Agenda Item H.5
Attachment 7
(***Full Version Electronic Only***)
September 2019

Status of the sablefish stock in U.S. waters in 2019

DRAFT for submission to the Pacific Fisheries Management Council

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Contents

EXECUTIVE SUMMARY

STOCK

This assessment reports the status of the sablefish (*Anoplopoma fimbria*, or 'black cod') resource off the coast of the United States (U.S.) from southern California to the U.S.-Canadian border using data through 2018. The resource is modeled as a single stock, however sablefish do disperse to and from offshore sea mounts and 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.

ECOSYSTEM CONSIDERATIONS

This assessment includes ecological factors based on the idea that research focused on the linkages within a social-ecological system (SES) and how they increase or decrease sustainability can help inform the management of natural resources (Ostrom, 2009). The SES framework requires consideration of extractive goals and human activities at a level that allows for ecological sustainability while also considering human well-being. Thus, the SES framework facilitates the consideration of environmental and human impacts on sablefish as well as sablefish impacts on the ecosystem and humans (e.g., Levin et al. 2016). An extensive SES analysis for sablefish can be found in Appendix A. This document focuses on the four following topics, which highlight the major aspects considered:

1. results of a Climate Vulnerability Assessment (CVA), which motivates points 2 and 3;
2. environmental drivers of recruitment;
3. shifts in the latitudinal distribution of sablefish biomass and the effects of these shifts on availability of the stock to selected ports; and
4. interaction of the sablefish fishery with other species, specifically whale entanglements.

Points (1) and (2) address environmental impacts on sablefish. Point (3) addresses impacts of sablefish on humans, while point (4) addresses impacts of the sablefish fishery on other species in the ecosystem. Section 2 details the use of a sea-level index as a survey of age-0 recruitment within the stock assessment.

CATCHES

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 by California, Oregon, and Washington, extending landings to the beginning of the U.S. West Coast sablefish fishery.

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 2.65% 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. 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. 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 a. Recent sablefish landings by fleet (mt and relative %) and summed across fleets (mt).

Year	Fixed-gear		Trawl		Total
	mt	%	mt	%	mt
2009	3,889	55.95	3,062	44.05	6,951
2010	4,059	61.51	2,540	38.49	6,599
2011	4,421	71.86	1,731	28.14	6,152
2012	3,669	70.70	1,520	29.30	5,189
2013	2,585	64.78	1,405	35.22	3,990
2014	2,862	68.76	1,300	31.24	4,162
2015	3,540	70.65	1,471	29.35	5,011
2016	3,826	72.13	1,479	27.87	5,305
2017	3,637	68.52	1,671	31.48	5,308
2018	3,550	70.37	1,495	29.63	5,045

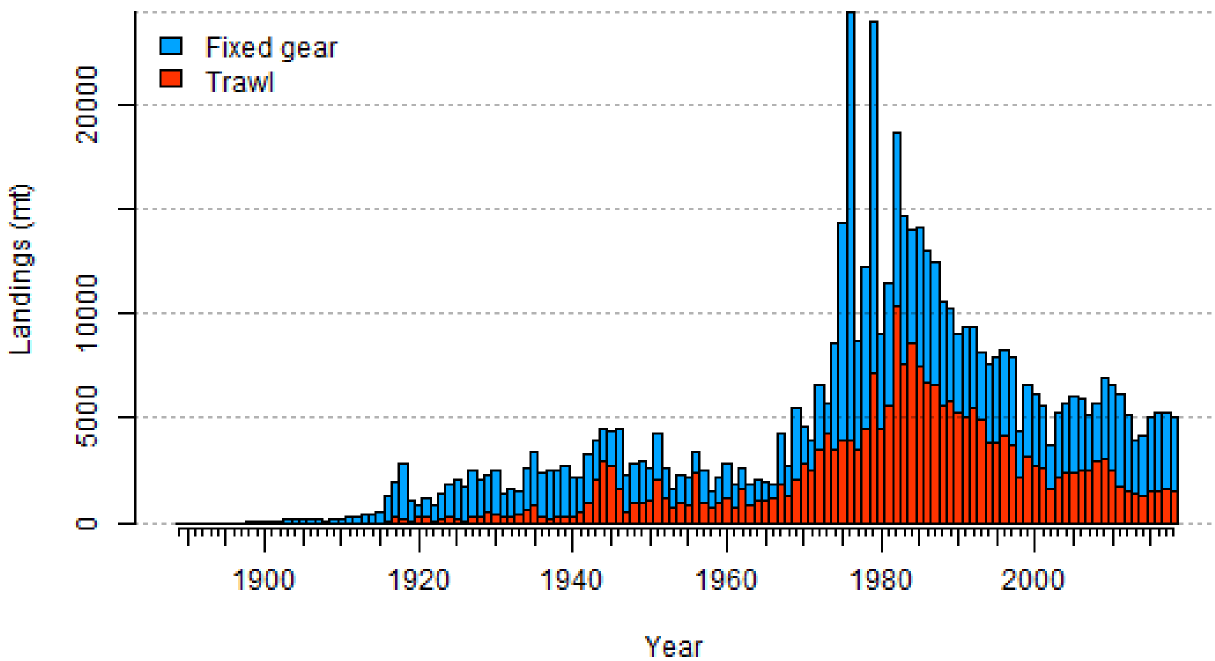

Figure a. Sablefish landings from 1890–2018 summarized by the gear types included in the base model, fixed-gear and trawl. Landings include those from foreign fleets, which are largely responsible for the peaks in 1976 and 1979.

DATA AND ASSESSMENT

The last benchmark stock assessment for sablefish took place during 2011, followed by an update assessment during 2015. Changes and additions between the 2015 update assessment and this assessment are listed in Section 3.2. This assessment used the most recent version of the Stock Synthesis modeling platform (3.30, released 2019-03-09). Primary data sources include landings and age-composition data from the retained catch. In 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 2003-2018. Note that the WCGBT Survey does not access the closed Cowcod Conservation areas in southern California. 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.

Of the externally estimated model parameters, (a) weight-length relationship, (b) maturity schedule, and (c) fecundity relationships, only the fecundity relationship was not updated. 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 explored via sensitivity analyses.

During the 2011 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. This 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.

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 2011 assessment. The larger number of between-lab reads from the AFSC and the NWFSC available for this 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. Therefore, 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 20^{th} 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 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. The point estimate of 2019 spawning biomass from the base model is 57,444 mt, however, the ~95% interval ranges broadly from 32,776 to 82,112 mt. The point estimate of 2019 spawning biomass relative to an unfished state (i.e., depletion) from the base model is 39% of unexploited levels (~95% interval: 26-52%).

Table b. Time series of spawning biomass (mt), age-0 recruitment (1000s), and depletion estimates from the base model and their associated 5% and 95% confidence intervals in parentheses.

Year	Spawning biomass		Age-0 recruitment		Depletion	
2010	60,844	(37,227-84,462)	15,081	(8,933-21,230)	0.41	(0.29-0.53)
2011	56,030	(33,653-78,407)	4,821	(2,413-7,229)	0.38	(0.27-0.49)
2012	54,048	(32,029-76,066)	3,803	(1,612-5,994)	0.37	(0.26-0.48)
2013	53,475	(31,512-75,439)	29,761	(17,536-41,985)	0.36	(0.25-0.47)
2014	53,617	(31,615-75,620)	5,103	(2,320-7,885)	0.36	(0.25-0.47)
2015	53,172	(31,289-75,054)	11,678	(6,017-17,339)	0.36	(0.25-0.47)
2016	52,469	(30,588-74,350)	56,319	(32,578-80,061)	0.36	(0.24-0.47)
2017	53,373	(30,839-75,906)	1,644	(5-3,284)	0.36	(0.25-0.48)
2018	54,624	(31,340-77,909)	3,719	(0-9,716)	0.37	(0.25-0.49)
2019	57,444	(32,776-82,112)	12,857	(0-48,750)	0.39	(0.26-0.52)

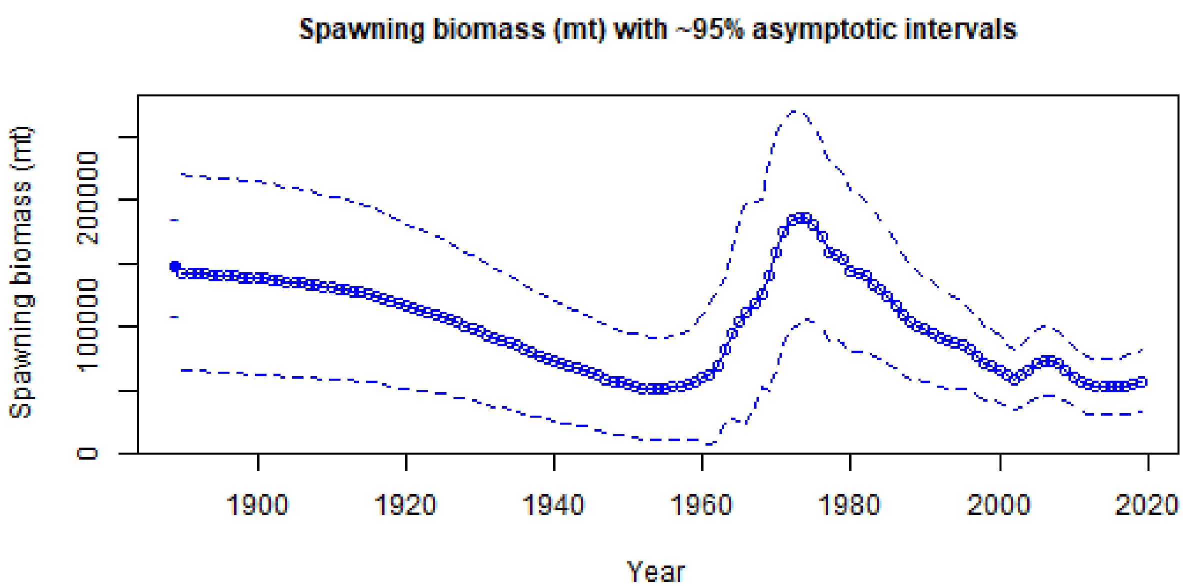

Figure b. Time series of estimated sablefish spawning biomass (mt) from the base model (circles) with ~95% intervals (dashed lines).

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. The 2016 cohort is estimated to be the largest since the mid-1970s.

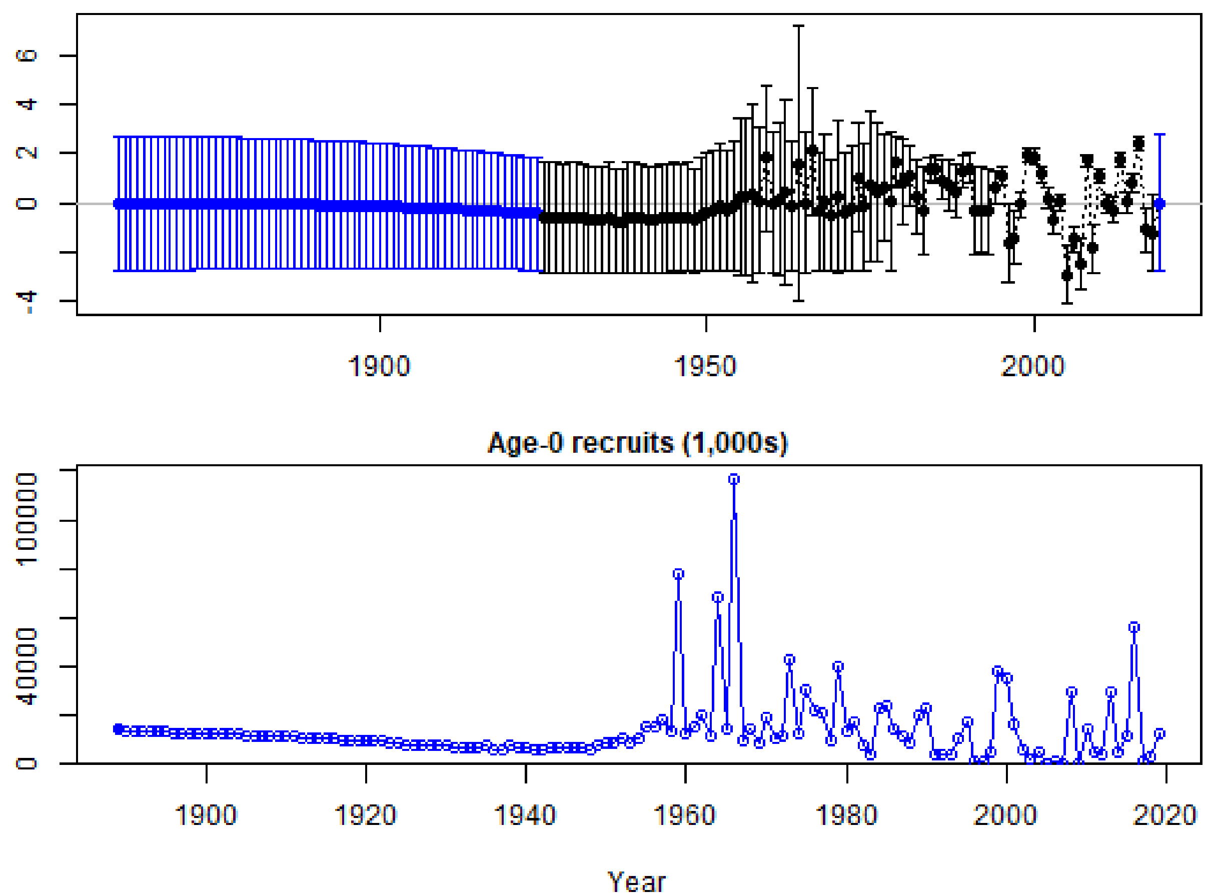

Figure c. Time series of estimated recruitment deviations from the base model (solid line) with ∼95% intervals (vertical lines; upper panel) and recruitment without intervals (lower-panel).

REFERENCE POINTS

Unfished spawning biomass was estimated to be 147,729 mt (109,022-186,436, ∼95% interval). The abundance of sablefish was estimated to have dropped below the target reference point of 40% of this estimated value of unfished spawning biomass during the 2000s and generally remained below the target through 2018. The estimate of the target spawning stock biomass was 59,092 (43,609-74,574, ∼95% interval), which gives a catch of 7,363 mt (4,269-10,456, ∼95% interval). The stock was estimated to be just below the target stock size in the beginning of 2019 at 57,444 mt (32,776-82,112, ∼95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield. The estimate of the stock's current level of depletion was 38.9%.

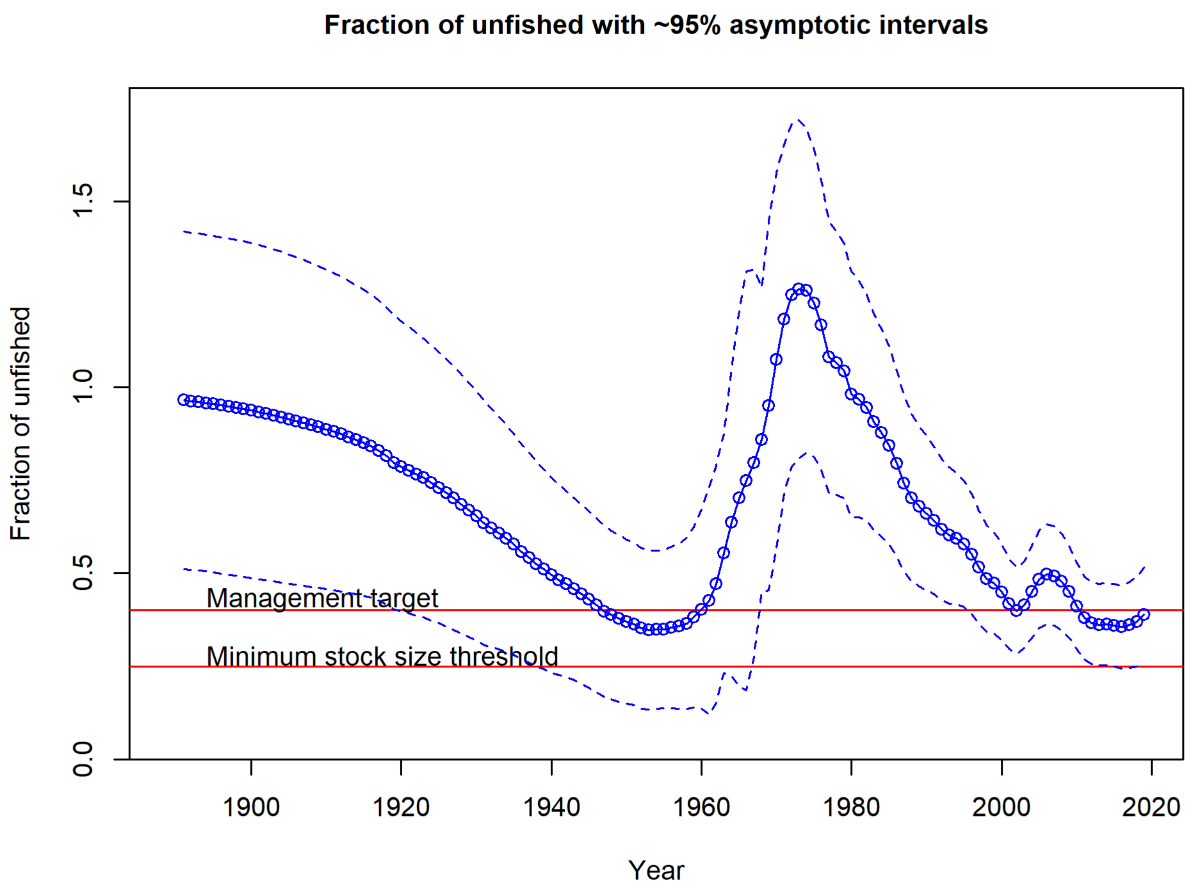

Figure d. Time series of estimated depletion (i.e., spawning biomass relative to unfished spawning biomass) from the base model (circles) with ∼ 95% intervals (dashed lines).

EXPLOITATION STATUS

Equilibrium yield at the fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 8,077 mt (4,684-11,470, ~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. The spawner potential ratio (*SPR*) exceeded the fishing mortality target/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, while since 2015 it has been between 83 and 95%.

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

Year	Total catch	Rel. 1-SPR		Exploitation rate	
2009	7,373	1.006	(0.737-1.275)	0.045	(0.028-0.062)
2010	7,018	1.051	(0.778-1.323)	0.047	(0.029-0.065)
2011	6,251	1.094	(0.829-1.360)	0.046	(0.028-0.064)
2012	5,280	0.934	(0.668-1.200)	0.036	(0.022-0.050)
2013	4,052	0.799	(0.545-1.053)	0.029	(0.018-0.041)
2014	4,240	0.801	(0.545-1.058)	0.030	(0.018-0.041)
2015	5,091	0.923	(0.650-1.195)	0.037	(0.022-0.051)
2016	5,403	0.954	(0.675-1.233)	0.041	(0.024-0.057)
2017	5,424	0.859	(0.584-1.133)	0.036	(0.022-0.051)
2018	5,132	0.825	(0.552-1.098)	0.035	(0.021-0.050)

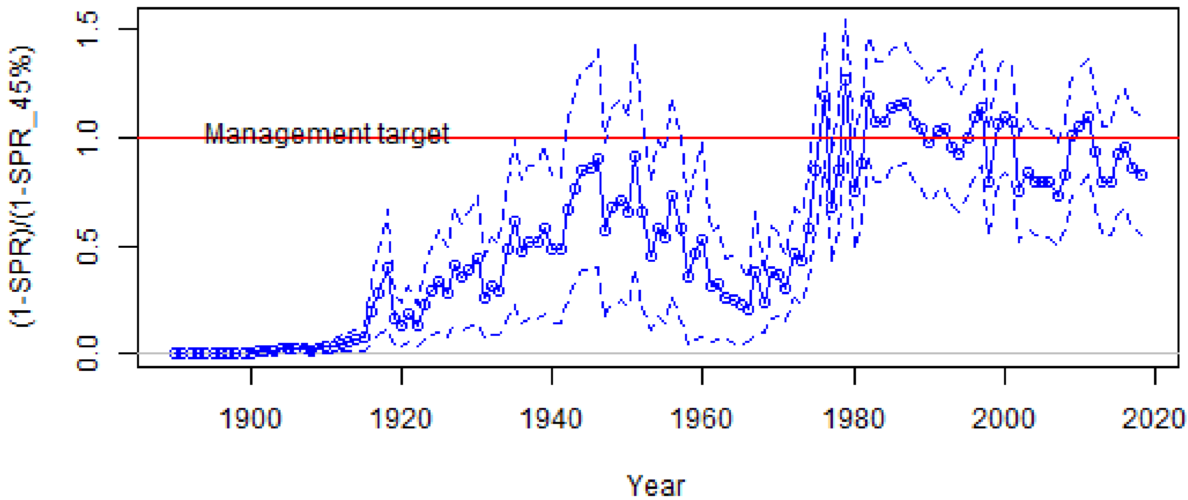

Figure e. Time series of estimated relative spawning potential ratio (1-SPR/1-SPR$_{Target=0.45\%}$) from the base model (points) with ∼95% intervals (dashed lines). Values above 1.0 (red, horizontal line) reflect harvests in excess of the current overfishing proxy.

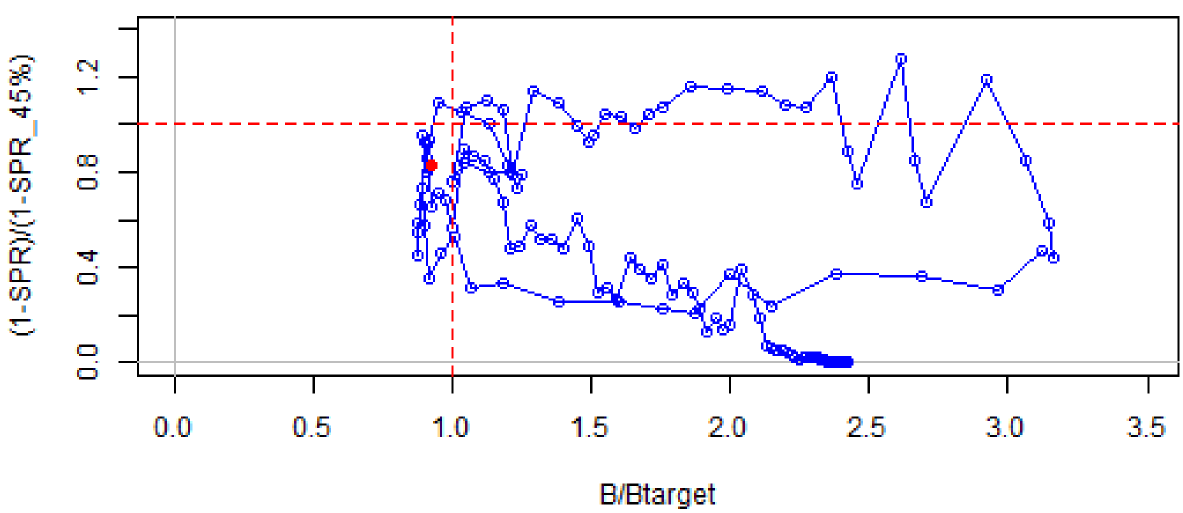

Figure f. Estimated relative spawning potential ratio (1-SPR/1-SPR$_{Target=0.45\%}$) vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The filled, red circle indicates the last year of available data, 2018.

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 d. Recent trend in overfishing limits (OFLs), annual catch limits (ACLs), landings, and estimated (est.) total dead catch (mt). Limits are summed across the southern and northern management areas where separate values were applied. Dead catch includes discards, which are estimated within the stock assessment, and therefore, dead catch may differ from total mortality reports used by management.

Year	OFL	ACL	Landings	Est. dead catch
2009	9,914	8,423	6,951	7,372.96
2010	9,217	7,729	6,599	7,017.63
2011	8,808	6,813	6,152	6,251.04
2012	8,623	6,605	5,189	5,280.13
2013	6,621	5,451	3,990	4,051.93
2014	7,158	5,909	4,162	4,239.63
2015	7,857	6,512	5,011	5,091.38
2016	8,526	7,121	5,305	5,402.67
2017	8,050	7,117	5,308	5,424.41
2018	8,329	7,419	5,045	5,131.61
2019	8,489	7,596		

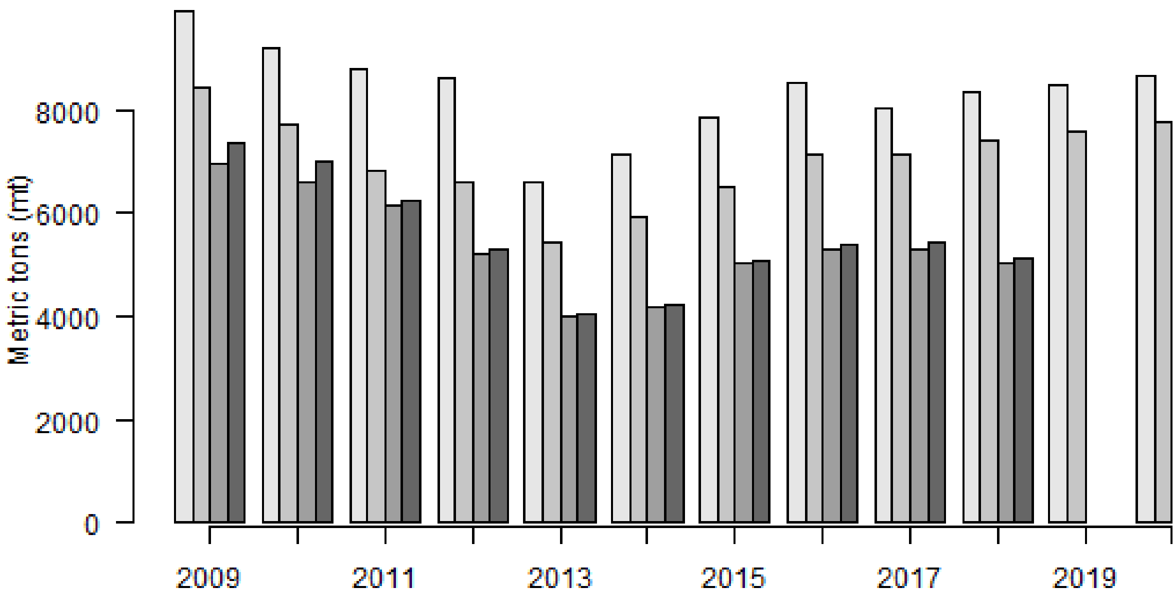

Figure g. Recent (and current) sablefish overfishing limits (OFLs; lightest gray) and annual catch limits (ACLs; light gray) compared to recent landings (gray) and estimated dead catch (dark gray) from the base model. Dead catch excludes discarded fish that are predicted to have survived.

UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

The data available for sablefish off the U.S. West Coast are not informative with respect to absolute size and productivity. This is, in part, due to the one-way-trip nature of the historical series (i.e., a slow and steady decline in spawning biomass), which can be consistent with a larger less productive stock, a smaller more productive stock, or many combinations in between. While the historical catches provide some information about the minimum stock size necessary to remove the catches from the population, there is limited information in the data regarding the upper limit of the stock size. The above factors are also confounded by movement of sablefish between the region included in this assessment and regions to the north. 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^*=0.4 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 2016-2018 catches were used to distribute catches among the fisheries.

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. Projections are provided through 2030 (Table e).

Forecasts from the 2015 assessment update projected the spawning biomass to increase by 9.3% from 2015 to 2019 given specified harvests, whereas the current assessment estimated the increase at 8.0%. Estimates of unexploited spawning biomass are 2% lower than that estimated in 2015 and 19% lower than the 2011 estimate. Percent of unfished biomass in 2019 was estimated at 39%, while the 2015 stock assessment forecasted it to be 38%.

Table e. The sablefish stock assessment is a Category 1 stock assessment, thus projections and decision tables are based on using $P^* = 0.40$ and the Pacific Fisheries Management Council (PFMC) approved time series of sigma values for stock projections that provide the multipliers on the over fishing limit (OFL), these values are all less than 1. The OFL multipliers are combined with the 40-10 harvest control rule, where applicable, to calculate OFLs and Annual Catch Limits (ACLs). 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. Therefore, ABCs are not displayed. The total catches in 2019 and 2020 were set at the PFMC Groundfish Management Team requested values of 6,145.4 mt for 2019 and 6,287.9 mt for 2020, just below the PFMC agreed ACLs for sablefish. The average 2016-2018 catch was used to distribute catches among the fisheries.

Year	OFL (mt)	ACL (mt)	Spawning biomass (mt)	Depletion
2019	8,489	7,596	57,444	38.88 %
2020	8,648	7,755	63,350	42.88 %
2021	9,402	8,208	68,120	46.11 %
2022	9,040	7,811	68,778	46.56 %
2023	8,877	7,599	68,177	46.15 %
2024	8,713	7,388	67,482	45.68 %
2025	8,579	7,207	66,984	45.34 %
2026	8,479	7,055	66,691	45.14 %
2027	8,411	6,930	66,555	45.05 %
2028	8,368	6,837	66,525	45.03 %
2029	8,346	6,752	66,564	45.06 %
2030	8,339	6,679	66,652	45.12 %

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 2019 and 2020, which are just 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 2019 spawning biomass from the base model. Specifically, the 2019 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 2019 spawning biomass values for the high and low states of nature. The mid-level catch streams were based on the 40-10 harvest control rule. At the request of the Groundfish Management Team representative at the STAR panel, the high and low catch streams were set using the Category 1 values of $P^* = 0.45$ and $P^* = 0.35$, respectively.

Spawning stock biomass in 2019 ranges across the three states of nature from 42,968 to 71,915 mt, with corresponding stock status between 38% to 41% of the unfished stock size. The decision table suggests that all catch scenarios under both the base and high state of nature result in increases 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, maintaining the stock within the precautionary zone.

Table f. 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 2019. The low and high states of nature are based on the 2019 SSB ± 1.15·base model SSB standard deviation. The fixed value of unfished recruitment was used to find each state of nature. The results are conditioned on the 2019 and 2020 catches, provided by the Pacific Fisheries Management Council Groundfish Management Team (GMT), being achieved exactly. The low and high catch streams are based on the GMT's requested P* values of 0.35 and 0.45.

			Low state (0.25)		Base (0.5)		High state (0.25)	
Catch scenario	Year	Total catch	SSB	Depletion	SSB	Depletion	SSB	Depletion
P*=0.35	2019	6,145	42,968	38%	57,444	39%	71,915	41%
	2020	6,288	47,594	42%	63,350	43%	79,161	45%
	2021	7,644	51,414	45%	68,120	46%	84,950	49%
	2022	7,269	51,922	46%	69,059	47%	86,290	50%
	2023	7,064	51,094	45%	68,740	47%	86,292	50%
	2024	6,849	49,847	44%	68,316	46%	86,367	50%
	2025	6,668	48,544	43%	68,079	46%	86,781	50%
	2026	6,513	47,297	41%	68,038	46%	87,474	50%
	2027	6,382	46,136	40%	68,145	46%	88,349	51%
	2028	6,279	45,063	40%	68,354	46%	89,327	51%
	2029	6,182	44,064	39%	68,629	46%	90,356	52%
	2030	6,105	43,135	38%	68,953	47%	91,411	53%
P*=0.4	2019	6,145	42,968	38%	57,444	39%	71,915	41%
	2020	6,288	47,594	42%	63,350	43%	79,161	45%
	2021	8,208	51,414	45%	68,120	46%	84,950	49%
	2022	7,811	51,636	45%	68,778	47%	86,008	49%
	2023	7,599	50,517	44%	68,177	46%	85,727	49%
	2024	7,388	48,988	43%	67,482	46%	85,532	49%
	2025	7,207	47,411	42%	66,984	45%	85,685	49%
	2026	7,055	45,902	40%	66,691	45%	86,129	49%
	2027	6,930	44,489	39%	66,555	45%	86,761	50%
	2028	6,837	43,169	38%	66,525	45%	87,503	50%
	2029	6,752	41,925	37%	66,564	45%	88,300	51%
	2030	6,679	40,750	36%	66,652	45%	89,126	51%
P*=0.45	2019	6,145	42,968	38%	57,444	39%	71,915	41%
	2020	6,288	47,594	42%	63,350	43%	79,161	45%
	2021	8,791	51,414	45%	68,120	46%	84,950	49%
	2022	8,375	51,342	45%	68,488	46%	85,717	49%
	2023	8,158	49,920	44%	67,594	46%	85,142	49%
	2024	7,946	48,097	42%	66,618	45%	84,666	49%
	2025	7,758	46,241	41%	65,851	45%	84,551	49%
	2026	7,614	44,468	39%	65,304	44%	84,740	49%
	2027	7,499	42,799	38%	64,918	44%	85,125	49%
	2028	7,401	41,226	36%	64,643	44%	85,624	49%
	2029	7,331	39,739	35%	64,445	44%	86,188	50%
	2030	7,275	38,320	34%	64,296	44%	86,782	50%

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.

Table g. Summary of sablefish reference points as estimated using the base model. Yields include discard mortality. Given steepness is a fixed parameter, the uncertainty in these reference points remains an underestimation.

Quantity	Estimated value	~95% intervals
Unfished total biomass (mt)	350,340	244,366-456,314
Unfished 4+ biomass (mt)	327,697	231,618-423,776
Unfished spawning biomass (SB_0, mt)	147,729	109,022-186,436
Unfished recruitment (R_0, thousands)	15,022	7,633-22,411
Current depletion	38.88%	26.10-51.67%
Reference points based on $SB_{40\%}$		
MSY Proxy spawning biomass ($SB_{40\%}$, mt)	59,092	43,609-74,574
Relative spawning depletion at $SB_{40\%}$	40.00%	
SPR resulting in $SB_{40\%}$	50.00%	
Exploitation rate resulting in $SB_{40\%}$	4.64%	3.89-5.40%
Yield with $SPR_{SB40\%}$ at $SB_{40\%}$ (mt)	7,363	4,269-10,456
Reference points based on SPR proxy for MSY		
Spawning biomass at $SPR_{MSY-proxy}$ (SPR_{proxy}, mt)	56,728	41,865-71,591
Relative spawning depletion at SPR_{proxy}	38.40%	
SPR_{proxy}	45.00%	
Exploitation rate corresponding to SPR_{proxy}	4.88%	4.09-5.67%
Yield with SPR_{proxy} at SB_{SPR} (mt)	7,488	4,342-10,633
Reference points based on estimated MSY values		
Spawning biomass at MSY (SB_{MSY}, mt)	36,734	27,093-46,375
Relative spawning depletion at SB_{MSY}	24.87%	
SPR_{MSY}	32.92%	32.71-33.12%
Exploitation rate corresponding to SPR_{proxy}	7.49%	6.29-8.69%
Yield with SPR_{proxy} at SB_{SPR} (mt)	8,077	4,684-11,470

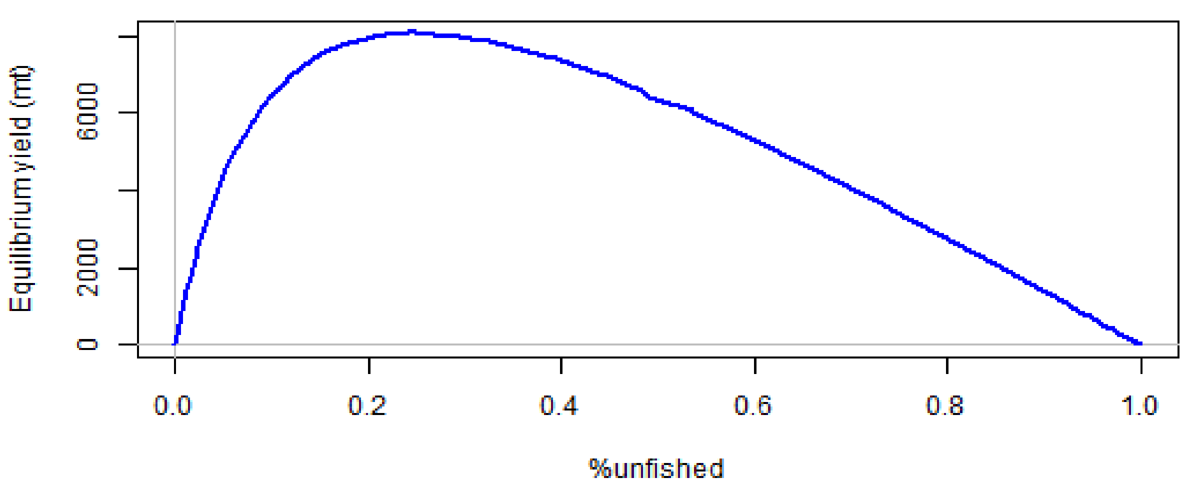

Figure h. Equilibrium yield curve (total dead catch) for the base model.

1 INTRODUCTION

1.1 DISTRIBUTION AND STOCK STRUCTURE

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 et al., 2012; Hanselman et al., 2015; Rogers et al., in preparation), regions to the north of the U.S. west coast, and to the western Pacific (Fujioka et al., 1988; Heifetz and Fujioka, 1991; Hanselman et al., 2015; Rogers et al., in preparation). See Figures 1, 2, and 3 for the region included in this assessment.

While previous analyses suggests 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 fish move between the regions currently used for management (Hanselman et al., 2015; Sogard and Berkeley, 2017; Rogers et al., in preparation). Analyses of sablefish 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 et al., 2014; Gertseva et al., 2017; Kapur et al., in review). While geographic break points 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. Geographic break points in sablefish growth along western North America include those 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.

Smaller sablefish are generally found in shallower waters, but sablefish show an ontogenetic shift to a fully mixed (adult and juvenile) demographic near the shelf-slope break (i.e., 100-300 m). Beyond the shelf-slope break, the adult population is dominated by older (but generally not larger) individuals (Methot, 1994) and younger fish become increasingly rare (see Section 2.1). Important for all modeling efforts, the stock is distributed beyond the greatest depth sampled by any of the surveys and beyond the deepest commercial fishing areas. Fish in the deepest areas tend to be the oldest individuals, but not the largest individuals, suggesting that age rather than size dictates depth distribution. However, the interaction of environmental conditions and seasonal movements that produce an increase in age with depth are largely unknown. Research in these deeper habitats occupied by sablefish is potentially difficult because they extend across 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 spawning occurring in February (Guzmán et al., 2017). Spawning occurs along the continental shelf-slope break in waters deeper than 300 m. This winter-time spawning may result in reduced availability to the commercial fishery during the winter months. 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 in current records 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 et al., 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

The National Oceanic and Atmospheric Administration (NOAA) document titled Implementing a Next Generation Stock Assessment Enterprise, An update to the NOAA Fisheries Stock Assessment Improvement Plan (Lynch et al., 2018) calls for bringing an ecosystem perspective into the assessment process. Moreover, introducing this perspective to the assessment process is a key component of the NOAA Fisheries Ecosystem-Based Fisheries Management (EBFM) Policy (NOAA National Oceanic and Atmospheric Administration, 2016), which calls for incorporation of ecosystem considerations into the management of living marine resources. Uptake of EBFM principles and tools into the assessment process can be done through including ecosystem information in assessments, harvest control rules, and management decisions that are coordinated across species-specific management plans and account for diverse trade-offs (NOAA National Oceanic and Atmospheric Administration, 2016; Lynch et al., 2018). Guidelines for incorporating ecosystem considerations into fisheries management advice form the core of Guiding Principle 5 for implementing the NOAA EBFM Policy.

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

An extensive SES analysis for sablefish can be found in Appendix A. This document focuses on the four following topics, which highlight the major aspects considered:

1. results of a Climate Vulnerability Assessment (CVA), which motivates points 2 and 3;
2. environmental drivers of recruitment;
3. shifts in the latitudinal distribution of sablefish biomass and the effects of these shifts on availability of the stock to selected ports; and
4. interaction of the sablefish fishery with other species, specifically whale entanglements.

Points (1) and (2) address environmental impacts on sablefish. Point (3) addresses impacts of sablefish on humans, while point (4) addresses impacts of the sablefish fishery on other species in the ecosystem.

1.3.1 SUMMARY OF SES ANALYSIS

The CVA of sablefish (McClure and Haltuch, in preparation) suggests that processes affecting recruitment are sensitive to climatic and, therefore, oceanic drivers. Given high climate vulnerability, changes in the abundance, productivity, and spatial distribution of sablefish are likely, and these changes are likely to impact fishing fleets and communities because of the high value of this fishery. The CVA also suggests that sablefish are likely to shift distribution in response to climate variability.

Strong coast-wide recruitment appears to be associated with good recruitment north of Cape Mendocino ($\sim 40°$N). Modeling work shows that strong recruitment is correlated with transport and temperature in the northern portion ($40° - 48°$N) of the U.S. West Coast, specifically with the northern transport of yolk-sac larvae (Tolimieri et al., 2018). A re-analysis of the relationship between sea level and recruitment found that variation around the stock-recruitment curve was negatively correlated with sea level north of Cape Mendocino. Reliable sea-level data are available back to 1925; the ability to produce an environment-recruitment index with this time series may allow for both hindcasting to better represent stock dynamics during data-poor time periods and nowcasting of recruitment with robust estimates of uncertainty.

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

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

1.3.2 CLIMATE VULNERABILITY ASSESSMENT

A recent CVA (McClure and Haltuch, in preparation) suggests that sablefish is a good candidate for an analysis of the ecological and socioeconomic conditions relevant to sablefish ecology and management. Overall, sablefish have moderate biological sensitivity to climate variability but high climate exposure (Figure 4). Sablefish showed sensitivity to factors affecting early life history and settlement requirements, population growth rate, and the spawning cycle. Sablefish ranked very high in their likelihood of experiencing distributional shifts due to climate effects. That is, high adult mobility, high dispersal of early life stages, and lack of habitat specificity suggest that sablefish may respond to climate variability by shifting distribution, which may affect the fishery's access to the stock.

1.3.3 ENVIRONMENTAL DRIVERS OF RECRUITMENT

Year-class strength plays a fundamental role in marine species setting age structure and abundance trends. Strong year classes in sablefish appear to be associated with ecosystem processes occurring in the northern portion of the U.S. West Coast (north of Cape Mendocino, $\sim 40°$N) (Schirripa and Colbert, 2006; Tolimieri et al., 2018). This conclusion is supported by the following three lines of evidence: (1) the distribution of age-0 recruits, (2) results from stage-specific and spatiotemporal models using oceanic variables to predict recruitment, and (3) a reanalysis of the relationship between sea level and recruitment.

Distribution and abundance of age-0 recruits

Age-0 sablefish captured by the Northwest Fisheries Science Center (NWFSC) West Coast Groundfish Bottom Trawl (WCGBT) Survey were most abundant in shelf and upper-slope waters around San Francisco Bay and from Cape Mendocino to the mouth of the Columbia River (Figure 5). The abundance of age-0 recruits varied through time with peaks in recruitment in 2004, 2008, 2010, 2013, and 2016. However, most strong recruitment years, with the exception of 2010, were associated with high recruitment north of Cape Mendocino. Recent modeling work suggests that strong age-0 recruitment is associated, in part, with the northerly transport of yolk-sac larvae at depths between 1000-1200 m (Tolimieri et al., 2018), which may lead to better overlap between feeding larvae and copepod prey than when the larvae transport is not as defined.

Oceanographic drivers of recruitment

Recent stage-specific and spatiotemporal modeling (Tolimieri et al., 2018) using Regional Ocean Modeling System (ROMS) output for the northern California Current area ($40-48°$N) was able to predict 57% of the of the variation in age-0 recruitment not accounted for by the stock-recruitment relationship (i.e., residuals around the stock-recruitment curve) for years 1981 to 2010. Residuals around the stock-recruitment relationship were correlated with (1) colder conditions at 50-1200 m during the spawner preconditioning period, (2) warmer water temperatures at 300-825 m during the egg stage, (3) stronger cross-shelf transport at 300-825 m to near-shore nursery habitats during the egg stage, (4) stronger long-shore transport at 1000-1200 m to the north during the yolk-sac stage, and (5) cold surface-water temperatures during the larval stage (Appendix A).

Cooler temperatures (quantified as degree days) during the pre-spawning period may result in lower metabolic costs for females, allowing the availability of more energy for reproduction or may be indicative of good feeding conditions. Onshore transport during the egg stage averts advection of eggs and larvae and maintains them near settlement habitat, while warmer water leads to faster development. Transport to the north during the yolk-sac stage likely moves larvae to better feeding conditions once they rise to the surface, and cold water during the larval stage may be associated with both better feeding conditions and reduced starvation risk due to lowered metabolic costs. Likewise, transport to the north may give age-0 fish access to a larger region of shelf habitat. In conjunction with the analysis of the distribution of age-0 fish, this work suggests that oceanic processes in the northern portion of the California Current are important for determining recruitment success.

Sea level and recruitment

Research and assessments during recent decades have examined the relationship between sea level, measured via tide gauges, and sablefish recruitment (Schirripa and Methot, 2001; Schirripa and Colbert, 2005, 2006; Schirripa, 2007; Schirripa et al., 2009; Stewart et al., 2011; Johnson et al., 2016). Prior to sea level, relationships between copepods and sablefish were investigated because copepods are an important food source for sablefish larvae and juveniles (Grover and Olla, 1986, 1987, 1990; McFarlane and Beamish, 1990). Changes in sea level serve as a proxy for large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport. These changes directly impact the transport of water masses, nutrients, and organisms (Schirripa and Colbert, 2006; Lorenzo et al., 2013). Historically, the sea-level index evaluated within the stock assessment modeling context consisted of a spatiotemporal (April, May, and June) average using data from four tide-gauge stations in the northern California Current. During early research, a number of covariates at several temporal and regional aggregations were tested, resulting in a total of almost 900 unique combinations (Stewart et al., 2011). Not all of these time series were independent. Sea level was selected, in part, as a replacement for the copepod index because their correlation and the increased temporal coverage of the sea-level data. The 2011 assessment (Stewart et al., 2011) suggested there is little chance of selecting a randomly generated time-series with the observed R^2 between recruitment and sea level, supporting the hypothesis that the relationship between sablefish recruitment and sea level is not spurious, but noted that repeated testing of these types of relationships remains necessary.

While biologically meaningful, the sea level-recruitment relationship is weak ($\sim R^2 = 0.35$), and use of the index in recent years has not had a large effect on assessments because much of the variation in recruitment is captured in the age-structure data (Stewart et al., 2011). Additionally, previous analyses (e.g., Schirripa 2007) have selected tide-gauge locations based on the strength of the resulting relationship with recruitment, potentially biasing the results. ROMS models have had some success explaining sablefish recruitment (Tolimieri et al., 2018), but the available time-series cover a limited period (1980-2010). While the ROMS models can be updated, limited environmental-forcing data means that the models cannot necessarily be projected back in time with much confidence. Thus, ROMS-based indicators cannot be used to hindcast recruitment to better incorporate recruitment dynamics for early periods.

The ROMS-based recruitment analysis showed higher recruitment with stronger poleward transport at depth, while the sea-level analysis showed more successful recruitment with lower sea level in the northern California Current. This lower sea level is typically correlated with stronger upwelling and southern alongshore surface flow (Connolly et al., 2014). However, lower sea level in the northern California Current is also related to a stronger alongshore sea-level/pressure gradient (higher in the south, lower in the north), which drives a stronger poleward deep current. This undercurrent is strongest between 100 m and 500 m, but poleward flows extend deeper. Thus the ROMS analysis and the sea level analysis corroborate each other.

Section 2 and Appendix A contain a re-analysis of the relationship between sea level and recruitment conducted for and used in this assessment. This relationship has been modeled in the sablefish stock assessment both via the internal population dynamics as a direct offset to the expected value for recruitment (Maunder and Watters, 2003; Schirripa and Colbert, 2005) and as a survey index of age-0 recruitment deviations (Schirripa, 2007; Stewart et al., 2011; Johnson et al., 2016). The former method makes it difficult to determine the appropriate degree of recruitment variability for the deviations themselves and requires that the environmental series be treated as if it is known without error. The latter method, which was used in this assessment, allows for observation error in the environmental series.

The topic of model-selection, robustness, and validation for the relationship between sea level and recruitment was a recurrent theme in STAR panels and with the Pacific Fisheries Management Council (PFMC) Science and Statistical Committee between 2002 and 2007. Prior to 2011, the use of the sea-level index was contentious. During 2011, the sea-level data were used as an index of recruitment in a sensitivity analysis using the data from 1970 forward, although the sea-level data start in 1925. Using only the data from 1970 forward did not influence model results because the information in the length- and age- composition data largely agreed with the information in the sea-level data (Stewart et al., 2011; Johnson et al., 2016).

Distributional shifts in stock biomass and availability to ports

Shifting stock biomass may affect the availability of sablefish to fishers operating out of specific ports (adapted from Selden et al. in preparation) conditioned on the idea that sablefish landings largely reflect local stock availability, such that more sablefish are caught when local availability is high than when it is low. Sablefish biomass has declined by 42% since its high in 1972, contributing to varying sablefish availability to ports across the coast. The population centroid first shifted north during 1980 to 1992 then south by 2013. The centroid of biomass then began shifting north, as illustrated in the trawl-survey data, but has not moved as far north as in the 1990s. Declines in sablefish biomass in conjunction with northward distribution shifts during 1980-1992 led to particularly strong losses in availability to southern ports like Morro Bay and Fort Bragg, California, while availability was maintained at more northern ports like Coos Bay and Astoria, Oregon (Figure 6). Southward shifts of sablefish from 1992-2013, coincident with further declines in biomass, led to dramatic declines in availability for northern ports and a stabilization or increase in availability to southern ports.

Whale entanglements

Whale entanglements in fisheries using pot gears have the potential to limit effort due to protections for marine mammals. Coincident with the anomalous warming of the California Current in 2014-2016, observations of whales entangled in fishing gear occurred at levels far greater than that observed in the preceding decade (Figure 7). Observed entanglements were most numerous in 2015 and 2016, with the majority involving humpback whales (*Megaptera novaeangliae*). Based on preliminary data, observed entanglements appear to have declined in 2017 but were still greater than those observed during 2000 to 2013. Of the portion of whale entanglements that can be identified by fishery in California Current waters, most entanglements appear to be with gear targeting Dungeness crab (*Metacarcinus magister*).

There have been two documented takes of humpback whales in the sablefish fisheries, one in the Limited Entry Sablefish pot sector in 2014 and one in the Open Access Fixed Gear pot sector in 2016. However, model estimated fleet-wide entanglements were consistently above the 5-year running average threshold from 2002-2017 in the combined Limited Entry Sablefish and Open Access Fixed Gear pot sectors (Hanson et al., 2019). This result was largely due to the Open Access Fixed Gear pot sector, while entanglements in the Limited Entry Sablefish pot sector were consistently below the threshold.

1.4 HISTORICAL AND CURRENT FISHERY

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 8). 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 (Van Houten 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, divided approximately 67% from fixed gear and 33% 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.

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 2.65% larger than the landings input into the stock assessment model over the last decade.

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 1). 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 2 and 3). Since the inception of the catch shares program in 2011, the WCGOP observer program data show that catch shares vessesl 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 were data are near complete. 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, 2003-2017, was downloaded on 6/5/2019. Coverage rates of all sectors can be found at https://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm.

In 2018, the ex-vessel value of the sablefish fishery was estimated at 25.3 million dollars (pers. comm., E. Steiner). This represents a five-year low, where the previous year, 2017, represented the five-year high at 35.0 million dollars.

1.5 MANAGEMENT HISTORY AND PERFORMANCE

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 (Table 2; See Appendix B 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 sablefishspecific limits, various limits were in place for the overall landings of deep-water complex species (Stewart et al., 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 6,621 (2013) to 9,914 mt (2009) during the last decade (Table 3). Catch targets (ACLs, formerly OYs) ranged from 5,451 (2013) to 8,423 mt (2009) 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 5 below.

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 (Table 4).

1.6 FISHERIES IN 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 (pers. comm., B. Williams; see Table 5 and Hanselman et al. (2018) for a full account of sablefish fisheries in Alaska).

The sablefish fishery in British Columbian waters has a similar history to those in U.S. waters (Table 5). 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).

2 DATA

The following sources of data were used in building this assessment (Figure 9):

- Fishery-independent data, including relative abundance indices and length and age data from the Northwest Fisheries Science Center (NWFSC) West Coast Groundfish Bottom Trawl (WCGBT) Survey (2003-2018), and, relative abundance indices and age data from the NWFSC slope survey (1998-2002), the Alaska Fisheries Science Center (AFSC) Slope Survey (1997-2001), and the Triennial Shelf Survey (1980-2004). Input sample sizes were based on the number of tows length and marginal age compositions, whereas CAAL input sample sizes were based on the number of fish sampled.

- Estimates of fecundity, maturity, weight-length relationships, and ageing imprecision.

- Informative sex-specific priors on natural mortality based upon meta-analytical relationships with other life-history parameters derived from data across a number of fish stocks (Figure 10).

- Reported commercial and reconstructed landings (1890-2018).

- Biological data (ages) from the commercial port sampling programs (1983-2018). Input sample sizes for the composition data were based on the number of port samples.

- Estimates of commercial discard length and mean weight and fraction discarded in the fishery obtained from the West Coast Groundfish Observer Program (WCGOP; 2002-2017) and 1986-1988 from (Pikitch et al., 1988). Input sample sizes for discard length compositions were based on the number of observed trips.

- Environmental index of age-0 recruitment derived from tide-gauge measurements of sea level (Figure 11).

2.1 FISHERY-INDEPENDENT DATA

2.1.1 NORTHWEST FISHERIES SCIENCE CENTER WEST COAST GROUNDFISH BOTTOM TRAWL SURVEY

The WCGBT Survey has maintained a consistent stratified random-grid survey design over the period 2003-2018, including depths from 55-1,280 m (Bradburn et al., 2011). WCGBT data are used to estimate a relative index of abundance for several groundfish species including sablefish which are captured in a high proportion of survey hauls over most of the west coast shelf and slope depths (Table 6; Figure C.3).

The survey design divides the U.S. West Coast into ∼13,000 adjacent cells of equal area. Typically, four chartered industry vessels conduct tows in randomly selected grid cells as they travel from north to south during one of two passes from late-May to early-October. The design therefore incorporates both vessel-to-vessel differences in catchability and variability associated with selecting a relatively small number (∼700) of cells from the large population of possible cells. Note that the WCGBT Survey is not permitted to access the Cowcod Conservation areas in southern California.

The data were analyzed using vector-autoregressive spatiotemporal models (Thorson and Barnett, 2017; Thorson, 2019) available within the `VAST` R package. VAST allows for the estimation of the variation in density for multiple locations across time and categories (e.g., species or age classes) and has been reviewed, endorsed, and recommended by the Pacific Fishery Management Council's Scientific and Statistical Committee for estimating abundance indices. Spatial and spatiotemporal variation is specifically included in both model components, i.e., encounter probabilities and positive catch rates, which are modeled using logit- and log-links, respectively. Gamma and log-normal error structures were investigated for the positive catch-rate component of the model to allow for skewness in the estimated distribution (Maunder and Punt, 2004). Vessel-year effects were included for each unique combination of vessel and year to account for the random selection of commercial vessels from those that were available (Helser et al., 2004; Thorson and Ward, 2014). In summary, the survey biomass density (weight per area swept) was a function of year, latitude, longitude, and vessel-year. Spatial variation was approximated using 500 knots and the results were corrected for transformation bias (Thorson and Kristensen, 2016) using an algorithm in Template Model Builder (Kristensen et al., 2016). Further details regarding the structure of the spatiotemporal model available in `VAST` are available in the user manual. Specific details of how VAST was configured to estimate an index of abundance from WCGBT Survey data are available in `VASTWestCoast`, which contains scripts specific to fitting `VAST` to data from surveys operating off of the U.S. West Coast. For example, a covariate was included for survey pass (i.e., 'first' or 'second') to account for the incomplete sampling during the second pass of the 2013 WCGBT Survey when the survey was cut short and no stations south of 37°N were sampled (Figure C.5) or seasonal, latitudinal movement.

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

The estimated index shows a relatively precise and strong declining trend from 2003-2008, stabilization from 2008 through 2016, and an increasing trend between 2017 and 2018 (Figure 12). The increase in the most recent years is largely due to increases in densities off of the coast of Washington. Q-Q plots suggested that the gamma distribution (Figures 13 and C.1) fit the data better than a log- normal distribution (results not shown). No spatial or spatiotemporal patterns were found in the Pearson residuals (Figures 14-21).

Sampled lengths were binned into 37 bins from <18 (cm) to $\geq$90 (cm) to summarize the sex- and year-specific length data. Unsexed fish were assigned to males and females using a 50:50 ratio. Sablefish were well sampled (Table 6), and the data broadly show modes for age-0 fish (18-28 cm), age-1 fish (28-38 cm), and adults to $\sim$80 cm (Figure 22). Large cohorts are visible beginning in 2008, 2010, 2011, 2013, and 2016 showing clear progress in the length-composition data over time (Figure 23).

Age structures are generally collected from a subset of the fish that have been measured for length. Thus, it is common to include these data as conditional age-at-length (CAAL) compositions. Summarizing the data in this way consists of tabulating the ages within a given length category, where marginal compositions perform the additional step of summing age tabulations across all lengths. Thus, CAAL compositions treat the distribution of ages for each length category as separate observations, conditioned on the lengths from which they came. When a data set is representative of the population, utilizing CAAL data can be beneficial. However, recent research has called into question using CAAL data when they are not representative of the population because it can lead to bias and imprecise estimates of the population age structure and derived model quantities (Lee et al., 2019). When CAAL are representative of the population, three benefits may be realized by using CAAL compositions compared to using standard marginal age compositions. First, including CAAL data in the model-fitting process incorporates uncertainty due to sampling and missing data, whereas externally created age-length keys are often input without error. Second, CAAL data tabulated for each length bin removes the problem of double counting information on sex ratios and year-class strengths such as when marginal age-compositions are used along with length compositions and the same fish are contributing to two likelihood components, which are assumed to be independent. CAAL compositions thus allow only additional information provided by the age data (relative to the generally far more numerous length observations) to be captured. Third, CAAL observations facilitate internal estimation of basic growth parameters (length at age and K) and distribution of lengths at a given age, usually governed by two parameters, the coefficient of variation of length at a specified young age and the coefficient of variation of length at a much older age. Without CAAL data, coefficient of variation's can only be derived from accurately aged and measured marginal age- and length-composition observations where strong and well-separated cohorts exist. Estimating the growth specifications within the stock assessment model facilitates the inclusion of this major source of uncertainty in the assessment results. CAAL data from the WCGBT Survey are used in the base model because these are the most representative source of sablefish age and length data from the U.S. West Coast.

Age distributions included 51 bins from age 0 to age 50 and older. Approximately one-quarter as many fish were aged as were measured for length, but these fish were collected from a similar number of tows (Table 6). CAAL compositions confirm cohorts seen in the length compositions, although, signals are dominated largely by age-1 fish (Figures 24-26). An appreciable number of fish are also observed in age classes above age 10. Data confirm the the rapid growth trajectory over the first several years of life, with growth slowing rapidly after 10 years old. Dimorphic growth is also pronounced, with virtually all sablefish above 70 cm being female.

2.1.2 NORTHWEST FISHERIES SCIENCE CENTER SLOPE SURVEY

The NWFSC Slope survey preceded the WCGBT Survey, starting in 1998 and ending in 2002. However, the southern and shallow areas were not sampled during this survey as they are in the WCGBT Survey (Figure C.9). The survey covered depths ranging from 183-1,280 m and used small (i.e., <93 ft) chartered commercial fishing vessels. This survey consists of fewer tows than the WCGBT Survey and the fraction of tows that sampled ages is much lower (Table 7).

`VAST` was used in a similar fashion to that specified for fitting the WCGBT Survey data to estimate a relative index of abundance (see Appendix C for details). No random component for vessel-year was included for this survey. The estimated index shows a relatively flat trajectory over the survey period except for the increase in 2000 (Figure 27). Q-Q plots suggested that the gamma distribution (Figures 28 and C.7) fit the data, better than a log-normal distribution (results not shown). No spatial or spatiotemporal patterns were found in the Pearson residuals (Figures 29-34).

The length-compositions for the NWFSC Slope Survey showed the 1999 cohort as age-1, -2, and -3, but did not observe them at age-0 (Figure 35); this is expected because generally age-0 fish are present only over shallower depths. Dimorphic growth is visible in the data. The marginal age distributions corroborate the strong 1999 year-class and show some evidence for a strong 1995 cohort, as well as a protracted distribution of ages above age 10 (Figure 36).

2.1.3 ALASKA FISHERIES SCIENCE CENTER SLOPE SURVEY

The Alaska Fisheries Science Center (AFSC) Slope Survey was conducted over depths from 183-1,280 m, north of 34.5°N in 1997, 1999, 2000, and 2001 (Figure C.13). Limited sampling in earlier years covered only relatively small and inconsistent portions of the coast and are therefore insufficient to provide an index of abundance. This survey had a very high degree of both positive tows and biological sampling (Table 8).

A relative index of abundance was estimated using `VAST`. The parameterization differed from that used for the WCGBT Survey in the following three ways (see Appendix C for more details): no random component for vessel-year was included, 150 knots were used for the spatial component, and the encounter probability was fixed at one for any year where all tows encountered the species. The estimated index shows an increase from 1999 to 2001 (Figure 37). Q-Q plots suggested that the gamma distribution (Figures 38 and C.11) fit the data, better than a log-normal distribution (results not shown). No spatial or spatiotemporal patterns were found in the Pearson residuals (Figures 39 and 40).

Similar to the NWFSC Slope Survey biological data, the length compositions for the AFSC Slope Survey show a strong 1999 cohort, a few age-0 fish in 2000 and 2001, and dimorphic growth (Figure 41). The marginal age compositions are similar as well, with the exception of a seemingly anomalous number of males at the largest sizes (Figure 42).

2.1.4 TRIENNIAL SHELF SURVEY

Prior to the 2015 update, the Triennial Shelf Surveys conducted by the AFSC in 1980, 1983, 1986, 1989, 1992, 1995, 1998, and 2001 and by the NWFSC in 2004 provided the longest time series of information regarding abundance of sablefish especially for younger fish occurring at the shallowest depths (Weinberg et al. 2002; Figure C.16). Sampling occurred over depths from 55 to 366 m (500 m after 1992) and from 36.5°N (34.5°N after 1992) to the Canadian border.

An estimated index was modeled using `VAST`. The parameterization differed from that used for the WCGBT Survey in the following two ways (see Appendix C for more details): no random component for vessel-year was included because it was estimated at zero and 250 knots were used for the spatial component. The estimated index shows an overall increase and an increase from 1995 to 2004 (Figure 43). However, the overall trend may not be reliable because of changes in timing, with the surveys occurring much earlier in 1995 and after, as well as movement of the survey into deeper waters between 1992 and 1995. To address this change in timing, sablefish assessments since 2007 have estimated catchability separately for the two portions of the time-series. Q-Q plots suggested that the gamma distribution (Figures 44 and C.14) fit the data, better than a log-normal distribution (results not shown). No spatial or spatiotemporal patterns were found in the Pearson residuals (Figures 45-48).

Lengths were collected for a large number of fish; however, age-sampling was relatively sparse (Table 9). Length compositions were variable and conspicuously missing age-0 fish in the early years of the survey (Figure 49). The age compositions show a truncated age structure (Figure 50) despite the survey sampling large individuals. This can be expected given the very limited depth range covered by the survey.

2.1.5 OTHER FISHERY-INDEPENDENT DATA

Pot surveys were conducted by the National Marine Fisheries Service (NMFS) in 1979, 1980, 1981, 1983, 1985, 1987, and 1989 in northern International North Pacific Fisheries Commission (INPFC) areas (U.S. Vancouver and Columbia) and in 1984, 1986, 1988, and 1991 in southern (Eureka, Monterey, and Conception) INPFC areas (Parks and Hughes, 1981; Parks and Shaw, 1983, 1985, 1987, 1989; Kimura and Balsinger, 1985). The number of fish per pot and biological data were collected according to the following grade-specific categories: large (>68 cm); medium (62-67 cm); small (52-61 cm); and extra-small (<51 cm) fish. Early sablefish stock assessments had little choice but to use the geographically limited and variable pot surveys as indices of abundance. Over time, growing time-series of trawl-survey indices, conflicting abundance trends, and incomplete spatial coverage within the pot surveys have led to their exclusion from all recent stock assessments. These indices have not been revisited for this assessment, but future work could re-evaluate the possibility that there is some useful information in these data through updated analysis or modeling methods.

2.1.6 ENVIRONMENTAL INDICES

Research and assessments during recent decades have examined the relationship between sea level, measured via tide gauges, and sablefish recruitment (Schirripa and Methot, 2001; Schirripa and Colbert, 2005, 2006; Schirripa, 2007; Schirripa et al., 2009; Stewart et al., 2011; Johnson et al., 2016). Changes in sea level serve as a proxy for large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport. These changes directly impact the transport of water masses, nutrients, and organisms (Schirripa and Colbert, 2006; Lorenzo et al., 2013). The sea-level index evaluated within the stock assessment modeling context consisted of a spatiotemporal (April, May, and June) average using data from 4 tide-gauge stations in the northern California Current. Earlier assessments tested a number of covariates at several temporal and regional aggregations, resulting in a total of almost 900 unique possible combinations (Stewart et al., 2011). Not all of these time series were independent. Additionally, the previous selection of sea level was, in part, to replace the copepod index on the basis of the correlation between the two indices, with sea level providing a more complete time series (Stewart et al., 2011). Copepods are an important food source for larvae and juveniles (Grover and Olla, 1987; McFarlane and Beamish, 1990)). The 2011 assessment (Stewart et al., 2011) suggested that there is little chance of selecting a randomly generated time-series with the observed R^2 between recruitment and sea level, supporting the hypothesis that the relationship between sablefish recruitment and sea level is not spurious. However, repeated testing of these types of relationships remains necessary.

While biologically meaningful, the sea level-recruitment relationship is weak ($\sim R^2 = 0.35$), and use of the index in recent years has not had a large effect on assessments because much of the variation in recruitment is already captured in the age-structure data (Stewart et al., 2011). Additionally, previous analyses have selected tide-gauge locations based on the strength of the resulting relationship with recruitment, potentially biasing the results (Schirripa, 2007; Johnson et al., 2016). ROMS models have had some success explaining of sablefish recruitment (Tolimieri et al., 2018), but the available time-series cover a limited period (1980-2010). While the ROMS models can be updated, limited environmental-forcing data means that the models cannot necessarily be projected back in time with much confidence. Thus the ROMS-based indicators cannot be used to hindcast recruitment to better incorporate recruitment dynamics for early periods.

A re-analysis of the sea level-recruitment relationship was conducted for this assessment that included all tide-gauge data available for the U.S. West Coast (see Appendix A for full details including model selection, validation, and testing). The goals of this analysis were to (1) re-examine the sea level-recruitment relationship to develop a stronger predictive relationship, (2) produce a more statistically justifiable sea-level index, and (3) extend the time span of any environmental sea-level index to allow for both hindcasting and forecasting of sablefish recruitment. Even a weakly correlated index might allow for qualitative forecasting, while hindcasting recruitment would better describe recruitment dynamics in early model periods when size and age data were not available to inform the assessment.

The re-analysis had two steps. First, dynamic factor analysis (DFA; Zuur et al. 2003*a*,*b*) was used to find common trends in mean second quarter sea level at sixteen stations spanning Neah Bay to San Diego along the U.S. West Coast (Figure A33). Second, model selection was then used to find the combination of dynamic factors that best explained residuals around the stock-recruitment relationship from the 2015 assessment (Johnson et al. 2016). This approach describes coast-wide sea level and avoids *a priori* selection of locations.

The best DFA model had five dynamic factors (Figure A37). The time series available at each tide-gauge location varied (Figure A34), but DFA can combine time series with missing data and of unequal length. The resulting dynamic factors span 1925-2018 (second quarter data for 2019 were not available the time of this analysis). The first dynamic factor was positively correlated with sea level with the strongest correlations north of Cape Mendocino (Figure A35). The second dynamic factor was negatively correlated with sea level, most strongly at central stations. The third dynamic factor was negatively correlated with sea level with the strongest correlations south of Cape Mendocino and especially south of Monterey Bay. The remaining factors showed no particular pattern.

The best-fit linear model (Table A2), which explained 35% of the variation in recruitment around the stock-recruit curve (Figure 51), was

$$Stock - recruitment\ residuals \sim DF1 + DF3 + DF3^2, \tag{2.1}$$

where $DF1$ and $DF3$ are the first and third dynamic factors (Figure A35). This analysis included the years 1975–2015 because of a paucity of size and age data prior to 1975 and because assessment-based biomass and recruitment estimates were available through 2015 (Johnson et al., 2016). Sablefish recruitment was negatively correlated with sea level north of Cape Mendocino ($DF1$), while the relationship was somewhat more complex in the south ($DF3$) due to the inclusion the quadratic term for $DF3$.

Comparison of predicted recruitment residuals from the best-fit model with those from the stock-recruitment relationship in the 2015 assessment show a good overall fit (Figure A36). However, the relationship was weak (R^2 = 0.35), largely because the model failed to predict lower than expected recruitments in 2005, 2006, and 2009 and underestimated the strength of the higher than predicted recruitments in 1976, 1979, 1999, and 2013. Nevertheless, the model did predict peaks in the recruitment residuals in these four years. Thus, the relationship functions as a conservative indicator of sablefish recruitment success.

The years 2016-2018 extend beyond the recruitment and biomass estimates in the last sablefish stock assessment, so we cannot compare them directly to assessment estimates. However, they can be compared to estimates of sablefish recruitment from the WCGBT Survey (Figure A7). The index predicted higher than expected (based on the stock-recruitment relationship) recruitment for 2016, which is corroborated by a peak in the abundance of age-0 sablefish in the trawl survey in this year. However, while the index also suggests higher than expected recruitment in 2018, this prediction is not observed in the trawl data. Good recruitment for sablefish appears related, in part, to cooler temperatures during the female pre-conditioning period prior to spawning (Tolimieri et al., 2018). The 2018 year class follows several years of a marine heat wave (i.e., ‘the blob’), which may have reduced female condition and resulted in lower realized recruitment than that expected by the sea-level index.

Comparing the distribution of age-0 recruits (Figure A7) to the model performance (Figure A39) suggests that strong over predictions (more than 1.0 standard deviation above the assessment derived stock recruitment residual) may be due to failure to account for processes in the south in some way, regardless of the fact that $DF3$ does account for sea level south of Cape Mendocino. For example, the model over predicted recruitment in 2005-2007, 2009, and 2011. All of these years, with the exception of 2011, saw lower recruitment in the area around San Francisco Bay. For 2011, the model predicted recruitment fairly close to that expected by the stock-recruitment relationship, and actual age-0 abundance was somewhat lower. Conversely, the model predictions were underestimates of the recruitment peaks in 2010 and 2013 when there were strong recruitments around San Francisco Bay and Point Conception.

Appendix A provides a more comprehensive analysis of the sea-level index.

The sea level-recruitment relationship has been modeled both via the internal population dynamics as a direct offset to the expected value for recruitment (Maunder and Watters, 2003; Schirripa and Colbert, 2005) and as a survey index of age-0 recruitment deviations (Schirripa, 2007; Stewart et al., 2011; Johnson et al., 2016). The former method makes it difficult to determine the appropriate degree of recruitment variability for the deviations themselves and also requires that the environmental series be treated as if it is known without error. The latter method allows for observation error in the environmental series.

The topic of model-selection, robustness, and validation for the sea level-recruitment relationship was a recurrent theme in STAR panels and with the Pacific Fisheries Management Council Science and Statistical Committee between 2002 and 2007. Prior to 2011, the use of the sea-level index was contentious. During 2011, the sea-level data were used as a survey index of recruitment in a sensitivity using the data from 1970 forward, although the sea-level data begin during 1925. Using only the data from 1970 forward did not influence model results because the information in the length- and age-composition data largely agreed with the information in the sea-level data (Stewart et al., 2011; Johnson et al., 2016). This assessment uses the DF1 and associated uncertainty, spanning 1925 through 2018, from the analysis above as a survey index of age-0 recruitment. Using the sea level time series prior to 1970, rather than limiting the data to the period in which length- and age-composition data inform recruitment strength as was done in during 2011, provides the opportunity to allow for both hindcasting recruitment and nowcasting of recruitment in the absence of survey data during the current assessment year, or in future 'catch only'assessments conducted for management. Both hindcasting during historically data poor periods and nowcasting in the absence of current survey data may better represent stock dynamics.

2.2 FISHERY-DEPENDENT DATA

2.2.1 HISTORICAL COMMERCIAL LANDINGS

The historical commercial catch reconstruction used for this assessment is the same as that used in the last assessment for Oregon and California (Table 1; Figure 8). A new reconstruction was available from Washington that extended the catch history back to 1890. The most recent historical catches (from 1986 to present for Oregon and from 1981 to present for California and Washington) were extracted from Pacific Fisheries Information Network (PacFIN) during the end of May 2019.

For California, 1916–1968 commercial landings rely on estimates from the reconstruction efforts by the Southwest Fisheries Science Center and California Department of Fish and Game (CDFG; Ralston et al. 2010). Reconstructions utilized spatial information regarding groundfish landings back to 1931. This method is probably reliable for sablefish because they are identified as a separate market category. Landings estimates for 1916-1931 were available from published CDFG Bulletins. Fisheries statistics of the U.S., published by the U.S. Fish Commission, extended the series back to 1908. Catch from 1908 was estimated to be less than 16 mt and was linearly extrapolated to zero in the first year of the model. The cumulative catch during this period was relatively small, and although there is uncertainty in apportionment to gear type, catches were split between fixed-gear and trawl fleets based on the earliest ratio recorded.

Oregon reconstruction efforts extend historical catches back to 1927 (Karnowski et al., 2014). Low et al. (1976) provided total landings from 1915-1926. Information prior to 1915 remains undocumented. Thus, a linear extrapolation from 10 to 0 mt between 1915 and the first year of the model was applied.

Washington completed a historical catch reconstruction for this 2019 assessment (pers comm., Tien-Shui Tsou). These catches represent the best available landed catch information and are highly similar to the historical catches used in past sablefish stock assessments. The following information sources were included in the reconstruction:

1. 1890-1908: U.S. Fish Commission bulletin,
2. 1915-1952: PMFC bulletin 3, appendix (page 130, using a conversion factor of 1.75 for dressed fish),
3. 1953-1969: Washington Statistical bulletin, and
4. 1970-1980: Washington fish ticket database.

Catch area assignments were based on Seattle market reports and Washington Statistical bulletins. Gear type was based on PMFC bulletin 3 (page 44, Table 2) and Washington Statistical bulletins. During this reconstruction, it was found that catches during approximately 1935 to 1950 were slightly higher than those used previously because dressed fish were erroneously treated as whole fish rather than being expanded using the Washington Department of Fish and Wildlife (WDFW) conversion factor for that period.

2.2.2 FOREIGN CATCHES

Foreign catches are included in the state-specific reconstructions (Table 1) and were large in the late 1970s. Reconstructions for foreign catches were performed in 2007, based on records in the

HAL data base and have since remained unchanged (Van Houten Lynde, 1986).

2.2.3 FISHERY CATCH-PER-UNIT-EFFORT

Trawl fishery logbook data, collected by CDFG, Oregon Department of Fish and Wildlife, and WDFW, date back to the 1970s. Records provide tow-by-tow information regarding groundfish species including sablefish. The 1997 sablefish assessment (Crone et al., 1997) considered the use of a time series of standardized catch per unit effort (CPUE) based on the analyses described in Brodziak (1997), filtering the raw tow data for a 'deep-water' catch strategy (Dover, thornyheads, and sablefish i.e., DTS; Brodziak 1997; Crone et al. 1997). Variable patterns were observed, and these were speculatively linked to management changes. Given the varied management history, inherent uncertainties associated with the use of fishery-dependent CPUE, and conflicting trends identified in earlier analyses, a commercial CPUE series has not been included in any recent sablefish stock assessment. The topic was not revisited for this assessment.

Another potential source of fishery-dependent information is the bycatch of sablefish in the midwater whiting fishery (Sampson et al., 1997). Anecdotal reports indicated that bycatch includes many small fish in years of above average recruitment. During the 2011 assessment, a preliminary investigation revealed that the length compositions from this source showed small fish associated with the 1999 and 2008 cohorts. Inclusion of these data (catch and length compositions) are included as a model sensitivity.

2.2.4 FISHERY BIOLOGICAL DATA

Data for all states were extracted from PacFIN's Biological Data System (BDS). Broadly, the weighting of commercial biological samples was conducted via the following method using the R package `PacFIN.Utilities`.

1. Expand the sample weight of lengths (or ages) from the state recorded subsample, consisting of one or more baskets of fish, to the estimated total catch in that market category (or trip for ungraded samples). This step accounts for differences in the fraction of each landing (or market category) that was actually sampled and is important during periods where there are some differences in the number of baskets or fish that comprise a 'sample'. When sample weights were unavailable, as is always the case for fish landed in Washington, gender-specific weight-length relationships were used to approximate the weight of the sample.

2. Sum the trip-expanded values within gear and state combinations. Data sampled from larger landings thus account for more weight in the sum to better reflect the total catch.

3. Expand the values to the reconstructed gear-specific landings, ensuring that if one state sampled landings very heavily but is responsible for only a small fraction of the total landings it will not be weighted too heavily.

4. Sum the number of port-side samples included in the compositions by year and gear for the

input sample size.

Length compositions were aggregated without regard to sex, as was done in the previous assessment, to limit the exclusion of data and allow for a longer time series of length data than what would be available if all unsexed fish were removed (Table 10). State-specific dorsal-to-fork length conversions were applied when appropriate. Sex-specific marginal age-compositions were calculated assigning unsexed fish to males and females using a 50:50 ratio. Generally, far more trips (and fish) have been sampled for length than for age (Table 10), and the number of biological fishery samples is relatively small when compared to the sampling of other groundfish species. Year and fleet combinations with less than three tows were removed from the analysis.

Across time, length-compositions for each gear show differing distributions (Figure 22). The fixed-gear fishery captures the broadest size spectrum (Figure 22). The fixed-gear fishery retained almost no small fish (<40 cm) in the early years (Figure 52), with small fish only being landed recently (Figure 53). An apparent increase in the average size of fish caught by pots led to changes in the average length distribution landed by fixed gears between the late 2002 and roughly 2010. For the trawl fishery, the early years are quite variable due to small sample-sizes (Figure 54). This gear type appears to routinely land a much larger fraction of fish <40 cm, giving a very slight indication of the 1999, 2008, 2013, and 2015 cohorts as age-1 and age-2 fish (Figures 54 and 55).

The WCGOP provided information regarding length-compositions of discarded sablefish from 2002-2018. These samples were analyzed using a weighting method consistent with that applied to port samples described above. In aggregate, these samples reflect the sorting out of smaller fish from the retained catch, with all gears discarding sablefish at age-1 and several observations of age-0 fish as well (Figures 52-55). Annual distributions from all fleets are highly variable due to limited sample sizes and probably only informative about the general size ranges that are discarded. It is important to note that all fleets have at some time discarded some sablefish 50-60^{+} cm in length. These fish are large enough to be valuable (and at least as large as the average retained sablefish), implying that size-based sorting is not the only reason for discarding and that no size or age is likely to be completely retained under all conditions. With the implementation of the trawl catch share program, discarding is now directly accounted for and more than likely different than years prior to 2011.

In aggregate, generally more females are observed in the fishery age compositions than males (Figure 56); however, the male distributions contain relatively more of the oldest sablefish (Figures 57-60). The annual fishery age distributions provide a reasonably clear picture of several prominent cohorts identified in other data sets despite the lack of very young fish. For example, the strong 2008 cohort can be tracked fairly clearly in both the male and female fixed-gear age compositions starting in 2010 as two year olds (Figures 57 and 58). The same is true for subsequent strong cohorts in 2013 and 2016. The fixed-gear fishery also shows evidence of a strong cohort beginning in the early 1990s (Figures 57 and 58). Age-composition data from the fixed-gear fishery is subject to more inter-annual variability, potentially attributable to spatial and depths changes in where the fishery was concentrated during different periods of time (anecdotally, the fishery operated in relatively deep water during the late 1980s when the oldest fish were observed). Tracking cohorts in the age data for the trawl fishery provides the clearest picture of the above-average year-classes common to all series because this sector has tended to retain the smallest fish of all sectors (Figures 59 and 60).

Also available from the WCGOP program were mean body weight observations from the discarded catch between 2002-2018. These were available for some hauls where length data were not collected. Fixed-gear annual body weight values were the larger than those from trawl gear (Figure 61).

2.2.5 DISCARD RATIO ESTIMATES

The WCGOP estimates commercial fishery discard ratios for the period between 2003 to present using data collected by gear type, fishery (e.g., open access, limited entry), and species/management units. The discard ratios were computed as the total estimated discarded weight (lbs) on observed trips divided by the estimated total catch (discarded and retained). To aggregate these ratios into the gear types modeled in this assessment, each state, fishery, and gear combination was weighted by the total estimated catch (discarded and retained weight). Thus, the discard rates represent weighted estimates from each contributing segment within each gear type. Uncertainty in these values was quantified via bootstrapping the individual observations and then aggregating to the total estimate, providing a distribution of the discard rate. From this distribution, a standard error associated with year specific discard ratio estimate was also estimated. Note that these methods are different than those used by WCGOP to estimate total discards but explicitly consider differences in catch by sector, state, and gear.

Additional years of data were available for the trawl fleet from the 'Pikitch study' conducted from 1985-1987 (Pikitch et al., 1988) and the Enhanced Data Collection Program (EDCP; Sampson 2002) conducted from 1996-2000. Discard rates and their corresponding standard errors for 1986-1988 were taken from a re-analysis completed by the NWFSC during 2017 (pers comm., John Wallace). Discard rates ranged from 6-22% for the fixed gear fishery over the period 1986-2017 (Figure 62). The early estimates of discard rates for the trawl fishery from the 1980s averaged 36.3%. More recent trawl estimates peaked in 2002 at 58.2%. After the implementation of the catch share program in 2011, discard rate estimates for the trawl fleet have dropped as low as 0.5% in 2012, with the highest observed rate of 3.2% in 2017.

2.2.6 DISCARD MORTALITY ESTIMATES

Discard mortality rates have been the subject of numerous research studies. Sablefish lacking a swim-bladder (and therefore the propensity for severe barotrauma), may survive after capture, depending on the specific conditions that they experience during the process. Warmer water results in higher mortality because the physiological stress of transitioning from very cold bottom temperatures to warmer surface water and air temperatures can be great (Davis et al., 2001). Furthermore, fixed gears are less physically damaging to sablefish compared to fish that spend an extended period in a trawl cod-end with a large catch volume. Treatment and handling of captured fish, including time-on-deck are also likely to be important for subsequent survival.

Analysis of discard mortality is hampered by the lack of available temperature information. Substantial efforts as part of the 2005 assessment resulted in a detailed model-based approach that used seasonal average water temperatures to predict variable annual discard mortality rates over the historical time- series, corrected for estimated differences among gear types (Schirripa and Colbert, 2005). Ultimately the approach was too complex to be supported by the available data with which to assign temperature and other individual fishing trip variables.

In 2011, discard mortality estimates were corrected to be consistent with those used by the Pacific Fisheries Management Council's Groundfish Management Team (GMT) in predicting in-season total mortality and the National Oceanic and Atmospheric Administration's annual calculation of total mortality for comparison with harvest regulations. These values are 20% discard mortality for sablefish captured with fixed gear and 50% discard mortality for sablefish captured with trawls. An exception to this is age-0 fish for which discard mortality is assumed to be 100%. These rates were used in this assessment.

2.3 BIOLOGICAL DATA

A number of biological parameters were estimated outside the assessment model. These values are treated as fixed (Table 11), and therefore, uncertainty reported for the stock assessment results does not include any uncertainty associated with these quantities. The estimation methods are described below.

2.3.1 WEIGHT-LENGTH RELATIONSHIP

The weight-length relationship is based on the WCGBT Survey data collected from 2003 through 2018. Male and female curves were fit separately using the assumption of normally distributed residuals about the log-linear relationship $W = aL^b$. Parameter estimates derived from this analysis (Table 11) are consistent with published studies and previous sablefish assessments. Estimated sex-specific relationships fit the data well and indicate little differences between males and females (Figure 63).

2.3.2 MATURITY SCHEDULE

Maturity is modeled as a logistic function of length, where the probability that individual i is mature is based on the length of individual i (L_i), length at 50% maturity ($L_{50\%}$), and a rate parameter (β). Most studies report estimates of $L_{50\%}$, while fewer report estimates of β. Although several studies exist for Alaska, Canada, and the U.S. West Coast, the results are variable. In general, $L_{50\%}$ is greater for sablefish in Alaska and Canada than off the U.S. West Coast (Parks and Shaw, 1983; McFarlane and Beamish, 1990). Estimates of $L_{50\%}$ are smaller for sablefish in deeper waters (Fujiwara and Hankin, 1988) and for older individuals (Methot, 1994); these latter effects are linked due to the likely ontogenetic movement of mature individuals offshore. Additionally, stressed individuals (such as those with tags) appear to have higher $L_{50\%}$ (McFarlane and Beamish, 1990). In general, studies from similar areas (Parks and Shaw, 1987, 1988), time-frames (Parks and Shaw, 1983), and designs (McFarlane and Beamish, 1990) estimate considerable variability in $L_{50\%}$. Variability could represent sampling error or variability in the biological processes influencing maturity, or both. In aggregate, variability among areas, years, and studies appears to represent a range of 2-4 cm between lower and upper estimates of $L_{50\%}$.

Historical estimates of $L_{50\%}$ for female sablefish off the U.S. West Coast range from approximately 56 cm (Parks and Shaw, 1983; Fujiwara and Hankin, 1988; Methot, 1994) to 60 cm (Hunter et al., 1989). Fujiwara and Hankin (1988) report an estimate of 0.13 for β. A recent study, which included 477 female sablefish found $L_{50\%}$ to decrease from north to south and with increasing depth (Head et al. 2014). Coast-wide estimates of $L_{50\%}$ were somewhat smaller than historical estimates at 54.64 cm. Here, we used a combination of data published during 2014 as well as additional coast wide samples collected and analyzed between 2014 and 2018 by NWFSC staff (pers. comm., M. Head), $L_{50\%}$ = 55.190 cm (Table 11) and β = -0.421. The maturity schedule suggests a slightly more protracted size range over which sablefish mature than has been estimated in recent assessments (Figure 64).

2.3.3 FECUNDITY

Available data suggests that sablefish are determinate spawners (i.e., total oocytes at the beginning of the spawning season is equivalent to total annual spawning output) and spawn 3-4 times per year (Hunter et al., 1989; Macewicz and Hunter, 1994). The total number of oocytes at the beginning of the spawning season appears to be linearly proportional to weight (Hunter et al., 1989), implying that spawning output for a mature female is also proportional to weight. This assumption has been used in previous sablefish stock assessments and is retained here (Table 11) in the absence of new information. Data on skipped spawning are unavailable, as are data on environmental effects or other factors that could cause fecundity to vary nonlinearly with weight.

2.3.4 NATURAL MORTALITY

From 1992 to 2007 a single fixed value for natural mortality (M) of 0.07 was assumed in all sablefish stock assessments (Schirripa, 2007). Improvements in the understanding of the importance of M estimates on stock assessment model uncertainty, and the growing number of assessments identifying differences in M among male and female groundfish, make a fixed value approach undesirable. Furthermore, the maximum aged sablefish on record is over 100 years. This assessment, as well as the 2011 assessment, uses prior probability distributions for males and females based on a hybrid method including both the Hoenig (1983) method using maximum observed age and the Pauly (1980) meta-analysis of M for a wide range of fish species. The method calculates prediction intervals, using input information including the maximum observed age, average temperature, and growth parameters (Hamel, 2015; Then et al., 2015). Results of the analysis, from which the priors for M were developed, were relatively insensitive to the choice of specific input parameters and generally quite uncertain, $ln(M)$ = -2.93857, SD = 0.438 for females and $ln(M)$ = -2.89857, SD =

0.438 for males (Figure 10). Both priors resulted in a substantial probability density over the range 0.06-0.20. This is somewhat higher than might be expected, largely because sablefish grow very rapidly relative to most other long-lived fish.

2.3.5 GROWTH

Range-wide investigations of sablefish growth suggest that growth varies across the northeastern Pacific, with a generally increasing cline in length-at-age with latitude (Echave et al., 2012; Gertseva et al., 2017; McDevitt, 1987; Kapur et al., in review). Break points in growth have been identified at around 50°N (approximately the northern end of Vancouver Island, Canada), where north of this breakpoint female asymptotic-length estimates were consistently over 70 cm and south of this breakpoint female asymptotic-length estimates were below 66 cm (Kapur et al., in review). A second break point was identified by Kapur et al. (in review) at 36°N (approximately Monterey, California), where asymptotic size for females and males to the south were 60.43 cm and 55 cm, respectively.

Female sablefish generally reach larger sizes and older ages than males. For example, a female sablefish can grow larger than 100 cm and have a maximum age greater than 100 years old, while the largest and oldest male sablefish observed was about 90 cm and 90 years old, respectively. However, relatively few sablefish reach these large sizes and old ages. Estimates of the maximum size of sablefish in the California Current have declined since the 1980s, likely due to both sustained fishing pressure over time and the use of the early pot survey data that selected larger and older fish to fit growth curves. For example, survey data used in the 1988 assessment were from the 1983 and 1985 pot surveys that selected larger and older fish, leading to von Bertalanffy estimates of asymptotic length of 77.5 cm for females and 64.5 cm for males. Subsequent assessments resulted in a decline in the estimated maximum size as more size-at-age data from other surveys and fisheries were included. For example, growth in the 2005 assessment estimated asymptotic length at 66.2 cm (females) and 55.8 cm (males). The most recent assessment produced similar estimates (Table 12).

2.3.6 AGEING BIAS AND IMPRECISION

Observed sablefish ages are derived from visually counting rings on otoliths using 'break-and-burn' methods. These counts can be large because sablefish are long-lived and the repeatability of individual age estimates is imperfect, especially for older fish. Age-reading staff have indicated that sablefish can be difficult to age. The observed age can differ (sometimes substantially) from the true age of a fish (i.e., 'reading error'). Aging error can be decomposed into the difference between true age and average-read age (bias) and variability around that average read age (precision). The bias and precision for aging methods or labs for west coast groundfish is estimated as a hierarchical model using readily available software (Punt et al., 2008) and data consisting of comparisons among and within methods or labs ('cross-reads' or 'double-reads').

A large number of double age reads were available for estimating sablefish age error, thousands of samples, including a large number of reasonably old (>40 years) sablefish (Figures 65-67). While sablefish lack a true age validation study, data from the AFSC include <30 individuals with known ages (i.e., no bias and perfect precision), with most fish <age 20, obtained from tag-recapture studies in Alaska. Between laboratory reads from the NWFSC, AFSC, Alaska Department of Fish and Game, and Fisheries and Oceans Canada were also available. Age-error analyses pool samples within a laboratory, estimating a single vector of precision and bias across the age bins.

In 2011, initial inspection of the data revealed that NWFSC ages were biased (low) by one to three years relative to the small sample of tagged fish, which appeared to be aged more accurately by the AFSC. Data were then analyzed using the ageing-error model from Punt et al. (2008), which estimates (1) the true proportion-at-age in the sample and (2) the bias and precision for each of four laboratories. This model treats the 'true' age for each otolith as a random effect and estimates the marginal likelihood of all other fixed effects while integrating across these random effects. Stepwise (i.e., forward and backward) model selection was used to select among all combinations of three precision models (i.e., linear and a Holling's-form for either standard deviation or coefficient of variation for precision) and two bias models (i.e., linear or Holling's-form) for each laboratory, as well as the maximum age for which a proportion-at-age parameter was estimated (possibly ranging from 2 to 80 years). Model comparisons were conducted using the Akaike Information Criterion. Stepwise model selection identified a model with Holling's-form bias and Holling's-form standard deviation of precision for each laboratory. Biases were very large and negative (i.e., reads were lower than the true age) and the standard deviation was increasing with true age for all laboratories (Figure 66). Initial modeling during the 2011 assessment was completed using the estimates suggesting that ages were both highly imprecise and very biased. However, these model runs suggested that the degree of bias estimated from initial ageing error analyses was incompatible with observed cohorts moving through the population and produced poor residual patterns and unrealistically low estimates of natural mortality. Based on these findings the information used to estimate ageing error properties was re-evaluated.

The 2011 comparison of the larger sample of otoliths, containing older fish, collected during trawl survey operations revealed that there was likely a much greater consistency among labs for west coast fish (Figure 65). It was concluded that the 'perfect' ages derived from the tagging experiment were not broadly representative of the aging methods for the fishery and survey samples available and that the initial analysis of bias was heavily influenced by these few fish. Therefore, the 2011 assessment estimated age error using only the NWFSC double-reads. This analysis assumed that the ages were unbiased but estimated the age imprecision such that by age 50 observed ages could differ from true ages by up to 11-12 years (Figure 67).

The age error analysis for this assessment used the same software and methods as the 2011 assessment. Given that a large number of between lab reads from the AFSC and the NWFSC were available for this assessment, this age error analysis uses the between laboratory reads for the AFSC and NWFSC as well as the double reads from the NWFSC and treats both AFSC and NWFSC ages 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 (Figure 67).

3 ASSESSMENT MODEL

3.1 HISTORY OF MODELING APPROACHES

3.1.1 PREVIOUS ASSESSMENTS

The first sablefish stock assessment was completed in 1984 (Francis, 1984), followed by frequent assessments since then (e.g., Francis 1985; McDevitt 1987; Methot and Hightower 1988, 1989, 1990; Methot 1992, 1994; Crone et al. 1997; Methot et al. 1998; Schirripa and Methot 2001; Schirripa 2002; Schirripa and Colbert 2005; Schirripa 2007; Stewart et al. 2011; Johnson et al. 2016). The 1984 assessment examined CPUE data from the 1979 to 1983 NMFS pot survey (Francis, 1984). Subsequent stock assessments were based on age-structured frameworks of varying complexity.

The 1985 age-structured assessment utilized a simulation model, estimating M, average weight-at-age, recruitment, and relative age-specific catchability, to examine maximum sustainable yield (MSY). The model relied on NMFS trawl and pot surveys as well as parameter estimates generated from independent research. The 1987 sablefish assessment extended the NMFS survey time-series and primarily consisted of a modified yield-per-recruitment analysis focusing on the minimum size limit (22 in) implemented in 1983.

In 1988, a catch-at-age analysis using an early version of the Stock Synthesis (SS) modeling framework, which is the basis for all subsequent assessments, was implemented (Methot and Hightower, 1988). This model included two fleets, fixed gear and trawl, and two years of fishery biological data. NMFS trawl and pot surveys provided indices of abundance, and estimates of exploitation rate were based on tag-recapture information generated from a tagging study that began in 1971. The 1989 sablefish stock assessment followed a similar approach; revisions in the age-determination criteria for sablefish caused an increase in the observed proportion of old fish and a decrease in the estimate of M from 0.15 to 0.09. The 1990 sablefish assessment (Methot and Hightower, 1990) explicitly modeled stock structure with a northern population (U.S. Vancouver and Columbia INPFC areas) and a southern population (Eureka, Monterey, and Conception INPFC areas). Including spatial structure was motivated by differences in growth rates and the perception of low migration rates. The spatial models facilitated comparisons between and amongst areas with signals in the raw data.

In 1992, the assessment reverted to a single stock area, excluding the Conception INPFC area (Methot, 1992). Data from the Triennial Shelf trawl survey were used to extrapolate survey estimates to the entire assessment area (Monterey through U.S. Vancouver INPFC areas). Analysis focused on exploring the trade-off in fitting the trawl-survey biomass and the trend from the pot survey. The depth stratified age- and length-composition data suggested that movement of sablefish into deep water was more closely related to their age than size. The 1994 sablefish assessment (Methot, 1994) was similar to the 1992 analysis. The survey was used as an absolute measure of biomass after extrapolation to the coast-wide level. The 1997 assessment (Crone et al., 1997) added CPUE data. No single model was found that fit all indices well. The 1998 assessment

(Methot et al., 1998)focused on the inclusion and exclusion of the pot survey index and the use of commercial logbook CPUE.

The 2001 assessment Schirripa and Methot (2001) focused on evaluating the sensitivity of the results to the treatment of the survey data and trade-offs among pot survey and logbook indices of abundance. This assessment was the first to introduce the possibility that sablefish recruitment may be linked to environmental factors. The 2002 assessment (Schirripa, 2002) was an update to Schirripa and Methot (2001) and focused mainly on newly available data from existing sources. It was the first assessment to detect the strong 1999 and 2000 cohorts in the 2001 data, following many years of below average recruitment. A significant relationship between recruitment and sea level was identified.

Several important changes were made to the sablefish assessment in 2005 (Schirripa and Colbert, 2005). Landings (and the modeled time-period) were extended back to the year 1900. Separate selectivity curves were implemented for the trawl surveys, and years with limited geographic coverage in the Triennial Shelf Survey were eliminated. Discard data from the relatively new observer program were included and discard mortality was investigated. Sea level was used as an explicit offset in the population dynamics to expected recruitment.

The 2007 assessment (Schirripa, 2007) included newly available data and changed the treatment of the sea level index of recruitment within the stock assessment model to be a survey index of recruitment with observation error, rather than an explicit offset in the population dynamics to expected recruitment. The assessment made the explicit assumption that catchability for the WCGBT Survey was equal to 0.56, which was modeled by using only the shelf region. Uncertainty was investigated and reported primarily through alternate values for catchability.

The 2011 stock assessment (Stewart et al., 2011) reduced the number of parameters used to model fishery dynamics. Historical management actions were condensed to those that had a strong influence on fishery behavior (sorting and retention, selectivity, or both). Previously fixed leading parameters, M and trawl survey catchability, were estimated or used analytical solutions. Changes lead to increased, more realistic, estimates of uncertainty around stock size estimates. Repeated testing of the correlation between sea level and recruitment continued to find a significant relationship that explained approximately 35% of the variability in recruitment deviations. The sea-level data was used from 1970 forward, a period with length- and age-composition data, and was not retained in the base model because the index provided a recruitment signal largely consistent with that provided by the composition data. Finally, the large number of deviations about annual growth and annual selectivity curves estimated in the 2007 model were reduced, with the net effect that uncertainty was increased. The sensitivity of model results to (M), equilibrium recruitment, and steepness (h), which was estimated prior to 2011, was investigated via likelihood profiles. The 2015 stock assessment (Johnson et al., 2016) was an update to the 2011 stock assessment, maintaining the same model structure and focused on adding the new data and retuning the model given the new data.

In summary, assessments have largely drawn the similar conclusions regarding historical trends. Since the 1970s, the sablefish resource has show a rapid, persistent decline due to many years with low recruitment and high fishing intensity during 1970s and 1980s (Figure 68). Uncertainty regarding the absolute scale of the sablefish population has remained high, with previous assessment models suggesting that unfished spawning biomass ranges between just under 100,000 mt up to approximately 250,000 mt.

3.1.2 RESPONSE TO 2011 STAR PANEL AND 2015 PFMC RECOMMENDATIONS

The 2011 STAR panel and 2015 update stock assessment review identified a number of future assessment recommendations. Progress on each issue is summarized below.

1. *Complete and review the Washington catch reconstruction and review the California and Oregon catch reconstructions.*

   The California and Oregon historical catch reconstructions were reviewed and approved by the Pacific Fishery Management Council's Science and Statistical Committee. The WDFW catch reconstruction for sablefish was presented at the 2019 pre-stock assessment workshop and was agreed as the best available catch reconstruction for Washington sablefish.

2. *Conduct new studies of maturity by length and age based on more comprehensive coastwide and depth-based sampling and using histological techniques for determining maturity stage.*

   A recent study by Head et al. (2014) provided new estimates of critical life-history parameters for sablefish based on data specific to the U.S. West Coast. Additional coast-wide maturity data have been collected and analyzed using histological techniques to produce a revised maturity relationship for this stock assessment.

3. *Conduct new studies on maturity and age-reading error.*

   While backlogged samples have been aged and additional between-lab reads have been completed, no additional studies on ageing error were performed. The estimation of ageing error was updated for this assessment using new data. The most accurate histological methods have been used to produce sablefish maturity data.

4. *Use commercial size-graded market categories for commercial length- and age-composition expansion.*

   The `PacFIN-Utilities` code has been improved to use all available commercial size graded market category available. Past assessments may not have appropriately used size grades, or size grades may not have been available in PacFIN. Additionally, in the process of revising the PacFIN code a number of errors in the PacFIN database were identified and corrected by the states. For example, biological samples for research that were entered incorrectly into PacFIN as random port samples were corrected, and therefore removed from the data used to build commercial compositions. The `PacFIN-Utilities` code was also improved such that the age data expansions used only the weights of the aged fish, as opposed to the weights of all fish in a biological sample, as was done previously.

5. *Evaluate methods to capture information regarding environmental and ecosystem variability in stock assessments.*

   This stock assessment provides an improved re-analysis of the sea-level data coast-wide. Additionally, this document provides information on ecological and social considerations with respect to the sablefish fishery (see Appendix A).

6. *Explore alternative error distribution assumptions for compositional data within SS.*

   This 2019 stock assessment compares the use of the multinomial and Dirichlet-Multinomial error distributions; the Harmonic mean and Francis approaches were investigated for weighting multinomial distributions.

7. *Develop guidelines for use of the Lorenzen model for age-dependent M.*

   A post-doc began working with NWFSC staff on this topic during January 2019. However, there is no simulation work on implementing a Lorenzen curve within SS to provide the basis for new guidance for this stock assessment. It remains unclear how to scale the Lorenzen curve for a given species given noisy data or limited contrast in F needed to precisely estimate age-specific M. This assessment does provide a set of sensitivity model runs with respect to alternative treatment of M.

8. *Modify the SS code to allow changes to the plus-group age without data restructuring.*

   While a good idea, it is outside of the scope of this analysis to modify SS. Alternative data plus-group specifications continue to require restructuring the data.

9. *Further investigate potential inaccuracy in using maximum likelihood estimates and the normal distribution to approximate confidence limits for estimates of spawning biomass. It may be feasible to conduct a full Bayesian analysis of uncertainty.*

   This request is largely outside of the scope of this stock assessment. Although SS can operate using Monte Carlo Markov Chain (MCMC) methods, time did not permit the use of MCMC. Alternatively, asymptotic uncertainty estimates, model sensitivity runs, and likelihood profiles are provided.

10. *Consider joint assessments with Canadian and Alaskan scientists.*

    This is a long standing request of many stock assessments for transboundary stocks that is outside of the scope of the stock assessments routinely provided for management decisions. However, collaborative research activities among northeast Pacific sablefish scientists are ongoing since 2017 and have gathered momentum during 2019 with the hiring of a post-doctoral researcher at Department of Fisheries and Oceans Canada and a PhD student at the University of Washington. Current analyses are focused on northeast Pacific-wide synthesis of basic biological data and tagging data needed to parameterize operating models for management strategy evaluation.

3.2 DESCRIPTION OF NEW MODELING APPROACHES

The 2015 update stock assessment model was transitioned into SS version 3.30.13, released 2019-03-09, this transitioned model matched the time series of spawning biomass and stock depletion estimated in the 2015 stock assessment (Figure 69). The 2019 model implements the following structural model changes:

1. Fixing stock-recruitment *h* at 0.7 to be consistent with the current understanding of the productivity of groundfish in the California Current. All of the other stock assessments approved by the Pacific Fisheries Management Coundil for groundfish off the U.S. West Coast either report an estimated value of *h* or rely upon a fixed *h*. Typically, *h* is fixed at values larger than 0.6, which is what it was fixed at in Stewart et al. (2011); Johnson et al. (2016). Note that likelihood profiles from both this assessment as well as past assessments show that the data are uninformative with respect to *h* for sablefish.

2. Concerns regarding bycatch of sablefish in the Pacific hake fishery were raised early in the stock assessment process. Therefore, the inclusion of an additional fleet to account for sablefish bycatch in the hake fishery is evaluated as a sensitivity.

3. For this assessment, similar to the 2011 stock assessment, a concerted effort was put forth to reduce the number of estimated parameters. The cubic spline used for age-based fisheries selectivity in the 2011 assessment required 15-17 parameters. In this assessment, a double-normal parameterization was implemented for age-based fishery selectivity, which requires 6-10 parameters. The double-normal parameterization fit the age-composition data from the fisheries better or similarly to the previously used cubic spline parameterization in all comparisons.

4. Sea-level data were not included in the 2011 or 2015 base models but were rather investigated as a sensitivity. Including this time series of data, which began in 1970, did not add any new information to the model due to a similar recruitment signal available from the length- and age-composition data. The sea-level time series has since been reanalyzed to start in 1925 and is now included in the base model to inform historical recruitment rather than assuming that recruitments directly relate to the stock-recruitment curve. Recruitment deviations for sablefish are rarely close to the stock-recruitment curve, and thus, using the weakly predictive sea-level data is an improvement from using the fit of the stock-recruitment curve. In the future, sea level could be used to inform recruitment in the absence of other data sources. If available, ROMs data based on Tolimieri et al. (2018) could also be used as a predictor for future recruitment.

5. The bin structure for the smallest bin included for length data changed from 20 to 18 cm to capture fish in 18 cm bin that were previously aggregated into the 20 cm bin. The bin structure for the largest bin included for the age data changed from 35 to 50 years. The use of 35 years as the beginning of the age plus group resulted in large amounts of ages in the plus groups for all surveys except the Triennial Shelf Survey. In some cases, the proportion of ages in the plus group was larger than the peak of the distribution of ages of young fish.

Therefore, the plus group was changed to 50, a value that resulted in a small proportion of ages in the plus groups for survey data. To accommodate the increase in the plus group for the age data, the plus group for age in the population dynamics was changed from 50 to 70 years.

6. This assessment combined the hook-and-line and pot gears into a single fixed-gear fleet. This consolidation of two fleets into one was done because both of these fleets both catch larger fish, were subject to the same regulatory rules, and because catches from pot gears dominated the fixed-gear landings only for a few years during the 1970s and early 1980s. Consequently, the number of selectivity parameters, which are are difficult, was reduced.

7. The STAR panel reviewers noted that the likelihood profiles for female M showed a strong conflict between the length data and age data with respect to plausible values of M. Therefore, all length data sets except the WCGBT Survey were removed from the model, allowing for only the ages and most recent survey data to inform the estimation of M.

8. Estimates from the sablefish model are sensitive to data weighting. Iterative data weighting using the Harmonic Mean or Francis methods, as well as the estimation of the Dirichlet-Multinomial data weighting parameters, was implemented for comparison purposes. For models that estimated the Dirichlet-Multinomial parameters, weighting parameters that were estimated at the upper bound of 7.0 were fixed at 5.0 giving full weight to those data sets. While the estimates from STAR panel draft model, with all length data, were largely insensitive to the method of data weighting used, estimates from the post-STAR model, with only length data from the WCGBT Survey, showed some differences between the iterative weighting methods and the Dirichlet-Multinomial method. Largely, estimates of the index of abundance from the most recent years of the WCGBT Survey under fit the data when estimating the Dirichlet-Multinomial parameters. The Francis method was agreed for use at the STAR panel because this method led to a better fit to the WCGBT Survey index than estimating the Dirichlet-Multinomial parameters. Estimating the Dirichlet-Multinomial parameters when only one length data set was used to fit the model led to less down weighting of the WCGBT Survey length data relative to the iterative data-weighting methods.

Many routes from the 2015 update stock assessment to a base model were explored in preliminary analyses. Results of each transitional step were path dependent. Thus, it was decided to systematically add all the new data before appreciably changing the model configuration (Figure 69).

3.3 GENERAL MODEL SPECIFICATIONS

This stock assessment uses SS version 3.30.13-safe, released on 2019-03-09. 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.

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 (Table 13). 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.

3.3.1 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 selected to be sufficiently wide to avoid truncating the search procedure during maximum likelihood estimation (Table 13).

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.

3.3.2 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.

For comparison, re-weighting using both the Harmonic Mean and Dirichlet-Multinomial methods was applied to the length and age compositions (Figure 70). For all methods, 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.

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.

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.

3.3.3 RECRUITMENT VARIATION

Data on σ_R will never be precise, even in years with data. Therefore, the estimation of recruitment deviations exhibits a compromise between fitting information in the data and the central tendency to pull estimates of log(recruitment) deviations towards zero. Simulation results show that utilizing a bias-adjustment procedure can improve estimates of σ_R (Methot and Taylor, 2011). Here, first the bias adjustment procedure within SS was updated to include the most recent data. Second, the RMSE of recruitment deviations was used to inform the σ_R, making the model internally consistent. σ_R was capped at a value of 1.4, the point at which the bias correction is no longer expected to perform well (Methot and Taylor, 2011).

3.3.4 ESTIMATED AND FIXED PARAMETERS

A total of 307 parameters were specified in the base model and 229 of them were estimated (Table 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, 1890. The main period of recruitment deviation estimation was chosen based on the first year of available sea-level data (i.e., 1925). The years in which mean bias was corrected for was based on methods developed by Methot and Taylor (2011) that estimates 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 ($\sim$<2 years). Selectivity was lower for older individuals.

Time blocks for fishery selectivity and retention schedules were based on previous research with respect to influential management 'milestones' and the recent introduction of catch shares within the trawl fishery (Table 14). Milestones include (a) 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; (b) 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 (c) full retention all sablefish within the trawl fishery with the implementation of the 2011 catch share program.

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 this 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.

3.4 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.

4 ASSESSMENT RESULTS

4.1 CONVERGENCE STATUS

To test for convergence, 100 trials of the base model were ran using randomly generated alternative initial values for each estimated parameter. A value of 0.1 was used to define the uniform distribution that is transformed into cumulative normal space and subsequently used to calculate these initial values based on the parameter bounds. Thus, each trial perturbs the initial values used for minimization with the intention of causing the search to traverse a broader region of the likelihood surface (Methot and Wetzel, 2013). The same (i.e., difference in likelihood of less than or equal to 0.5) or worse likelihood was found for 8 and 91 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.

4.2 BASE-MODEL RESULTS

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 15). Female and male sablefish showed similar rapid growth trajectories; with females growing to a slightly larger size at age 30 (62.509 cm) than males (56.312 cm) and showing a broader distribution of length at a given age (Figure 71). *M* for females (0.065) and males (0.059) were similar to values estimated in previous assessments (2011: 0.08 and 0.065 respectively; 2015: 0.076 and 0.062, respectively; Figure 10).

This assessment did not include time-varying growth. Differences were seen in the estimated weight-at-age compared to empirical weight at age collected by the WCGBT Survey (Figure 72). These differences were more prominent in the most recent years, which might be a cohort effect. Future research could investigate methods for modeling time varying growth.

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 16 and 17; Figure 73). The proportion of the spawning output that is unavailable to the surveys and fleets, which are all modeled using dome-shaped selectivity, has slightly decreased over time (Figure 74). 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 73). The trawl fishery selected younger fish than the fixed gear fleet and showed little difference between males and females (Figure 73). Retention schedules (Table 17) 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 75). Full retention of the largest individuals was assumed since the beginning of the 2011 catch-shares program for the trawl fishery (Figure 76).

The base model fit the trend (decline, then stabilization, and increase) in the WCGBT Survey well (Figure 77), such that the added variance parameter was set to zero. Fits to the NWFSC Slope Survey were generally flat (Figure 78), 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 79). Estimates of added variance were 0.16 and 0.05, respectively (Table 17). 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 80), although the estimated extra variance of 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. The estimated added standard deviation was 0.73, 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 (Figure 22), with residual patterns (Figures 81 and 82) 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 83-85). The slope survey fits to the marginal-age distributions also showed no glaring residual patterns in the age data (Figures 86 and 87). The selection of younger sablefish was evident for the Triennial Shelf Survey, with a larger residuals from 1995 forward (Figure 88).

Fits to the marginal age compositions for the fisheries were good (Figure 56). All fisheries show relatively small residuals, with patterns of large cohorts moving through the population at some point (Figures 89 and 90). Residual patterns might partially be the result of spatial differences in fishing, growth or movement. As requested by the STAR panel, spatially explicit composition data north and south of 36° N lat is provded in Appendix D.

The model was able to fit the mean body weights of the fishery discards and discard fractions well (Figures 61 and 62).

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 91). 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 68), with both the lowest and highest estimates occuring during the past 20 years. 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. The 2016 cohort is estimated to be the largest since the mid-1970s.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 92).

Catches were estimated from the beginning of the time series (Table 18). During the first half of the 20^{th} 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 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. The point estimate of 2019 spawning biomass from the base model is 57,444 mt, however, the ~95% interval ranges broadly from 32,776 to 82,112 mt. The point estimate of 2019 spawning biomass relative to an unfished state (i.e., depletion) from the base model is 39% of unexploited levels (~95% interval: 26-52%).Estimates indicate that the spawning biomass was near the target (Figure 93). The estimated time-series of total, age-4+ (Figure 94), and spawning biomass (Figure 95) track one another closely (Table 19). Forecasts from the 2015 assessment update projected the spawning biomass to increase by 9.3% from 2015 to 2019 given specified harvests, whereas the current assessment estimated the increase at 8.0%. Estimates of unexploited spawning biomass are 2% lower than that estimated in 2015 and 19% lower than the 2011 estimate. Percent of unfished biomass in 2019 was estimated at 39%, while the 2015 stock assessment forecasted it to be 38%.

4.3 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 (Table 20). 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. 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, and the Dirichlet-multinomial 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. Composition data weighting via the Harmonic mean and Francis methods were similar, while the Dirichlet-multinomial method suggested slightly different results.

The value of the parameter controlling recruitment variability was determined 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.

4.4 UNCERTAINTY AND SENSITIVITY ANALYSIS

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. 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.

4.4.1 SENSITIVITY ANALYSIS

Sensitivity analyses were chosen to provide more information about relatively obvious questions for any stock assessment such as sensitivity to key structural choices, 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. The order in which they are presented was not intended to reflect their importance; each run included here provided important information for developing or evaluating the base model and alternate states of nature.

The following model changes to data or parameter estimation had little impact on the base model.

1. Parameter phasing.

2. Estimating autocorrelation in the recruitment deviations.

Removing the sea level index of recruitment from the base model resulted in a stock trajectory that was highly similar to, and within, the range of uncertanty estimated in the base model (Table 21; Figure 96). Small differences in model estimates were driven by differences in recruitment estimates, largely those prior to 1980 before age-composition data are available (Figure 96) Results from a model run using the 2015 selectivity patterns were within the range of uncertainty estimated in the base model, although estimates of both unfished spawing biomass and stock status were lower (Table 21; Figure 97). Removing the WCGBT Survey index resulted in greater estimates of uncertainty around time series of spawning stock biomass and stock status, but more optimistic estimates of stock size and status at the end of the time series (Table 21; Figure 96).

A model runs implementing the following changes were largely withing the range of uncertainty estimated in the base model: 1) adding a hake bycatch fleet, 2) beginning the model in 1970 (a STAR panel request), and 3) estimating a single sex combined value for natural mortality (Table 22 and Figure 98). In the pre-STAR model draft 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. Estimates of unfished spawning biomass and stock status in the single M run were lower than the base model value, while the estimate of unfished biomass and stock status were higher in the run that began during 1970.

The scale of the estimated unfished spawning biomass is uncertain. To get a ball-park estimate of the scale of the northeast Pacific sablefish population, conditioned on the California Current assumptions and biology, a model run adding all northeast Pacific landings was completed. This model run suggests a northeast Pacific sablefish population that follows a similar stock trajectory and results in a similar stock status compared to the base model, but that unfished spawning stock biomass could have ranged from about 250,000 mt to about 1,500,000 mt (Table 23; Figure 99). This model sensitivity addresses, in a limited way, the long standing request for investigations into transboundary stock issues.

Models with a range of specifications for the age that defines the beginning of the plus group for the age data agreed regarding the strong increase in the spawning biomass during the 1960s to mid-1970s, followed by stock declines until recent years (Figures 100 and 101). The ages largely agreed regarding a period of high recruitments that drive this stock increase. This pattern was evident but less extreme in the 2011 and 2015 models due to the plus group being set at age 35. A similar pattern in spawning biomass trends was present in the AFSC stock assessment (Hanselman et al., 2018). Extending the plus group to age 50 allows for fish aged 35 to 50 to better inform what historical recruitment may have been during periods that previous models assumed there was no information regarding recruitment as well as provides the potential to track truncation or expansion of the 'old growth' population age structure due to changes in fishing pressure or recruitment.

In aggregate, these sensitivity analyses reflect the uncertainty in absolute stock size in this sablefish assessment. Hopefully, they also provide a basis for future investigations, as well as a method for prioritizing potential research studies.

4.4.2 RETROSPECTIVE ANALYSIS

A retrospective analysis was conducted by running the base model with data removed for the past 5 years. All retrospective model runs fall within the uncertainty estimates from the base model. There was limited evidence of a retrospective pattern in estimates of spawning biomass and stock status, such that the view of the stock becomes more pessimistic as data are removed (Figure 102). The retrospective pattern in stock status is largely driven by some of the largest recruitments observed for sablefish during 2013 and 2016.

4.4.3 HISTORICAL ANALYSIS

Estimates of the current stock size and relative depletion were highly consistent with prior stock assessments, particlarly from the 1970s forward, the period of time with good data for sablefish (Figure 103). 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.

4.4.4 LIKELIHOOD PROFILES

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

Female M (male 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 (Table 24; Figures 104-107). However, this is not a trivial parameter range and the assessment results vary considerably among these values in absolute scale (Figures 108 and 109).

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 (Table 25; Figures 110-114). 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 115).

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 (Table 26; Figure 116). Most of the values included in the profile led to similar trajectories of spawning stock biomass (Figure 117). The relative strengths of recent cohorts were also not strongly influenced by the value for h (Figure 118), and the relative depletion level is quite robust as well (Figure 119). Uncertainty from h was well inside the global estimation uncertainty captured via the asymptotic intervals about the maximum likelihood estimates.

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.

5 REFERENCE POINTS

Unfished spawning biomass was estimated to be 147,729 mt (109,022-186,436, ∼95% interval). The abundance of sablefish was estimated to have dropped below the target reference point of 40% of this estimated value of unfished spawning biomass during the 2000s and generally remained below the target through 2018. The estimate of the target spawning stock biomass was 59,092 (43,609-74,574, ∼95% interval), which gives a catch of 7,363 mt (4,269-10,456, ∼95% interval). The stock was estimated to be just below the target stock size in the beginning of 2019 at 57,444 mt (32,776-82,112, ∼95% interval). The stock was estimated to be above the depletion level that would lead to maximum yield (0.25; Figures 120 and 121). The estimate of the stock's current level of depletion was 38.9%. Equilibrium yield at the fishing mortality that leads to the maximum sustainable yield (F_{MSY}) is 8,077 mt (4,684-11,470, ∼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 122 and 123). The spawner potential ratio (SPR) exceeded the fishing mortality target/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, while since 2015 it has been between 83 and 95%. The phase plot shows the interaction of fishing intensity and biomass targets (Figure 121).

6 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 2016-2018 catches were used to distribute catches among the fisheries.

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.

The Pacific Fisheries Management Council has adopted a buffer on catch that increases with the time since the last assessment, causing the overfishing limit to decrease (Table 27). The multipliers on the overfishing limit, available in the model forecast file, are combined with the 40-10 harvest control rule to calculate overfishing limits, allowable biological catches, and annual catch limits. Total catches in 2019 and 2020 were set at the Pacific Fisheries Management Council's Groundfish Management Team requested values that are just under the approved annual catch limits, also available in the forecast file. Catch allocations used for the forecast reflect the average distribution of fishing intensity among fleets during the most recent three years. It is assumed that discarding and retention behavior does not differ from recent years.

The results of all catch forecasts are conditioned on (1) the expected levels of catch provided by the Groundfish Management Team, which are lower than the already-specified annual catch limits for 2019 and 2020 and (2) assume average recruitment from the stock-recruitment curve. Current medium-term base model projections of expected catch, spawning biomass, and depletion show an increasing trend through the projection period (Table 28). Projected increases beyond 2019 are expected to move the stock size to just above the target and are reliant upon continuing high estimates of recent recruitments as well as the realization of expected recruitment levels from the stock-recruitment relationship, despite many recent years of below-average recruitment.

The decision table reports 12-year projections for alternate states of nature (columns) and management options (rows) beginning in 2021 (Table 28). It is common to select an 'axis of uncertainty' from leading parameters, model structure, or historical catch levels, to best bracket the range of possible states of nature. For this assessment, due to the explicit inclusion of uncertainty in M and growth, asymptotic intervals are broad. Past assessments have investigated steepness as a possible axis of uncertainty, but even a broad range (from 0.3-0.9) underrepresented the forecast uncertainty relative to that implied by the parameter uncertainty already included in the base model.

Uncertainty in management quantities for the decision table was characterized using the asymptotic standard deviation for the 2019 spawning biomass from the base model. Specifically, the 2019 spawning biomass for the high and low states of nature are given by the base model mean ±1.15·standard deviation (i.e., the 12.5th and 87.5th percentiles). A search across fixed values of R_0 was used to attain the 2019 spawning biomass values for the high and low states of nature. The mid-level catch streams were based on the 40-10 harvest control rule. At the request of the Groundfish Management Team representative at the STAR panel, the high and low catch streams were set using the Category 1 values of $P^* = 0.45$ and $P^* = 0.35$, respectively.

Spawning stock biomass in 2019 ranges across the three states of nature from 42,968 to 71,915 mt, with corresponding stock status between 38% to 41% of the unfished stock size. The decision table suggests that all catch scenarios under both the base and high state of nature result in increases 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, maintaining the stock within the precautionary zone.

7 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., in review). The estimates represent the relative distribution of the sablefish population observed by the survey, not the entire population. Additionally, it is likely that fish from more northerly regions are migrating into U.S. West Coast waters (pers. comm., L. Rogers), which may bias the survey estimates of the distribution of fish in each region. Thus, these results should be interpreted with caution.

The average survey biomass, from 2003 to 2018, that has been distributed south of 36°N, is 26.30%. The average survey biomass, from 2003 to 2018, that has been distributed north of 36°N, is 73.70%. The 2011 and 2015 assessments estimated that 16.2% and 26.2% of the biomass was found south of Point Conception and 83.8% and 73.8% of the biomass was found to the north, respectively. The estimates from the WCGBT Survey show that the spatial distribution of sablefish along the U.S. West Coast appears to be relatively stable, particularly from 2008 to 2014 (Table 29).

8 RESEARCH 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.

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10 TABLES

Table 1. Total, including foreign, landings (mt) by fleet, fixed-gear (fix) and trawl.

Year	Fix	Trawl	Year	Fix	Trawl	Year	Fix	Trawl
1890	2	0	1933	1,094	429	1976	20,507	3,888
1891	6	0	1934	1,958	681	1977	5,244	3,498
1892	7	0	1935	2,481	902	1978	7,709	4,532
1893	10	0	1936	2,015	337	1979	16,772	7,116
1894	12	0	1937	2,297	232	1980	4,537	4,507
1895	17	0	1938	2,217	258	1981	5,864	5,552
1896	19	0	1939	2,448	295	1982	8,285	10,341
1897	21	0	1940	1,878	301	1983	7,118	7,534
1898	23	0	1941	1,652	488	1984	5,369	8,613
1899	25	0	1942	2,293	935	1985	6,618	7,500
1900	50	0	1943	1,838	2,085	1986	6,326	6,670
1901	76	1	1944	1,486	2,999	1987	5,872	6,556
1902	103	3	1945	1,691	2,726	1988	5,062	5,542
1903	129	4	1946	2,783	1,672	1989	4,410	5,808
1904	156	6	1947	1,717	516	1990	3,781	5,264
1905	138	7	1948	1,887	946	1991	4,319	5,003
1906	135	8	1949	1,987	983	1992	3,869	5,482
1907	142	10	1950	1,624	1,016	1993	3,148	4,963
1908	86	11	1951	2,253	2,012	1994	3,709	3,834
1909	141	12	1952	1,478	1,163	1995	4,012	3,860
1910	196	14	1953	965	692	1996	4,081	4,212
1911	252	15	1954	1,323	997	1997	4,122	3,774
1912	307	16	1955	1,289	898	1998	2,175	2,170
1913	362	18	1956	971	2,435	1999	3,408	3,164
1914	417	19	1957	1,599	952	2000	3,506	2,691
1915	472	20	1958	764	768	2001	3,013	2,602
1916	1,288	26	1959	1,234	984	2002	2,190	1,576
1917	1,695	286	1960	1,675	1,192	2003	3,011	2,219
1918	2,684	157	1961	1,055	756	2004	3,278	2,419
1919	919	105	1962	1,010	1,617	2005	3,600	2,403
1920	627	246	1963	949	869	2006	3,380	2,539
1921	846	322	1964	1,009	1,038	2007	2,622	2,493
1922	711	85	1965	910	1,024	2008	2,795	2,894
1923	1,259	169	1966	740	1,132	2009	3,889	3,062
1924	1,535	294	1967	2,460	1,819	2010	4,059	2,540
1925	1,869	227	1968	1,421	1,314	2011	4,421	1,731
1926	1,639	55	1969	3,411	2,068	2012	3,669	1,520
1927	2,206	312	1970	1,766	2,840	2013	2,585	1,405
1928	1,821	289	1971	1,407	2,480	2014	2,862	1,300
1929	1,815	468	1972	3,082	3,539	2015	3,540	1,471
1930	2,097	446	1973	1,397	4,276	2016	3,826	1,479
1931	1,067	330	1974	5,122	3,478	2017	3,637	1,671
1932	1,345	303	1975	10,334	3,966	2018	3,550	1,495

Table 2. Summary of key events in the sablefish fishery and groundfish management history. For a more complete summary of management actions since 1982 see Appendix B of this document and Appendix A of Stewart et al. (2011).

Year	Source
1942-1946	Market demands likely increase retention of previously unmarketable sablefish.
1955	First minimum size limit (26 in, in Oregon and Washington, later removed).
1982	First trip limits imposed on the trawl fishery.
1983	22 in minimum size limit north of Point Conception (allowance for some smaller fish).
1990-1993	Increasingly shorter fixed-gear seasons.
1997-1999	Sequential reductions in landings limits.
2003	Rockfish conservation areas close large portions of the shelf to trawling and fixed-gear fleets.
2011	Rationalization of the trawl fishery.

Table 3. Recent trend in overfishing limits (OFLs), annual catch limits (ACLs), landings, and estimated (est.) total dead catch (mt). Limits are summed across the southern and northern management areas where separate values were applied. Dead catch includes discards, which are estimated within the stock assessment, and therefore, dead catch may differ from total mortality reports used by management.

Year	OFL	ACL	Landings	Est. dead catch
2009	9,914	8,423	6,951	7,372.96
2010	9,217	7,729	6,599	7,017.63
2011	8,808	6,813	6,152	6,251.04
2012	8,623	6,605	5,189	5,280.13
2013	6,621	5,451	3,990	4,051.93
2014	7,158	5,909	4,162	4,239.63
2015	7,857	6,512	5,011	5,091.38
2016	8,526	7,121	5,305	5,402.67
2017	8,050	7,117	5,308	5,424.41
2018	8,329	7,419	5,045	5,131.61

Table 4. Recent sablefish landings by fleet (mt and relative %) and summed across fleets (mt).

	Fixed-gear		**Trawl**		**Total**
	mt	%	mt	%	mt
2009	3,889	55.95	3,062	44.05	6,951
2010	4,059	61.51	2,540	38.49	6,599
2011	4,421	71.86	1,731	28.14	6,152
2012	3,669	70.70	1,520	29.30	5,189
2013	2,585	64.78	1,405	35.22	3,990
2014	2,862	68.76	1,300	31.24	4,162
2015	3,540	70.65	1,471	29.35	5,011
2016	3,826	72.13	1,479	27.87	5,305
2017	3,637	68.52	1,671	31.48	5,308
2018	3,550	70.37	1,495	29.63	5,045

Table 5. Landings (mt) from Alaska (AK) and British Columbia (BC) for their hook-and-line (HKL), pot (POT), and trawl (TWL) sectors.

Year	AK HKL	AK POT	AK TWL	BC HKL	BC POT	BC TWL
1907	33.84					
1908	18.72					
1909	31.68					
1910	82.80					
1911	80.64					
1912	12.24					
1913	40.32					
1914	64.08					
1915	109.44					
1916	239.76					
1917	759.59					
1918	976.30					
1919	366.47					
1920	421.19					
1921	282.96					
1922	35.28					
1923	611.99					
1924	163.44					
1925	772.55					
1926	494.63					
1927	979.90					
1928	192.96					
1929	340.55					
1930	325.43					
1931	200.88					
1932	60.78					
1933	74.16					
1934	132.01					
1935	320.78					
1936	455.68					
1937	975.97					
1938	391.45					
1939	804.87					
1940	1075.71					
1941	1316.61					
1942	2947.62					
1943	2375.06					
1944	2184.05					
1945	1992.46					
1946	1530.01					

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Table 5. Landings (mt) from Alaska (AK) and British Columbia (BC) for their hook-and-line (HKL), pot (POT), and trawl (TWL) sectors.

Year	AK HKL	AK POT	AK TWL	BC HKL	BC POT	BC TWL
1947	2968.94					
1948	658.70					
1949	670.76					
1950	197.96					
1951	801.84					
1952	490.97					
1953	1271.02					
1954	752.84					
1955	733.43					
1956	688.53					
1957	804.74					
1958	363.48					
1959	536.41					
1960	1055.78	3100.00	0.00			
1961	494.67	16100.00	0.00			
1962	379.22	26400.00	0.00			
1963	319.20	10600.00	6300.00			
1964	319.81	3300.00	4000.00			
1965	884.99	900.00	7800.00	193.20	0.00	353.90
1966	496.46	3800.00	11800.00	499.70	0.00	406.90
1967	343.38	3900.00	15300.00	1441.90	0.00	203.60
1968	170.13	11200.00	19800.00	2682.30	0.00	232.00
1969	248.94	15400.00	21400.00	4882.30	0.00	191.30
1970	303.36	22700.00	15100.00	5284.10	0.00	269.90
1971	226.42	22900.00	20600.00	3173.00	0.00	350.30
1972	784.17	28500.00	24500.00	4635.70	0.00	1270.30
1973	704.14	23200.00	13700.00	3069.80	745.80	170.80
1974	587.32	25500.00	9100.00	4036.30	327.10	413.80
1975	963.78	23300.00	6600.00	6117.20	469.40	820.80
1976	751.29	25400.00	6300.00	5918.40	303.40	855.00
1977	438.17	18900.00	2500.00	3224.10	214.60	1357.50
1978	665.08	9200.00	1200.00	2160.20	634.60	1078.50
1979	960.36	10400.00	1500.00	1388.80	1480.10	1512.10
1980	651.39	8400.00	2000.00	447.60	3210.80	652.30
1981	505.81	11000.00	1600.00	326.10	3275.30	228.80
1982	691.58	10200.00	1800.00	343.60	3437.80	245.90
1983	878.31	10200.00	1600.00	451.40	3610.50	274.10
1984	992.99	10300.00	3800.00	365.10	3275.40	187.00
1985	1915.99	13000.00	1500.00	458.30	3501.30	233.10
1986	2369.84	21600.00	7300.00	619.20	3277.10	551.80
1987	2123.43	27600.00	7600.00	1268.60	2954.30	406.90

Continued on next page.

Table 5. Landings (mt) from Alaska (AK) and British Columbia (BC) for their hook-and-line (HKL), pot (POT), and trawl (TWL) sectors.

Year	AK HKL	AK POT	AK TWL	BC HKL	BC POT	BC TWL
1988	2387.76	29300.00	9100.00	1273.60	3488.50	637.30
1989	2247.79	27500.00	7300.00	928.60	3772.00	623.40
1990	1966.89	25532.00	4684.00	1371.80	3082.50	460.70
1991	2299.40	23343.33	3097.35	1179.20	3500.40	438.80
1992	2608.21	20988.79	2909.87	848.60	3719.70	448.70
1993	3219.73	22911.70	2505.60	424.20	4150.60	543.10
1994	2714.52	20639.11	2937.61	467.70	4057.70	483.10
1995	2659.83	18269.31	2612.61	474.30	3287.00	427.40
1996	2527.85	15340.69	2187.16	280.40	2989.20	190.90
1997	2618.26	13132.98	1631.52	431.10	3557.70	156.30
1998	2550.73	12577.73	1487.26	443.60	3777.60	376.10
1999	1819.87	11794.07	1984.51	627.90	3682.00	403.00
2000	1888.54	13940.04	2019.39	752.20	2752.60	326.10
2001	1480.43	12757.37	1782.90	564.40	2746.20	299.60
2002	1419.59	13056.52	2243.11	564.40	2178.10	267.10
2003	1377.94	14590.33	2060.23	640.50	1461.50	227.60
2004	1478.63	16431.99	1656.42	467.40	2153.30	344.70
2005	1373.76	15711.19	1556.25	1146.70	3197.00	277.10
2006	1362.68	14982.37	1246.33	1307.30	2796.20	441.80
2007	1122.28	15546.66	1235.39	971.80	2159.60	288.90
2008	1133.74	13863.57	1122.06	1246.20	1509.00	353.00
2009	925.01	12427.19	1056.73	1107.10	1192.80	223.20
2010	877.51	11406.85	1004.48	1096.30	994.40	208.70
2011	792.41	12167.36	1179.18	1082.40	815.00	175.70
2012	829.39	13328.90	1101.81	1150.00	902.90	154.70
2013	784.83	13066.38	1037.17	877.30	873.50	184.00
2014	666.26	10917.83	1025.24	984.90	593.50	132.40
2015	635.13	10215.18	1084.70	1328.60	1151.60	132.80
2016	563.66	9423.39	1338.24	1053.60	739.50	108.90
2017	615.58	9989.94	2279.96	972.60	740.50	104.90
2018	712.28	10458.64	3837.74	1156.30	928.30	169.90

Table 6. Summary of data used to produce the West Coast Groundfish Bottom Trawl Survey biomass index and composition data. A subset of the tows that contained sablefish were sampled for lengths and ages. The total number of fish sampled for lengths and ages are provided as well as the input sample size (N) for each year of age data used to fit the base model.

Year	Tows w/ length	Lengths	Length N	Tows w/ age	Ages	Age N
2003	420	5,799	999	383	1,389	911
2004	329	4,540	783	278	1,086	661
2005	445	5,567	1,059	415	1,575	987
2006	398	4,833	947	369	1,363	878
2007	422	4,470	1,004	396	1,259	942
2008	418	3,969	994	367	1,189	873
2009	417	3,676	992	382	1,175	909
2010	454	4,191	1,080	417	1,259	992
2011	455	4,674	1,082	425	1,193	1,011
2012	428	4,381	1,018	395	1,091	940
2013	307	3,280	730	285	992	678
2014	461	4,319	1,097	430	1,200	1,023
2015	420	4,910	999	401	1,197	954
2016	438	4,544	1,042	426	1,212	1,013
2017	459	4,883	1,092	442	1,219	1,051
2018	435	4,785	1,035	431	1,482	1,025

Table 7. Summary of data used to produce the Northwest Fisheries Science Center Slope Survey biomass index and composition data. Positive (+) tows contained sablefish and a subset of those tows were sampled for lengths and ages. The total number of fish sampled for lengths and ages are provided as well as the input sample size (N) for each year of age data used to fit the base model.

Year	+ tows	Tows w/ length	Lengths	Tows w/ age	Ages	Age N
1998	252	196	1,991	115	676	273
1999	295	293	3,036	127	478	302
2000	299	294	3,226	150	753	357
2001	306	298	2,942	135	617	321
2002	385	341	4,135	196	1,631	466

Table 8. Summary of data used to produce Alaska Fisheries Science Center Slope Survey biomass index and composition data. Positive (+) tows contained sablefish and a subset of those tows were sampled for lengths and ages. The total number of fish sampled for lengths and ages are provided as well as the input sample size (N) for each year of age data used to fit the base model.

Year	+ tows	Tows w/ length	Lengths	Tows w/ age	Ages	Age N
1997	174	173	5,182	153	1,485	364
1999	193	193	3,619	160	492	380
2000	206	206	4,740	198	1,665	471
2001	206	206	4,674	126	482	299

Table 9. Summary of data used to produce Triennial Shelf Survey biomass index and composition data. Positive (+) tows contained sablefish and a subset of those tows were sampled for lengths and ages. The total number of fish sampled for lengths and ages are provided as well as the input sample size (n) for each year of age data used to fit the base model.

Year	+ tows	Tows w/ length	Lengths	Tows w/ age	Ages	Age N
1980	117	16	1,944	0	0	0
1983	16	205	5,767	20	915	47
1986	104	104	4,896	1	68	2
1989	290	290	5,183	22	490	52
1992	222	222	6,919	47	550	111
1995	334	334	7,673	78	363	185
1998	267	267	7,442	79	432	188
2001	369	369	12,790	122	435	290
2004	296	296	8,753	239	490	568

Table 10. Number of port-side samples collected from the fishery. Ages and lengths were collected from the samples for composition data, where the number of samples rather than the number of fish were used to specify the input sample size.

Year	Fishery	Samples w ages	Ages	Samples w lengths	Lengths
1970	Fixed			1	365
1980	Fixed			5	500
1981	Fixed			1	100
1983	Fixed			15	1448
1986	Fixed	9	36	26	513
1987	Fixed	104	1091	119	2487
1988	Fixed	29	294	48	1191
1989	Fixed	32	284	76	2238
1990	Fixed	19	180	58	1500
1991	Fixed	24	571	66	1947
1992	Fixed			21	1069
1993	Fixed	8	170	202	5288
1994	Fixed	8	168	171	4592
1995	Fixed	18	318	171	4526
1996	Fixed	44	811	113	3025
1997	Fixed	76	1569	192	4379
1998	Fixed	15	289	65	1253
1999	Fixed	54	1060	115	2257
2000	Fixed	44	778	229	4878
2001	Fixed	63	789	157	3107
2002	Fixed	36	587	133	2931
2003	Fixed	25	446	175	4019
2004	Fixed	17	242	124	2626
2005	Fixed	53	871	197	3743
2006	Fixed	37	848	282	6119

2007	Fixed	97	1863	215	4573
2008	Fixed	10	449	367	8951
2009	Fixed	58	1351	402	7756
2010	Fixed	56	1201	391	8551
2011	Fixed	45	937	410	10682
2012	Fixed	82	967	481	10821
2013	Fixed	40	1151	407	8763
2014	Fixed	1	45	478	11217
2015	Fixed			625	13333
2016	Fixed	153	536	499	13756
2017	Fixed	113	944	398	11372
2018	Fixed	120	542	413	11089
1974	Trawl	114	950	1	133
1975	Trawl			1	241
1977	Trawl			1	348
1978	Trawl			20	947
1979	Trawl			6	6
1980	Trawl			62	3424
1981	Trawl			42	2439
1983	Trawl			8	800
1984	Trawl			1	100
1985	Trawl			2	2
1986	Trawl			136	3698
1987	Trawl	156	2454	175	5085
1988	Trawl	94	1452	123	3846
1989	Trawl	83	1241	159	4807
1990	Trawl	80	1138	175	4999
1991	Trawl	58	1689	168	5016
1992	Trawl	14	586	18	963
1993	Trawl	34	802	182	4921
1994	Trawl	30	648	155	4455
1995	Trawl	26	444	143	4239
1996	Trawl	45	986	119	3578
1997	Trawl	85	1836	142	3606
1998	Trawl	26	537	109	2274
1999	Trawl	32	699	142	3184
2000	Trawl	69	1430	152	3738
2001	Trawl	77	1308	148	3872
2002	Trawl	29	627	146	3914
2003	Trawl	29	684	162	3916
2004	Trawl	36	825	131	3672
2005	Trawl	57	1175	151	3524
2006	Trawl	77	1509	173	3665
2007	Trawl	82	1567	176	3920
2008	Trawl	8	160	157	3573

2009	Trawl	36	918	121	2808
2010	Trawl	36	865	120	3349
2011	Trawl	29	776	111	3015
2012	Trawl	4	71	135	3622
2013	Trawl	33	858	148	3896
2014	Trawl	47	851	141	3546
2015	Trawl			127	3933
2016	Trawl	55	274	118	3833
2017	Trawl	57	508	129	3759
2018	Trawl	67	210	115	2641

Table 11. Summary of biological parameters estimated externally and used as input for this stock assessment.

Quantity	Value	Source
Fecundity eggs/kilogram intercept	1.000	Various published studies (see text)
Fecundity slope	0.000	
Female maturity logistic slope	-0.421	Various published studies (see text)
Female length at 50% maturity	55.190	
Female weight-length coefficient (a)	0.000003315	All available survey data
Male weight-length coefficient (a)	0.000003371	
Female weight-length exponent (b)	3.27264	
Male weight-length exponent (b)	3.27008	

Table 12. Overview of survey methods and most recent von Bertalanffy growth function(VBGF) parameters used for sablefish in recent stock assessments. * denotes time-blocked VBGF parameters for the Alaska federal assessment from 1996-current. * denotes time-blocked VBGF parameters for the Alaska federal assessment from 1960-1995.

		VBGF parameters from recent assessments					
Region	Survey method	L_{inf} (cm)		k (years^{-1})		t_0 (years)	
U.S. West Coast (Johnson et al., 2016)	Trawl on chartered commercial fishing vessels	57	64	0.41	0.32	0 (fixed)	0 (fixed)
British Columbia, Canada	Stratified trap survey	68.99	72.00	0.29	0.25	32.50	32.50
Alaska (Hanselman et al., 2018)	Longline on chartered commercial fishing vessels	67.80* 65.30*	80.20* 75.60*	0.29* 0.28*	0.22* 0.21*	2.27	1.95

Table 13. Description of parameters in the base model. A total of 13 mortality, growth, and stock-recruitment parameters; 45 survey and fishery dynamics; and 171 recruitment-deviation parameters were estimated. Descriptions include the number of parameters estimated (N), the upper and lower bounds, and information about the mean and standard deviation (SD) of the prior, if one was specified.

Parameter	N	Bounds		Prior	Mean	SD
Female natural mortality (*M*)	1	0.01	0.11	Log normal	-2.94	0.438
Male *M*	1	0.01	0.11	Log normal	-2.90	0.438
Stock and recruitment						
$ln(R_0)$	1	8	12	Uniform		
Steepness (*h*)	-	NA	NA	Fixed	0.7	
Recruitment SD (σ_r)	-	NA	NA	Iterated	1.4	
Initial age deviations (ages 1-30 at age-0)	30	-4	4	Normal	0	σ_r
Recruitment deviations (1890-2018)	129	-4	4	Normal	0	σ_r
Forecast recruitment deviations (2019-2030)	12	-4	4	Normal	0	σ_r
Survey catchability and variability						
ln(*Q*) Tide guauge	-	-15	15			
ln(*Q*) WCGBT	-	-15	15			
ln(*Q*) NWFSC Slope	-	-15	15			
ln(*Q*) AFSC Slope	-	-15	5			
ln(*Q*) AFSC Shelf (1980-1992)	-	-15	15			
ln(*Q*) AFSC Shelf offset (1995-2004)	-	-3	1	Uniform		
Extra additive SD for survey indices	4	0.001	1.3	Uniform		
Selectivity, retention, & discard mortality						
(See text for detailed descriptions)						
Survey selectivity (double-normal)	17			Uniform		
Fishery selectivity (double-normal)	7			Uniform		
Fishery retention	0			Uniform		
Fishery discard	-			Fixed		
Time-varying retention	7			Uniform		
Time-varying selectivity	9			Uniform		
Individual growth						
Females:						
Length at age 0.5	1	22	35	Uniform		
Length at old age	1	60	70	Uniform		
von Bertalanffy growth (*K*)	1	0.15	0.45	Uniform		
CV of length at age 0.5	1	0.001	0.15	Uniform		
CV of length at age 30	1	0.01	0.3	Uniform		
Males:						
Length at age 0.5	1	15	35	Uniform		
Length at old age	1	50	60	Uniform		
von Bertalanffy *K*	1	0.2	0.55	Uniform		
CV of length at age 0.5	1	0.001	0.15	Uniform		
CV of length at age 30	1	0.01	0.3	Uniform		

Table 14. Time-varying retention and selectivity parameters included in the base model based on key events and management history (Table 2).

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
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 15. Stock-recruitment, mortality, and growth parameter estimates with their ∼95% interval from the base model.

Label	Estimate	Lower 5%	Upper 95%
NatM_p_1_Fem	0.0759	0.0603	0.0915
L_at_Amin_Fem	25.1516	24.6769	25.6263
L_at_Amax_Fem	62.6737	62.0190	63.3284
VonBert_K_Fem	0.3438	0.3280	0.3595
CV_young_Fem	0.0607	0.0519	0.0695
CV_old_Fem	0.1100	0.1044	0.1157
Wtlen_1_Fem	0.0000		
Wtlen_2_Fem	3.2726		
Mat50Mat_slope_Fem	-0.4210		
Eggs/kg_inter_Fem	1.0000		
Eggs/kg_slope_wt_Fem	0.0000		
NatM_p_1_Mal	0.0675	0.0565	0.0786
L_at_Amin_Mal	25.5019	24.9791	26.0247
L_at_Amax_Mal	56.3704	56.0484	56.6924
VonBert_K_Mal	0.4001	0.3836	0.4166
CV_young_Mal	0.0664	0.0580	0.0748
CV_old_Mal	0.0797	0.0760	0.0833
Wtlen_1_Mal	0.0000		
Wtlen_2_Mal	3.2701		
FracFemale	0.5000		
R_0	15021.6835	9185.3083	24566.5107

Table 16. Estimated catchability parameters from the base model.

Parameter	Estimate
Q-base-ENV(4)	0.13
Q-extraSD-ENV(4)	0.73
LnQ-base-AKSHLF(5)	0.45
Q-extraSD-AKSHLF(5)	0.16
Q-extraSD-AKSLP(6)	0.05
Q-extraSD-NWSLP(7)	0.16
LnQ-base-AKSHLF(5)-BLK1repl-1995	0.20

Table 17. Estimated selectivity parameters from the base model.

Parameter	Estimate
Age-DblN-ascend-se-FIX(9)	0.94
Age-DblN-descend-se-FIX(9)	3.98
AgeSel-1MaleatZero-FIX	0.09
AgeSel-1MaleatDogleg-FIX	-1.03
AgeSel-1MaleatMaxage-FIX	-0.60
Age-DblN-ascend-se-TWL(11)	-3.09
Age-DblN-end-logit-TWL(11)	-1.38
Age-DblN-ascend-se-AKSHLF(13)	-7.76
Age-DblN-descend-se-AKSHLF(13)	-6.55
Age-DblN-end-logit-AKSHLF(13)	-3.64
AgeSel-5MaleatZero-AKSHLF	0.65
AgeSel-5MaleatDogleg-AKSHLF	-0.05
AgeSel-5MaleatMaxage-AKSHLF	-8.21
Age-DblN-peak-AKSLP(14)	1.67
Age-DblN-descend-se-AKSLP(14)	-4.41
Age-DblN-end-logit-AKSLP(14)	0.01
Age-DblN-peak-NWSLP(15)	3.84
Age-DblN-ascend-se-NWSLP(15)	1.82
Age-DblN-descend-se-NWSLP(15)	-13.04
Age-DblN-end-logit-NWSLP(15)	0.62
Age-DblN-peak-NWCBO(16)	0.09
Age-DblN-ascend-se-NWCBO(16)	-9.41
Age-DblN-descend-se-NWCBO(16)	3.19
Retain-L-infl-FIX(1)-BLK2repl-1997	37.36
Retain-L-infl-FIX(1)-BLK2repl-2011	41.72
Retain-L-asymptote-logit-FIX(1)-BLK2repl-1997	2.14
Retain-L-infl-TWL(3)-BLK3repl-1982	48.08
Retain-L-infl-TWL(3)-BLK3repl-2011	32.20
Retain-L-asymptote-logit-TWL(3)-BLK3repl-1982	4.12
Age-DblN-peak-FIX(9)-BLK4repl-1997	3.41
Age-DblN-peak-FIX(9)-BLK4repl-2003	5.07
Age-DblN-peak-FIX(9)-BLK4repl-2011	3.05
Age-DblN-ascend-se-FIX(9)-BLK4repl-2003	1.45
Age-DblN-ascend-se-FIX(9)-BLK4repl-2011	-8.83
Age-DblN-descend-se-TWL(11)-BLK5repl-1982	2.33
Age-DblN-descend-se-TWL(11)-BLK5repl-2003	6.38
Age-DblN-descend-se-TWL(11)-BLK5repl-2011	7.34
Age-DblN-descend-se-AKSHLF(13)-BLK6repl-1995	2.76

Table 18. Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-$SPR_{Target=0.45\%}$), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Total catch	Rel. 1-SPR		Exploitation rate	
1890	2	0.000	(0.000-0.000)	0.000	(0.000-0.000)
1891	6	0.001	(0.000-0.001)	0.000	(0.000-0.000)
1892	7	0.001	(0.000-0.002)	0.000	(0.000-0.000)
1893	10	0.001	(0.000-0.002)	0.000	(0.000-0.000)
1894	12	0.002	(0.000-0.003)	0.000	(0.000-0.000)
1895	17	0.002	(0.000-0.004)	0.000	(0.000-0.000)
1896	19	0.003	(0.000-0.005)	0.000	(0.000-0.000)
1897	21	0.003	(0.001-0.005)	0.000	(0.000-0.000)
1898	23	0.003	(0.001-0.006)	0.000	(0.000-0.000)
1899	25	0.003	(0.001-0.006)	0.000	(0.000-0.000)
1900	51	0.007	(0.001-0.012)	0.000	(0.000-0.000)
1901	79	0.011	(0.002-0.019)	0.000	(0.000-0.000)
1902	107	0.014	(0.003-0.026)	0.000	(0.000-0.001)
1903	135	0.018	(0.004-0.033)	0.000	(0.000-0.001)
1904	163	0.022	(0.005-0.040)	0.001	(0.000-0.001)
1905	147	0.020	(0.004-0.036)	0.000	(0.000-0.001)
1906	146	0.020	(0.004-0.036)	0.000	(0.000-0.001)
1907	154	0.021	(0.005-0.038)	0.001	(0.000-0.001)
1908	98	0.014	(0.003-0.025)	0.000	(0.000-0.001)
1909	156	0.022	(0.005-0.039)	0.001	(0.000-0.001)
1910	213	0.030	(0.007-0.054)	0.001	(0.000-0.001)
1911	271	0.039	(0.008-0.069)	0.001	(0.000-0.001)
1912	328	0.047	(0.010-0.084)	0.001	(0.000-0.002)
1913	385	0.056	(0.012-0.100)	0.001	(0.001-0.002)
1914	443	0.065	(0.014-0.115)	0.002	(0.001-0.002)
1915	500	0.074	(0.017-0.131)	0.002	(0.001-0.003)
1916	1,332	0.192	(0.049-0.335)	0.005	(0.002-0.008)
1917	2,018	0.281	(0.085-0.478)	0.007	(0.003-0.012)
1918	2,884	0.396	(0.125-0.668)	0.011	(0.005-0.017)
1919	1,042	0.160	(0.040-0.280)	0.004	(0.002-0.006)
1920	893	0.137	(0.038-0.236)	0.003	(0.001-0.005)
1921	1,195	0.183	(0.052-0.313)	0.005	(0.002-0.007)
1922	809	0.131	(0.032-0.230)	0.003	(0.001-0.005)
1923	1,453	0.229	(0.063-0.396)	0.006	(0.002-0.009)
1924	1,863	0.290	(0.087-0.494)	0.008	(0.003-0.012)
1925	2,132	0.335	(0.101-0.570)	0.009	(0.004-0.014)
1926	1,718	0.285	(0.077-0.493)	0.007	(0.003-0.011)
1927	2,562	0.407	(0.131-0.684)	0.011	(0.005-0.017)
1928	2,147	0.357	(0.109-0.606)	0.009	(0.004-0.015)

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Table 18. Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-$SPR_{Target=0.45\%}$), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Total catch	Rel. 1-SPR		Exploitation rate	
1929	2,328	0.389	(0.124-0.653)	0.010	(0.004-0.016)
1930	2,590	0.438	(0.143-0.734)	0.012	(0.005-0.019)
1931	1,427	0.265	(0.073-0.456)	0.007	(0.003-0.011)
1932	1,680	0.315	(0.088-0.542)	0.008	(0.003-0.013)
1933	1,557	0.297	(0.086-0.509)	0.008	(0.003-0.012)
1934	2,697	0.488	(0.167-0.810)	0.013	(0.005-0.022)
1935	3,458	0.610	(0.231-0.989)	0.018	(0.007-0.029)
1936	2,396	0.475	(0.146-0.804)	0.013	(0.005-0.021)
1937	2,569	0.519	(0.161-0.876)	0.014	(0.005-0.023)
1938	2,516	0.521	(0.161-0.881)	0.014	(0.005-0.023)
1939	2,791	0.577	(0.188-0.966)	0.016	(0.006-0.026)
1940	2,221	0.487	(0.142-0.833)	0.013	(0.005-0.021)
1941	2,188	0.482	(0.145-0.819)	0.013	(0.005-0.022)
1942	3,232	0.672	(0.251-1.092)	0.020	(0.007-0.032)
1943	3,927	0.769	(0.328-1.210)	0.024	(0.008-0.041)
1944	4,490	0.852	(0.392-1.312)	0.029	(0.010-0.048)
1945	4,422	0.863	(0.389-1.336)	0.029	(0.009-0.049)
1946	4,460	0.900	(0.394-1.405)	0.031	(0.009-0.052)
1947	2,315	0.569	(0.159-0.978)	0.017	(0.005-0.028)
1948	2,973	0.681	(0.228-1.134)	0.022	(0.006-0.037)
1949	3,114	0.713	(0.246-1.180)	0.023	(0.006-0.040)
1950	2,792	0.655	(0.213-1.097)	0.021	(0.006-0.037)
1951	4,582	0.915	(0.405-1.425)	0.035	(0.009-0.061)
1952	2,837	0.660	(0.214-1.106)	0.022	(0.005-0.039)
1953	1,784	0.454	(0.111-0.797)	0.014	(0.003-0.025)
1954	2,503	0.582	(0.171-0.992)	0.020	(0.005-0.035)
1955	2,357	0.543	(0.147-0.939)	0.019	(0.004-0.033)
1956	3,913	0.729	(0.263-1.194)	0.030	(0.006-0.054)
1957	2,780	0.581	(0.151-1.010)	0.021	(0.004-0.038)
1958	1,719	0.354	(0.048-0.660)	0.013	(0.002-0.024)
1959	2,451	0.460	(0.070-0.850)	0.017	(0.003-0.032)
1960	3,429	0.529	(0.077-0.982)	0.023	(0.000-0.048)
1961	2,094	0.312	(0.059-0.564)	0.013	(0.000-0.027)
1962	2,961	0.330	(0.071-0.589)	0.018	(0.000-0.035)
1963	1,992	0.256	(0.066-0.445)	0.009	(0.002-0.016)
1964	2,226	0.254	(0.050-0.457)	0.009	(0.002-0.017)
1965	2,237	0.230	(0.043-0.416)	0.009	(0.000-0.019)
1966	2,174	0.205	(0.061-0.349)	0.008	(0.000-0.017)
1967	4,936	0.374	(0.090-0.658)	0.018	(0.005-0.031)
1968	3,141	0.238	(0.100-0.375)	0.010	(0.000-0.020)

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Table 18. Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-$SPR_{Target=0.45\%}$), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Total catch	Rel. 1-SPR		Exploitation rate	
1969	5,846	0.374	(0.160-0.589)	0.018	(0.000-0.036)
1970	4,910	0.366	(0.174-0.558)	0.012	(0.006-0.018)
1971	4,155	0.303	(0.149-0.456)	0.010	(0.005-0.015)
1972	6,991	0.468	(0.258-0.677)	0.016	(0.008-0.024)
1973	6,068	0.435	(0.226-0.645)	0.014	(0.008-0.021)
1974	9,155	0.586	(0.348-0.825)	0.022	(0.012-0.032)
1975	14,976	0.847	(0.561-1.132)	0.037	(0.020-0.054)
1976	25,157	1.188	(0.897-1.479)	0.066	(0.036-0.096)
1977	9,335	0.674	(0.419-0.929)	0.025	(0.013-0.036)
1978	12,982	0.850	(0.572-1.129)	0.035	(0.019-0.051)
1979	24,917	1.272	(1.000-1.543)	0.068	(0.038-0.098)
1980	9,819	0.748	(0.481-1.015)	0.028	(0.016-0.040)
1981	12,361	0.886	(0.609-1.162)	0.036	(0.020-0.051)
1982	20,504	1.198	(0.920-1.475)	0.062	(0.035-0.089)
1983	15,840	1.076	(0.797-1.354)	0.048	(0.028-0.067)
1984	15,068	1.077	(0.802-1.352)	0.047	(0.028-0.067)
1985	15,238	1.137	(0.861-1.412)	0.050	(0.029-0.070)
1986	14,333	1.147	(0.869-1.424)	0.050	(0.029-0.071)
1987	13,833	1.158	(0.880-1.436)	0.053	(0.030-0.075)
1988	11,678	1.068	(0.787-1.349)	0.045	(0.026-0.065)
1989	11,183	1.039	(0.760-1.318)	0.044	(0.026-0.062)
1990	9,976	0.981	(0.705-1.257)	0.040	(0.024-0.057)
1991	10,401	1.028	(0.751-1.306)	0.044	(0.026-0.062)
1992	10,416	1.043	(0.767-1.318)	0.046	(0.027-0.065)
1993	8,848	0.953	(0.685-1.222)	0.039	(0.023-0.055)
1994	8,013	0.925	(0.661-1.189)	0.035	(0.021-0.049)
1995	8,374	0.995	(0.727-1.262)	0.039	(0.023-0.054)
1996	9,045	1.095	(0.825-1.364)	0.045	(0.027-0.062)
1997	8,648	1.142	(0.874-1.409)	0.046	(0.028-0.064)
1998	4,684	0.793	(0.551-1.036)	0.026	(0.016-0.036)
1999	7,024	1.061	(0.800-1.322)	0.039	(0.024-0.054)
2000	6,989	1.099	(0.836-1.362)	0.042	(0.026-0.058)
2001	6,786	1.075	(0.810-1.341)	0.044	(0.027-0.061)
2002	4,408	0.756	(0.516-0.996)	0.030	(0.018-0.042)
2003	5,678	0.835	(0.581-1.089)	0.034	(0.021-0.047)
2004	6,082	0.799	(0.552-1.047)	0.032	(0.020-0.044)
2005	6,338	0.797	(0.549-1.045)	0.032	(0.020-0.044)
2006	6,216	0.792	(0.544-1.040)	0.032	(0.020-0.044)
2007	5,352	0.734	(0.494-0.974)	0.029	(0.018-0.040)
2008	5,934	0.827	(0.573-1.080)	0.034	(0.021-0.046)

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Table 18. Estimates of total dead catch (mt), relative 1-spawning potential ratio (SPR; 1-SPR/1-$SPR_{Target=0.45\%}$), and exploitation rate (catch/biomass of age-4+) from the base model. Approximate 95% intervals follow in parentheses.

Year	Total catch	Rel. 1-SPR		Exploitation rate	
2009	7,373	1.006	(0.737-1.275)	0.045	(0.028-0.062)
2010	7,018	1.051	(0.778-1.323)	0.047	(0.029-0.065)
2011	6,251	1.094	(0.829-1.360)	0.046	(0.028-0.064)
2012	5,280	0.934	(0.668-1.200)	0.036	(0.022-0.050)
2013	4,052	0.799	(0.545-1.053)	0.029	(0.018-0.041)
2014	4,240	0.801	(0.545-1.058)	0.030	(0.018-0.041)
2015	5,091	0.923	(0.650-1.195)	0.037	(0.022-0.051)
2016	5,403	0.954	(0.675-1.233)	0.041	(0.024-0.057)
2017	5,424	0.859	(0.584-1.133)	0.036	(0.022-0.051)
2018	5,132	0.825	(0.552-1.098)	0.035	(0.021-0.050)
2019	6,145	0.865	(0.585-1.145)	0.042	(0.025-0.059)

Table 19. Time series of total, age-4+, and spawning biomass (mt); age-0 recruitment (1000s); and depletion estimates from the base model and their associated 5% and 95% confidence intervals in parentheses.

Year	Total	Age-4+	Spawning biomass		Age-0 recruitment		Depletion	
1890	337,653	316,701	142,978	(65,859-220,097)	13,703	(0-50,560)		
1891	336,769	315,923	142,636	(65,622-219,650)	13,629	(0-50,215)	0.97	(0.51-1.42)
1892	335,828	315,105	142,275	(65,397-219,153)	13,552	(0-49,855)	0.96	(0.51-1.42)
1893	334,832	314,250	141,895	(65,159-218,631)	13,472	(0-49,479)	0.96	(0.51-1.41)
1894	333,779	313,312	141,490	(64,858-218,122)	13,387	(0-49,087)	0.96	(0.51-1.41)
1895	332,670	312,323	141,059	(64,496-217,622)	13,300	(0-48,680)	0.95	(0.50-1.41)
1896	331,505	311,282	140,601	(64,100-217,102)	13,208	(0-48,256)	0.95	(0.50-1.40)
1897	330,284	310,192	140,120	(63,698-216,542)	13,112	(0-47,815)	0.95	(0.50-1.40)
1898	329,008	309,052	139,614	(63,299-215,929)	13,013	(0-47,357)	0.95	(0.49-1.40)
1899	327,674	307,860	139,086	(62,914-215,258)	12,909	(0-46,882)	0.94	(0.49-1.39)
1900	326,281	306,616	138,533	(62,542-214,524)	12,801	(0-46,390)	0.94	(0.49-1.39)
1901	324,805	305,293	137,941	(62,169-213,713)	12,689	(0-45,880)	0.93	(0.48-1.38)
1902	323,241	303,891	137,309	(61,795-212,823)	12,572	(0-45,353)	0.93	(0.48-1.38)
1903	321,589	302,406	136,636	(61,417-211,855)	12,451	(0-44,808)	0.92	(0.48-1.37)
1904	319,847	300,838	135,921	(61,033-210,809)	12,326	(0-44,247)	0.92	(0.48-1.37)
1905	318,015	299,187	135,164	(60,642-209,686)	12,198	(0-43,671)	0.91	(0.47-1.36)
1906	316,136	297,494	134,393	(60,272-208,514)	12,065	(0-43,081)	0.91	(0.47-1.35)
1907	314,193	295,743	133,597	(59,910-207,284)	11,929	(0-42,477)	0.90	(0.47-1.34)
1908	312,175	293,923	132,771	(59,551-205,991)	11,789	(0-41,862)	0.90	(0.46-1.33)
1909	310,142	292,095	131,953	(59,231-204,675)	11,647	(0-41,237)	0.89	(0.46-1.33)
1910	307,983	290,144	131,072	(58,879-203,265)	11,502	(0-40,601)	0.89	(0.46-1.32)
1911	305,699	288,074	130,128	(58,494-201,762)	11,354	(0-39,958)	0.88	(0.45-1.31)
1912	303,291	285,883	129,120	(58,074-200,166)	11,204	(0-39,305)	0.87	(0.45-1.30)
1913	300,763	283,577	128,050	(57,622-198,478)	11,048	(0-38,634)	0.87	(0.45-1.29)
1914	298,116	281,156	126,919	(57,137-196,701)	10,886	(0-37,943)	0.86	(0.44-1.28)
1915	295,352	278,625	125,729	(56,622-194,836)	10,720	(0-37,236)	0.85	(0.44-1.26)
1916	292,473	275,987	124,482	(56,077-192,887)	10,553	(0-36,529)	0.84	(0.43-1.25)
1917	288,728	272,491	122,707	(55,030-190,384)	10,379	(0-35,800)	0.83	(0.43-1.23)

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Table 19. Time series of total, age-4+, and spawning biomass (mt); age-0 recruitment (1000s); and depletion estimates from the base model and their associated 5% and 95% confidence intervals in parentheses.

Year	Total	Age-4+	Spawning biomass		Age-0 recruitment		Depletion	
1918	284,278	268,335	120,565	(53,641-187,489)	10,207	(0-35,088)	0.82	(0.42-1.22)
1919	278,982	263,296	117,856	(51,709-184,003)	10,032	(0-34,368)	0.80	(0.40-1.19)
1920	275,514	260,072	116,264	(50,918-181,610)	9,860	(0-33,657)	0.79	(0.40-1.18)
1921	272,174	257,007	114,818	(50,302-179,334)	9,687	(0-32,944)	0.78	(0.39-1.16)
1922	268,504	253,620	113,214	(49,552-176,876)	9,518	(0-32,253)	0.77	(0.39-1.15)
1923	265,191	250,537	111,780	(48,992-174,568)	9,346	(0-31,556)	0.76	(0.38-1.13)
1924	261,224	246,826	109,974	(48,082-171,866)	9,170	(0-30,844)	0.74	(0.37-1.11)
1925	256,843	242,727	107,949	(46,973-168,925)	8,136	(0-27,471)	0.73	(0.37-1.10)
1926	251,996	238,349	105,745	(45,702-165,788)	8,152	(0-27,569)	0.72	(0.36-1.08)
1927	247,394	234,373	103,759	(44,665-162,853)	7,827	(0-26,228)	0.70	(0.35-1.06)
1928	241,787	229,639	101,312	(43,158-159,466)	7,621	(0-25,400)	0.69	(0.34-1.03)
1929	236,461	224,531	99,021	(41,747-156,294)	7,746	(0-25,951)	0.67	(0.33-1.01)
1930	230,944	219,356	96,581	(40,149-153,013)	7,644	(0-25,555)	0.65	(0.32-0.99)
1931	225,237	213,776	93,919	(38,339-149,500)	7,474	(0-24,880)	0.64	(0.31-0.96)
1932	220,776	209,298	91,914	(37,218-146,611)	7,142	(0-23,537)	0.62	(0.30-0.94)
1933	216,119	204,873	89,790	(35,996-143,583)	7,121	(0-23,470)	0.61	(0.29-0.92)
1934	211,653	200,724	87,834	(34,935-140,734)	7,068	(0-23,277)	0.59	(0.29-0.90)
1935	206,160	195,548	85,304	(33,298-137,309)	7,681	(0-25,836)	0.58	(0.28-0.87)
1936	200,221	189,556	82,397	(31,307-133,487)	6,381	(0-20,580)	0.56	(0.27-0.85)
1937	195,404	184,722	80,028	(29,874-130,182)	6,356	(0-20,501)	0.54	(0.26-0.82)
1938	190,474	179,946	77,643	(28,416-126,870)	7,670	(0-25,880)	0.53	(0.25-0.80)
1939	185,971	176,109	75,443	(27,087-123,798)	7,413	(0-24,813)	0.51	(0.24-0.78)
1940	181,587	171,148	73,134	(25,649-120,618)	7,083	(0-23,455)	0.50	(0.23-0.76)
1941	178,083	166,876	71,225	(24,634-117,816)	6,528	(0-21,215)	0.48	(0.23-0.74)
1942	174,729	164,046	69,583	(23,802-115,364)	6,603	(0-21,508)	0.47	(0.22-0.72)
1943	170,369	160,315	67,634	(22,521-112,748)	6,964	(0-22,957)	0.46	(0.21-0.70)
1944	165,418	155,928	65,639	(21,105-110,173)	7,021	(0-23,208)	0.44	(0.20-0.69)
1945	160,017	150,596	63,490	(19,549-107,432)	7,452	(0-25,003)	0.43	(0.19-0.67)

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Table 19. Time series of total, age-4+, and spawning biomass (mt); age-0 recruitment (1000s); and depletion estimates from the base model and their associated 5% and 95% confidence intervals in parentheses.

Year	Total	Age-4+	Spawning biomass		Age-0 recruitment		Depletion	
1946	154,954	145,236	61,245	(17,941-104,548)	6,809	(0-22,403)	0.41	(0.18-0.65)
1947	150,092	140,060	58,726	(16,076-101,377)	7,213	(0-24,060)	0.40	(0.17-0.63)
1948	147,808	137,293	57,319	(15,254-99,385)	6,188	(0-19,998)	0.39	(0.16-0.61)
1949	145,016	134,909	55,896	(14,348-97,444)	7,965	(0-27,202)	0.38	(0.16-0.60)
1950	142,558	132,286	54,597	(13,496-95,698)	8,623	(0-30,027)	0.37	(0.15-0.59)
1951	141,056	130,494	53,622	(12,924-94,320)	8,900	(0-31,318)	0.36	(0.14-0.58)
1952	138,453	126,419	51,980	(11,701-92,260)	10,612	(0-39,234)	0.35	(0.14-0.57)
1953	138,567	125,441	51,309	(11,321-91,297)	8,899	(0-31,397)	0.35	(0.13-0.56)
1954	140,249	126,275	51,446	(11,507-91,385)	10,921	(0-40,866)	0.35	(0.14-0.56)
1955	142,001	127,151	51,679	(11,485-91,873)	15,642	(0-67,642)	0.35	(0.14-0.56)
1956	145,655	129,904	52,356	(11,500-93,213)	15,333	(0-66,008)	0.35	(0.14-0.57)
1957	149,337	130,251	52,896	(11,038-94,754)	18,102	(0-85,166)	0.36	(0.14-0.58)
1958	156,093	132,888	53,986	(10,704-97,268)	13,832	(0-56,497)	0.37	(0.14-0.60)
1959	164,613	140,871	56,463	(10,649-102,278)	77,991	(0-296,166)	0.38	(0.14-0.63)
1960	187,941	148,833	59,528	(9,372-109,683)	12,893	(0-50,792)	0.40	(0.13-0.67)
1961	211,256	158,888	62,948	(6,656-119,240)	15,340	(0-64,660)	0.43	(0.12-0.73)
1962	234,236	166,475	69,694	(10,885-128,504)	20,482	(0-99,905)	0.47	(0.15-0.79)
1963	253,391	231,170	81,751	(24,010-139,492)	11,782	(0-43,943)	0.55	(0.23-0.88)
1964	268,327	243,762	94,162	(27,267-161,057)	68,434	(0-456,241)	0.64	(0.22-1.05)
1965	291,883	254,221	103,644	(25,512-181,776)	14,384	(0-56,667)	0.70	(0.19-1.21)
1966	313,453	266,644	110,669	(24,697-196,641)	116,578	(0-415,184)	0.75	(0.19-1.31)
1967	356,033	269,834	117,800	(35,844-199,756)	10,262	(0-35,967)	0.80	(0.28-1.32)
1968	392,246	320,348	126,880	(52,769-200,991)	14,789	(0-57,377)	0.86	(0.45-1.27)
1969	423,051	327,881	140,481	(49,362-231,600)	8,800	(0-29,531)	0.95	(0.45-1.45)
1970	439,602	422,384	158,648	(64,957-252,339)	19,623	(0-81,867)	1.07	(0.57-1.58)
1971	448,730	428,730	174,886	(86,282-263,490)	10,434	(0-36,141)	1.18	(0.71-1.65)
1972	450,571	431,774	184,470	(98,711-270,229)	12,274	(0-44,344)	1.25	(0.79-1.71)
1973	444,102	421,674	186,690	(103,148-270,232)	42,864	(0-137,044)	1.26	(0.81-1.72)

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Table 19. Time series of total, age-4+, and spawning biomass (mt); age-0 recruitment (1000s); and depletion estimates from the base model and their associated 5% and 95% confidence intervals in parentheses.

Year	Total	Age-4+	Spawning biomass		Age-0 recruitment		Depletion	
1974	442,152	418,201	186,134	(105,542-266,726)	12,906	(0-47,287)	1.26	(0.82-1.70)
1975	435,809	402,501	181,085	(103,554-258,616)	30,598	(0-124,637)	1.23	(0.81-1.64)
1976	426,422	381,823	172,398	(98,221-246,575)	22,637	(0-86,917)	1.17	(0.78-1.56)
1977	407,975	378,002	159,658	(89,068-230,248)	21,509	(0-68,585)	1.08	(0.71-1.45)
1978	405,610	367,147	157,415	(89,223-225,607)	10,121	(0-39,372)	1.07	(0.71-1.42)
1979	396,712	367,426	154,181	(88,289-220,073)	39,715	(0-80,280)	1.04	(0.70-1.39)
1980	379,914	350,471	144,902	(81,085-208,719)	13,675	(0-38,198)	0.98	(0.65-1.31)
1981	376,806	346,862	143,038	(81,271-204,805)	17,536	(0-38,971)	0.97	(0.65-1.29)
1982	370,325	331,647	139,745	(80,146-199,344)	7,580	(0-19,268)	0.95	(0.64-1.25)
1983	352,221	332,555	134,086	(76,825-191,347)	4,350	(0-12,162)	0.91	(0.62-1.20)
1984	334,467	317,695	129,733	(74,789-184,677)	23,440	(10,682-36,197)	0.88	(0.60-1.16)
1985	318,630	305,650	124,643	(72,167-177,119)	23,921	(9,311-38,532)	0.84	(0.58-1.11)
1986	305,388	285,260	117,390	(67,683-167,097)	15,059	(2,001-28,117)	0.79	(0.54-1.05)
1987	294,277	263,026	109,742	(62,861-156,623)	11,645	(0-23,749)	0.74	(0.51-0.98)
1988	283,458	257,019	103,861	(59,275-148,447)	9,073	(0-19,305)	0.70	(0.48-0.93)
1989	273,388	255,122	100,543	(57,642-143,444)	20,340	(5,977-34,704)	0.68	(0.47-0.90)
1990	265,090	247,659	97,762	(56,353-139,171)	23,374	(8,873-37,875)	0.66	(0.45-0.87)
1991	260,572	238,651	94,831	(55,011-134,651)	4,051	(0-11,634)	0.64	(0.44-0.84)
1992	253,817	227,215	91,316	(53,121-129,510)	4,132	(0-11,263)	0.62	(0.43-0.81)
1993	244,414	225,234	88,884	(51,997-125,770)	3,946	(0-10,959)	0.60	(0.42-0.78)
1994	233,746	227,950	87,782	(51,956-123,608)	10,500	(3,777-17,223)	0.59	(0.42-0.77)
1995	223,349	215,952	85,549	(51,058-120,041)	17,253	(10,347-24,159)	0.58	(0.41-0.75)
1996	214,666	202,552	81,399	(48,658-114,139)	1,040	(0-2,752)	0.55	(0.39-0.71)
1997	204,154	188,184	76,208	(45,339-107,078)	1,330	(0-2,782)	0.52	(0.36-0.67)
1998	192,444	179,685	71,771	(42,550-100,993)	4,971	(2,079-7,863)	0.49	(0.34-0.63)
1999	183,828	181,214	69,934	(42,079-97,790)	38,397	(23,760-53,034)	0.47	(0.34-0.61)
2000	180,643	167,969	66,327	(39,936-92,718)	35,115	(20,702-49,528)	0.45	(0.32-0.58)
2001	185,648	154,771	61,825	(37,054-86,595)	16,329	(8,556-24,101)	0.42	(0.30-0.54)

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Table 19. Time series of total, age-4+, and spawning biomass (mt); age-0 recruitment (1000s); and depletion estimates from the base model and their associated 5% and 95% confidence intervals in parentheses.

Year	Total	Age-4+	Spawning biomass		Age-0 recruitment		Depletion	
2002	193,754	145,469	58,927	(35,296-82,558)	6,132	(2,926-9,337)	0.40	(0.28-0.51)
2003	202,261	167,361	61,368	(37,415-85,321)	2,558	(960-4,156)	0.42	(0.30-0.53)
2004	205,018	189,332	66,584	(41,150-92,017)	5,524	(3,117-7,931)	0.45	(0.33-0.58)
2005	203,343	196,194	71,451	(44,563-98,340)	282	(0-632)	0.48	(0.35-0.62)
2006	197,015	192,272	73,499	(45,980-101,018)	1,230	(491-1,968)	0.50	(0.36-0.63)
2007	187,650	183,135	72,787	(45,507-100,067)	454	(0-957)	0.49	(0.36-0.63)
2008	176,850	175,899	70,583	(44,134-97,032)	29,976	(18,382-41,570)	0.48	(0.35-0.61)
2009	171,199	162,821	66,592	(41,421-91,763)	827	(0-1,709)	0.45	(0.33-0.57)
2010	164,300	148,730	60,844	(37,227-84,462)	15,081	(8,933-21,230)	0.41	(0.29-0.53)
2011	160,487	134,559	56,030	(33,653-78,407)	4,821	(2,413-7,229)	0.38	(0.27-0.49)
2012	157,139	147,775	54,048	(32,029-76,066)	3,803	(1,612-5,994)	0.37	(0.26-0.48)
2013	153,632	139,139	53,475	(31,512-75,439)	29,761	(17,536-41,985)	0.36	(0.25-0.47)
2014	156,175	143,495	53,617	(31,615-75,620)	5,103	(2,320-7,885)	0.36	(0.25-0.47)
2015	158,311	139,233	53,172	(31,289-75,054)	11,678	(6,017-17,339)	0.36	(0.25-0.47)
2016	160,153	132,681	52,469	(30,588-74,350)	56,319	(32,578-80,061)	0.36	(0.24-0.47)
2017	172,400	149,120	53,373	(30,839-75,906)	1,644	(5-3,284)	0.36	(0.25-0.48)
2018	183,183	145,746	54,624	(31,340-77,909)	3,719	(0-9,716)	0.37	(0.25-0.49)
2019	190,935	147,444	57,444	(32,776-82,112)	12,857	(0-48,750)	0.39	(0.26-0.52)

Table 20. Adjusted mean input standard errors and root-mean-squared error (RMSE) of fits to discard and mean body weight data resulting from tuning the base model.

Fleet	SD adj.	Mean SD after adj.	RMSE
Discard ratio:			
Fixed-gear	0.00	0.03	0.03
Trawl	0.00	0.05	0.06
Mean body weight:			
Fixed-gear	0.30	0.37	0.20
Trawl	0.00	0.24	0.14

Table 21. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities for the base model and the base model with the sea-level data removed, 2015 selectivity assumptions, and the West Coast Groundfish Bottom Trawl Survey index removed.

Label	Base	No sea level	2015 Selectivity	No WCGBT Index
TOTAL	3306.51	3259.01	3227.54	3186.14
Catch	0.00	0.00	0.00	0.00
Survey	-4.99	-50.55	-2.74	27.87
Discard	-36.38	-35.95	-89.53	-83.55
Mean_body_wt	-19.30	-19.36	-28.29	-25.58
Length_comp	334.59	333.99	311.89	312.98
Age_comp	2995.95	2995.30	2997.97	2918.33
Recruitment	36.19	35.12	38.09	35.53
Parm_priors	0.45	0.46	0.15	0.55
NatM_p_1_Fem_GP_1	0.08	0.08	0.07	0.08
L_at_Amin_Fem_GP_1	25.15	25.15	25.09	25.07
L_at_Amax_Fem_GP_1	62.67	62.67	62.48	62.46
VonBert_K_Fem_GP_1	0.34	0.34	0.35	0.35
CV_young_Fem_GP_1	0.06	0.06	0.06	0.06
CV_old_Fem_GP_1	0.11	0.11	0.11	0.11
NatM_p_1_Mal_GP_1	0.07	0.07	0.06	0.07
L_at_Amin_Mal_GP_1	25.50	25.50	25.43	25.40
L_at_Amax_Mal_GP_1	56.37	56.37	56.29	56.24
VonBert_K_Mal_GP_1	0.40	0.40	0.40	0.41
CV_young_Mal_GP_1	0.07	0.07	0.07	0.07
CV_old_Mal_GP_1	0.08	0.08	0.08	0.08
SR_LN(R0)	9.62	9.63	9.25	9.74
SSB_2019	57443.90	58649.40	38033.30	67346.80
Recr_2019	12856.70	13108.40	8383.01	14965.30
SPRratio_2019	0.87	0.85	0.91	0.64
F_2019	0.04	0.04	0.05	0.03
Bratio_2019	0.39	0.39	0.30	0.44
ForeCatch_2019	6145.40	6145.40	4577.80	4577.80
OFLCatch_2019	7925.41	8107.87	5444.43	8607.35
ForeCatchret_2019	6030.76	6030.76	4479.96	4468.50

Table 22. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities for the base model, the base model with the hake bycatch fleet, beginning the model in 1970, and estimating a single natural mortality parameter (M).

Label	Base	Hake bycatch	Begin in 1970	Single M
TOTAL	3306.51	6639.91	3231.98	3310.50
Catch	0.00	0.00	0.00	0.00
Survey	-4.99	-2.84	-33.53	-4.99
Discard	-36.38	-3.68	-37.27	-36.20
Mean_body_wt	-19.30	-25.87	-19.61	-19.29
Length_comp	334.59	3415.13	333.09	334.48
Age_comp	2995.95	3189.81	2949.71	2994.60
Recruitment	36.19	66.78	30.97	41.87
Parm_priors	0.45	0.57	1.11	0.02
F_Ballpark			7.51	
NatM_p_1_Fem_GP_1	0.08	0.04	0.09	0.06
L_at_Amin_Fem_GP_1	25.15	27.68	25.15	25.15
L_at_Amax_Fem_GP_1	62.67	64.78	62.67	62.67
VonBert_K_Fem_GP_1	0.34	0.28	0.34	0.34
CV_young_Fem_GP_1	0.06	0.05	0.06	0.06
CV_old_Fem_GP_1	0.11	0.11	0.11	0.11
NatM_p_1_Mal_GP_1	0.07	0.04	0.08	0.00
L_at_Amin_Mal_GP_1	25.50	27.03	25.50	0.01
L_at_Amax_Mal_GP_1	56.37	56.52	56.37	-0.11
VonBert_K_Mal_GP_1	0.40	0.39	0.40	0.15
CV_young_Mal_GP_1	0.07	0.06	0.07	0.09
CV_old_Mal_GP_1	0.08	0.08	0.08	-0.32
SR_LN(R0)	9.62	8.47	10.02	9.15
SSB_2019	57443.90	45203.50	72407.60	40805.70
Recr_2019	12856.70	3926.68	19757.80	7560.90
SPRratio_2019	0.87	1.29	0.69	1.15
F_2019	0.04	0.06	0.03	0.06
Bratio_2019	0.39	0.33	0.43	0.30
ForeCatch_2019	6145.40	6181.08	6145.40	6145.40
OFLCatch_2019	7925.41	4011.32	11011.70	4854.08
ForeCatchret_2019	6030.76	6053.55	6030.84	6030.76
Age_likeAKSHLF	35.59	32.49	35.96	35.53
Age_likeAKSLP	87.31	127.28	86.87	87.01
Age_likeFIX	315.17	323.35	317.29	316.27
Age_likeNWCBO	2153.55	2237.88	2100.54	2154.17
Age_likeNWSLP	95.80	144.06	96.53	96.57
Age_likeTWL	308.53	324.76	312.52	305.05
Catch_likeFIX	0.00	0.00	0.00	0.00
Catch_likehake		0.00		

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Table 22. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities for the base model, the base model with the hake bycatch fleet, beginning the model in 1970, and estimating a single natural mortality parameter (*M*).

Label	Base	Hake bycatch	Begin in 1970	Single M
Catch_likeTWL	0.00	0.00	0.00	0.00
Disc_likeFIX	-47.91	-47.61	-47.86	-47.97
Disc_likeTWL	11.53	43.93	10.59	11.77
Length_likehake		2960.25		
Length_likeNWCBO	334.59	454.88	333.09	334.48
mnwt_likeFIX	-7.39	-7.23	-7.37	-7.36
mnwt_likeTWL	-11.90	-18.64	-12.24	-11.93
Surv_likeAKSHLF	-7.47	-8.50	-10.50	-7.25
Surv_likeAKSLP	-6.56	-6.75	-6.05	-6.74
Surv_likeENV	45.62	48.52	19.17	45.59
Surv_likeNWCBO	-32.28	-31.85	-31.88	-32.31
Surv_likeNWSLP	-4.30	-4.26	-4.28	-4.28

Table 23. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities for the base model compared to a model that includes sablefish landings from all of the northeast Pacific.

Label	Base	landings
TOTAL	3306.51	3165.51
Catch	0.00	0.00
Survey	-4.99	-3.16
Discard	-36.38	-83.11
Mean_body_wt	-19.30	-25.58
Length_comp	334.59	310.33
Age_comp	2995.95	2932.49
Recruitment	36.19	33.42
Parm_priors	0.45	1.12
NatM_p_1_Fem_GP_1	0.08	0.09
L_at_Amin_Fem_GP_1	25.15	25.07
L_at_Amax_Fem_GP_1	62.67	62.48
VonBert_K_Fem_GP_1	0.34	0.35
CV_young_Fem_GP_1	0.06	0.06
CV_old_Fem_GP_1	0.11	0.11
NatM_p_1_Mal_GP_1	0.07	0.08
L_at_Amin_Mal_GP_1	25.50	25.40
L_at_Amax_Mal_GP_1	56.37	56.25
VonBert_K_Mal_GP_1	0.40	0.41
CV_young_Mal_GP_1	0.07	0.07
CV_old_Mal_GP_1	0.08	0.08
SR_LN(R0)	9.62	11.62
SSB_2019	57443.90	417484.00
Recr_2019	12856.70	100406.00
SPRratio_2019	0.87	0.11
F_2019	0.04	0.00
Bratio_2019	0.39	0.50
ForeCatch_2019	6145.40	4577.80
OFLCatch_2019	7925.41	56333.70
ForeCatchret_2019	6030.76	4467.24

Table 24. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of female natural mortality (M; columns).

Label	Female M=0.064	Female M=0.066	Female M=0.069
TOTAL	3307.57	3307.17	3306.70
Catch	0.00	0.00	0.00
Survey	-5.02	-5.00	-4.99
Discard	-36.21	-36.24	-36.28

Continued on next page.

Table 24. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of female natural mortality (M; columns).

Label	Female M=0.064	Female M=0.066	Female M=0.069
Mean_body_wt	-19.31	-19.30	-19.30
Length_comp	335.10	335.01	334.88
Age_comp	2993.03	2993.48	2994.19
Recruitment	39.95	39.20	38.15
Parm_priors	0.02	0.03	0.05
NatM_p_1_Fem_GP_1	0.06	0.07	0.07
L_at_Amin_Fem_GP_1	25.15	25.15	25.15
L_at_Amax_Fem_GP_1	62.67	62.67	62.67
VonBert_K_Fem_GP_1	0.34	0.34	0.34
CV_young_Fem_GP_1	0.06	0.06	0.06
CV_old_Fem_GP_1	0.11	0.11	0.11
NatM_p_1_Mal_GP_1	0.06	0.06	0.06
L_at_Amin_Mal_GP_1	25.50	25.50	25.50
L_at_Amax_Mal_GP_1	56.37	56.37	56.37
VonBert_K_Mal_GP_1	0.40	0.40	0.40
CV_young_Mal_GP_1	0.07	0.07	0.07
CV_old_Mal_GP_1	0.08	0.08	0.08
SR_LN(R0)	9.29	9.35	9.42
SSB_2019	48311.80	49630.00	51762.20
Recr_2019	9113.20	9631.36	10482.80
SPRratio_2019	1.02	0.99	0.95
F_2019	0.05	0.05	0.05
Bratio_2019	0.36	0.36	0.37
OFLCatch_2019	6110.29	6376.40	6803.12
ForeCatchret_2019	6030.79	6030.78	6030.77
Age_likeAKSHLF	35.53	35.54	35.56
Age_likeAKSLP	87.73	87.66	87.55
Age_likeFIX	315.27	315.23	315.19
Age_likeNWCBO	2152.56	2152.70	2152.94
Age_likeNWSLP	96.03	96.00	95.94
Age_likeTWL	305.91	306.35	307.02
Catch_likeFIX	0.00	0.00	0.00
Catch_likeTWL	0.00	0.00	0.00
Disc_likeFIX	-47.94	-47.94	-47.93
Disc_likeTWL	11.73	11.70	11.65
Length_likeNWCBO	335.10	335.01	334.88
mnwt_likeFIX	-7.39	-7.39	-7.39
mnwt_likeTWL	-11.92	-11.91	-11.91
Surv_likeAKSHLF	-7.44	-7.45	-7.46
Surv_likeAKSLP	-6.66	-6.64	-6.61
Surv_likeENV	45.70	45.71	45.71

Continued on next page.

Table 24. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of female natural mortality (M; columns).

Label	Female M=0.064	Female M=0.066	Female M=0.069
Surv_likeNWCBO	-32.32	-32.32	-32.32
Surv_likeNWSLP	-4.30	-4.30	-4.30

Table 25. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of the natural log of unexploited recruitment ($ln(R_0)$; columns).

Label	R0=9.37	R0=9.45	R0=9.53
TOTAL	3307.00	3306.73	3306.57
Catch	0.00	0.00	0.00
Survey	-5.00	-4.97	-4.97
Discard	-36.15	-36.23	-36.30
Mean_body_wt	-19.31	-19.30	-19.30
Length_comp	334.64	334.62	334.61
Age_comp	2993.75	2994.46	2995.17
Recruitment	38.85	37.86	37.00
Parm_priors	0.23	0.29	0.36
NatM_p_1_Fem_GP_1	0.07	0.07	0.07
L_at_Amin_Fem_GP_1	25.15	25.15	25.15
L_at_Amax_Fem_GP_1	62.68	62.68	62.68
VonBert_K_Fem_GP_1	0.34	0.34	0.34
CV_young_Fem_GP_1	0.06	0.06	0.06
CV_old_Fem_GP_1	0.11	0.11	0.11
NatM_p_1_Mal_GP_1	0.06	0.06	0.07
L_at_Amin_Mal_GP_1	25.50	25.50	25.50
L_at_Amax_Mal_GP_1	56.37	56.37	56.37
VonBert_K_Mal_GP_1	0.40	0.40	0.40
CV_young_Mal_GP_1	0.07	0.07	0.07
CV_old_Mal_GP_1	0.08	0.08	0.08
SR_LN(R0)	9.37	9.45	9.53
SSB_2019	50439.10	52553.10	54800.10
Recr_2019	9996.88	10847.30	11766.60
SPRratio_2019	0.97	0.93	0.90
F_2019	0.05	0.05	0.04
Bratio_2019	0.38	0.38	0.39
OFLCatch_2019	6640.46	7030.57	7443.17
ForeCatchret_2019	6030.79	6030.78	6030.77
Age_likeAKSHLF	35.53	35.55	35.57
Age_likeAKSLP	87.64	87.53	87.43
Age_likeFIX	315.16	315.14	315.14
Age_likeNWCBO	2152.96	2153.15	2153.34
Age_likeNWSLP	95.80	95.81	95.82
Age_likeTWL	306.66	307.27	307.88
Catch_likeFIX	0.00	0.00	0.00
Catch_likeTWL	0.00	0.00	0.00
Disc_likeFIX	-47.94	-47.93	-47.92
Disc_likeTWL	11.79	11.70	11.62
Length_likeNWCBO	334.64	334.62	334.61

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Table 25. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of the natural log of unexploited recruitment ($ln(R_0)$; columns).

Label	R0=9.37	R0=9.45	R0=9.53
mnwt_likeFIX	-7.40	-7.40	-7.39
mnwt_likeTWL	-11.92	-11.91	-11.90
Surv_likeAKSHLF	-7.43	-7.45	-7.46
Surv_likeAKSLP	-6.64	-6.61	-6.58
Surv_likeENV	45.67	45.69	45.67
Surv_likeNWCBO	-32.31	-32.31	-32.30
Surv_likeNWSLP	-4.29	-4.30	-4.30

Table 26. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of the steepness (*h*; columns).

Label	h=0.55	h=0.668	h=0.787	h=0.905
TOTAL	3306.93	3306.57	3306.39	3306.31
Catch	0.00	0.00	0.00	0.00
Survey	-4.48	-4.90	-5.19	-5.39
Discard	-36.33	-36.37	-36.40	-36.41
Mean_body_wt	-19.31	-19.30	-19.29	-19.29
Length_comp	334.46	334.58	334.63	334.66
Age_comp	2996.24	2995.99	2995.88	2995.86
Recruitment	35.83	36.12	36.33	36.47
Parm_priors	0.51	0.46	0.42	0.40
NatM_p_1_Fem_GP_1	0.08	0.08	0.08	0.07
L_at_Amin_Fem_GP_1	25.15	25.15	25.15	25.15
L_at_Amax_Fem_GP_1	62.67	62.67	62.67	62.67
VonBert_K_Fem_GP_1	0.34	0.34	0.34	0.34
CV_young_Fem_GP_1	0.06	0.06	0.06	0.06
CV_old_Fem_GP_1	0.11	0.11	0.11	0.11
NatM_p_1_Mal_GP_1	0.07	0.07	0.07	0.07
L_at_Amin_Mal_GP_1	25.50	25.50	25.50	25.50
L_at_Amax_Mal_GP_1	56.37	56.37	56.37	56.37
VonBert_K_Mal_GP_1	0.40	0.40	0.40	0.40
CV_young_Mal_GP_1	0.07	0.07	0.07	0.07
CV_old_Mal_GP_1	0.08	0.08	0.08	0.08
SR_LN(R0)	9.76	9.64	9.57	9.52
SR_BH_steep	0.55	0.67	0.79	0.90
SSB_2019	59342.40	57767.40	56790.50	56269.00
Recr_2019	12699.80	12825.70	12955.40	13110.50
SPRratio_2019	0.84	0.86	0.87	0.88
F_2019	0.04	0.04	0.04	0.04
Bratio_2019	0.36	0.38	0.40	0.41
OFLCatch_2019	8281.57	7985.31	7803.73	7704.99
ForeCatchret_2019	6030.87	6030.78	6030.71	6030.67
Age_likeAKSHLF	35.56	35.58	35.60	35.61
Age_likeAKSLP	87.25	87.30	87.34	87.36
Age_likeFIX	315.14	315.16	315.19	315.20
Age_likeNWCBO	2153.66	2153.56	2153.52	2153.51
Age_likeNWSLP	95.76	95.79	95.83	95.85
Age_likeTWL	308.88	308.59	308.41	308.32
Catch_likeFIX	0.00	0.00	0.00	0.00
Catch_likeTWL	0.00	0.00	0.00	0.00
Disc_likeFIX	-47.91	-47.91	-47.91	-47.92
Disc_likeTWL	11.58	11.54	11.52	11.51

Continued on next page.

Table 26. Likelihood components by data type, estimated biological parameters, and terminal year derived quantities over fixed values of the steepness (*h*; columns).

Label	h=0.55	h=0.668	h=0.787	h=0.905
Length_likeNWCBO	334.46	334.58	334.63	334.66
mnwt_likeFIX	-7.39	-7.39	-7.39	-7.40
mnwt_likeTWL	-11.92	-11.90	-11.90	-11.89
Surv_likeAKSHLF	-7.47	-7.47	-7.47	-7.47
Surv_likeAKSLP	-6.54	-6.55	-6.57	-6.57
Surv_likeENV	46.08	45.70	45.43	45.25
Surv_likeNWCBO	-32.26	-32.28	-32.29	-32.30
Surv_likeNWSLP	-4.29	-4.30	-4.30	-4.30

Table 27. The sablefish stock assessment is a Category 1 stock assessment, thus projections and decision tables are based on using $P^* = 0.40$ and the Pacific Fisheries Management Council (PFMC) approved time series of sigma values for stock projections that provide the multipliers on the over fishing limit (OFL), these values are all less than 1. The OFL multipliers are combined with the 40-10 harvest control rule, where applicable, to calculate OFLs and Annual Catch Limits (ACLs). 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. Therefore, ABCs are not displayed. The total catches in 2019 and 2020 were set at the PFMC Groundfish Management Team requested values of 6,145.4 mt for 2019 and 6,287.9 mt for 2020, just below the PFMC agreed ACLs for sablefish. The average 2016-2018 catch was used to distribute catches among the fisheries.

Year	OFL (mt)	ACL (mt)	Spawning biomass (mt)	Depletion
2019	8,489	7,596	57,444	38.88 %
2020	8,648	7,755	63,350	42.88 %
2021	9,402	8,208	68,120	46.11 %
2022	9,040	7,811	68,778	46.56 %
2023	8,877	7,599	68,177	46.15 %
2024	8,713	7,388	67,482	45.68 %
2025	8,579	7,207	66,984	45.34 %
2026	8,479	7,055	66,691	45.14 %
2027	8,411	6,930	66,555	45.05 %
2028	8,368	6,837	66,525	45.03 %
2029	8,346	6,752	66,564	45.06 %
2030	8,339	6,679	66,652	45.12 %

Table 28. 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 2019. The low and high states of nature are based on the 2019 SSB $\pm$ 1.15·base model SSB standard deviation. The fixed value of unfished recruitment was used to find each state of nature. The results are conditioned on the 2019 and 2020 catches, provided by the Pacific Fisheries Management Council Groundfish Management Team (GMT), being achieved exactly. The low and high catch streams are based on the GMT's requested P* values of 0.35 and 0.45.

			Low state (0.25)		Base (0.5)		High state (0.25)	
Catch scenario	Year	Total catch	SSB	Depletion	SSB	Depletion	SSB	Depletion
P*=0.35	2019	6,145	42,968	38%	57,444	39%	71,915	41%
	2020	6,288	47,594	42%	63,350	43%	79,161	45%
	2021	7,644	51,414	45%	68,120	46%	84,950	49%
	2022	7,269	51,922	46%	69,059	47%	86,290	50%
	2023	7,064	51,094	45%	68,740	47%	86,292	50%
	2024	6,849	49,847	44%	68,316	46%	86,367	50%
	2025	6,668	48,544	43%	68,079	46%	86,781	50%
	2026	6,513	47,297	41%	68,038	46%	87,474	50%
	2027	6,382	46,136	40%	68,145	46%	88,349	51%
	2028	6,279	45,063	40%	68,354	46%	89,327	51%
	2029	6,182	44,064	39%	68,629	46%	90,356	52%
	2030	6,105	43,135	38%	68,953	47%	91,411	53%
P*=0.4	2019	6,145	42,968	38%	57,444	39%	71,915	41%
	2020	6,288	47,594	42%	63,350	43%	79,161	45%
	2021	8,208	51,414	45%	68,120	46%	84,950	49%
	2022	7,811	51,636	45%	68,778	47%	86,008	49%
	2023	7,599	50,517	44%	68,177	46%	85,727	49%
	2024	7,388	48,988	43%	67,482	46%	85,532	49%
	2025	7,207	47,411	42%	66,984	45%	85,685	49%
	2026	7,055	45,902	40%	66,691	45%	86,129	49%
	2027	6,930	44,489	39%	66,555	45%	86,761	50%
	2028	6,837	43,169	38%	66,525	45%	87,503	50%
	2029	6,752	41,925	37%	66,564	45%	88,300	51%
	2030	6,679	40,750	36%	66,652	45%	89,126	51%
P*=0.45	2019	6,145	42,968	38%	57,444	39%	71,915	41%
	2020	6,288	47,594	42%	63,350	43%	79,161	45%
	2021	8,791	51,414	45%	68,120	46%	84,950	49%
	2022	8,375	51,342	45%	68,488	46%	85,717	49%
	2023	8,158	49,920	44%	67,594	46%	85,142	49%
	2024	7,946	48,097	42%	66,618	45%	84,666	49%
	2025	7,758	46,241	41%	65,851	45%	84,551	49%
	2026	7,614	44,468	39%	65,304	44%	84,740	49%
	2027	7,499	42,799	38%	64,918	44%	85,125	49%
	2028	7,401	41,226	36%	64,643	44%	85,624	49%
	2029	7,331	39,739	35%	64,445	44%	86,188	50%
	2030	7,275	38,320	34%	64,296	44%	86,782	50%

Table 29. Estimates of the relative proportion of sablefish biomass located south and north of 36°N lat. using data from the West Coast Groundfish Bottom Trawl Survey fit to a vector autoregressive spatiotemporal model. The average across years is used to apportion future annual catch limits to the two areas.

Year	South	North
2003	0.24	0.76
2004	0.26	0.74
2005	0.32	0.68
2006	0.29	0.71
2007	0.35	0.65
2008	0.31	0.69
2009	0.32	0.68
2010	0.27	0.73
2011	0.25	0.75
2012	0.23	0.77
2013	0.30	0.70
2014	0.23	0.77
2015	0.22	0.78
2016	0.22	0.78
2017	0.21	0.79
2018	0.20	0.80

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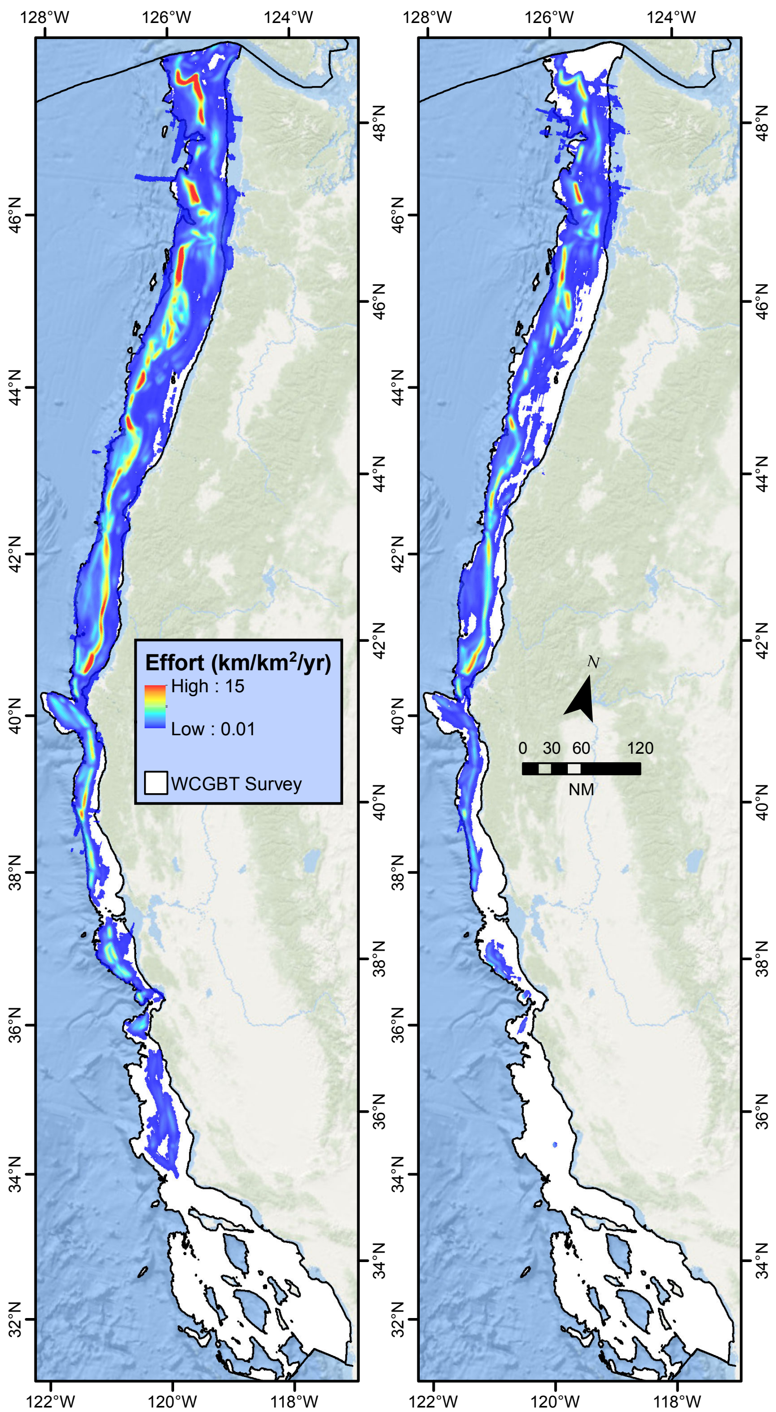


Figure 1. Spatial footprint of effort using trawl gear (km/km^2/yr) in the sablefish fishery before catch shares (2003–2010; left) and post catch shares (2011–2017; right) in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white). Fishery data are from Pacific Fisheries Information Network logbooks and the West Coast Groundfish Observer Program.

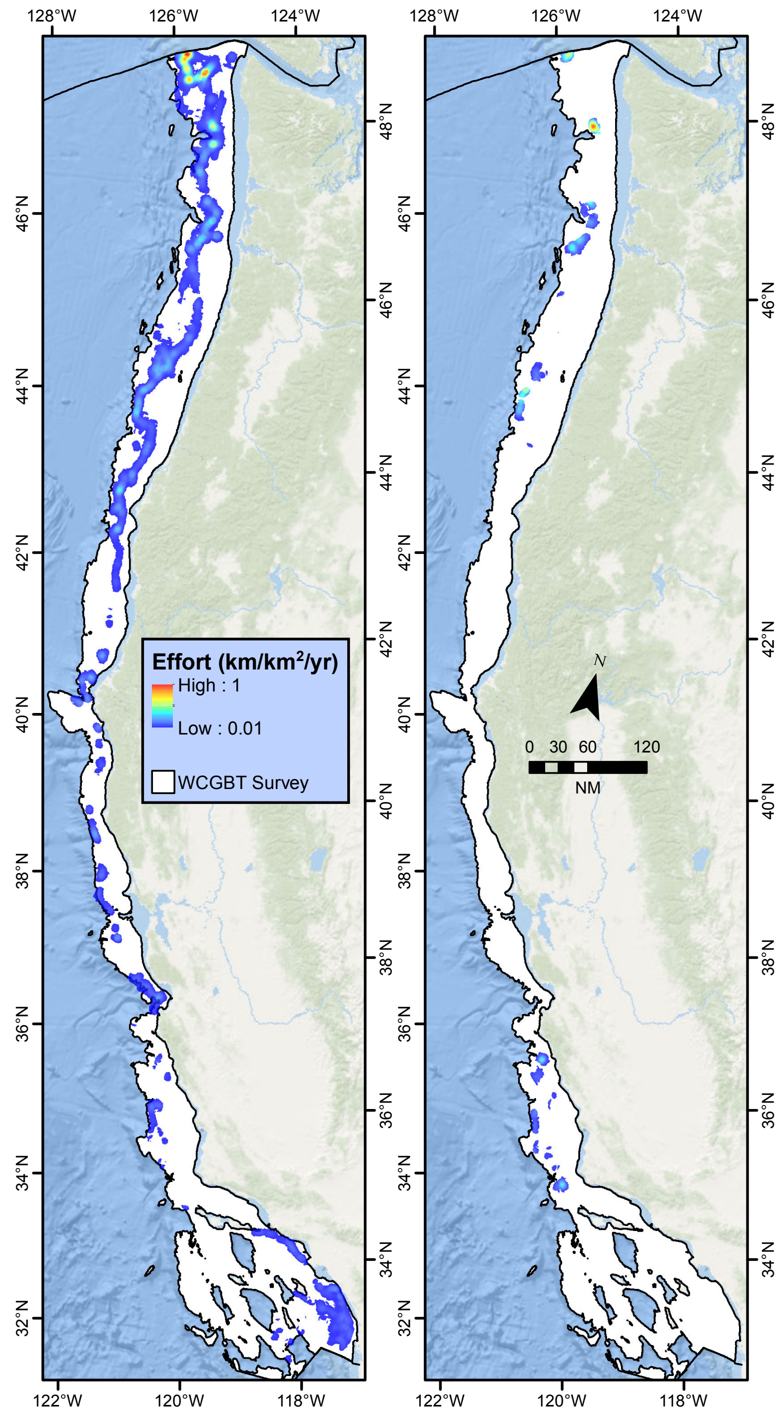


Figure 2. Spatial footprint of effort using hook-and-line gear (km/km^2/yr) in the sablefish fishery with non catch-share vessels since 2003 (2003–2017; left) and with catch-share vessels since 2011 (2011–2017; right) as observed by the West Coast Groundfish Observer Program in comparison to the spatial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

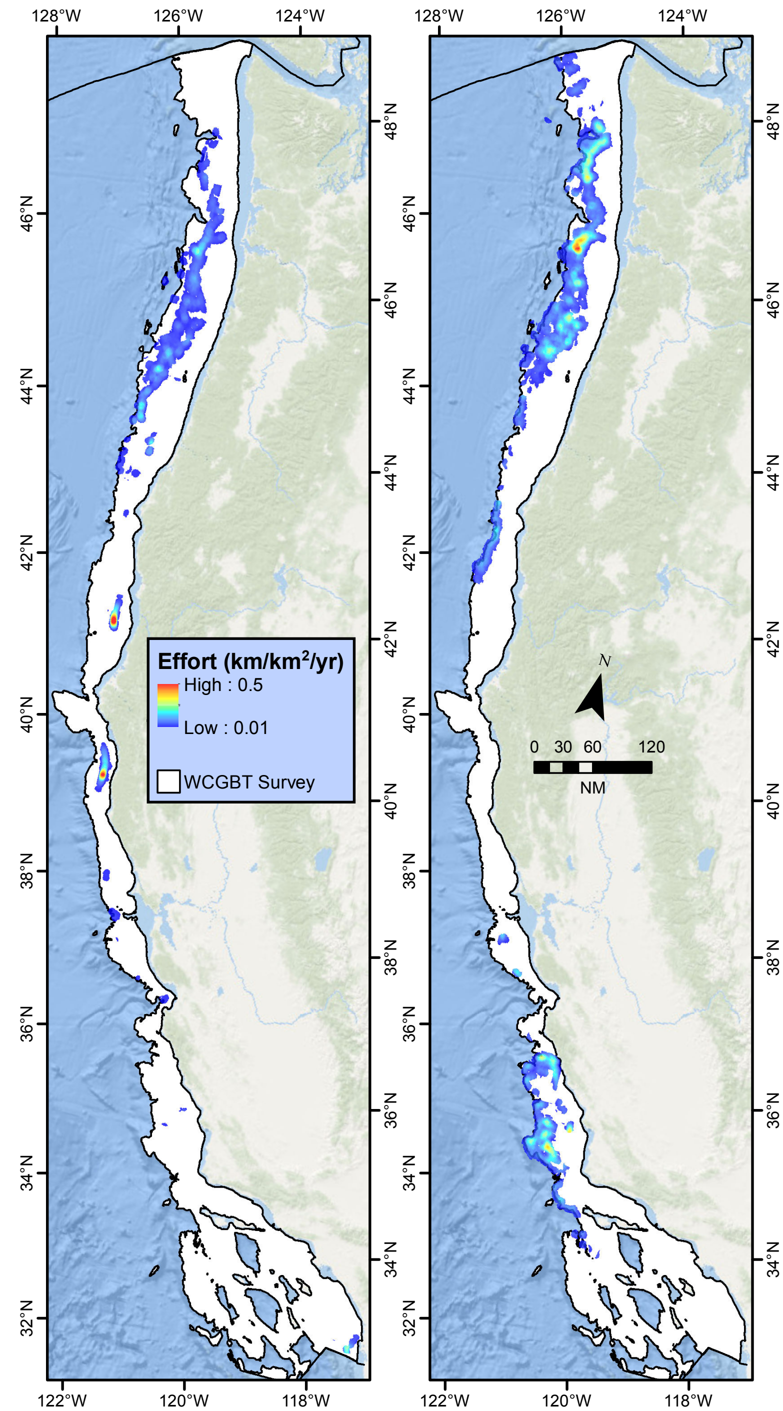


Figure 3. Spatial footprint of effort using pot gear (km/km^2/yr) in the sablefish fishery with non catch-share vessels since 2003 (2003–2017; left) and with catch-share vessels since 2011 (2011–2017; right) in comparison to the spatial footprint of the West Coast Groundfish Bottom Trawl (WCGBT) Survey (white).

Sablefish – *Anoplopoma fimbria*

Overall Vulnerability Rank = Moderate

Biological Sensitivity = Moderate
Climate Exposure = High
Data Quality = 71% of scores ≥ 2

	Anoplopoma fimbria	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.3	2.8	
	Prey Specificity	1.3	3	
	Adult Mobility	1.3	2.5	
	Dispersal of Early Life Stages	1.3	2.3	
	Early Life History Survival and Settlement Requirements	2.6	2	
	Complexity in Reproductive Strategy	2.2	1.5	
	Spawning Cycle	1.9	2.8	
	Sensitivity to Temperature	1.9	2	
	Sensitivity to Ocean Acidification	1.6	2	
	Population Growth Rate	3	2.3	
	Stock Size/Status	1.8	2.8	
	Other Stressors	1.6	1.3	
	Sensitivity Score	Moderate		
Exposure variables	Mean Sea Surface Temperature	3.1	2.5	
	Mean Sea Surface Salinity	1.4	1.5	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.8	
	Currents	2	1	
	Phenology of Upwelling	2	2	
	Subsurface Oxygen	2.3	1.8	
	Exposure Score	High		
Overall Vulnerability Rank		Moderate		

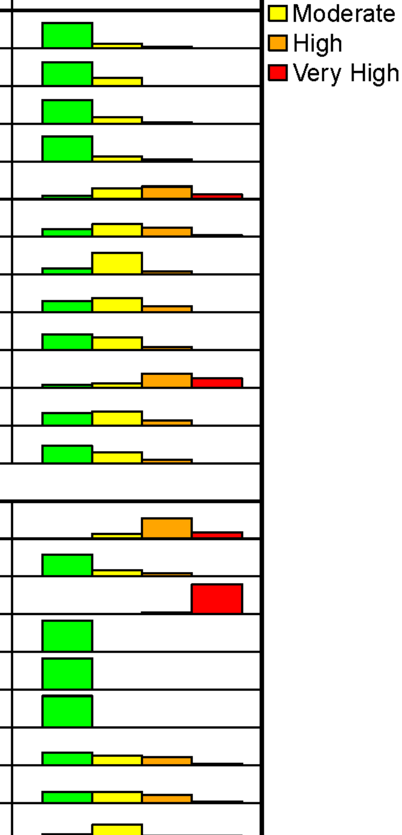


Figure 4. Results of the Climate Vulnerability Analysis (CVA) for sablefish (McClure and Haltuch, in preparation).

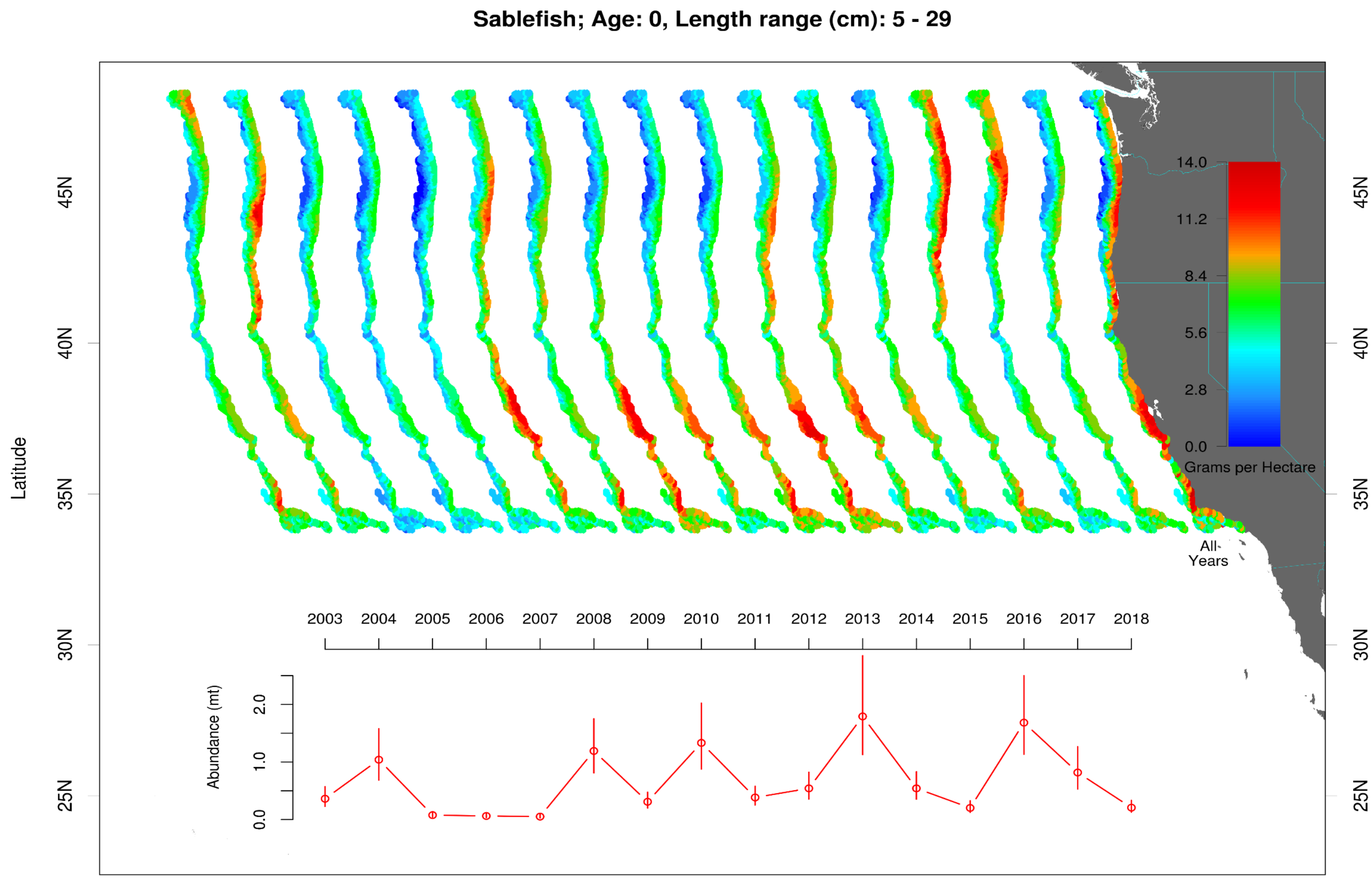


Figure 5. Spatial distribution (gm · ha^{-1}) and time series of abundance (mt) for age-0 sablefish recruits from 2003-2018 along the U.S. West Coast. Data are from the West Coast Groundfish Bottom Trawl Survey for 2003-2018 (Keller et al., 2017) and were analyzed via vector-autoregressive spatiotemporal modeling (`VAST`) to quantify spatial and temporal patterns in the sablefish biomass and calculate a coast-wide index of abundance. See Appendix A for more details.

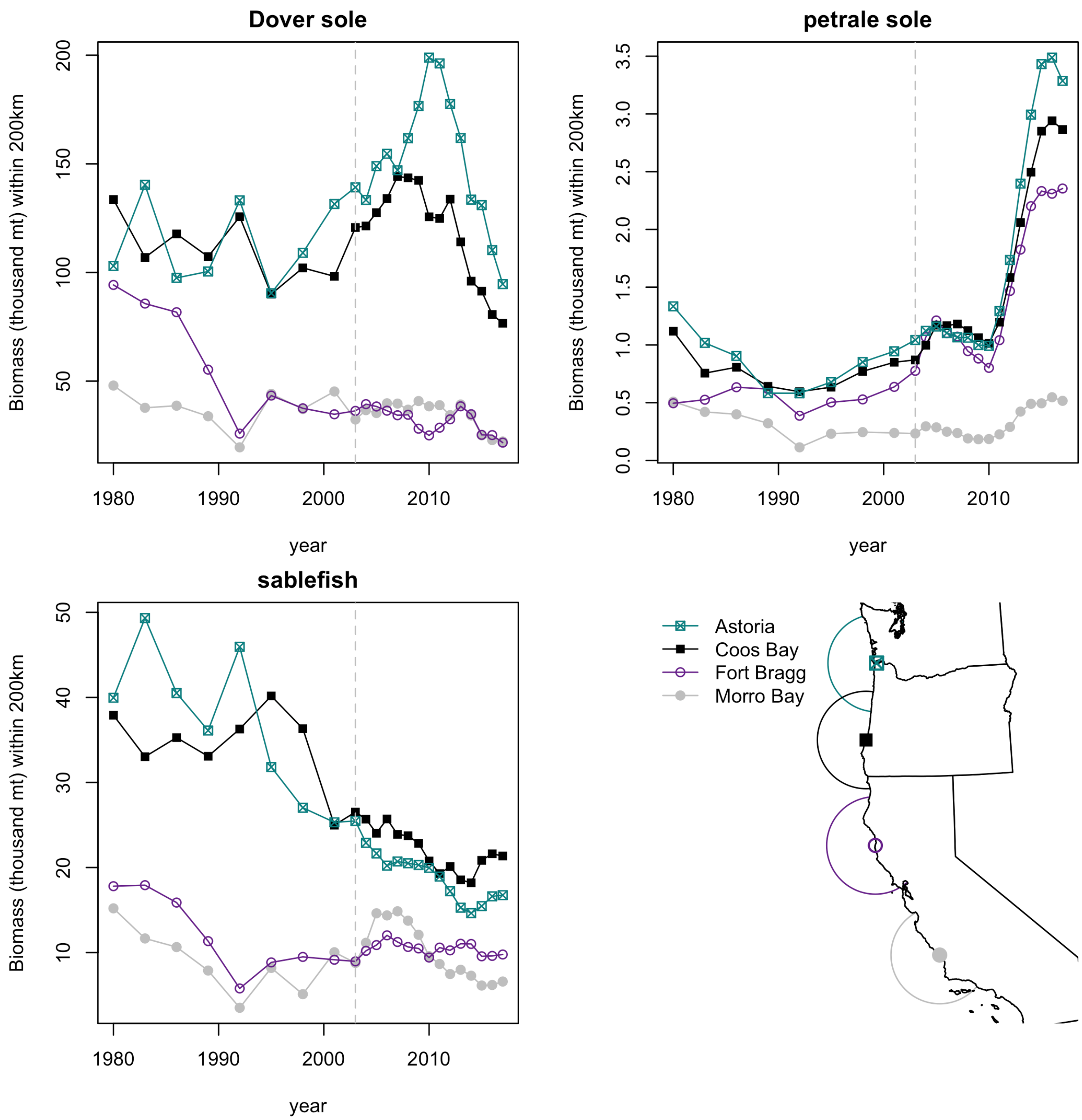


Figure 6. Time series of biomass (thousand mt) for dover sole, petrale sole, and sablefish (panels) within 200 km of four focal ports (colors) along the U.S. West Coast.

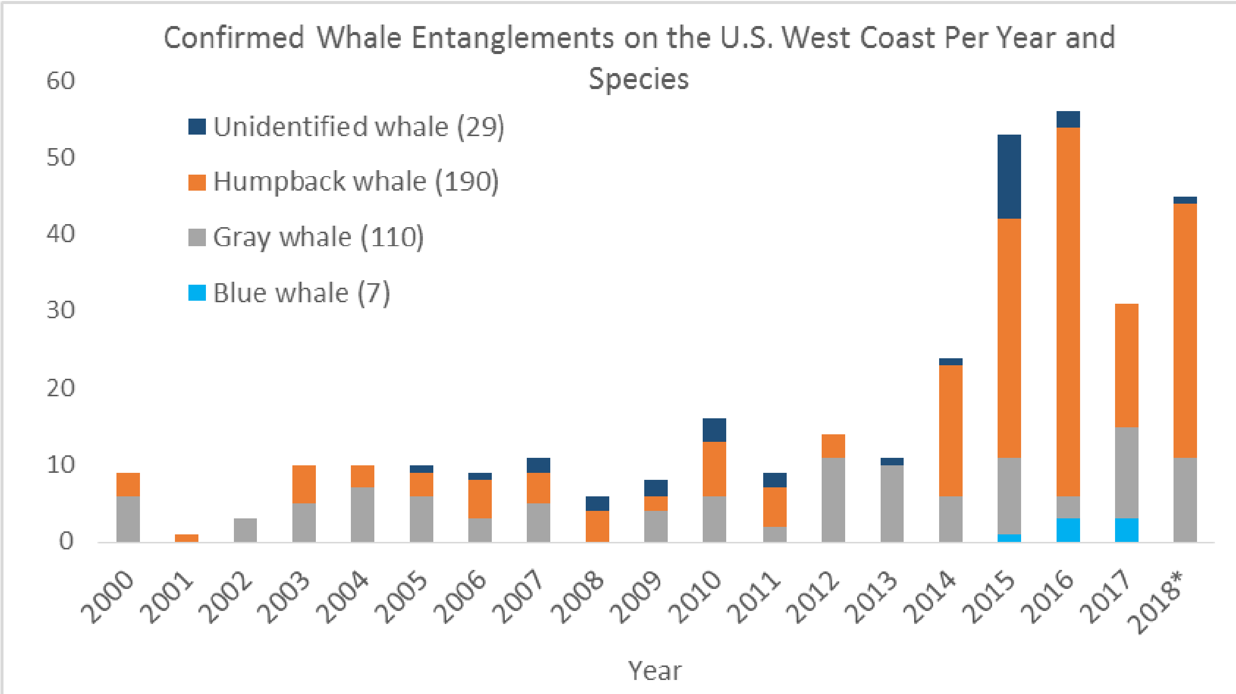


Figure 7. Numbers of whales reported as entangled in fishing gear along the U.S. West Coast from 2000-2019. Reproduced with permission from Harvey et al. (2019).

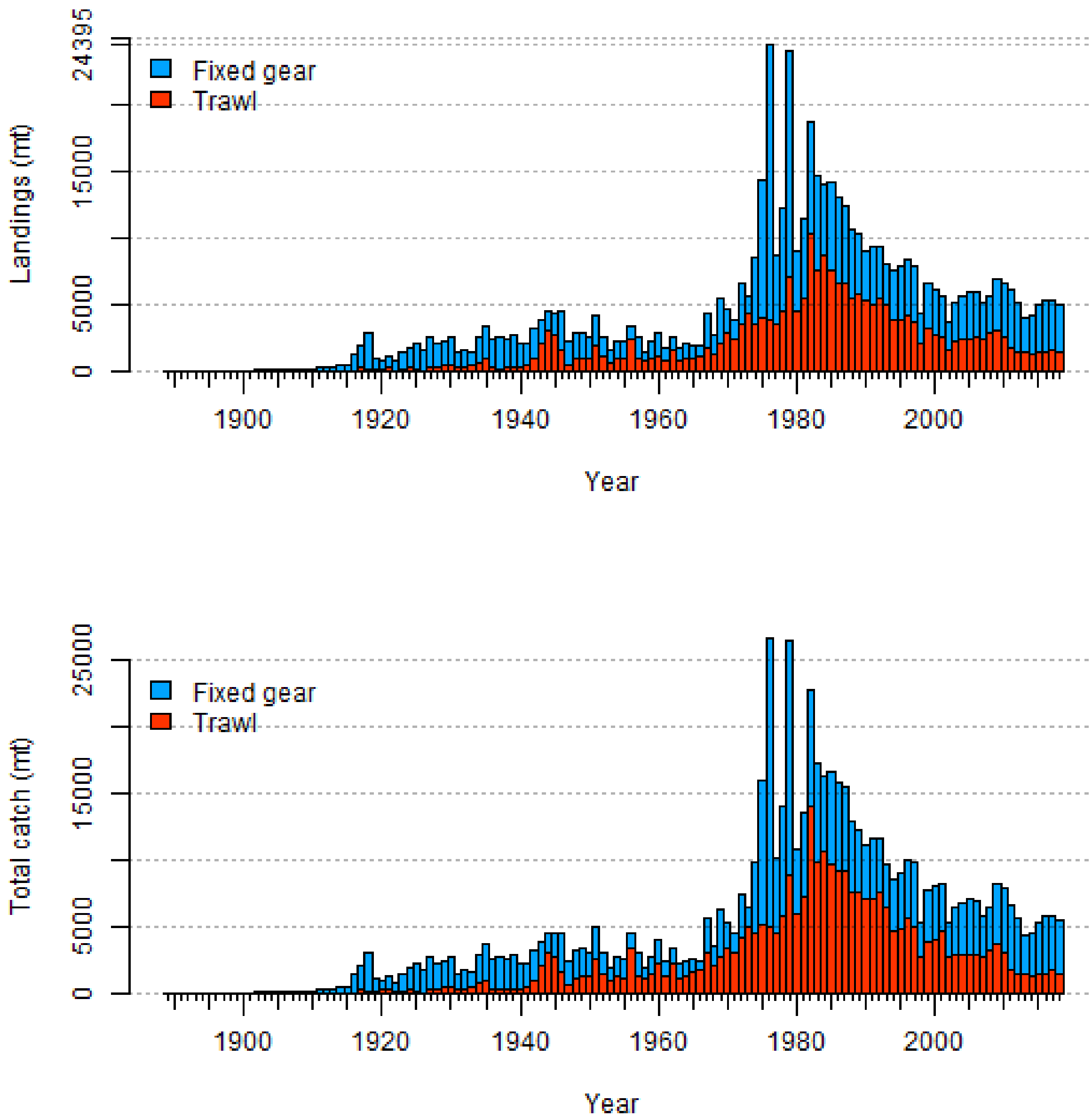


Figure 8. Sablefish landings (mt; top panel) and total catch (mt; bottom panel) by gear groupings (color) included in the base model. Landings from foreign fleets are included and are largely responsible for the peaks in 1976 and 1979.

Figure 9. Overview of data sources used in this stock assessment. Circles are proportional to catches, precision, or sample size within a given data type (i.e., bold labels).

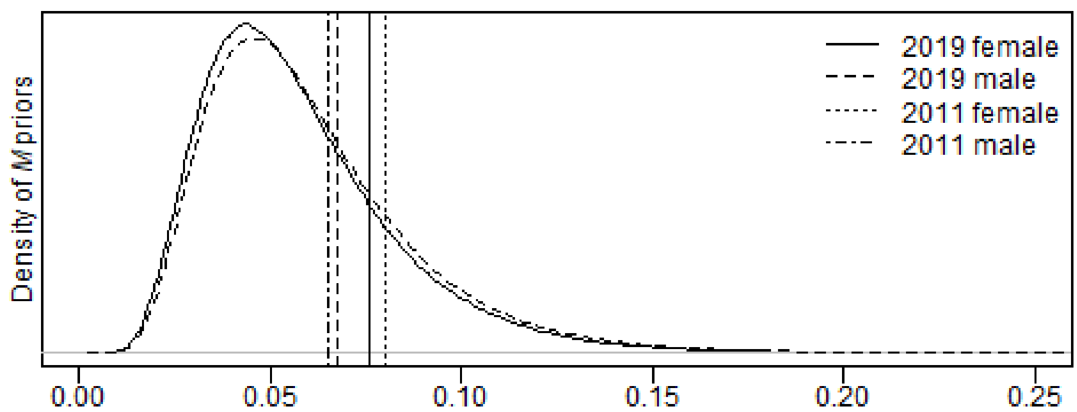


Figure 10. Prior for female (solid line) and male (dashed line) natural mortality (*M*). Vertical lines delineate estimates from the current and previous benchmark base models (see legend).

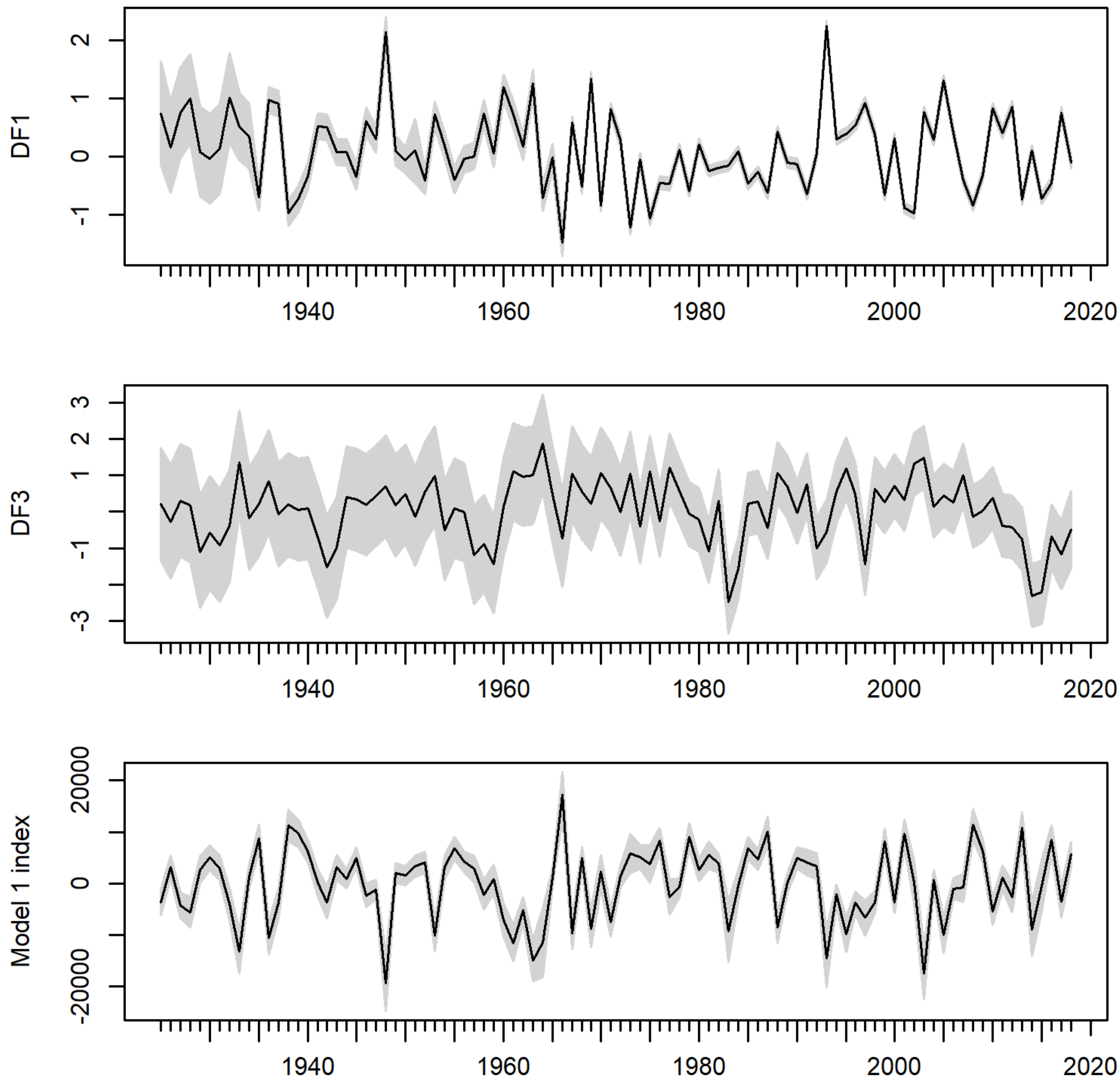


Figure 11. Time series of the first and third dynamic factors for sea level and the combined index (DF1 + DF3 + $DF3^2$) for 1925-2018.

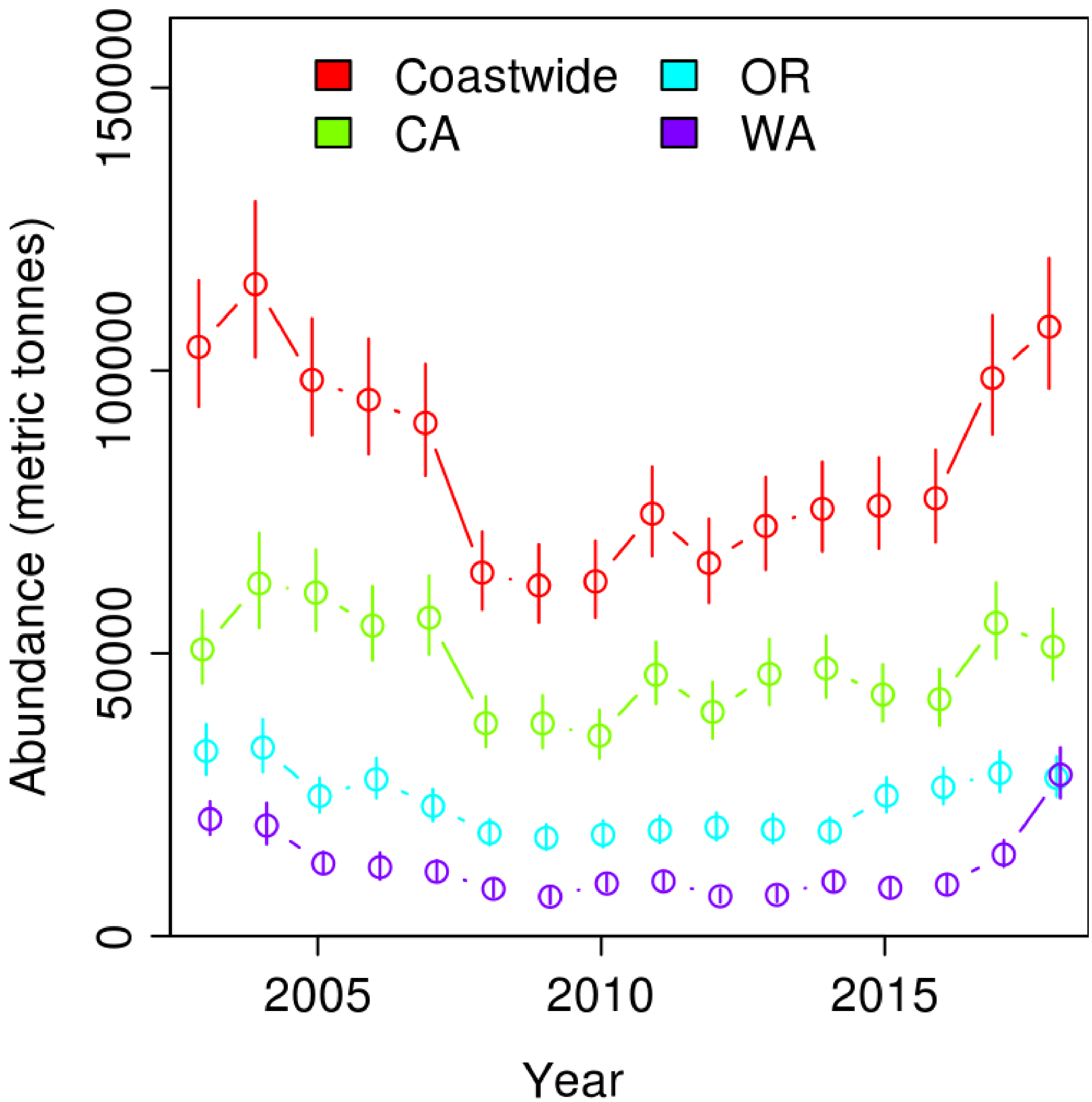


Figure 12. Estimated index of relative abundance (mt) for the West Coast Groundfish Bottom Trawl Survey, with 5 and 95% intervals. Region-specific estimates are included for Washington (WA), Oregon (OR), and California (CA), as well as the coast-wide estimate.

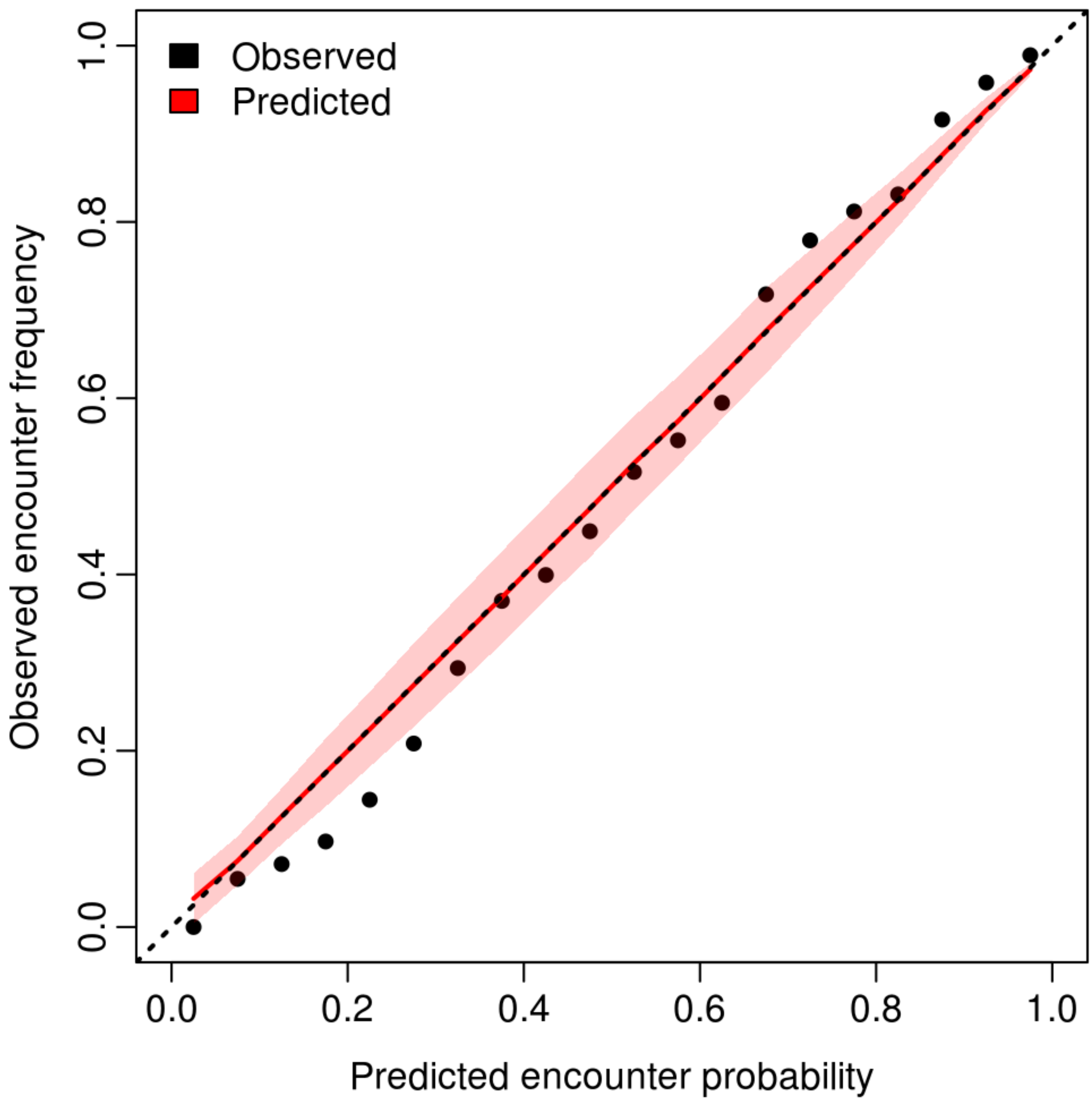


Figure 13. Observed (black points) vs. predicted (red polygon) quantiles from a gamma distribution for encounter probability when fitting a vector-autoregressive spatiotemporal model to data from the West Coast Groundfish Bottom Trawl Survey.

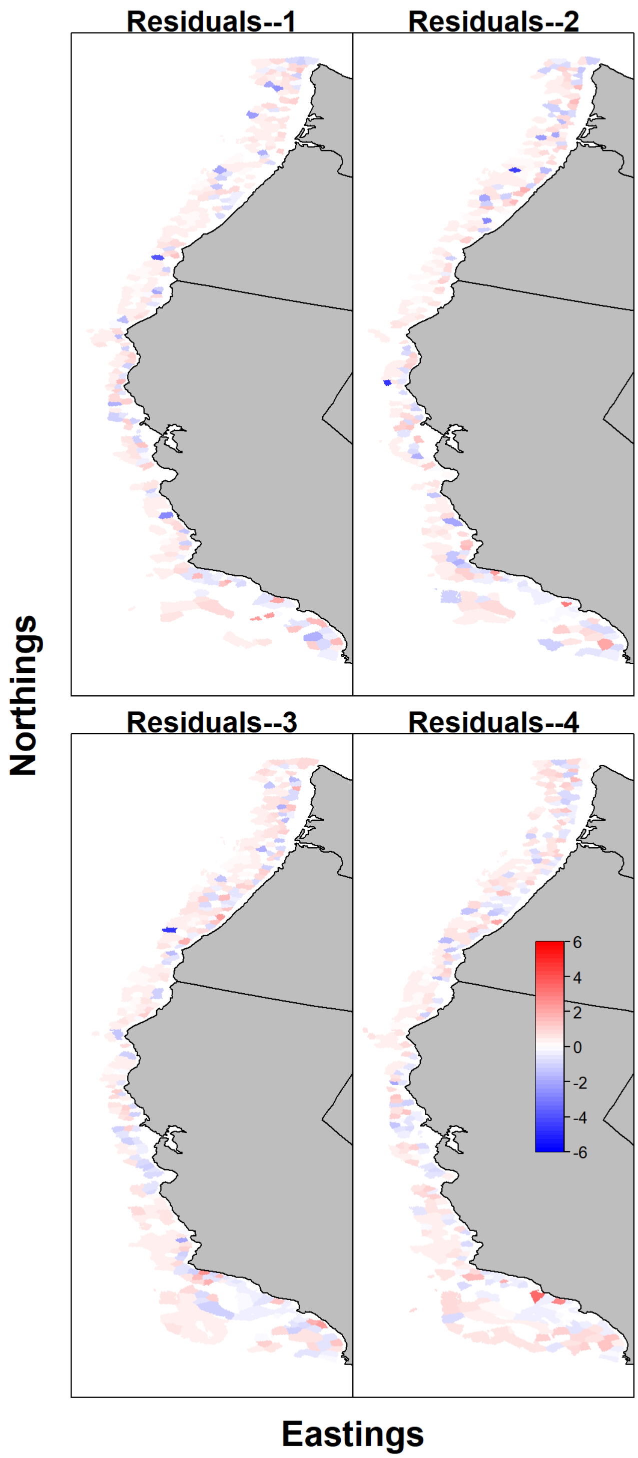


Figure 14. Pearson residuals across space and time (panels) for predicted encounter rates for the West Coast Groundfish Bottom Trawl Survey; panel 1 of 4.

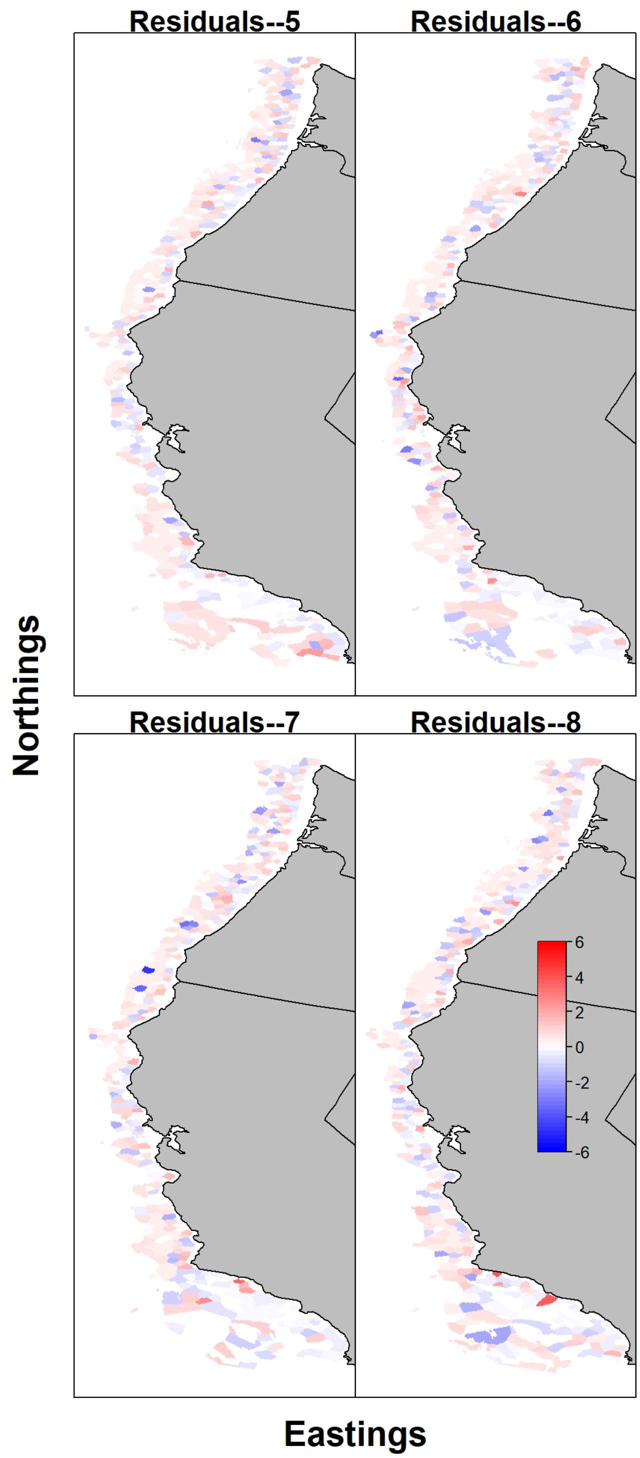


Figure 15. Pearson residuals across space and time (panels) for predicted encounter rates for the West Coast Groundfish Bottom Trawl Survey; panel 2 of 4.

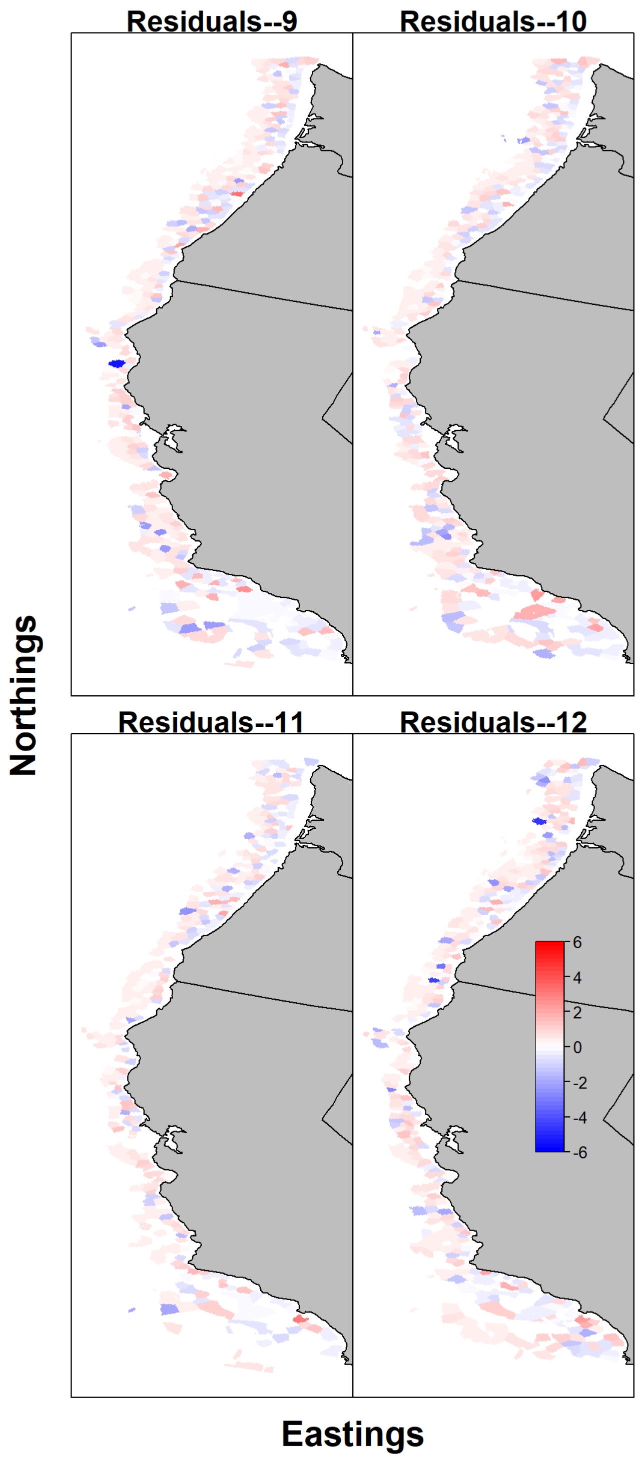


Figure 16. Pearson residuals across space and time (panels) for predicted encounter rates for the West Coast Groundfish Bottom Trawl Survey; panel 3 of 4.

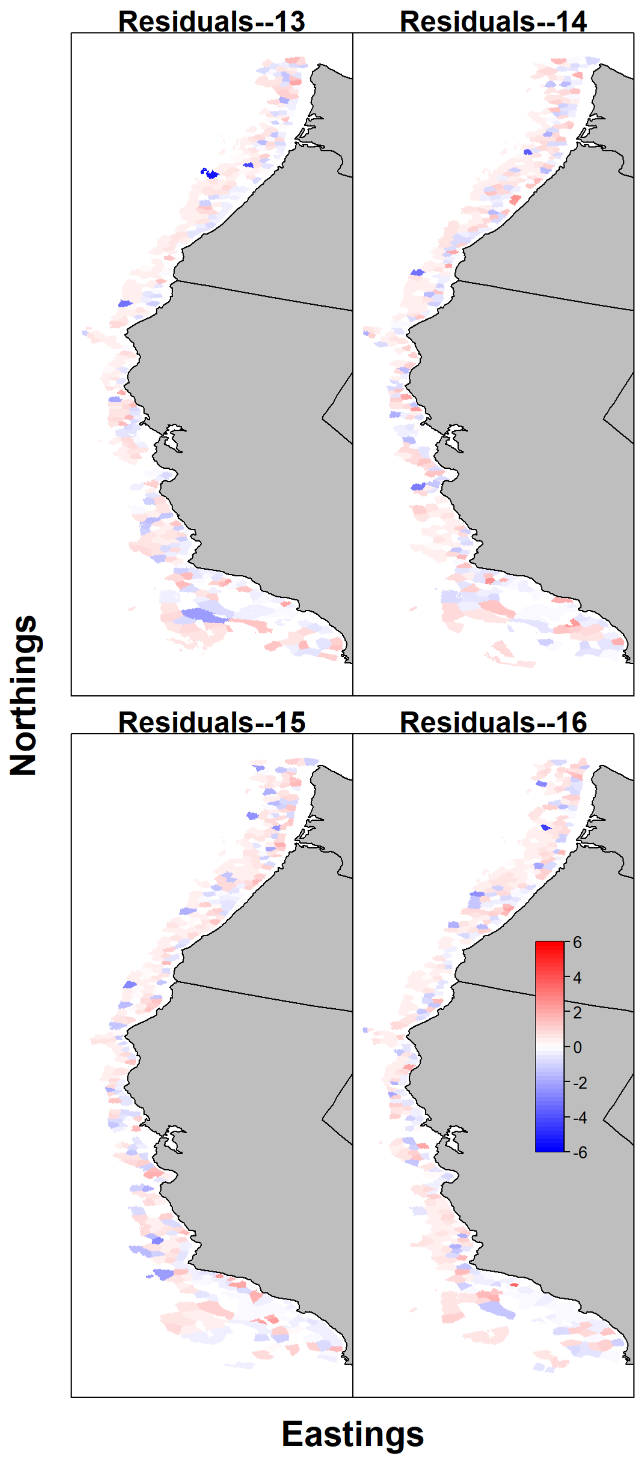


Figure 17. Pearson residuals across space and time (panels) for predicted encounter rates for the West Coast Groundfish Bottom Trawl Survey; panel 4 of 4.

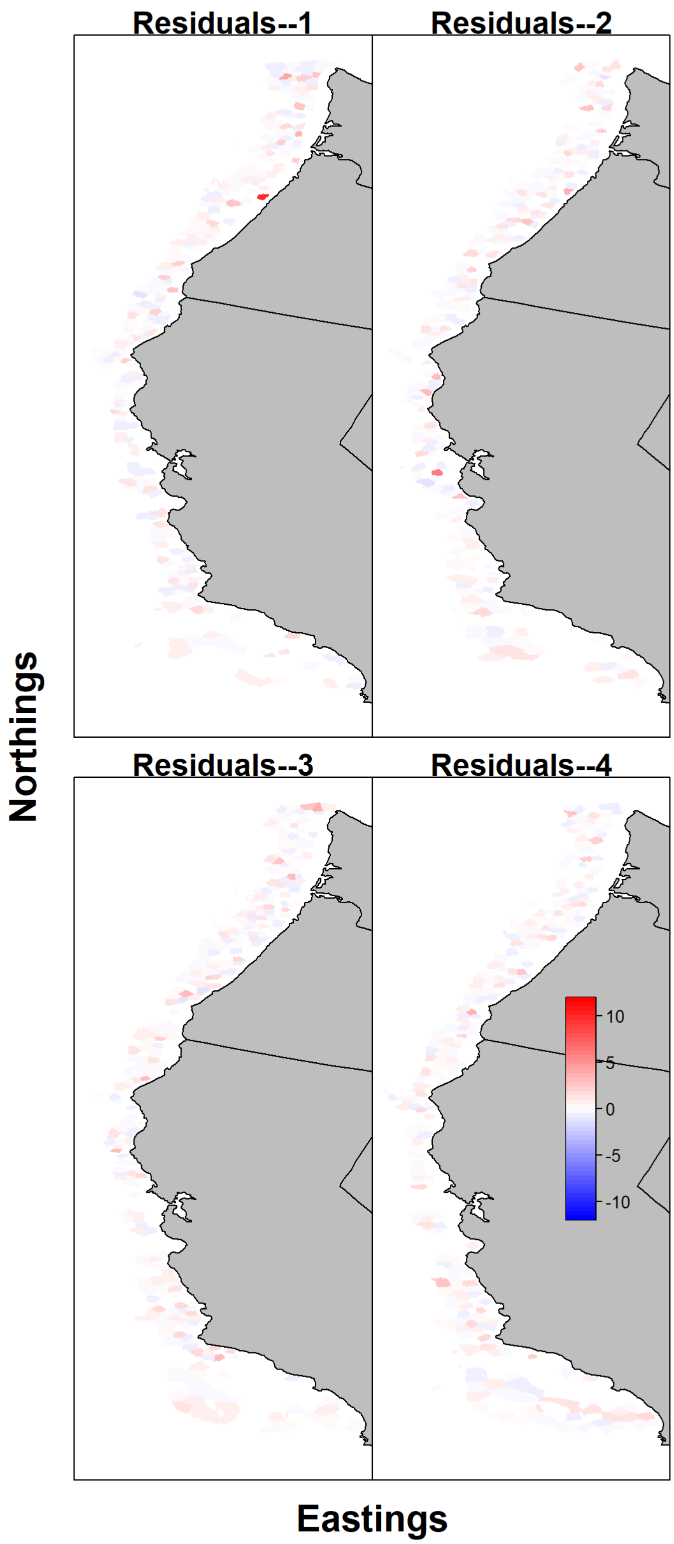


Figure 18. Pearson residuals across space and time (panels) for predicted catch rates for the West Coast Groundfish Bottom Trawl Survey; panel 1 of 4.

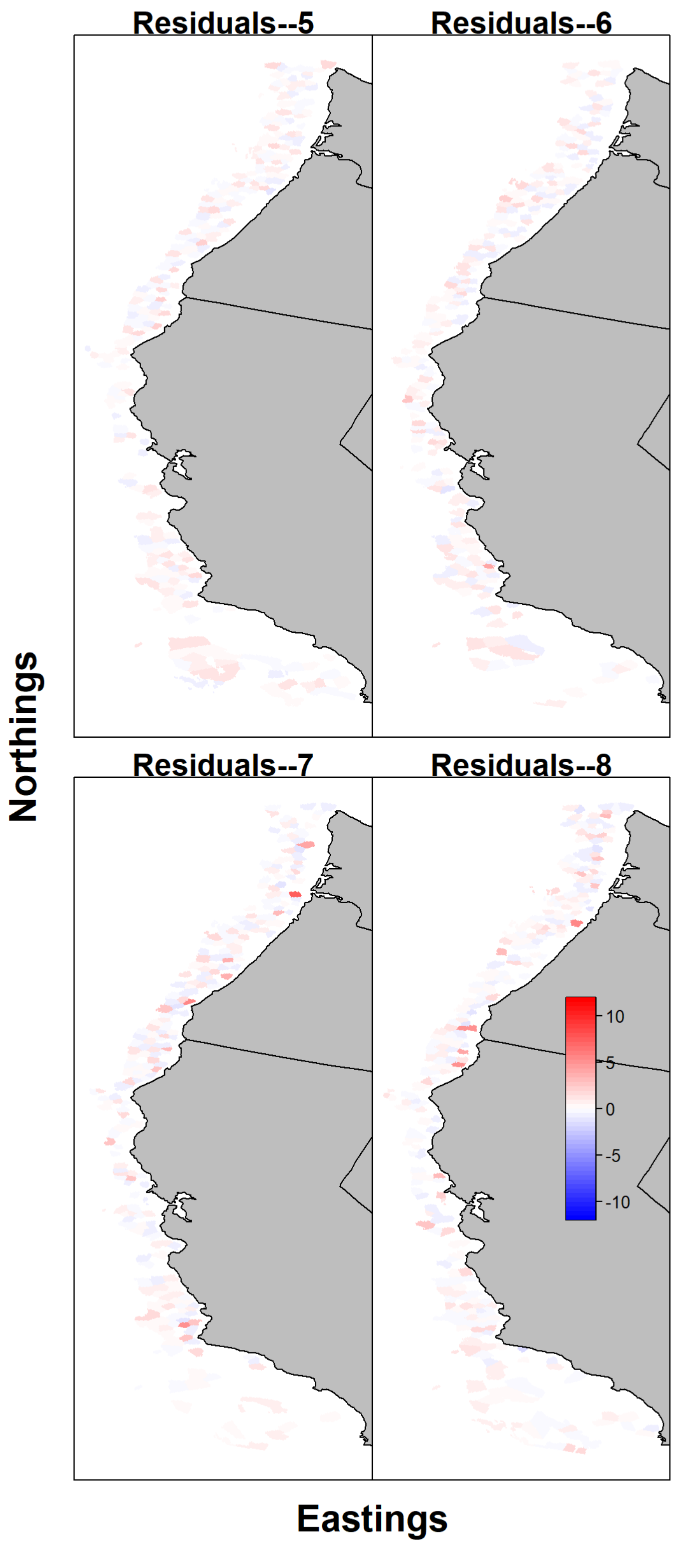


Figure 19. Pearson residuals across space and time (panels) for predicted catch rates for the West Coast Groundfish Bottom Trawl Survey; panel 2 of 4.

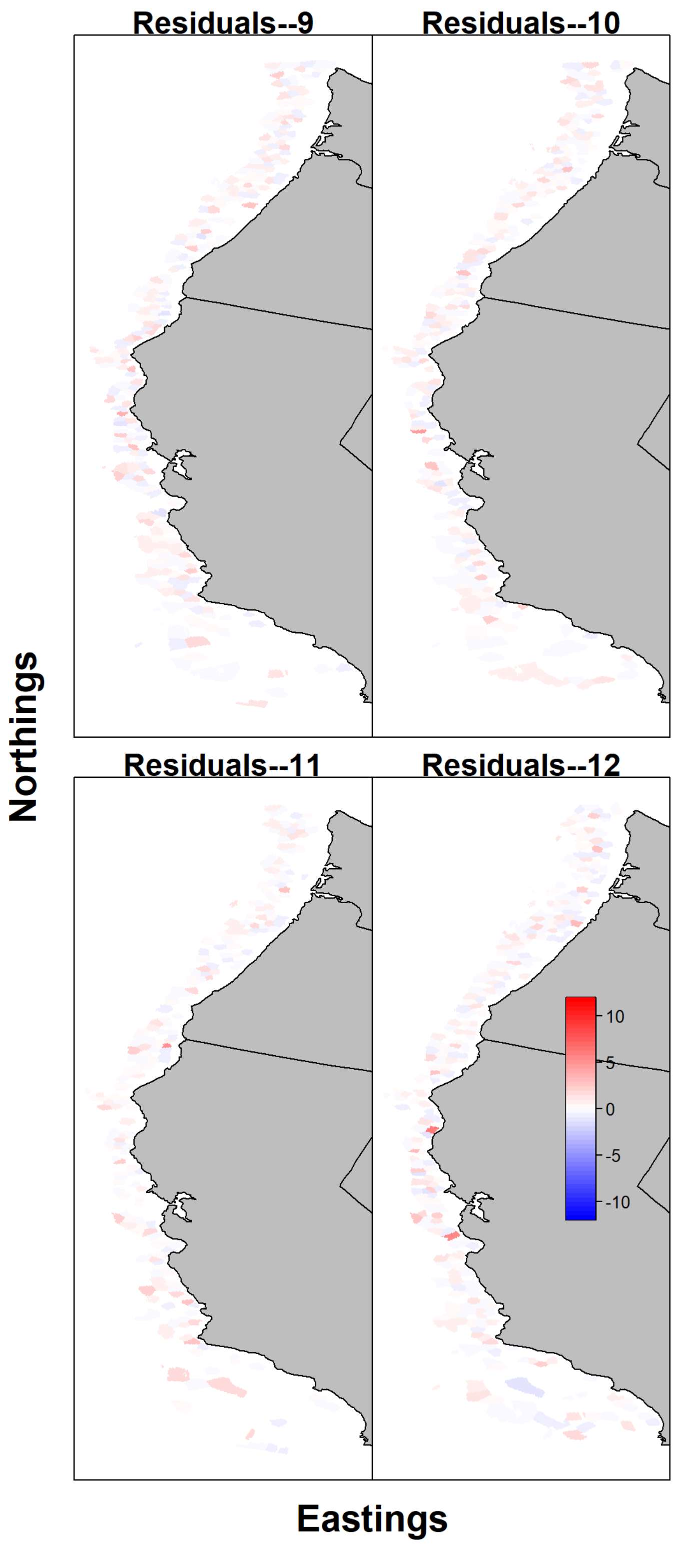


Figure 20. Pearson residuals across space and time (panels) for predicted catch rates for the West Coast Groundfish Bottom Trawl Survey; panel 3 of 4.

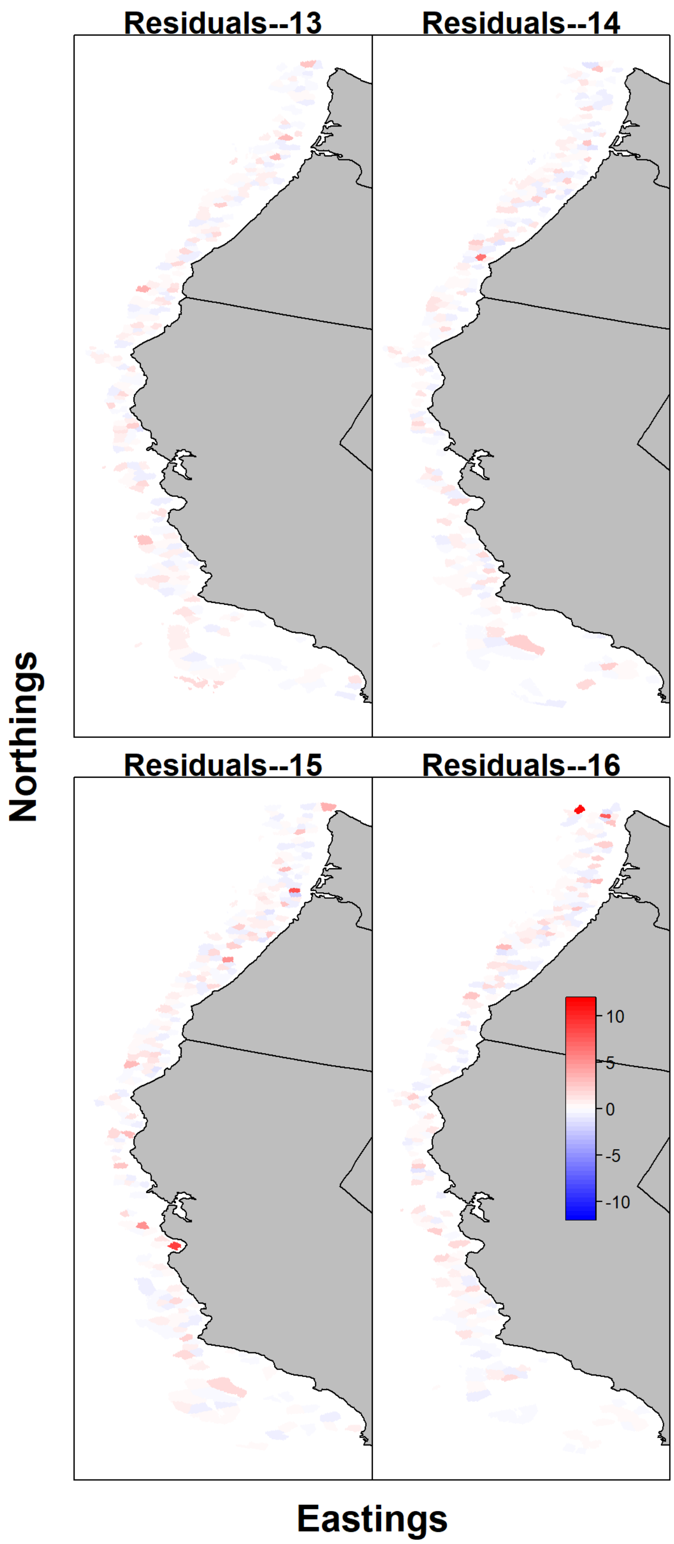


Figure 21. Pearson residuals across space and time (panels) for predicted catch rates for the West Coast Groundfish Bottom Trawl Survey; panel 4 of 4.

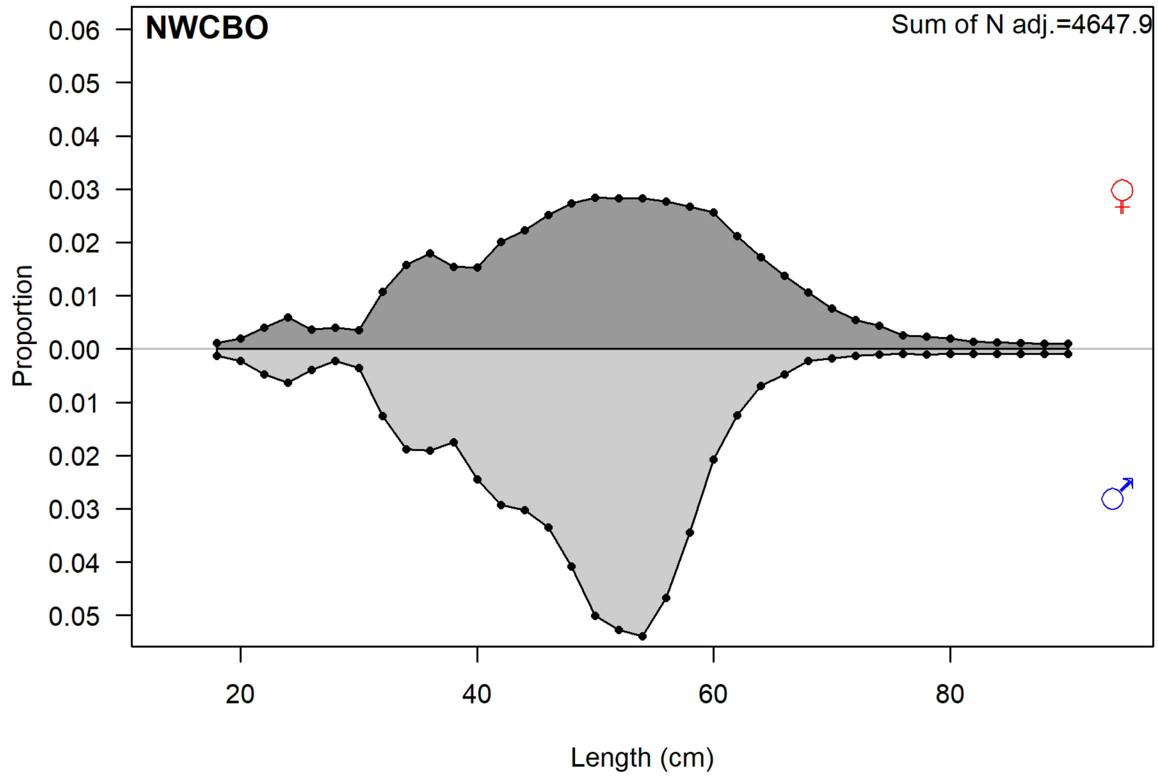


Figure 22. Length compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportions for sex-specific data.

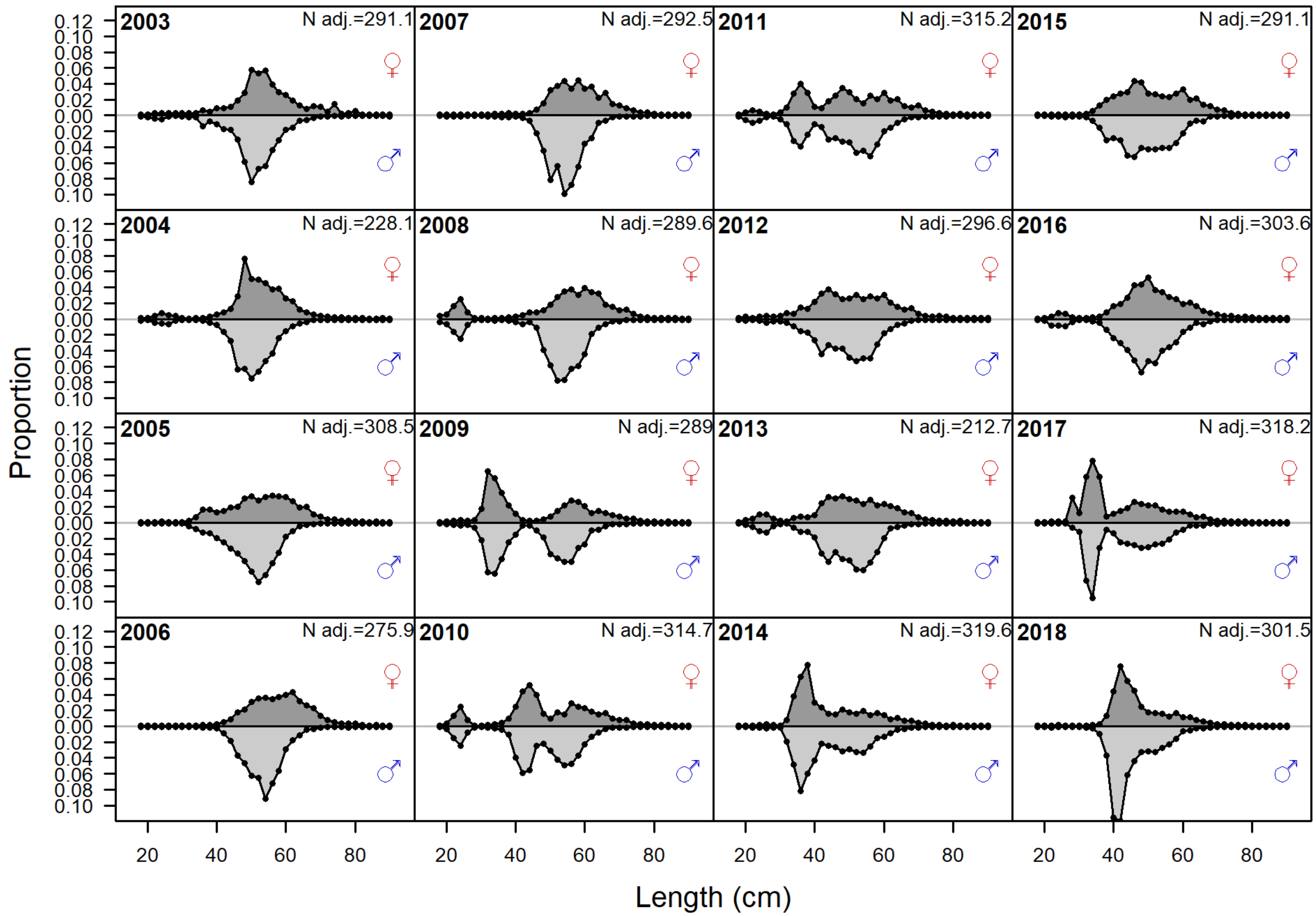


Figure 23. Year-specific (panels) length compositions from the West Coast Groundfish Bottom Trawl Survey. Input sample sizes are noted in the upper right-hand corner of each panel. Female fish are represented as positive proportions, and males are represented as negative proportions.

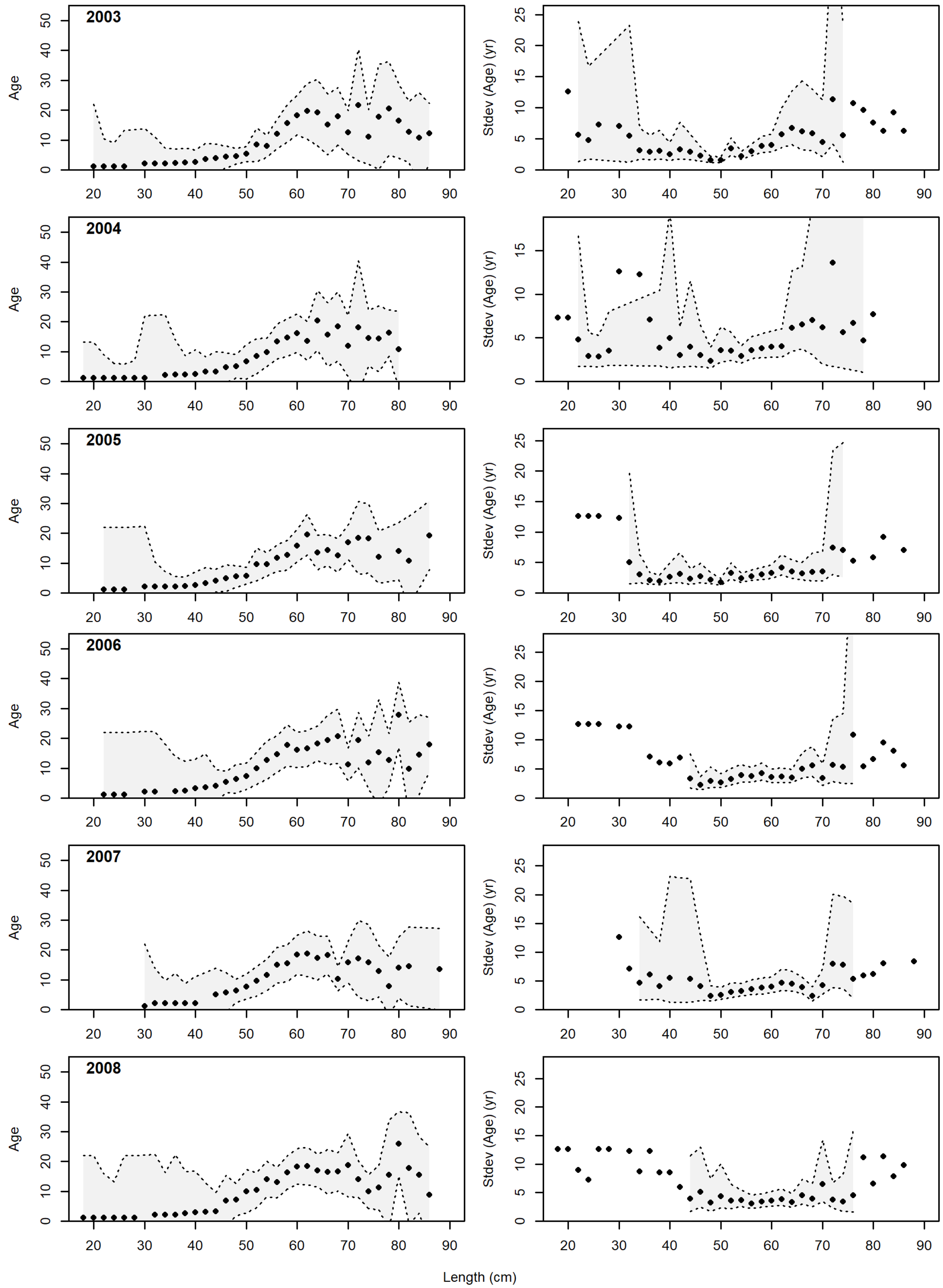


Figure 24. Year-specific conditional age-at-length data (left) and standard deviation (stdev) at age (right) from the West Coast Groundfish Bottom Trawl Survey. Shaded areas are confidence intervals based on adding 1.64 standard errors of the mean to the mean age and 90% intervals from a chi-square distribution for the stdev of mean age.

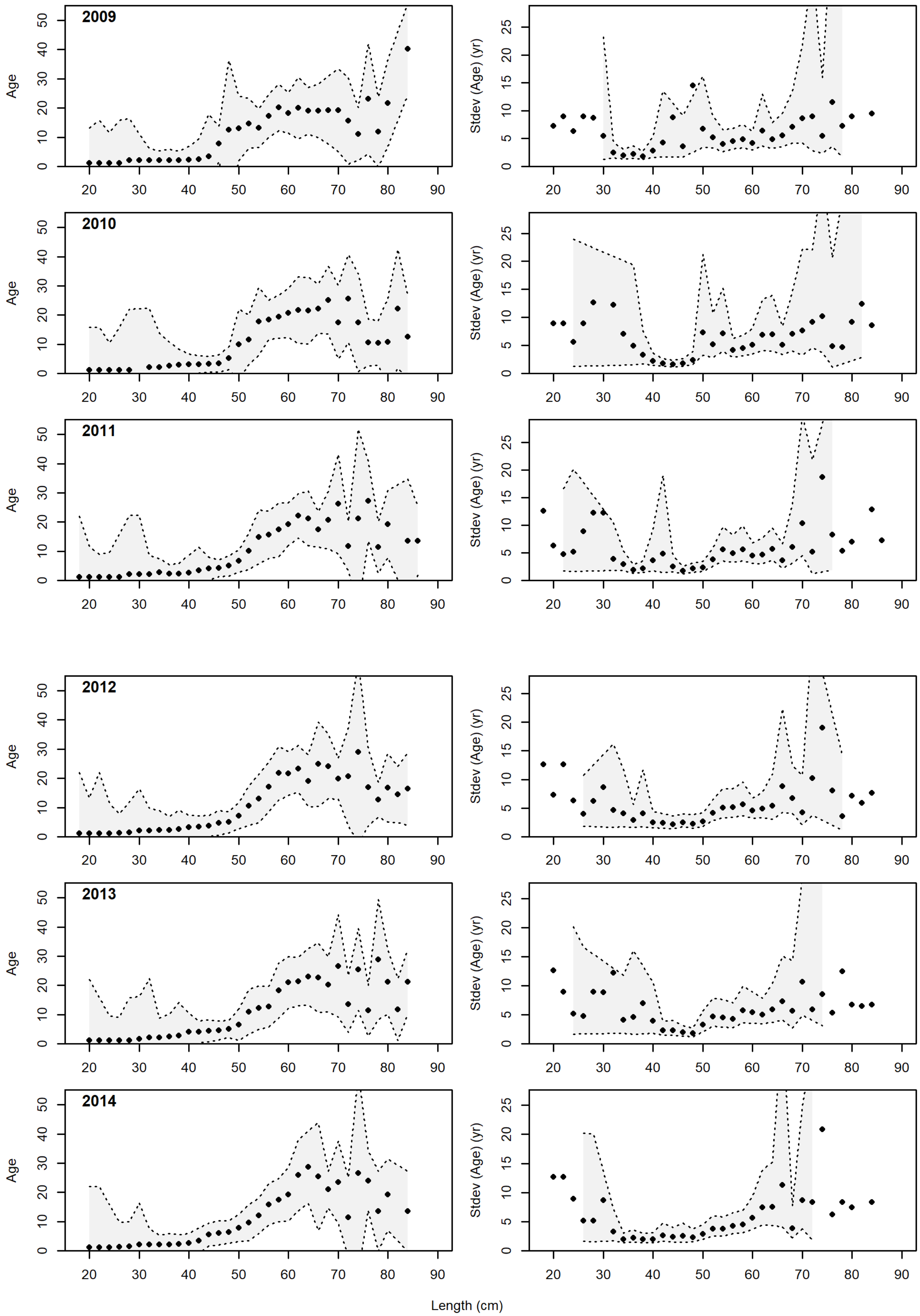


Figure 25. The continuation of Figure 24 but for more recent years.

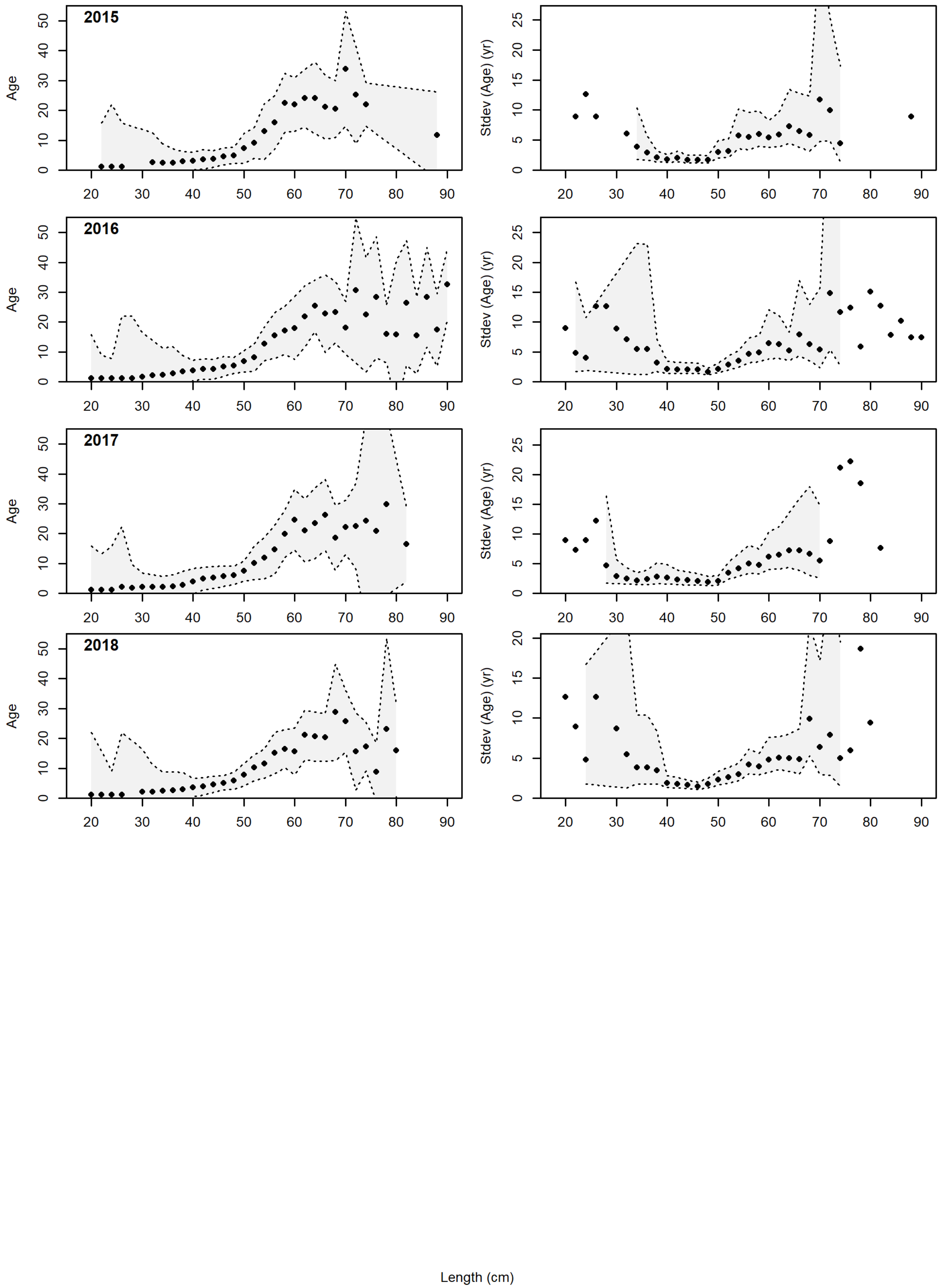


Figure 26. The continuation of Figure 24 but for the most recent years.

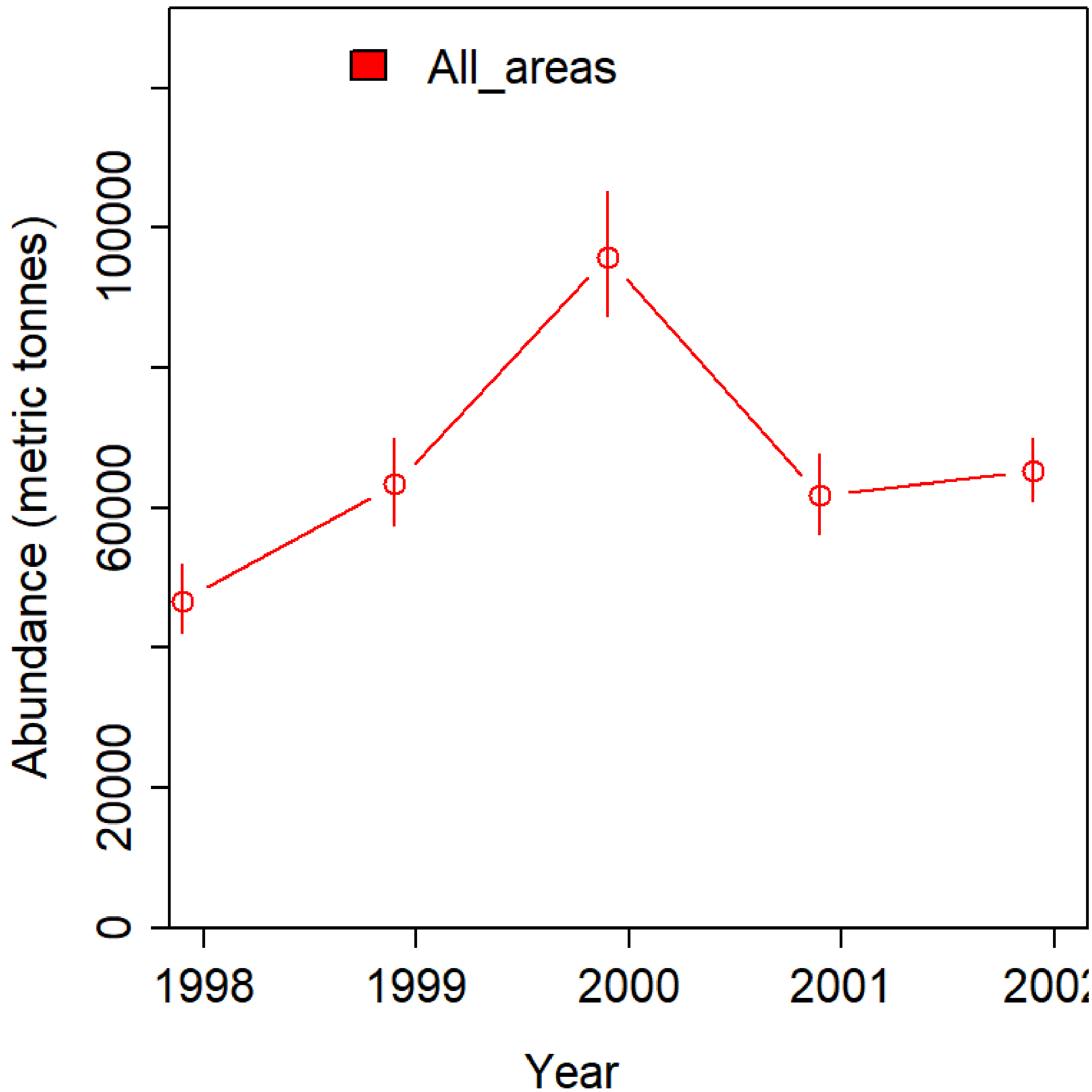


Figure 27. Estimated index of relative abundance for the Northwest Fisheries Science Center (NWFSC) Slope Survey, with 5 and 95% intervals.

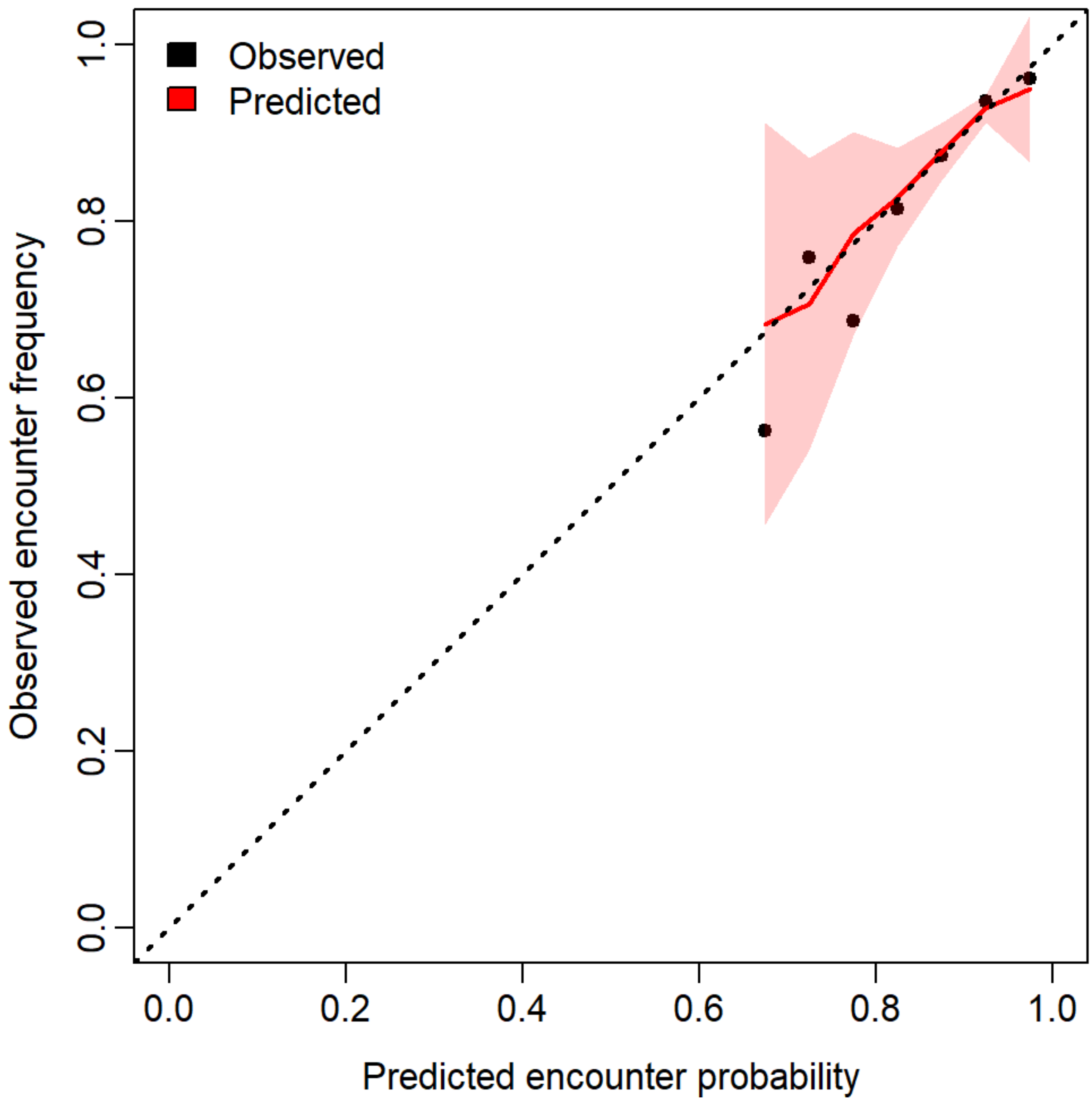


Figure 28. Observed (black points) vs. predicted (red polygon) quantiles from a gamma distribution for encounter probability when fitting a vector-autoregressive spatiotemporal model to data from the Northwest Fisheries Science Center (NWFSC) Slope Survey.

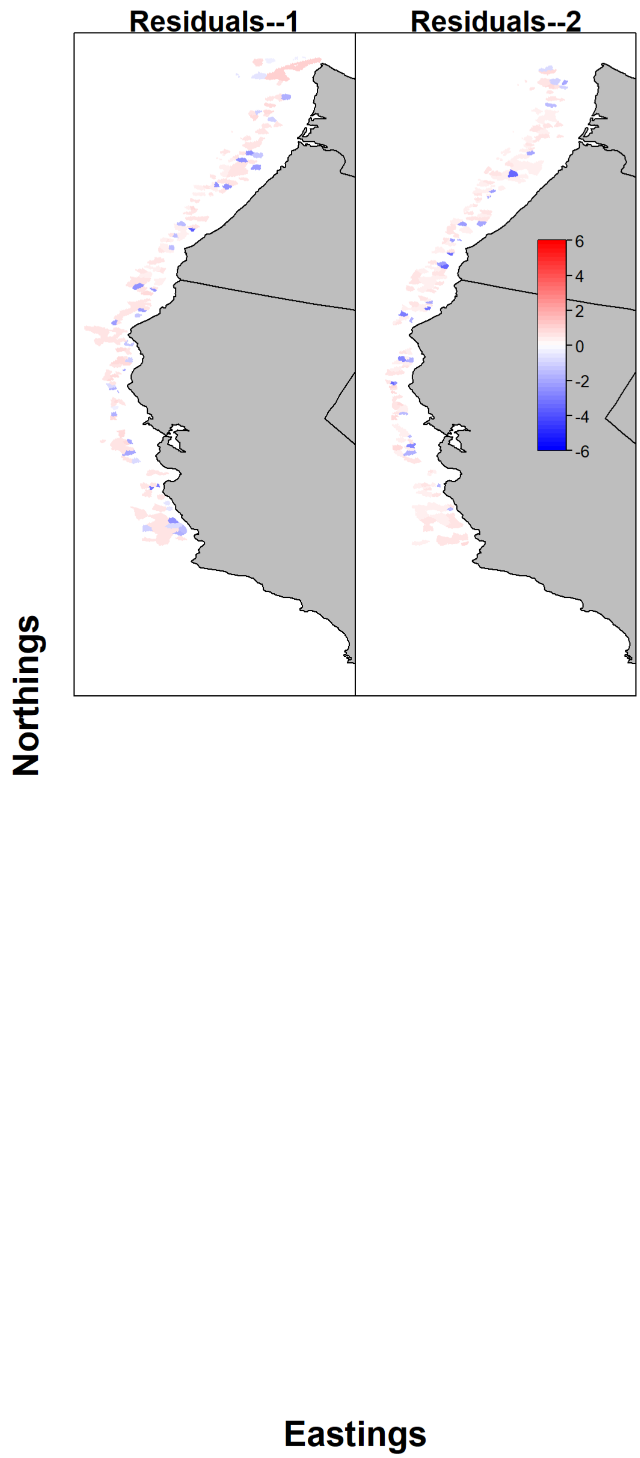


Figure 29. Pearson residuals across space and time (panels) for predicted encounter rates for the Northwest Fisheries Science Center (NWFSC) Slope Survey; panel 1 of 3.

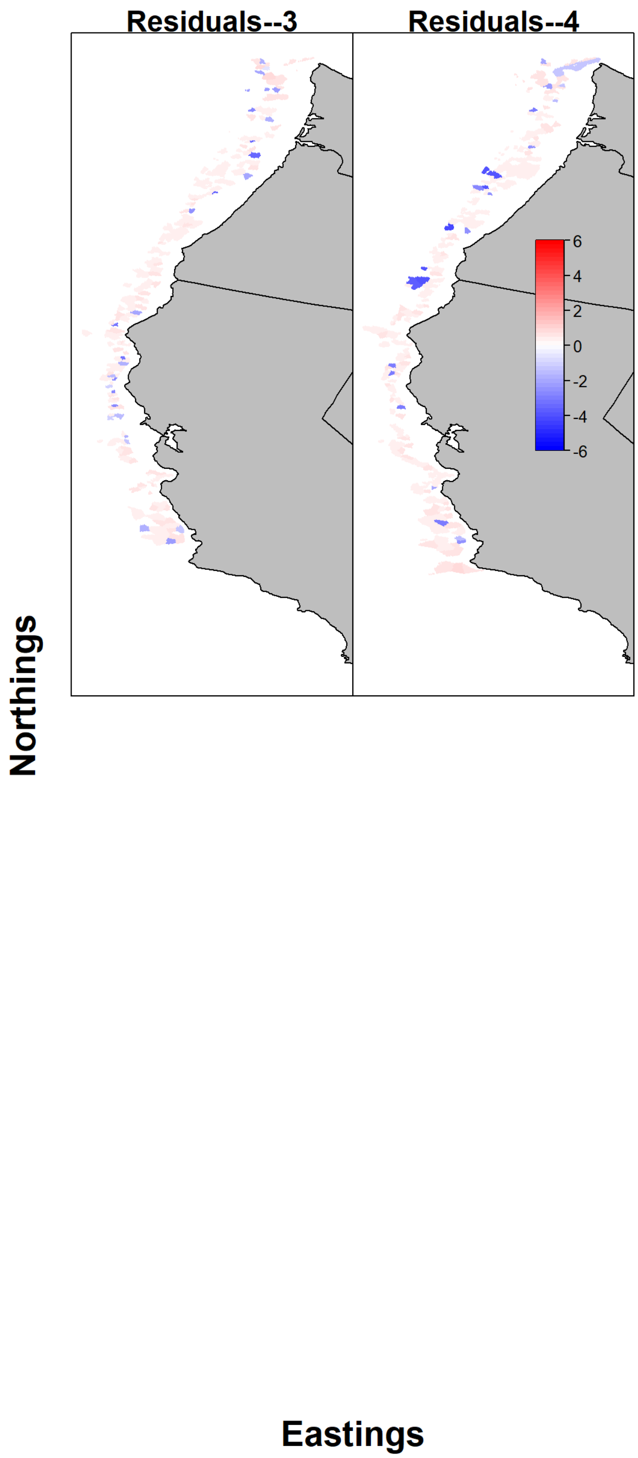


Figure 30. Pearson residuals across space and time (panels) for predicted encounter rates for the Northwest Fisheries Science Center (NWFSC) Slope Survey; panel 2 of 3.

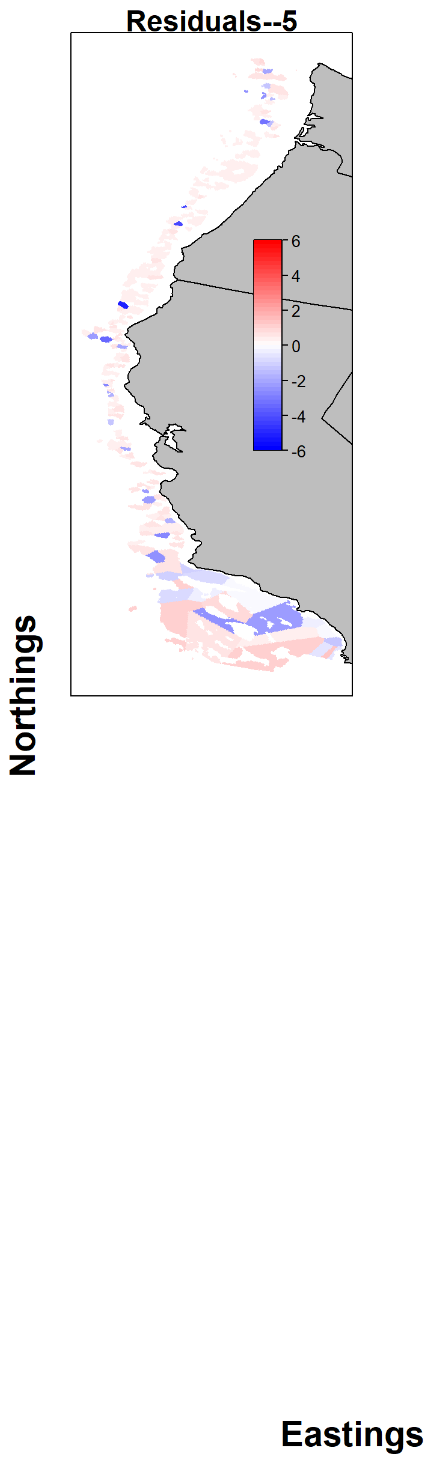


Figure 31. Pearson residuals across space and time (panels) for predicted encounter rates for the Northwest Fisheries Science Center (NWFSC) Slope Survey; panel 3 of 3.

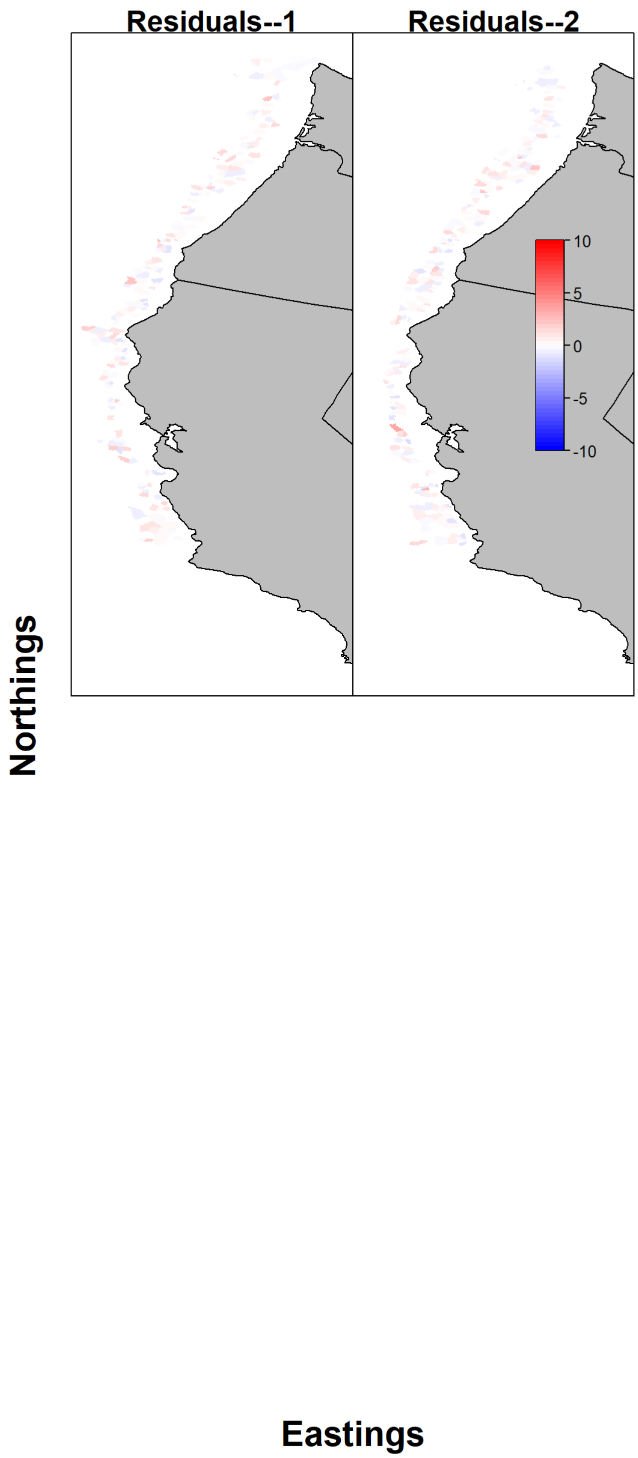


Figure 32. Pearson residuals across space and time (panels) for predicted catch rates for the Northwest Fisheries Science Center (NWFSC) Slope Survey; panel 1 of 3.

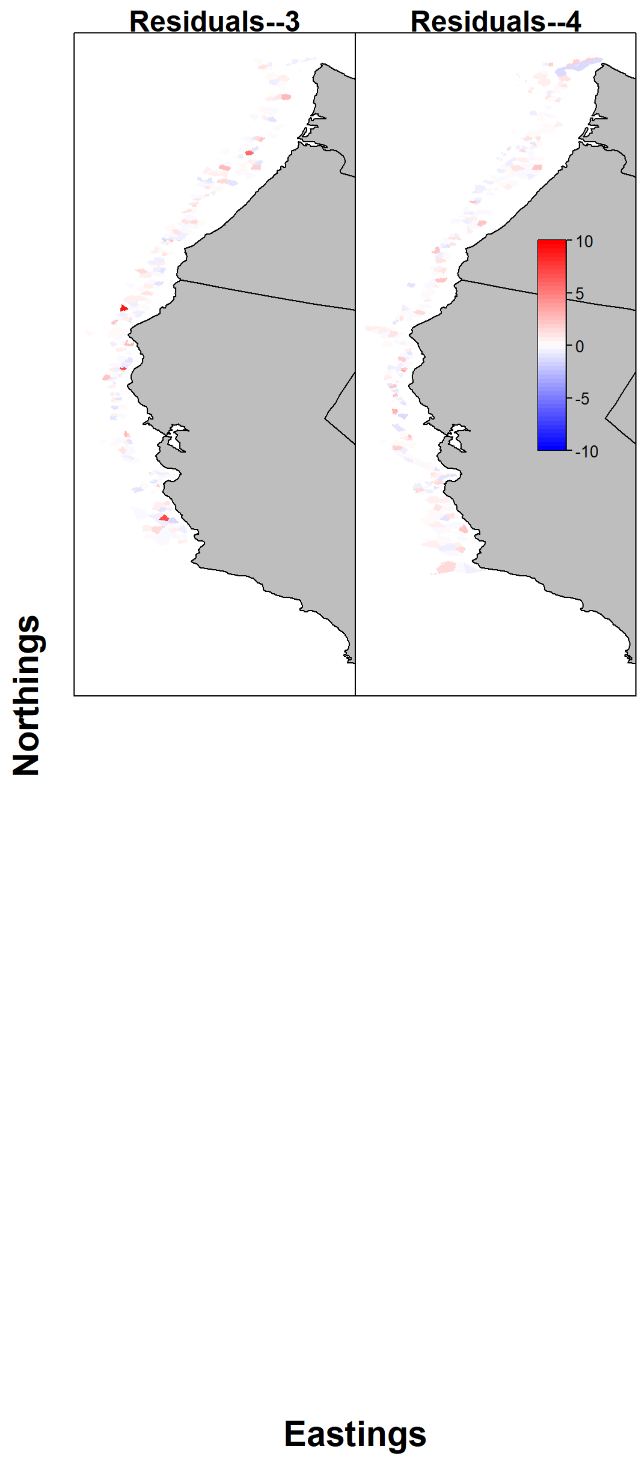


Figure 33. Pearson residuals across space and time (panels) for predicted catch rates for the Northwest Fisheries Science Center (NWFSC) Slope Survey; panel 2 of 3.

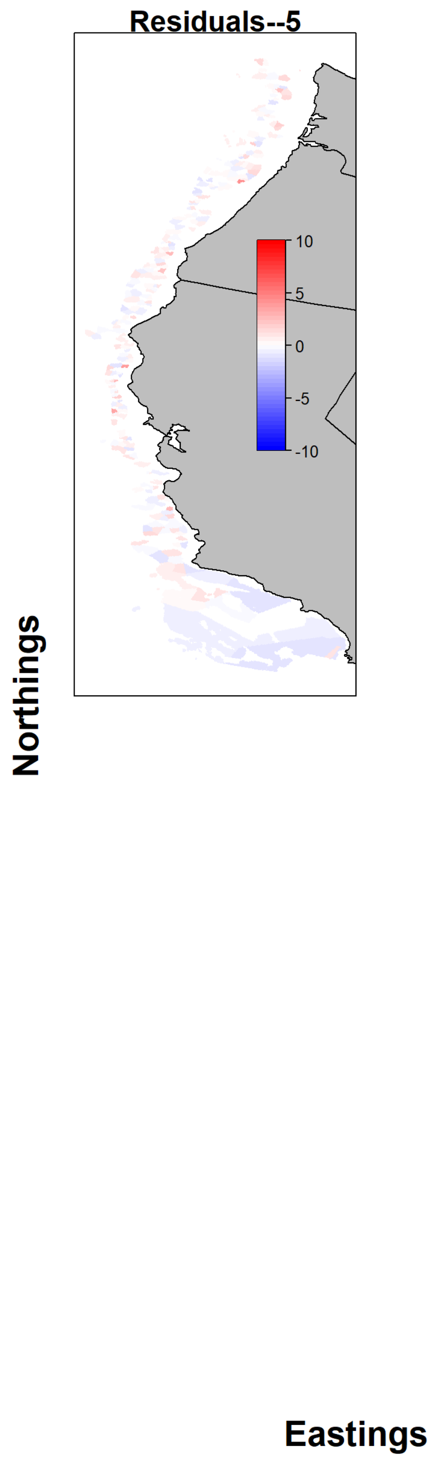


Figure 34. Pearson residuals across space and time (panels) for predicted catch rates for the Northwest Fisheries Science Center (NWFSC) Slope Survey; panel 3 of 3.

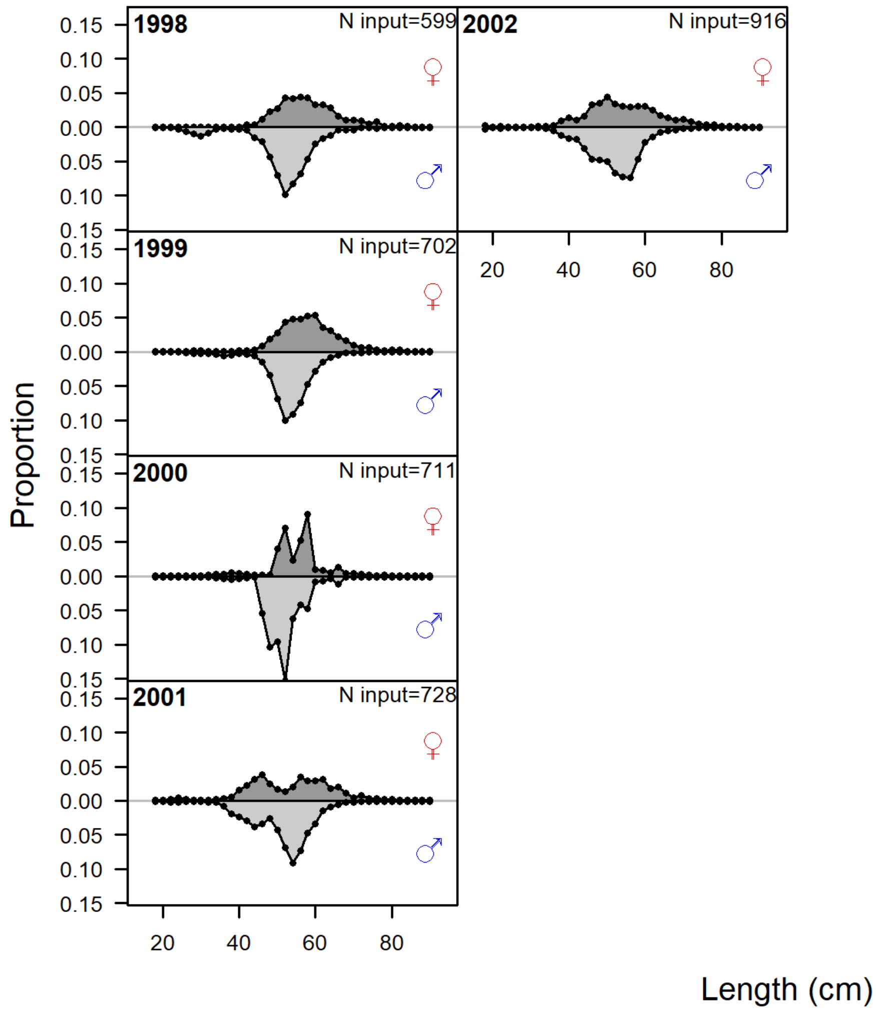


Figure 35. Year-specific (panels) length compositions from the Northwest Fisheries Science Center Slope Survey. Input sample sizes are noted in the upper right corner and year in the left corner. Female fish are represented as positive proportions, and males are represented as negative proportions.

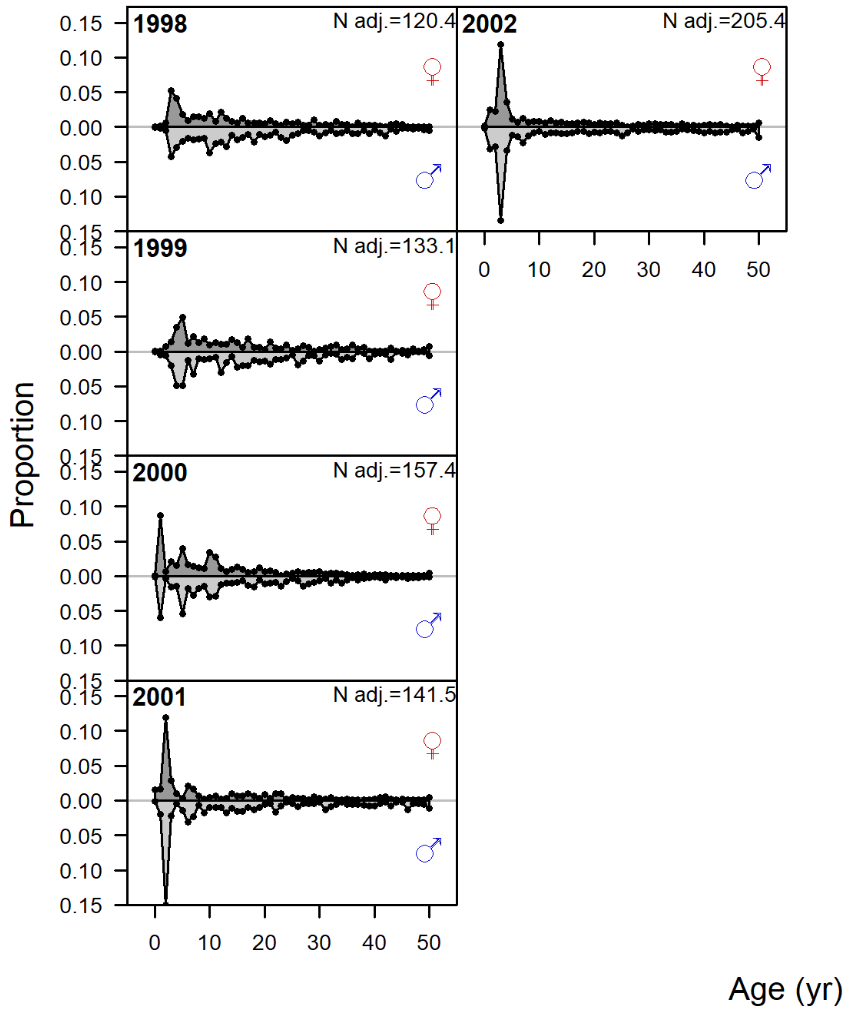


Figure 36. Marginal age compositions from the Northwest Fisheries Science Center Slope Survey. See Figure 35 for more information.

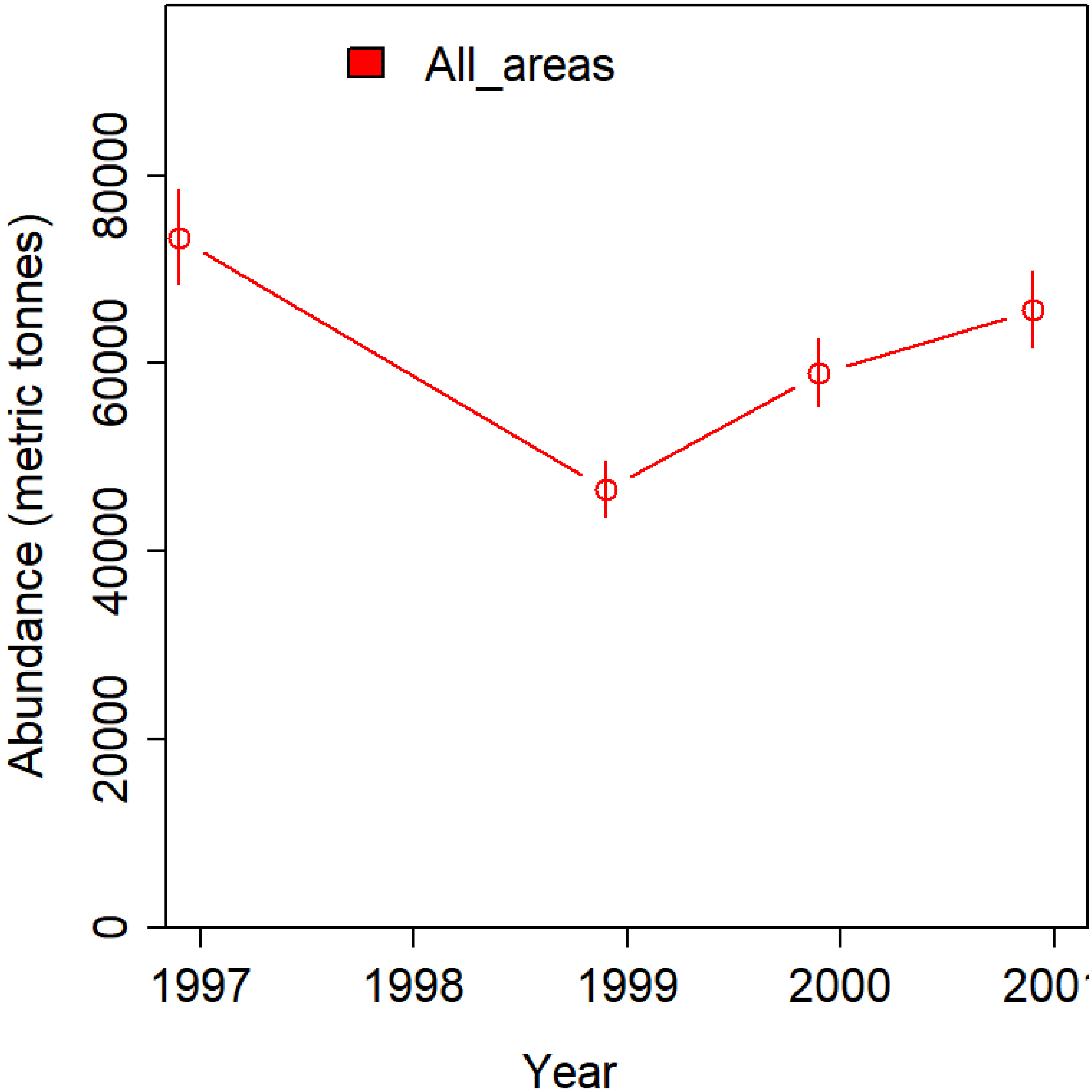


Figure 37. Estimated index of relative abundance for the Alaska Fisheries Science Center (AFSC) Slope Survey, with 5 and 95% intervals.

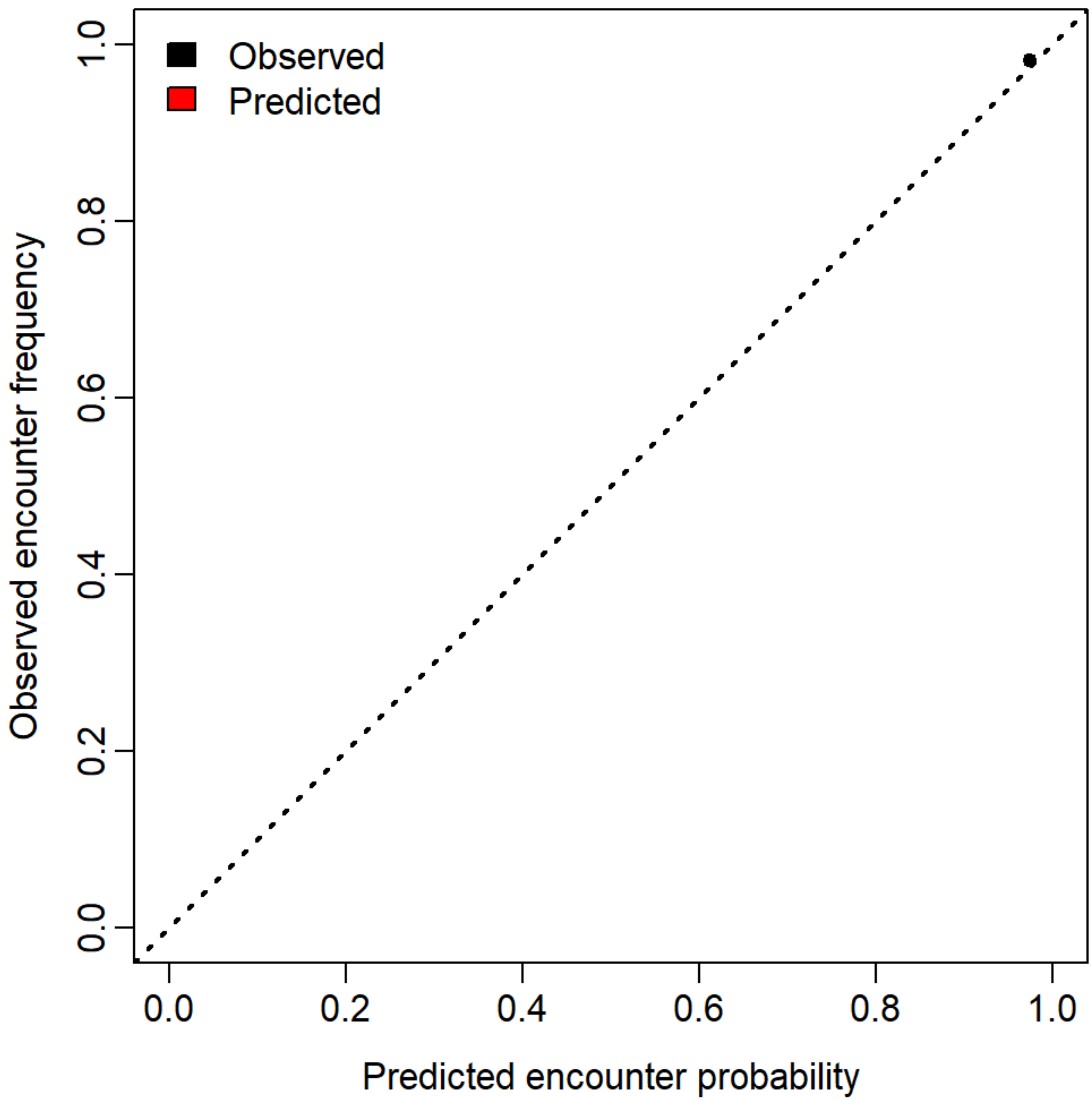


Figure 38. Observed (black points) vs. predicted (red polygon) quantiles from a gamma distribution for encounter probability when fitting a vector-autoregressive spatiotemporal model to data from the Alaska Fisheries Science Center (AFSC) Slope Survey.

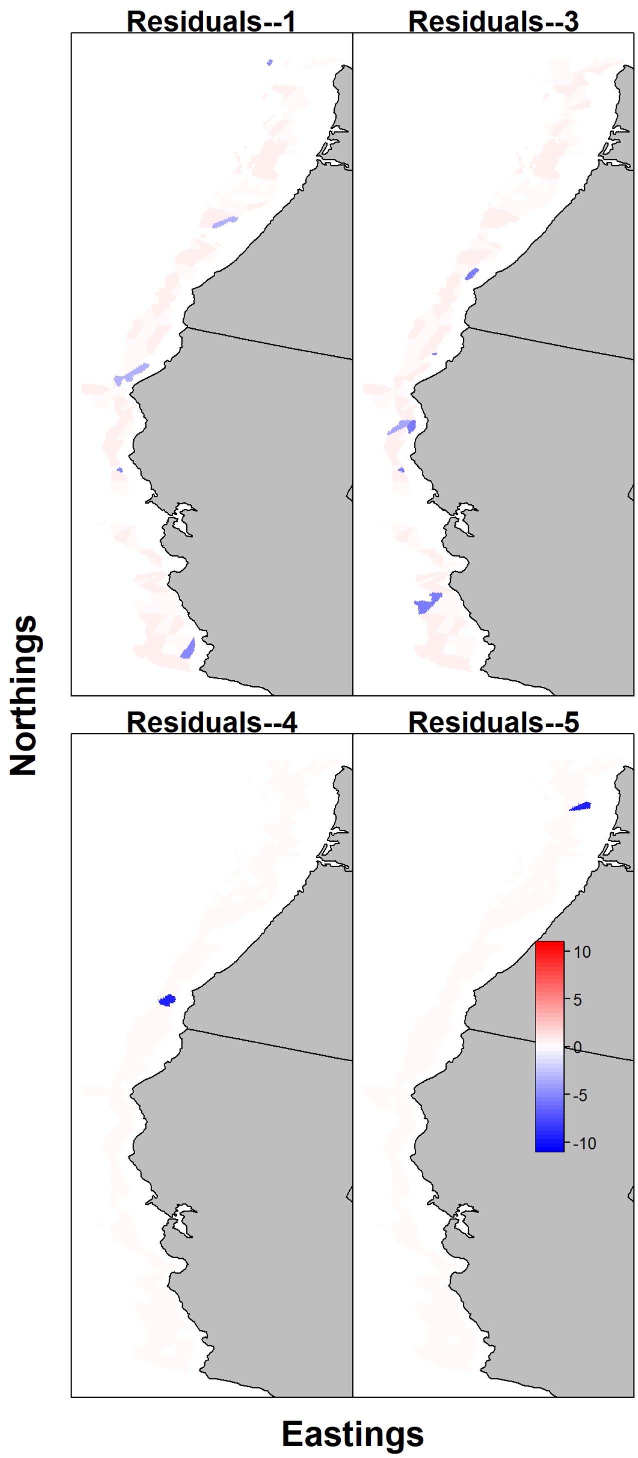


Figure 39. Pearson residuals across space and time (panels) for predicted encounter rates for the Alaska Fisheries Science Center (AFSC) Slope Survey.

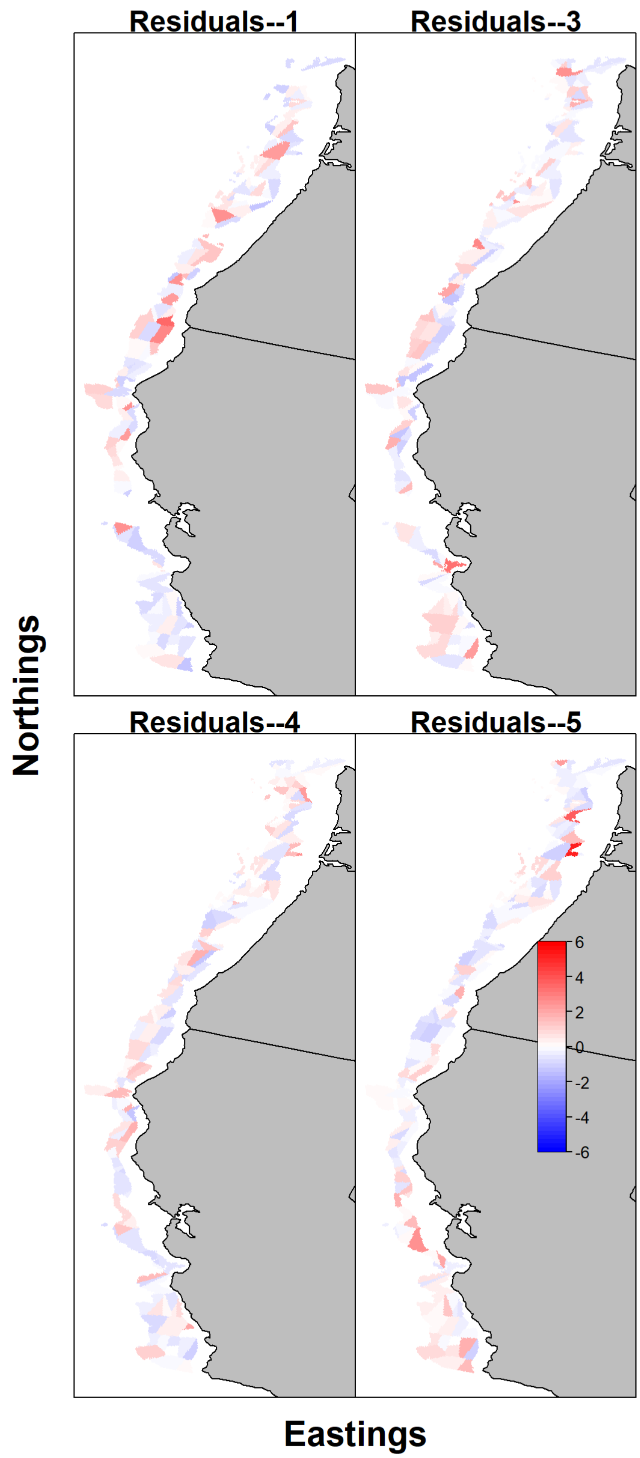


Figure 40. Pearson residuals across space and time (panels) for predicted catch rates for the Alaska Fisheries Science Center (AFSC) Slope Survey.

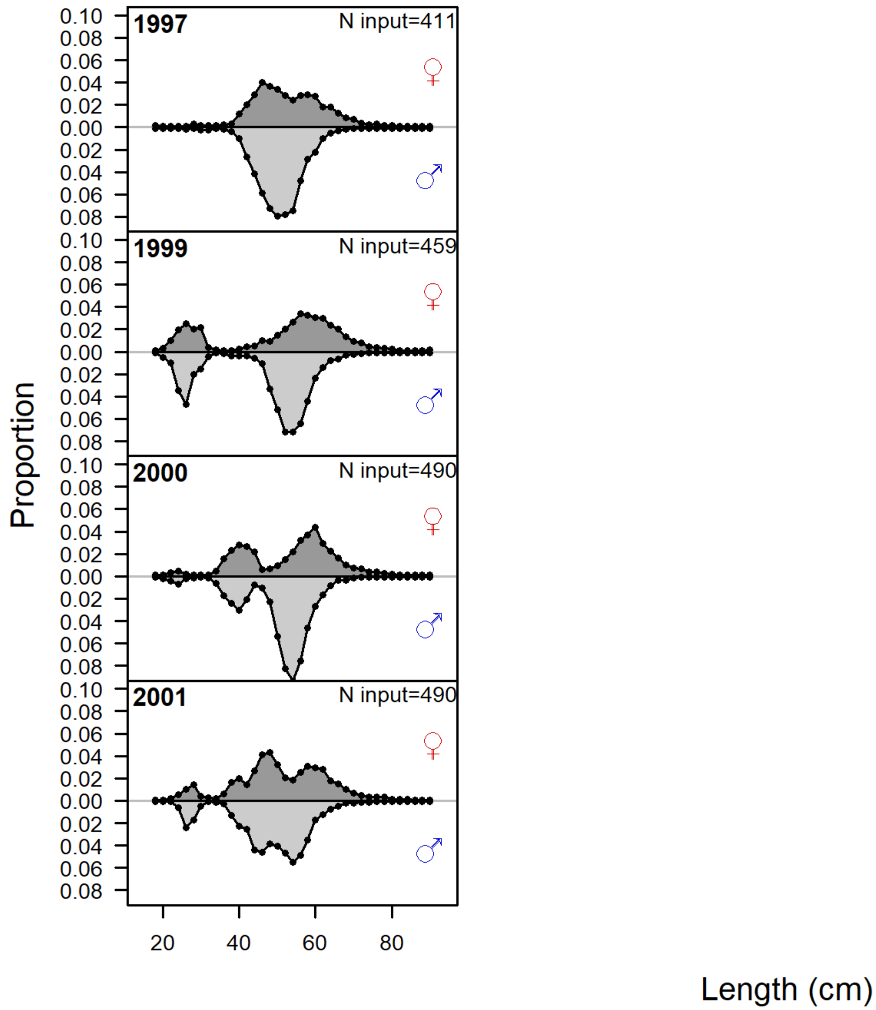


Figure 41. Year-specific (panels) length compositions from the Alaska Fisheries Science Center Slope Survey. Input sample sizes are noted in the upper right corner and year in the left corner. Female fish are represented as positive proportions, and males are represented as negative proportions.

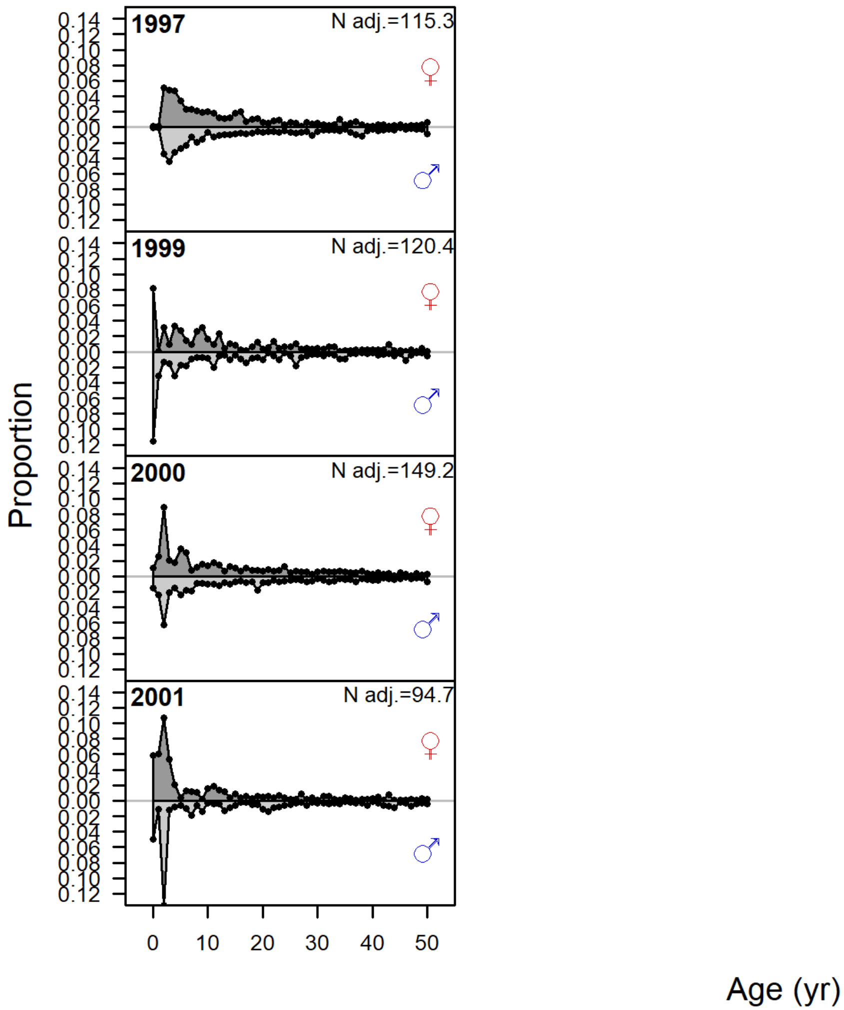


Figure 42. Marginal age compositions from the Alaska Fisheries Science Center Slope Survey. See Figure 41 for more information.

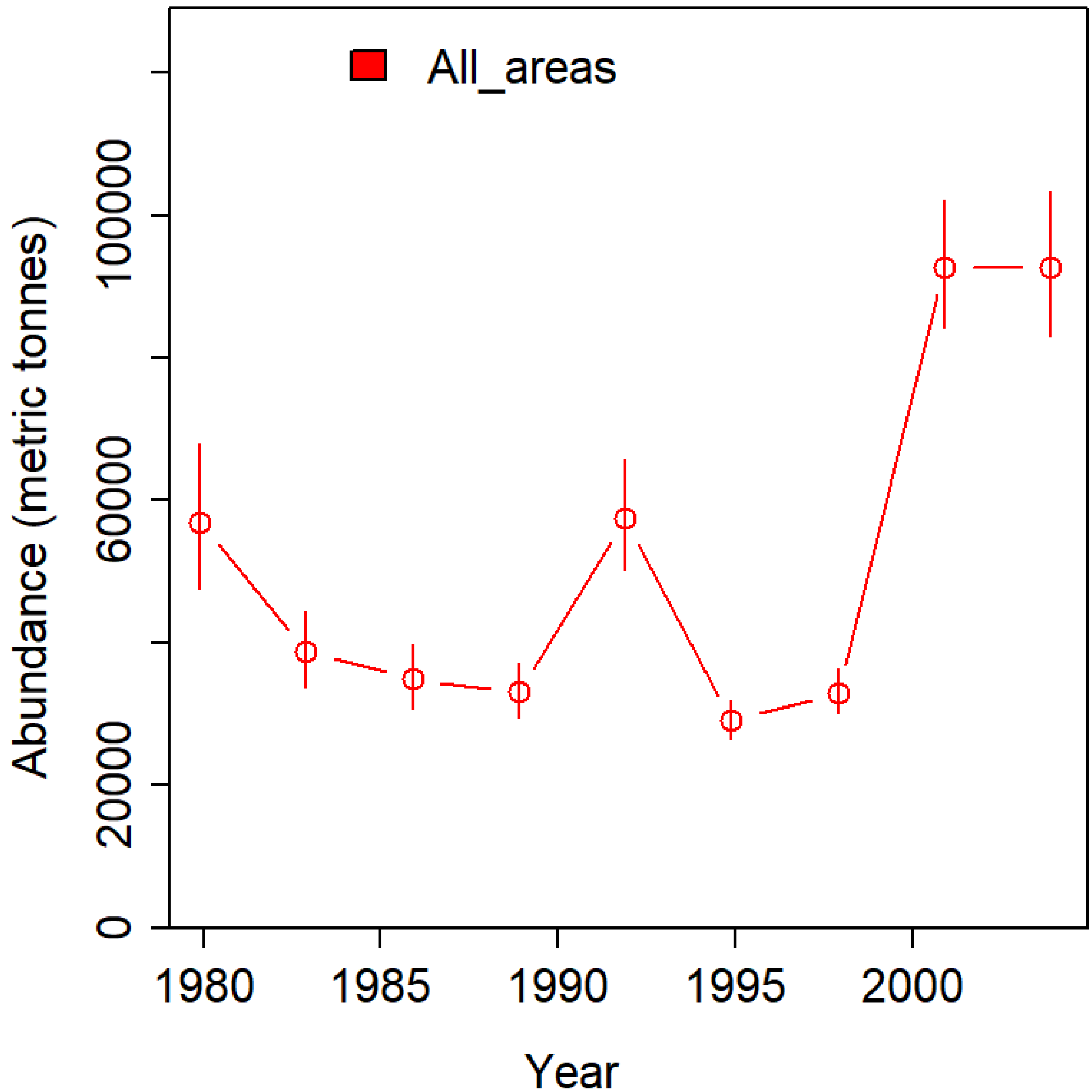


Figure 43. Estimated index of relative abundance for the Triennial Shelf Survey, with 5 and 95% intervals.

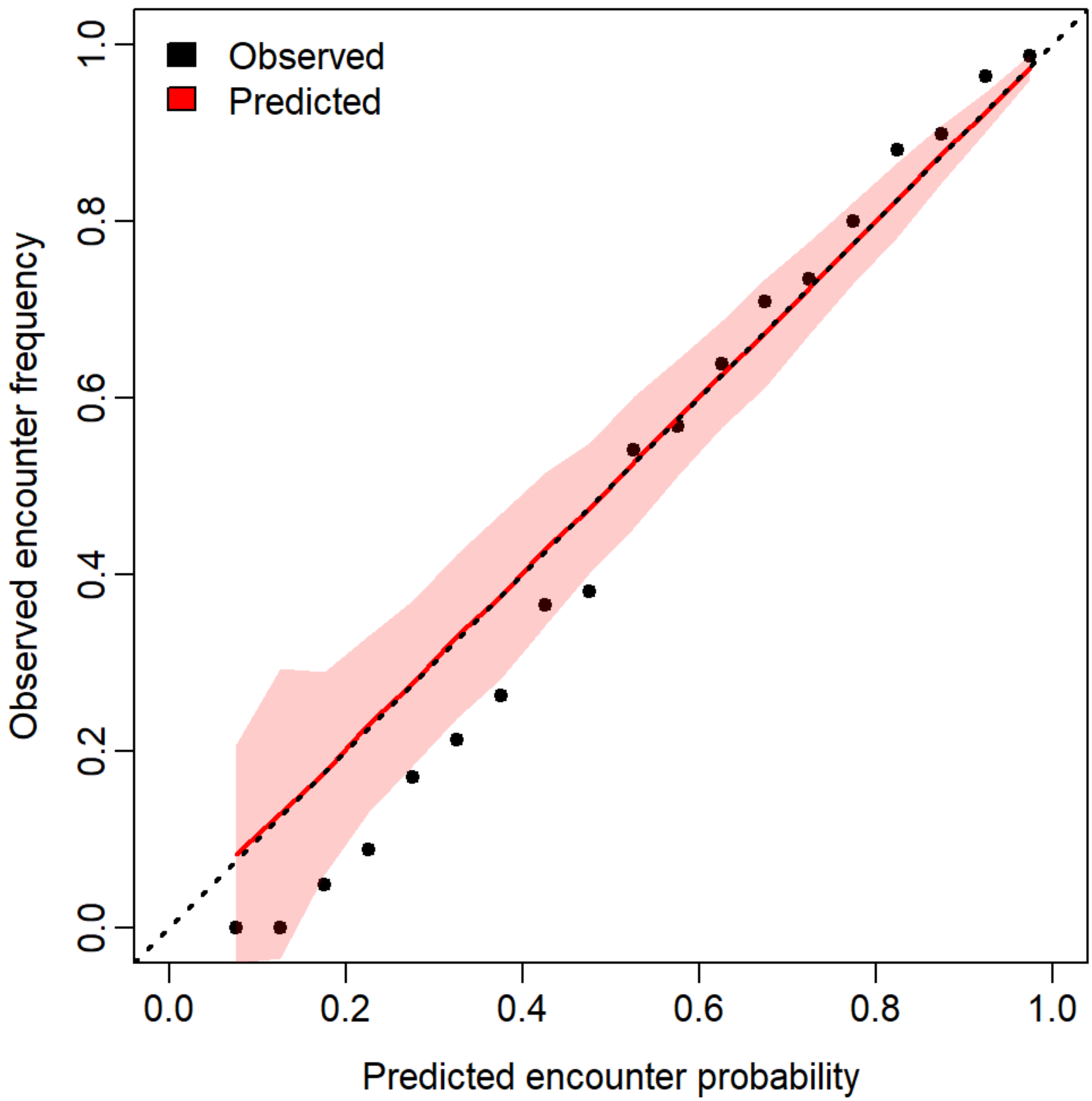


Figure 44. Observed (black points) vs. predicted (red polygon) quantiles from a gamma distribution for encounter probability when fitting a vector-autoregressive spatiotemporal model to data from the Triennial Shelf Survey.

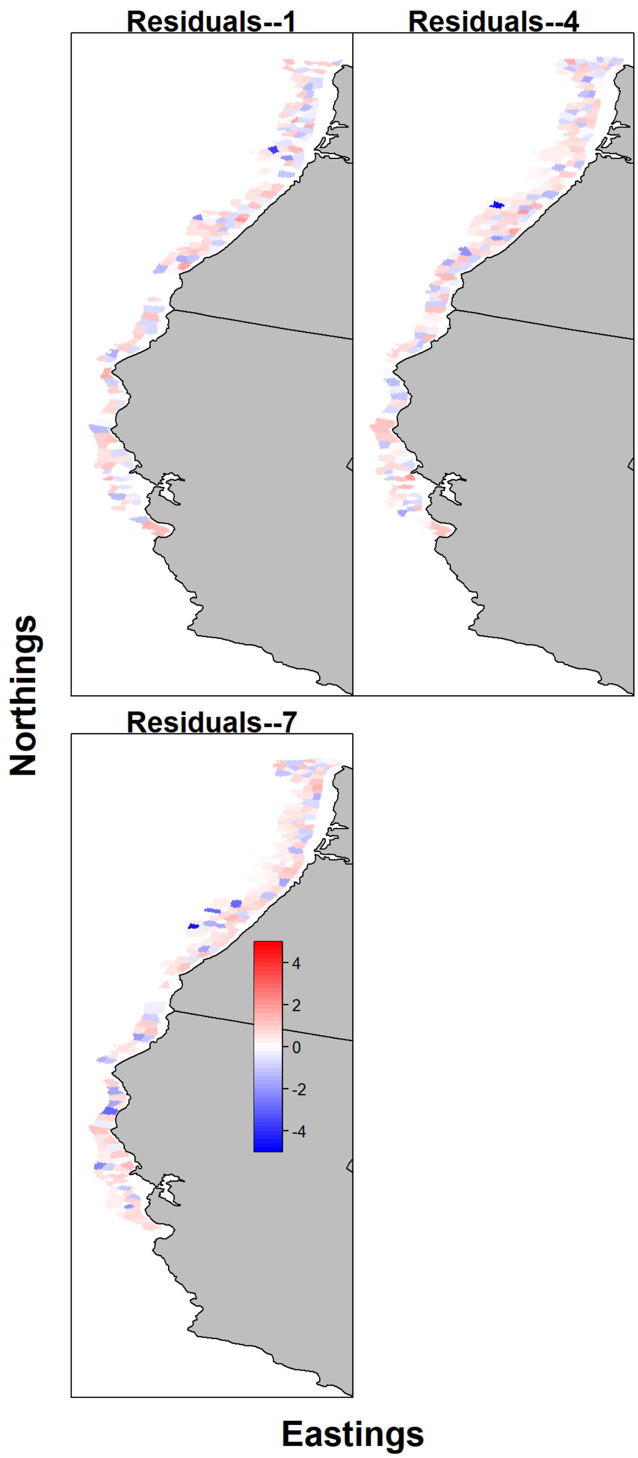


Figure 45. Pearson residuals across space and time (panels) for predicted encounter rates for the Triennial Shelf Survey; panel 1 of 2.

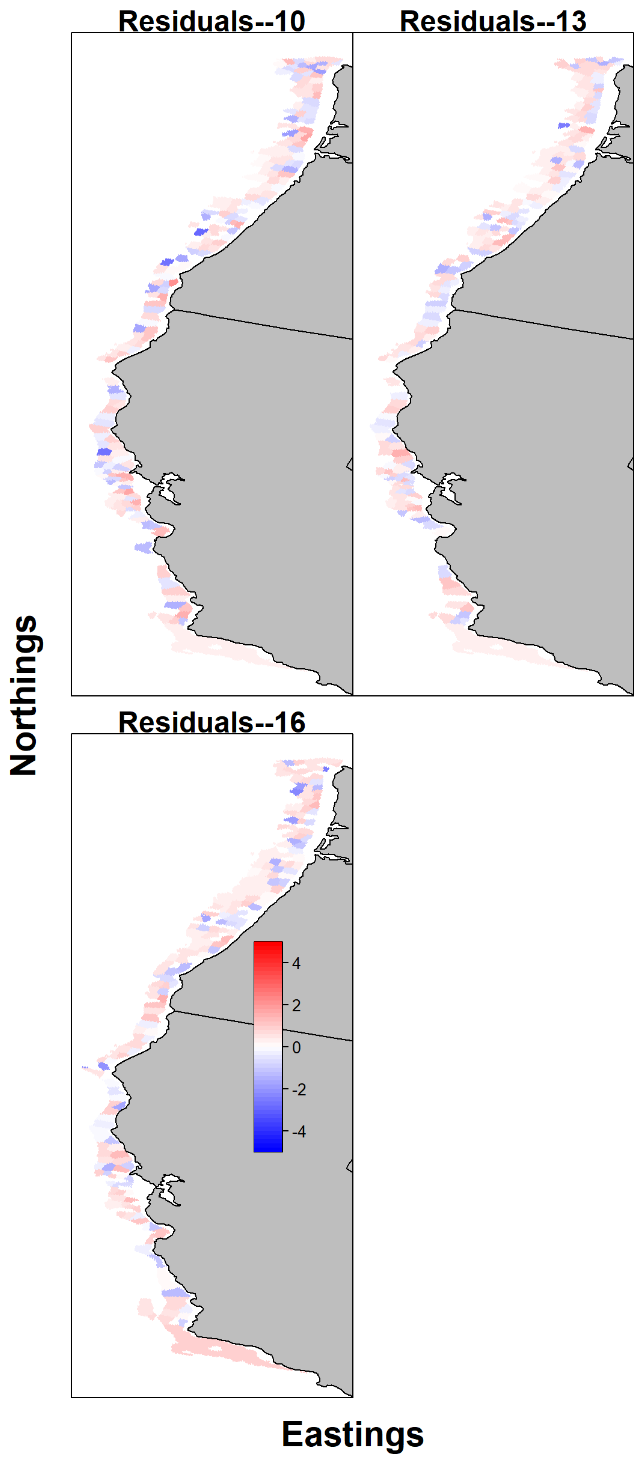


Figure 46. Pearson residuals across space and time (panels) for predicted encounter rates for the Triennial Shelf Survey; panel 2 of 2.

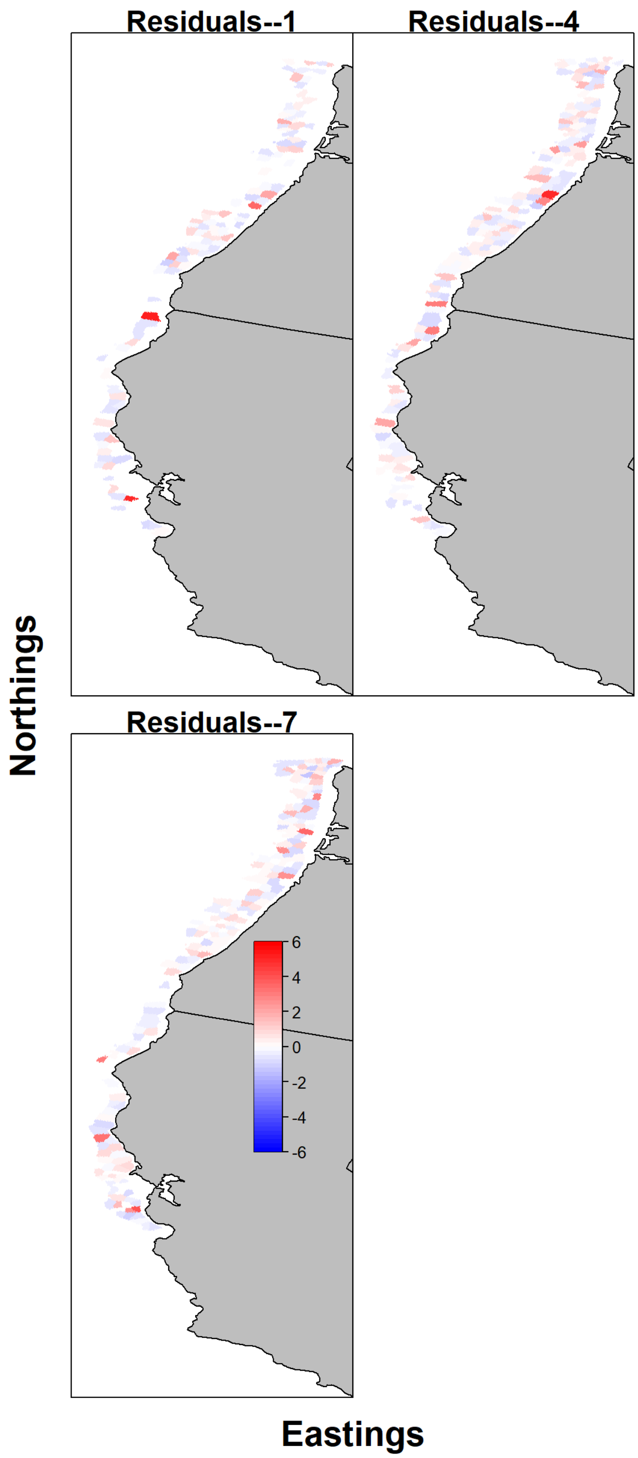


Figure 47. Pearson residuals across space and time (panels) for predicted catch rates for the Triennial Shelf Survey; panel 1 of 2.

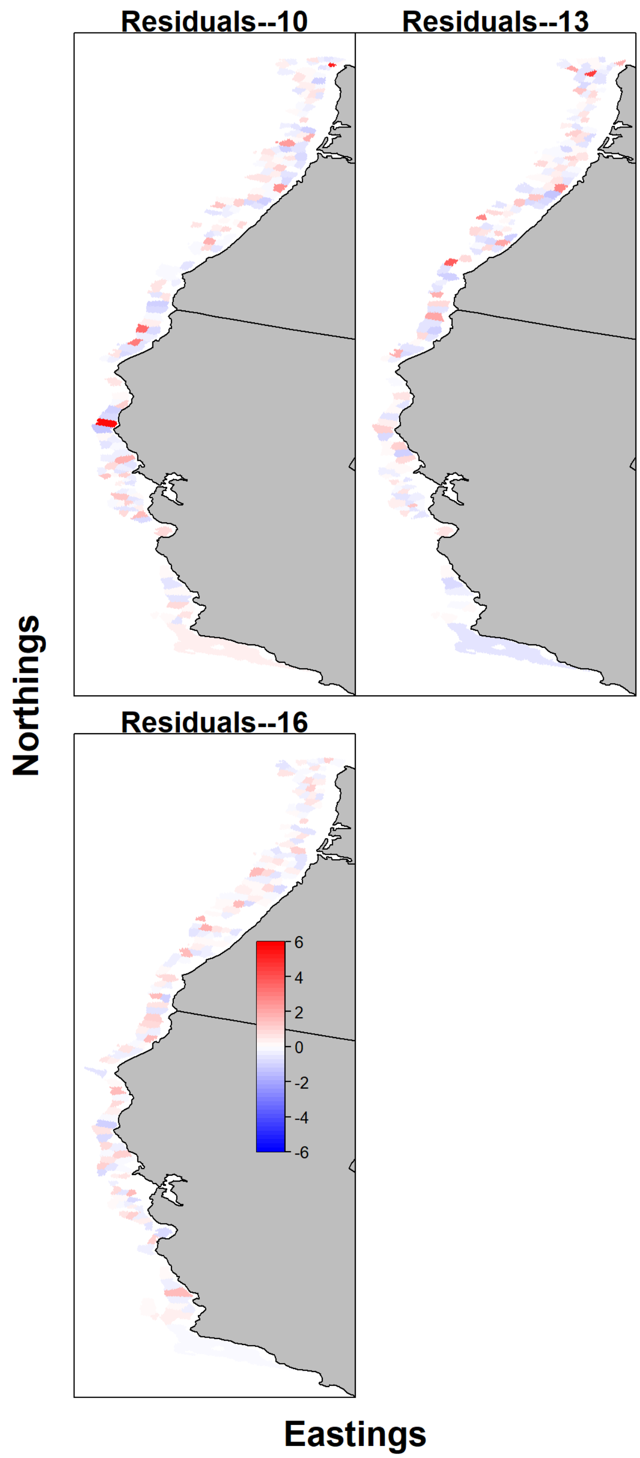


Figure 48. Pearson residuals across space and time (panels) for predicted catch rates for the Triennial Shelf Survey; panel 2 of 2.

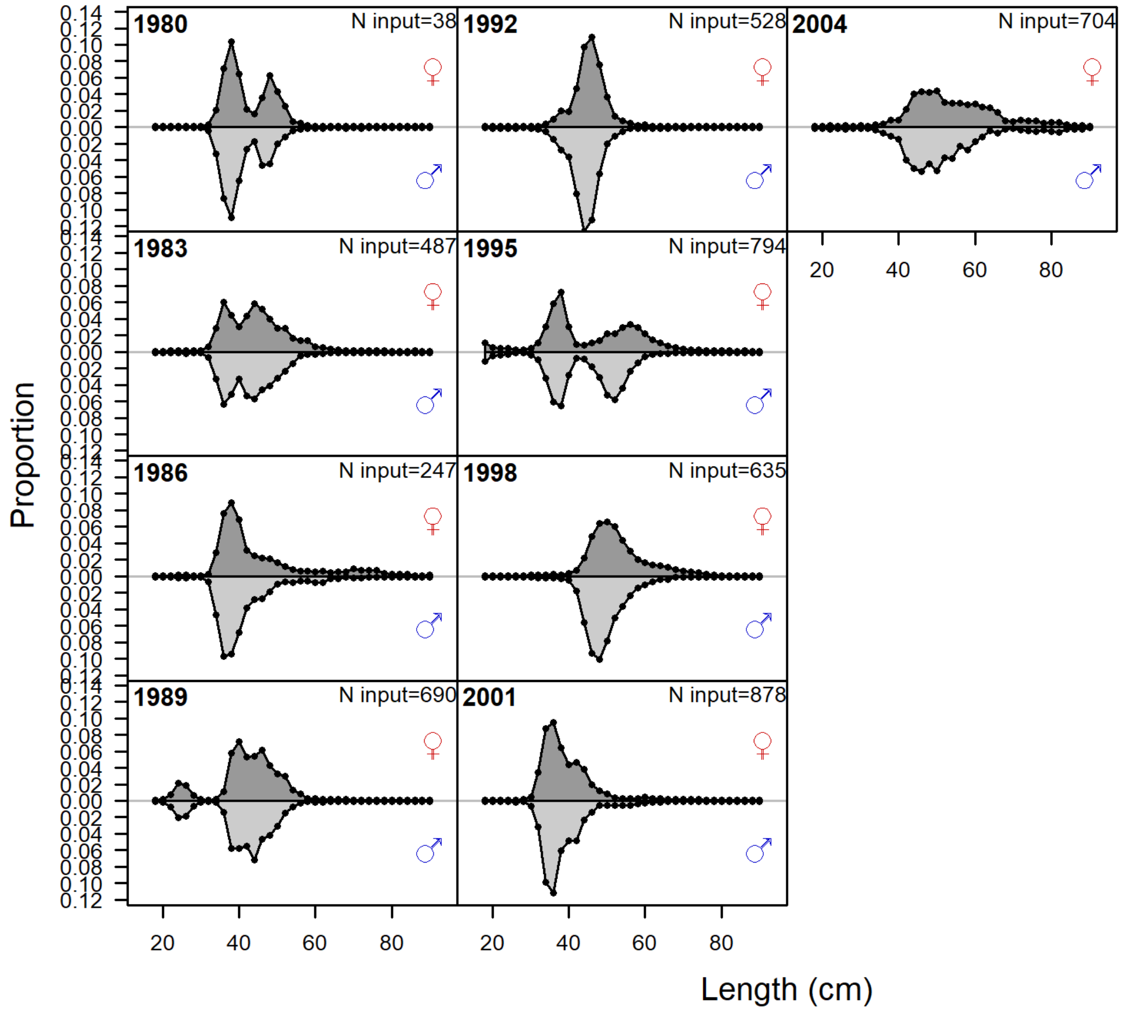


Figure 49. Year-specific (panels) length compositions from the Triennial Shelf Survey. Input sample sizes are noted in the upper right corner and year in the left corner. Female fish are represented as positive proportions, and males are represented as negative proportions.

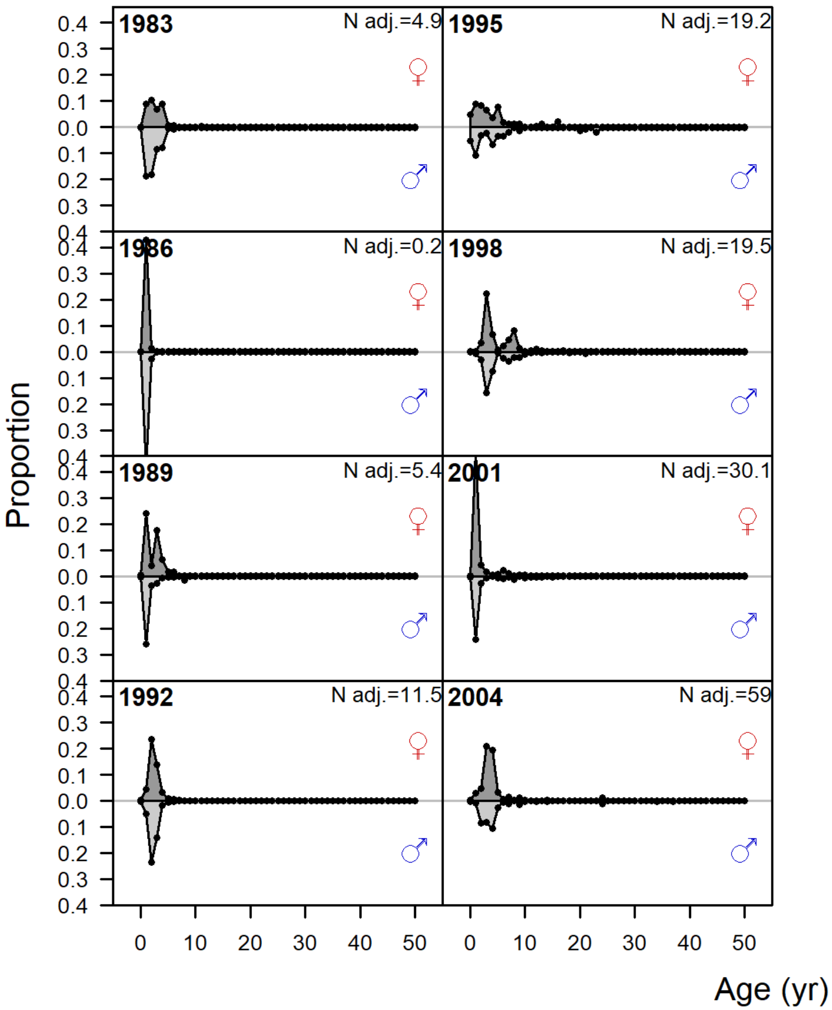


Figure 50. Marginal age compositions from the Triennial Shelf Survey. See Figure 49 for more information.

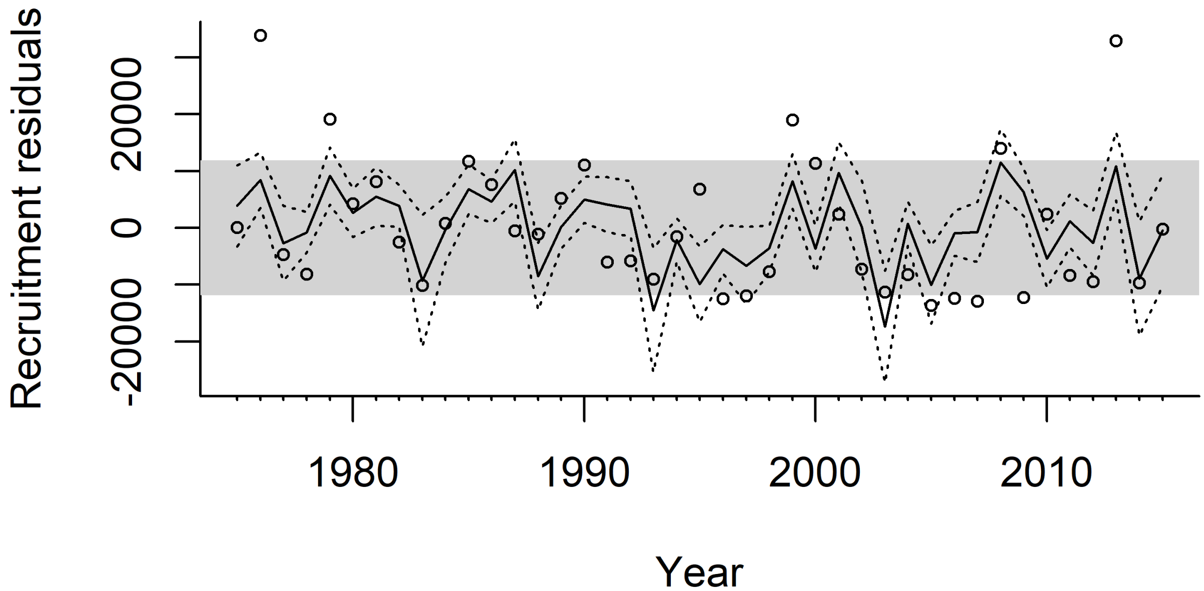


Figure 51. Residuals around the stock-recruitment relationship for 1975-2015. Solid line is the predicted recruitment residuals from Model 1. Assessment residuals (open circles) are the difference between estimated recruitment from the stock assessment and the theoretical stock-recruitment relationship. Grey envelope indicates ± 1.0 standard deviations of the assessment recruitment residuals from 1975-2015. See Model validation and testing for more information.

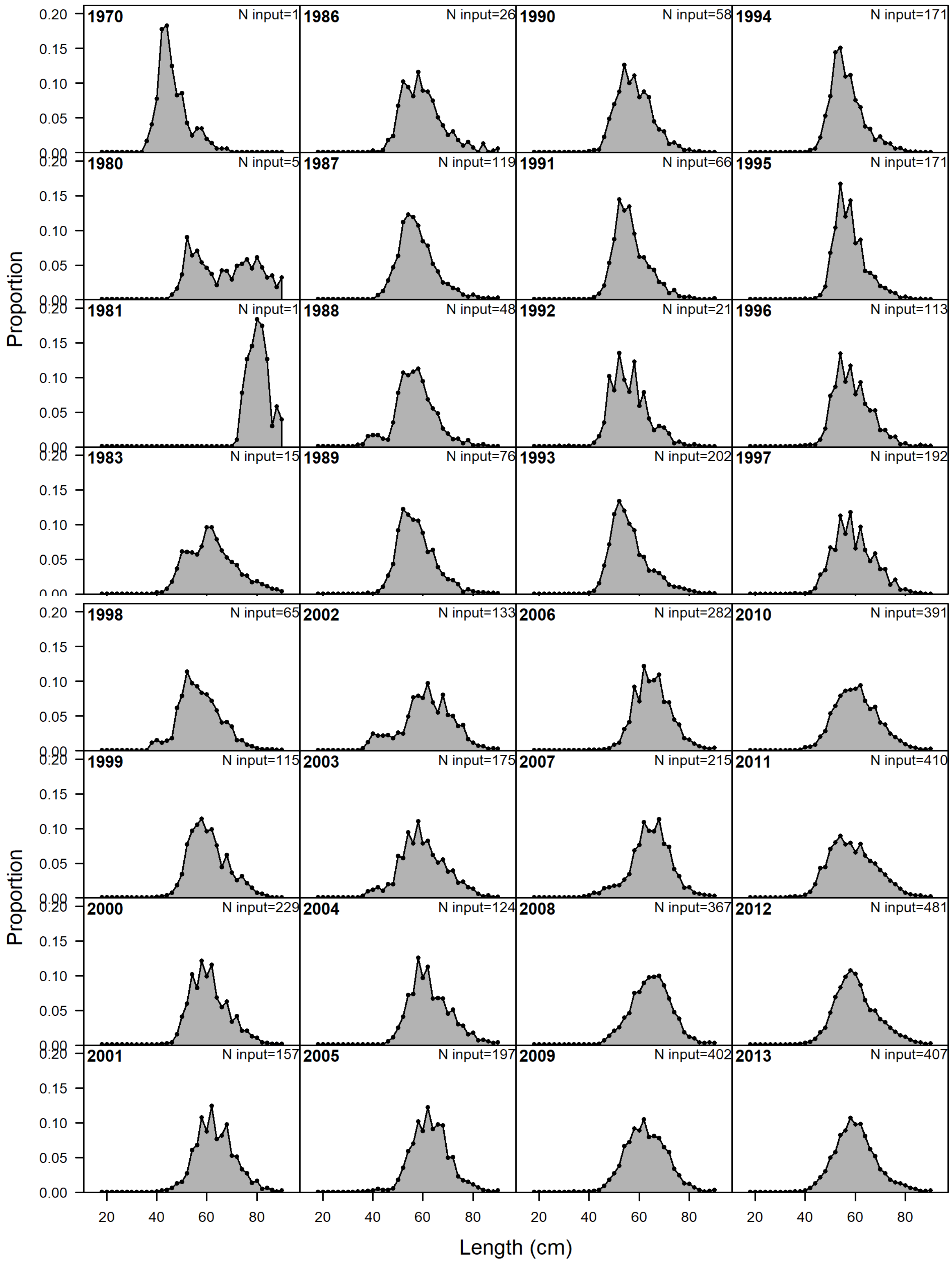


Figure 52. Year-specific (panels) length compositions from the fixed-gear fleet. Input sample sizes are noted in the upper right corner and year in the left corner.

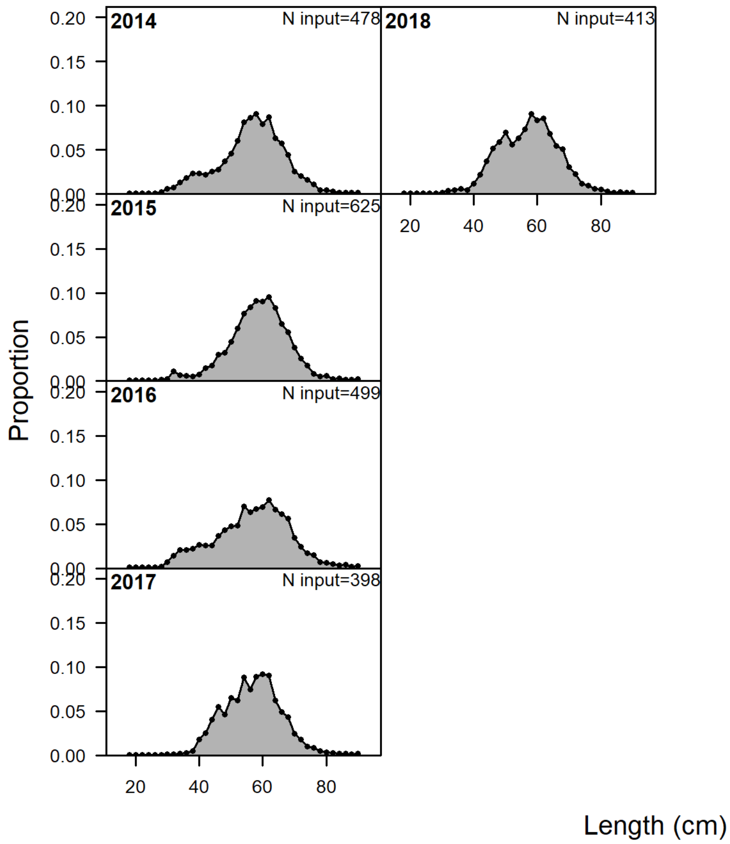


Figure 53. Continuation of Figure 52 for more recent years.

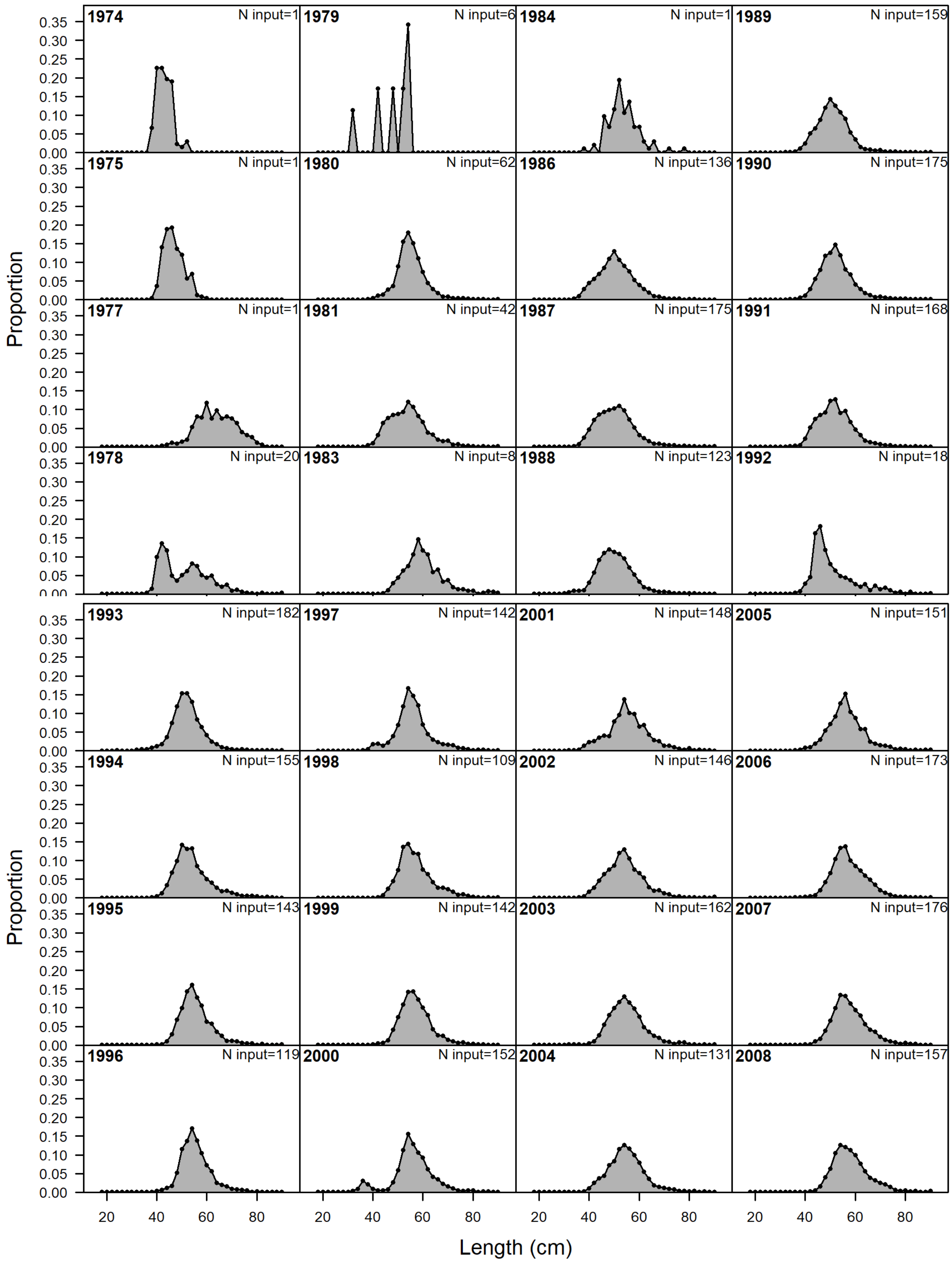


Figure 54. Year-specific (panels) length compositions from the trawl fleet. Input sample sizes are noted in the upper right corner and year in the left corner.

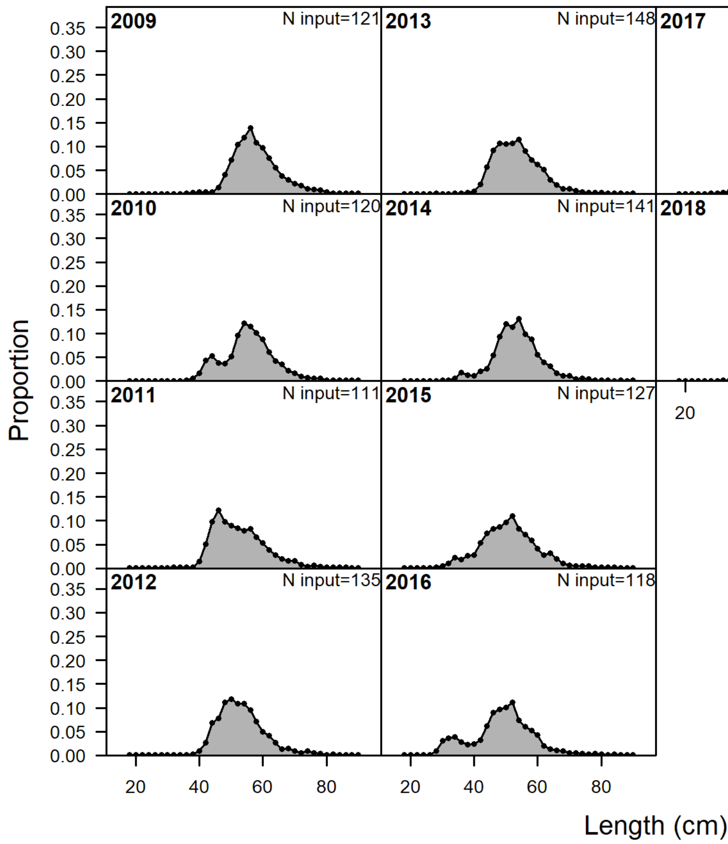


Figure 55. Continuation of Figure 54 for more recent years.

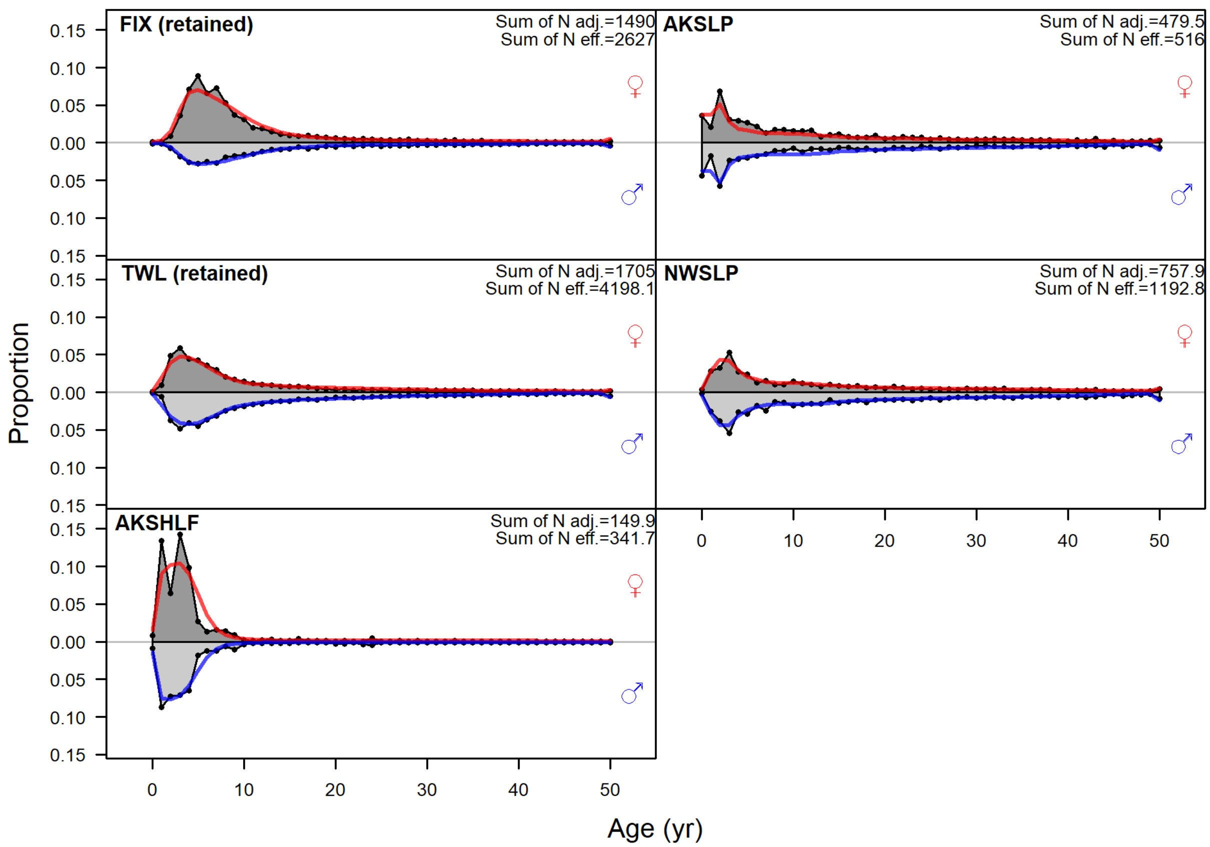


Figure 56. Age compositions aggregated across all years from each data source included in the base model. Females are represented using positive proportions and males are represented using negative proportions for sex-specific data. Fits are shown using solid lines.

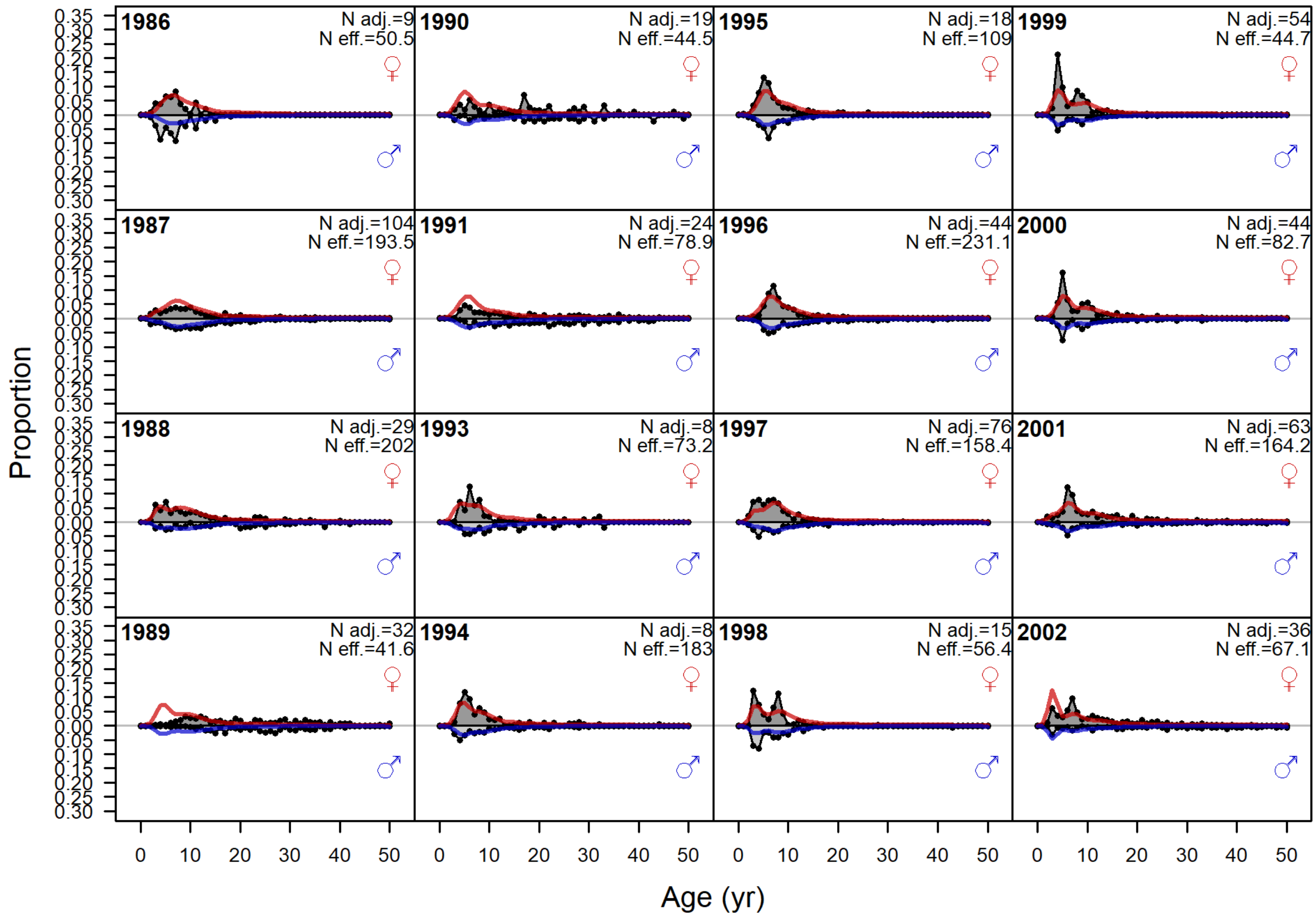


Figure 57. Age compositions for female and male sablefish from the retained catch in the fixed-gear fishery by year.

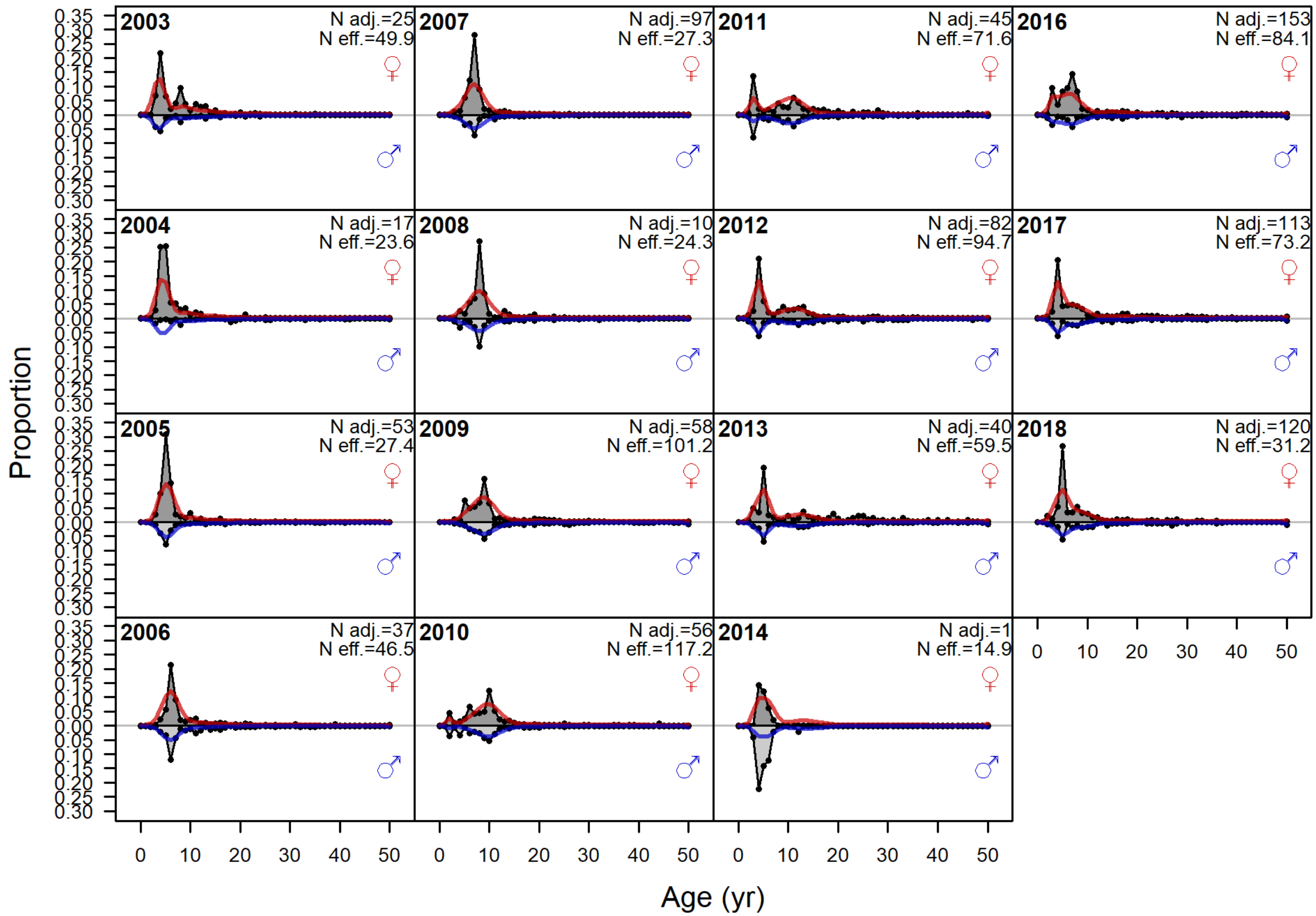


Figure 58. Age compositions for female and male sablefish from the retained catch in the fixed-gear fishery by year. A continuation of Figure 57 for more recent years.

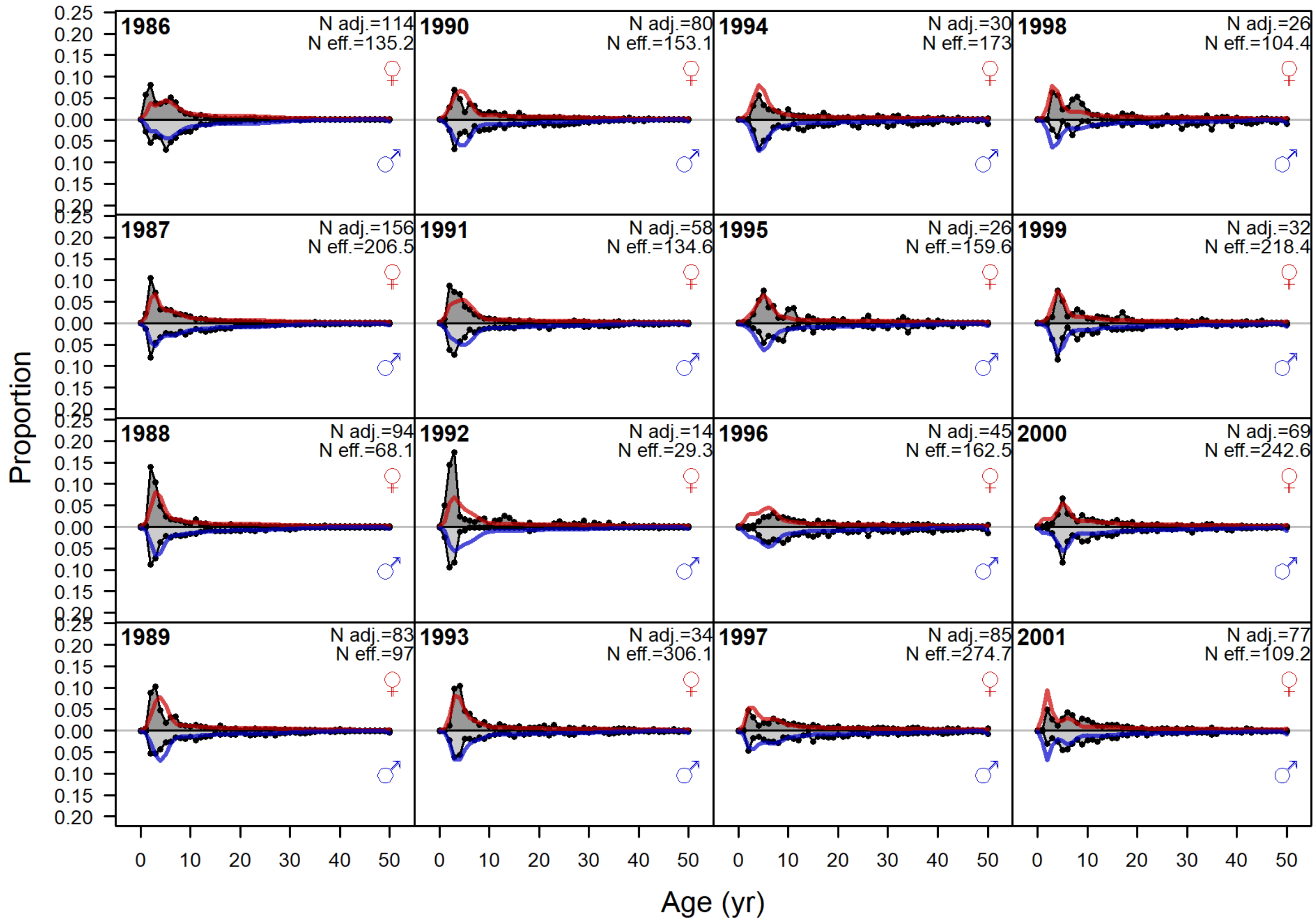


Figure 59. Age compositions for female and male sablefish from the retained catch in the trawl fishery by year.

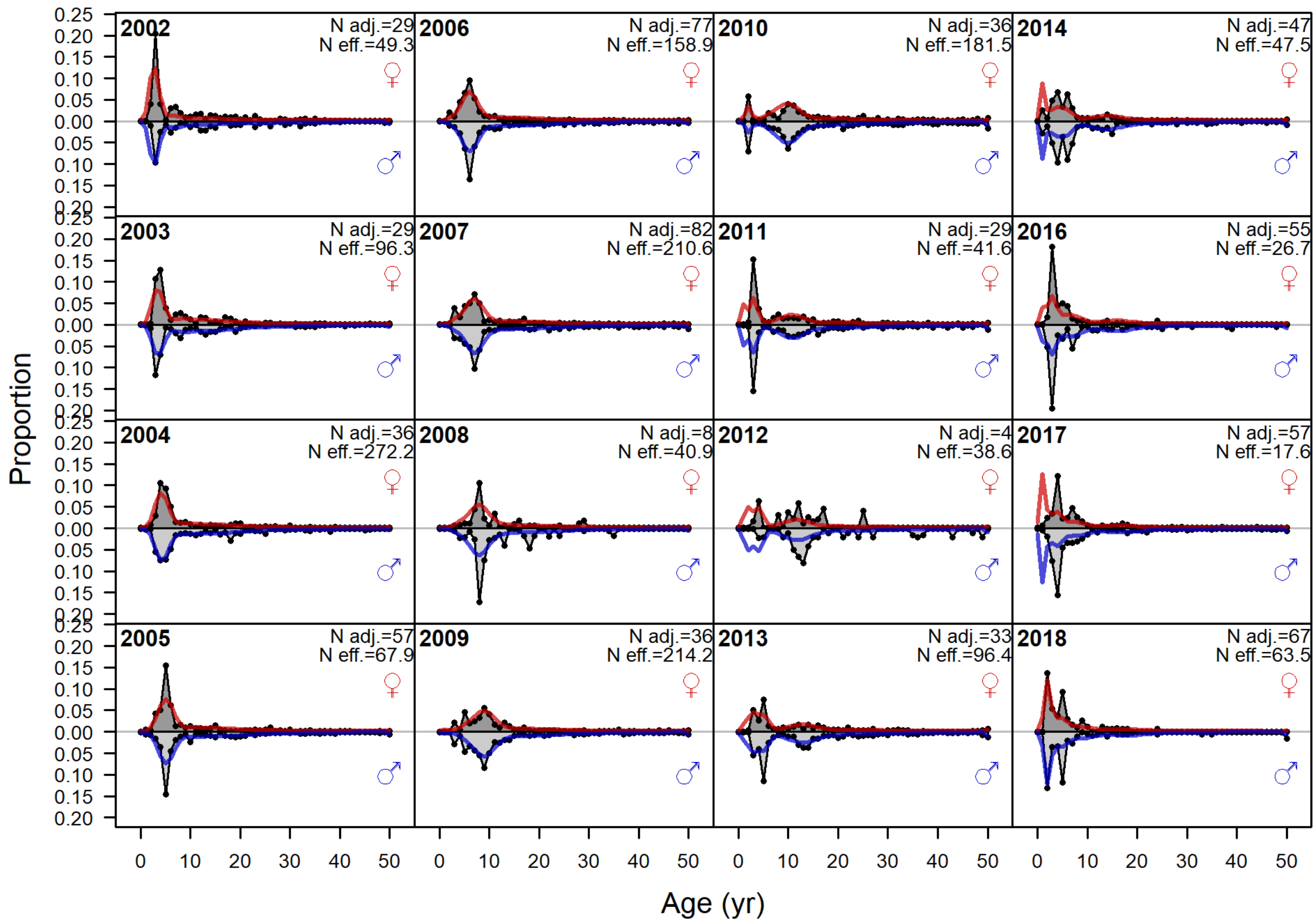


Figure 60. Age compositions for female and male sablefish from the retained catch in the trawl fishery by year. A continuation of Figure 59 for more recent years.

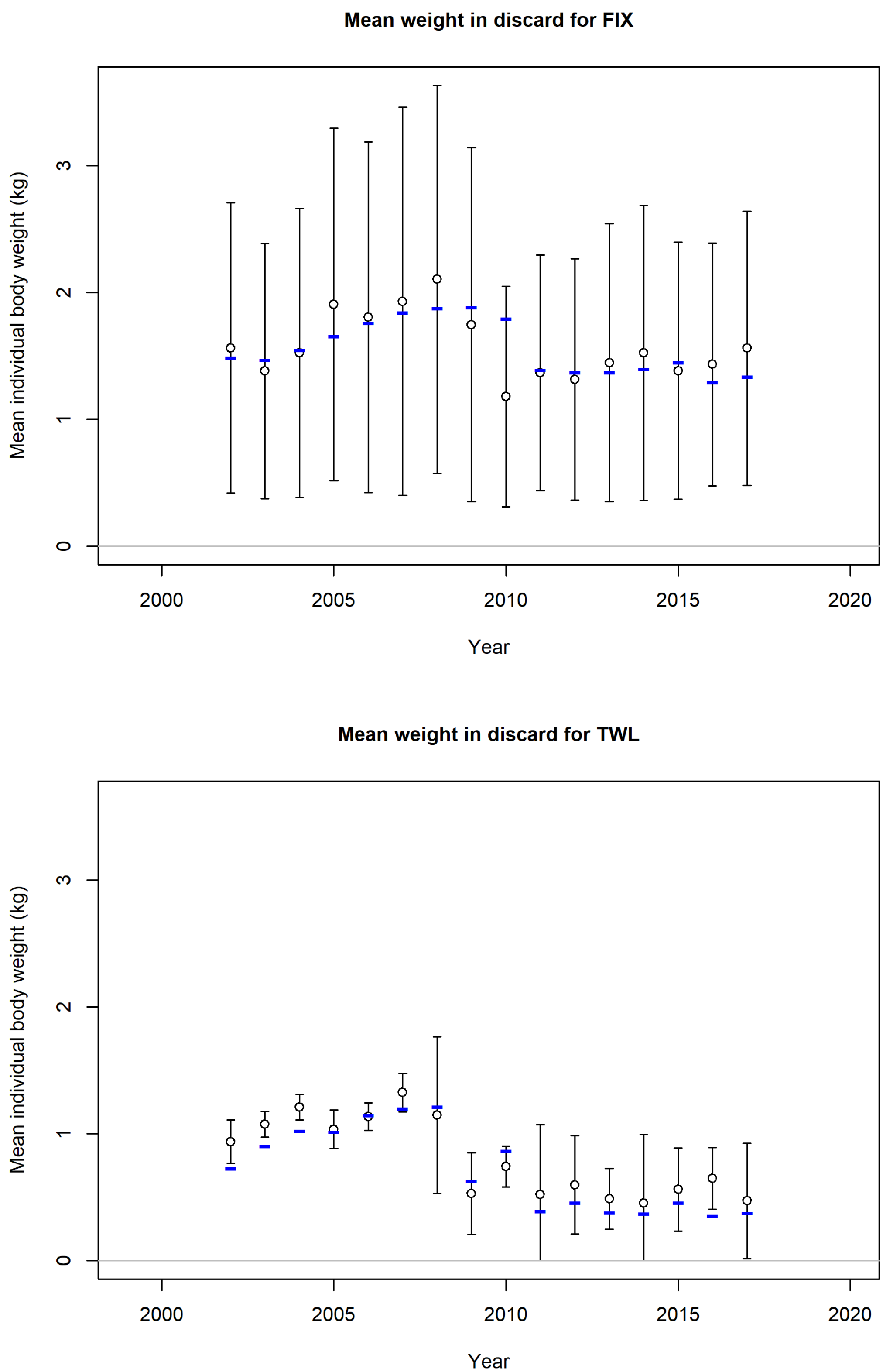


Figure 61. Fit to the fishery discard mean body weight data.

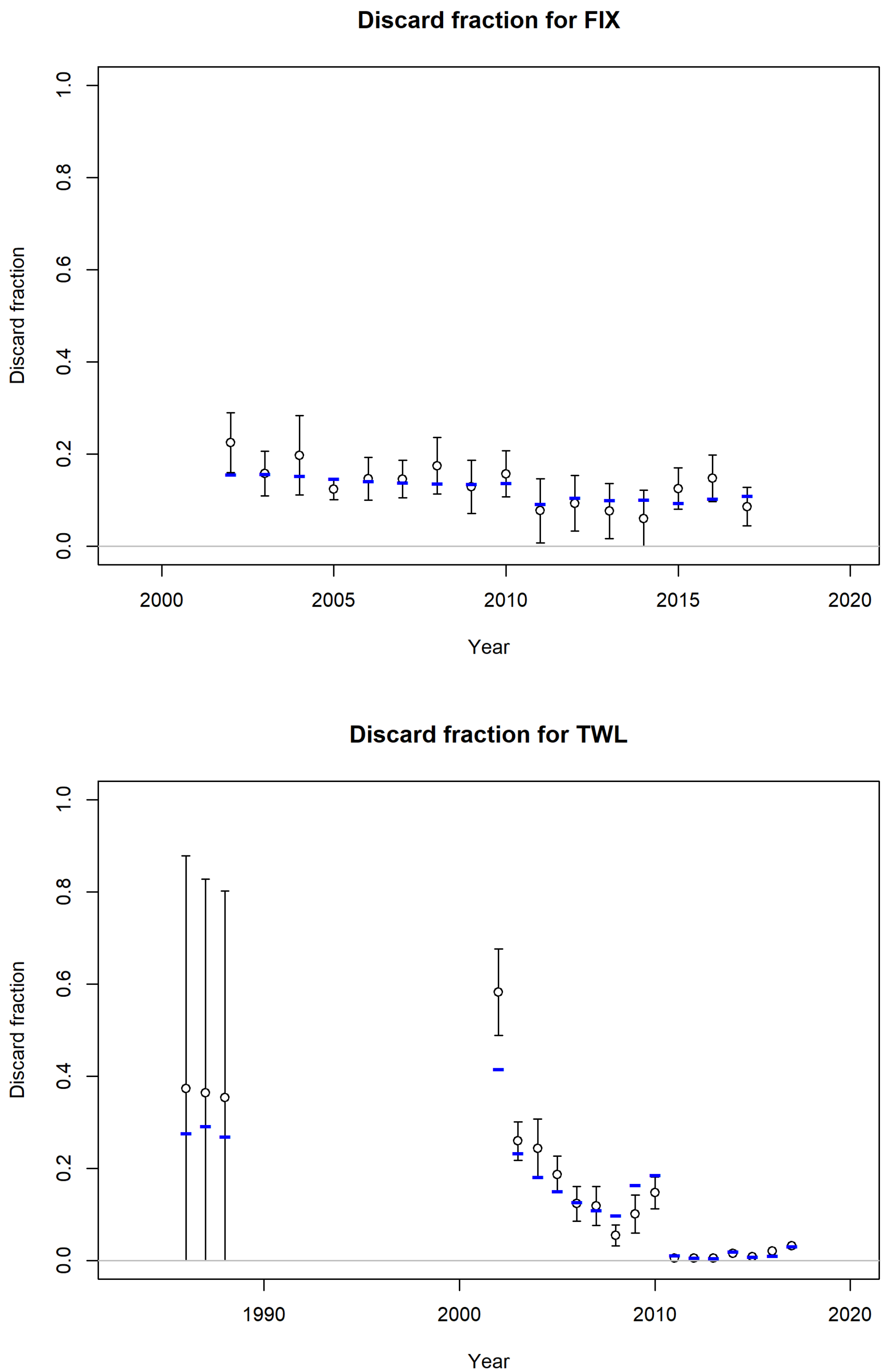


Figure 62. Fit to the fishery discard fraction data.

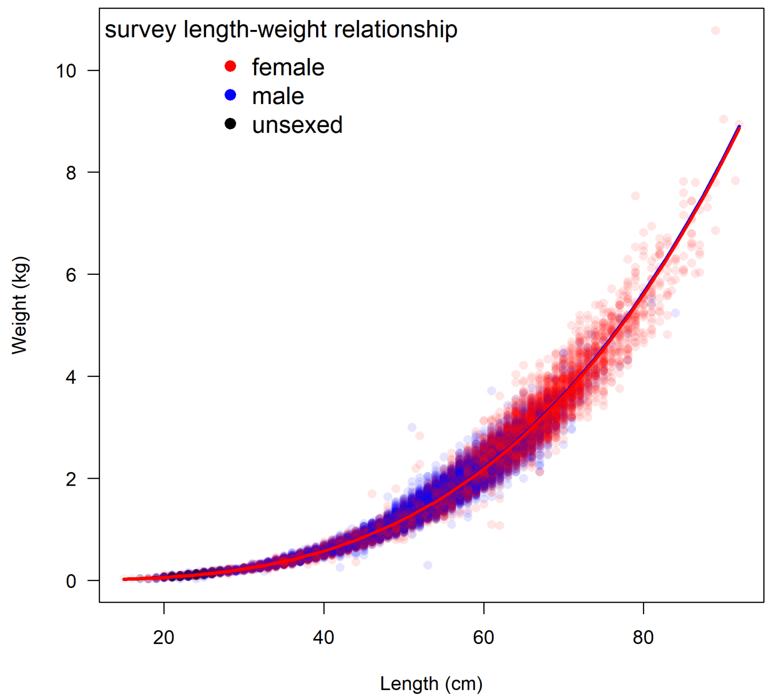


Figure 63. Estimated weight-length relationships for male (blue) and female (red) sablefish. Data are weight-length observations of individual fish sampled during the West Coast Groundfish Bottom Trawl Survey.

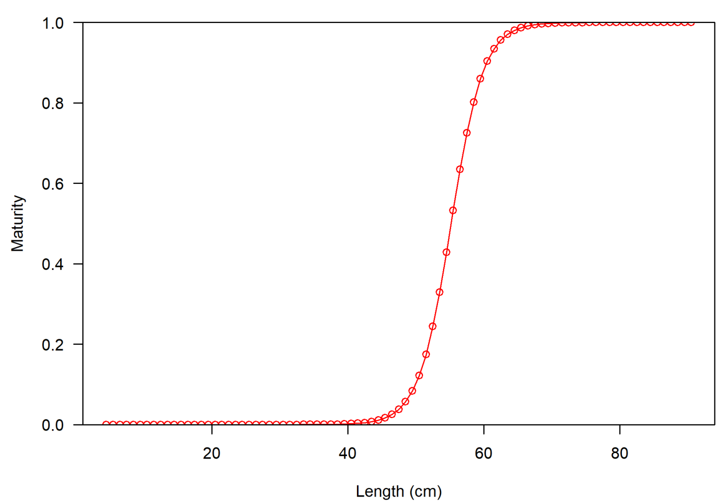


Figure 64. Female maturity curve derived from published studies.

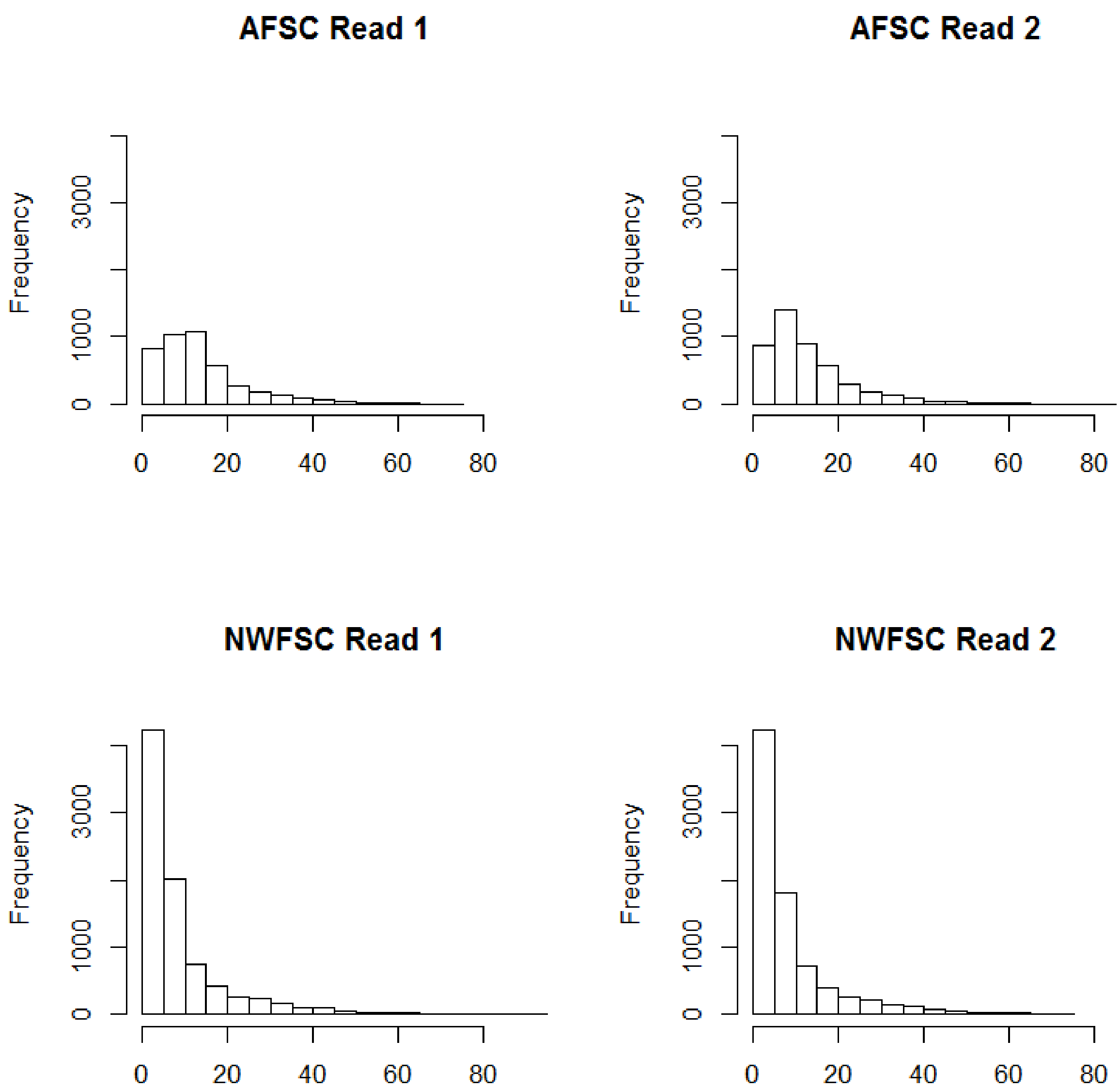


Figure 65. Summary of all age reads included in the analysis of within- and among-aging lab (Alaska Fisheries Science Center, AFSC; Northwest Fisheries Science Center, NWFSC) bias.

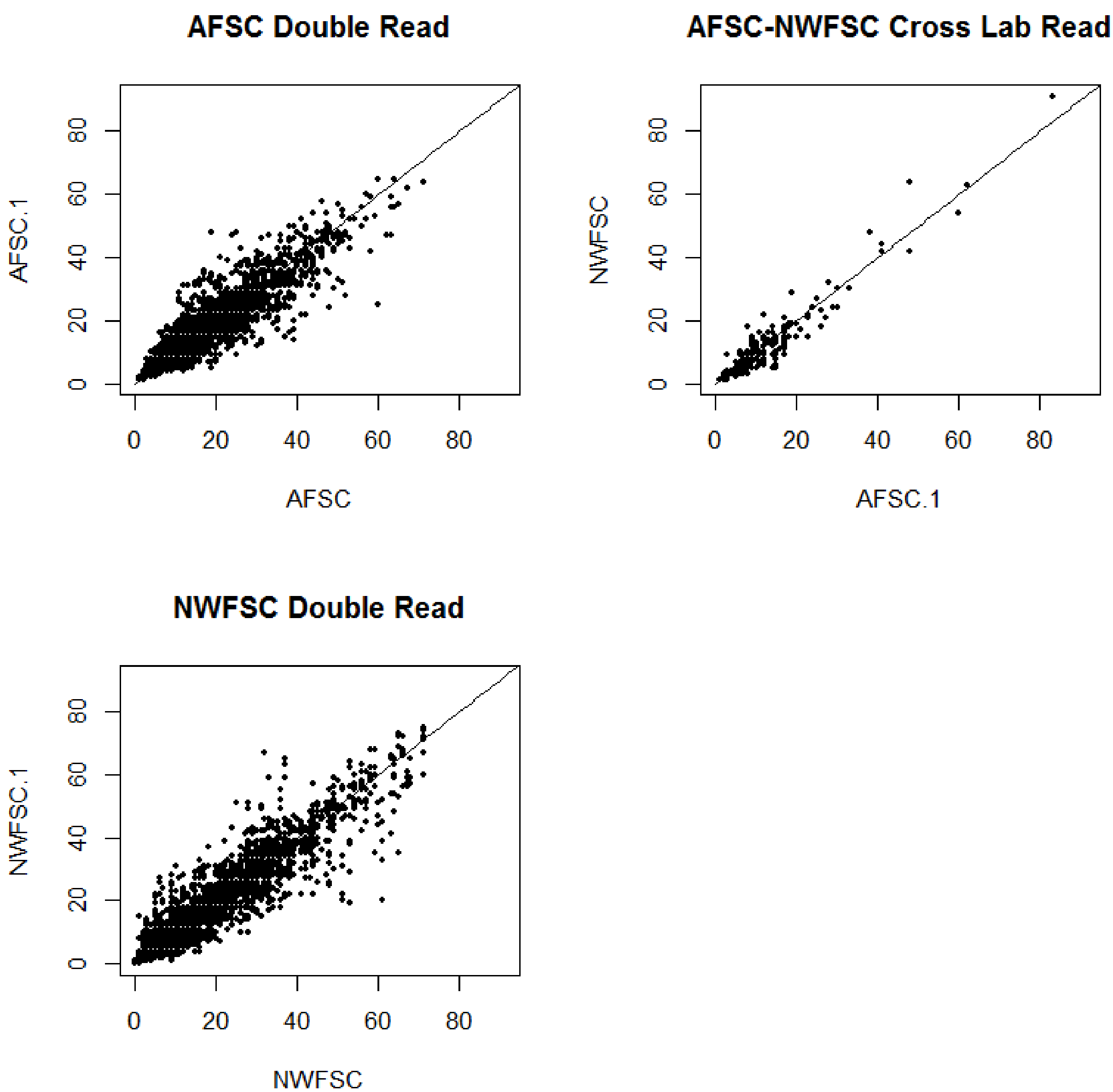


Figure 66. Summary of ageing bias and imprecision, for various the Alaska Fisheries Science Center (AFSC) and Northwest Fisheries Science Center (NWFSC) ageing labs used in preliminary modeling. Solid lines indicates a 1:1 relationship.

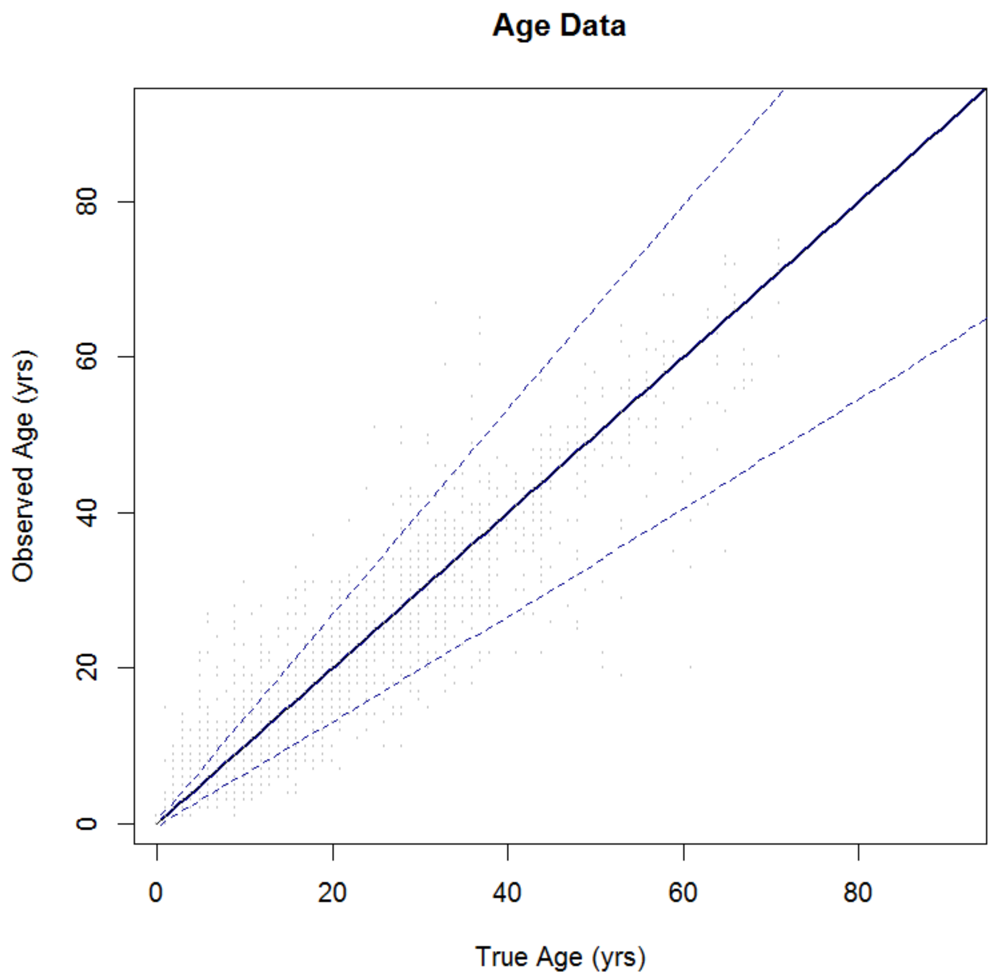


Figure 67. Summary of double read ages from west coast sablefish. The diagonal is the 1:1 relationship (i.e., no bias estimated) and the dashed lines encompass two standard deviations.

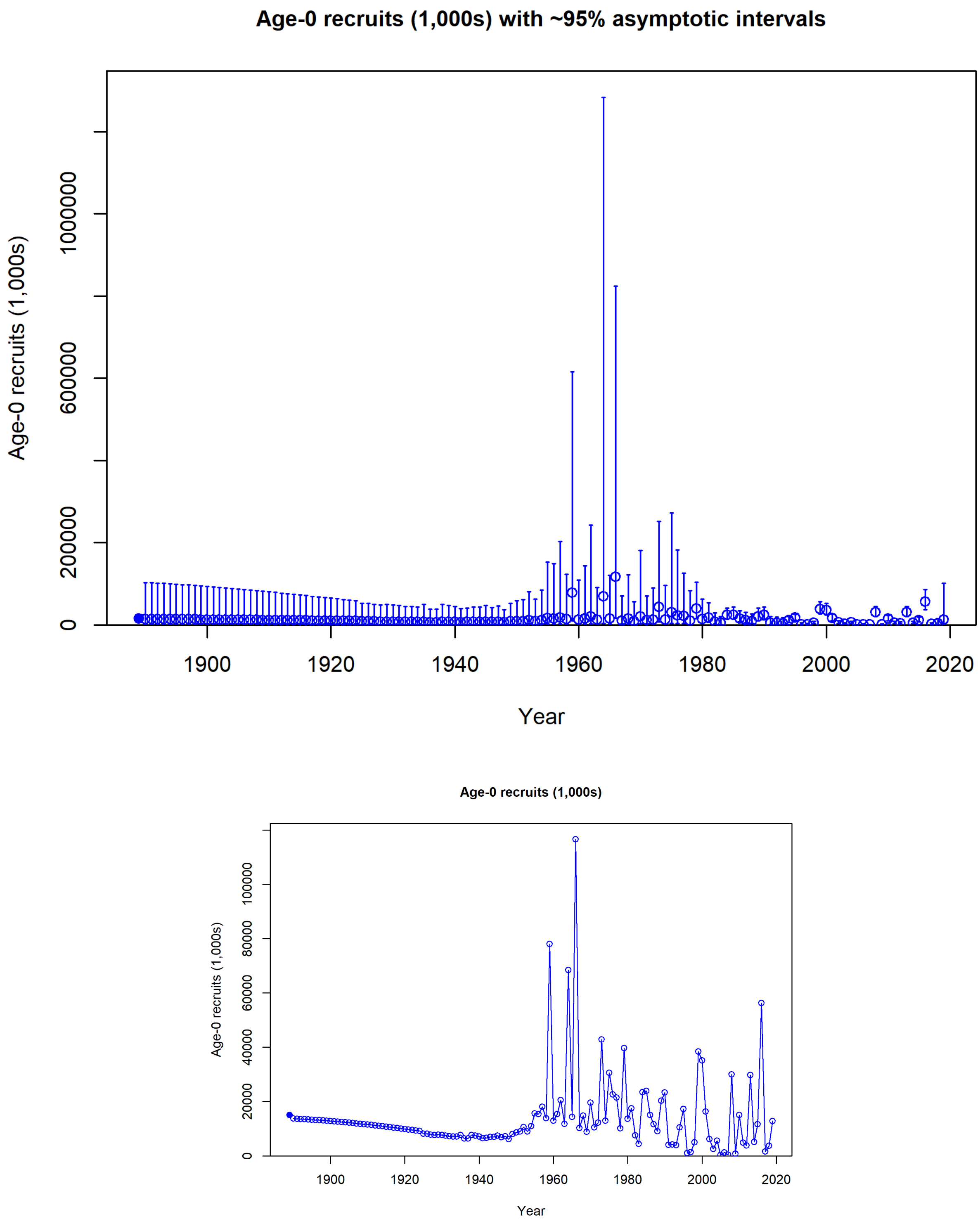


Figure 68. Time series of estimated sablefish recruitments for the base model (solid line) with ∼95% intervals (vertical lines; upper panel) and without intervals to better visualize recent estimated trends (lower panel).

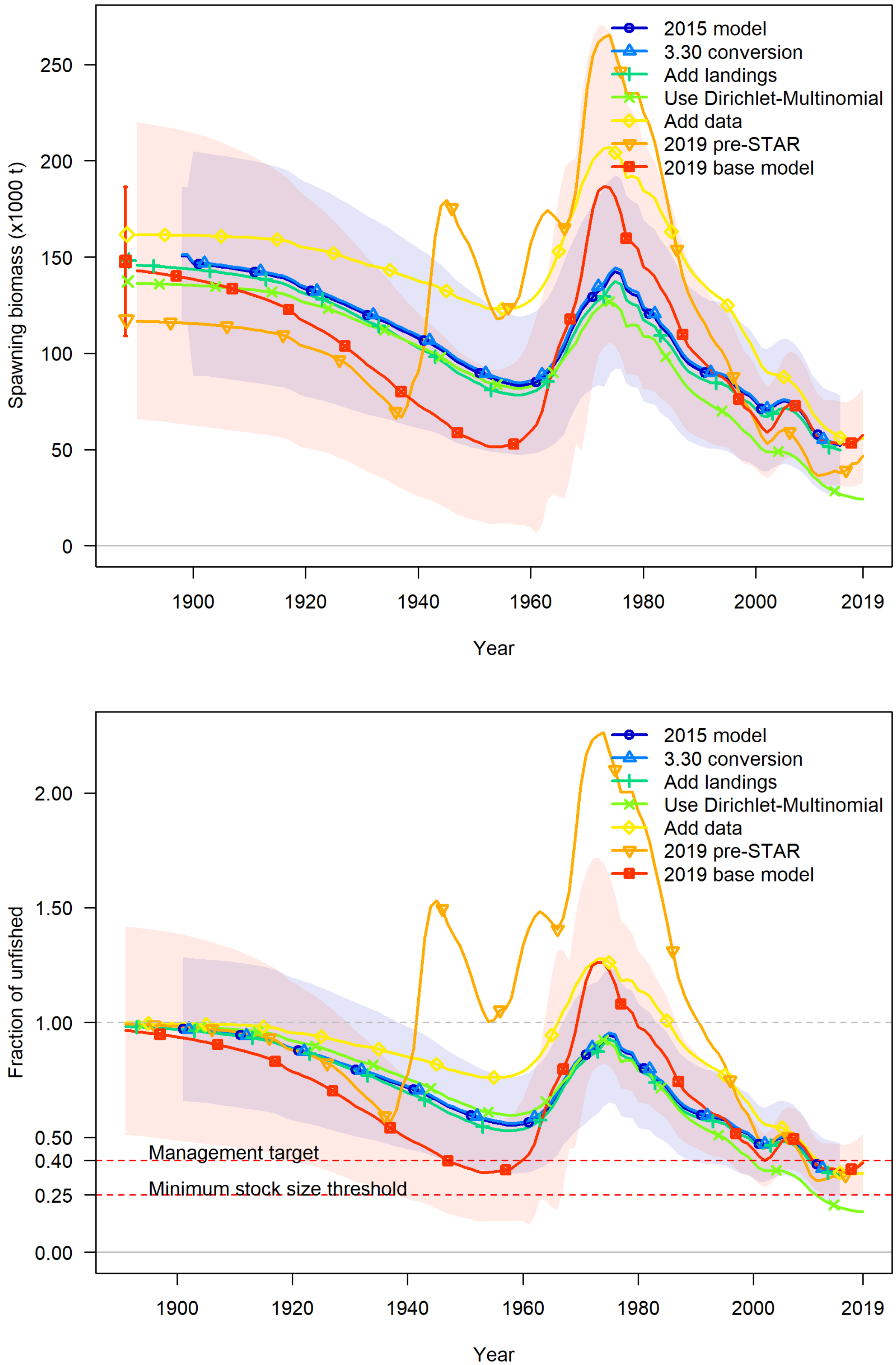


Figure 69. Bridging steps from the 2015 assessment update in Stock Synthesis version 3.24 to the base model in Stock Synthesis version 3.30. Uncertainty is shown for the 2015 and current base models.

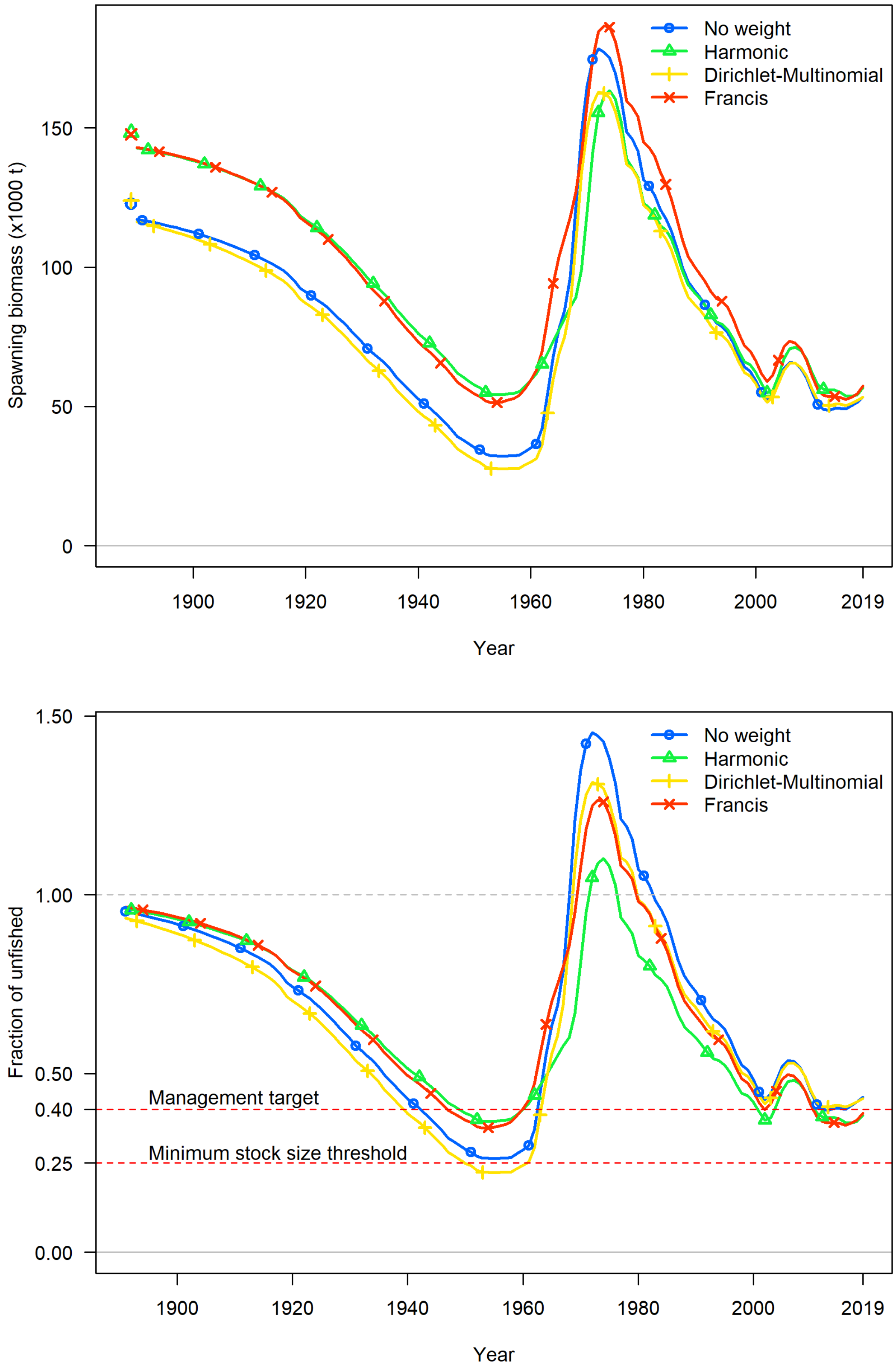


Figure 70. Changes in spawning stock biomass and depletion for alternative data-weighting methods used to downweight the compositional data.

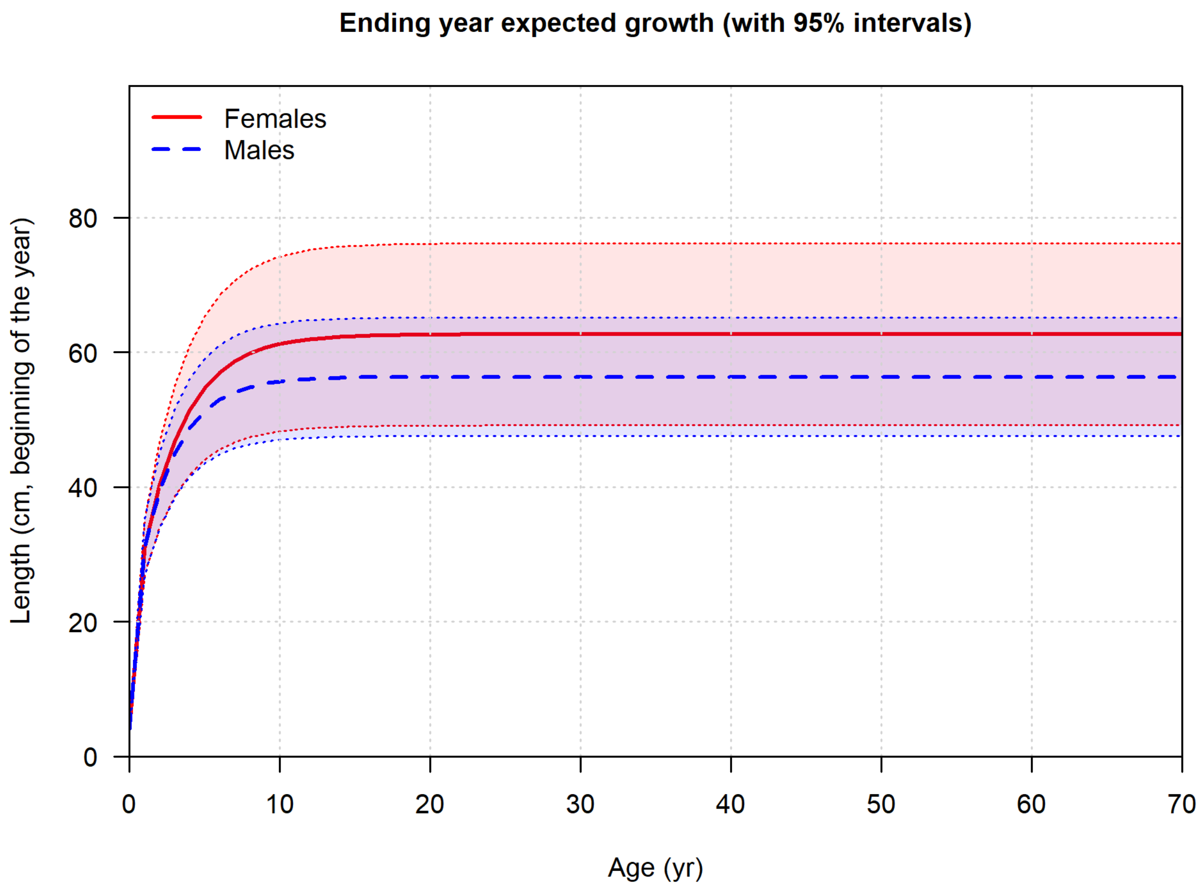


Figure 71. Growth curve for females and males with $\sim$ 95% intervals (dashed lines) indicating the expectation and individual variability of length-at-age for the base model.

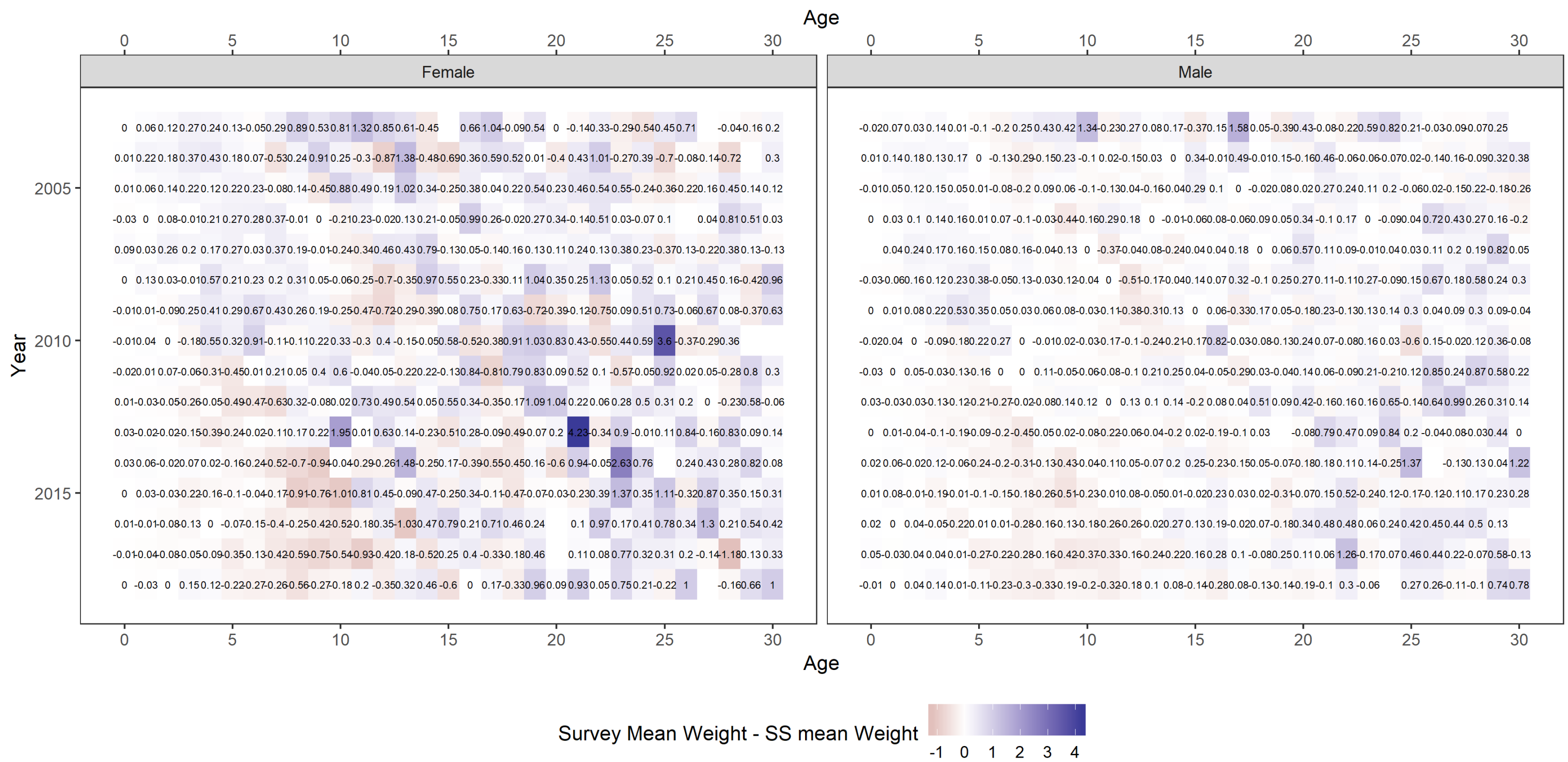
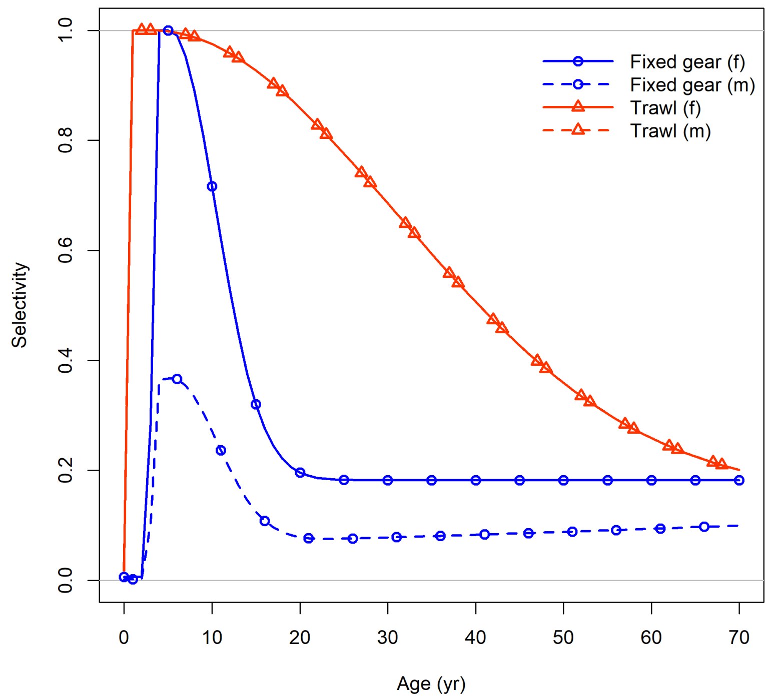


Figure 72. Sex-specific (panels) empirical weight-at-age data from the West Coast Groundfish Bottom Trawl Survey compared to estimated weight-at-age from the base model. White indicates no difference.



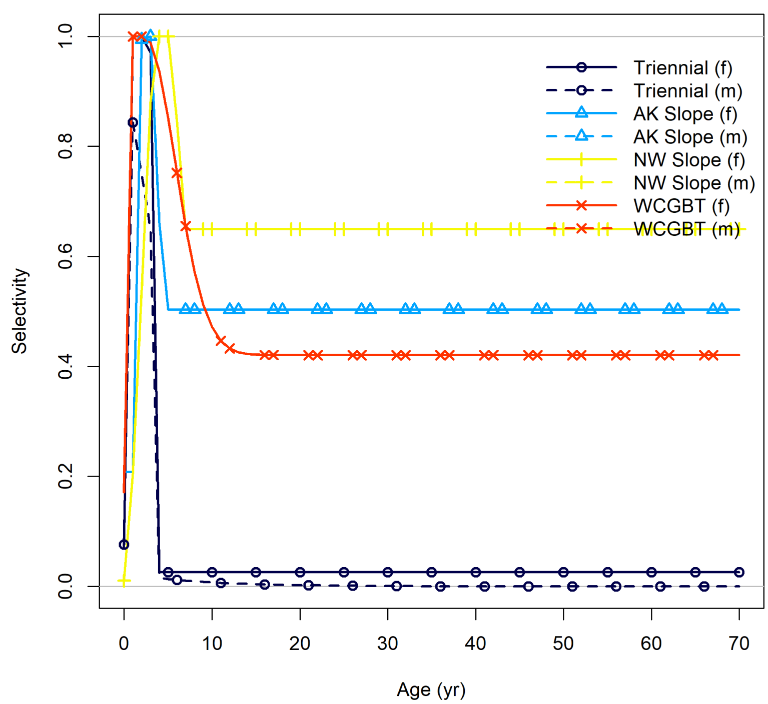


Figure 73. Fleet-specific (colors) selectivity at age in the terminal year of the model for fishery fleets (upper) and surveys (lower). Solid lines are female-specific and dashed lines are male-specific selectivities.

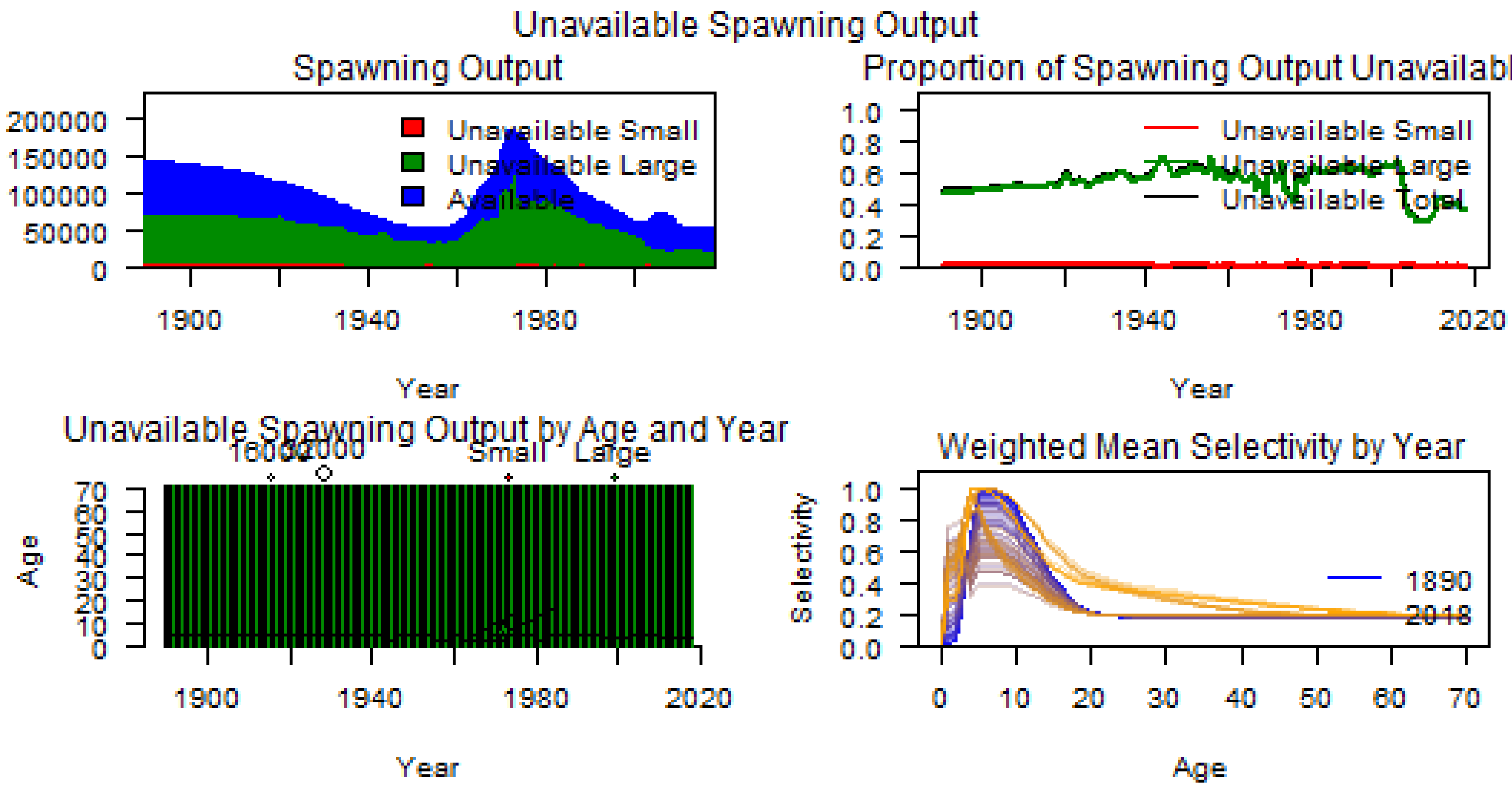


Figure 74. Estimates of unavailable spawning output from the base model (upper left panel) and the proportion unavailable with respect to the total spawning biomass (upper right panel). Estimates are also provided by age and year (lower left panel) given dome-shaped selectivity across time for all fleets and surveys (lower right panel).

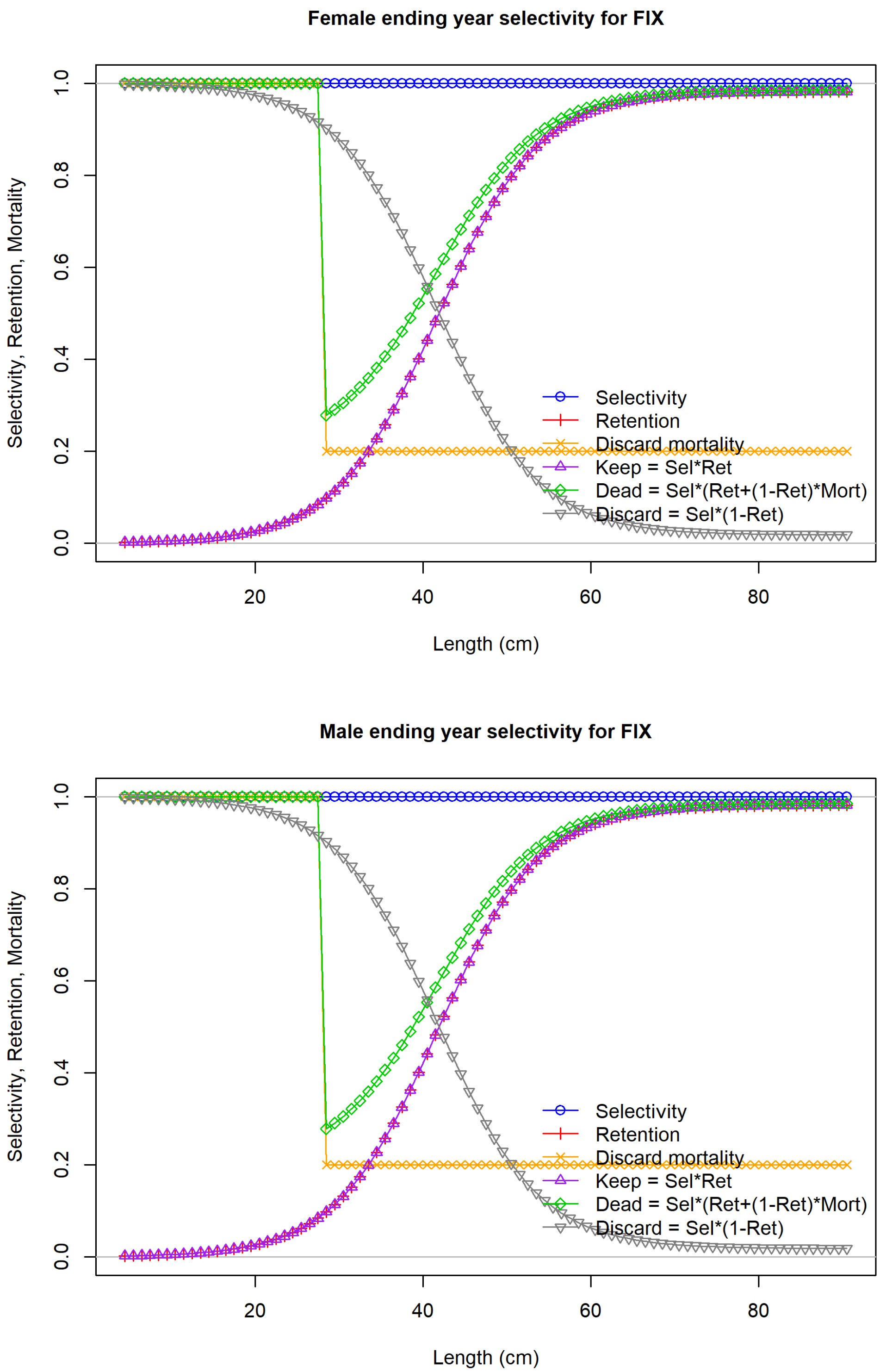


Figure 75. Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the fixed-gear fishery.

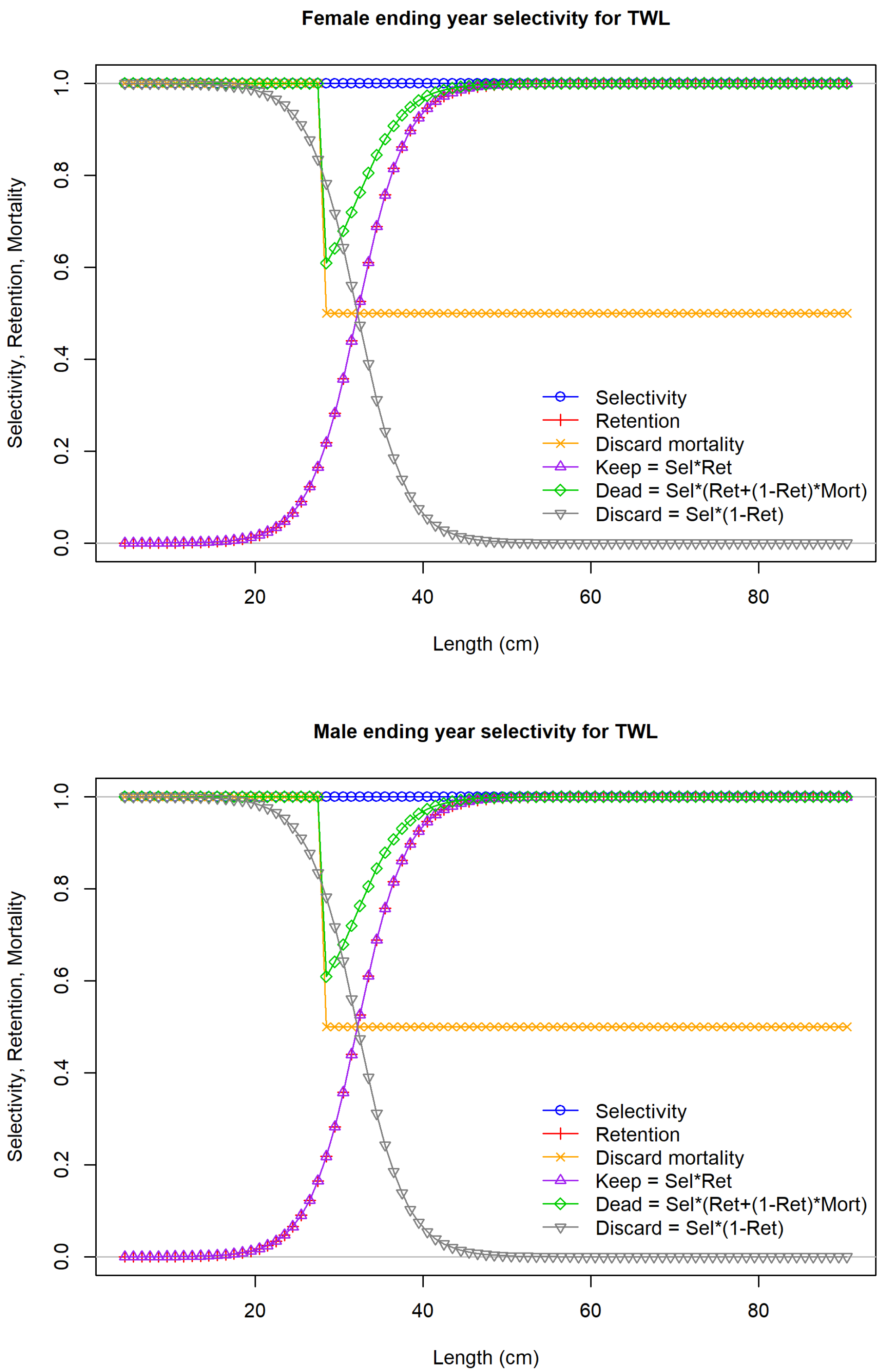


Figure 76. Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the trawl fishery.

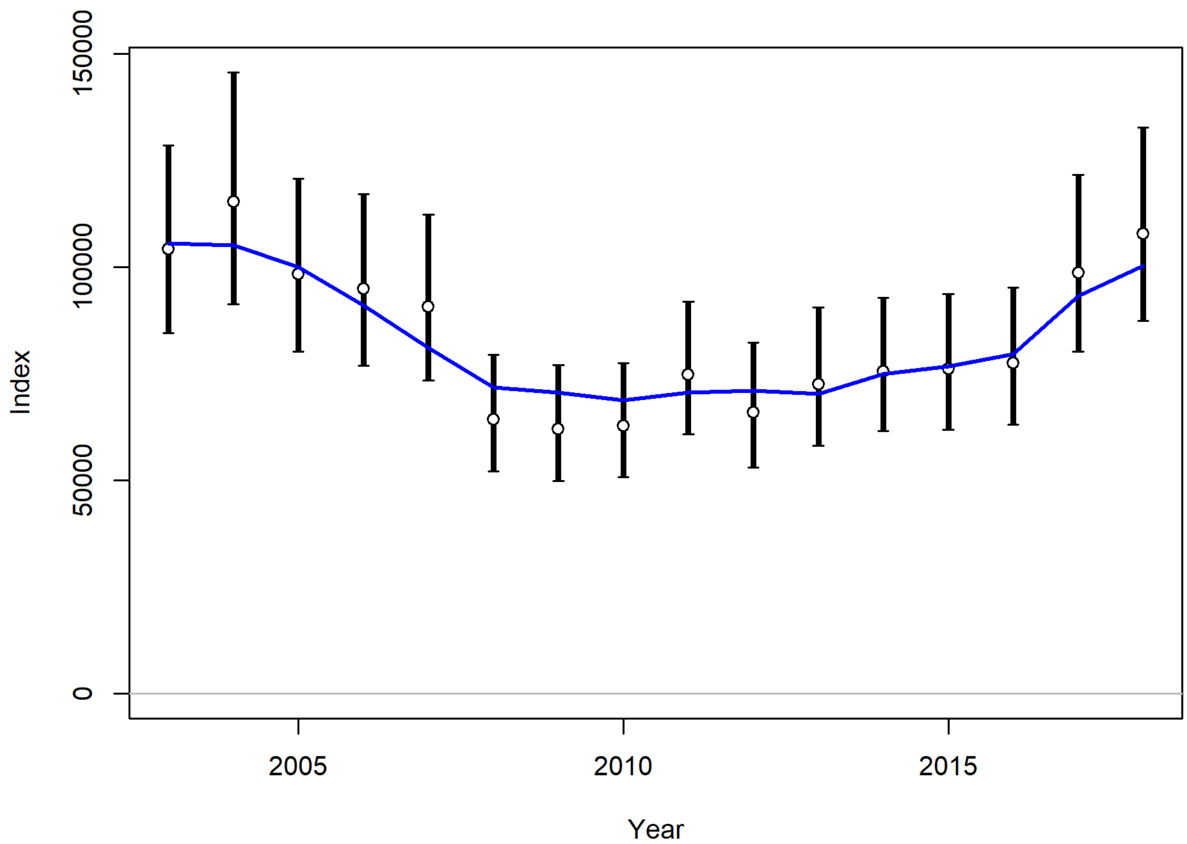


Figure 77. Fit to the West Coast Groundfish Bottom Trawl Survey.

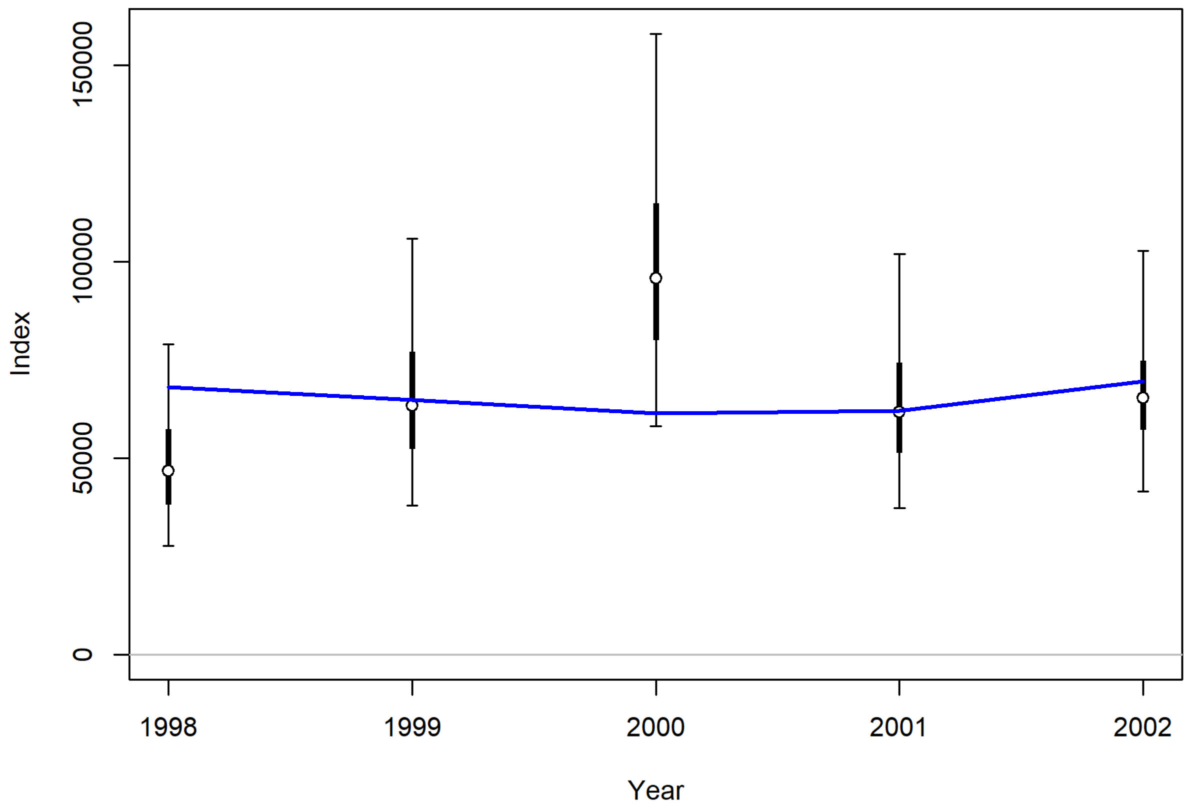


Figure 78. Fit to the Northwest Fisheries Science Center Slope Survey.

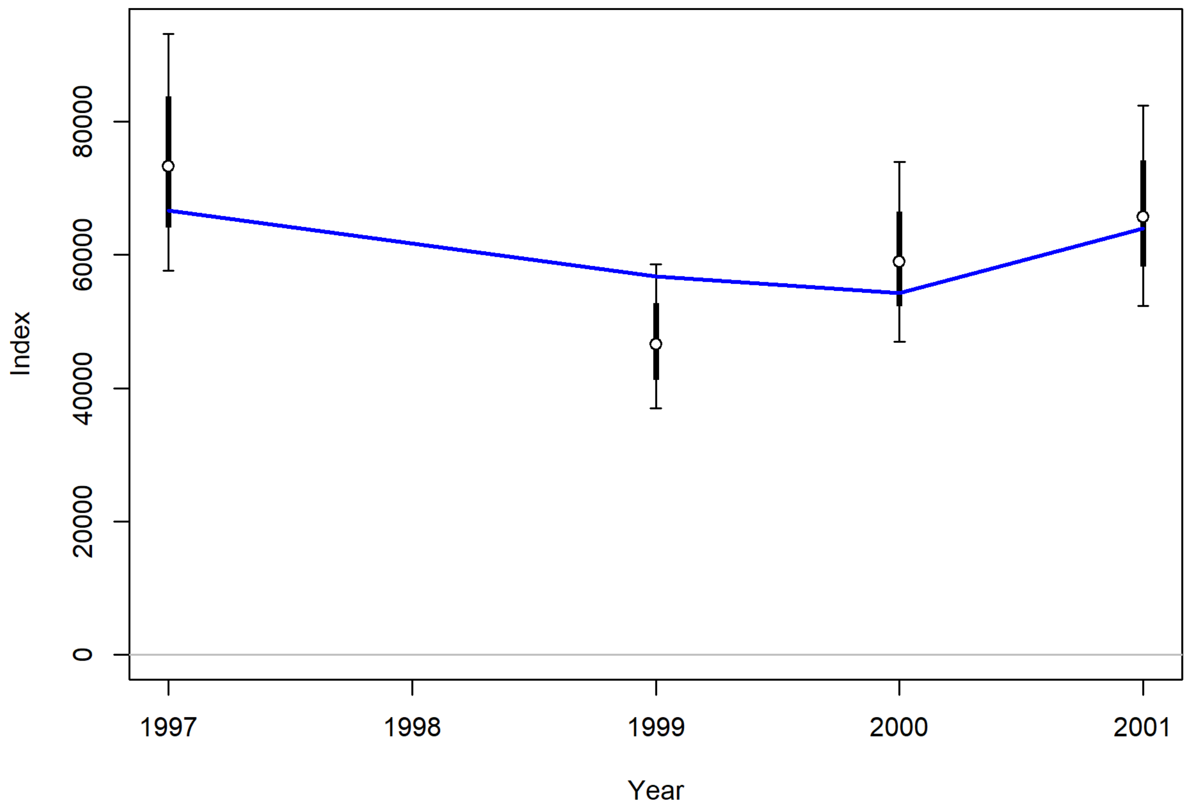


Figure 79. Fit to the Alaska Fisheries Science Center Slope Survey.

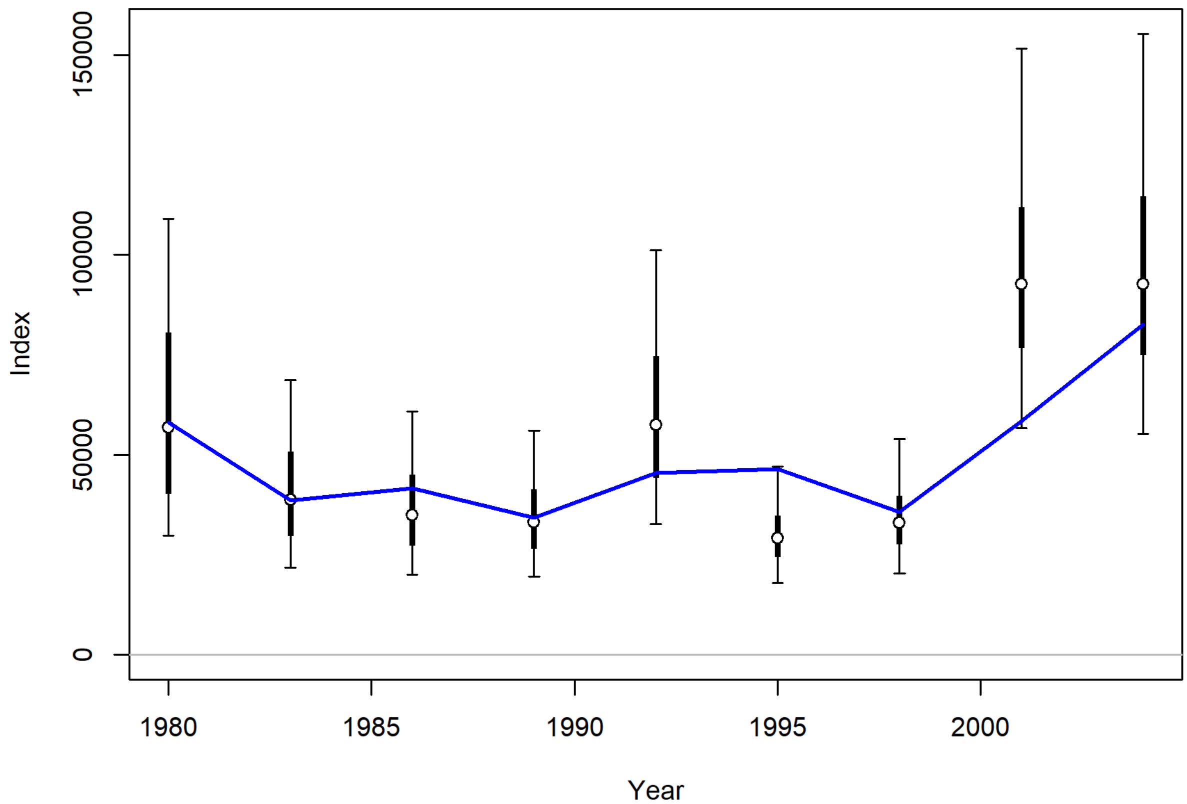


Figure 80. Fit to the Triennial Shelf Survey.

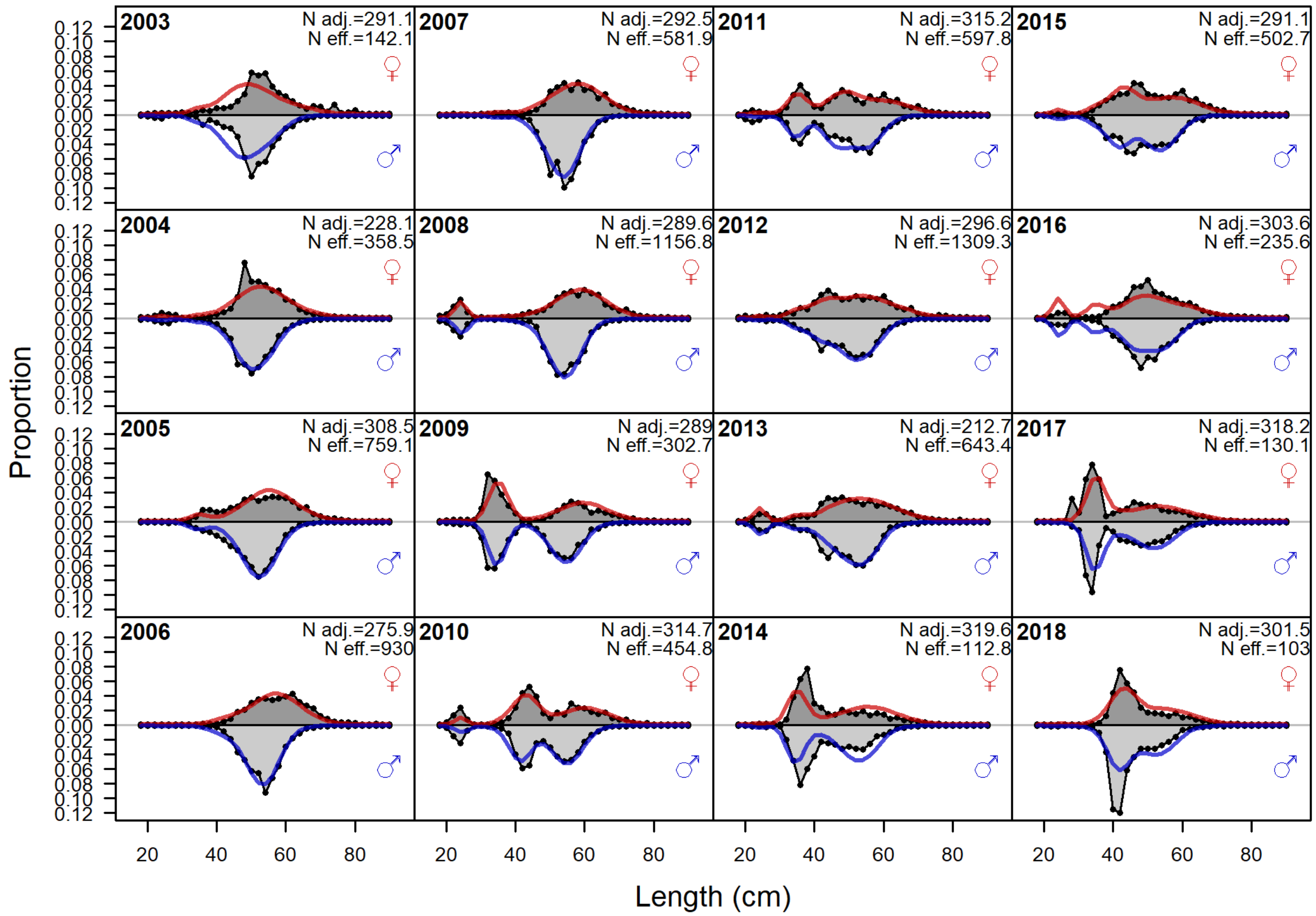


Figure 81. Fits to the West Coast Groundfish Bottom Trawl Survey length-composition data by sex.

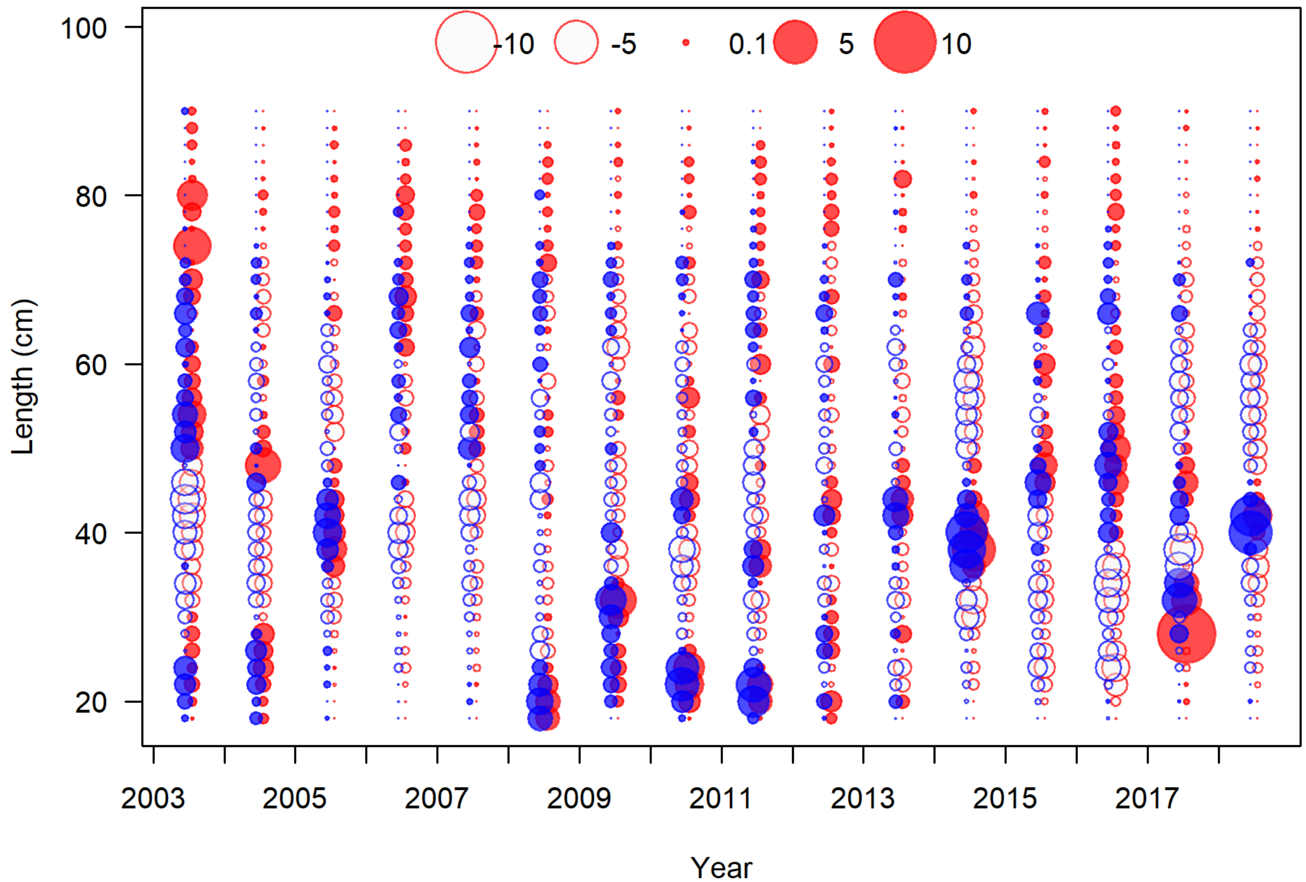


Figure 82. Pearson residuals for the fits to West Coast Groundfish Bottom Trawl length compositions. Filled circles represent positive residuals (*observed* − *expected*) and red and blue indicate females and males, respectively.

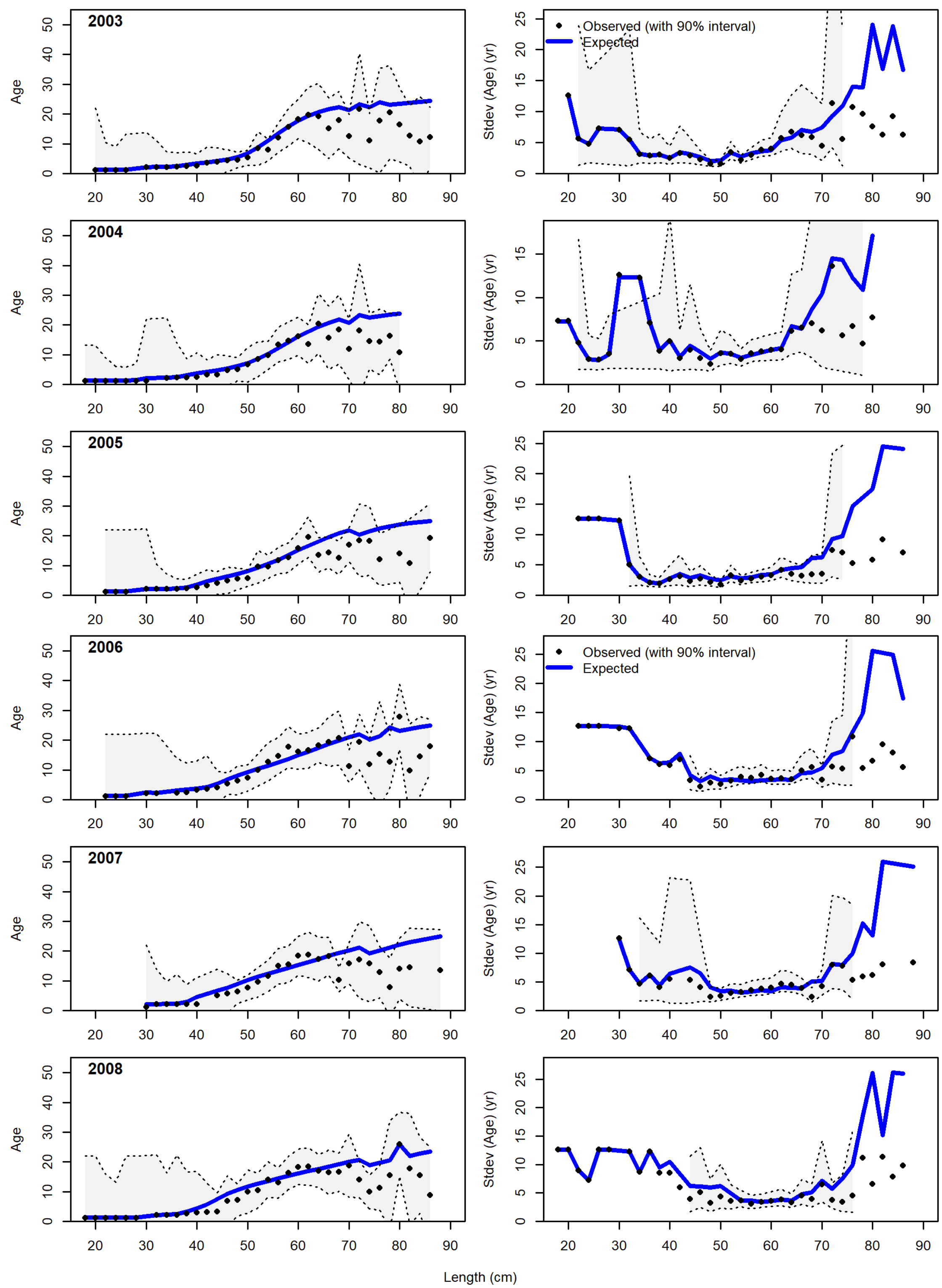


Figure 83. Year-specific conditional age-at-length data (left) and standard deviation (stdev) at age (right) from the West Coast Groundfish Bottom Trawl Survey. Shaded areas are confidence intervals based on adding 1.64 standard errors of the mean to the mean age and 90% intervals from a chi-square distribution for the stdev of mean age.

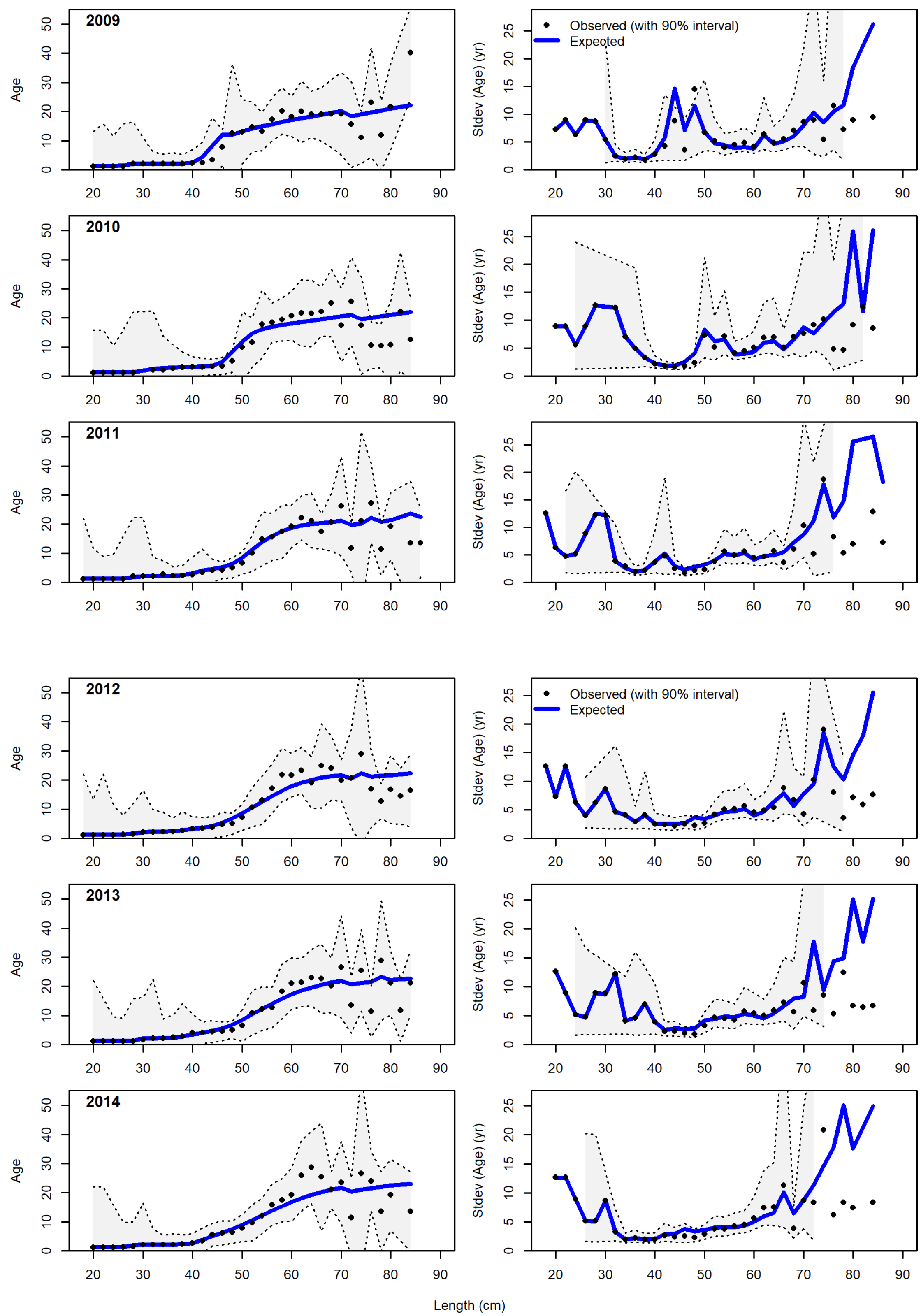


Figure 84. The continuation of Figure 83 but for more recent years.

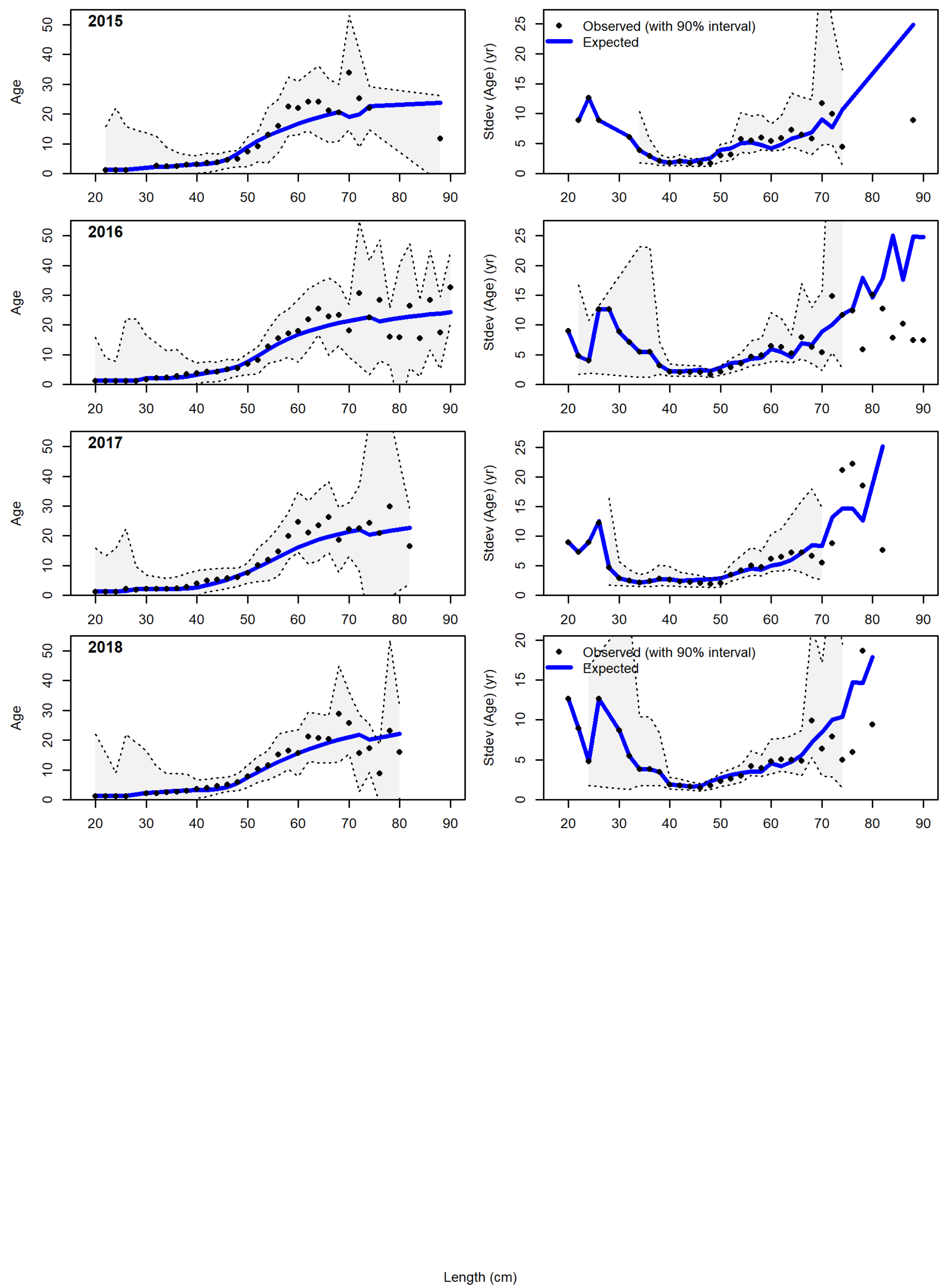


Figure 85. The continuation of Figure 83 but for the most recent years.

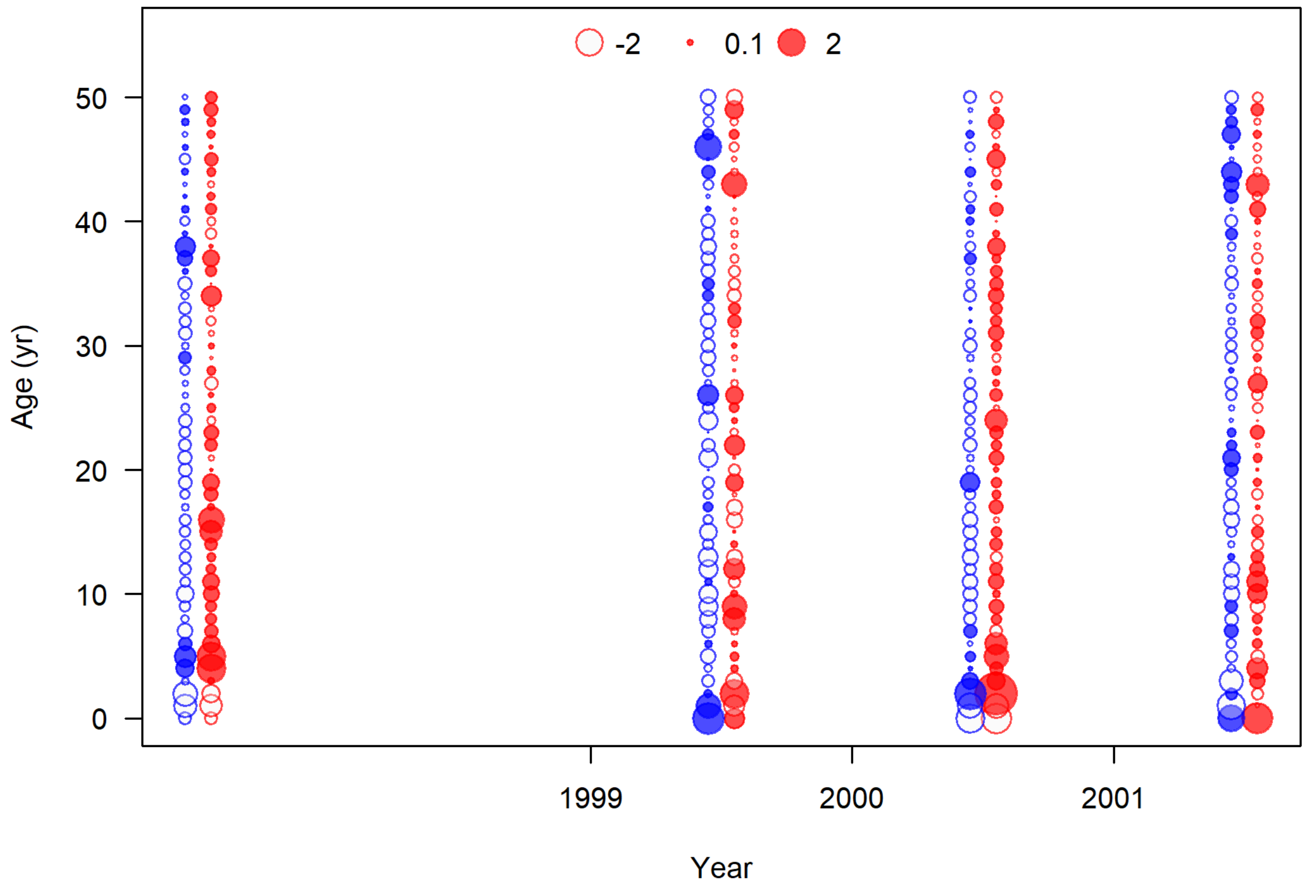


Figure 86. Pearson residuals for the fits to the Alaska Fisheries Science Center Slope Survey age-composition data. Filled circles represent positive residuals (*observed* − *expected*) where red and blue are female and male, respectively.

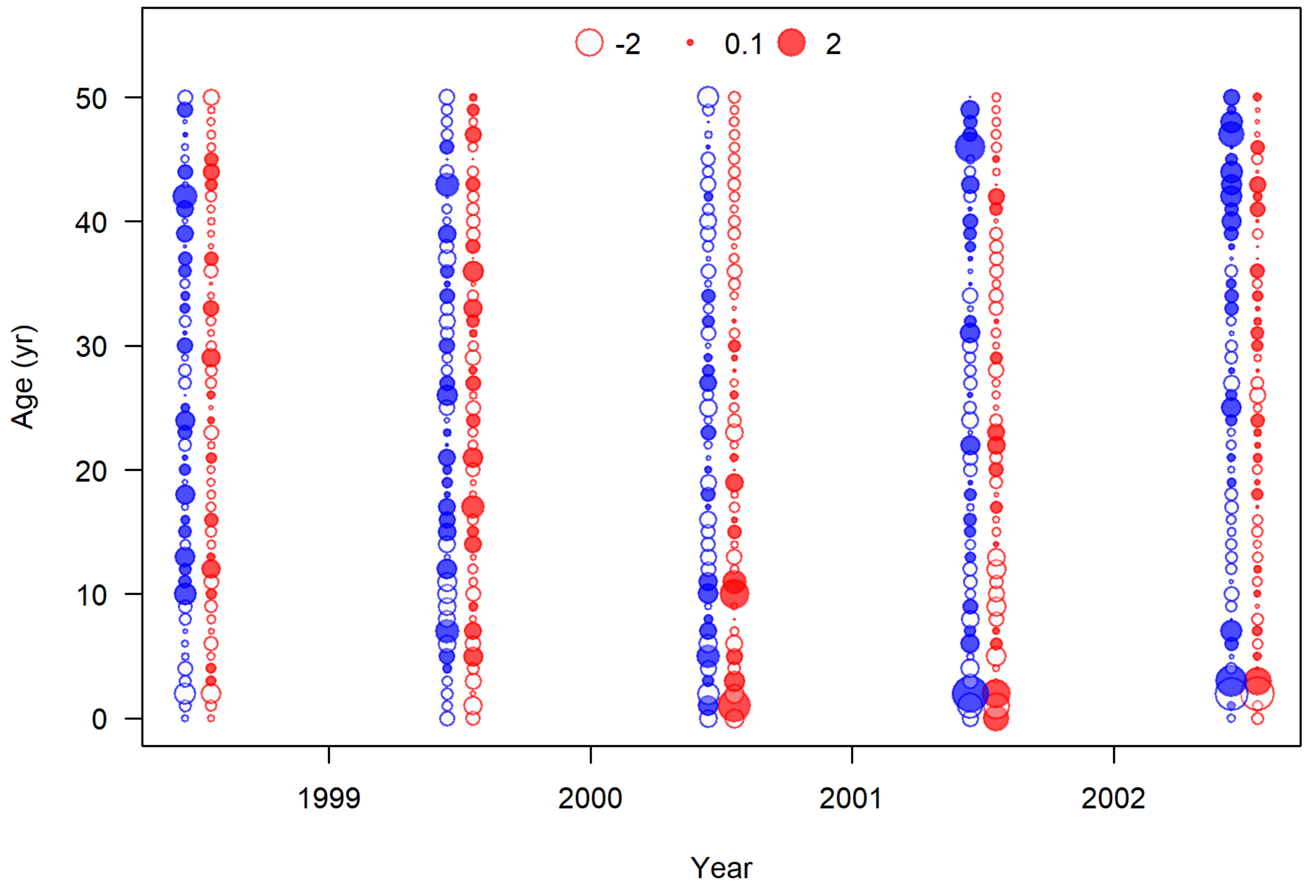


Figure 87. Pearson residuals for the fits to the Northwest Fisheries Science Center Slop Survey age-composition data. Filled circles represent positive residuals (*observed* − *expected*) where red and blue are female and male, respectively.

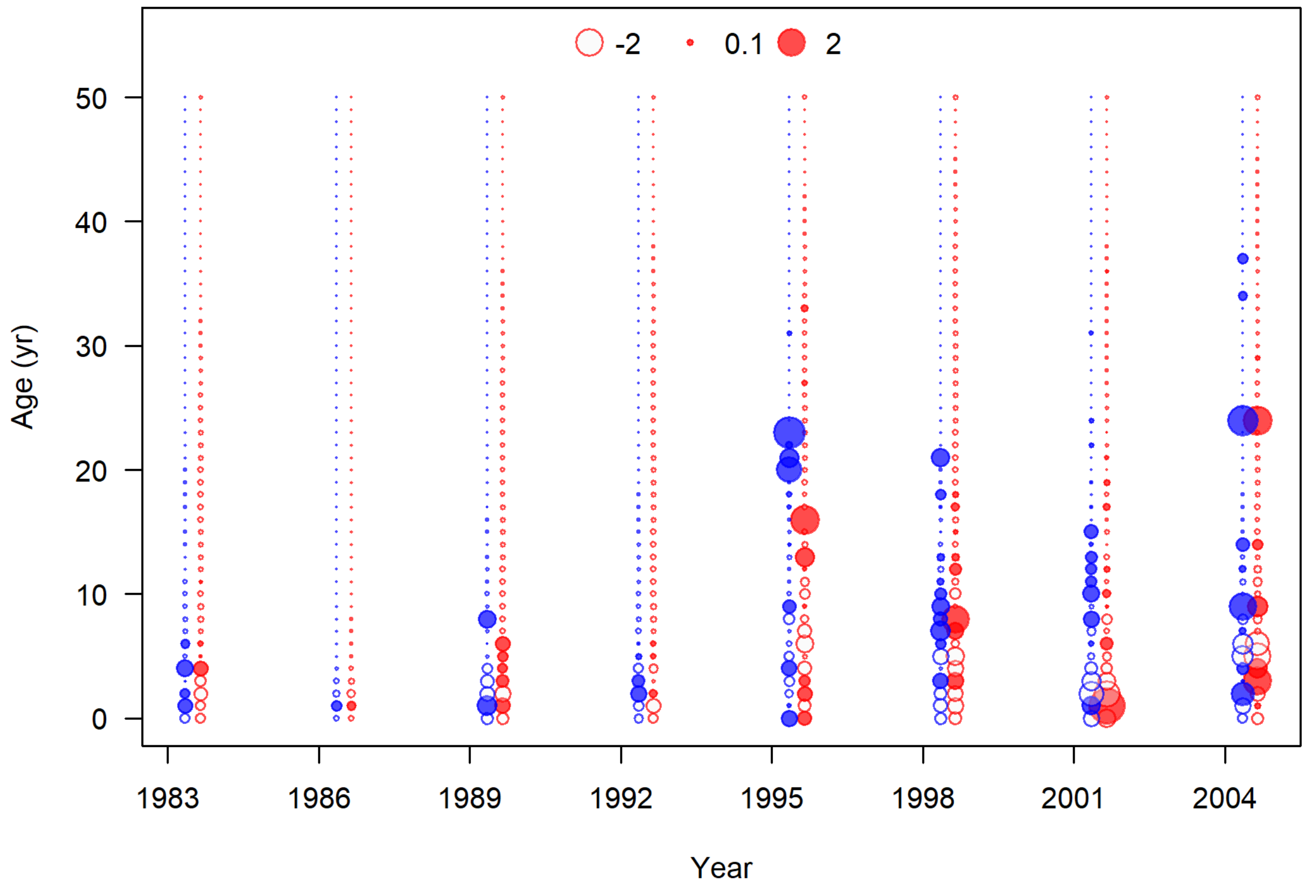


Figure 88. Pearson residuals for the fits to the Triennial Shelf Survey age-composition data. Filled circles represent positive residuals (*observed* – *expected*) where red and blue are female and male, respectively.

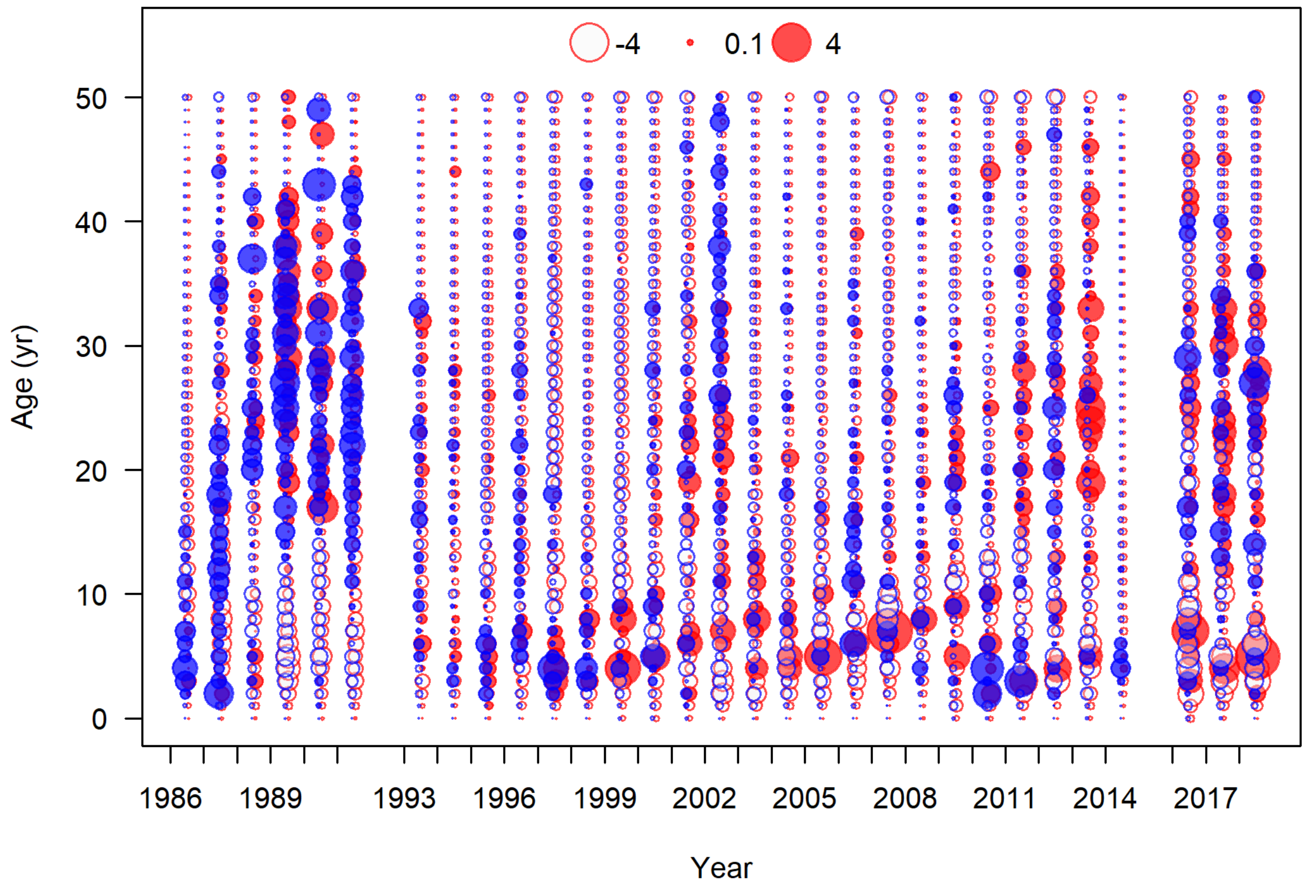


Figure 89. Pearson residuals for the fits to the fixed-gear retained age-composition data. Filled circles represent positive residuals (*observed* – *expected*) where red and blue are female and male, respectively.

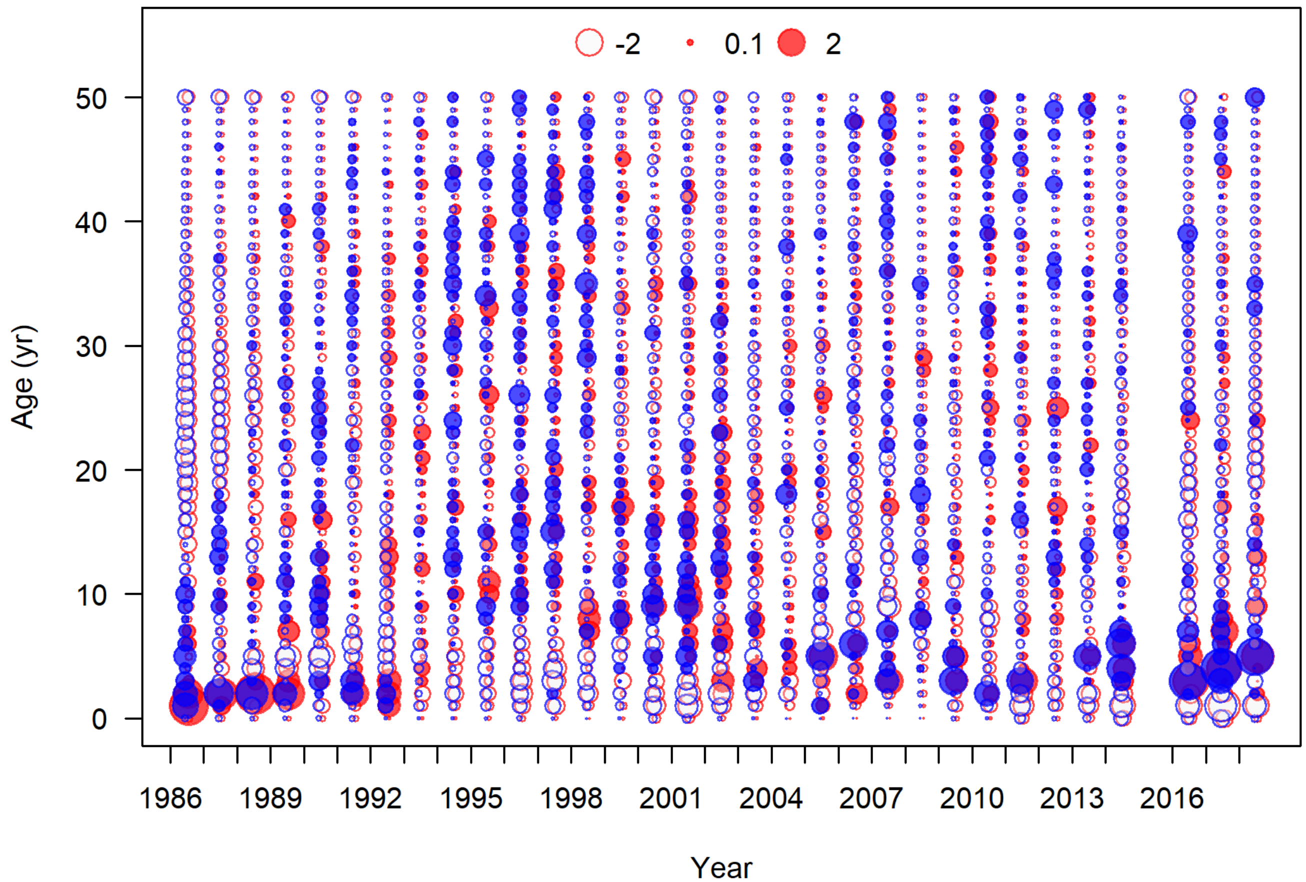


Figure 90. Pearson residuals for the fits to the trawl retained age-composition data. Filled circles represent positive residuals (*observed* − *expected*) where red and blue are female and male, respectively.

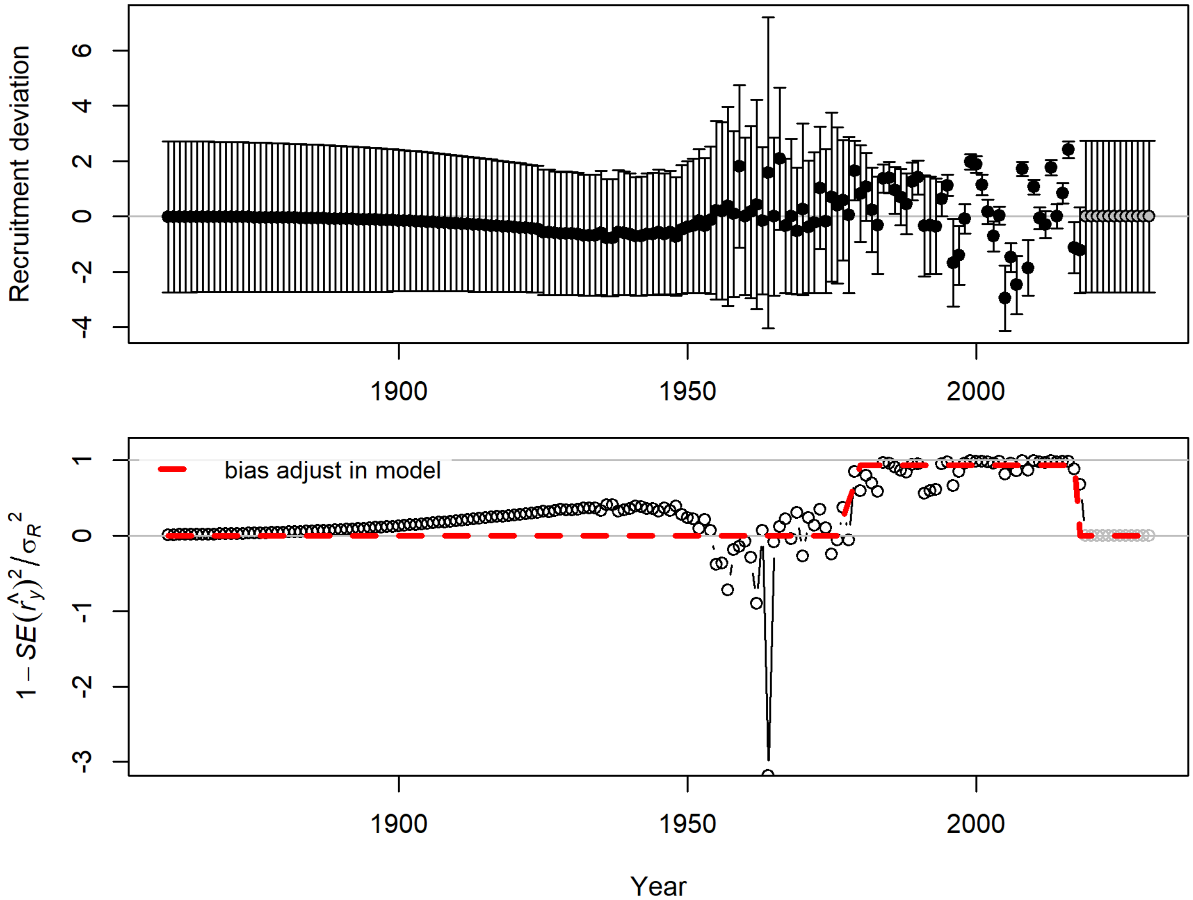


Figure 91. Estimated recruitment deviation time-series (upper panel) and bias adjustment relative to the ratio of recruitment estimation uncertainty and σ_r (lower panel).

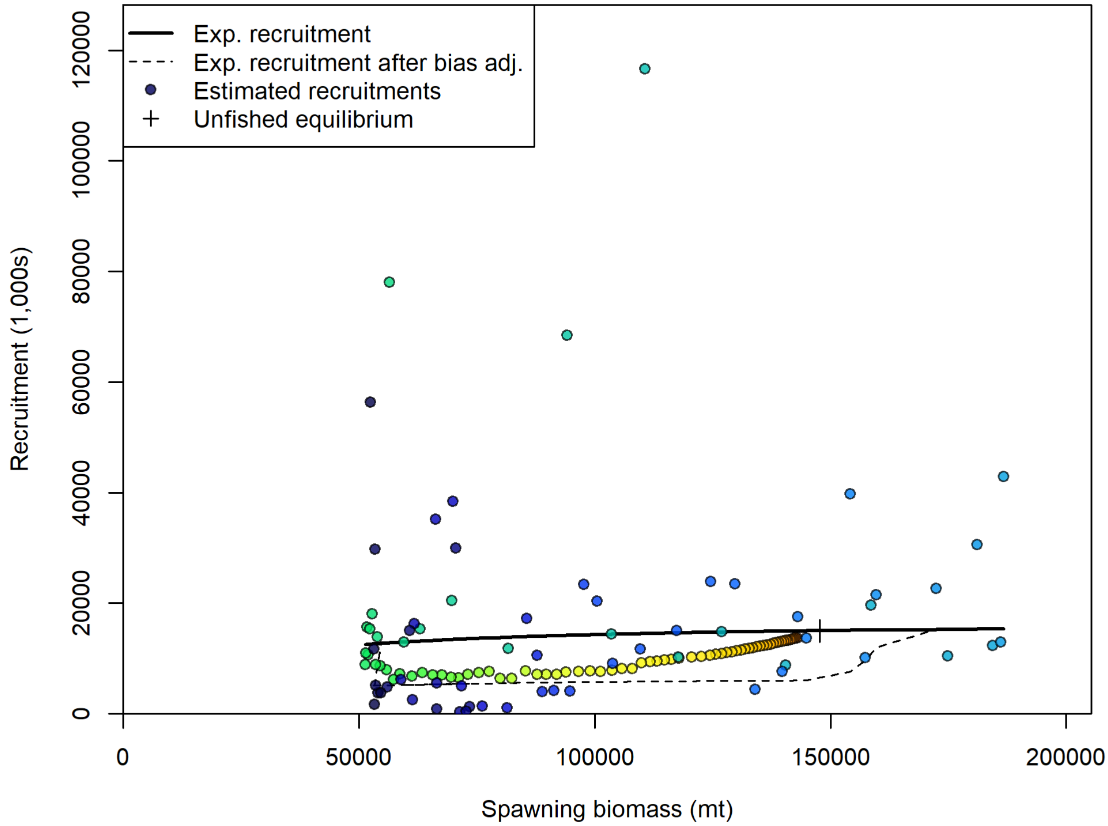


Figure 92. Estimated stock-recruitment function for the base model.

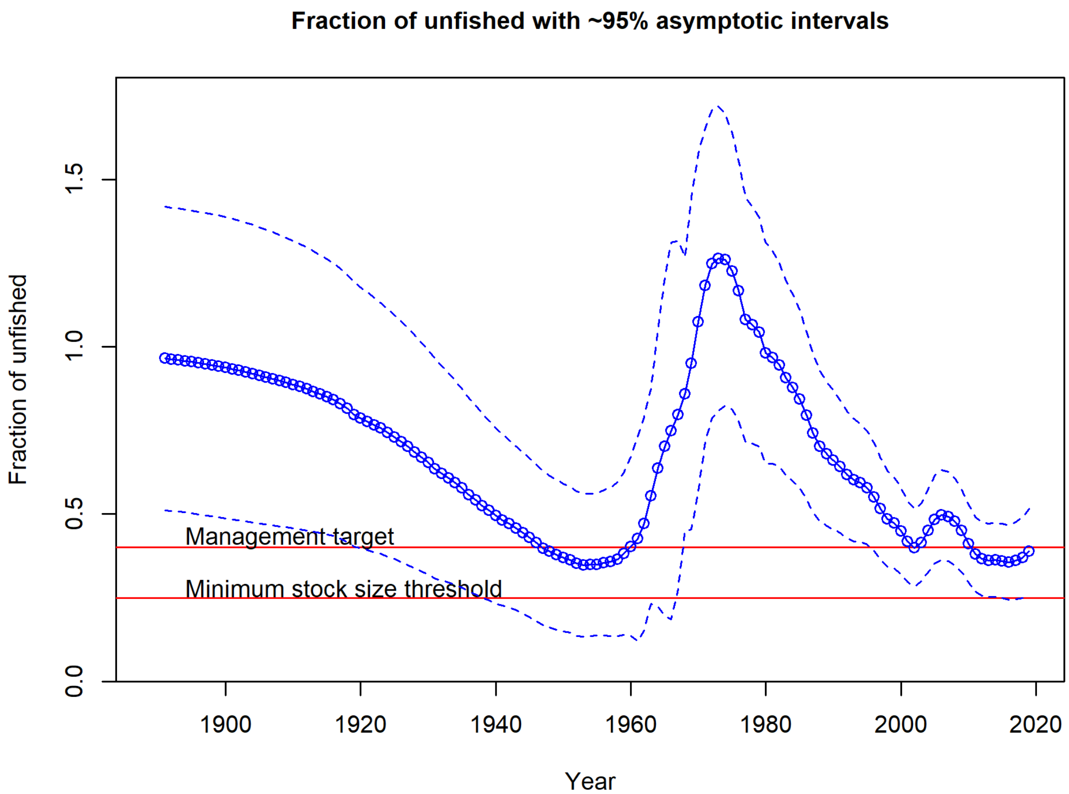


Figure 93. Time series of estimated relative spawning depletion from the base model (solid line) with ∼95% interval (dashed lines).

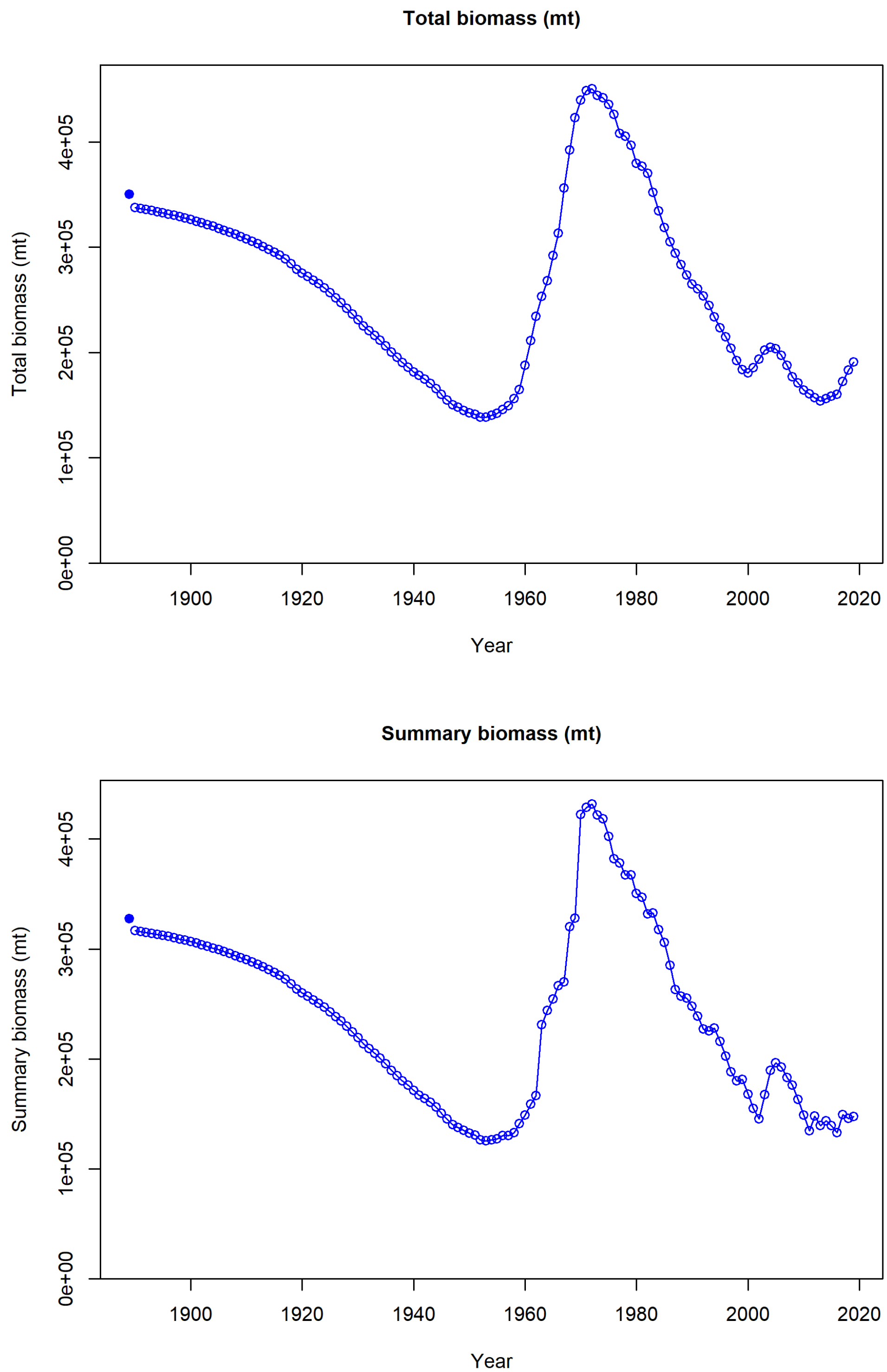


Figure 94. Estimated total (upper panel) and summary (age-4+; lower panel) biomass (age-4+) time-series for the base model.

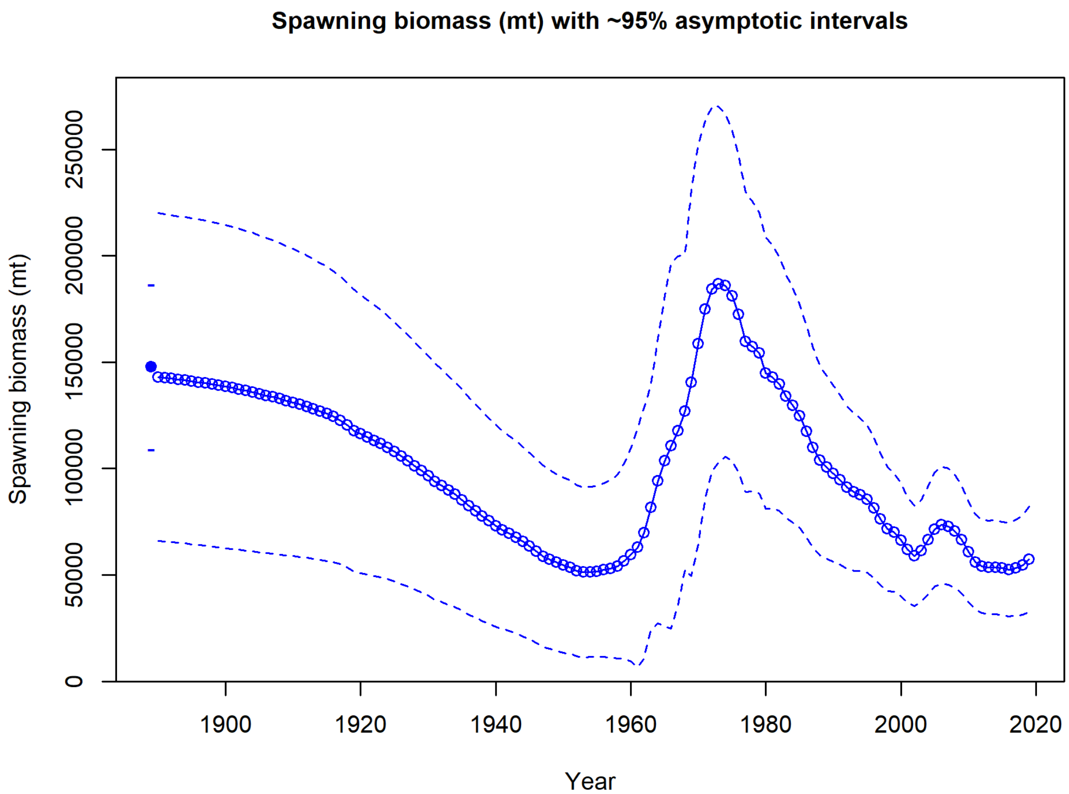


Figure 95. Estimated spawning biomass time-series for the base model (solid line) with ∼95% interval (dashed lines).

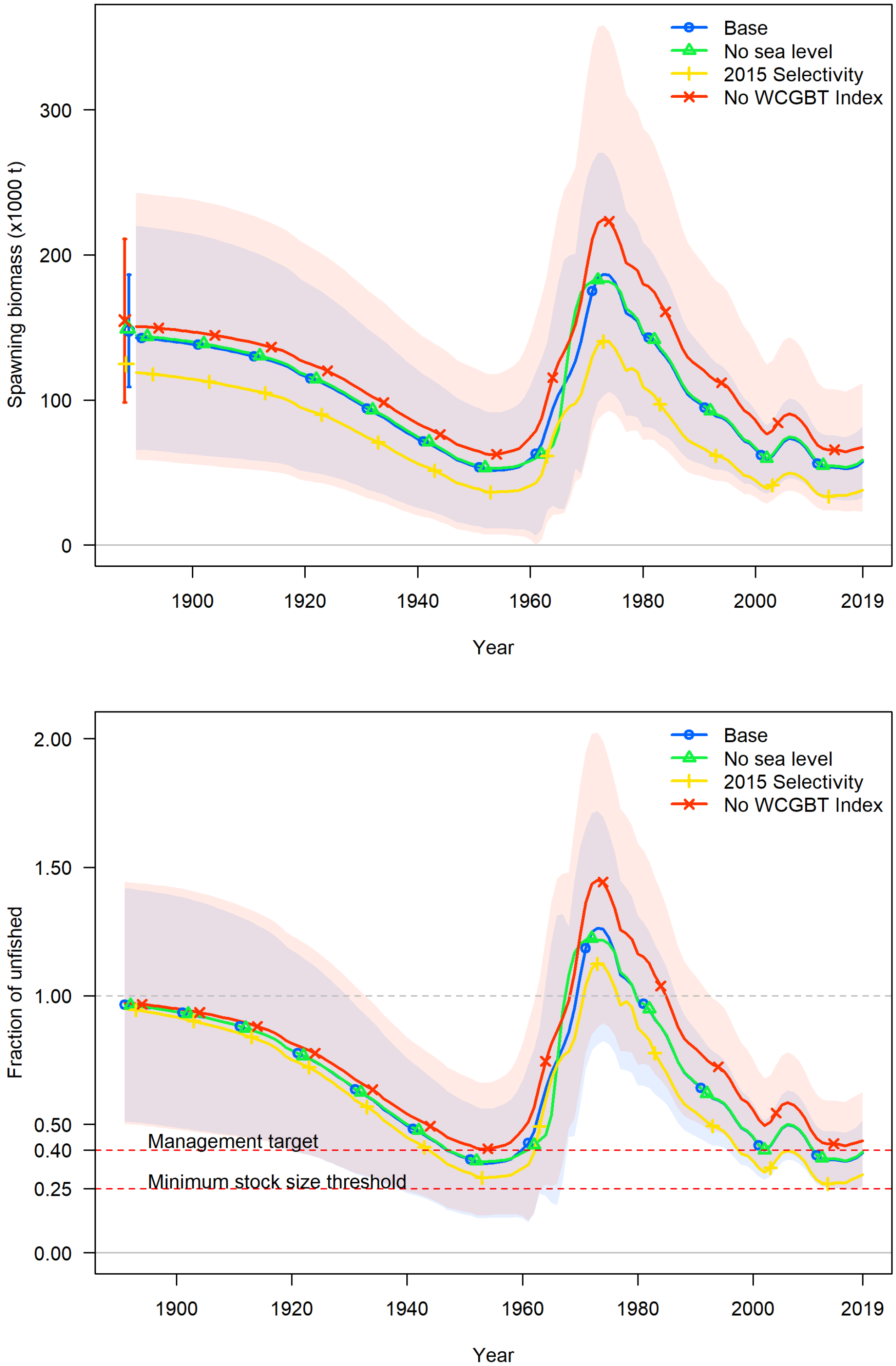


Figure 96. Sensitivity in spawning biomass and depletion to removing the sea-level data from the base model, assuming the same selectivity as the 2015 base model, and removing the West Coast Groundfish Bottom Trawl Survey index from the base model.

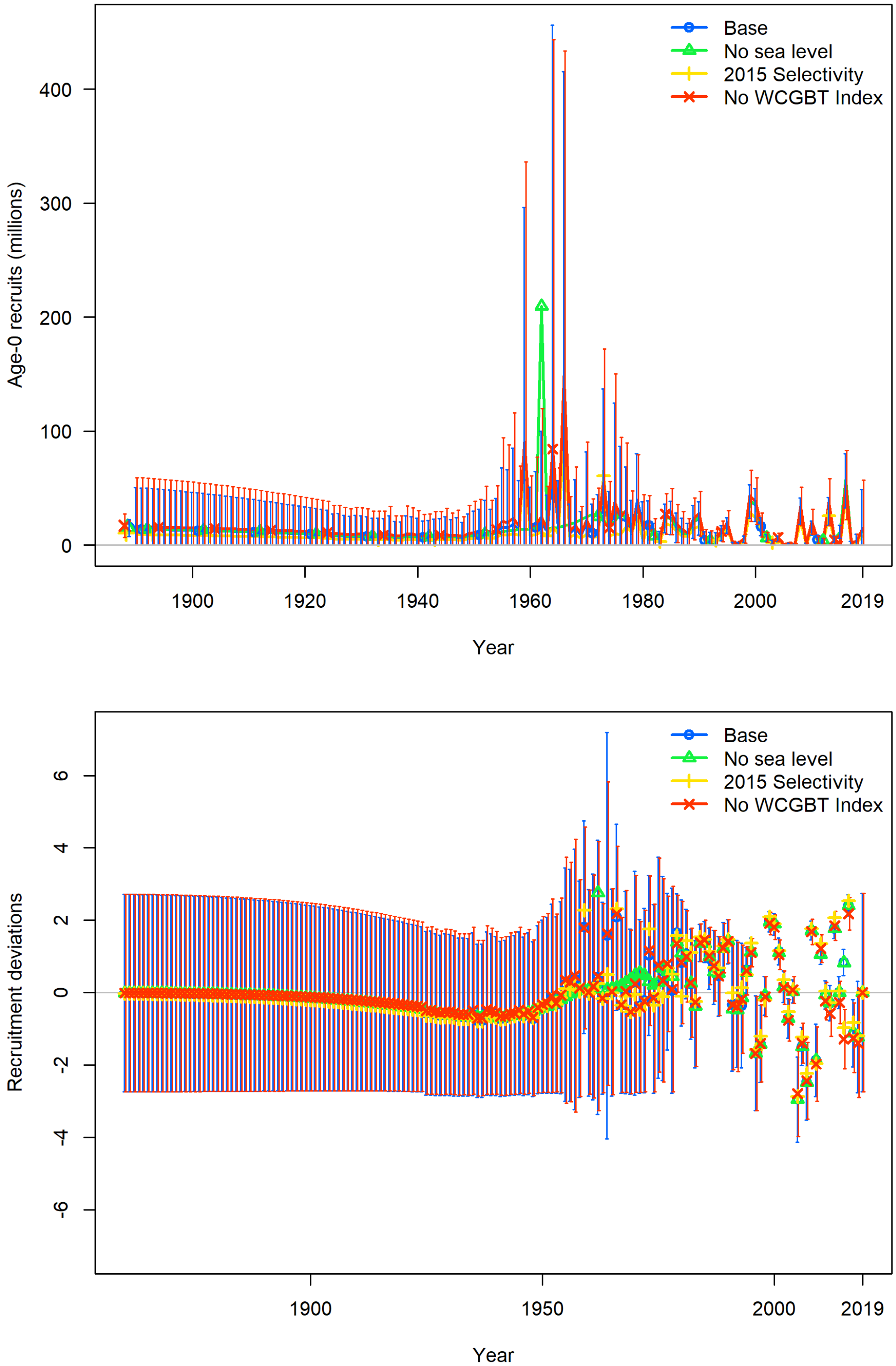


Figure 97. Sensitivity in recruitment to removing the sea-level data from the base model, assuming the same selectivity as the 2015 base model, and removing the West Coast Groundfish Bottom Trawl Survey index from the base model. Millions of age-0 recruits are shown in the upper panel, and recruitment deviations are shown in the lower panel.

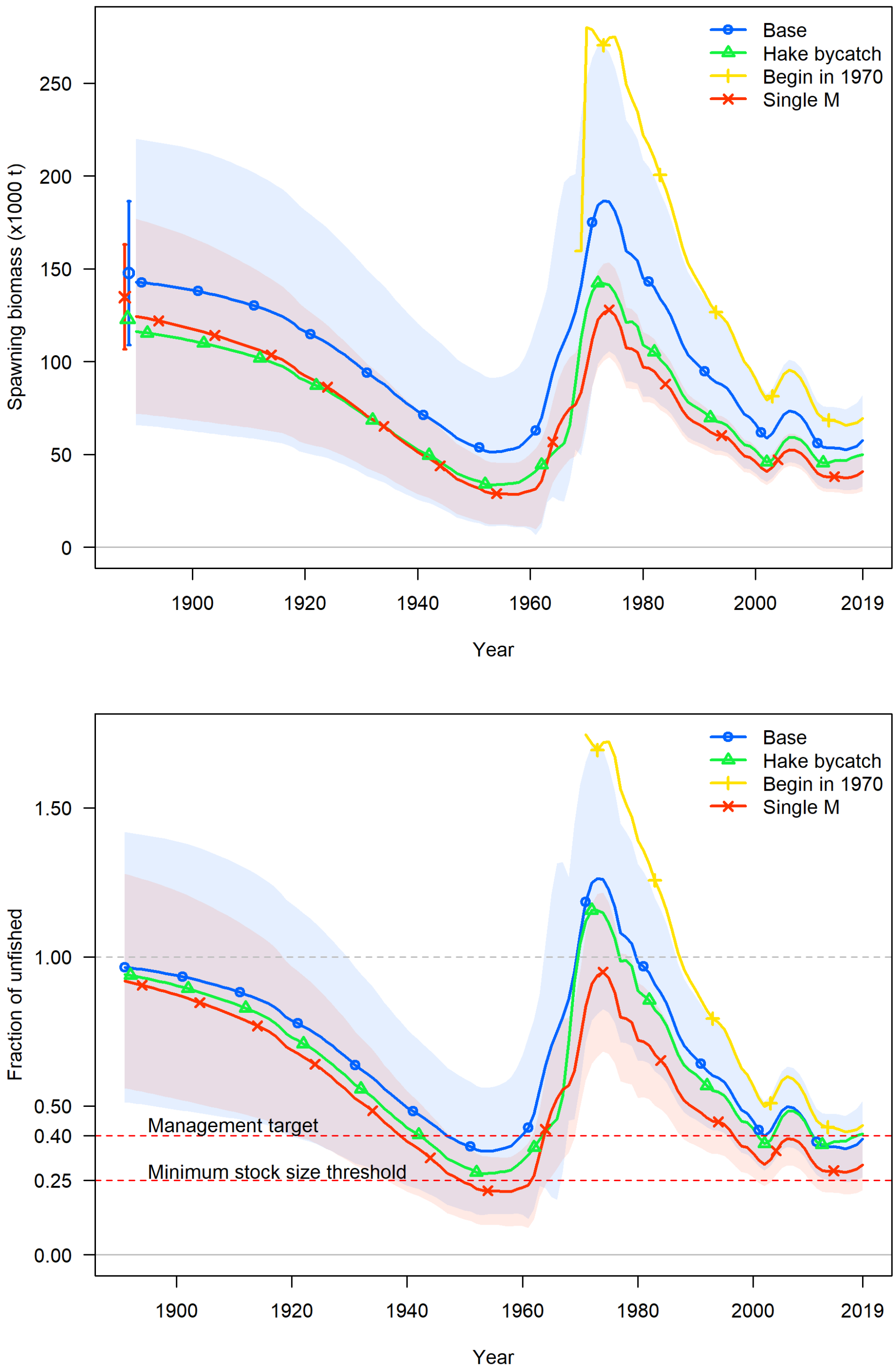


Figure 98. Sensitivity in spawning biomass and depletion to adding the hake bycatch fleet, beginning the model in 1970, and estimating a single natural mortality (*M*) parameter from the base model.

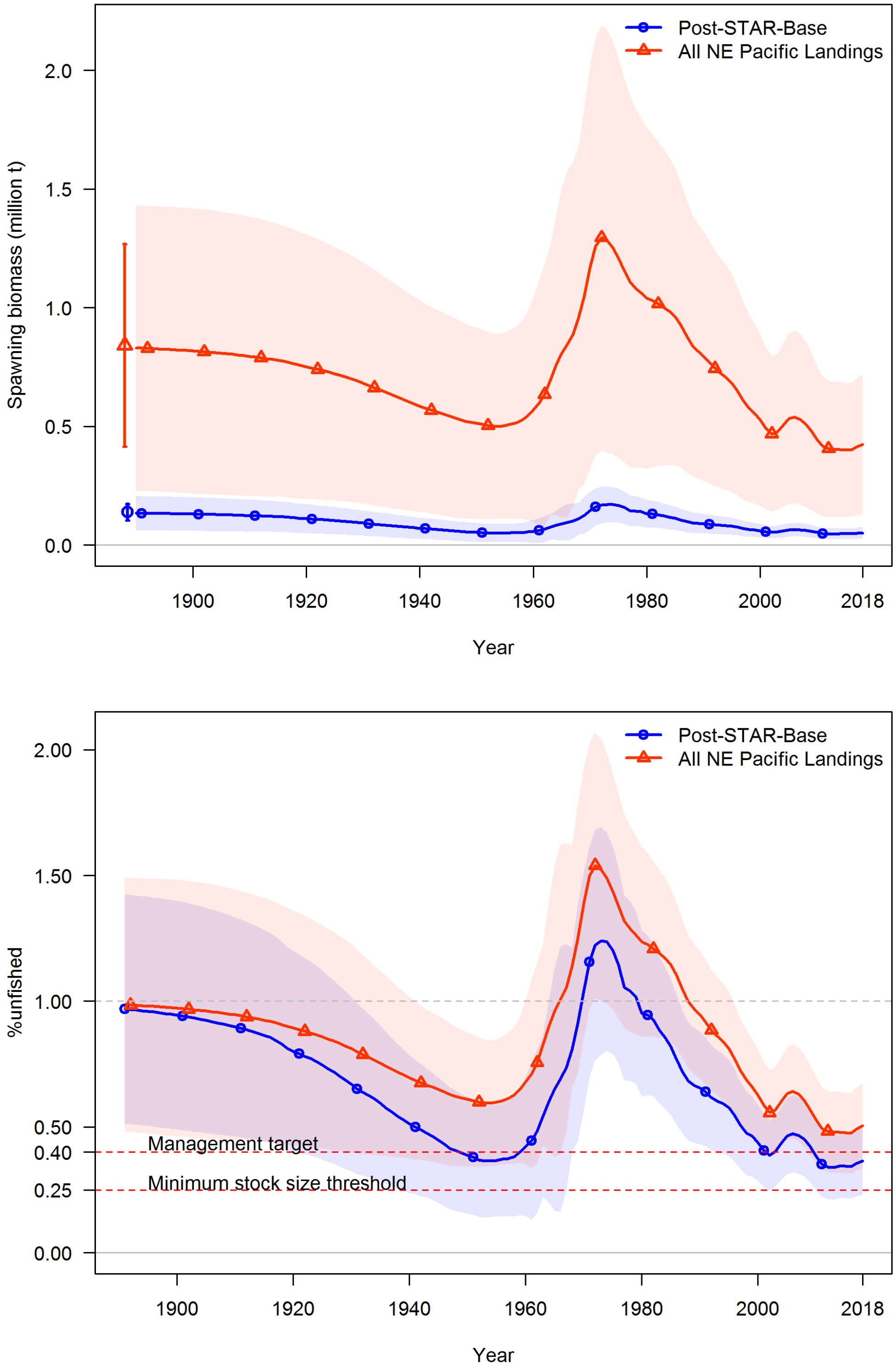


Figure 99. Sensitivity to adding landings for all of the northeast Pacific from the base model.

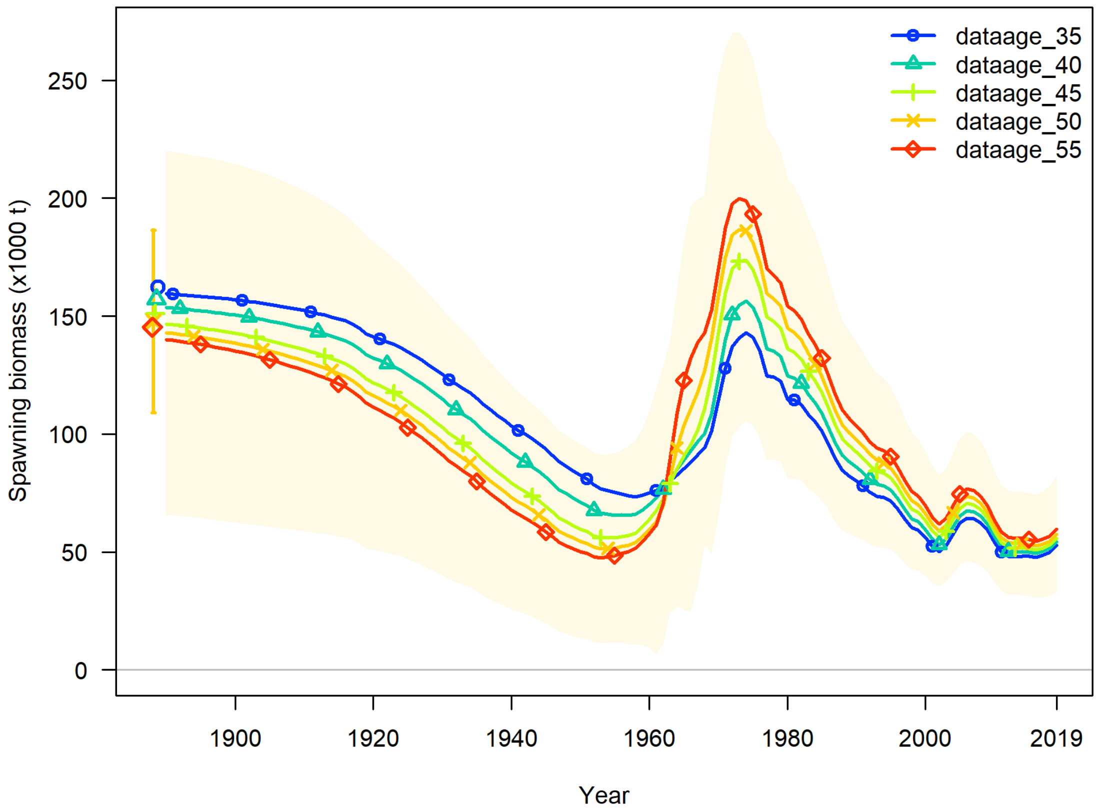


Figure 100. Sensitivity analysis on spawning biomass to the plus-group age used for the age-composition data.

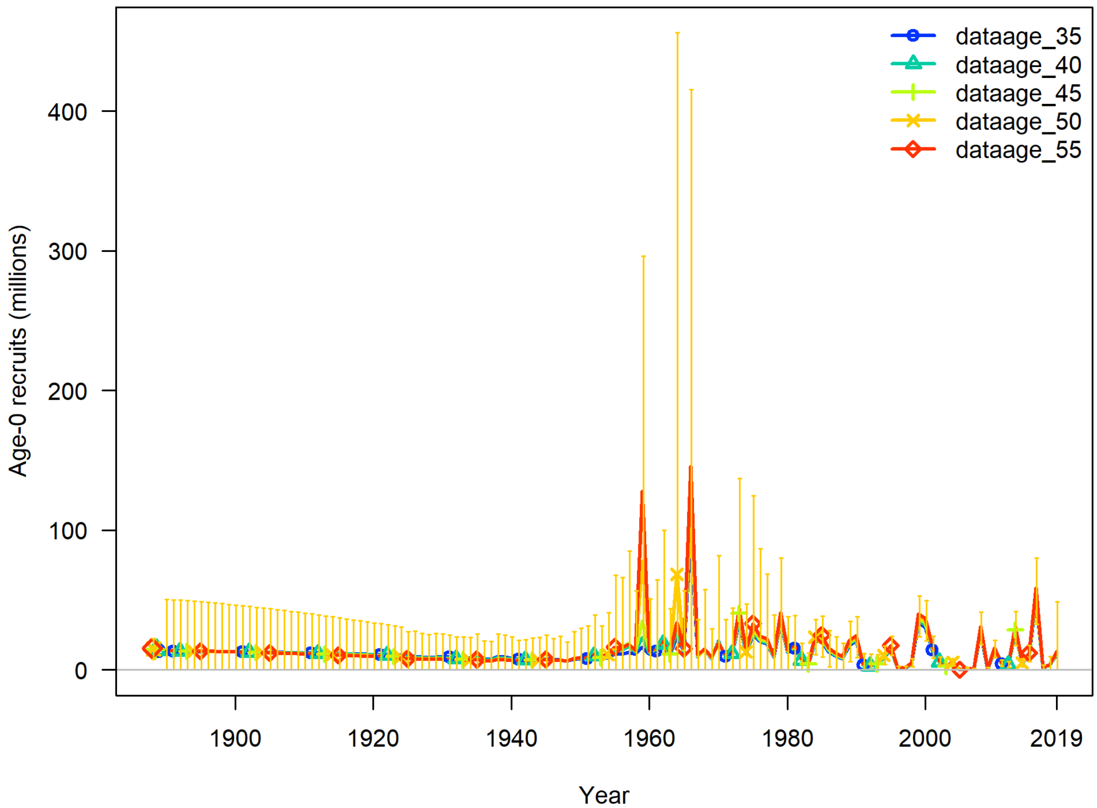


Figure 101. Sensitivity analysis on recruitment to the plus-group age used for the age-composition data.

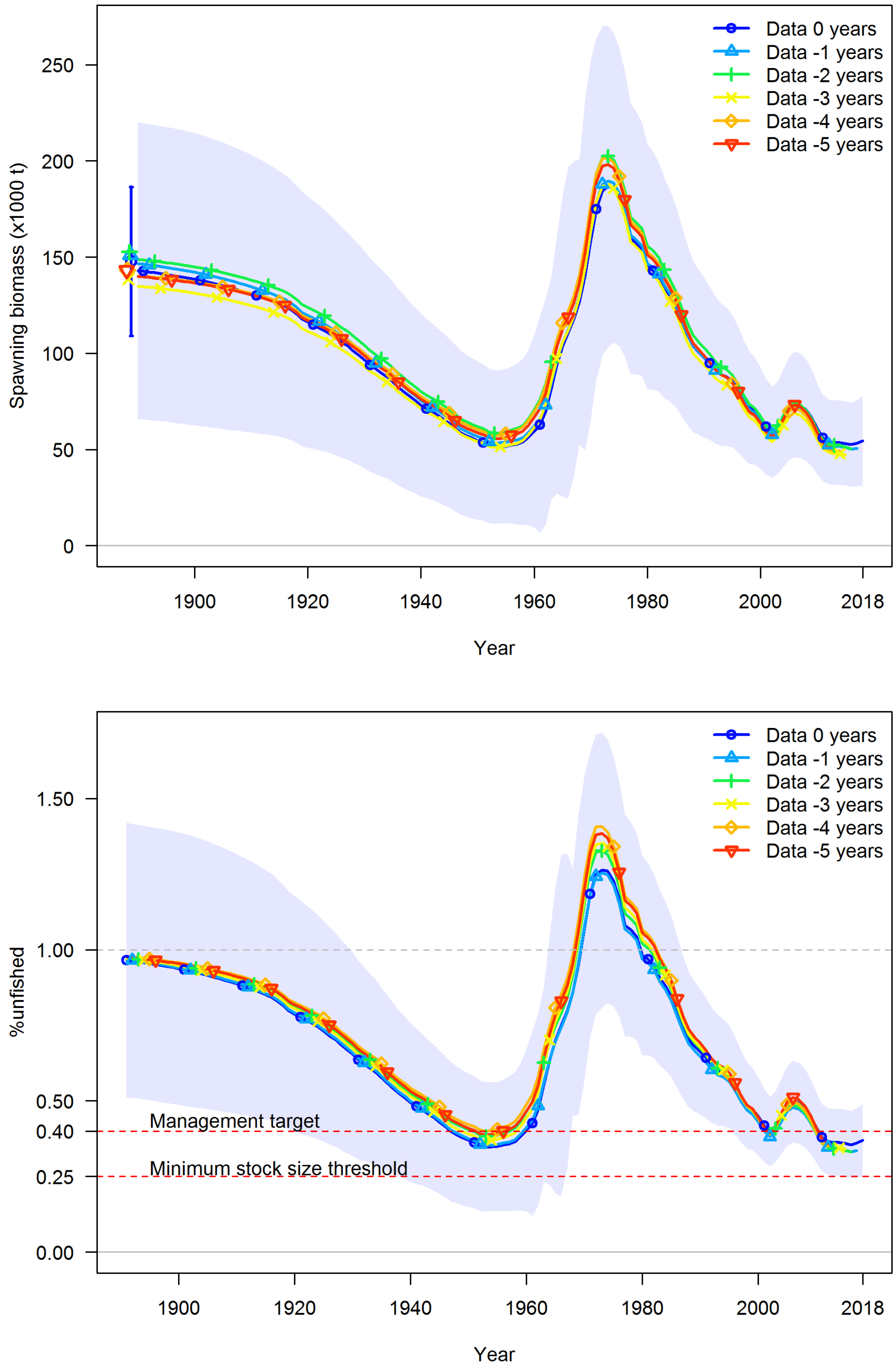


Figure 102. Retrospective analysis using the base model for comparison.

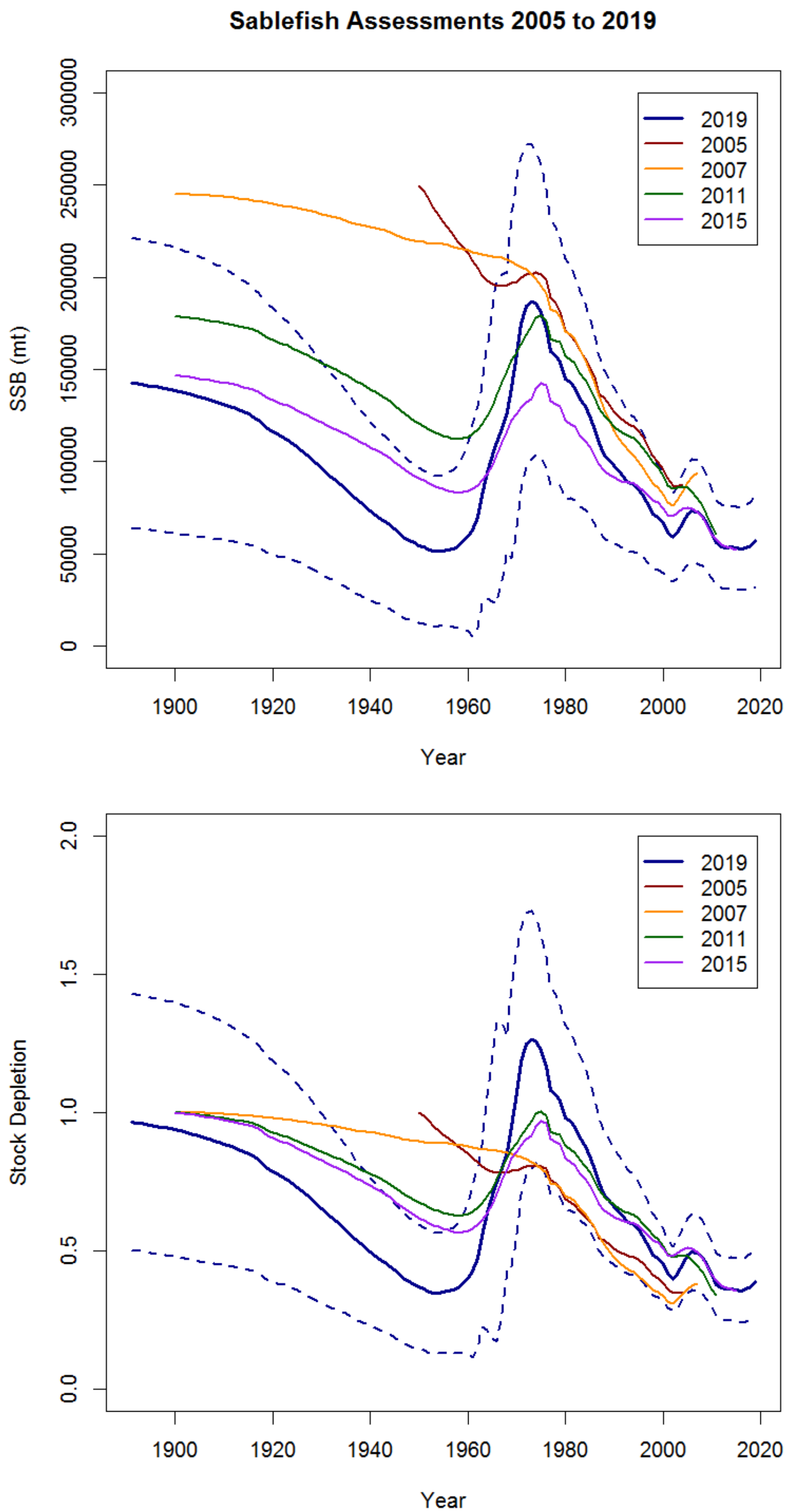


Figure 103. Comparisons of spawning stock biomass (SSB; mt) and relative depletion between the current assessment and the last four modeling exercises performed since 2005. Model-specific trajectories are represented with colored lines and the dashed line is the uncertainty about the currently estimated time series.

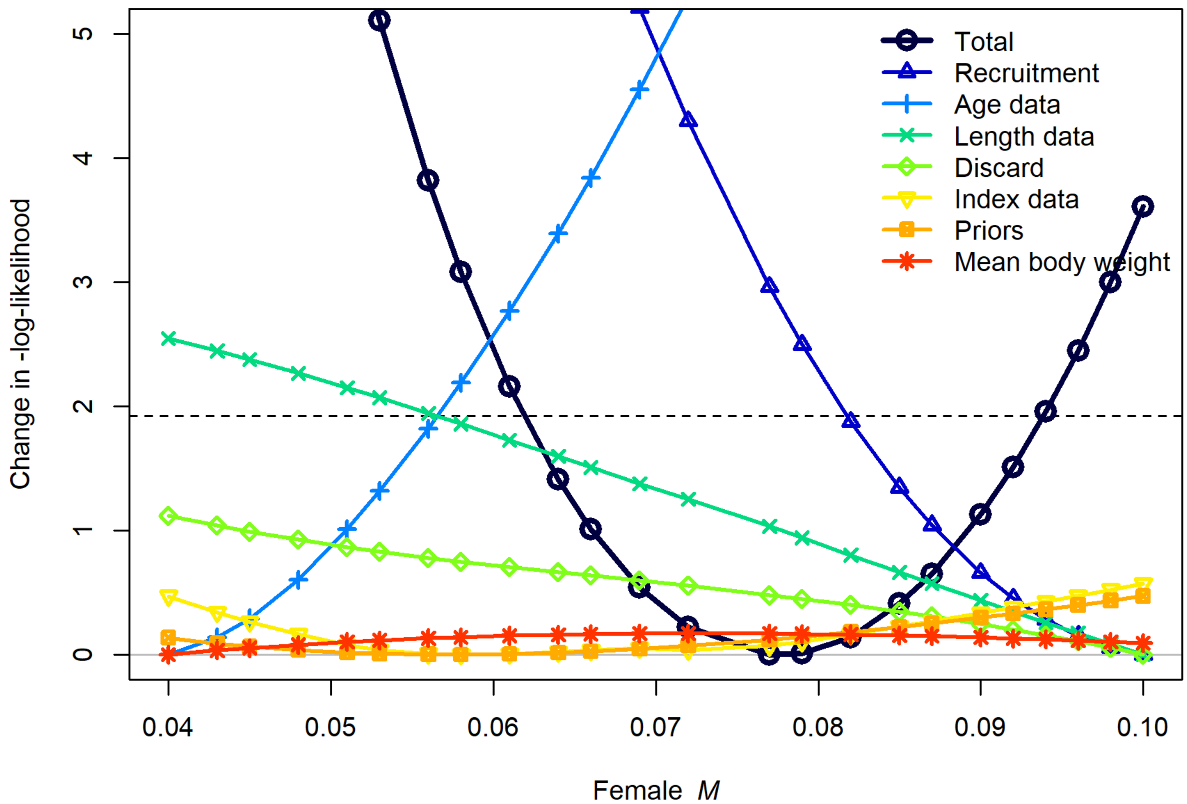


Figure 104. Results of a likelihood profile for female natural mortality (*M*) by data type.

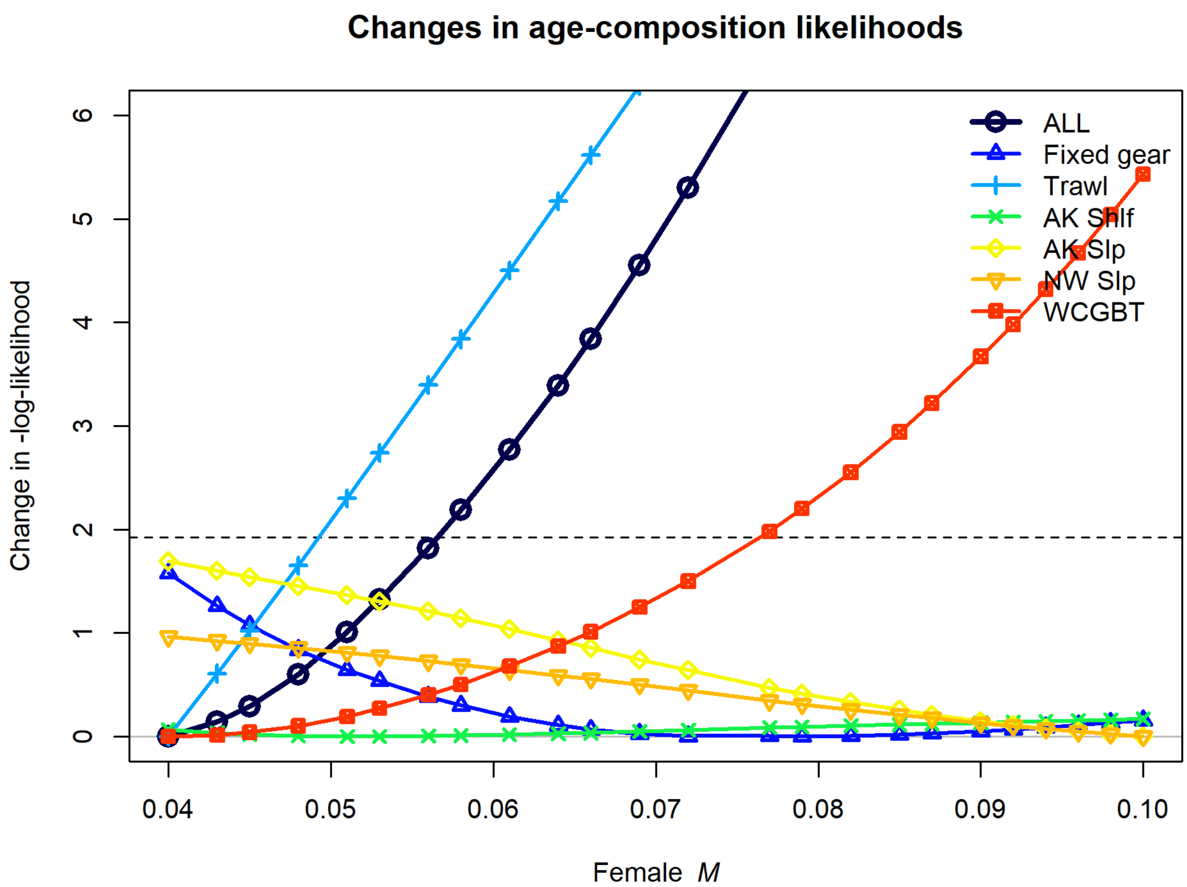


Figure 105. Age likelihoods from a likelihood profile for female natural mortality (*M*) by data type.

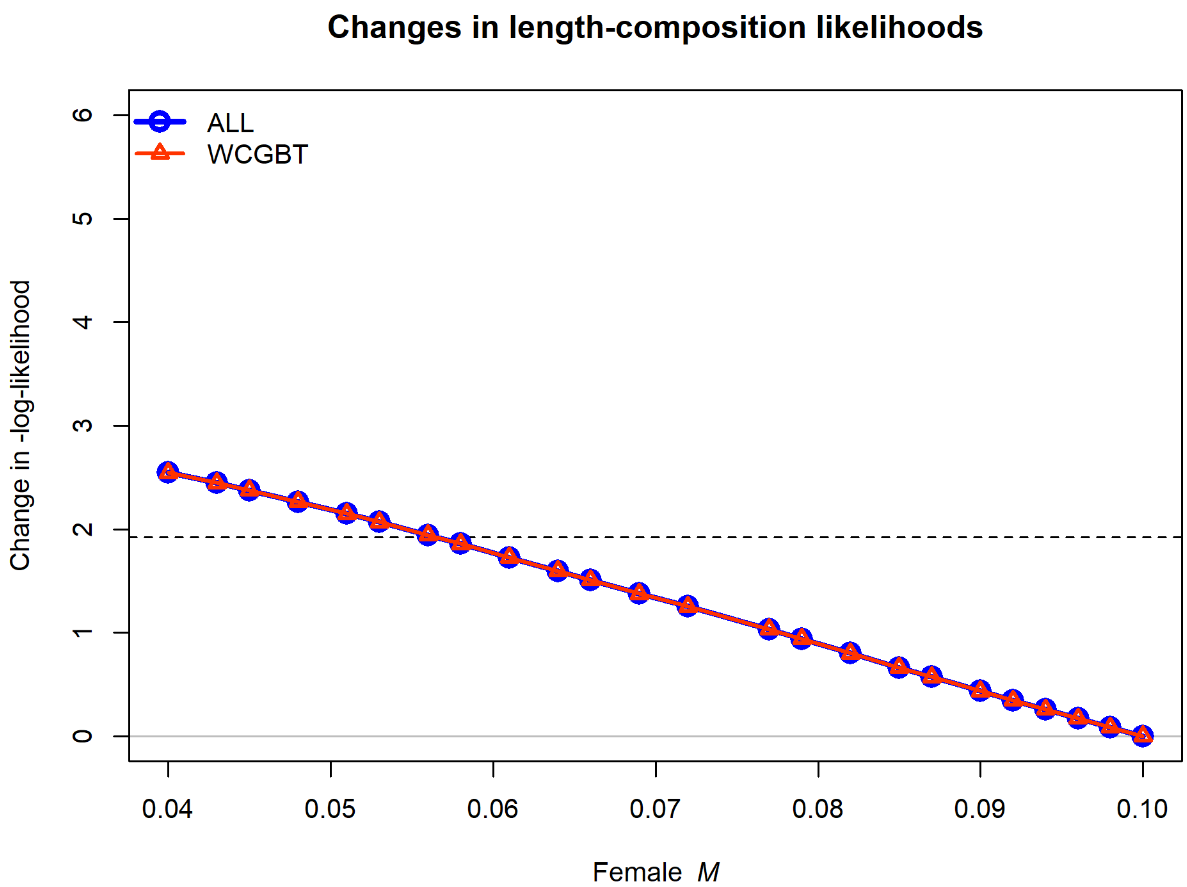


Figure 106. Length likelihoods from a likelihood profile for female natural mortality (M) by data type.

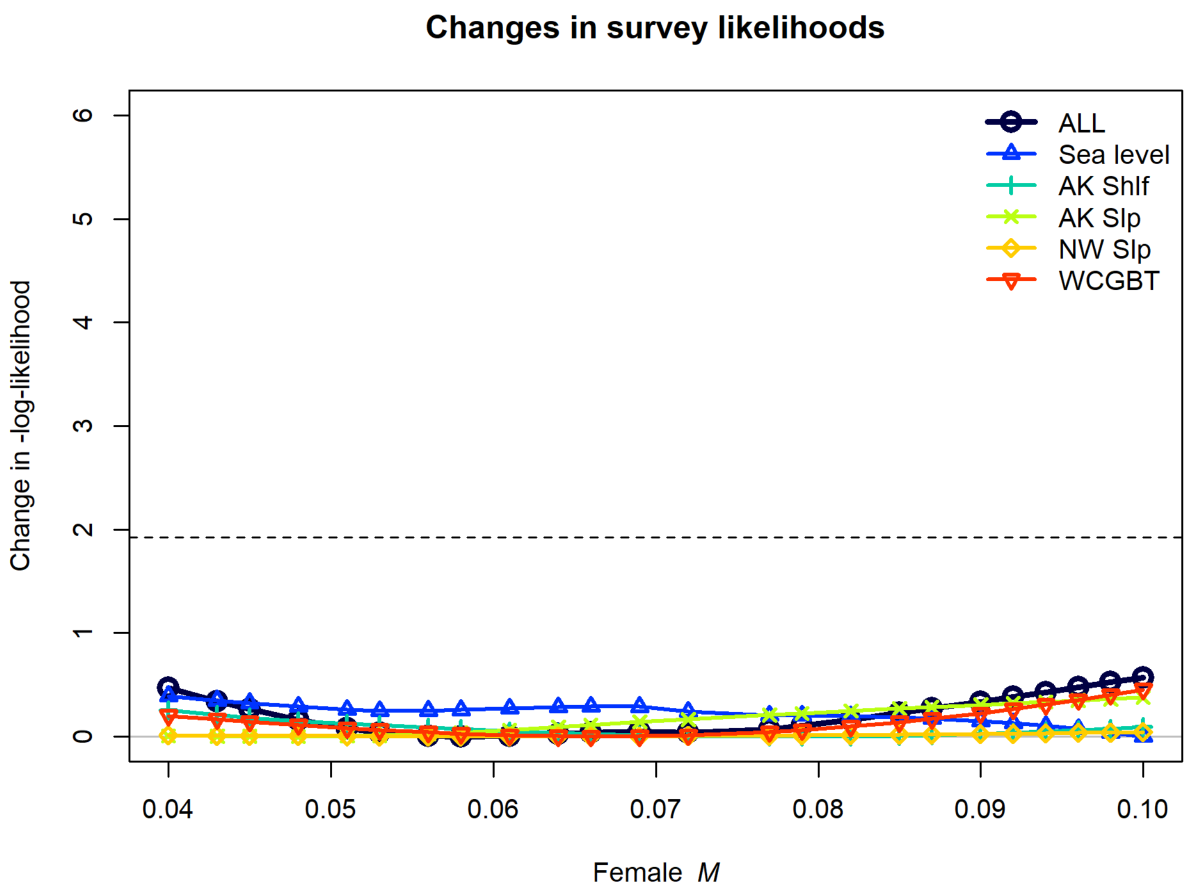


Figure 107. Survey likelihoods from a likelihood profile for female natural mortality (*M*) by data type.

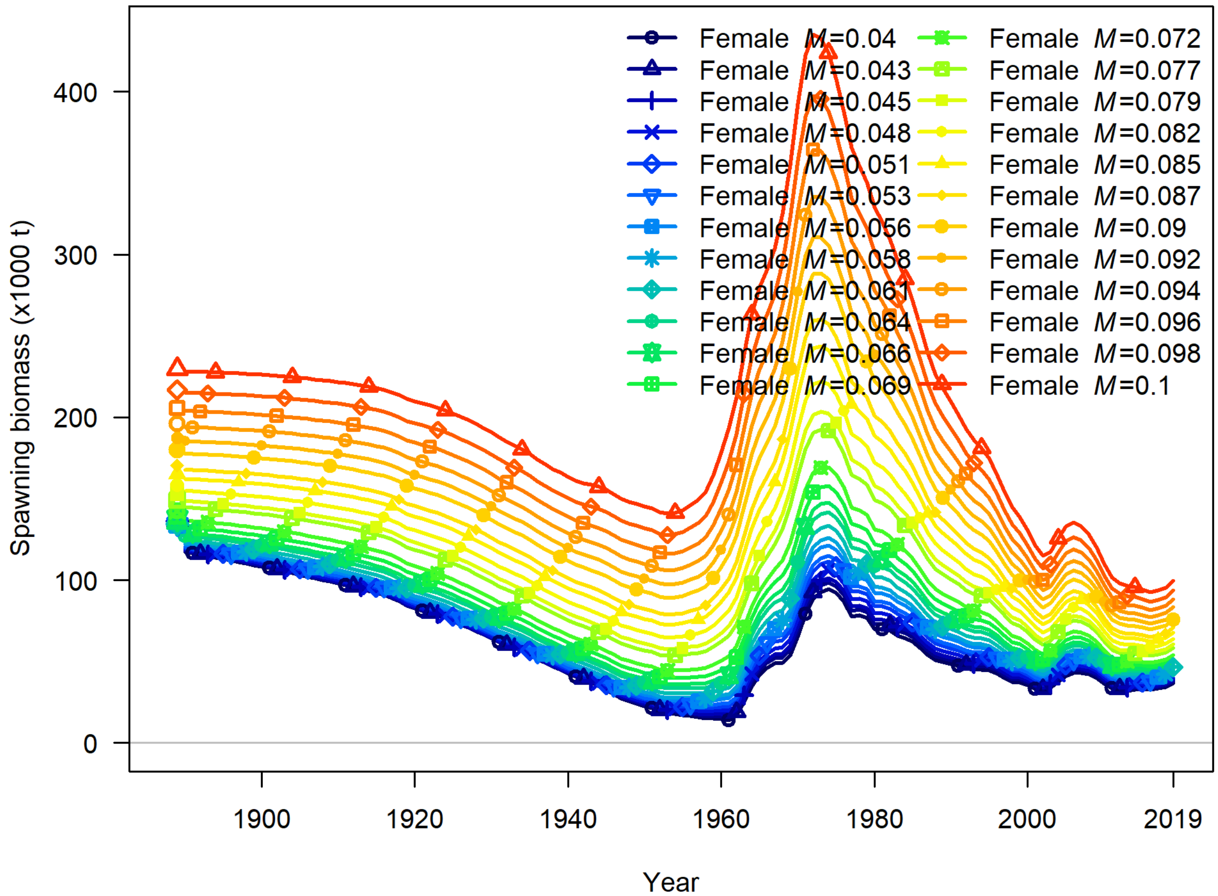


Figure 108. Time-series of spawning stock biomass for different fixed values of female natural mortality (M).

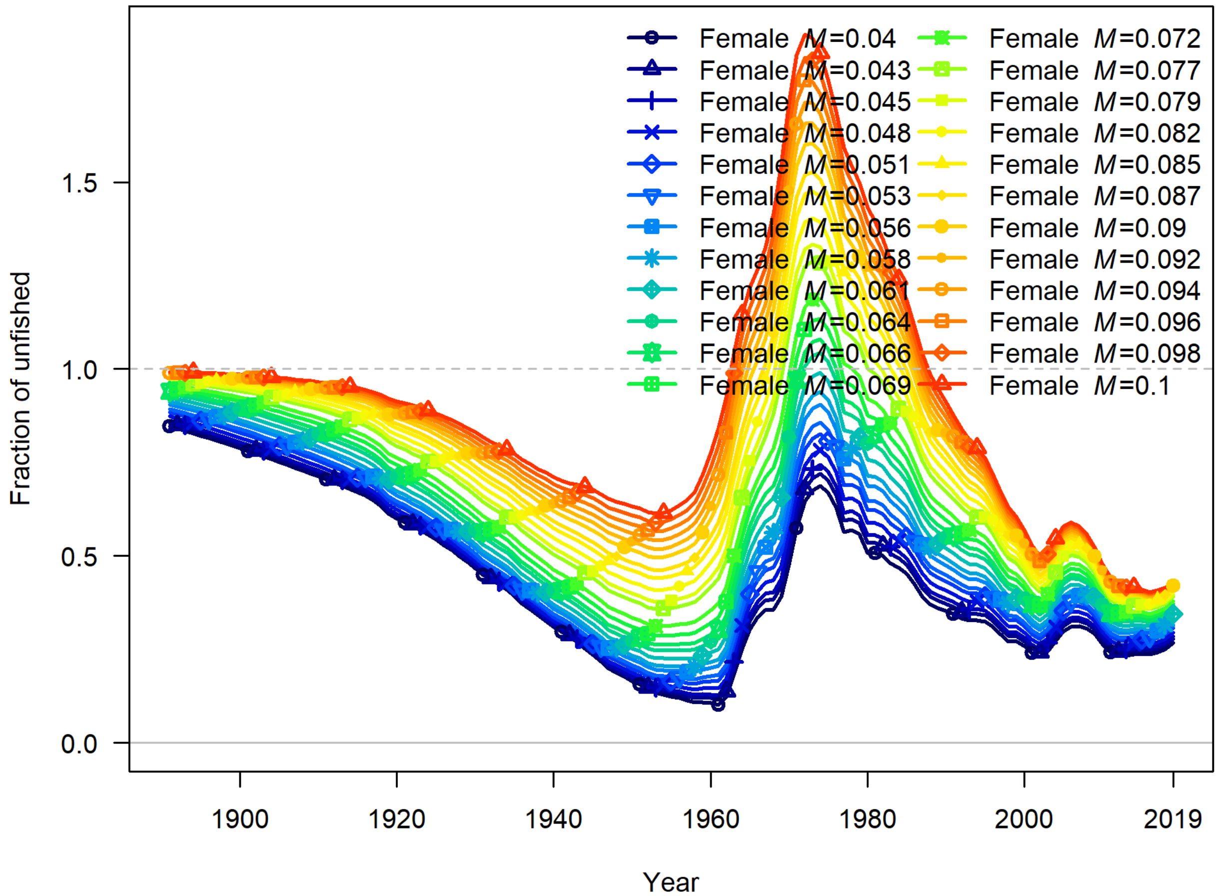


Figure 109. Time-series of relative depletion for different fixed values of female natural mortality (M).

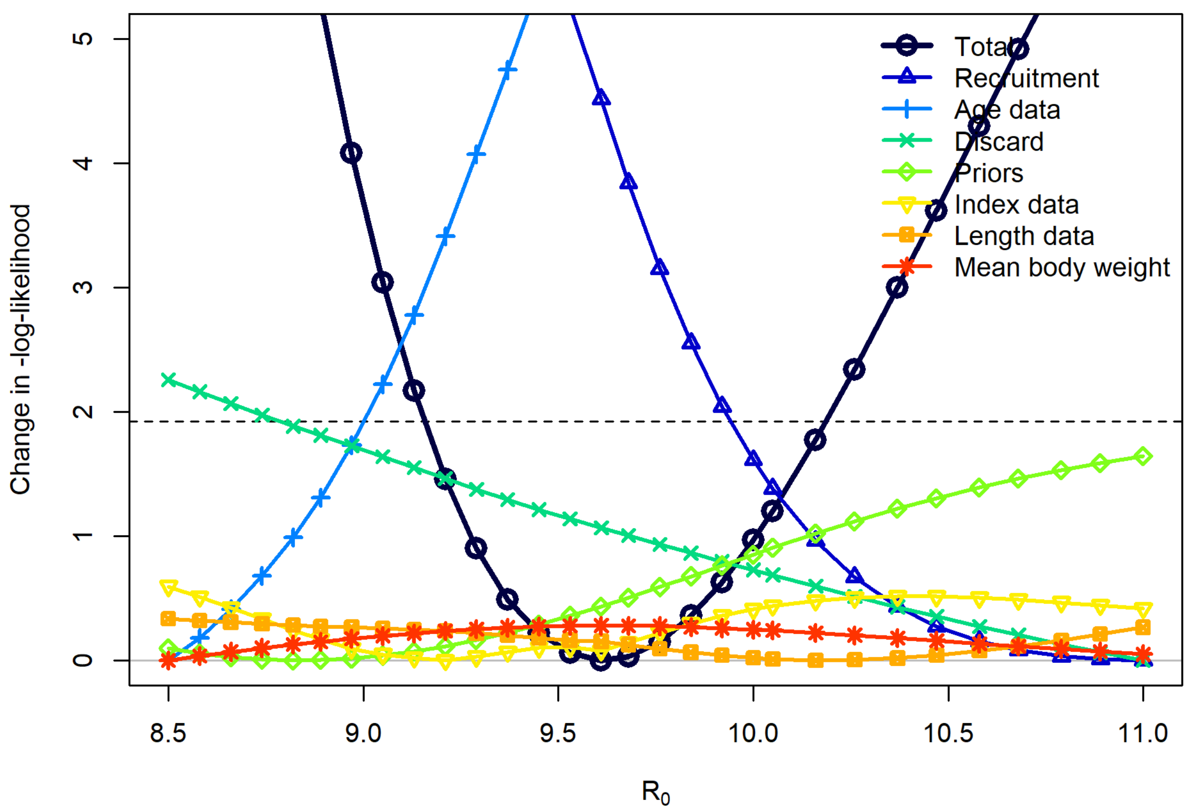


Figure 110. Results of a likelihood profile for equilibrium recruitment (R_0) by data type.

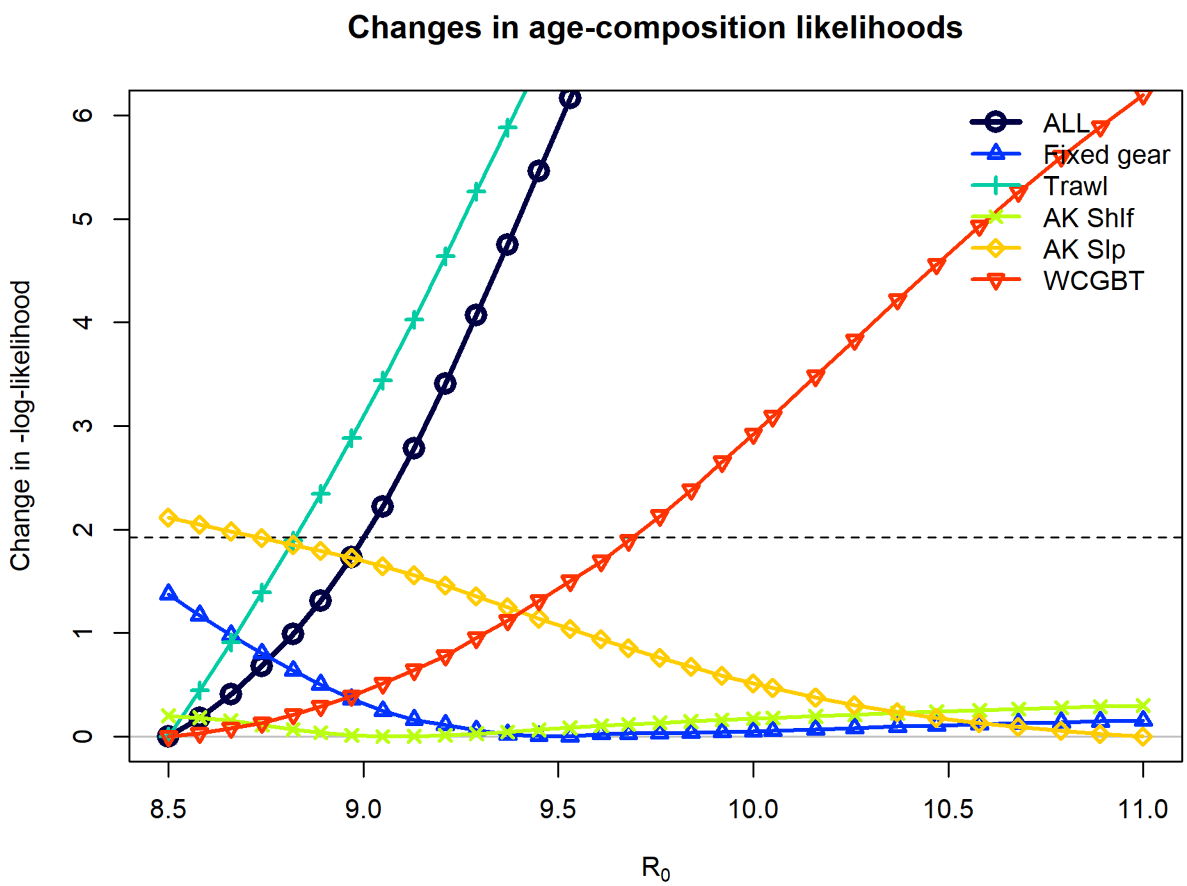


Figure 111. Age likelihoods from a likelihood profile for equilibrium recruitment (R_0) by data type.

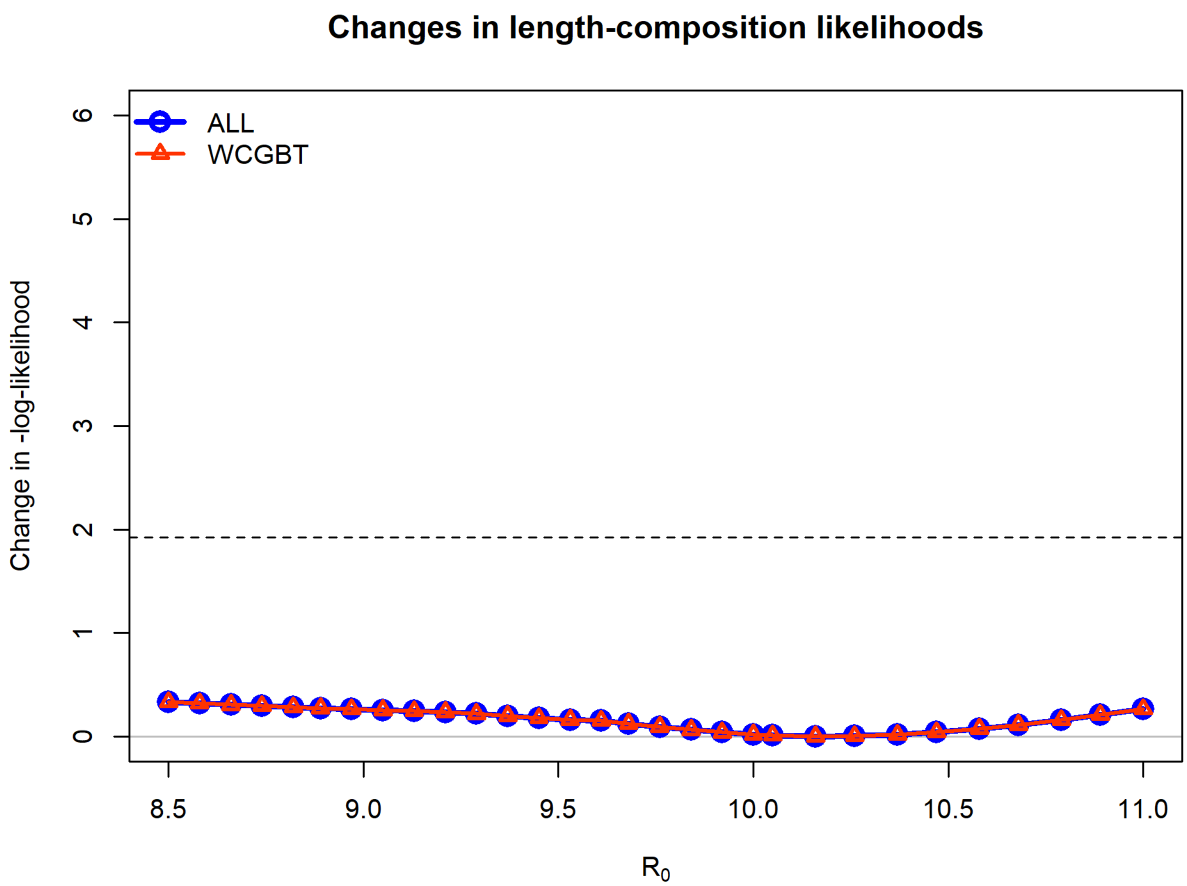


Figure 112. Length likelihoods from a likelihood profile for equilibrium recruitment (R_0) by data type.

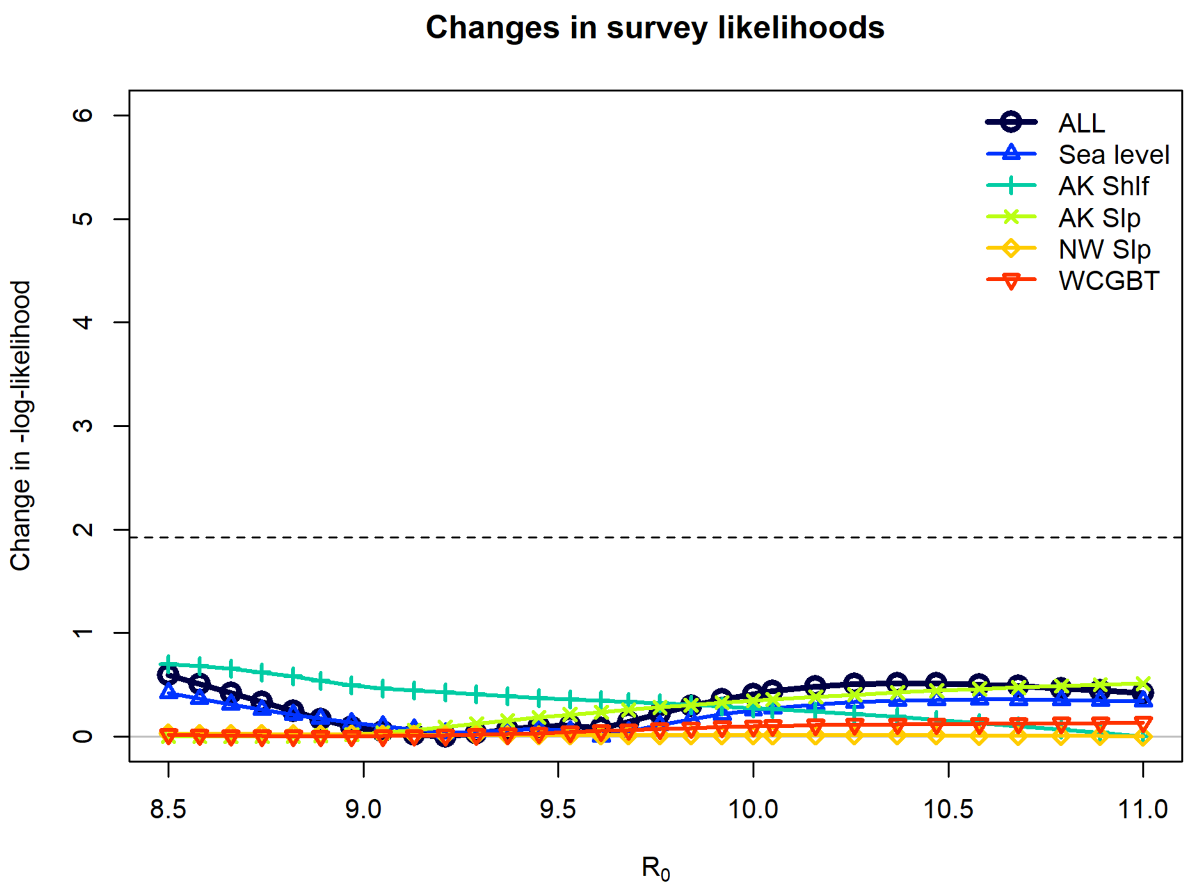


Figure 113. Survey likelihoods from a likelihood profile for equilibrium recruitment (R_0) by data type.

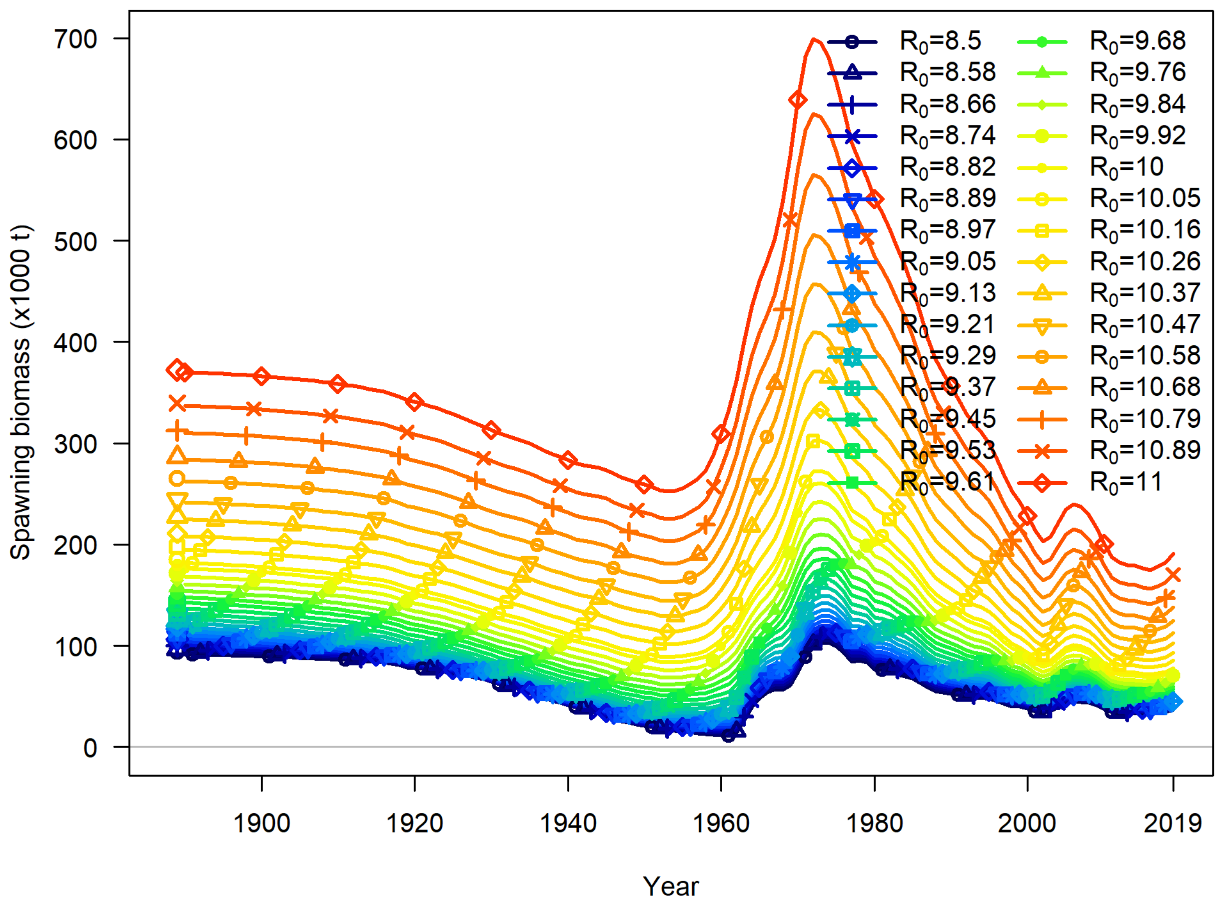


Figure 114. Time-series of spawning stock biomass for different fixed values of equilibrium recruitment (R_0).

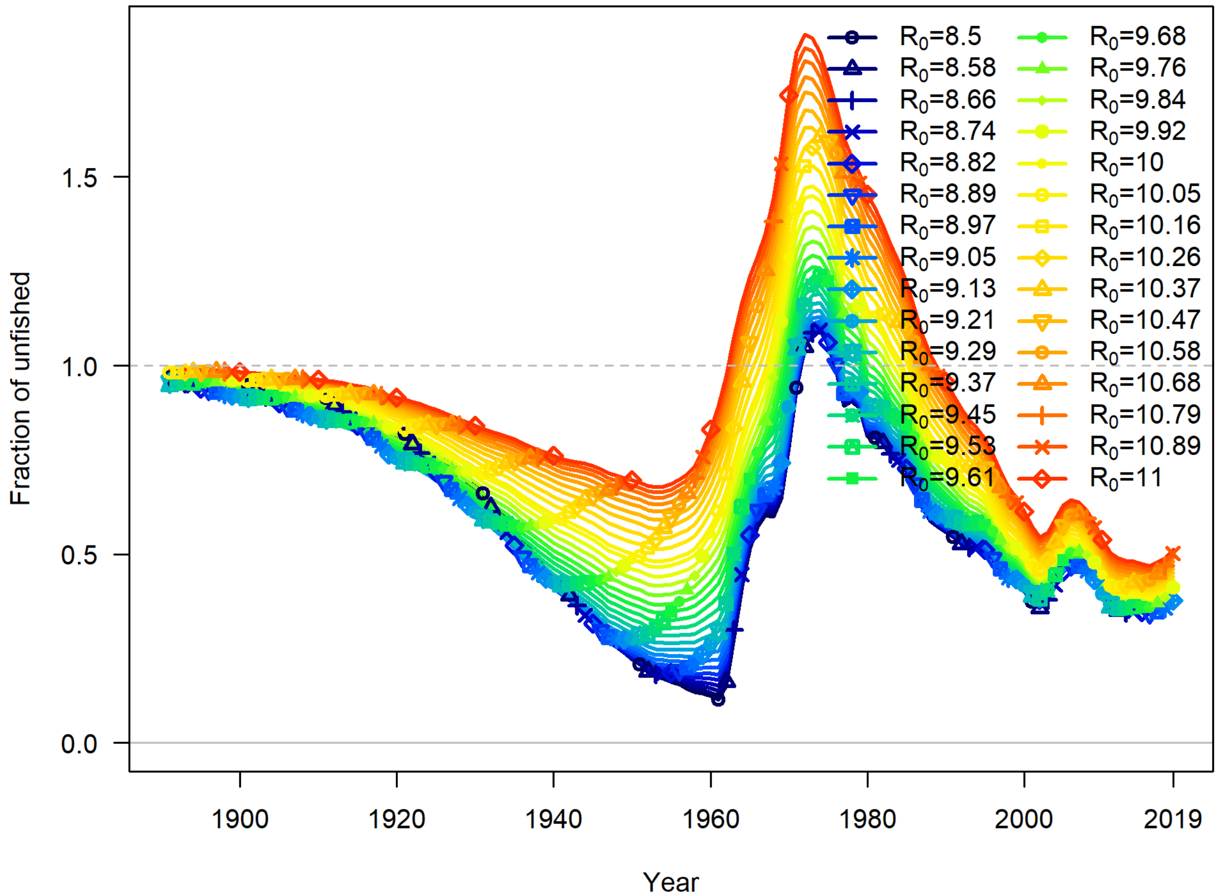


Figure 115. Time-series of relative depletion for different fixed values of equilibrium recruitment (R_0).

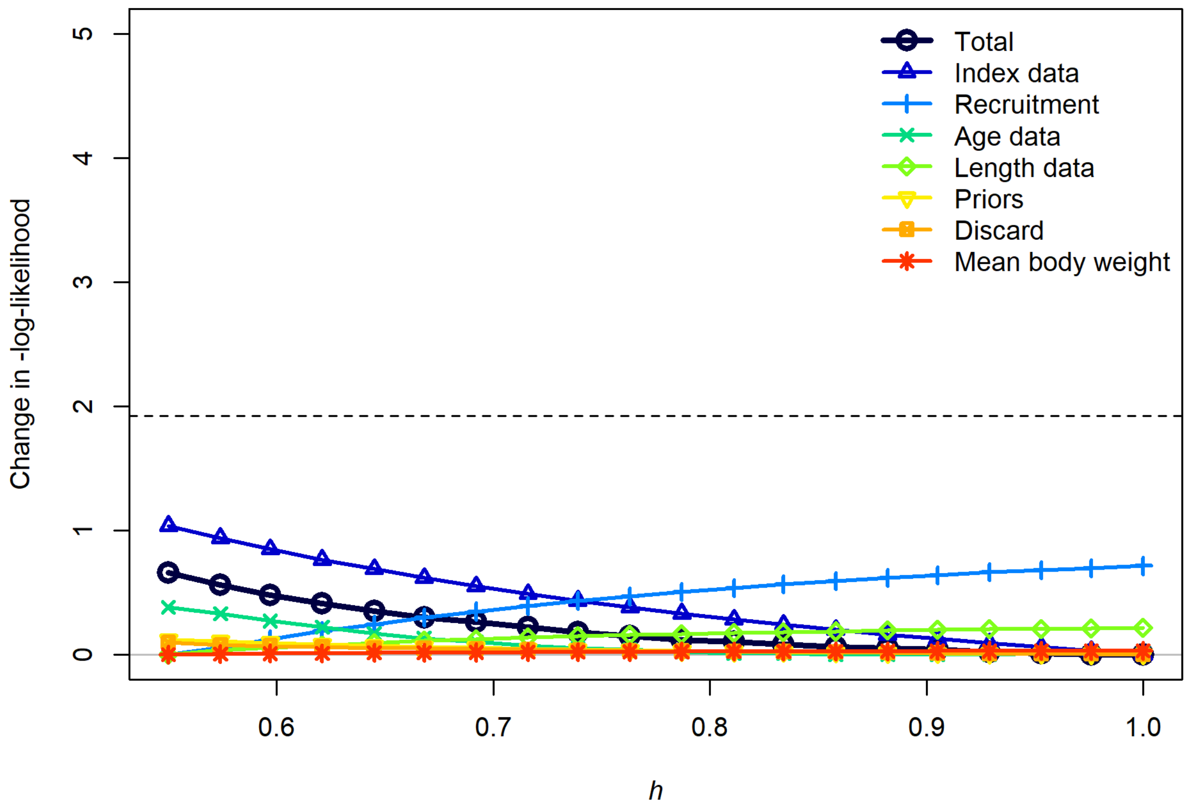


Figure 116. Results of a likelihood profile for steepness (*h*) by data type.

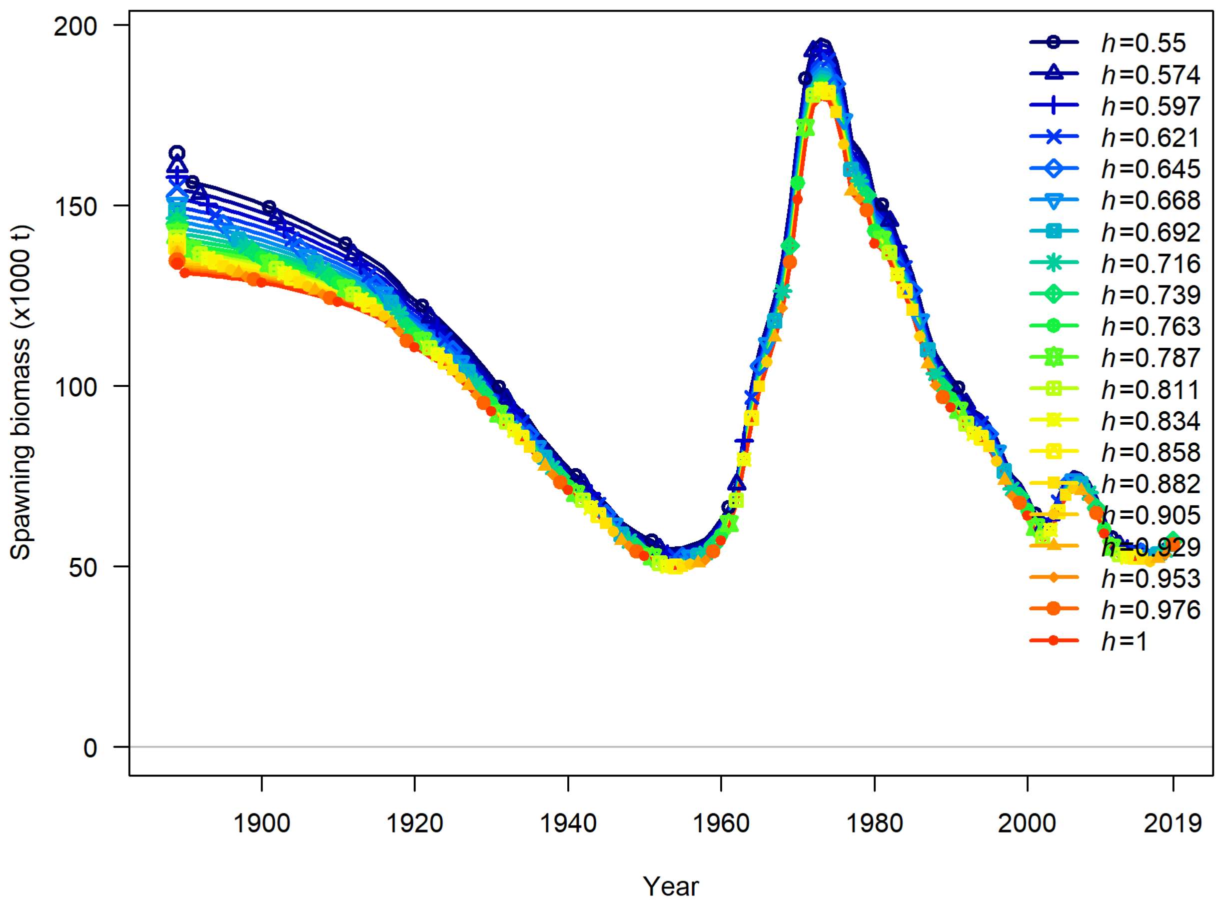


Figure 117. Time-series of spawning stock biomass for different fixed values of steepness (*h*).

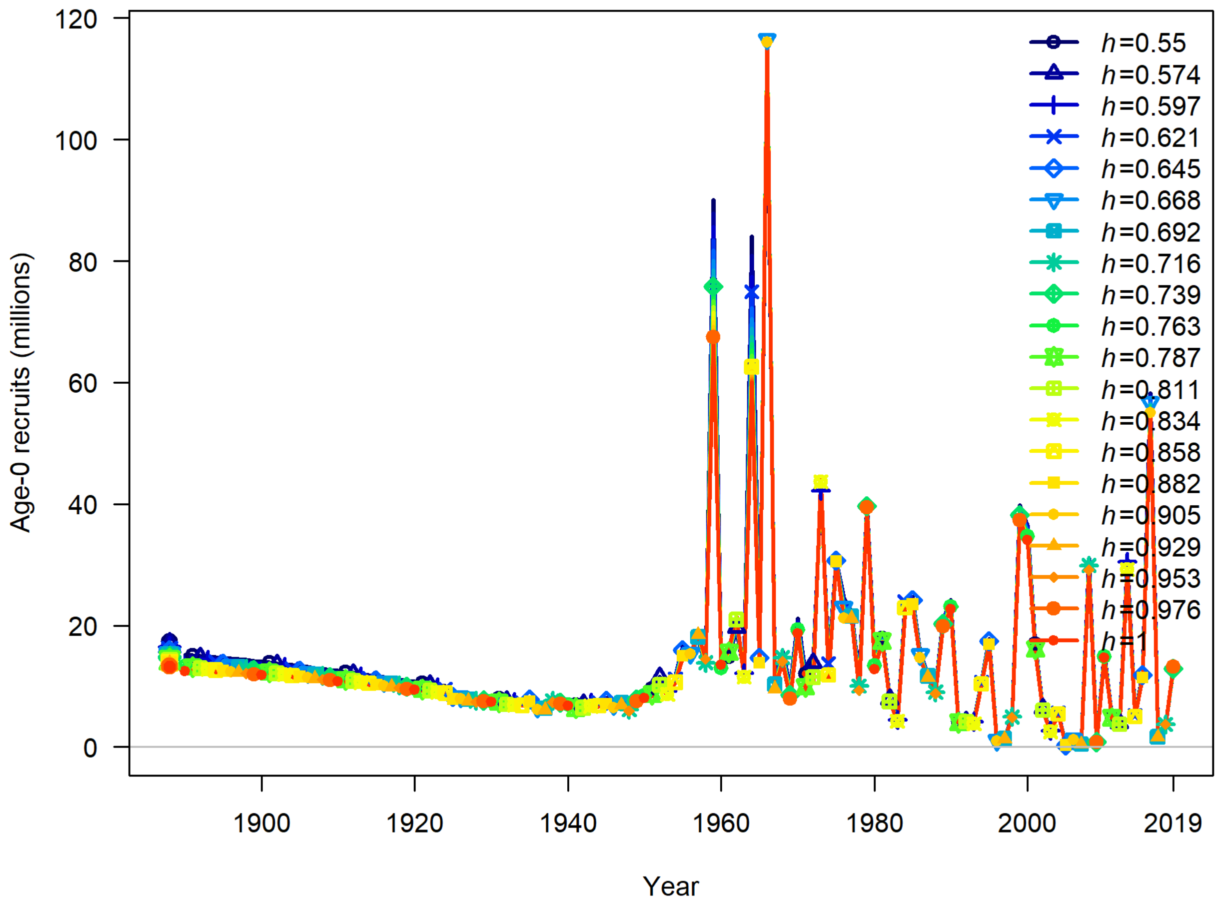


Figure 118. Time-series of relative recruitment for different fixed values of steepness (*h*) (vertical lines).

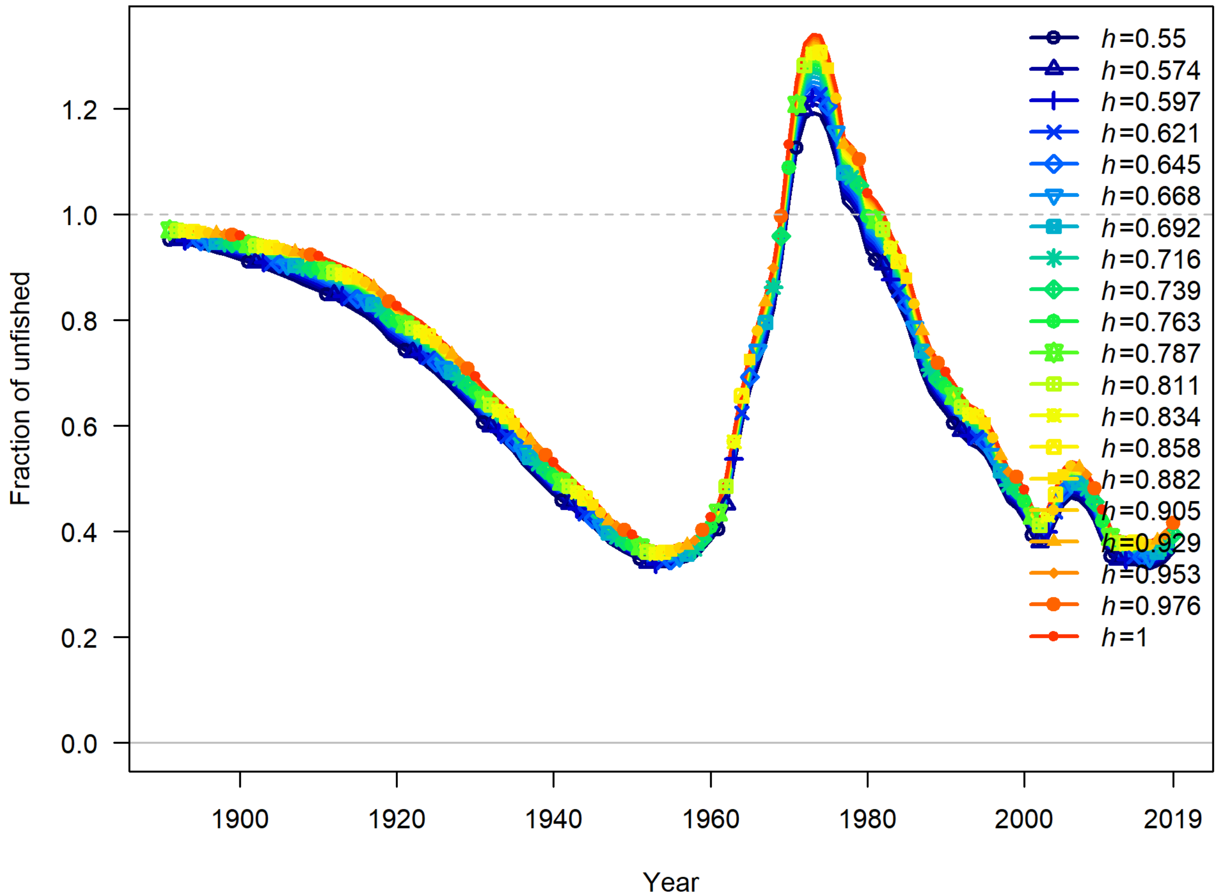


Figure 119. Time-series of relative depletion for different fixed values of steepness (*h*).

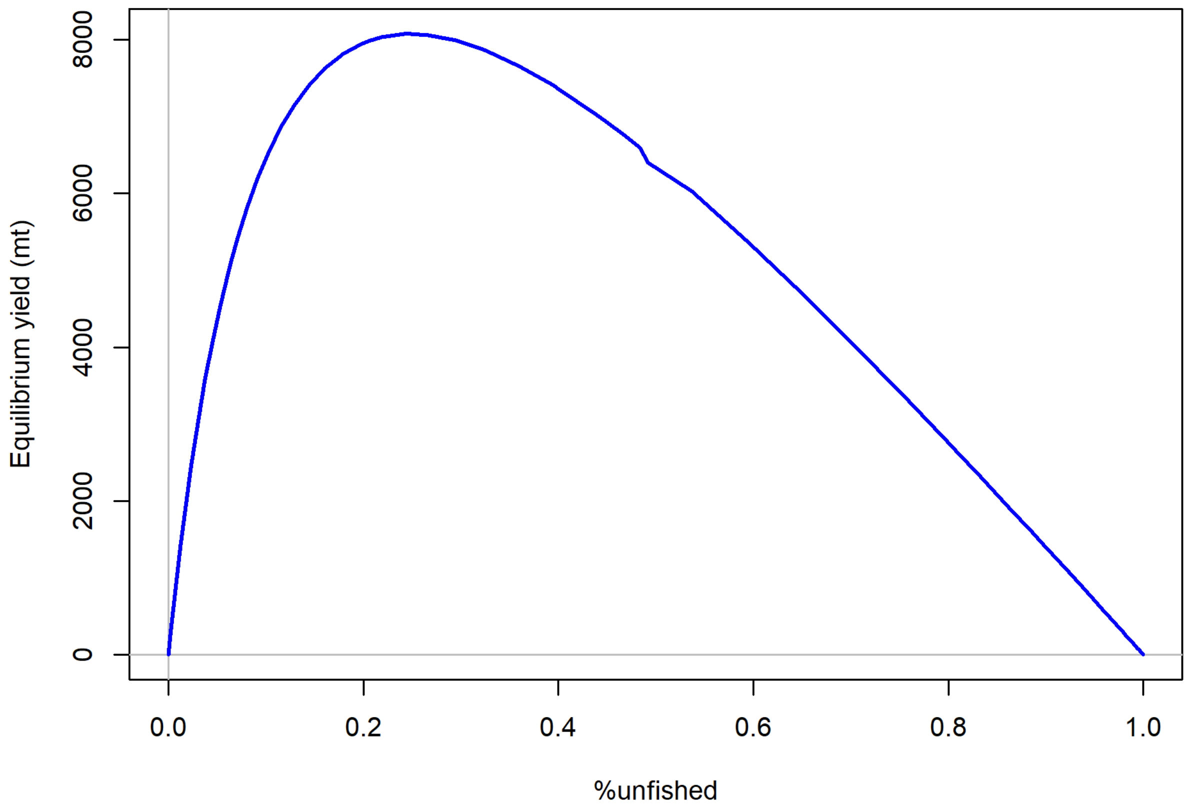


Figure 120. Equilibrium yield curve (total dead catch) for the base model.

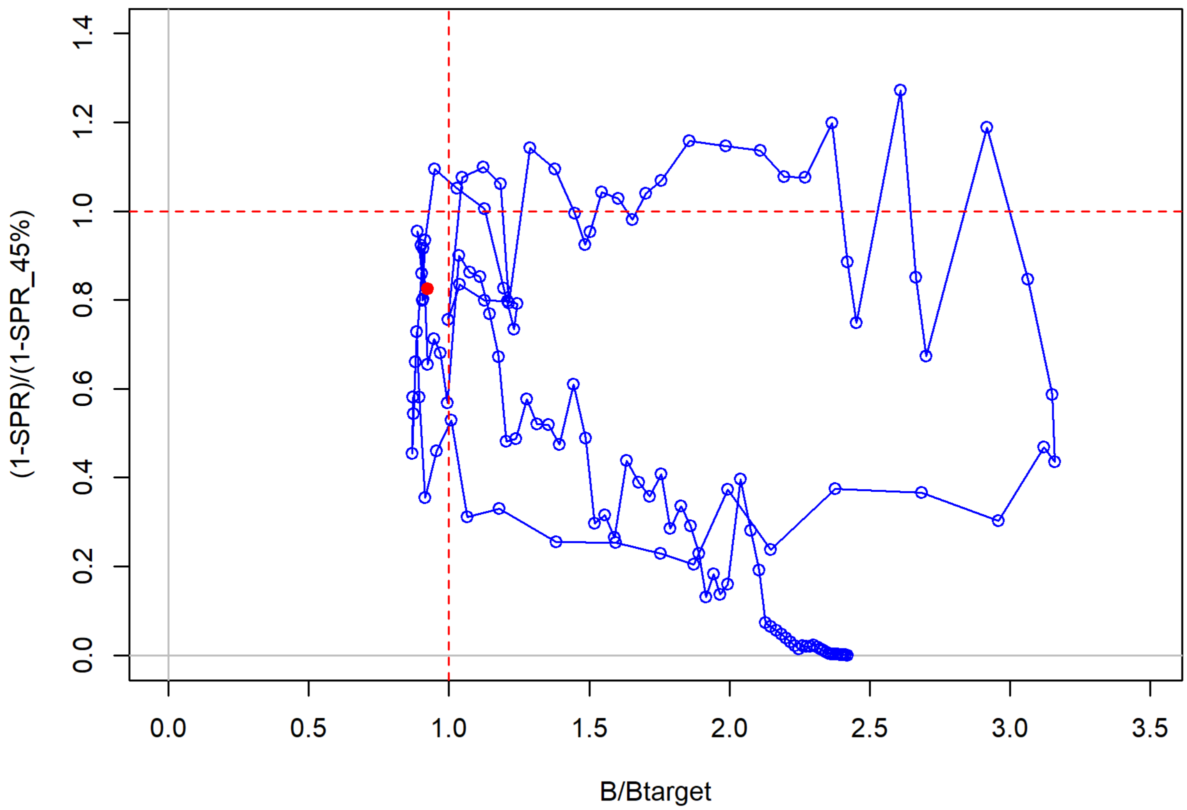


Figure 121. Estimated relative spawning potential ratio relative to the proxy target/limit of 45% vs. estimated spawning biomass relative to the proxy 40% level from the base model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The filled red circle indicates 2014. Plot is based on maximum likelihood estimation results.

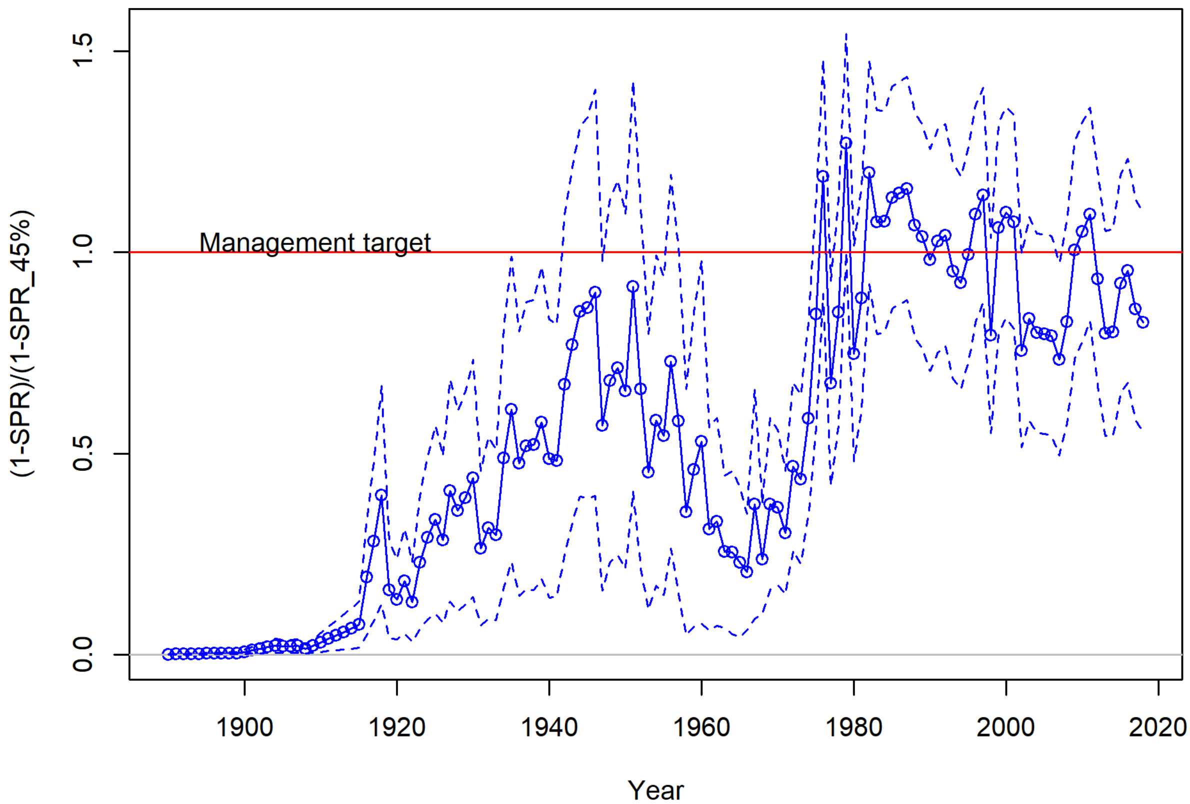


Figure 122. Time series of estimated relative 1-spawning potential ratio ($1-SPR/1-SPR_{Target=0.45\%}$) for the base model (round points) with ∼95% intervals (dashed lines). Values of relative 1-SPR above 1.0 reflect harvests in excess of the current overfishing proxy.

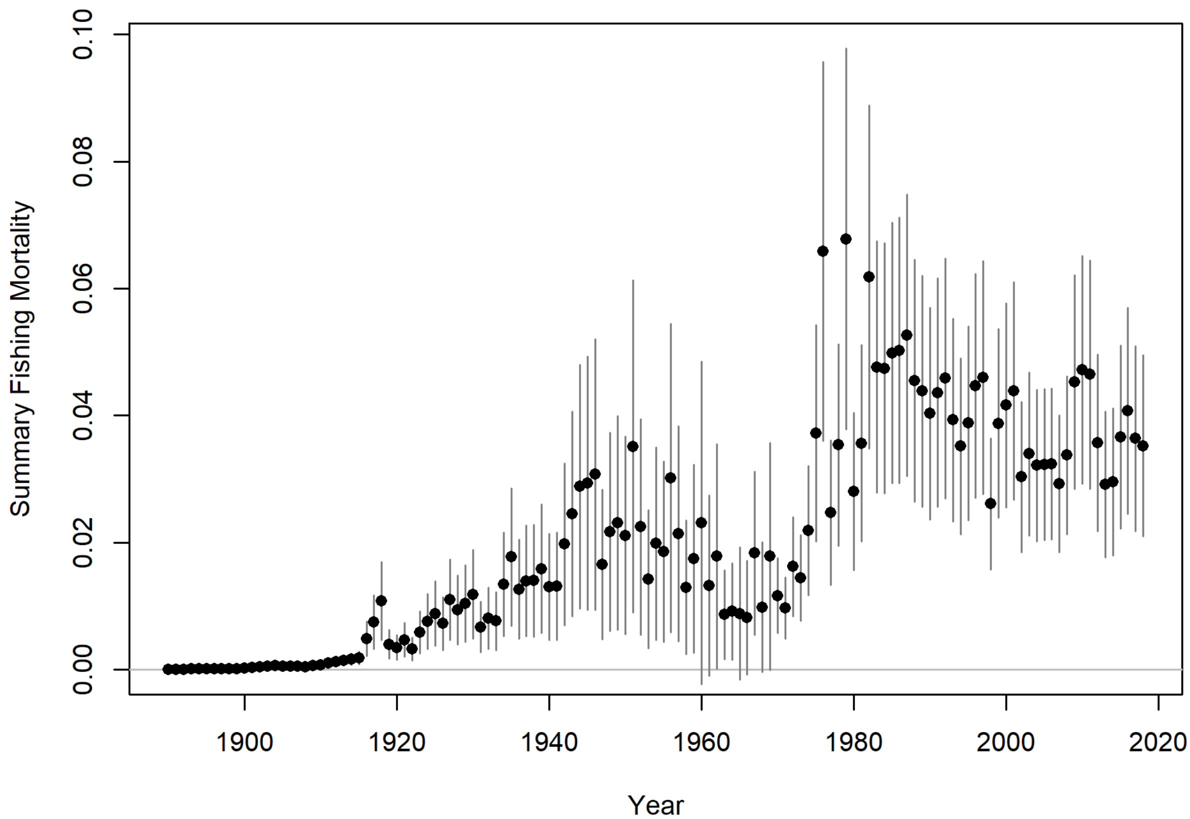


Figure 123. Time series of estimated exploitation fraction (catch/age 4 and older biomass) and their associated uncertainty (vertical lines) for the base model.

A ENVIRONMENTAL INDICES

Appendix A: Ecosystem Considerations

Ecological and socio-economic considerations for sablefish, Anoplopoma fimbria off the West Coast of the U.S.

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The NOAA Stock Assessment Improvement Process calls for bringing an ecosystem perspective into the assessment process and

> *"advocates for expanding the scope of the stock assessment paradigm to be more holistic and ecosystem-linked. This means that more ecosystem and socioeconomic factors that affect the dynamics of fish stocks and fisheries are directly taken into account, and more goals of fishery management are taken into account in the evaluation of sustainable harvest policies"*

(Lynch et al. 2018). Moreover, introducing this perspective to the assessment process is a key component of the NOAA Fisheries Ecosystem-Based Fisheries Management (EBFM) Policy (NOAA 2016), which promotes the incorporation of ecosystem considerations into living marine resource management. Uptake of EBFM principles and tools into the assessment process can be done through including ecosystem information in assessments, harvest control rules, and as a basis for making management decisions that are coordinated across species management plans and account for diverse tradeoffs (NOAA 2016, Lynch et al. 2018). Guidelines for incorporating ecosystem considerations into fisheries management advice forms the core of Guiding Principle 5 for implementing the NOAA EBFM Policy.

This Ecosystem Considerations section is based on the idea of social-ecological system (SES), which "explicitly acknowledges linkages and feedback between human and biophysical systems " (Levin et al. 2016). Figure A1 provides a summary of the SES framework for the California Current. Inclusion of ecological and socio-economic considerations in the sablefish stock assessment will help to move towards an ecosystem-based approach to fisheries management. The SES framework requires that we consider extractive goals and conduct human activities at a level that allows ecological sustainability while also considering human well-being by considering both environmental and human impacts on sablefish, as well as sablefish impacts on the ecosystem and humans (Levin et al. 2016). Below we consider both the ecological and socio-economic factors relevant to the sablefish SES.

Figure A1. A conceptualization of the social-ecological system of the California Current showing broad bio-physical and social drivers, the potential mediating effects of habitat and local social systems and the management endpoints of ecological integrity and human well-being. Human activities are placed at the center, suggesting they are the most tangible points of connection between the social and ecological systems, yet can only be understood in the context of broader drivers and local variability. Instead of arrows, the spherical matrix represents the multidirectional interconnections among all elements. Reproduced from (Levin et al. 2016)

Why sablefish

On the US West Coast, fisheries landed 5275 metric tons with an ex-vessel value of $24.7 million in 2018 (Figure A2) making sablefish one of the most valuable stocks in the region. However, the stock has been in decline since the mid 1970's, due to a combination of fishing pressure and a period of lower than expected recruitments (Johnson et al. 2016). As landings have fallen, price per pound and ex-vessel revenue have increased (Figure A2) making sablefish a stock with high value but limited availability.

Decades of foundational research make sablefish are a perfect candidate for the development of ecosystem considerations useful for fisheries management. Sablefish recruitment is correlated with sea level (Schirripa & Colbert 2006) —a proxy indicator for other physical drivers in the northeast Pacific Ocean—and this correlation explains sufficient variability for inclusion in the assessment as described in the main body of this sablefish stock assessment.

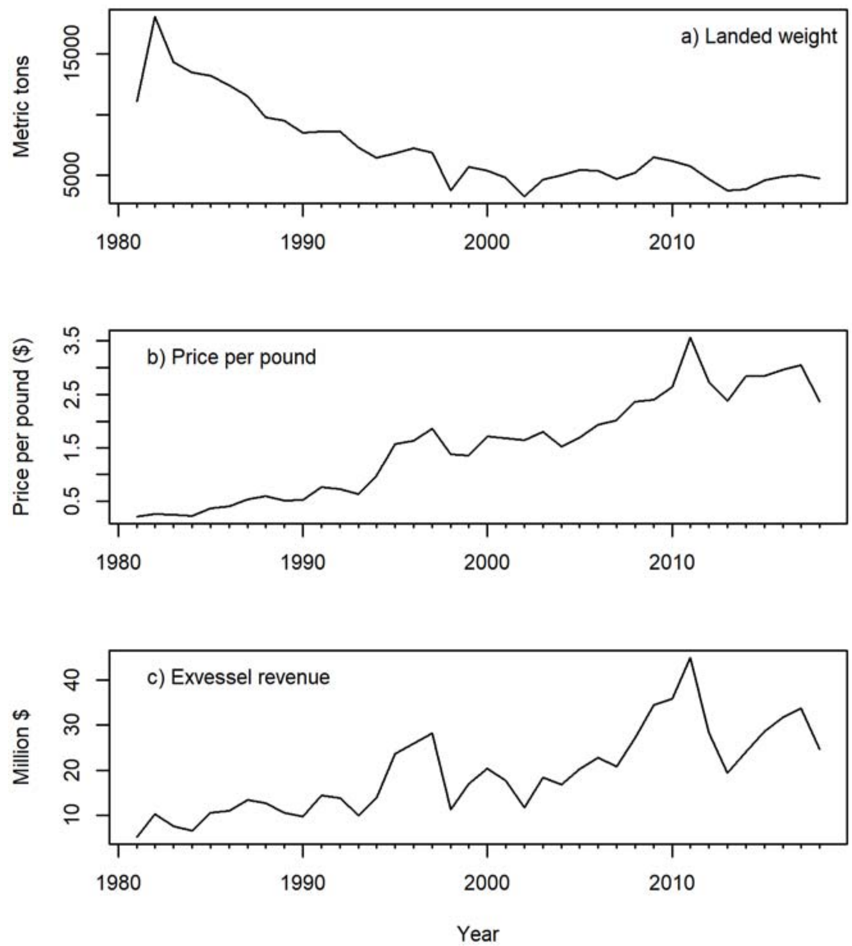
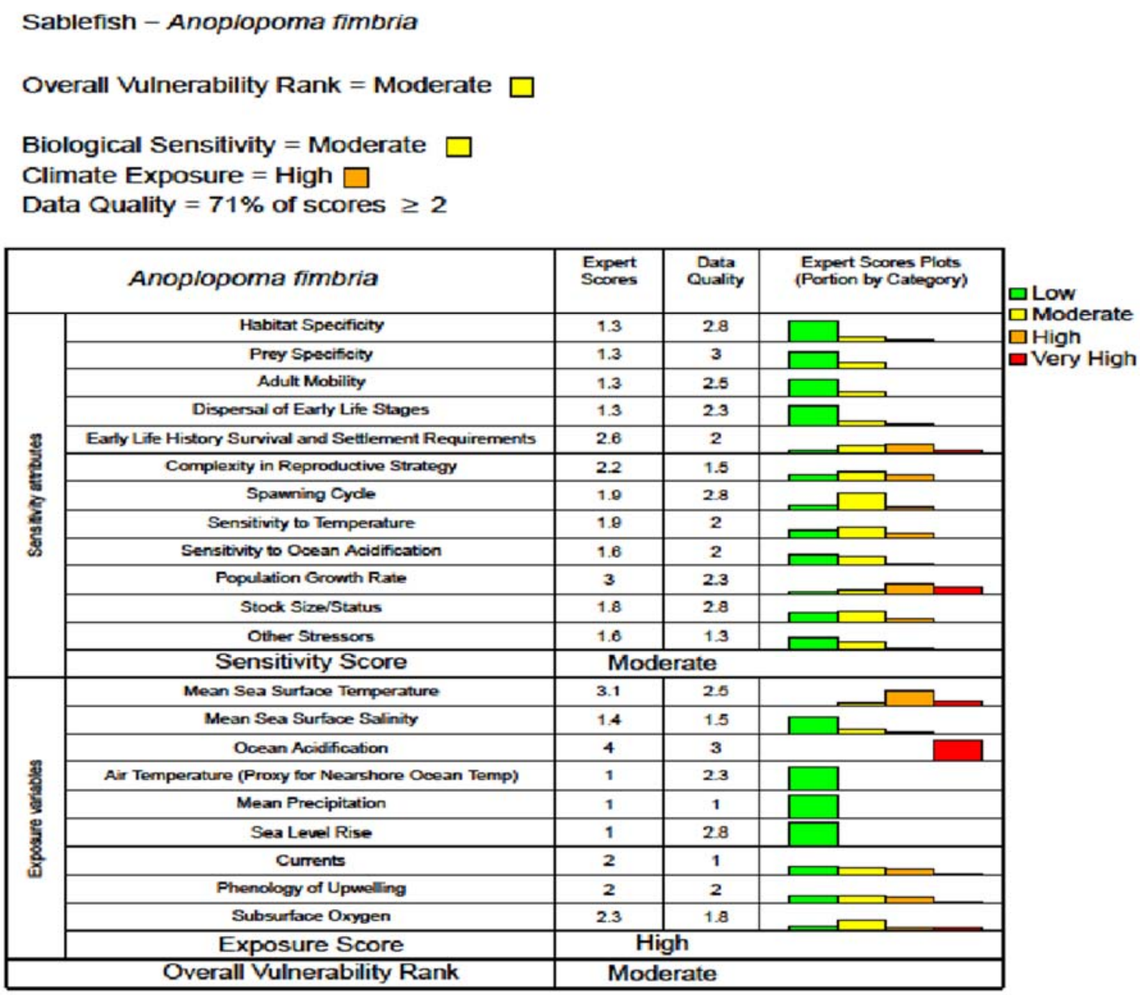


Figure A2. Fishery performance for sablefish a) landed weight, b) price per pound, and c) exvessel revenue for 1981-2018. https://reports.psmfc.org/pacfin

The case for an ecosystem considerations for sablefish is bolstered by research demonstrating that model-derived oceanographic indices can by effective at predicting recruitment in sablefish (Tolimieri et al. 2018), and by a recent Climate Vulnerability Assessment (CVA) (McClure & et al in prep), which suggests that sablefish recruitment is likely vulnerable to climate variability (Figure A3). The CVA found that sablefish showed sensitivity to factors affecting Early Life History and Settlement Requirements, Population Growth Rate and the Spawning cycle. This same CVA suggests that sablefish are likely to experience shifts in distribution related to climate, which may affect the availability of the stock to individual ports. That is, high Adult Mobility, high Dispersal of Early Life Stages and lack of Habitat Specificity suggest that sablefish may respond to climate variability by shifting distribution, which may affect the fishery's access to the stock. Both topics are investigated further below. Furthermore, the sablefish fishery is responsible for bycatch of protected and non-protected living marine resources (LMRs) connecting sablefish stock and fishery dynamics to other fisheries and LMRs. Changes to management strategies and fishing practices have further implications for sablefish habitat, coastal economies, and human well-being that are not currently explicitly considered in stock assessments.



Sablefish – *Anoplopoma fimbria*

Overall Vulnerability Rank = Moderate

Biological Sensitivity = Moderate
Climate Exposure = High
Data Quality = 71% of scores ≥ 2

	Anoplopoma fimbria	Expert Scores	Data Quality	Expert Scores Plots (Portion by Category)
Sensitivity attributes	Habitat Specificity	1.3	2.8	
	Prey Specificity	1.3	3	
	Adult Mobility	1.3	2.5	
	Dispersal of Early Life Stages	1.3	2.3	
	Early Life History Survival and Settlement Requirements	2.6	2	
	Complexity in Reproductive Strategy	2.2	1.5	
	Spawning Cycle	1.9	2.8	
	Sensitivity to Temperature	1.9	2	
	Sensitivity to Ocean Acidification	1.6	2	
	Population Growth Rate	3	2.3	
	Stock Size/Status	1.8	2.8	
	Other Stressors	1.6	1.3	
	Sensitivity Score	Moderate		
Exposure variables	Mean Sea Surface Temperature	3.1	2.5	
	Mean Sea Surface Salinity	1.4	1.5	
	Ocean Acidification	4	3	
	Air Temperature (Proxy for Nearshore Ocean Temp)	1	2.3	
	Mean Precipitation	1	1	
	Sea Level Rise	1	2.8	
	Currents	2	1	
	Phenology of Upwelling	2	2	
	Subsurface Oxygen	2.3	1.8	
	Exposure Score	High		
	Overall Vulnerability Rank	Moderate		

Figure A3. Results of climate vulnerability analysis from (McClure & et al in prep).

Here we provide a summary of the impacts of ecological factors on sablefish and of the impacts of changes in the sablefish stock on the broader social-ecological system of which it is a part. This synthesis provides a template for future work outlining ecosystem considerations in US West Coast fisheries and beyond, with an eye toward increasing connectivity among individual fisheries management decisions.

Summary

Data from the West Coast Groundfish Bottom Trawl Survey (WCGBTS) suggest strong recruitment in 2016 but low recruitment since. The strong 2016 year class is corroborated by increased catch of sablefish in the at-sea hake fishery in 2017 and 2018 as this age class grows and becomes vulnerable to the hake fishery. However, most indicators suggest poor conditions for recruitment in 2018 and 2019 with warm PDO conditions and late dates for the biological spring transition. Likewise, the availability of northern zooplankton decreased sharply in 2019, suggesting poor feeding conditions for sablefish larvae and juveniles and therefore poor recruitment in 2019. A sea-level index did a generally good job of predicting variation in recruitment around the stock-recruitment relationship. However, the sea-level indictor predicted above average recruitment in 2018, which was not observed in the age-0 data.

There was some evidence that the recent marine heatwave may have affected female condition, especially northern waters and for younger fishes. Condition of age-6 (older juveniles) females was low north of Cape Mendocino in 2015 and 2016, and both older juvenile (age-6) and adult (age-7+) fishes showed declines during the heatwave years, although the trends varied. However, both older juveniles and adults appear to have recovered from effects of the blob and are in either good or average condition as of 2018. Nevertheless, currently weak El Niño conditions suggest the potential for reduced growth, although the effects of El Niño on sablefish growth tend to be slight.

Prey availability appears to be average too good for both juvenile and adult sablefish. However, competitor and predator abundance appears to be increasing or high as of 2018.

An increase in the number of whale entanglements suggests detrimental effects of the sablefish fishery on whale mortality, specifically for humpback whales where entanglements appear to have exceeded allowed limits for several years.

Total mortality (catch plus discard) of sablefish was generally at the ACL in 2017 and 2018. As is well known, sablefish catch limits restrict activity in the Dover sole – thornyhead – sablefish fishery (DTS) resulting in lost economic opportunity. Bycatch of choke and recently rebuilt species in sablefish sectors was low compared to their ACLs. Of the examined species, only petrale sole reached their ACL in recent years. However, bycatch in the sablefish sectors was only several metric tons compared to an ACL of > 3000 metric tons, suggesting that any effect is small.

An analysis of changes in the latitudinal distribution of sablefish biomass, showed that shifting sablefish biomass affects the availability of the stock to individual ports and can impact landings from those ports. The center of gravity of that sablefish stock distribution shifted south from the 1980s through 2000s but from 2013 began shifting north again.

Table A1. Indicators presented and prognosis.

Process	Indicator	Relationship	Prognosis
Ecological considerations			
Recruitment	Abundance of age-0 sablefish[4] & Distribution of age-0 fishes[4]	Index of recruitment	Low abundance of age-0 fishes in the WCGBTS overall and especially north of Cape Mendocino in 2018 suggest low recruitment in 2018
	Northern copepod anomaly[1]	Index for the abundance of large, high-food quality copepods	Recent declines in 2019 suggest worsening feeding conditions for age-0 fishes and potentially lower recruitment in 2019
	Pacific Decadal Oscillation (PDO)[1]	High frequency of strong year-classes under cold (negative) PDO conditions	Recent high (warm) PDO suggest poor recruitment conditions, but the most recent values are neutral
	Biological Spring Transition (BST)[2]	Earlier spring transitions results in higher likelihood of good recruitment	Late timing (high day of year) BST in 2017 & 2018 suggests poor recruitment in these years
	Sea level recruitment index	Index of recruitment quantified as residuals around the stock-recruitment relationship	Index predicted good recruitment in 2016 and 2018. While 2016 recruitment is estimated to be one of the strongest in recent decades, the latter prediction is not corroborated by age-0 abundance in the WCGBTS
Growth and condition	Female condition	Indicator of overall health quantified as ratio of observed to expected weight	Condition of age-5&6 fishes (juveniles) was close to expected in 2018. Condition of age-7+ fishes (adults) was high in 2018 both north and south of Cape Mendocino.
	Ocean Niño Index (ONI)[1]	Lower growth under El Niño conditions (for fishes 20 -1 110 cm)	El Niño conditions suggest poor conditions for growth in 2019

Adult Distribution	Center of Gravity (CoG)[4] & Distribution of adult sablefish[4]	Center of Gravity for sablefish biomass (WCGBTS)	The distribution of stock biomass has shifted to the north since 2013, which may impact the availability of the resource to fishing ports. Explored more fully in the socio-economic section
Species Interactions	Juvenile Prey	Availability of prey affects growth and survival	Prey availability was high in 2018 suggesting good feeding conditions for juvenile sablefish
	Adult prey	Availability of prey affects growth and survival	Prey availability was either high or average for most prey taxa in 2018 suggesting average to good feeding conditions.
	Predators and competitors	Predators and competitors affect growth and survival	The abundance of sablefish predators/competitors was high in 2018 suggesting the potential for increased natural mortality or reduced growth.
	Whale entanglements[8]	Reported entanglements of whales in various fishing gears. Take of whales may limit fishing for sablefish.	Whale entanglements have increased in recent years. Estimated fleet-wide entanglements were consistently above the 5-year running average threshold over from 2002-2017 in the combined LE Sablefish and Open Access Fixed Gear pot sectors
Socio-economic considerations			
	Sablefish catch in the at-sea hake sector[5]	Sablefish may limit hake catch or require changes in fishing activity to avoid take of sablefish. Additionally, sablefish catch in the hake fishery may act as an indicator of incoming age classes	High 2017-2018 catch indicates ageing and growth of the 2016 age class, which the at-sea hake sector may have to avoid to reduce bycatch
	Sablefish catch and the DTS fishery	Sablefish ACL limits catch of Dover sole and thornyheads	Total fishing mortality in the sablefish sector reached the ACL in 2017 the north, which limits catch of Dover sole and thornyheads.
	Bycatch of choke and recently rebuilt species[1,5]	Potential to restrict fishing for sablefish as choke or recently rebuilt species reach catch limits (ACL) (PacFIN)	Bycatch in sablefish directed sectors was low compared to their ACLs for the species analyzed (several mt vs 1000's of mt). Petrale landings remain near the ACL, but bycatch only several metric tons compared to a recent ACL of >3000, so any effects are likely to be minor.

[1]El nino, PDO, copepod, and total fishing mortality data available from: http://oceanview.pfeg.noaa.gov;

[2]BST available from: https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ec-biological-spring-trans.cfm;

[3]SSH data available from: https://tidesandcurrents.noaa.gov/sltrends/data/,

[4]Data for CoG, adult distribution, juvenile distribution, and juvenile abundance from Northwest Fisheries Science Center's (NWFSC) U.S. West Coast Groundfish Bottom Trawl Survey for Washington, Oregon, and California for 2003 – 2018 (WCGBTS, Keller et al 2017): https://www.nwfsc.noaa.gov/data/map,;

[5]Landings data from: https://pacfin.psmfc.org/;

[8]Reproduced from WCRO (2018) and Harvey et al. (2019)

Structure of the document

The document has the following structure:

- Summary
- Review of life history
- Ecological considerations presented by process (recruitment, growth, mortality)
- Socio-economic considerations
- Methodology
- Data sources

<u>*Presentation of indicators*</u>

The presentation of many indicators herein follows that if the California Current Integrated Ecosystem Assessment report to the PFMC (Harvey et al. 2018). See Figure A4 for details.

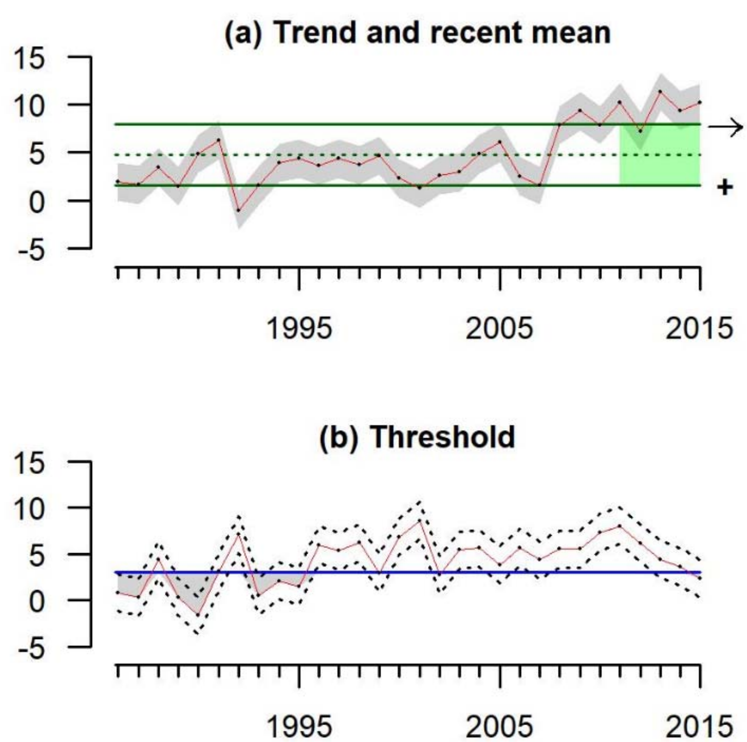


Figure A4. (a) Sample time-series plot, with indicator data relative to the mean (dashed line) and 1.0 s.d. (solid lines) of the full time series. Arrow at the right indicates if the trend over the most recent 5 years (shaded green) was positive, negative or neutral. Symbol at the lower right indicates if the recent mean was greater than, less than, or within 1.0 s.d. of the long-term mean. When possible, times series indicate observation error (grey envelope), defined for each plot (e.g., s.d, s.e., or 95% confidence intervals); (b) Sample time-series plot with the indicator plotted relative to a threshold value (blue line). Dashed lines indicate upper and lower observation error, again defined for each plot.

Sablefish life-history

Sablefish (*Anoplopoma fimbria*) are bathydemersal inhabiting deep waters (175 – 2740 m) along the west coast of North America from the Baja California through Alaska and extending west (and south) to Japan (Hart 1973, Mason et al. 1983, Allen & Smith 1988, Johnson et al. 2016). While adults can inhabit waters 750 m or greater and with a temperature of approximately 5° C, they may undertake diel vertical migration ascending and average of 250 m (range 43 – 668 m) at night and into waters in the range of 6-10° C (Goetz et al. 2018). This vertical migration is likely tied to pursuit of diverse food resources. Likewise, juvenile fishes in nearshore habitats in Alaska also make diel vertical migrations with vertical excursion occurring primarily around dawn and dusk (Coutre et al. 2015).

Stock Structure

Genetic analyses have not found strong population structure and suggest a single panmictic genetic population for sablefish in waters along in the northeastern Pacific from California to Alaska (Jasonowicz et al. 2017), potentially the result of ability of adult sablefish to move large distances (Hanselman et al. 2015). Historically sablefish have been assessed and managed as closed populations based on political boundaries for Alaska, British Columbia, and the U.S. west coast. This document focuses on the U.S. west coast population.

The maturity and reproductive success of the U.S. west coast stock differs north and south of Cape Mendocino (~40.4 °N) (Head et al. 2014). Maximum body size is larger and growth rates are slower north of Cape Mendocino.

Spawning, the larval stage and recruitment

Sablefish are iteroparous and oviparous (Love 2011). Spawning occurs from December to March with a peak in February. Most spawning takes place at the edge of the continental shelf at depths greater than 300 m with eggs (~2.1 mm diameter) initially found from 200 m to greater than 825 m (Mason et al. 1983, Kendall & Matarese 1987, Hunter et al. 1989, Moser et al. 1994). The energetic status of females may influence their propensity to spawn, and the quality and number of eggs produced (Sogard et al. 2008, Rodgveller et al. 2016). Thus, the summer and fall prior to spawning (June-Dec) may be important for female preconditioning, and female condition may affect fecundity and recruitment (Tolimieri et al. 2018). Eggs are buoyant, rising to 200-300 m in the water column but are most common between 240 and 480 m, where they remain for approximately 12-17 days until hatching (Mason et al. 1983, Boehlert & Yoklavich 1985, Kendall & Matarese 1987, McFarlane & Beamish 1992, Moser et al. 1994). Post hatch, larvae sink to 1000-1200 m where they can be found between February and May as yolk-sack larvae. By 14-17 days post-hatch larvae have consume about 50% of their yolk sack and may show initial attempts at feeding approximately a week later. By 40-days post hatch larvae are in surface waters from the 500-m isobath out to 150 nautical miles (277 km) from shore where they are found between February and May (Brock 1940, McFarlane & Beamish 1992, Moser et al. 1994). Pelagic juveniles are also found in these surface waters and are present from April through November (Mitchell & Hunter 1970, Kendall & Matarese 1987). Sablefish settle to the benthos as age-0 recruits between August and November with most fish likely settling to habitats 250 m or shallower. Given sufficient food, juvenile sablefish are capable of tolerating and thriving at increased temperatures up 22°C. Beyond this temperature growth and survival are severely compromised (Sogard & Olla 2001).

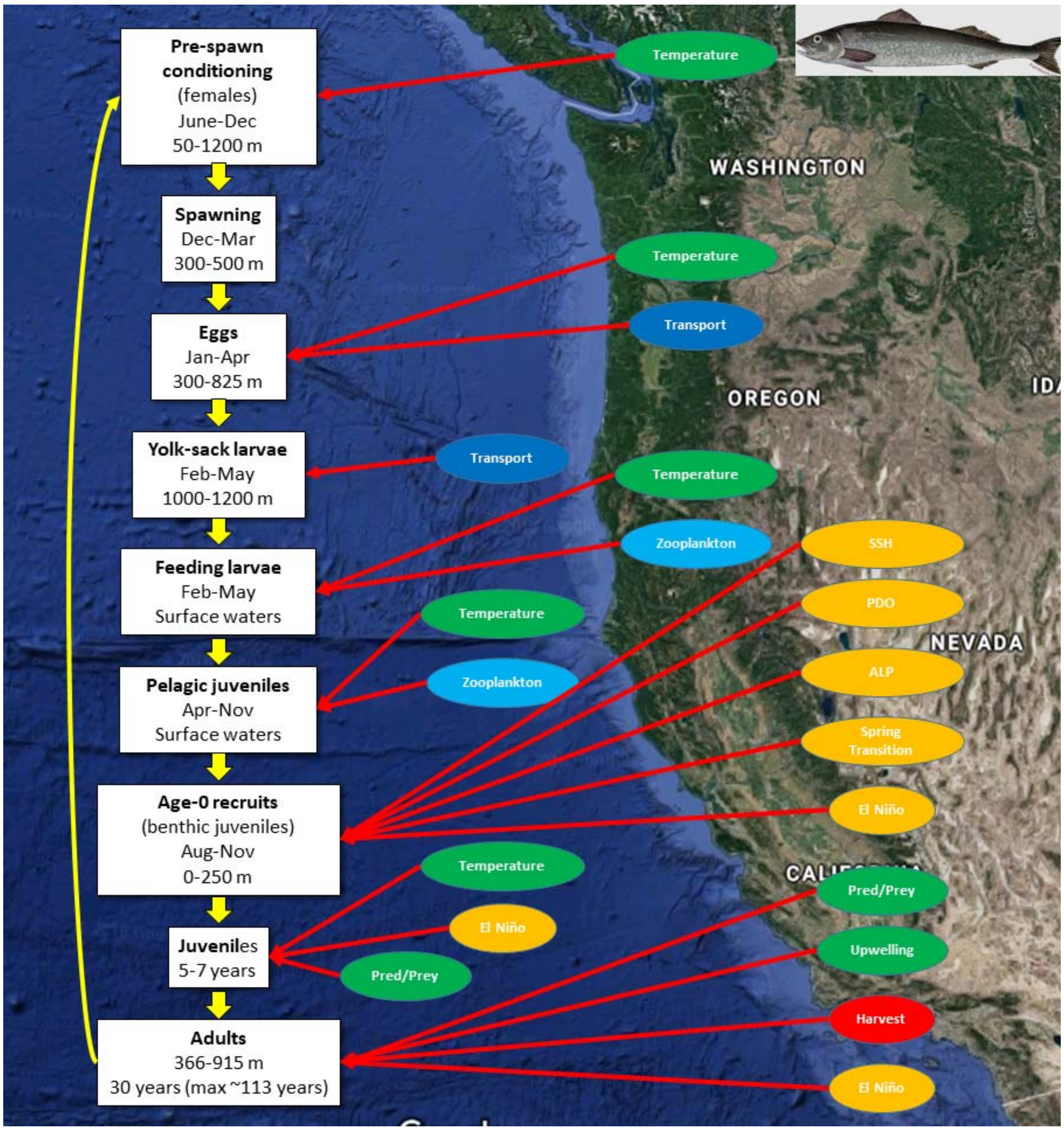


Figure A5. Sablefish life history. For pre-spawning through adults, the text indicates the period of time they are found and depth range. Ellipses indicate various critical processes that affect sablefish population dynamics at each stage. See Table A1 for descriptions of indicators reflecting these processes, and the current prognosis.

Recruitment and year-class strength

In the Northeast Pacific off of British Columbia and in the Gulf of Alaska, there is evidence that that climate strongly influences recruitment in sablefish. Strong year-classes have generally followed large scale shifts to above average SST and more intense Aleutian Low Pressure (ALP) in the British Columbian waters (McFarlane & Beamish 2001). Sablefish year classes from 1960 to 1976 were generally below average, followed by an exceptionally large 1977 year class and generally above average recruitment from 1978 to 1990, with subsequent year classes generally below average (King et al. 2000, King et al. 2001). Stronger year classes also occurred during periods of more intensive ALP, more frequent southwesterly winds, below average temperatures in the subarctic Pacific (King et al. 2000, McFarlane & Beamish 2001, Hollowed et al. 2008). The timing of the spring transition affects the spatial and temporal overlap of copepod abundance and first feeding sablefish larvae from January to April (Hollowed et al. 2008). Note, however, that these results pertain largely to the waters off British Columbia and in the Gulf of Alaska. The effects of climate on species' ecology differs between the Gulf of Alaska and the California Current for sablefish and other species, especially salmon (Bakun 1996, Beamish & Bouillon 1996, Kimura et al. 1998).

In the California Current, strong year classes are more likely under cool (negative) Pacific Decadal Oscillation (PDO) conditions (this document) and show some relationship to the timing of the spring transition (also this document). In addition, strong year classes are associated with higher abundance of cold-water, northern copepods (McFarlane & Beamish 1992, McFarlane & Beamish 2001, Schirripa 2007). Recruitment is also negatively correlated with sea level north of Cape Mendocino, which acts as a proxy for basin scale processes and the availability of northern copepods (Schirripa & Colbert 2006). The relationship between sablefish recruitment and sea level is explored more fully below.

Recruitment: temperature and transport

Sablefish recruitment-environment investigations along the US west coast have largely focused on large-scale climate or oceanographic variables (Schirripa & Methot 2001, Schirripa & Colbert 2006, Schirripa et al. 2009, Sogard 2011, Shotwell et al. 2014, Coffin & Mueter 2015). However, the resulting relationships have not had a large effect on stock-assessment results because use in the assessment has generally been restricted to 1970 forward, year that also had good data on year-class strength from fishery and fishery-independent surveys already informing the stock assessment estimates of age-0 recruitment (Schirripa et al. 2009, Stewart et al. 2011, Johnson et al. 2016). An environment-based recruitment index needs to explain 50% or more of the variation around the stock recruitment curve to reduce uncertainty around recruitment estimates within the current assessment framework (Basson 1999, Johnson et al. 2016).

Recent stage- and spatio-temporally-specific modelling using ROMS output (Tolimieri et al. 2018) was able to predict 57% of the variation in age-0 recruitment not accounted for by the stock-recruitment relationship (i.e., residuals around the stock-recruitment curve) in the sablefish assessment. Residuals around the stock-recruitment relationship were positively correlated with (1) colder conditions during the spawner preconditioning period, (2) warmer water temperatures during the egg stage, (3) stronger cross-shelf transport to near-shore nursery habitats during the egg stage, (4) stronger long-shore transport to the north during the yolk-sack stage, and (5) cold surface water temperatures during the larval stage (Figure A6).

Cooler temperatures (quantified as degree days) during the pre-spawning period may result in lower metabolic costs for females, allowing more energy available for reproduction or may be indicative of good feeding conditions. Onshore transport during the egg stage averts advection of eggs and larvae and maintains them near settlement habitat, while warmer water leads to faster development. Transport to the north during the yolk-sack stage likely moves larvae to better feeding conditions once they rise to the surface, and cold water during the larval stage may be associated with both better feeding conditions and reduced starvation risk due to lowered metabolic costs.

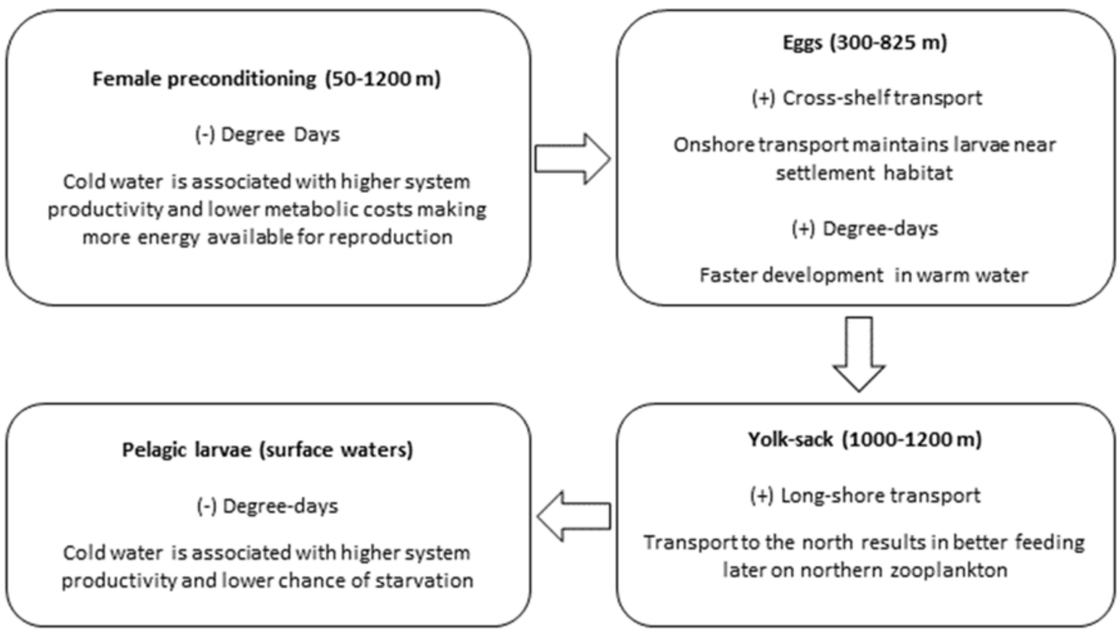


Figure A6. Oceanic drivers of recruitment of age-0 sablefish from Tolimieri et al. (2018). Sign in parentheses indicates the relationship of partial correlation. Additional text gives hypothesized effect on sablefish biology.

Ecological Considerations

The ecological considerations for sablefish are the environmental and ecological processes that drive changes in the biomass, distribution and abundance of sablefish by acting on biological processes like recruitment, growth and mortality. Some indices, like the sea level index, may be incorporated into and considered within the assessment framework. Other indices may serve more qualitatively to inform uncertainty with the modeling framework to due variable environmental conditions such as climate variation that may affect recruitment or potential interspecific interactions like predation may alter natural mortality. Selection of ecological indices was based on both literature review and additional analysis for some variables (see: *Methods* for additional information).

Recruitment

Distribution and abundance of age-0 recruits

Evidence suggests that strong sablefish year classes are associated with ecosystem processes occurring in the northern portion of the stock (north of Cape Mendocino, ~ 40 ^{o}N) (Schirripa & Colbert 2006, Tolimieri et al. 2018). Age-0 sablefish captured by the NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) were most abundant in shelf and upper slope waters around San Francisco Bay and from Cape Mendocino to the Columbia River mouth (Figure A7). The abundance of age-0 recruits from 2003-2018 was variable through time with peaks in recruitment in 2004, 2008, 2010, 2013 and 2016. However, most strong recruitment years (2004, 2008, 2013, 2016) were associated with strong recruitment north of Cape Mendocino. Strong age-0 recruitment is associated in part with the northerly transport of yolk-sac larvae at depths between 1000-1200 m (Tolimieri et al. 2018), which may lead to better overlap between feeding larvae and copepod prey.

Comparison of the juvenile habitat map (see *Ecological Considerations: Habitat*, Figure A25) with the distribution of age-0 sablefish recruits (Figure A7) provides some interesting results. Age-0 sablefish appear to be distributed farther inshore in shallower water than would be suggested by the maps of habitat suitability. However, both analyses suggest that the area just south of the Columbia River may play an important role in sablefish population dynamics. Years with high recruitment show high juvenile density in these northern waters (Figure A7). These recruitments are then observed in the assessment model estimates, which are based on the sablefish NWFSC WCGBTS length- and age-composition data. These results suggest that high recruitment to these northern waters gives juveniles access to appropriate juvenile habitat as they age and move to deeper water, which leads to strong age-class representation in the sablefish stock.

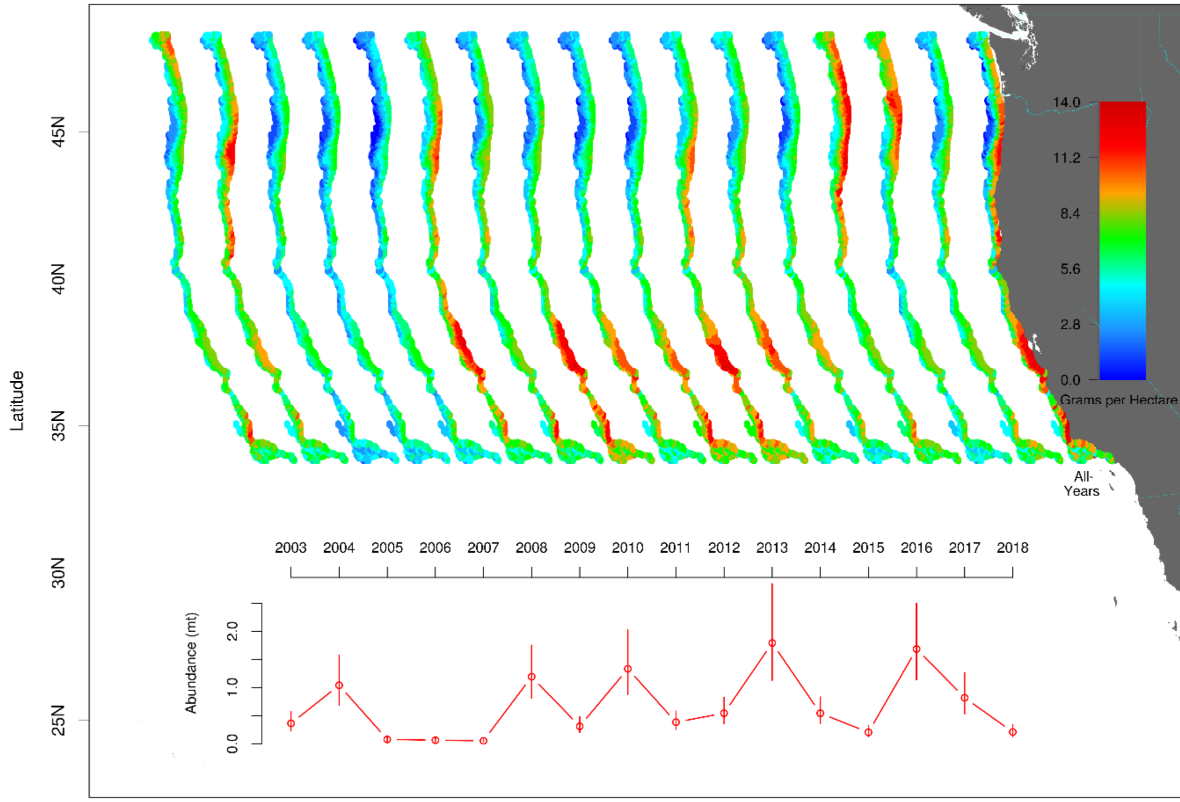


Figure A7. Distribution and time series of abundance for age-0 sablefish recruits from 2003-2018 along the US west coast from the NMFS trawl survey calculated using VAST. See Methods for more detail.

Northern copepods

Higher abundance of large, northern copepods is correlated with strong sablefish year classes (McFarlane & Beamish 1992, McFarlane & Beamish 2001, Schirripa 2007). Additionally, modeling using oceanic drivers derived from ROMS output, indicates that longshore transport to the north during the yolk-sac stage (at 100-1200 m) leads to higher recruitment of age-0 fish (Tolimieri et al. 2018). This northerly transport during the non-feeding yolk-sac stage may result in greater overlap between feeding larvae and high-food-quality northern copepods.

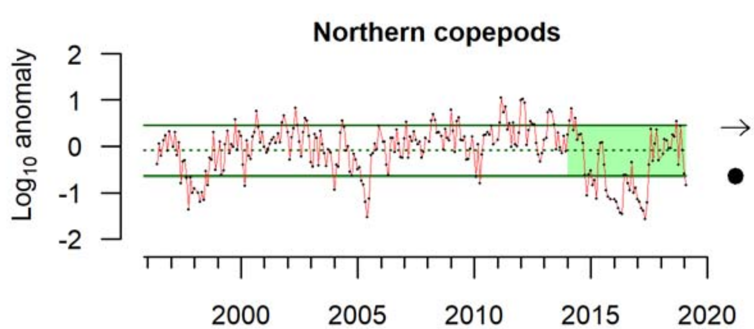


Figure A8. Northern copepod anomaly (mg C m^{-3}) for 1996 – 2018 at approximately 44.6 ^{o}N. Data available from: https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/.

The abundance of northern copepods declined overall from 2013-2018 and was low from 2015-2017 (Figure A8). In early 2018 the abundance of northern copepods increased and returned to within one standard deviation of the long-term mean suggesting average conditions. However, the index dropped sharply in the most recent observations to below 1.0 of the long-term mean, suggesting potentially poor feeding conditions for sablefish larvae and juveniles in 2019.

Pacific Decadal Oscillation (PDO)

Trends in sablefish production appear related to decadal-scale patterns of climate and ocean conditions. In the Gulf of Alaska sablefish experience a higher frequency of strong year-classes under positive (warm) PDO conditions (McFarlane & Beamish 1992, McFarlane et al. 2000). However, in the California Current Ecosystem, the relationship is reversed: under negative (cold) PDO conditions, there is a higher probability of strong recruitment (see: Methods Pacific Decadal Oscillation). This reversal of the relationship between climate is seen for multiple species and climatic indicators (Bakun 1996, Beamish & Bouillon 1996, Kimura et al. 1998).

The PDO has been positive for the past five years but decreased to near zero in early 2019 before increasing slightly through march 2019 (Figure A11) indicating generally poor recruitment conditions.

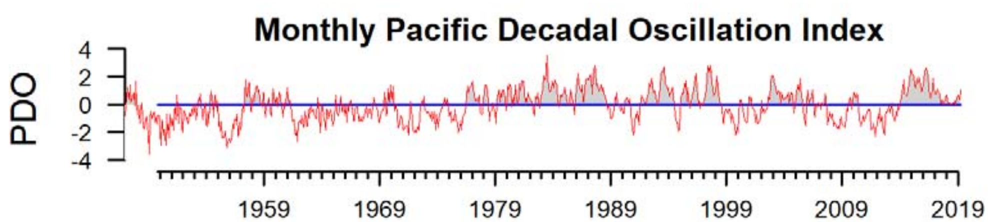


Figure A9. Monthly average of the Pacific Decadal Oscillation. Data available from: https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

Biological spring transition

Previous work has noted potential relationships between sablefish recruitment and the date of the biological spring transition (Peterson et al. 2014). The biological spring transition occurs when the cold-water, northern copepod community replaces the warm-water, southern copepod community sometime in the spring (Peterson et al. 2014). The physical spring transition is defined here as the date of the minimum the cumulative upwelling index value[1] (Bakun 1973, Bograd et al. 2009).

[1] https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/dc-phys-spring-trans.cfm

Figure A10 shows the relationship between the residuals around the sablefish Beverton-Holt stock-recruitment relationship from the 2015 assessment (Johnson et al. 2016, Tolimieri et al. 2018) and the date of the spring transition (represented as day of year). While the linear relationship is weak and non-significant for the biologically determined data (Figure A10), higher than expected recruitment was observed primarily when the spring transition occurred early in the year (low day of year). Therefore, we set a threshold day 125 (May 5th) for the date of the biological spring transition as an indicator of potentially good recruitment conditions. The date of the physical spring transition did not correlate with recruitment success and is not examined further.

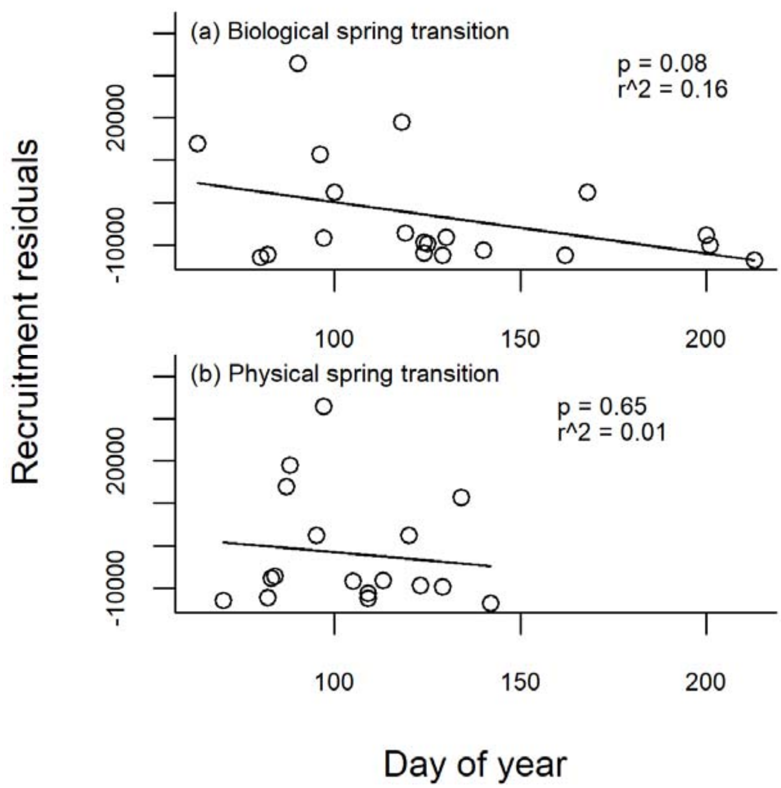


Figure A10. Relationship between sablefish recruitment (here residuals around the stock-recruitment relationship from the 2015 assessment and the dates of the biological and physical spring transitions expressed as day of year.

The spring transition in 2017 and 2018 was later in the year suggesting the potential for poor sablefish recruitment (Figure A11), which is seen in Figure A7. Note, however, that this relationship is not entirely predictive as moderate or high recruitment occurred in 1995, 1999 and 2010 when the date of the spring transition was not overly early. Likewise, the spring transition was not observed in 2016, but age-0 sablefish were abundant in the trawl survey in 2016 (Figure A7).

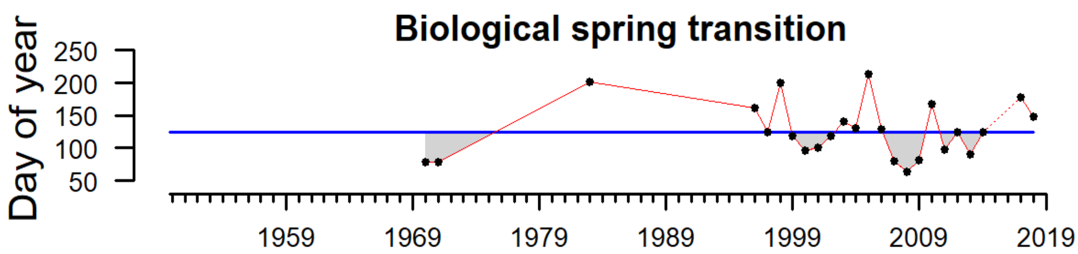


Figure A11. Biological spring transition. Day of year is Julian day. Data available from: https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ec-biological-spring-trans.cfm

Sea level

Previous research and assessments have examined the relationship between sea level and sablefish recruitment (Schirripa & Colbert 2005, 2006, Schirripa 2007, Schirripa et al. 2009, Stewart et al. 2011, Johnson et al. 2016). Changes in sea level serve as a proxy for large-scale climate forcing that drives regional changes in alongshore and cross-shelf ocean transport. These changes directly impact the transport of water masses, nutrients, and organisms (Schirripa & Colbert 2006, Di Lorenzo et al. 2013).

We conducted a re-analysis of the sea level-recruitment relationship by first using dynamic factor analysis to find common trends among sixteen tide-gauge stations from Neah Bay to San Diego. Next, we used model to selection to find the combination of dynamic factors that best explained variation in recruitment around the sablefish stock-recruitment curve. See Methods for more detail.

We used the sea level-recruitment relationship from the best-fit model (Model 1, see Methods) to predict expected recruitment residuals (residuals around the stock-recruitment curve) for 1925-2018, with 2018 being the most recent year with second quarter data available for sea level at the time of writing this report (Figure A47). We predicted the recruitment residuals and not recruitment because we cannot reconstruct recruitment through 2018 without the estimate of biomass for these years from the stock assessment. However, they can be compared to estimates of sablefish recruitment from the NWFSC trawl survey (Figure A7). The index predicts higher than expected (based on the stock-recruitment relationship) recruitment for 2016, which is corroborated by a peak in the abundance of age-0 sablefish in the trawl survey in this year. However, while the index also suggests higher than expected recruitment in 2018, this prediction is not observed in the trawl data (Figure A7). Good recruitment for sablefish appears related, in part, to cooler temperatures during the female pre-conditioning period prior to spawning (Tolimieri et al. 2018). The 2018 year class follows several years of a marine heat wave (aka, 'the blob'), which may have reduced female condition and resulted in lower realized recruitment than that expected by the sea level index. Condition of juveniles (age-5 &6) female sablefish north of Cape Mendocino was low in 2015 and 2016 but recovered but 2017(See: Growth and condition: female condition index, below). The exact relationship is not clear, but low condition of juvenile fishes in 2015 and 2016 may have delayed the onset of reproduction in these individuals and reduced reproductive output. Likewise, the probability of strong recruitment is higher under negative (cold) PDO conditions and the PDO has been warm over the last several years, which may help to explain the lower than expected (based on sea level) recruitment in 2018.

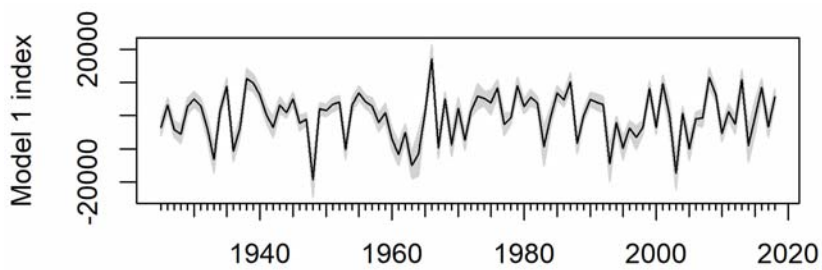


Figure A12. Sea level index for sablefish recruitment. The index are the stock-recruitment residuals in 1000's of recruits (variability around the stock-recruitment relationship).

Comparing the distribution of age-0 recruits (Figure A7) to the model performance (see Methods: Sea Level, Figure A39) suggests that strong over-predictions (more than 1.0 s.d. above the assessment-derived stock recruitment residual) may be due to failure to account for processes in the south in some way, regardless of the fact that DF3 does account for sea level south of Cape Mendocino. For example, the model over-predicted recruitment in 2004, 2005-2007, 2009 and 2011. All these years, with the exception of 2011, saw low recruitment in the area around San Francisco Bay. For 2011 the model predicted recruitment fairly close to that expected by the stock-recruitment relationship, and actual age-0 abundance was somewhat lower. Conversely, the model under-predicted the recruitment peaks in 2010, and 2013 when there was strong recruitment around San Francisco Bay and Point Conception. These failed predictions may also be related to differences in source waters (Schroeder et al. 2019), which is not captured in the sea-level index. Further, more mechanistic-based research, may help to improve recruitment predictions.

Note, the ROMS-based recruitment analysis showed higher recruitment with stronger poleward transport at depth, while the sea-level analysis showed more successful recruitment with lower sea level in the northern California Current. This lower sea level is typically correlated with stronger upwelling and southern alongshore surface flow (Connolly et al. 2014). However, lower sea level in the northern California Current is also related to a stronger alongshore sea-level/pressure gradient (higher in the south, lower in the north), which drives a stronger poleward deep current. This undercurrent is strongest between 100 – 500 m, but poleward flows extend deeper.

Growth and condition

Female condition index

Fish condition (here, observed body mass divided by expected body mass x 100) is an overall indicator of health and energy reserves, which is important for actions such as migration, reproduction and survival (Stevenson & Woods 2006). For example, recruitment success in sablefish is positively correlated with colder water conditions from June to December of the year prior spawning (Tolimieri et al. 2018). Cooler temperatures during the pre-spawning period may result in lower metabolic costs for females, allowing more energy available for reproduction or may be indicative of good prey resources resulting in better female condition. Sablefish may skip spawning (Head et al. 2014) and condition may affect the onset of reproduction.

Sablefish mature at approximately 7 years (50% mature at 6.86 years, Head et al. 2014, Johnson et al. 2016). Therefore, we calculated condition for age-7+ females, most of which would be reproductive, and for age-6 females, which would be just initiating maturation and be a indicator of potential changes in reproductive output of the population.

For adult (age-7+) sablefish the broad trends in condition were similar with a decrease in from 2003 through about 2006 followed by variability around the long-term mean and an increase in condition in 2018 (Figure A13). However there was variation between the two regions with high condition for northern fish in 2013 but low condition for southern fish in the same year. Similarly, northern fish had low condition in 2016 during the marine heat wave (aka 'the blob') but southern fish were in more or less average condition.

Condition was more variable for juvenile (age-6) sablefish than for adults (age-7+) with larger fluctuation in condition (Figure A13). Notably, northern juvenile had low condition in declining condition in 2014-2016 with low 2015 and 2016 during the years of the marine heat wave, which may help to explain lower than expected (based on the sea-level indicator) recruitment in 2018.

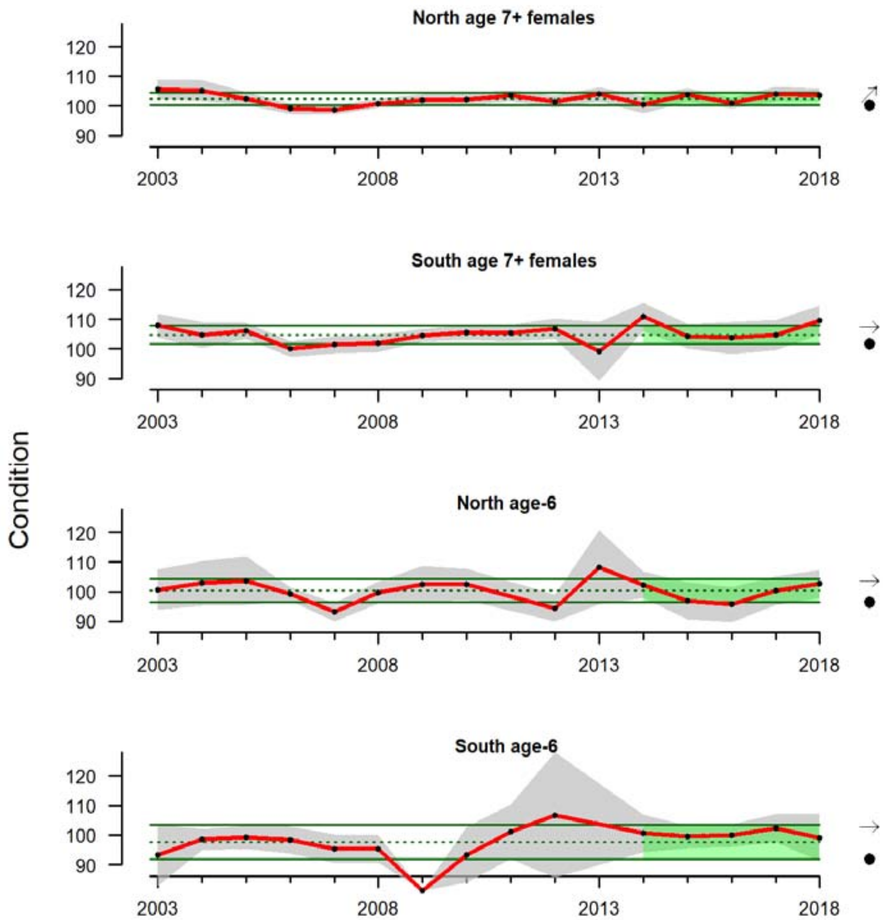


Figure A13. Condition index for female sablefish for August-October for age-7+ and age-6 fishes north or south of Cape Mendocino. The condition index is the actual weight divided by the expected weight from the length-weight relationship (in each region) multiplied by 100. Thus a value of 103% means that the fish's weight is 3% more than expected and the fish is in good condition. Grey envelopes indicate 95% confidence limits. Data from the WCGBTS.

Ocean Niño Index (ONI)

In the California Current, Sablefish growth (20 – 110 cm fishes) is lower under El Niño conditions, although the effect is weak (Kimura et al. 1998). Note, the relationship with El Niño is reversed in the Alaska. The monthly Ocean Niño Index (ONI) showed El Niño conditions in 2016 indicating the potential for reduced growth during that year. The ONI is presently increasing and just above the 0.5 C threshold (blue line in (Figure A11). "El Niño is likely to continue through the Northern Hemisphere summer 2019 (70% chance) and fall (55-60% chance).[2]", with the potential for lower sablefish growth.

[2] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml, May 9, 2019

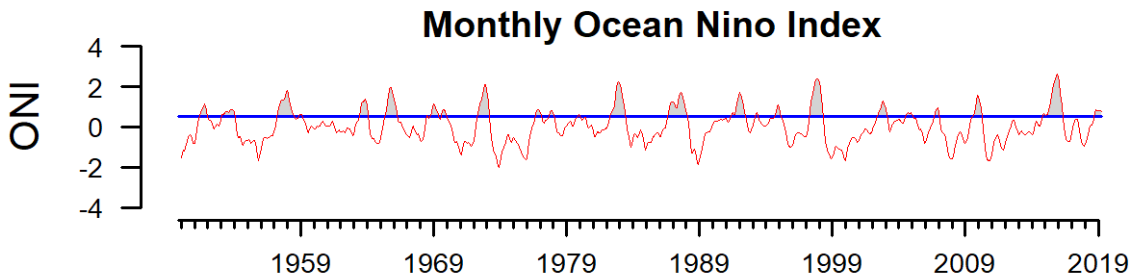


Figure A14. Monthly Ocean Nino Index. Blue line indicates the El Niño threshold of 0.5 C. An El Niño event occurs when the ONI exceeds 0.5 C for five consecutive months (Peterson et al. 2014). Data available from: https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/.

Species interactions

Sablefish food web

Understanding a species' food-web connections helps to identify important interspecific interactions, especially prey and predator relationships. The diet data for the food web presented below (Figure A20) are based on the literature review by Wipple et al. (2017), as used to parameterize diets of adult predators in recent California Current ecosystem modeling using the Atlantis modeling software (Marshall et al. 2017).

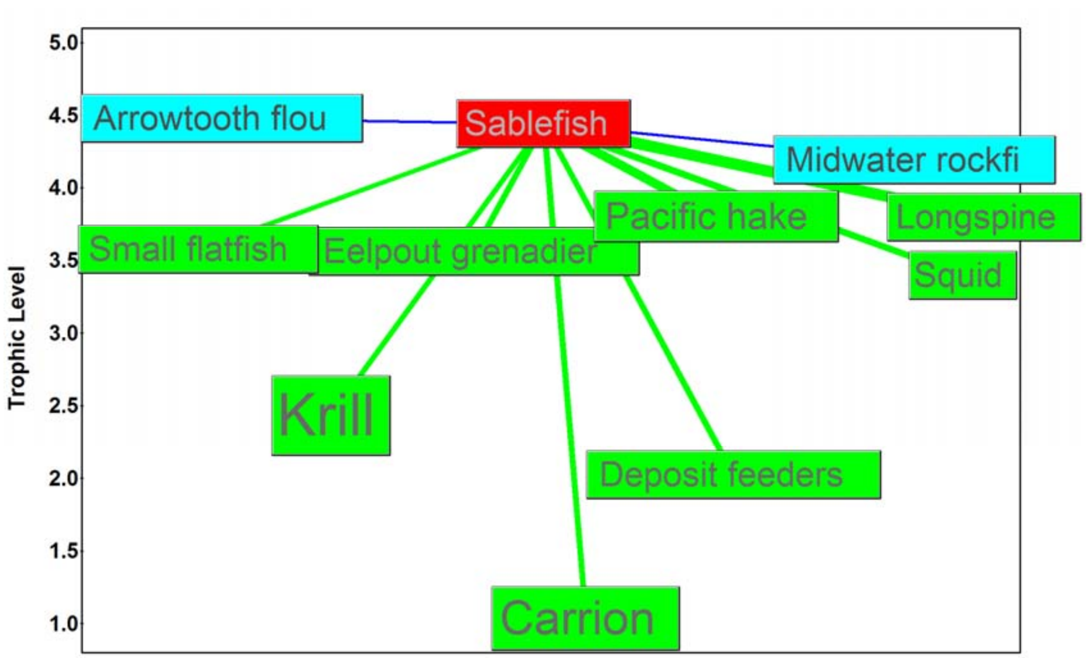


Figure A15. Food web diagram for sablefish. The focal group (sablefish) is in red, and major prey items are in green. Turquoise colored groups are both prey and predators of sablefish (for instance, juvenile sablefish may be eaten by arrowtooth flounder, but adult sablefish may eat juvenile arrowtooth flounder). Only major predators and prey are shown here, specifically prey that cumulatively account for 80% of sablefish diets, and predators that account for 80% of predation mortality on sablefish. Position in the y-direction is approximately related to trophic level. Size of the box is related to logarithm of biomass of the group. Links between boxes represent links in the food web. The diagram excludes minor prey items and predators that inflict small proportions of predation *mortality on the focal group. Food web visualization software (Ecoviz 2.3.6) was provided by Dr. Kerim Aydin, NOAA AFSC (Dufault et al. 2009, Marshall et al. 2017, Wipple et al. 2017).*

Below we separate sablefish prey into juvenile and adult diets. This division emphasizes some prey groups that are not obvious in the food web above, specifically small planktivorous fishes as prey for juveniles.

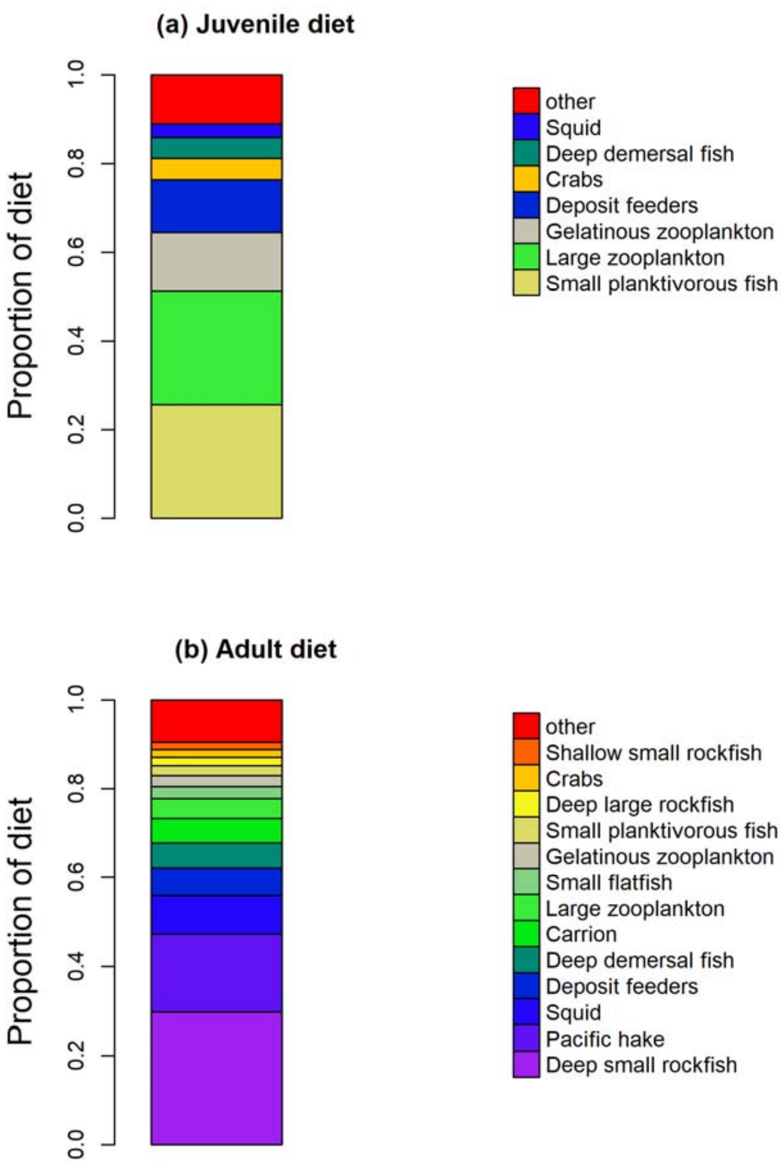
Sablefish are generalist predators (Dufault et al. 2009, Marshall et al. 2017, Wipple et al. 2017). Small planktivorous fishes and large zooplankton make up approximately 50% of the diet of juvenile fishes (Figure A20a). Small plantivoroes include: adult northern anchovy *Engraulis mordax* and Pacific sardine *Sardinops sagax*, and both juvenile and adult Pacific herring *Clupea pallasii*. Adults consume a wide range of prey, but deep small rockfishes, Pacific hake *Merluccius productus*, and squid make up approximately 60% of their diet (Figure A20b). Deep small rockfish include: adult longspine thornyhead *Sebastolobus altivelis*, sharpchin rockfish *Sebastes zacentrus*, and both adult and juvenile splitnose rockfish *Sebastes diploproa*. See (Dufault et al. 2009) for a more complete examination, with data available on the Dryad Digital Repository[3] (Wipple et al. 2017).

In Alaska sablefish are capable of taking advantage of temporal pulses in food resources (Coutre et al. 2015) and show strong seasonal and annual variation in diet. For example, in 2012 sablefish diet was diverse and included large amounts of invertebrates. However, in 2013 diets were dominated by herring and salmon offal. In both years, salmon comprised a large portion of the diet in September when there were large numbers of pink salmon *Oncorhynchus gorbuscha* in the system.

Prey availability appears important for juvenile survival in Alaska. Survival of age-0 sablefish through to age-2 fish appears correlated with chlorophyll-a concentration during late August and pink salmon abundance during the age-0 stage (Yasumiishi et al. 2015), and may be useful as an index of age-0 to age-2 recruitment in that system.

Figure A16. Diets of (a) juveniles and (b) sablefish from diet studies and Atlantis modeling. See Dufault et al. (2009) Table A1 for a complete listing of species by functional group.

[3]https://datadryad.org/resource/doi:10.5061/dryad.412nn)



Water temperature (degree days) during the several months prior to spawning correlates with recruitment success of age-0 rockfishes along the US west coast north of Cape Mendocino (~ 40 N) (Tolimieri et al. 2018). This effect may be the result of lower water temperature reducing metabolic costs and allowing females to divert energy towards reproduction. However, it also likely indexes food availability through upwelling-related processes. Thus food availability is likely important for egg production and subsequent recruitment (Tolimieri et al. 2018).

We report prey availability for juvenile and adult sablefish showing indices of abundance for their primary prey. Data for the northern California current come from the NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey (JSOES). Data from the central California Current region come from the SWFSC Rockfish Recruitment and Ecosystem Assessment Survey. Data for the southern California Current regions come from CalCOFI surveys. All time series were taken from the Integrated California Current Integrated Ecosystem Assessment (CCIEA)[4] (Harvey et al. 2018).

Additionally, we provide addition time series on the abundance of small deep rockfishes and Pacific hake YOY and smaller fishes from the NMFS U.S. WCGBTS (labeled 'trawl" in the figures below). While hake are midwater fish, the trawl survey does take substantial numbers and the index provides reasonable information on relative abundance. For the

[4] https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

trawl time series we calculated the mean annual CPUE (kg per ha) for hake YOY and small hake. Trawl data are available from the FRAM Data Warehouse[5].

Prey resources for juvenile sablefish

There was little information available on prey for juvenile sablefish in the northern region of the California Current (Cape Mendocino) with the only available time series being market squid. However, availability of market squid has been high in recent years and was the highest observed in the time series in 2018, suggest potentially good feeding conditions (Figure A22) in recent years.

In the central region (between Cape Mendocino and Point Conception), both adult and YOY anchovy showed strong increases in abundance in 2018 (Figure A22). Adult sardine showed a small increase, and YOY sardine also showed a peak in abundance. The abundance of krill (large zooplankton) was variable but as of 2017 the catch was just above the upper 1.0 s.d. bound indicating potentially good food resources for that year. Overall, prey resources for juvenile sablefish appear to be relatively good for 2018.

In the southern portion of the California Current (south of Point Conception), anchovy increased in abundance over the last five years by more than 1.0 sd of the long-term mean (Figure A22) and were above 1.0 s.d. of the long-term mean in 2018. Sardine remained low over the last five years, just above the lower 1.0 sd bound for its long-term mean. The high abundance of anchovy suggests that food abundance is at least acceptable juvenile sablefish in the southern California Current region.

Prey resources for adult sablefish

For adult sablefish, prey resources in the northern (Cape Flattery to Cape Mendocino) and central (Cape Mendocino to Point Conception) portion of its range appear to be good relative to the last 10-15 years (Figure A23). Deep-small rockfishes, small flatfishes and small hake have all increased by more than 1.0 sd of the long-term mean. Additionally, while they showed no specific trends, deep demersal fishes sand market squid in the north and krill, hake YOY and market squid in the central region were at or above their long-term mean over the last few years.

In the southern region, the prey field for adult sablefish appears neutral to poor. Deep-small rockfish were within 1.0 sd of the long-term mean as were hake. However, deep demersal fishes, small flat fishes, hake YOY and market squid all decreased in abundance over the last five years by more than 1.0 sd of the long-term mean.

[5] https://www.nwfsc.noaa.gov/data/map

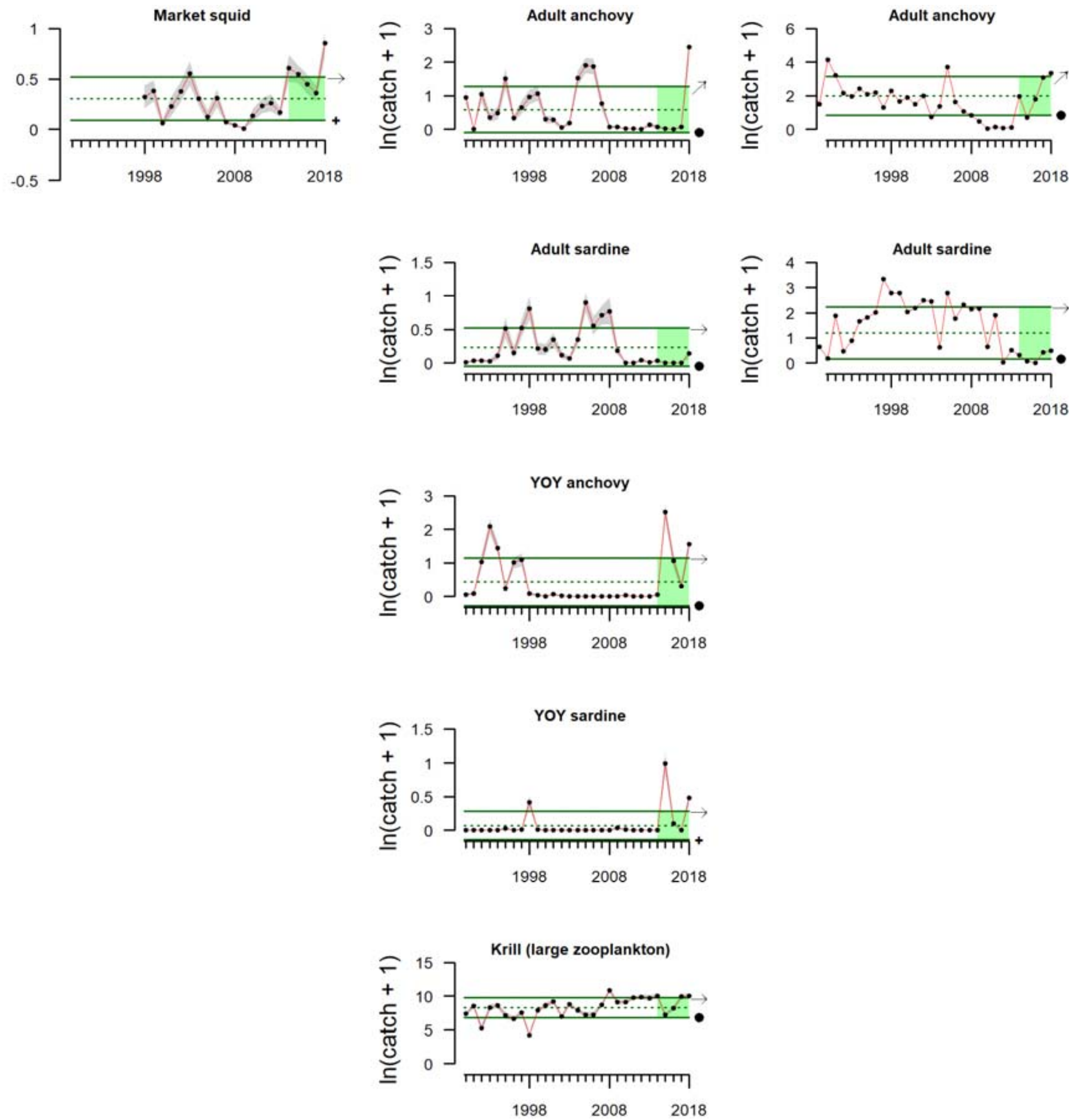


Figure A17. Availability of major prey taxa for juvenile sablefish from 1990-2018 in the north (Cape Flattery to Cape Mendocino, left column), central (Cape Mendocino to Point Conception, central column), and southern (south of Point Conception, right column) California Current. Reproduced from (Harvey et al. 2019).

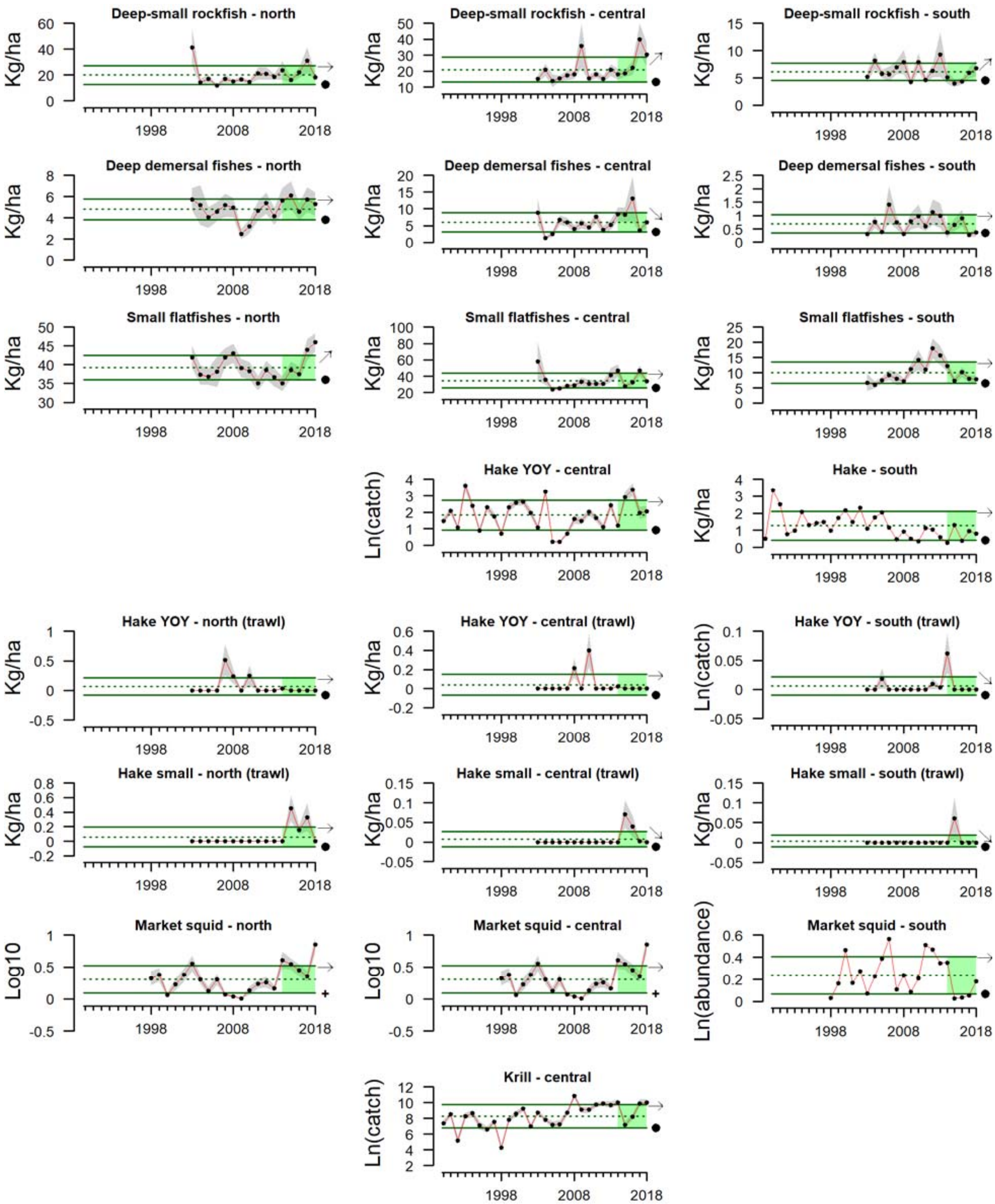


Figure A18. Availability of major prey taxa for adult sablefish in the California Current Ecosystem. Left column is for the northern CCE, central column is for the central CCE and right column is for the southern CCE. Ln(catch) is ln(catch +1); Log10 is $\log_{10}(\text{catch km}^{-1} + 1)$.

Predators and potential competitors

Atlantis modeling suggests that some species may interact with sablefish as predators on juveniles but also as prey for older stages. In Figure A20, these are midwater rockfishes and arrowtooth flounder. Since these fishes act as both predators on young sablefish and prey for older sablefish, their potential impacts are difficult to predict. North of Cape Mendocino, the catch of arrowtooth in the WCGBTS decreased over the last five years by more than 1.0 s.d. of the long-term time series; abundance between Cape Mendocino and Point Conception fluctuated over the last five years but was close to the long-term average in 2018 (Figure A24). Conversely, midwater rockfishes showed an increase over the same period in both the northern and the central regions but experienced a drop to average conditions in the central region in 2018. In the south, midwater rockfishes were variable but did not show specific trends. Given the low numbers south of Point Conception, these data may be less reliable. In all three regions, the abundance of predators/competitor was approximately average in 2018 compared to 2003 – 2018.

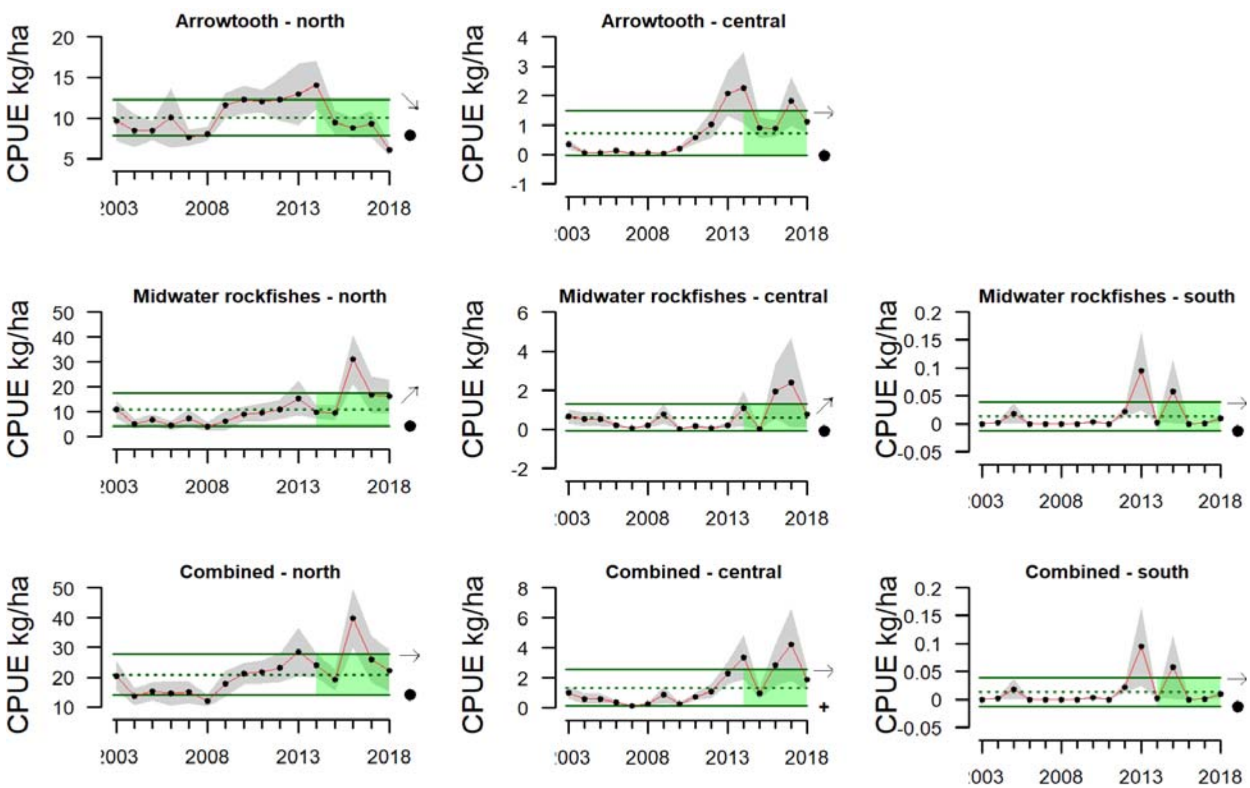


Figure A19. Mean catch per unit effort (CPUE) of potential sablefish competitors identified in the Atlantis model of the California Current food web; North = Cape Flattery to Cape Mendocino; central = Cape Mendocino to Point Conception; and south from of Point Conception. Data from the WCGBTS.

Habitat

For marine fishes, understanding a species' spatial distribution is necessary for delineating Essential Fish Habitat (EFH), which is important for an ecosystem-based management approach to fisheries. In the United States, the National Marine Fisheries Service (NMFS) and regional fisheries councils are required to identify EFH (NOAA 1996, Simpson et al. 2017).

Adult sablefish appear to be generalists in terms of bottom habitat (Love 2011) but are associated with upwelling habitats of low SST and high sea surface salinity (Juan-Jorda et al. 2009) and have lower growth during El Nino conditions off the U.S. west coast (Kimura et al. 1998). Adults are highly mobile with estimates of movement are variable ranging from 15 to over 1000 nautical miles. However, most individuals likely move less than 500 nautical miles (Shaw & Parks 1997, Kimura et al. 1998, Maloney 2004, Love 2011, Hanselman et al. 2015).

We present habitat information from two sources: Levin and Wells (2011) and the Groundfish Essential Fish Habitat Synthesis (NMFS 2013) because the two reports provide different analyses and cover different life-history stages.

Levin and Wells (2011) provide separate maps of habitat suitability for juvenile and adult sablefish. Habitat suitability was as a function of a number of covariates, including depth, latitude and substrate, and expert opinion (NMFS 2005, 2013)[6]. Figure A25 shows predicted habitat suitability for juvenile sablefish along the US west coast. Figure A26 shows predicted habitat suitability for adult sablefish along the US west coast.

The Groundfish Essential Fish Habitat Synthesis (NMFS 2013) provides combined age-1+ maps of probability of occurrence and abundance based on the WCGBTS from 2003 –2011 and includes multiple covariates for sablefish including: depth, bottom temperature, sediment grain size, and distance to rock for both the occurrence and abundance models. For brevity, we include only NWFSC model results here.

Figure A27 shows the probability of occurrence and predicted abundance for juvenile and adult sablefish from the NWFSC models. There is a clear depth trend with sablefish occurring more frequently and being at higher abundance deeper waters on the slope versus the shelf. In fact, in the NWFSC model, depth and temperature were the most important predictors.

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[6] More detailed information about the development of the data and analytical procedures used to produce the HSPs are described in the document: *Pacific States Marine Fisheries Commission. 2004. Risk Assessment for the Pacific Groundfish FMP*, which is included as Appendix A to the FEIS. Additionally, Appendix D of this document includes a *Report on Updates Made to the Production of Essential Fish Habitat Suitability Probability Map*.

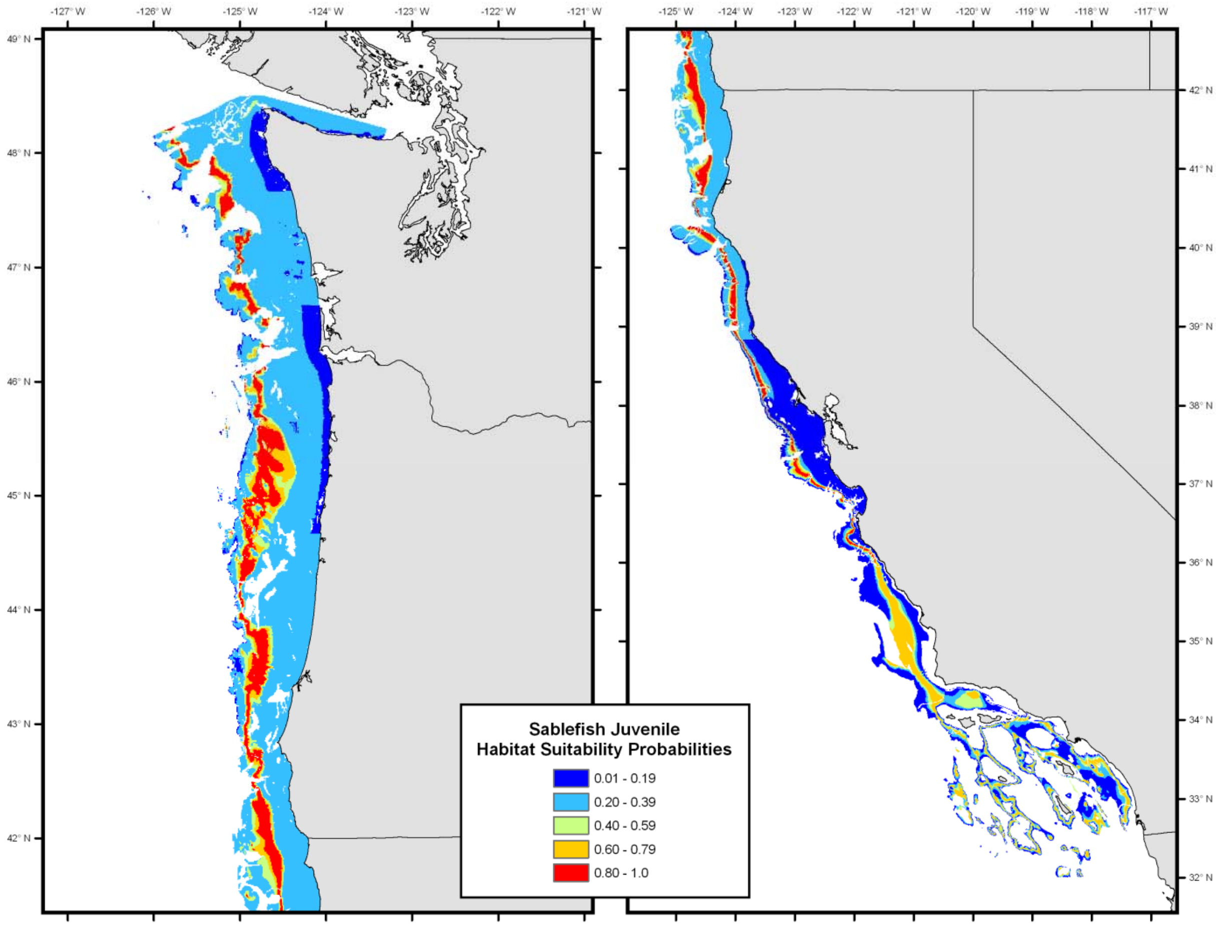


Figure A20. Habitat Suitability Probabilities for Sablefish Anoplopoma fimbria juvenile. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

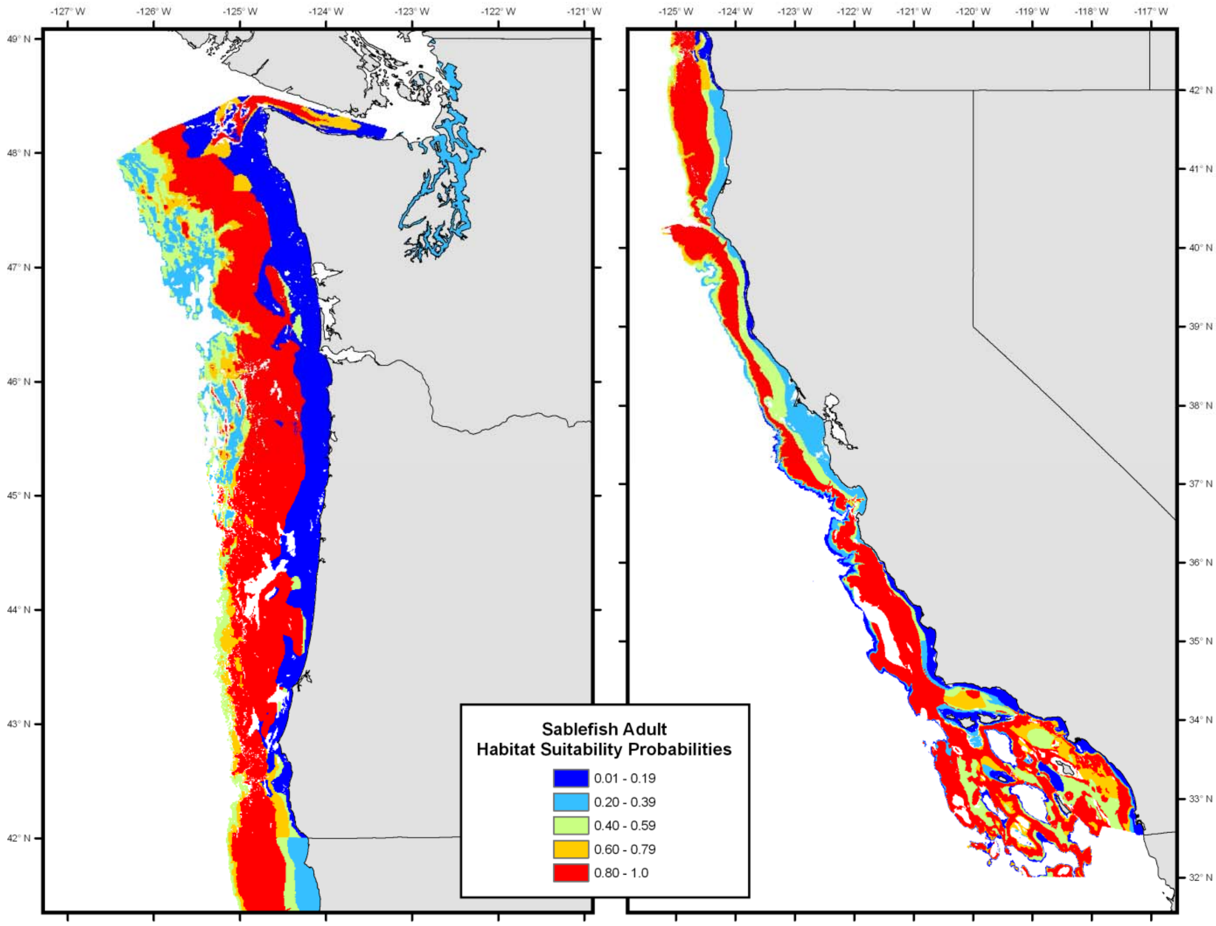


Figure A21. Habitat Suitability Probabilities for Sablefish Anoplopoma fimbria adult. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

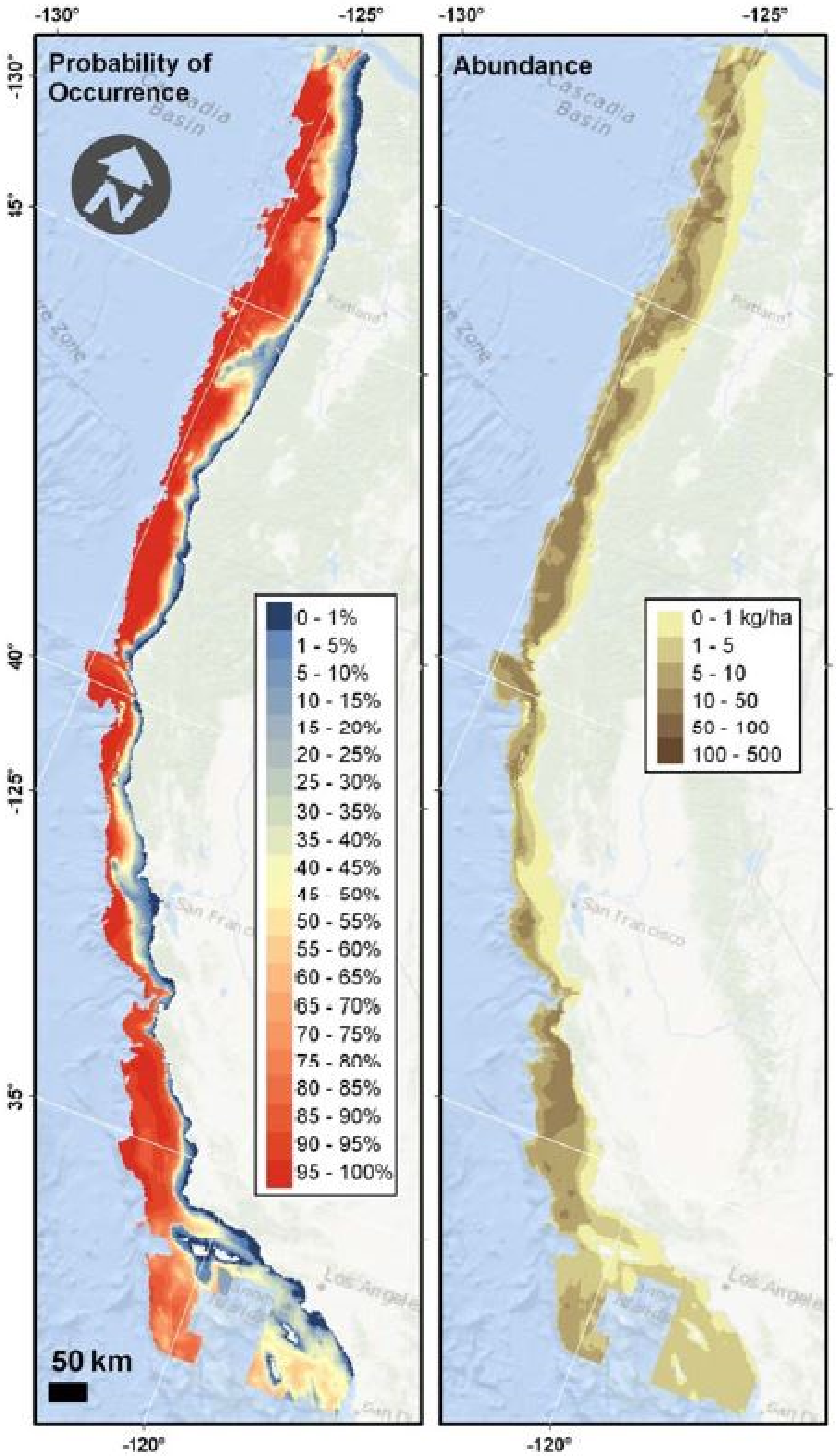


Figure A22. Mean probability of occurrence and mean predicted abundance for age 1+ sablefish. Reproduced from (NMFS 2013) Groundfish Essential Fish Habitat Synthesis Report: http://www.pcouncil.org/wp-content/uploads/Groundfish_EFH_Synthesis_Report_to_PFMC_FINAL.pdf

Socio-economic considerations

Sablefish play an important role in the US West coast social-ecological system by virtue of their high value to individual fishers and fishing communities and because of their potential effects on other fisheries and living marine resources. Here we detail key considerations about sablefish in the context of this broader system. There is a variety of ways to characterize the influence of changing sablefish stock dynamics on the fishery. We do not attempt to cover all of those influences comprehensively here. Rather, we focus on four topics:

(1) The impacts of shifts in the latitudinal distribution of sablefish biomass on specific communities along the coast
(2) Interactions with non-fishery bycatch, specifically marine mammals
(3) Potential effects of sablefish quota limitations on other fisheries
(4) Potential interactions between other species' quota limitations and sablefish

Future work could integrate other aspects of how changes in sablefish stock dynamics and associated management strategies influence safety-at-sea (Pfeiffer & Gratz 2016), livelihoods, and other aspects of human well-being. Points (3) and (4) are addressed briefly here. See PFMC and NMFS (2017) and Steiner (2019) for a more complete analysis of catch and bycatch and their socio-economic implications.

Shifting distribution of stock biomass and availability to ports

Shifting stock biomass may affect availability to ports (adapded from Selden et al. in prep). Sablefish biomass has declined by more than 50% since 1980, though this decline has not been uniform across the coast. Rather, the population centroid first moved north from 1980 to 1992 then south again by 2013 (Figure A17, Figure A28). Biomass began moving north again concurrent with an increase in biomass in the trawl survey (Figure A28), but has not moved as far north as in the 1990s. Declines in sablefish biomass in conjunction with northward distribution shifts during 1980-1992 led to particularly strong losses in availability to southern ports like Morro Bay and Fort Bragg, CA, while availability was maintained at more northern ports like Coos Bay and Astoria, Oregon. Southward shifts of sablefish from 1992-2013, coincident with further declines in biomass, led to dramatic declines in availability for northern ports and a stabilization or increase in availability to southern ports. Sablefish landings largely reflect local availability, such that more sablefish are caught when local availability is high than when it is low (Figure A29).

Note, the analysis here focuses on the access to sablefish by individual ports, but other factors such as the location and availability of processors are likely to be important.

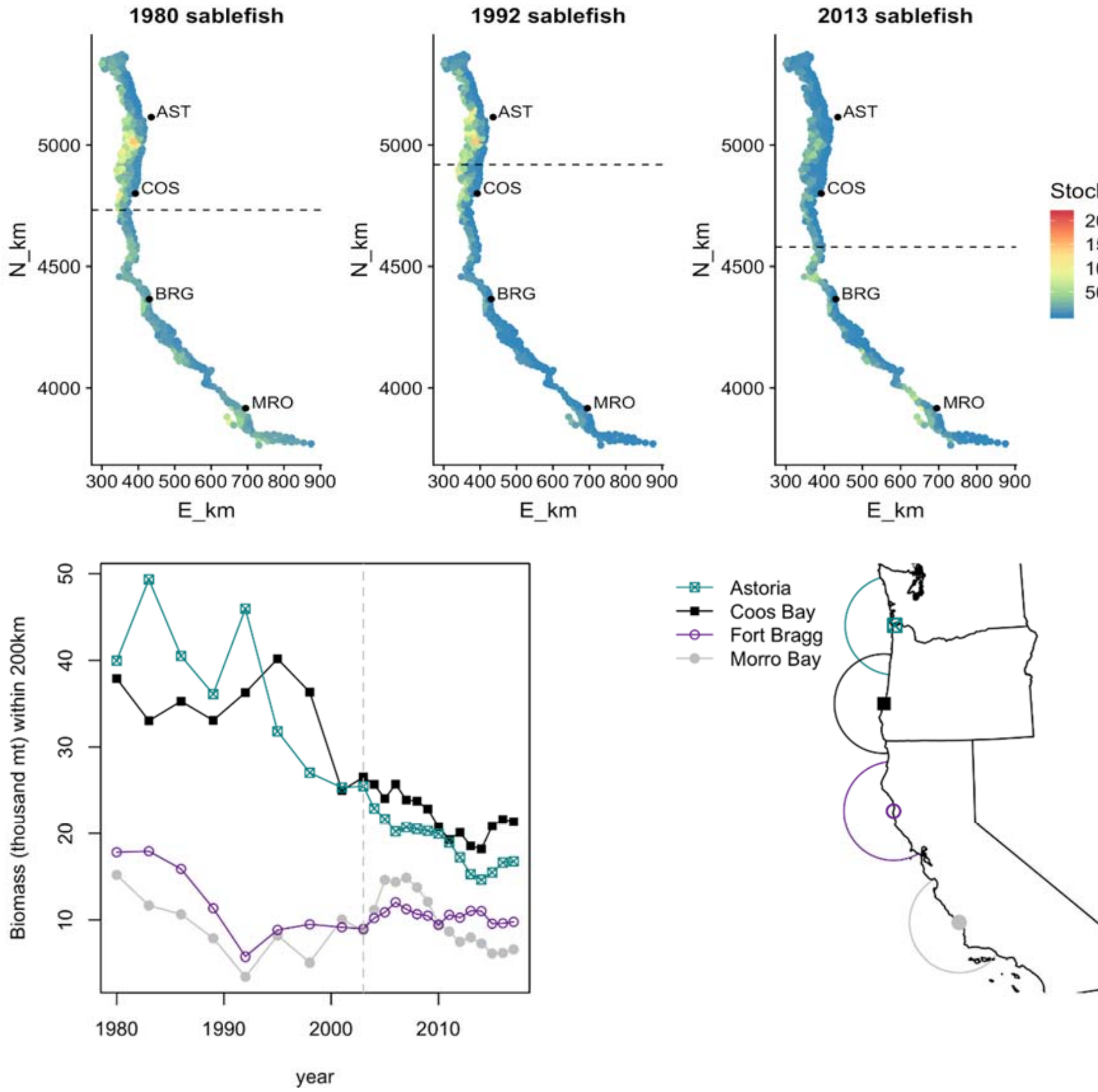


Figure A23. (Top) Sablefish stock biomass (mt, Eq. 1) compared with the location of four ports, displayed for years in which the center of gravity represented by the dashed line was intermediate (1980), the northern extreme (1992), and the southern extreme (2013) in the time series from Figure A1. Note the relatively high biomass in southern California (near MRO) in 1980 and 2013, but not 1992. (Bottom) Time series of changes in availability of sablefish stock biomass to each focal port.

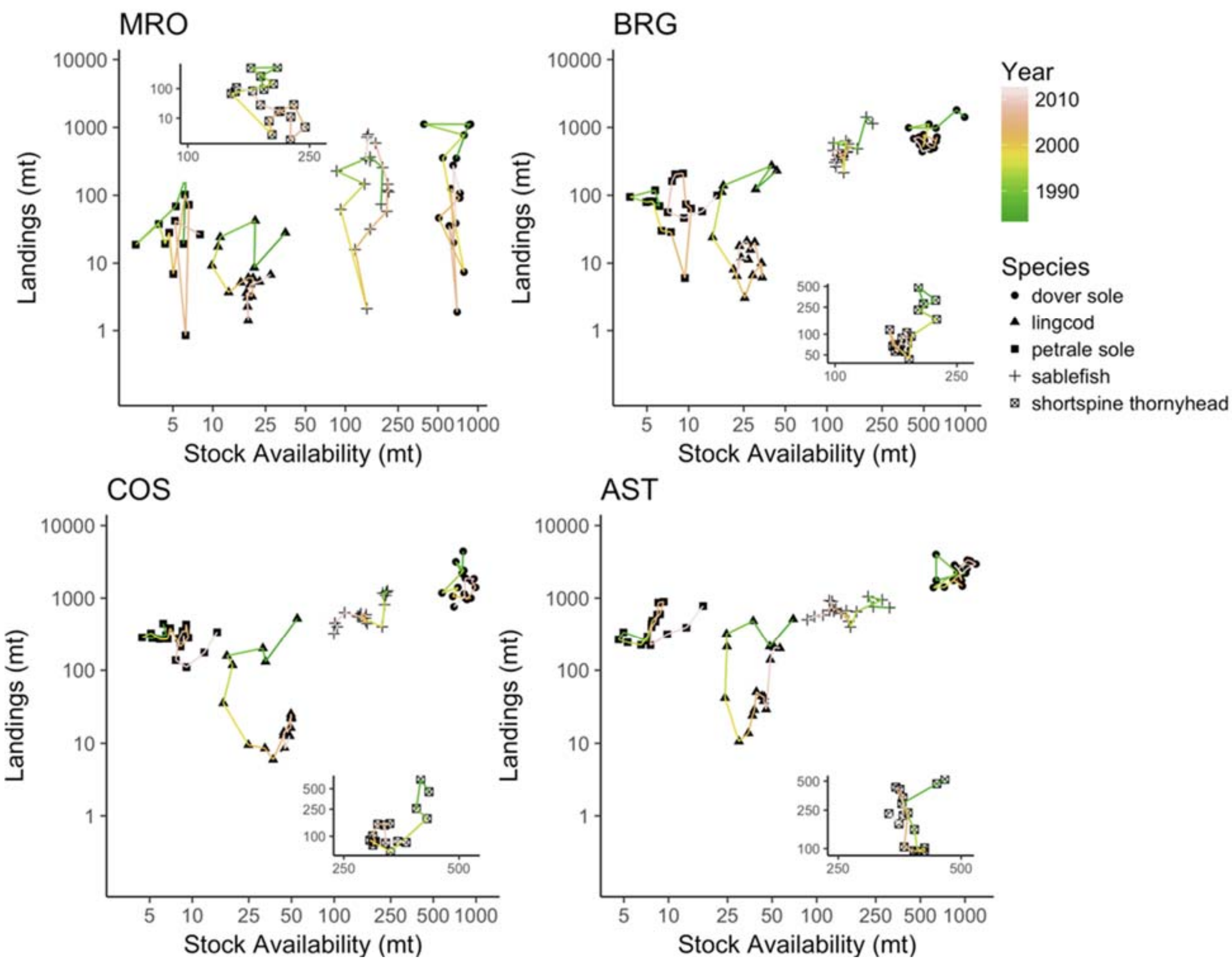


Figure A24. Time series of landings (mt) vs stock availability (mt, Eq. 2) for 4 focal ports. (Inset) Shortspine thornyhead landings vs. stock availability. Colors of line segments range from dark green in 1981 to light orange in 2013. Adapted from Selden et al. (in review)

Interaction of the sablefish fishery with other species and fisheries

Activity in the sablefish fishery interacts with both other species and other fisheries. These interactions have the potential to directly impact mortality in protected species, limit activity in the sablefish sector, and limit activity in other fisheries. For example, as a choke species, sablefish have the potential to limit fishing on other species as sablefish reach annual catch limits (ACLs) or quota limitations (Leonard & Steiner 2017, Lomeli et al. 2017).

Non-Fisheries Bycatch-whale entanglements

Whale entanglements in the sablefish pot sectors have the potential to limit effort in these sectors due to protections for marine mammals. Coincident with the anomalous warming of the California Current in 2014-2016, observations of whales entangled in fishing gear occurred at levels far greater than in the preceding decade (Figure A31). Observed entanglements were most numerous in 2015 and 2016, with the majority involving humpbacks. Most observations occurred in California waters. Based on preliminary data, observed entanglements appeared to decline in 2017, but were still greater than in years from 2000 to 2013. The majority of entanglements occur in gear that cannot be identified visually. Of the portion that can be identified, most appears to be Dungeness crab gear.

There have been two documented takes of a humpback whale in sablefish fisheries—one in the Limited Entry (LE) sablefish pot fishery sector in 2014 and one in the Open Access Fixed Gear pot fishery sector in 2016. However, based on Bayesian modeling procedures, the estimated fleet-wide entanglements were consistently above the 5-year running average threshold over from 2002-2017 in the combined LE Sablefish and Open Access Fixed Gear Pot sectors (Hanson et al. 2019). This result was largely due to the Open Access Fixed Gear Pot sector, which had entanglements consistently above the 5-year running average threshold, while entanglements in the LE sablefish pot sector were consistently below the threshold.

Many interacting factors could be causing the increased numbers of observed entanglements, including shifts in oceanographic conditions and prey fields that brought the whales closer to shore, as well as changes in distribution and timing of fishing effort; the NOAA West Coast Region will continue to follow this issue as conditions in the CCE change, and the CCIEA team is involved in analyses with researchers from NOAA, other agencies, and academic partners.

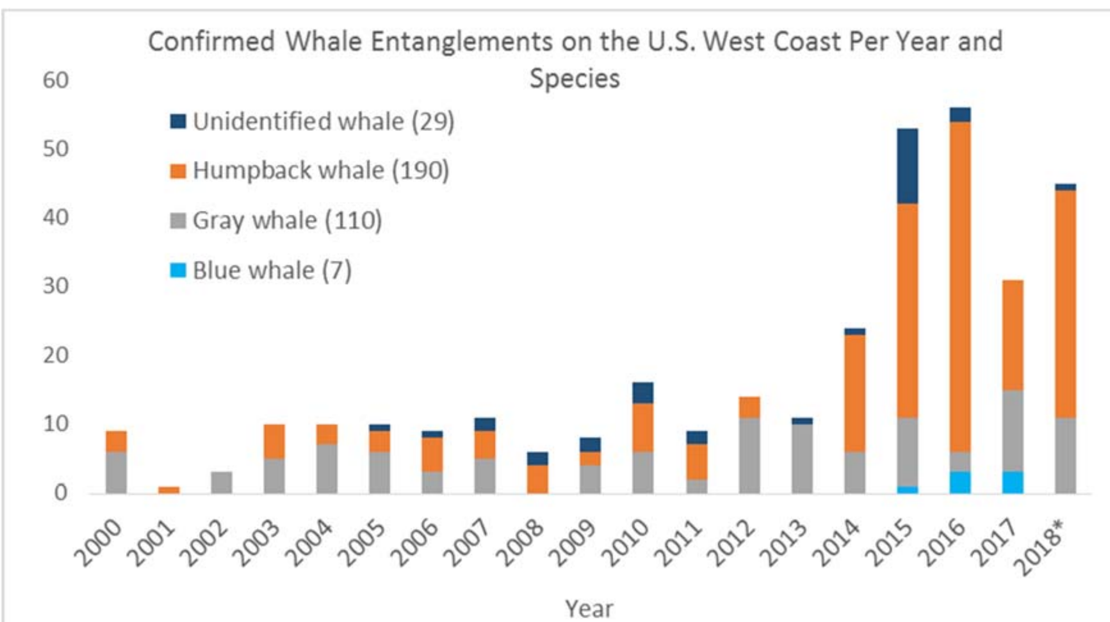


Figure A25. Numbers of whales reported as entangled in fishing gear along the West Coast from 2000-2018. Reproduced from (Harvey et al. 2019). See also (WCRO 2018).

Total fishing mortality for sablefish

Sablefish are caught in a range of fisheries sectors (Figure A30). In 2017, absolute total fishing mortality (landings plus estimated discard mortality) was highest in the catch shares (CS) bottom trawl and limited entry (LE) sablefish hook and line fisheries (Figure A30a). However, sablefish made up only a small proportion of the total catch in the trawl fishery (Figure A30b). Other sectors such as LE Sablefish hook and line, CS electronic monitoring (EM) pot, LE sablefish pot and CS pot were clearly (or perhaps, obviously) directed at sablefish with most of the catch (total fishery mortality, Figure A30b) being sablefish. Some fisheries such as LE fixed gear (FG) and daily-trip-limit (DTL) pot with little overall catch primarily caught sablefish fishery (Figure A30b).

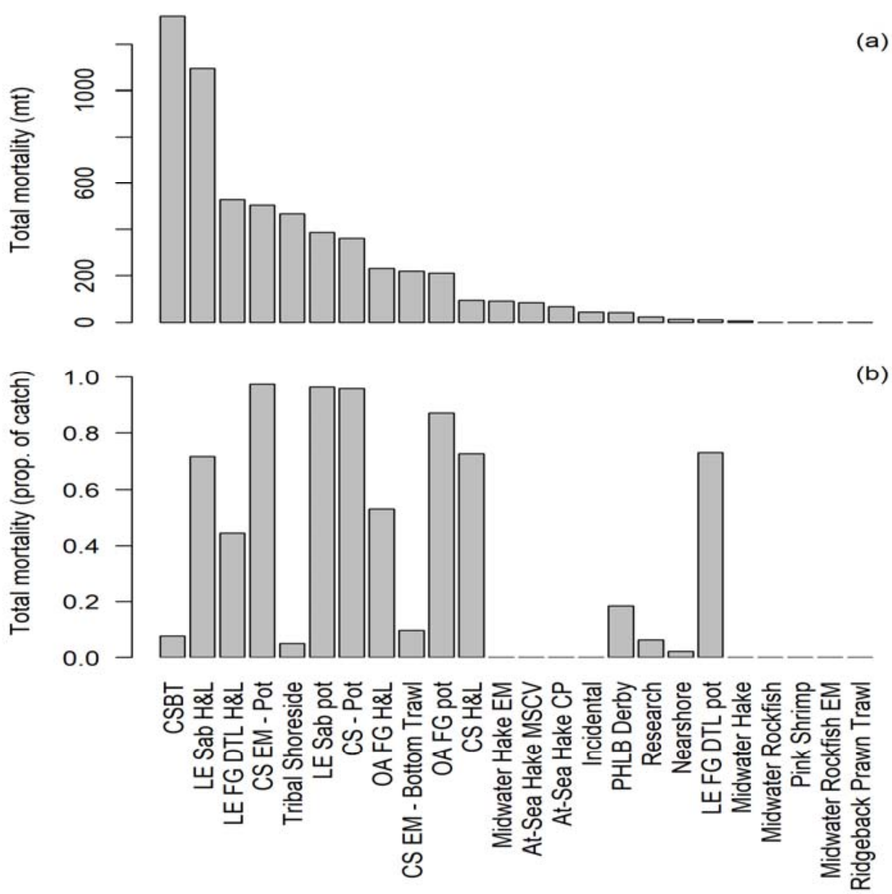


Figure A26. Sablefish catch statistics in 24 sectors of US west coast fisheries in 2017. (a) Total fishing mortality in metric tons (mt) for sablefish (landings + discard mortality) (b) Total fishing mortality for sablefish as a proportion of total fishing mortality of all species. LE = limited entry, CS = catch shares, OA = open access, EM = electronic monitoring, FG = fixed gear and H&L = hook and line. Data from the Groundfish Expanded Mortality Multiyear report (GEMM) through 2017, available from: https://www.nwfsc.noaa.gov/data/map

Bycatch of choke and recently rebuilt species

Catch of choke and recently rebuilt species within fisheries sectors that target or have high catch of sablefish has the potential to restrict sablefish or other fishery effort due to quota limitations for these species. Likewise, bycatch within the sablefish sectors may limit effort directed at the choke or recently rebuilt species.

Here we present total fishing mortality (landings plus estimated discard mortality) for 11 species: black rockfish, bocaccio, canary rockfish, cowcod, darkblotched rockfish, lingcod, Pacific hake, Pacific Ocean perch, widow rockfish and yelloweye rockfish[7]. These species are caught several fishery sectors targeting sablefish (Figure A32). In all cases, the mortality in the sablefish sectors was quite low compared the ACLs of these species. In 2017, lingcod was the species most commonly caught with sablefish across all seven sectors, with the exception of the LE FG DTL hook and line fishery, where black rockfish were the highest bycatch species.

Total fishing mortality of the selected species has been well below the annual catch limits (ACL) for all species and sectors Figure A33) with the exception of petrale sole, which has increased since 2010 and was just under the ACL in 2017. Petrale sole were caught in the limited entry sablefish hook and line sector and the catch shares EM pot fishery (Figure A32). However, bycatch of petrale within the sablefish sectors was only several metric tons compared to ACLs of 3000 metric tons. As such, any effects would appear to be minimal.

[7]Groundfish Expanded Mortality Multiyear report, through 2017, data available from: https://www.nwfsc.noaa.gov/data/map

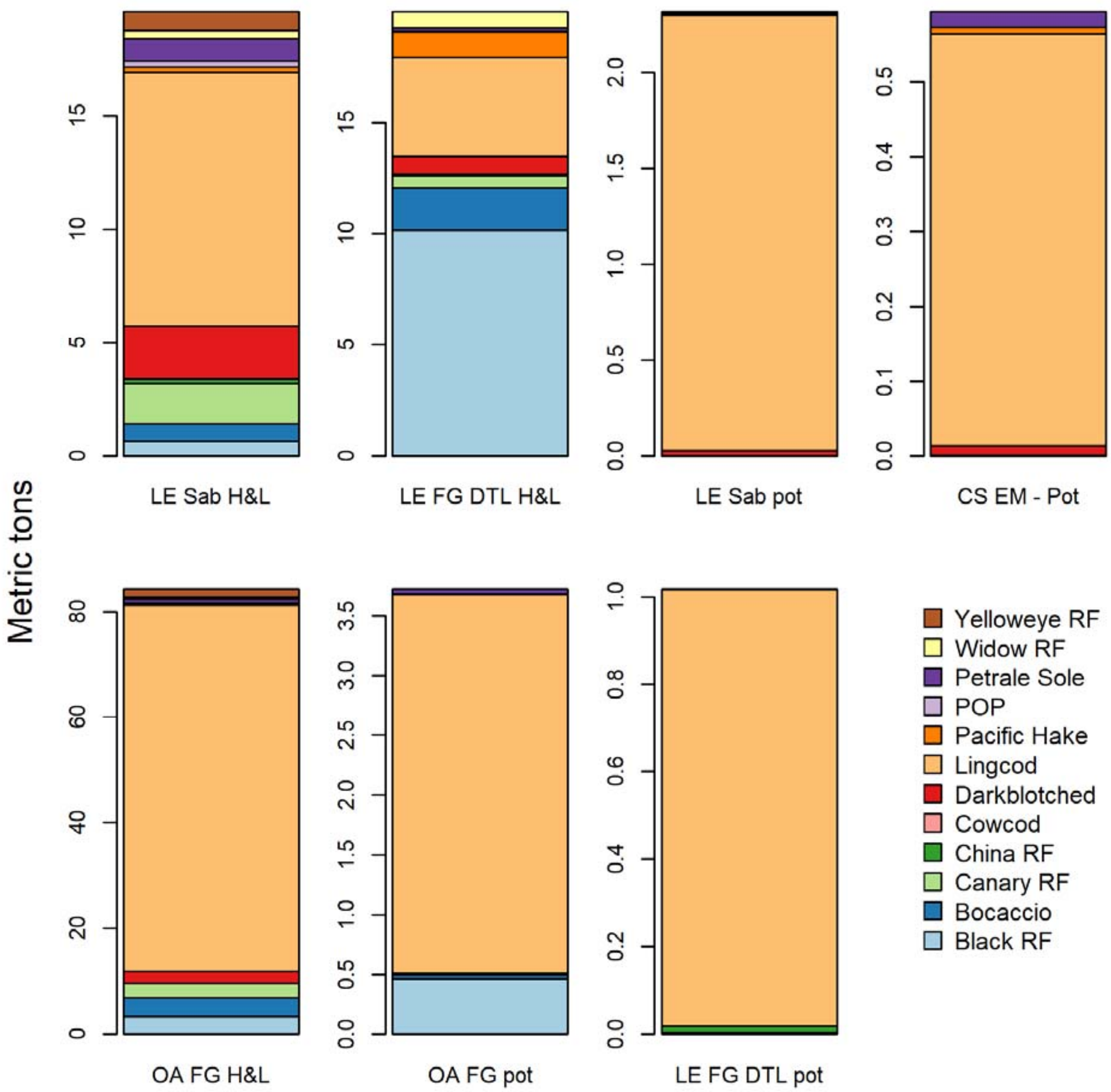


Figure A27. Total fishing mortality (catch plus estimated discards) in 2017 of weak and recently rebuilt species in various fishery sectors targeting sablefish. LE = limited entry, CS = catch shares, OA = open access, EM = electronic monitoring, FG = fixed gear and H&L = hook and line. Data from the Groundfish Expanded Mortality Multiyear report (GEMM) through 2017, available from: https://www.nwfsc.noaa.gov/data/map

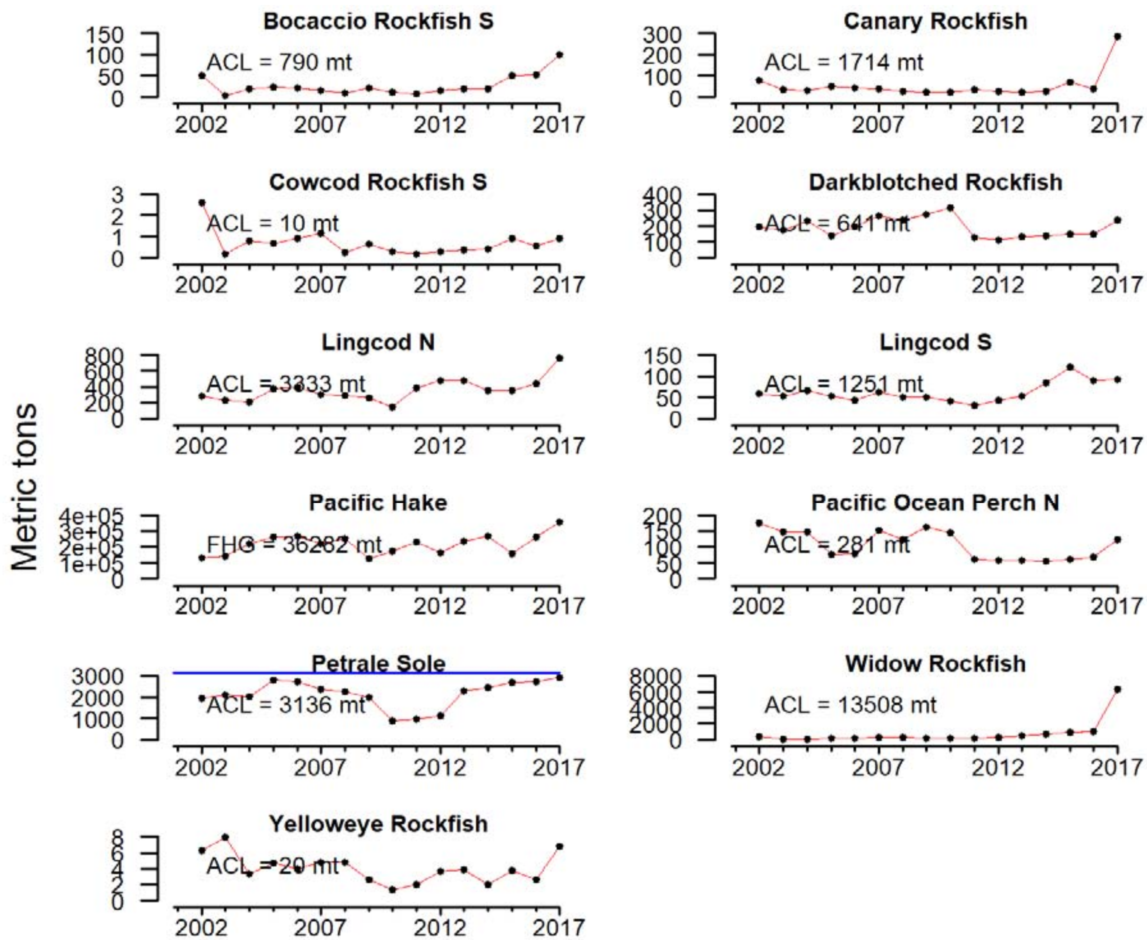


Figure A28. Total fishing mortality (landings plus estimated discard mortality) across all fisheries sectors for eleven recently rebuilt or weak stocks. ACL is the annual catch limit for 2017-2018 in metric tons (mt). FHG is the fishery harvest guideline for Pacific hake. Blue line, when included, indicates the ACL or FHG threshold (CFR 660)

Catch in the hake fishery

By catch of sablefish in the hake fishery has the potential to limit activity. Catch in the hake fishery may also act as a leading indicator for the aging of strong year classes as they enter the hake fishery and are caught. There was a rise in sablefish bycatch in both the at-sea and shore-side hake fisheries from 2016 – 2018 (Figure A34), likely due to the aging of the strong 2016 age class. Cautions from the Region to the fleet to reduce sablefish bycatch seem to have resulted in a decrease in sablefish bycatch as of December 2018, although catch in 2018 remained high in both sectors relative to 2011 – 2016 (V. Tuttle, pers. Comm.).

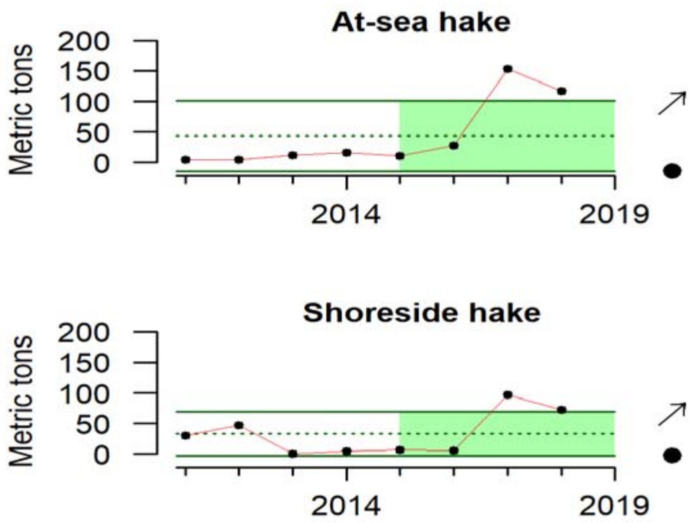


Figure A29. Catch of sablefish in the At-Sea and Shoreside hake fisheries from 2011-2018. Data available from: GEMM; https://reports.psmfc.org/pacfin/

Sablefish total fishing mortality and the DTS fishery

Sablefish are caught as part of the Dover sole – thornyhead – sablefish fishery (DTS fishery), and sablefish quota constrains catch of Dover sole and thornyheads in the DTS trawl fishery with attainment for both these species well below their ACL or TAC (PFMC & NMFS 2017). Total fishing mortality for sablefish rose from a low in 2013 and reached the 2017-2018 annual catch limit (ACL) for sablefish north of 36N in 2017 (Figure A35). Total fishing mortality in the south was well below the ACL in 2017 and has remained so since 2012. Total fishing mortality for Dover sole and thornyheads was well below the species' ACLs in 2017 (Figure A35).

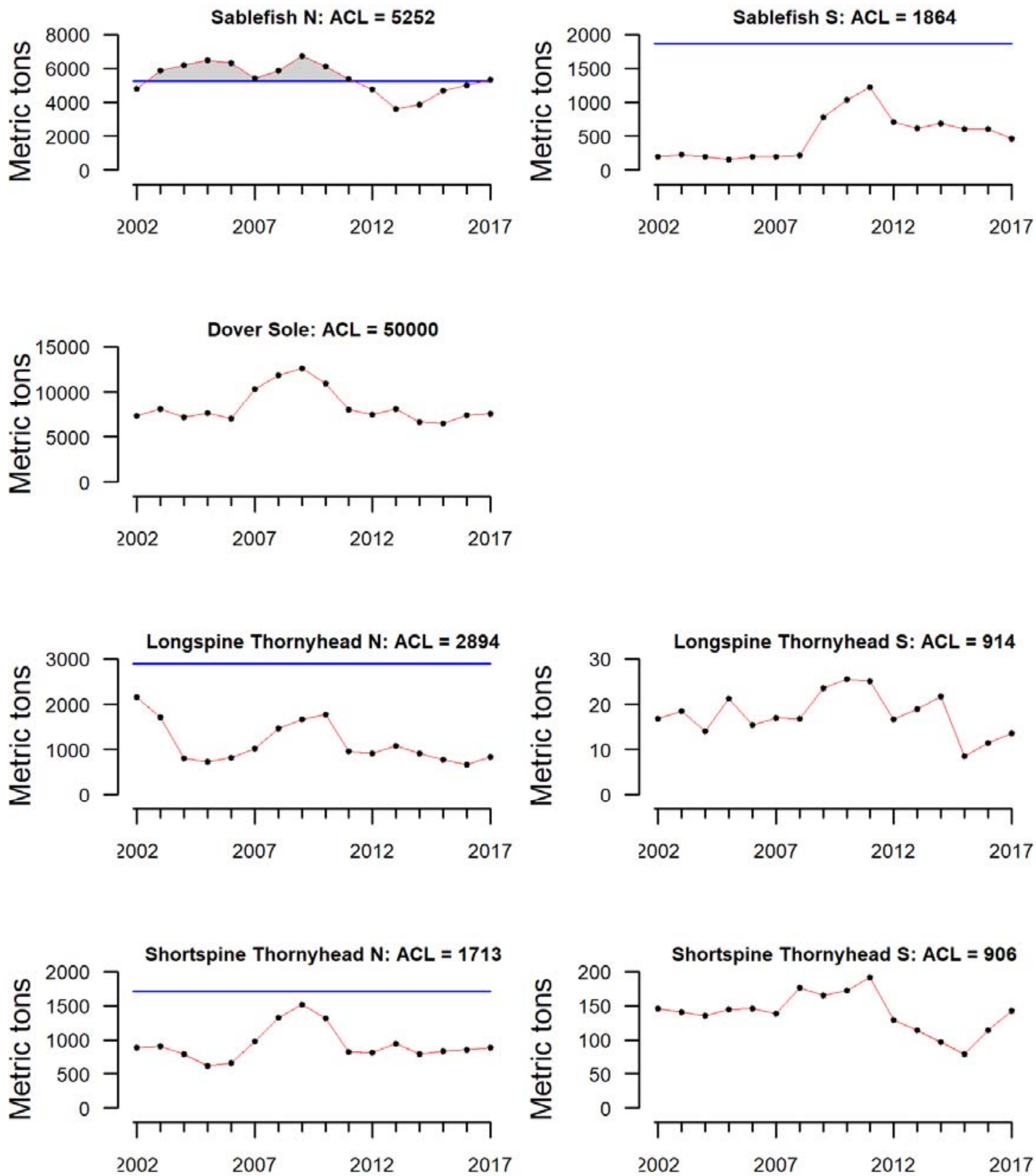


Figure A30. Total fishing mortality of sablefish, Dover sole and thornyheads from 2002 – 2017. North and south of 36 ^{o}N for sablefish; coast-wide for Dover sole and north (N) and south (S) of 34^{o}27 N for longspine and shortspine thornyheads. ACL is the acceptable catch limit for 2017.

Methods

Female condition index

The condition index (CI) is a relative measure of the overall health of the fish quantified as the observed weight of an individual relative to the expected weight from the length-weight relationship for the species:

$$CI = W_{obsserved}/W_{expected} * 100$$

(Ricker 1973, Ricker 1975, Stevenson & Woods 2006). We used data from the WCGBTS to calculate the condition index for female sablefish north and south of Cape Mendocino (~ 40 ^{o}N) because maturity and growth differ between the two areas (Head et al. 2014) . Sablefish mature at approximately 7 years (50% mature at 6.86 years, Head et al. 2014, Johnson et al. 2016). Therefore, we calculated condition for age-7+ females, most of which would be reproductive, and for age-6 females, which would be just initiating maturation next year and be a indicator of potential changes in reproductive output of the population.

First we calculated the length-weight relationship as:

$$Log(W_i) = log(a) + b*log(L_i)$$

There was a strong relationship on the log-scale in both the north and south ($r^2 = 0.98$ for both)(Figure A36).

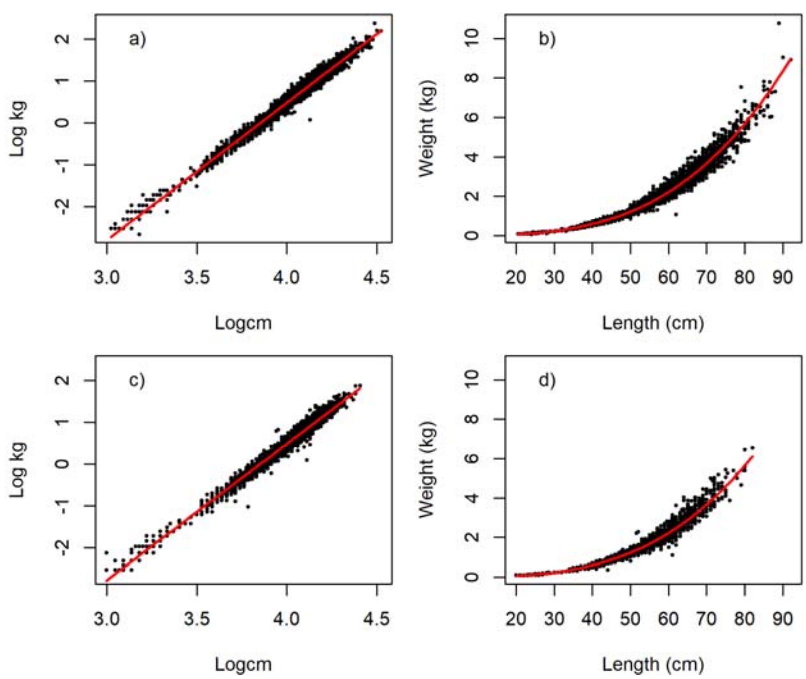


Figure A31. Length weight relationship for female sablefish > 40 cm north and south of Cape Mendocino. a) log relationship north, b) back-transformed relationship north, $W = (3.275 \times 10^{-6})*L^{3.278}$, c) log relationship south, d) back-transformed relationship south, $W = (3.3636 \times 10^{-6})*L^{3.252}$. Red line is the predicted relationship.

Next, we back-transformed the resulting relationship (equation) to the original data scale to obtain the length-weight relationship as $W = aL^b$. We then caculated condition for each individual as:

$$\text{Individual Condition Index} = W_{observed}/W_{expected} * 100$$

Finally, we then averaged the Individual Condition Index by year to obtain an annual index of female condition north and south of Cape Mendocino.

Pacific Decadal Oscillation (PDO)

Previous work on sablefish in the Gulf of Alaska has shown that strong year classes are more common during warm PDO regimes (King et al. 2000, McFarlane et al. 2000). However, the Gulf of Alaska and the California Current tend to show reverse patterns in terms of productivity in relations to the PDO. Therefore, here, we briefly examine the relationship off of the west coast of the U.S. using the mean spring (April – June) PDO (Figure A37a) and sablefish recruitment residuals (residuals around the stock recruitment curve from the previous assessment; Johnson et al. 2016).

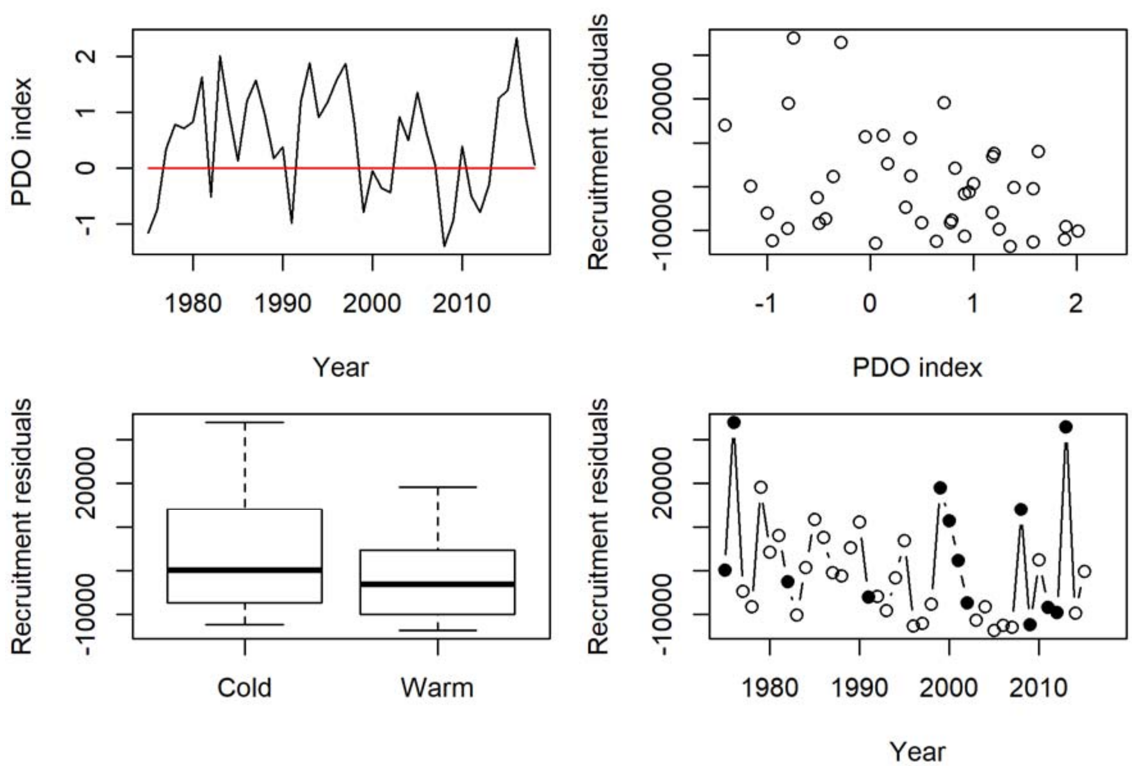


Figure A32. Relationship between sablefish recruitment and the Pacific Decadal Oscillation (PDO). A) The mean spring (April = June) from 1975 – 2015, b) relationship between the PDO and residuals around the stock-recruitment curve, c) mean recruitment residuals in cold (negative) and positive (warm) recruitment regimes, d) recruitment residuals from 1975 to 2015. Black points are cold PDO years, open points are warm PDO years, dashed lines represent +/- 1.0 s.d. and the solid red line is the mean recruitment residual from 1975-2015.

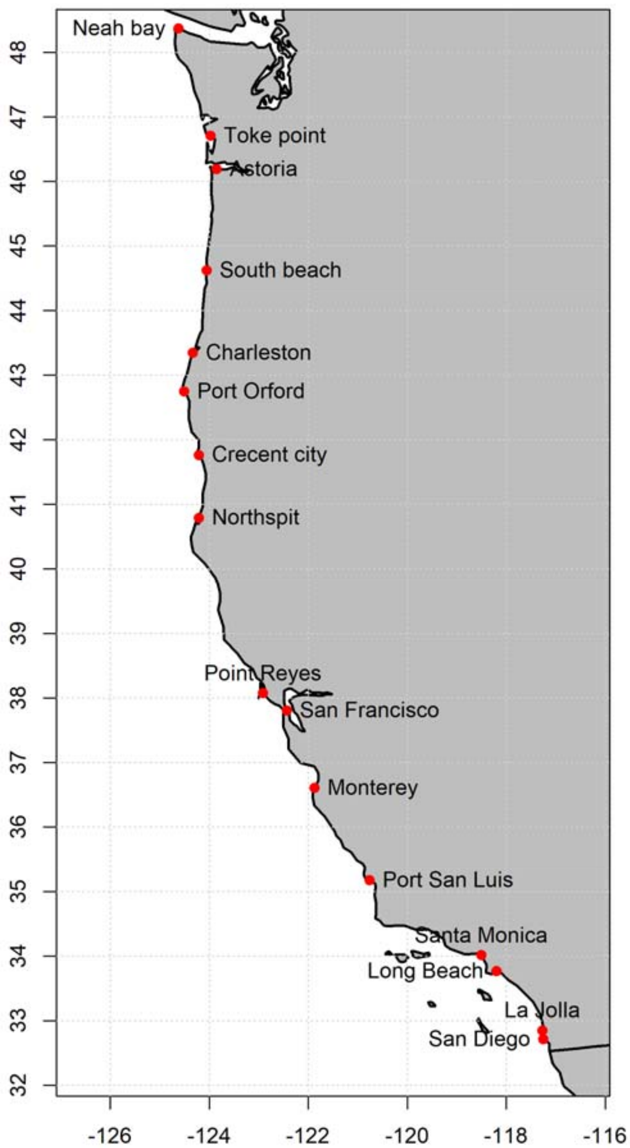
Recruitment residuals were negatively correlated with the mean spring PDO index (Figure A37b), but the relationship was very weak ($r^2 = 0.1$, $p = 0.04$), and mean recruitment residuals did not differ between warm and cold PDO regimes (Figure A37c, $p = 0.06$). However, the probability of high recruitment (recruitment residuals more than 1.0 s.d. above the long-term mean) was significantly higher during cold PDO regimes than during warm ones ($p = 0.016$, Generalized Linear Model, logit link, binomial distribution; Figure A37d) with four out of five high recruitment years coming in cold PDO conditions. Thus the relationship does not appear to be strongly linear, but better than expected recruitment (based on the stock-recruitment curve) is more likely to occur under cold PDO conditions. Note, however, that positive PDOs do not preclude good recruitment; it is just less likely to occur.

Sea level and recruitment

There is an established relationship between sea level and sablefish recruitment (Schirripa & Colbert 2006, Schirripa 2007), which has been examined in previous assessments (Schirripa & Colbert 2005, Schirripa 2007, Johnson et al. 2016). However, while biologically meaningful, the relationship has not been strong enough ($\sim r^2 = 0.30$) to inform stock assessments because much of the variation in recruitment is already caught in the age-structure data. Additionally, previous analyses have selected tide-gauge locations based on the strength of the resulting relationship with recruitment.

Figure A33. Location of tide gauges used in the sea level analysis. Data from (https://co-ops.nos.noaa.gov, interannual variation.

Establishing a stronger predictive relationship between sea level and recruitment would be beneficial because it would allow hindcasting of recruitment and better estimation of B_0. Doing so without making a priori decisions about which gauges to include would produce a more robust index. Such a predictor would also allow more real-time prediction of recruitment in the absence of updated ROMS output. Nevertheless, even with a weak sea



level-recruitment relationship, the sea level time series is valuable as a qualitative predictor of the likelihood of good or bad recruitment.

Here, we investigate a different approach using multiple time series covering the full extent of the US west coast from San Diego, CA north to Neah Bay, WA (Figure A38). Previous analyses have used sea level time series from individual tide gauges (Schirripa & Colbert 2006) or the average of multiple tide gauges from one region (Schirripa 2007, Johnson et al. 2016). We obtained time series of monthly mean sea level with the seasonal cycles and linear trend removed from NOAA Tides and Currents for 16 stations[8]. We then calculated an annual mean second quarter (April to June) sea level, when sablefish larvae are in the water column (Figure A39), consistent with the timing of previous work. We then used dynamic factor analysis (DFA, Zuur et al. 2003a, Zuur et al. 2003b, Holmes et al. 2012, Holmes et al. 2014) to reduce the number of variables and to understand synchrony in sea level variation along the coast. The resulting dynamic factors were in a model fitting exercise to see how well the resulting factors explained sablefish recruitment. Locations varied in the availability of time-series data (Figure A39), but DFA can integrate time series with missing data and of different lengths.

[8] https://co-ops.nos.noaa.gov, interannual variation

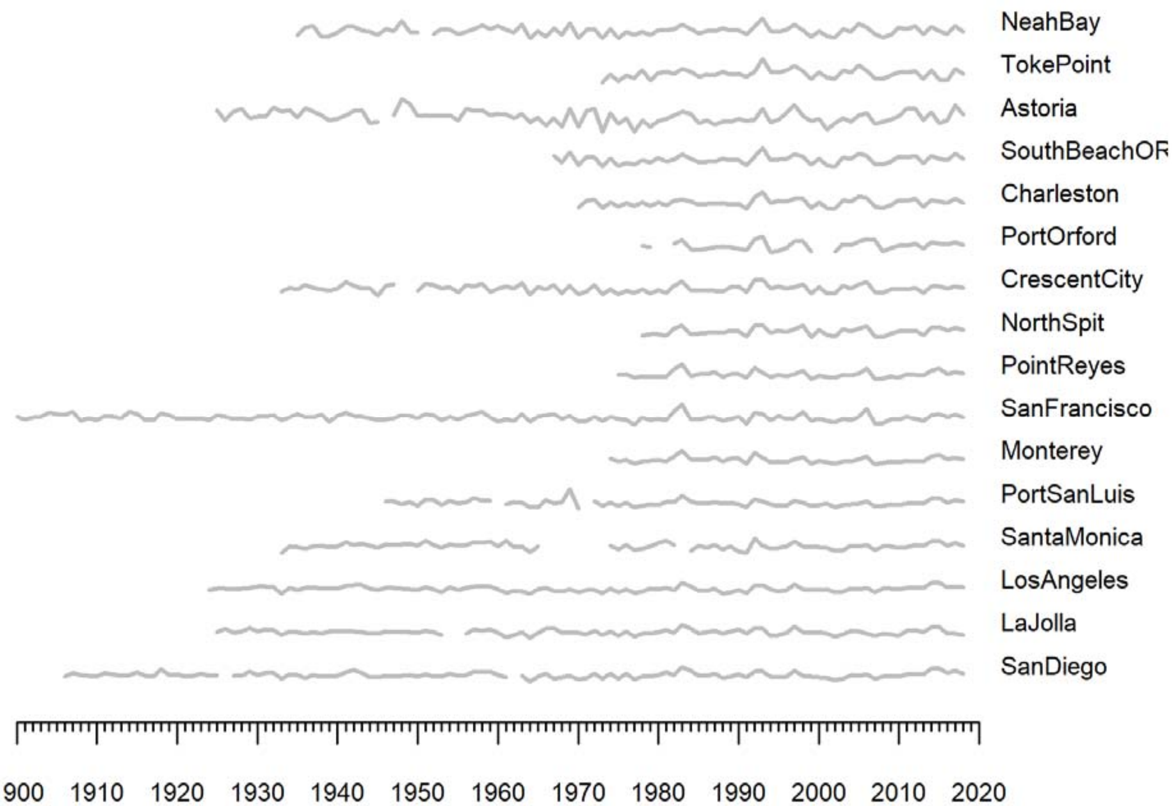


Figure A34. Mean monthly sea level in the second quarter (April-June) at 16 stations along the UW west coast from 1900 to 2018. Average seasonal cycle and linear trend have been removed.

Dynamic factor analysis

We fit multiple DFA models allowing up to 10 factors and exploring multiple structures for the observational variance-covariance matrix: diagonal and equal, or diagonal and unequal. We then used Akiake's Information Criterion, adjusted for small sample size, to choose the best-fit model (lowest delta AICc) (Burnham & Anderson 1998). The available time series varied in length and contained missing data (Figure A39). DFA can handles such data sets (Zuur et al. 2003a, Zuur et al. 2003b). We included the years 1925-2018 in the analysis.

One model emerged as the best fit model with a delta AICc 2.90 points lower than the next best model. The best-fit model had five factors (DFs) and a diagonal and unequal R matrix. DF1 largely explained variation in sea level from Northspit to the north (positive loading), while mid-latitude sea level locations loaded on DF2 (negative loading) (Figure A40). DF3 characterized variation in sea level among southern sites from Point Reyes south (negative loadings), while DF4 and DF5 included variation among locations that did not appear related to latitude.

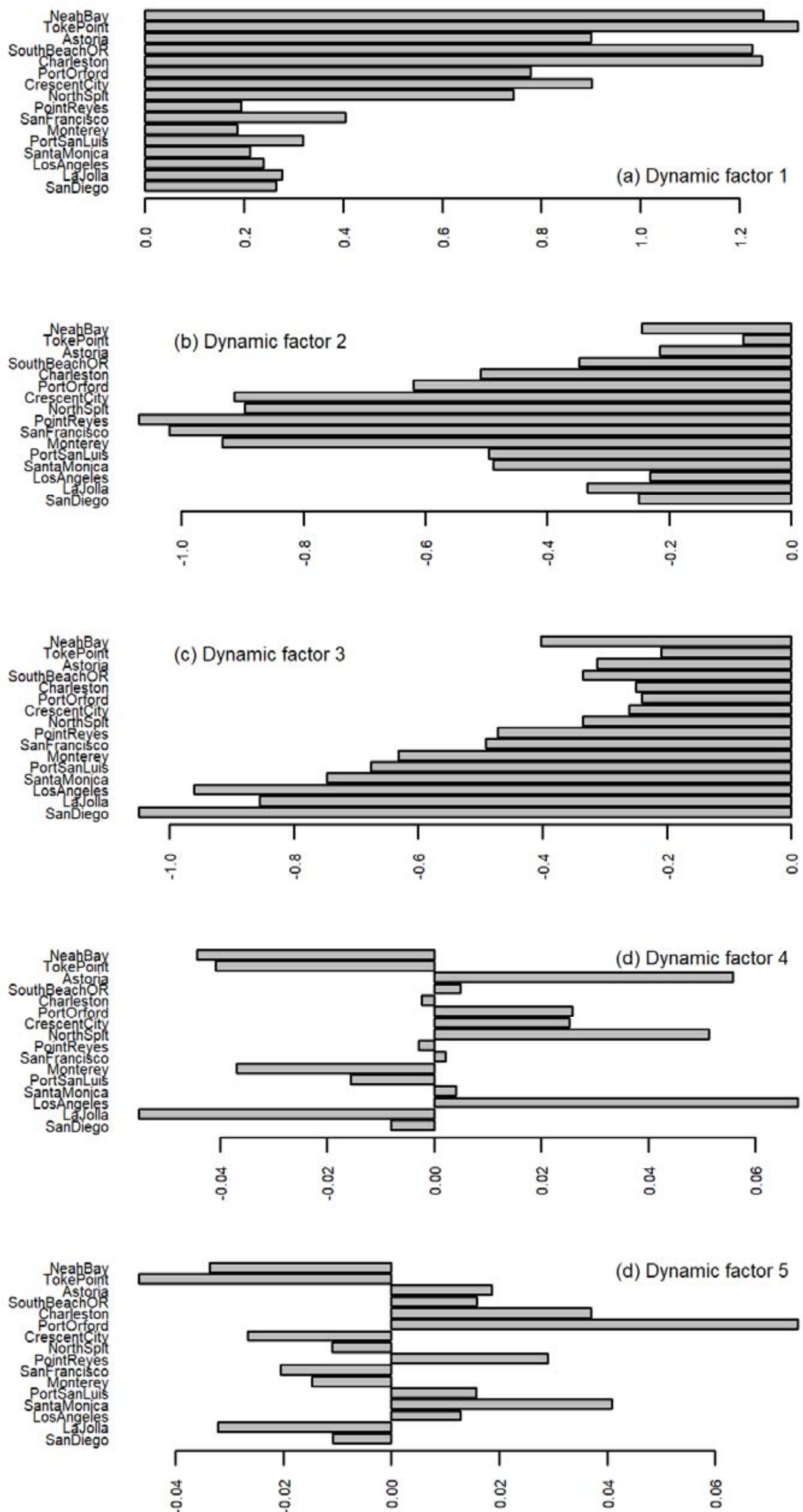


Figure A35. Varimax-rotated loadings for each tide-gauge location on each dynamic factor.

Index selection

Next we used the recruitment residuals as the response variable in general linear models using the four DFA factors as predictor variables. Residuals were calculated as the difference between a) assessment-model-based recruitments and the b) predicted recruitments from the stock recruitment curve in the 2015 assessment (Johnson et al. 2016). We limited the time period to 1975 - 2015 because of a paucity of size and age data prior to 1975 and because assessment-based biomass and recruitment estimates were available through 2015 (Johnson et al. 2016). We included both linear and quadratic terms in the model fitting but required a model including a quadratic term (eg, $DF3^2$) also include its linear counterpart (DF3). We then ran all possible combinations and used Akiake's Information Criterion (for small sample sizes, AICc) to compare candidate models (Burnham & Anderson 1998). See Tolimieri et al. (2018) for more detail.

Two models had delta AICc values less than 2.0 with r^2 values of 0.35 and 0.37 (Table A2). Both models included DF1 suggesting that recruitment of sablefish was strongly controlled by factors in the northern portion of their range (Figure A41, Table A2), which is consistent with previous work by Schirripa and Colbert (2006) and Tolimieri et al. (2018). Note, it is also consistent with the distribution and abundance of age-0 recruits in strong recruitment years (see *Habitat: Spatial distribution of age-0 recruits*, below). Both models also included DF3 and $DF3^2$, suggesting that conditions to the south were also important.

Table A2. Models with delta AICc values less than 2.0. B_0 = intercept. DF1 = dynamic factor 1. AICc is Akiake's Information Criterion corrected for small sample size. Values are coefficients for the model for b_0 and DFs. See Table A3 for standard errors..

Model	**b_0**	**DF1**	**DF2**	**DF3**	**$DF3^2$**	**R2**	**dAIC**	**Weight**
Model 1	3744	-8588		-3938	-3910	0.35	0.00	0.71
Model 2	3262	-8359	2059	-3772	-3548	0.37	1.80	0.29

Model 1 had the lowest AICc and fewest parameters and was chosen as the best-fit model. Model 1 (recruitment residuals = DF1 + DF3 + $DF3^2$) explained 35% of the variation in recruitment around the stock-recruitment curve from the sablefish assessment (Figure A44, Table A2, Table A3). Recruitment residuals were negatively correlated with DF1, DF3 and $DF3^2$ (Table A2, Figure A41). Thus, sablefish recruitment was negatively correlated with sea level north of Cape Mendocino, while the relationship to the south was somewhat more complicated due to the inclusion of the quadratic term for DF3.

Table A3. Parameter estimates and bias from the best-fit model for the sablefish sea level-recruitment relationship, not including additional predictors beyond the DFs, . $R^2 = 0.35$. See Model Validations and Testing for further detail.

Parameter	Coefficient	S.E.	Bias
Intercept	3774	2002	-90
DF1	-8588	2328	-372
DF3	-3938	1991	-58
$DF3^2$	-3910	1342	3.787574

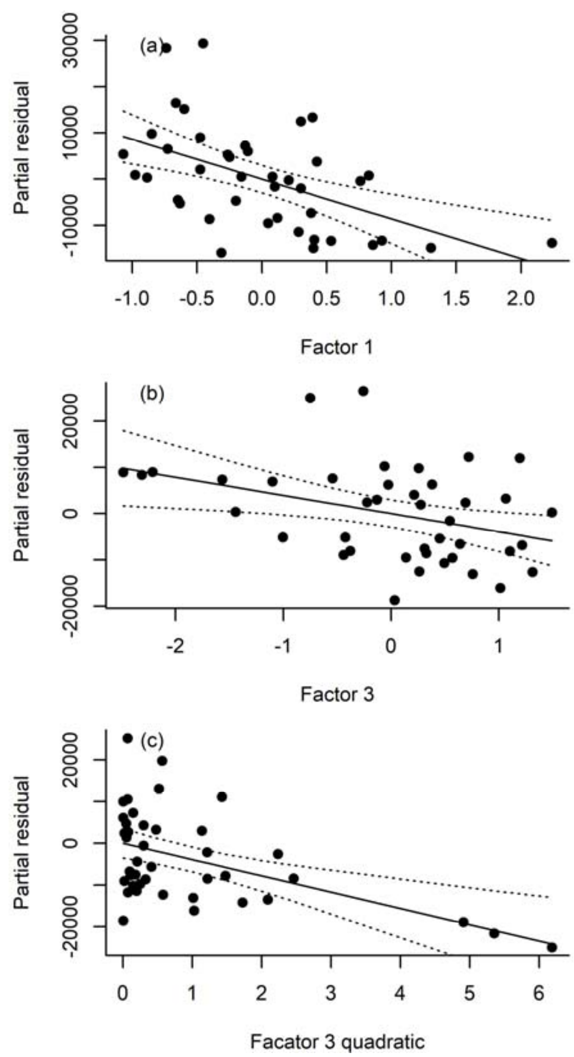


Figure A36. Partial residual plots for model 1, resids ~ DF1 + DF3 + $DF3^2$.

Previous sea level work using the Schirripa sea level index noted a decline in sea level in the 1970s. This drop can be seen to some extent in DF4 and DF5 (Figure A42). While the

DF1 derived sea level index also shows this drop, it appears less extreme when compared directly to the Schirripa index, in part because of lower values in the earlier period (Figure A43). However, from approximately 1975 to 1990 there does appear to be reduced variability in DF1. The decrease in sea level is not evident in DF2 or DF3.

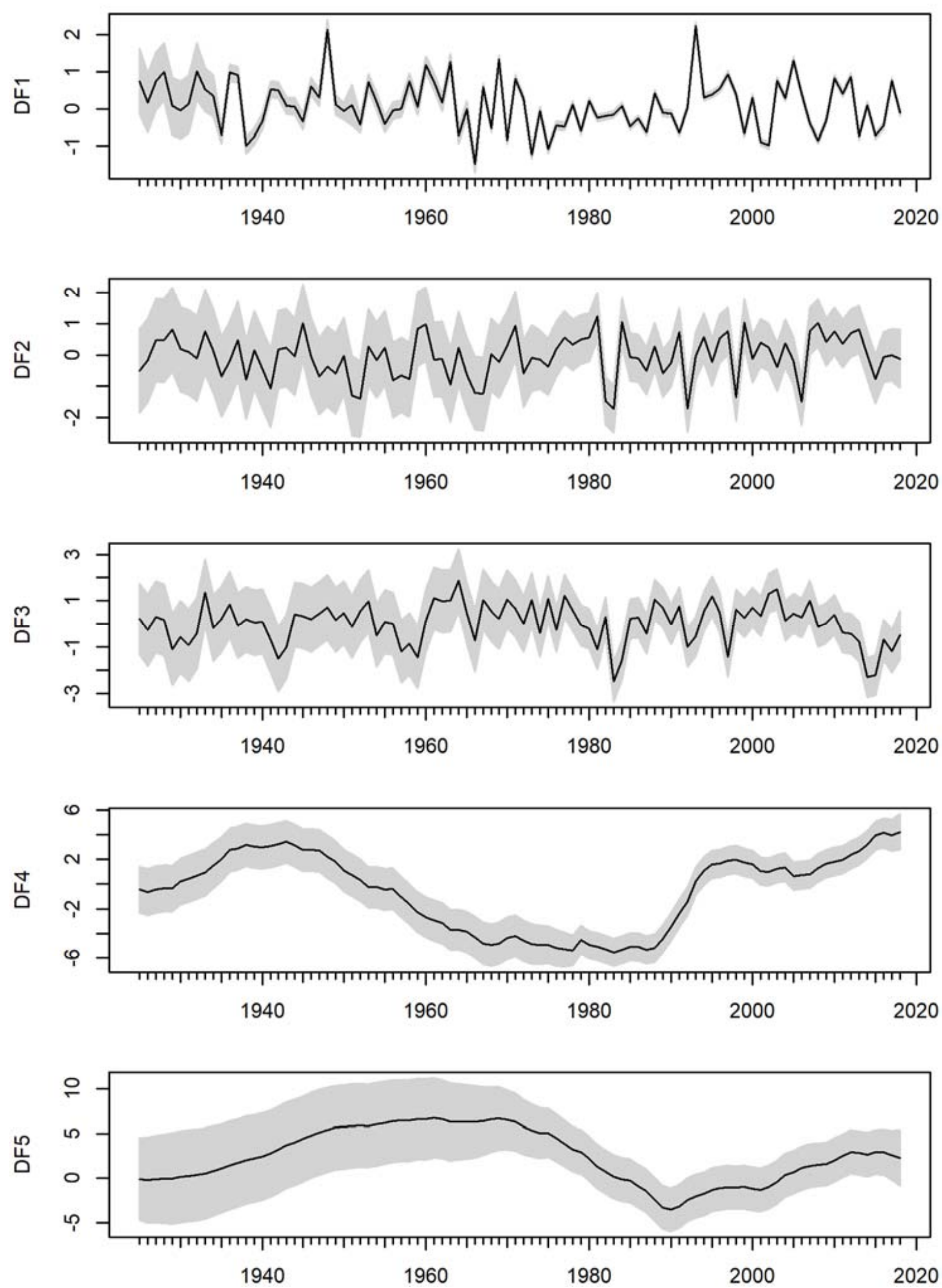


Figure A37. Time series of dynamic factors from the SHH that explained significant variation in sablefish recruitment. Grey envelopes are the 95% confidence interval.

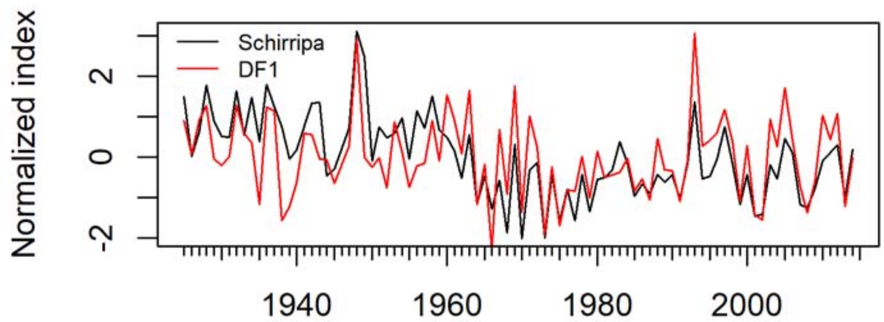


Figure A38. Trends for the first dynamic factor (DF1) from the DFA analysis and the Schirripa sea level-index used in previous sablefish assessments. Both indices were normalized for presentation on the same scale.

Model 1 did a generally good job of predicting variation around the stock recruitment relationship for sablefish from 1975 to 2015 (Figure A44). The moderate predictive power ($r^2 = 0.35$) appears to be due to the model failing to predict lower than expected recruitments in 2005, 2006 and 2009 and underestimating the strength of the higher than predicted recruitments in 1976, 1979, 1999, and 2013. Nevertheless, the model did predict positive residuals in these years.

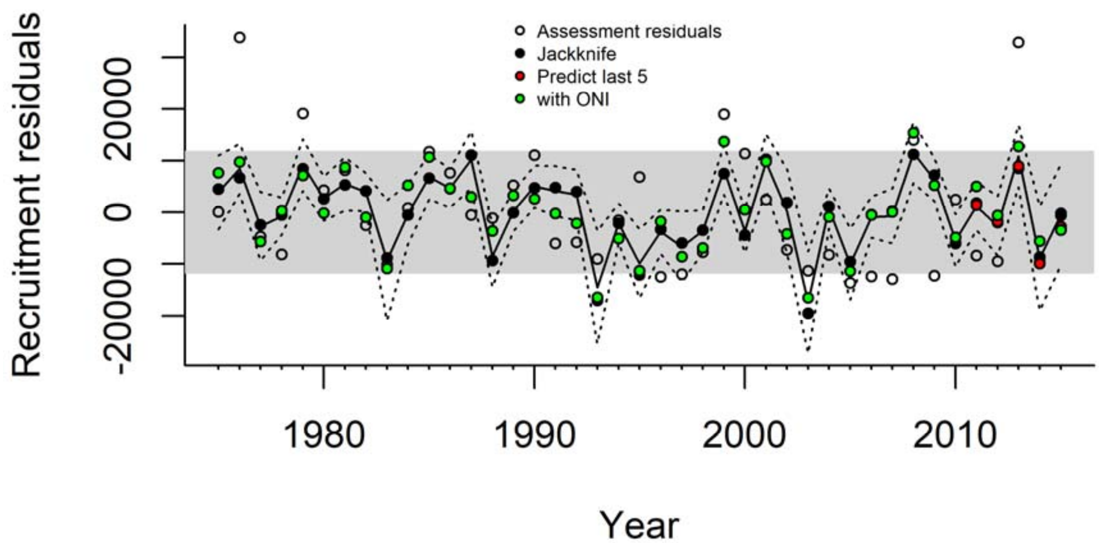


Figure A39. Sablefish recruitment residuals around the stock-recruitment relationship. Solid line is the predicted recruitment residuals from Model 1. Assessment residuals are the difference between estimated recruitment from the stock assessment and the theoretical stock-recruitment relationship. Jackknife residuals are from a leave-one-out refitting analysis; Predict last five residuals are based on fitting Model 1 to 1975-2010 and then predicting 2011-2015; and ONI residuals are for Model 1 + the Ocean Niño Index . Grey envelope indicates +/- 1.0 s.d. of the assessment recruitment residuals from 1975-2015. See Model validation and testing for more information.

Comparing the distribution of age-0 recruits (Figure A7, below) to the model performance (Figure A44) suggests that strong over predictions (more than 1.0 s.d. above the assessment derived stock recruitment residual) may be due to failure to account for processes in the south, regardless of the fact that DF3 does account for sea level south of Cape Mendocino. For example, the model over predicted recruitment in 2004, 2005-2007, 2009 and 2011. All these years, with the exception of 2011, saw lower recruitment in the area around San Francisco Bay. For 2011 the model predicted recruitment fairly close to that expected by the stock-recruitment relationship, and actual age-0 abundance was somewhat lower. Conversely, the model under predicted the recruitment peaks in 2010, and 2013 when there strong recruitment around San Francisco Bay and Point Conception.

Model validation and testing

Performance of the best fit model was evaluated following Tolimieri et al. (2018) and Haltuch et al. (in review). Evaluation used

1) resampling with replacement of recruitment residuals to estimate r^2 values using 1000 randomized data sets,
2) bootstrapping whole years with replacement to estimate bias and calculate standard error of the parameter estimates,
3) Annual jackknife resampling to determine the effect of any single year on the r^2,
4) resampling annual recruitments where the annual recruitment means and standard deviations were taken from the sablefish stock assessment (Johnson et al. 2016, Table 15), then recalculating recruitment residuals and refitting the model 1000 times, since the dependent variable was based on stock assessment estimated recruitments,
5) refitting the model using data for 1975-2010 and predicting recruitments for 2011-2015, and
6) jackknife resampling to re-run the entire model fitting and comparison exercise, to determine if removal of any individual year would change the selected oceanographic variables.
7) The entire model fitting exercise was re-run 1000 times using the re-sampled sablefish recruitments with error (from Step 4 above), comparing AIC selected models from each run. See Tolimieri et al. (2018) for more details on model testing.
8) Finally, we evaluated residuals from the best fit model for signs of autocorrelation. The model validation here was applied to Model 1 (Table A2).

Model testing were as follows:

1) Randomly resampling the recruitment residuals (with replacement) gave a median expected $r^2 = 0.08$ (95% C.I. = 0.01-0.21) for the core model suggesting that the observed value of $r^2 = 0.35$ was unlikely to be observed at random.
2) Bias estimates are shown in Table A3
3) Removing individual years and refitting the best-fit model (jackknifing) had little impact on the model fit (median $r^2 = 0.35$, 95% C.I. = 0.33 – 0.40, Figure A44, Figure A45).

4) Resampling individual recruitments with error produced no noticeable change in the fit (median $r^2 = 0.35$, 95% C.I. = 0.35051 – 0.35052).

5) Fitting the model: residuals ~ Intercept + DF1 + DF3 + $DF3^2$ for 1975 – 2010 and predicting recruitment for 2011-2015 produced little deviation from the best-fit model suggesting that the relationship has held through time and has some predictive value (Figure A44).

6) Using the jackknife resampling and re-running the entire model fitting process produced results consistent with the primary analysis. All best-fit models from the refitting matched the original best-fit model with residuals ~ Intercept + DF1 + DF3 + $DF3^2$.

7) The results from resampling the recruitment values (with error) and re-running the entire model fitting exercise 1000 times also produced only best-fit models that matched the original one with residuals ~ Intercept + DF1 + DF3 + $DF3^2$.

8) Evaluation of model residuals showed some evidence for autocorrelation of the residuals at a lag of five (5) (Figure A46), which matches with the onset of reproduction (50% mature at 5-7 years). We therefore fit five additional models using the gls package in R. We refit Model 1 (a) to obtain comparable AICc's because the gls package (needed for including autocorrelation) uses REML not least squares. Since the Ocean Niño Index has been shown to affect productivity sablefish we also fit the Model 1 + ONI (e).

a. Intercept + DF1 + DF3 + $DF3^2$ to recalculate the AICc (AICc = 812.1)
b. Intercept + Year + DF1 + DF3 + $DF3^2$ (AICc = 801.9)
c. Intercept + DF1 + DF3 + $DF3^2$ + AR1 autocorrelation (AICc = 814.8)
d. Intercept + Year + DF1 + DF3 + $DF3^2$ + AR1 autocorrelation (AICc = 804.5)
e. Intercept + DF1 + DF3 + $DF3^2$ + ONI (AICc = 792.5)

Including year lowered the model including year (b) had the lowest AICc and differed from the base model by 10.19 AICc points indicating a significant decline in recruitment through time not related to spawning biomass. However, predicted recruitments from model (b) explained only marginally more variation ($r^2 = 0.37$) and produced only marginal differences in predicted recruitments (Figure A44). Including the mean second quarter ONI produced the best-fit model and explained 43% of the variation in recruitment residuals ($r^2 = 0.43$). This model did not show signs of autocorrelation (Figure A46).

Table A4. Model parameters for Model 1 + ONI. $R^2 = 0.24$

Parameter	Coefficient	S.E.
Intercept	3426	1913
DF1	-7718	2254
DF3	-4959	1954
$DF3^2$	-3419	1299
ONI	-6570	3012

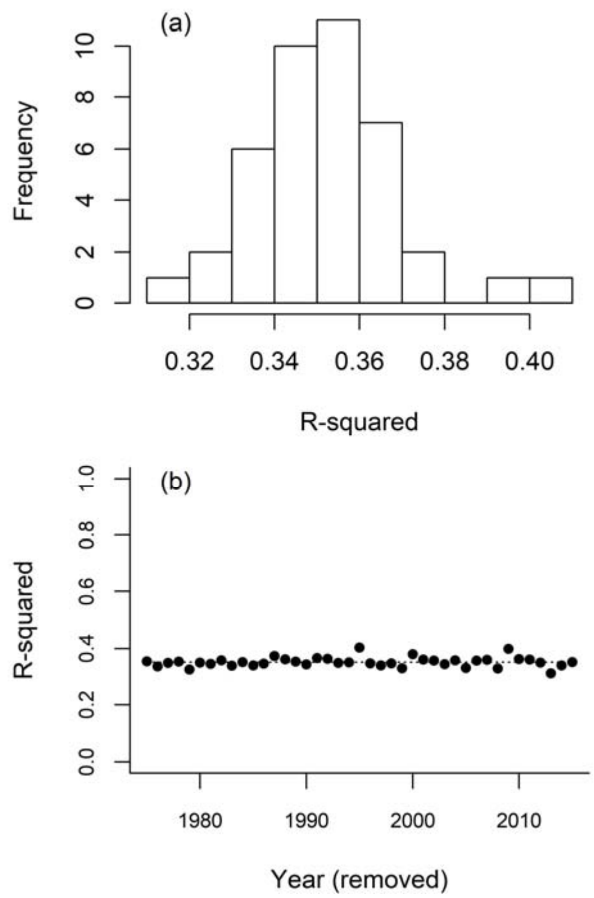


Figure A40. Results of jackknife re-fitting of the best-fit model from the sea level-recruitment analysis. Results were consistent with those of the primary model (median $r^2 = 0.35$, 95% C.I. = 0.33 – 0.40). (a) distribution of r^2 values, (b) r^2 value with identified year removed.

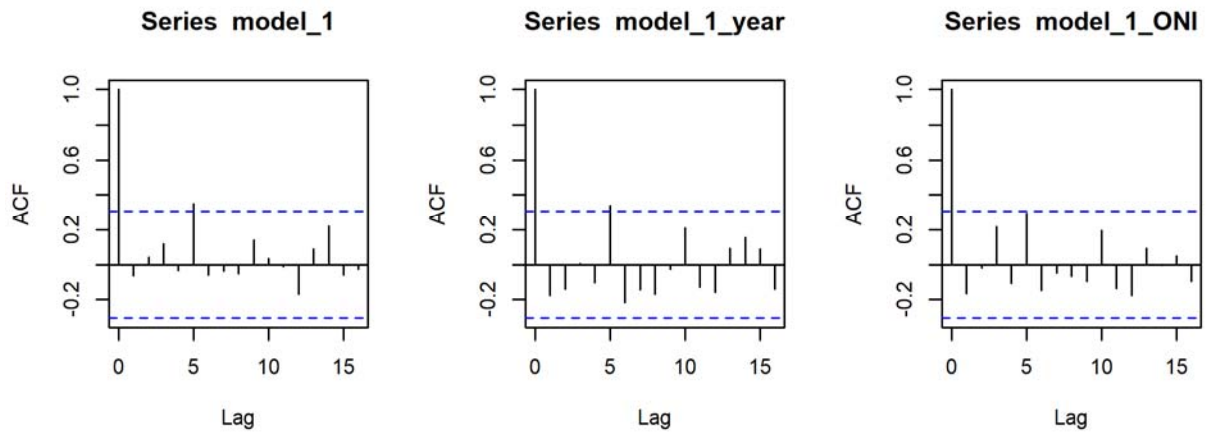


Figure A41. Left panel shows the autocorrelation function for Model 1. There is significant autocorrelation at a lag of 5 years. Central panel shows the ACF when year was included in the model. The right pane shows the ACF when the ONI index was added to the model. Residuals for the latter two fits do not show signs of autocorrelation.

<u>Environment-recruitment index</u>

We used the sea level-recruitment relationship derived above for Model 1 and Model 1 + ONI to predict expected recruitment residuals (residuals around the stock-recruitment curve) for 1925-2018, with 2018 being the most recent year with second quarter data available for sea level at the time of writing this report (Figure A47). We predict the recruitment residuals and not recruitment because we cannot reconstruct recruitment through 2018 without the estimate of biomass for these years from the stock assessment.

The years 2016 – 2018 extend beyond the recruitment and biomass estimates in the most recent sablefish stock assessment, so we cannot compare them directly to assessment estimates. However, they can be compared to estimates of sablefish recruitment from the NWFSC trawl survey (Figure A7), which allows us to evaluate the efficacy of the index in predicting recruitment. The index predicts higher than expected (based on the stock-recruitment relationship) recruitment for 2016, which is corroborated by a peak in the abundance of age-0 sablefish in the trawl survey in this year. However, while the index also suggests higher than expected recruitment in 2018, this prediction is not observed in the trawl data. Good recruitment for sablefish appears related, in part, to cooler temperatures during the female pre-conditioning period prior to spawning (Tolimieri et al. 2018). The 2018 year class follows several years of a marine heat wave (aka, 'the blob'), which may have reduced female condition and resulted in lower realized recruitment than that expected by the sea level index.

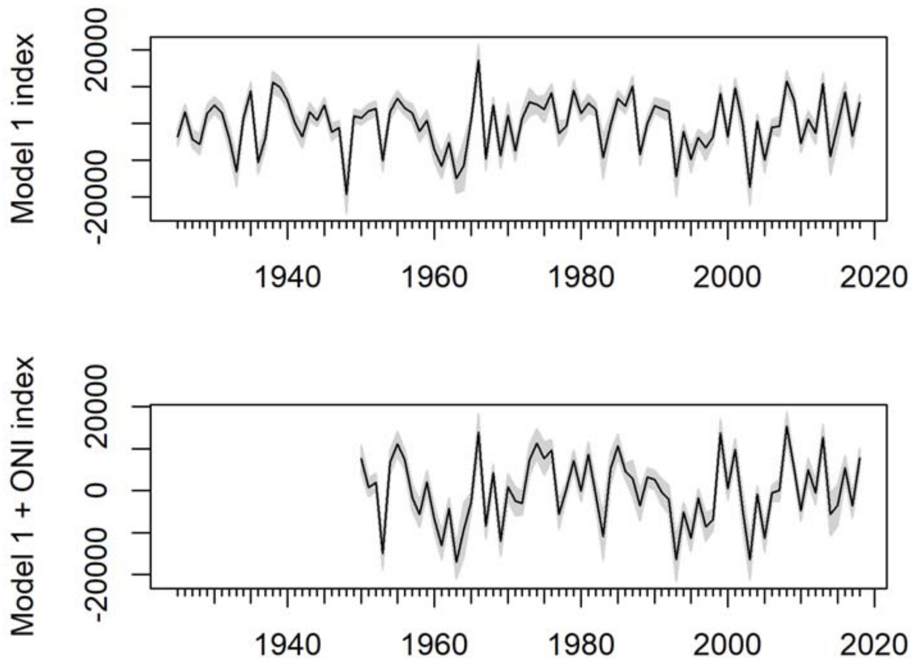


Figure A42. Sea level recruitment index for sablefish from 1925 – 2018. The top pane shows expected residuals around the stock recruitment curve based on Model 1 (Recruitment index ~ DF1 + DF3 +DF3^2). The lower pane shows the same for Model 1 + Ocean Niño Index (Recruitment index ~ DF1 + DF3 +DF3^2 + ONI.

<u>*Hindcasting recruitment*</u>

The sea level index of recruitment may be useful for hindcasting recruitment during the period where little size and age data exist to inform the assessment. Model 1 was used to predict recruitment from 1925 through 2015 by estimating the predicted recruitment from the stock-recruitment curve plus the environmental index (sea level index)(Figure A48). We also include Model 1 + Year and Model 1 + ONI results from above (see also *Model validation and testing,* below).

During the period where the stock assessment is informed by size and age data (ca. 1975 on) there is a good relationship between the assessment recruitment and both the three sea level-based indices (Figure A48). However, the environmental index tended to under predict extreme high recruitments seen in the assessment time series, as noted above (Figure A44).

Prior to ~ 1975 the assessment recruitment is quite smooth and low. The sea level indices provide a more variable recruitment time series for 1925-1975. The sea level indices fluctuated but did so around the stock-recruitment relationship. However, from the late 1950's though mid 1970's sea level-predicted recruitment for Model 1 and Model 1 + ONI was largely below that estimated form the assessment.

Notably, inclusion of the 'Year' term lead to higher predicted recruitment (sea level-Year index) in the early portion of the time series (Figure A48). At present it is not clear that Year should be included in an environmental index of sablefish recruitment. The term catches the overall decline in recruitment from 1975-2015 unrelated to stock size. However, given that the California Current Ecosystem is subject to decadal scale changes in the environment, this year trend may not be consistent in the long term (i.e., back to 1925). Including spring ONI produced largely similar results but tended predict slightly higher highs and lower lows than the sea level index alone (Figure A44 and Figure A48). In all cases, the indices failed to predict some of the extreme high recruitments and missed the low recruitments in the 2000's (as seen in Figure A44 and Figure A48, as well), but adding the ONI reduced the discrepancy to some extent.

Dynamic factors and sea level indices used in the hind casting can be found in Table A5.

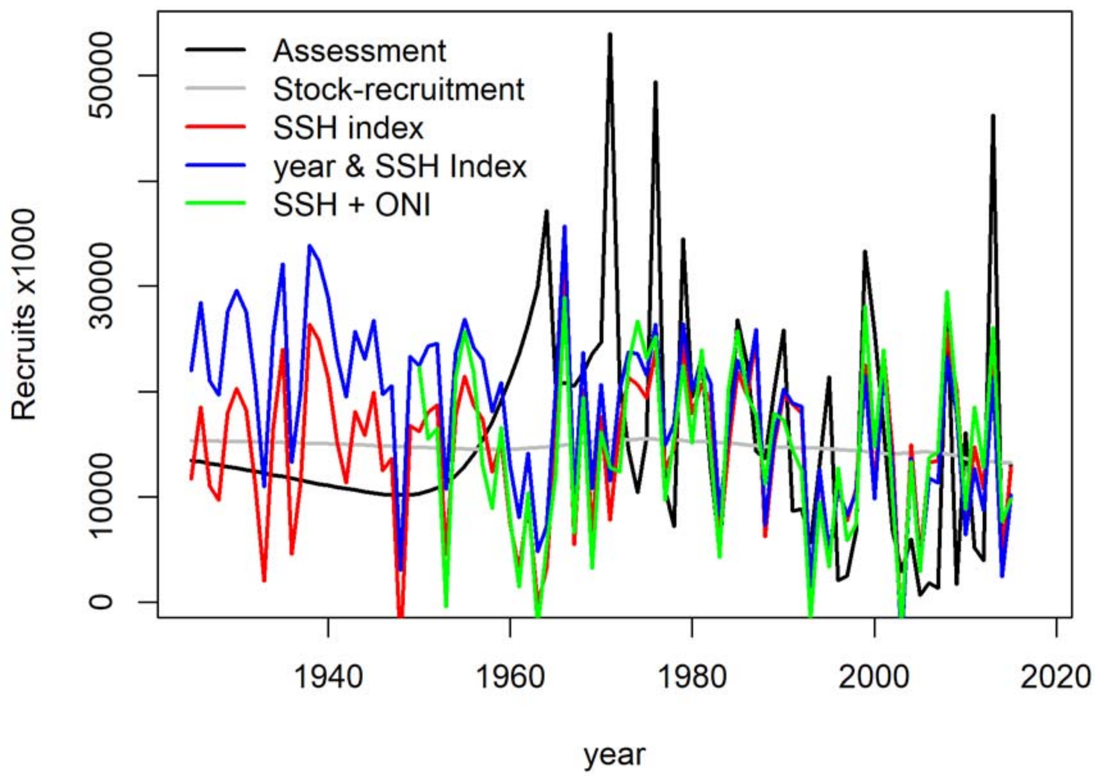


Figure A43. Sablefish recruitment. Assessment is the recruit abundance from the sablefish stock assessment; Stock-recruitment is the predicted recruitment from the stock-recruitment relationship in the stock assessment; sea level index is the predicted recruitment based on the stock-recruitment relationship plus the sea level index (Model 1, Table A2); sea level-Year includes Model 1 with a Year term added. sea level + ONI is Model 1 + the Ocean Niño Index (Table A4).

Table A5. Dynamic factors and predicted sea level indices from the dynamic factor analysis and the model fitting. DF = dynamic factor, SL = sea level index from the best-fit model, SL_ONI = best-fit model plus Ocean Niño Index, se = standard error. SL indices are predicted residuals around the stock-recruitment curve from the 2015 assessment (Johnson et al. 2016).

Year	DF1	DF1_se	DF3	DF3_se	SL_index	SL_index_se	SL_ONI_index	SL_ONI_index_se
1925	0.74248	0.88714	0.20824	-1.53996	-3621.90	2477.20		
1926	0.15516	0.78771	-0.27888	-1.56637	3205.73	2201.13		
1927	0.74576	0.77931	0.31024	-1.54105	-4258.46	2460.24		
1928	0.99238	0.77532	0.17428	-1.54881	-5583.47	2904.08		
1929	0.07486	0.77333	-1.10324	-1.55493	2686.85	2528.61		
1930	-0.03835	0.77245	-0.56261	-1.55822	5051.43	2352.44		
1931	0.12325	0.77218	-0.92626	-1.55703	2978.69	2462.95		
1932	1.00707	0.76402	-0.38958	-1.54601	-3963.93	3131.35		
1933	0.51712	0.58445	1.35593	-1.42919	-13224.94	4164.79		
1934	0.34645	0.56178	-0.18619	-1.42764	1366.47	2229.67		
1935	-0.71186	0.22293	0.21116	-1.43254	8851.84	2540.63		
1936	0.96977	0.22210	0.83325	-1.42582	-10580.14	3199.84		
1937	0.90424	0.22218	-0.08226	-1.41783	-3724.04	2846.06		
1938	-0.98348	0.22227	0.19641	-1.41223	11266.13	3017.61		
1939	-0.73809	0.22237	0.06028	-1.40825	9831.41	2679.51		
1940	-0.33589	0.22248	0.09873	-1.40517	6201.93	2121.46		
1941	0.51730	0.22258	-0.69597	-1.40259	148.38	2597.33		
1942	0.49996	0.22269	-1.52304	-1.40028	-3621.57	3094.39		
1943	0.07452	0.22280	-0.99576	-1.39822	3148.52	2484.14		
1944	0.06856	0.22294	0.40147	-1.39653	944.28	1777.63		
1945	-0.35025	0.22355	0.33325	-1.39534	5005.64	1989.84		
1946	0.60086	0.24025	0.19126	-1.39532	-2312.29	2278.05		
1947	0.29089	0.22818	0.42877	-1.38156	-1161.29	1886.62		
1948	2.13866	0.25750	0.70324	-1.40505	-19325.75	5402.11		
1949	0.10334	0.25773	0.17480	-1.40271	2048.87	1879.50		
1950	-0.06650	0.22944	0.47790	-1.36990	1540.38	1780.18	7577.70	3245.83
1951	0.09686	0.55047	-0.13257	-1.36342	3365.70	2096.34	822.82	2312.58

Year	DF1	DF1_se	DF3	DF3_se	SL_index	SL_index_se	SL_ONI_index	SL_ONI_index_se
1952	-0.42560	0.22838	0.54618	-1.36478	4082.07	2042.58	1909.01	2186.22
1953	0.71983	0.22736	0.98086	-1.36633	-10062.04	3113.85	-15056.90	3747.53
1954	0.18319	0.22652	-0.50375	-1.36799	3162.48	2325.18	6818.23	2777.76
1955	-0.41264	0.22661	0.09786	-1.36484	6865.18	2203.03	11151.51	2875.09
1956	-0.04774	0.22763	-0.00816	-1.35670	4186.05	2018.37	7272.98	2387.54
1957	-0.00138	0.22782	-1.19639	-1.35145	2870.84	2581.22	-1546.90	3185.74
1958	0.73784	0.22805	-0.87479	-1.34836	-2139.70	2892.43	-5605.73	3181.00
1959	0.04341	0.22812	-1.45316	-1.34715	837.26	2800.57	2070.10	2727.49
1960	1.18548	0.22603	0.13898	-1.35179	-7059.69	3267.78	-6653.51	3119.00
1961	0.72525	0.22892	1.10325	-1.34367	-11587.83	3462.23	-13095.42	3370.32
1962	0.15927	0.23205	0.96975	-1.35497	-5119.37	2527.73	-4206.52	2444.42
1963	1.26037	0.23049	1.00182	-1.33703	-14949.18	4039.69	-17109.15	3974.21
1964	-0.71410	0.23153	1.88789	-1.33348	-11492.80	6710.51	-9346.49	6468.82
1965	-0.01129	0.23269	0.47199	-1.33076	1111.47	1772.15	-2808.54	2465.70
1966	-1.48569	0.22955	-0.74004	-1.33430	17276.28	4357.37	13951.49	4422.47
1967	0.58437	0.10119	1.04356	-1.31237	-9641.87	3109.38	-8470.81	3010.76
1968	-0.52860	0.10618	0.54099	-1.30194	5009.18	2166.84	4260.13	2092.85
1969	1.33710	0.11141	0.20873	-1.28665	-8731.25	3550.47	-12041.22	3707.46
1970	-0.84468	0.10748	1.07210	-1.25247	2282.54	3273.38	852.14	3186.95
1971	0.81148	0.10954	0.65994	-1.23696	-7526.54	2699.99	-2517.24	3448.21
1972	0.26861	0.11418	-0.00298	-1.20747	1449.03	2061.42	-3012.51	2835.49
1973	-1.23194	0.11506	1.04830	-1.15975	5899.39	3783.51	7285.07	3660.35
1974	-0.05353	0.11603	-0.39947	-1.03323	5153.05	2280.83	11209.48	3525.56
1975	-1.07090	0.11728	1.10208	-0.99310	3852.33	3649.04	7635.88	3885.27
1976	-0.45299	0.11520	-0.25786	-0.96911	8389.93	2495.86	9725.25	2455.49
1977	-0.47623	0.11119	1.21408	-0.93908	-2709.97	3372.01	-5666.69	3486.93
1978	0.11839	0.09988	0.56895	-0.89651	-778.69	1828.18	292.47	1809.72
1979	-0.59993	0.09678	-0.06148	-0.87463	9123.74	2554.94	7121.33	2601.57
1980	0.20769	0.09526	-0.22210	-0.86602	2642.26	2180.48	-135.14	2436.56
1981	-0.25121	0.09470	-1.10067	-0.86225	5499.19	2630.58	8695.81	2903.24
1982	-0.20122	0.09465	0.30908	-0.86018	3881.64	1875.64	-932.11	2839.45

Year	DF1	DF1_se	DF3	DF3_se	SL_index	SL_index_se	SL_ONI_index	SL_ONI_index_se
1983	-0.15833	0.09468	-2.48678	-0.86106	-9282.58	5905.28	-10886.03	5674.18
1984	0.08069	0.09490	-1.56851	-0.85908	-391.41	2961.02	5214.47	3816.04
1985	-0.47667	0.09501	0.21377	-0.85888	6817.41	2200.29	10684.59	2745.38
1986	-0.26469	0.09505	0.27421	-0.85880	4643.54	1940.50	4640.21	1848.85
1987	-0.63377	0.09506	-0.44230	-0.85876	10163.92	2817.69	2964.68	4254.11
1988	0.42506	0.09507	1.06555	-0.85875	-8541.63	3006.56	-3566.80	3661.41
1989	-0.10967	0.09507	0.68974	-0.85874	109.82	1920.66	3189.55	2311.20
1990	-0.12884	0.09507	-0.02577	-0.85873	4949.59	2062.73	2596.59	2241.82
1991	-0.64930	0.09507	0.75822	-0.85873	4086.87	2460.43	-245.05	3072.20
1992	0.04729	0.09507	-1.00516	-0.85873	3345.88	2488.03	-2154.21	3460.59
1993	2.23919	0.09507	-0.54264	-0.85873	-14500.57	5546.35	-16419.56	5357.10
1994	0.30037	0.09506	0.54322	-0.85874	-2128.31	1926.91	-5091.45	2283.73
1995	0.39092	0.09506	1.19391	-0.85874	-9887.95	3413.44	-11282.66	3314.47
1996	0.53310	0.09504	0.49388	-0.85876	-3732.67	2163.17	-1781.19	2246.76
1997	0.92475	0.09501	-1.44371	-0.85878	-6661.96	3475.32	-8605.15	3428.89
1998	0.37879	0.09490	0.63823	-0.85882	-3614.81	2073.74	-6923.87	2490.89
1999	-0.66405	0.09462	0.25574	-0.85892	8184.33	2439.57	13716.78	3440.05
2000	0.30189	0.09438	0.71823	-0.85946	-3693.70	2096.60	501.48	2772.78
2001	-0.88554	0.09438	0.32670	-0.85946	9645.43	2773.34	9830.03	2643.71
2002	-0.97799	0.09462	1.31156	-0.85892	252.61	4140.01	-4214.58	4444.32
2003	0.76044	0.09490	1.49358	-0.85882	-17390.28	5009.23	-16468.32	4791.32
2004	0.28271	0.09501	0.13795	-0.85878	698.58	1978.69	-862.93	2016.55
2005	1.30469	0.09505	0.44896	-0.85876	-10016.69	3499.06	-11376.25	3391.55
2006	0.39659	0.09506	0.26246	-0.85875	-964.66	2011.45	-536.69	1926.47
2007	-0.40567	0.09507	1.01230	-0.85876	-764.86	2693.69	70.24	2594.86
2008	-0.84958	0.09507	-0.13092	-0.85878	11489.00	2983.14	15413.21	3363.64
2009	-0.31330	0.09507	0.03350	-0.85883	6298.57	2148.58	5235.85	2104.27
2010	0.82552	0.09508	0.38115	-0.85894	-5414.38	2588.84	-4806.15	2482.28
2011	0.40436	0.09509	-0.37813	-0.85919	1201.47	2377.70	4954.72	2844.64
2012	0.85672	0.09512	-0.42428	-0.85976	-2646.50	2912.39	-580.41	2932.00
2013	-0.73860	0.09518	-0.75085	-0.86107	10839.83	3062.34	12717.85	3042.05

Year	DF1	DF1_se	DF3	DF3_se	SL_index	SL_index_se	SL_ONI_index	SL_ONI_index_se
2014	0.09975	0.09528	-2.31264	-0.86415	-8916.99	5133.36	-5605.95	5121.00
2015	-0.72697	0.09543	-2.21475	-0.87161	-469.77	4946.03	-3452.25	4906.73
2016	-0.45551	0.09562	-0.68424	-0.89010	8520.06	2685.52	5426.71	2925.31
2017	0.75346	0.09570	-1.18367	-0.93646	-3543.48	3039.05	-3630.68	2895.79
2018	-0.11253	0.09590	-0.48562	-1.05388	5700.87	2345.26	7703.04	2415.63

Future Research

Overall Model 1 and Model 1 + ONI were competent predictors of sablefish recruitment. However, in years where these models failed, the two models tended to under-predict highs giving an overall conservative prediction of recruitment. This result suggests that some additional factor overwhelms the sea level relationship in these years. Identification of this factor or factors may substantially increase the ability to produce an informative environmental index of sablefish recruitment.

Additionally, future work should evaluate the impact hindcasting recruitment to the earlier years of the assessment period to examine the effects on estimates of B_0 and the overall results from the sablefish stock assessment.

Distribution of age-0 sablefish

We used geostatistical, delta-general linear mixed models implemented via vector-autoregressive spatio-temporal modeling (VAST, Thorson et al. 2015, Thorson & Barnett 2017, Thorson 2019) to analyze and quantify spatial and temporal patterns in the abundance juvenile (age-0) sablefish and to identify juvenile habitat (in terms of spatial distributions, not bottom type). Data were from the Northwest Fisheries Science Center's (NWFSC) U.S. West Coast Groundfish Bottom Trawl Survey for 2003 – 2018 (Keller et al. 2017).

Catch per unit effort (CPUE) was the dependent variable, calculated as the biomass divided by the swept area of the net. The year of capture, vessel, tow location (latitude and longitude), and depth were the predictor variables. We applied one, common intercept across years, which allowed variation in to be explained by spatial and spatio-temporal variation terms, both of which were included in the model. This parameterization prevents the model from forcing abundance to increase or decrease coast-wide in a given year as would be the case yearly intercept. We used gamma-distribution errors for the positive catch rates with "Poisson-link" function that approximates a Tweedie distribution but is more computationally efficient (Tweedie 1984, Thorson 2019). We used 600 knots. See Tolimieri (in prep.) for more detail on the analysis and Thorson (2019) for more detail on VAST.

Shifting distribution of stock biomass and availability to ports

We combined two sources of information (see Selden et al. in prep) to estimate stock biomass b(s,t) for sablefish along the West Coast:

(1) Stock assessment estimate of total population biomass B(t), developed based on many different data sources. The estimates account for age- and length-based selectivity and catchability within available survey data. By doing so, the assessment

also estimates the proportion of total abundance that is not vulnerable to a given survey gear.

(2) Spatio-temporal estimates of biomass-density d(s,t) at each location, where each location is associated with area a(s) within the sampling domain. These estimates are obtained from available survey data from two different survey sampling designs: the Triennial Bottom Trawl Survey (TBTS, operating 1977-2004) and the West Coast Groundfish Bottom Trawl Survey (WCGBTS, operating 2003-present). The sampling domain was limited to that of the both surveys to assure that results were comparable between methods (approximately 55-500 m and 34-48 ^{o}N). Spatio-temporal analysis allows us to estimate the spatial distribution of biomass vulnerable to each sampling gear.

We used geostatistical, delta-general linear mixed models implemented via vector-autoregressive spatio-temporal modeling (VAST, Thorson et al. 2015, Thorson & Barnett 2017, Thorson 2019) to analyze and quantify spatial and temporal patterns in the abundance adult sablefish. We used a conventional delta model, which separates density into two components: 1) the probability of encountering sablefish at any location (logit link and binary distribution), and 2) the expected density when encountered (lognormal distribution). We modeled biomass as a first-order, random walk process. We did not included spatial variation in density instead but did included spatiotemporal variation. Julian day was included as a catchability variable accounting for differences across the sampling period. We used 600 knots. Note, the parameterization of the VAST model here is based on Thorson and Barnett (2017), which differs from that used in estimating the indices for the assessment. Future reports should consider the appropriate parameterization should indices on availability be included in the Ecosystem Considerations document.

These two data sources predict total biomass (biomass both vulnerable and invulnerable to the trawl survey) at each location using the following equation:

$$b(s,t) = B(t)\frac{a(s)d(s,t)}{\sum_{s=1}^{n} a(s)d(s,t)}$$

Estimates of biomass density $d_{(s,t)}$ (in units kg/km2) associated with each spatial location s were multiplied by the area a(s) associated with each location (km2) to generate a location-specific biomass estimate (in units kg). Relative biomass in each location was calculated by dividing the area-level biomass (kg) by the region-wide biomass (kg). Total stock biomass (mt) associated with each location $b_{(s,t)}$ was computed by multiplying the relative biomass in each location by the total stock-level spawning biomass (mt).

This calculation implicitly assumes that the ratio of vulnerable and invulnerable biomass is constant across space within each year. Future research could develop a spatio-temporal assessment model to estimate spatial variation in catchability, but the current effort is the first to correct estimates of spatial distribution from a spatio-temporal model to account for vulnerability estimates from a stock assessment model (arising from the net effect of catchability and selectivity-at-age estimates).

An index of port-specific stock availability for each species $A_{(p,t)}$ was created from the log of the average stock biomass (metrics tons) weighted by the inverse distance (D) of the location to a port (km):

$$A(p,t) = \frac{\sum_{s=1}^{n} \log\left(b(s,t)\right) \frac{1}{D(s,p)}}{\sum_{s=1}^{n} \frac{1}{D(s,p)}}$$

Data sources

CalCOFI surveys

Time series used in this report taken from the from the California Current Integrated Ecological Assessment.

Data available from:
https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

Groundfish Expanded Mortality Multiyear (GEMM)

The Groundfish Expanded Mortality Multiyear (GEMM) data includes total estimated discard, discard with discard mortality rates (DMRs) applied, landings, catch (discard and landings), and mortality (discard with DMRs applied and landings) for all species and groupings recorded in A-SHOP, WCGOP, EM, and PacFIN data for the years 2002 to 2017. The data do not include recreational mortality estimates but do include research mortality estimates for 2005 to 2017. See (Somers et al. 2018) and https://www.nwfsc.noaa.gov/data/metadata/observer.gemm_fact for more detail.

Data available from: https://www.nwfsc.noaa.gov/data/map

These data are also available as a processed report that is accessible and 508-compliant at https://repository.library.noaa.gov/view/noaa/19774

NOAA Northwest Fisheries Science Center Juvenile Salmon & Ocean Ecosystem Survey

Time series used in this report taken from the from the California Current Integrated Ecological Assessment.

Data available from:
https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

Ocean Niño Index

Data available from:
https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/.

Pacific Fisheries Information Network (PacFIN)

The nation's first regional fisheries data network,

PacFIN is a regional fisheries data network that combines information from federal and state data collection. Cooperative agency and industry partners supply data from commercial fisheries off the coasts of Washington, Oregon and California. PacFIN provides accurate estimates of commercial catch and value from the following agencies:

- California Department of Fish & Wildlife (CDFW)
- Oregon Department of Fish & Wildlife (ODFW)
- Washington Department of Fish & Wildlife (WDFW)
- National Oceanic and Atmospheric Administration (NOAA)
- Pacific States Marine Fisheries Commission (PSMFC)
- Pacific Fisheries Management Council (PFMC)

Data available from: https://reports.psmfc.org/pacfin

Pacific Decadal Oscillation

Data available from:

https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

Predators and Prey

Data available from:

https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

see also WCGBTS

Southwest Fisheries Science Center Rockfish Recruitment and Ecosystem Assessment *Survey.*

Time series used in this report taken from the from the California Current Integrated Ecological Assessment.

Data available from:
https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/

Biological spring transition

Data and more information available from:
https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ec-biological-spring-trans.cfm

Triennial Bottom Trawl Survey (TBTS)

The survey was designed to sample rockfishes and used a Poly Nor'Eastern trawl with a footrope equipped with roller bobbins to allow fishing in rough habitat (Weinberg et al. 2002, Keller et al. 2017) using a transect-based design. The depth and latitudinal extents varied through time but range between 55-500 m and 34-50° N. See Weinberg et al. (2002) and Keller et al. (2017) for more detail.

Data available from: https://www.nwfsc.noaa.gov/data/map

West Coast Groundfish Bottom Trawl Survey (WCGBTS)

Northwest Fisheries Science Center's (NWFSC) U.S. West Coast Bottom Trawl Survey of Groundfish Resources off Washington, Oregon, and California (WCGBTS, Keller et al. 2017) is conducted annually in two passes. The survey is a depth-stratified, random sample that spans approximately 32–48.58°N and 55–1280 m (see Bradburn et al. 2011 for a detailed description of the sampling design). The survey uses a standard Aberdeen-net with 25.9-m headrope, 31.7-m footrope with small rubber discs, and an additional 3.8-cm liner extending from the middle of the net through the codend, to retain smaller fish and invertebrates. The net was towed at ~2.2 knots for a nominal 15 minutes (an average of 20 minutes on bottom time including liftoff lag, Wallace & West 2006) and swept area ranged from 0.89 to 5.5 ha (median: 1.7 ha).

Data available from: https://www.nwfsc.noaa.gov/data/map

Zooplankton

Time series used in this report taken from the from the California Current Integrated Ecological Assessment.

Data and more information available from:
https://www.integratedecosystemassessment.noaa.gov//regions/california-current-region/.

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B SUMMARY OF INFLUENCING MANAGEMENT ACTIONS

Table B1. Influencing management actions taken since 1982 that pertain to the sablefish fishery.

Effective Date	Management action taken
10/13/82	Sablefish OY exceeded; 3,000 pounds trip limit imposed (coast-wide OY = 13,400 mt).
11/30/82	Extended sablefish trip limit of 3,000 pounds for remainder of 1982. Increased sablefish OY 30% to 17,400 mt for 1982 and recommended this for 1983 (ABC = 13,400 mt).
01/01/83	Established a 22-inch total length size limit on sablefish in all areas north of Point Conception (excluding Monterey Bay), with an incidental trip limit for fish smaller than 22 inches of 333 fish, 1,000 pounds or 10% of weight of all sablefish on board, to be adjust as necessary to stay within the 17,400 mt OY (ABC = 13,400 mt).
06/28/83	Retained the 22-inch size limit on sablefish, but set incidental allowance of small fish (<22 inches) at 5,000 pounds per trip.
01/01/84	Continued 22-inch size limit on sablefish as in 1983; retained 5,000 pounds incidental allowance of small fish (<22 inches); fishery closes when coast-wide OY of 17,400 mt is reached (ABC = 13,400 mt).
01/10/85	Continued 22-inch size limit on sablefish in all areas north of Point Conception (abolished Monterey Bay exclusion); retained 5,000 pounds incidental landing limit for sablefish less than 22 inches.
11/25/85	Established that 90% of sablefish quota had been reached and established a trip limit of 13% sablefish in all trawl landings containing sablefish.
12/06/85	Established that sablefish quota (OY) had been exceeded on November 22, 1985, and prohibited further landings of sablefish until January 1, 1986.
01/01/86	Continued the 22-inch size limit on sablefish in all areas north of Point Conception; retained 5,000-pound incidental landing limit for sablefish smaller than 22 inches; coast-wide OY = 13,600 mt; ABC = 10,300 mt.
08/22/86	Emergency Regulations: Allocated the estimated remaining sablefish OY between trawl and fixed gear at 55% and 45%, respectively. Established an 8,000-pound sablefish trip limit on trawl gear. Retained the current regulation of a 5,000-pound trip limit on sablefish smaller than 22 inches. Any further landings of sablefish by trawl gear to be prohibited after trawl quota is reached. Any further landings of sablefish by fixed gear to be prohibited after fixed gear quota is reached. Any further landings of sablefish to be prohibited after the coast-wide OY is reached.

10/23/86	Fixed gear sablefish quota reached; fixed gear fishery closed. Sablefish quotas revised (2,800 mt trawl; 2,300 mt fixed gear).
11/20/86	Extended sablefish emergency regulation until the end of the year.
01/01/87	Allocated the sablefish OY between trawl and fixed gear at 52% (6,200 mt) and 48% (5,800 mt), respectively; if the quota for either gear type is reached, sablefish becomes a prohibited species for that gear; coast-wide OY and ABC =12,000 mt. Established coast-wide 5,000-pound trawl and 100-pound fixed gear trip limits (round weights) for sablefish smaller than 22-inches total length (16-inches dorsal total length).
04/05/87	Changed the size limit for processed sablefish from 16.0 inches to 15.5 inches (dorsal total length).
04/27/87	Increased the trip limit for sablefish smaller than 22 inches (total length) caught by fixed gear from 100 pounds to 1,500 pounds coast-wide
10/02/87	Established trawl trip limit for sablefish at 6,000 pounds or 20% of the legal fish on board, whichever is greater, including no more than 5,000 pounds of sablefish under 22 inches.
10/14/87	Closed the nontrawl (fixed gear) sablefish fishery because the nontrawl allocation of 5,800 mt was reached.
10/22/87	Closed the sablefish trawl fishery because the trawl allocation of 6,200 mt was reached.
01/01/88	Allocated the sablefish OY between trawl and nontrawl (fixed gear) at 5,200 and 4,800 mt, respectively; if the quota for nontrawl gear is reached, sablefish becomes a prohibited species for that gear; manage the trawl fishery to achieve the trawl allocation, provided that up to an additional 800 mt may be added to the trawl allocation for unavoidable incidental catch; coast-wide OY = 9,200 to 10,800 mt; ABC = 10,000 mt. For trawl-caught sablefish, established a trip limit of 6,000 pounds or 20% of legal fish on board, whichever is greater, with only two landings above 1,000 pounds allowed per vessel per week; no restriction on landings less than 1,000 pounds Continued the 22-inch total length size limit (15.5-inch dorsal length) on sablefish in all areas; 5,000-pound trawl and 1,500-pound nontrawl incidental landing limits for sablefish smaller than the minimum size limit.
08/03/88	Increased the trawl sablefish allocation to 6,000 mt; reduced the trawl trip limit to one landing per week, not to exceed 2,000 pounds (including sablefish smaller than 22 inches). Changed the nontrawl trip limit for sablefish smaller than 22 inches to 1,500 pounds or 3% of all sablefish on board, whichever is greater.

08/26/88	Closed the nontrawl sablefish fishery because the nontrawl allocation of 4,800 mt was reached
10/05/88	Removed the restriction that no more than 1 landing of sablefish by trawlers may be made during any week; reduced the weekly trip limit for yellowtail rockfish north of Coos Bay from 10,000 to 7,500 pounds (biweekly and twice weekly options to remain in effect).
01/01/89	For coast-wide sablefish, management measures designed to achieve the low end of the OY range (10,400 to 11,000 mt). After 22 mt set aside from the 10,400 mt harvest guideline for the Makah Indian fishery, the remaining 10,378 mt allocated 5,397 mt (52%) for trawl gear and 4,981 mt (48%) for nontrawl (fixed) gear. Established a coast-wide trawl trip of 1,000 pounds or 45% of the deepwater complex (consisting of sablefish, Dover sole, arrowtooth flounder and thornyheads), whichever is greater. Within the 45% trawl limit, no more than 5,000 pounds of sablefish smaller than 22 inches (total length) may be taken per trip. If fishing under the 1,000-pound limit, all sablefish may be smaller than 22 inches. The coast-wide nontrawl trip limit for sablefish smaller than 22 inches set at the greater of 1,500 pounds or 3% of all sablefish on board. The harvest guideline may be increased by up to 600 mt to enable small fisheries to continue operating after a gear allocation is met and to allow for landings of sablefish caught incidentally while fishing for other species. If the upper end of the OY range (11,000 mt) is reached, all further landings will be prohibited (coast-wide ABC = 9,000 mt; OY = 10,400 to 11,000 mt).
04/26/89	Established coast-wide weekly trip limit on the deepwater complex (consisting of sablefish, Dover sole, arrowtooth flounder and thornyheads) of only 1 landing above 4,000 pounds per week, not to exceed 30,000 pounds. No limit on the number of landings of deepwater complex less than 4,000 pounds. For each landing of the deepwater complex, no more than 1,000 pounds or 25% of the deepwater complex, whichever is greater, may be sablefish. If fishing under the 25% limit, no more than 5,000 pounds may be sablefish under 22 inches (total length). If fishing under the 1,000-pound limit, all sablefish may be under 22 inches. Biweekly and twice weekly trip limit options for trawl-caught sablefish are available but require appropriate declaration to state in which fish are landed.
07/17/89	Established a coast-wide nontrawl sablefish trip limit of 100 pounds with no frequency limit for the remainder of the year, until the nontrawl allocation is reached, or until OY is reached, whichever occurs first. Because the trip limit is smaller than the limit on fish less than 22 inches, the 22-inch minimum size provision is rescinded.
10/04/89	Removed the overall trawl poundage and trip frequency limits for the deepwater complex, while retaining the separate trip limit for sablefish at 25% of the deepwater complex or 1,000 pounds, whichever is greater. Increased the nontrawl trip limit to 2,000 pounds or 20% of all groundfish on board, whichever is less, when more than 100 pounds of sablefish on board. Because the trip limit remains small, the entire landing may be made up of sablefish less than 22 inches.

01/01/90	The ABC and OY for sablefish set at 8,900 mt. [NMFS did not approve the Council's recommendations for sablefish management. The trawl and nontrawl restrictions in effect at the end of 1989 continued in effect on January 1, 1990. Specifically, the nontrawl trip limit remained at 2,000 pounds or 20% of all fish on board, whichever is greater, for all landings greater than 100 pounds. The trawl trip limit remained as the greater of 1,000 pounds or 25% of the deepwater complex.]
01/31/90	NMFS disapproved the Council's recommendations to modify the trawl/nontrawl sablefish allocations and management measures to achieve them. The nontrawl sablefish trip limit was rescinded as a result of NMFS' disapproval of the Council's recommendations. Thus, the nontrawl fishery was unlimited by any catch restrictions. The limit on sablefish less than 22 inches was not reinstated. A nontrawl trip limit of 500 pounds will go into effect when 300 mt of the nontrawl quota remains. The estimated tribal sablefish catch to the end of the year (300 mt) subtracted from the OY of 8,900 mt. The remaining 8,600 mt was allocated 58% (4,988 mt) to trawl gear and 42% (3,612 mt) to nontrawl gears. Continued in effect the coast-wide trawl trip of 1,000 pounds or 25% of the deepwater complex (consisting of sablefish, Dover sole, arrowtooth flounder and thornyheads), whichever is greater. Within the 25% trawl limit, no more than 5,000 pounds of sablefish smaller than 22 inches (total length) may be taken per trip. If fishing under the 1,000-pound limit, all sablefish may be smaller than 22 inches.
03/21/90	Reestablished the nontrawl trip limit for sablefish less than 22-inches total length at 1,500 pounds or 3% of all sablefish on board, whichever is greater.
06/24/90	Established a nontrawl sablefish trip limit of 500 pounds when 300 mt of the nontrawl quota remained. The 500-pound limit replaces the trip limit for sablefish smaller than 22 inches.
10/03/90	In order to reduce trawl sablefish landings so the trawl quota would not be exceeded, established a 15,000-pound trip limit on the deepwater complex (sablefish, Dover sole and thornyheads); allowed only one landing per week of the deepwater complex above 1,000 pounds; and maintained the current sablefish trip limit of 1,000 pounds or 25% of the deepwater complex, whichever is greater. Biweekly and twice weekly landing options are provided. The 5,000-pound trip limit for sablefish smaller than 22 inches remained in effect for landings made under the biweekly option.
01/01/91	Established a coast-wide weekly trawl trip for the deepwater complex (sablefish, Dover sole and thornyheads) of 27,500 pounds (including no more sablefish than 1,000 pounds or 25% of the deepwater complex, whichever is greater, and no more than 7,500 pounds of thornyheads). Only one landing above 4,000 pounds of deepwater complex per week. Biweekly and twice weekly options available. Of those sablefish taken under the weekly and biweekly trip limits, no more than 5,000 pounds of sablefish smaller than 22 inches (total length) may be taken per trip. All sablefish taken under the twice weekly limit may be smaller than 22 inches.

04/01/91	Revised nontrawl sablefish trip limit to a limit only on sablefish smaller than 22 inches (1,500 pounds or 3% of all sablefish on board, whichever is greater, effectively opening the nontrawl sablefish season.
05/24/91	Established a nontrawl trip limit of 500 pounds of sablefish.
07/07/91	Closed the nontrawl sablefish fishery because the nontrawl quota had been exceeded.
09/30/91	Established (by emergency regulation) a daily sablefish trip limit of 300 pounds for nontrawl gears.
01/01/92	For the deepwater complex (sablefish, Dover sole, and thornyheads), established a cumulative landing limit per specified 2-week period of 55,000 pounds of which no more than 25,000 pounds may be thornyheads. In any landing, no more than 25% of the deepwater complex may be sablefish, unless less than 1,000 pounds of sablefish are landed, in which case the percentage does not apply. In any landing, no more than 5,000 pounds of sablefish may be smaller than 22 inches (total length). For the nontrawl sablefish fishery, established a daily-trip-limit of 500 pounds from January 1 through February 29.
03/01/92	For the nontrawl sablefish fishery, establish a daily-trip-limit of 1,500 pounds from March 1 through March 31. However, if 440 mt is projected to be reached during this period, the daily-trip-limit may be reduced to 500 pounds through March 31.
04/01/92	Delay the opening of the nontrawl sablefish fishery until May 12 (Emergency Rule).
04/17/92	For the nontrawl sablefish fishery, reduced the daily-trip-limit to 250 pounds until the opening of the "regular" nontrawl sablefish season.
05/12/92	Established (by emergency regulation) the opening date of the "regular" nontrawl sablefish fishery.
05/27/92	Established a nontrawl daily-trip-limit of 250 pounds of sablefish.
01/01/93	For the deepwater complex (sablefish, Dover sole and thornyheads), established a cumulative landing limit per specified 2-week period of 45,000 pounds of which no more than 20,000 pounds may be thornyheads. In any landing, no more than 25% of the deepwater complex may be sablefish, unless less than 1,000 pounds of sablefish are landed, in which case the percentage does not apply. In any landing, no more than 5,000 pounds of sablefish may be smaller than 22 inches (TL). For the nontrawl sablefish fishery, established a daily-trip-limit of 250 pounds from January 1 through May 12.

04/01/93	Established a flexible starting date for the "regular" season for the fixed gear (nontrawl) sablefish fishery, including 72-hour closed periods both immediately before and immediately after the regular season. The flexible starting date will precede by 3 days the earliest sablefish fixed gear season in the Gulf of Alaska. For 1993, the season opened May 12.
04/21/93	Reduced the cumulative trip limit for the deepwater complex from 45,000 pounds per 2-week period to 60,000 pounds per 4-week period, while maintaining the trawl-caught sablefish limit at 25% of the deepwater complex per landing. Also reduced the thornyhead trip limit from 20,000 pounds cumulative per 2-week period to 35,000 pounds cumulative per 4-week period.
06/02/93	Closed the "regular season" for sablefish caught with nontrawl gear. On June 5, 1993, the 250-pound daily-trip-limit for sablefish caught with nontrawl gear was reimposed
09/08/93	Reduced the trip limit for trawl-caught sablefish to the greater of 1,000 pounds, or 25% of the deepwater complex not to exceed 3,000 pounds.
12/01/93	Reduced the cumulative trip limits for the Dover sole/thornyhead/trawl-caught sablefish (DTS) complex. The previous limit was 60,000 pounds per 4-week period, of which no more than 35,000 pounds could be thornyheads and, in any trip, the limit for trawl-caught sablefish was the greater of 1,000 pounds or 25% of the complex up to 3,000 pounds. The new limit allows no more than 5,000 pounds of species in the DTS complex to be taken, retained, possessed or landed per vessel per trip, of which no more than 1,000 pounds may be sablefish. Only one landing of fish in the DTS complex may be made in any 1-week period.
01/01/94	For the DTS complex established a cumulative limit of 50,000 pounds per month of which no more than 30,000 pounds may be thornyheads and no more than 12,000 pounds may be trawl-caught sablefish. The sablefish trip limit is 1,000 pounds or 25% of the DTS complex, whichever is greater, and applies to each trip. Management of the sablefish fishery north of the 36°N latitude (the northern boundary of the Conception area), deduct 300 mt from the 7,000 mt harvest guideline for the northwest Washington treaty Indian tribes and allocate the remaining 6,070 mt between the limited entry and open access fisheries. The limited entry portion is allocated 3,520 mt (58%) to trawl gear and 2,550 mt (42%) to pot and longline gears. Nontrawl sablefish daily-trip-limit of 250 pounds north of 36°N latitude and 350 pounds south of 36°N latitude through May 11, 1994. Only one landing of sablefish caught with nontrawl gear may be made per day, coast-wide. (The regular season started May 15, following a 72-hour closure May 12-14.). Sablefish daily limit of 250 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Limit of one landing of sablefish per vessel per day.

05/15/94	Opened regular season for the nontrawl sablefish fishery off Washington, Oregon, and California for limited entry permitted vessels with longline and/or pot endorsements. Current trip limits continued until 0001 hours (local time) May 12, 1994, which marked the beginning of a 72-hour closure of the fishery for vessels operating in the regular season. Effective May 15, 1994 at 0001 hours (local time), the only trip limit in effect for sablefish caught with nontrawl gear is 1,500 pounds or 3% of all legal sablefish on board, whichever is greater, for sablefish smaller than 22 inches. Sablefish trip limits for open access gears did not change.
06/04/94	Closed nontrawl sablefish limited entry fishery off Washington, Oregon and California with a 72-hour closure beginning at 0001 hours (local time) June 4 and ending at 2400 hours (local time) June 6. During the closure, the taking and retaining, possessing or landing of sablefish taken with nontrawl gear by a vessel operating in the limited entry fishery was prohibited.
07/01/94	Reduced the trip limits for Dover sole, thornyheads, and trawl-caught sablefish (DTS complex) in the groundfish fishery off Washington, Oregon and California. The new cumulative limit is 30,000 pounds of the DTS complex per vessel per calendar month, of which no more than 8,000 pounds may be thornyheads and no more than 6,000 pounds may be trawl-caught sablefish. In any trip, no more than 1,000 pounds or 33.333% of the legal thornyheads and Dover sole, whichever is greater, may be trawl-caught sablefish smaller than 22 inches. (This is the equivalent of 25% of the DTS complex.)
12/01/94	Prohibited all commercial sablefish fishing north of 36°N latitude.
01/01/95	Established a cumulative DTS limit of 35,000 pounds per month north of Cape Mendocino and 50,000 pounds per month south of Cape Mendocino. Within the DTS complex limit not more than 20,000 pounds may be thornyheads, of which not more than 4,000 pounds per month may be shortspine thornyhead. For trawl-caught sablefish the cumulative limit is 6,000 pounds per month including a trip limit of 1,000 pounds or 25% of the DTS complex, whichever is greater, per trip. In any landing, no more than 500 pounds of sablefish may be smaller than 22 inches. Sablefish for management of the sablefish fishery north of the 36°N latitude (the northern boundary of the Conception area), deduct 780 mt from the 7,100 mt harvest guideline for the northwest Washington treaty Indian tribes and allocate the remaining 6,320 mt between the limited entry and open access fisheries. The limited entry portion is allocated 3,420 mt (58%) to trawl gear and 2,480 mt (42%) to pot and longline gears. Nontrawl sablefish daily-trip-limit of 300 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Only one landing of sablefish caught with nontrawl gear may be made per day, coast-wide. (The regular season started August 6, following a 24 to 72 hour closure). Sablefish daily limit of 300 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Limit of one landing of sablefish per vessel per day, and daily-trip-limits may not be accumulated.

02/17/95	Delayed the opening of the 1995 regular nontrawl sablefish season until completion of the proposed regulation to modify the season opening date and management structure. (Under the framework regulation currently governing the fishery, the nontrawl sablefish regular season would start February 26, preceded by a 72-hour closure beginning February 23. This regulation tied the opening date to the Alaska season, which was changed to open March 1.)
05/01/95	Increased the harvest guideline for sablefish by 700 mt to 7,800 mt to correct 1994 landings estimate. The open access allocation becomes 463 mt. The limited entry allocation becomes 6,557 mt with 3,803 mt (58%) allocated to trawl gear and 2,754 mt (42%) allocated to nontrawl gears. The cumulative monthly limit for trawl-caught sablefish increased from 6,000 to 7,000 pounds.
07/01/95	Dover sole, thornyheads, and trawl-caught sablefish (DTS) complex: cumulative limit of 35,000 pounds per month north of Cape Mendocino, California and 50,000 pounds per month south of Cape Mendocino; within the DTS complex limit, not more than 20,000 pounds may be thornyheads, of which not more than 4,000 pounds per month may be shortspine thornyhead. For trawl-caught sablefish, the cumulative limit is 6,000 pounds per month including a trip limit of 1,000 pounds or 25% of the DTS complex, whichever is greater, per trip. In any landing, no more than 500 pounds of sablefish may be smaller than 22 inches.
07/14/95	Removed the trip limit that required trawl-caught sablefish to comprise no more than 1,000 pounds or one third of the Dover sole and thornyheads. The 7,000-pound monthly cumulative trip limit, which includes a limit of 500 pounds of sablefish smaller than 22 inches per trip, remains in effect. Delayed the opening date of the limited entry nontrawl sablefish regular season and establish a new season structure. The regular season will begin on August 6 and is designed to close when 70% of the limited entry nontrawl harvest guideline is reached. Due to the short nature of the fishery, the closing date will be determined and announced in advance. The 1995 closure date was August 13 at noon. Prior to the start of the season, sablefish taken with fixed gear in the limited entry or open access fishery may not be retained from noon August 3 until noon August 6. In addition, all fixed gear (open access and limited entry) used to take and retain groundfish must be out of the water from noon August 3 until noon August 6, except that pot gear may be baited and deployed after noon on August 5. When the regular season ends at noon August 13, the daily-trip-limit will be reestablished. About 3 weeks after the end of the regular season, if an adequate amount of the nontrawl allocation remains, the limited entry fishery may resume for a one-month mop-up season under a cumulative monthly trip limit for each vessel. This would be followed by resumption of the small daily-trip-limits.
08/06/95	The regular nontrawl sablefish season opened at noon, August 6. During the regular season, the only trip limit in effect applies to sablefish smaller than 22 inches (56 cm) total length, which prohibits taking and retaining, possessing, or landing more than 1,500 pounds (680 kg) or 3% of all sablefish on board, whichever is greater, and applies per vessel per trip.

09/01/95	Established a one-month cumulative trip limit of 5,500 pounds of sablefish per vessel with a valid limited entry permit with longline or pot endorsement. On October 1, 1995 the daily-trip-limit of 300 pounds (350 pounds in the Conception management area) resumes.
09/08/95	The trawl minimum mesh size now applies throughout the net. Removed the legal distinction between bottom and roller trawls and the requirement for continuous riblines. Clarified the distinction between bottom and pelagic (midwater) trawls. Modified chafing gear requirements. Changed the term "doubleply mesh" to "double-bar mesh."
11/30/95	Prohibited further landings of thornyheads and trawl-caught sablefish for the remainder of the year and reduce the cumulative monthly limit of Dover sole to 3,000 pounds per vessel.
01/01/96	Established cumulative vessel limits for specified 2-month periods rather than 1-month periods, with the target harvest level per month being 50% of the 2-month limit. However, vessels could land as much as 60% of the 2-month limit in either of the two months, so long as the total did not exceed the specified limit.
01/01/96	Established a cumulative DTS limit of 70,000 pounds per two month period north of Cape Mendocino and 100,000 pounds per month south of Cape Mendocino. Within the DTS complex not more than 20,000 pounds may be thornyheads, of which not more than 4,000 pounds per two months may be shortspine thornyhead. For trawl-caught sablefish the cumulative limit is 12,000 pounds per 2-months. For trawl-caught sablefish, the cumulative limit is 12,000 pounds per 2-months. In any landing, no more than 500 pounds of sablefish may be smaller than 22 inches. Nontrawl sablefish outside the regular derby and mop-up seasons, a daily-trip-limit of 300 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Only one landing of sablefish caught with nontrawl gear may be made per day, coast-wide. During the derby and mop-up seasons, there is a per trip limit on the amount of sablefish that may be smaller than 22 inches total length (or 15.5 inches heads off): the amount of small sablefish may not exceed 1,500 pounds round weight or 3% of the sablefish larger than 22 inches, whichever is greater. The product recovery ratio (PRR) established by the state where the fish is or will be landed will be used to convert the processed weight to round weight for the purposes of applying the trip limit; the PRR currently is 1.6 in Washington, Oregon, and California. Sablefish daily limit of 300 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Limit of one landing of sablefish per vessel per day, and daily-trip-limits may not be accumulated.
04/15/96	Delay the opening date of the regular limited entry nontrawl sablefish fishery (derby) from August 6 to September 1.
05/03/96	Prohibited further landings of thornyheads by vessels fishing with open access gear and landing north of Point Conception; established a cumulative monthly limit of 2,100 pounds of sablefish for vessels fishing with open access gear north of the Conception management area (i.e., north of 36°N latitude). The 300-pound daily-trip-limit remained in effect.

09/06/96	Closed the limited entry nontrawl sablefish derby at noon by re-establishing the 300-pound daily-trip-limit north of 36°N latitude and 350-pound daily-trip-limit south of 36°N latitude.
01/01/97	Established a cumulative DTS limit of 70,000 pounds per two months period north of Cape Mendocino and 100,000 pounds per month south of Cape Mendocino. Within the DTS complex not more than 20,000 pounds may be thornyheads, of which not more than 4,000 pounds per two months may be shortspine thornyhead. For trawl-caught sablefish the cumulative limit is 12,000 pounds per 2-months. For Dover sole north of Cape Mendocino the cumulative limit is 38,000 pounds per two months. In any landing, no more than 500 pounds of sablefish may be smaller than 22 inches. Nontrawl sablefish in 1997 the derby north of 36°N latitude will be replaced by a 3-week cumulative limit that will open sometime between August 1 and September 30. A sablefish endorsement will be required for participation in the cumulative fishery, and vessels without endorsements may not fish for or land sablefish during the 3-week season or subsequent mop-up season, if any. There will be a 48-hour closure before and after the three-week season. Outside the 3-week cumulative season, the mop-up season and associated closures, there will be a daily-trip-limit of 300 pounds (round weight), and only one landing of sablefish caught with nontrawl gear may be made per day. South of 36°N latitude there will be no cumulative or mop-up seasons; there will be a daily-trip-limit of 350 pounds (round weight), and only one landing of sablefish caught with nontrawl gear may be made per day. During the 3-week cumulative and mop-up seasons north of 36°N latitude, there is a per trip limit on the amount of sablefish that may be smaller than 22 inches total length (or 15.5 inches heads off): the amount of small sablefish may not exceed 1,500 pounds round weight or 3% of the sablefish larger than 22 inches, whichever is greater. The product recovery ratio (PRR) established by the state where the fish is or will be landed will be used to convert the processed weight to round weight for the purposes of applying the trip limit; the PRR currently is 1.6 in Washington, Oregon, and California. Sablefish daily limit of 300 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Limit of one landing of sablefish per vessel per day, and daily-trip-limits may not be accumulated. North of 36°N latitude, there will also be a cumulative limit of 1,500 pounds per month.
05/01/97	Reduced the DTS complex cumulative 2-month limit for Dover sole north of Cape Mendocino to 30,000 pounds. Reduced the overall limit of thornyheads to 15,000 pounds and reduced the two-month cumulative limit on shortspines to 3,000 pounds. The cumulative limit for DTS complex was reduced to 57,000 pounds per two months north of Cape Mendocino.
07/01/97	Reduced monthly cumulative limit for fixed gear sablefish daily-trip-limit fishery North of 36°N latitude from 5,100 pounds to 600 pounds. Reduced the cumulative limit for fixed gear sablefish open-access north of 36°N latitude from 1,500 pounds to 600 pounds.
07/28/97	Requirement for a sablefish endorsement on limited entry permits for permit holders to participate in the regular and mop-up limited entry fixed gear sablefish fishery north of 36°N latitude.

08/22/97	Set dates for the 1997 fixed gear limited entry sablefish season for August 25 at noon through September 3 at noon, with an equal cumulative limit of 34,100 pounds and a pre-and post season 48 hour closure. For 1998 and beyond, a framework is established that allows the start date of the regular, north of 36°N latitude limited entry fixed gear sablefish season to be set for any day from August 1 through September 30.
09/01/97	Changed from two month cumulative limits to one month cumulative limits for Dover sole, thornyheads, and trawl-caught sablefish. Authorized fixed gear sablefish fishers in the daily-trip-limit fishery South of 36°N latitude to make one landing per week above the 350-pound daily-trip-limit but not more than 1,050 pounds (this was designed to help vessels making longer trips reduce their discard). A fisher may not make a landing larger than 350 pounds and then continue to land sablefish under the daily-trip-limit for the rest of the week.
10/01/97	Reduced the monthly limit of DTS complex to 11,000 pounds north of Cape Mendocino and 38,500 pounds south of Cape Mendocino. Within these limits, no more than 1,500 pounds could be Dover sole north of Cape Mendocino, and 30,000 pounds south of Cape Mendocino; no more than 2,000 pounds coast wide could be trawl-caught sablefish; and no more than 7,500 pounds coast wide could be thornyheads. No more than 1,500 pounds of the thornyheads could be shortspine thornyheads. Fixed gear limited entry sablefish mop-up season begins October 1 at noon through October 15 at noon. Vessels may land one cumulative limit of 8,500 pounds. Following the mop-up fishery, fixed-gear limited entry daily-trip-limits will be 300 pounds per day, with an increased 1,500-pound monthly limit. Open-Access Sablefish increased the open-access monthly cumulative limit to 1,500 pounds.
01/01/98	Established coast wide cumulative limit of 40,000 pounds of Dover sole in the January-February period and 18,000 pounds per two-month period thereafter; not more than 5,000 pounds of sablefish, not more than 10,000 pounds of longspine thornyheads, and not more than 4,000 pounds of shortspine thornyhead. Nontrawl sablefish: North of 36°N latitude, a daily-trip-limit of 300 pounds (round weight) and a cumulative limit of 1,500 pounds per two-month period. Only one landing of sablefish caught with nontrawl gear may be made per day. South of 36°N latitude there will be no cumulative or mop-up seasons; there is a daily-trip-limit of 350 pounds (round weight), and only one landing of sablefish caught with nontrawl gear may be made per day. Open access gear: daily limit of 300 pounds north of 36°N latitude and 350 pounds south of 36°N latitude. Limit of one landing of sablefish per vessel per day, and daily-trip-limits may not be accumulated. North of 36°N latitude, there is a cumulative limit of 600 pounds per two-month period.

05/01/98	Increased the 2-month cumulative limit for Dover sole to 22,000 pounds, for longspine thornyheads to 12,000 pounds, for shortspine thornyheads to 5,000 pounds, and for trawl-caught sablefish to 6,000 pounds. The overall DTS complex cumulative limit was removed. Fixed Gear Sablefish: North of 36°N lat., increased the cumulative limit to 1,800 pounds per 2-month period, but retained the 300-pound daily limit. South of 36°N lat., gave fishers the option to choose each week to make daily landings of sablefish of up to 350 pounds, per day, or make a single landing above 350 pounds, but not exceeding 1,050 pounds (effective May 3). Fixed gear sablefish: north of 36°N Lat: increased the 2-month cumulative limit to 700 pounds.
07/01/98	Open Access Fixed Gear Sablefish: increased the 2-month cumulative north of 36°N lat. to 1,800 pounds.
09/01/98	All limited entry cumulative limits became monthly limits
10/01/98	Trawl-caught Sablefish: increased monthly limit to 5,000 pounds. Fixed-Gear Sablefish: increased the 2 month cumulative limit to 2,700 pounds; on November 1, instituted 1,500-pound monthly limit.
11/01/98	Fixed-Gear Sablefish: changed to monthly limit, instituted 1,500-pound monthly limit.
01/01/99	A new three-phase cumulative limit period system was introduced. Phase 1 is a single cumulative limit period that is three months long, from January 1- March 31. Phase 2 has three separate 2-month cumulative limit periods of April 1- May 31, June 1-July 31, and August 1- September 30. Phase 3 has three separate 1-month cumulative limit periods of October 1-31, November 1-30, and December 1-31. For all species except POP and bocaccio, there was no monthly limit within the cumulative landing limit periods. An option was available to apply cumulative trip limits lagged by 2 weeks (from the 16th to the 15th) to limited entry trawl vessels when their permits were renewed for 1999. Vessels authorized to operate in this "B" platoon could take and retain, but not land, groundfish during January 1-15, 1999. Trawl-caught Sablefish: Phase 1: 13,000 pounds per period; Phase 2: 10,000 pounds per period; Phase 3: 6,000 pounds per period. At any time of year unless otherwise announced, no more than 500 pounds per trip may be trawl-caught sablefish smaller than 22 inches total length. 22 inches total length is equivalent to 15.5 inches headed; processed weight will be converted to round weight using the States' conversion factor of 1.6. Nontrawl Sablefish: north of 36°N latitude, a daily trip limit of 300 pounds and a cumulative trip limit of 2,400 pounds per 2-month period; south of 36°N latitude, the daily trip limit is either (1) 350 pounds with no cumulative limit on the amount of sablefish that may be retained in a month; or (2) one landing of sablefish per week above 350 pounds, but not to exceed 1,050 pounds. Only one landing of sablefish caught with nontrawl gear may be made per day coast-wide, and daily trip limits may not be accumulated. A limited entry permit holder must have a permit with a sablefish endorsement to participate in either the regular or mop-up seasons. Open access gear: North of 36°N latitude, 300 pounds per day, 1,800 pounds per 2 month period. 2 month periods for sablefish landings are January 1 - February 28; March 1 - April 30; May 1 - June 30;

	July 1 - August 31; September 1 - October 31; November 1 - December 31. South of 36°N latitude, 350 pounds per day.
05/01/99	Trawl-caught Sablefish: 2-month cumulative trip limit for the period April 1 through May 31 increased from 10,000 pounds to 12,000 pounds. Beginning June 1, 2-month cumulative trawl-caught sablefish trip limit will revert to 10,000 pounds.
07/02/99	Fixed-gear Sablefish: daily trip limit continues to be 300 pounds, but the 2-month cumulative trip limit for the period July 1 through August 31 increased from 2,400 pounds to 4,200 pounds. Beginning September 1, the 2-month cumulative trip limit will be converted to a 1-month cumulative trip limit of 2,100 pounds. Open Access: daily trip limit continues to be 300 pounds, but the 2-month cumulative trip limit for the period July 1 through August 31 increased from 1,800 pounds to 3,000 pounds. Beginning September 1, the 2-month cumulative trip limit will be converted to a 1-month cumulative trip limit of 1,500 pounds.

08/16/99	Tiered cumulative limit fishery ("regular season"): limited entry, fixed gear sablefish fishery off Washington, Oregon, and California, north of 36°N latitude, regular season begins at noon on August 16 and ends at noon on August 25. Only limited entry permit holders with sablefish endorsements may participate in the regular season. A participant in the regular sablefish season may catch no more than the amount associated with the tier assigned to his permit. The cumulative landings limits associated with each tier are: 84,800 pounds for Tier 1; 38,300 pounds for Tier 2, and 22,000 pounds for Tier 3 (all limits are round weight). No vessel may catch more than one cumulative limit. Aside from the overall tiered cumulative limits for the regular season, the only trip limit in effect is for sablefish smaller than 22 inches total length, which may comprise no more than 1,500 pounds or 3% of all legal sablefish 22 inches or larger, whichever is greater. This limit applies per vessel per trip.
01/01/00	New cumulative trip limit periods were defined as follows: A cumulative trip limit is the maximum amount that may be taken and retained, possessed, or landed per vessel in a specified period of time without a limit on the number of landings or trips, unless otherwise specified. The minimum size limit for headed sablefish, which corresponds to 22 in. (56 cm) TL for whole fish, is 15.5 in. (39 cm). Trawl trip limits for the year were set at 7,000 pounds bimonthly for January-March, 10,000 pounds bimonthly for May-October, and 3,500 pounds bimonthly for November-December. The trip limits for limited-entry fixed gear for North of 36°N latitude were set at 300 pounds per day and 2,100 pounds bimonthly for January-April or one landing above 300 pounds but less than 600 pounds per week and less than 1,800 pounds bimonthly, and 300 pounds per day and 2,100 pounds bimonthly for May-December. The trip limits for limited-entry fixed gear for South of 36°N latitude were set at 350 pounds per day or 1 landing above 350 pounds per week; up to 1,050 pounds for January-December. The trip limits for the open access gear (except exempted trawl gear) for North of 36°N latitude were set at 300 pounds per day, but not more than 2,100 pounds bimonthly for January-December. The trip limits for the open access gear (except exempted trawl gear) for South of 36°N latitude were set at 350 pounds per day for January-December.
01/01/01	DTS complex. For 2001, differential trip limits are introduced for the DTS complex== (Dover sole, shortspine thornyhead, longspine thornyhead, sablefish) north and south of the management line at 40°10'N lat. Vessels operating in the limited entry trawl fishery are subject to crossover provisions when making landings that include any one of the four species in the DTS complex. [Example: The January-February cumulative limit for Dover sole north of 40°10' N lat. is 65,000 lb (29,484 kg) and the cumulative limit for sablefish in that same period and area is 5,000 lb (2,268 kg), while the cumulative limits south of 40°10' N lat. are 35,000 lb (15,876 kg) for Dover sole and 8,000 lb (3,629 kg) for sablefish. Under the crossover provisions, a vessel may not take and retain Dover sole north of 40°10'N lat. and then travel south of 40°10'N lat. in that same 2-month period to take and retain the higher sablefish limit in the south.
05/01/00	Limited Entry and Open Access Non-Trawl fisheries: north of 36°N lat., the 2-month cumulative trip limit for sablefish is increased from 2,100 lb to 2,400 lb. The 300 lb daily trip limit remains in effect.

07/17/00	Limited Entry and Open Access Non-Trawl Fisheries north of 36°N lat.: 2-month cumulative trip limit for sablefish is increased from 2,400 lb to 3,300 lb. The 300 lb daily trip limit remains in effect. Details for the limited entry, primary fixed gear sablefish fishery will be announced via a separate public notice, to follow immediately.
10/02/00	Limited entry trawl fishery, the 2-month cumulative trip limit is increased from 10,000 to 12,000 lb for the September to October period beginning October 2, 2000, and then changes to a 1-month limit of 6,000 lb for the November and December periods. The per-trip limit of 500 lb for sablefish smaller that 22 inches is removed for the remainder of the year. Limited entry fixed gear daily trip limit fishery north of 36°N lat., the 2-month cumulative trip limit increases from 3,300 lb to 8,000 lb, beginning October 2, 2000, and continuing through the end of the year. The daily trip limit is increased to either: (1) 400 lb per day, or (2) one landing of sablefish per week above 400 lb, but not to exceed 1,000 lb. A vessel may not use both options in one week. A week is seven days, Sunday through Saturday. Open access, daily trip limit fisheries, the 2-month cumulative limit is removed, beginning October 2, 2000. The daily trip limit is increased to either: (1) 300 lb per day or (2) one landing of sablefish per week above 300 lb, but not to exceed 1,200 lb. A vessel may not use both options in one week. A week is seven days, Sunday through Saturday.
01/01/01	The size limit for trawlers and limited entry, fixed-gear regular and mop-up sablefish fisheries has been eliminated. DTS complex. For 2001, differential trip limits are introduced for the DTS complex: (Dover sole, shortspine thornyhead, longspine thornyhead, sablefish) north and south of the management line at 40°10’N. lat. Vessels operating in the limited entry trawl fishery are subject to crossover provisions when making landings that include any one of the four species in the DTS complex. [Example: The January-February cumulative limit for Dover sole north of 40°10’N. lat. is 65,000 lb (29,484 kg) and the cumulative limit for sablefish in that same period and area is 5,000 lb (2,268 kg), while the cumulative limits south of 40°10’N. lat. are 35,000 lb (15,876 kg) for Dover sole and 8,000 lb (3,629 kg) for sablefish. Under the crossover provisions, a vessel may not take and retain Dover sole north of 40°10’N. lat. and then travel south of 40°10’N. lat. in that same 2-month period to take and retain the higher sablefish limit in the south.]. The limited entry sablefish allocation is further allocated 58% to trawl gear and 42% to nontrawl gear. Nontrawl trip and size limits: To take, retain, possess, or land sablefish during the regular, or mop-up season for the nontrawl limited entry sablefish fishery, the owner of a vessel must hold a limited entry permit for that vessel, affixed with both a gear endorsement for longline or trap (or pot) gear, and a sablefish endorsement. See 50 CFR 663.23(a)(2)(i). A sablefish endorsement is not required to participate in the limited entry daily trip limit fishery.
10/01/01	Taking and retaining, possessing or landing was prohibited by limited entry trawl for the DTS complex coast-wide

2001 final	The fishery was closed during October-November and there was a 1,000-pound per trip limit during December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily and 2,700 pounds bimonthly for January-June, 300 daily, 900 weekly and 3,600 pounds bimonthly for July-August, and 300 daily, 900 weekly, and 1,800 pounds bimonthly for September-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily and 2,700 pounds bimonthly for January-June, 300 daily, 800 weekly, and 4,800 pounds bimonthly for July-August, and 300 daily, 800 weekly, and 2,400 pounds bimonthly for September-December. In the southern area the limits for sablefish taken by the open access fishery were set at 350 pounds daily for January-December.
2002 final	In the northern area the limits for sablefish taken by large-footrope trawls were 6,000 pounds bimonthly for January-April, 3,500 pounds bimonthly for May-June, 3,000 pound bimonthly for July-August, 3,500 pounds bimonthly for September-October, and 2,600 pounds bimonthly for November-December. In the southern area the limits for sablefish taken were 4,500 pounds bimonthly for January-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 800 weekly, and 2,400 pounds bimonthly for January-September, and 300 daily, 900 weekly and 2,700 pounds for October and bimonthly for November-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-April, and 300 daily and 900 pounds weekly for May-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 800 weekly, and 2,400 pounds bimonthly for January-September, and 300 daily, 900 weekly, and 2,700 pounds for October and bimonthly for November-December. In the southern area the limits for sablefish taken by the open access fishery were set at 350 daily and 1,050 pounds weekly for January-April, and 300 daily and 900 pounds weekly for May-December.
2003 final	In the northern area the limits for sablefish taken by large-footrope trawls were 6,000 pounds bimonthly for January-April, 10,000 pounds bimonthly for May-June, 9,000 pounds bimonthly for July-October, and 7,000 pounds bimonthly for November-December. The limits for sablefish taken by small-footrope trawls and selective gear were 6,000 pounds bimonthly for January-April, 3,000 pounds bimonthly for May-October, and 7,000 pounds bimonthly for November-December. In the southern area the limits for sablefish taken were 6,000 pounds bimonthly for January-April, 10,000 May-June, 9,000 pounds bimonthly for July-October, and 7,000 pounds bimonthly for November-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 800 weekly, and 3,200 pounds bimonthly for January-October, and 300 daily, 900 weekly and 3,600 pounds bimonthly for November-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 800 weekly, and 3,200 pounds bimonthly for January-October, and 300 daily, 900 weekly, and 3,600 pounds for November-December. In

	the southern area the limits for sablefish taken by the open access fishery were set at 350 daily and 1,050 pounds weekly for January-December.
2004 final	In the northern area the limits for sablefish taken by large-footrope trawls were 9,300 pounds bimonthly for January-April, 16,000 pounds bimonthly for May-August, and 17,000 pounds bimonthly for September-December. The limits for sablefish taken by small-footrope trawls and selective gear were 2,000 pounds bimonthly for January-April, 10,000 pounds bimonthly for May-August, and 17,000 pounds bimonthly for September-December. In the southern area the limits for sablefish taken were 11,250 pounds bimonthly for January-April, 14,500 pounds bimonthly for May-June, 13,000 pounds bimonthly for July-August, and 17,000 pounds bimonthly for September-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 900 weekly, and 3,600 pounds bimonthly for January-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 900 weekly, and 3,600 pounds bimonthly for January-December. In the southern area the limits for sablefish taken by the open access fishery were set at 350 daily and 1,050 pounds weekly for January-December.
03/11/05	The sablefish tier 1 limit was reduced from 64,100 pounds to 64,000 pounds
06/17/05	Increased limited entry trawl trip limits for longspine and shortspine thornyheads, sablefish, and slope rockfish.
09/23/05	Increase the trawl RCA to 0-250 fm north of 36°N lat. and 50-250 fm south of 36°N lat. with changes in Dover sole, thornyhead, and sablefish limited entry trawl trip limits to respond to conservation concerns for petrale sole and canary rockfish. Increase the trawl RCA to 0-250 fm north of 36°N lat. and 50-250 fm south of 36° N lat. with changes in Dover sole, thornyhead, and sablefish limited entry trawl trip limits to respond to conservation concerns for petrale sole and canary rockfish.

2005 final	In the northern area the limits for sablefish taken by large-footrope trawls were 9,500 pounds bimonthly for January-April, 17,000 pounds bimonthly for May-June, 18,000 pounds bimonthly for July-October, and 11,000 pounds bimonthly for November-December. The limits for sablefish taken by small-footrope trawls and selective gear were 1,500 pounds bimonthly for January-February, 10,000 pounds bimonthly for March-June, 15,000 pounds bimonthly for July-October, and 11,000 pounds bimonthly for November-December. In the southern area the limits for sablefish taken were 14,000 pounds bimonthly for January-June, 16,000 pounds bimonthly for July-October, and 9,000 pounds bimonthly for November-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 900 weekly, and 3,600 pounds bimonthly for January-August and monthly for September, and 500 daily, 1,500 weekly and 9,000 pounds October and bimonthly for November-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 900 weekly, and 3,600 pounds bimonthly for January-August and monthly for September, and 500 daily, 1,500 weekly, and 9,000 pounds for October and bimonthly November-December. In the southern area the limits for sablefish taken by the open access fishery were set at 350 daily and 1,050 pounds weekly for January-December.
09/19/06	Close the open access daily trip limit fishery north of 36°N lat. for sablefish on October 1.
2006 final	In the northern area the limits for sablefish taken by large-footrope trawls were 7,000 pounds monthly for January-February, 14,000 pounds bimonthly for March-April, and 20,000 pounds bimonthly for May-December. The limits for sablefish taken by small-footrope trawls and selective gear were 2,500 pounds monthly for January-February, 7,000 pounds bimonthly for March-April, 13,500 pounds bimonthly for May-August, 7,000 pounds bimonthly for September-October, and 5,000 pounds bimonthly for November-December. In the southern area the limits for sablefish taken were 8,500 pounds monthly for January-February, 17,000 pounds bimonthly for March-October, and 20,000 pounds bimonthly for November-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 1,000 weekly, and 5,000 pounds bimonthly for January-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-August, 350 daily and 1,050 pounds weekly for September, 500 daily and 1,050 pounds weekly for October, 500 daily and 1,050 pounds weekly for November, and 300 daily, 1,050 weekly and 3,000 pounds for December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 1,000 weekly, and 5,000 pounds bimonthly for January-April, 300 daily, 1,000 weekly and 3,000 pounds bimonthly for May-August and for the month of September, and was closed from October-December. In the southern area the limits for sablefish taken by the open access fishery were set at 350 daily and 1,050 pounds weekly for January-August, 350 daily and 1,050 pounds weekly for September, 500 daily and 1,050 pounds weekly for October-November, and 300 daily, 1,050 weekly, and 3,000 pounds for December.

11/16/07	The Council adopted the following exempted fishing permits (EFP) and bycatch caps for 2008: 50 mt (20 mt before July 1 and 30 mt after July 1) for The Nature Conservancy and Environmental Defense.
2007 final	In the northern area the limits for sablefish taken by large-footrope trawls were 13,000 pounds bimonthly for January-April, 15,000 pounds bimonthly for May-August, 22,000 pounds bimonthly for September-October, and 30,000 pounds bimonthly for November-December. The limits for sablefish taken by small-footrope trawls and selective gear were 5,000 pounds bimonthly for January-February, 8,000 pounds bimonthly for March-April, and 5,000 pounds bimonthly for May-December. In the southern area the limits for sablefish taken were 14,000 pounds bimonthly for January-August, 22,000 pounds bimonthly for September-October, and 30,000 pounds bimonthly for November-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 1,000 weekly, and 5,000 pounds bimonthly for January-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 700 weekly, and 2,100 pounds bimonthly for January-December. In the southern area the limits for sablefish taken by the open access fishery were set at 300 daily and 700 pounds weekly for January-July, and 350 daily and 1,050 pounds weekly for August-December.
09/22/08	The Council adopted a 165 mt sablefish cap for this EFP next year.
2008 final	In the northern area the limits for sablefish taken by large-footrope trawls were 14,000 pounds bimonthly for January-April, 19,000 pounds bimonthly for May-June, 24,000 pounds bimonthly for September-October, and 19,000 pounds bimonthly for November-December. The limits for sablefish taken by small-footrope trawls and selective gear were 5,000 pounds bimonthly for January-June and 7,000 pounds bimonthly for July-December. In the southern area the limits for sablefish taken were 14,000 pounds bimonthly for January-April, 19,000 pounds bimonthly for May-June, 24,000 pounds bimonthly for September-October, and 19,000 pounds bimonthly for November-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 1,000 weekly, and 5,000 pounds bimonthly for January-June, 500 daily, 1,000 weekly, and 5,000 pounds bimonthly for July-October, and 500 daily, 1,000 weekly, and 6,500 pounds bimonthly for November-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 350 daily and 1,050 pounds weekly for January-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 800 weekly, and 2,400 pounds bimonthly for January-April, 300 daily, 800 weekly, and 2,200 pounds bimonthly for May-December. In the southern area the limits for sablefish taken by the open access fishery were set at 300 daily and 700 pounds weekly for January-July, 300 daily, 700 weekly, and 1,000 pounds for August, and 300 daily, 700 weekly, 2,100 pounds bimonthly for August-December.

2009 final	In the northern area the limits for sablefish taken by large-footrope trawls were 18,000 pounds bimonthly for January-April, 22,000 pounds bimonthly for May-October, and 18,000 pounds bimonthly for November-December. The limits for sablefish taken by small-footrope trawls and selective gear were 5,000 pounds bimonthly for January-February, 7,500 pounds bimonthly for March-October, and 5,000 pounds bimonthly for November-December. In the southern area the limits for sablefish taken were 20,000 pounds bimonthly for January-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 300 daily, 1,000 weekly, and 5,000 pounds bimonthly for January-April, 500 daily, 1,500 weekly, and 5,500 pounds bimonthly for May-June, and 500 daily, 1,000 weekly, and 6,000 pounds bimonthly for July-August, 2,000 weekly and 7,000 pounds bimonthly for September-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 400 daily and 1,500 pounds weekly for January-August and 3,000 pounds weekly for September-December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 800 weekly, and 2,400 pounds bimonthly for January-June, and 300 daily, 950 weekly, and 2,750 pounds bimonthly for July-December. In the southern area the limits for sablefish taken by the open access fishery were set at 400 daily, 1,500 weekly, and 8,000 pounds bimonthly for January-August, and 400 daily and 2,500 pounds weekly for September-December.
2010 final	In the northern area the limits for sablefish taken by large-footrope trawls were 20,000 pounds bimonthly for January-April, 24,000 pounds bimonthly for May-October, and 20,000 pounds bimonthly for November-December. The limits for sablefish taken by small-footrope trawls and selective gear were 9,000 pounds bimonthly for January-December. In the southern area the limits for sablefish taken were 22,000 pounds bimonthly for January-December. In the northern area the limits for sablefish taken by limited-entry trawl gear were set at 1,750 weekly and 7,000 pounds bimonthly for January-June, 1,500 weekly and 8,500 pounds bimonthly for July-October, 1,750 pounds weekly for November, 2,000 pounds weekly for December, and 8,000 pounds bimonthly for November-December. In the southern area the limits for sablefish taken by limited-entry trawl gear were set at 400 daily and 1,500 pounds weekly for January-August, 3,000 pounds weekly for September, 2,800 pounds weekly for October-November, and 1,800 pounds weekly for December. In the northern area the limits for sablefish taken by the open access fishery were set at 300 daily, 800 weekly, and 2,400 pounds bimonthly for January-June, 300 daily, 950 weekly, and 2,750 pounds bimonthly for July-October, 300 daily and 950 pounds weekly for November, 400 daily and 1,500 pounds weekly for December, and 4,500 pounds bimonthly for November-December. In the southern area the limits for sablefish taken by the open access fishery were set at 400 daily, 1,500 weekly, and 8,000 pounds bimonthly for January-August, 400 daily and 2,500 pounds weekly for September, 800 weekly and 1,600 pounds for October, 800 daily, 800 weekly, and 1,600 pounds for November, and closed for December.

2011	1/1/2011 - 3600 South - sablefish, limited entry fixed gear, 2000 lbs per week 1/1/2011 - 4010 North - sablefish, limited entry fixed gear, 1900 lbs per week not to exceed 6500 lbs per 2 months 1/1/2011- 4010 North - minor slope rockfish north including splitnose and darkblotched, open access gears, per trip, no more than 25 % (by weight) of sablefish landed 1/1/2011 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 800 lbs not to exceed 2400 lbs per 2 months 1/1/2011 - 3600 South - sablefish, open access gear, 400 lbs per day or 1 landing of up to 1500 lbs per week not to exceed 6000 lbs per 2 months 1/1/2011 - ALL Sablefish managed in part by IFQ 3/1/2011 - 3600 South - sablefish, open access gear, 300 lbs per day or 1 landing of up to 1200 lbs per week not to exceed 2100 lbs per 2 months 3/1/2011 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 950 lbs not to exceed 1900 lbs per 2 months 3/1/2011 - 4010 North - sablefish, limited entry fixed gear, 2000 lbs per week not to exceed 7000 lbs per 2 months 3/1/2011 - 3600 South - sablefish, limited entry fixed gear, 2100 lbs per week 7/1/2011 - 4010 North - sablefish, limited entry fixed gear, 2000 lbs per week not to exceed 3500 lbs per 2 months 7/1/2011 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 1050 lbs not to exceed 2100 lbs per 2 months 11/1/2011 - 3600 South - sablefish, open access gear, 300 lbs per day or 1 landing of up to 1500 lbs per week not to exceed 3100 lbs per 2 months
2012	1/1/2012 - 3600 South - sablefish, open access gear, 300 lbs per day or 1 landing of up to 1350 lbs per week not to exceed 6000 lbs per 2 months 1/1/2012 - 4010 North - minor slope rockfish north including splitnose and darkblotched, open access gears, per trip, no more than 25 % (by weight) of sablefish landed 1/1/2012 - 4010 North - sablefish, limited entry fixed gear, 1300 lbs per week not to exceed 5000 lbs per 2 months 1/1/2012 -3600 South - sablefish, limited entry fixed gear, 1800 lbs per week 1/1/2012 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 900 lbs not to exceed 1800 lbs per 2 months 5/1/2012 - 4010 North - sablefish, limited entry fixed gear, 1000 lbs per week not to exceed 4000 lbs per 2 months 9/1/2012 - 4010 North - sablefish, limited entry fixed gear, 800 lbs per week not to exceed 1600 lbs per 2 months 11/1/2012 - 3600 South - sablefish, open access gear, 350 lbs per day or 1 landing of up to 1750 lbs per week not to exceed 3500 lbs per 2 months

2013	1/1/2013 - 3600 South - sablefish, open access gear, 300 lbs per day or 1 landing of up to 1450 lbs per week not to exceed 2920 lbs per 2 months 1/1/2013 - 4010 North - sablefish, limited entry fixed gear, 950 lbs per week not to exceed 28500 lbs per 2 months 1/1/2013 - 3600 South - sablefish, limited entry fixed gear, 1880 lbs per week 1/1/2013 - 4010 North - minor slope rockfish north including splitnose and darkblotched, open access gears, per trip, no more than 25 % (by weight) of sablefish landed 1/1/2013 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 700 lbs not to exceed 1400 lbs per 2 months 7/1/2013 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 800 lbs not to exceed 1600 lbs per 2 months 7/1/2013 - 4010 North - sablefish, limited entry fixed gear, 1110 lbs per week not to exceed 3300 lbs per 2 months 11/1/2013 - 4010 North - sablefish, open access gears, 300 lbs per day or 1 landing per week up to 800 lbs not to exceed 1600 lbs per 2 months 12/3/2013 - 4010 North - sablefish, open access gear, 300 lbs per day or 1 landing per week of up to 1200 lbs not to exceed 2400 lbs from November1-December 31 12/3/2013 - 4010 North - sablefish, limited entry fixed, 1850 lbs per week and may land an additional 2200 lbs not to exceed 5500 lbs cumulative from November 1, 2013-December 31, 2013 12/3/2013 - 4010 South - sablefish, limited entry fixed, 1850 lbs per week and may land an additional 2200 lbs not to exceed 5500 lbs cumulative from November 1, 2013-December 31, 2013 12/3/2013 - 3600 South - sablefish, open access gear, 380 lbs per day or 1 landing per week of up to 1800 lbs not to exceed 3800 lbs from November1-December 32
2014	1/1/2014 - 4010 North - non-trawl, limited entry, sablefish, 950 lbs per week not to exceed 2850 per 2 months 1/1/2014 - 3600 South - non-trawl, limited entry, sablefish, 2000 lbs per week 1/1/2014 - 4010 North - non-trawl, open access, minor slope rockfish including darkblotched and splitnose rockfish, no more than 25% by weight of the sablefish landed 1/1/2014 - 4010 North - non-trawl, open access, sablefish, 300 lbs per day or 1 landing per week up to 800 lbs, not to exceed 1600 lbs per 2 months 1/1/2014 - 3600 South - non-trawl, open access, sablefish, 300 lbs per day, or 1 landing per week up to 1600 lbs, not to exceed 3200 lbs per 2 months 7/1/2014 - 4010 North - non-trawl, open access, sablefish, 350 lbs per day or 1 landing per week up to 1600 lbs, not to exceed 3200 lbs per 2 months 7/1/2014 - 4010 North - non-trawl, limited entry, sablefish, 1000 lbs per week, not to exceed 3000 lbs per 2 months

2015	1/1/2015 - 4010 North - non-trawl, limited entry, sablefish, 1025 lbs per week not to exceed 3075 per 2 months 1/1/2015 - 3600 South - non-trawl, limited entry, sablefish, 2000 lbs per week 1/1/2015 - 4010 North - non-trawl, open access, minor slope rockfish including darkblotched and splitnose rockfish, no more than 25% by weight of the sablefish landed 1/1/2015 - 4010 North - non-trawl, open access, sablefish, 300 lbs per day or 1 landing per week up to 900 lbs, not to exceed 1800 lbs per 2 months 1/1/2015 - 3600 South - non-trawl, open access, sablefish, 50 lbs per day, no more than 1000 lbs per 2 months 7/1/2015 - 4010 North - non-trawl, open access, sablefish, 350 lbs per day or 1 landing per week up to 1600 lbs, not to exceed 3200 lbs per 2 months 7/1/2015 - 4010 North - non-trawl, limited entry, sablefish, 1125 lbs per week, not to exceed 3375 lbs per 2 months 11/1/2015 - 4010 North - non-trawl, limited entry, sablefish, closed
2016	1/1/2016 - 4010 North - non-trawl, limited entry, sablefish, 1275 lbs per week not to exceed 3375 per 2 months 1/1/2016 - 3600 South - non-trawl, limited entry, sablefish, 2000 lbs per week 1/1/2016 - 4010 North - non-trawl, open access, minor slope rockfish including darkblotched and splitnose rockfish, no more than 25% by weight of the sablefish landed 1/1/2016 - 4010 North - non-trawl, open access, sablefish, 300 lbs per day or 1 landing per week up to 1000 lbs, not to exceed 2000 lbs per 2 months 1/1/2016 - 3600 South - non-trawl, open access, sablefish, 300 lbs per day, or 1 landing per week of up to 1600 lbs, no more than 3200 lbs per 2 months 7/1/2016 - 4010 North - non-trawl, open access, sablefish, 300 lbs per day or 1 landing per week up to 850 lbs, not to exceed 1700 lbs per 2 months 7/1/2016 - 4010 North - non-trawl, limited entry, sablefish, 1125 lbs per week, not to exceed 3375 lbs per 2 months 9/1/2016 - 4010 North - non-trawl, open access, sablefish, 300 lbs per day or 1 landing per week up to 750 lbs, not to exceed 1500 lbs per 2 months
2017	Sablefish North of 36: LEFG: --Jan-Aug: 1,000 weekly, 2,000 bimonthly --Sep-Oct: 1,200 weekly, 2,400 bimonthly --Nov-Dec: 1,400 weekly, 2,800 bimonthly OA: --Jan-Feb: 300 lbs daily, 1,000 lbs weekly, 2,000 bimonthly --Mar-Apr: 300 lbs daily, 900 lbs weekly, 1,800 bimonthly --May-Aug: 300 lbs daily, 1,000 lbs weekly, 2,000 bimonthly --Sept-Oct: 300 lbs daily, 1,150 lbs weekly, 2,300 bimonthly --Nov-Dec: 300 lbs daily, 1,300 lbs weekly, 2,300 bimonthly Sablefish South of 36: LEFG: 2,000 lbs weekly OA: 300 lbs daily, 1600 lbs weekly, 3,200 lbs bimonthly

2018	Sablefish North of 36: LEFG: --Jan-Feb: 1,125 lbs weekly, 3,375 lbs bimonthly --Mar-Jun: 1,100 lbs weekly, 3,300 lbs bimonthly --Sep-Oct: 1,250 lbs weekly, 3,750 lbs bimonthly --Nov-Dec: 1,400 lbs weekly, 4,200 lbs bimonthly OA: --Jan-Aug: 300 lbs daily, 1,000 lbs weekly, 2,000 lbs bimonthly --Sept-Oct: 300 lbs daily, 1,200 lbs weekly, 2,400 lbs bimonthly --Nov-Dec: 300 lbs daily, 1,400 lbs weekly, 2,800 lbs bimonthly Sablefish South of 36 LEFG: 2,000 lbs weekly OA: --Jan-Aug: 300 lbs daily, 1600 lbs weekly, 3,200 lbs bimonthly --Sept-Oct: 300 lbs daily, 1600 lbs weekly, 4,000 lbs bimonthly --Nov-Dec: 300 lbs daily, 1600 lbs weekly, 4,800 lbs bimonthly

C VAST OUTPUT

C.1 TABLES

Table C.1. Design-based estimates and their standard errors (se) in log space for the West Coast Groundfish Bottom Trawl Survey.

Year	Value	log se
2003	141883306.17	0.18
2004	132379634.69	0.19
2005	96336855.45	0.06
2006	102764619.80	0.11
2007	95078632.05	0.08
2008	68931270.97	0.07
2009	67518532.26	0.08
2010	70790780.04	0.09
2011	73385760.52	0.06
2012	68612253.23	0.07
2013	74096845.55	0.09
2014	81173010.37	0.11
2015	83937922.63	0.12
2016	86272508.51	0.08
2017	116884462.86	0.13
2018	131429177.09	0.15

Table C.2. Settings used for the the vector auto-regressive spatiotemporal model used to fit data from the West Coast Groundfish Bottom Trawl Survey.

Setting name	Setting used
Number of knots	500
Maximum gradient	< 1e-06
Is hessian positive definite?	Yes
Was bias correction used?	Yes
Distribution for measurement errors	Gamma
Spatial effect for encounter probability	Yes
Spatio-temporal effect for encounter probability	Yes
Spatial effect for positive catch rate	Yes
Spatio-temporal effect for positive catch rate	Yes

Table C.4. Parameter estimates and their standard errors from the vector auto-regressive spatiotemporal model used to fit data from the West Coast Groundfish Bottom Trawl Survey.

Name	Estimate	Standard error
ln_H_input	-1.04	0.12
ln_H_input	-0.30	0.10
beta1_ft	0.85	0.52

Table C.4. Parameter estimates and their standard errors from the vector auto-regressive spatiotemporal model used to fit data from the West Coast Groundfish Bottom Trawl Survey.

Name	Estimate	Standard error
beta1_ft	0.75	0.53
beta1_ft	0.76	0.52
beta1_ft	-0.05	0.51
beta1_ft	-0.03	0.51
beta1_ft	-0.06	0.51
beta1_ft	-0.13	0.51
beta1_ft	0.07	0.51
beta1_ft	0.23	0.51
beta1_ft	-0.17	0.52
beta1_ft	0.28	0.52
beta1_ft	0.40	0.51
beta1_ft	-0.06	0.51
beta1_ft	0.10	0.51
beta1_ft	0.14	0.51
beta1_ft	-0.12	0.51
lambda1_k	0.33	0.08
L1_z	0.22	0.04
L_omega1_z	3.21	0.31
L_epsilon1_z	0.91	0.08
logkappa1	-3.58	0.13
beta2_ft	6.21	0.16
beta2_ft	6.32	0.17
beta2_ft	6.19	0.16
beta2_ft	6.20	0.16
beta2_ft	6.23	0.16
beta2_ft	5.90	0.16
beta2_ft	5.88	0.16
beta2_ft	5.98	0.15
beta2_ft	5.94	0.16
beta2_ft	5.86	0.17
beta2_ft	5.91	0.17
beta2_ft	5.92	0.16
beta2_ft	6.05	0.16
beta2_ft	5.90	0.16
beta2_ft	6.23	0.16
beta2_ft	6.27	0.16
lambda2_k	-0.02	0.04
L2_z	-0.11	0.02
L_omega2_z	-1.33	0.08
L_epsilon2_z	-0.74	0.03
logkappa2	-2.73	0.13

Table C.4. Parameter estimates and their standard errors from the vector auto-regressive spatiotemporal model used to fit data from the West Coast Groundfish Bottom Trawl Survey.

Name	Estimate	Standard error
logSigmaM	-0.05	0.01

Table C.3. Parameters included in the vector auto-regressive spatiotemporal model used to fit data from the West Coast Groundfish Bottom Trawl Survey.

Name	n	Type
beta1_ft	16	Fixed
beta2_ft	16	Fixed
L_epsilon1_z	1	Fixed
L_epsilon2_z	1	Fixed
L_omega1_z	1	Fixed
L_omega2_z	1	Fixed
L1_z	1	Fixed
L2_z	1	Fixed
lambda1_k	1	Fixed
lambda2_k	1	Fixed
ln_H_input	2	Fixed
logkappa1	1	Fixed
logkappa2	1	Fixed
logSigmaM	1	Fixed
Epsiloninput1_sft	8256	Random
Epsiloninput2_sft	8256	Random
eta1_vf	61	Random
eta2_vf	61	Random
Omegainput1_sf	516	Random
Omegainput2_sf	516	Random

Table C.5. Design-based estimates and their standard errors (se) in log space for the Northwest Fisheries Science Center Slope Survey.

Year	Value	log se
1998	33359949.02	0.07
1999	48037976.71	0.14
2000	47462669.03	0.08
2001	38727535.09	0.06
2002	45935986.20	0.05

Table C.6. Settings used for the the vector auto-regressive spatiotemporal model used to fit data from the Northwest Fisheries Science Center Slope Survey.

Setting name	Setting used
Number of knots	500
Maximum gradient	< 1e-06
Is hessian positive definite?	Yes
Was bias correction used?	Yes
Distribution for measurement errors	Gamma
Spatial effect for encounter probability	Yes
Spatio-temporal effect for encounter probability	Yes
Spatial effect for positive catch rate	Yes
Spatio-temporal effect for positive catch rate	Yes

Table C.7. Parameters included in the vector auto-regressive spatiotemporal model used to fit data from the Northwest Fisheries Science Center Slope Survey.

Name	n	Type
beta1_ft	5	Fixed
beta2_ft	5	Fixed
L_epsilon1_z	1	Fixed
L_epsilon2_z	1	Fixed
L_omega1_z	1	Fixed
L_omega2_z	1	Fixed
ln_H_input	2	Fixed
logkappa1	1	Fixed
logkappa2	1	Fixed
logSigmaM	1	Fixed
Epsiloninput1_sft	2580	Random
Epsiloninput2_sft	2580	Random
Omegainput1_sf	516	Random
Omegainput2_sf	516	Random

Table C.8. Parameter estimates and their standard errors from the vector auto-regressive spatiotemporal model used to fit data from the Northwest Fisheries Science Center Slope Survey.

Name	Estimate	Standard error
ln_H_input	0.39	0.33
ln_H_input	-0.25	0.25
beta1_ft	1.40	0.44
beta1_ft	1.97	0.45
beta1_ft	2.08	0.45
beta1_ft	2.24	0.46
beta1_ft	2.26	0.43
L_omega1_z	0.93	0.27
L_epsilon1_z	0.00	0.91
logkappa1	-4.80	0.53
beta2_ft	6.39	0.10
beta2_ft	6.60	0.10
beta2_ft	6.79	0.10
beta2_ft	6.58	0.09
beta2_ft	6.65	0.08
L_omega2_z	-0.55	0.10
L_epsilon2_z	0.80	0.09
logkappa2	-2.41	0.14
logSigmaM	-0.23	0.02

Table C.9. Design-based estimates and their standard errors (se) in log space for the Alaska Fisheries Science Center Slope Survey.

Year	Value	log se
1997	7010.43	0.07
1999	4635.96	0.09
2000	5935.72	0.08
2001	6446.28	0.09

Table C.10. Settings used for the the vector auto-regressive spatiotemporal model used to fit data from the Alaska Fisheries Science Center Slope Survey.

Setting name	Setting used
Number of knots	150
Maximum gradient	0.000005
Is hessian positive definite?	Yes
Was bias correction used?	Yes
Distribution for measurement errors	Gamma
Spatial effect for encounter probability	Yes
Spatio-temporal effect for encounter probability	Yes
Spatial effect for positive catch rate	Yes
Spatio-temporal effect for positive catch rate	Yes

Table C.11. Parameters included in the vector auto-regressive spatiotemporal model used to fit data from the Alaska Fisheries Science Center Slope Survey.

Name	n	Type
beta1_ft	4	Fixed
beta2_ft	4	Fixed
L_epsilon1_z	1	Fixed
L_epsilon2_z	1	Fixed
L_omega1_z	1	Fixed
L_omega2_z	1	Fixed
ln_H_input	2	Fixed
logkappa1	1	Fixed
logkappa2	1	Fixed
logSigmaM	1	Fixed
Epsiloninput1_sft	830	Random
Epsiloninput2_sft	830	Random
Omegainput1_sf	166	Random
Omegainput2_sf	166	Random

Table C.12. Parameter estimates and their standard errors from the vector auto-regressive spatiotemporal model used to fit data from the Alaska Fisheries Science Center Slope Survey.

Name	Estimate	Standard error
ln_H_input	0.74	0.84
ln_H_input	-1.17	1.35
beta1_ft	3.38	0.42
beta1_ft	3.47	0.41
beta1_ft	5.33	1.00
beta1_ft	5.33	1.00
L_omega1_z	0.00	0.22
L_epsilon1_z	0.00	0.26
logkappa1	-5.63	1965.34
beta2_ft	7.17	0.12
beta2_ft	6.71	0.11
beta2_ft	6.92	0.11
beta2_ft	7.03	0.11
L_omega2_z	1.21	0.39
L_epsilon2_z	0.00	0.27
logkappa2	-2.68	0.38
logSigmaM	-0.21	0.03

Table C.13. Design-based estimates and their standard errors (se) in log space for the Triennial Shelf Survey.

Year	Value	log se
1977	20154515.47	0.10
1980	63023847.82	0.39
1983	34232559.25	0.22
1986	33101863.00	0.20
1989	45297218.57	0.30
1992	77261769.12	0.28
1995	23242344.57	0.15
1998	31633971.68	0.16
2001	104693278.72	0.27
2004	94530621.16	0.28

Table C.14. Settings used for the the vector auto-regressive spatiotemporal model used to fit data from the Triennial Shelf Survey.

Setting name	Setting used
Number of knots	250
Maximum gradient	< 1e-06
Is hessian positive definite?	Yes
Was bias correction used?	Yes
Distribution for measurement errors	Gamma
Spatial effect for encounter probability	Yes
Spatio-temporal effect for encounter probability	Yes
Spatial effect for positive catch rate	Yes
Spatio-temporal effect for positive catch rate	Yes

Table C.15. Parameters included in the vector auto-regressive spatiotemporal model used to fit data from the Triennial Shelf Survey.

Name	n	Type
beta1_ft	9	Fixed
beta2_ft	9	Fixed
L_epsilon1_z	1	Fixed
L_epsilon2_z	1	Fixed
L_omega1_z	1	Fixed
L_omega2_z	1	Fixed
ln_H_input	2	Fixed
logkappa1	1	Fixed
logkappa2	1	Fixed
logSigmaM	1	Fixed
Epsiloninput1_sft	6650	Random
Epsiloninput2_sft	6650	Random
Omegainput1_sf	266	Random
Omegainput2_sf	266	Random

Table C.16. Parameter estimates and their standard errors from the vector auto-regressive spatiotemporal model used to fit data from the Triennial Shelf Survey.

Name	Estimate	Standard error
ln_H_input	-0.36	0.11
ln_H_input	-0.38	0.12
beta1_ft	0.35	0.56
beta1_ft	0.85	0.55
beta1_ft	1.68	0.56
beta1_ft	1.03	0.54
beta1_ft	0.66	0.54
beta1_ft	1.14	0.54
beta1_ft	-0.08	0.54
beta1_ft	1.45	0.54
beta1_ft	1.23	0.55
L_omega1_z	-2.70	0.32
L_epsilon1_z	0.88	0.12
logkappa1	-3.63	0.14
beta2_ft	6.53	0.35
beta2_ft	5.88	0.33
beta2_ft	5.73	0.34
beta2_ft	5.44	0.32
beta2_ft	5.64	0.32
beta2_ft	5.54	0.32
beta2_ft	6.16	0.33
beta2_ft	6.74	0.31
beta2_ft	6.70	0.32
L_omega2_z	1.54	0.14
L_epsilon2_z	1.64	0.09
logkappa2	-3.24	0.07
logSigmaM	0.14	0.01

C.2 FIGURES

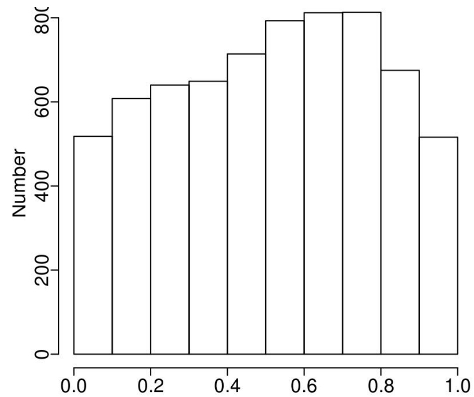


Figure C.1. Predicted quantiles from a gamma distribution binned by encounter probability for the West Coast Groundfish Bottom Trawl Survey.

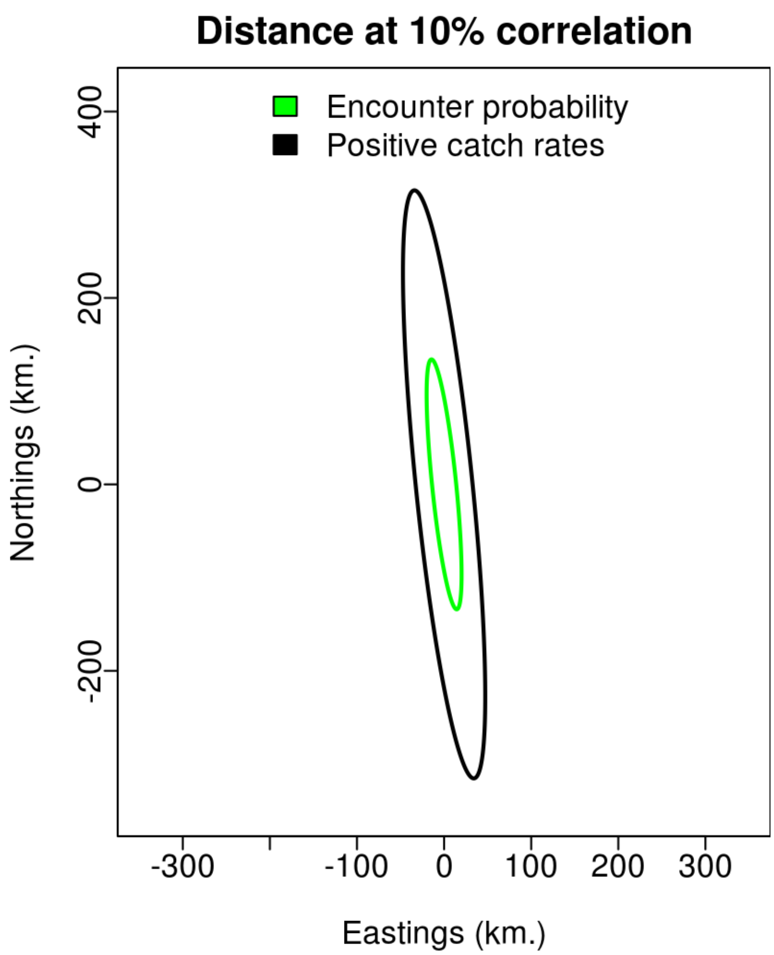


Figure C.2. Aniosotropy for the West Coast Groundfish Bottom Trawl Survey.

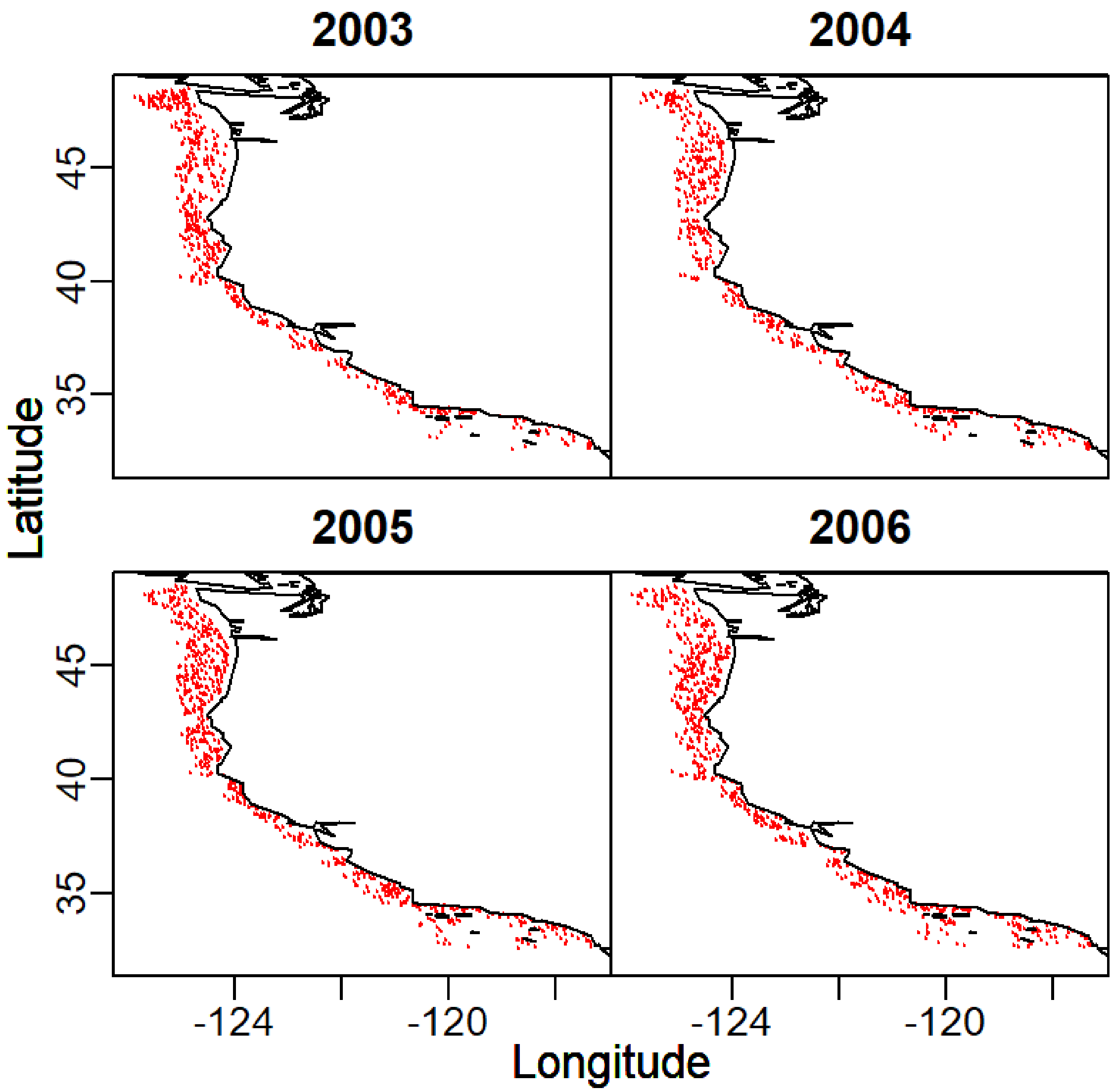


Figure C.3. Sample locations by year for the West Coast Groundfish Bottom Trawl Survey.

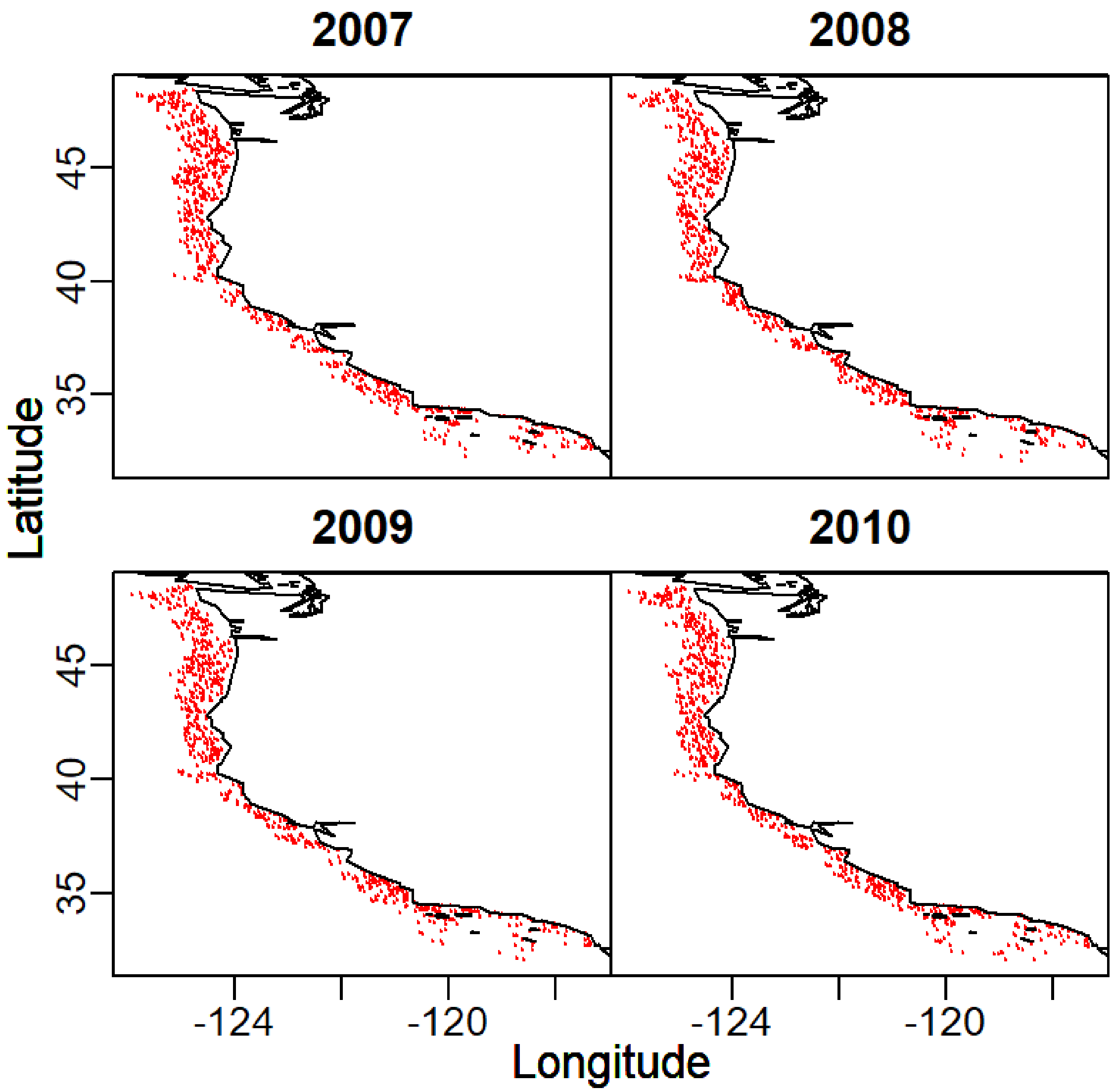


Figure C.4. Sample locations by year for the West Coast Groundfish Bottom Trawl Survey; a continuation of Figure C.3.

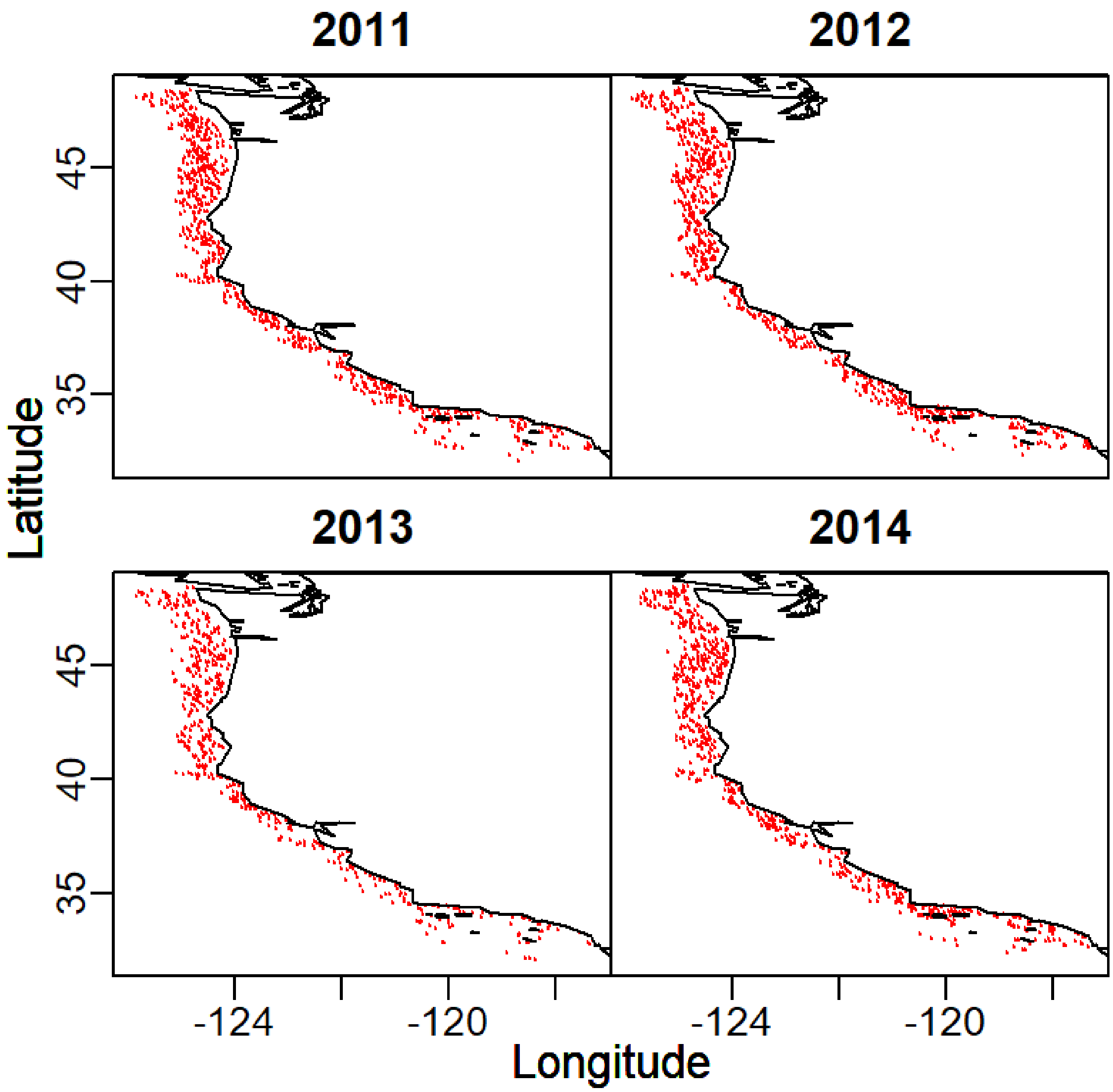


Figure C.5. Sample locations by year for the West Coast Groundfish Bottom Trawl Survey; a continuation of Figure C.4.

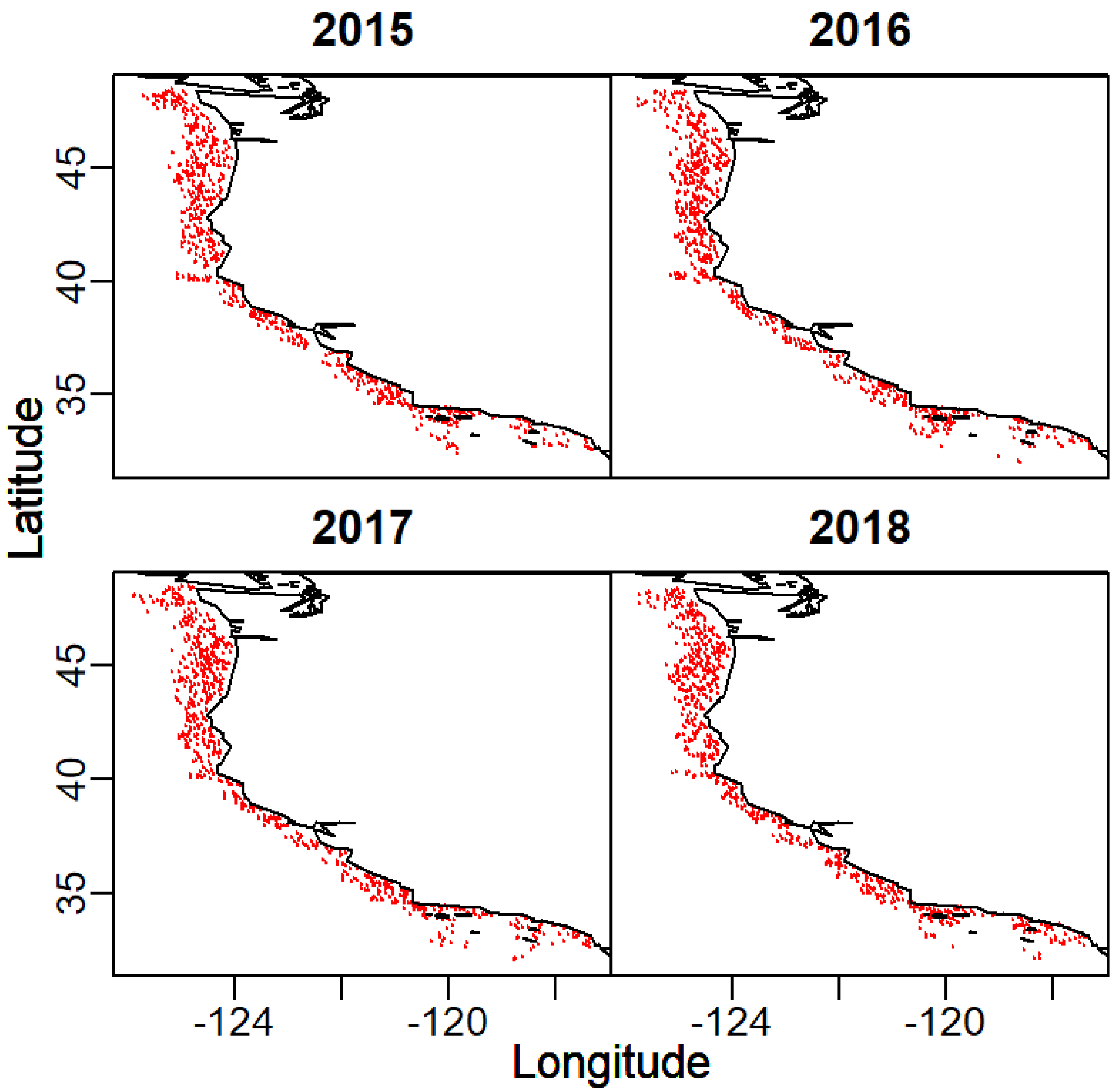


Figure C.6. Sample locations by year for the West Coast Groundfish Bottom Trawl Survey; a continuation of Figure C.5.

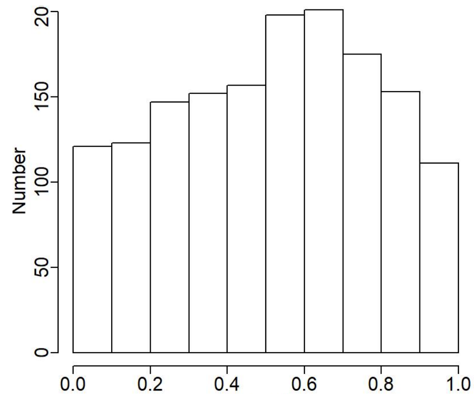


Figure C.7. Predicted quantiles from a gamma distribution binned by encounter probability for the Northwest Fisheries Science Center Slope Survey.

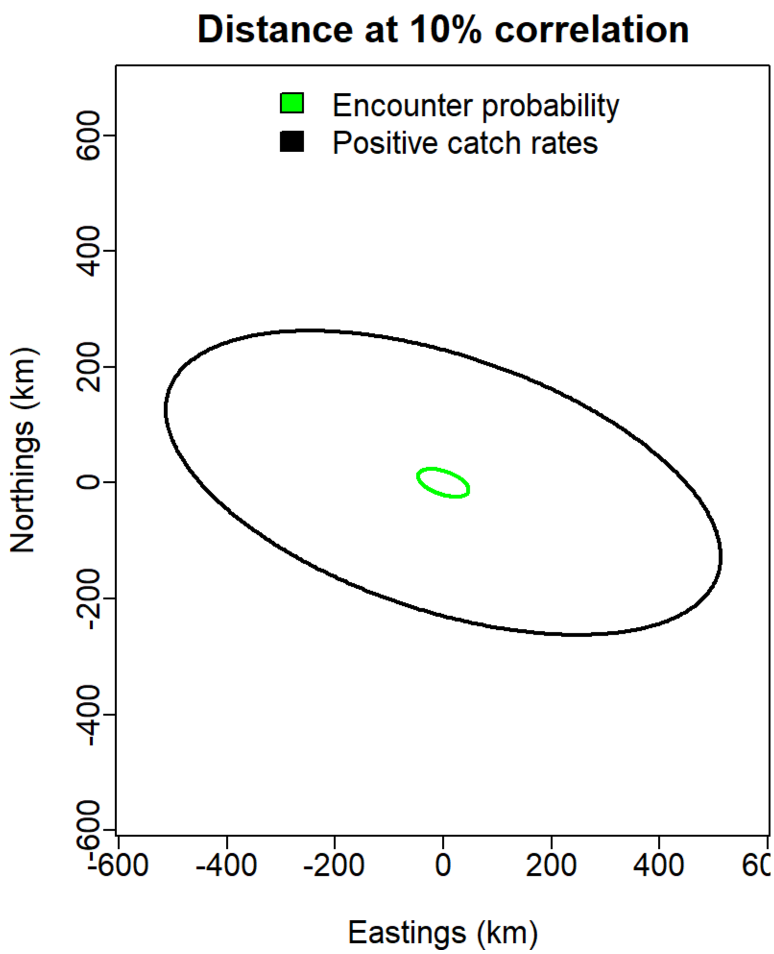


Figure C.8. Aniosotropy for the Northwest Fisheries Science Center Slope Survey.

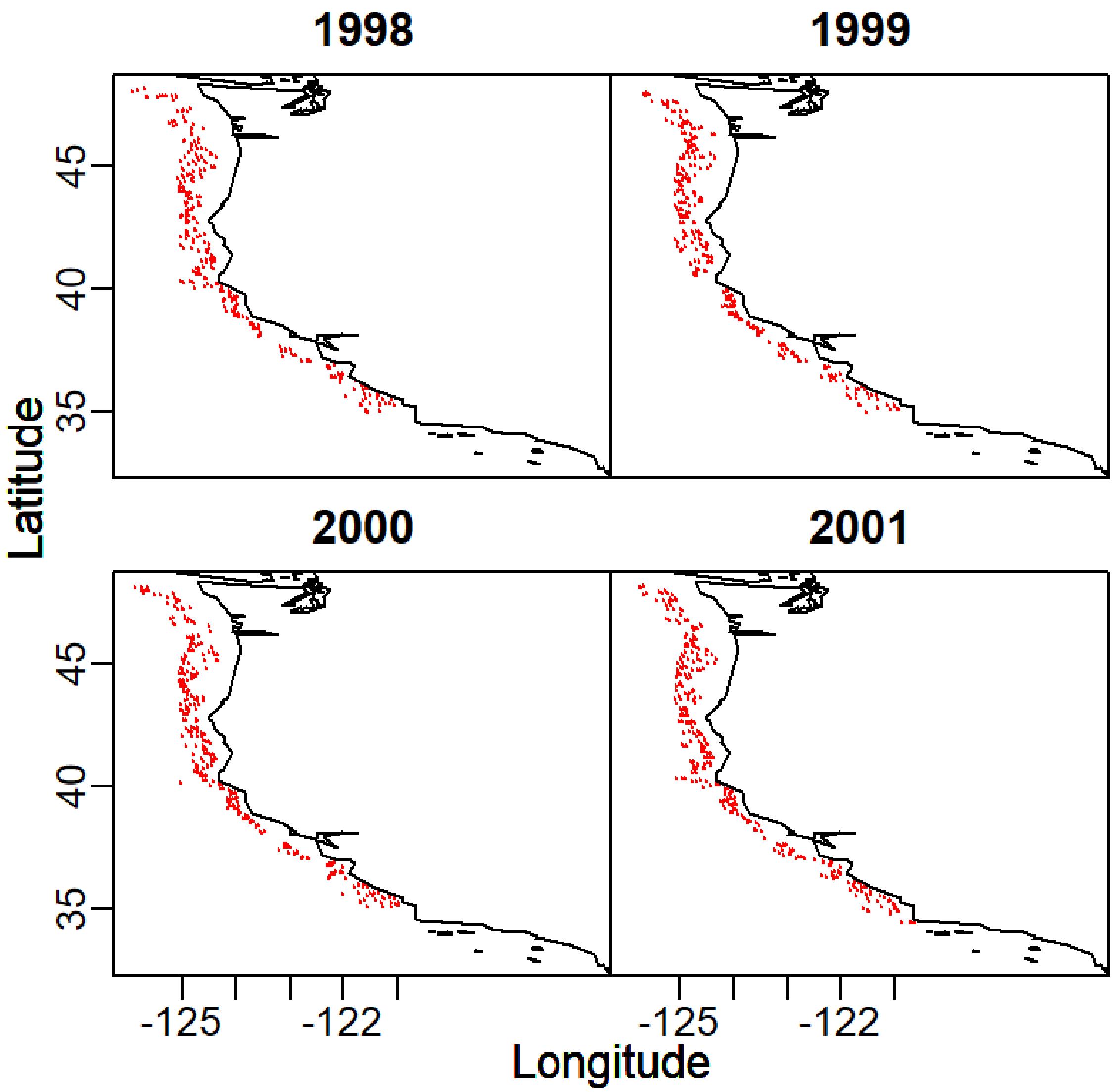


Figure C.9. Sample locations by year for the Northwest Fisheries Science Center Slope Survey.

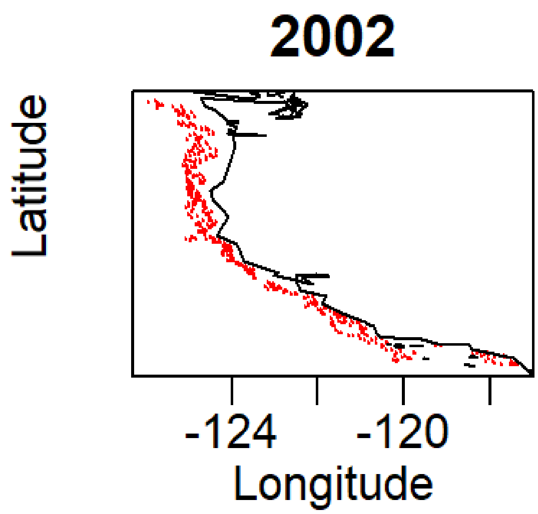


Figure C.10. Sample locations by year for the Northwest Fisheries Science Center Slope Survey; a continuation of Figure C.9.

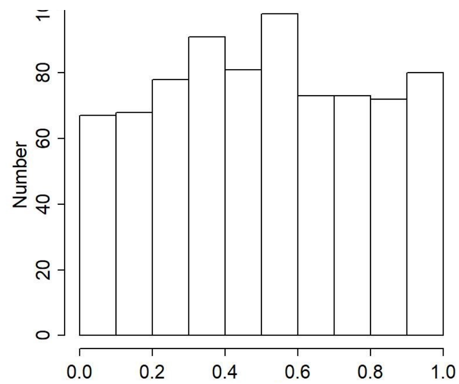


Figure C.11. Predicted quantiles from a gamma distribution binned by encounter probability for the Alaska Fisheries Science Center Slope Survey.

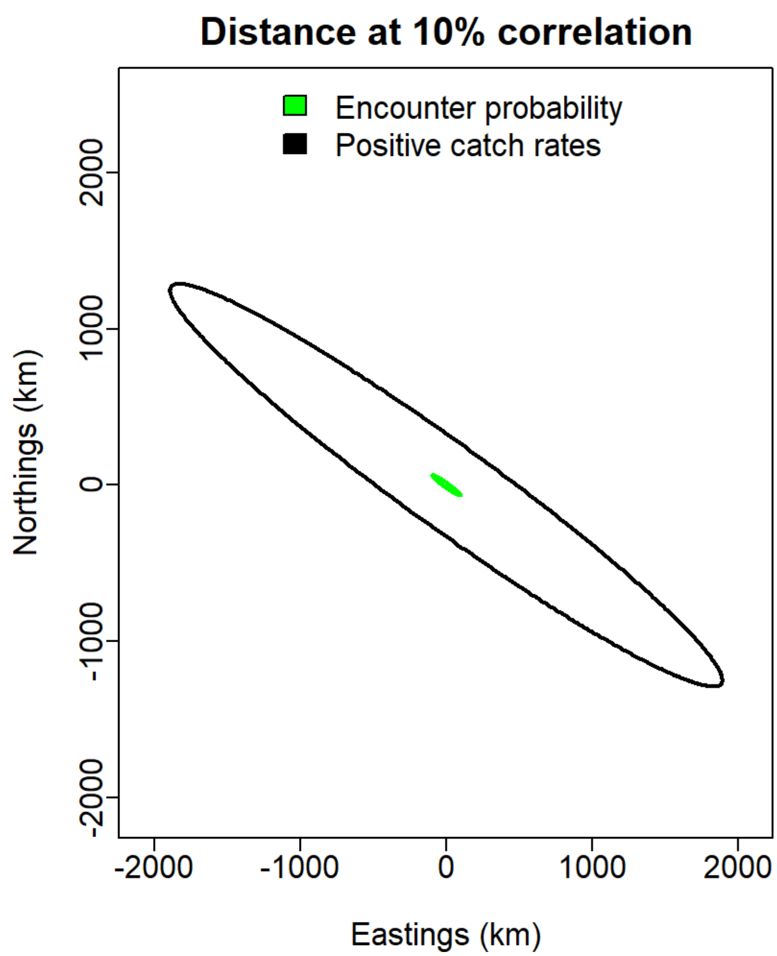


Figure C.12. Aniosotropy for the Alaska Fisheries Science Center Slope Survey.

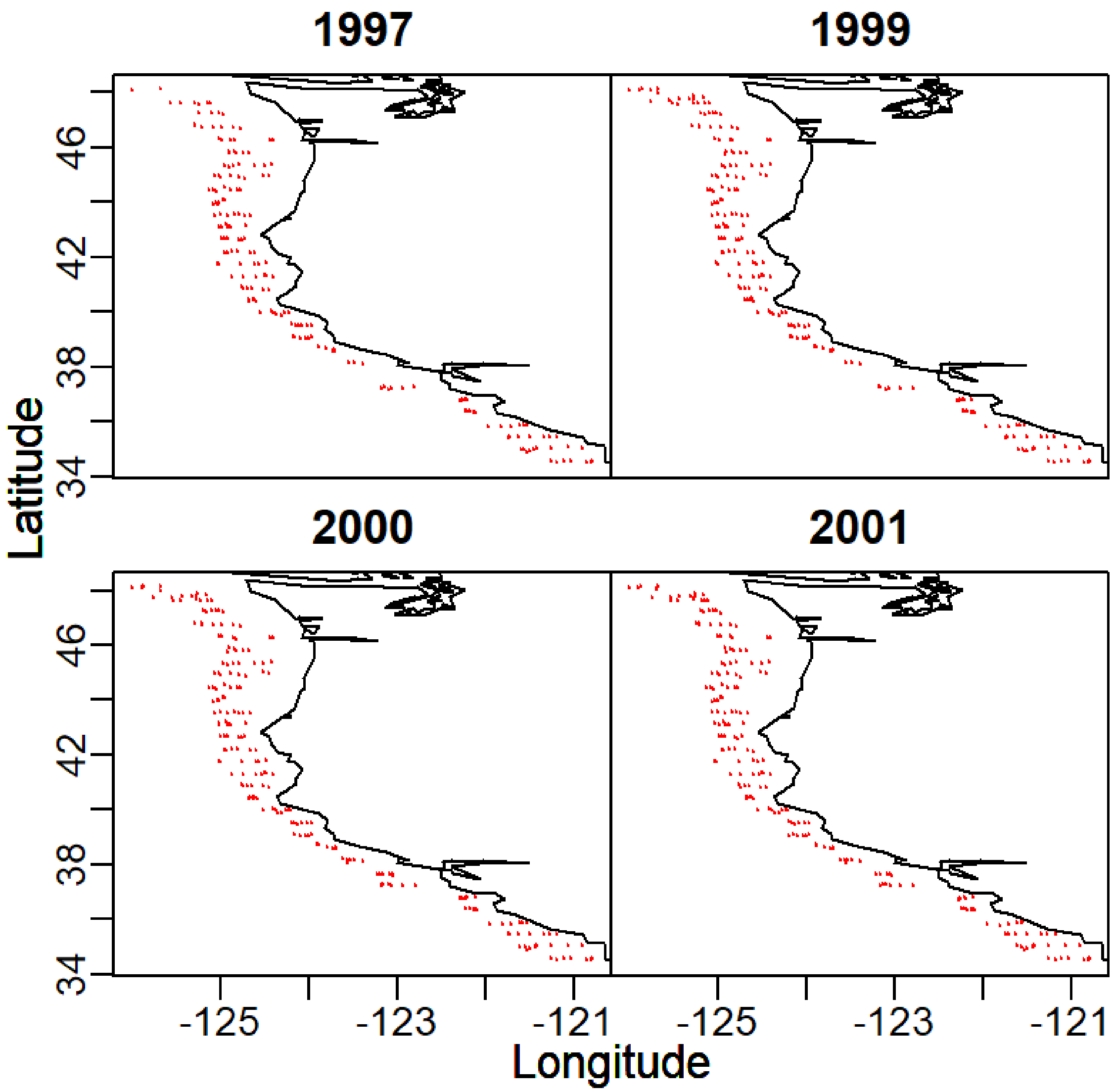


Figure C.13. Sample locations by year for the Alaska Fisheries Science Center Slope Survey.

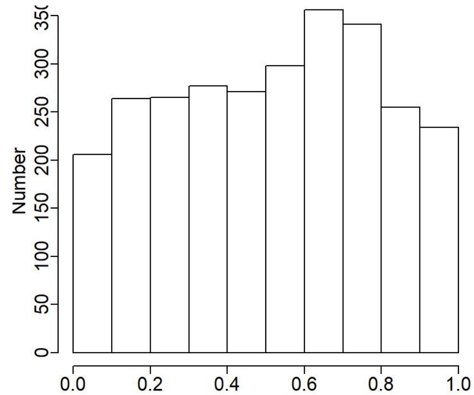


Figure C.14. Predicted quantiles from a gamma distribution binned by encounter probability for the Triennial Shelf Survey.

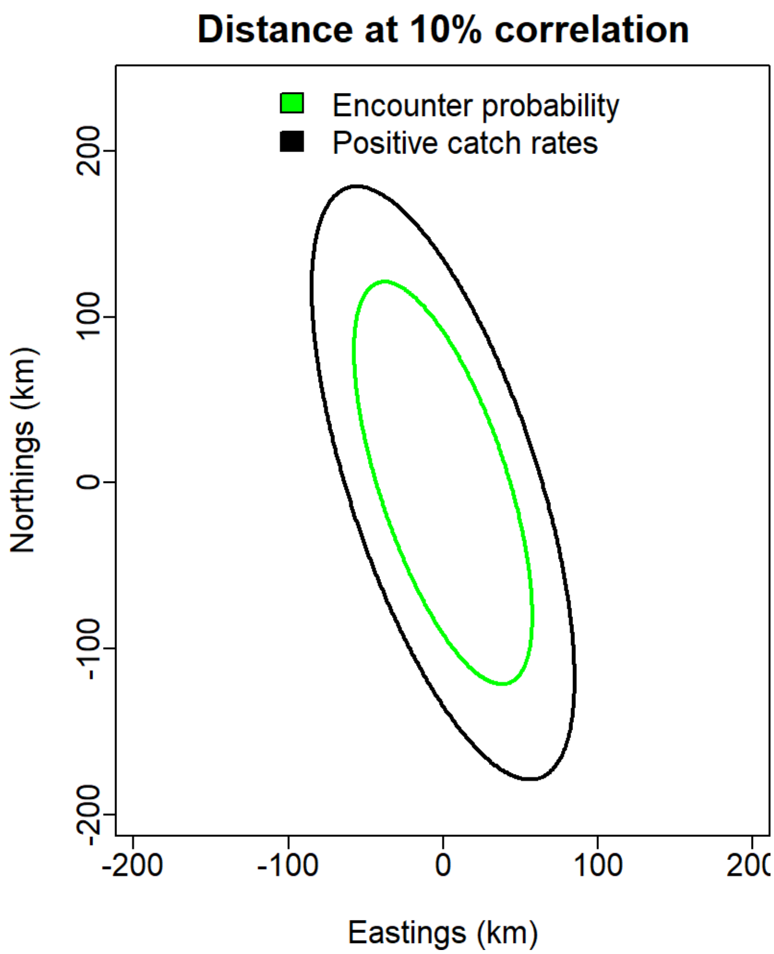


Figure C.15. Aniosotropy for the Triennial Shelf Survey.

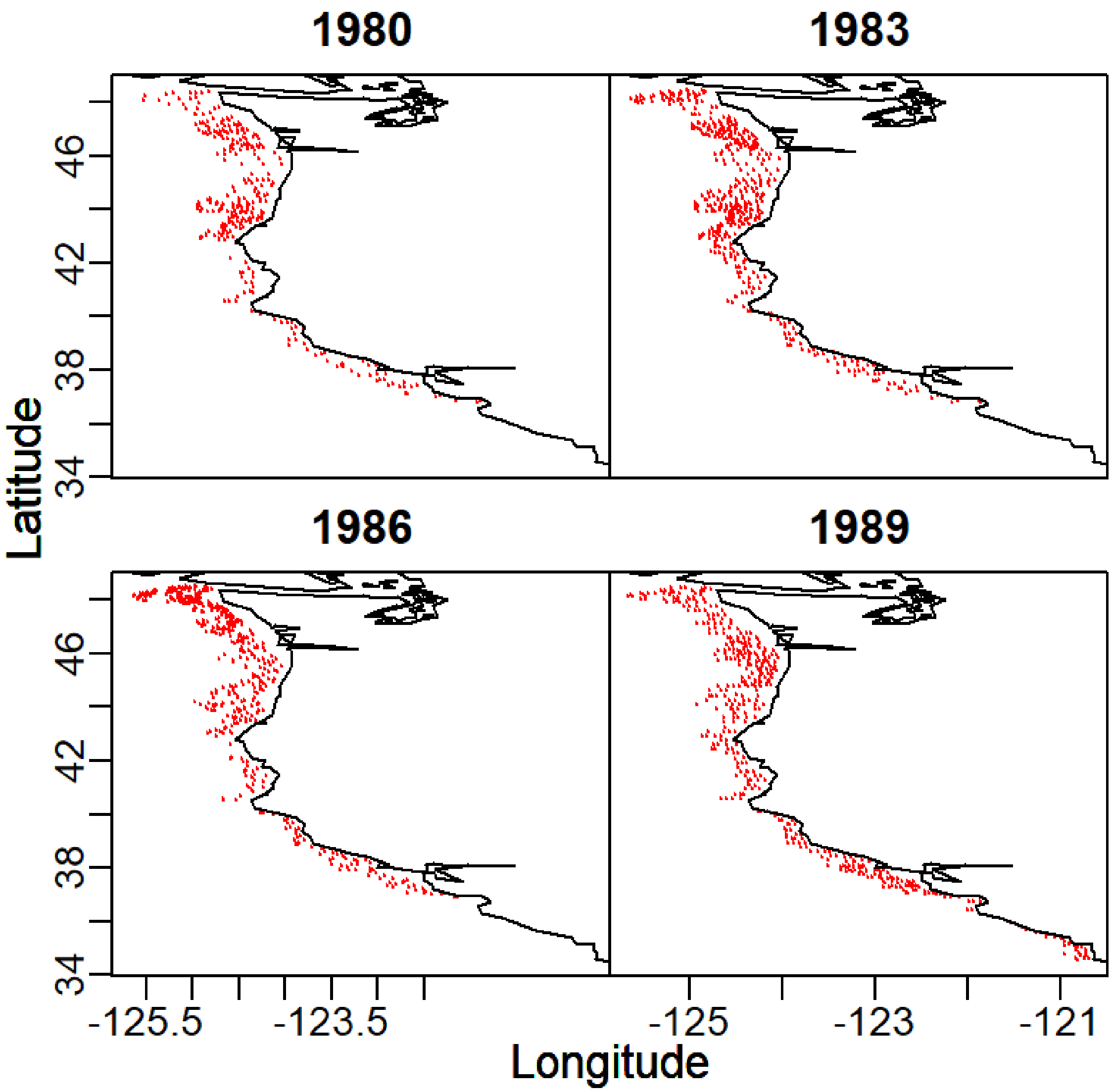


Figure C.16. Sample locations by year for the Triennial Shelf Survey.

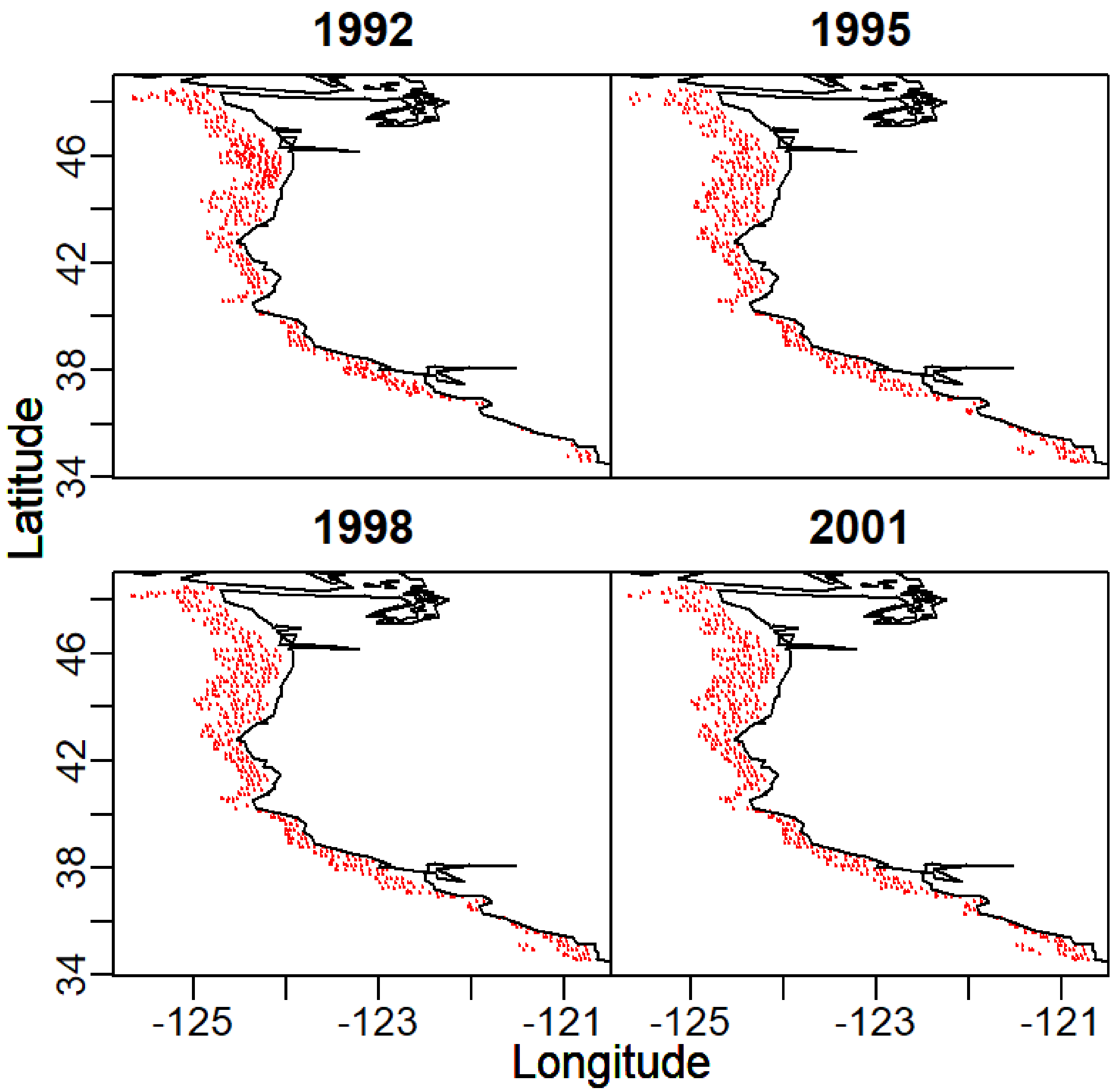


Figure C.17. Sample locations by year for the Triennial Shelf Survey; a continuation of Figure C.16.

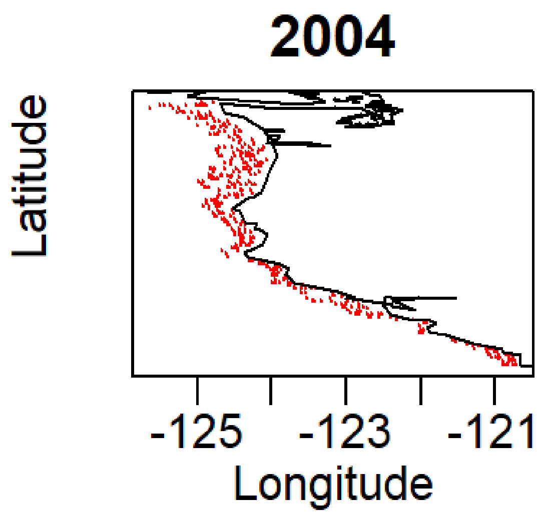


Figure C.18. Sample locations by year for the Triennial Shelf Survey; a continuation of Figure C.17.

D SPATIALLY-EXPLICIT FISHERY COMPOSITION DATA

Fleet-specific age and length compositions for north and south of 36° N latitude are provided for the years in which there are data. Data were pulled from the Pacific Fisheries Information Network's database. Catches specific to the Conception area as defined by the International North Pacific Fisheries Commission (INPFC) areas were removed from the fleet-specific yearly catches used in the base model to determine North and South catches. These catches were then used to weight the area- and fleet-specific composition data in the same manner that catches were weighted for the base model. This weighting was done using the `PacFIN.Utilities` R package. The number of port-side samples and number of fish sampled per year are available in Table 1. Plots of the data by year are available in Figures 2 and 3.

1 Tables

Table 1: Number of port-side samples and number of fish sampled for length and ages north (N) and south (S) of 36 degrees N latitude.

Type	Year	Fleet	N port samples	N fish	S port samples	S fish
Age	1986	Fixed	9	65		
Age	1987	Fixed	104	1091		
Age	1988	Fixed	28	292	1	2
Age	1989	Fixed	32	284		
Age	1990	Fixed	19	180		
Age	1991	Fixed	24	571		
Age	1993	Fixed	8	170		
Age	1994	Fixed	8	168		
Age	1995	Fixed	18	318		
Age	1996	Fixed	44	862		
Age	1997	Fixed	76	1569		
Age	1998	Fixed	15	291		
Age	1999	Fixed	54	1060		
Age	2000	Fixed	44	780		
Age	2001	Fixed	63	790		
Age	2002	Fixed	36	588		
Age	2003	Fixed	25	446		
Age	2004	Fixed	17	242		
Age	2005	Fixed	53	872		
Age	2006	Fixed	37	853		
Age	2007	Fixed	97	1865		
Age	2008	Fixed	10	449		
Age	2009	Fixed	58	1351		
Age	2010	Fixed	56	1201		
Age	2011	Fixed	45	937		
Age	2012	Fixed	82	972		
Age	2013	Fixed	40	1152		
Age	2014	Fixed	1	45		
Age	2016	Fixed	153	537		
Age	2017	Fixed	113	945		
Age	2018	Fixed	120	542		
Age	1986	Trawl	102	847	12	110
Age	1987	Trawl	149	2359	7	171
Age	1988	Trawl	85	1334	9	133
Age	1989	Trawl	77	1150	6	91

Continued on next page.

Table 1: Number of port-side samples and number of fish sampled for length and ages north (N) and south (S) of 36 degrees N latitude.

Type	Year	Fleet	N port samples	N fish	S port samples	S fish
Age	1990	Trawl	72	1014	8	125
Age	1991	Trawl	54	1679	4	109
Age	1992	Trawl	14	694		
Age	1993	Trawl	31	757	3	61
Age	1994	Trawl	26	555	4	103
Age	1995	Trawl	21	366	5	78
Age	1996	Trawl	36	771	9	246
Age	1997	Trawl	75	1598	10	248
Age	1998	Trawl	23	466	3	72
Age	1999	Trawl	32	699		
Age	2000	Trawl	69	1431		
Age	2001	Trawl	75	1284	2	35
Age	2002	Trawl	28	611	1	22
Age	2003	Trawl	29	685		
Age	2004	Trawl	36	825		
Age	2005	Trawl	57	1176		
Age	2006	Trawl	77	1509		
Age	2007	Trawl	82	1604		
Age	2008	Trawl	8	161		
Age	2009	Trawl	36	920		
Age	2010	Trawl	36	865		
Age	2011	Trawl	29	777		
Age	2012	Trawl	4	72		
Age	2013	Trawl	33	870		
Age	2014	Trawl	47	851		
Age	2016	Trawl	55	290		
Age	2017	Trawl	57	510		
Age	2018	Trawl	67	210		
Length	1970	Fixed	1	365		
Length	1980	Fixed	5	500		
Length	1981	Fixed	1	100		
Length	1983	Fixed	15	1448		
Length	1986	Fixed	26	513		
Length	1987	Fixed	119	2487		
Length	1988	Fixed	47	1178	1	13

Continued on next page.

Table 1: Number of port-side samples and number of fish sampled for length and ages north (N) and south (S) of 36 degrees N latitude.

Type	Year	Fleet	N port samples	N fish	S port samples	S fish
Length	1989	Fixed	76	2238		
Length	1990	Fixed	58	1500		
Length	1991	Fixed	66	1947		
Length	1992	Fixed	21	1069		
Length	1993	Fixed	202	5288		
Length	1994	Fixed	171	4592		
Length	1995	Fixed	170	4505	1	21
Length	1996	Fixed	113	3025		
Length	1997	Fixed	191	4376	1	3
Length	1998	Fixed	65	1253		
Length	1999	Fixed	83	1623		
Length	1999	Fixed	219	4708	32	634
Length	2000	Fixed	156	3081	10	170
Length	2001	Fixed	110	2169	1	26
Length	2002	Fixed	152	3251	23	762
Length	2003	Fixed	124	2626	23	768
Length	2005	Fixed	178	3401	19	342
Length	2006	Fixed	255	5771	27	348
Length	2007	Fixed	191	4215	24	358
Length	2008	Fixed	276	7289	91	1662
Length	2009	Fixed	294	5785	108	1971
Length	2010	Fixed	275	6250	116	2301
Length	2011	Fixed	319	9210	91	1472
Length	2012	Fixed	403	9488	78	1333
Length	2013	Fixed	305	7192	102	1571
Length	2014	Fixed	366	8867	112	2350
Length	2015	Fixed	462	10121	163	3212
Length	2016	Fixed	336	10124	163	3632
Length	2017	Fixed	304	9130	94	2242
Length	2018	Fixed	349	9684	64	1405
Length	1974	Trawl	1	133		
Length	1975	Trawl	1	241		
Length	1977	Trawl	1	348		
Length	1978	Trawl	20	947		
Length	1979	Trawl	6	6		

Continued on next page.

Table 1: Number of port-side samples and number of fish sampled for length and ages north (N) and south (S) of 36 degrees N latitude.

Type	Year	Fleet	N port samples	N fish	S port samples	S fish
Length	1980	Trawl	62	3424		
Length	1981	Trawl	42	2439		
Length	1983	Trawl	8	800		
Length	1984	Trawl	1	100		
Length	1985	Trawl	2	2		
Length	1986	Trawl	124	3337	12	361
Length	1987	Trawl	167	4859	8	226
Length	1988	Trawl	113	3541	10	305
Length	1989	Trawl	148	4463	11	344
Length	1990	Trawl	162	4602	13	397
Length	1991	Trawl	155	4625	13	391
Length	1992	Trawl	18	963		
Length	1993	Trawl	174	4696	8	225
Length	1994	Trawl	143	4094	12	361
Length	1995	Trawl	134	3977	9	262
Length	1996	Trawl	108	3274	11	304
Length	1997	Trawl	132	3354	10	252
Length	1998	Trawl	98	1993	11	281
Length	1999	Trawl	134	2983	8	201
Length	2000	Trawl	148	3652	4	86
Length	2001	Trawl	133	3384	15	488
Length	2002	Trawl	134	3610	12	304
Length	2003	Trawl	145	3533	17	383
Length	2004	Trawl	124	3415	7	257
Length	2005	Trawl	144	3289	7	235
Length	2006	Trawl	167	3518	6	147
Length	2007	Trawl	174	3884	2	36
Length	2008	Trawl	150	3392	7	181
Length	2009	Trawl	120	2782	1	26
Length	2010	Trawl	120	3349		
Length	2011	Trawl	110	2973	1	42
Length	2012	Trawl	135	3622		
Length	2013	Trawl	148	3896		
Length	2014	Trawl	141	3546		
Length	2015	Trawl	127	3933		

Continued on next page.

Table 1: Number of port-side samples and number of fish sampled for length and ages north (N) and south (S) of 36 degrees N latitude.

Type	Year	Fleet	N port samples	N fish	S port samples	S fish
Length	2016	Trawl	118	3833		
Length	2017	Trawl	129	3759		
Length	2018	Trawl	115	2641		

2 Figures

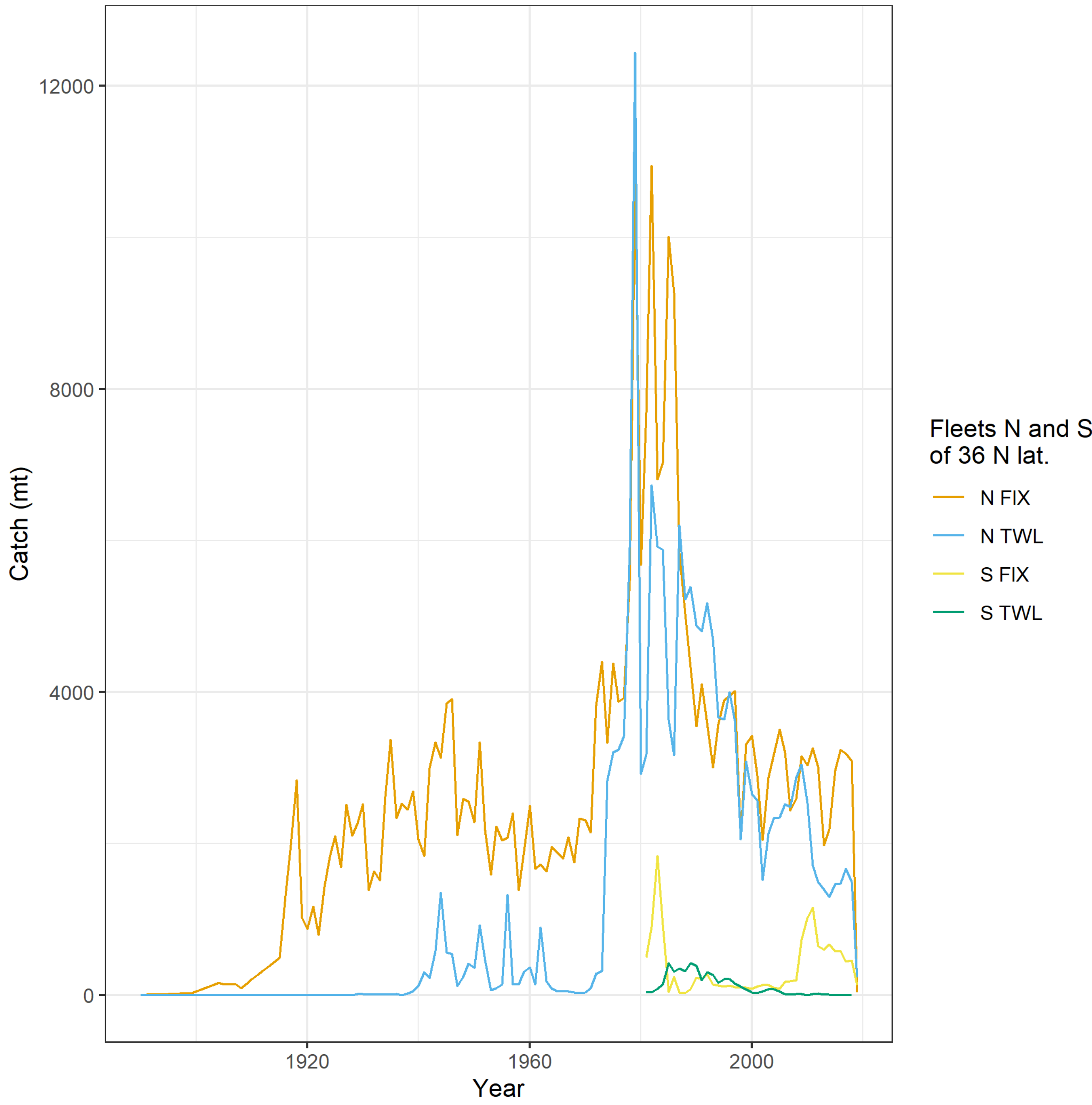


Figure 1: Catches (mt) north and south of 36° N latitude for fixed gear and trawl.

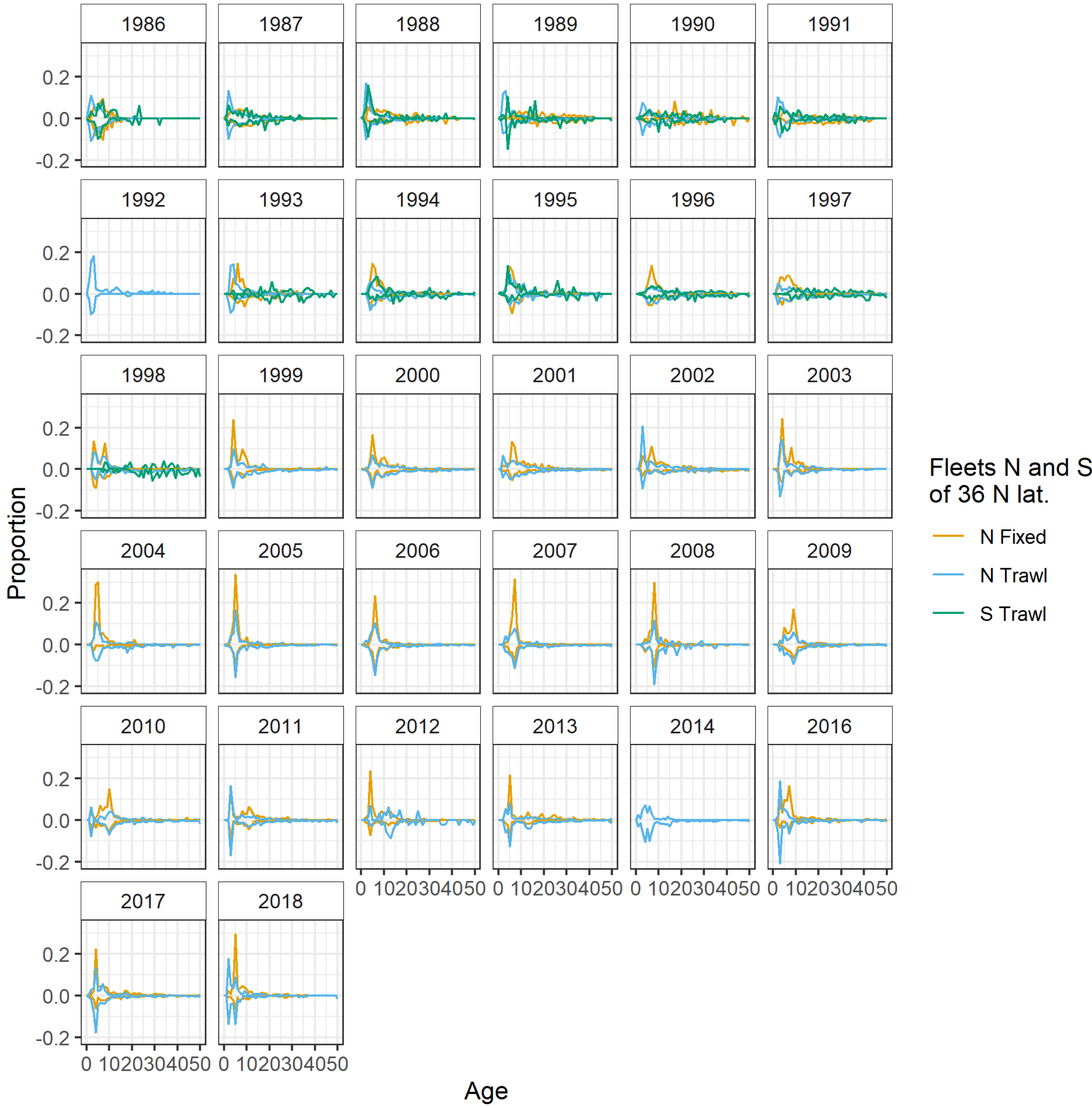


Figure 2: Age-composition data for the two fleets, fixed gear and trawl, north and south of 36° N latitude. Female compositions are shown as positive values and male compositions are shown as negative values.

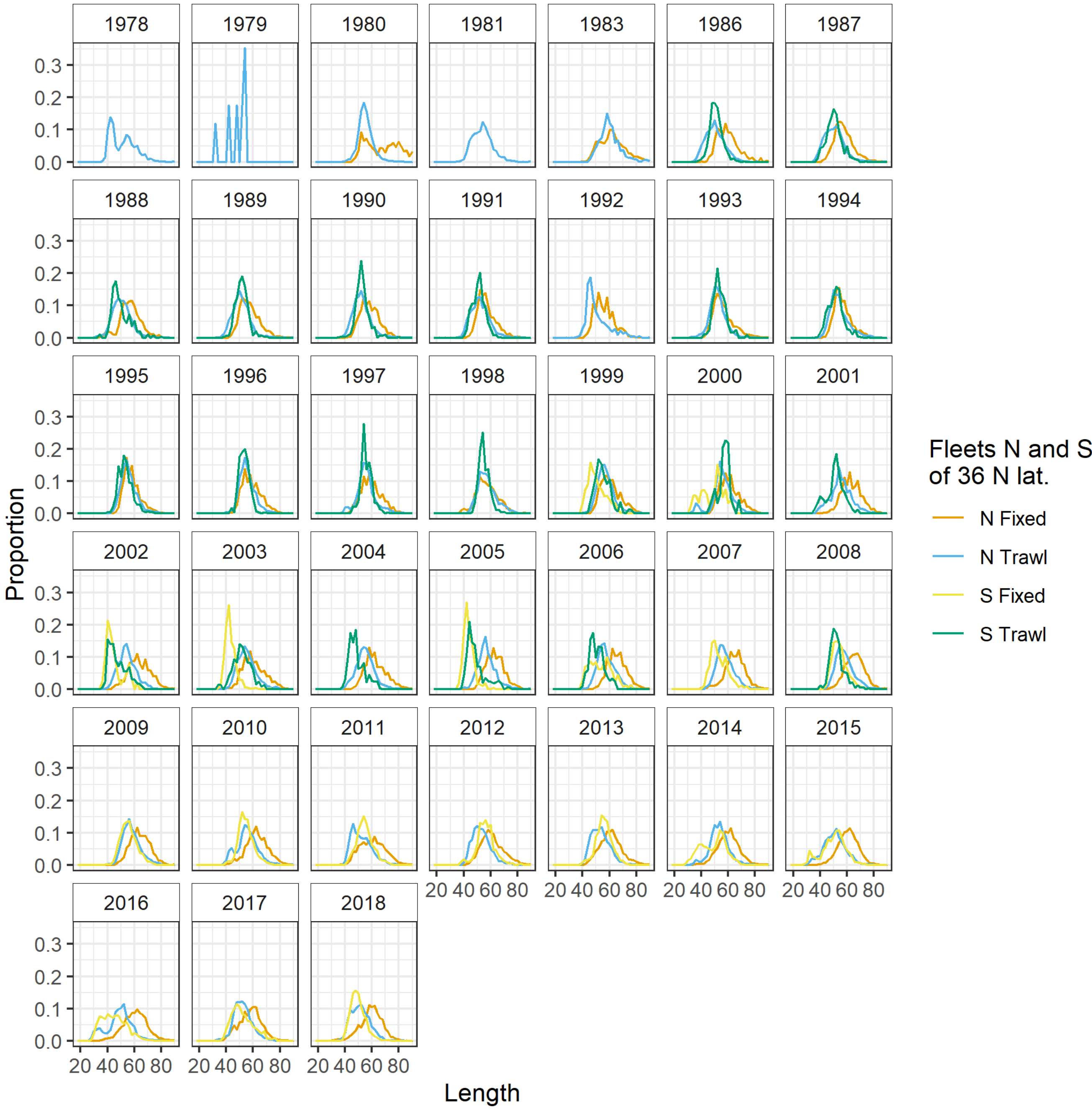
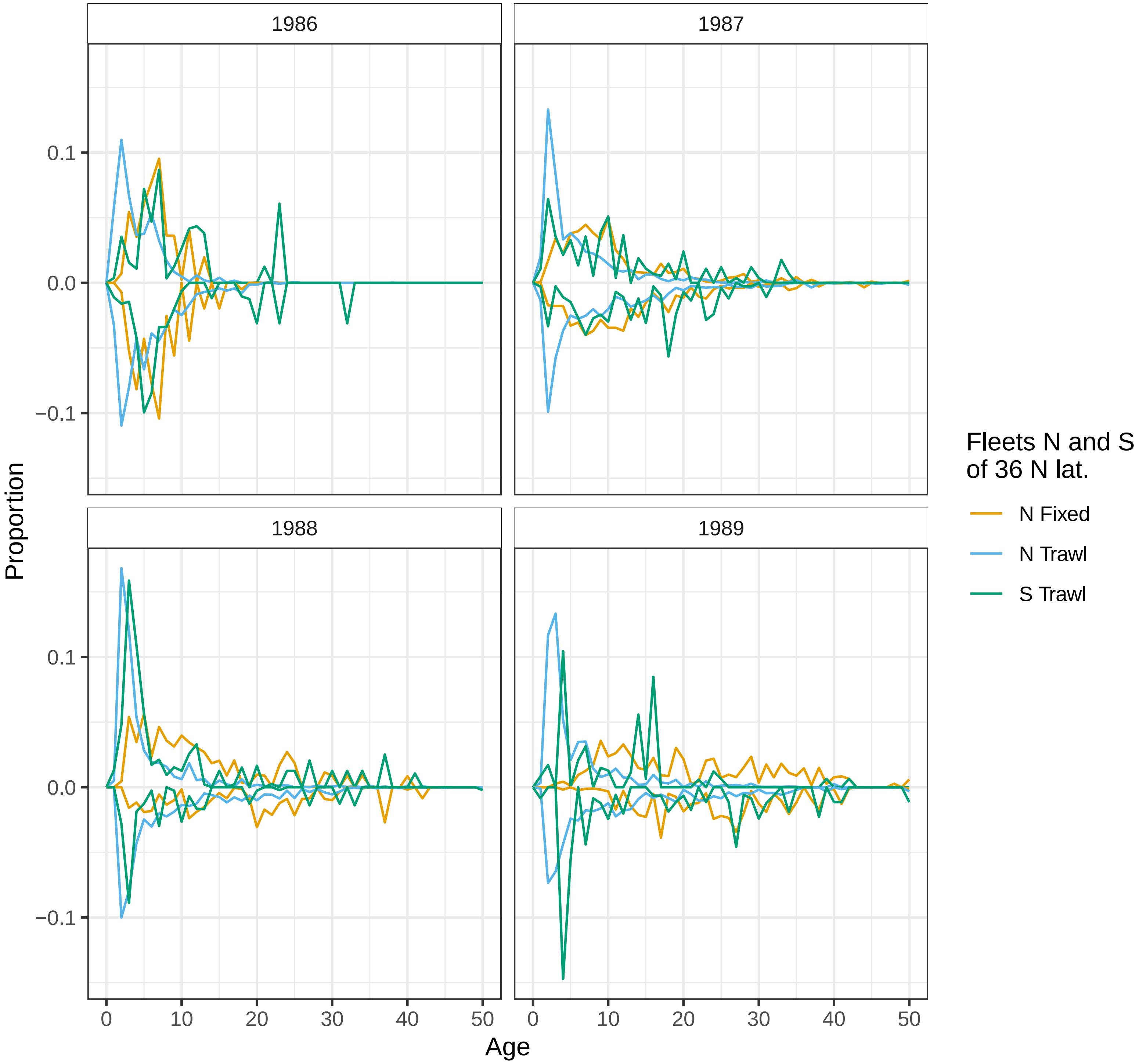
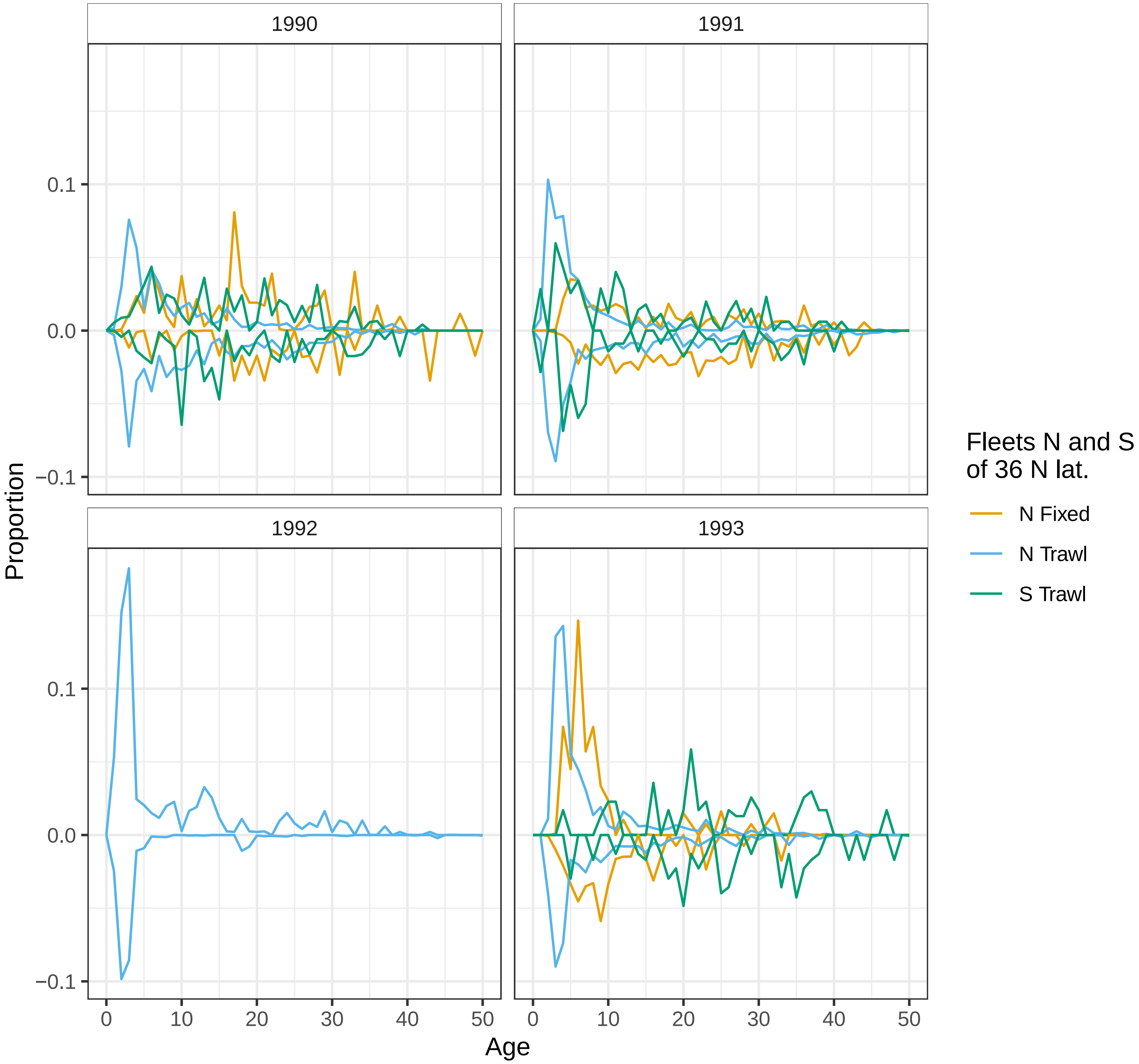


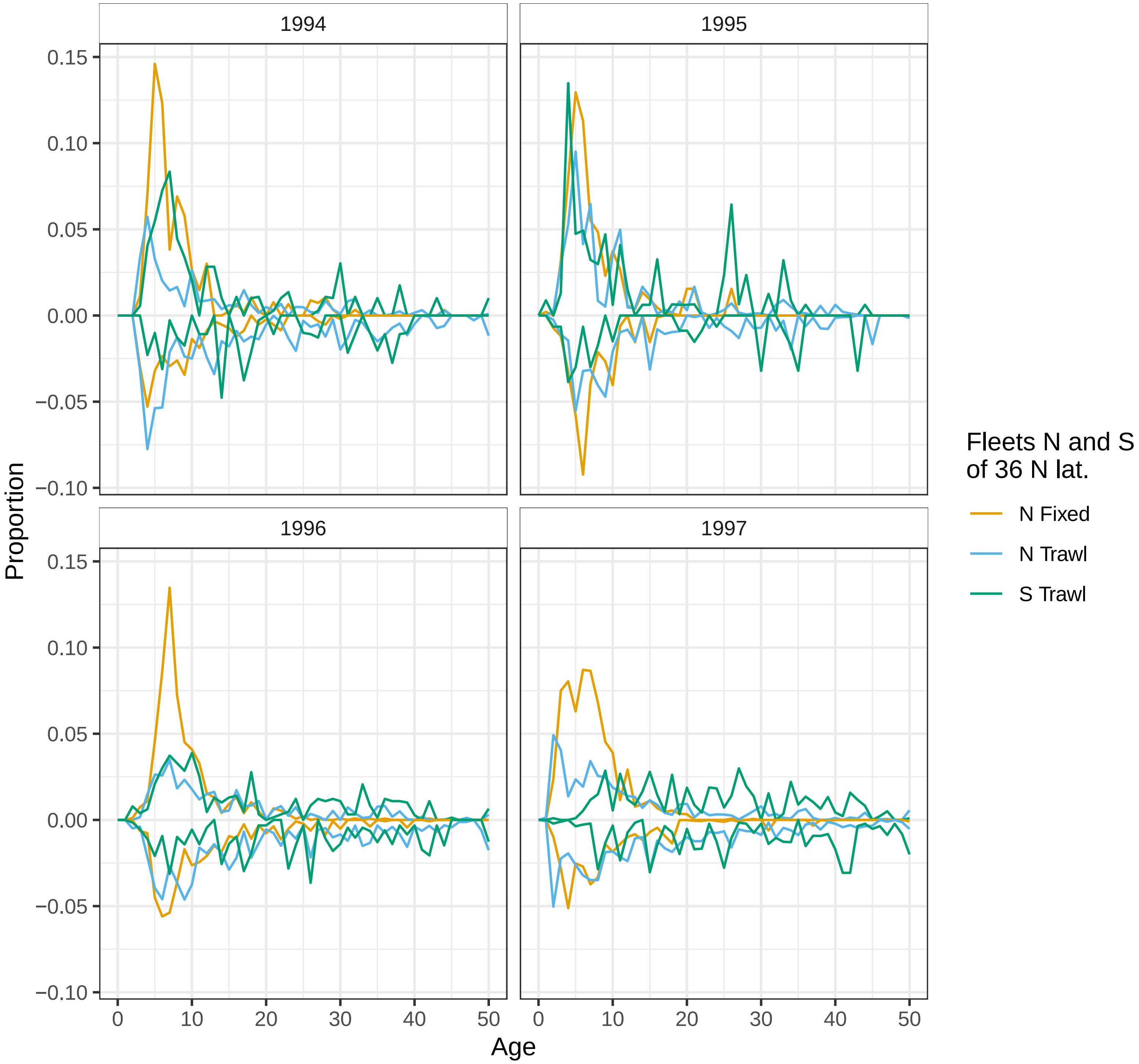
Figure 3: Length-composition data for the two fleets, fixed gear and trawl, north and south of 36° N latitude.

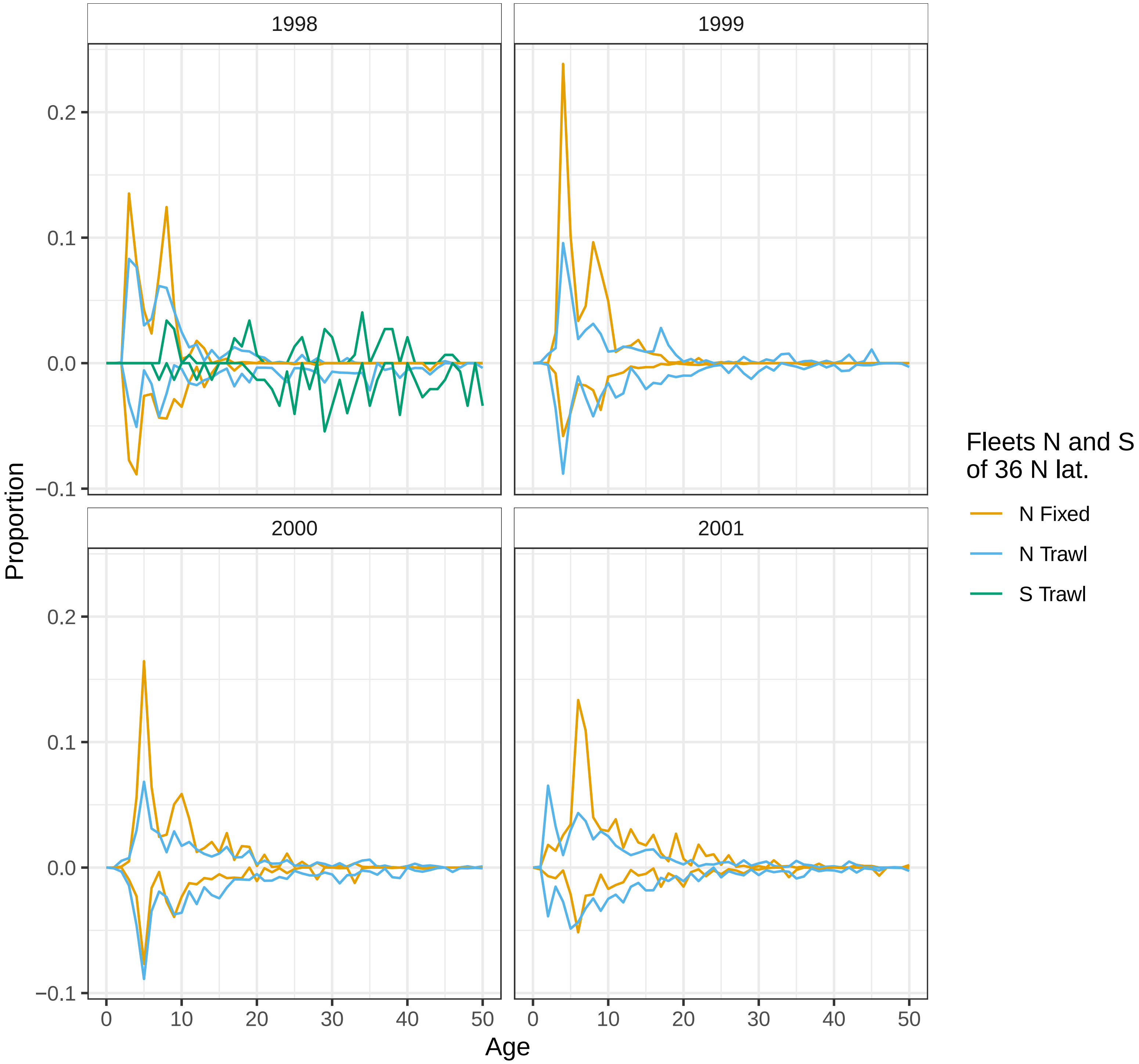
2.1 Year-specific age compositions

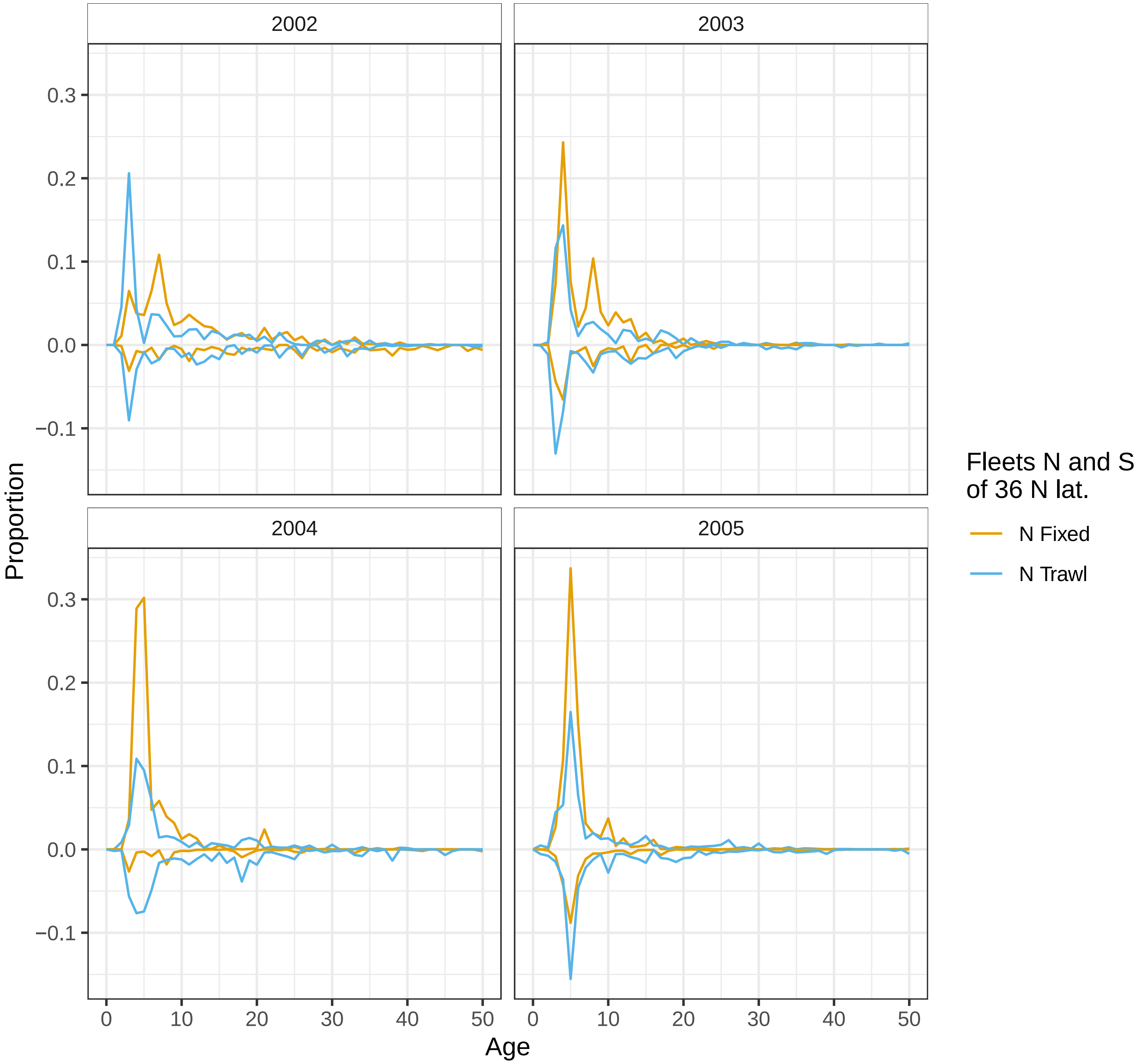


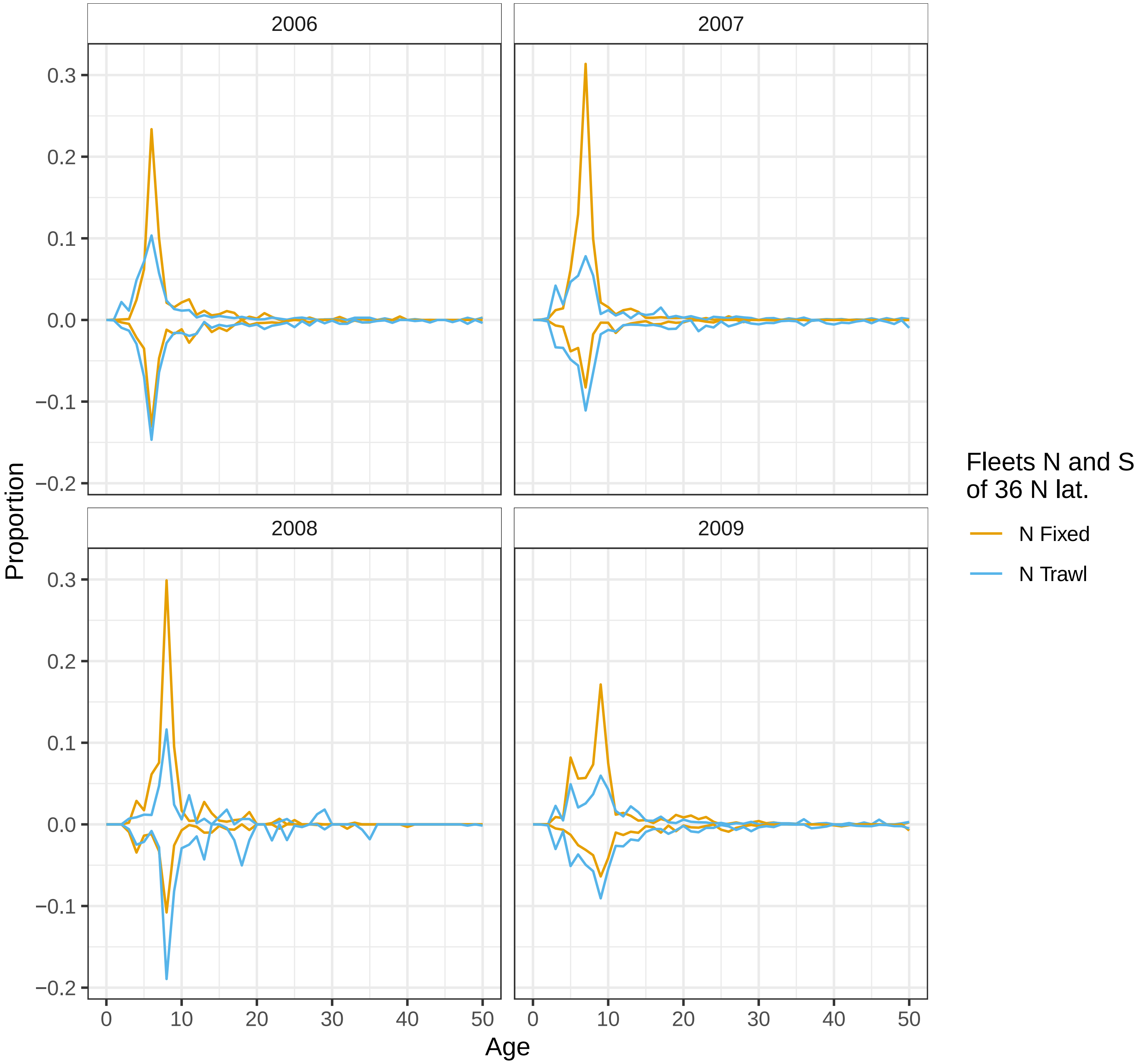
1986
1987
1988
1989
Proportion
0.1
0.0
−0.1
0
10
20
30
40
50
Age
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl

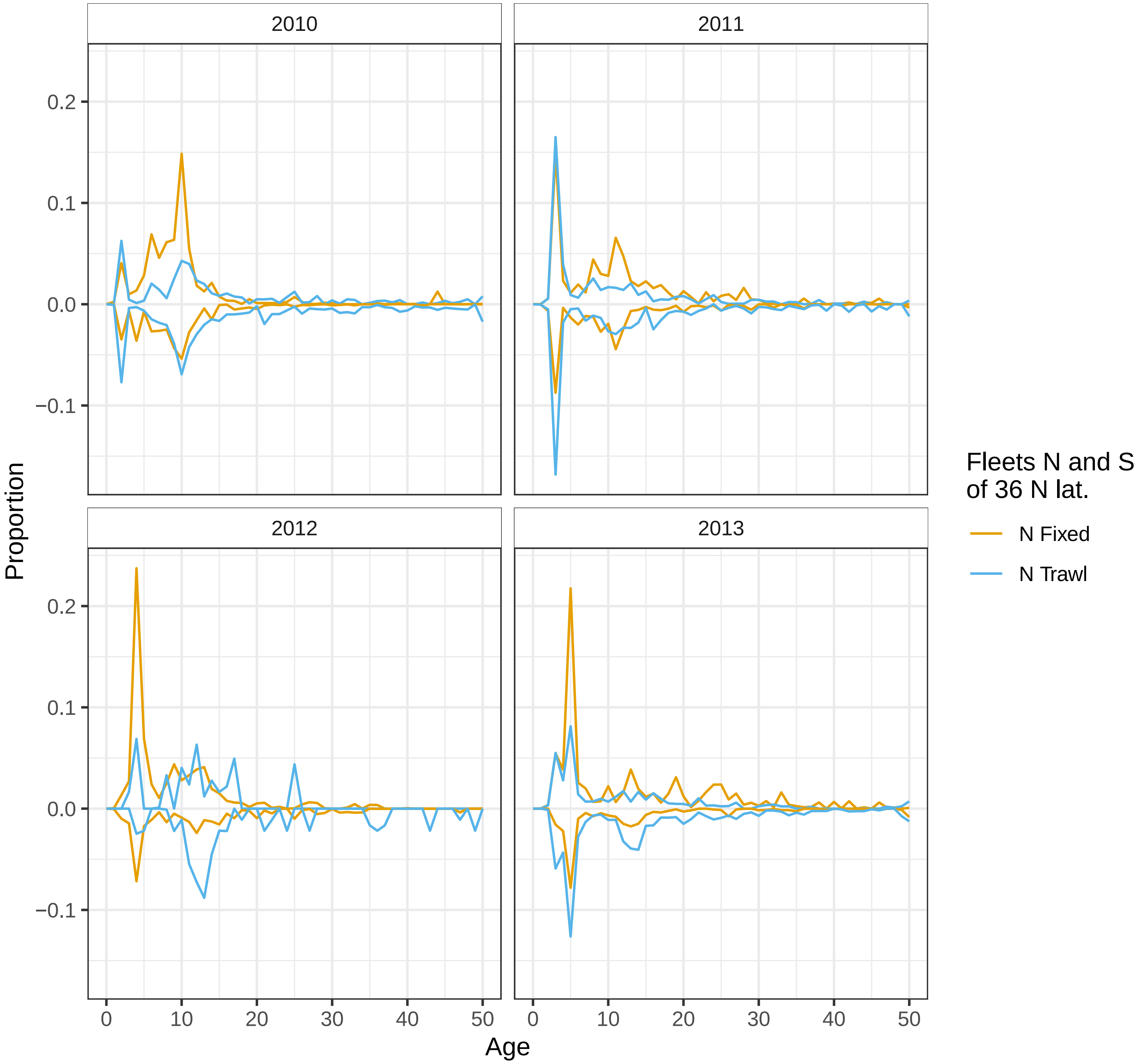

1990
1991
1992
1993
0.1
0.0
−0.1
Proportion
0
10
20
30
40
50
Age
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl

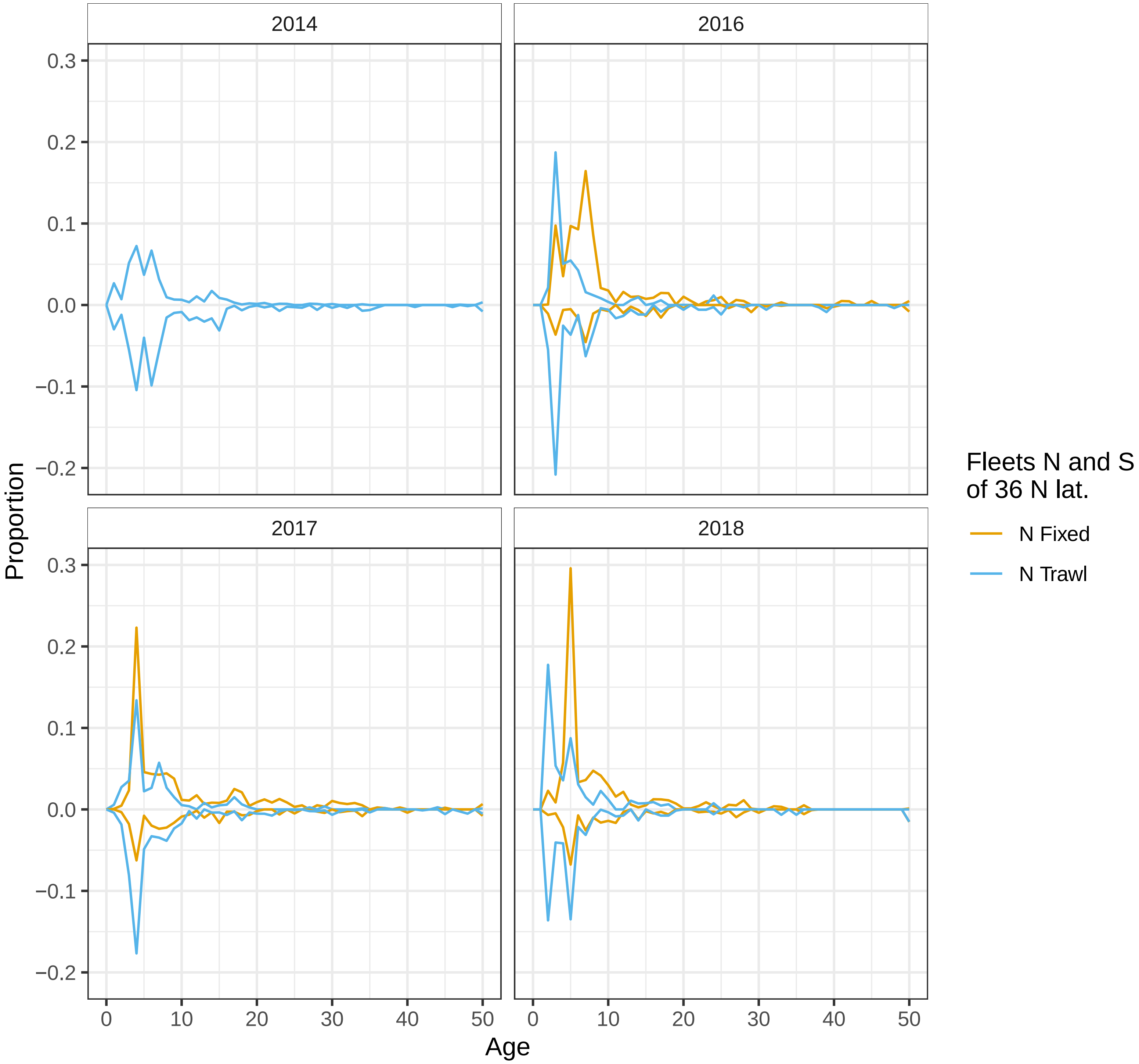

1994
1995
1996
1997
Proportion
0.15
0.10
0.05
0.00
−0.05
−0.10
Age
0
10
20
30
40
50
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl


1998
1999
2000
2001
Proportion
0.2
0.1
0.0
−0.1
Age
0
10
20
30
40
50
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl

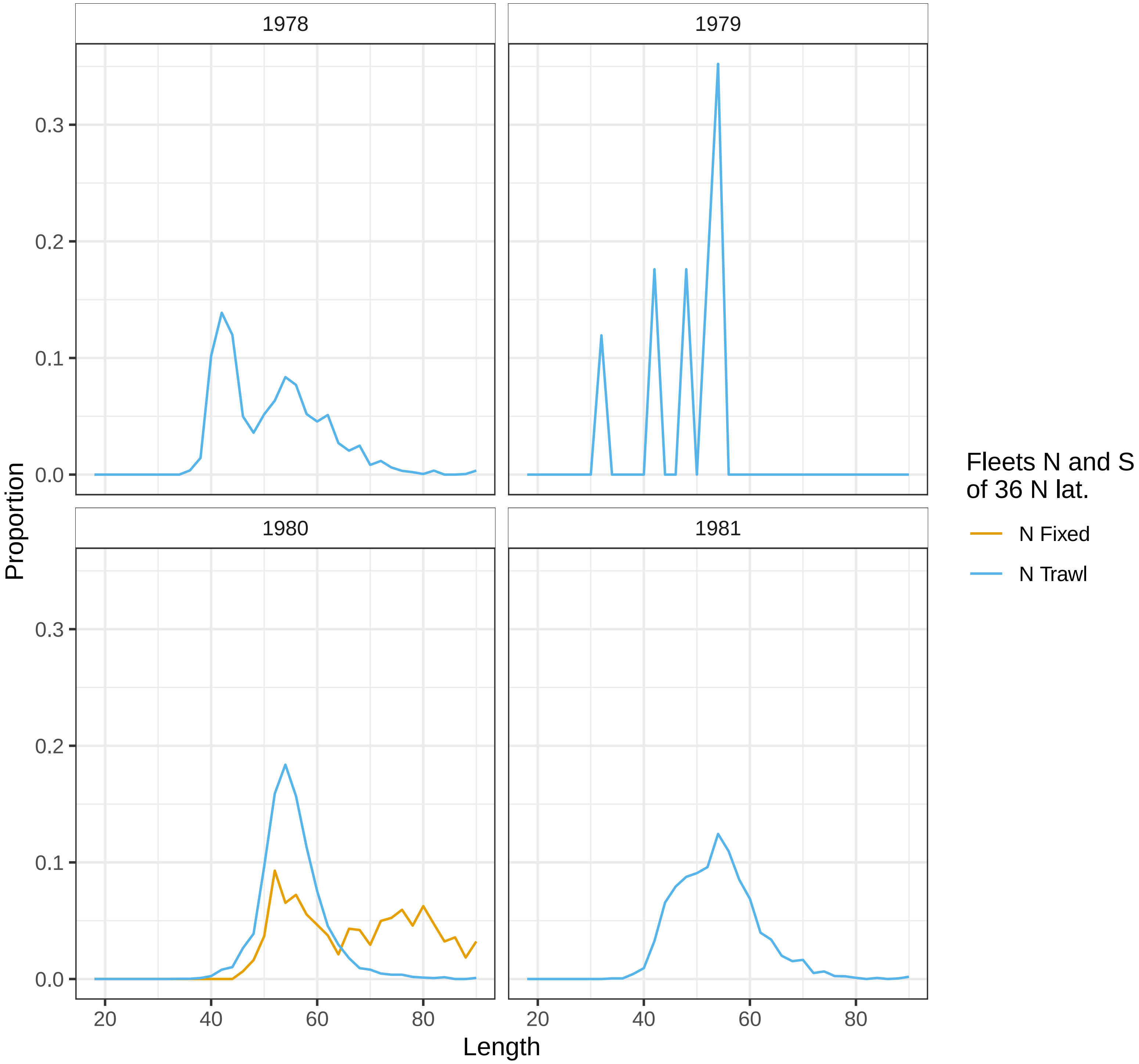

2002
2003
2004
2005
Proportion
Age
0.3
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
Fleets N and S of 36 N lat.
N Fixed
N Trawl


2006
2007
2008
2009
Proportion
Age
0.3
0.2
0.1
0.0
−0.1
−0.2
0
10
20
30
40
50
Fleets N and S of 36 N lat.
N Fixed
N Trawl

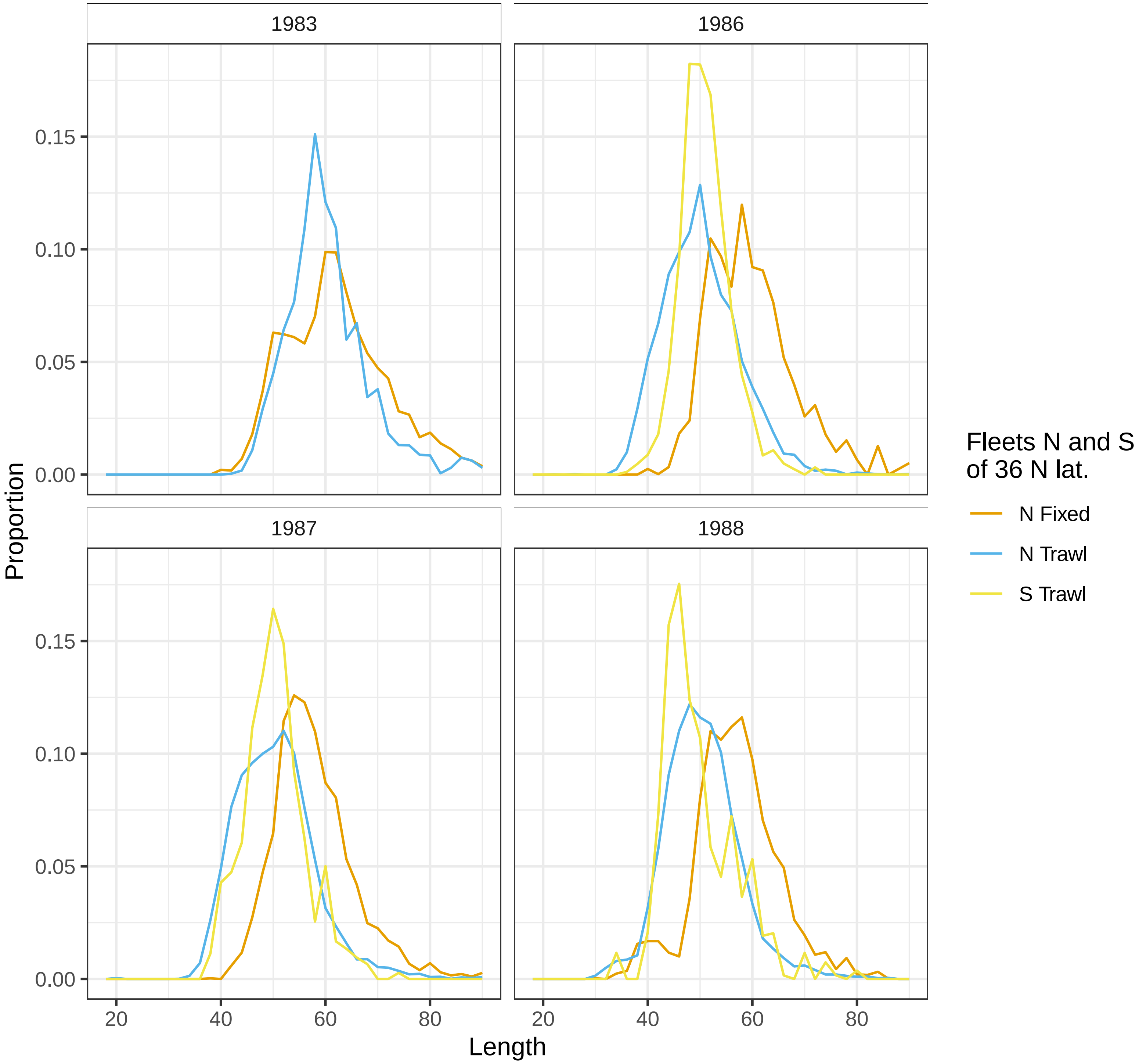

2010
2011
2012
2013
0.2
0.1
0.0
−0.1
0
10
20
30
40
50
Proportion
Age
Fleets N and S of 36 N lat.
N Fixed
N Trawl

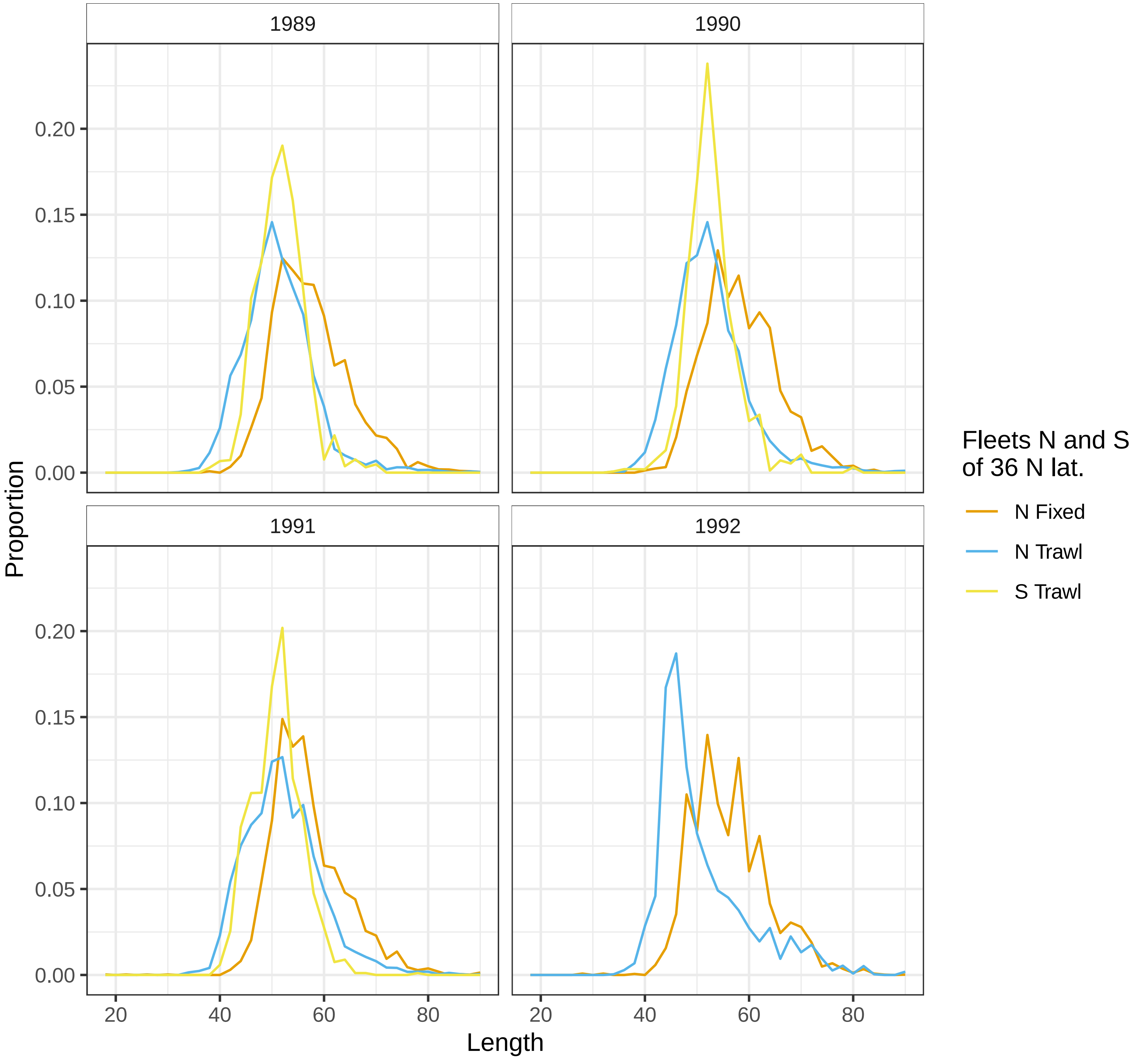

2014
2016
2017
2018
Proportion
Age
0.3
0.2
0.1
0.0
−0.1
−0.2
0
10
20
30
40
50
Fleets N and S of 36 N lat.
N Fixed
N Trawl

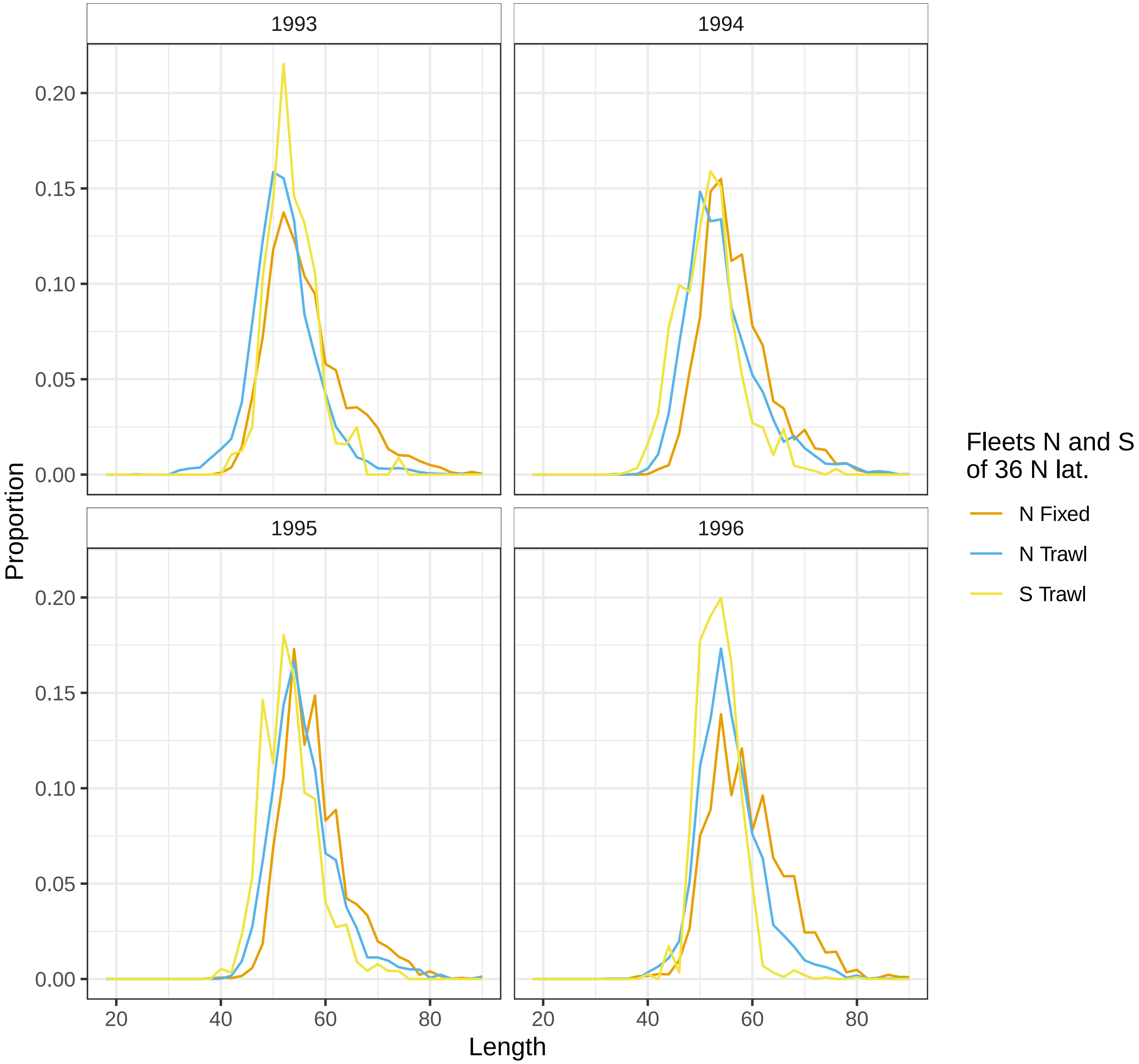
2.2 Year-specific length compositions

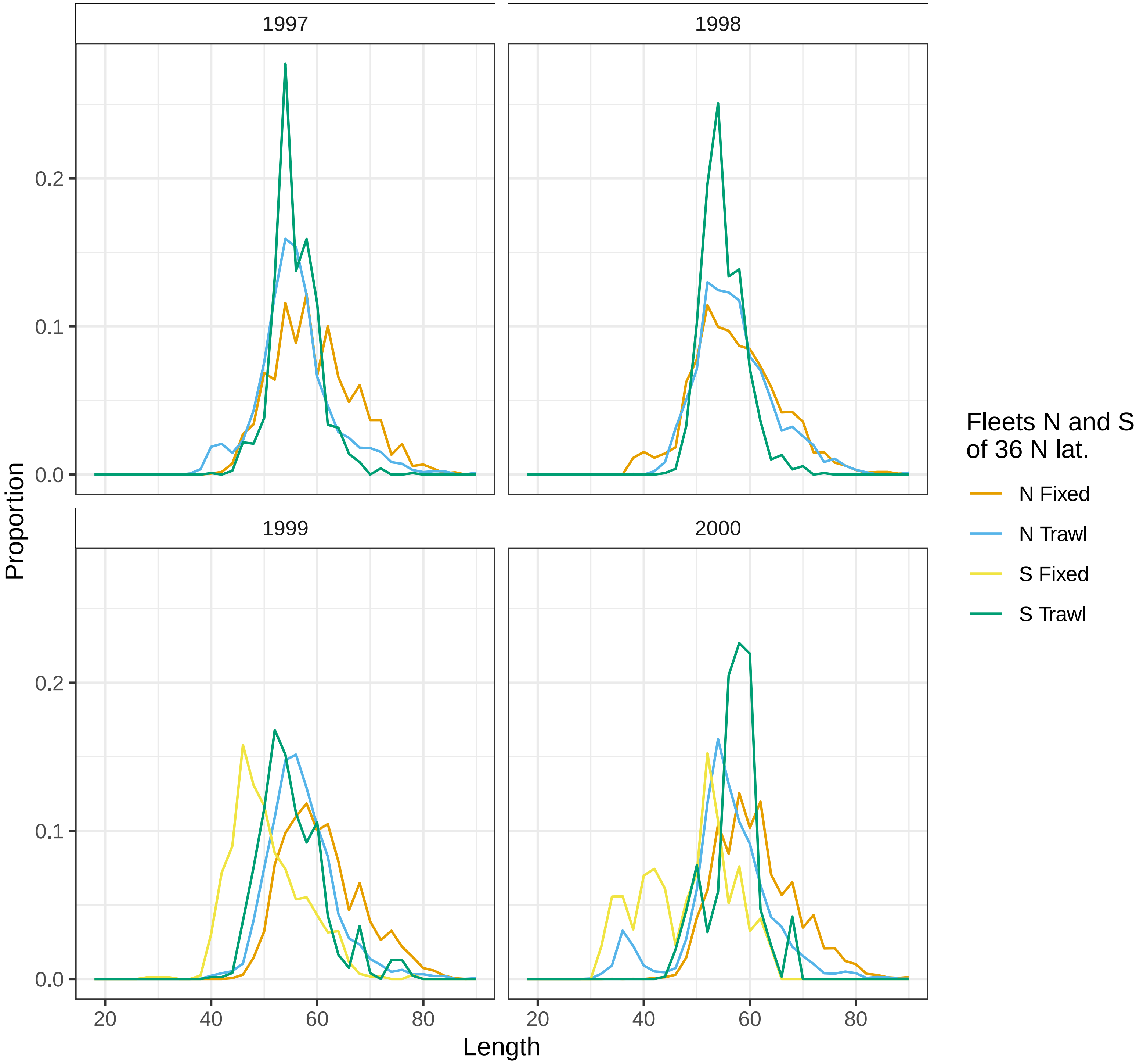


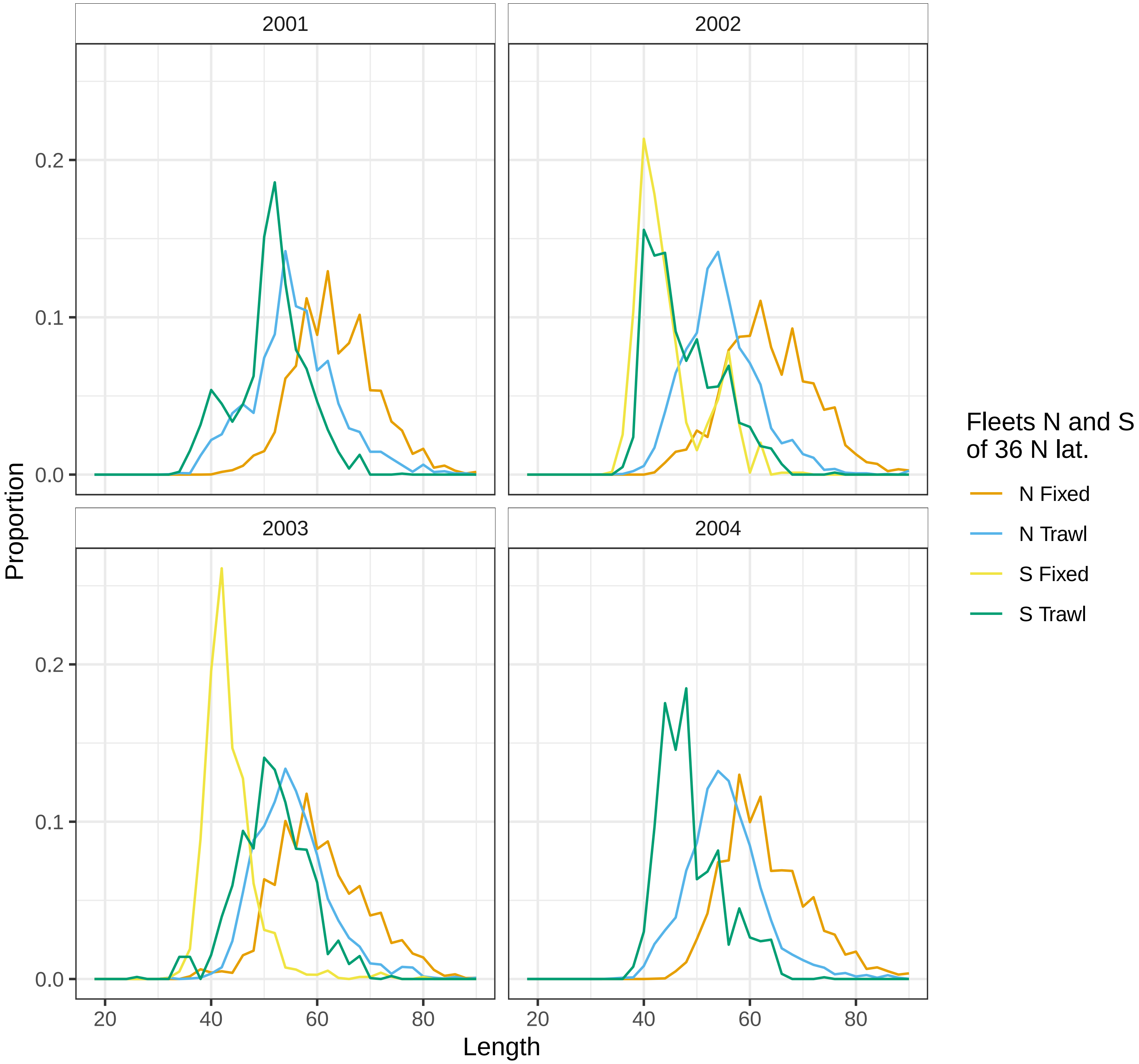
1978
1979
1980
1981
Proportion
0.0
0.1
0.2
0.3
20
40
60
80
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl


1983
1986
1987
1988
0.15
0.10
0.05
0.00
20
40
60
80
Proportion
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl

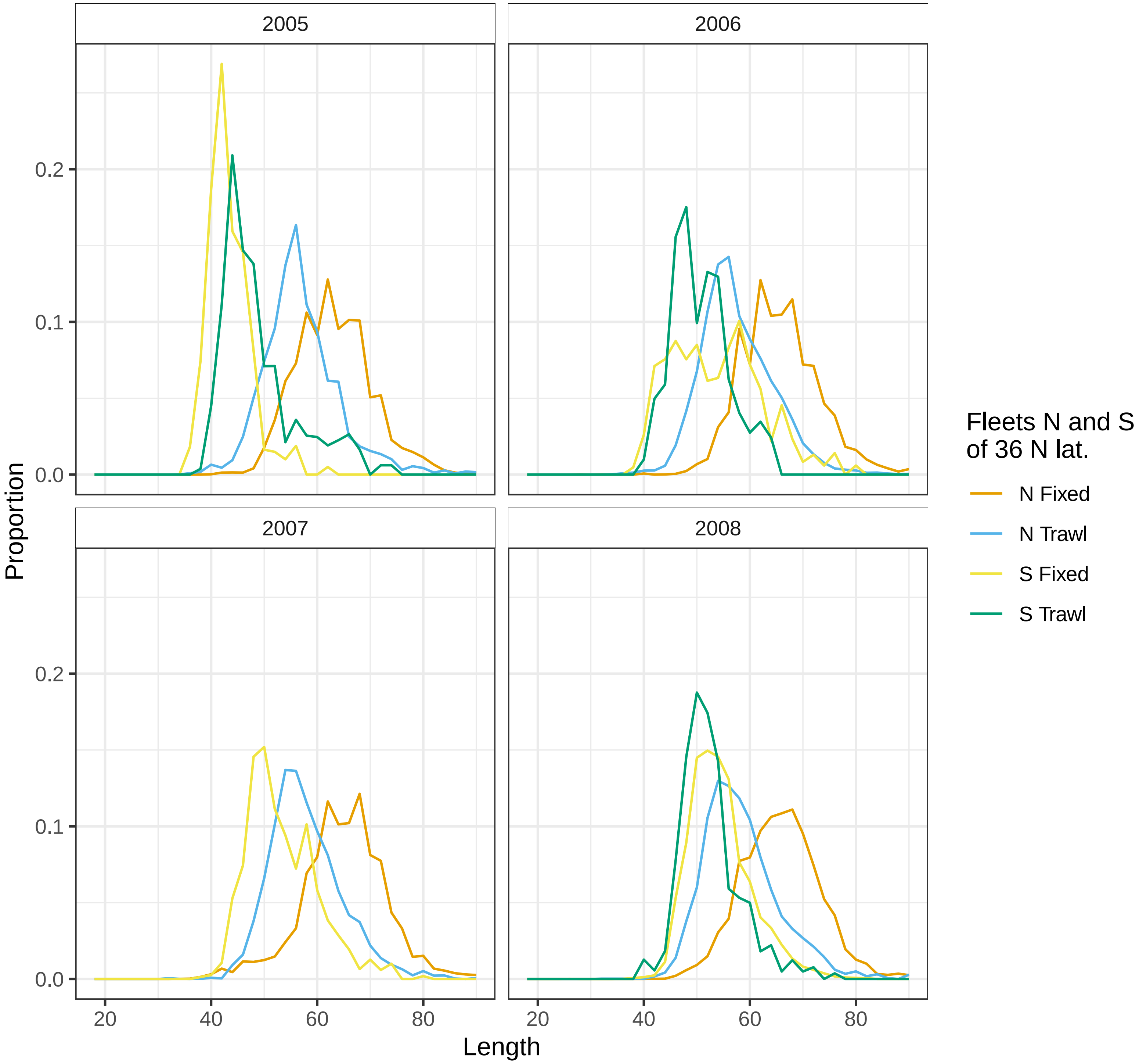

1989
1990
1991
1992
0.20
0.15
0.10
0.05
0.00
20
40
60
80
Length
Proportion
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl

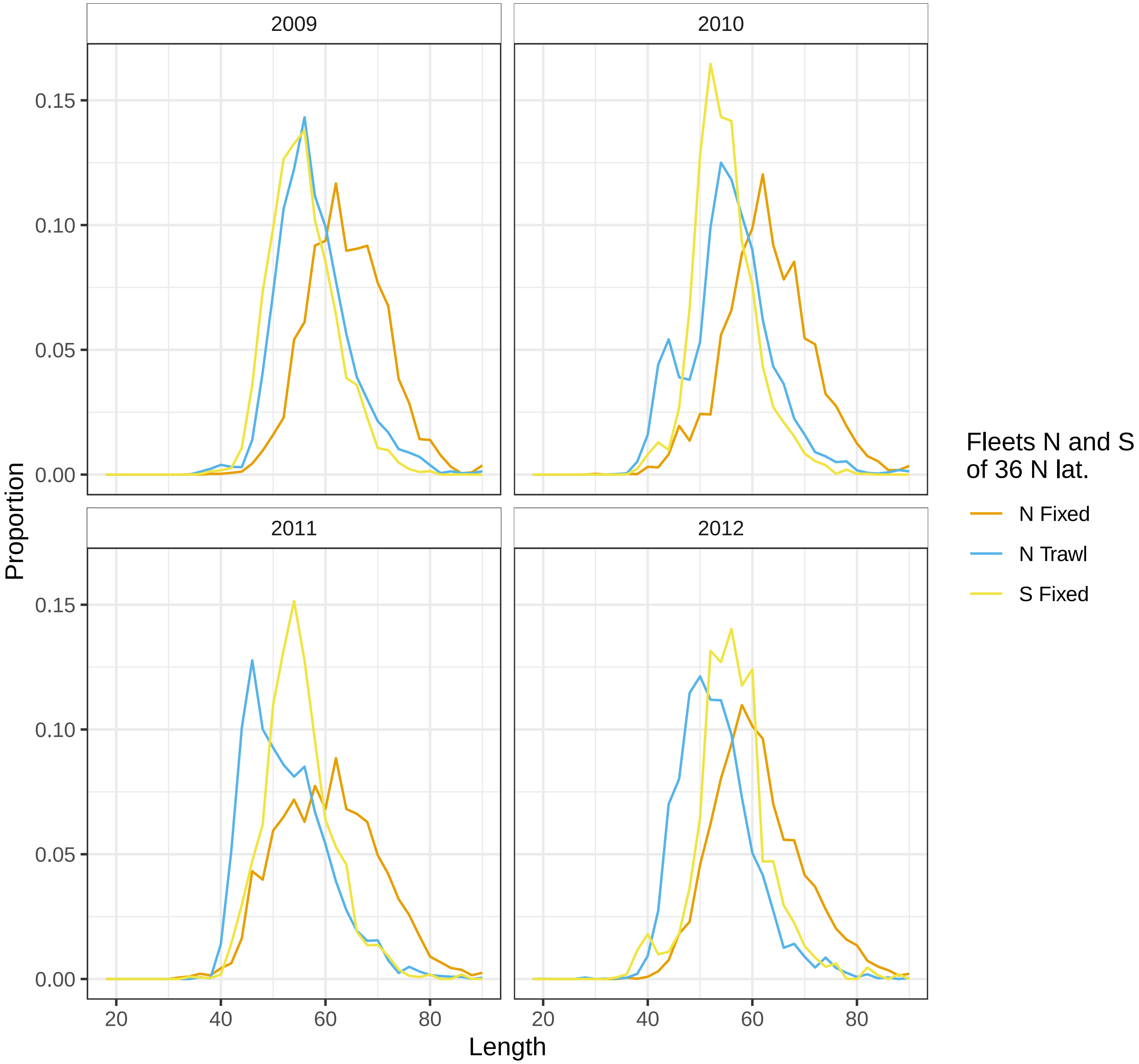

1993
1994
1995
1996
Proportion
Length
0.00
0.05
0.10
0.15
0.20
20
40
60
80
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Trawl

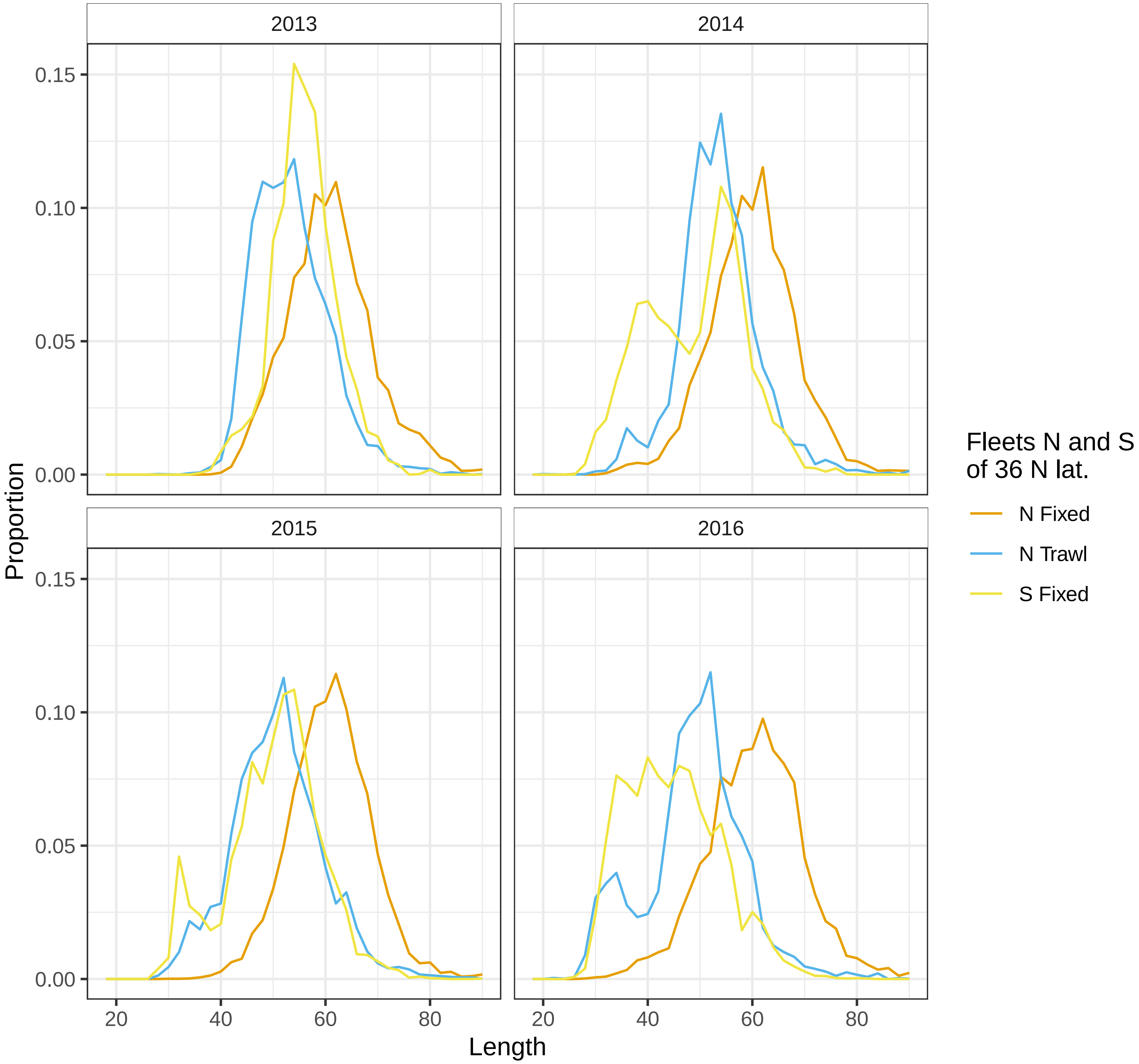

1997
1998
1999
2000
Proportion
0.0
0.1
0.2
20
40
60
80
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Fixed
S Trawl

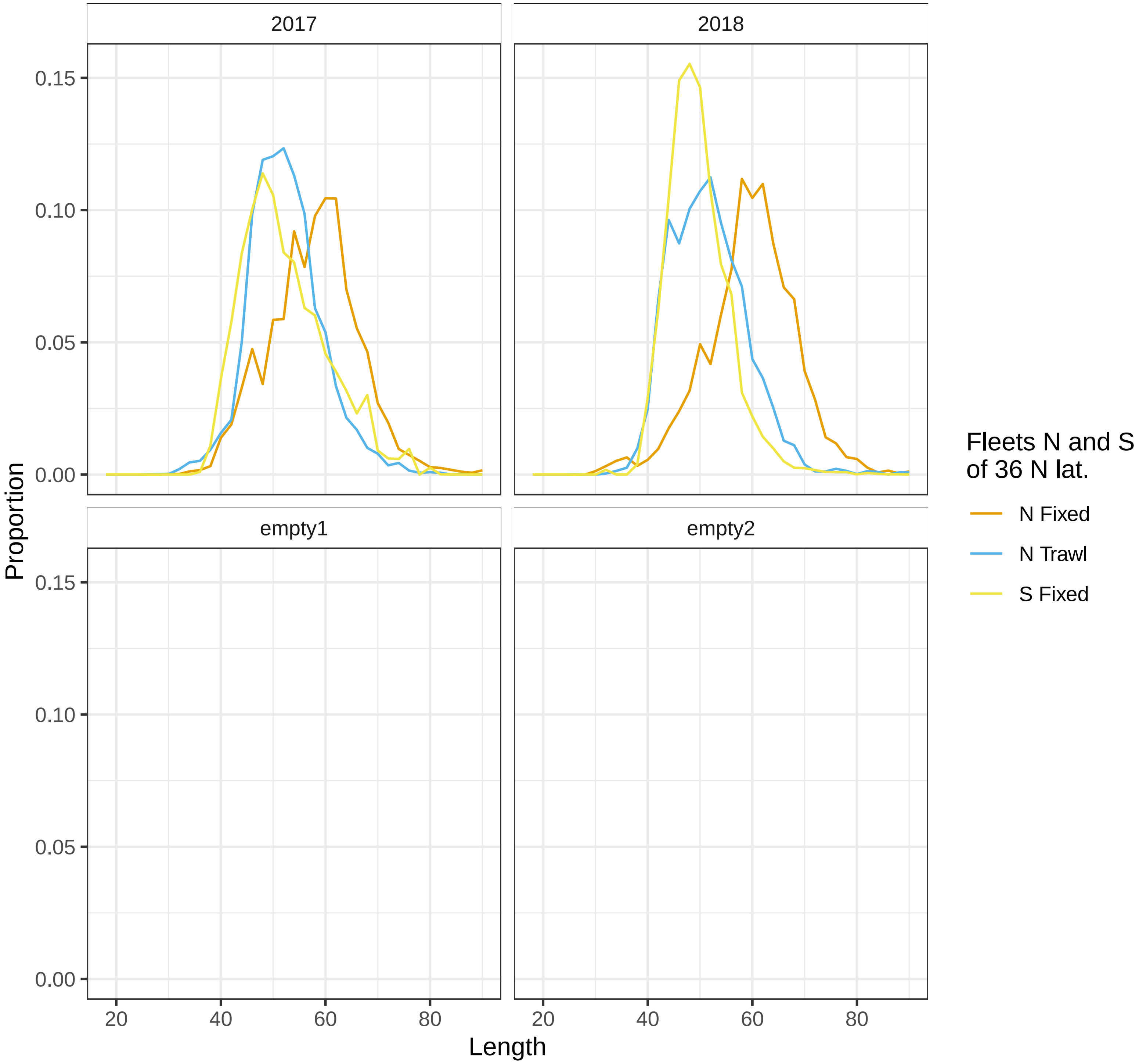


2001
2002
2003
2004
0.0
0.1
0.2
Proportion
20
40
60
80
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Fixed
S Trawl


2005
2006
2007
2008
Proportion
0.0
0.1
0.2
0.0
0.1
0.2
20
40
60
80
20
40
60
80
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Fixed
S Trawl


2009
2010
2011
2012
0.15
0.10
0.05
0.00
20
40
60
80
Proportion
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Fixed


2013
2014
2015
2016
Proportion
0.00
0.05
0.10
0.15
20
40
60
80
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Fixed


2017
2018
empty1
empty2
0.15
0.10
0.05
0.00
20
40
60
80
Proportion
Length
Fleets N and S of 36 N lat.
N Fixed
N Trawl
S Fixed