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

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Executive Summary

Stock

This 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 continental U.S., Canada, and Alaska and across the Aleutian Islands to the western Pacific. Their movement is not explicitly accounted for in this analysis.

Landings

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 U.S. 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 landings inputs remain unchanged due to changes in fixed and estimated parameter values, priors, or parameterizations. Model estimates of fishery discards 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 been divided approximately 67%/33% between fixed and trawl gears, respectively, during the most recent decade. 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, thus 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	Total Dead
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

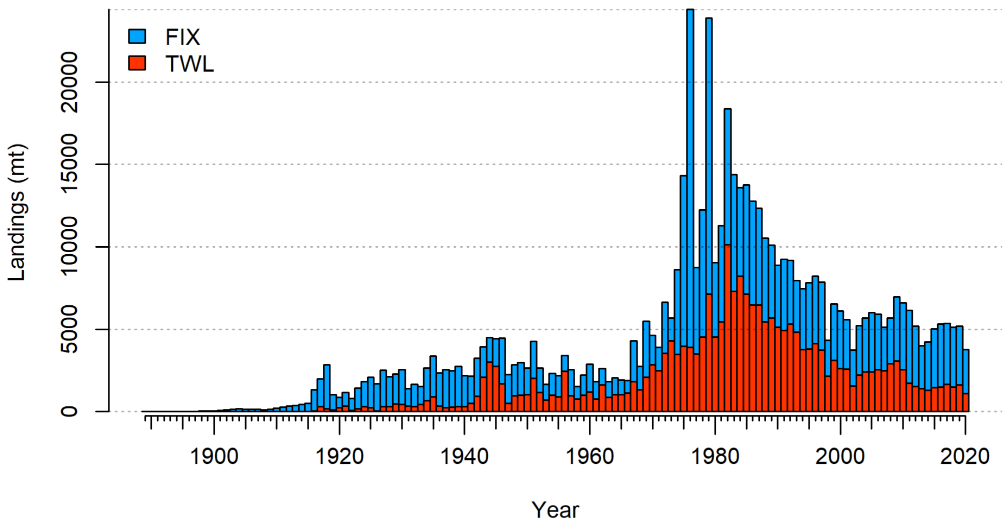


Figure i: Sablefish landings from 1890–2020 summarized by the gear types included in the base model, fixed-gear and trawl. Landings include those from foreign fleets, which are largely responsible for the peaks in 1976 and 1979.

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 to include the most recent data, covering the period 2003-2019 (Figure 4); the updated index was consistent with the previous (Figures 5 and 6). 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 with the latest tide gauge data (Figures 7 and 8).

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 addition of new data for this update assessment, modelers identified a large influx of younger, small fish observable in the age compositions of commercially landed catch, which was also visible in the discard length compositions of those commercial fleets (Figure 9). This latter dataset was not used in the 2019 benchmark, nor were any commercial length compositions, due to conflicts between the age and length data. Absent the data or flexibility to account for increased discarding, a model which conformed to the Terms of Reference for an update assessment was unable to satisfactorily fit to the composition data from the two commercial fleets (Figures 10 and 11) nor the WCGBTS survey (Figure 12), and greatly overestimated the 2019 index (Figure 13). We rectify this issue 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 14-17).

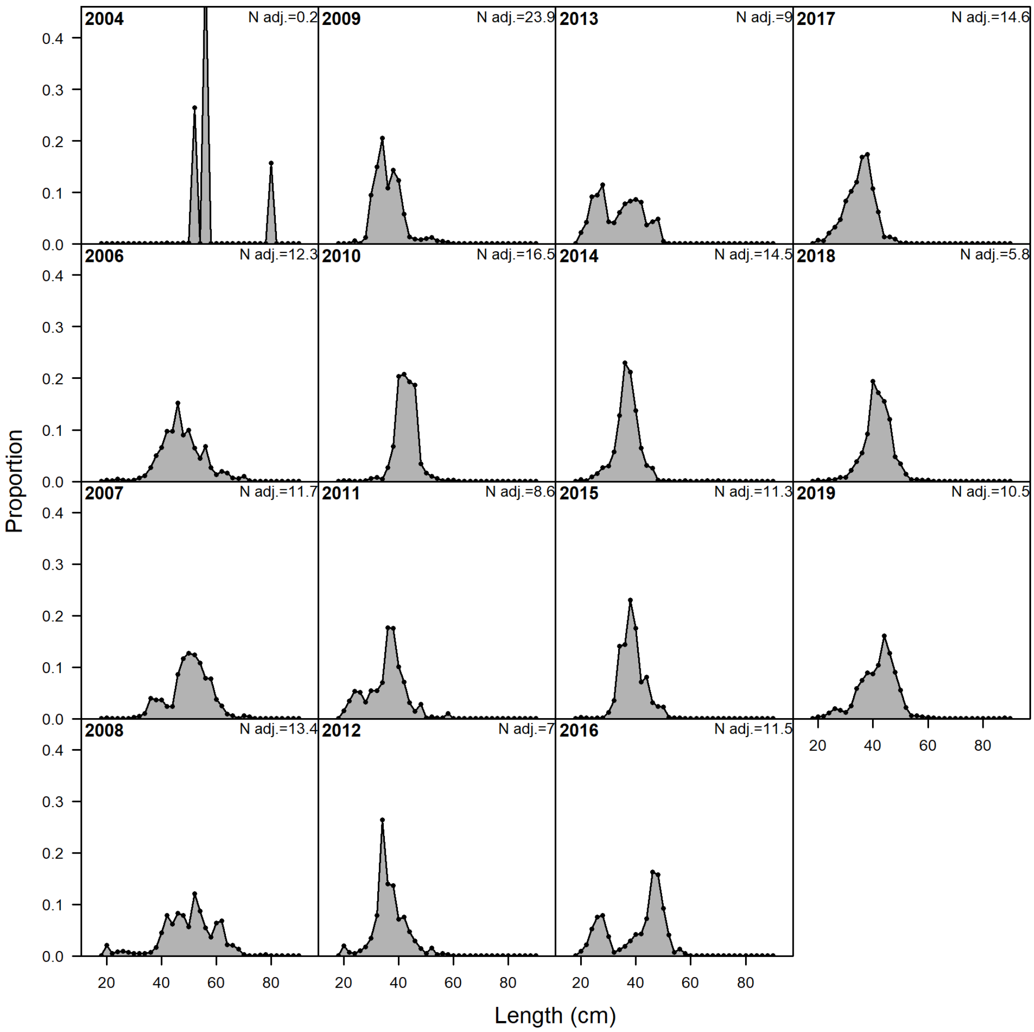


Figure ii: Recent length compositions (2004-2019) of discarded sablefish from the trawl gear fishery, aggregated across sexes.

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, this analysis uses 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

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 1940s to 1970s. Subsequently, biomass is estimated to have declined between the mid-1970s and the early 2010s, with the largest peaks in harvests during the 1970s followed by harvests that were, on average, higher than pre-1970s harvest through the 2000s. At the same time, there were a higher frequency of generally lower than average recruitments from the 1980s forward. Despite estimates of harvest rates that were largely below overfishing rates from the 1990s forward and a few high recruitments from the 1980s forward, the spawning biomass has only recently begun to increase. This stock assessment does suggest spawner per recruitment rates higher than the target during some years from the 1990s 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 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 107,748 mt to 230,002 mt. The point estimate of 2021 spawning biomass from the base model is 97,802, 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	80351.5	32648.13	128054.9	0.48	0.32	0.63
2012	79223.0	31838.52	126607.5	0.47	0.31	0.63
2013	79605.1	32059.90	127150.3	0.47	0.31	0.63
2014	80187.9	32563.52	127812.3	0.47	0.31	0.64

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

Year	Spawning Biomass (mt)	Lower Interval	Upper Interval	Fraction Unfished	Lower Interval	Upper Interval
2015	79676.1	32447.44	126904.8	0.47	0.31	0.63
2016	78633.2	31824.56	125441.8	0.47	0.31	0.62
2017	79326.7	31972.79	126680.6	0.47	0.31	0.63
2018	80687.2	32503.64	128870.8	0.48	0.31	0.64
2019	83925.1	33936.02	133914.2	0.50	0.33	0.67
2020	90756.5	37136	144377.0	0.54	0.35	0.72
2021	97801.9	40802.42	154801.4	0.58	0.38	0.77

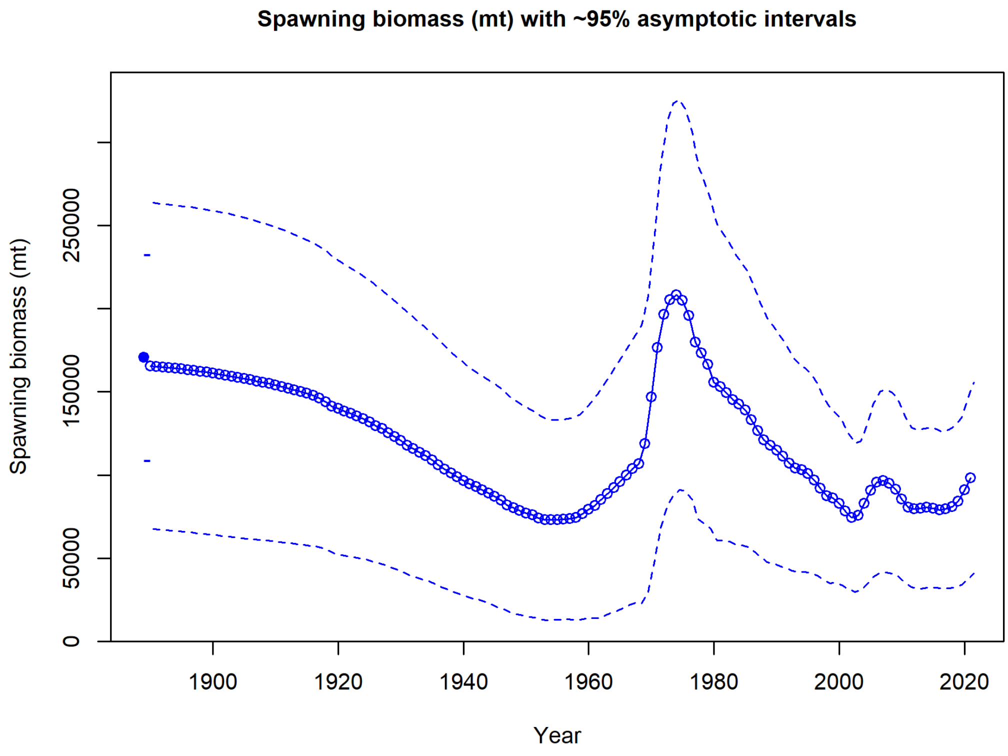
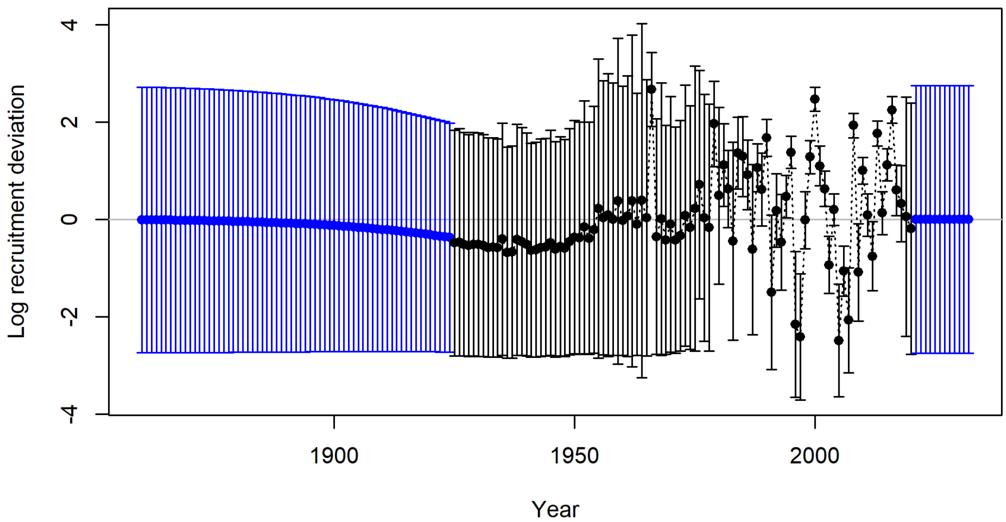


Figure iii: Time series of estimated sablefish spawning biomass (mt) from the base model (circles) with 95% intervals (dashedlines).

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. The period with a higher frequency of high recruitments contributed to a large increase in stock biomass that has 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 a slightly increasing spawning stock size.



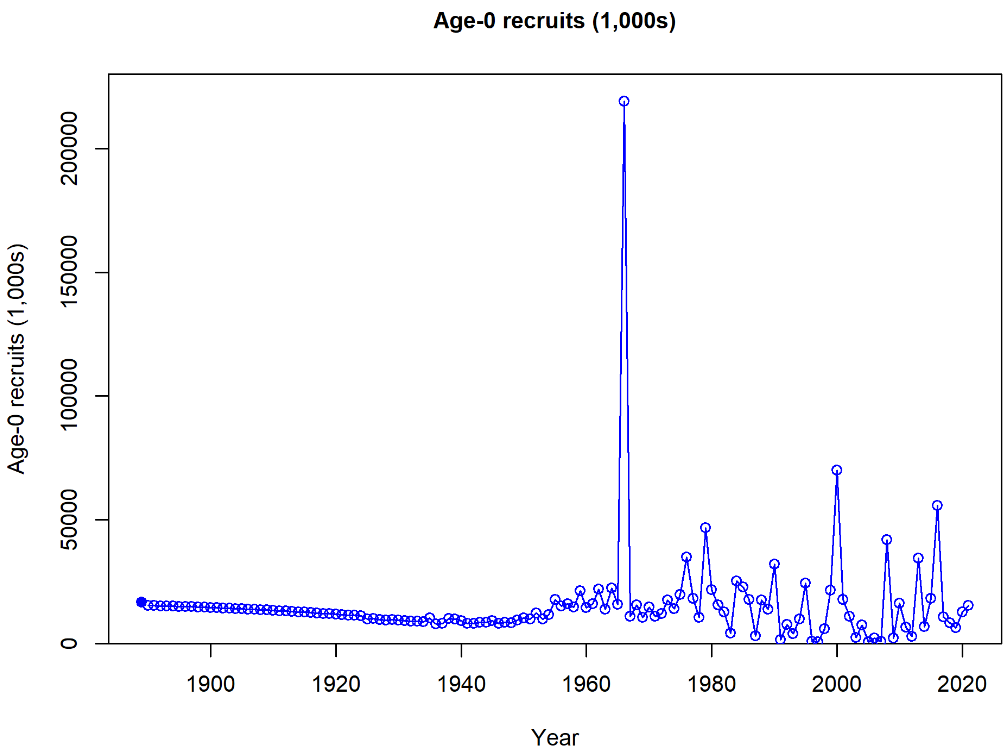


Figure iv: Time series of estimated recruitment deviations from the base model (solid line) with 95% intervals (vertical lines; upper panel) and recruitment without intervals (lower-panel).

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 (0.25) (Figures 20 and 21). The estimate of the stock's current 2021 level of depletion was 0.579.

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

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Biomass (mt)	168875	107749	230001
Unfished Age 4+ Biomass (mt)	393647	242084	545209
Unfished Recruitment (R0)	16392	6585	26197
Spawning Biomass (mt) (2021)	97802	40801	154802
Fraction Unfished (2021)	0.58	0.38	0.77
Proxy Spawning Biomass (mt) SB40 Percent	67550	43099	92001
SPR Resulting in SB40 Percent	0.464286		
Exploitation Rate Resulting in SB40 Percent	0.043	0.04	0.05
Yield with SPR Based On SB40 Percent (mt)	8209	3857	12562
Proxy Spawning Biomass (mt) (SPR45)	64848	41376	8832
Exploitation Rate Corresponding to SPR45	0.045	0.04	0.05
Yield with SPR45 at SB SPR (mt)	8350	3924	12776
Spawning Biomass (mt) at MSY (SB MSY)	41701	26527	56876
SPR MSY	0.327	0.32	0.33
Exploitation Rate Corresponding to SPR MSY	0.07	0.06	0.08
MSY (mt)	9024	4242	13806

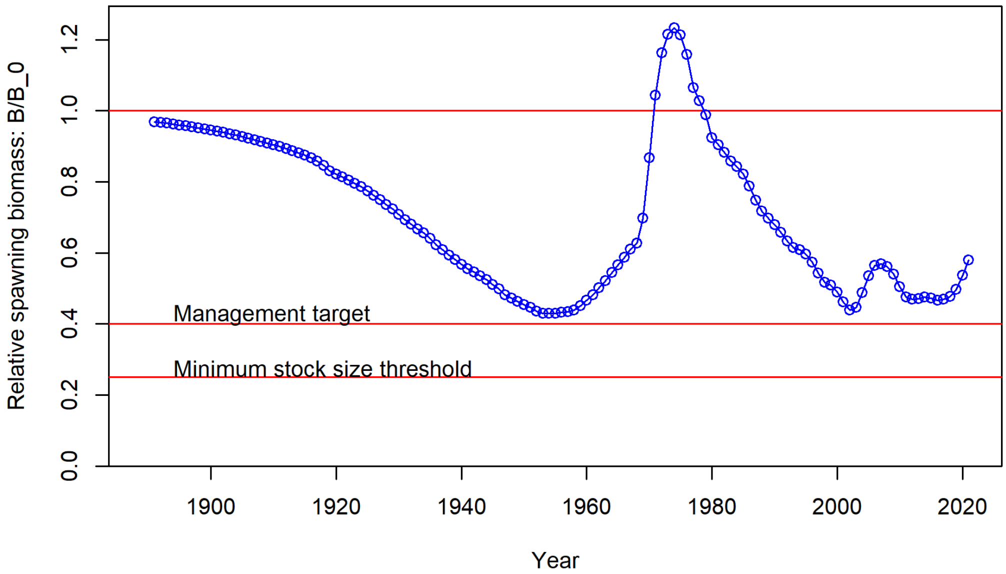


Figure v: Time series of estimated depletion (i.e., spawning biomass relative to unfished spawning biomass) from the base model (circles) with 95% intervals (dashed lines).

Exploitation Status

Equilibrium yield at the fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 9,024 mt (4,242-13,807, 95% interval). 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 22 and 23). The spawner potential ratio (SPR) exceeded the fishing mortality target or overfishing level ($SPR_{45\%}$) that stabilizes the stock at the target (i.e., $(1 - SPR)/[1 - SPR_{45\%}]$) during the late 2000s and early 2010s, and was between 62 and 76% from 2015-2019, descending to 40% in 2020. In Table 4, the column 'Rel. 1-SPR' shows values and associated uncertainty for $(1 - SPR)/[1 - SPR_{45\%}]$.

Table iv: 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	Total Catch	Rel 1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2011	6149.25	0.97	0.60	1.34	0.03	0.01	0.05
2012	5184.8	0.75	0.41	1.09	0.02	0.01	0.04
2013	3987.2	0.61	0.31	0.92	0.02	0.01	0.03
2014	4216.46	0.61	0.30	0.92	0.02	0.01	0.03
2015	5025.23	0.71	0.37	1.05	0.02	0.01	0.04
2016	5305.81	0.76	0.41	1.10	0.03	0.01	0.04
2017	5350.64	0.68	0.36	1.01	0.02	0.01	0.04
2018	5126.94	0.66	0.34	0.98	0.02	0.01	0.04
2019	5193.71	0.62	0.31	0.92	0.02	0.01	0.04
2020	3762.75	0.40	0.18	0.63	0.01	0.01	0.02

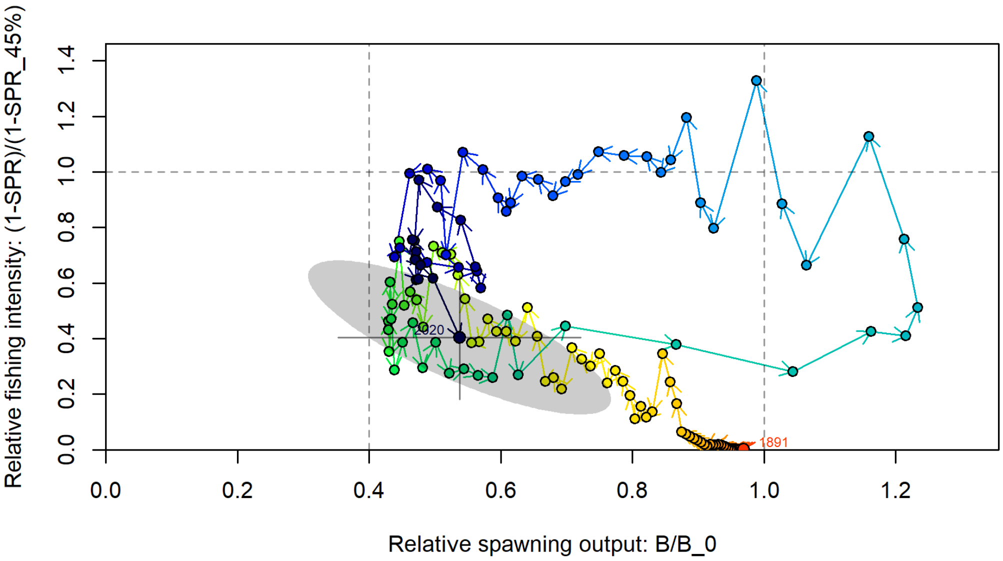


Figure vi: Estimated relative spawning potential ratio $(1 - SPR/1 - SPR_{Target=0.45\%})$ vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The ~~filled,~~ dark blue circle indicates the last year of available data, 2020.

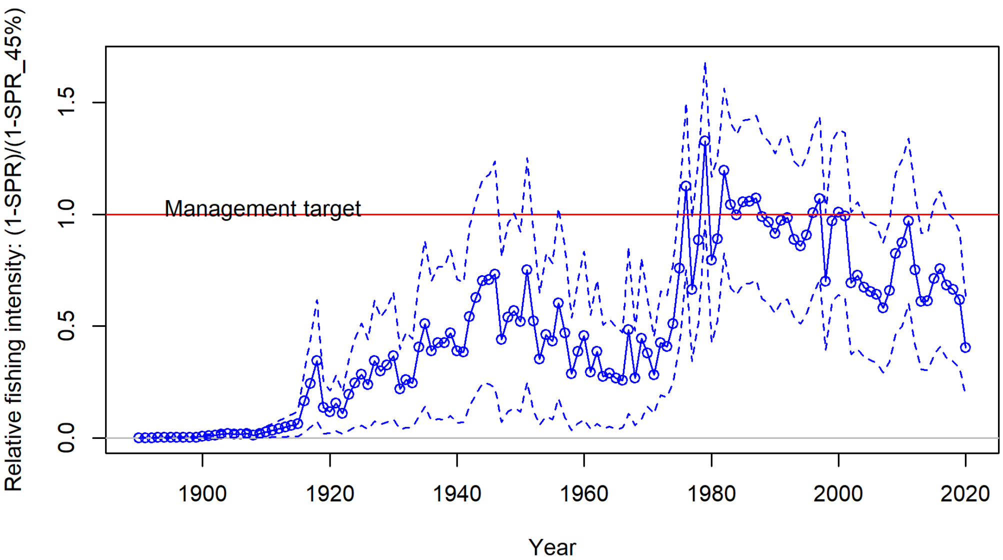


Figure vii: Time series of estimated relative spawning potential ratio (1-SPR/1-SPRTarget=0.45%) from the base model (points) with 95% intervals (dashed lines). Values above 1.0 (red, horizontal line) reflect harvests in excess of the current overfishing proxy.

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 ~~from sablefish stock assessment~~ 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 ~~(previously termed ABCs)~~ and 65% of the annual catch limits ~~(previously termed OYs)~~.

Table v: Recent trend in the overfishing limits (OFL), the annual catch limits (ACLs), the total landings, and 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.

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 scale 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. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in ~~many~~ 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 typically overlapped among the investigated models. The uncertainty will remain until a more informative time-series, better quality demographic and biological information are accumulated, or a range-wide analysis is completed for sablefish.

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 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 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 demographic component of the stock, but it does not survey the entire stock as sablefish reside in waters deeper than 1280 m, the survey limit, and to the north. 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.

Harvest Projections

Previous sablefish stock assessments have been designated as Category 1 stock assessments. ~~Thus,~~ projections and decision tables are based on P^*=0.45 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. ~~The multipliers are combined with the 40-10 harvest control rule to calculate overfishing limits, acceptable biological catches, and annual catch limits.~~ The total catches in 2021 and 2022 were set at the Pacific Fisheries Management Council Groundfish Management Team requested values, below th~~at~~ Pacific Fisheries Management Council annual catch limits for sablefish. The average ratio between GMT-specified 2~~,~~021-2~~,~~022 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%. Estimates of unexploited spawning biomass ~~are~~ 13% higher than that estimated in 2019 and 19% lower than the 2011 estimate. Percent of unfished biomass in 2021 was estimated at 0.58, while the 2019 benchmark assessment forecasted it to be 0.46.

Table vi: 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 ~~and are therefore~~ lower than the ACL ~~or~~ ABC for those years~~. Similarly, the predicted OFLs presented here for 2021 and 2022 are not the same as those used by the GMT to define fixed catches in 2021-2022~~; see Table 6 for GMT-defined ACLs and OFLs in 2021 and 2022.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	13117.00	7405.00	265655	97801.9	0.58
2022	12515.20	7055.00	261481	99956.5	0.59
2023	11577.10	10824.60	253540	99449.9	0.59
2024	10669.80	9922.92	246090	95943.8	0.57
2025	10120.60	9371.67	241976	93063.3	0.55
2026	9837.41	9070.09	238823	90925.0	0.54
2027	9742.34	8933.73	236280	89290.8	0.53
2028	9735.24	8888.27	234037	87941.5	0.52
2029	9747.17	8860.17	231955	86743.8	0.51
2030	9746.00	8810.38	229993	85644.5	0.51
2031	9725.92	8753.33	228162	84634.2	0.50
2032	9691.91	8683.95	226462	83707.8	0.50

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 ~~middle~~ row of the decision table ~~to be consistent with the central panel being the base case run at the agreed-upon buffer level~~. 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 ~~thir~~d 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~~ using the Category 1 P* = 0.45 catch stream~~. The decision table suggests that all catch scenarios ~~under both the base and high~~ state of nature result in ~~in~~creases in stock size~~ such that~~ the stock remains ~~either at or~~ above the target stock size at the end of the projection period. However, all catch scenarios under the low state of nature~~ result in declines in stock size throughout the projection period,~~ driv~~ing~~ the stock into the precautionary zone ~~in all low-state catch scenarios by year~~ 20~~29~~.

Table vii: 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 middle row of the decision table to be consistent with the central panel being the base case run at the agreed-upon buffer level. Catches are total dead biomass, i.e., dead discard plus catch.

Year	Catch	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*=0.45	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
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

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 because of time constraints resulting from the federal government furlough, 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 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.)). 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 California Current. 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 cohabitation 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.

1.3 Ecosystem Considerations

A detailed summary of 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.

GIANCARLO: SALMON SURVEY TEXT?

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 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 24). 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 25 and 26). 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 ~~increasing~~ 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 shorted to May 15 through June 3. In 1995, the open season lasted one week, from August 3 to August 13. The open season spanned only six days in 1996, from September 1 to September 6. In 1997, nine 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 3 below.

1.6 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).

1.6.1 AFSC 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 ~~seen as~~ complete surveys are included in assessments.

1.6.2 California Collaborative Fisheries Research Program

Since 2007, the California Collaborative Fisheries Research Program (CCFRP) has monitored several areas in California to evaluate the performance of Marine Protected Area (MPA)s and understand nearshore fish populations (Wendt and Starr 2009; Starr et al. 2015). In 2017, the survey expanded beyond the four MPAs in central California (Año Nuevo, Point Lobos, Point Buchon, and Piedras Blancas) to include the entire California coast. Fish are collected by volunteer anglers aboard Commercial passenger fishing vessel (CPFV)s guided by one of the following academic institutions based on proximity to fishing location: Humboldt State University; Bodega Marine Laboratories; Moss Landing Marine Laboratories; Cal Poly San Luis Obispo; University of California, Santa Barbara; and Scripps Institution of Oceanography.

Surveys consist of fishing with hook-and-line gear for 30-45 minutes within randomly chosen 500 by 500 m grid cells within and outside MPAs. Prior to 2017, all fish were measured for length and release or descended to depth; since then, some were sampled for otoliths and fin clips.

1.6.3 AFSC/NWFSC West Coast 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.

1.6.4 NWFSC West Coast Groundfish Bottom Trawl Survey

The NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) is based on a random-grid design; covering the coastal waters from a depth of 55-1,280 m (Bradburn, Keller, and Horness 2011). This design generally uses four industry-chartered vessels per year assigned to a roughly equal number of randomly selected grid cells and divided into two 'passes' of the coast. Two vessels fish from north to south during each pass between late May to early October. This design therefore incorporates both vessel-to-vessel differences in catchability, as well as variance associated with selecting a relatively small number (approximately 700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian borders.

2 Assessment Model

2.1 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 27). 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 WCGBTS survey (Figures 10, 11, and 12), greatly overestimated the 2019 index, and distorted the recruitment patterns to suggest two large recruitment events since 2016 (Figure 13). During the addition of new data for this update assessment, modelers identified a large influx of younger, small fish observable in the age compositions of commercially landed catch, which was also visible in the discard length compositions of those commercial fleets (Figure 9). This latter dataset was not used in the benchmark, nor were any commercial length compositions, due to conflicts between the age and length data. We rectify ~~this issue~~ 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 (Figure 17). 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 ~~is~~ sex-specific with growth curves for males and females but ~~only~~ tracks 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. 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).

Ages 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 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. ~~Although,~~ sex-specific M and selectivity can result in significant departures from equality due to differential M over age and sex. Model files including the SS executable, data, control, starter, and forecast files are archived with the Pacific Fisheries Management Council.

2.1.1 Priors

Uniform (non-informative) priors were applied to all estimated parameters in the base model with the ~~following~~ exceptions~~: (a)~~ male and female M ~~and (b)~~ h. 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. ~~Like~~ 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 under-estimates 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.

2.1.2 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.

For comparison, re-weighting using the Harmonic Mean method was applied to the length and age compositions (Figure 28). Input sample sizes were based on the number of port-side samples, the number of observed trips, or the number of tows. Input sample sizes were multiplied by either a constant or an estimated parameter specific to each combination of data type (i.e., age or length) and fleet/survey. Multipliers enabled the mean input sample size to roughly equal the effective sample size based on model fit.

Variance estimates from the standardization of abundance information from the trawl surveys can be reasonably considered minimum estimates at best. Thus, an additive constant was freely estimated for each survey. Estimating additional variance components speeds the process of iterative re-weighting among data sources and propagates the uncertainty about the true survey index variance into the model results.

2.1.3 Estimated and fixed parameters

A total of 313 parameters were specified in the base model and 235 of them were estimated (Tables 12 and 13). 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. 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, 1~~,~~890. 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.

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 a value that fit the data. 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 (∼<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).

Parameters and time periods that indicated little change over time upon initial evaluation were not included in the base model. 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 ~~main~~ 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~~, then t~~his inflection parameter was 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 most recent time period was assumed in the trawl fishery due to the requirement of full catch accounting with the implementation of the catch shares program. Peak fishery selectivity and the ascending limb of selectivity was 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 P4 of the Triennial Shelf Survey from 1995 forward to allow for changes in survey design. Discarded mortality was assumed to be 100% for age-0 (less than 28 cm) sablefish and decline rapidly to 20% for the fixed-gear fleet and 50% for the trawl fleet (for 29 cm and above, while splitting the difference at 28 cm). These values are consistent with those used by the Pacific Fisheries Management Council for management purposes.

2.2 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 (1) be as objective as possible and (2) 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 U.S. California Current, and (4) the use of a time- and age-invariant (but sex-specific) M.

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 in the California Current do not exist independently of the population that occurs in British Columbia 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.

2.3 Base Model Results

2.4 Convergence status

LEE QI HELP UPDATE 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 same (i.e., difference in likelihood of less than or equal to 0.5) or worse likelihood was found for trials, respectively. The trial with a lower negative log likelihood was unstable. Thus, 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 29). M for females (0.07) and males (0.06) were similar to values estimated in previous assessments (2011: 0.08 and 0.065 respectively; 2015: 0.076 and 0.062, 2019: 0.06 and 0.06, respectively; Figure 30).

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 13; Figure 31).

The fixed gear fisheries showed males were less selected than females, individuals of approximately age 20 and older were much less available to the fishery on a relative basis (Figure 33). The trawl fishery selected younger fish than the fixed gear fleet and showed little difference between males and females (Figure 33). Retention schedules (Table 13) 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 32). 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 34).

The base model fit the trend (decline, then stabilization, and increase) in the WCGBT Survey well (Figure 35), 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 36), 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 37). Estimates of added variance were 0.16 and 0.04, respectively (Table 13). 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 38), 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 39). 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 12 and 42) 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 43-46). The slope survey fits to the marginal-age distributions also showed no glaring residual patterns in the age data (Figures 48- 50). The selection of younger sablefish was evident for the Triennial Shelf Survey, with a larger residuals from 1995 forward (Figure 52).

Fits to the marginal age compositions for the fisheries were good (Figure 47). All fisheries show relatively small residuals, with patterns of large cohorts moving through the population at some point (Figures 48 and 49). 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 53 and 54).

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 55). This stock assessment was able to estimate cohort strengths further back in time due to the increased plus group, extended to 50 years. 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 18), 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 56).

Catches were estimated from the beginning of the time series (Table 16). 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 90,756 mt; however, the $ 95 $95% interval: 35% to 72%. Estimates indicate that the spawning biomass was near the target (Figure 19). The estimated time-series of total, age-4+ (Figure 58), and spawning biomass (Figure 59) track one another closely (Table 17).

2.5 Data weighting

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~~. Estimated variances for the surveys were within reasonable ranges~~, except for the WCGBT Survey, for which the estimated added variance 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 14). 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

28). ~~The model weighted using the Harmonic method was 350 likelihood points worse than that using the Francis method.~~

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 fixed 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 14) . In addition, the WCGBTS 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 28 and Table 15).

The value of the parameter controlling recruitment variability was determined in 2019 using an iterative procedure with the aim of ensuring that the value of 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.

2.6 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.

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 2.5 on Data Weighting).
2. Use of the 2019 Francis data weights in lieu of the tuned Francis weights (described above in Section 2.5 on Data Weighting).

3. Inclusion of the At-Sea Hake Observer Program data (landings and length compositions).
4. Inclusion of the commercially landed length compositions for the fixed-gear and trawl fleets.

We also explored various parameter phasings, which had little impact on the base model.

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Adding information about sablefish abundance gained from the Pacific hake (*Merluccius productus*) fishery did not lead to significant changes relative to the base model. In the post-STAR model adding a hake bycatch fleet resulted in a lower estimate of unfished spawning biomass. This difference is likely due to the removal of all other length composition data except for the WCGBTS data and, in this sensitivity run, the hake discard length compositions. Young (i.e., age-0) fish are caught in this mid-water trawl fishery as bycatch and it was hypothesized that including sablefish lengths sampled by the hake fishery would be informative about recruitment. However, the time series does not appear to be long enough relative to the modeled period to be informative and the ongoing WCGBT Survey samples age-0 sablefish.

2.7 Retrospective analysis

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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 60 and 61). The retrospective pattern in stock status is largely driven by some of the largest recruitments observed for sablefish during 2013 and 2016 (Figure 62).

2.8 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 65). 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 retrospective runs which truncate the series to 2019 or ~~prior~~ are within the narrower uncertainty bounds from the 2019 benchmark, while the increasing perception of the stock is consistent across all models which include the new data and timeblocking structure (Figures 63 and 64).

2.9 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.

GIANCARLO Female M (male mortality is 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 surveys 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 66). However, this is not a trivial parameter range and the assessment results vary considerably among these values in absolute scale (Figure 68).

LEE QI Unexploited equilibrium recruitment (R_0) was found to be insignificantly different over 9.2-10.2, values which led to a broad range of stock sizes (Figures 69-70). 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 71).

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 no support in the data over a broad range of explored values (Figure 72). Most of the values included in the profile led to similar trajectories of spawning biomass (Figure 73).

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.

3 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 (0.25) (Figures 20 and 21). The estimate of the stock's current 2021 level of depletion was 0.579.

Equilibrium yield at the fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 9,024 mt (4,242-13,807, ~95% interval). 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 22 and 23). The spawner potential ratio (SPR) exceeded the fishing mortality target or overfishing level ($SPR_{45\%}$) that stabilizes the stock at the target (i.e., $(1 - SPR)/[1 - SPR_{45\%}]$) during the late 2000s and early 2010s, and was between 62 and 76% from 2015-2019, descending to 40% in 2020. In Table 4, the column 'Rel. 1-SPR' shows values and associated uncertainty for $(1 - SPR)/[1 - SPR_{45\%}]$.

The phase plot shows the interaction of fishing intensity and biomass targets (Figure 21).

4 Harvest projections and decision tables

Previous sablefish stock assessments have been designated as Category 1 stock assessments. Thus, projections and decision tables are based on P^*=0.4 and the values of sigma 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 sigmas provide the multipliers on the overfishing limit, these values are all less than 1. The multipliers are combined with the 40-10 harvest control rule to calculate overfishing limits, acceptable biological catches, and annual catch limits. The total catches in 2019 and 2020 were set at the Pacific Fisheries Management Council Groundfish Management Team requested values, just below that Pacific Fisheries Management Council annual catch limits for sablefish. The average 2~~,~~017-2~~,~~020 catches were used to distribute catches among the fisheries. All forecasts of catches are of total dead biomass, i.e., dead discard plus catch.

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%. Estimates of unexploited spawning biomass are 13%higher than that estimated in 2019 and 19% lower than the 2011 estimate. Percent of unfished biomass in 2021 was estimated at 0.58, while the 2019 benchmark assessment forecasted it to be 0.46.

5 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.

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7 References

Bradburn, M. J., A. A. Keller, and B. H. Horness. 2011. "The 2003 to 2008 U.S. West Coast Bottom Trawl Surveys of Groundfish Resources Off Washington, Oregon, and California: Estimates of Distribution, Abundance, Length, and Age Composition." NMFS-NWFSC-114. Seattle, WA: U.S. Department of Commerce.

Browning, R. J. 1980. "Fisheries of the North Pacific: History, Species, Gear, & Processes." Anchorage, AK: Alaska Northwest Publishing Company.

Echave, K. B., D. H. Hanselman, M. D. Adkison, and M. F. Sigler. 2012. "Interdecadal Change in Growth of Sablefish (*Anoplopoma Fimbria*) in the Northeast Pacific Ocean." *Fisheries Bulletin* 210: 361–74.

Eschmeyer, W. N., and E. S. Herald. 1983. *A Field Guide to Pacific Coast Fishes of North America*. Boston, MA: Houghton Mifflin Co.

Francis, R. I. C. C. 2011. "Data Weighting in Statistical Fisheries Stock Assessment Models." *Canadian Journal of Fisheries and Aquatic Sciences* 68 (6): 1124–38.

Fujioka, J. T., F. R. Shaw, G. A. McFarlane, T. Sasaki, and B. E. Bracken. 1988. "Description and Summary of the Canadian, Japanese and U.S. Joint Data Base of Sablefish Tag Releases and Recoveries During 1977-1983." NMFS F/NWC-137. U.S. Department of Commerce.

Gertseva, V. V., S. E. Matson, and J. Cope. 2017. "Spatial Growth Variability in Marine Fish: Example from Northeast Pacific Groundfish." *ICES Journal of Marine Science* 74 (6): 1602–13.

Guzmán, J. M., J. A. Luckenback, M. A. Middleton, K. C. Massee, C. Jensen, F. W. Goetz, A. J. Jasonowicz, and P. Swanson. 2017. "Reproductive Life History of Sablefish (*Anoplopoma Fimbria*) from the U.S. Washington Coast." *PLOS One* 12 (9): 0184413. https://doi.org/10.1371/journal.pone.0184413.

Haltuch, Melissa A, Kelli F Johnson, Nick Tolimieri, Maia S Kapur, and CA Castillo-Jordan. 2019. "Status of the sablefish stock in US waters in 2019." September. Pacific Fisheries Management Council, 7700 Ambassador Place NE, Suite 200, Portland, OR. https://www.pcouncil.org/wp-content/uploads/2019/10/sablefish%7B/_%7D20191022.pdf.

Hanselman, D. H., J. Heifetz, K. B. Echave, and S. C. Dressel. 2015. "Move It or Lose It: Movement and Mortality of Sablefish Tagged in Alaska." *Canadian Journal of Fish and Aquatic Sciences* 72 (2): 238–51. https://doi.org/10.1139/cjfas-2014-0251.

Hart, J. L. 1973. "Pacific Fishes of Canada." 180. St. Andrews, NB, Canada: Fisheries Research Board of Canada Bulletin.

Head, M. A., A. A. Keller, and M. Bradburn. 2014. "Maturity and Growth of Sablefish, *Anoplopoma Fimbria*, Along the U.S. West Coast." *Fisheries Research* 159: 56–67.

Heifetz, J., and J. T. Fujioka. 1991. "Movement Dynamics of Tagged Sablefish in the Northeastern Pacific." *Fisheries Research* 11: 355–74.

Jasonowicz, A. J., F. W. Goetz, G. W. Goetz, and K. M. Nichols. 2017. "Love the One You're with: Genomic Evidence of Panmixia in the Sablefish (*Anoplopoma Fimbria*)." *Canadian Journal of Fisheries and Aquatic Science* 74: 377–87.

Johnson, K. F., M. B. Rudd, M. Pons, C. A. Akselrud, Q. Lee, F. Hurtado-Ferro, M. A. Haltuch, and O. S. Hamel. 2016. "Status of the U.S. Sablefish Resource in 2015." Portland, OR: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments.

Kapur, M, M Haltuch, B Connors, L Rogers, A Berger, E Koontz, J Cope, et al. 2020. "Oceanographic features delineate growth zonation in Northeast Pacific sablefish." *Fisheries Research* 222 (July). https://doi.org/10.1016/j.fishres.2019.105414.

Kronlund, A. R. 2010. "Management Procedures for the Multi-Gear Sablefish (Anoplopoma Fimbria) Fishery in British Columbia, Canada." Nanaimo, BC: Department of Fisheries; Oceans Canada.

Low, L. L., G. K. Tanonaka, and H. H. Shippen. 1976. "Sablefish of the Northeastern Pacific Ocean and Bering Sea." Seattle, WA: U.S. Department of Commerce.

Lynde, M. V. H. 1986. "The Historical Annotated Landings (HAL) Database: Documentation of Annual Harvest of Groundfish from the Northeast Pacific and Eastern Bering Sea from 1956 to 1980." NMFS F/NWC-103. Seattle, WA: U.S. Department of Commerce.

McAllister, M. K., and J. N. Ianelli. 1997. "Bayesian Stock Assessment Using Catch-Age Data and the Sampling-Importance Resampling Algorithm." *Canadian Journal of Fisheries and Aquatic Sciences* 54: 284–300.

McDevitt, S. A. 1987. "The Status of the Sablefish Resource in Waters Off the U.S. West Coast." Portland, OR: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Methot, R. D. 1994. "Assessment of the West Coast Sablefish Stock in 1994." Portland, OR: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Methot, R. D., and I. G. Taylor. 2011. "Adjusting for Bias Due to Variability of Estimated Recruitments in Fishery Assessment Models." *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1744–60.

Methot, R. D., and C. R. Wetzel. 2013. "Stock Synthesis: A Biologial and Statistical Framework for Fish Stock Assessment and Fishery Management." *Fisheries Research* 142: 86–99.

Morita, S. H., K. Morita, and A. Nishimura. 2012. "Sex-Biased Dispersal and Growth in Sablefish (*Anoplopoma Fimbria*) in the Northeastern Pacific Ocean." *Environmental Biology of Fishes* 94: 505–11.

Rogers, L. A., S. Anderson, B. Connors, S. Cox, M. A. Haltuch, and D. Hanselman. n.d. "Quantifying Sablefish Movement Probabilities to Inform Fishery Management in the Northeast Pacific."

Schirripa, M. J. 2007. "Status of the sablefish Resource Off the Continental U.S. Pacific Coast in 2007." Portland, OR: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Shaw, F. R., and N. B. Parks. 1997. "Movement Patterns of Tagged Sablefish, *Anoplopoma Fimbria*, Recovered on Seamounts in the Northeast Pacific Ocean and Gulf of Alaska." NMFS 130. Seattle, WA: U.S. Department of Commerce.

Sogard, S. M., and S. A. Berkeley. 2017. "Patterns of Movement, Growth, and Survival of Adult Sablefish (*Anoplopoma Fimbria*) at Contrasting Depths in Slope Waters Off Oregon." *Fisheries Bulletin* 115: 233–51.

Starr, R. M., D. E. Wendt, C. L. Barnes, C. I. Marks, D. Malone, G. Waltz, K. T. Schmidt, et al. 2015. "Variation in Responses of Fishes Across Multiple Reserves Within a Network of Marine Protected Areas in Temperate Waters." *PLoS One2* 10 (3): p.e0118502.

Stewart, I. J., J. T. Thorson, and C. Wetzel. 2011. "Status of the U.S. Sablefish Resource in 2011." Portland, OR: Pacific Fishery Management Council. http://www.pcouncil.org/groundfish/stock-assessments/.

Tolimieri, N., M. A. Haltuch, Q. Lee, M. G. Jacox, and S. J. Bograd. 2018. "Oceanographic Drivers of Sablefish Recruitment in the California Current." *Fisheries Oceanography* 27: 458–74.

Weinberg, K. L., M. E. Wilkins, F. R. Shaw, and M. Zimmermann. 2002. "The 2001 Pacific West Coast Bottom Trawl Survey of Groundfish Resources: Estimates of Distribution, Abundance and Length and Age Composition." NOAA Technical Memorandum NMFS-AFSC-128. U.S. Department of Commerce.

Wendt, D. E., and R. M. Starr. 2009. "Collaborative Research: An Effective Way to Collect Data for Stock Assessments and Evaluate Marine Protected Areas in California." *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science.* 1: 315–24.

8 Tables

8.1 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	Total Dead
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 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	80351.5	32648.13	128054.9	0.48	0.32	0.63
2012	79223.0	31838.52	126607.5	0.47	0.31	0.63
2013	79605.1	32059.90	127150.3	0.47	0.31	0.63
2014	80187.9	32563.52	127812.3	0.47	0.31	0.64
2015	79676.1	32447.44	126904.8	0.47	0.31	0.63
2016	78633.2	31824.56	125441.8	0.47	0.31	0.62
2017	79326.7	31972.79	126680.6	0.47	0.31	0.63
2018	80687.2	32503.64	128870.8	0.48	0.31	0.64
2019	83925.1	33936.02	133914.2	0.50	0.33	0.67
2020	90756.5	37136.00	144377.0	0.54	0.35	0.72
2021	97801.9	40802.42	154801.4	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	2
OFL	8808	8623	6621	7158	7857	8526	8050	8239	8489	8648	9
ACL	6813	6605	5451	5909	6512	7121	7117	7419	7750	7896	8
Total Catch	6149.25	5184.8	3987.2	4216.46	5025.23	5305.81	5350.64	5126.94	5193.71	3762.75	N
Total Dead	6253.97	5283.6	4050.48	4294.9	5105.52	5401.39	5465.76	5220.22	5372.81	3882.69	N
(1-SPR)/(1-SPR 45%)	0.970534	0.750879	0.610802	0.612182	0.712245	0.756253	0.683499	0.663391	0.61702	0.403801	N
Exploitation Rate	0.0316251	0.0240422	0.0191978	0.0199865	0.0243055	0.0269717	0.0249791	0.0243026	0.0243915	0.014874	N
Age 4+ Biomass (mt)	197753	219764	210986	214890	210057	200261	218814	214801	220274	261038	37
Spawning Biomass (mt)	80351.5	79223	79605.1	80187.9	79676.1	78633.2	79326.7	80687.2	83925.1	90756.5	97
Lower Interval	32648.1325[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Upper Interval	128054.867[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Recruits	6445.91	2759.31	34307.6	6708.58	18010.9	55594.5	10688.7	8151.38	6274.11	12455.3	15
Lower Interval	2238.0045[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 9844.1634[illegible]	- [illegible]	[illegible]
Upper Interval	10653.8154[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fraction Unfished	0.475804	0.469122	0.471384	0.474836	0.471805	0.465629	0.469736	0.477792	0.496966	0.537418	0.5
Lower Interval	0.3167139[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Upper Interval	0.6348940[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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	Total Catch	Rel 1-SPR	Lower Interval	Upper Interval	Exploitation Rate	Lower Interval	Upper Interval
2011	6149.25	0.97	0.60	1.34	0.03	0.01	0.05
2012	5184.8	0.75	0.41	1.09	0.02	0.01	0.04
2013	3987.2	0.61	0.31	0.92	0.02	0.01	0.03
2014	4216.46	0.61	0.30	0.92	0.02	0.01	0.03
2015	5025.23	0.71	0.37	1.05	0.02	0.01	0.04
2016	5305.81	0.76	0.41	1.10	0.03	0.01	0.04
2017	5350.64	0.68	0.36	1.01	0.02	0.01	0.04
2018	5126.94	0.66	0.34	0.98	0.02	0.01	0.04
2019	5193.71	0.62	0.31	0.92	0.02	0.01	0.04
2020	3762.75	0.40	0.18	0.63	0.01	0.01	0.02

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

Year	Recruitment	Lower Interval	Upper Interval	Recruitment Deviations	Lower Interval	Upper Interval
2011	6445.91	2238.00	10653.82	0.09	-0.34	0.52
2012	2759.31	353.79	5164.83	-0.76	-1.47	-0.04
2013	34307.60	15326.03	53289.17	1.76	1.51	2.02
2014	6708.58	2238.47	11178.69	0.13	-0.31	0.57
2015	18010.90	7329.57	28692.23	1.12	0.79	1.45
2016	55594.50	24621.97	86567.03	2.25	1.98	2.52
2017	10688.70	3033.88	18343.52	0.60	0.08	1.12
2018	8151.38	518.63	15784.13	0.32	-0.45	1.10
2019	6274.11	-9844.16	22392.38	0.05	-2.41	2.51
2020	12455.30	-21008.34	45918.94	-0.19	-2.77	2.39
2021	15207.70	-27593.80	58009.20	0.00	-2.74	2.74

Table 6: Recent trend in the overfishing limits (OFL), the annual catch limits (ACLs), the total landings, and 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.

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	-	-

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 and are therefore lower than the ACL or ABC for those years. Similarly, the predicted OFLs presented here for 2021 and 2022 are not the same as those used by the GMT to define fixed catches in 2021-2022; see Table 6 for GMT-defined ACLs and OFLs in 2021 and 2022.

Year	Predicted OFL (mt)	ABC Catch (mt)	Age 4+ Biomass (mt)	Spawning Biomass (mt)	Fraction Unfished
2021	13117.00	7405.00	265655	97801.9	0.58
2022	12515.20	7055.00	261481	99956.5	0.59
2023	11577.10	10824.60	253540	99449.9	0.59
2024	10669.80	9922.92	246090	95943.8	0.57
2025	10120.60	9371.67	241976	93063.3	0.55
2026	9837.41	9070.09	238823	90925.0	0.54
2027	9742.34	8933.73	236280	89290.8	0.53
2028	9735.24	8888.27	234037	87941.5	0.52
2029	9747.17	8860.17	231955	86743.8	0.51
2030	9746.00	8810.38	229993	85644.5	0.51
2031	9725.92	8753.33	228162	84634.2	0.50
2032	9691.91	8683.95	226462	83707.8	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 ± 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 middle row of the decision table to be consistent with the central panel being the base case run at the correct buffer level. Catches are total dead biomass, i.e., dead discard plus catch.

Year scenario	Catch	Total catch	Low state (0.25) SSB	Low state (0.25) Depletion	Base (0.5) SSB	Base (0.5) Depletion	High state (0.25) SSB	High state (0.25) 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*=0.45	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
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

8.2 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.

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 @Haltuch2019b).

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	2010	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	0.07	0.06	0.09
L_at_Amin_Fem_GP_1	25.72	24.83	26.61
L_at_Amax_Fem_GP_1	62.46	61.22	63.70
VonBert_K_Fem_GP_1	0.34	0.31	0.37
CV_young_Fem_GP_1	0.06	0.04	0.07
CV_old_Fem_GP_1	0.11	0.10	0.12
Wtlen_1_Fem_GP_1	0.00		
Wtlen_2_Fem_GP_1	3.27		
Mat50%_Fem_GP_1	55.19		
Mat_slope_Fem_GP_1	-0.42		
Eggs/kg_inter_Fem_GP_1	1.00		
Eggs/kg_slope_wt_Fem_GP_1	0.00		
NatM_p_1_Mal_GP_1	0.06	0.05	0.07
L_at_Amin_Mal_GP_1	26.93	25.92	27.93
L_at_Amax_Mal_GP_1	56.62	55.99	57.25
VonBert_K_Mal_GP_1	0.37	0.34	0.40
CV_young_Mal_GP_1	0.07	0.06	0.09
CV_old_Mal_GP_1	0.08	0.07	0.08
Wtlen_1_Mal_GP_1	0.00		
Wtlen_2_Mal_GP_1	3.27		
FracFemale_GP_1	0.50		
SR_LN(R0)	9.71	9.11	10.30
Q_base_ENV(4)	0.09	0.04	0.14
Q_extraSD_ENV(4)	0.31	0.20	0.42
LnQ_base_AKSHLF(5)	0.32	-0.21	0.86
Q_extraSD_AKSHLF(5)	0.18	0.04	0.31
Q_extraSD_AKSLP(6)	0.04	-0.04	0.11

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_NWSLP(7)	0.16	0.00	0.32
LnQ_base_AKSHLF(5)_BLK1repl_1995	-0.07	-0.62	0.48

Table 13: 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
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

Table 13: Estimated selectivity parameters from the base model. *(continued)*

Label	Estimate
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
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

Table 13: Estimated selectivity parameters from the base model. *(continued)*

Label	Estimate
Age-DblN-descend-se-AKSHLF(5)-BLK6repl-1995	3.17

Table 14: Comparison of Francis weights between the 2019 Benchmark and proposed 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 15: Comparison of likelihoods and parameter estimates between the proposed 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 16: Landings (mt) by fleet for all years, total landings (mt), and total mortality (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 16: 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 16: 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 17: 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

Table 17: 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
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
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

Table 17: 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
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
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

Table 17: 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
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
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

Table 17: 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
2032	249245	83707.8	226462	0.50	14780.60	8683.96	0.93	0.04

9 Figures

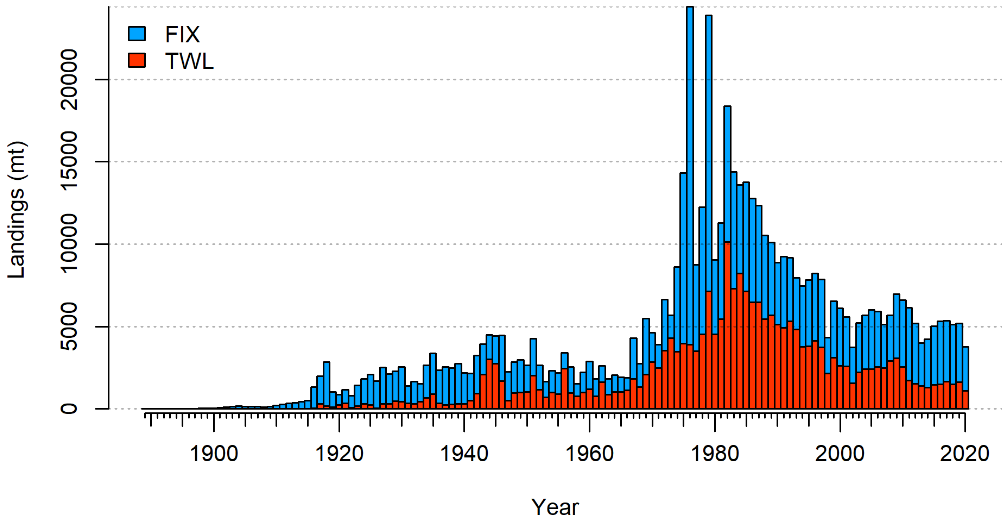


Figure 1: Sablefish landings from 1890–2020 summarized by the gear types included in the base model, fixed-gear and trawl. Landings include those from foreign fleets, which are largely responsible for the peaks in 1976 and 1979.

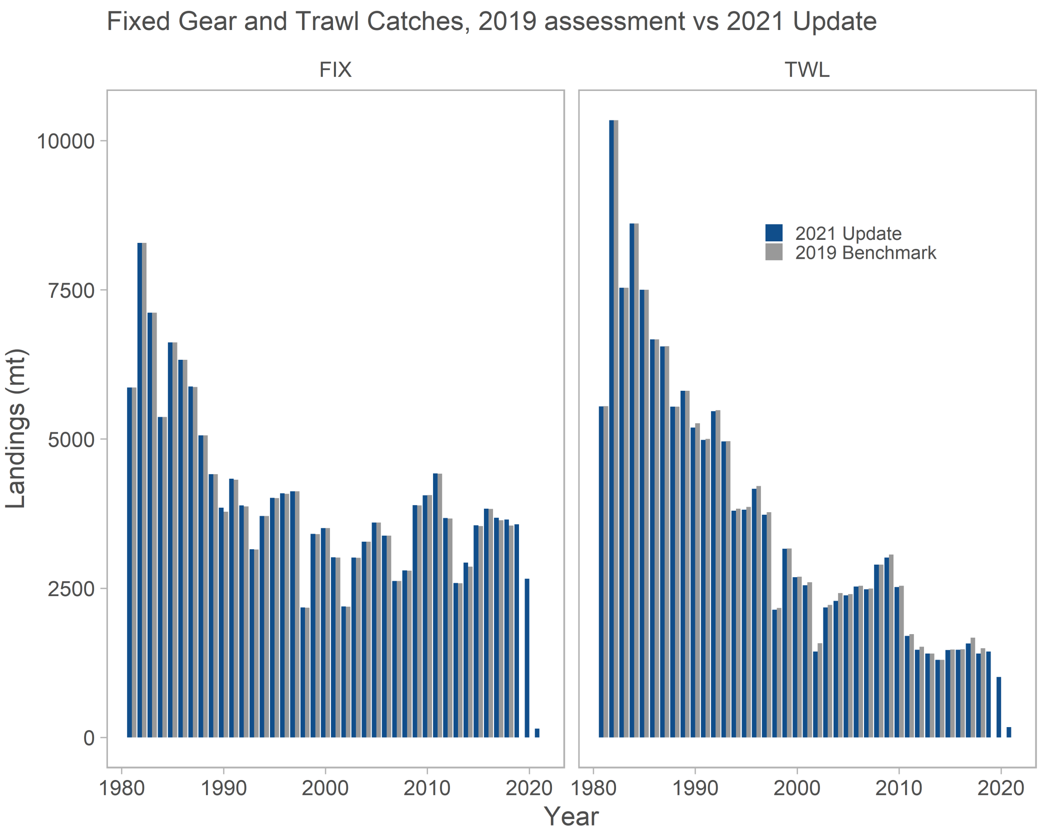


Figure 2: Comparison of landings by fleet used in 2019 Benchmark Assessment (grey bars) and in present update (blue bars), 1982-2020. Historically reconstructed landings remain unchanged.

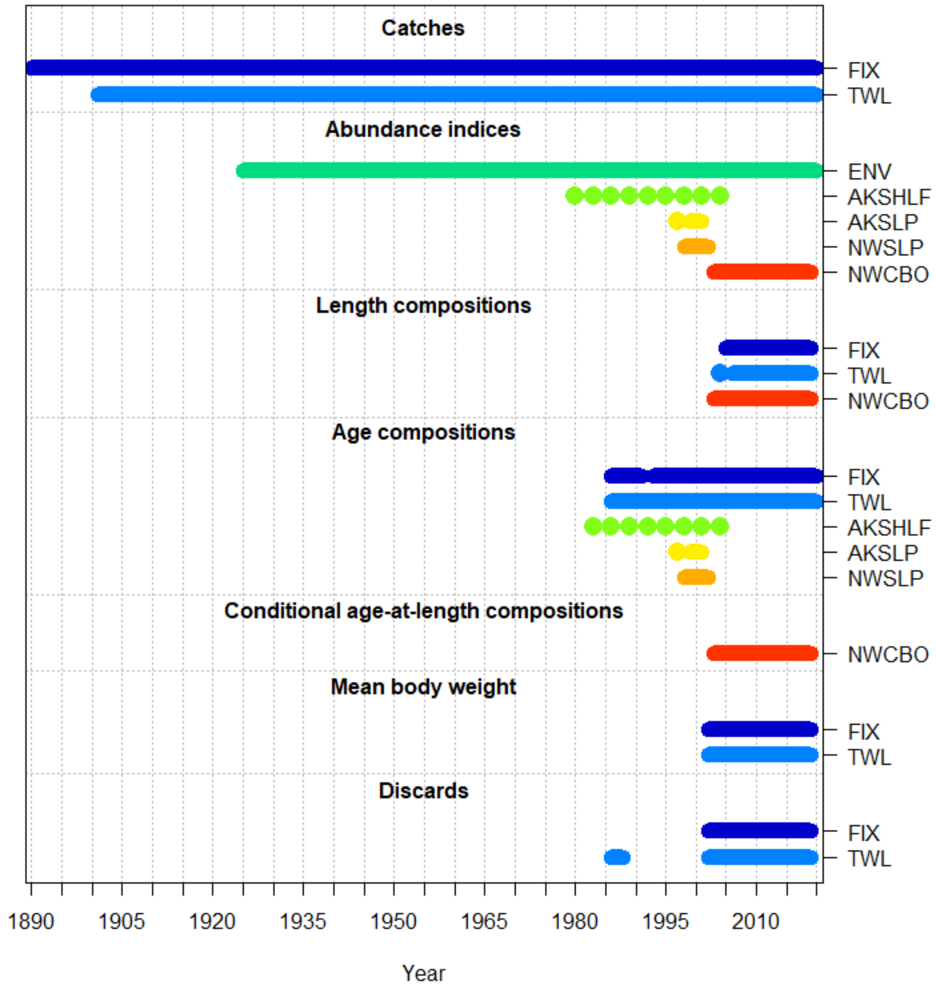


Figure 3: Summary of data sources used in the base model.

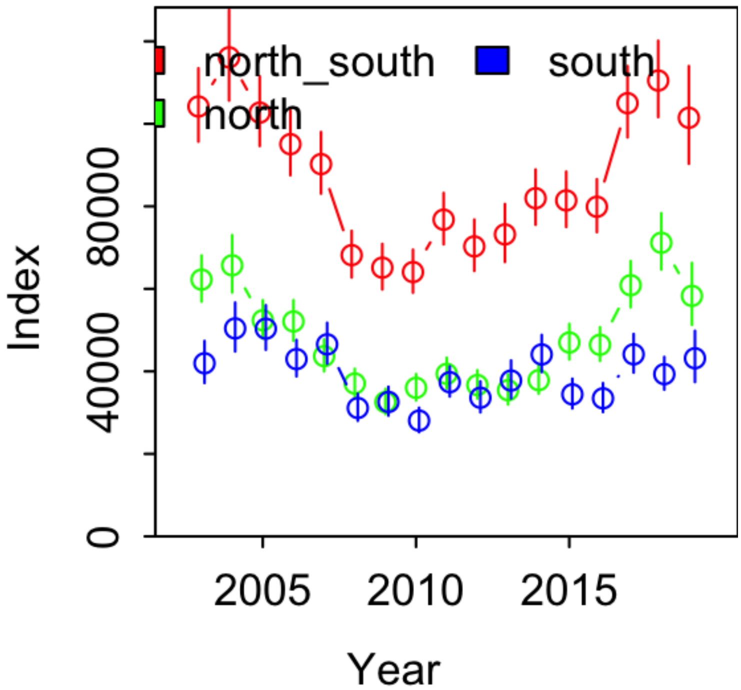


Figure 4: Estimated index of relative abundance (mt) for the West Coast Groundfish Bottom Trawl Survey, with 5% and 95% intervals. Region-specific estimates are included for north and south of 36 degrees N ('north' and 'south', respectively), as well as the coast-wide estimate ('north-south').

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.

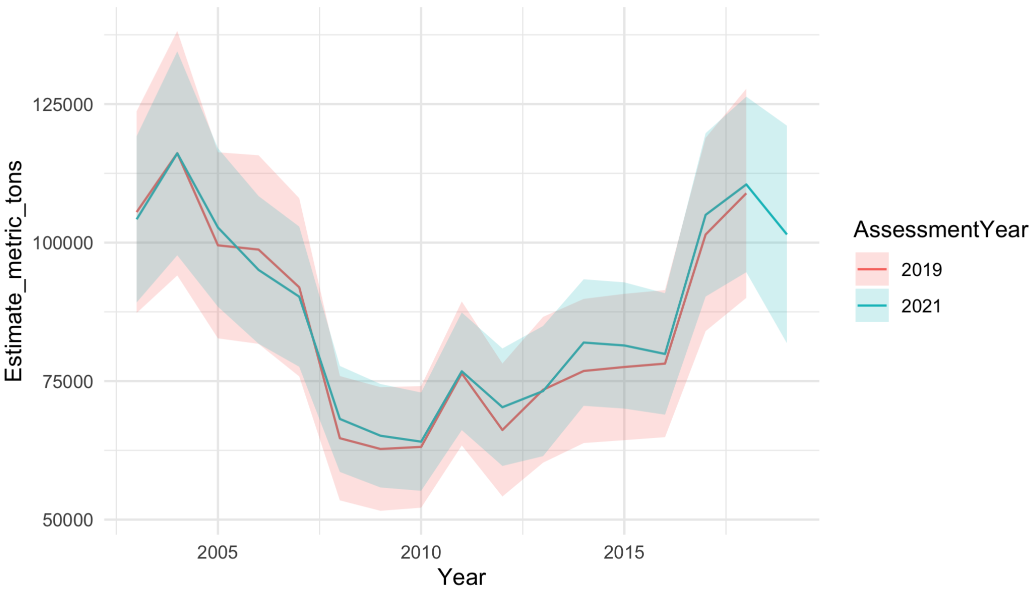


Figure 6: Comparison between WCGBTS Index of abundance standardized using VAST in the 2019 Benchmark (red lines) and the re-standardization using one more year of data for the present update (blue lines). Shaded area reflects 95% confidence interval.

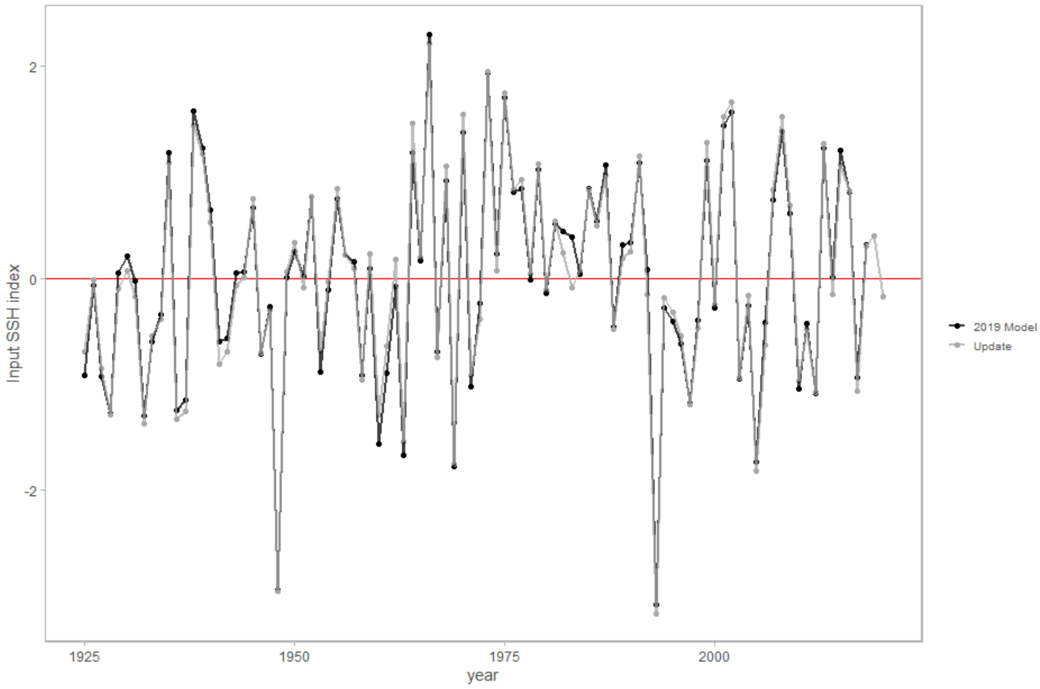


Figure 7: Comparison of SSH input data between 2019 benchmark assessment and 2021 update using new tide-gauge records.

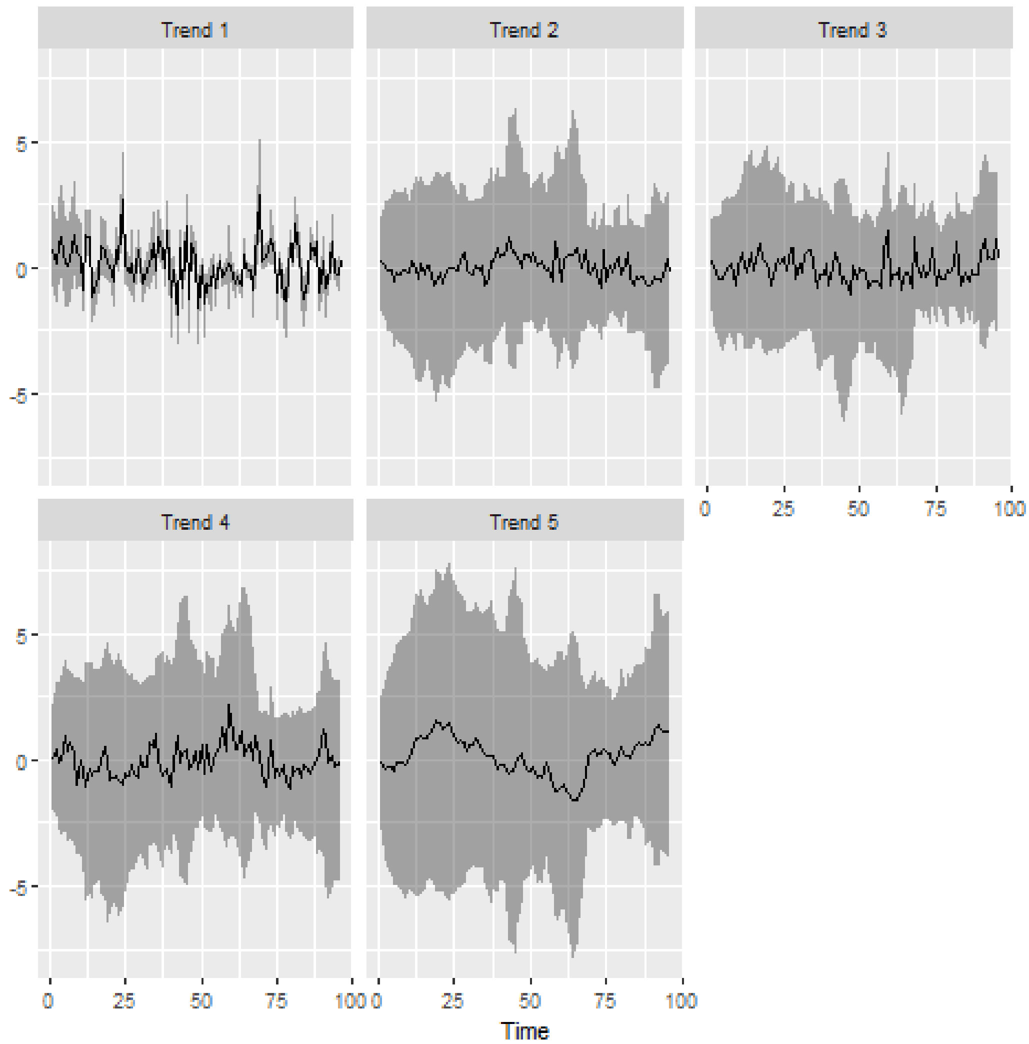


Figure 8: Time series of dynamic factors from the SSH analysis that explained significant variation in sablefish recruitment. Grey envelopes are the 95% confidence interval.

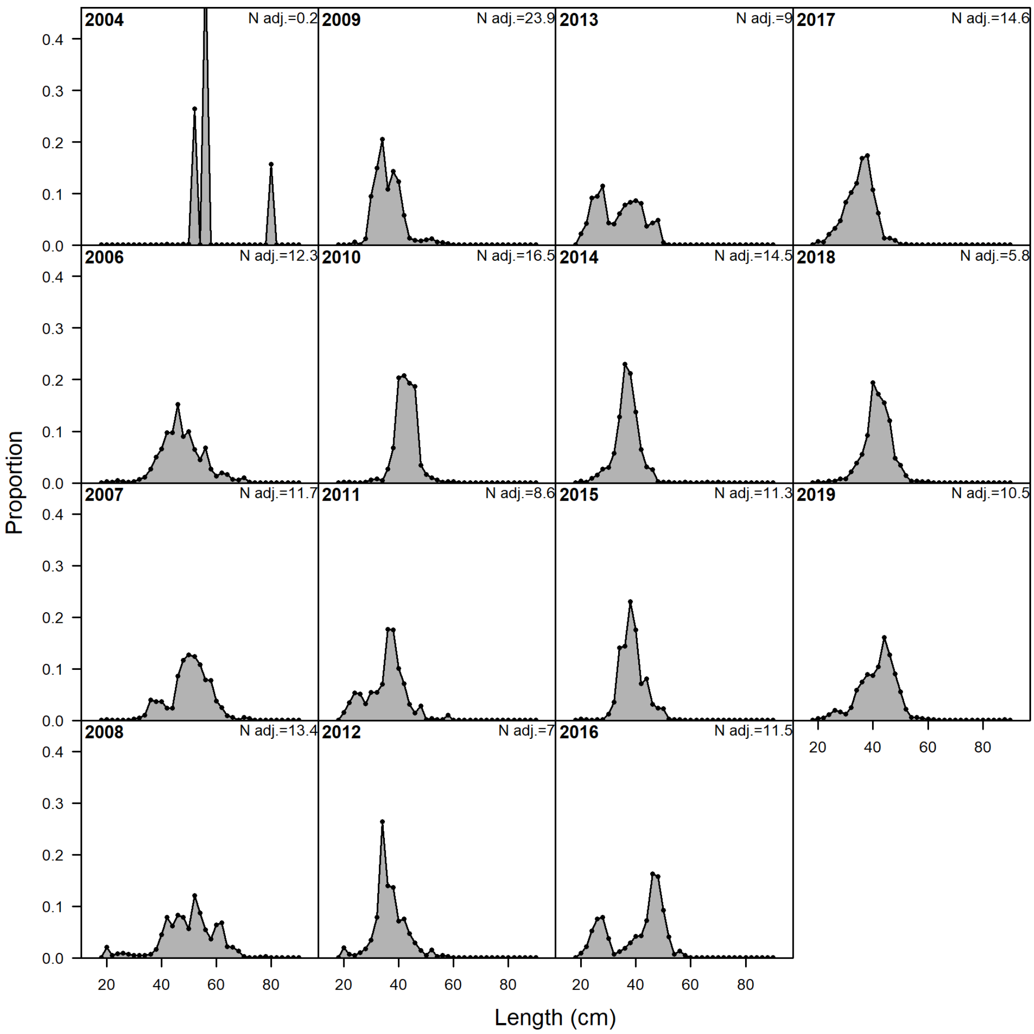


Figure 9: Recent length compositions (2004-2019) of discarded sablefish from the trawl gear fishery, aggregated across sexes.

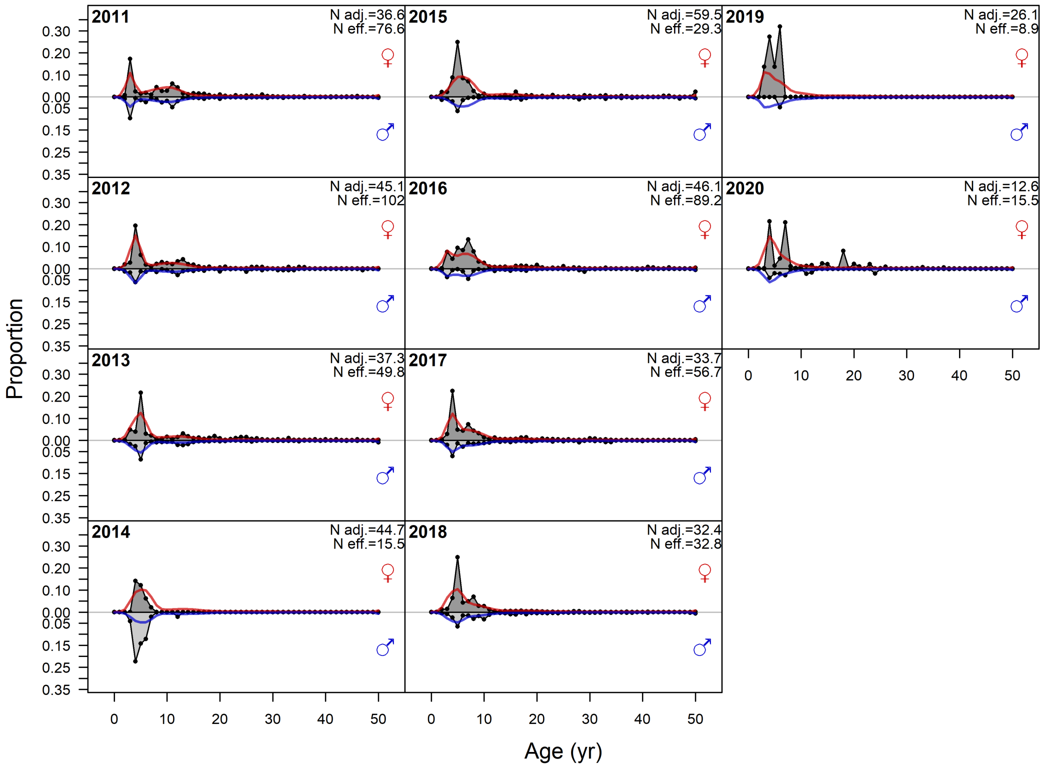


Figure 10: Age compositions for female and male sablefish from the retained catch in the fixed gear fishery in recent years, from a model which conforms to the Terms of Reference.

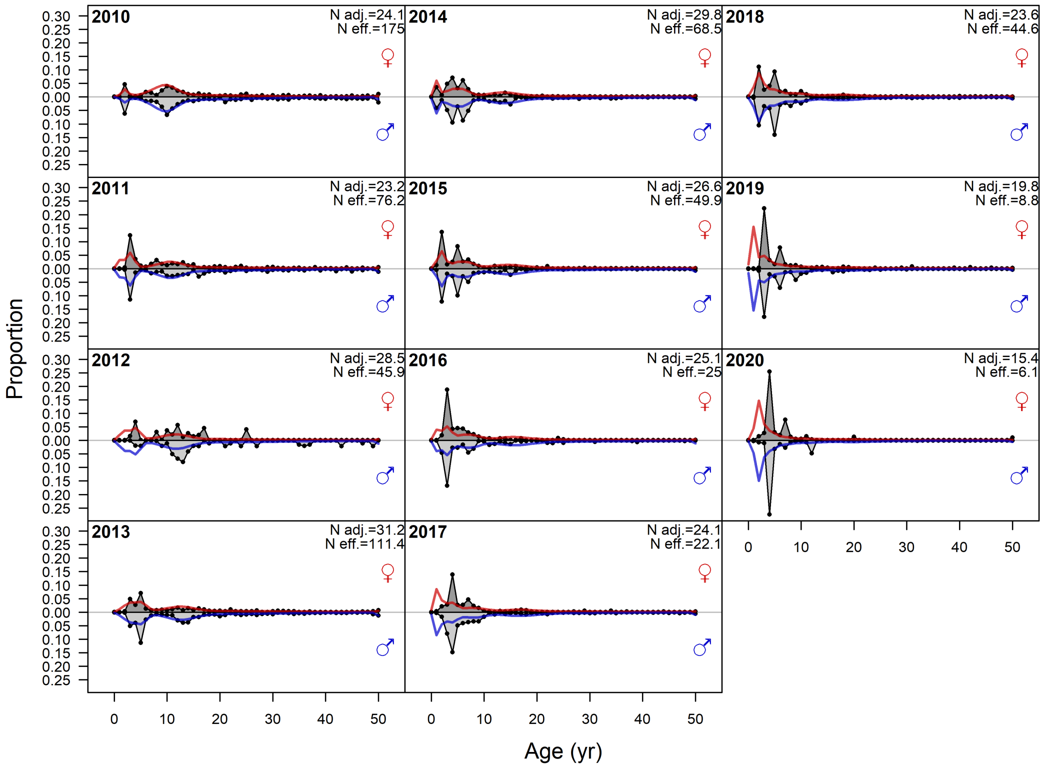


Figure 11: Age compositions for female and male sablefish from the retained catch in the trawl fishery in recent years, from a model which conforms to the Terms of Reference.

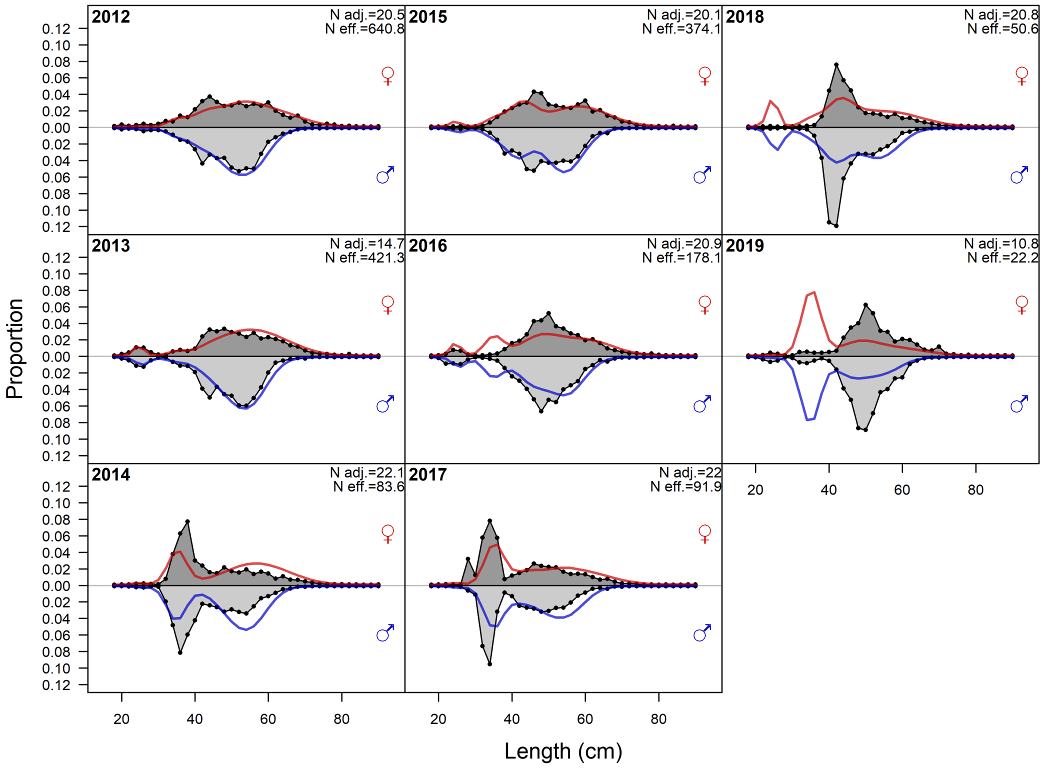


Figure 12: Length compositions for female and male sablefish from the WCGBTS survey in recent years, from a model which conforms to the Terms of Reference.

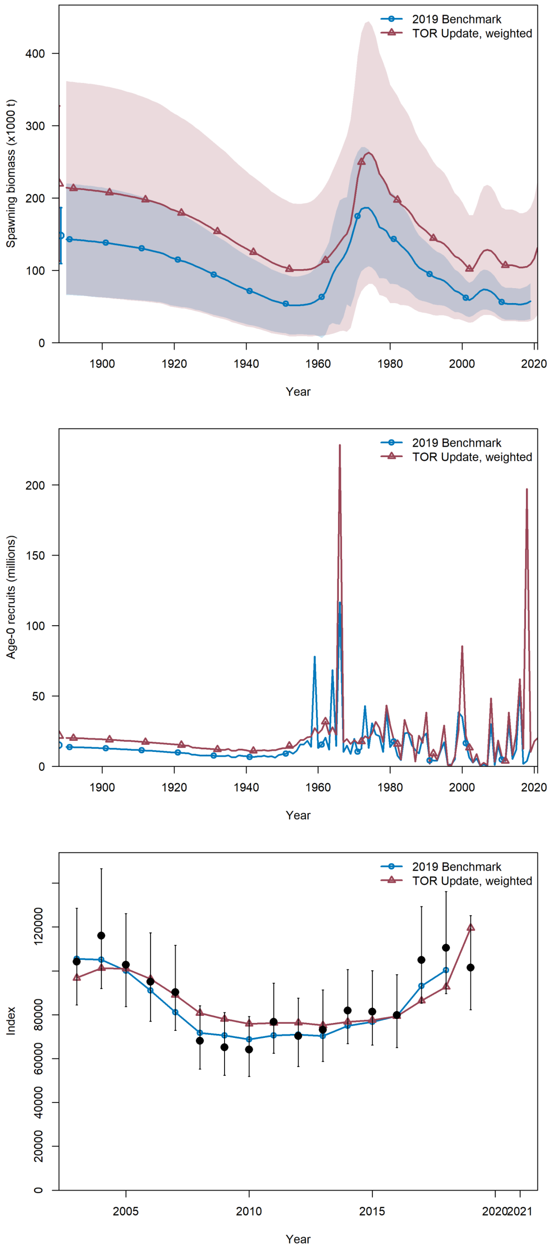


Figure 13: Comparison of derived quantities between the 2019 Benchmark assessment (blue lines), and an update assessment which conforms to the Terms of Reference (red lines). Top to bottom: spawning biomass, age-0 recruits, and fits to the WCGBTS Index of abundance.

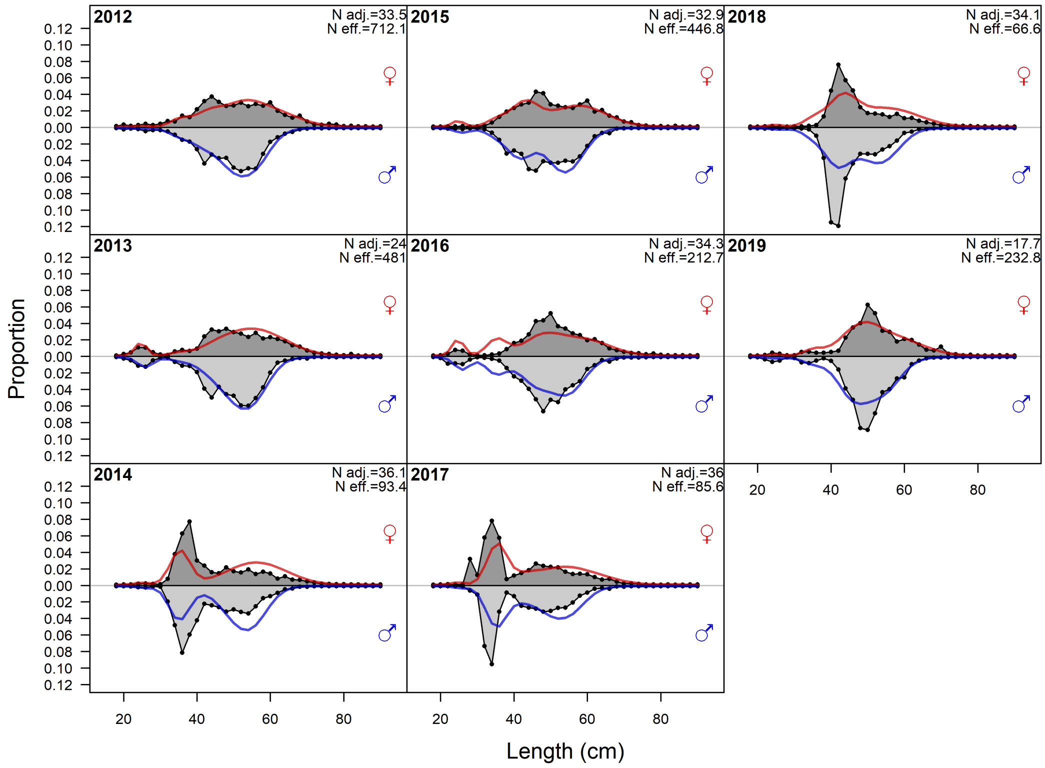


Figure 14: Length compositions for female and male sablefish from the WCGBTS survey in recent years, from the base model.

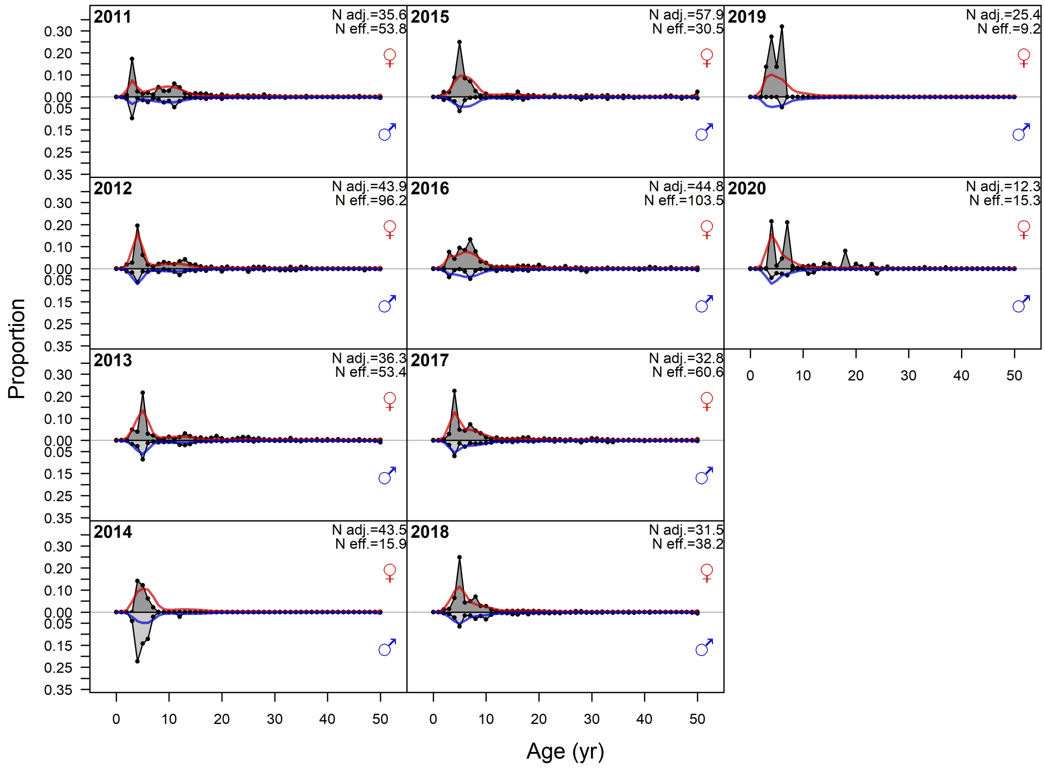


Figure 15: Age compositions for female and male sablefish from the retained catch in the fixed gear fishery in recent years from the base model.

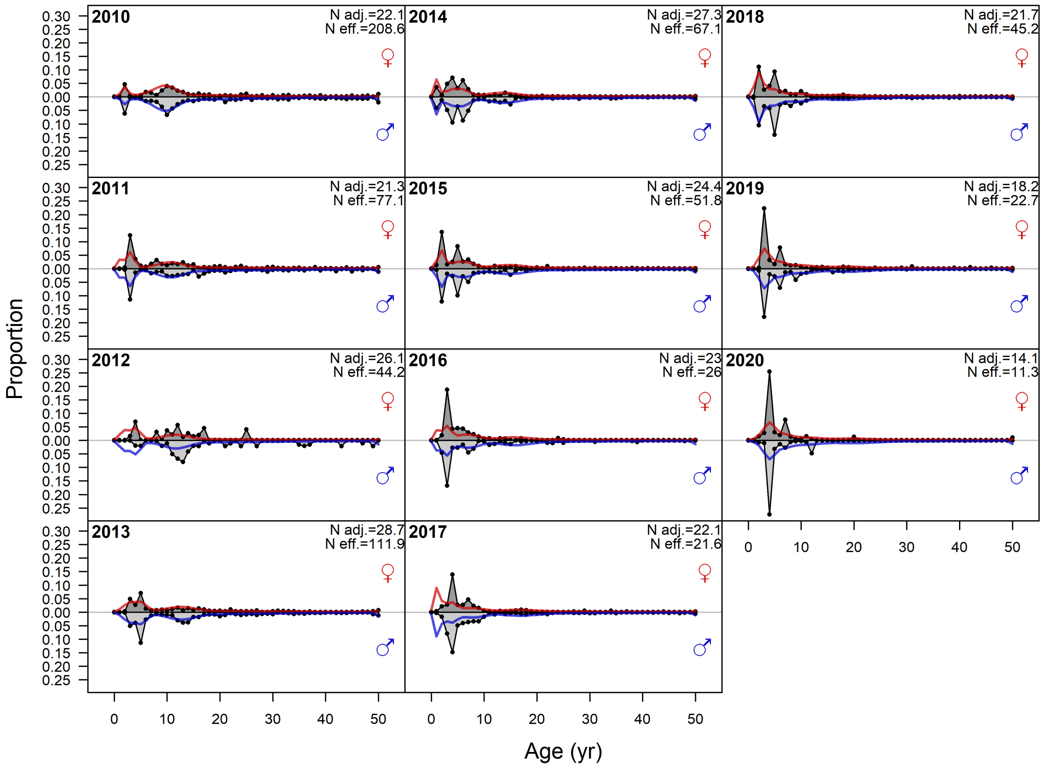


Figure 16: Age compositions for female and male sablefish from the retained catch in the trawl fishery in recent years from the base model.

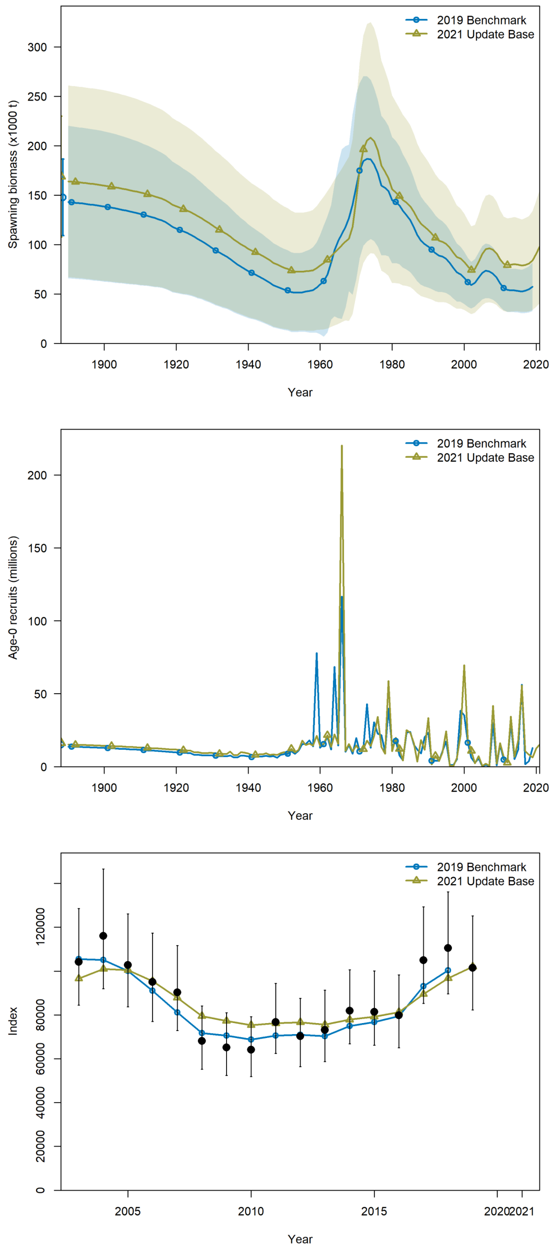
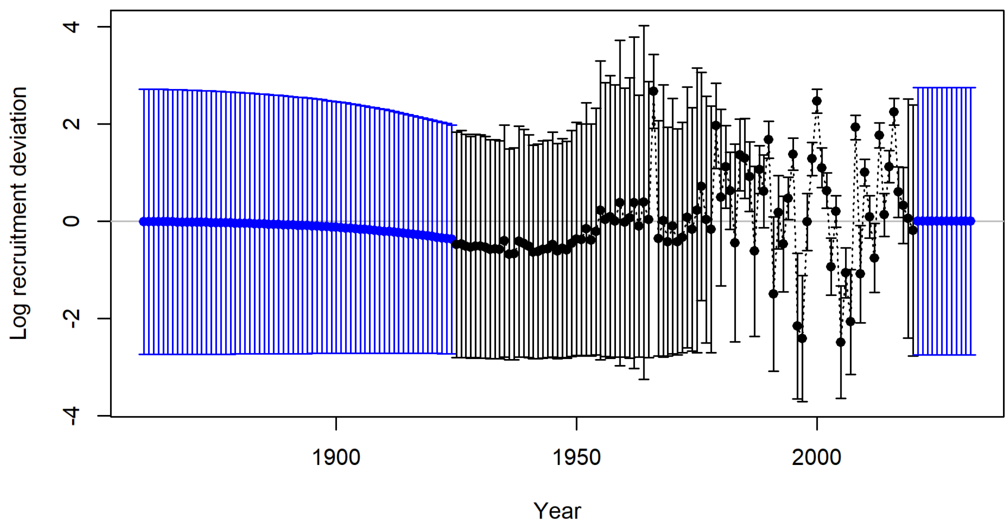


Figure 17: Comparison of selected derived quantities between the 2019 Benchmark assessment (blue lines) and update base model (green lines). Top to bottom: spawning biomass, age-0 recruits, and fits to the WCGBTS Index of abundance.



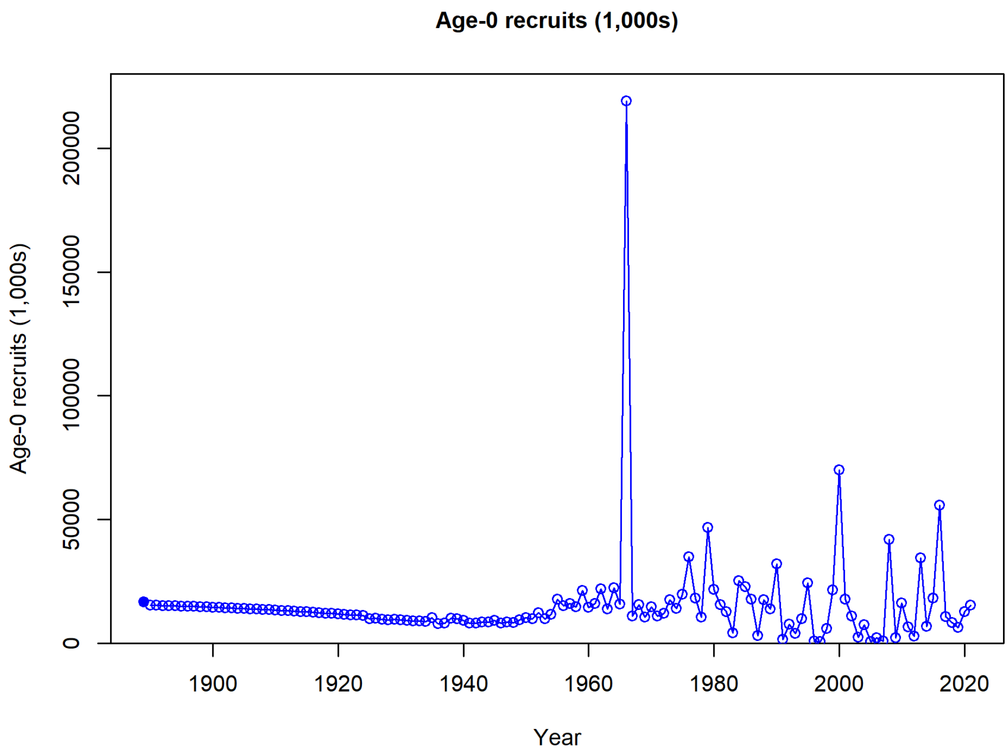


Figure 18: Time series of estimated recruitment deviations from the base model (solid line) with 95% intervals (vertical lines; upper panel) and recruitment without intervals (lower panel).

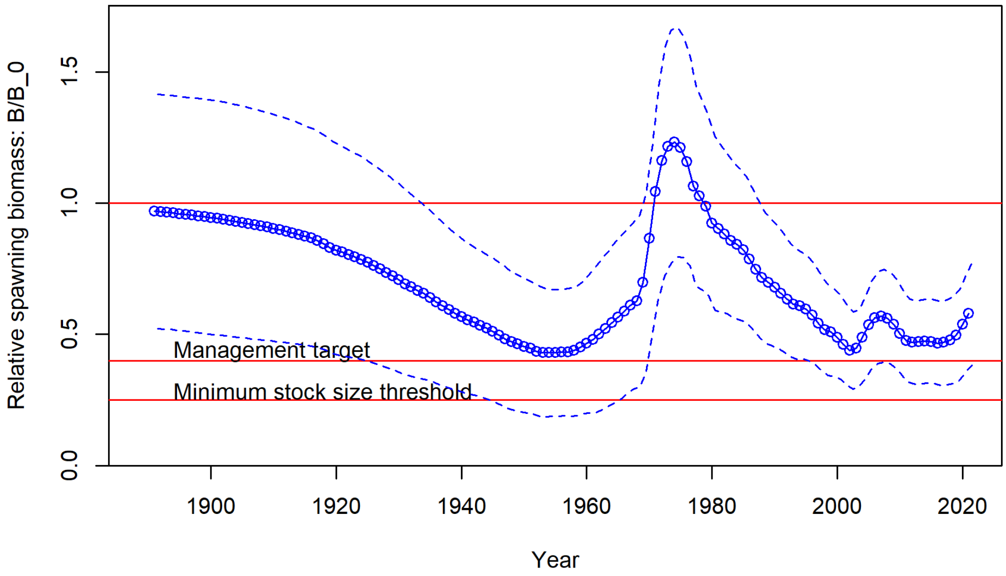


Figure 19: Time series of estimated depletion (i.e., spawning biomass relative to unfished spawning biomass) from the base model (circles) with 95% intervals (dashed lines).

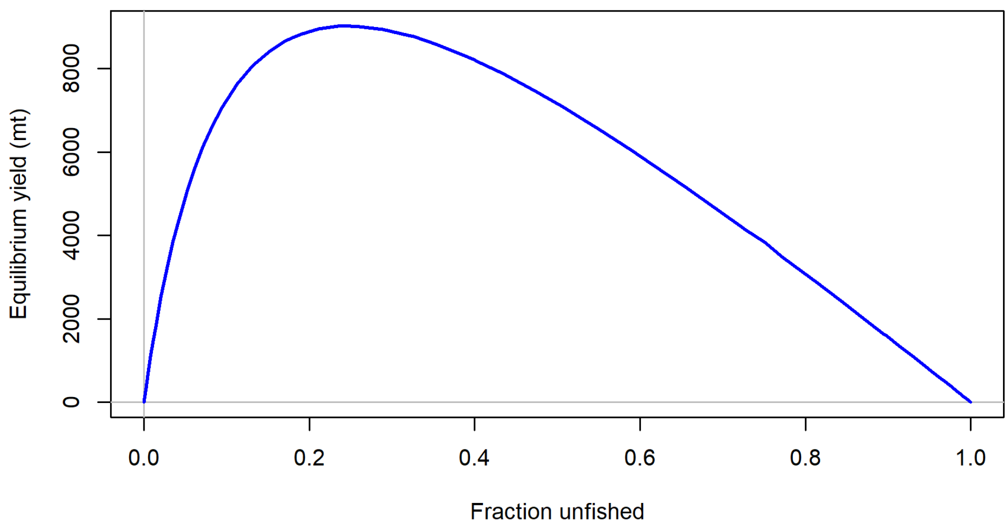


Figure 20: Equilibrium yield curve (total dead catch) for the base model.

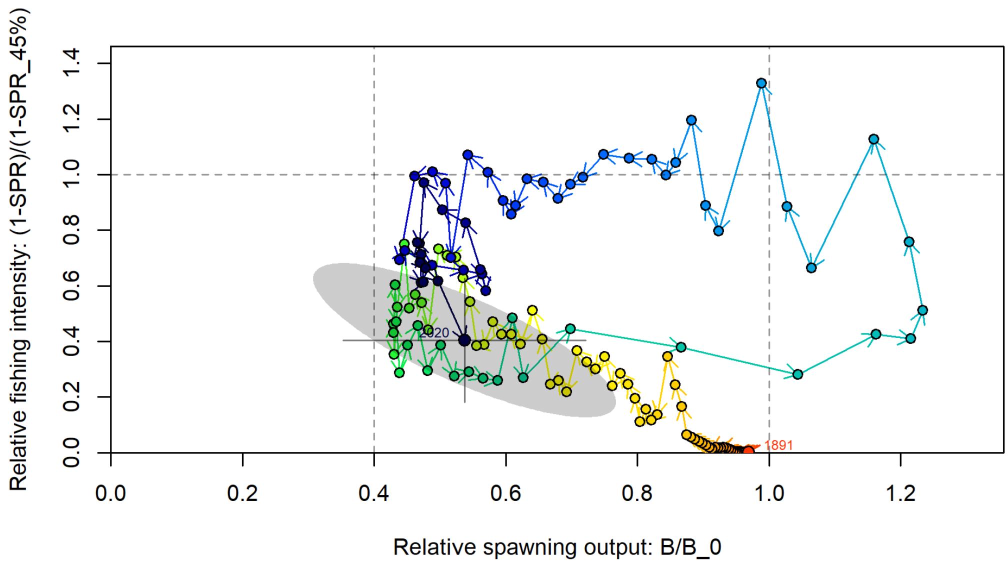


Figure 21: Estimated relative spawning potential ratio relative to the proxy target/limit of 45% vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The dark blue circle indicates 2020. Plot is based on maximum likelihood estimation results.

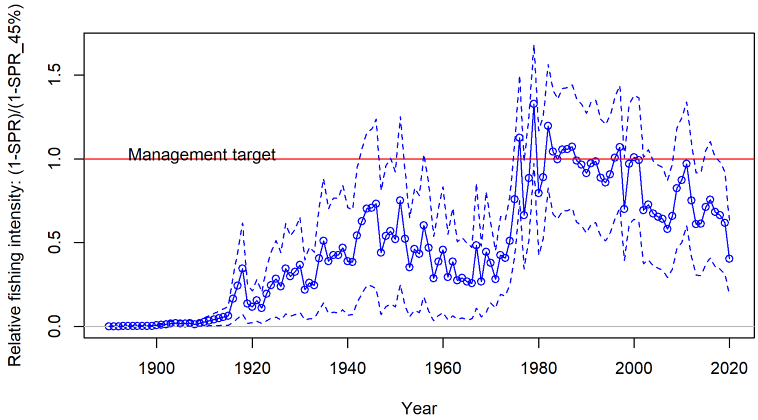


Figure 22: Time series of estimated relative 1-spawning potential ratio ($1 - SPR/1 - SPR_{Target=0.45\%}$) for the base model (round points) with ~95% intervals (dashed lines). Values of relative 1-SPR above 1.0 reflect harvests in excess of the current overfishing proxy.

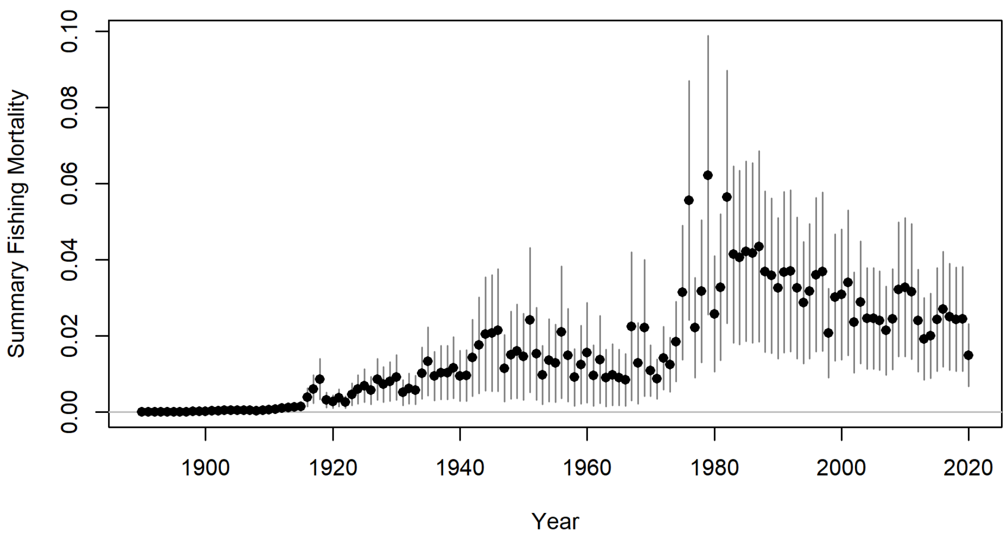


Figure 23: Time series of estimated exploitation fraction (catch/age 4 and older biomass) and their associated uncertainty (vertical lines) for the base model.

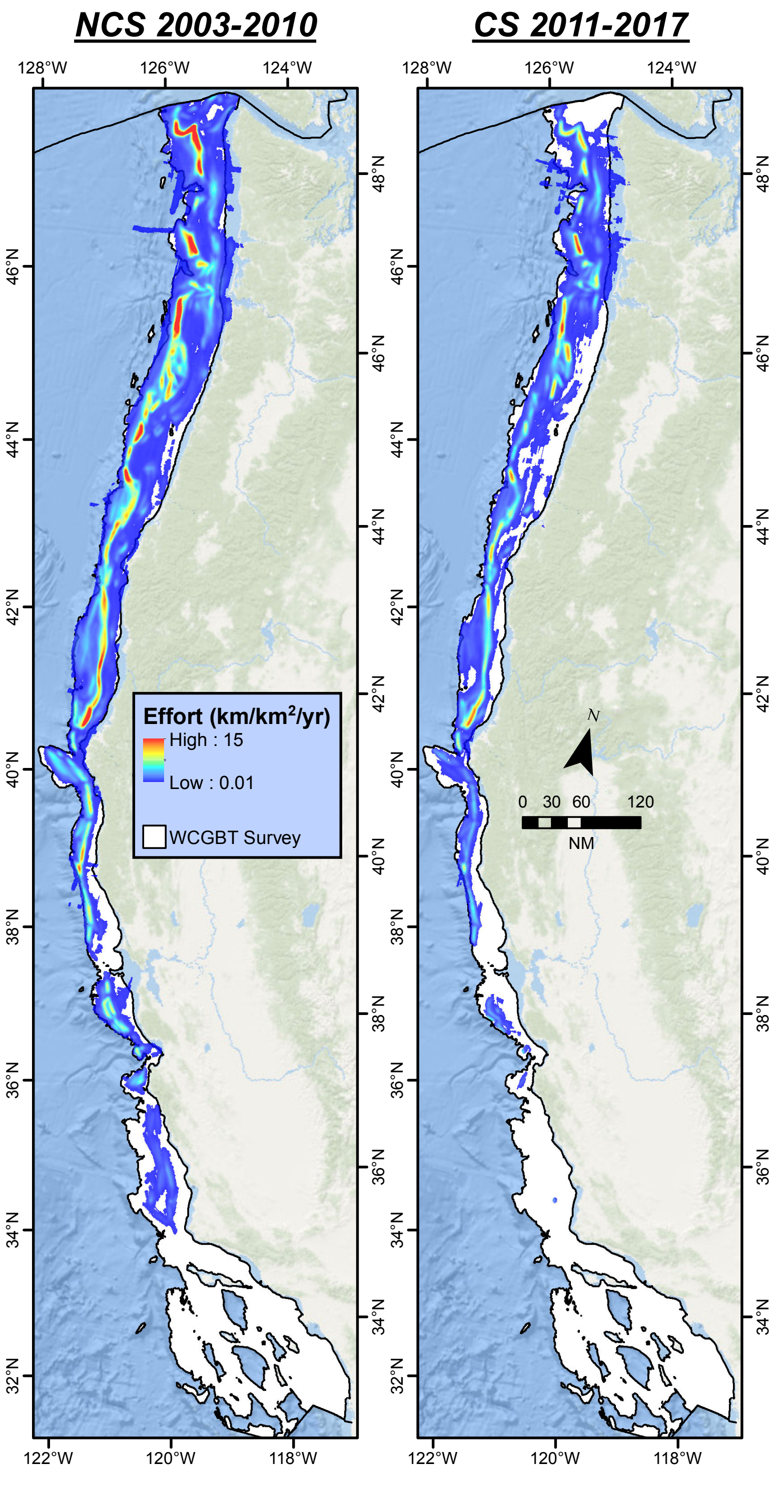


Figure 24: Spatial footprint of effort using trawl gear (km/km^2/yr) in the sablefish fishery before catch shares (2003–2010; left) and post catch shares (2011–2017; right) in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white). Fishery data are from Pacific Fisheries Information Network logbooks and the West Coast Groundfish Observer Program.

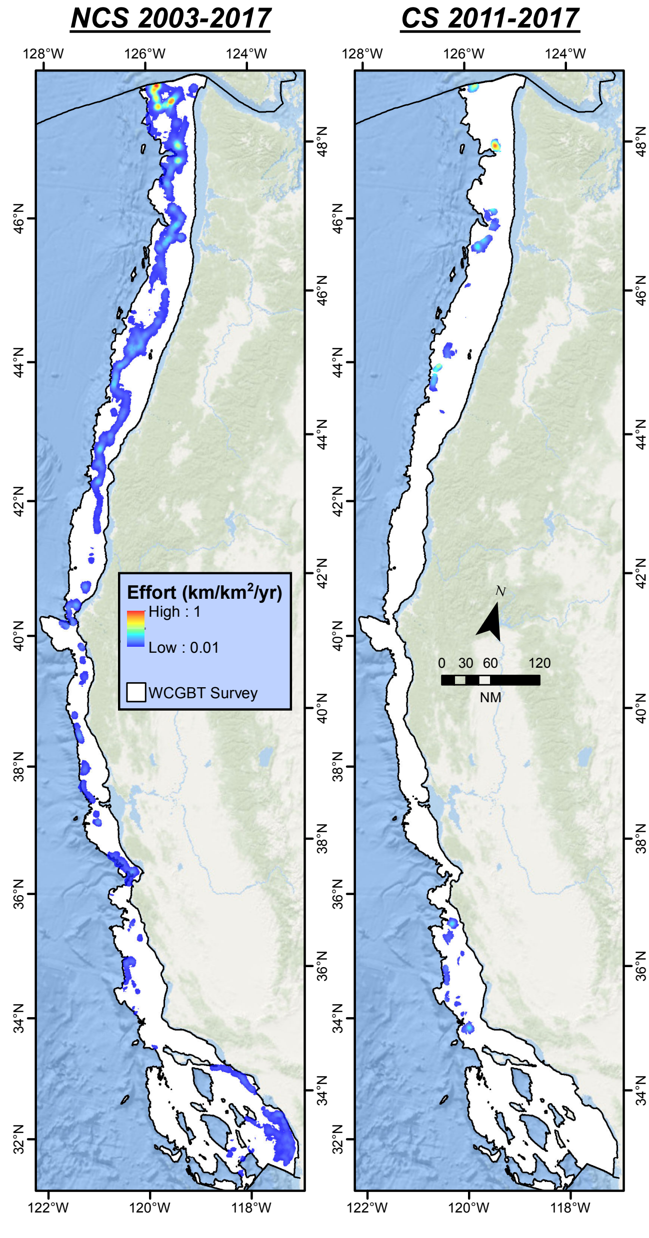


Figure 25: Spatial footprint of effort using hook-and-line gear (km/km^2/yr) in the sablefish fishery with non catch-share vessels since 2003 (2003–2017; left) and with catch-share vessels since 2011 (2011–2017; right) as observed by the West Coast Groundfish Observer Program in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white).

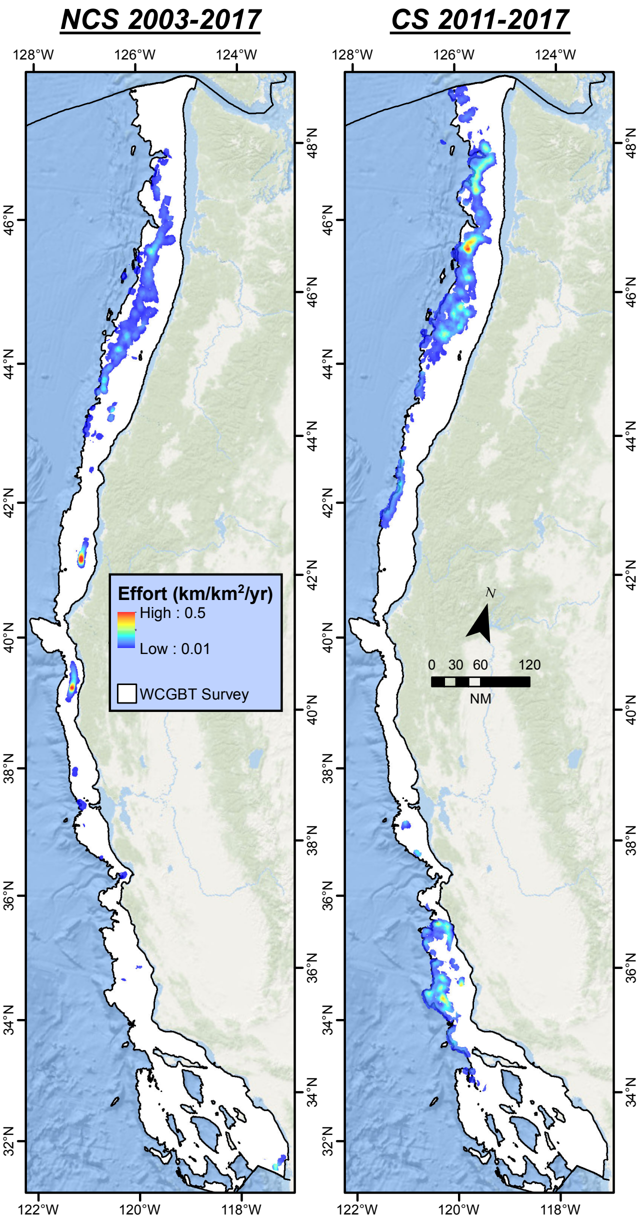


Figure 26: Spatial footprint of effort using pot gear (km/km^2/yr) in the sablefish fishery with non catch-share vessels since 2003 (2003–2017; left) and with catch-share vessels since 2011 (2011–2017; right) in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white)

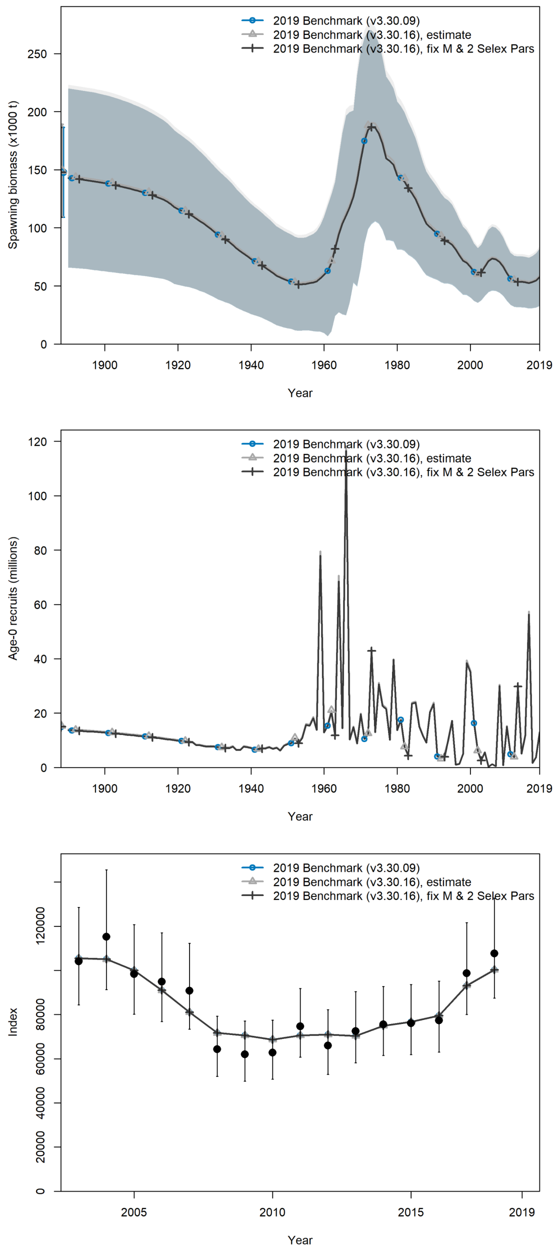


Figure 27: Comparison of derived quantities between the 2019 Benchmark assessment (blue lines), a bridged model which matches the estimation structure of the benchmark in Stock Synthesis v3.30.16 (light grey lines) and a model which fixes natural mortality and the descending limb standard error for the 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.

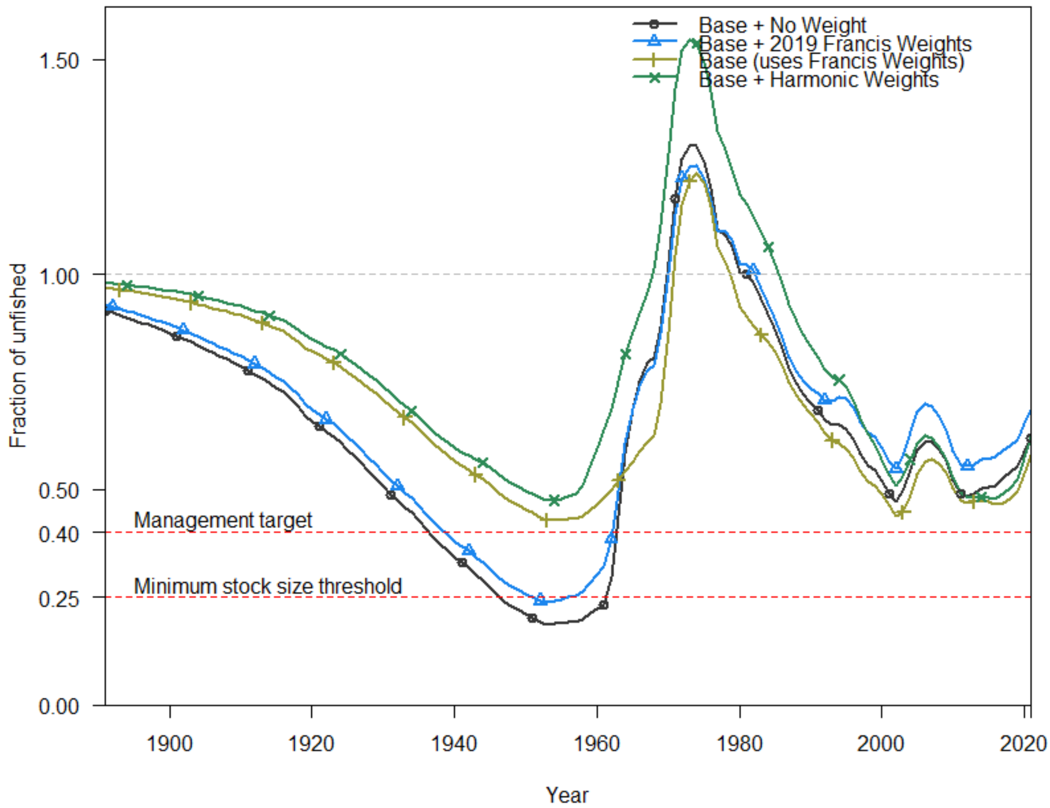


Figure 28: Changes in spawning stock biomass and depletion for alternative data-weighting methods used to downweight the compositional data.

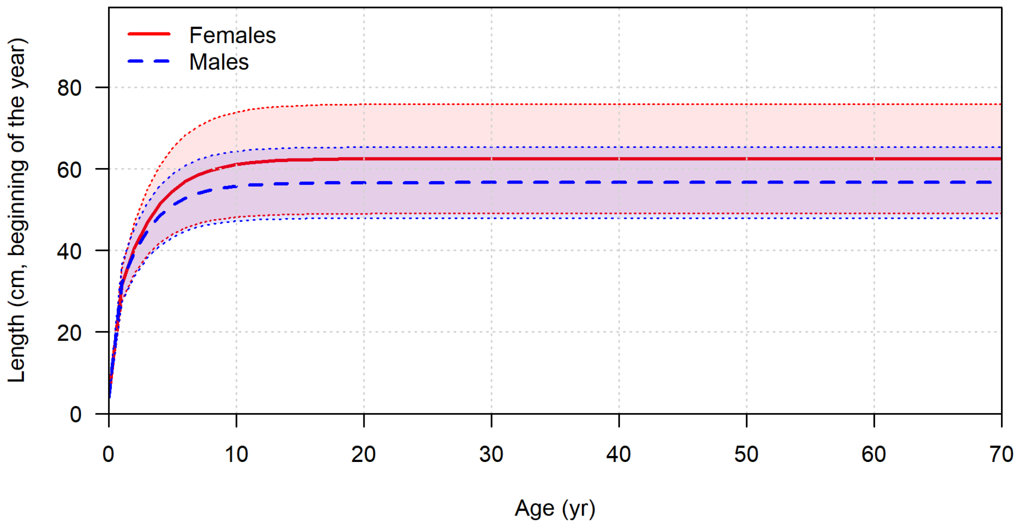


Figure 29: Growth curve for females and males with 95% intervals (dashed lines) indicating the expectation and individual variability of length-at-age for the base model.

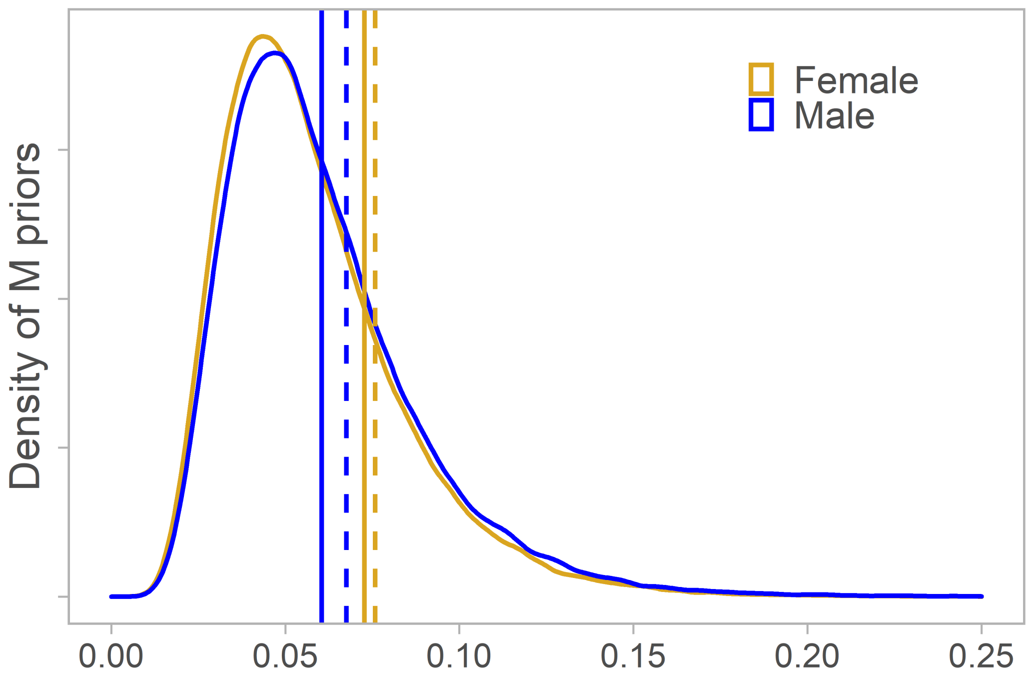
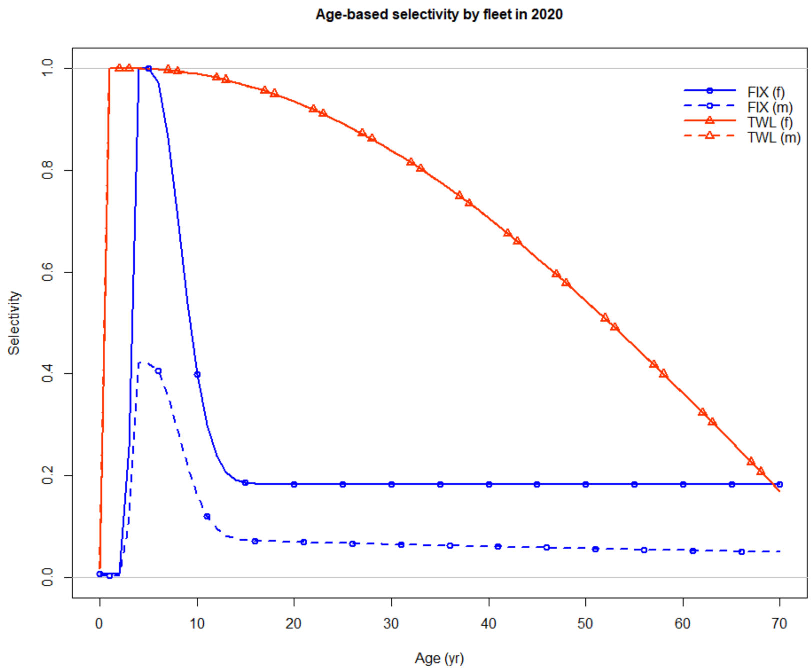


Figure 30: Prior for female (gold) and male (blue) natural mortality (M). Vertical lines delineate estimates from the current base models (solid lines) and 2019 benchmark assessment (dashed line).



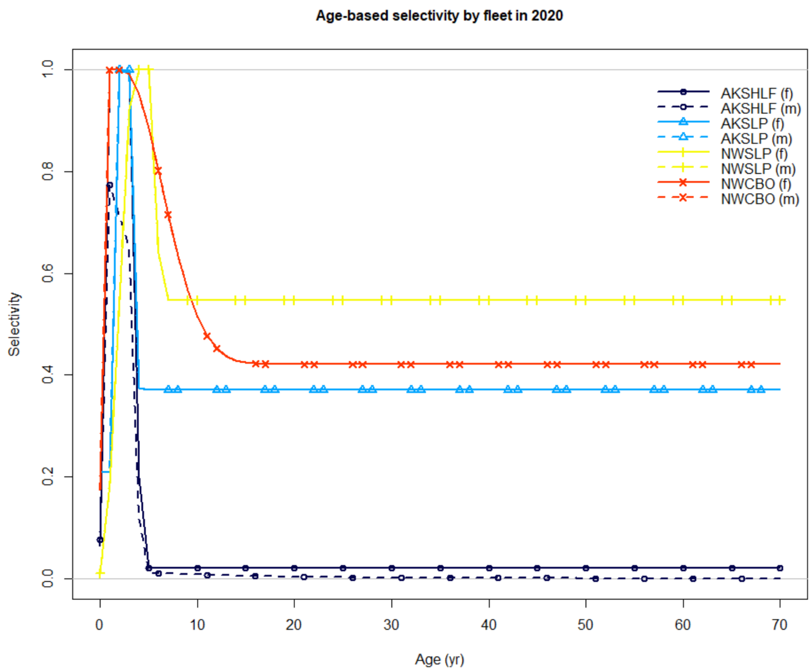


Figure 31: Fleet-specific (colors) selectivity at age in the terminal year of the model for fishery fleets (upper) and surveys (lower). Solid lines are female-specific and dashed lines are male-specific selectivities.

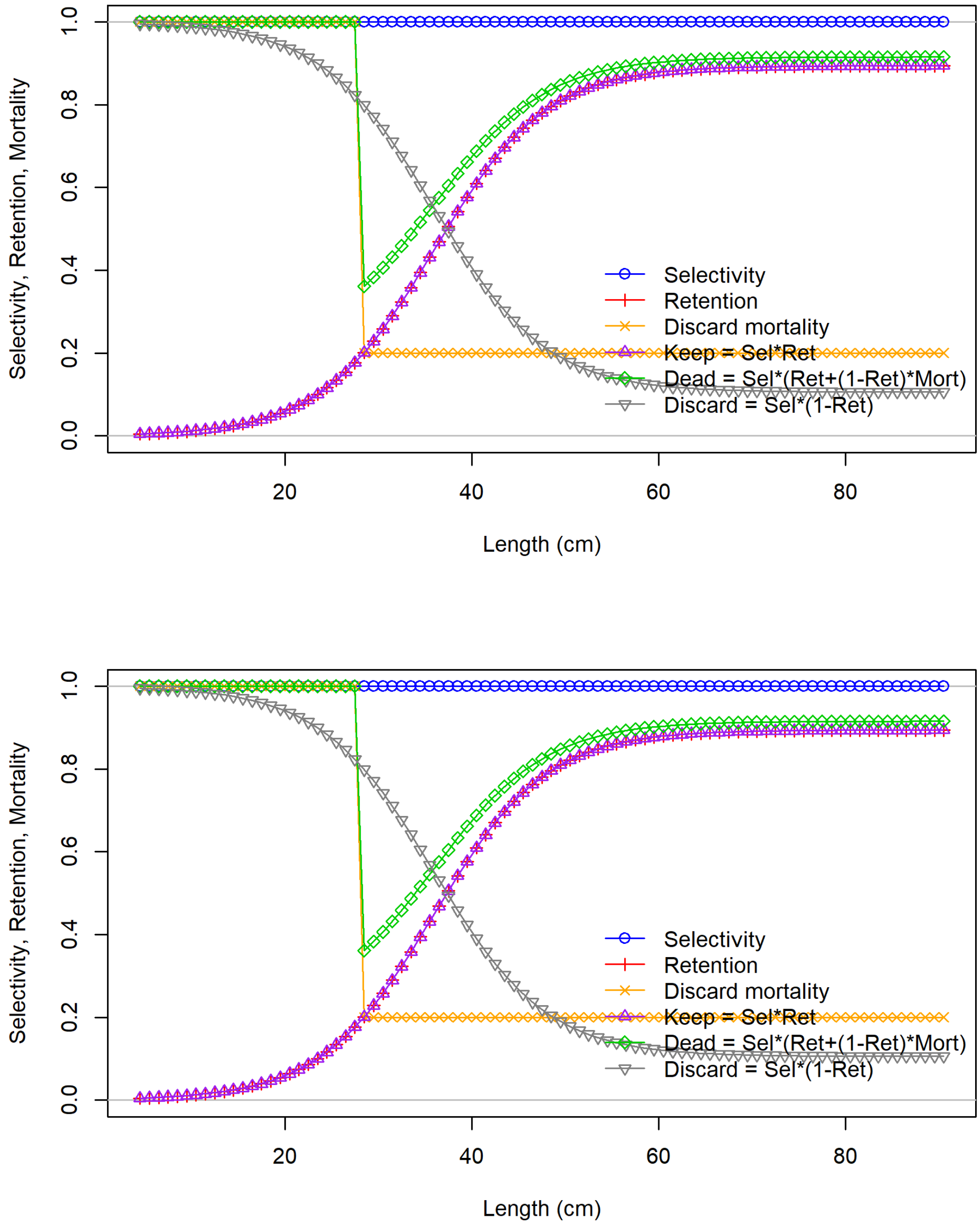


Figure 32: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the fixed-gear fishery.

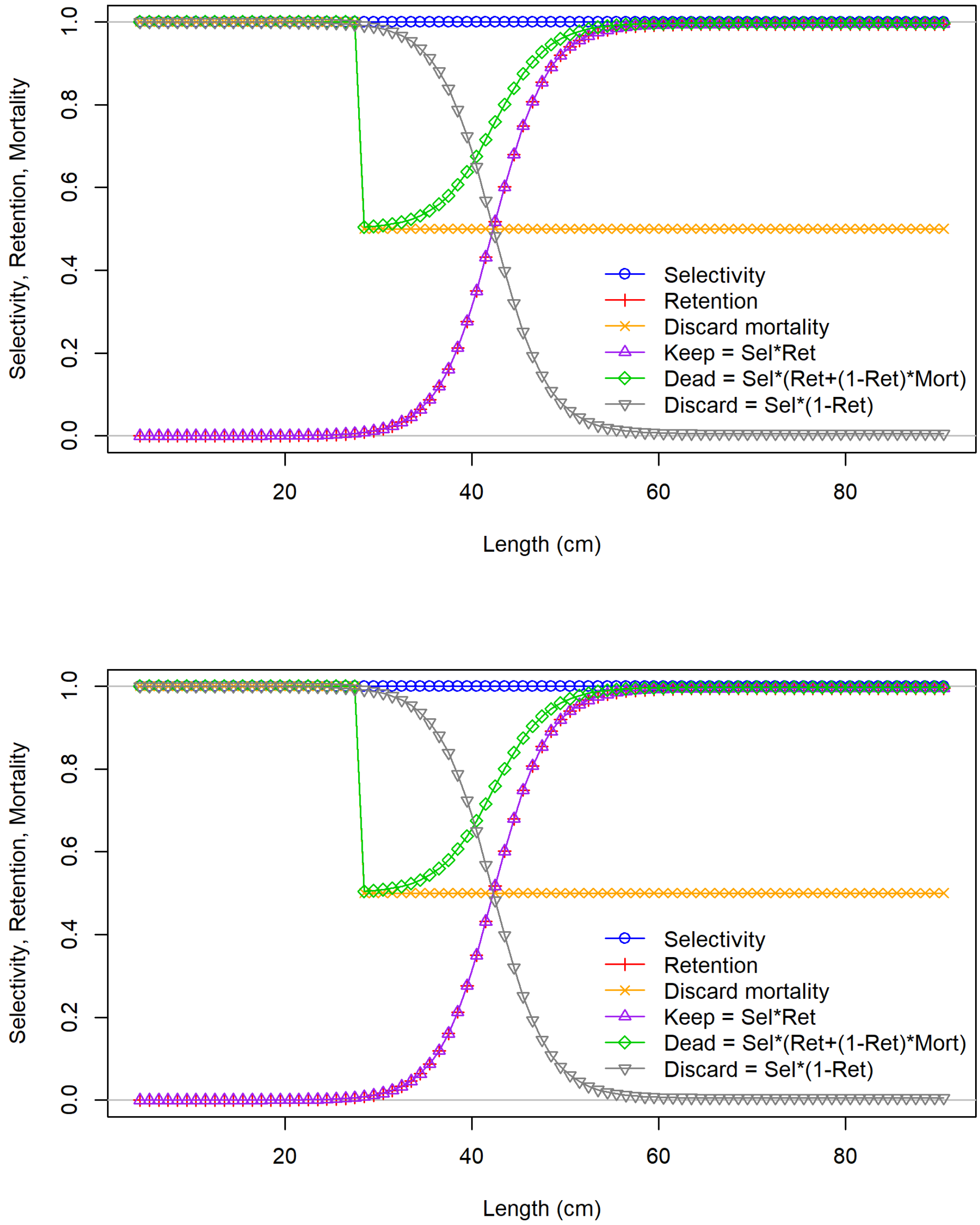
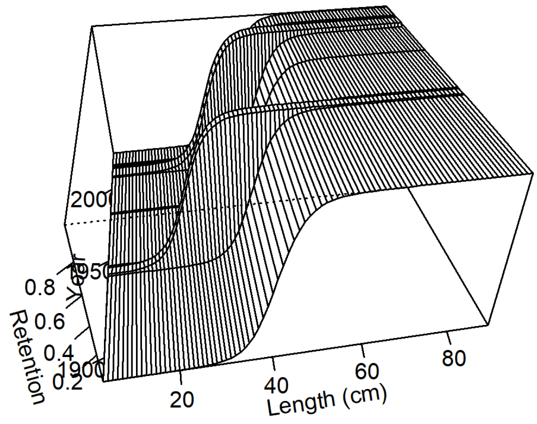


Figure 33: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the fixed-gear fishery.



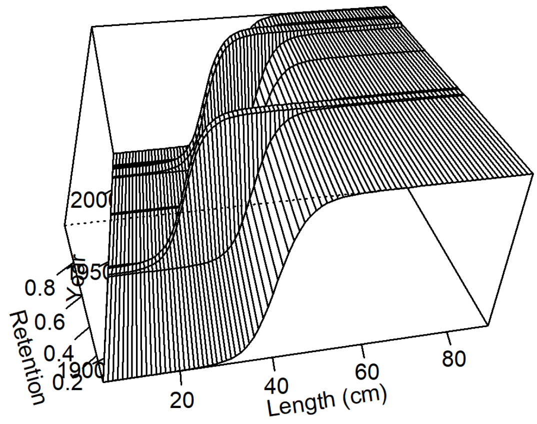


Figure 34: Estimated time-varying retention and discard mortality for females (upper panel) and males (lower panel) for the trawl fishery.

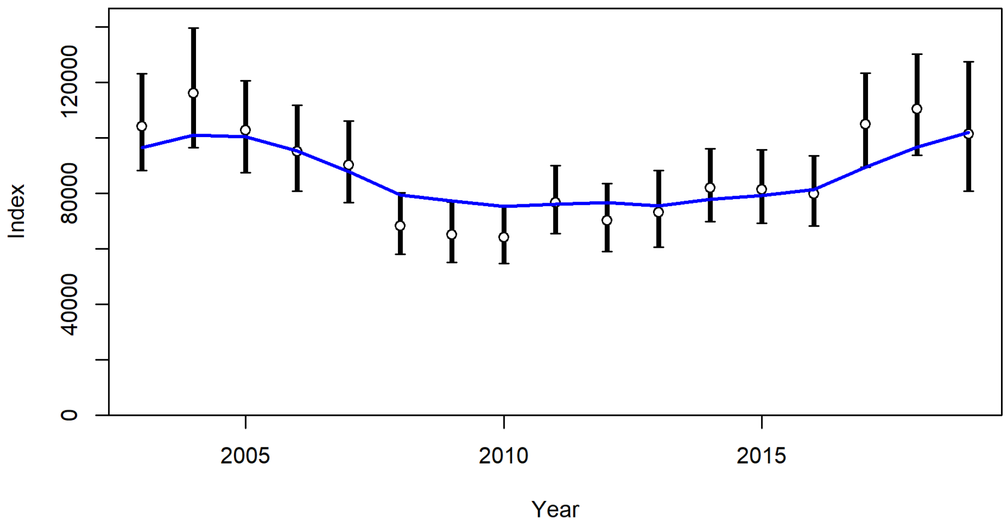


Figure 35: Fit to the West Coast Groundfish Bottom Trawl Survey.

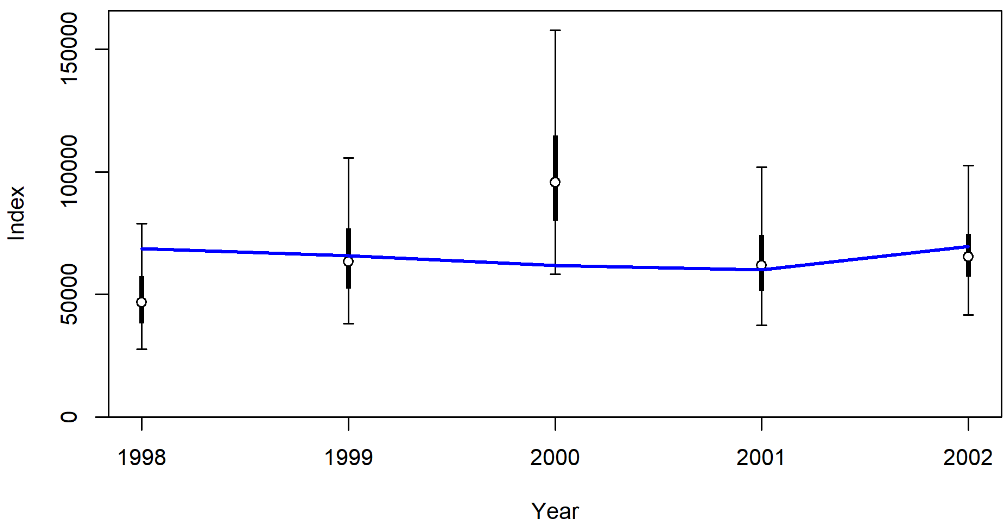


Figure 36: Fit to the Northwest Fisheries Science Center Slope Survey.

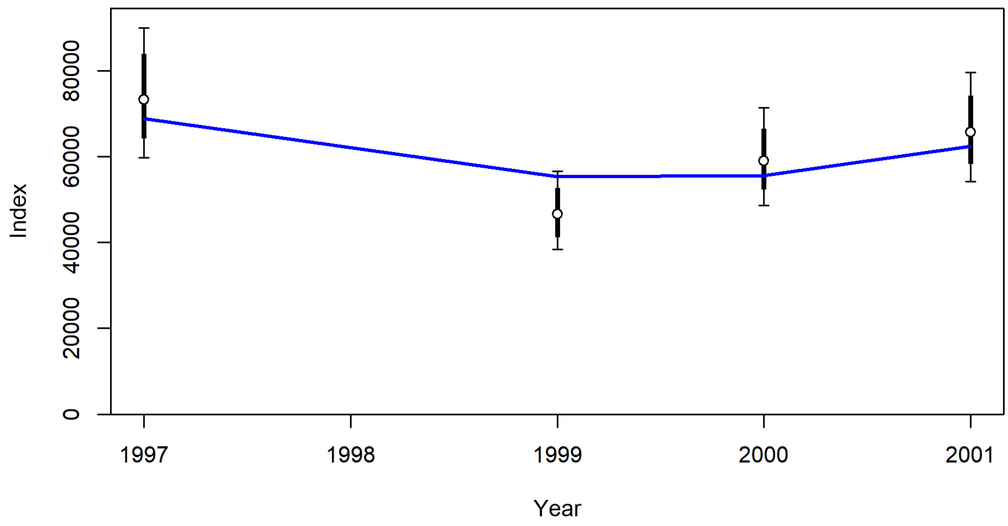


Figure 37: Fit to the Alaska Fisheries Science Center Slope Survey.

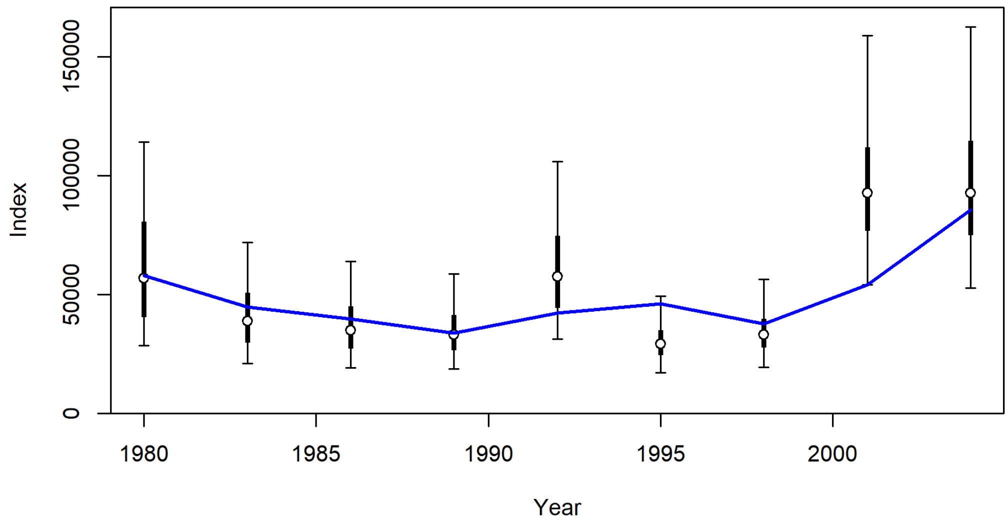


Figure 38: Fit to the Triennial Shelf Survey.

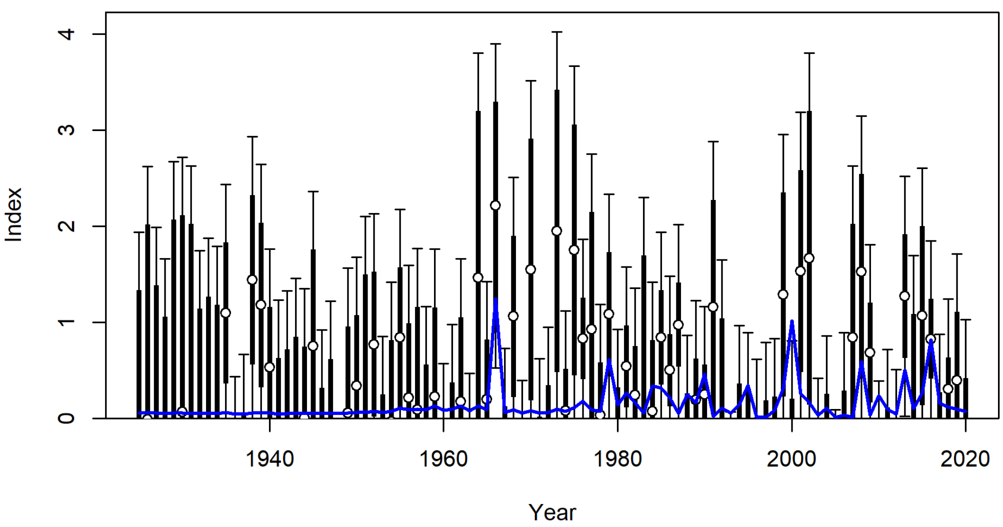


Figure 39: Fit to the sea-level index of recruitment.

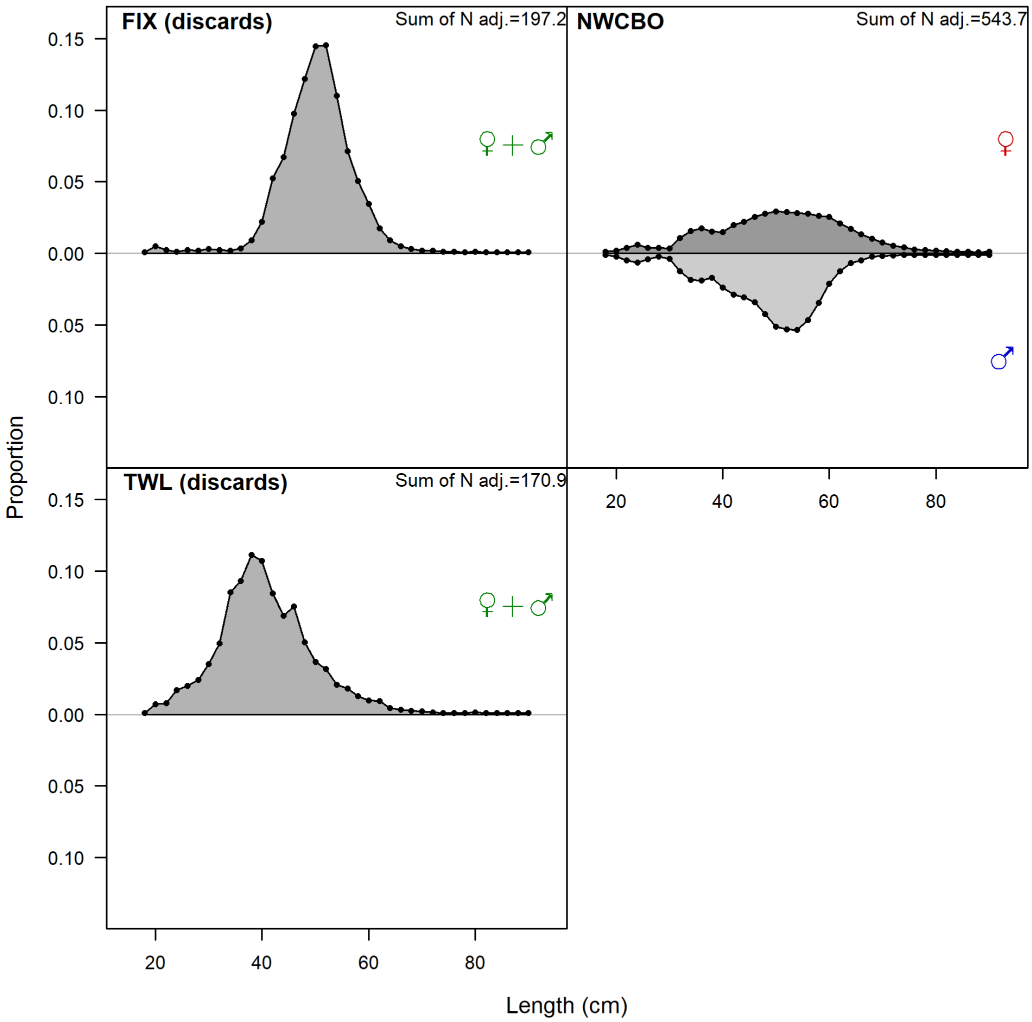


Figure 40: Length compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportions for sex-specific data.

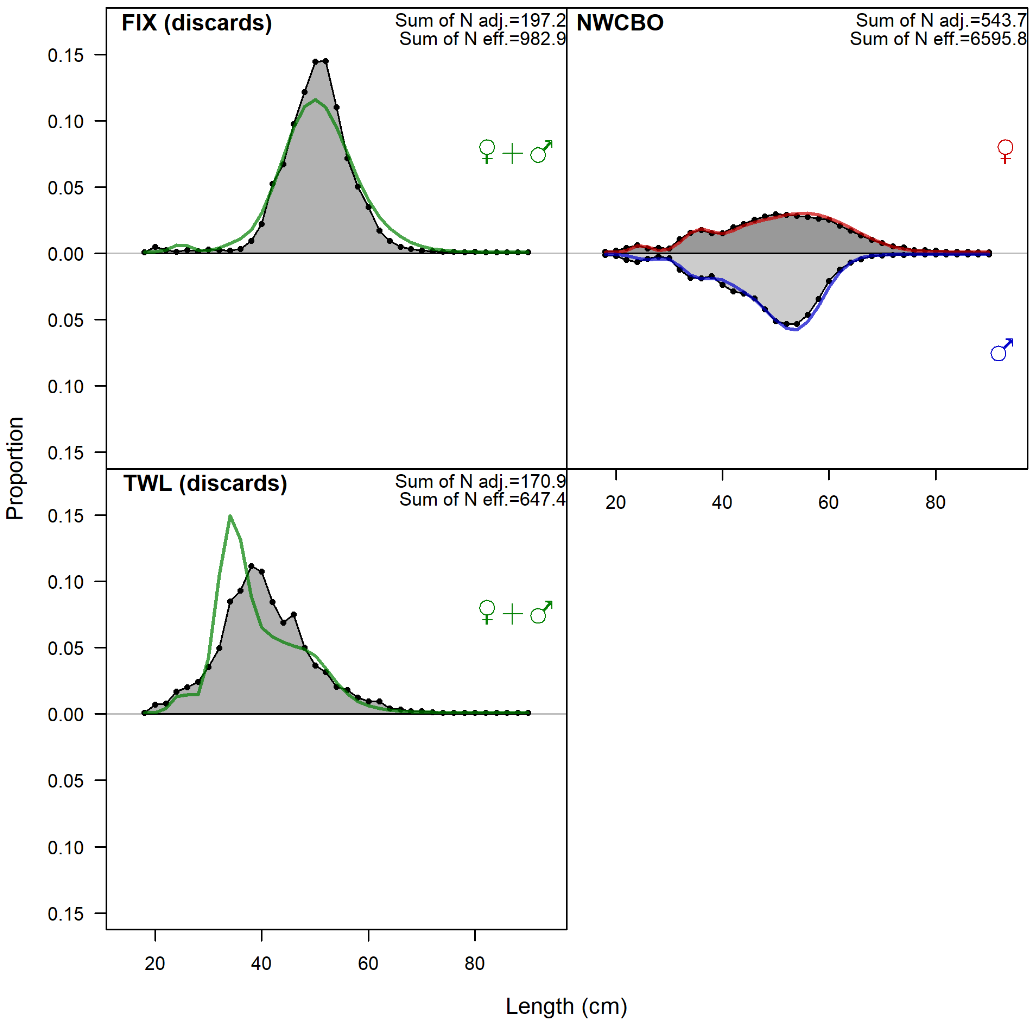


Figure 41: Length compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportions for sex-specific data. Fits are shown using solid lines.

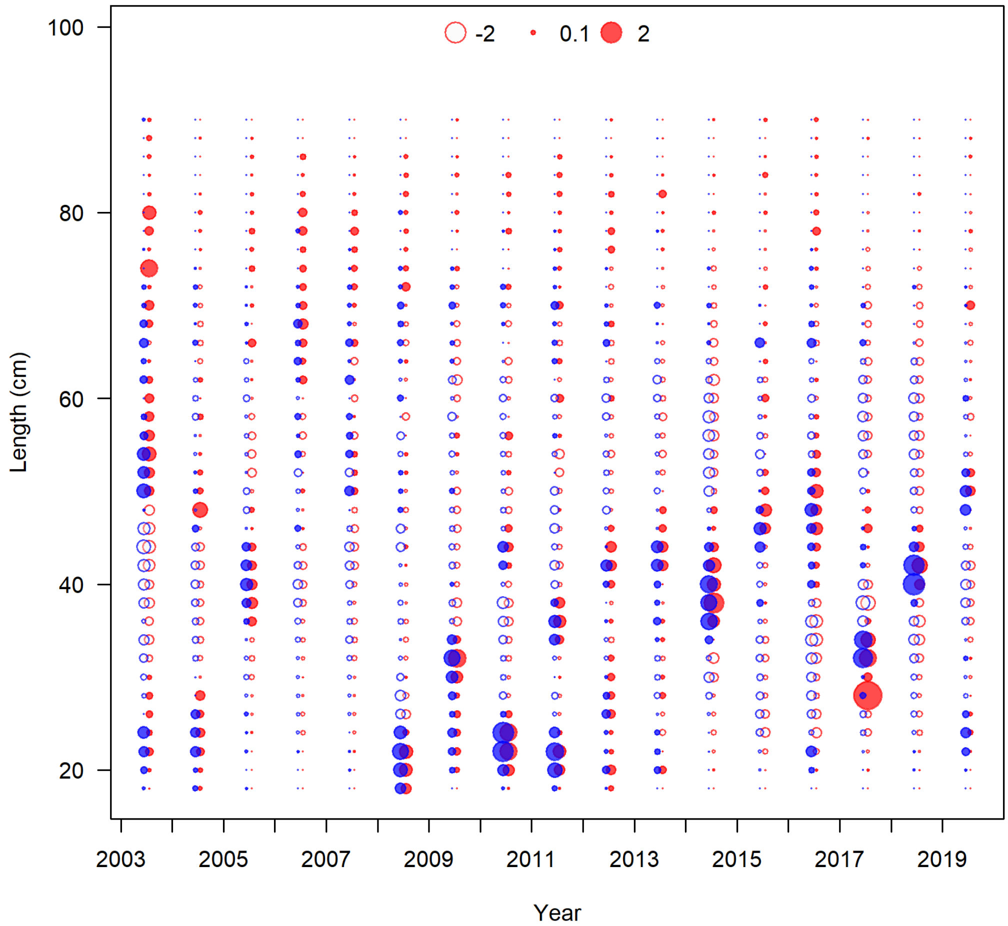


Figure 42: Pearson residuals for the fits to West Coast Groundfish Bottom Trawl length compositions. Filled circles represent positive residuals(observed-expected) and red and blue indicate females and males, respectively.

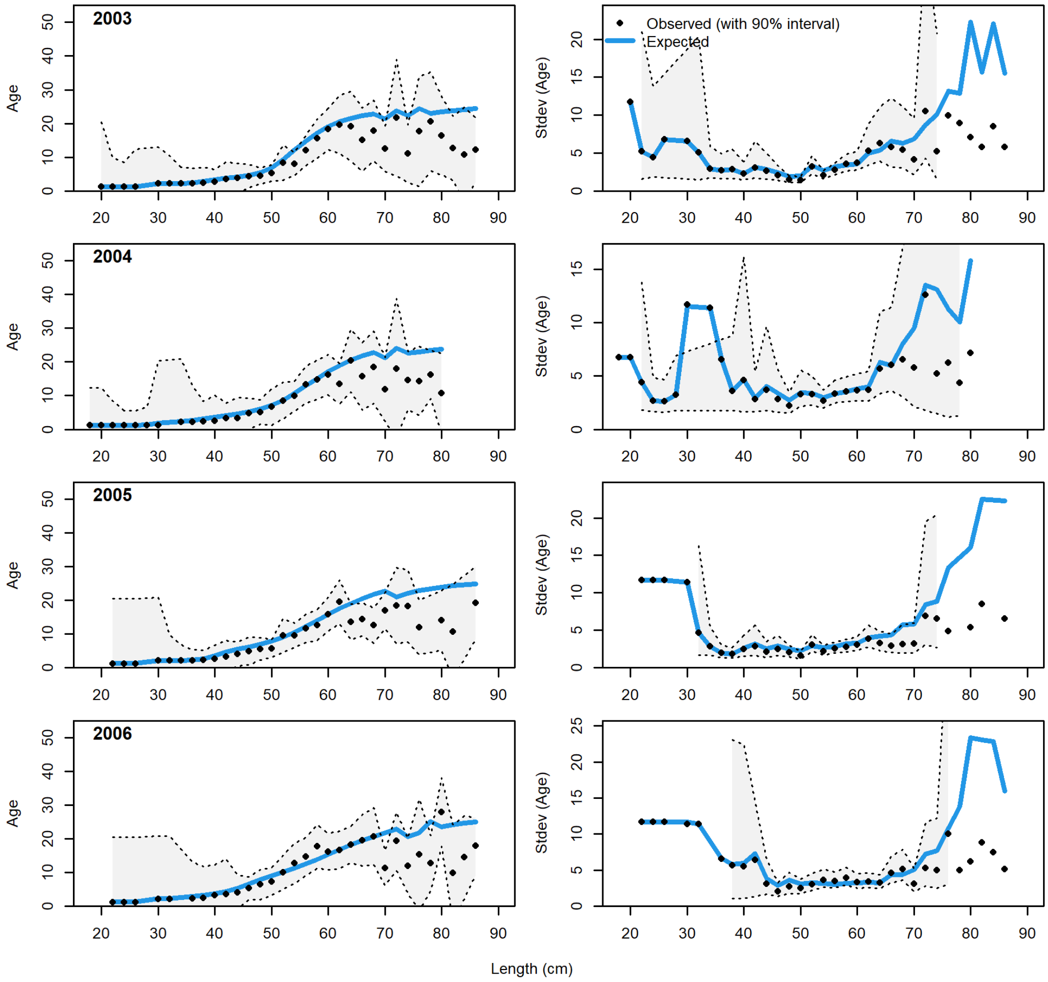


Figure 43: Year-specific conditional age-at-length data (left) and standard deviation (stdev) at age (right) from the West Coast Groundfish Bottom Trawl Survey. Shaded areas are confidence intervals based on adding 1.64 standard errors of the mean to the mean age and 90% intervals from a chi-square distribution for the stdev of mean age.

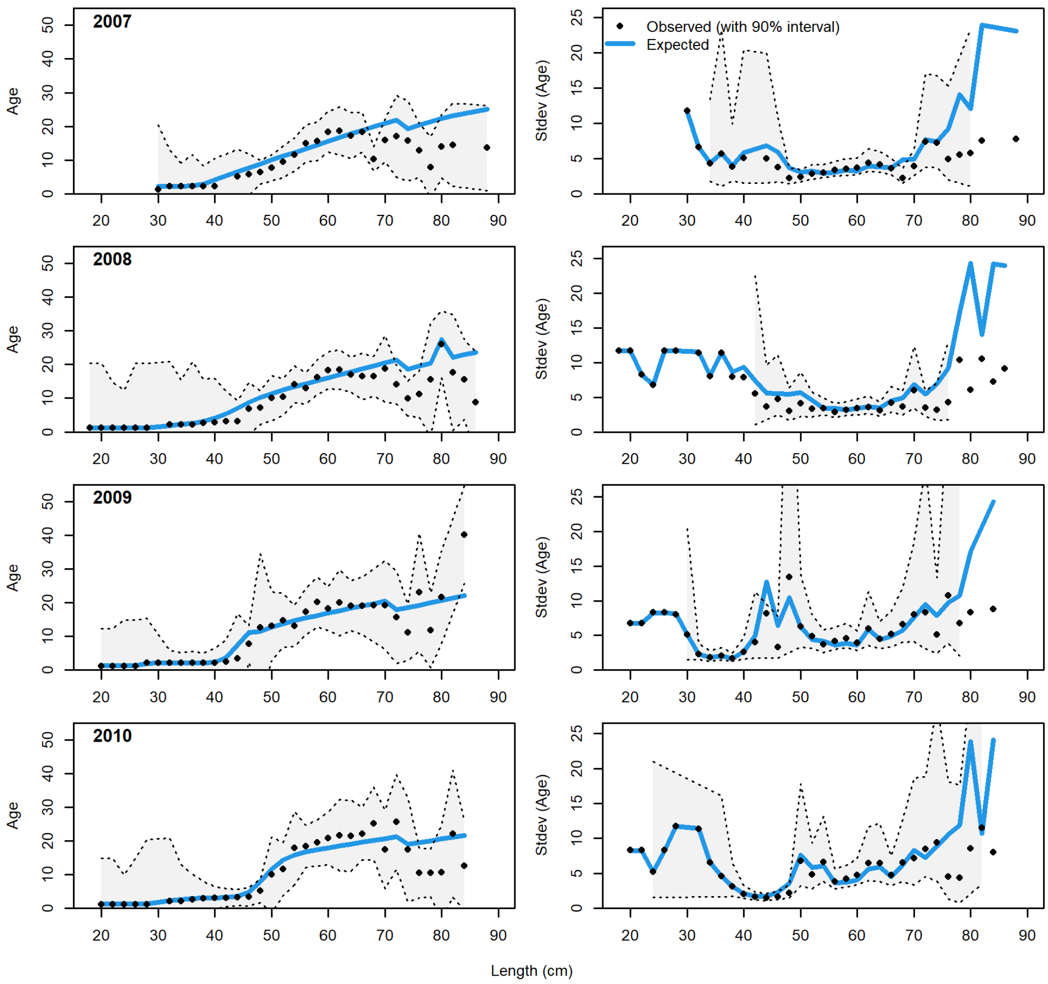


Figure 44: The continuation of Figure 43 but for more recent years.

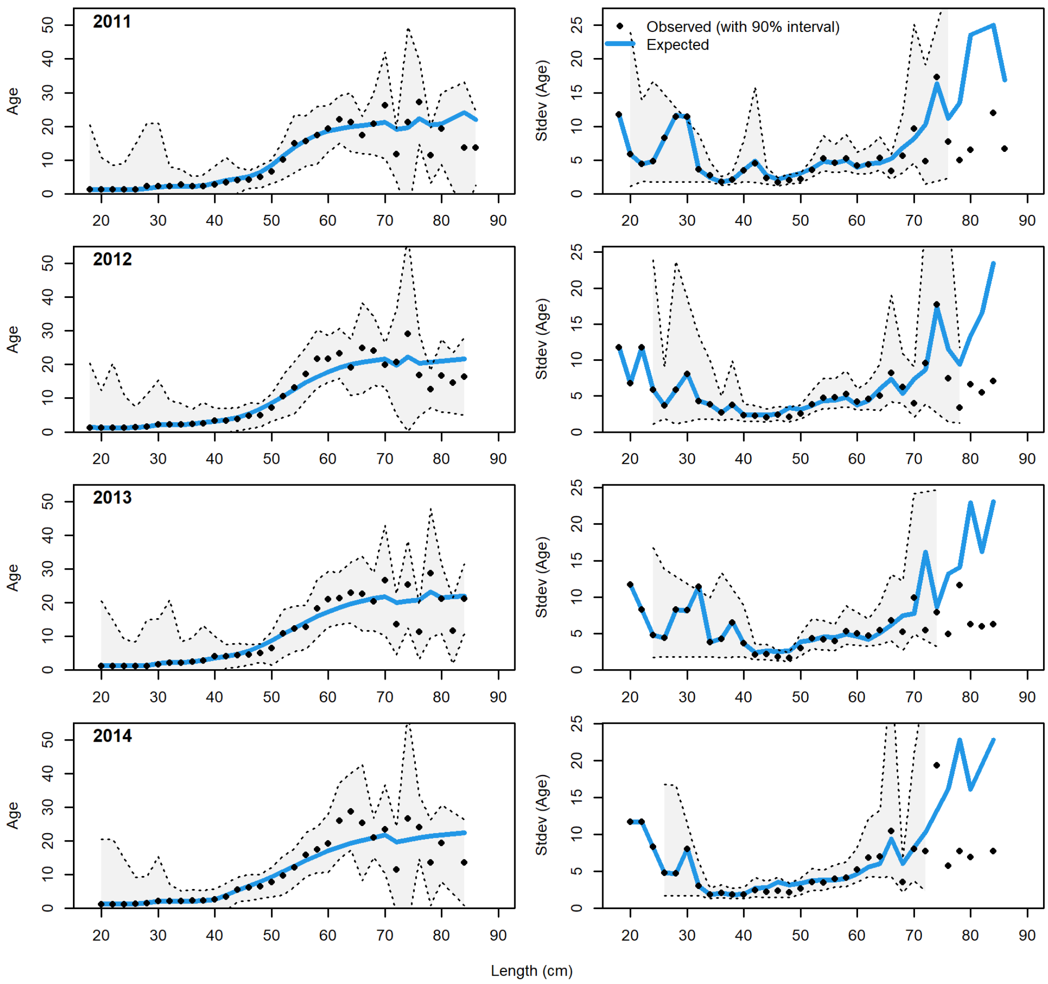


Figure 45: The continuation of Figure 43 but for more recent years.

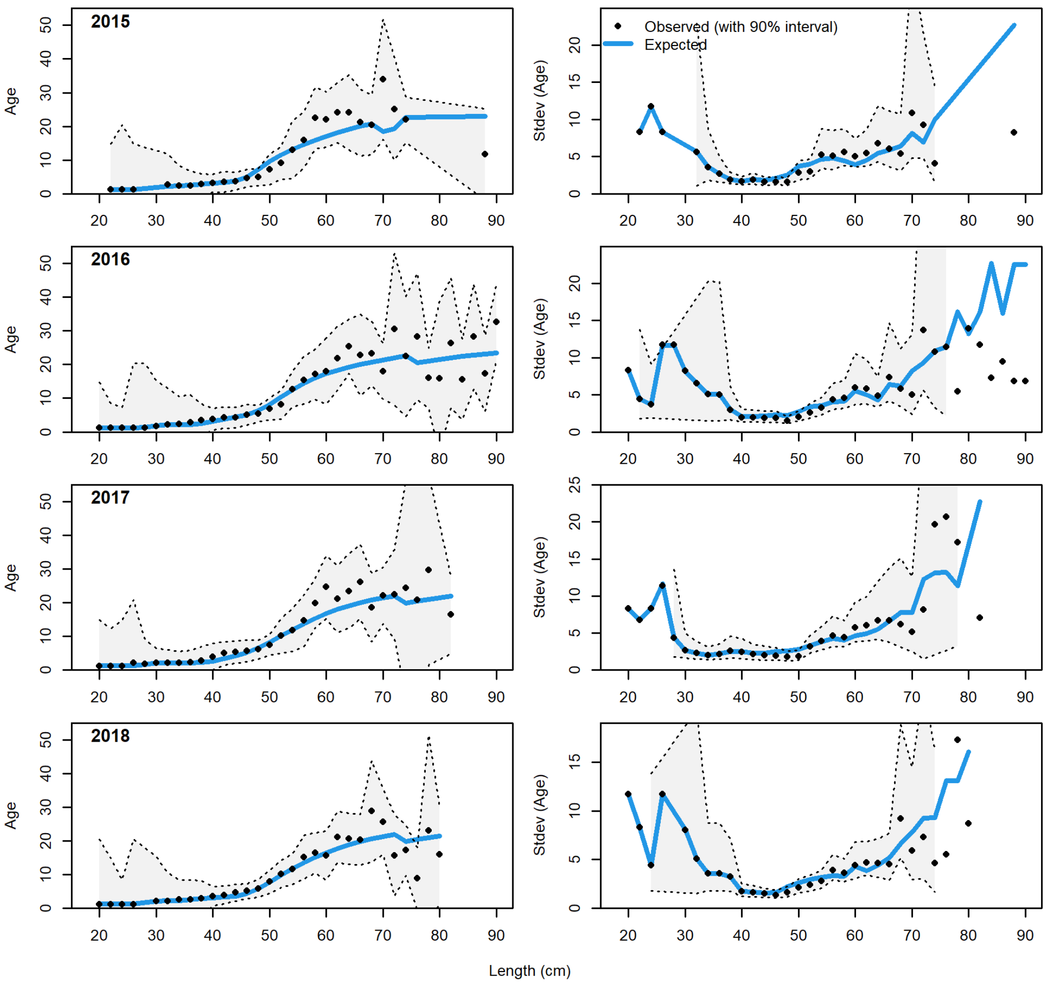


Figure 46: The continuation of Figure 43 but for more recent years.

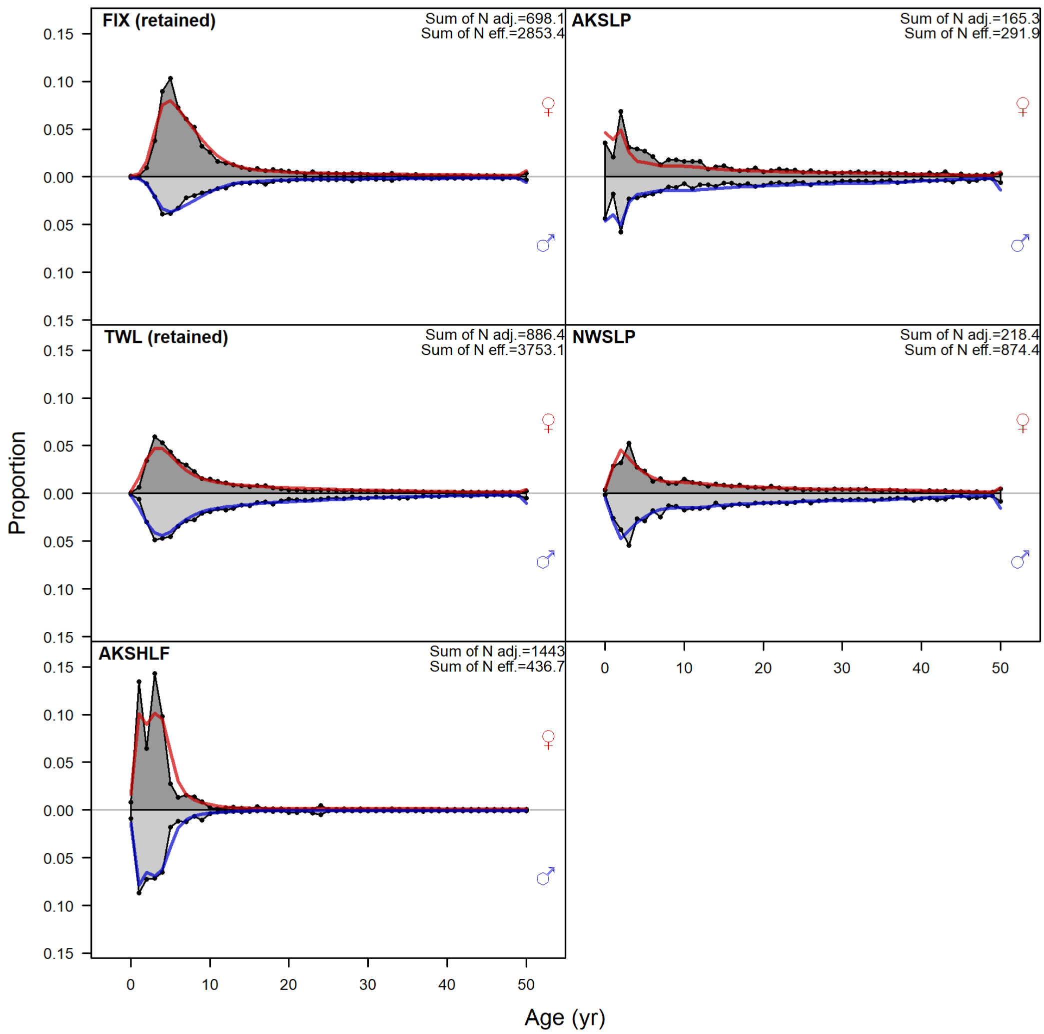


Figure 47: Age compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportionsfor sex-specific data. Fits are shown using solid lines.

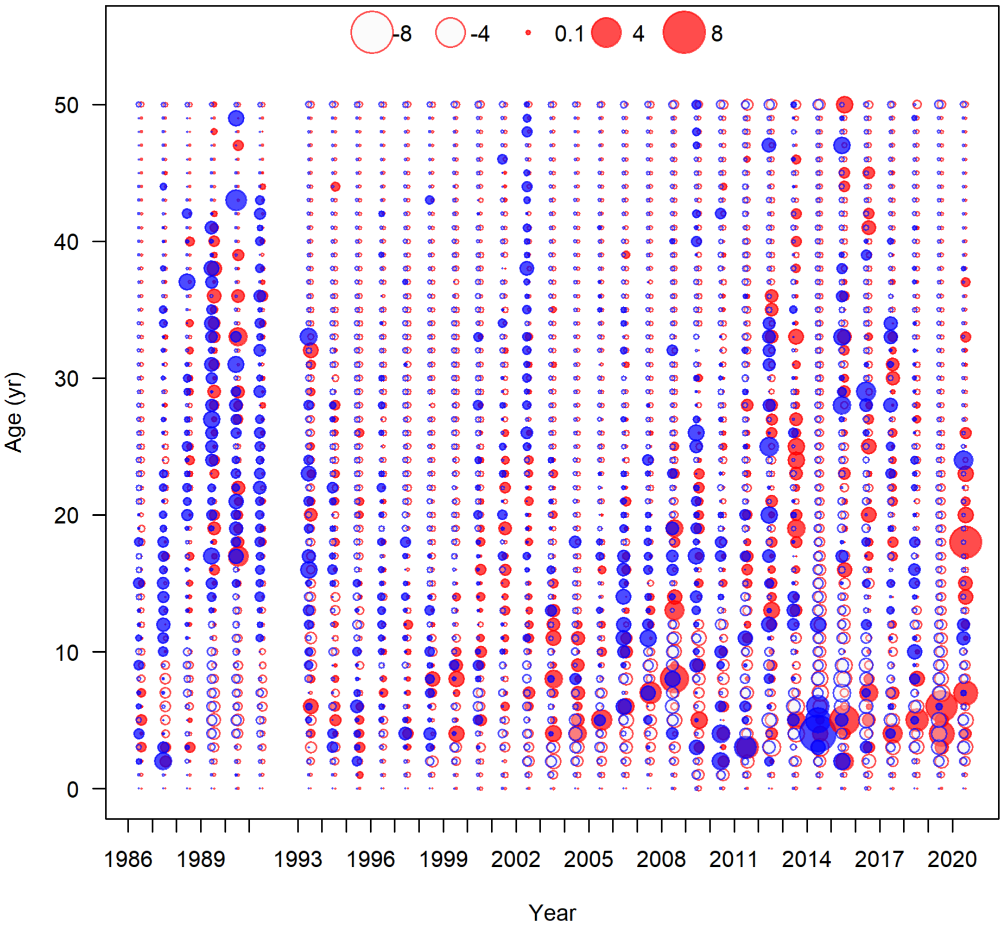


Figure 48: Pearson residuals for the fits to the fixed gear retained age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

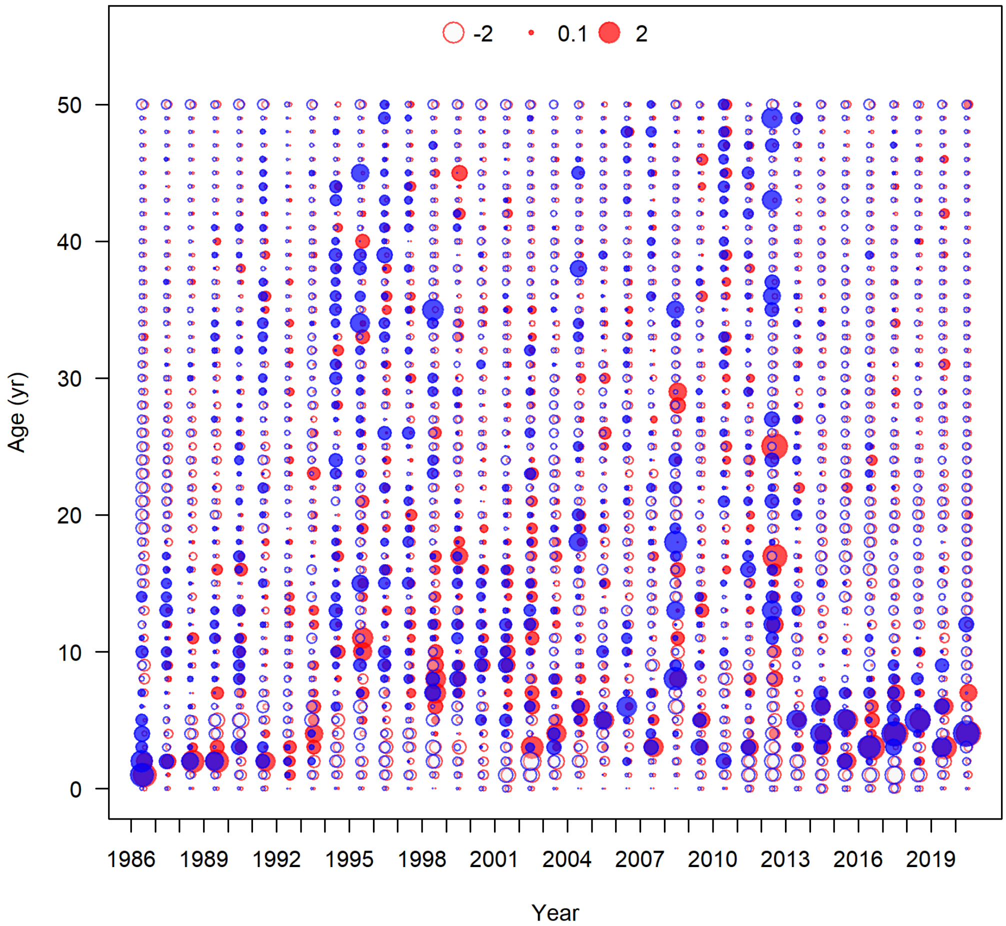


Figure 49: Pearson residuals for the fits to the trawl gear retained age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

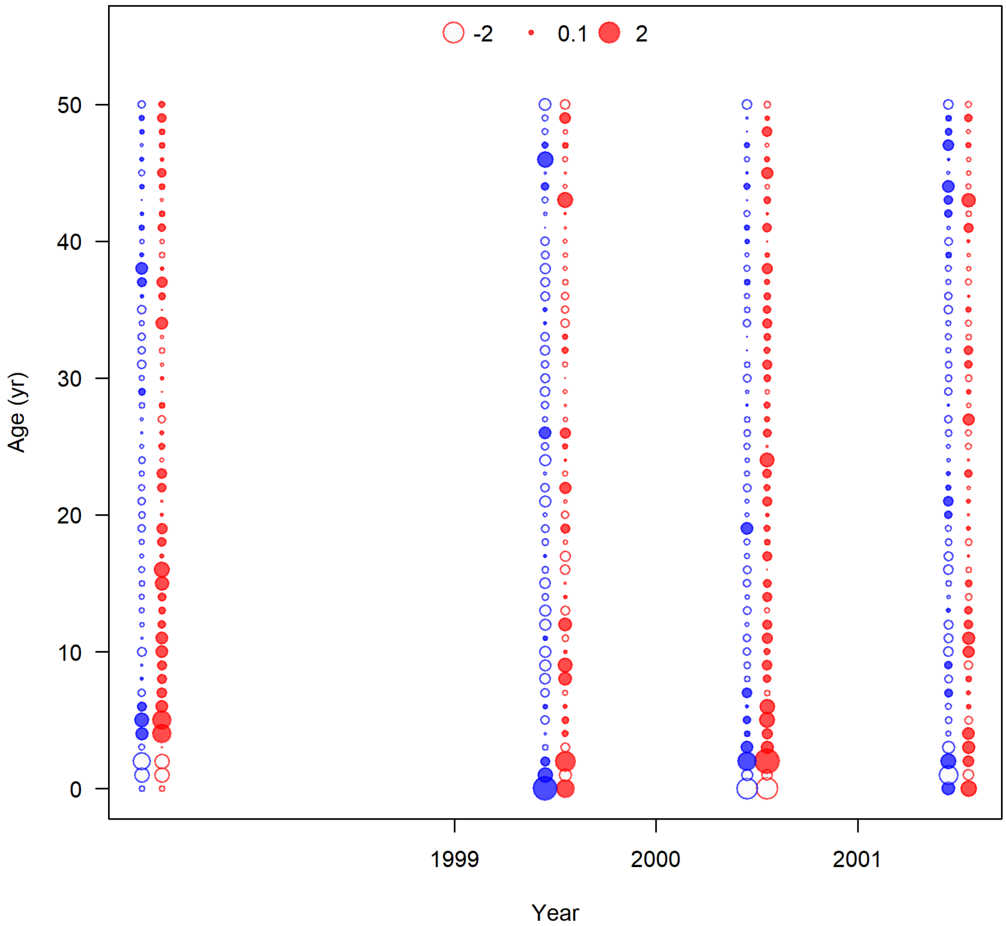


Figure 50: Pearson residuals for the fits to the Alaska Fisheries Science Center Slope Survey age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

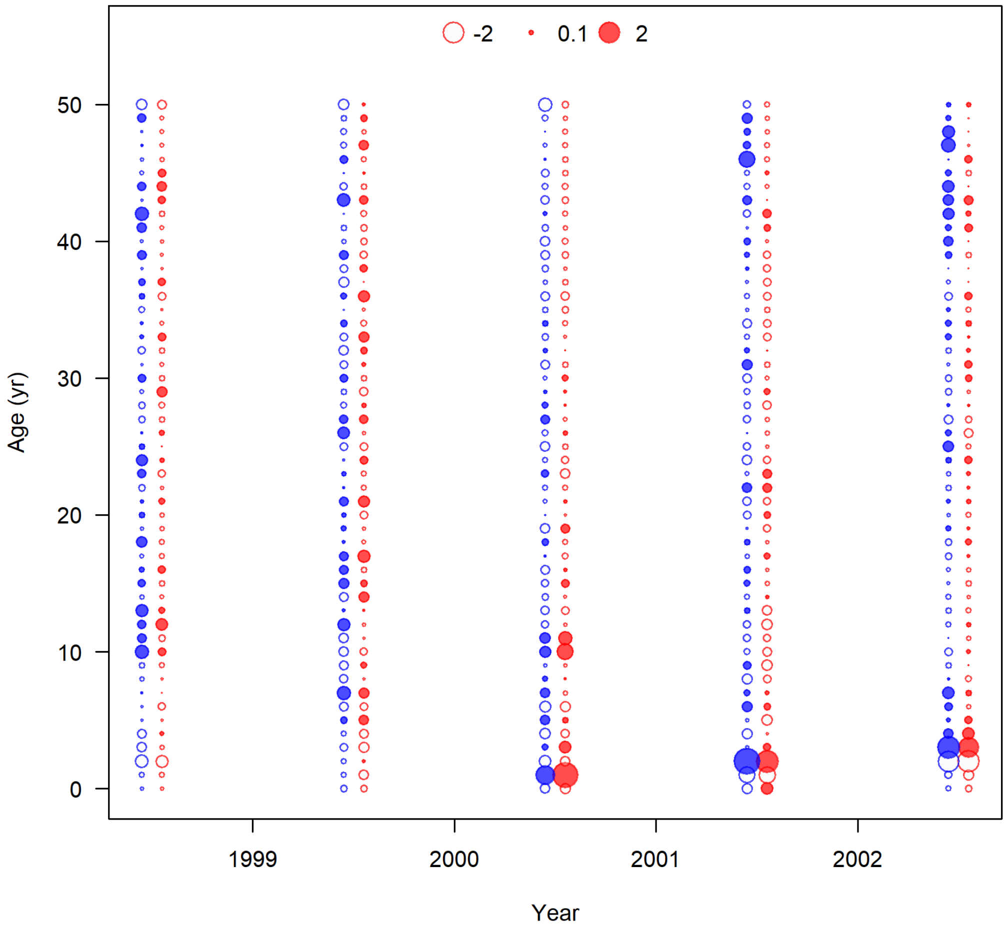


Figure 51: Pearson residuals for the fits to the Northwest Fisheries Science Center Slope Survey age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.

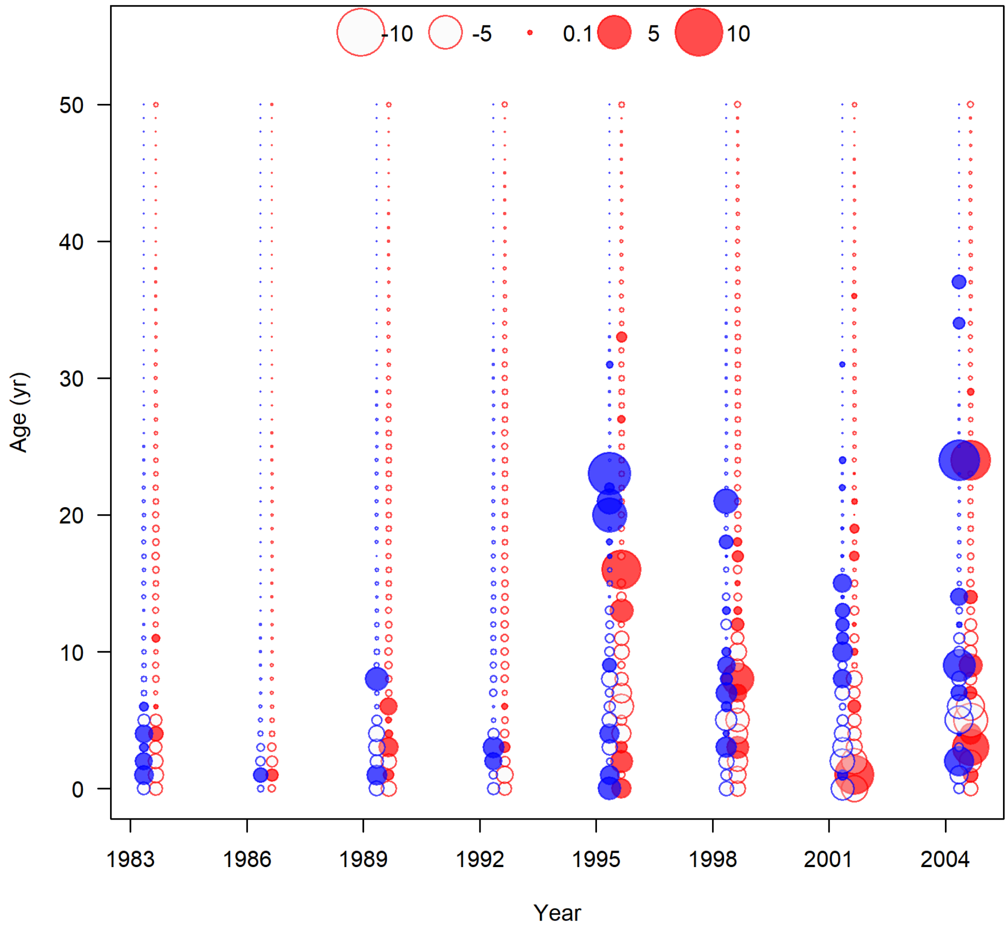
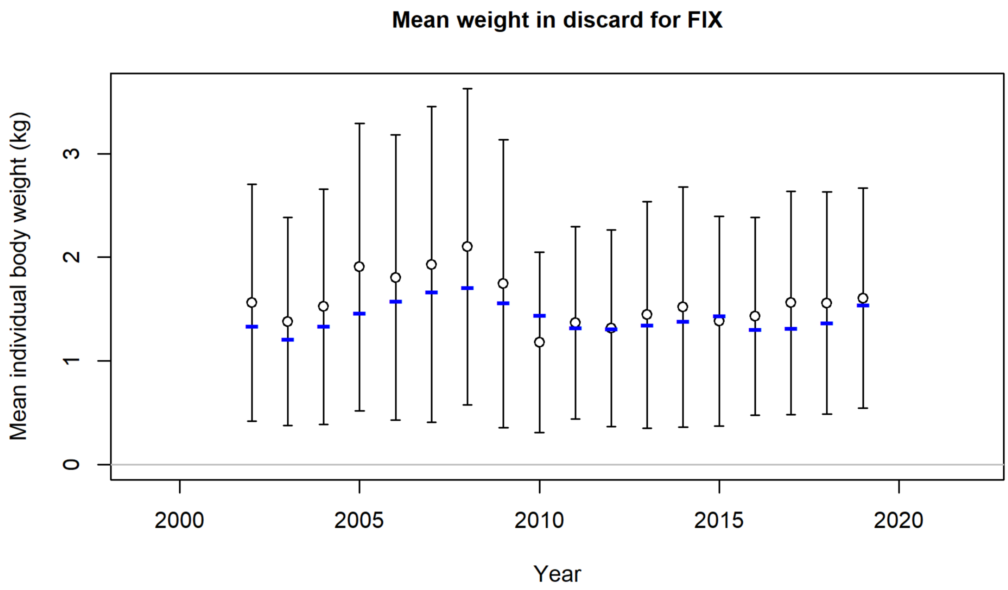


Figure 52: Pearson residuals for the fits to the Triennial Shelf Survey age-composition data. Filled circles represent positive residuals (observed-expected) where red and blue are female and male, respectively.



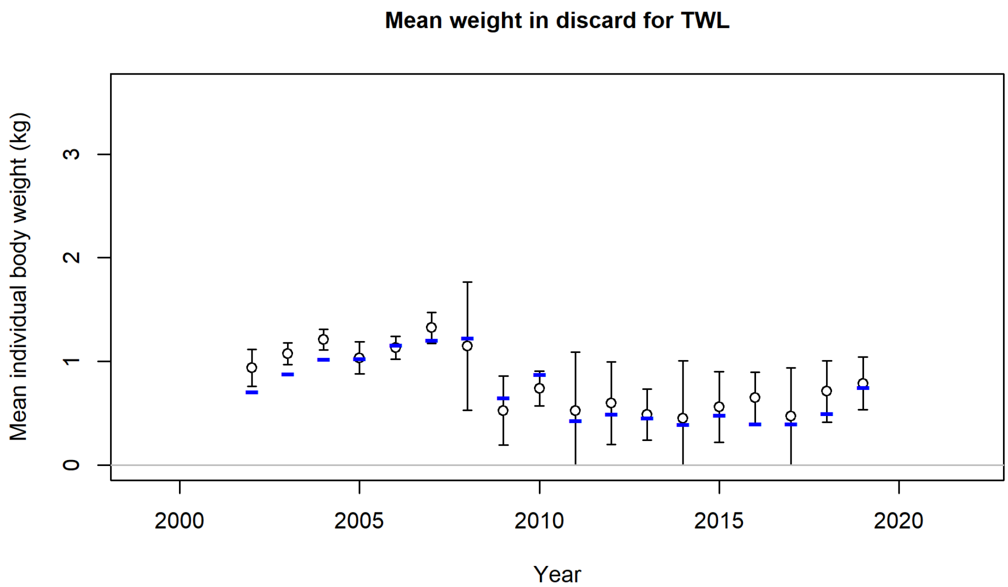


Figure 53: Fit to the fishery discard mean body weight data.

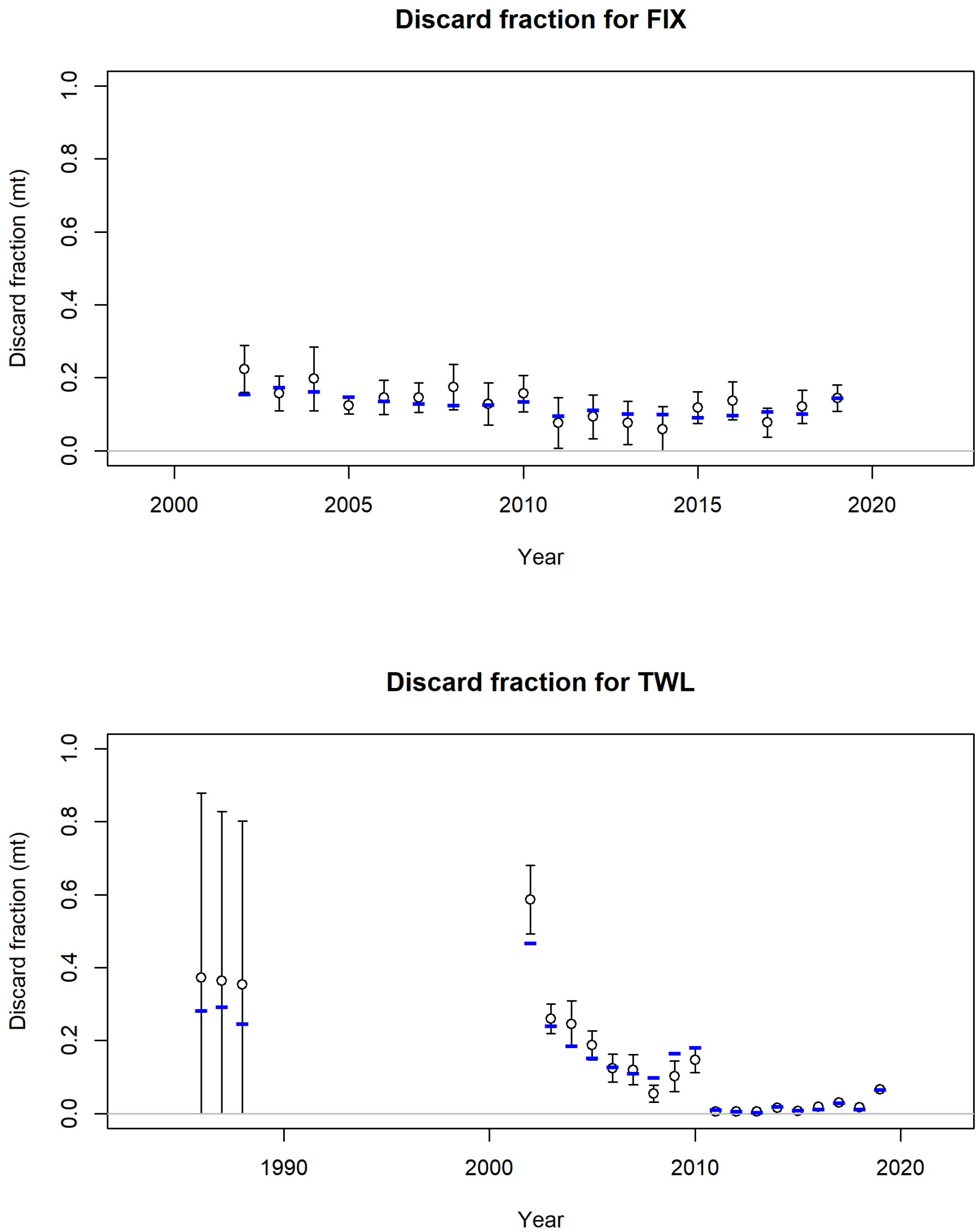


Figure 54: Fit to the fishery discard fraction data.

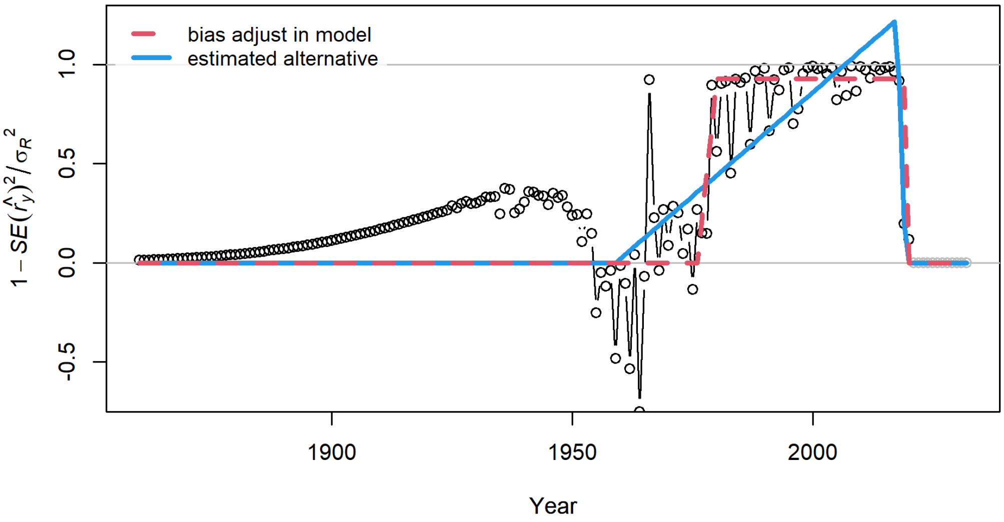


Figure 55: Estimated recruitment deviation time-series (upper panel) and bias adjustment relative to the ratio of recruitment estimation uncertainty and σ_r (lower panel).

UPDATE PLOT BASED ON OSH COMMENTS

UPDATE H INTERPOLATED FIG

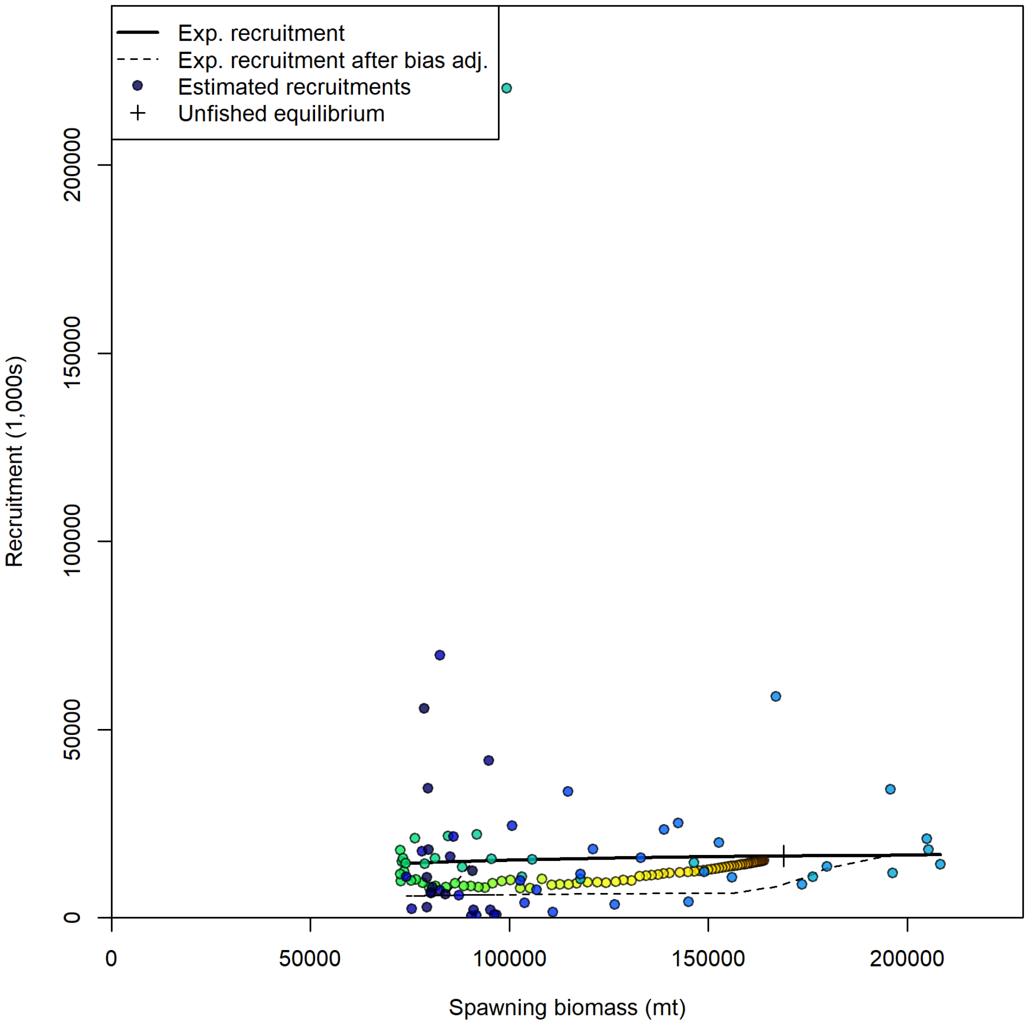


Figure 56: Estimated stock-recruitment function for the base model.

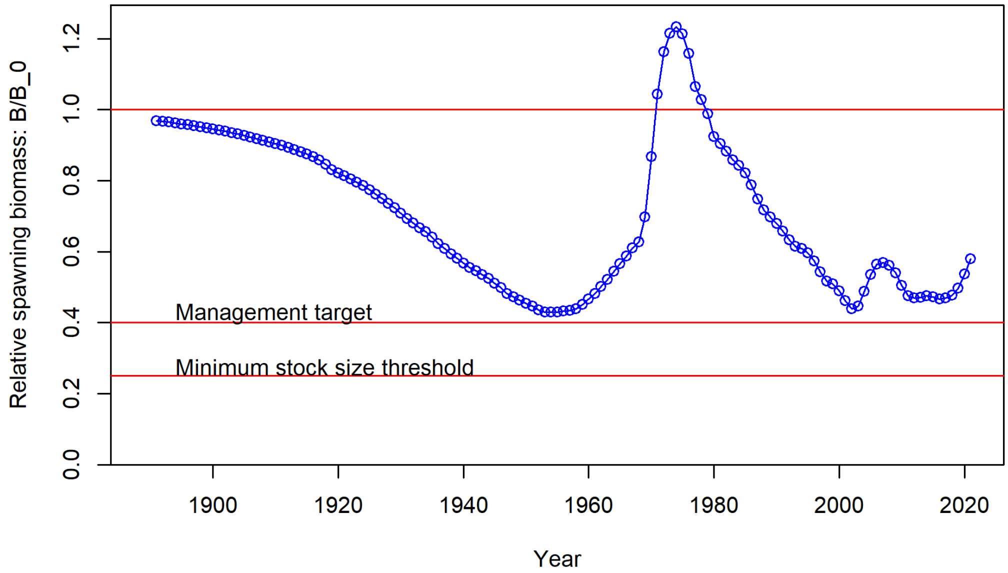


Figure 57: Estimated spawning biomass time-series for the base model (solid line) with 95% interval(dashed lines).

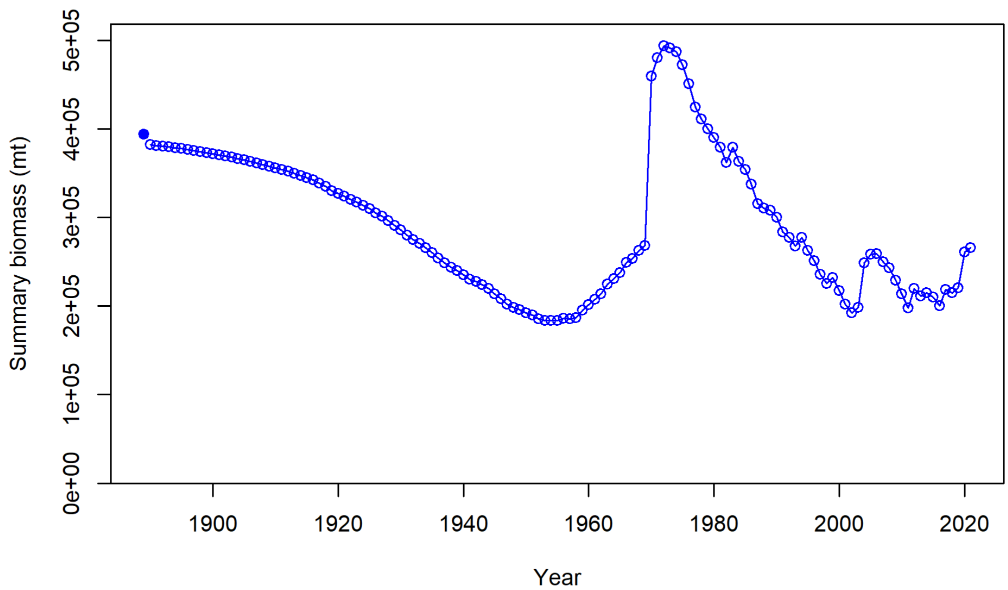


Figure 58: Estimated spawning biomass time-series for the base model (solid line) with 95% interval(dashed lines).

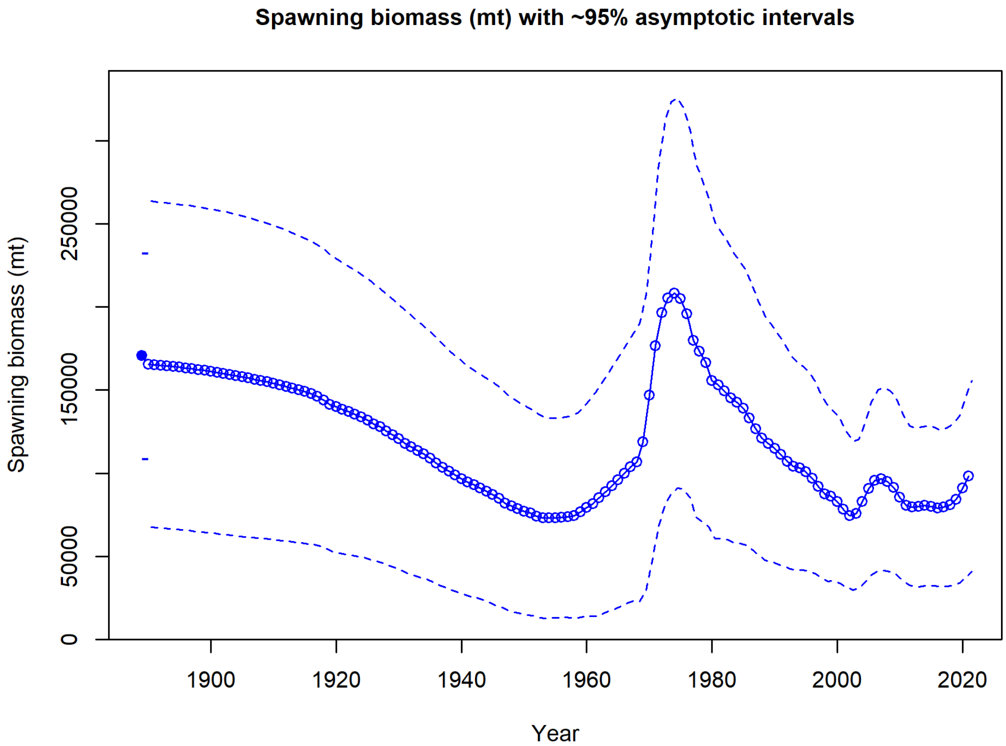


Figure 59: Estimated spawning biomass time-series for the base model (solid line) with 95% interval (dashed lines).

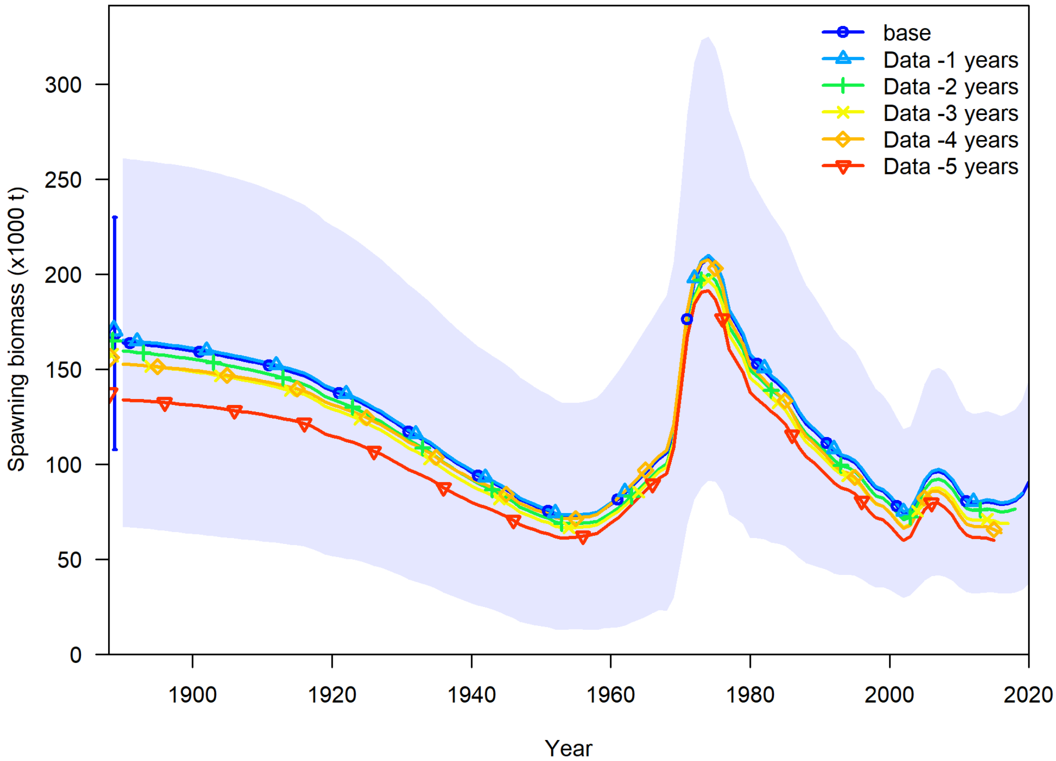


Figure 60: Trends in SSB from a retrospective analysis using the base model for comparison.

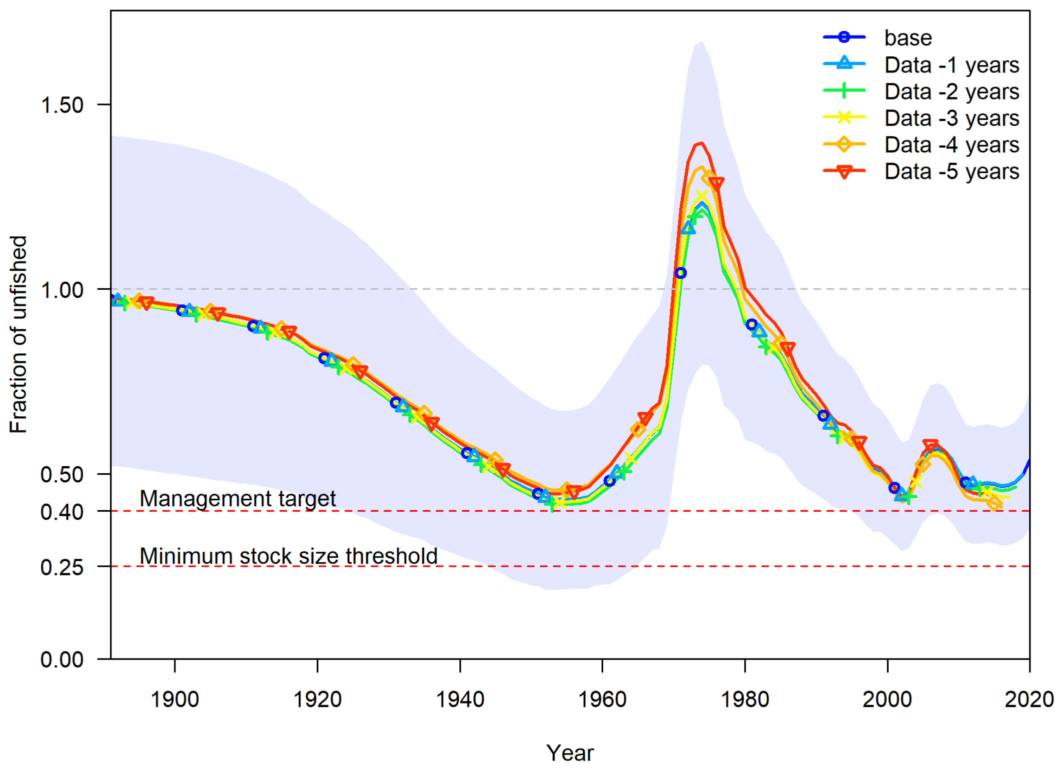


Figure 61: Trends in depletion from a retrospective analysis using the base model for comparison.

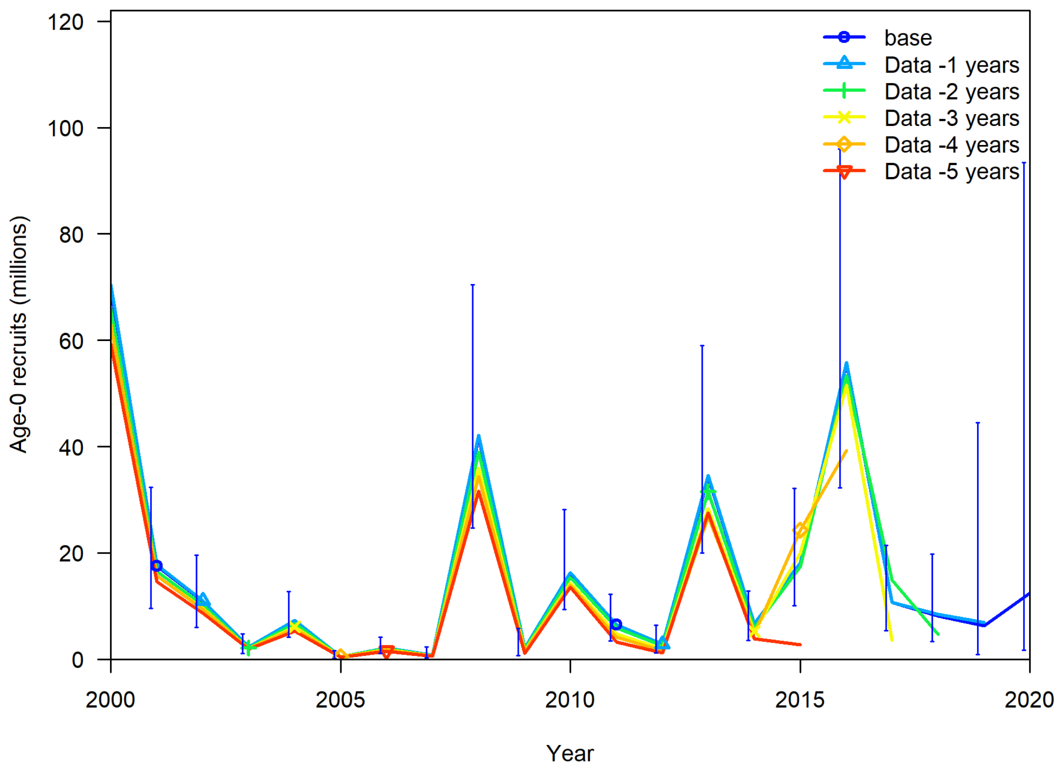


Figure 62: Trends in last 20 years of recruitment from a retrospective analysis using the base model for comparison.

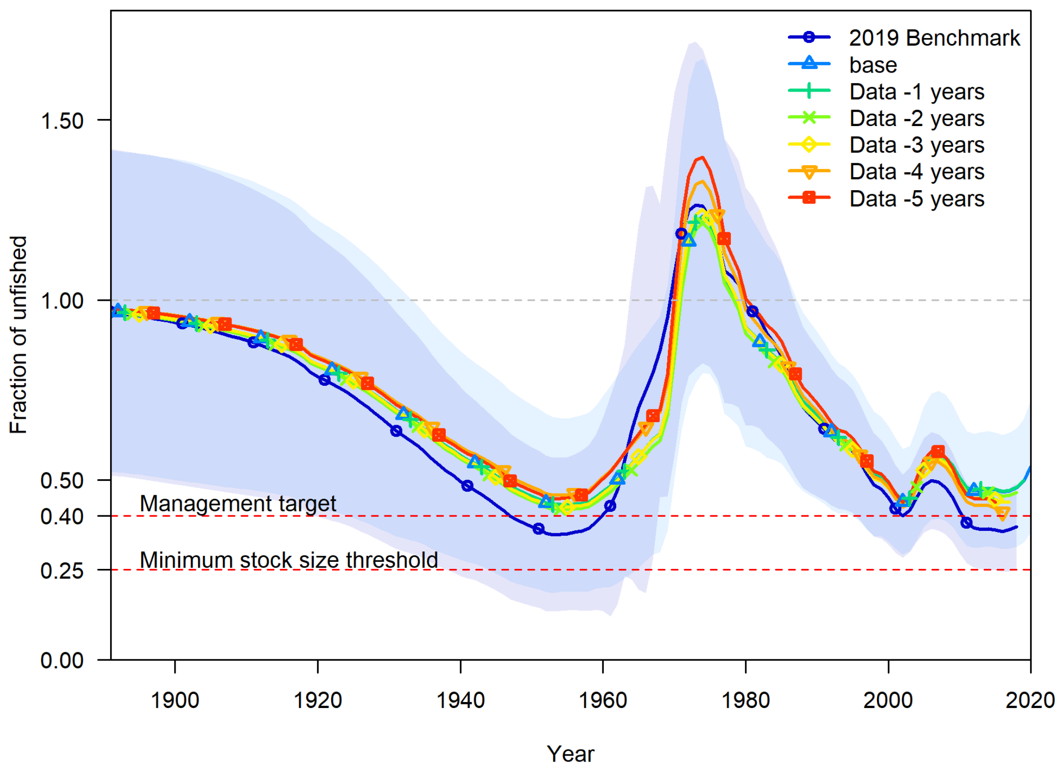


Figure 63: Trends in depletion from a retrospective analysis using the base model, with the 2019 Benchmark model shown for comparison.

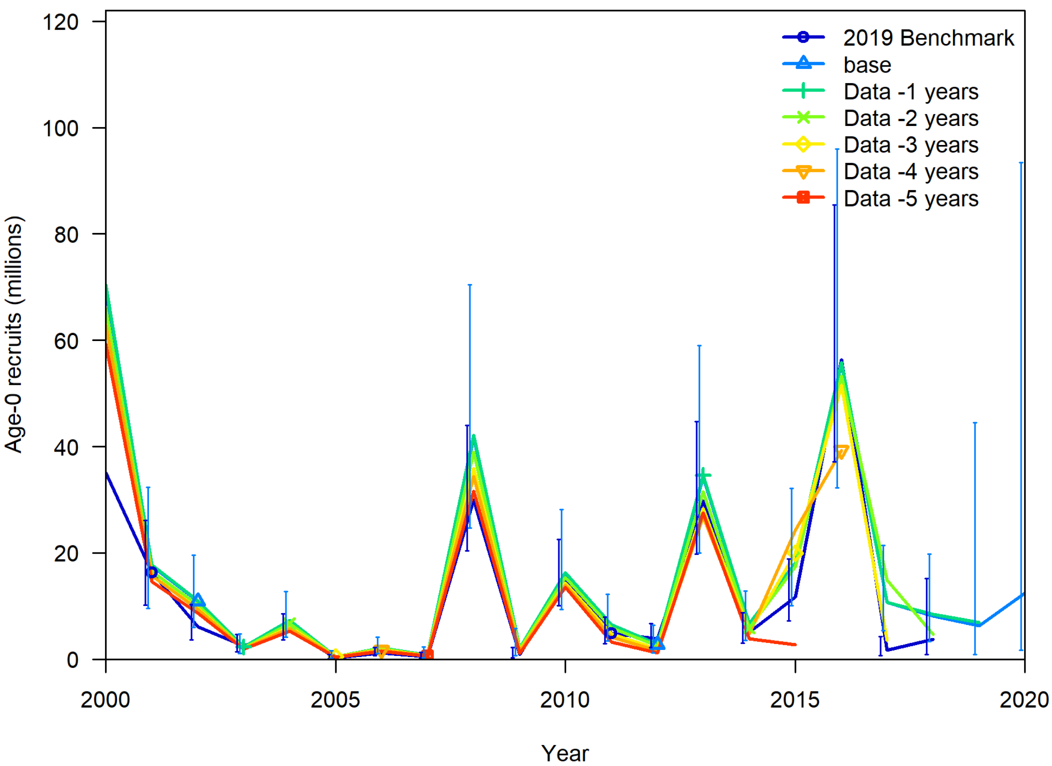


Figure 64: Trends in last 20 years of recruitment from a retrospective analysis using the base model, with the 2019 benchmark model shown for comparison.

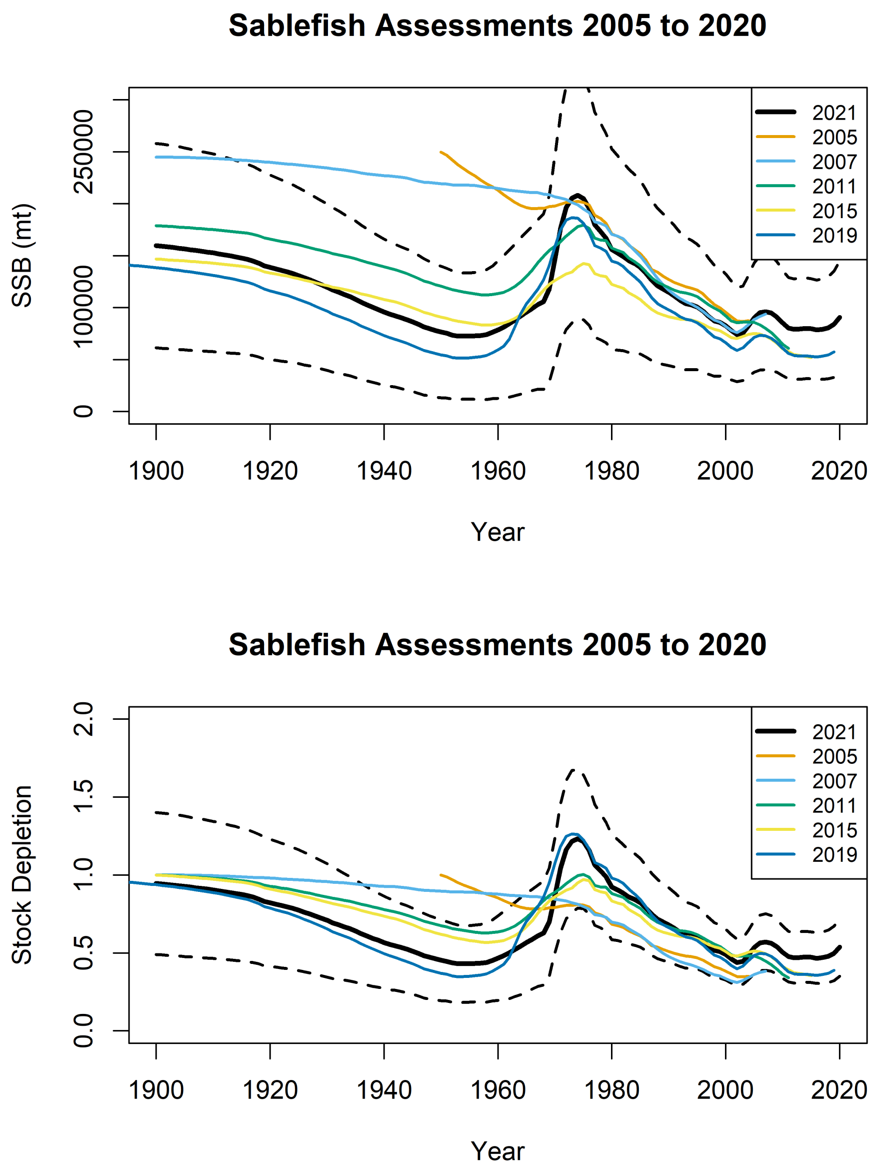


Figure 65: Comparisons of spawning stock biomass (SSB; mt) and relative depletion between the current assessment and the last five modeling exercises performed since 2005. Model-specific trajectories are represented with colored lines and the dashed line is the uncertainty about the currently estimated time series.

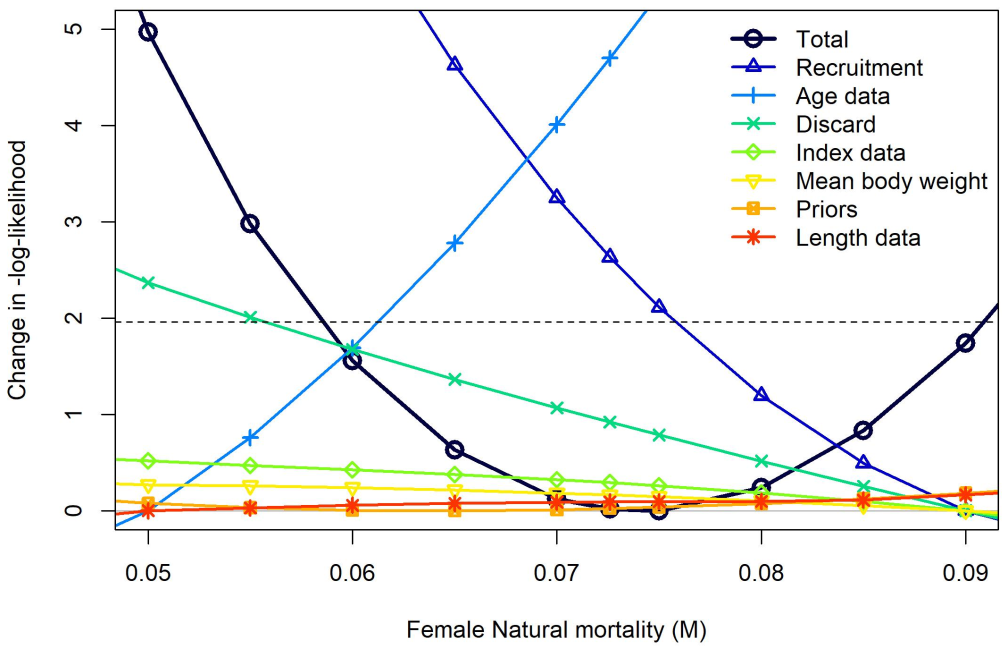


Figure 66: Results of a likelihood profile for female natural mortality (M) by data type.

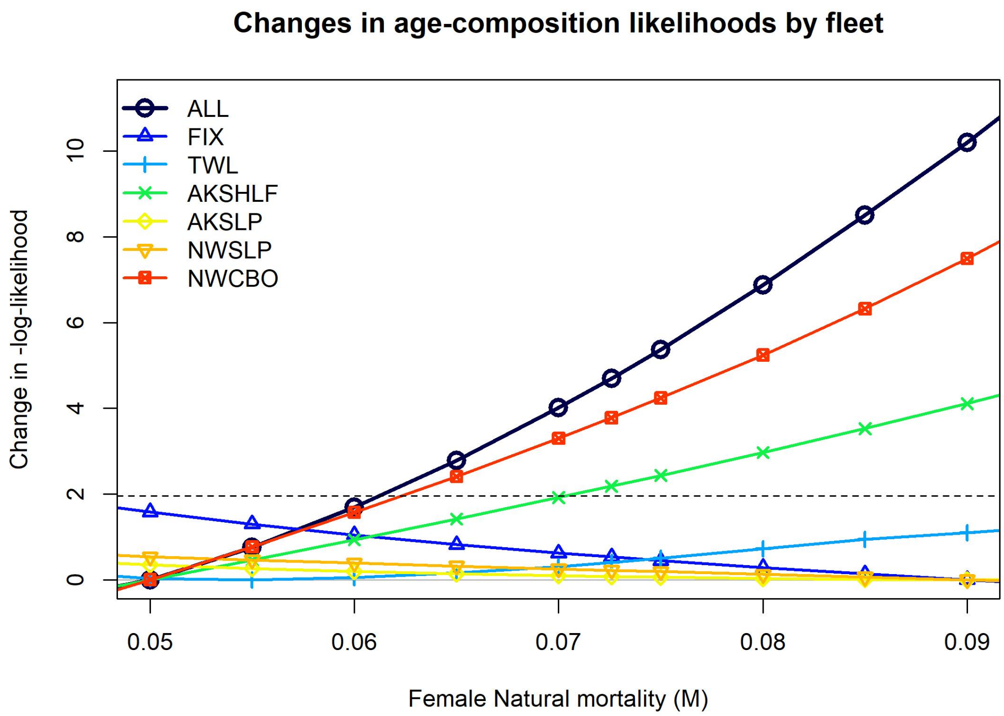


Figure 67: Age likelihoods from a likelihood profile for female natural mortality (M) by data type.

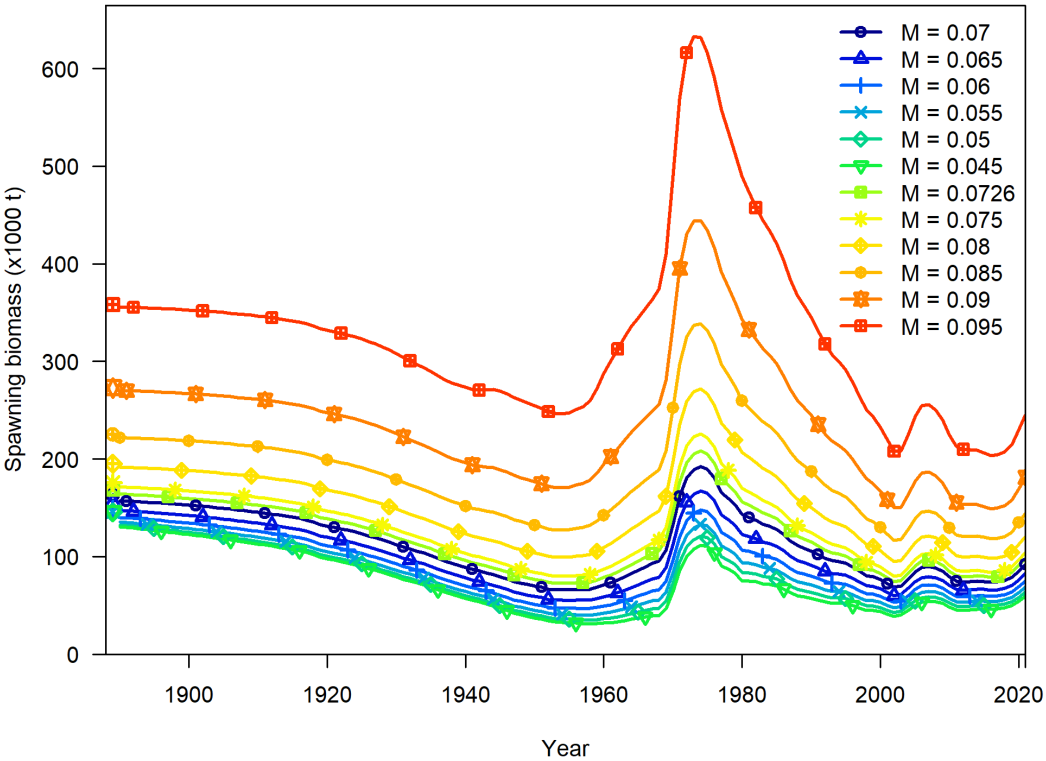


Figure 68: Time-series of spawning stock biomass for different fixed values of female natural mortality(M).

Figure 69: Results of a likelihood profile for equilibrium recruitment (R0) by data type.

Figure 70: Age likelihoods from a likelihood profile for equilibrium recruitment (R0) by data type.

Figure 71: Time-series of relative depletion for different fixed values of equilibrium recruitment (R0).

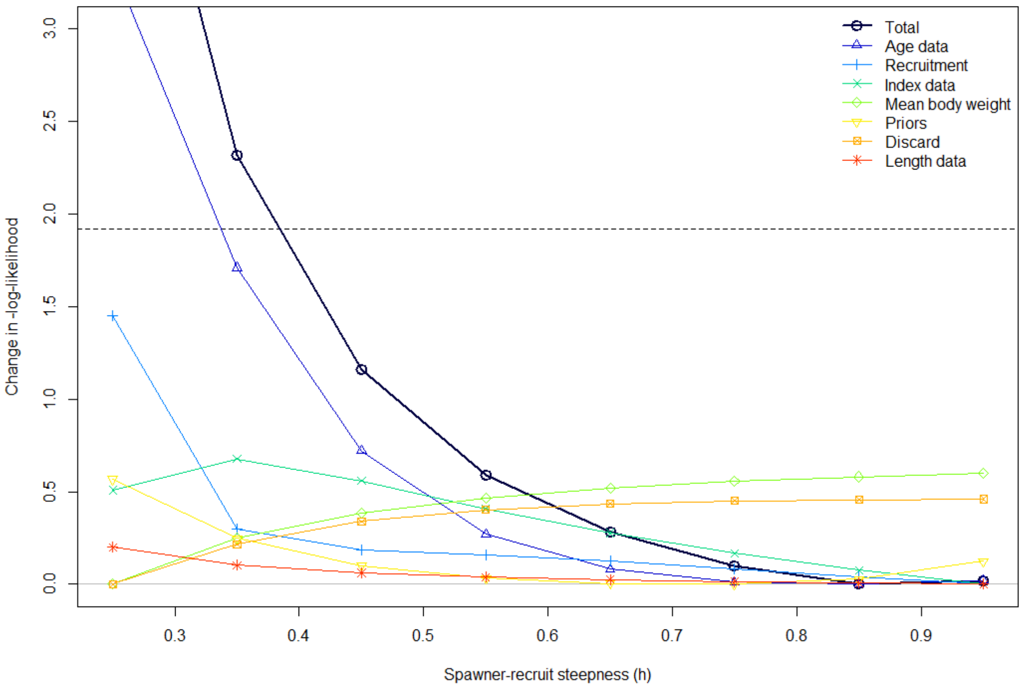


Figure 72: Results of a likelihood profile for steepness (h) by data type.

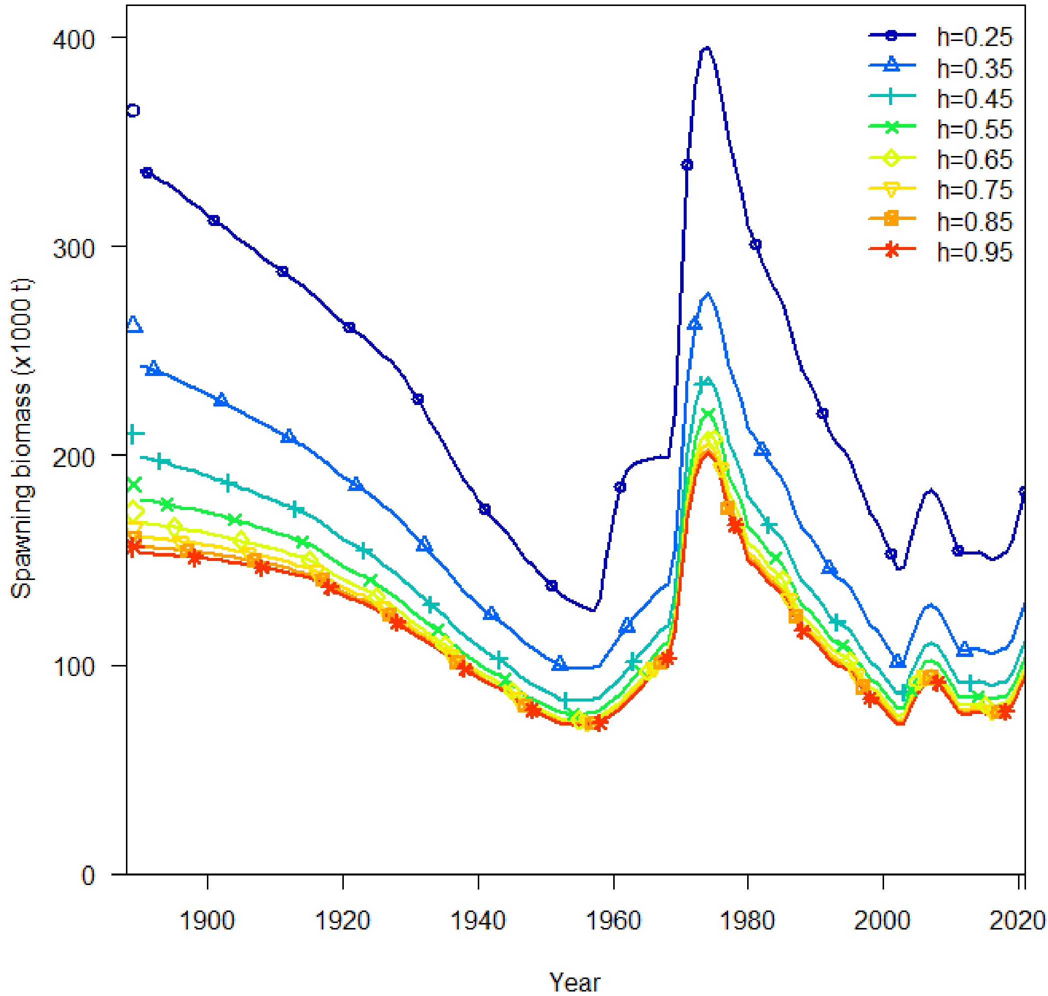


Figure 73: Time-series of spawning stock biomass for different fixed values of steepness (h).