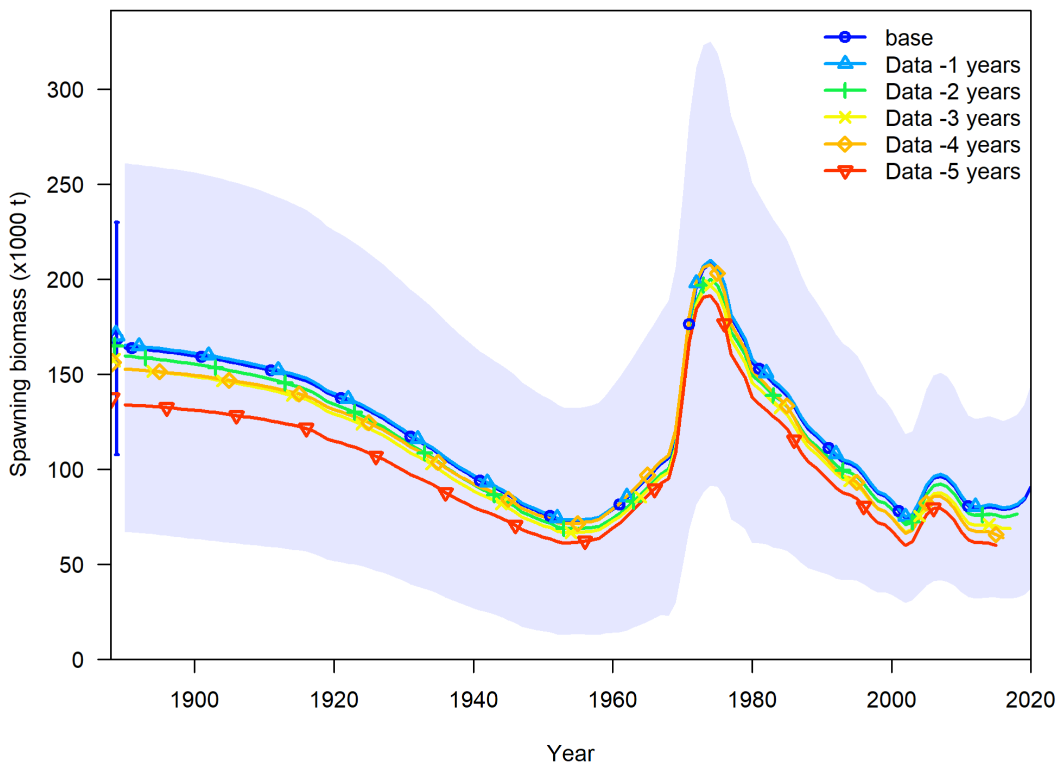


Figure 75: Trends in SSB from a retrospective analysis using the base model for comparison.

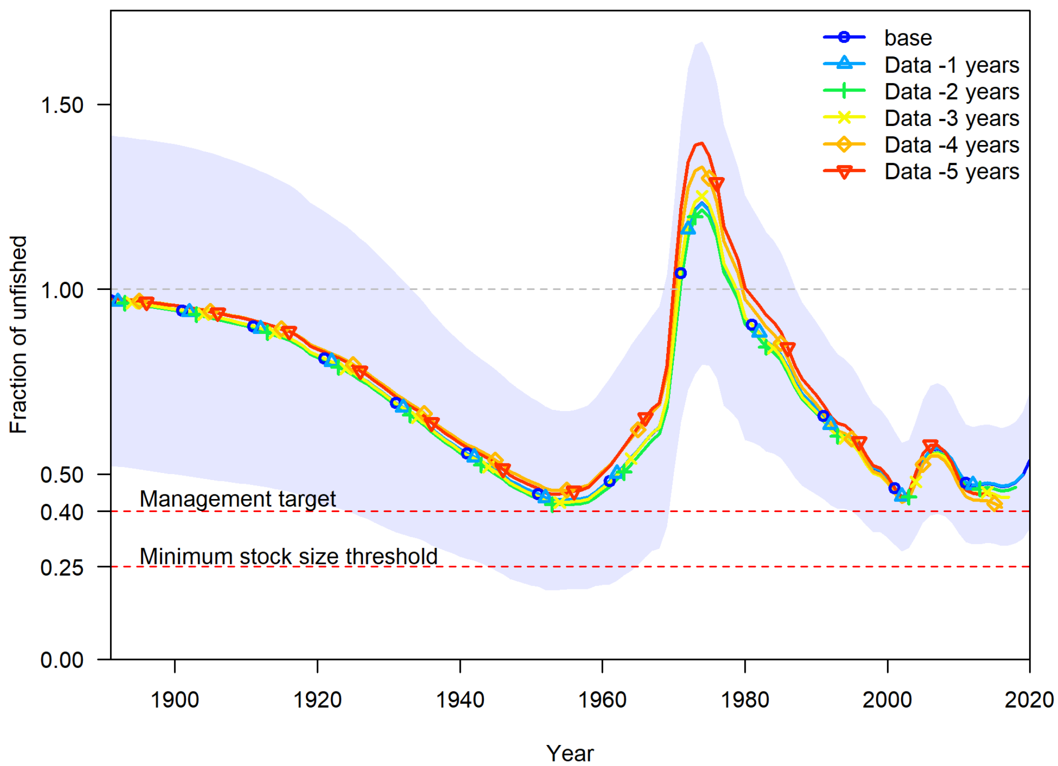


Figure 76: Trends in depletion from a retrospective analysis using the base model for comparison.

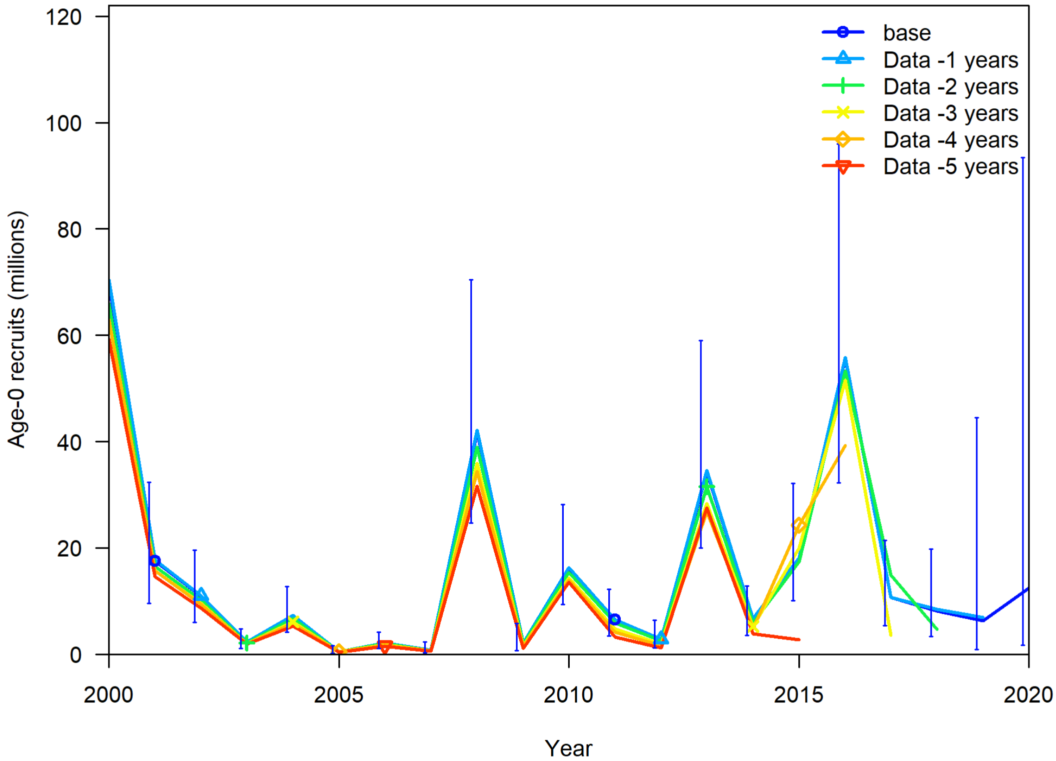


Figure 77: Trends in last 20 years of recruitment from a retrospective analysis using the base model for comparison.

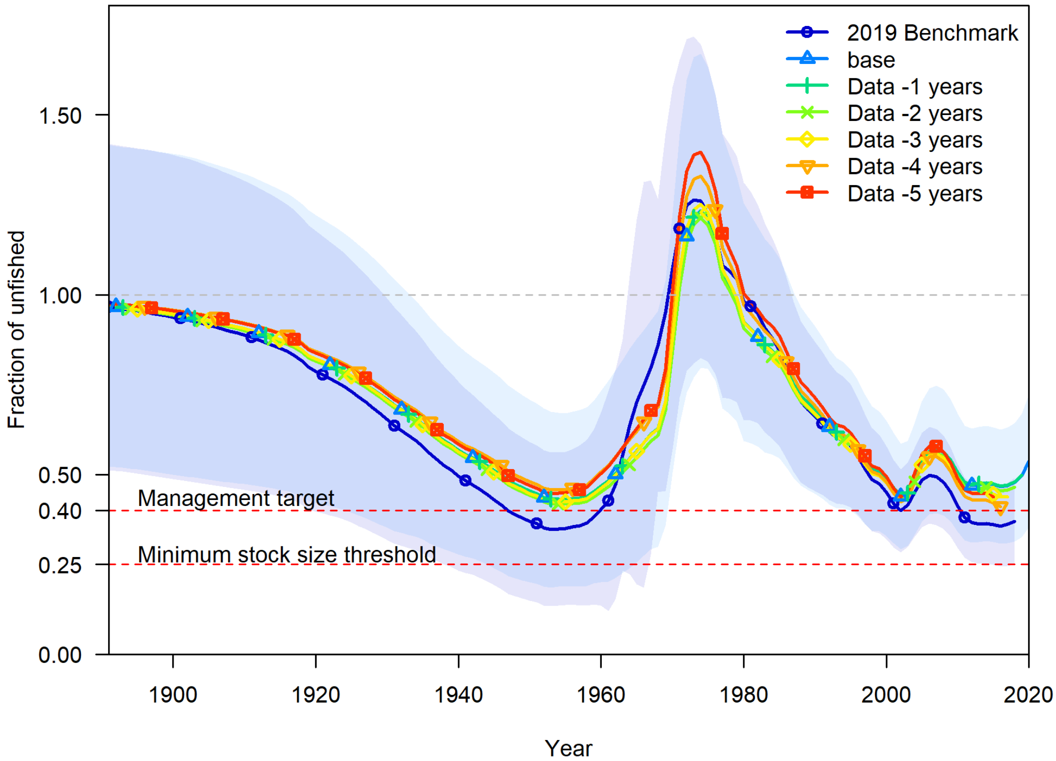


Figure 78: Trends in depletion from a retrospective analysis using the base model, with the 2019 benchmark model shown for comparison.

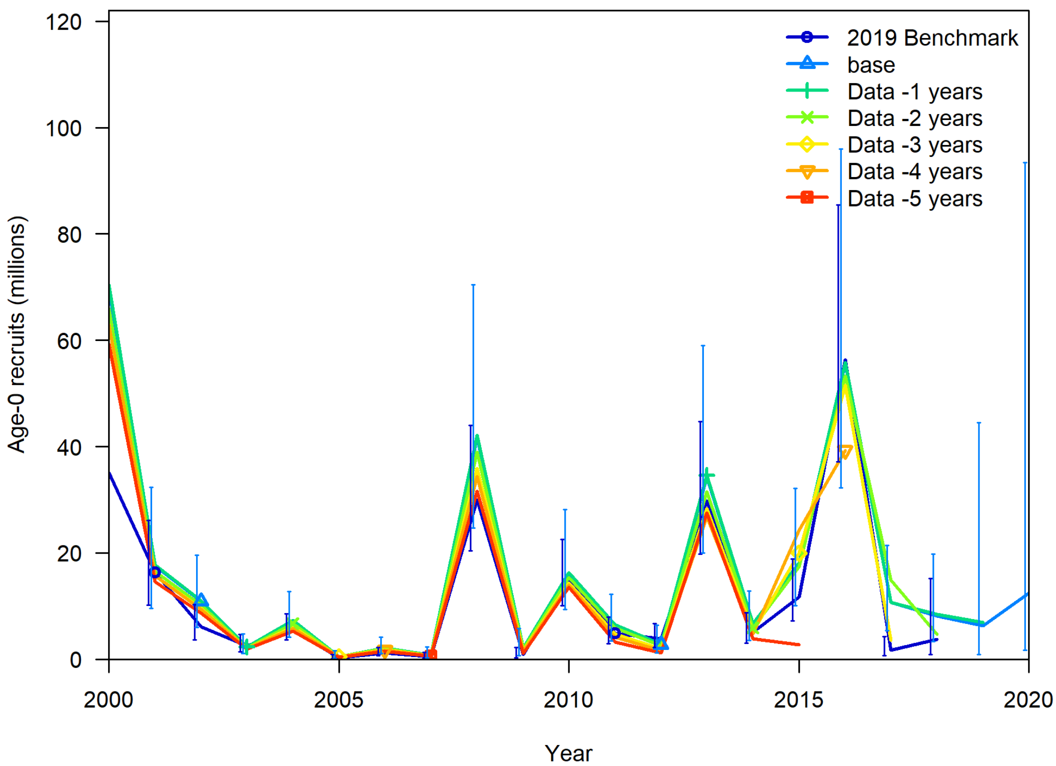
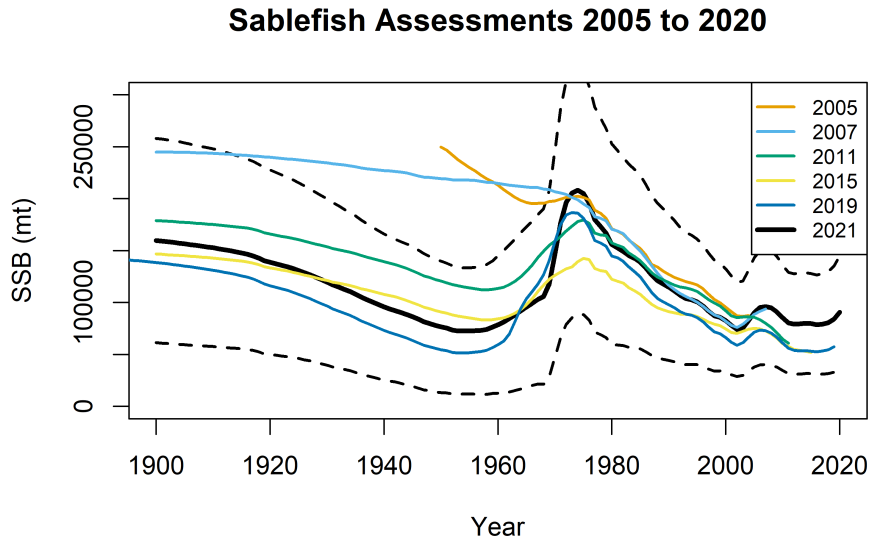


Figure 79: Trends in last 20 years of recruitment from a retrospective analysis using the base model, with the 2019 benchmark model shown for comparison.



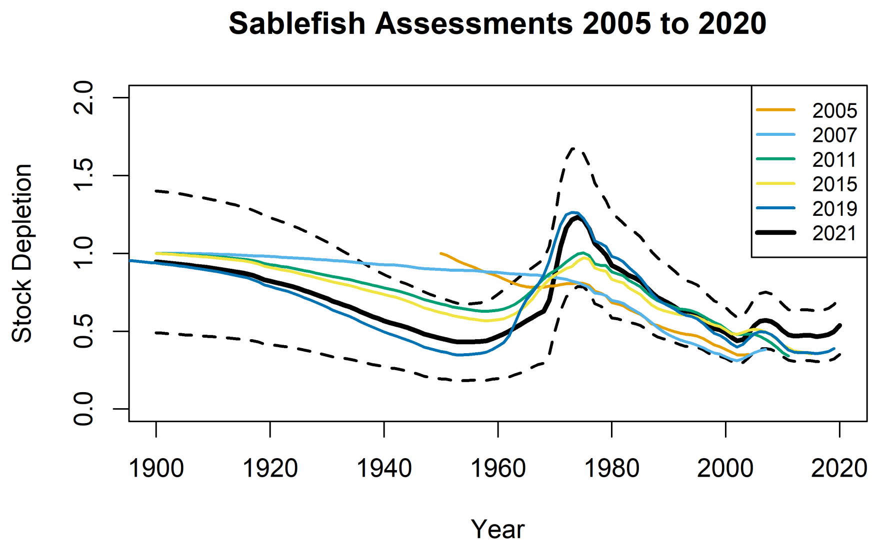


Figure 80: Comparisons of spawning stock biomass (SSB; mt) and relative depletion between the current assessment and the last five modeling exercises performed since 2005. Model-specific trajectories are represented with colored lines and the dashed line is the uncertainty about the currently estimated time series.

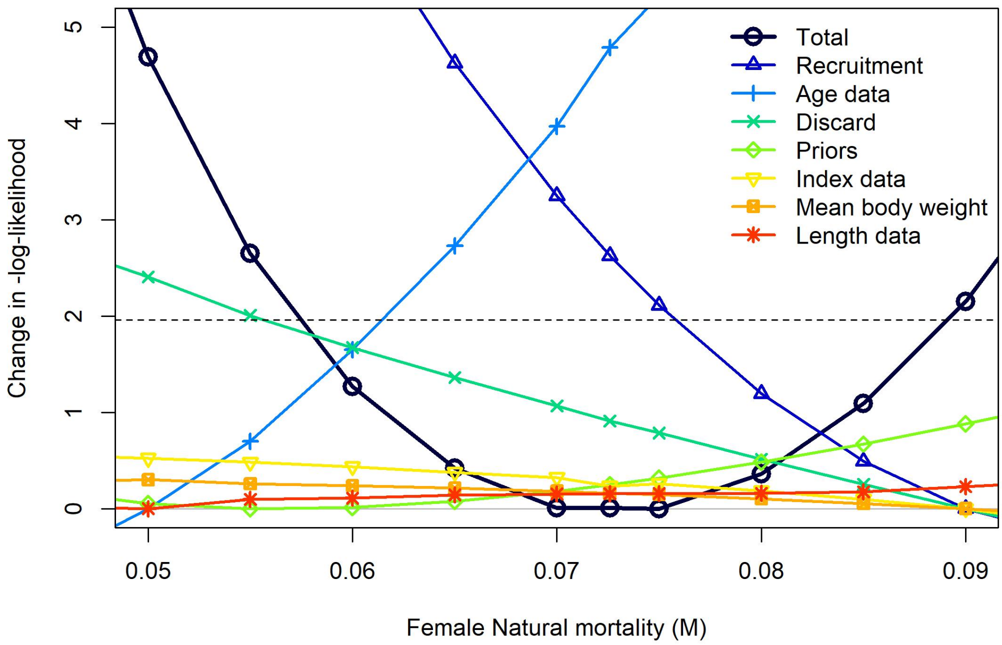


Figure 81: Results of a likelihood profile for female natural mortality (M) by data type.

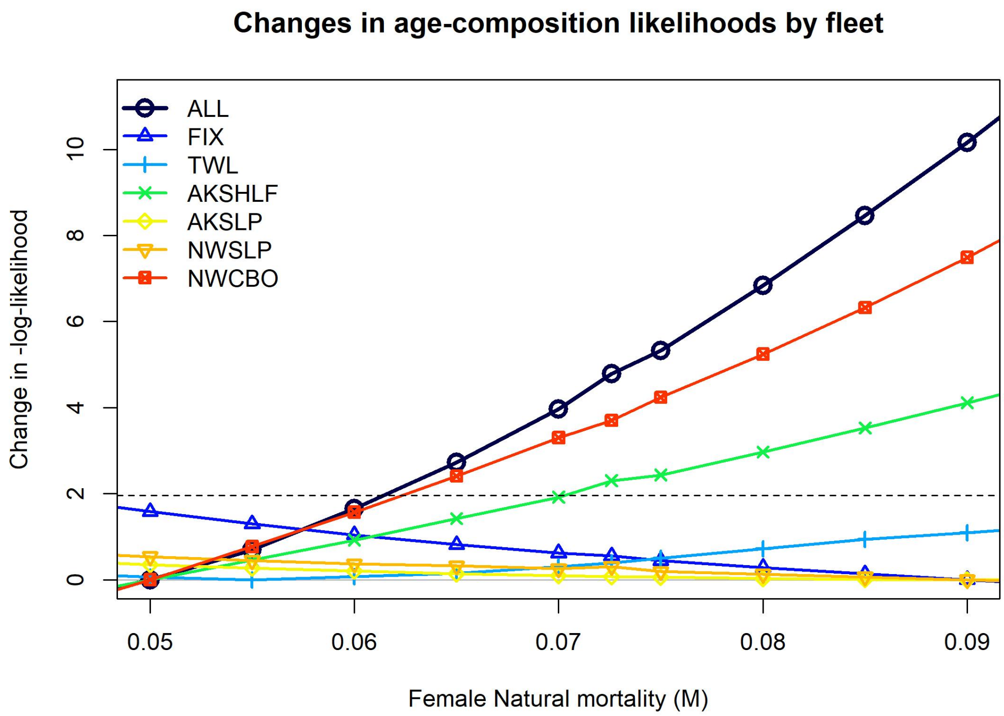


Figure 82: Age likelihoods from a likelihood profile for female natural mortality (M) by data type.

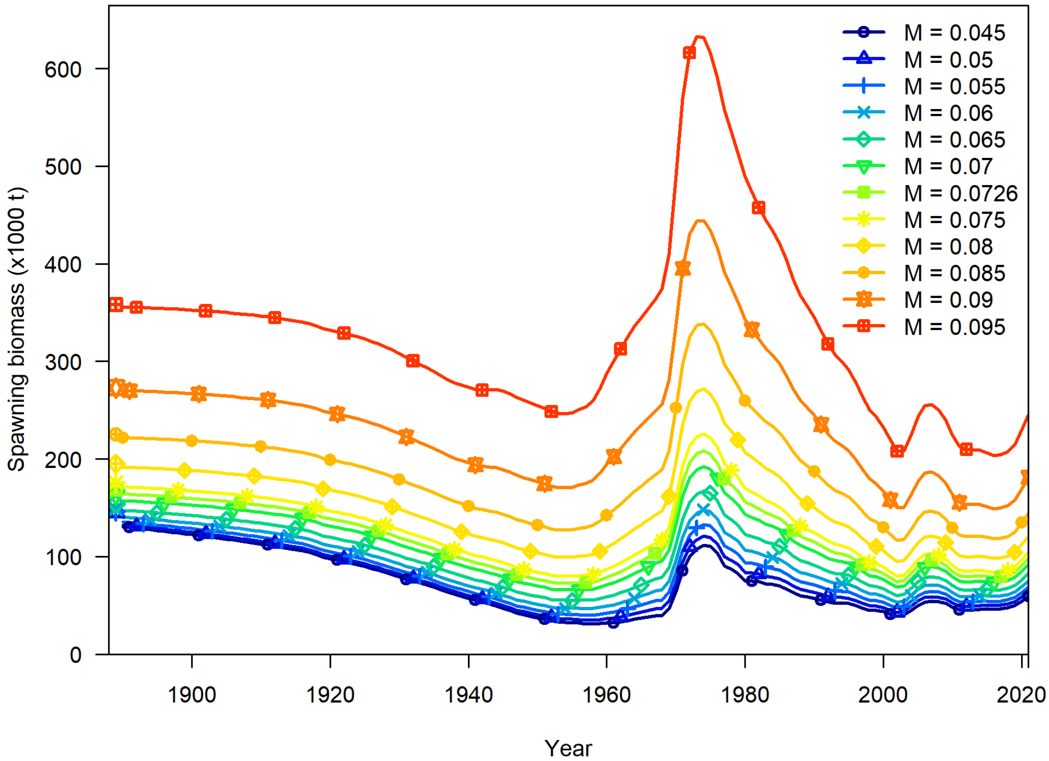


Figure 83: Time-series of spawning stock biomass for different fixed values of female natural mortality(M).

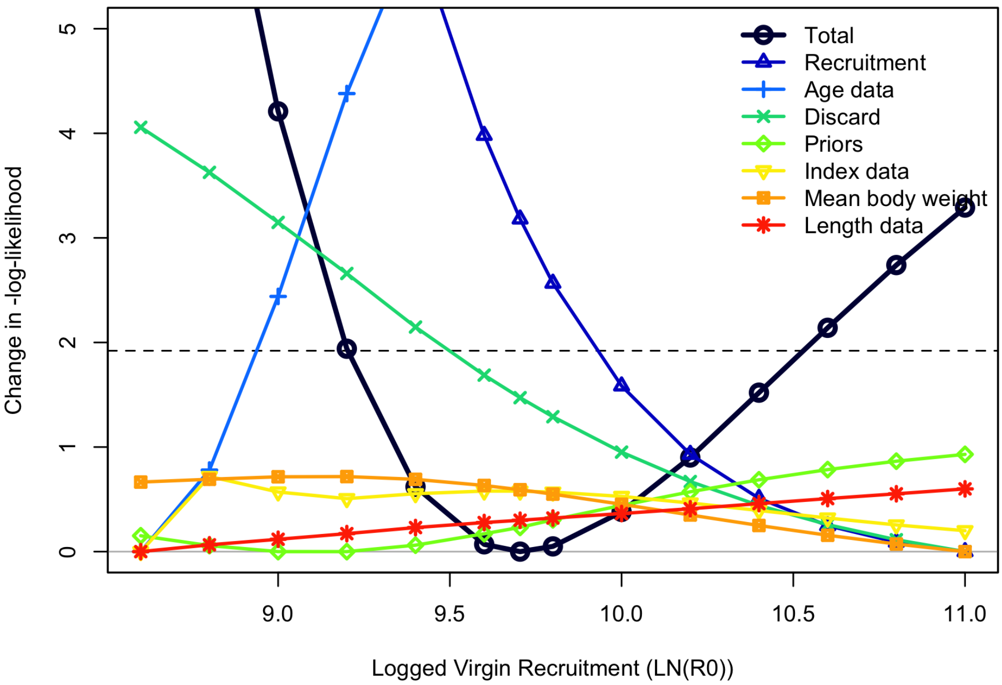


Figure 84: Results of a likelihood profile for equilibrium recruitment (R0) by data type.

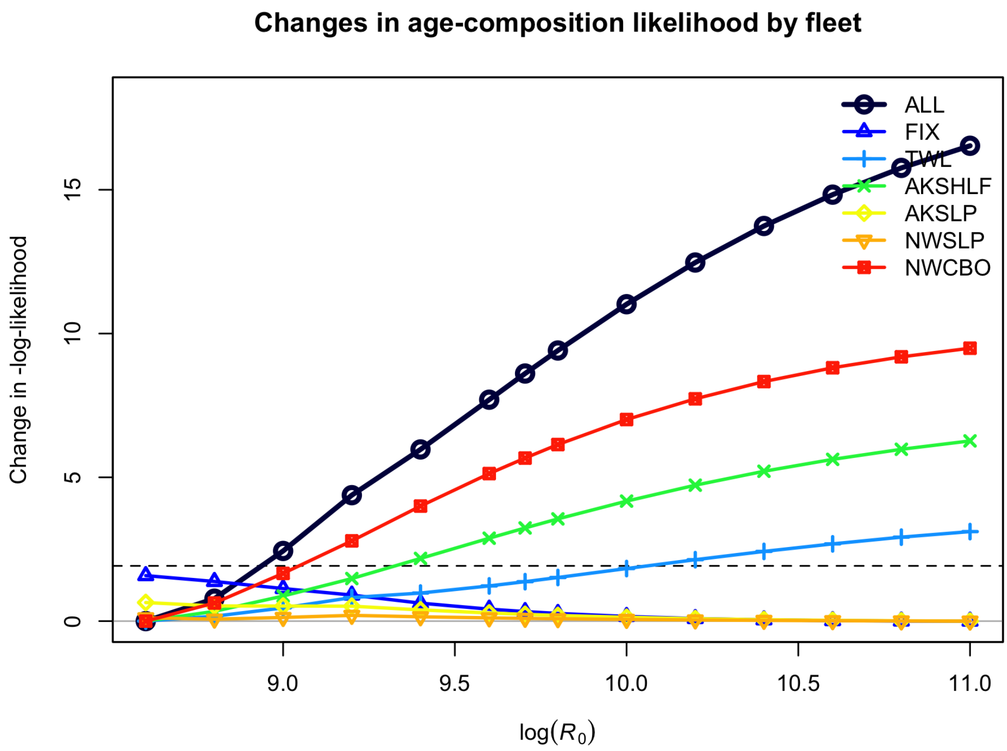


Figure 85: Age likelihoods from a likelihood profile for equilibrium recruitment (R0) by data type.

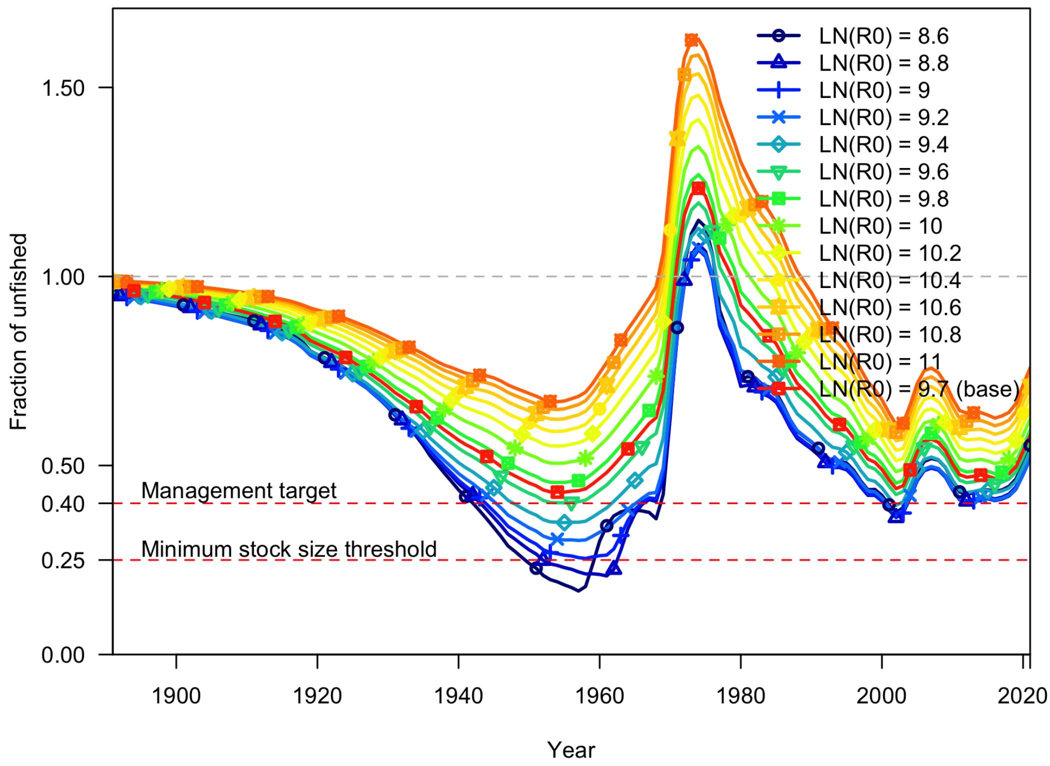


Figure 86: Time-series of relative depletion for different fixed values of equilibrium recruitment (R0).

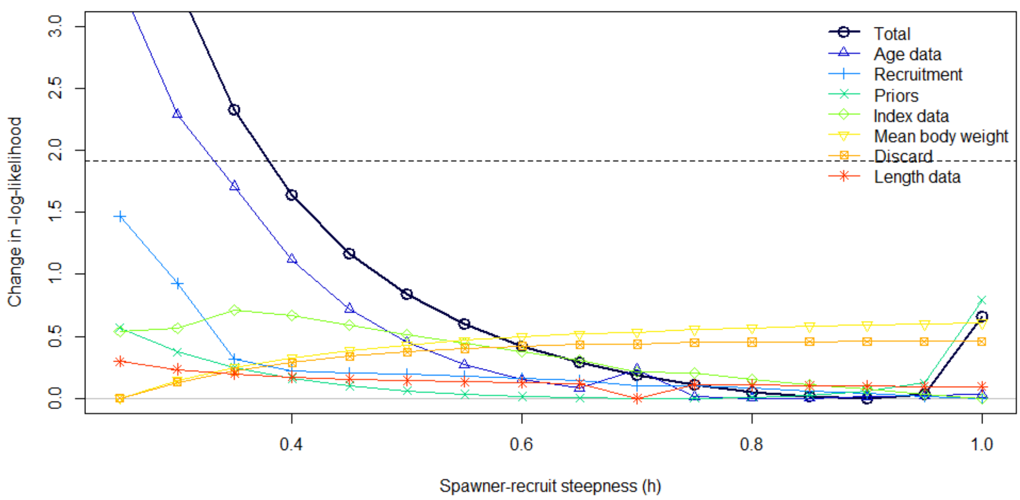


Figure 87: Results of a likelihood profile for steepness (h) by data type.

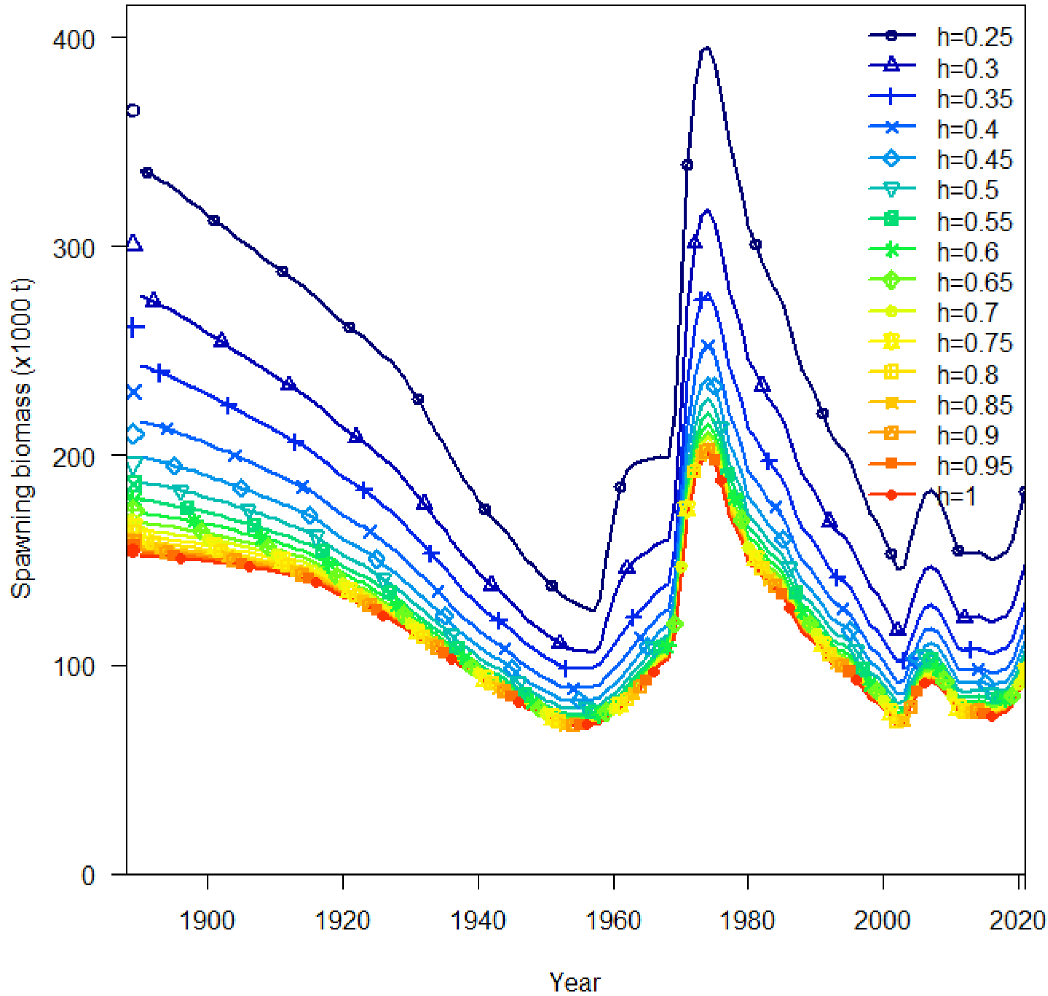


Figure 88: Time-series of spawning stock biomass for different fixed values of steepness (h).

10 Tables

10.1 Executive Summary Tables

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

Year	Fixed-gear	Trawl	Total Landings	Model-Estimated Total Dead Catch
2011	4,420.85	1,728.40	6,149.25	6,253.97
2012	3,670.22	1,514.58	5,184.80	5,283.60
2013	2,585.07	1,402.13	3,987.20	4,050.48
2014	2,924.26	1,292.20	4,216.46	4,294.90
2015	3,554.94	1,470.29	5,025.23	5,105.52
2016	3,829.86	1,475.95	5,305.81	5,401.39
2017	3,680.67	1,669.97	5,350.64	5,465.76
2018	3,648.68	1,478.26	5,126.94	5,220.22
2019	3,568.27	1,625.44	5,193.71	5,372.81
2020	2,660.03	1,102.72	3,762.75	3,882.69

Table 2: Estimated recent trend in spawning biomass, the fraction unfished and the associated 95 percent intervals.

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2011	80,351.5	32,648.1	128,054.9	0.48	0.32	0.63
2012	79,223.0	31,838.5	126,607.5	0.47	0.31	0.63
2013	79,605.1	32,059.9	127,150.3	0.47	0.31	0.63
2014	80,187.9	32,563.5	127,812.3	0.47	0.31	0.64
2015	79,676.1	32,447.4	126,904.8	0.47	0.31	0.63
2016	78,633.2	31,824.6	125,441.8	0.47	0.31	0.62
2017	79,326.7	31,973.0	126,680.6	0.47	0.31	0.63
2018	80,687.2	32,503.6	128,870.8	0.48	0.31	0.64
2019	83,925.1	33,936.0	133,914.2	0.50	0.33	0.67
2020	90,756.5	37,136.0	144,377.0	0.54	0.35	0.72
2021	97,801.9	40,802.4	154,801.4	0.58	0.38	0.77

Table 3: Summary of recent estimates and managment quantities.

Quantity	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
OFL	8,808	8,623	6,621	7,158	7,857	8,526	8,050	8,239	8,489	8,648	9,402
ACL	6,813	6,605	5,451	5,909	6,512	7,121	7,117	7,419	7,750	7,896	8,791
Total Catch	6,149.25	5,184.80	3,987.20	4,216.46	5,025.23	5,305.81	5,350.64	5,126.94	5,193.71	3762.75	
Total Dead	6,253.97	5,283.60	4,050.48	4,294.90	5,105.52	5,401.39	5,465.76	5,220.22	5,372.81	3,882.69	
(1-SPR)/(1-SPR_45%)	0.97	0.75	0.61	0.61	0.71	0.76	0.68	0.66	0.62	0.40	
Exploitation Rate	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.01	
Age 4+ Biomass (mt)	197,753	219,764	210,986	214,890	210,057	200,261	218,814	214,801	220,274	261,038	375,550
Spawning Biomass (mt)	80,352	79,223	79,605	80,188	79,676	78,633	79,327	80,687	83,925	90,757	97,802
Lower Interval	32,648	31,839	32,060	32,564	32,447	31,825	31,973	32,504	33,936	37,136	40,802
Upper Interval	128,055	126,607	127,150	127,812	126,905	125,442	126,681	128,871	133,914	144,377	154,801
Recruits	6,445.91	2,759.31	34,307.6	6,708.58	18,010.90	55,594.50	10,688.70	8,151.38	6,274.11	12,455.30	15,207.70
Lower Interval	4,178.80	1,354.63	26,613.44	4,305.72	12,988.99	42,481.78	6,368.27	3,745.37	536.41	944.73	978.10
Upper Interval	9,942.98	5,620.57	44,226.2	10,452.37	24,974.42	72,754.68	17,940.25	17,740.57	73,384.74	164,209.86	236,453.47
Fraction Unfished	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.48	0.50	0.54	0.58
Lower Interval	0.32	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.33	0.35	0.38
Upper Interval	0.63	0.63	0.63	0.64	0.63	0.62	0.63	0.64	0.67	0.72	0.77

Table 4: Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-SPRTarget=0.45%), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Model-Estimated Total Dead Catch	Rel 1-SPR	Interval	Exploitation Rate	Interval
2011	6,253.97	0.97	0.60–1.34	0.0316	0.0138–0.0494
2012	5,283.60	0.75	0.41–1.09	0.0240	0.0106–0.0375
2013	4,050.48	0.61	0.31–0.92	0.0192	0.0084–0.0300
2014	4,294.90	0.61	0.30–0.92	0.0200	0.0088–0.0311
2015	5,105.52	0.71	0.37–1.05	0.0243	0.0108–0.0379
2016	5,401.39	0.76	0.41–1.10	0.0270	0.0119–0.0421
2017	5,465.76	0.68	0.36–1.01	0.0250	0.0110–0.0389
2018	5,220.22	0.66	0.34–0.98	0.0243	0.0107–0.0379
2019	5,372.81	0.62	0.31–0.92	0.0244	0.0107–0.0381
2020	3,882.69	0.40	0.18–0.63	0.0149	0.0066–0.0231

Table 5: Estimated recent trend in Recruitment and recruitment deviations and the 95 percent intervals.

Year	Recruit-ment	Lower Interval	Upper Interval	Recruit-ment Devia-tions	Lower Interval	Upper Interval
2011	6,445.91	4,178.8	9,942.98	0.0896	-0.3438	0.5231
2012	2,759.31	1,354.63	5,620.57	-0.756	-1.4674	-0.0445
2013	34,307.60	26,613.44	44,226.2	1.7635	1.5095	2.0174
2014	6,708.58	4,305.72	10,452.37	0.13	-0.3134	0.5734
2015	18,010.90	12,988.99	24,974.42	1.1189	0.792	1.4458
2016	55,594.50	42,481.78	72,754.68	2.2487	1.9797	2.5177
2017	10,688.70	6,368.27	17,940.25	0.598	0.0801	1.1158
2018	8,151.38	3,745.37	17,740.57	0.3235	-0.4541	1.1012
2019	6,274.11	536.41	73,384.74	0.054	-2.4053	2.5133
2020	12,455.30	944.73	164,209.86	-0.1864	-2.7654	2.3926
2021	15,207.70	978.10	236,453.47	0	-2.7439	2.7439

Table 6: Recent trend in the overfishing limits (OFL), the annual catch limits (ACLs), the total landings, and model-estimated total dead catch (”total mortality”, mt). Note that the Acceptable Biological Catches (ABCs) and ACLs are equal because the stock is estimated to be above 40% of the unfished spawning biomass, and the PFMC has not seen fit to lower the ACLs for other reasons.

Year	OFL	ACL	Landings	Total Mortality
2011	8,808	6,813	6,149.25	6,253.97
2012	8,623	6,605	5,184.80	5,283.60
2013	6,621	5,451	3,987.20	4,050.48
2014	7,158	5,909	4,216.46	4,294.90
2015	7,857	6,512	5,025.23	5,105.52
2016	8,526	7,121	5,305.81	5,401.39
2017	8,050	7,117	5,350.64	5,465.76
2018	8,239	7,419	5,126.94	5,220.22
2019	8,489	7,750	5,193.71	5,372.81
2020	8,648	7,896	3,762.75	3,882.69
2021	9,402	8,791	-	-
2022	9,005	8,375	-	-

Table 7: Projections of potential OFLs (mt), ABCs (mt), estimated spawning biomass and fraction unfished. The total catches in 2021 and 2022 were set at the PFMC Groundfish Management Team requested values of 7,405 mt for 2021 and 7,055 mt for 2022 which are about 20% lower than the ACL = ABC for those years; see Table 6 for GMT-defined ACLs and OFLs in 2021 and 2022.

Year	Predicted OFL (mt)	*Catches* (2021-22) or ABCs (2023+) (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	-	*7,405.00*	265,655	97,801.9	0.58
2022	-	*7,055.00*	261,481	99,956.5	0.59
2023	11,577.1	10,824.6	253540	99,449.9	0.59
2024	10,669.8	9,922.9	246090	95,943.8	0.57
2025	10,120.6	9,371.7	241976	93,063.3	0.55
2026	9,837.4	9,070.1	238823	90,925.0	0.54
2027	9,742.3	8,933.7	236280	89,290.8	0.53
2028	9,735.2	8,888.3	234037	87,941.5	0.52
2029	9,747.2	8,860.2	231955	86,743.8	0.51
2030	9,746.0	8,810.4	229993	85,644.5	0.51
2031	9,725.9	8,753.3	228162	84,634.2	0.50
2032	9,691.9	8,684.0	226462	83,707.8	0.50

Table 8: Decision table of 12-year projections of spawning stock biomass (SSB) and % unfished (depletion) for alternative states of nature (columns) and management options (rows) beginning in 2021. Low and high states of nature are based on the 2021 SSB $\pm$ 1.15·base model SSB standard deviation and the resulting unfished recruitment was used for the projections. Results are conditioned on the 2021 and 2022 catches, provided by the Pacific Fisheries Management Council Groundfish Management Team (GMT), being achieved exactly. The alternative catch streams are based on the GMT's requested P* values of 0.35 and 0.40. Note that values for the agreed-upon buffer level of P* = 0.45 is presented as the third row of the decision table as it represents the highest exploitation level among the three catch streams. Catches are total dead biomass, i.e., dead discard plus catch.

	Year	Total	Low state (0.25)		Base (0.5)		High state (0.25)	
scenario		catch	SSB	Depletion	SSB	Depletion	SSB	Depletion
P^*=0.35	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	9,412	65,396	0.51	99,450	0.59	134,266	0.64
	2024	8,608	62,150	0.49	96,661	0.57	131,626	0.63
	2025	8,101	59,177	0.46	94,436	0.56	129,680	0.62
	2026	7,796	56,750	0.44	92,909	0.55	128,548	0.62
	2027	7,649	54,732	0.43	91,867	0.54	127,974	0.61
	2028	7,570	52,951	0.41	91,099	0.54	127,714	0.61
	2029	7,504	51,310	0.40	90,483	0.54	127,626	0.61
	2030	7,437	49,770	0.39	89,967	0.53	127,646	0.61
	2031	7,342	48,316	0.38	89,530	0.53	127,742	0.61
	2032	7,247	46,956	0.37	89,175	0.53	127,911	0.61
P^*=0.40	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	10,107	65,396	0.51	99,450	0.59	134,266	0.64
	2024	9,252	61,794	0.48	96,308	0.57	131,273	0.63
	2025	8,722	58,494	0.46	93,761	0.56	129,004	0.62
	2026	8,421	55,765	0.44	91,935	0.54	127,568	0.61
	2027	8,282	53,451	0.42	90,602	0.54	126,699	0.61
	2028	8,218	51,380	0.40	89,546	0.53	126,149	0.60
	2029	8,168	49,449	0.39	88,643	0.52	125,774	0.60
	2030	8,117	47,616	0.37	87,840	0.52	125,509	0.60
	2031	8,039	45,869	0.36	87,117	0.52	125,324	0.60
	2032	7,950	44,214	0.35	86,479	0.51	125,215	0.60
P^*=0.45	2021	7,405	64,916	0.51	97,802	0.58	131,513	0.63
	2022	7,055	66,222	0.52	99,957	0.59	134,550	0.65
	2023	10,825	65,396	0.51	99,450	0.59	134,266	0.64
	2024	9,923	61,426	0.48	95,935	0.57	130,908	0.63
	2025	9,372	57,787	0.45	93,014	0.55	128,302	0.62
	2026	9,070	54,742	0.43	90,821	0.54	126,550	0.61
	2027	8,934	52,126	0.41	89,130	0.53	125,375	0.60
	2028	8,888	49,760	0.39	87,727	0.52	124,528	0.60
	2029	8,860	47,532	0.37	86,483	0.51	123,858	0.59
	2030	8,810	45,402	0.36	85,346	0.51	123,298	0.59
	2031	8,753	43,364	0.34	84,304	0.50	122,829	0.59
	2032	8,684	41,415	0.32	83,351	0.49	122,438	0.59

10.2 Additional Tables

Table 9: Comparison of likelihoods by type across bridged model runs.

Label	2019 benchmark (v3.30.09)	2019 benchmark (v3.30.16), estimate	2019 benchmark (v3.30.16), fix M & 2 Selex Pars
TOTAL_like	3306.51	3306.81	3306.51
Survey_like	-4.99	-4.41	-4.99
Length_comp_like	334.59	334.63	334.59
Age_comp_like	2995.95	2995.88	2995.95
Parm_priors_like	0.45	0.47	0.45

Table 10: Likelihood components by source for the base update assessment model.

Label	Total
TOTAL	3432.67
Catch	0.00
Equil catch	0.00
Survey	-18.74
Discard	-77.89
Mean body wt	-23.40
Length comp	140.35
Age comp	3376.93
Recruitment	35.14
InitEQ Regime	0.00
Forecast Recruitment	0.00
Parm priors	0.28
Parm devs	0.00
Crash Pen	0.00

Table 11: Time-varying retention and selectivity parameters included in the base model based on key events and management history (See Management appendix of Haltuch et al. (2019)).

Fixed-gear retention		Trawl retention		Reason
Start year	End year	Start year	End year	Reason
1942	1946	1942	1946	WWII, full retention
1947	1996	1947	1981	Post-war fishery development
1997	2010	1982	2010	Management trip limits
2011	2018	2011	2018	Catch shares
2019	2020	2019	2020	Influx of smaller fish and higher discarding
Fixed-gear selectivity		Trawl selectivity		Reason
1997	2002	1982	2002	Management trip limits
2003	2010	2003	2010	Rockfish conservation area
2011	2018	2011	2018	Catch shares

Table 12: Stock-recruitment, mortality, growth and catchability parameter estimates with their 95% interval from the base model.

Label	Estimate	Lower 5%	Upper 95%
NatM_p_1_Fem_GP_1	0.0726	0.0568	0.0883
L_at_Amin_Fem_GP_1	25.7200	24.8300	26.6100
L_at_Amax_Fem_GP_1	62.4600	61.2200	63.7000
VonBert_K_Fem_GP_1	0.3433	0.3145	0.3721
CV_young_Fem_GP_1	0.0573	0.0437	0.0708
CV_old_Fem_GP_1	0.1095	0.1017	0.1173
Wtlen_1_Fem_GP_1	0.0000		
Wtlen_2_Fem_GP_1	3.2730		
Mat50%_Fem_GP_1	55.1900		
Mat_slope_Fem_GP_1	-0.4210		
Eggs/kg_inter_Fem_GP_1	1.0000		
Eggs/kg_slope_wt_Fem_GP_1	0.0000		
NatM_p_1_Mal_GP_1	0.0605	0.0496	0.0713
L_at_Amin_Mal_GP_1	26.9300	25.9200	27.9300
L_at_Amax_Mal_GP_1	56.6200	55.9900	57.2500
VonBert_K_Mal_GP_1	0.3713	0.3442	0.3984
CV_young_Mal_GP_1	0.0749	0.0620	0.0878
CV_old_Mal_GP_1	0.0784	0.0730	0.0838
Wtlen_1_Mal_GP_1	0.0000		
Wtlen_2_Mal_GP_1	3.2700		
CohortGrowDev	1.0000		
FracFemale_GP_1	0.5000		
SR_LN(R0)	9.7050	9.1060	10.3000
Q_base_ENV(4)	0.0861	0.0352	0.1371
Q_extraSD_ENV(4)	0.3093	0.1987	0.4200
LnQ_base_AKSHLF(5)	0.3251	-0.2136	0.8638
Q_extraSD_AKSHLF(5)	0.1785	0.0436	0.3134

Table 12: Stock-recruitment, mortality, growth and catchability parameter estimates with their 95% interval from the base model. *(continued)*

Label	Estimate	Lower 5%	Upper 95%
Q_extraSD_AKSLP(6)	0.0362	-0.0384	0.1107
Q_extraSD_NWSLP(7)	0.1623	0.0010	0.3236
LnQ_base_AKSHLF(5)_BLK1repl_1995	-0.0716	-0.6238	0.4805

Table 13: Input sea-surface height index and standard error.

Year	Input SSH Index	Std. Error
1925	-0.69	1.03
1926	-0.01	1.04
1927	-0.86	1.14
1928	-1.29	1.20
1929	-0.10	1.10
1930	0.07	1.04
1931	-0.18	1.12
1932	-1.37	1.28
1933	-0.54	0.92
1934	-0.39	0.80
1935	1.09	0.37
1936	-1.33	0.59
1937	-1.25	0.67
1938	1.44	0.45
1939	1.18	0.44
1940	0.53	0.32
1941	-0.81	0.73
1942	-0.69	0.72
1943	-0.06	0.47
1944	0.00	0.38
1945	0.75	0.51
1946	-0.71	0.52
1947	-0.30	0.47
1948	-2.96	1.14
1949	0.06	0.46
1950	0.33	0.38
1951	-0.09	0.81
1952	0.77	0.39
1953	-0.68	0.47
1954	-0.04	0.43
1955	0.84	0.37
1956	0.22	0.39
1957	0.09	0.55

Table 13: Input sea-surface height index and standard error. *(continued)*

Year	Input SSH Index	Std. Error
1958	-0.96	0.77
1959	0.23	0.47
1960	-1.29	0.64
1961	-0.64	0.52
1962	0.17	0.45
1963	-1.55	0.72
1964	1.46	0.89
1965	0.20	0.32
1966	2.21	0.55
1967	-0.75	0.44
1968	1.06	0.43
1969	-1.76	0.79
1970	1.55	0.69
1971	-0.92	0.47
1972	-0.39	0.37
1973	1.95	0.75
1974	0.07	0.22
1975	1.75	0.67
1976	0.83	0.22
1977	0.93	0.62
1978	0.03	0.28
1979	1.08	0.33
1980	-0.11	0.22
1981	0.54	0.22
1982	0.24	0.26
1983	-0.09	0.91
1984	0.07	0.38
1985	0.84	0.25
1986	0.50	0.19
1987	0.97	0.22
1988	-0.48	0.38
1989	0.19	0.22
1990	0.25	0.16
1991	1.16	0.57
1992	-0.15	0.61
1993	-3.16	1.34
1994	-0.18	0.28
1995	-0.32	0.31
1996	-0.55	0.28
1997	-1.20	0.70
1998	-0.48	0.36
1999	1.29	0.54
2000	-0.25	0.23
2001	1.53	0.54
2002	1.67	0.78

Table 13: Input sea-surface height index and standard error. *(continued)*

Year	Input SSH Index	Std. Error
2003	-0.93	0.38
2004	-0.17	0.21
2005	-1.82	0.67
2006	-0.63	0.47
2007	0.84	0.60
2008	1.53	0.52
2009	0.68	0.27
2010	-0.97	0.38
2011	-0.48	0.30
2012	-1.07	0.50
2013	1.27	0.33
2014	-0.15	0.63
2015	1.07	0.48
2016	0.82	0.21
2017	-1.06	0.68
2018	0.30	0.17
2019	0.40	0.36
2020	-0.17	0.30

Table 14: Estimated selectivity parameters from the base model.

Label	Estimate
Retain-L-infl-FIX(1)	41.00
Retain-L-width-FIX(1)	6.01
Retain-L-asymptote-logit-FIX(1)	10.00
Retain-L-maleoffset-FIX(1)	0.00
Retain-L-infl-TWL(3)	41.00
Retain-L-width-TWL(3)	2.90
Retain-L-asymptote-logit-TWL(3)	10.00
Retain-L-maleoffset-TWL(3)	0.00
Age-DblN-peak-FIX(1)	5.00
Age-DblN-top-logit-FIX(1)	-4.00
Age-DblN-ascend-se-FIX(1)	0.19
Age-DblN-descend-se-FIX(1)	2.84
Age-DblN-start-logit-FIX(1)	-5.00
Age-DblN-end-logit-FIX(1)	-1.50
AgeSel-1MaleDogleg-FIX	0.00
AgeSel-1MaleatZero-FIX	0.06
AgeSel-1MaleatDogleg-FIX	-0.84
AgeSel-1MaleatMaxage-FIX	-1.31
Age-DblN-peak-TWL(3)	1.00

Table 14: Estimated selectivity parameters from the base model. *(continued)*

Label	Estimate
Age-DblN-top-logit-TWL(3)	-4.00
Age-DblN-ascend-se-TWL(3)	-2.40
Age-DblN-descend-se-TWL(3)	-9.00
Age-DblN-start-logit-TWL(3)	-4.03
Age-DblN-end-logit-TWL(3)	-1.60
Age-DblN-peak-AKSHLF(5)	1.00
Age-DblN-top-logit-AKSHLF(5)	-4.00
Age-DblN-ascend-se-AKSHLF(5)	-9.74
Age-DblN-descend-se-AKSHLF(5)	-1.01
Age-DblN-start-logit-AKSHLF(5)	-2.50
Age-DblN-end-logit-AKSHLF(5)	-3.86
AgeSel-5MaleDogleg-AKSHLF	0.00
AgeSel-5MaleatZero-AKSHLF	-0.54
AgeSel-5MaleatDogleg-AKSHLF	-0.17
AgeSel-5MaleatMaxage-AKSHLF	-6.16
Age-DblN-peak-AKSLP(6)	1.47
Age-DblN-top-logit-AKSLP(6)	-4.00
Age-DblN-ascend-se-AKSLP(6)	-4.00
Age-DblN-descend-se-AKSLP(6)	-5.97
Age-DblN-start-logit-AKSLP(6)	-1.34
Age-DblN-end-logit-AKSLP(6)	-0.53
Age-DblN-peak-NWSLP(7)	3.59
Age-DblN-top-logit-NWSLP(7)	-4.00
Age-DblN-ascend-se-NWSLP(7)	1.49
Age-DblN-descend-se-NWSLP(7)	-3.30
Age-DblN-start-logit-NWSLP(7)	-4.57
Age-DblN-end-logit-NWSLP(7)	0.19
Age-DblN-peak-NWCBO(8)	0.09
Age-DblN-top-logit-NWCBO(8)	-4.00
Age-DblN-ascend-se-NWCBO(8)	-8.45
Age-DblN-descend-se-NWCBO(8)	3.48
Age-DblN-start-logit-NWCBO(8)	-4.00
Age-DblN-end-logit-NWCBO(8)	-0.32
Retain-L-infl-FIX(1)-BLK2repl-1942	25.00
Retain-L-infl-FIX(1)-BLK2repl-1947	38.96
Retain-L-infl-FIX(1)-BLK2repl-1997	40.35
Retain-L-infl-FIX(1)-BLK2repl-2011	41.37
Retain-L-infl-FIX(1)-BLK2repl-2019	35.92
Retain-L-asymptote-logit-FIX(1)-BLK2repl-1942	10.00
Retain-L-asymptote-logit-FIX(1)-BLK2repl-1947	10.00
Retain-L-asymptote-logit-FIX(1)-BLK2repl-1997	2.54
Retain-L-asymptote-logit-FIX(1)-BLK2repl-2011	4.01
Retain-L-asymptote-logit-FIX(1)-BLK2repl-2019	2.14
Retain-L-infl-TWL(3)-BLK3repl-1942	25.00
Retain-L-infl-TWL(3)-BLK3repl-1947	45.93
Retain-L-infl-TWL(3)-BLK3repl-1982	47.75

Table 14: Estimated selectivity parameters from the base model. *(continued)*

Label	Estimate
Retain-L-infl-TWL(3)-BLK3repl-2011	33.75
Retain-L-infl-TWL(3)-BLK3repl-2019	42.27
Retain-L-asymptote-logit-TWL(3)-BLK3repl-1942	10.00
Retain-L-asymptote-logit-TWL(3)-BLK3repl-1947	10.00
Retain-L-asymptote-logit-TWL(3)-BLK3repl-1982	3.74
Retain-L-asymptote-logit-TWL(3)-BLK3repl-2011	10.00
Retain-L-asymptote-logit-TWL(3)-BLK3repl-2019	5.33
Age-DblN-peak-FIX(1)-BLK4repl-1997	3.15
Age-DblN-peak-FIX(1)-BLK4repl-2003	5.04
Age-DblN-peak-FIX(1)-BLK4repl-2011	3.06
Age-DblN-ascend-se-FIX(1)-BLK4repl-1997	-1.24
Age-DblN-ascend-se-FIX(1)-BLK4repl-2003	1.85
Age-DblN-ascend-se-FIX(1)-BLK4repl-2011	-8.68
Age-DblN-descend-se-TWL(3)-BLK5repl-1982	2.06
Age-DblN-descend-se-TWL(3)-BLK5repl-2003	6.60
Age-DblN-descend-se-TWL(3)-BLK5repl-2011	9.18
Age-DblN-descend-se-AKSHLF(5)-BLK6repl-1995	3.17

Table 15: Comparison of Francis weights between the 2019 benchmark and 2021 update base model.

Label	2019 Weights	2021 Update Weights
len FIX	NA (not in model)	0.095328
len TWL	NA (not in model)	0.044144
len NWCBO	0.291349	0.032931
age FIX	1	0.101402
age TWL	1	0.193659
age AKSHLF	0.103912	1
age AKSLP	0.316743	0.109196
age NWSLP	0.440877	0.12705
age NWCBO	0.246557	0.286539

Table 16: Comparison of likelihoods and parameter estimates between the 2021 update base model, which was iteratively weighted using the Francis method, and the same model using the 2019 benchmark weights.

Label	Base	Base with 2019 Weights
Total Likelihood	3432.67	7064.72
Survey Likelihood	-18.7403	-23.9026
Length comp Likelihood	140.351	1409.14
Age comp Likelihood	3376.93	5549.82
Parm priors Likelihood	0.282114	0.260356
NatM p 1 Fem GP 1	0.0725861	0.0716219
L at Amin Fem GP 1	25.7207	27.2095
L at Amax Fem GP 1	62.4569	62.2122
VonBert K Fem GP 1	0.343282	0.353679
CV young Fem GP 1	0.0572535	0.0687359
CV old Fem GP 1	0.109531	0.102166
NatM p 1 Mal GP 1	0.060472	0.0604435
L at Amin Mal GP 1	26.926	26.2399
L at Amax Mal GP 1	56.6228	55.9886
VonBert K Mal GP 1	0.371287	0.43448
CV young Mal GP 1	0.0749235	0.0959105
CV old Mal GP 1	0.0783725	0.0775673
SR LN(R0)	9.70454	9.43696
SPRratio 2019	0.61702	0.663576
SPRratio 2021	0.765683	0.653669
F 2019	0.0243915	0.0272988
F 2021	0.0330918	0.0261667
Bratio 2019	0.496966	0.617103
Bratio 2021	0.579137	0.683158
SSB Virgin thousand mt	168.875	131.097
Totbio unfished	419070	321441
SmryBio unfished	393647	300404
Recr Virgin millions	16.3918	12.5435
SSB Btgt thousand mt	67.55	52.439
SPR Btgt	0.464286	0.464286
SSB MSY thousand mt	41.702	32.153
SPR MSY	0.327623	0.326123
Retain L infl FIX(1) BLK2repl 2019	35.9209	45.5014
Retain L asymptote logit FIX(1) BLK2repl 2019	2.13517	3.65292
Retain L asymptote logit TWL(3) BLK3repl 2019	5.32676	9.99992
annF Btgt	0.0431076	0.0446488
annF MSY	0.0700526	0.0731536

Table 17: Landings (mt) by fleet for all years, total landings (mt), and and model-estimated total dead catch ('total dead', mt) summed by year.

Year	Fixed-gear	Trawl	Total Landings	Total Dead
1890	2.12	0.00	2.12	2.14
1891	6.08	0.00	6.08	6.16
1892	6.75	0.00	6.75	6.84
1893	10.05	0.00	10.05	10.18
1894	12.25	0.00	12.25	12.41
1895	16.65	0.00	16.65	16.87
1896	18.68	0.00	18.68	18.92
1897	20.70	0.00	20.70	20.97
1898	22.73	0.00	22.73	23.03
1899	24.75	0.00	24.75	25.08
1900	49.89	0.00	49.89	50.55
1901	76.30	1.37	77.67	78.76
1902	102.71	2.75	105.46	106.98
1903	129.12	4.13	133.25	135.19
1904	155.53	5.51	161.04	163.41
1905	138.10	6.88	144.98	147.20
1906	135.20	8.26	143.46	145.72
1907	142.00	9.64	151.64	154.06
1908	85.79	11.02	96.81	98.56
1909	141.05	12.37	153.42	155.97
1910	196.32	13.71	210.03	213.39
1911	251.58	15.06	266.64	270.80
1912	306.84	16.41	323.25	328.21
1913	362.10	17.76	379.86	385.62
1914	417.36	19.11	436.47	443.03
1915	472.48	20.12	492.60	499.93
1916	1287.88	26.32	1314.20	1332.62
1917	1694.92	286.38	1981.31	2019.33
1918	2683.77	157.05	2840.82	2884.82
1919	919.08	105.43	1024.51	1042.42
1920	627.01	245.84	872.85	894.55
1921	846.41	321.89	1168.30	1196.99
1922	711.23	84.53	795.76	809.73
1923	1259.02	169.43	1428.45	1454.23
1924	1534.96	293.77	1828.73	1864.84
1925	1869.37	227.41	2096.78	2133.67
1926	1639.23	55.29	1694.52	1718.98
1927	2205.99	312.45	2518.44	2563.45
1928	1820.93	288.62	2109.55	2148.15
1929	1814.85	468.39	2283.24	2330.49
1930	2096.51	445.83	2542.34	2592.41
1931	1066.82	330.36	1397.18	1428.12
1932	1345.15	303.32	1648.46	1681.62
1933	1094.08	428.73	1522.81	1558.89
1934	1958.01	681.41	2639.42	2699.73
1935	2481.48	901.51	3382.99	3461.88
1936	2015.35	336.95	2352.30	2397.82
1937	2296.59	231.52	2528.11	2570.53
1938	2217.14	257.96	2475.10	2517.45
1939	2448.23	295.40	2743.63	2793.34
1940	1878.04	301.44	2179.48	2222.78
1941	1652.36	487.74	2140.09	2190.67
1942	2293.38	935.37	3228.75	3232.16

Table 17: Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt) summed by year. *(continued)*

Year	Fixed-gear	Trawl	Total Landings	Total Dead
1943	1838.17	2084.58	3922.75	3926.95
1944	1485.58	2998.92	4484.50	4489.45
1945	1690.96	2726.11	4417.07	4422.03
1946	2782.52	1672.34	4454.86	4459.84
1947	1716.51	516.31	2232.82	2315.08
1948	1886.90	945.65	2832.55	2972.18
1949	1986.53	983.06	2969.59	3115.87
1950	1623.74	1016.48	2640.22	2793.47
1951	2253.00	2011.83	4264.83	4577.88
1952	1477.81	1163.16	2640.97	2830.29
1953	965.21	691.62	1656.83	1779.62
1954	1323.34	997.10	2320.44	2495.70
1955	1289.13	898.32	2187.45	2347.03
1956	970.89	2434.90	3405.79	3893.23
1957	1599.31	951.73	2551.04	2764.61
1958	764.11	768.06	1532.16	1694.82
1959	1234.49	984.39	2218.88	2424.23
1960	1675.39	1191.87	2867.26	3140.20
1961	1055.49	756.02	1811.51	1977.31
1962	1010.21	1616.57	2626.78	2938.96
1963	948.97	869.38	1818.36	2006.92
1964	1008.75	1037.79	2046.54	2254.89
1965	909.90	1023.56	1933.46	2142.02
1966	740.20	1132.49	1872.69	2106.05
1967	2459.77	1819.11	4278.88	5700.44
1968	1421.13	1313.86	2734.99	3359.94
1969	3410.91	2067.98	5478.89	5925.45
1970	1765.93	2839.89	4605.82	4982.18
1971	1407.28	2479.75	3887.03	4170.52
1972	3082.13	3538.53	6620.66	6991.06
1973	1396.59	4275.50	5672.09	6068.19
1974	5122.47	3478.06	8600.53	8995.28
1975	10333.70	3966.03	14299.73	14811.57
1976	20506.80	3888.01	24394.81	25045.64
1977	5243.54	3497.85	8741.39	9370.43
1978	7708.79	4532.11	12240.90	13006.32
1979	16772.00	7116.30	23888.30	24879.21
1980	4537.32	4506.94	9044.26	10058.19
1981	5855.33	5437.39	11292.72	12432.86
1982	8247.92	10117.70	18365.62	20442.89
1983	7112.16	7280.22	14392.38	15680.69
1984	5363.84	8215.94	13579.78	14734.11
1985	6611.02	7141.24	13752.26	14914.46
1986	6311.73	6456.36	12768.09	14104.25
1987	5871.70	6454.05	12325.75	13716.47
1988	5062.31	5446.62	10508.93	11456.30
1989	4410.42	5667.45	10077.87	11015.77
1990	3780.55	5108.30	8888.85	9759.06
1991	4319.25	4932.10	9251.35	10392.76
1992	3868.54	5311.01	9179.55	10281.74
1993	3147.79	4808.73	7956.52	8730.70
1994	3708.95	3759.34	7468.29	7968.20
1995	4011.64	3795.59	7807.23	8318.36

Table 17: Landings (mt) by fleet for all years, total landings (mt), and total mortality (mt) summed by year. *(continued)*

Year	Fixed-gear	Trawl	Total Landings	Total Dead
1996	4080.78	4131.29	8212.07	9042.94
1997	4121.76	3734.32	7856.08	8673.40
1998	2175.02	2142.96	4317.98	4673.20
1999	3408.12	3117.12	6525.24	6974.06
2000	3505.46	2615.74	6121.20	6697.35
2001	3012.75	2563.61	5576.36	6871.87
2002	2190.07	1556.61	3746.68	4513.93
2003	3010.56	2213.78	5224.34	5703.88
2004	3278.36	2410.93	5689.29	6092.07
2005	3599.66	2396.47	5996.13	6337.75
2006	3380.39	2536.10	5916.49	6210.87
2007	2621.13	2486.01	5107.14	5341.24
2008	2796.21	2890.67	5686.88	5928.94
2009	3889.01	3061.45	6950.46	7367.34
2010	4054.53	2539.32	6593.85	7003.45
2011	4420.85	1728.40	6149.25	6253.97
2012	3670.22	1514.58	5184.80	5283.60
2013	2585.07	1402.13	3987.20	4050.48
2014	2924.26	1292.20	4216.46	4294.90
2015	3554.94	1470.29	5025.23	5105.52
2016	3829.86	1475.95	5305.81	5401.39
2017	3680.67	1669.97	5350.64	5465.76
2018	3648.68	1478.26	5126.94	5220.22
2019	3568.27	1625.44	5193.71	5372.81
2020	2660.03	1102.72	3762.75	3882.69

Table 18: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR 45%)	Exploitation Rate
1890	405749	163972.0	382012	0.97	15122.00	2.14	0.00	0.00
1891	404869	163640.0	381233	0.97	15055.50	6.16	0.00	0.00
1892	403935	163290.0	380417	0.97	14986.20	6.84	0.00	0.00
1893	402950	162923.0	379566	0.96	14914.00	10.18	0.00	0.00
1894	401911	162533.0	378633	0.96	14838.90	12.41	0.00	0.00
1895	400820	162119.0	377653	0.96	14760.70	16.87	0.00	0.00
1896	399677	161680.0	376625	0.96	14679.30	18.92	0.00	0.00
1897	398483	161219.0	375550	0.95	14594.40	20.97	0.00	0.00
1898	397237	160738.0	374430	0.95	14505.90	23.03	0.00	0.00
1899	395939	160235.0	373262	0.95	14413.60	25.08	0.00	0.00
1900	394588	159711.0	372045	0.95	14317.30	50.55	0.01	0.00
1901	393158	159152.0	370757	0.94	14217.10	78.76	0.01	0.00
1902	391645	158555.0	369392	0.94	14113.00	106.98	0.01	0.00
1903	390049	157920.0	367949	0.94	14005.40	135.19	0.02	0.00
1904	388368	157248.0	366428	0.93	13894.50	163.41	0.02	0.00
1905	386602	156537.0	364827	0.93	13780.00	147.20	0.02	0.00
1906	384792	155813.0	363189	0.92	13661.90	145.72	0.02	0.00

Table 18: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR 45%)	Exploitation Rate
1907	382924	155069.0	361497	0.92	13539.60	154.06	0.02	0.00
1908	380986	154296.0	359740	0.91	13413.60	98.56	0.01	0.00
1909	379037	153534.0	357980	0.91	13285.00	155.97	0.02	0.00
1910	376966	152712.0	356102	0.90	13154.50	213.39	0.03	0.00
1911	374772	151831.0	354106	0.90	13022.60	270.80	0.03	0.00
1912	372457	150890.0	351993	0.89	12887.00	328.21	0.04	0.00
1913	370023	149890.0	349764	0.89	12745.10	385.62	0.05	0.00
1914	367472	148831.0	347423	0.88	12595.60	443.03	0.06	0.00
1915	364804	147715.0	344973	0.87	12442.90	499.93	0.06	0.00
1916	362021	146545.0	342416	0.87	12291.80	1332.62	0.17	0.00
1917	358368	144861.0	338999	0.86	12132.20	2019.33	0.24	0.01
1918	354001	142821.0	334914	0.85	11972.90	2884.82	0.34	0.01
1919	348777	140221.0	329931	0.83	11807.30	1042.42	0.14	0.00
1920	345374	138705.0	326759	0.82	11644.10	894.55	0.12	0.00
1921	342093	137334.0	323747	0.81	11479.00	1196.99	0.16	0.00
1922	338474	135808.0	320406	0.80	11317.70	809.73	0.11	0.00
1923	335206	134441.0	317359	0.80	11152.40	1454.23	0.19	0.00
1924	331274	132710.0	313676	0.79	10980.10	1864.84	0.25	0.01
1925	326912	130764.0	309597	0.77	9775.53	2133.67	0.28	0.01
1926	322007	128637.0	305222	0.76	9913.06	1718.98	0.24	0.01
1927	317324	126714.0	301233	0.75	9490.01	2563.45	0.34	0.01
1928	311579	124330.0	296474	0.74	9250.06	2148.15	0.30	0.01
1929	306056	122070.0	291145	0.72	9450.82	2330.49	0.33	0.01
1930	300310	119643.0	285821	0.71	9365.17	2592.41	0.37	0.01
1931	294348	116972.0	279971	0.69	9151.94	1428.12	0.22	0.01
1932	289605	114916.0	275158	0.68	8771.19	1681.62	0.26	0.01
1933	284630	112733.0	270447	0.67	8755.94	1558.89	0.24	0.01
1934	279822	110717.0	266021	0.66	8658.74	2699.73	0.41	0.01
1935	273950	108134.0	260520	0.64	10284.20	3461.88	0.51	0.01
1936	267870	105171.0	254136	0.62	7799.76	2397.82	0.39	0.01
1937	262816	102708.0	248888	0.61	7874.64	2570.53	0.43	0.01
1938	257597	100260.0	243652	0.59	10039.40	2517.45	0.42	0.01
1939	252975	98068.9	240312	0.58	9666.47	2793.34	0.47	0.01
1940	248579	95759.2	234837	0.57	9075.17	2222.78	0.39	0.01
1941	245103	93820.3	230069	0.56	7995.19	2190.67	0.38	0.01
1942	241652	92209.0	227525	0.55	8079.23	3232.16	0.54	0.01
1943	237063	90368.4	224049	0.54	8369.40	3926.95	0.63	0.02
1944	231729	88490.8	219698	0.52	8436.82	4489.45	0.70	0.02
1945	225805	86382.8	213876	0.51	9173.28	4422.03	0.71	0.02
1946	220201	84072.2	207920	0.50	8036.47	4459.84	0.73	0.02
1947	214666	81397.8	202028	0.48	8430.11	2315.08	0.44	0.01
1948	211623	79776.1	198523	0.47	8133.39	2972.18	0.54	0.01
1949	208171	78138.8	195683	0.46	9241.07	3115.87	0.57	0.02
1950	205059	76595.5	192187	0.45	10081.00	2793.47	0.52	0.01
1951	202939	75366.8	189512	0.45	9833.75	4577.88	0.75	0.02
1952	199603	73531.2	185189	0.44	12292.90	2830.29	0.52	0.02
1953	199096	72658.0	183489	0.43	9740.28	1779.62	0.35	0.01
1954	199998	72562.4	183775	0.43	11544.70	2495.70	0.46	0.01
1955	200861	72539.4	183660	0.43	17909.70	2347.03	0.43	0.01
1956	204001	72962.9	186119	0.43	14912.80	3893.23	0.60	0.02
1957	206785	73214.9	185470	0.43	15735.10	2764.61	0.47	0.01
1958	211813	74003.2	186954	0.44	14423.00	1694.82	0.29	0.01

Table 18: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR 45%)	Exploitation Rate
1959	218398	76205.1	195332	0.45	21143.40	2424.23	0.39	0.01
1960	226149	78746.6	201417	0.47	14240.00	3140.20	0.46	0.02
1961	233028	81279.2	207679	0.48	15711.80	1977.31	0.29	0.01
1962	241012	84605.0	213725	0.50	21605.50	2938.96	0.39	0.01
1963	249214	88139.9	224918	0.52	13503.50	2006.92	0.28	0.01
1964	257333	91854.2	230920	0.54	22161.90	2254.89	0.29	0.01
1965	266341	95449.0	237401	0.57	15609.70	2142.02	0.27	0.01
1966	274829	99285.2	249075	0.59	220342.00	2106.05	0.26	0.01
1967	335666	103099.0	253644	0.61	10773.30	5700.44	0.48	0.02
1968	390908	105801.0	262983	0.63	15509.40	3359.94	0.27	0.01
1969	442934	117917.0	268474	0.70	10284.10	5925.45	0.44	0.02
1970	478308	146379.0	459427	0.87	14552.60	4982.18	0.38	0.01
1971	500821	176229.0	480207	1.04	10793.70	4170.52	0.28	0.01
1972	511625	196299.0	493717	1.16	11886.90	6991.06	0.42	0.01
1973	510472	205308.0	491151	1.22	18010.40	6068.19	0.41	0.01
1974	505429	208275.0	486834	1.23	14144.00	8995.28	0.51	0.02
1975	494039	204892.0	472486	1.21	20931.80	14811.57	0.76	0.03
1976	476917	195746.0	451149	1.16	34095.80	25045.64	1.13	0.06
1977	454316	179811.0	424521	1.06	13566.60	9370.43	0.66	0.02
1978	446967	173568.0	410828	1.03	8843.33	13006.32	0.88	0.03
1979	433933	166961.0	400110	0.99	58709.10	24879.21	1.33	0.06
1980	419557	155984.0	390342	0.92	10638.40	10058.19	0.80	0.03
1981	418078	152668.0	379433	0.90	19929.80	12432.86	0.89	0.03
1982	414289	149051.0	362284	0.88	12137.20	20442.89	1.20	0.06
1983	399415	144988.0	378975	0.86	4137.94	15680.69	1.04	0.04
1984	384154	142381.0	363082	0.84	25175.50	14734.11	1.00	0.04
1985	370974	138846.0	353853	0.82	23427.50	14914.46	1.05	0.04
1986	359298	133034.0	337711	0.79	15929.10	14104.25	1.06	0.04
1987	348846	126423.0	315440	0.75	3419.76	13716.47	1.07	0.04
1988	335756	121081.0	310605	0.72	18219.90	11456.30	0.99	0.04
1989	325473	117897.0	307837	0.70	11615.70	11015.77	0.96	0.04
1990	314813	114731.0	300195	0.68	33468.50	9759.06	0.91	0.03
1991	310687	110981.0	283270	0.66	1399.02	10392.76	0.97	0.04
1992	303048	106863.0	277625	0.63	7433.31	10281.74	0.98	0.04
1993	293824	103876.0	267656	0.62	3850.08	8730.70	0.89	0.03
1994	283168	102757.0	277423	0.61	9836.95	7968.20	0.86	0.03
1995	272436	100679.0	262596	0.60	24339.50	8318.36	0.91	0.03
1996	265014	96752.6	250938	0.57	704.37	9042.94	1.01	0.04
1997	254933	91619.2	235548	0.54	541.30	8673.40	1.07	0.04
1998	243067	87304.8	225432	0.52	5894.78	4673.20	0.70	0.02
1999	234111	85897.0	231783	0.51	21514.70	6974.06	0.97	0.03
2000	226417	82606.6	217407	0.49	69677.30	6697.35	1.01	0.03
2001	235580	78017.1	202295	0.46	17570.60	6871.87	0.99	0.03
2002	247510	74104.0	192151	0.44	10865.10	4513.93	0.69	0.02
2003	260995	75410.6	198234	0.45	2277.30	5703.88	0.73	0.03
2004	267813	82490.0	248499	0.49	7243.73	6092.07	0.67	0.02
2005	269384	90497.0	258167	0.54	499.96	6337.75	0.66	0.02
2006	264799	95212.3	259196	0.56	2107.05	6210.87	0.64	0.02
2007	256132	96184.2	249884	0.57	768.18	5341.24	0.58	0.02
2008	245042	94814.0	243353	0.56	41725.60	5928.94	0.66	0.02
2009	241872	91041.9	229030	0.54	2029.67	7367.34	0.82	0.03
2010	236498	85111.8	213797	0.50	16187.40	7003.45	0.87	0.03

Table 18: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Biomass (mt)	Total Biomass 4+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	(1-SPR)/(1-SPR 45%)	Exploitation Rate
2011	234090	80351.5	197753	0.48	6445.91	6253.97	0.97	0.03
2012	231379	79223.0	219764	0.47	2759.31	5283.60	0.75	0.02
2013	227296	79605.1	210986	0.47	34307.60	4050.48	0.61	0.02
2014	230136	80187.9	214890	0.47	6708.58	4294.90	0.61	0.02
2015	231760	79676.1	210057	0.47	18010.90	5105.52	0.71	0.02
2016	234433	78633.2	200261	0.47	55594.50	5401.39	0.76	0.03
2017	247736	79326.7	218814	0.47	10688.70	5465.76	0.68	0.02
2018	260117	80687.2	214801	0.48	8151.38	5220.22	0.66	0.02
2019	270037	83925.1	220274	0.50	6274.11	5372.81	0.62	0.02
2020	275029	90756.5	261038	0.54	12455.30	3882.69	0.40	0.01
2021	278378	97801.9	265655	0.58	15207.70	7405.00	0.68	0.03
2022	276698	99956.5	261481	0.59	15264.20	7055.00	0.68	0.03
2023	274881	99449.9	253540	0.59	15251.10	10824.59	0.96	0.04
2024	269477	95943.8	246090	0.57	15157.40	9922.92	0.96	0.04
2025	265341	93063.3	241976	0.55	15076.00	9371.67	0.95	0.04
2026	262107	90925.0	238823	0.54	15012.80	9070.10	0.95	0.04
2027	259435	89290.8	236280	0.53	14962.90	8933.73	0.95	0.04
2028	257087	87941.5	234037	0.52	14920.60	8888.28	0.95	0.04
2029	254921	86743.8	231955	0.51	14882.10	8860.17	0.94	0.04
2030	252891	85644.5	229993	0.51	14846.00	8810.38	0.94	0.04
2031	251001	84634.2	228162	0.50	14812.20	8753.33	0.94	0.04
2032	249245	83707.8	226462	0.50	14780.60	8683.96	0.93	0.04

11 Appendix: Auxiliary files

Auxiliary Stock Synthesis Files, including starter, forecast, data and control, are available at https://www.pcouncil.org/groundfish/stock-assessments/by-species/sablefish/