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2017 Assessment Update for the US West Coast Stock of Arrowtooth Flounder

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Some members of the class after the formal review of the assessment.
Photo credit: Martin Dorn.

Executive Summary

Stock

This report is an update stock assessment for the US West Coast stock of Arrowtooth Flounder (*Atheresthes stomias*). This assessment treats the Arrowtooth Flounder off California, Oregon and Washington as a unit stock although this species also occurs off British Columbia, in the Gulf of Alaska, and into the Bering Sea.

Catches

Arrowtooth Flounder are caught primarily by trawlers operating out of ports in Washington and Oregon. Catches of Arrowtooth Flounder by trawlers from California are more limited. There are limited markets for Arrowtooth Flounder because of their poor flesh quality, and many caught incidentally while fishing for other species are discarded at sea. Historically, landed catches of Arrowtooth Flounder were primarily sold as animal food for mink ranches. Since the late 1970s landed catches of Arrowtooth Flounder have been used for human consumption, as fillets or as headed-and-gutted product. Significant, but unreported quantities are caught and discarded at sea, until the recent implementation of full observer coverage at-sea of the trawl catch shares program.

Table a. Recent landed catches (mt) of Arrowtooth Flounder by state, 2007-2016.

Year	California	Oregon	Washington
2007	59.7	1629.2	569.0
2008	44.5	2141.7	469.8
2009	45.4	2834.9	957.1
2010	67.7	2290.8	865.3
2011	86.2	1667.3	568.6
2012	99.3	1494.8	735.8
2013	117.7	1635.4	234.6
2014	75.1	1103.7	65.4
2015	92.2	1158.3	70.2
2016	58.3	986.0	53.9

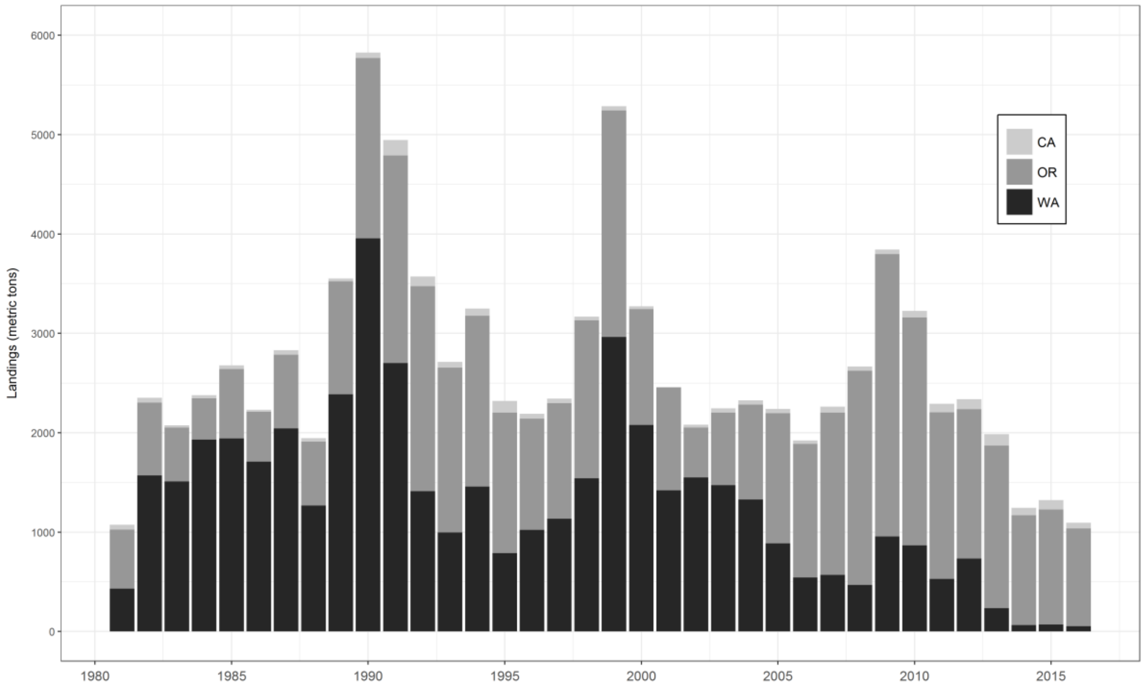

Figure a. Landings of Arrowtooth Flounder by state, 1981 to 2016.

Data and assessment

This assessment updates the last full assessment for Arrowtooth Flounder, which was completed in 2007. The assessment model, which uses a new release of the Stock Synthesis software (Version 3.30.03.03), follows the same structure as the 2007 assessment with catches partitioned to three fleets: a “mink-food” fleet that accounts for all landed catches of Arrowtooth Flounder from the outset of the assessment period (1916) through 1980; a “fillet” fleet that accounts for all landed catches of Arrowtooth Flounder from 1981 through 2016; and a “discard” fleet that accounts for Arrowtooth Flounder caught and discarded while fishing for Dover Sole, English Sole, and Petrale Sole throughout the assessment period. Catches assigned to the fillet fleet include an estimate of fish discarded at sea. Catches assigned to the “discard fleet” were derived on the basis of the landed catches of Dover Sole, English Sole, and Petrale Sole, as was done for the 2007 assessment. Compared to the 2007 assessment, the current update assessment had many more years of at-sea observations of discards on which to base the estimated proportions of Arrowtooth Flounder discarded in association with landed catches of Arrowtooth Flounder (by the fillet fleet) and the estimated ratio of Arrowtooth Flounder discarded relative to the landed catches of Dover Sole, English Sole, and Petrale Sole (by the “discard fleet”), but there remains considerable uncertainty regarding the magnitude and biological characteristics (length and sex) of the discarded catches, especially for years prior to the start of regular at-sea observations of discards.

As in the 2007 assessment, there are four sources of fishery independent information from surveys conducted by the National Marine Fisheries Service (NMFS): the Triennial shelf survey (1980-2004); the Alaska Fisheries Science Center (AFSC) slope survey (1997, 1999-2001); the Northwest Fisheries Science Center (NWFSC) slope survey (1999-2002); and the NWFSC slope-shelf survey (2003-2016). The 2007 assessment had only four sets of annual observations from the NWFSC slope-shelf survey, whereas this update has 14.

The assessment model includes observed age- and length-compositions by sex from the fillet fleet and more limited observations from the "discard fleet". Length-compositions were also available for all surveys except the NWFSC slope survey. Age readings from otoliths were available for some years for the landed catches by the fillet fleet and for the NWFSC slope-shelf survey.

The assessment model treats the sexes separately to account for the large differences in growth, with female Arrowtooth Flounder attaining much larger sizes than males. Also, the sexes have distinct assumed rates of natural mortality (0.216 yr^{-1} for females; 0.30 yr^{-1} for males), based on an updated meta-analysis of the relationship between natural mortality and maximum age for other flatfish species.

With very few exceptions (noted in the main text) the update assessment model conforms almost exactly to the structure and configuration of the 2007 stock assessment model. However, there have been significant revisions to the data used in the 2007 assessment and this update includes many more years of observations of sex-, length-, and age-compositions.

Stock Biomass

The base case assessment model estimates that the spawning biomass underwent a period of fairly rapid decline during the 1970s and subsequent increase through the 1980s, reaching a peak of almost 75,630 mt in 1991, well above the estimated unfished level of spawning biomass (65,448 mt). After 1991, the spawning biomass declined to a low in 2010 of 29,626 mt, the second lowest value in the series. The spawning biomass has been increasing steadily since 2010 and is estimated to be almost 56,710 mt at the start of 2017, almost 87% of the unfished level and well above the minimum stock size threshold of 12.5% for Council-managed flatfish species.

Table b. Abundance estimates for Arrowtooth Flounder, 2007-2017.

Year	Spawning biomass (mt)	~95% Interval			Relative depletion
2007	39,750	32,159	-	47,342	60.7%
2008	37,066	29,397	-	44,734	56.6%
2009	34,124	26,423	-	41,824	52.1%
2010	29,626	21,507	-	37,746	45.3%
2011	30,771	21,431	-	40,111	47.0%
2012	33,898	23,002	-	44,793	51.8%
2013	37,306	24,676	-	49,937	57.0%
2014	38,876	25,030	-	52,722	59.4%
2015	41,095	25,896	-	56,294	62.8%
2016	46,983	28,978	-	64,989	71.8%
2017	56,710	34,243	-	79,178	86.6%

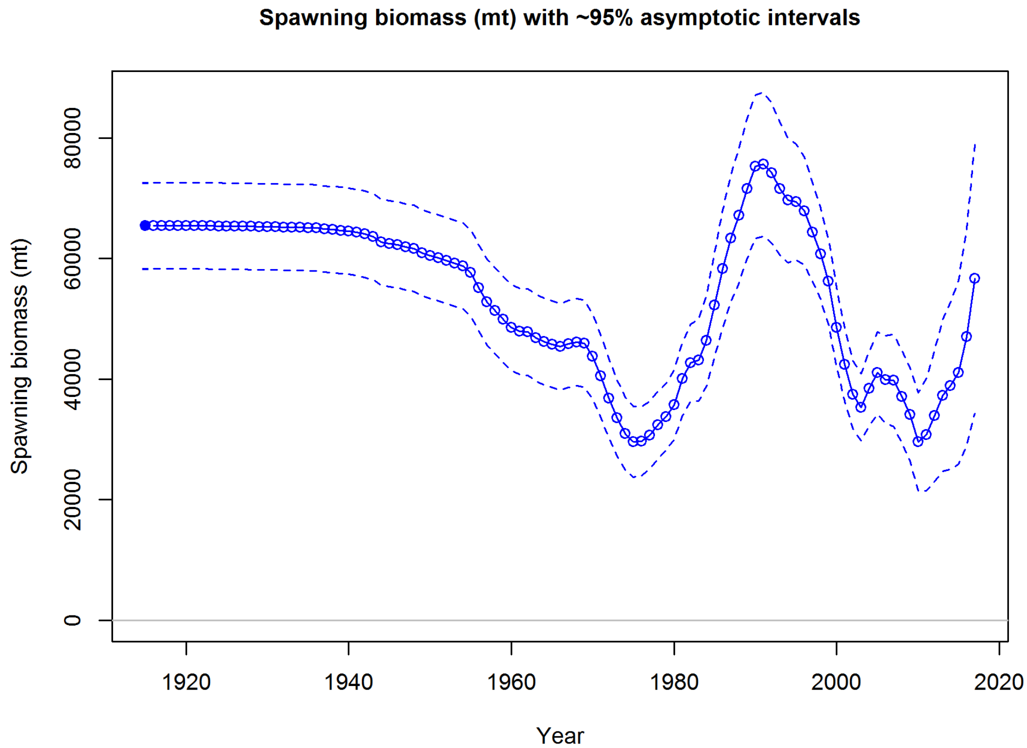

Figure b. Estimated spawning biomass of Arrowtooth Flounder, 1916-2017.

Recruitment

The update assessment model followed the configuration of the 2007 assessment in allowing recruitment estimates to start deviating in 1965 from the average values predicted by the spawner-recruit curve. The initial deviations resulted in a period of low recruitment through the late 1960s followed by a period of generally high recruitment during the late 1970s and early 1980s, low recruitment during the 1990s (except for a very high recruitment in 1999), and then very high recruitment during 2011 to 2013.

Table c. Estimated age-0 recruitment for Arrowtooth Flounder, 2007-2017.

Year	Age 0 recruits, thousands	~95% Interval		
2007	36,830	21,905	-	61,925
2008	91,791	65,127	-	129,372
2009	20,910	11,266	-	38,809
2010	31,862	19,606	-	51,779
2011	114,024	78,006	-	166,673
2012	135,892	90,339	-	204,415
2013	155,499	99,298	-	243,509
2014	8,232	2,972	-	22,803
2015	31,214	8,344	-	116,762
2016	49,955	10,414	-	239,636
2017	50,277	10,481	-	241,181

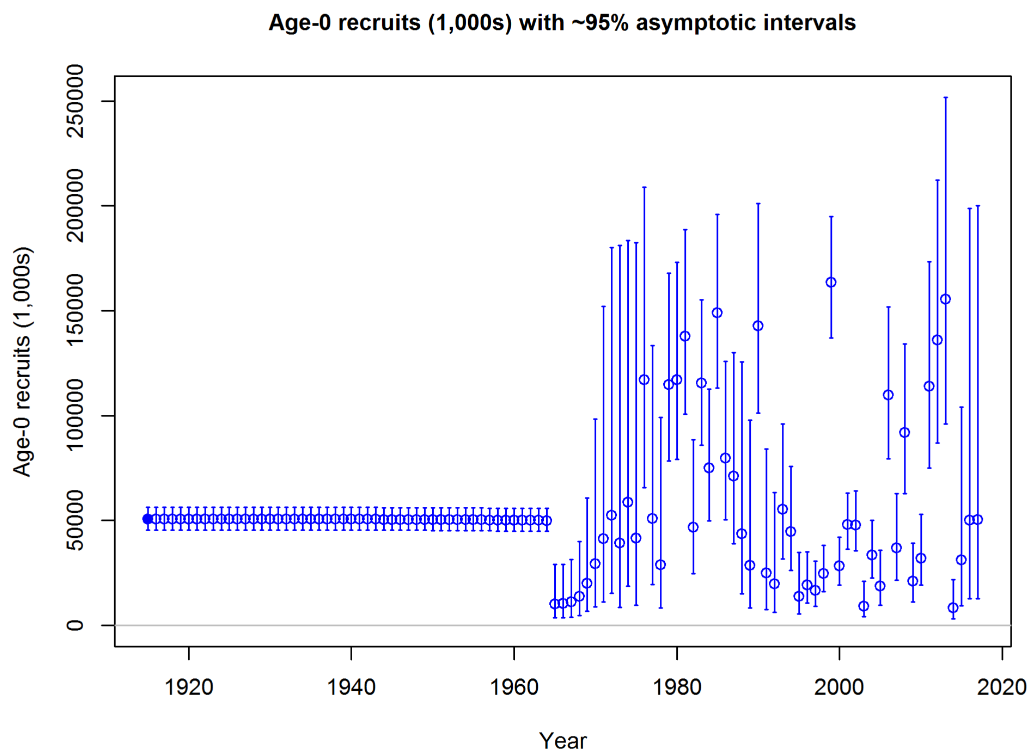

Figure c. Estimated recruitment of Arrowtooth Flounder, 1916-2017.

Exploitation status

The spawning potential ratio (SPR) measures the relative impact of exploitation on the stock in terms of the reduction in spawning potential relative to an unfished stock, which would have an SPR value of 1. The series of estimates of (1-SPR) from the base model indicate that exploitation has been below the management target rate of 70% (100% - 30%) for the entire assessment period and currently is relatively low.

Table d. Recent catches, spawning potential ratio (SPR) estimates, and estimated exploitation rate (catch / Age 3+ biomass).

Year	Catches	Age 3+ biomass	Estimated SPR	Exploitation Rate
2007	4716.2	58876.8	0.575	8.01%
2008	4365.0	59745.8	0.585	7.31%
2009	7936.3	46684.4	0.410	17.00%
2010	4513.2	55953.8	0.530	8.07%
2011	3059.0	62757.1	0.624	4.87%
2012	2892.6	64917.4	0.655	4.46%
2013	2901.4	66240.1	0.674	4.38%
2014	2196.7	71387.5	0.748	3.08%
2015	2038.1	73471.6	0.777	2.77%
2016	1898.6	75638.1	0.809	2.77%
2017	13804 *	43930.3	0.380	31.4%

* The 2017 catch shown here is the adopted ACL; the realized 2017 catch is likely to be much lower.

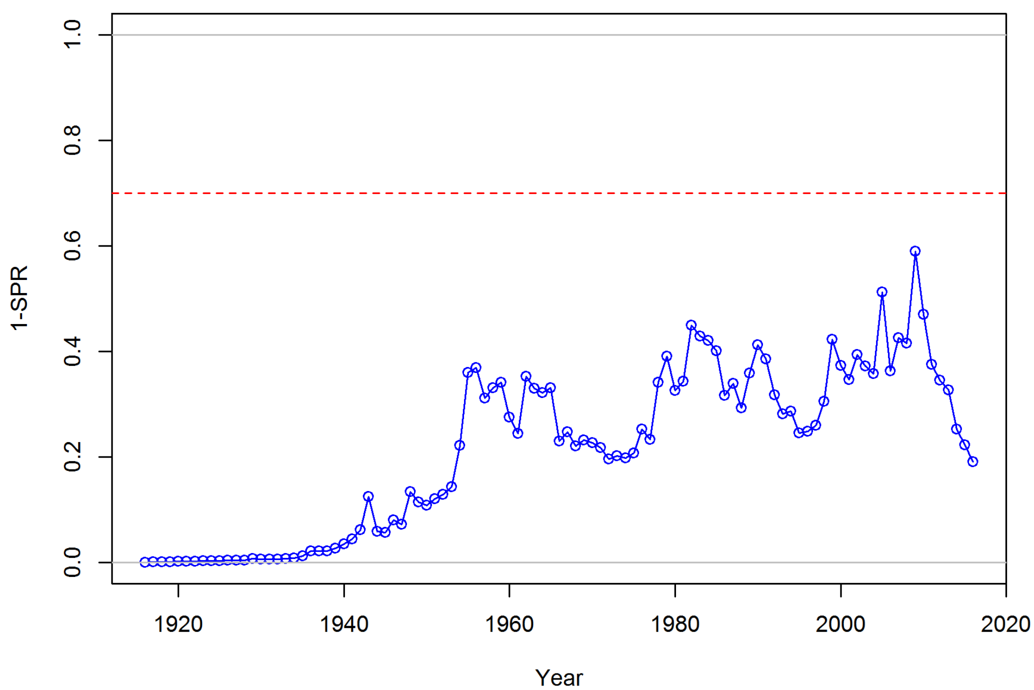

Figure d. Times series of estimated spawning potential ratio (SPR) rates.

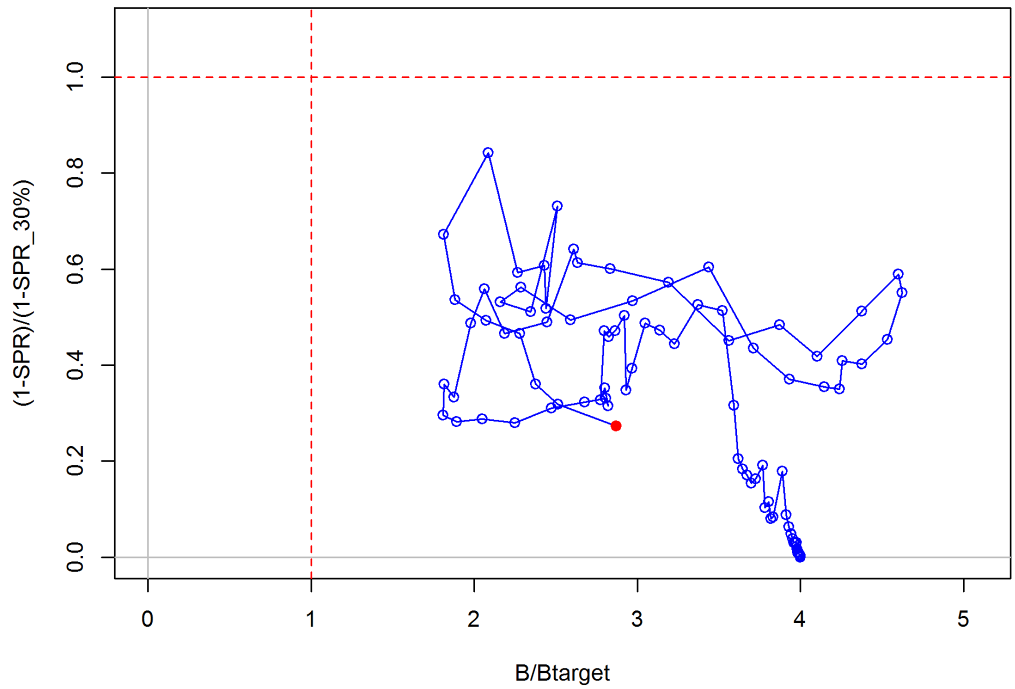

Figure e. Phase plot of the relative depletion (biomass status) versus the relative spawning potential ratio (SPR) rate (exploitation status). The red point represents the ending year of the assessed period, 2016.

Ecosystem considerations

Studies that examined ecosystem interactions of fishes in the California Current System (CCS) have classified Arrowtooth Flounder into the functional group of "large flatfish", with Pacific Halibut and Petrale Sole. This group is the highest trophic level flatfish in the CCS. While Arrowtooth Flounder is both a predator and prey of Pacific Halibut in the Gulf of Alaska, in the CCS the only significant trophic interaction between these species is predation by Pacific Halibut of juvenile Arrowtooth Flounder. Overall, Arrowtooth Flounder has the strongest potential for trophic interactions as a predator of many macroinvertebrates and juvenile fishes in the CCS. Neither this update assessment nor the 2007 stock assessment included any form of explicit ecosystem interactions in the assessment model.

Reference Points

The update assessment estimated that the unfished stock of Arrowtooth Flounder in terms of spawning biomass was 65,448.2 mt, with an age-0 recruitment of 50,487.8 thousand recruits, and an age-3+ summary biomass of 88,804.5 mt.

Table e. Key reference points for Arrowtooth Flounder.

Unfished stock	Estimate	95% confidence limits Lower	Upper
Spawning biomass (mt)	65448.2	58305.7	72590.7
Age-0 recruits (thousands of fish)	50487.8	45075.1	55900.5
Summary (Age-3+) biomass (mt)	88804.5	79172.4	98436.6

	Yield reference points		
	SB25%	SPR30%	MSY est.
Spawning Potential Ratio (SPR)	0.2704	0.3000	0.1990
Exploitation rate	0.2029	0.1843	0.2606
Yield	6774.8	6634.9	6943.4
Spawning biomass (mt)	16362.0	18355.3	11558.7
SSB / SSB0	25.0%	28.0%	17.7%

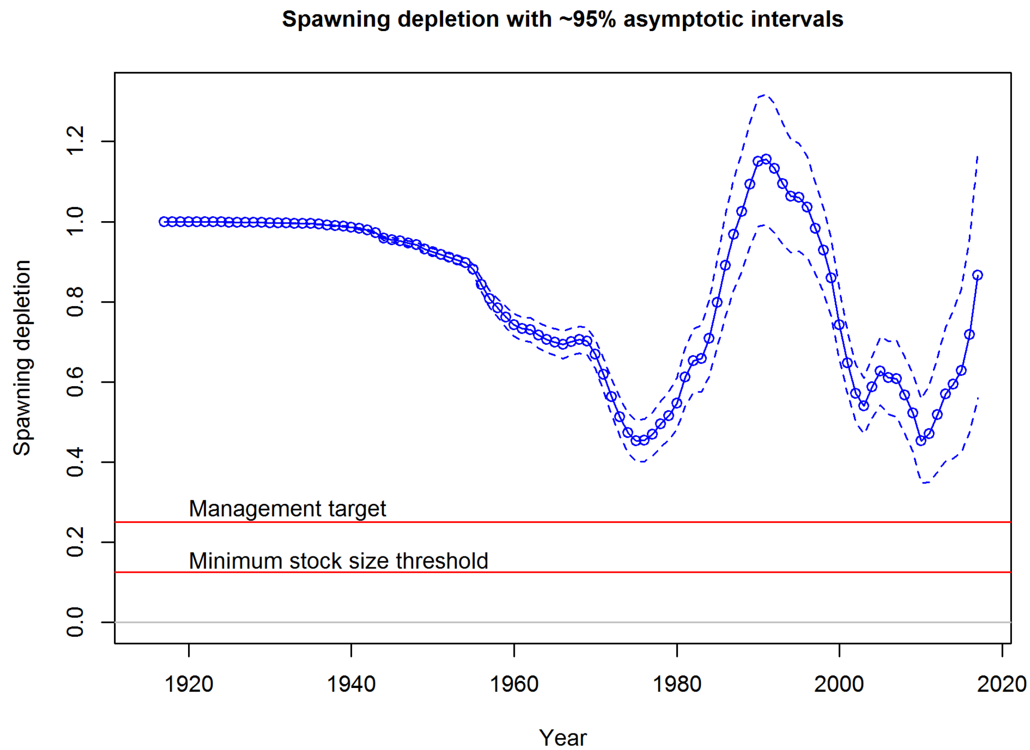

Figure f. Estimated relative depletion for Arrowtooth Flounder.

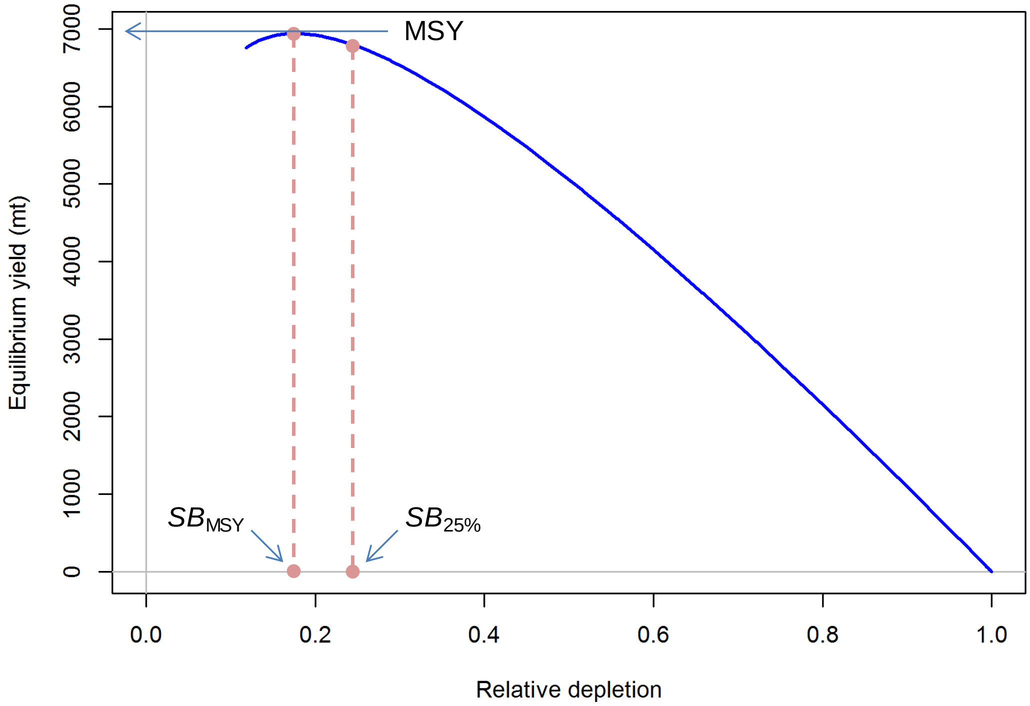

Figure g. Estimated equilibrium yield versus relative spawning biomass for Arrowtooth Flounder.

Management performance

The 2007 stock assessment estimated Arrowtooth Flounder to be at 79% of the estimated unfished spawning biomass (95% CI: 58.1%-99.5%). Based on that assessment, the 2009 coast-wide ACL was increased from 5,800 mt to 11,267 mt. Following the 2009 assessment of Petrale Sole and based on analysis and advice of the Scientific and Statistical Committee (SSC), the Council adopted new default reference points for West Coast flatfish species: an F_{MSY} proxy of F30%, a B_{MSY} proxy-target of $B_{25\%}$, and a minimum stock size threshold (MSST) of $B_{12.5\%}$ (half of the B_{MSY} proxy). Fishing mortality rates (measured in terms of SPR) have been below the current F-target for flatfish of $SPR_{30\%}$ and the current assessment estimates that Arrowtooth Flounder at the start of 2017 are 86.6% of the estimated unfished spawning biomass and will be slightly larger at the start of 2018 even if 2017 catches attain the ACL. Recent coast-wide annual landings have not exceeded the ACL.

Table g. Recent total catches and commercial landings (mt) relative to the management guidelines. Estimated total catch reflects the commercial landings plus estimated discards.

Year	OFL *	ABC	ACL *	Coastwide landings	Coastwide catch **
2007	5800	-	5800	2258	4716
2008	5800	-	5800	2656	4365
2009	11267	-	11267	3837	7936
2010	10112	-	10112	3224	4513
2011	18211	-	15174	2322	3059
2012	14460	12049	12049	2330	2893
2013	7391	6157	6157	1988	2901
2014	6912	5758	5758	1244	2197
2015	6599	5497	5497	1321	2038
2016	6396	5328	3241	1098	1899
2017	16571	13804	13804	NA	NA

* Prior to 2011, the OFL was referred to as "ABC" and the ACL was referred to as "OY".

** Total catch as estimated in this assessment does not represent the official estimation of total mortality as conducted each year by the West Coast Groundfish Observer Program (WCGOP, NMFS, NWFSC). The WCGOP's Total Mortality Report represents the estimation of total mortality each year to determine the official stock status related to overfishing.

Unresolved problems and major uncertainties

This update assessment used almost the exact same model configuration and structure as used in the 2007 assessment, which greatly constrained how both assessment models could account for certain features of the data, such as the preponderance of female Arrowtooth Flounder in the fillet fleet catches. According to the 2007 assessment document, the stock assessment team (STAT) went to the stock assessment review (STAR) with a draft assessment model that included a retention curve for the fillet fishery and had length-composition observations for fish discarded on trips that also landed Arrowtooth Flounder (i.e., the fillet fleet) as data to inform the retention curve. The STAT's draft assessment model was also configured to estimate discard rates based on observations of the fractions of the Arrowtooth Flounder catches retained and landed by the fillet fleet. However, due to poor model performance and other reasons described in the 2007 assessment document and STAR Panel report, during the 2007 STAR meeting the STAT adopted the simpler model structure that was inherited by the current update assessment: no retention curve for the fillet fleet and estimated discards by this fleet are added to its catch stream. This structure and the additional assumption that all fishery selection curves are asymptotic and constant through time greatly limits how the assessment model can account for observed changes in the length-compositions. Also, newer length-at-age observations from the NWFSC slope-shelf survey indicate possible changes in length-at-age for Arrowtooth Flounder. Although it is unclear that a different model structure would resolve various discrepancies that were evident in the fit of the update assessment model to the available data (e.g., rather poor residual patterns in the fits to the NWFSC slope-shelf survey biomass index and in the fits to most of the compositional data), future assessments should explore whether the current simplified model structure may be inadvertently distorting the results.

Decision table

The decision table considers the uncertainty in 'states of nature' regarding natural mortality rates (*M*) for females and males, which is a departure from the 2007 assessment. The 2007 decision table considered uncertainty in natural mortality rates for both sexes and past catches and this approach produced very extreme high and low states. The decision table here uses three states of nature based on the natural mortality prior and observations of maximum age for female and male Arrowtooth Flounder.

In developing the states of nature, we attempted to provide high and low states that each represented about 25% of the probability space, with the base model representing the other 50%. To do this, when considering uncertainty in a single parameter, it is common to set the high and low states at the 12.5% and 87.5% quantiles of the prior distribution (or other measure of uncertainty distribution) for that parameter, which corresponds to points 1.15 standard deviations from the median, the best estimate. In the natural mortality prior the data used in its development through meta-analysis were subject to error, implying that the prior included both variability in the relationship between maximum age and *M* and error in the estimates of maximum age and *M* that inform the prior. We assumed half of the variance in the relationship was due to this error and therefore used *M* values for the high and low states that were ± 1.15 x 0.707 x SD from the median (in log space).

The three states of nature were therefore: (1) the low state (female M = 0.15 yr^{-1}, male M = 0.21 yr^{-1}), (2) the base case (female M = 0.216 yr^{-1}, male M = 0.30 yr^{-1}), and (3) the high state (female M = 0.31 yr^{-1}, male M = 0.43 yr^{-1}). ABC catch streams were developed from each of these states of nature for 2019 through 2028, assuming ACL catches are removed in 2017 and 2018, a P* of 0.40, and a Category 2 stock designation (sigma = 0.72). These catch streams are applied to each state of nature, with the results highlighting the uncertainty in the absolute scale of the stock and the impact of assuming one state when another is true.

Table h. Decision table for Arrowtooth Flounder based on status quo catches during 2017 and 2018, projected catches for 2019-2028, and alternative assumptions about the female and male natural mortality rates (see text for details). Columns range over low, mid, and high states of nature, and rows range over catch streams from those states of nature. ABCs are based on the assumptions that P*=0.40 and σ=0.72 for a Category 2 designation, and the ACLs are taken in 2017 (13,804mt) and 2018 (13,743mt).

			State of nature					
			Low $M_{female} = 0.15\ yr^{-1}$ $M_{male} = 0.21\ yr^{-1}$		Base case $M_{female} = 0.216\ yr^{-1}$ $M_{male} = 0.30\ yr^{-1}$		High $M_{female} = 0.31\ yr^{-1}$ $M_{male} = 0.43\ yr^{-1}$	
Relative probability			0.25		0.50		0.25	
Management decision	Year	Catch (mt)	Spawning bio. (mt)	Depletion	Spawning bio. (mt)	Depletion	Spawning bio. (mt)	Depletion
ABC catches from "Low" state of nature	2019	7,062	35,586	0.68	52,226	0.80	124,842	0.68
	2020	6,902	33,340	0.63	49,396	0.75	119,590	0.65
	2021	6,434	30,372	0.58	46,166	0.71	118,830	0.64
	2022	5,857	27,509	0.52	43,460	0.66	121,985	0.66
	2023	5,318	25,062	0.48	41,431	0.63	126,928	0.69
	2024	4,877	23,110	0.44	40,040	0.61	132,413	0.72
	2025	4,537	21,615	0.41	39,176	0.60	137,796	0.75
	2026	4,284	20,495	0.39	38,713	0.59	142,761	0.77
	2027	4,096	19,666	0.37	38,537	0.59	147,174	0.80
	2028	3,958	19,052	0.36	38,558	0.59	151,004	0.82
Base Case ABC catches	2019	15,578	35,586	0.68	52,226	0.80	124,842	0.68
	2020	13,302	26,920	0.51	42,528	0.65	113,095	0.61
	2021	11,035	19,288	0.37	34,656	0.53	108,321	0.59
	2022	9,272	13,487	0.26	29,345	0.45	109,503	0.59
	2023	8,135	9,375	0.18	26,132	0.40	113,772	0.62
	2024	7,478	6,489	0.12	24,308	0.37	119,228	0.65
	2025	7,113	4,362	0.08	23,287	0.36	124,798	0.68
	2026	6,904	2,643	0.05	22,687	0.35	129,955	0.70
	2027	6,773	*	-	22,299	0.34	134,501	0.73
	2028	6,682	*	-	22,021	0.34	138,404	0.75
ABC catches from "High" state of nature	2019	57,469	35,586	0.68	52,226	0.80	124,842	0.68
	2020	38,893	*	-	9,838	0.15	80,519	0.44
	2021	29,277	*	-	*	-	61,501	0.33
	2022	26,107	*	-	*	-	57,183	0.31
	2023	26,081	*	-	*	-	58,224	0.32
	2024	26,757	*	-	*	-	59,861	0.32
	2025	27,176	*	-	*	-	60,612	0.33
	2026	27,241	*	-	*	-	60,539	0.33
	2027	27,119	*	-	*	-	60,139	0.33
	2028	26,971	*	-	*	-	59,780	0.32

* The model was unable to remove the catch during the year before – the stock "crashed".

Table i. Projected OFL and ACL catches from the Arrowtooth Flounder base model assuming ACL catches during 2017 and subsequent years.

Year	Spawning biomass (mt)	ACL catch (mt)	OFL catch (mt)
2017	56,710.3	13,804 *	16,571 *
2018	57,160.2	13,743 *	13,861 *
2019	52,225.6	17,873.1	18,695.7
2020	40,700.0	14,632.2	15,305.6
2021	31,930.1	11,696.9	12,235.2
2022	26,382.0	9,575.2	10,015.9
2023	23,277.3	8,305.5	8,687.7
2024	21,666.2	7,629.5	7,980.7
2025	20,835.2	7,281.3	7,616.4
2026	20,365.9	7,090.3	7,416.6
2027	20,053.1	6,969.1	7,289.9
2028	19,812.9	6,879.7	7,196.3

* Values from the 2015 catch-only update assessment.

Research and data needs

Addressing the following research and data needs could improve future assessments of Arrowtooth Flounder.

1. *Reevaluation and reconstruction of historical flatfish removals, including Arrowtooth Flounder*. Historical estimates of discards are a large contributor to total removals. The current modelling exercise of using co-occurring flatfish species as predictors of discard could use further exploration. The Arrowtooth Flounder catch history for Washington should be reconstructed using all available data including catch by gear and by region. The reconstruction should include an envelope of high and low values to set bounds for exploration of alternative catch histories. As has been recommended previously by a variety of STAR Panels, the reconstruction of historical landings needs to be done comprehensively (i.e., with other species) to ensure efficiency and consistency.
2. *Exploration of foreign fleet catches of flatfish*. There were large removals of rockfish species by foreign fleets during the mid-1960s to mid-1970s (Rogers, 2003). We were unable to locate information on possible removals of flatfish species by the foreign fleet but it seems likely that some flatfish catches occurred. This should be explored for the next assessment of Arrowtooth Flounder and may also be relevant for the assessment of Dover Sole.
3. *Reevaluation of the value of stock-recruitment steepness for Arrowtooth Flounder*. In the base case model, steepness was set at 0.902 based on Dorn's meta-analysis (personal communication). While model results are not sensitive to the value of steepness, it would have an effect on MSY calculations and OFL and ABC values at lower stock sizes.
4. *Research to provide information on survey catchability*. The absolute scale of the stock is still quite uncertain. The calculated catchability associated with the NWFSC slope-shelf trawl survey ranges from 0.2 to 0.8 across the three states of nature.

5. *Evaluation of stock boundaries and the feasibility of a bilateral assessment with Canadian scientists*. This could perhaps be accomplished through the Technical Subcommittee of the US Canada groundfish working group.

6. *Discrepancies between CalCOM and PacFIN compositional data*. Given concerns that the PacFIN system may include biological data for California that are not fully compatible with the software used to process the PacFIN data to produce expanded compositional data, we obtained expanded data from CalCOM (D. Pearson, SWFSC) but they did not appear reasonable (see Figure 9). The source(s) of these discrepancies should be investigated and resolved. Ideally the information from all three states should be housed in PacFIN because this would allow development of standardized data processing and error-checking and facilitate the development of stock assessments.

7. *Evaluation of maturity and fecundity relationships*. New studies on both the maturity and fecundity relationships for Arrowtooth Flounder would be beneficial. The maturity versus length relationship used in this update and the 2007 assessment is based on a study done in 1993.

8. *Age-reading error study*. The age-reading errors assumed for this assessment were taken directly from the 2007 assessment; that assessment took the standard deviation of aging error from an assessment of English Sole. A study is needed to conduct and analyze cross-readings of Arrowtooth Flounder otoliths (surface and break-and-burn reads) to develop improved ageing error vectors for the next assessment of Arrowtooth Flounder (even if it is only an update assessment).

9. *Age-reading of otoliths from the fishery off California*. A collection of unread Arrowtooth Flounder otoliths that is available for fish landed in California should be read to provide possibly more representative age-at-length compositions for the fishery. The fishery age-at-length compositions in this update assessment were based entirely on fish landed in Oregon and Washington.

10. *Evaluation of the spatial variability of productivity processes*. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research. This stock shows clear evidence of a latitudinal gradation in abundance and other traits.

Table j. Summary table of recent catches, regulations, and stock status between 2007 and 2017.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Landings (mt)	2258	2656	3837	3224	2322	2330	1988	1244	1321	1098	NA
Est. catch (incl. discards, mt)	4716	4365	7936	4513	3059	2893	2901	2197	2038	1899	NA
Overfishing limit (OFL, mt)	5800	5800	11267	10112	18211	14460	7391	6912	6599	6396	16571
Annual catch limit (ACL, mt)	5800	5800	11267	10112	15174	12049	6157	5758	5497	3241	13804
Spawn. potential ratio (SPR)	0.575	0.585	0.410	0.530	0.624	0.655	0.674	0.748	0.777	0.809	0.380
Exploitation rate (%) *	8.01%	7.31%	17.0%	8.07%	4.87%	4.46%	4.38%	3.08%	2.77%	2.77%	31.40%
Age 3+ biomass (mt)	58877	59746	46684	55954	62757	64917	66240	71388	73472	75638	43930
Spawning biomass (mt)	39750	37066	34124	29626	30771	33898	37306	38876	41095	46983	56710
Lower 2.5% conf. limit	32159	29397	26423	21507	21431	23002	24676	25030	25896	28978	34243
Upper 2.5% conf. limit	47342	44734	41824	37746	40111	44793	49937	52722	56294	64989	79178
Recruits (1000s age-0 fish)	36830	91791	20910	31862	114024	135892	155499	8232	31214	49955	50277
Lower 2.5% conf. limit	21905	65127	11266	19606	78006	90339	99298	2972	8344	10414	10481
Upper 2.5% conf. limit	61925	129372	38809	51779	166673	204415	243509	22803	116762	239636	241181
Depletion	0.607	0.566	0.521	0.453	0.470	0.518	0.570	0.594	0.628	0.718	0.866
Lower 2.5% conf. limit	0.512	0.470	0.424	0.349	0.349	0.375	0.403	0.409	0.424	0.474	0.560
Upper 2.5% conf. limit	0.702	0.662	0.618	0.557	0.592	0.661	0.737	0.779	0.832	0.962	1.173

* Exploitation rate calculated as catch / age-3+ biomass.

Introduction

Life history and ecology

Arrowtooth Flounder (*Atheresthes stomias*) are an abundant medium-large sized flatfish of the right-eyed *Pleuronectidae* family. Arrowtooth Flounder range from Northern California north to the eastern Bering Sea and are typically found at depths ranging from 50 to 800 meters (m). Reaching sizes of approximately 90 centimeters (cm) fork-length (FL), Arrowtooth Flounder females grow quite substantially larger than males which appear to not typically grow above 68 cm FL. Size and age at maturity vary from report to report, but general estimates of age at fifty percent maturity seem to range from four to seven years for males and seven to ten years for females, with sizes being 28 to 42.2 cm and 36.8 to 47 cm respectively (Love 2011).

Arrowtooth Flounder are batch spawners and produce between 103 thousand to 2.4 million eggs per year. Spawning generally occurs from fall to winter at the deeper end of their typical range, near, or on the continental shelf (Rickey 1995); they appear to move inshore during the summer months (Zimmerman and Goddard 1996). Eggs, which are approximately 2.5 millimeters (mm) in diameter, are externally fertilized. Pelagic egg and larval periods last several months with larvae spending approximately four weeks in the upper 100 m of the water column before settling to the bottom by early spring (Fargo and Starr 2001).

Predatory in nature, Arrowtooth Flounder are piscivorous, but also eat euphausiids, various shrimps, and worms (Love 2011). Studies performed in the Bering Sea show a diet made up primarily of Walleye Pollock (*Gadus chaliogrammus*) (Yang and Livingston 1986), while stomach contents from Arrowtooth Flounder off of Oregon and Washington show a primary diet of Pacific Whiting (a.k.a. Pacific Hake, *Meruccius productus*) (Buckley et. al. 1999). Skates, Dogfish, Shortspine Thornyhead, Pacific Halibut, coastal sharks, orcas, toothed whales, and harbor seals have all been found to be predators of juvenile Arrowtooth Flounder. The larger of these predators are also likely to consume adult Arrowtooth Flounder as part of their diets.

Stock structure considerations

A literature review was unable to find any research (e.g., genetics) conducted to identify population structure pertinent to assessment or management, as was the case when the full assessment was conducted in 2007. While we agree with Kaplan and Helser's statement that there is likely some connectivity with the population off of British Columbia and possibly the Gulf of Alaska, this update assessment assumes that the US West Coast population is composed of a single stock, as was done in the full assessment.

Stock boundaries and other notable geographic features

A map of the US West Coast is provided in Figure 1.

Important features of life history that affect management

Not much is known about migration patterns of Arrowtooth Flounder, but there is evidence that they move to deeper water (400m) as they grow (Zimmerman and Goddard 1996, Blood et al. 2007) and appear to have a widespread bathymetric distribution (Wilderbuer et al. 2008). Arrowtooth exhibit sexual dimorphism in size as males are significantly smaller than females. There is also evidence that sex ratio varies by depth stratum. Females tend to dominate shallower waters (200m) and males dominate deeper waters (>450m). The sex ratio is approximately even at 400m (Blood et al. 2007).

Ecosystem considerations

Studies have examined ecosystem interactions of fishes in the California Current System (CCS) and classified Arrowtooth Flounder into the functional group of "large flatfish", along with Pacific Halibut and Petrale Sole. These flatfish account for the highest trophic level flatfish in the CCS (Field and Francis 2006). While Arrowtooth Flounder is both a predator and prey of Pacific Halibut in the Gulf of Alaska (Gaichas et al. 2010), in the CCS the only significant trophic interaction between these species is predation by Halibut of juvenile Arrowtooth Founder. Overall, Arrowtooth Flounder has the strongest potential for trophic interactions as a predator of many macroinvertebrates and juvenile fishes in the CCS (Field et al. 2006). We found no studies to suggest any environmentally driven aspects to the growth or recruitment dynamics for Arrowtooth Flounder.

Important features of current fishery and relevant history of fishery

Arrowtooth Flounder has been caught by trawl fleets for decades along the U.S. West Coast. Low flesh quality and a lack of market has limited targeting of this species. However, a significant portion is landed in other bottomfish fisheries and discarded as bycatch. The previous assessment identified three main sources of arrowtooth mortality from commercial fishing methods: 1) the mink food fishery (1928-1980), 2) the fillet fishery (1981-2006), and 3) the bycatch trawl fishery (1956-2006). Since the previous stock assessment, historical catch reconstruction for Arrowtooth Flounder, and Dover, English, and Petrale Soles has been completed for Oregon and California groundfish fisheries (Ralston et al., 2010; Karnowski et al., 2014). In this update assessment (compared to the 2007 assessment) the revised data series were expanded for the mink food fishery to include landings from 1916 to1980, the fillet fishery to include landings from 1981 to 2016, and the bycatch trawl fishery to include landings from 1916 to 2016.

The mink-food fishery and mink-food fleet

The mink production industry in Washington and Oregon was the primary market for Arrowtooth Flounder from the 1950s through the 1970s (Kaplan and Helser 2007). Flatfish fisheries for mink food peaked in the late 1950s coinciding with a downturn in the fillet market, and continued to slow through the mid-1970s (Hosie 1976). Arrowtooth Flounder and other flatfish were also components in California's mink and pet food production beginning in the early 1950s (Kaplan and Helser 2007). It was reported that fish for animal food was the result of bycatch from fisheries targeting fillet markets.

Historical landings reconstruction for Oregon and California has shifted the data series referred to as the mink food fishery in the previous assessment from 1928 back to 1916 (Karnowski et al. 2014). Washington does not have a complete historical catch reconstruction. It only goes back to 1978. Washington's information for landings of Arrowtooth Flounder prior to 1978 was derived from a ratio of Washington to Oregon landings of Arrowtooth Flounder for the period 1956 to 1960 and applying the ratio to the Oregon landings of Arrowtooth Flounder.

As in the previous assessment, this update refers to all landed catches of Arrowtooth Flounder prior to 1981 as being associated with the "mink-food fleet". Also, this update assessment, like the 2007 assessment, assumes that there were no discards of Arrowtooth Flounder associated with the landed catches of Arrowtooth Flounder prior to 1981 because the market for mink-food would accept fish that were small or of poor-quality. Discards of Arrowtooth Flounder that occurred prior to 1981 are accounted for by the "discard fleet" (below).

The fishery for Arrowtooth Flounder for human consumption, the fillet fleet

In the 1970s the Arrowtooth Flounder fillet market began to develop in Washington and became fully established during the early 1980s. Over time a market also developed for a headed-and-gutted product, but the quality of the fillets, fishery regulations, and inconsistent demand for Arrowtooth Flounder led to fluctuations in landings (Kaplan and Helser 2007). Recently food grade additives have been developed and successfully used on Arrowtooth Flounder products. These additives have been shown to inhibit the action of an enzyme released from a parasite that causes the softening of the fish's flesh. Arrowtooth Flounder is now being sold in various forms including fillet, headed-gutted-tailed, round, frozen engawa, and as surimi.

We assume here that all landings from 1981 to 2016 are part of the targeted fillet fishery and in the assessment model these landings are associated with the "fillet fleet". Because at-sea observer data indicate that trawlers that land Arrowtooth Flounder also often discard portions of their Arrowtooth Flounder catches, the "fillet fleet" catch series for the assessment model is inflated by an estimated discard fraction to account for these unreported discards. The procedures used to derive the discard fractions are described below in the section *Estimates of discard fractions and ratios*.

The discard fishery and the discard fleet

Based on the knowledge that Arrowtooth Flounder co-occur with other flatfish that are targeted in the US West Coast bottom trawl fishery and given that limited landings of Arrowtooth Flounder are made each year, it is likely that many bottom trawl trips encounter Arrowtooth Flounder as bycatch that is discarded at sea. This supposition is supported by the discards of groundfish (including Arrowtooth Flounder) recorded each year since 2001 by the West Coast Groundfish Observer Program (WCGOP). Even with the availability of historical reconstructions of landings from the California and Oregon fisheries, there is still a general lack of historical records of discards and a reconstruction was therefore required.

A 13% discard ratio was applied to the coastwide landings of Dover, English, and Petrale Soles for the years 1956-2006 in the 2007 assessment. This ratio (Arrowtooth Flounder discards to landings of Dover, English and Petrale Soles) was derived on the basis of WCGOP data for the first six years of the program (2001-2006). For this update assessment discard ratios were recalculated using WCGOP sampling data for each state through 2015, the most recent year for which the WCGOP data were available. The data and procedures used to derive the discard ratios are described below in the section *Estimates of discard fractions and ratios*. This update assessment associates the discarded Arrowtooth Flounder derived from the landings of Dover, English and Petrale Soles with the "discard fleet", which was usually described as the "bycatch trawl" fishery in the 2007 assessment.

The reconstructed landings of Arrowtooth Flounder are presented in Table 1. The reconstructed catches (landings plus discards) of Arrowtooth Flounder are presented in Table 2 and Figure 2. Further details on these data series are provided below in the section *Fishery-dependent data*.

Summary of management history

Management of the fishery for Arrowtooth Flounder began in the late 1980s with the implementation of weekly trip limits on the deepwater complex (consisting at that time of Sablefish, Dover Sole, Arrowtooth Flounder and thornyheads) and annual quotas. Arrowtooth Flounder was later managed as part of the “Other Fish” complex, and in 1991 as a member of the “Other Flatfish” complex. In 1992, Arrowtooth Flounder was removed from “Other Flatfish” complex and an allowable biological catch (ABC) of 5,800 metric tons was established based on the peak historical catch level prior to the development of the Arrowtooth Flounder fishery.

Starting in 2000, the Council established trip limits for Arrowtooth Flounder, placed restrictions on the use of large footropes, and in 2002 began using area closures for both trawl and fixed-gear groups to limit catch and bycatch of overfished rockfish stocks. A list of management measures specific to Arrowtooth Flounder is included in Table 3.

Following the 2007 assessment of Arrowtooth Flounder, the ABC (now referred to as the overfishing limit, OFL), increased from 5,800 to 11,267 metric tons. Recent landings, however, have remained relatively stable (Table 1), likely as a result of constraining bycatch of rockfish and Pacific Halibut as well as limited market conditions for Arrowtooth Flounder. In 2011, NOAA Fisheries implemented the West Coast Groundfish Trawl Individual Fishing Quota (IFQ) or “catch shares” program. This system creates individual quotas for most of the managed groundfish species. This change in management system has likely affected fishing behavior and effort.

The 2017 OFL is 16,571 metric tons, based on the most recent catch-only update assessment (Wallace and Budrick, 2015). A 16.7% reduction in the 2017 OFL due to scientific uncertainty (the P* approach for a Category 2, catch-only update) resulted in an ACL of 13,804 mt.

Management performance

The 2007 stock assessment estimated Arrowtooth Flounder to be at 79% of the estimated unfished spawning biomass (95% CI: 58.1%-99.5%). Based on that assessment, the 2009 coast-wide ACL was increased from 5,800 mt to 11,267 mt. Following the 2009 assessment of Petrale Sole and based on analysis and advice of the Scientific and Statistical Committee (SSC), the Council adopted new default reference points for west coast flatfish species: an F_{MSY} proxy of F30%, a B_{MSY} proxy target of $B_{25\%}$, and a minimum stock size threshold (MSST) of $B_{12.5\%}$ (half of the B_{MSY} proxy). Fishing mortality rates (measured in terms of SPR) have been below the current F-target for flatfish of $SPR_{30\%}$ and the current assessment estimates that Arrowtooth Flounder at the start of 2017 are 86.6% of the estimated unfished spawning biomass and will be slightly larger at the start of 2018 even if 2017 catches attain the ACL. Recent coast-wide annual landings have not exceeded the ACL.

A summary of performance of the fishery relative to overfishing levels and annual catch limits is given in Table 4.

Description of fisheries for Arrowtooth Flounder off Alaska and Canada

Eastern Bering Sea

Arrowtooth Flounder is managed as a single stock in the Eastern Bering Sea and the Aleutian Islands (BSAI), although little is known about stock structure. Historically, Arrowtooth Flounder have been mostly discarded at sea and continue to be captured primarily in pursuit of higher value species in the BSAI. However, the percentage of Arrowtooth Flounder retained in catches has increased and remained high in 2015 (84%) and 2016 (83%) with the implementation of regulations and initiatives by the North Pacific Management Council and National Marine Fishery Service (NMFS) to reduce bycatch and discard of fish species in the BSAI (Spies, et al 2016). An age-structured stock assessment model, developed using AD Model Builder software, was used to model the population dynamics of Arrowtooth Flounder in the BSAI. The model is a length-based approach where survey and fishery length-composition observations are used to calculate estimates of population numbers-at-age using a length-age (growth) matrix. Total catch estimates, trawl survey biomass estimates and associated standard errors from the eastern Bering Sea shelf, eastern Bering Sea slope, and Aleutian Islands surveys, and sex-specific trawl survey length-frequencies and fishery length-frequencies from observer sampling were included in the assessment. Model runs were evaluated with natural mortality fixed at 0.2 yr^{-1} for females and 0.35 yr^{-1} for males. Parameters in the model were estimated simultaneously using the maximum likelihood estimation procedure. The 2016 model estimates total biomass (910,012 tons) to be lower than the 2014 assessment (1,023,440 tons) and observes a downward shift in historical biomass, with the projected age 1+ total biomass for 2017 at 779,195 tons (Figure 3).

Gulf of Alaska

Arrowtooth Flounder are managed as a single stock in the Gulf of Alaska (GOA). Historically, Arrowtooth Flounder has not been targeted as a commercial fishery; however, recent processing developments have resulted in "arrowshimi" being successfully marketed from Arrowtooth Flounder, which is typically sold in Asian markets. Starting in 2006, GOA Arrowtooth Flounder was moved to a biennial stock assessment schedule to coincide with the annual GOA groundfish trawl surveys. These surveys occur in odd years, and for these years a full assessment of Arrowtooth Flounder is conducted. In 2015, a new generalized model was introduced to run Arrowtooth Flounder BSAI and GOA stock assessment models (Spies, et al 2015). The model structure was developed following Fournier and Archibald's (1982) methods, with parameters estimated using AD Model Builder. Natural mortality was fixed at 0.2 yr^{-1} for females and 0.35 yr^{-1} for males in the model, and weight at age data were fit to a von Bertalanffy growth curve. Data components included fishery catch, the International Pacific Halibut Commission trawl survey, fishery size-compositions, and NMFS trawl and exploratory surveys (including age- and length-compositions). Estimates of Arrowtooth Flounder biomass in the current GOA model have increased from a low of 390,626 tons in 1970 to a high of 2,103,860 tons in 2016. The stock is not overfished and is not approaching an overfished state.

British Columbia

In 2015, a formal statistical catch-at-age model (Integrated Statistical Catch-at-Age Model) was used for the first time to assess Arrowtooth Flounder in British Columbia (DFO 2015). This annual, female-only model was applied and tuned to four series of fishery-independent trawl surveys, annual estimates of commercial catch since 1996, and age-composition data from the commercial fishery and from three of the four survey series. Estimated parameters included natural mortality, survey catchability, recruitment, and selectivity. A Bayesian Markov Chain Monte Carlo procedure was used to calculate the uncertainty associated with parameter estimation. The spawning biomass has remained relatively stable, with a moderate increasing trend over the time series and a median spawning biomass estimate (mature females only) at the start of 2015 of 296,271 tons (Figure 4). Catches of Arrowtooth Flounder have continued to stay well below the total allowable catch of 15,000 tons.

Data

Fishery-dependent data

Washington landings and discards

Arrowtooth Flounder landed in Washington are primarily caught by commercial trawl gear. Recreational removals of Arrowtooth Flounder were not accounted for but are assumed to be negligible.

Washington – Historical commercial landings (1916 – 1986)

Unlike Oregon and California, which have developed and published historical groundfish landings reconstructions, at the time this assessment was being prepared Washington had not completed a historical reconstruction. However, reconstructed landings for Arrowtooth Flounder back to 1978 were available and used in the current assessment. The Washington landings reconstruction project had not yet been able to apportion landings of Arrowtooth Flounder before 1978 to those caught in US waters versus those caught in Canadian waters. The Washington series of Arrowtooth Flounder landings available from the 2007 assessment was considered to be incomplete. Non-zero landings of Arrowtooth Flounder in that series began in 1956 with landings of 1910 mt. To extend the series backwards in time, which seemed much more reasonable than assuming there had been no landings, we used the state landings series from the 2007 assessment to develop a ratio estimator with which we estimated Washington landings of Arrowtooth Flounder from Oregon landings of Arrowtooth Flounder. The WA-to-OR ratio of Arrowtooth Flounder is quite variable (Figure 5, lower panel), but for the years 1956-1980 they are reasonably well correlated ($r = 0.703$, $r^2 = 0.494$). We chose to use the period 1956-1960 as being most representative of the WA-to-OR ratio for the period prior to 1978 and used this ratio (0.988) to derive Washington landings of Arrowtooth Flounder for years prior to 1978.

Washington – Modern commercial landings (1978 – 2016)

Annual commercial landings of Arrowtooth Flounder from Washington from 1978 – 2016 were obtained from Washington's fish ticket system (WaFT; accessed 04/12/2017, K. Hinton, WDFW). We chose to not use landings data for Washington from the Pacific Fishery Information Network (PacFIN, http://pacfin.psmfc.org/) due to large discrepancies for some years with the data from the WaFT system, on which the PacFIN data were supposed to be based. PacFIN staff were made aware of these discrepancies.

Washington – Estimation of commercial discards

Landings data for Arrowtooth Flounder and Dover, English, and Petrale Sole were extracted from WaFT (accessed 04/12/17; K. Hinton, WDFW) for trips that landed Arrowtooth Flounder, as well as trips that did not land Arrowtooth Flounder, but that had landed Dover, English, or Petrale Soles. The first series was used to derive estimated discards of Arrowtooth Flounder for the fillet fleet; the second series was used to derive estimated discards of Arrowtooth Flounder for the "discard fleet" by applying discard ratios to the summed landings of Dover, English, or Petrale Sole for trips that did not land Arrowtooth Flounder. Details of the methods used to derive the discard estimates are provided below in the section *Methods used for estimating discards by the fillet fleet and "discard fleet"*.

Because the Washington landings reconstruction for landings of the three Sole species were not available for the years prior to 1978, we needed an approach for deriving landings of the three Sole species to which we could apply the discard ratio and estimate a catch series for the discard fishery. We took the Dover Sole landings for Washington from the 2011 stock assessment for Dover Sole (Hicks and Wetzel, 2011), but state-level landings series for English Sole and Petrale Sole were not available in the recent published stock assessments for those species. We derived estimates of the annual landings of English Sole using the ratio of the landings of English Sole during 1978-1987 over the landings of Dover Sole during the same years and the same approach for Petrale Sole and for the "SOLE-GENERAL" category. The 1978-1987 landings for the Sole species were only from trips that also landed some Arrowtooth Flounder. The ratios were 0.1194 for English Sole, 0.1297 for Petrale Sole, and 0.0083 for SOLE-GENERAL. These landings series are shown in Figure 6.

Oregon landings and discards

Arrowtooth Flounder landed in Oregon are primarily caught by commercial trawl gear. Very few are landed recreationally; recreational removals were assumed to be negligible and were not accounted for.

Oregon – Historical commercial landings (1916 – 1986)

Historical commercial landings of Arrowtooth Flounder from Oregon were included in the assessment's catch series for the period 1916 to 1986. The Oregon Department of Fish and Wildlife (ODFW), in cooperation with the Northwest Fisheries Science Center, completed a comprehensive commercial landings reconstruction in 2014 for all commercially landed species from 1886 – 1986 (Karnowski et al. 2014). The reconstruction does not include estimates of recreational landings, foreign fleet catches, or discards of commercial landings. Historical landings in Oregon of Dover Sole, English Sole, and Petrale Sole were also used to estimate historical discards of Arrowtooth Flounder.

The reconstruction methodology included multiple data sources and several steps. First, the annual landings were determined by gear of each market category, which typically included multiple species historically. Species-compositions were then developed for each market category by gear, year, and where available, spatial stratum. These species-compositions were applied to the market categories and summed across gear types to obtain a species-specific landings time series. Details of the reconstruction methodology can be found in Karnowski et al. (2014), and the landings data series are available upon request from ODFW.

Although the PacFIN system houses Oregon landings data for the years 1981-1986, these data are considered to be incomplete compared to the data available from the ODFW commercial landings reconstruction. The methods used to develop the Oregon data housed in PacFIN are now considered to be incorrect for the years prior to 1986.

Oregon – Modern commercial landings (1987 – 2016)

Annual commercial landings of Arrowtooth Flounder from Oregon from 1987 – 2016 were obtained from PacFIN (accessed March 16, 2017; P. Mirick, ODFW).

Oregon – Estimation of commercial discards

To estimate the amounts of Arrowtooth Flounder discarded annually, trips with any landings of Dover Sole, English Sole, and Petrale Sole were obtained from PacFIN (accessed March 16, 2017; P. Mirick, ODFW). These trips were separated into trips that landed Arrowtooth Flounder (the fillet fleet) and those that did not (to derive estimated discards of Arrowtooth Flounder for the “discard fleet”). Details of the methods used to derive the discard estimates are provided below in the section *Methods used for estimating discards by the fillet fleet and “discard fleet”*.

California landings and discards

The California landings reconstruction (Ralston et al. 2010), which was completed since the last full assessment in 2007, forms the basis for the historical California landings data used in this update assessment. Compared to the landings data used in the 2007 assessment, the reconstruction provides more representative estimates of landings for the period prior to 1981. The CalCOM program (California Cooperative Groundfish Survey, http://calcomfish.ucsc.edu/) or PacFIN programs provided landings data for all years thereafter through 2015. Preliminary landings data for 2016 were obtained from D. Pearson (NMFS, Southwest Fisheries Science Center (SWFSC)).

The trawl fishery is the primary source of both landings and discards of Arrowtooth Flounder in California, with only limited amounts being caught by the recreational and commercial fixed-gear fisheries.

Depending on the time period and fleet, either landings of Arrowtooth Flounder or landings of Sole species (Dover, English, and Petrale Soles, to which discard rates for Arrowtooth Flounder were applied) were used to account for the Arrowtooth Flounder catches (landings plus discards). Landings were extrapolated or interpolated for periods for which the fisheries encountering these species were known to occur, but no landings were reported. Landings for Arrowtooth Flounder were interpolated for the period 1946 to 1949 with a linear ramp between the average landings from 1943 to 1945 and the average landings from 1950 to 1952. Landings of Arrowtooth Flounder were extrapolated for 1916 to 1932 using the average of landings from 1943 to 1945 with a linear ramp down to zero in 1916. Landings data were not available for Dover Sole from 1916 to 1942 so a linear ramp, from zero in 1916 to the average of landings from 1943 to 1945, was used to provide approximate values. Dover Sole landings for 1946 and 1947 were estimated using the average from 1943 to 1945 for 1946 and the average from 1948 to 1950 for 1947. Linear ramps provided approximate landings for English and Petrale Sole from 1916-1930, starting from zero in 1916 and increasing to the 1931-1945 average values.

Because market demand for Arrowtooth Flounder is limited and has varied over time, catches of Arrowtooth Flounder are often discarded at sea and accounting for discards of Arrowtooth Flounder caught incidentally while pursuing more desirable species was an integral aspect of estimating total catches of Arrowtooth Flounder. The assessment assumes that Arrowtooth Flounder were regularly discarded in the trawl fishery while targeting co-occurring Dover, English, and Petrale Soles. The Arrowtooth Flounder discards by the fillet fleet were estimated by applying discard fractions to the landings of Arrowtooth Flounder; Arrowtooth Flounder discards by the “discard fleet” were estimated by applying discard ratios to the landings of the three Sole species. Details of the methods used to derive the discard estimates are provided below in the section *Methods used for estimating discards by the fillet fleet and “discard fleet”*.

Discard fractions and discard ratios

This update assessment apportions the catches of Arrowtooth Flounder to three fleets, as explained above in the section *Important features of current fishery and relevant history of fishery*. The catch series for the fillet fleet and the “discard fleet” include annual estimates of the discarded amounts of Arrowtooth Flounder. Discard fractions were applied to the landed catches of Arrowtooth Flounder to estimate the total catch based on the following relationship.

$$Catch = Landings \,/\, (\, 1 - Discard\_fraction \,)$$

Discard ratios were applied to the landed catches of Dover Sole, English Sole, and Petrale Sole to estimate the total catch of Arrowtooth Flounder by the "discard fleet" based on the following relationship.

$$Arrowtooth\_catch = Discard\_ratio * sum(\, Dover, English, Petrale\ Soles\ landings\,)$$

Estimated values for the discard fractions and discard ratios were derived on a state- and year-specific basis from observer data of at-sea discards of Arrowtooth Flounder. The discard fractions were based on data from observed trips that landed Arrowtooth Flounder; the discard ratios were based on data from observed trips that landed any Dover, English, or Petrale Soles, but no Arrowtooth Flounder. The at-sea discard observations were from two time periods, 1985-1978 (the Pikitch study, data provided by J. Wallace, NWFSC) and 2002-2015 (West Coast Groundfish Observer Program, WCGOP). The estimated discard fractions and discard ratios are provided in Table 5 and displayed in Figure 7.

Methods used for estimating discards by the fillet fleet and "discard fleet"

We used similar methods for all three states to estimate the annual discards by the fillet fleet and "discard fleet". The overall biomass discard ratio of Arrowtooth Flounder relative to the sum of Petrale Sole, Dover Sole, and English Sole landings, was the ratio of the total discard of Arrowtooth Flounder to the total landings of these three species in all observed trips without Arrowtooth Flounder landings. This was done for the entire coast and for each state individually, for observed years 2002 through 2010 combined, as there was an expectation of a change in discarding behavior following the implantation of catch shares in 2011. The resulting discard ratios were 0.128 for the entire coast (matching the result for the 2007 assessment, but not used), and 0.517 for WA, 0.096 for OR, and 0.015 for CA. The discard fractions were calculated using a similar approach but using the amounts of discarded Arrowtooth Flounder on observed trips relative to the amounts of Arrowtooth Flounder caught on those same observed trips.

Year- and state-specific estimates of the discard fractions and discard ratios, which were available for the years 2002-2015 (Table 5), were multiplied with the corresponding landings series: landings of Arrowtooth Flounder by state for the fillet fleet; summed landings by state of Dover, English, and Petrale Soles for the "discard fleet". For 2016, for which no observer data were available, we applied the average for each state of the discard fractions and ratios for 2013 to 2015. For years prior to 2002 we used an assumed 9.0% discard fraction for all three states to derive the state-specific discards of Arrowtooth Flounder by the fillet fleet and the following assumed discard ratios to derive the state-specific discards of Arrowtooth Flounder by the "discard fleet": 0.50 for Washington; 0.10 for Oregon; and 0.015 for California. The assumed discard fraction and discard ratios are roughly in keeping with average observed values (see Figure 7).

There are some slight inconsistencies in how we developed the estimated discards for each state's "discard fleet" and how they are applied. The discard ratios were based on observer data for trips that did not land Arrowtooth Flounder and are likely to differ from ratios based on data from all trips (including ones that landed Arrowtooth Flounder). However, we did not always have landings series for the three Sole species that were restricted to trips that did not land Arrowtooth Flounder. Such landings series were available as follows: for the years 1978 to 2016 for Washington; for 1981 to 2016 for Oregon. The available California landings series were for all trips, including those that landed Arrowtooth Flounder. In hindsight, we probably should have developed and applied two sets of discard ratios (the set we developed, based on trips that did not land any Arrowtooth Flounder, and another set for all trips, including those that landed Arrowtooth Flounder) and applied the ratio that was appropriate for the available landings series. We are of the opinion that this would have had a small influence on the resulting catch series as outlined below.

In fact, values for all observed hauls (including ones on trips that did not land Arrowtooth Flounder) from 2002-2010 provide ratios of 0.509 (versus 0.517 if restricted to trips that landed Arrowtooth Flounder) for WA, 0.063 (vs 0.096) for OR, and 0.014 (vs. 0.015) for CA, and 0.094 (vs. 0.128) coastwide. The discard ratios (versus the three other flatfish species) are 0.102 (vs. 0.517) for WA, 0.047 (vs 0.096) for OR, and 0.009 (vs. 0.015) for CA, and 0.094 (vs. 0.128) coastwide for only those hauls that retained Arrowtooth Flounder. If the values by state were applied that included hauls retaining Arrowtooth Flounder, only Oregon would have an appreciably different result. Note that in the early years, it is not likely that Arrowtooth Flounder were targeted and retained in any substantial numbers, and using these alternative numbers from many decades later depends upon the relative number of hauls that targeted and/or at least retained Arrowtooth Flounder versus those that did not.

Catch series: 2007 assessment versus 2017 update assessment

Figure 8 compares the catch series used in the 2007 assessment with those used in the current update assessment. There are some notable differences in the historical catches prior to 1981 (the PacFIN era). The cumulative landings by the mink-food fishing fleet at the end of 1980 (the last year any catches were associated with the mink-food fleet) were slightly less than 36 thousand mt in the 2007 assessment and somewhat larger in the 2017 updated catch series, almost 44 thousand mt. However, there are relatively larger differences in earlier years. For example, the cumulative catches at the end of 1941 were 2174 mt in the 2007 assessment versus only 267 in the update. All of the mink-food catches prior to 1942 in the 2007 assessment were attributed to landings in Oregon and the 2007 assessment document lists the NMFS Annual Commercial Landings database as the source of this information. We did not investigate where or how the NMFS database acquired its data series, but instead used landings data provided directly by the states as described in sections above.

Another large difference in the two catch series arises for the “discard fleet”. In the 2007 assessment the catches by the “discard fleet” begin abruptly with the first catches (1,449 mt) taken in 1956. In contrast, catches by the “discard fleet” in the current update assessment begin in 1917 and the cumulative catch at the end of 1956 is 14,538 mt. As described in sections above, the current update assessment used a variety of methods to develop catch reconstructions that did not assume catches of zero when no reported landings were available.

Catch estimates versus WCGOP total mortality estimates

Although this update assessment’s annual estimates of Arrowtooth Flounder discards were based on data collected by the WCGOP, the estimated catch series (landings plus discards) are not identical to the WCGOP estimates of total mortality of Arrowtooth Flounder (Table 6); for some years there are marked differences. For all years except 2004, the catches in this assessment are larger than the WCGOP total mortality estimates and over the period for which the WCGOP total mortality estimates are available (2004-2015) the update assessment estimates cumulative catches that are almost 8500 mt larger than the WCGOP total mortality estimates. Because we developed our own methods for estimating the discard fractions and discard ratios, and did this on a state-by-state basis, we were not expecting to find an exact correspondence between our estimates and those from WCGOP, but we do not know the exact source(s) of the discrepancies.

Compositional data from the fisheries

Commercial biological data from Washington, Oregon, and California were obtained from PacFIN (accessed April 25, 2017; J. Wallace, NWFSC). The download included length and age data for commercially sampled Arrowtooth Flounder. Landings for all three states were also obtained separately from PacFIN (accessed March 8, 2017; J. Wallace, NWFSC). Final length, age and age-at-length compositions were developed using the PacFIN Utilities R package (https://github.com/nwfsc-assess/PacFIN.Utilities). This package filters raw PacFIN biological data for unsuitable samples and expands the raw observations in two ways. The first expansion is to the sample level (a fishing trip), to account for fish that were not sampled, and the second expansion accounts for the size of the landing from which the sample data were obtained relative to the overall landings.

Summary tallies by state of the length and age data collected from the commercial landings are shown in Table 7. It is notable that no age data were available from California but the expansion process includes landings from California. Implicit in this expansion is the untested assumption that the age- and length-composition samples from Oregon and Washington are representative of the Arrowtooth Flounder landed in California.

Length-composition series for the fillet fleet were developed using two methodologies for expanding the sample compositional data to represent the compositions of the overall landings. In the first series, we used the PacFIN Utilities software package (in R) to develop coastwide length-compositions based on data downloaded from the PacFIN Biological Data Samples (BDS) repository. The second series was based on a separate California-only length-composition series provided by D. Pearson (SWFSC) on 04/24/2017. This series for California was combined with a length-composition series for Oregon and Washington to produce a second coastwide length-compositions data series. The Oregon/Washington series was processed using the PacFIN Utilities package and PacFIN BDS data for Oregon and Washington only. In theory the biological data for California housed in the PacFIN BDS are identical to the biological data housed in CalCOM, but the fishery sampling program in California has some unusual features compared to the programs in Oregon and Washington. There were some very large differences between the two length-composition series (e.g., Figure 9). There was insufficient time to identify the source(s) of the differences and resolve which data series was most accurate. For this update assessment we chose to use the length-composition series that was based only on the PacFIN data.

Fishery-independent data

While it is important that stock assessments include information taken directly from the fisheries on the biological characteristics of the fish, such data may paint a distorted picture of the stock's conditions because perceived changes in the traits of the fish were caused by changes in the fishing gear and/or fishing locations. Surveys conducted by fisheries agencies using standardized fishing gear and protocols provide data that are less prone to "measurement drift" and are an important element of stock assessments. This update stock assessment includes fishery-independent data from four sources, described below.

Survey biomass indices

The distribution of Arrowtooth Flounder covers the continental shelf and slope of the US West Coast. Because of the broad spatial extent of this population, the assessment used biomass indices from four independent west coast surveys conducted by the National Marine Fisheries Service, including the Alaska Fisheries Science Center (AFSC) Triennial shelf survey; the AFSC slope survey; the Northwest Fisheries Science Center (NWFSC) slope survey; and the NWFSC slope-shelf survey. Only the data from the NWFSC slope-shelf survey were updated for this assessment, contributing an additional 10 years of survey data. The temporal spans of the various sources and types of data used in the assessment model, including data from the four surveys, are shown in Figure 10.

The AFSC Triennial survey was conducted every third year from 1977 – 2004. Details of the methods and data from the AFSC Triennial shelf survey are described in the 2007 assessment document (Kaplan and Helser 2007). Data from the AFSC slope survey were for the four years that the survey covered the full spatial range from the Canadian border to Pt. Conception up to 1000 meters depth (1997, 1999-2001). (Prior to 1997 this survey covered only a portion of the coast each year.) Additional information on the methods of the survey is described in Lauth et al. (1998) and in the 2007 assessment document. The current assessment made no changes to the AFSC Triennial or slope survey biomass indices or composition data.

From 1998 – 2002, the NWFSC conducted a "slope-only" survey designed to focus on a specific subset of West Coast groundfish species, including Sablefish, Dover Sole and thornyheads. The survey was based on a fixed-transect design and covered depths from 183-1280 m. As in the 2007 assessment, we included NWFSC Slope Survey data from 1999-2002. Additional information regarding the spatial extent and survey methodology can be found in Keller et al. (2005) and the 2007 assessment document. The current assessment made no changes to the NWFSC slope survey biomass index. No composition data were available for this survey.

In 2003, the NWFSC began conducting an annual coastwide shelf-slope survey covering depths ranging from 50 m to 1280 m. The survey, which is ongoing, uses a stratified random block design following similar protocols to the NWFSC slope survey. For the current update assessment we developed a revised and extended biomass index for the shelf-slope survey, including data for the years 2003 – 2016. The updated data were extracted from the NWFSC survey database on 04/28/2017 and represent the most current information available.

In the 2007 assessment, the authors developed a biomass index for each of the four surveys using biological features of the populations (average body size and catch density) to post-stratify the haul-specific data. The catch density by depth and latitude are illustrated in Figure 11. For this update assessment we adjusted the strata used for developing the biomass index and composition data series for the NWFSC shelf-slope survey, which was the only survey that extended beyond 2007. We chose to use the stratification scheme developed for the 2015 data moderate assessment of Arrowtooth Flounder (Cope 2015), which defined the strata boundaries to give at least five hauls catching Arrowtooth Flounder for each stratum. This resulted in six strata across two depth ranges, 55-183 m and 184-549 m. The latitudinal bounds of the strata were set at 37.5, 40.5, 44.0, 47.0, and 49.0 deg. (Figure 12).

Indices were developed using a Delta-GLM approach due to the high occurrence of zero-catch hauls in all the surveys. This approach uses a binomial error component for the presence or absence of Arrowtooth Flounder in the hauls and a gamma distribution for magnitude of the Arrowtooth Flounder catches in the positive hauls. This update assessment used the exact same biomass indices as the 2007 assessment for the AFSC Triennial, AFSC slope, and NWFSC slope survey. Details on applying the Delta GLM models to develop these indices can be found in Helser et al. (2004) and the 2007 assessment (Kaplan and Helser 2007).

There have been significant developments in the methods available to derive biomass indices based on trawl survey data since the 2007 assessment was conducted. The analysis in the 2007 assessment used the Delta-GLM "mixed-model" (Delta-GLMM) approach to develop the biomass index for the NWFSC shelf-slope survey. The "mixed" portion of the model refers to a vessel component being included as a random effect to account for variation resulting from the four separate vessels conducting the survey within each year and varying among years. Recent advances to the Delta-GLMM approach developed by Thorson et al. (2015) allow for spatiotemporal autocorrelation among locations and the model can be configured to explore parameters as either fixed or random effects. This new approach and associated software has proven to be faster and generally increases the precision in the biomass estimates (Thorson et al. 2015). While the geostatistical model developed by Thorson et al. (2015) differs from the method used in the 2007 assessment to develop the biomass index for the NWFSC shelf-slope survey, it can mimic the Delta-GLMM model used in the 2007 assessment if it is configured to exclude model components for spatial and temporal autocorrelations while allowing for a random vessel effect and random vessel-year interaction.

We attempted to apply the software used in the 2015 data moderate assessment for Arrowtooth Flounder (Cope 2015), which was a newer version of the software used for the 2007 assessment, but were unable to get the software to run.

The geostatistical Delta-GLMM approach (VAST, R package VAST available at https://github.com/james-thorson/VAST) was applied to the updated NWFSC Shelf-Slope Survey data using a configuration that mimics the analysis completed for the 2007 assessment. We modeled biomass with a binomial error component for the presence-absence of Arrowtooth Flounder and a gamma distribution for the biomass density (kg/ha) for positive-catch hauls, and included a random vessel effect term and a random vessel-year interaction term.

To evaluate the possible effect of changing from the Delta-GLMM approach used in the 2007 assessment to the approach implemented in the VAST model, we applied the VAST model to the NWFSC shelf-slope survey data for 2003 through 2006 with the same strata boundaries as the 2007 assessment and compared the biomass index produced by the VAST model to the biomass index used in the 2007 assessment. We obtained the results shown below.

	2007 Assessment		VAST		% diff
Year	Biomass (mt)	SD ln(Index)	Biomass (mt)	SD ln(Index)	
2003	23,976	0.25	25,796	0.16	3.66
2004	19,571	0.27	14,756	0.18	-14.03
2005	22,603	0.28	21,640	0.16	-2.18
2006	22,551	0.30	22,516	0.17	-0.08

The results are similar and the two indices are highly correlated (r = 0.996), but we note that the two indices are not on the 1:1 line and there was a 14% decrease for the 2004 index value. Overall, the uncertainty in the estimates of biomass was reduced using the VAST approach. Comparisons of these two biomass indices are shown in Figure 13, which also compares these indices to the standard swept-area biomass estimates produced as part of the NWFSC survey data package (values included in Table 10).

To derive the biomass index for the NWFSC shelf-slope survey for the update assessment we applied the VAST model to the complete data series for the survey using the modified strata boundaries described above and shown in Figure 12. The predicted biomass values by stratum and overall are given in Table 8.

Visual inspection of the Q-Q plot indicated a slight deviation from the assumed distribution for positive catch rates (Figure 14). Additionally, a map of Pearson residuals indicated a high occurrence of positive residuals, suggesting the model may have slightly underestimated the probability of encounter for Arrowtooth Flounder relative to the observed data (Figure 15).

Survey length-composition series

Length frequency samples were available for the AFSC Triennial and slope surveys and the NWFSC shelf-slope survey (but not for the NWFSC slope survey). We maintained the same length-composition series for the AFSC Triennial and slope surveys as in the 2007 assessment, both of which had relatively low sample sizes (< 44 tows/year). Details on the sample sizes associated with these surveys is presented in the 2007 assessment and not repeated here.

Updating the NWFSC slope-shelf survey series with new data contributed an additional 10 years of length observations to the time series (Table 9). Length frequencies were generated by sex using the stratification described above. Lengths were grouped into 2 cm bins ranging from 6 - 82 cm. The length frequencies were then expanded to the area associated with each stratum and weighted by numbers of fish (abundance) in each stratum to determine the annual length-compositions. The estimates of swept-area abundance used for the expansions for the revised NWFSC slope-shelf survey are provided in Table 10.

Survey age-at-length composition series

Four additional years of age-composition data (2013 - 2016) were included as part of the updated NWFSC shelf-slope survey data series. Ages were determined from otoliths processed and read by the Cooperative Aging lab in Newport, Oregon and compiled as both marginal and conditional age-at-length distributions by sex and year. Age distributions included single age bins for ages 1 - 28.

As in the 2007 assessment, the marginal compositions were included to provide a mechanism for displaying the model fits to the observations but these compositions did not directly inform the model's overall likelihood. Age data that informed the model took the form of conditional age-at-length compositions, which were configured as separate compositions by sex (as in the 2007 assessment) and included in the model's overall likelihood (as in the 2007 assessment). Using conditional age-at-length data avoids the problem of double-use of the same fish in both length- and age-compositions and is a better source of information for estimating growth coefficients. A more in-depth rationale is provided in the 2007 assessment document.

The update assessment model used the same ageing-error vectors as the 2007 assessment. One, associated with older surface reads of otoliths (prior to 1998), was assumed to be slightly biased.

The other, associated with break-and-burn age-readings, was assumed to be unbiased. As in the 2007 assessment, no double-age-readings were available for Arrowtooth Flounder and the standard deviation of aging error was taken from an English Sole assessment (Stewart 2007).

Sample sizes for the NWFSC length- and age-compositions are presented in Table 9.

Sources used to estimate biological parameters

Natural mortality

Hamel (2015) developed a method for combining meta-analytic approaches to relating the natural mortality rate *M* to other life-history parameters such as longevity, size, growth rate and reproductive effort, to provide a prior on *M*. In that same issue of the *ICES Journal of Marine Sciences*, Then et al. (2015) provided an updated data set of estimates of *M* and related life history parameters across a large number of fish species, from which to develop an *M* estimator for fish species in general. They concluded by recommending *M* estimates be based on maximum age (*Amax*) alone, based on an updated Hoenig non-linear least squares estimator $M = 4.899\ Amax^{-0.916}$. The approach of basing *M* priors on maximum age alone was one that was already being used for US West Coast rockfish assessments. However, in fitting the alternative model forms relating *M* to *Amax*, Then et al. (2015) did not consistently apply their transformation. In particular, in real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of *M* to *Amax*. Therefore, it would be reasonable to fit all models under a log transformation. This was not done.

Revaluating the data used in Then et al. (2015) by fitting the one-parameter *Amax* model under a log-log transformation (such that the slope is forced to be -1 in the transformed space (as in Hamel (2015)), the point estimate for *M* is:

$$M = 5.4 / Amax$$

The above relationship also provides the median value of the prior. The prior is defined as a lognormal with mean = ln(5.4 / *Amax*) and SE = 0.4384 and illustrated in Figure 16. Using maximum ages of 25 and 18 years for Arrowtooth Flounder females and males respectively (these being the third oldest ages in the slope-shelf survey database for each gender and regarding the top two ages as outliers in age estimation), the point estimates (and medians of the priors) for *M* are 0.216 yr^{-1} for females and 0.300 yr^{-1} for males. These values were used in the update assessment. The 2007 assessment used *M* values of 0.166 yr^{-1} for females and 0.274 yr^{-1} for males.

Sex-specific natural mortality and the sex-ratio

When the sexes do not experience the same mortality rate the sex-ratio will change with age. If one assumes a 50:50 sex-ratio at birth (as in the current assessment and in most assessments including the 2007 assessment) and constant mortality rates, the male-to-female sex ratio will conform to the following relationship (Sampson, 2015).

$$N_{Male} : N_{Female}(Age) = exp[(Z_{Female} - Z_{Male}) * Age]$$

Figure 17 explores the implications of the sex-specific natural mortality rates (*M*) used in the current assessment by plotting the predicted male-to-female sex ratio based on *M* values of 0.216 yr^{-1} for females and 0.300 yr^{-1} for males and comparing the predicted ratios at age with the values of the ratios based on the age-compositions by sex from the NWFSC slope-shelf survey from the early (2003-2006) and late (2013-2016) periods, for which survey age data are available. The observed ratios decline more steeply than the predicted curve, which suggests that the difference in total mortality rates between the sexes ($Z_{Female} – Z_{male}$) is greater than the difference in assumed natural mortality rates ($M_{Female} – M_{male}$).

Steepness

This update assessment used the same assumed value for the steepness of the Beverton-Holt spawner-recruit curve as had been used in the 2007 assessment, a value of 0.902. This value was the mean value of the prior from a meta-analysis by Martin Dorn (NMFS / Alaska Fisheries Science Center) of US West Coast stocks of flatfish. This meta-analysis has not been updated since the 2007 assessment (M. Dorn, AFSC, personal communication).

Maturity

Female length at maturity was modeled in the same way as in the 2007 assessment using a length-based logistic function:

$$\text{Proportion Mature} = 1 / (1 + \exp(\text{Slope} *(\text{Length} – \text{Inflection})))$$

Stark (2008) examined female maturity in the Gulf of Alaska and found that 50% of females were mature at 46 cm. There were no data from California, Oregon or Washington to inform new maturity estimates, and the differences between the Gulf of Alaska and the California Current System led us to use estimates from Rickey (1993) as was done for the 2007 assessment (Kaplan and Helser 2007). The *Slope* parameter was set at 0.5 and the *Inflection* parameter at 37.3 cm, which results in a relationship with 5% of females mature at 31cm, 50% mature at 37cm and 95% are mature at 43 cm (Figure 18).

Length-weight relationship

We estimated the parameters defining the length-weight relationship externally to the Stock Synthesis model using routines in R version 3.3.2 and a set of length and weight data for Arrowtooth Flounder collected during the NWFSC shelf-slope survey during 2003-2015. The length-weight relationship has the standard form

$$\text{Weight} = a * \text{Length}^{b}$$

A separate length-weight relationship was estimated for each sex. The estimated parameters were $a = 4.49 * 10^{-6}$, and $b = 3.197$ for females; $a = 5.434 * 10^{-6}$ and $b = 3.132$ for males (Figure 19).

Environmental or ecosystem data used

The 2007 assessment did not include any environmental drivers (e.g., for recruitment) or use any ecosystem data. Biological parameters for recruitment, natural mortality, and growth were assumed to be time-invariant. Because the current assessment is an update, we could not add complications such as environmental drivers to the model. Further, there is too little known about the population dynamics of Arrowtooth Flounder to justify the use of an environmental driver. Doing so would be based on pure speculation.

Model

History of modeling approaches used for this stock.

The most recent full stock assessment for Arrowtooth Flounder off the US West Coast was the 2007 assessment by Kaplan and Helser (2007), for which the current assessment is an update. The structure and data elements for that assessment will be described below in the section *Description of the base model and general model specifications*, where we provide details of the current update assessment model.

There have been two other stock assessments for Arrowtooth Flounder off the US West Coast. One, Rickey (1993), compiled available information regarding the stock and its biological traits and conducted an equilibrium analysis to derive yield-per-recruit estimates and fishing rate targets (e.g., $F_{0.1}$ and $F_{35\%}$). That assessment did not estimate biomass trajectories or evaluate stock status. The other assessment, Cope (2015), was a data moderate assessment that used catch series and biomass indices but no compositional data and the model had a greatly simplified structure (e.g., no recruitment deviations and selection curves were taken from the 2007 assessment). The assessment attempted three different approaches to estimation: maximum likelihood estimation, Markov chain Monte Carlo, and Extended Simple Stock Synthesis (XSSS, Cope et al. 2013). The last two approaches are fully Bayesian. The assessment was not accepted by the PFMC's Scientific and Statistical Committee for technical reasons. The SSC minutes state

> "… the Bayesian analyses all exhibited results that were unexpected given the observed data or had reused the data inappropriately, and MLE-based approaches are not endorsed for data-moderate assessments. The difficulty in obtaining robust results using data moderate methods may be due to the history of light exploitation of arrowtooth flounder, and survey indices that show flat or increasing trends."
>
> SSC Minutes, June 11-12, 2015

Because the Cope (2015) data-moderate assessment was not accepted for providing management advice, a catch-only update of the 2007 assessment was prepared (Wallace and Budrick, 2015) to produce revised projections of catch and spawning biomass.

Responses to 2007 STAR panel recommendations

The 2007 STAR panel made three recommendations specific to the assessment for Arrowtooth Flounder, indicated below in italics and followed by the update STAT's responses.

- *The Arrowtooth Flounder catch history should be reconstructed using all available data including catch by gear and by region. The reconstruction should include an envelope of high and low values to set bounds for exploration of alternative catch histories. As has been recommended previously by a variety of STAR Panels, the reconstruction of historical landings needs to be done comprehensively (i.e., with other species) to ensure efficiency and consistency.*

Groundfish historical landed catch reconstructions were completed for California in 2010 (Ralston et al., 2010) and for Oregon in 2014 (Karnowski et al., 2014) and a reconstruction for

Washington is currently underway. Although the Washington reconstruction has focused for this assessment cycle on species other than flatfish, a partial reconstruction for Arrowtooth Flounder was available back to 1958. For this update assessment the STAT did its own reconstruction of Washington landed catch of Arrowtooth Flounder for years prior to 1958 (described above in the sections *Washington – Historical commercial landings (1916 – 1986)* and *Washington – Estimation of commercial discards*).

The states' historical reconstructions have only been for landed catches but significant amounts of Arrowtooth Flounder are caught and discarded at sea. For this update assessment the STAT did its own reconstruction of at-sea discards, based primarily on information from the WCGOP, as described in section *Methods used for estimating discards by the fillet fleet and "discard fleet"*.

The states' reconstructions did not develop "high and low values to set bounds for the exploration of alternative catch histories", although work is currently underway to develop methods for estimating uncertainty in catch estimates when they are based on species-compositions (e.g., rockfish, see PFMC 2017). For this update assessment the STAT developed alternative catch histories using discard proportions to account for uncertainty in the at-sea discards associated with landed catches of Arrowtooth Flounder (made by the fillet fleet) and discard ratios to account for uncertainty in the at-sea discards of Arrowtooth Flounder associated with landed catches of Dover Sole, English Sole, and Petrale Sole (made by the "discard fleet"). This is described below in section *Sensitivity to catch histories*.

- *Evaluate the feasibility of a bi-lateral assessment with Canadian scientists, perhaps through the TSC (Technical Subcommittee of US Canada groundfish working group).*

Conducting an assessment of Arrowtooth Flounder across an increased portion of its geographic range is beyond the scope of an update assessment. Furthermore, international coordination and planning for trans-boundary assessments will require inter-governmental agreements and commitments that only currently exist for a few species (e.g., Pacific Halibut and Pacific Hake).

- *Investigate the importance of calendar date on catch rates from the triennial survey and propose an adjustment, if needed.*

The current STAT did not investigate the issue of how survey timing might affect the survey biomass index or compositional data for Arrowtooth Flounder. This issue, which applied primarily to the Triennial shelf survey (e.g., see Stewart, 2007) is much less of a concern today because the annual NWFSC slope-shelf survey has been much more consistent in its timing and sampling protocols.

The 2007 STAR Panel also made some recommendations for all groundfish assessments, to which the STAT offers no responses.

New modeling approaches and changes from the 2007 assessment

Because this is an update assessment the STAT was limited in the changes it could make to the assessment model structure. The primary changes were with the data used to estimate parameters of the model, which included revisions to most of the data series included in the 2007 assessment and extensions of the series to 2016.

Bridge from the 2007 assessment

The 2007 assessment for Arrowtooth Flounder was conducted in Stock Synthesis version 2.0g. Rather than working with this now-outdated software, the STAT began bridging to the 2017 assessment model by transitioning in two steps to the newest version of the Stock Synthesis software (version 3.30.01.12). The transitions involved rearrangements of the data series in the assessment model, but no changes to the data values. The first step was a hand-translation of the SS 2.0 input files so they would work with Stock Synthesis version 3.24; the second step was a semi-automated translation of the version 3.24 input files so they would work with Stock Synthesis version 3.30. This second step was accomplished using the special-purpose software, SS_trans.exe.

The translation from SS 2.0 to SS 3.24 resulted in some small changes in the stock assessment results. For example, the estimate of unfished spawning biomass increasing by 0.19%; the estimate of spawning biomass in 2006 increasing by 1.06%. The translation from SS 3.24 to SS 3.30 also resulted in changes in the results. The estimate of unfished spawning biomass increased an additional 0.13% and the estimate of 2006 spawning biomass increased by an additional 0.44%. The changes are almost imperceptible in Figure 20. Additional details are provided in Table 11.

The SS 2.0 model included some "ghost fleets" that provided a mechanism for including marginal age-composition data that would not influence the model's fit to the overall data but would produce predicted fits to the observations, for visual inspection. These ghost fleets were removed from the model, reducing the number of fleets from nine to seven. In the update model marginal age-compositions are assigned directly to their associated fleets and flagged (using a negative index number) so that Stock Synthesis does not include them in the likelihood computations but still outputs fitted values for visual inspection.

<u>Part 1: Revised data through 2006, revisions to priors (M) and other control file adjustments</u>

For most of the data series included in the update assessment we changed what was used in the 2007 assessment. Some of the most substantial changes were in the catch series. For example, in the data underlying the 2007 assessment there was an abrupt and dramatic increase in the catch in 1956, which jumped to 1911 mt from zero landings of Arrowtooth Flounder in Washington for all prior years. Also, there were no landings of Arrowtooth Flounder in California prior to 1950 in the 2007 assessment. For the current update assessment we extended the catch series back to 1916 for all three states. We also developed revised series for the compositional data from the fishery (the fillet fleet and "discard fleet") and a revised biomass index for the NWFSC slope-shelf survey and associated compositional data, for which there were many more years of data available than in 2007. Because there were no new data available for the other three surveys (the Triennial shelf survey, the AFSC slope survey, and the NWFSC slope survey), the data from the 2007 assessment for these surveys was left intact.

We added revised data to the SS 3.30 version of the 2007 assessment model in a stepwise manner, as outlined in Table 11 (steps E to L), noting changes in the assessment results at each step. Also during this phase of the bridging process we updated the natural mortality coefficients (step M), the coefficients for the length-weight relationships (step N), and turned on a feature that estimates an "*extra_SD*" parameter for each of the survey catchability coefficients (step O). These *extra_SD* parameters allow for extra variability in the survey process that is not accounted for by the survey biomass standard deviations that are input to the model. The 2007 assessment used an iterative tuning approach to account for extra variation in the survey catchability coefficients for all surveys except the NWFSC slope-shelf survey. At the last step (P.1) the model was tuned using the McAllister-Ianelli approach to adjust the input effective-N values that control the relative weights given to the different compositional data sources. Also, the bias-adjustment coefficients for the spawner-recruit relationship were iteratively tuned using the coefficient values calculated by the R4SS software, which was applied after most of the Synthesis runs to monitor the assessment results.

Some of the more dramatic changes in the assessment results for spawning biomass are shown in Figure 20. Updating the fishery age-composition data (at step G) and the priors for natural mortality (at step M) produced quite large changes in the spawning biomass trajectory, indicating the importance of these particular model elements.

<u>Part 2: New data through 2016</u>

After revising all the data elements in the developing model up through 2006 and making the other changes noted directly above, we made some needed adjustments to the model dimensions and then added new data elements as appropriate for the years 2007 through 2016 (steps Q.1 to Q.4). We also added an *extra_SD* parameter for the NWFSC slope-shelf survey (step T), even though the survey catchability coefficient for this survey had not been tuned in the 2007 assessment model.

After revising the data through 2016 and making various other stepwise adjustments as detailed in Table 12 the model was once again iteratively retuned (step U). Also, an additional round of model tuning was required after a new version of the Stock Synthesis software was released on 05/09/2017 (step V). Some of the steps led to large changes in the assessment model's estimates of the spawning biomass trajectory, as illustrated in Figure 21.

The final set of McAllister-Ianelli tuning weights for the compositional data and Methot and Taylor (2011) recruitment bias-adjustment coefficients for the base model are given in Table 13.

Description of the base model and general model specifications

The model for this update assessment conformed to the basic structure used in the 2007 assessment except as noted below. The major changes were in the data to which the model was fitted, which have been described in various sections above.

To conduct this assessment we used the Stock Synthesis executable file identified as version SS-V3.30.03.03-opt, compiled on 05/08/2017. The 2007 assessment was conducted using the SS 2.0g software.

Model structure

In the update assessment model there are three fleets (fisheries) described as (1) the mink-food fleet, (2) the fillet-fleet, and (3) the "discard fleet". The model does not have any internal mechanism to account for the discarding of fish. Instead, discards were included in the catch series input to the model for the fillet and "discard" fleets. The discards were calculated using the methods described above in section *Methods used for estimating discards by the fillet fleet and "discard fleet"*. The selection curves for the fishing fleets were entirely length-based and all were assumed to be asymptotic in shape. It was not possible to estimate selection curve parameters for the mink-food fleet because there are no length-composition data for this fleet. Instead the 2007 STAT fixed the selection curve parameters for this fleet at values that were roughly equivalent to the selection curve parameters associated with the Triennial shelf survey.

We did not change from this approach and simply used the parameter values chosen by the 2007 STAT.

There are four surveys in the model: (1) the NWFSC slope-shelf survey (2003-2016); (2) the Triennial Shelf Survey (1980-2004); (3) the AFSC slope survey (1997, 1999-2001); and (4) the NWFSC slope survey (1999-2002). These fleets (as ordered here) are identified in the Stock Synthesis model as fleets 4 to 7. The index for the NWFSC slope-shelf survey was updated as described above in the section *Survey biomass indices*. The biomass indices for surveys (2) through (4) had no additional years of data available and were taken directly from the 2007 assessment without modification. As noted in that section we diverged from the 2007 assessment in terms of the software and statistical model we used to develop the index. The selection curves for the surveys were entirely length-based and all were assumed to be asymptotic in shape for the females with offsets for the males that allowed the male selection curve to be dome-shaped.

The assessment model includes observed age- and length-compositions by sex from the fillet fleet and additional (but still limited) observations from the "discard fleet". Length-compositions were also available for all surveys except the NWFSC slope survey. The selection curve for this survey was mirrored from the AFSC slope survey, as was done in the 2007 assessment model. Age readings from otoliths were available for some years for the landed catches by the fillet fleet and for the NWFSC slope-shelf survey and were treated as separate compositions by sex. Figure 10 provides an easily understood visualization of the different sources of composition data and their availability by fleet and year.

The assessment model treats the sexes separately to account for the large differences in growth, with female Arrowtooth Flounder attaining much larger sizes than males. As in the 2007 assessment, the only growth parameters that were estimated were the maximum length parameter and von Bertalanffy growth coefficient, both of which differed by sex. The sexes have distinct assumed rates of natural mortality (0.216 yr^{-1} for females; 0.30 yr^{-1} for males) that were based on an updated meta-analysis of the relationship between natural mortality and maximum age for other flatfish species. The 2007 assessment used the following rates of natural mortality: 0.166 yr^{-1} for females and 0.274 yr^{-1} for males.

The assessment model uses the same ageing-error vectors as the 2007 assessment. One, associated with older surface reads of otoliths (prior to 1998), is assumed to be slightly biased. The other, associated with break-and-burn age-readings, is assumed to be unbiased.

Recruitment is modeled using a Beverton-Holt stock-recruit curve with steepness fixed at 0.902, as in the 2007 assessment. The σ_R parameter that controls recruitment variability was fixed at 0.8, as in the 2007 assessment. The update assessment model begins in 1916 from an equilibrium age-structure with assumed catches of zero in prior years, which is also how the 2007 assessment was configured.

Changes from the 2007 assessment model structure

The update assessment model estimated *extra_SD* parameters for all four surveys, which is a slight departure from the configuration of the 2007 assessment model, which estimated additional variance components only for the Triennial shelf and AFSC slope surveys. Other changes from the 2007 assessment, not noted in the section directly above, were the use of updated coefficients for the length-weight relationships.

Model parameters

The parameters used in the update assessment model are listed in Table 14, along with their lower and upper bounds and an indication of whether each parameter was fixed or estimated.

Base model selection and evaluation

Because this was an update assessment we were very constrained in the changes we could make to the model structure. Consequently we did no exploration to evaluate the possible advantages of using other model forms, such as time-varying selection or allowing domed selection in the fishing fleets.

Likelihood profile on natural mortality

Because natural mortality is a key parameter in any stock assessment, we conducted likelihood profiles simultaneously across the *Female_M* and *Male_M* parameters, which in the base model were fixed at the median values of the priors developed by Owen Hamel (see section *Natural mortality* above). The values in the base model were 0.216 yr^{-1} for *Female_M* and 0.300 yr^{-1} for *Male_M*. The likelihood surface is shown in Figure 22 and the corresponding values of unfished spawning biomass are shown in Figure 23.

We attempted to estimate the *Female_M and Male_M* parameters in a sensitivity run but the model did not converge and produced nonsensically large estimates of spawning biomass. However, when fixing *Female_M* and estimating *Male_M*, it was estimated at 0.307 yr^{-1}, quite close to the fixed value.

Likelihood profile on spawner-recruit steepness

The likelihood profile over the spawner-recruit steepness parameter (Figure 24) indicated that the data available to the assessment model provide little information regarding the value of steepness.

Likelihood profile on ln(*R*0)

The likelihood profile over the ln(*R*0) parameter (Figure 25 and Table 15) indicated tensions among the likelihood components, with the length-compositions (and the survey biomass indices, to a lesser extent) tending to force ln(*R*0) away from lower values and the age-at-length compositions tending to force ln(*R*0) away from higher values. These tensions among the different data sources were also evident during the tuning of the base model, which took numerous iterations to converge. Also, the profile indicates that the survey indices provide little information regarding the scale of the stock.

Residual plots

The framework underlying the Stock Synthesis approach to stock assessments makes major assumptions about the statistical characteristics of the data sources that inform the model. Some of the assumptions are with regard to structural features of the underlying population dynamics processes. Other assumptions are related to the characteristics of the sampling processes that generate the data used to estimate the parameters of the model. A key diagnostic approach for evaluating whether any fundamental assumptions may have been violated is visual inspection of plots of the observed data overlain by the model's predictions for these same quantities. A second related approach is inspection of plots of the residuals from the fits, which can help to identify unusual patterns (e.g., long sequences of positive or negative residuals) that might indicate misspecification of the assessment model.

Figures 26 and 27 provide comparison plots of the survey biomass index observations with the values predicted by the base model. Figures 28 to 37 are plots of the observed and model-predicted length-compositions by year and fleet, and include bubble-pots of the residuals for the fits to the length-composition data. Figure 38 shows the observed and model-predicted compositions aggregated across all the years for which data are available. Figures 39 – 42 show observed and predicted values for the conditional age-at-length data included in the base assessment model. The left-hand panels in these figures display the mean age-at-length values; the right-hand display the corresponding standard deviations of age-at-length. Figures 43 and 44 are the marginal age-compositional data (ghosts) that were included to aid interpretation, but they did not contribute to the likelihood.

Model convergence

The Stock Synthesis software was able to invert the Hessian matrix from the base model and the various likelihood profiles we conducted showed no evidence of jaggedness in the surface, which can be a tell-tale that the model may sometimes be converging to alternative solutions. We conducted 100 runs with initial parameter values jittered using a coefficient of 0.2 and 83 of those runs converged to the same negative log-likelihood value and very similar estimates of unfished spawning biomass as the base model (Figure 45). Most importantly, there were no runs with a smaller negative log-likelihood value than the base model's value. We concluded that the base model had produced the set of estimated parameters that were the maximum likelihood estimates.

Base-model results

The likelihood components associated with the base model and the model's estimates for all explicit parameters (except recruitment deviations) and their associated standard deviations are given in Table 16. Estimates of some key derived quantities are also shown in that table. For some of the fishery selection curves the parameter that controls selection of males relative to females, described in the table as "*Ln(Male sel./female sel.) at dogleg*" were very close to their upper bounds of zero, which suggests that the some aspect of the data was driving the male selection curve to exceed the female selection curve. The base model's estimates of spawning biomass and recruitment and their associated standard deviations are given in Table 17.

The base model's estimated growth curves are shown in Figure 46. The unusual kink at the start of the curve is probably the result of choosing an initial length bin that is too large. To fix this would have required modifications to the model that we deemed inappropriate for an update assessment. Further, because appreciable quantities of such small fish are not caught in either the fisheries or the surveys, this strange growth curve is likely to have a minimal effect on the assessment results.

The estimated selection curves for the fishing fleets and surveys are shown in Figure 47. The estimated stock-recruitment curve and estimated (recruitment, spawning biomass) points are shown in Figure 48. As is generally true of such plots for many species, the points are widely scattered around the curve, which is indicative of high variability in recruitment for this stock. Figure 49 indicates that the base model was fully tuned with regard to the spawner-recruit bias adjustments.

Table 18 provides the base model's estimates of spawning biomass, age-0 recruitment, depletion, and exploitation for the entire period covered by the assessment (1916-2017). The estimated time-series of spawning biomass, depletion, recruitment, and exploitation are depicted in Figures 50 - 53.

The base model estimates indicate that the spawning biomass underwent a period of fairly rapid decline during the 1970s and subsequent increase through the 1980s, reaching a peak of almost 76 thousand mt in 1991, well above the estimated unfished level of spawning biomass (65,448 mt). After 1991 the spawning biomass declined to a low in 2010 of 29,607 mt, the second lowest value in the series. Since 2010 the spawning biomass has been increasing steadily and is estimated to be 56,710 mt at the start of 2017, almost 87% of the unfished level and well above the minimum stock size threshold of 12.5% that the Council uses for its managed flatfish species. The two distinct periods of increasing spawning biomass were driven in part by very high levels of recruitment during several previous years. Recruitment during the late 1970s and early 1980s was generally high, but was followed by several years of low recruitment during the 1990s (except for a very high recruitment in 1999), and then very high recruitment during 2011 to 2013.

Evaluation of uncertainty in model results

Sensitivity to assumptions about model structure

The base model uses assumed values for two key biological parameters, natural mortality and steepness. Unfortunately neither of these parameters can be well-estimated given the data available, as indicated by the likelihood profile analyses described above. One source of uncertainty explored in the 2007 assessment was the catch histories. In fact, uncertainty in catches, in conjunction with uncertainty regarding natural mortality, was used as the major axis of uncertainty in the decision table in the 2007 assessment.

Sensitivity to catch histories

To explore the influence of catch uncertainty on the base model we developed two alternative catch history scenarios by modifying some of the coefficients used to derive the catch series.

Washington landings of Arrowtooth Flounder prior to 1978 input to the base model were estimated by applying a ratio to the Oregon reconstructed landings series, as explained in the section *Washington – Historical commercial landings (1916 – 1986)*. The WA:OR landings ratio was based on the ratio of the summed landings for the period 1956 to 1960. Ratios calculated on an annual basis during this period are quite variable. We used this variability as a mechanism for choosing low and high WA:OR ratio values that are representative of the uncertainty underlying the reconstructed WA landings of Arrowtooth Flounder.

We calculated the standard deviation of the log of the 1956-1960 annual ratios of WA:OR landings of Arrowtooth Flounder and used this to derive WA:OR ratios representing the lower and upper 25th percentiles of the distribution of the average log(WA:OR landings) value. The derived average WA:OR landings ratios were Low = 0.8068 and High = 1.209.

To account for discarded Arrowtooth Flounder in the base model catch reconstruction we developed state-specific discard fractions and discard ratios (shown in Table 5) with which to estimate the discard series for the fillet and "discard" fleets, based on data from the West Coast Groundfish Observer Program (WCGOP), as explained above in the sections *Discard fractions* *and discard ratios* and *Methods used for estimating discards by the fillet fleet and "discard fleet"*. During the years when the WCGOP data were regularly collected (2002-2015), the coefficients were quite variable from one year to the next. Assuming this variability reflects uncertainty in the average values for the coefficients in years prior to 2002 provides a mechanism for choosing low and high coefficient values that are representative of the uncertainty underlying the discards.

We calculated the standard deviations of the logits of the discard fractions on a state-specific basis and used these to derive discard fractions to represent the lower and upper 25th percentiles of the distribution of the average of the logit(*discard_fraction*) values. The derived average *discard_fractions* were as follows:

discard_fraction	WA	OR	CA
Low	6.54%	7.16%	6.88%
High	12.26%	11.25%	11.69%

We took a similar approach to develop low and high *discard_ratio* values but treated the *discard_ratio* data as being lognormally distributed rather than normally distributed on the logit scale. The derived average discard_ratios were as follows:

discard_ratio	WA	OR	CA
Low	0.3657	0.0818	0.0117
High	0.6837	0.1222	0.0192

We applied the sets of low and high *discard_fractions* to the fillet fleet landings series (for years prior to 2002) to generate alternative series of fillet fleet discards and catches (landings plus discards). Similarly we applied the sets of low and high *discard_ratios* to the Dover Sole + English Sole + Petrale Sole landings series (for years prior to 2002) to generate alternative series of "discard fleet" removals (landings plus discards).

The alternative catch scenarios are shown in the upper two panels of Figure 54 and the estimated spawning biomass trajectories based on the alternative catch scenarios are compared to the base model catch series in the lower panel. The alternative catch series had only a modest influence on the spawning biomass trajectory compared to the sensitivity to other fixed elements of the model (e.g., natural mortality). The 2017 spawning biomass estimated for the high catch scenario is 1.14 times the value estimated for the low catch scenario. This is in stark contrast to the sensitivity to alternative catch streams in the 2007 assessment, in which the low and high catch scenarios were based on multiplying the base model catches by half and by two. The 2007 spawning biomass estimated for the high catch scenario is slightly over four times the value estimated for the low catch scenario.

Table 19 provides a summary of the likelihood components and key derived quantities for the sensitivity to catch history and the additional sensitivity evaluations described directly below.

Sensitivity to weighting method

We used the McAllister-Ianelli method in the base model for iteratively tuning the input effective N values that influence how much weight is applied to any composition observation. STATs have been encouraged to use the alternative composition weighting approach developed in Francis (2011) because there is concern that the McAllister-Ianelli method may give undue weight to compositions at the expense of goodness-of-fit to the survey biomass indices. The 2007 STAT used the McAllister-Ianelli method to tune the 2007 assessment.

We attempted to use the Francis method during Phase 2 in the development of the base model but found that the weighting coefficients for conditional age-at-length composition series tended to zero with successive iterations during the tuning process, thus resulting in a model that completely ignored the conditional age-at-length compositions. For the base model, we decided to use only the McAllister-Ianelli method for tuning the composition weights. However, we conducted a sensitivity run that used Francis weighting for the length-composition series and McAllister-Ianelli weighting for the conditional age-at-length compositions.

We also conducted a sensitivity run that used the Dirichlet multinomial (DM) option (Thorson et al., 2016), a new feature in Stock Synthesis 3.30. For a compositional data series that has the DM option turned on there is an additional estimated parameter that has the effect of down-weighting the input sample-sizes associated with each annual compositional observation for that series. For the DM sensitivity run the DM parameters associated with four of the seven compositional components went to the upper bound, which has the effect of making the effective sample-sizes for that series equal to the input sample-sizes.

The resulting biomass trajectories, which are shown in Figure 55, were quite sensitive to the choice of weighting method. For the base model and these two sensitivity runs, the variance adjustments for the compositional data (or equivalent) are shown in Table 20. It should be noted that the DM approach does not allow the effective sample-sizes to exceed the input-sample sizes. Given that the input-samples sizes were based either on the number of tows (for surveys) or the number of fishing trips (for fishing fleets) with sampled fish lengths, there is no *a prior* reason to assume that the ratio of effective sample-size to input sample-size should not exceed one.

Parameter uncertainty

Table 16 provides the values for the main estimated parameter and their standard deviations. Table 17 provides the estimated annual recruitment and the spawning biomass values at the start of each year and their associated standard deviations. The σ value (log-scale coefficient of variation) for the 2017 spawning biomass is 0.202.

Retrospective analysis

A five-year retrospective analysis was conducted in which data from the last year of the data series were sequentially excluded from the model fitting. This technique can indicate structural problems in an assessment, such as time-variation in a key element that was assumed to be time-invariant. Results from the retrospective analysis are shown in Figure 56 and Table 21.

The estimated 2011 spawning biomass was strongly affected by the number of years of data included in the model, ranging from a value of 36,144 mt if 2011 was the last year with data to a value of 30,771 mt in the base model (data ending with 2016). Also strongly affected were the estimated recruitment deviations for 2008-2010 and the estimated growth parameters. For example, the parameter for length at age-30 for females varies from 72.79 cm if 2011 is the last year with data to 69.77 cm for the base model. It seems likely that these differences were driven by the NWFSC slope-shelf survey conditional age-at-length data series, which are available from two distinct periods, 2003-2006 and 2013-2016. Comparisons of the lengths-at-age from these two periods suggest that there was a fairly substantial reduction in growth (Figure 57), although a change in age-reading error could also account for the observed discrepancies between periods. In the retrospective analysis, the results based on data ending in 2011 and 2012 were only informed by data from the early period of NWFSC slope-shelf survey conditional age-at-length data.

Historical analysis

Figure 20, developed as part of the bridge from the 2007 assessment to the current base model, provides a comparison of those two models.

Reference points

The base update assessment model estimated that the unfished stock of Arrowtooth Flounder would have spawning biomass for 65448.2 mt, Age 0 recruitment of 50487.8 thousand recruits, and the Age 3+ summary biomass of 88804.5 mt. The following are key reference points for Arrowtooth Flounder.

		95% confidence limits	
Unfished stock	Estimate	Lower	Upper
Spawning biomass (mt)	65448.2	58305.7	72590.7
Age 0 recruits (thousands of fish)	50487.8	45075.1	55900.5
Summary (Age 3+) biomass (mt)	88804.5	79172.4	98436.6

	Yield reference points		
	SB25%	SPR30%	MSY est.
Spawning Potential Ratio (SPR)	0.2704	0.3000	0.1990
Exploitation rate	0.2029	0.1843	0.2606
Yield	6774.8	6634.9	6943.4
Spawning biomass (mt)	16362.0	18355.3	11558.7
SSB / SSB0	25.0%	28.0%	17.7%

Figure g shows the estimated equilibrium yield as a function of depletion, and includes some of the reference points.

Harvest projections and decision table

Harvest projections

Three sets of harvest projections were developed using the base model to cover the period 2017 to 2028 (Table 22). The first projection assumes catches consistent with the Annual Catch Limit (ACL) already specified by the Council for 2017-2018 followed by ten years during which the Acceptable Biological Catches (ABC) are taken each year based on a P* of 0.40 and a category 2 stock designation ($\sigma = 0.72$). This projection is used in the decision table (below). The second projection assumes ACL catches during 2017-2018 followed by ten years during which catches are taken each year consistent with the Overfishing Limits (OFL, with no buffer for scientific uncertainty). The third projection assumes constant annual catches equal to recent five-year average catches (510 mt/yr by the “discard fleet”, 1875 mt/yr by the fillet fleet).

Decision table

The decision table (Table 23) considers the uncertainty in 'states of nature' regarding natural mortality rates (M) for females and males, which is a departure from the 2007 assessment. The 2007 decision table considered uncertainty in both natural mortality rates and past catches and this approach produced very extreme high and low states. The decision table here uses three states of nature based on the natural mortality prior and observations of maximum age for female and male Arrowtooth Flounder.

In developing the states of nature, we attempted to provide high and low states that each represented about 25% of the probability space, with the base model representing the other 50%. To do this, when considering uncertainty in a single parameter, it is common to set the high and low states at the 12.5% and 87.5% quantiles of the prior distribution (or other measure of uncertainty distribution) for that parameter, which corresponds to points 1.15 standard deviations from the median. In the natural mortality prior the data used in its development through meta-analysis were subject to error, implying that the prior included both variability in the relationship between maximum age and *M* and error in the estimates of maximum age and *M* that inform the prior. We assumed half of the variance in the relationship was due to this error and therefore used M values for the high and low states that were ± 1.15 x 0.707 x SD from the median (in log space).

The three states of nature were therefore: (1) the low state (female M = 0.15 yr^{-1}, male M = 0.21 yr^{-1}), (2) the base case (female M = 0.216 yr^{-1}, male M = 0.30 yr^{-1}), and (3) the high state (female M = 0.31 yr^{-1}, male M = 0.43 yr^{-1}). ABC catch streams were developed from each of these states of nature for 2019 through 2028, assuming ACL catches are removed in 2017 and 2018, a P* of 0.40 and a category 2 stock designation (sigma = 0.72). These catch streams are applied to each state of nature, with the results highlighting the uncertainty in the absolute scale of the stock and the impact of assuming one state when another is true.

Regional management considerations

Arrowtooth Flounder off the US West Coast are at the southern end of their range, as is apparent from the distinct cline in biomass density with latitude that is evident in the catches by the NWFSC slope-shelf survey. Catches by state also support the notion that Arrowtooth Flounder are most prevalent off Washington, much less abundant off northern California, and essentially absent farther south in California. Such regional differences in abundance could lead to localized over-fishing if disproportionate amounts were taken from less populous areas. However, that would require far increased targeting of Arrowtooth Flounder or associated stocks in those areas, which is unlikely to occur given the recent catch history. There is no evidence of population structure in the literature, nor from general observations of the stock. The stock currently appears to be very abundant, implying that active management of the fisheries that catch Arrowtooth Flounder is not likely to be needed in then near or medium term.

Unresolved problems and major uncertainties

This update assessment used almost the exact same model configuration and structure as used in the 2007 assessment, which greatly constrained how both assessment models could account for certain features of the data, such as a preponderance of female Arrowtooth Flounder in the fillet fleet catches. According to the 2007 assessment document, the stock assessment team (STAT) went to the stock assessment review (STAR) with a draft assessment model that included a retention curve for the fillet fishery and had length-composition observations for fish discarded on trips that also landed Arrowtooth Flounder (i.e., the fillet fleet) as data to inform the retention curve. The STAT's draft assessment model was also configured to estimate discard rates based on observations of the fractions of the Arrowtooth Flounder catches retained and landed by the fillet fleet. However, due to poor model performance and other reasons described in the 2007 assessment document and STAR Panel report, during the 2007 STAR meeting the STAT adopted the simpler model structure that was inherited by the current update assessment: no retention curve for the fillet fleet and estimated discards by this fleet are added to its catch stream. This structure and the additional assumption that all fishery selection curves are asymptotic and constant through time greatly limits how the assessment model can account for observed changes in the length-compositions.

One important feature in the Arrowtooth Flounder compositional data that should be considered in the next assessment for this stock is that Arrowtooth Flounder discarded by the fillet fleet (trips with landed Arrowtooth Flounder) have an appreciably different length-composition from the fish retained by the fillet fleet (Figure 54). The configuration of this update assessment (and the 2007 assessment) fundamentally assumed that Arrowtooth Flounder discarded by the fillet fleet had the same composition as the fish that were retained. The fish discarded by the fillet fleet also appear to have a different length-composition from the fish discarded by the "discard fleet" (Figure 58).

Another source of fishery removals of Arrowtooth Flounder that may warrant consideration in the next assessment is the catches of Arrowtooth Flounder in the pink shrimp fishery. Although this fishery does not catch (and discard) large amounts of Arrowtooth Flounder in terms of weight, the fish are very small (Figure 59) and the removals could be appreciable in terms of numbers.

A final consideration for the next assessment is that newer length-at-age observations from the NWFSC slope-shelf survey indicate possible changes in growth-in-length for Arrowtooth Flounder. Although it is unclear that a different model structure would resolve various discrepancies that were evident in the fit of the update assessment model to the available data (e.g., rather poor residual patterns in the fits to the NWFSC slope-shelf survey biomass index and in the fits to most of the compositional data), future assessment should explore whether the current simplified model structure may be inadvertently distorting the results.

Prioritized research and data needs

Addressing the following research and data needs could improve future assessments of Arrowtooth Flounder.

1. *Reevaluation and reconstruction of historical flatfish removals, including Arrowtooth Flounder*. Historical estimates of discards are a large contributor to total removals. The current modelling exercise of using co-occurring flatfish species as predictors of discard could use further exploration. The Arrowtooth Flounder catch history for Washington should be reconstructed using all available data including catch by gear and by region. The reconstruction should include an envelope of high and low values to set bounds for exploration of alternative catch histories. As has been recommended previously by a variety of STAR Panels, the reconstruction of historical landings needs to be done comprehensively (i.e., with other species) to ensure efficiency and consistency.

2. *Exploration of foreign fleet catches of flatfish*. There were large removals of rockfish species by foreign fleets during the mid-1960s to mid-1970s (Rogers, 2003). We were unable to locate information on possible removals of flatfish species by the foreign fleet but it seems likely that some flatfish catches occurred. This should be explored for the next assessment of Arrowtooth Flounder and may also be relevant for the assessment of Dover Sole.

3. *Reevaluation of the value of stock-recruitment steepness for arrowtooth*. In the base case model, steepness was set at 0.902 based on Dorn's meta-analysis (personal communication). While model results are not sensitive to the value of steepness, it would have an effect on MSY calculations and OFL and ABC values at lower stock sizes.

4. *Research to provide information on survey catchability*. The absolute scale of the stock is still quite uncertain. The calculated catchability associated with the NWFSC trawl survey ranges from 0.2 to 0.8 across the three states of nature.

5. *Evaluation of stock boundaries and the feasibility of a bilateral assessment with Canadian scientists*. This could perhaps be accomplished through the Technical Subcommittee of the US Canada groundfish working group.

6. *Discrepancies between CalCOM and PacFIN compositional data*. Given concerns that the PacFIN system may include biological data for California that are not fully compatible with the software used to process the PacFIN data to produce expanded compositional data, we obtained expanded data from CalCOM (D. Pearson, SWFSC) but they did not appear reasonable (see Figure 7). The source(s) of these discrepancies should be investigated and resolved. Ideally the information from all three states should be housed in PacFIN because this would allow development of standardized data processing and error-checking and facilitate the development of stock assessments.

7. *Evaluation of maturity and fecundity relationships*. New studies on both the maturity and fecundity relationships for Arrowtooth Flounder would be beneficial. The maturity versus length relationship used in this update and the 2007 assessment is based on a study done in 1993.

8. *Age-reading error study*. The age-reading errors assumed for this assessment were taken directly from the 2007 assessment; that assessment took the standard deviation of aging error from an assessment of English Sole. A study is needed to conduct and analyze cross-readings of Arrowtooth Flounder otoliths (surface and break-and-burn reads) to develop improved ageing error vectors for the next assessment of Arrowtooth Flounder (even if it is only an update assessment).

9. *Age-reading of otoliths from the fishery off California*. A collection of unread Arrowtooth Flounder otoliths that is available for fish landed in California should be read to provide possibly more representative age-at-length compositions for the fishery. The fishery age-at-length compositions in this update assessment were based entirely on fish landed in Oregon and Washington.

10. *Evaluation of the spatial variability of productivity processes*. The extent of spatial variability on productivity processes such as growth, recruitment, and maturity is currently unknown and would benefit from further research. This stock shows clear evidence of a latitudinal gradation in abundance and other traits.

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Auxiliary files

The following auxiliary files were provided to John DeVore, PFMC staff, and will be archived with this assessment document:

Stock Synthesis files:

- arrowtooth_2017.ctl
- arrowtooth_2017.dat
- starter.ss
- forecast.ss

The numerous R4SS output files for the base model were placed in a compressed folder called “plots-arrowtooth_2017-BASE.zip”.

The base model estimates of annual numbers at age by sex were provided as a csv file called “Arrowtooth_2017-Numbers_at_age.csv”.

Tables

Table 1. Reconstructed landings (mt) of Arrowtooth Flounder by state.

	California	Oregon	Washington
Pre-1916		17.54*	
1916	0.00	0.54	0.00
1917	0.06	0.51	0.50
1918	0.12	0.48	0.48
1919	0.18	0.45	0.45
1920	0.24	0.43	0.42
1921	0.30	0.40	0.39
1922	0.37	0.37	0.36
1923	0.43	0.34	0.34
1924	0.49	0.31	0.31
1925	0.55	0.28	0.28
1926	0.61	0.26	0.25
1927	0.67	0.24	0.24
1928	0.73	0.00	0.00
1929	0.79	10.34	10.21
1930	0.85	7.37	7.28
1931	0.91	4.60	4.55
1932	0.97	4.97	4.91
1933	1.04	10.47	10.35
1934	1.10	13.42	13.26
1935	1.16	7.28	7.19
1936	1.22	10.43	10.31
1937	1.28	12.66	12.50
1938	1.34	7.60	7.51
1939	1.40	6.90	6.81
1940	1.46	12.76	12.60
1941	1.52	11.26	11.13
1942	1.58	40.15	39.66
1943	2.35	240.19	237.26
1944	2.06	47.83	47.25
1945	0.53	10.13	10.00
1946	**	25.17	24.86
1947	**	57.84	57.13
1948	**	245.81	242.81
1949	**	244.29	241.31
1950	39.71	97.96	96.76
1951	27.13	182.95	180.73
1952	51.17	200.40	197.96
1953	40.08	440.64	435.28
1954	254.53	676.50	668.26

	California	Oregon	Washington
1955	339.40	1484.92	1466.84
1956	483.57	1450.38	1432.72
1957	422.90	1110.87	1097.35
1958	261.16	1208.73	1194.01
1959	338.56	1265.53	1250.12
1960	456.55	542.84	536.23
1961	27.42	695.77	687.30
1962	24.04	1311.77	1295.80
1963	7.87	1067.03	1054.04
1964	4.42	1140.69	1126.80
1965	5.26	1235.50	1220.46
1966	1.59	659.86	651.82
1967	2.74	794.58	784.91
1968	6.08	545.96	539.31
1969	4.53	530.27	523.82
1970	2.78	404.80	399.87
1971	1.21	360.76	356.37
1972	74.37	170.95	168.87
1973	107.16	153.91	152.03
1974	95.49	89.55	88.46
1975	32.08	145.43	143.66
1976	84.02	95.30	94.14
1977	100.83	143.48	141.73
1978	93.71	184.83	224.99
1979	108.05	347.59	396.05
1980	55.71	221.08	343.54
1981	***	628.25	***
1982	***	733.68	***
1983	***	540.56	***
1984	***	417.06	***
1985	***	698.31	***
1986	***	502.41	***

* The annual landings of Arrowtooth Flounder in Oregon prior to 1916 in Oregon's historical reconstruction were trivially small and were treated as zeroes in the assessment model.

** The California catch reconstruction provides no landings for the years flagged with **.

*** The CA and WA landings reconstruction end with 1980, at which point PacFIN records begin. The OR landings reconstruction continues to 1986 because the OR landings in PacFIN for 1982-1986 are considered to less accurate than the reconstructed landings.

Table 2. Reconstructed catches of Arrowtooth Flounder (mt, landings plus discards) by state.

Year	CA: Mink Food	CA: Fillet	CA: Discard	OR: Mink Food	OR: Fillet	OR: Discard	WA: Mink Food	WA: Fillet	WA: Discard
1916	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1917	0.1	0.0	3.7	0.5	0.0	0.0	0.5	0.0	0.0
1918	0.1	0.0	7.4	0.5	0.0	0.0	0.5	0.0	0.0
1919	0.2	0.0	11.1	0.5	0.0	0.0	0.4	0.0	0.0
1920	0.3	0.0	14.7	0.4	0.0	0.0	0.4	0.0	0.0
1921	0.3	0.0	18.4	0.4	0.0	0.0	0.4	0.0	0.0
1922	0.4	0.0	22.1	0.4	0.0	0.0	0.4	0.0	0.0
1923	0.4	0.0	25.8	0.3	0.0	0.0	0.3	0.0	0.0
1924	0.5	0.0	29.5	0.3	0.0	0.0	0.3	0.0	0.0
1925	0.6	0.0	33.2	0.3	0.0	0.0	0.3	0.0	0.0
1926	0.6	0.0	36.8	0.3	0.0	0.0	0.3	0.0	0.0
1927	0.7	0.0	40.5	0.2	0.0	0.0	0.2	0.0	0.0
1928	0.8	0.0	44.2	0.0	0.0	0.0	0.0	0.0	0.0
1929	0.8	0.0	47.9	10.3	0.0	0.2	10.2	0.0	0.0
1930	0.9	0.0	51.6	7.4	0.0	0.2	7.3	0.0	0.0
1931	0.9	0.0	53.8	4.6	0.0	0.2	4.5	0.0	0.0
1932	1.0	0.0	53.5	5.0	0.0	2.3	4.9	0.0	0.0
1933	1.1	0.0	47.9	10.5	0.0	1.2	10.3	0.0	0.0
1934	1.1	0.0	54.1	13.4	0.0	0.7	13.3	0.0	0.0
1935	1.2	0.0	56.1	7.3	0.0	1.3	7.2	0.0	59.7
1936	1.3	0.0	52.0	10.4	0.0	4.4	10.3	0.0	153.4
1937	1.3	0.0	52.9	12.7	0.0	22.3	12.5	0.0	132.6
1938	1.4	0.0	54.7	7.6	0.0	1.0	7.5	0.0	163.6
1939	1.5	0.0	57.0	6.9	0.0	67.6	6.8	0.0	154.4
1940	1.5	0.0	47.0	12.8	0.0	121.5	12.6	0.0	186.7
1941	1.6	0.0	30.3	11.3	0.0	144.2	11.1	0.0	294.2
1942	1.6	0.0	19.9	40.1	0.0	281.7	39.7	0.0	314.7
1943	2.4	0.0	27.7	240.2	0.0	477.9	237.3	0.0	438.1
1944	2.1	0.0	28.7	47.8	0.0	197.5	47.3	0.0	313.6
1945	0.5	0.0	52.2	10.1	0.0	233.5	10.0	0.0	314.9
1946	1.6	0.0	69.2	25.2	0.0	452.1	24.9	0.0	331.1
1947	20.5	0.0	140.8	57.8	0.0	237.9	57.1	0.0	273.2
1948	29.9	0.0	175.3	245.8	0.0	403.9	242.8	0.0	401.7
1949	39.3	0.0	110.5	244.3	0.0	266.9	241.3	0.0	322.5
1950	39.7	0.0	135.6	98.0	0.0	517.2	96.8	0.0	296.5
1951	27.1	0.0	115.6	183.0	0.0	557.0	180.7	0.0	238.3
1952	51.2	0.0	133.0	200.4	0.0	474.5	198.0	0.0	334.5
1953	40.1	0.0	111.1	440.6	0.0	210.2	435.3	0.0	264.4
1954	254.5	0.0	121.5	676.5	0.0	254.4	668.3	0.0	463.3
1955	339.4	0.0	108.4	1484.9	0.0	223.8	1466.8	0.0	710.4

Year	CA: Mink Food	CA: Fillet	CA: Discard	OR: Mink Food	OR: Fillet	OR: Discard	WA: Mink Food	WA: Fillet	WA: Discard
1956	483.6	0.0	101.3	1450.4	0.0	237.8	1432.7	0.0	586.2
1957	422.9	0.0	110.4	1110.9	0.0	322.1	1097.3	0.0	229.7
1958	261.2	0.0	98.6	1208.7	0.0	342.5	1194.0	0.0	403.8
1959	338.6	0.0	88.5	1265.5	0.0	341.9	1250.1	0.0	266.4
1960	456.5	0.0	95.4	542.8	0.0	411.2	536.2	0.0	686.3
1961	27.4	0.0	90.4	695.8	0.0	370.9	687.3	0.0	445.4
1962	24.0	0.0	98.6	1311.8	0.0	456.0	1295.8	0.0	459.9
1963	7.9	0.0	118.0	1067.0	0.0	467.6	1054.0	0.0	609.3
1964	4.4	0.0	113.2	1140.7	0.0	415.7	1126.8	0.0	343.5
1965	5.3	0.0	124.6	1235.5	0.0	315.1	1220.5	0.0	312.7
1966	1.6	0.0	123.0	659.9	0.0	417.1	651.8	0.0	197.1
1967	2.7	0.0	108.3	794.6	0.0	378.9	784.9	0.0	142.6
1968	6.1	0.0	117.6	546.0	0.0	383.2	539.3	0.0	309.1
1969	4.5	0.0	133.2	530.3	0.0	444.8	523.8	0.0	289.8
1970	2.8	0.0	148.7	404.8	0.0	455.2	399.9	0.0	375.4
1971	1.2	0.0	138.8	360.8	0.0	460.9	356.4	0.0	248.0
1972	74.4	0.0	195.0	171.0	0.0	479.0	168.9	0.0	232.5
1973	107.2	0.0	194.4	153.9	0.0	422.4	152.0	0.0	241.1
1974	95.5	0.0	179.2	89.5	0.0	477.4	88.5	0.0	277.2
1975	32.1	0.0	206.0	145.4	0.0	457.5	143.7	0.0	269.4
1976	84.0	0.0	204.2	95.3	0.0	481.8	94.1	0.0	674.4
1977	100.8	0.0	187.3	143.5	0.0	375.2	141.7	0.0	583.7
1978	93.7	0.0	186.3	184.8	0.0	549.9	225.0	0.0	1461.6
1979	108.0	0.0	214.1	347.6	0.0	725.0	396.0	0.0	1721.7
1980	55.7	0.0	170.6	221.1	0.0	573.3	343.5	0.0	1532.5
1981	0.0	52.6	176.7	0.0	690.4	696.1	0.0	474.4	1278.1
1982	0.0	53.0	184.6	0.0	806.2	1064.3	0.0	1724.4	1705.3
1983	0.0	27.1	155.2	0.0	594.0	1050.0	0.0	1660.8	1873.2
1984	0.0	35.6	169.9	0.0	458.3	725.0	0.0	2120.8	2060.5
1985	0.0	41.5	209.1	0.0	767.4	675.4	0.0	2135.5	1819.7
1986	0.0	20.7	192.9	0.0	552.1	608.4	0.0	1877.9	1099.8
1987	0.0	49.9	193.6	0.0	802.3	653.8	0.0	2246.6	1359.4
1988	0.0	39.9	150.9	0.0	694.1	791.7	0.0	1393.5	1577.3
1989	0.0	31.1	144.3	0.0	1238.4	928.1	0.0	2623.6	1657.1
1990	0.0	59.5	118.4	0.0	1923.1	797.0	0.0	4346.3	1363.8
1991	0.0	172.0	139.0	0.0	2270.9	952.2	0.0	2967.1	1244.7
1992	0.0	108.7	146.3	0.0	2222.5	679.3	0.0	1553.0	1007.4
1993	0.0	62.5	112.2	0.0	1809.3	689.8	0.0	1095.8	996.8
1994	0.0	80.6	82.5	0.0	1883.1	418.8	0.0	1600.8	764.3
1995	0.0	128.4	107.7	0.0	1549.1	388.9	0.0	868.0	765.0
1996	0.0	55.5	117.0	0.0	1226.1	467.5	0.0	1125.0	777.7

Year	CA: Mink Food	CA: Fillet	CA: Discard	OR: Mink Food	OR: Fillet	OR: Discard	WA: Mink Food	WA: Fillet	WA: Discard
1997	0.0	52.2	101.9	0.0	1272.6	451.5	0.0	1246.2	725.5
1998	0.0	40.9	67.2	0.0	1747.2	430.6	0.0	1693.0	591.7
1999	0.0	47.0	71.6	0.0	2497.5	497.3	0.0	3257.5	618.3
2000	0.0	29.7	63.9	0.0	1282.5	554.0	0.0	2285.0	694.4
2001	0.0	10.5	51.4	0.0	1134.5	469.6	0.0	1560.3	622.5
2002	0.0	35.2	27.6	0.0	999.0	700.7	0.0	2052.1	440.9
2003	0.0	44.4	33.4	0.0	1103.5	310.7	0.0	1857.9	290.1
2004	0.0	51.8	41.0	0.0	1031.4	235.3	0.0	1514.1	573.8
2005	0.0	47.9	68.0	0.0	1373.4	515.5	0.0	1034.3	3525.2
2006	0.0	35.3	53.4	0.0	1453.5	557.0	0.0	596.3	957.1
2007	0.0	79.4	61.8	0.0	1779.1	1089.8	0.0	614.1	1092.0
2008	0.0	53.9	68.6	0.0	2260.9	721.5	0.0	488.7	771.4
2009	0.0	68.8	76.7	0.0	3140.7	848.8	0.0	1067.5	2733.8
2010	0.0	80.9	39.7	0.0	2611.9	563.5	0.0	927.3	289.8
2011	0.0	99.6	25.9	0.0	1777.2	284.4	0.0	605.5	266.3
2012	0.0	135.8	36.2	0.0	1570.6	205.7	0.0	745.4	198.9
2013	0.0	150.4	30.1	0.0	1856.7	343.6	0.0	327.9	192.7
2014	0.0	123.3	75.3	0.0	1420.1	361.4	0.0	95.2	121.4
2015	0.0	157.4	56.3	0.0	1380.8	247.6	0.0	71.1	125.0
2016	0.0	88.5	54.5	0.0	1184.7	377.1	0.0	67.6	126.2

Table 3. Summary of Pacific Fisheries Management Council management measures specific to Arrowtooth Flounder since 1 January 2007. This information is from a download of Commercial Regulations Data included in the CalCOM Database.

Regulation Date	Mgmt Area	Regulation
1/1/2007	40º10' South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2007	40º10' North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2007	40º10' South	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2007	40º10' North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2007	38º00' South	Arrowtooth Flounder, limited entry trawl, 10,000 lbs per 2 months
1/1/2007	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, 100,000 lbs per 2 months
1/1/2007	40º10' North	Arrowtooth Flounder, limited entry trawl, selective flatfish trawl, 90,000 lbs per 2 months
1/1/2007	40º10' North	Arrowtooth Flounder, limited entry trawl, multiple bottom trawl gear, 90,000 lbs per 2 months
3/1/2007	38º00' South	Other flatfish including English Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 110000 lbs per 2 months no more than 30,000 lbs per 2 months may be Petrale Sole
5/1/2007	38º00' South	Other flatfish including English Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 110,000 lbs per 2 months no more than 25,000 lbs per 2 months may be Petrale Sole
5/1/2007	38º00' South	Arrowtooth Flounder, limited entry trawl, arrowtooth included in other flatfish limits
5/1/2007	40º10' North	Arrowtooth Flounder, limited entry trawl, multiple bottom trawl gear, Arrowtooth Flounder included in other flatfish limits
5/1/2007	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 70,000 lbs per 2 months including Arrowtooth Flounder, no more than 15,000 lbs per 2 months may be Petrale Sole
5/1/2007	40º10' North	Arrowtooth Flounder, limited entry trawl, selective flatfish trawl, Arrowtooth Flounder included in other flatfish limits
5/1/2007	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, Arrowtooth Flounder included in other flatfish limits

Regulation Date	Mgmt Area	Regulation
5/1/2007	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 70,000 lbs per 2 months including Arrowtooth Flounder, no more than 15,000 lbs per 2 months may be Petrale Sole
5/1/2007	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 70,000 lbs per 2 months including Arrowtooth Flounder, no more than 15,000 lbs per 2 months may be Petrale Sole
9/1/2007	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 70,000 lbs per 2 months including Arrowtooth Flounder, no more than 15,000 lbs per 2 months may be Petrale Sole
9/1/2007	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 30,000 lbs per 2 months including Arrowtooth Flounder, no more than 8,000 lbs per 2 months may be Petrale Sole
9/1/2007	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 70,000 lbs per 2 months including arrowtooth, no more than 15,000 lbs per 2 months may be Petrale Sole
9/1/2007	38º00' South	Other flatfish including English Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 150,000 lbs per 2 months no more than 30,000 lbs per 2 months may be Petrale Sole
11/1/2007	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 30,000 lbs per 2 months including Arrowtooth Flounder, no more than 8,000 lbs per 2 months may be Petrale Sole
11/1/2007	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, large and small footrope gear, 150,000 lbs per 2 months including Arrowtooth Flounder
11/1/2007	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 30,000 lbs per 2 months including Arrowtooth Flounder, no more than 8,000 lbs per 2 months may be Petrale Sole
1/1/2008	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, 150,000 lbs per 2 months
1/1/2008	40º10' North	Arrowtooth Flounder, limited entry trawl, selective flatfish trawl, 10,000 lbs per 2 months
1/1/2008	40º10' North	Arrowtooth Flounder, limited entry trawl, multiple bottom trawl gear, 10,000 lbs per 2 months
1/1/2008	40º10' South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2008	40º10' North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted

Regulation Date	Mgmt Area	Regulation
1/1/2008	40º10' South	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2008	40º10' North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2008	40º10' South	Arrowtooth Flounder, limited entry trawl, 10,000 lbs per 2 months
3/1/2008	40º10' South	Other flatfish including English Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 110,000 lbs per 2 months no more than 30,000 lbs per 2 months may be Petrale Sole
5/1/2008	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 50,000 lbs per 2 months including Arrowtooth Flounder, no more than 18,000 lbs per 2 months may be Petrale Sole
5/1/2008	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 50,000 lbs per 2 months including Arrowtooth Flounder, no more than 18,000 lbs per 2 months may be Petrale Sole
5/1/2008	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 50,000 lbs per 2 months including Arrowtooth Flounder, no more than 18,000 lbs per 2 months may be Petrale Sole
7/1/2008	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 18,000 lbs per 2 months may be Petrale Sole
7/1/2008	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 18,000 lbs per 2 months may be Petrale Sole
7/1/2008	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 80000 lbs per 2 months including arrowtooth, no more than 18000 lbs per 2 months may be Petrale Sole
9/1/2008	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 16,000 lbs per 2 months may be Petrale Sole
9/1/2008	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 16,000 lbs per 2 months may be Petrale Sole
9/1/2008	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 16,000 lbs per 2 months may be Petrale Sole
11/1/2008	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 80,000 lbs per 2 months including Arrowtooth Flounder. Other flounder, no more than 10,000 lbs per 2 months may be Petrale Sole

Regulation Date	Mgmt Area	Regulation
11/1/2008	40º10' North	Petrale Sole, limited entry trawl, selective flatfish trawl, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 10,000 lbs per 2 months may be Petrale Sole
11/1/2008	40º10' North	Other flatfish including English Sole and Starry Flounder, limited entry trawl, selective flatfish trawl, 80,000 lbs per 2 months including Arrowtooth Flounder, no more than 10,000 lbs per 2 months may be Petrale Sole
11/1/2008	40º10' South	Other flatfish including English Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 110,000 lbs per 2 months
1/1/2009	40º10' South	Arrowtooth Flounder, limited entry trawl, 10,000 lbs per 2 months
1/1/2009	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, 150,000 lbs per 2 months
1/1/2009	40º10' North	Arrowtooth Flounder, limited entry trawl, selective flatfish trawl, 90,000 lbs per 2 months
1/1/2009	40º10' North	Arrowtooth Flounder, limited entry trawl, multiple bottom trawl gear, 90,000 lbs per 2 months
1/1/2009	40º10' North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2009	40º10' South	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2009	40º10' North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2009	40º10' South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
3/1/2009	40º10' South	Other flatfish including english Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 110,000 lbs per 2 months no more than 30,000 lbs per 2 months may be Petrale Sole
10/28/2009	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, 180,000 lbs per 2 months
11/1/2009	40º10' South	Other flatfish including English Sole and Starry Flounder, Arrowtooth Flounder, and Petrale Sole, limited entry trawl, 110,000 lbs per 2 months
1/1/2010	40º10' North	Arrowtooth Flounder, limited entry trawl, multiple bottom trawl gear, 90,000 lbs per 2 months
1/1/2010	40º10' South	Arrowtooth Flounder, limited entry trawl, 10,000 lbs per 2 months

Regulation Date	Mgmt Area	Regulation
1/1/2010	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, 150,000 lbs per 2 months
1/1/2010	40º10' North	Arrowtooth Flounder, limited entry trawl, selective flatfish trawl, 90,000 lbs per 2 months
1/1/2010	40º10' South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2010	40º10' North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2010	40º10' South	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2010	40º10' North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
7/1/2010	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 60,000 lbs per 2 months including Arrowtooth Flounder, no more than 6,300 lbs per 2 months may be Petrale Sole
9/1/2010	40º10' North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 70,000 lbs per 2 months including Arrowtooth Flounder, no more than 6,300 lbs per 2 months may be Petrale Sole
9/1/2010	40º10' North	Arrowtooth Flounder, limited entry trawl, multiple bottom trawl gear, 100,000 lbs per 2 months
9/1/2010	40º10' South	Arrowtooth Flounder, limited entry trawl, 12,000 lbs per 2 months
9/1/2010	40º10' North	Arrowtooth Flounder, limited entry trawl, selective flatfish trawl, 100,000 lbs per 2 months
9/1/2010	40º10' North	Arrowtooth Flounder, limited entry trawl, large and small footrope gear, 180,000 lbs per 2 months
1/1/2011	All	West Coast Groundfish Trawl IFQ Program implemented
1/1/2011	40º10' North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2011	40º10' South	Arrowtooth Flounder,limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted

Regulation Date	Mgmt Area	Regulation
1/1/2011	40º10’ North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2011	40º10’ South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2011	ALL	Arrowtooth Flounder managed in part by IFQ
1/1/2012	40º10’ South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2012	40º10’ South	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2012	40º10’ North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2012	40º10’ North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2013	40º10’ North	Arrowtooth Flounder, open access gears, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2013	40º10’ North	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2013	40º10’ South	Arrowtooth Flounder, limited entry fixed gear, 5,000 lbs per month, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2013	40º10’ South	Arrowtooth Flounder, open access gear, 3,000 lbs per month, no more than 300 lbs of which may be species other than Pacific Sanddabs, south of 42ºN when fishing for other flatfish and using 12 or less number 2 hooks and 1 lb or smaller weight, fishing in the RCA is permitted
1/1/2014	40º10’ North	Non-trawl, limited entry, Arrowtooth Flounder, 5,000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2014	40º10’ South	Non-trawl, limited entry, Arrowtooth Flounder, 5,000 lbs per month, with a gear restriction allowing fishing inside RCA

Regulation Date	Mgmt Area	Regulation
1/1/2014	40º10' North	Non-trawl, open access, Arrowtooth Flounder, 3,000 lbs per month, no more than 300 lbs may be species other than Pacific Sanddabs
1/1/2014	40º10' South	Non-trawl, open access, Arrowtooth Flounder, 3,000 lbs per month of which no more than 300 lbs may be species other than Pacific Sanddabs
1/1/2015	40º10' North	Non-trawl, limited entry, Arrowtooth Flounder, 5,000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2015	40º10' South	Non-trawl, limited entry, Arrowtooth Flounder, 5,000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2015	40º10' North	Non-trawl, open access, Arrowtooth Flounder, 3,000 lbs per month, no more than 300 lbs may be species other than Pacific Sanddabs
1/1/2015	40º10' South	Non-trawl, open access, Arrowtooth Flounder, 3,000 lbs per month of which no more than 300 lbs may be species other than Pacific Sanddabs
1/1/2016	40º10' North	Non-trawl, limited entry, Arrowtooth Flounder, 5,000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2016	40º10' South	Non-trawl, limited entry, Arrowtooth Flounder, 5,000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2016	40º10' North	Non-trawl, open access, Arrowtooth Flounder, 3,000 lbs per month, no more than 300 lbs may be species other than Pacific Sanddabs
1/1/2016	40º10' South	Non-trawl, open access, Arrowtooth Flounder, 3,000 lbs per month of which no more than 300 lbs may be species other than Pacific Sanddabs

Table 4. Total catch and commercial landings (mt) relative to the management guidelines. Estimated total catch reflects the commercial landings plus estimated discards.

Year	OFL *	ABC	ACL *	Coastwide landings	Coastwide catch **
1994	5800	-	-	3244	4830
1995	5800	-	-	2316	3807
1996	5800	-	-	2190	3769
1997	5800	-	-	2340	3850
1998	5800	-	-	3168	4571
1999	5800	-	-	5280	6989
2000	5800	-	-	3273	4910
2001	5800	-	-	2462	3849
2002	5800	-	-	2085	4256
2003	5800	-	-	2326	3640
2004	5800	-	5800	2326	3447
2005	5800	-	5800	2185	6564
2006	5800	-	5800	1880	3653
2007	5800	-	5800	2258	4716
2008	5800	-	5800	2656	4365
2009	11267	-	11267	3837	7936
2010	10112	-	10112	3224	4513
2011	18211	-	15174	2322	3059
2012	14460	12049	12049	2330	2893
2013	7391	6157	6157	1988	2901
2014	6912	5758	5758	1244	2197
2015	6599	5497	5497	1321	2038
2016	6396	5328	3241	1098	1899
2017	16571	13804	13804		

* Prior to 2011, the OFL was referred to as "ABC" and the ACL was referred to as "OY".

** Total catch as estimated in this assessment does not represent the estimation of total mortality as conducted each year by the NMFS, NWFSC West Coast Groundfish Observer Program (WCGOP). The NWFSC's Total Mortality Report represents the estimation of total mortality each year to determine the official stock status related to overfishing.

Table 5. Estimated Arrowtooth Flounder discard fractions and discard ratios. Details are provided in the section *Discard fractions and discard ratios*. Shaded cells indicate that no direct observations were available.

	Fillet fleet discard fractions, D / (D+R)				ATF discarded / (Dover+English+Petrale landed)			
Year	Overall	WA	OR	CA	Overall	WA	OR	CA
1985	9.9%				0.2443	0.1647	0.2686	
1986	0.9%	0.9%	0.7%		0.1670	0.2836	0.1178	
1987	10.4%	20.7%	6.0%		0.1530	0.3701	0.0648	
2002	39.3%	24.4%	49.5%	17.4%	0.1096	0.3498	0.2001	0.0069
2003	25.0%	20.7%	26.7%	2.1%	0.0457	0.2068	0.0629	0.0087
2004	9.2%	12.3%	7.6%	14.4%	0.0602	0.4244	0.0516	0.0129
2005	10.3%	14.2%	8.7%	8.4%	0.4560	2.2263	0.1006	0.0211
2006	9.8%	8.6%	10.4%	5.6%	0.1442	0.8143	0.1137	0.0192
2007	8.8%	7.3%	8.4%	24.7%	0.1071	0.8416	0.1792	0.0160
2008	5.3%	3.9%	5.3%	17.3%	0.0940	0.6386	0.0927	0.0169
2009	10.1%	10.3%	9.7%	34.1%	0.2013	1.8636	0.1044	0.0203
2010	11.2%	6.7%	12.3%	16.4%	0.0750	0.2790	0.0793	0.0139
2011	6.5%	6.1%	6.2%	13.5%	0.0412	0.2774	0.0536	0.0100
2012	5.1%	1.3%	4.8%	26.9%	0.0361	0.1925	0.0398	0.0152
2013	15.0%	28.4%	11.9%	21.7%	0.0360	0.1665	0.0524	0.0111
2014	24.0%	31.2%	22.3%	39.1%	0.0459	0.2018	0.0627	0.0296
2015	17.8%	1.3%	16.1%	41.4%	0.0349	0.2047	0.0411	0.0232

Table 6. Comparison of catches (mt) of Arrowtooth Flounder estimated in this update assessment versus total mortality estimates reported by the West Coast Groundfish Observer Program (WCGOP).

	Annual catches (mt)	
Year	This update	WCGOP
2004	3447	5668
2005	6564	3706
2006	3653	3105
2007	4716	3099
2008	4365	3409
2009	7936	5443
2010	4513	4090
2011	3059	2666
2012	2893	2508
2013	2901	2510
2014	2197	1843
2015	2038	1780
Cumulative	48283	39827

Table 7. Annual numbers of trips and fish underlying the length- and age-composition series that inform the assessment model.

	- - - - - - Number of trips - - - - - -				- - - - - Number of fish - - - - -			
Year	CA	OR	WA	Total	CA	OR	WA	Total
A. Length-composition data								
1982	0	0	1	1	0	0	1	1
1986	0	0	19	19	0	0	950	950
1987	0	1	21	22	0	150	1050	1200
1988	0	0	16	16	0	0	800	800
1989	0	0	17	17	0	0	850	850
1990	0	7	12	19	0	374	600	974
1991	0	11	28	39	0	550	1367	1917
1992	0	13	17	30	0	650	850	1500
1993	0	0	18	18	0	0	900	900
1994	0	0	20	20	0	0	1000	1000
1995	0	0	22	22	0	0	1098	1098
1996	0	0	18	18	0	0	900	900
1997	0	0	18	18	0	0	900	900
1998	0	0	20	20	0	0	1001	1001
1999	0	0	22	22	0	0	1099	1099
2000	0	0	21	21	0	0	1050	1050
2001	0	0	16	16	0	0	800	800
2002	0	0	10	10	0	0	500	500
2003	5	0	6	11	153	0	300	453
2004	0	0	6	6	0	0	300	300
2005	10	0	4	14	161	0	200	361
2006	28	26	7	61	549	534	605	1688
2007	16	51	11	78	368	1561	1050	2979
2008	16	52	9	77	321	1489	900	2710
2009	13	53	14	80	304	1420	1365	3089
2010	14	82	9	105	337	2232	833	3402
2011	26	65	9	100	750	1893	899	3542
2012	31	45	11	87	982	1219	1100	3301
2013	26	41	4	71	862	1029	500	2391
2014	15	51	6	72	581	1260	600	2441
2015	25	56	6	87	636	1257	600	2493
2016	23	58	9	90	702	1354	215	2271
B. Age-composition data								
1986		0	17	17		0	847	847
1987		0	20	20		0	995	995
1988		0	15	15		0	729	729
1989		0	16	16		0	778	778
1990		7	12	19		374	599	973
1991		7	11	18		349	550	899

	- - - - - - Number of trips - - - - - -				- - - - - Number of fish - - - - -			
Year	CA	OR	WA	Total	CA	OR	WA	Total
1998		0	20	20		0	300	300
2003		0	6	6		0	299	299
2004		0	6	6		0	266	266
2005		0	4	4		0	198	198
2013		1	0	1		29	0	29

Table 8. Biomass estimates (mt) based on the VAST analysis of the NWFSC slope-survey using a Delta-GLMM configuration similar to the approach used in the 2007 assessment.

Year	Biomass (mt)	SD	Biomass	SD	Biomass	SD
	- - - - Stratum A - - - -		- - - - Stratum B - - - -		- - - - Stratum C - - - -	
2003	9450.5	1517.6	1085.8	174.4	3429.6	550.73
2004	5608.7	1024.9	644.4	117.8	2035.4	371.94
2005	7659.0	1198.1	880.0	137.7	2779.4	434.77
2006	8042.9	1307.3	924.1	150.2	2918.7	474.41
2007	6820.3	1052.9	783.6	121.0	2475.1	382.10
2008	6730.4	1036.1	773.3	119.0	2442.5	376.01
2009	9616.7	1467.9	1104.9	168.7	3489.9	532.69
2010	10530.2	1561.9	1209.9	179.5	3821.4	566.81
2011	10735.2	1590.0	1233.5	182.7	3895.8	577.01
2012	10970.9	1667.4	1260.5	191.6	3981.3	605.11
2013	14592.7	2385.6	1676.7	274.1	5295.7	865.74
2014	14112.4	2084.7	1621.5	239.5	5121.4	756.55
2015	8715.4	1281.8	1001.4	147.3	3162.8	465.16
2016	8531.1	1245.7	980.2	143.1	3095.9	452.07
	- - - - Stratum D - - - -		- - - - Stratum E - - - -		- - - - Stratum F - - - -	
2003	3840.7	616.7	2434.8	391.0	5015.8	805.4
2004	2279.4	416.5	1445.0	264.1	2976.7	544.0
2005	3112.6	486.9	1973.2	308.7	4064.9	635.9
2006	3268.6	531.3	2072.1	336.8	4268.7	693.8
2007	2771.8	427.9	1757.1	271.3	3619.8	558.8
2008	2735.2	421.1	1734.0	266.9	3572.1	549.9
2009	3908.2	596.5	2477.6	378.2	5104.0	779.1
2010	4279.5	634.8	2713.0	402.4	5588.8	829.0
2011	4362.8	646.2	2765.8	409.6	5697.6	843.9
2012	4458.6	677.6	2826.5	429.6	5822.7	885.0
2013	5930.5	969.5	3759.6	614.6	7745.0	1266.1
2014	5735.3	847.2	3635.9	537.1	7490.0	1106.5
2015	3541.9	520.9	2245.4	330.2	4625.6	680.3
2016	3467.0	506.3	2197.9	320.9	4527.8	661.2
	- - - - Total - - - -		log-scale SD			
2003	25257.1	1954.2	0.07726			
2004	14989.6	1319.8	0.08788			
2005	20469.1	1542.7	0.07526			
2006	21495.1	1683.4	0.07819			
2007	18227.7	1355.8	0.07428			
2008	17987.5	1334.2	0.07407			
2009	25701.4	1890.2	0.07344			
2010	28142.7	2011.2	0.07137			
2011	28690.5	2047.4	0.07127			
2012	29320.5	2147.1	0.07313			

Year	Biomass (mt)	SD	Biomass	SD	Biomass	SD
2013	39000.1	3071.9	0.07864			
2014	37716.4	2684.5	0.07109			
2015	23292.7	1650.6	0.07077			
2016	22800.0	1604.1	0.07027			

Table 9. Annual numbers of fish lengths and ages and tows from which the fish lengths were taken for the NWFSC slope-shelf survey.

Year	Lengths	Ages	Tows	Lengths	Ages	Tows	Lengths	Ages	Tows
	- - - - Stratum A - - - -			- - - - Stratum B - - - -			- - - - Stratum C - - - -		
2003	2582	235	70	507	32	14	239	41	24
2004	1253	225	71	98	20	6	461	62	26
2005	1953	364	84	402	59	13	383	110	29
2006	1205	224	83	196	17	6	441	57	31
2007	1680	-	102	388	-	14	534	-	35
2008	1377	-	86	386	-	23	348	-	36
2009	1362	-	78	235	-	14	520	-	42
2010	1483	-	107	384	-	18	586	-	41
2011	1012	-	81	190	-	12	746	-	63
2012	607	-	60	262	-	15	696	-	57
2013	707	101	52	217	35	12	452	75	33
2014	1462	150	104	252	30	15	459	57	41
2015	1238	136	96	276	32	20	483	59	40
2016	1129	129	94	156	16	7	583	79	51
	- - - - Stratum D - - - -			- - - - Stratum E - - - -			- - - - Stratum F - - - -		
2003	570	104	36	492	79	32	106	18	12
2004	565	100	30	302	61	20	23	14	11
2005	900	187	46	272	108	27	19	19	11
2006	623	72	25	528	86	33	38	15	9
2007	525	-	37	411	-	35	6	-	3
2008	629	-	30	450	-	35	33	-	16
2009	687	-	42	613	-	38	48	-	15
2010	701	-	44	364	-	27	180	-	23
2011	465	-	36	408	-	33	236	-	36
2012	717	-	46	414	-	29	344	-	36
2013	389	54	26	315	53	21	447	81	38
2014	615	48	30	524	50	34	326	60	43
2015	982	77	52	522	50	33	340	44	34
2016	664	84	55	453	52	35	263	39	36
	- - - - - - - Total - - - - - - -								
2003	4496	509	188						
2004	2702	482	164						
2005	3929	847	210						
2006	3031	471	187						
2007	3544	-	226						
2008	3223	-	226						
2009	3465	-	229						
2010	3698	-	260						
2011	3057	-	261						
2012	3040	-	243						

Year	Lengths	Ages	Tows	Lengths	Ages	Tows	Lengths	Ages	Tows
2013	2527	399	182						
2014	3638	395	267						
2015	3841	398	275						
2016	3248	399	278						

Table 10. Summary of NWFSC slope-shelf survey hauls and swept-area estimates of biomass (mt) and abundance (1000s fish). Figure 10 indicates how the stratum identifiers correspond to geographic regions.

Year	No. Hauls	No. +Hauls	Biomass-mt	N Fish-1000s	No. Hauls	No. +Hauls	Biomass-mt	N Fish-1000s
	- - - - - - - - Stratum A - - - - - - - -				- - - - - - - - Stratum B - - - - - - - -			
2003	87	71	35463.2	59962.9	19	15	8390.3	4368.8
2004	97	74	19386.4	20060.6	7	6	6044.2	5782.1
2005	115	84	22888.6	25943.4	14	13	7880.0	6687.8
2006	114	83	8772.6	10985.9	8	6	8589.8	8550.8
2007	129	102	14673.2	14604.6	18	14	7089.2	5269.7
2008	115	87	16806.8	22148.0	23	23	5913.1	6356.9
2009	109	78	24864.9	28466.7	15	14	10336.4	7854.6
2010	125	107	21440.9	28551.8	21	18	12401.6	8724.7
2011	114	81	22379.2	26971.6	13	12	9595.6	7363.6
2012	93	61	8490.9	12148.0	16	15	9585.0	6857.0
2013	79	52	17587.5	21715.9	13	12	23075.4	14101.5
2014	136	104	12685.5	24001.6	15	15	20484.6	15127.2
2015	105	96	19314.5	27988.8	21	20	4533.1	3914.3
2016	116	95	16351.1	22537.0	8	7	8008.1	6140.6
	- - - - - - - - Stratum C - - - - - - - -				- - - - - - - - Stratum D - - - - - - - -			
2003	30	24	2976.6	2372.9	40	36	2547.0	5197.7
2004	39	28	6607.1	7538.8	30	30	3836.6	7395.7
2005	40	29	3598.2	3424.6	62	47	3628.7	6859.2
2006	45	31	21771.7	9231.7	45	25	4362.8	5786.1
2007	54	35	5965.5	5107.2	46	37	2973.6	4697.6
2008	46	36	4322.3	4088.2	35	30	4272.0	14050.0
2009	56	42	6064.9	6389.7	45	42	5111.9	17977.4
2010	50	42	7906.1	10342.2	49	44	4107.3	19784.8
2011	69	64	9535.1	10570.5	52	38	4005.0	10878.3
2012	69	57	14818.3	11381.6	57	46	4349.7	11038.8
2013	43	33	6680.4	8387.5	35	26	3931.8	9733.2
2014	49	41	14234.6	16214.0	33	30	6016.3	24545.6
2015	50	41	5361.5	6877.3	54	52	5464.0	22190.7
2016	54	51	9256.3	8152.9	57	55	3025.1	9068.4
	- - - - - - - - Stratum E - - - - - - - -				- - - - - - - - Stratum F - - - - - - - -			
2003	43	32	1820.9	2928.8	51	12	818.8	969.3
2004	23	20	2644.4	3546.8	48	11	183.1	231.7
2005	32	27	2546.2	2414.4	63	11	142.4	149.4
2006	37	33	4977.5	4756.9	65	9	349.9	286.3
2007	45	35	2990.4	2520.1	51	3	113.4	64.3
2008	40	35	3374.6	2960.4	65	16	157.9	258.0
2009	47	38	5972.2	11568.4	54	16	158.8	473.9
2010	35	27	6565.9	16514.6	64	23	603.9	2112.2

Year	No. Hauls	No. +Hauls	Biomass-mt	N Fish-1000s	No. Hauls	No. +Hauls	Biomass-mt	N Fish-1000s
2011	36	33	9018.1	13815.1	63	36	1642.8	3300.9
2012	35	29	13638.1	11721.6	66	36	2663.7	3989.7
2013	30	23	5439.8	7653.5	59	38	4040.8	6061.3
2014	37	34	9900.0	18978.9	73	44	5408.6	6586.2
2015	39	33	5814.5	10122.2	65	34	2627.0	5160.1
2016	41	35	6338.0	6972.0	58	36	2530.0	3156.1

Table 11. Stepwise construction of a bridge from the 2007 assessment model to the 2017 update model. Fishing fleets are the (1) mink-food, (2) fillet, and (3) discard fleets; survey fleets are the (4) NWFSC slope-shelf, (5) Triennial shelf, (6) AFSC slope, and (7) NWFSC slope surveys.

Part 1: Revising the data in the 2007 assessment (through 2006 but not beyond).

Step	Description	SB[0]	2007 %change	Step %change	SB[2006]	2007 %change	Step %change
	Start from the 2007 assessment model (SS version 2.0g).	80313.5			60633.4		
A	Hand translation of the SS 2.0 files to SS version 3.24.	80465.7	0.2%	0.2%	61274.5	1.1%	1.1%
B	Transformed from SS 3.24 to SS 3.30.	80574.1	0.3%	0.1%	61544.2	1.5%	0.4%
C	Removed ghost fleets and fixed selection bounds w warnings.	80574.1	0.3%	0.0%	61544.1	1.5%	0.0%
D	Changed survey-Q to non-float.	80574.1	0.3%	0.0%	61544.1	1.5%	0.0%
E	Updated the catch series, all fleets (thru 2006).	79399.5	-1.1%	-1.5%	56359.8	-7.0%	-8.4%
F	Updated the fishery length-comp data, all fleets (2 & 3, thru 2006).	77365.3	-3.7%	-2.6%	53003.2	-12.6%	-6.0%
G	Updated the fishery age-comp data (conditional only), fleet 2 (thru 2006).	59560.7	-25.8%	-23.0%	38785.1	-36.0%	-26.8%
H	Updated the NWFSC slope-shelf biomass index (thru 2006 based on the full series).	59062.8	-26.5%	-0.8%	37192.7	-38.7%	-4.1%
I	Updated the fishery marginal age-comp data, fleet 2 (thru_2006).	59062.8	-26.5%	0.0%	37192.7	-38.7%	0.0%
J	Updated the NWFSC slope-shelf length-comp data (thru 2006).	59178.3	-26.3%	0.2%	35425.7	-41.6%	-4.8%
K	Updated the NWFSC slope-shelf age@L comps (thru 2006).	59350.1	-26.1%	0.3%	35844.5	-40.9%	1.2%
L	Updated the NWFSC slope-shelf marginal age-comp data (thru 2006).	59350.1	-26.1%	0.0%	35844.5	-40.9%	0.0%
M	Updated the priors for M - both sexes.	86868.0	8.2%	46.4%	72837.4	20.1%	103.2%
N	Updated the length-weight curve coefficients - both sexes.	86892.1	8.2%	0.0%	73276.4	20.9%	0.6%
O	Changed survey Q setups for Flts 5 & 6 to include additional SE.	86915.4	8.2%	0.0%	73312.8	20.9%	0.0%
P.1	Tuned input effective Ns for length-comps (Flts 2,3,6) and SR bias adjustments.	71608.4	-10.8%	-17.6%	66006.5	8.9%	-10.0%

Table 12. Stepwise construction of a bridge from the 2007 assessment model to the 2017 update model. Fishing fleets are the (1) mink-food, (2) fillet, and (3) discard fleets; survey fleets are the (4) NWFSC slope-shelf, (5) Triennial shelf, (6) AFSC slope, and (7) NWFSC slope surveys.

Part 2: Adding new data through 2016 to the 2007 assessment.

Step	Description	SB[0]	%change from SS2.0	Step %change	SB[2006]	%change from SS2.0	Step %change
	Start from the 2007 assessment model (SS version 2.0g).	80313.5			60633.4		
P.1	Tuned input effective Ns for length-comps (Flts 2,3,6) and SR bias adjustments	71608.8	-10.8%		66006.9	8.9%	
P.2	Fixed bad fleet ID for NWFSC slope-shelf age-at-length comps; no retuning needed	71608.4	-10.8%	0.0%	66006.5	8.9%	0.0%
Q.n	New data for 2007 thru 2016.						
Q.1	Catch series + Fishery length-comp data, fleets 2 & 3	55233.4	-31.2%	-22.9%	26504.7	-56.3%	-59.8%
Q.2	+ NWFSC slope-shelf biomass index	60498.2	-24.7%	9.5%	38793.7	-36.0%	46.4%
Q.3	+ NWFSC slope-shelf length-comp. data	58791.0	-26.8%	-2.8%	35481.7	-41.5%	-8.5%
Q.4	+ NWFSC slope-shelf cond. age-at-length comp. data	59020.1	-26.5%	0.4%	54373.6	-10.3%	53.2%

Step	Description	SB[0]	%change from SS2.0	Step %change	SB[2016]	%change from Q.4	Step %change
Q.4	New data for 2007 thru 2016.	59020.1	-26.5%		72370.0		
R	Tune input effective Ns for length-comps (Flts 2,3,6) and SR bias adjustments.	50114.8	-37.6%	-15.1%	77734.9	7.4%	7.4%
T	Include extra_SD in NWFSC slope-shelf survey and tune its comp-data.	44986.0	-44.0%	-12.6%	34500.9	-52.3%	-55.4%
U	Extra_SD for all surveys; MI comp-data weighting for all fleets.	44024.8	-45.2%	-2.1%	34622.3	-52.1%	0.4%
V	Switched to new SS 3.30 and retuned. → **The base model**.	65448.2	-18.5%	48.7%	46983.4	-35.1%	35.7%

Table 13. Base model McAllister-Ianelli tuning weights for the compositional data and Methot and Taylor (2011) recruitment bias-adjustment coefficients.

Compositional data weights

Fleet	Length	Age-at-length
Fillet	1.677	0.421
Discard	0.752	
NWFSC slope-shelf	0.580	0.451
Triennial shelf	0.186	
AFSC slope	0.997	

Recruitment bias-adjustments

Coefficient	Value
Last early year with no bias-adjustment	1959.1
First year with full bias-adjustment	1984
Last year with full bias-adjustment	2013.2
First recent year with no bias-adjustment	2016
Maximum bias-adjustment	0.8172

Table 14. Base model parameters (estimated or fixed) and their low and high boundaries.

Parameter description	Est / Fixed	Low Bnd	High Bnd
Natural mortality, females	Fixed		
Length at age-1, females	Fixed		
Length at age-30, females	Est	40	90
VB growth coefficient, females	Est	0.05	0.25
CV length at age-1, females	Fixed		
CV length at age-30, females	Fixed		
Weight-length alpha, females	Fixed		
Weight-length beta, females	Fixed		
Length at 50% maturity, females	Fixed		
Maturity-length slope coefficient, females	Fixed		
Eggs/kg intercept, females	Fixed		
Eggs/kg slope, females	Fixed		
Natural mortality, males	Fixed		
Length at age-1, males	Fixed		
Length at age-30, males	Est	30	70
VB growth coefficient, males	Est	0.05	0.5
CV length at age-1, males	Fixed		
CV length at age-30, males	Fixed		
Weight-length alpha, males	Fixed		
Weight-length beta, males	Fixed		
Fraction female at birth	Fixed		
Spawner-recruit parameters			
loge(R0)	Est	5	25
steepness	Fixed		
sigma R	Fixed		
Recruitment deviations, 1965-2015	Est	-5	5
Survey catchability parameters			
Ln(Q), NWFSC slope-shelf survey	Est	-15	15
extra_SD, NWFSC slope-shelf survey	Est	0	0.5
Ln(Q). Triennial survey	Est	-15	15
extra_SD, Triennial survey	Est	0	0.5
Ln(Q), AFSC slope survey	Est	-15	15
extra_SD, AFSC slope survey	Est	0	0.5
Ln(Q) NWFSC slope survey	Est	-15	15
extra_SD, NWFSC slope survey	Est	0	0.5
Selection parameters			
Length at peak selection, Mink-food fleet	Fixed		
Width of top, Mink- food fleet	Fixed		

Parameter description	Est / Fixed	Low Bnd	High Bnd
Ascending width, Mink-food fleet	Fixed		
Descending width, Mink-food fleet	Fixed		
Final selection, Mink-food fleet	Fixed		
Initial selection, Mink-food fleet	Fixed		
Length at peak selection, Fillet fleet	Fixed		
Width of top, Fillet fleet	Fixed		
Ascending width, Fillet fleet	Est	-1	10
Descending width, Fillet fleet	Fixed		
Final selection, Fillet fleet	Fixed		
Initial selection, Fillet fleet	Fixed		
Length at male dogleg, Fillet fleet	Fixed		
ln(Rel. selection) at Lmin, Fillet fleet	Fixed		
ln(Rel. selection) at the dogleg, Fillet fleet	Est	-3	0
ln(Rel. selection) at the Lmax, Fillet fleet	Est	-3	0
Length at peak selection, Discard fleet	Est	15	79
Width of top, Discard fleet	Fixed		
Ascending width, Discard fleet	Est	-1	9
Descending width, Discard fleet	Fixed		
Final selection, Discard fleet	Fixed		
Initial selection, Discard fleet	Fixed		
Length at peak selection, NWFSC slope-shelf survey	Est	15	79
Width of top, NWFSC slope-shelf survey	Fixed		
Ascending width, NWFSC slope-shelf survey	Est	-1	10
Descending width, NWFSC slope-shelf survey	Fixed		
Final selection, NWFSC slope-shelf survey	Fixed		
Initial selection, NWFSC slope-shelf survey	Fixed		
Length at male dogleg, NWFSC shelf-slope survey	Fixed		
ln(Rel. selection) at Lmin, NWFSC shelf-slope survey	Fixed		
ln(Rel. selection) at the dogleg, NWFSC shelf-slope survey	Est	-3	0
ln(Rel. selection) at the Lmax, NWFSC shelf-slope survey	Est	-3	0
Length at peak selection, Triennial survey	Est	15	79
Width of top, Triennial survey	Fixed		
Ascending width, Triennial survey	Est	-1	9
Descending width, Triennial survey	Fixed		
Final selection, Triennial survey	Fixed		
Initial selection, Triennial survey	Fixed		
Length at male dogleg, Triennial survey	Fixed		
ln(Rel. selection) at Lmin, Triennial survey	Fixed		
ln(Rel. selection) at the dogleg, Triennial survey	Est	-3	0
ln(Rel. selection) at the Lmax, Triennial survey	Est	-3	0
Length at peak selection, AFSC slope survey	Est	15	79
Width of top, AFSC slope survey	Fixed		

Parameter description	Est / Fixed	Low Bnd	High Bnd
Ascending width, AFSC slope survey	Est	-1	9
Descending width, AFSC slope survey	Fixed		
Final selection, AFSC slope survey	Fixed		
Initial selection, AFSC slope survey	Fixed		
Length at male dogleg, AFSC slope survey	Fixed		
ln(Rel. selection) at Lmin, AFSC slope survey	Fixed		
ln(Rel. selection) at the dogleg, AFSC slope survey	Est	-3	0
ln(Rel. selection) at the Lmax, AFSC slope survey	Est	-3	0

Table 15. Likelihood profile over parameter ln(*R*0). The yellow highlighted cells in each likelihood component row indicate the column-entry with the smallest negative log-likelihood.

ln(*R*0) =	10.4295	10.6295	10.7295	10.8295	10.9295	11.0295	11.2295
Likelihood component				Base			
Total	2859.3	2843.5	2839.4	2837.8	2839.5	2843.7	2855.3
Indices	-10.05	-11.13	-11.71	-12.43	-13.31	-14.10	-15.10
4.Slope-shelf	-7.31	-8.34	-8.87	-9.50	-10.21	-10.76	-11.20
5.Triennial	2.985	2.965	2.943	2.903	2.809	2.658	2.293
6.AFSC_Slope	-1.674	-1.715	-1.745	-1.793	-1.874	-1.978	-2.197
7.NWFSC_slope	-4.041	-4.040	-4.039	-4.037	-4.032	-4.023	-3.998
LenComp	967.3	962.2	959.6	956.4	953.6	952.5	952.9
2.Fillet	375.4	369.8	366.8	363.1	359.7	357.8	356.4
3.Discard	126.8	126.6	126.6	126.4	126.1	125.9	125.8
4.Slope-shelf	282.0	281.4	281.3	281.2	281.2	281.8	283.4
5.Triennial	107.4	108.3	108.8	109.4	109.9	110.2	110.1
6.AFSC_Slope	75.7	76.1	76.2	76.4	76.7	76.9	77.2
AgeComp	1852.8	1860.2	1865.1	1871.6	1878.9	1885.4	1895.7
2.Fillet	932.7	940.8	946.3	954.2	964.1	973.6	988.4
4.Slope-shelf	920.1	919.4	918.8	917.4	914.8	911.8	907.3
Derived quantity							
SB[0]	43804.5	53532.3	59187.8	65449.4	72371.3	80032.9	97923.5
SB[2016]	30147.3	36224.4	40325.8	46993.8	58687.0	75530.7	122983

Table 16. Likelihood components for the base model and estimated parameters (except recruitment deviations) and their standard deviations.

Model Likelihoods	Base Model
Likelihood components	-Ln(Likelihood)
Total	2837.84
Survey indices	-12.42
Length_comps	956.40
Age_comps	1871.63
Recruitment	14.13
Forecast_Recruitment	8.10

Parameter	MLE	SD
Stock recruit		
Ln(Rzero)	10.8295	0.054698
Catchability (analytical solution)		
ln(Q) - NWFSC shelf/slope	-0.60666	0.16298
Extra_SD	0.23241	0.06104
ln(Q) - Triennial	-3.02758	0.282062
Extra_SD	0.47066	0.20002
ln(Q) - AFSC slope survey	-2.6459	0.1958
Extra_SD	0.11946	0.13974
ln(Q) - NWFSC slope survey	-2.0083	0.1868
Extra_SD	7.517E-08	6.381E-05
Selectivity (double normal):		
NWFSC shelf/slope		
Peak	61.485	3.1434
Var-ascending (ln)	7.095	0.2137
Ln(Male sel./female sel.) at dogleg	-1.631E-07	7.93E-05
Ln(Male sel./female sel.) at max length	-0.60265	0.30204
Triennial shelf		
Peak	31.712	1.6181
Var-ascending (ln)	4.587	0.3830
Ln(Male sel./female sel.) at dogleg	-1.422E-08	2.767E-05
Ln(Male sel./female sel.) at max length	-0.05964	0.67179
AFSC slope		
Peak	31.463	1.232
Var-ascending (ln)	3.458	0.3752
Ln(Male sel./female sel.) at dogleg	-6.150E-08	9.584E-05
Ln(Male sel./female sel.) at max length	-0.96601	0.87326
Fillet Fleet		
Var-ascending (ln)	5.408	0.02916
Ln(Male sel./female sel.) at dogleg	-1.136E-08	2.084E-05
Ln(Male sel./female sel.) at max length	-1.557E-05	5.757E-03
Discard Fleet		

Parameter	MLE	SD
Peak	58.2202	1.8767
Var-ascending (ln)	5.9374	0.1254
Individual growth		
Length at age max (age 30) females	69.772	0.49118
von Bertalanffy K females	0.17062	0.003041
Length at age max (age 30) males	44.404	0.22501
von Bertalanffy K males	0.35870	0.007283
Derived quantities		
SB[0]	65448.2	3644.1
2017 Spawning biomass	56710.3	11463.0
2017 Depletion	0.8665	0.1564
MSY (Yield with SPR(msy-proxy) @SBspr	6634.9	369.9
BMSY (SSB_SPR_tgt)	18355.3	1022.01

Table 17. Base model estimates of spawning biomass and recruitment time-series and their associated standard deviations.

Year	SpBio	StDev	Recruitment	StDev
Unfished	65448.2	3644.1	50487.8	2761.6
1916	65448.2	3644.1	50487.8	2761.6
1917	65448.2	3644.1	50487.8	2761.6
1918	65444.4	3644.1	50487.7	2761.6
1919	65437.8	3644.1	50487.6	2761.6
1920	65428.8	3644.1	50487.4	2761.6
1921	65417.7	3644.1	50487.1	2761.6
1922	65404.8	3644.1	50486.9	2761.6
1923	65390.3	3644.1	50486.6	2761.6
1924	65374.6	3644.1	50486.2	2761.6
1925	65357.7	3644.1	50485.9	2761.6
1926	65339.8	3644.1	50485.5	2761.6
1927	65321.3	3644.1	50485.1	2761.6
1928	65302.0	3644.1	50484.7	2761.6
1929	65282.4	3644.1	50484.3	2761.6
1930	65247.1	3644.0	50483.6	2761.6
1931	65215.9	3644.0	50482.9	2761.6
1932	65190.2	3644.0	50482.4	2761.6
1933	65165.6	3644.0	50481.8	2761.6
1934	65142.0	3644.0	50481.3	2761.6
1935	65112.0	3644.0	50480.7	2761.6
1936	65043.2	3644.0	50479.2	2761.6
1937	64901.3	3644.0	50476.2	2761.6
1938	64771.6	3643.9	50473.5	2761.6
1939	64654.2	3643.9	50470.9	2761.6
1940	64504.2	3643.8	50467.7	2761.6
1941	64301.9	3643.8	50463.3	2761.6
1942	64032.0	3643.7	50457.5	2761.6
1943	63629.7	3643.6	50448.6	2761.7
1944	62709.1	3643.2	50428.0	2761.7
1945	62463.5	3643.1	50422.3	2761.8
1946	62270.0	3643.0	50417.9	2761.8
1947	61895.6	3643.0	50409.2	2761.9
1948	61676.3	3642.9	50404.1	2761.9
1949	60943.7	3642.6	50386.6	2762.0
1950	60485.8	3642.5	50375.5	2762.1
1951	60077.0	3642.7	50365.5	2762.2
1952	59644.1	3642.8	50354.7	2762.3
1953	59197.7	3642.9	50343.4	2762.5
1954	58751.0	3642.8	50331.9	2762.6
1955	57627.5	3642.4	50302.4	2763.0

Year	SpBio	StDev	Recruitment	StDev
1956	55156.5	3641.0	50233.2	2764.2
1957	52812.0	3640.5	50161.8	2765.9
1958	51342.8	3642.0	50113.8	2767.3
1959	49864.2	3644.1	50062.8	2769.0
1960	48547.6	3646.7	50014.9	2770.8
1961	47929.1	3652.2	49991.5	2771.9
1962	47809.5	3657.9	49986.9	2772.3
1963	46863.7	3660.4	49949.8	2774.0
1964	46200.3	3665.3	49922.8	2775.4
1965	45768.9	3670.8	10179.7	5853.1
1966	45354.4	3676.4	10259.9	5844.8
1967	45802.9	3685.3	11103.8	6343.5
1968	46142.0	3691.1	13687.0	8062.0
1969	45906.4	3667.8	20041.9	12309.7
1970	43803.3	3591.5	29377.9	19982.1
1971	40471.5	3482.6	41248.7	30819.9
1972	36832.5	3355.2	52332.9	36566.2
1973	33523.7	3222.3	39124.3	35929.5
1974	30955.2	3096.7	58510.7	37245.8
1975	29607.8	2998.9	41531.3	36392.5
1976	29721.0	2916.1	117077.0	35390.6
1977	30685.2	2854.1	50746.5	26629.0
1978	32357.4	2849.1	28742.8	20143.9
1979	33722.5	2835.3	114692.0	22565.3
1980	35754.3	2928.2	117070.0	23584.6
1981	40029.2	3111.7	137852.0	22181.5
1982	42707.6	3276.8	46601.1	15645.1
1983	43103.2	3462.3	115476.0	17548.4
1984	46372.0	3844.9	74872.2	15797.2
1985	52207.5	4420.4	148856.0	21021.6
1986	58295.8	4997.0	79575.0	18853.8
1987	63352.4	5408.5	71148.8	22382.5
1988	67122.4	5714.2	43561.3	25369.0
1989	71572.3	5918.1	28542.4	19865.1
1990	75246.9	6061.3	142770.0	25166.2
1991	75629.7	6079.1	24849.4	17059.9
1992	74145.7	5923.2	19769.1	12874.4
1993	71599.4	5617.6	55216.0	15940.1
1994	69629.2	5264.9	44495.9	12328.6
1995	69377.3	4913.7	13610.3	6913.4
1996	67846.2	4557.2	19157.1	6026.0
1997	64311.7	4196.8	16547.2	5338.9
1998	60747.4	3882.1	24621.5	5546.1

Year	SpBio	StDev	Recruitment	StDev
1999	56233.0	3611.4	163432.0	14773.5
2000	48582.2	3343.9	28364.9	5784.6
2001	42386.5	3085.9	47868.5	6787.8
2002	37400.5	2859.5	47651.3	7258.6
2003	35311.4	2847.2	9122.0	4052.1
2004	38400.1	3163.4	33480.2	6905.2
2005	41045.1	3475.1	18520.0	6401.7
2006	39913.6	3717.4	109822.0	18266.9
2007	39750.2	3873.2	36830.0	10228.5
2008	37065.5	3912.6	91791.3	17951.7
2009	34123.7	3928.8	20909.9	6858.0
2010	29626.3	4142.7	31861.5	8425.9
2011	30770.8	4765.3	114024.0	24704.4
2012	33897.6	5558.7	135892.0	31312.0
2013	37306.3	6444.0	155499.0	38821.6
2014	38876.0	7064.5	8232.4	4338.0
2015	41095.3	7754.6	31213.9	21138.3
2016	46983.4	9186.5	49954.5	40064.5
2017	56710.3	11463.0	50277.4	40322.1

Table 18. Estimated time-series for biomass, depletion, and exploitation from the base model.

Year	Total biomass (mt)	Age-3+ biomass (mt)	Spawning biomass (mt)	Age-0 Recruits (1000s)	Depletion % of Bzero	F rate
1916	92,017	88,805	65,448	50,488	-	-
1917	92,017	88,805	65,448	50,488	-	0.01%
1918	92,013	88,800	65,444	50,488	100.0%	0.01%
1919	92,005	88,793	65,438	50,488	100.0%	0.01%
1920	91,995	88,783	65,429	50,487	100.0%	0.02%
1921	91,983	88,770	65,418	50,487	100.0%	0.02%
1922	91,969	88,756	65,405	50,487	99.9%	0.03%
1923	91,953	88,740	65,390	50,487	99.9%	0.03%
1924	91,936	88,723	65,375	50,486	99.9%	0.03%
1925	91,917	88,705	65,358	50,486	99.9%	0.04%
1926	91,898	88,685	65,340	50,486	99.8%	0.04%
1927	91,878	88,665	65,321	50,485	99.8%	0.05%
1928	91,857	88,644	65,302	50,485	99.8%	0.05%
1929	91,836	88,623	65,282	50,484	99.7%	0.08%
1930	91,794	88,581	65,247	50,484	99.7%	0.08%
1931	91,758	88,546	65,216	50,483	99.6%	0.07%
1932	91,730	88,518	65,190	50,482	99.6%	0.08%
1933	91,704	88,491	65,166	50,482	99.6%	0.08%
1934	91,676	88,464	65,142	50,481	99.5%	0.09%
1935	91,642	88,429	65,112	50,481	99.5%	0.15%
1936	91,565	88,353	65,043	50,479	99.4%	0.26%
1937	91,407	88,195	64,901	50,476	99.2%	0.27%
1938	91,263	88,051	64,772	50,474	99.0%	0.27%
1939	91,136	87,924	64,654	50,471	98.8%	0.33%
1940	90,973	87,761	64,504	50,468	98.6%	0.44%
1941	90,749	87,538	64,302	50,463	98.2%	0.56%
1942	90,451	87,240	64,032	50,458	97.8%	0.80%
1943	89,998	86,787	63,630	50,449	97.2%	1.64%
1944	88,906	85,696	62,709	50,428	95.8%	0.74%
1945	88,660	85,450	62,464	50,422	95.4%	0.73%
1946	88,481	85,273	62,270	50,418	95.1%	1.06%
1947	88,082	84,874	61,896	50,409	94.6%	0.93%
1948	87,844	84,636	61,676	50,404	94.2%	1.77%
1949	86,964	83,758	60,944	50,387	93.1%	1.46%
1950	86,418	83,212	60,486	50,376	92.4%	1.42%
1951	85,985	82,780	60,077	50,366	91.8%	1.57%
1952	85,501	82,297	59,644	50,355	91.1%	1.69%
1953	84,993	81,789	59,198	50,343	90.4%	1.84%

Year	Total biomass (mt)	Age-3+ biomass (mt)	Spawning biomass (mt)	Age-0 Recruits (1000s)	Depletion % of Bzero	F rate
1954	84,419	81,216	58,751	50,332	89.8%	3.00%
1955	82,992	79,790	57,628	50,302	88.1%	5.43%
1956	79,828	76,630	55,157	50,233	84.3%	5.60%
1957	76,916	73,721	52,812	50,162	80.7%	4.47%
1958	75,216	72,025	51,343	50,114	78.4%	4.87%
1959	73,524	70,337	49,864	50,063	76.2%	5.05%
1960	71,990	68,807	48,548	50,015	74.2%	3.97%
1961	71,483	68,301	47,929	49,992	73.2%	3.39%
1962	71,523	68,342	47,810	49,987	73.0%	5.34%
1963	70,345	67,168	46,864	49,950	71.6%	4.95%
1964	69,596	66,419	46,200	49,923	70.6%	4.73%
1965	68,353	65,925	45,769	10,180	69.9%	4.87%
1966	67,338	65,418	45,354	10,260	69.3%	3.13%
1967	66,773	66,108	45,803	11,104	70.0%	3.35%
1968	64,360	63,632	46,142	13,687	70.5%	2.99%
1969	60,838	59,931	45,906	20,042	70.1%	3.21%
1970	56,473	55,226	43,803	29,378	66.9%	3.24%
1971	52,155	50,362	40,472	41,249	61.8%	3.11%
1972	48,638	46,186	36,833	52,333	56.3%	2.86%
1973	46,155	43,429	33,524	39,124	51.2%	2.93%
1974	45,769	42,492	30,955	58,511	47.3%	2.84%
1975	46,429	43,647	29,608	41,531	45.2%	2.87%
1976	49,642	45,036	29,721	117,077	45.4%	3.63%
1977	51,625	47,844	30,685	50,747	46.9%	3.20%
1978	55,229	50,290	32,357	28,743	49.4%	5.37%
1979	61,306	57,157	33,723	114,692	51.5%	6.15%
1980	65,478	60,891	35,754	117,070	54.6%	4.76%
1981	70,447	62,686	40,029	137,852	61.2%	5.37%
1982	75,233	68,844	42,708	46,601	65.3%	8.04%
1983	82,442	75,260	43,103	115,476	65.9%	7.12%
1984	89,397	85,020	46,372	74,872	70.9%	6.55%
1985	96,783	89,328	52,208	148,856	79.8%	6.32%
1986	101,771	95,974	58,296	79,575	89.1%	4.53%
1987	108,123	100,999	63,352	71,149	96.8%	5.25%
1988	113,497	109,219	67,122	43,561	102.6%	4.26%
1989	117,770	114,397	71,572	28,542	109.4%	5.79%
1990	119,888	115,444	75,247	142,770	115.0%	7.46%
1991	114,133	110,926	75,630	24,849	115.6%	6.98%
1992	109,145	103,881	74,146	19,769	113.3%	5.50%

Year	Total biomass (mt)	Age-3+ biomass (mt)	Spawning biomass (mt)	Age-0 Recruits (1000s)	Depletion % of Bzero	F rate
1993	107,463	105,376	71,599	55,216	109.4%	4.52%
1994	104,266	102,090	69,629	44,496	106.4%	4.73%
1995	98,889	96,295	69,377	13,610	106.0%	3.95%
1996	94,328	92,368	67,846	19,157	103.7%	4.08%
1997	88,953	87,960	64,312	16,547	98.3%	4.38%
1998	82,514	81,226	60,747	24,622	92.8%	5.63%
1999	77,254	73,337	56,233	163,432	85.9%	9.53%
2000	66,353	62,941	48,582	28,365	74.2%	7.80%
2001	61,930	55,431	42,387	47,869	64.8%	6.94%
2002	62,634	60,217	37,401	47,651	57.1%	7.07%
2003	62,903	60,589	35,311	9,122	54.0%	6.01%
2004	64,423	62,150	38,400	33,480	58.7%	5.55%
2005	64,563	63,495	41,045	18,520	62.7%	10.34%
2006	61,938	58,564	39,914	109,822	61.0%	6.24%
2007	59,087	56,397	39,750	36,830	60.7%	8.36%
2008	57,516	51,802	37,066	91,791	56.6%	8.43%
2009	56,695	53,948	34,124	20,910	52.1%	14.71%
2010	54,524	50,719	29,626	31,862	45.3%	8.90%
2011	57,982	54,761	30,771	114,024	47.0%	5.59%
2012	61,503	56,469	33,898	135,892	51.8%	5.12%
2013	65,646	57,332	37,306	155,499	57.0%	5.06%
2014	69,782	63,284	38,876	8,232	59.4%	3.47%
2015	79,612	73,937	41,095	31,214	62.8%	2.76%
2016	90,317	88,714	46,983	49,955	71.8%	2.14%
2017	97,118	94,534	56,710	50,277	86.6%	14.60%

Table 19. Likelihood components and key derived quantities from the sensitivity runs. See the main text for a description of the different sensitivity runs.

Sensitivity runs =	Base	Low catch	High catch	Francis wts	Dirichlet Mult.
Likelihood component					
Total	2837.8	2840.7	2835.2	1286.2	5681.7
Indices	-12.42	-12.36	-12.50	-14.86	-11.78
4.NWFSC slope-shelf	-9.50	-9.27	-9.77	-10.72	-7.67
5.Triennial	2.90	2.80	3.03	1.94	1.95
6.AFSC slope	-1.79	-1.85	-1.73	-2.12	-2.07
7.NWFSC slope	-4.04	-4.03	-4.04	-3.96	-3.99
LenComp	956.40	953.55	959.49	469.00	1622.37
2.Fillet	363.09	360.16	366.17	97.99	321.96
3.Discard	126.37	126.49	126.23	69.69	165.75
4.NWFSC slope-shelf	281.15	281.27	281.10	121.68	508.49
5.Triennial	109.36	109.21	109.55	147.96	549.03
6.AFSC slope	76.43	76.42	76.44	31.68	77.14
AgeComp	1871.63	1876.73	1866.59	815.48	4023.85
2.Fillet	954.20	957.84	950.85	403.25	2133.06
4.Slope/shelf	917.43	918.89	915.74	412.24	1890.79
Derived quantitities					
SB[0]	65448.2	61009.5	71463.3	66182.3	44875.1
SB[2016]	46983.4	44387.9	50684.0	53513.5	35959.4

Table 20. Comparison of compositional data multipliers for the base model and two alternative tuning methods applied as sensitivity runs.

Fleet	Base model	Francis tuning	DM tuning *
Length-compositions			
Fillet	1.677	0.374	100.0
`Discard	0.752	0.428	99.933
NWFSC slope-shelf	0.580	0.242	98.666
Triennial shelf	0.186	0.293	77.538
AFSC slope	0.997	0.472	100.0
Age-at-length compositions			
Fillet	0.421	0.177	100.0
NWFSC slope-shelf	0.451	0.205	100.0

* As it used in the Stock Synthesis model, the Dirichlet multinomial (DM) parameter (*Theta*) for a given compositional component is applied to the input sample-size for each annual compositional observation. This approach does not produce a simple multiplier of the input sample-sizes. Shown in the table are the effective sample-sizes given the estimated (or fixed) *Theta* values as transformed to an equivalent multiplier value given an input sample-size of 100. The following formula relates the effective sample-size (*Effective_N*) with the input sample-size (*Input_N*).

$$Effective\_N = \frac{1}{1 + exp(Theta)} + \frac{Input\_N \ * exp(Theta)}{1 + exp(Theta)}$$

The DM parameters were freely estimated for the length-compositional data from the discard fishing fleet, the NWFSC slope-shelf survey, and the Triennial survey. For the other compositional components the DM parameters were fixed at *Theta* = 15.

Table 21. Selected results from a five-year retrospective analysis of the base model, indicating the sensitivity of the base model to data from the most recent years.

Retro_YR =	2016 (base)	2015	2014	2013	2012	2011
Derived quantity or estimated parameter value						
SB[0]	65448	66765	69215	68563	66600	67118
SB[2011]	30771	31300	35398	37365	34060	36144
Female growth						
Length at Amax	69.77	70.04	70.51	71.57	72.58	72.79
VonBert K	0.1706	0.1706	0.1698	0.1647	0.1596	0.1585
Male growth						
Length at Amax	44.40	44.54	44.47	44.59	44.65	44.61
VonBert K	0.3587	0.3601	0.3719	0.3720	0.3741	0.3771
Recruitment						
SR ln(R0)	10.830	10.836	10.854	10.830	10.791	10.798
RecrDev[2008]	0.8799	0.8780	1.1043	1.3803	1.6696	1.6453
RecrDev[2009]	-0.5954	-0.5688	-0.2430	-0.1172	-0.0146	-0.2284
RecrDev[2010]	-0.1665	-0.1724	-0.0796	-0.2046	0.0345	-0.2136

Table 22. Projections of arrowtooth spawning biomass and depletion based on three assumed catch streams for the period 2017 to 2028. See text for details.

Year	Catch (mt)	Spawning biomass (mt)	Depletion
A. Catches (2019-2028) based on P*=0.45 and sigma=0.72.			
2017	13804	56710	0.87
2018	13743	57160	0.87
2019	15578	52226	0.80
2020	13302	42528	0.65
2021	11035	34656	0.53
2022	9272	29345	0.45
2023	8135	26132	0.40
2024	7478	24308	0.37
2025	7113	23287	0.36
2026	6904	22687	0.35
2027	6773	22299	0.34
2028	6682	22021	0.34
B. Catches (2019-2028) based on the OFL.			
2017	13804	56710	0.87
2018	13743	57160	0.87
2019	18696	52226	0.80
2020	15070	40045	0.61
2021	11887	30987	0.47
2022	9644	25392	0.39
2023	8339	22352	0.34
2024	7665	20828	0.32
2025	7328	20066	0.31
2026	7145	19640	0.30
2027	7027	19348	0.30
2028	6938	19117	0.29
C. Constant catches based on recent average catch.			
2017	2385	56710	0.87
2018	2385	65896	1.01
2019	2385	69615	1.06
2020	2385	69597	1.06
2021	2385	68424	1.05
2022	2385	66876	1.02
2023	2385	65155	1.00
2024	2385	63402	0.97
2025	2385	61722	0.94
2026	2385	60179	0.92
2027	2385	58800	0.90
2028	2385	57593	0.88

Table 23. Decision table for Arrowtooth Flounder based on status quo catches during 2017 and 2018, projected catches for 2019-2018, and alternative assumptions about the female and male natural mortality rates (see text for details). Columns range over low, mid, and high states of nature, and rows range over catch streams from those states of nature. ABCs are based upon the assumptions that P*=0.45 and σ=0.72 for a category 2 designation, and the ACLs are taken in 2017 (13,804mt) and 2018 (13,743mt).

			State of nature					
			Low $M_{female} = 0.15\ yr^{-1}$ $M_{male} = 0.21\ yr^{-1}$		Base case $M_{female} = 0.216\ yr^{-1}$ $M_{male} = 0.30\ yr^{-1}$		High $M_{female} = 0.31\ yr^{-1}$ $M_{male} = 0.43\ yr^{-1}$	
Relative probability			0.25		0.5		0.25	
Management decision	Year	Catch (mt)	Spawning bio. (mt)	Depletion	Spawning bio. (mt)	Depletion	Spawning bio. (mt)	Depletion
ABC catches from "Low" state of nature	2019	7,062	35,586	0.68	52,226	0.80	124,842	0.68
	2020	6,902	33,340	0.63	49,396	0.75	119,590	0.65
	2021	6,434	30,372	0.58	46,166	0.71	118,830	0.64
	2022	5,857	27,509	0.52	43,460	0.66	121,985	0.66
	2023	5,318	25,062	0.48	41,431	0.63	126,928	0.69
	2024	4,877	23,110	0.44	40,040	0.61	132,413	0.72
	2025	4,537	21,615	0.41	39,176	0.60	137,796	0.75
	2026	4,284	20,495	0.39	38,713	0.59	142,761	0.77
	2027	4,096	19,666	0.37	38,537	0.59	147,174	0.80
	2028	3,958	19,052	0.36	38,558	0.59	151,004	0.82
Base Case ABC catches	2019	15,578	35,586	0.68	52,226	0.80	124,842	0.68
	2020	13,302	26,920	0.51	42,528	0.65	113,095	0.61
	2021	11,035	19,288	0.37	34,656	0.53	108,321	0.59
	2022	9,272	13,487	0.26	29,345	0.45	109,503	0.59
	2023	8,135	9,375	0.18	26,132	0.40	113,772	0.62
	2024	7,478	6,489	0.12	24,308	0.37	119,228	0.65
	2025	7,113	4,362	0.08	23,287	0.36	124,798	0.68
	2026	6,904	2,643	0.05	22,687	0.35	129,955	0.70
	2027	6,773	*	-	22,299	0.34	134,501	0.73
	2028	6,682	*	-	22,021	0.34	138,404	0.75
ABC catches from "High" state of nature	2019	57,469	35,586	0.68	52,226	0.80	124,842	0.68
	2020	38,893	*	-	9,838	0.15	80,519	0.44
	2021	29,277	*	-	*	-	61,501	0.33
	2022	26,107	*	-	*	-	57,183	0.31
	2023	26,081	*	-	*	-	58,224	0.32
	2024	26,757	*	-	*	-	59,861	0.32
	2025	27,176	*	-	*	-	60,612	0.33
	2026	27,241	*	-	*	-	60,539	0.33
	2027	27,119	*	-	*	-	60,139	0.33
	2028	26,971	*	-	*	-	59,780	0.32

Figures

Figure 1. Map of the US West Coast.

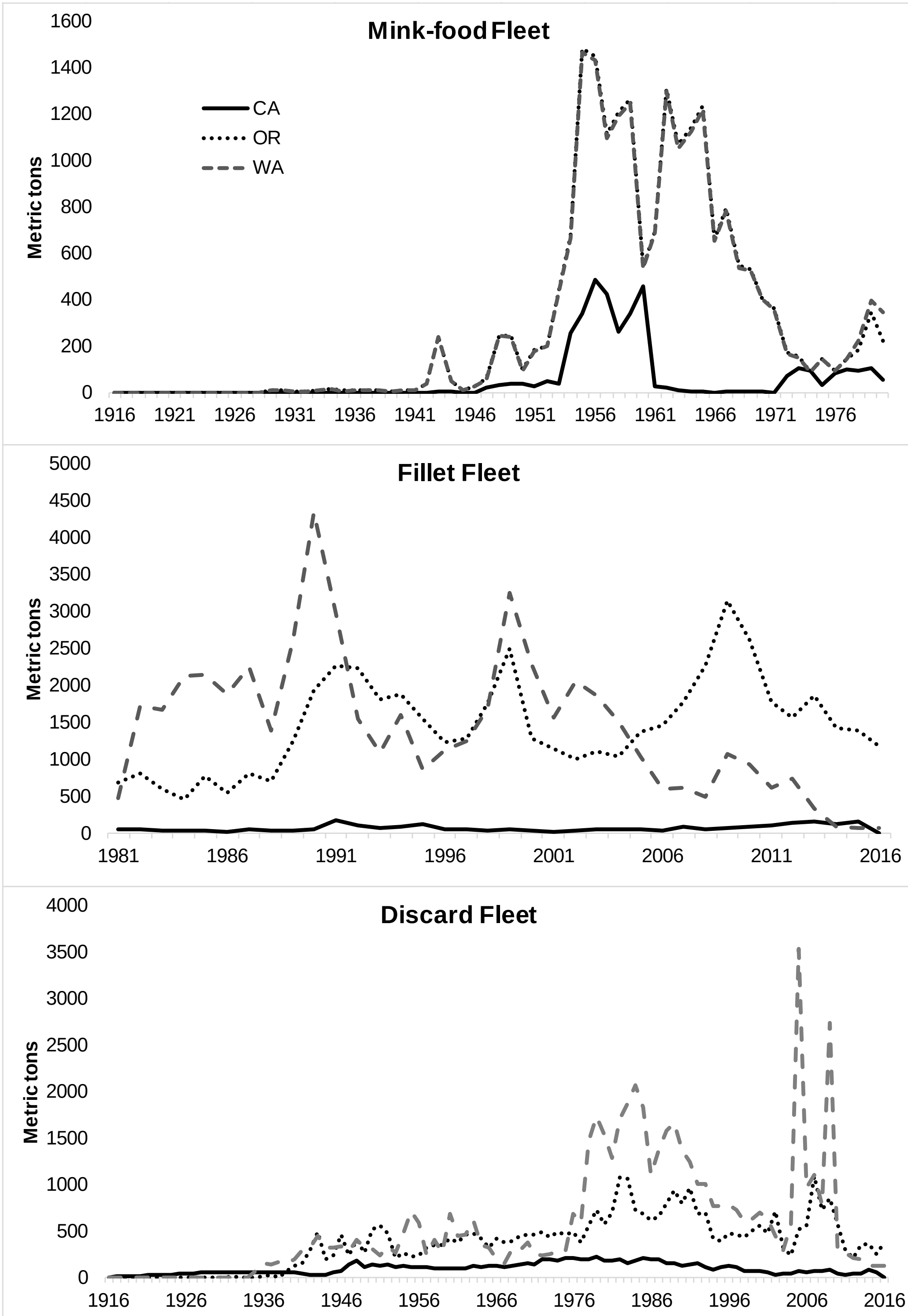


Figure 2. Reconstructed catch series of Arrowtooth Flounder by state for the A. mink-food, B. fillet, and C. discard fleets.

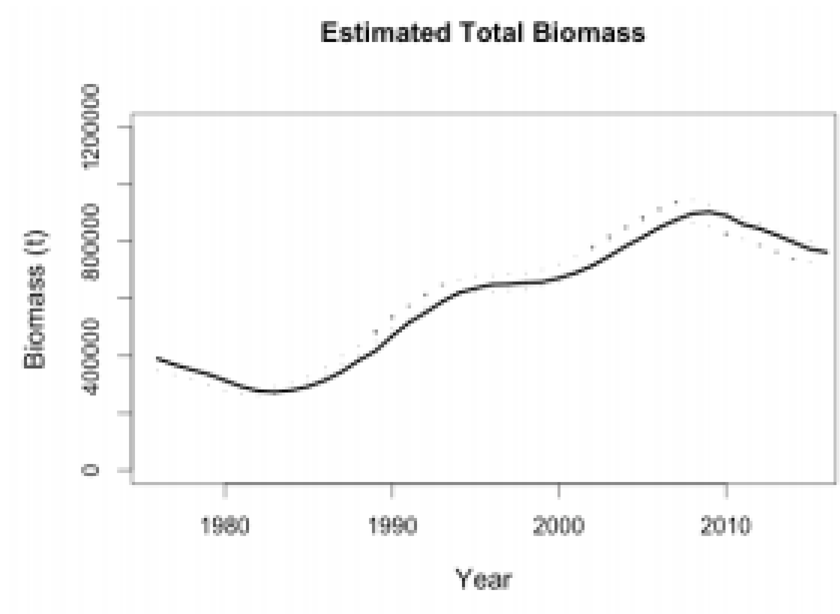


Figure 3. Estimated biomass trends for Arrowtooth Flounder in the Bering Sea, from Spies, et al. (2016).

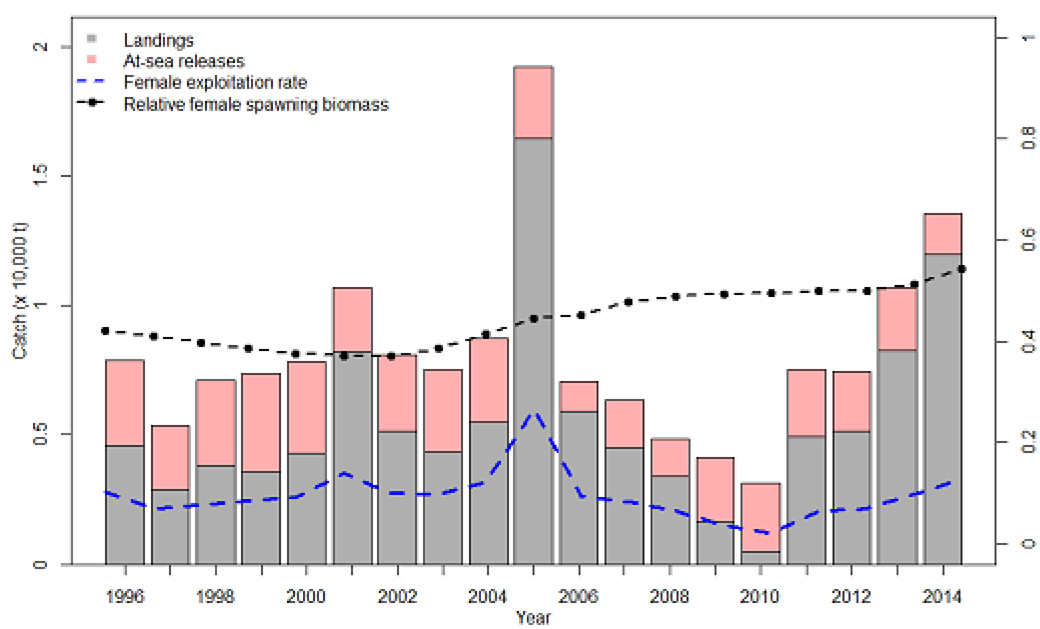


Figure 4. Estimated catches and biomass trends for Arrowtooth Flounder off British Columbia, from DFO (2015).

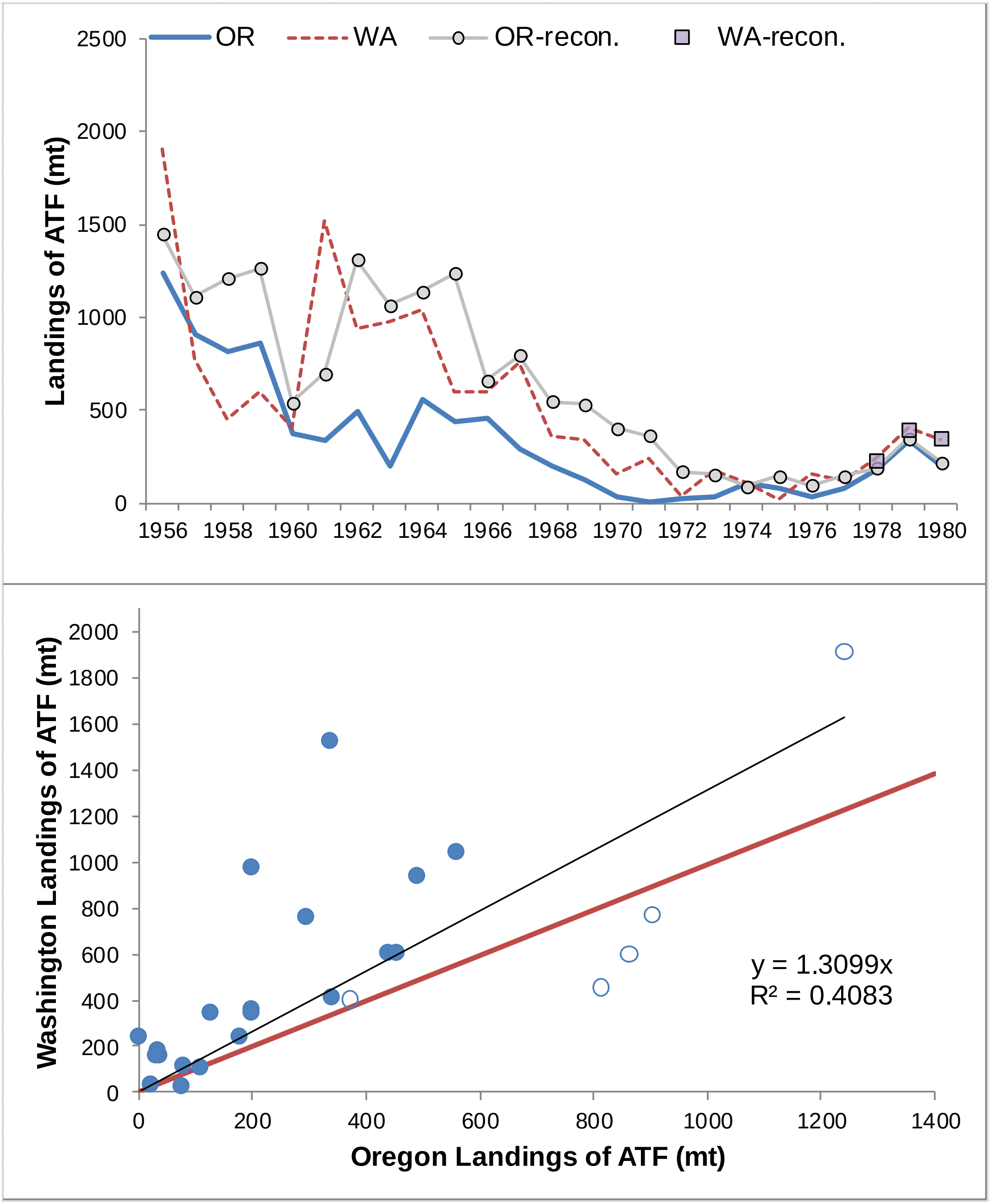


Figure 5. Washington versus Oregon historical landings of Arrowtooth Flounder (ATF) as reported in the 2007 stock assessment. The points shown as open circles in the lower panel (for the years 1956-1960) were used to derive the WA:OR ratio (0.988, shown as the thicker line) that was applied to the reconstructed Oregon landings of Arrowtooth Flounder to estimate Washington landings of Arrowtooth Flounder for years prior to 1978.

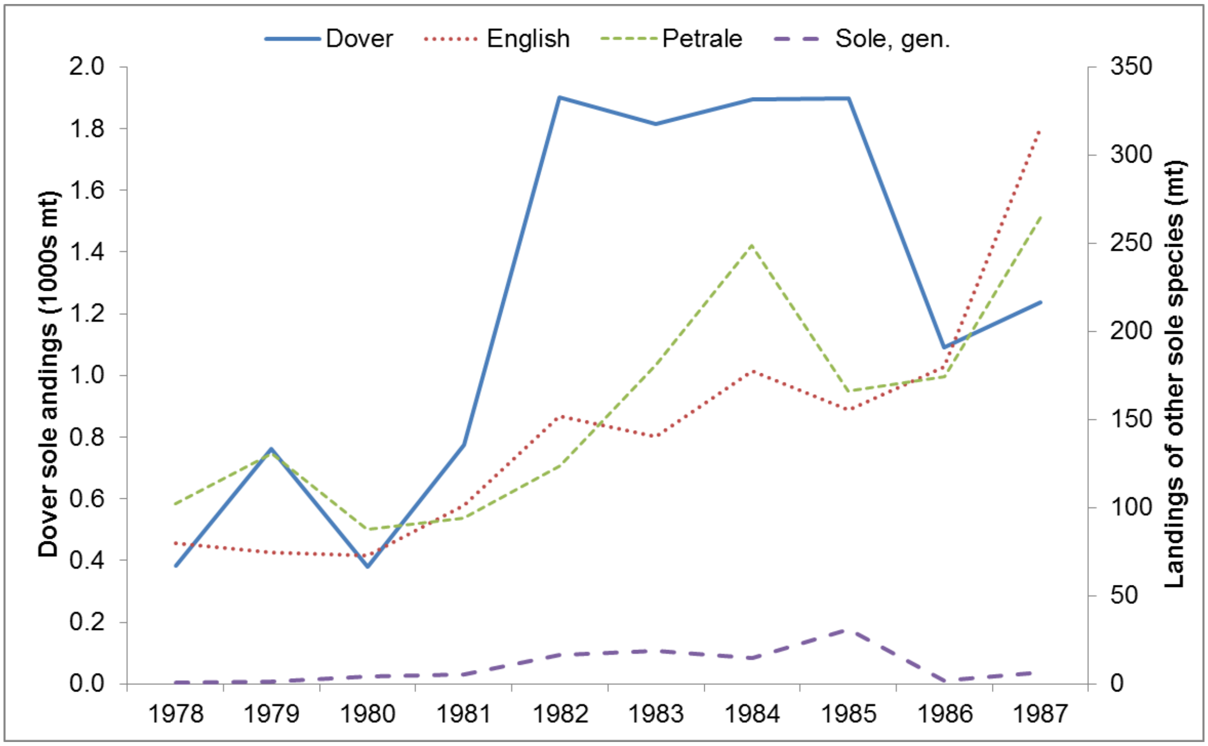


Figure 6. Washington landings of Sole species during 1978-1987, used to derive ratio estimators for English and Petrale Soles from landings of Dover Sole, for estimating WA Arrowtooth Flounder landings from Sole landings prior to 1978.

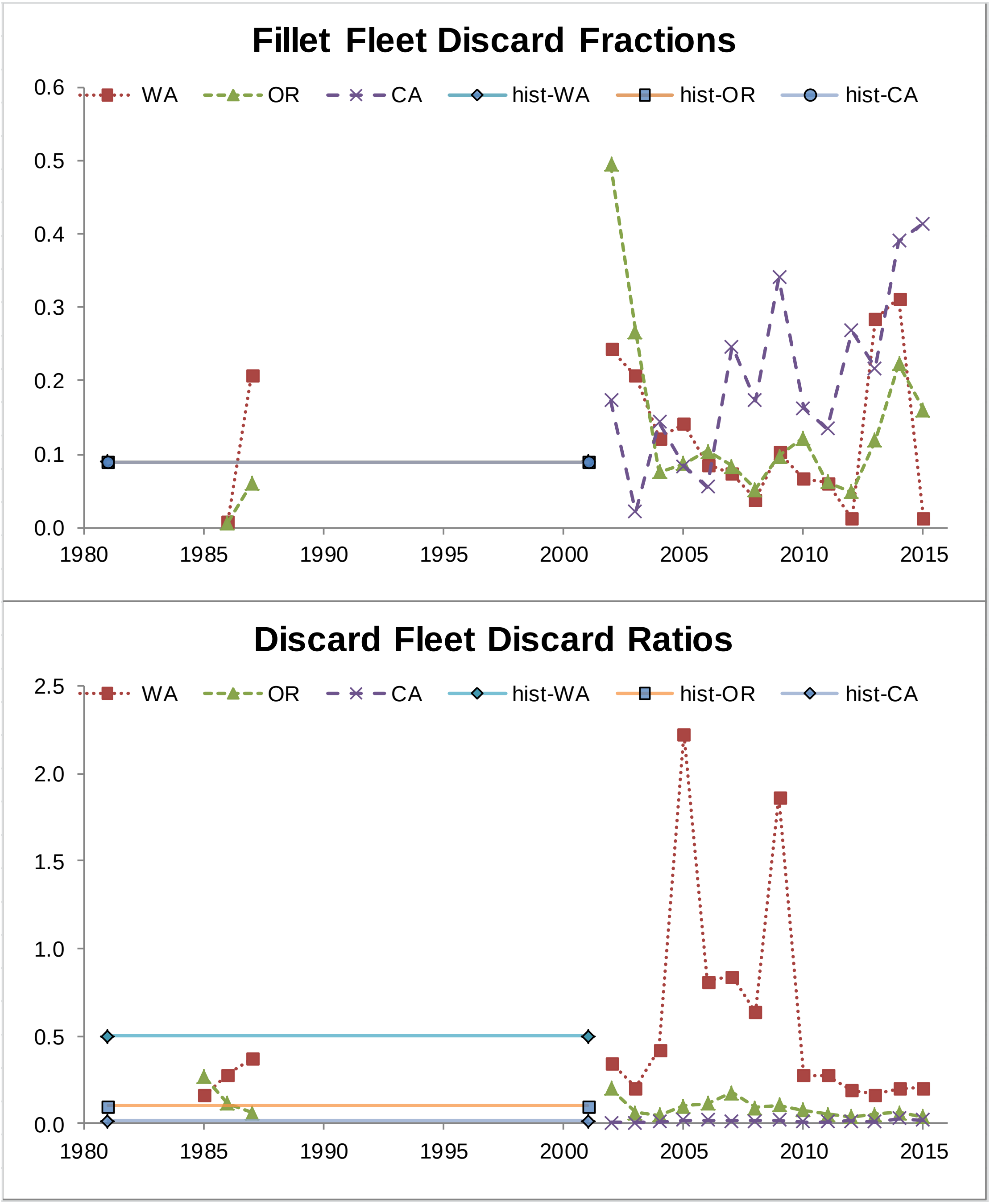


Figure 7. Estimated Arrowtooth Flounder discard fractions and discard ratios. Details are provided in the section *Discard fractions and discard ratios*.

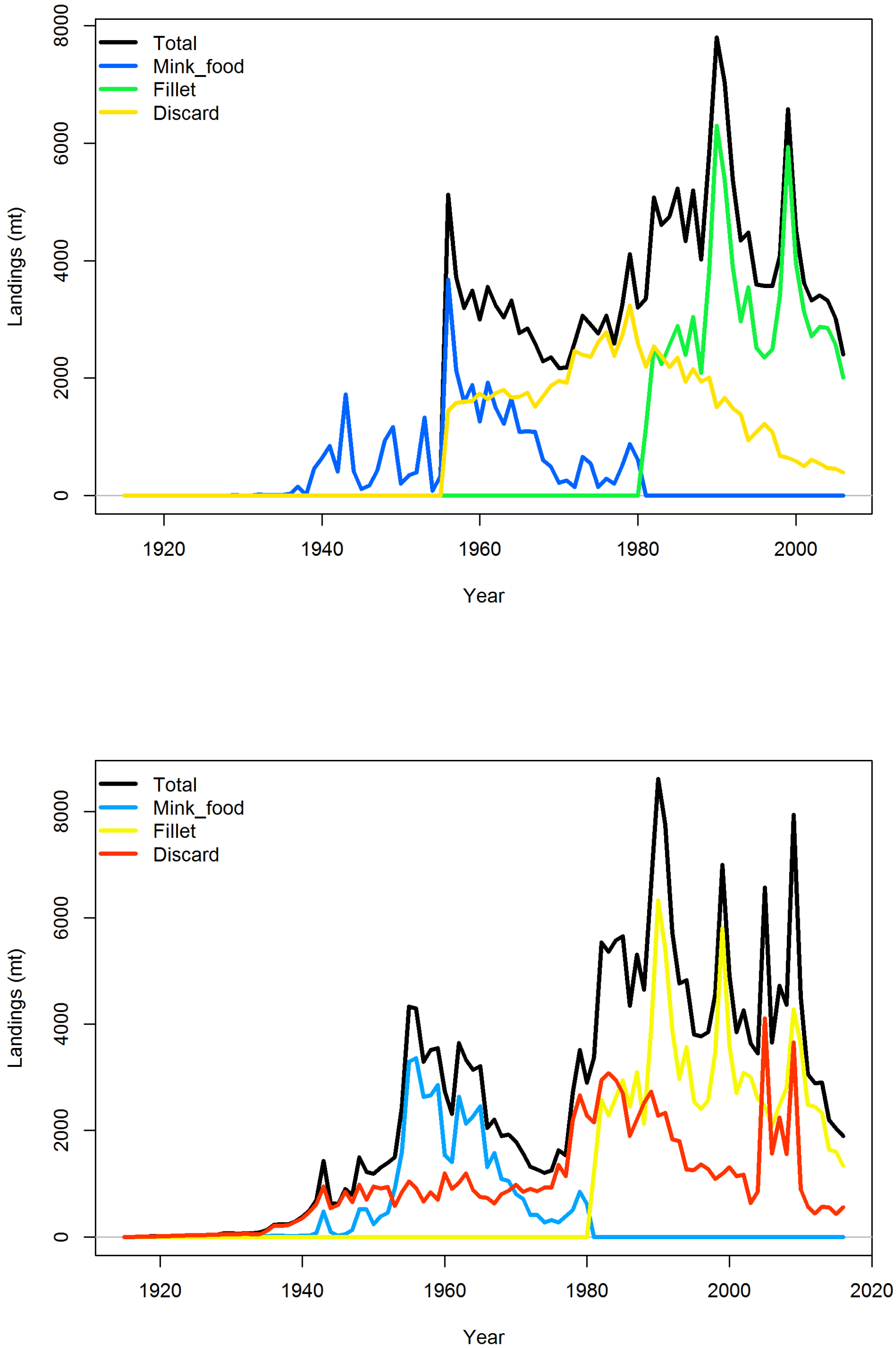


Figure 8. Comparison of the Arrowtooth Flounder catch history from the 2007 assessment (upper panel) with the catch history from the current update assessment (lower panel).

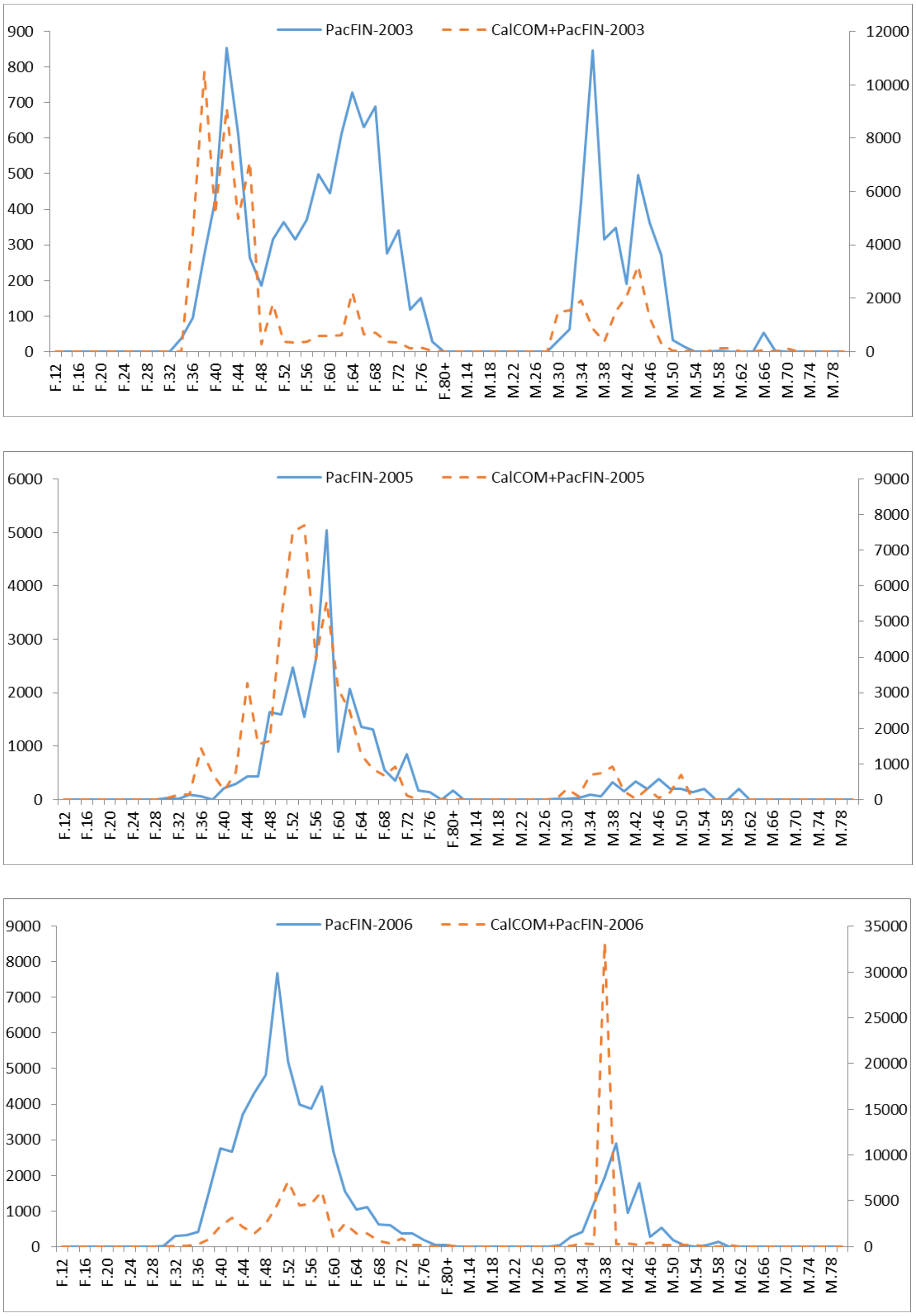


Figure 9. Example comparisons of length-compositions based exclusively on the PacFIN Utilities software expansion of coastwide biological data from the PacFIN BDS versus compositions based on PacFIN Utilities software expansion of OR & WA biological data from the PacFIN BDS plus a separate expansion of CA biological data from CalCOM. Note that the vertical scales differ between the series and between the panels. The source of the particularly large discrepancies evident for 2006 was unknown when this report was prepared.

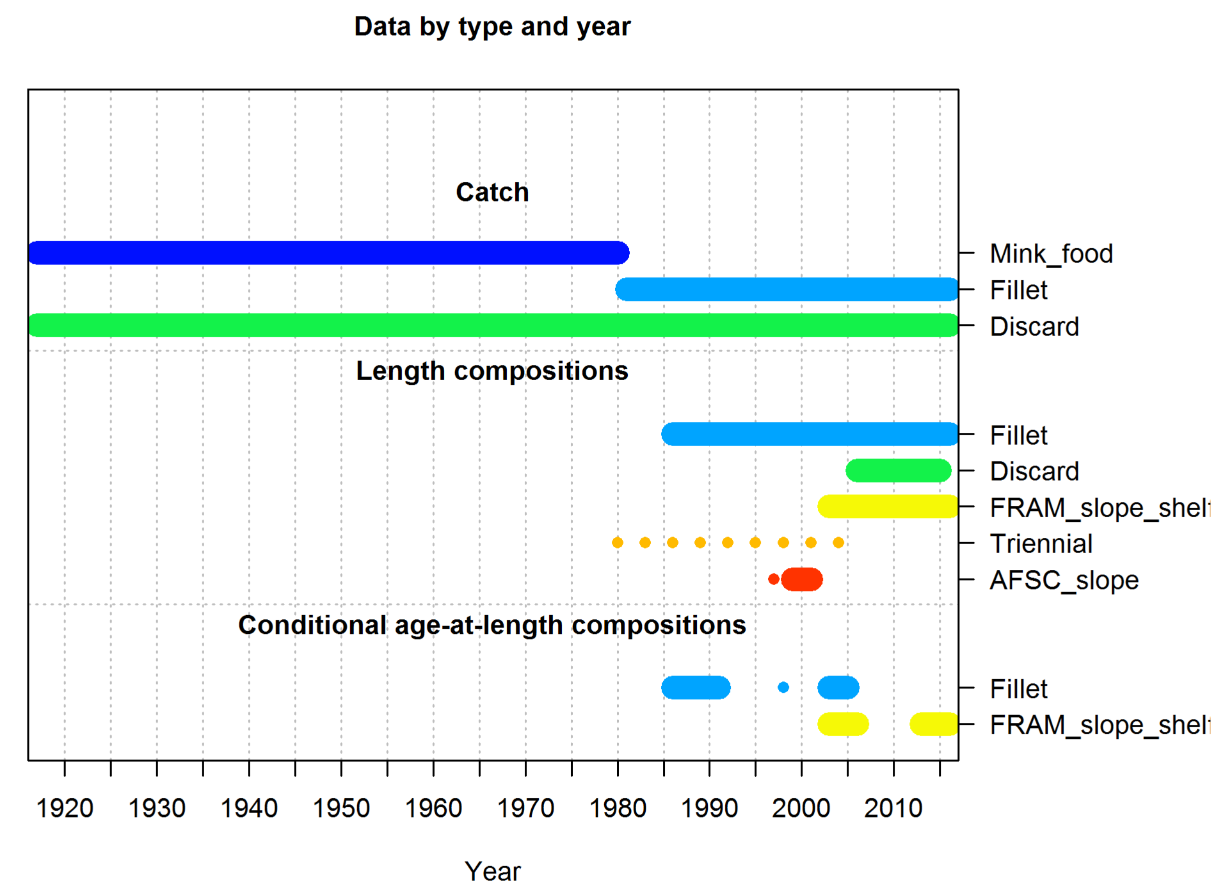
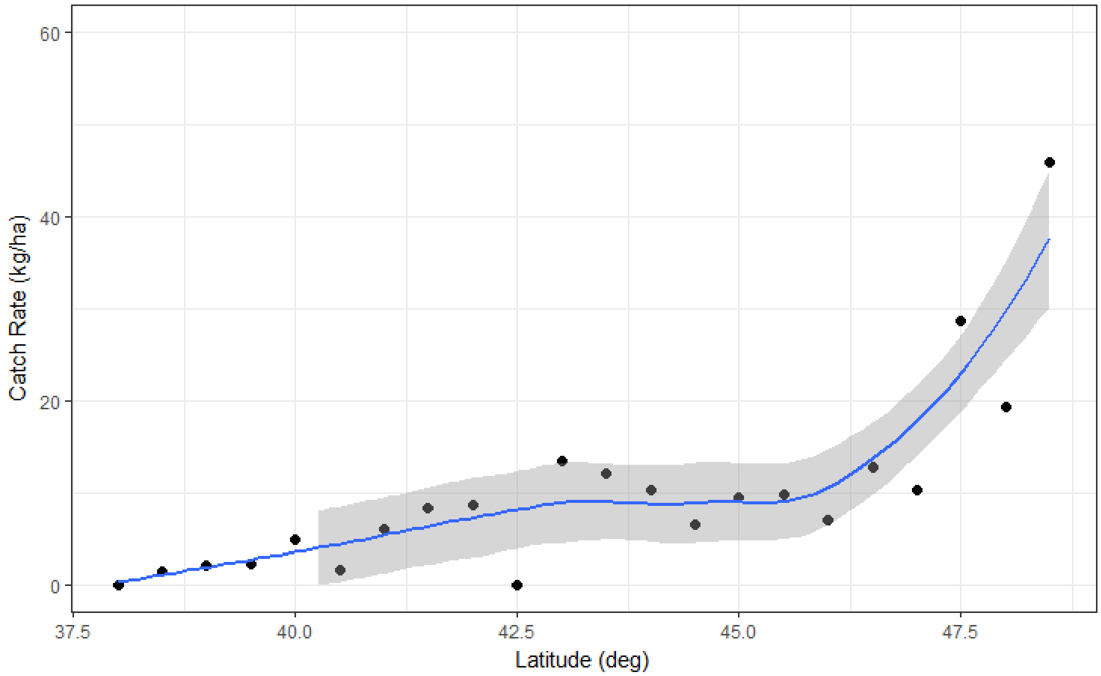


Figure 10. Diagram of the data sources used in the assessment model and their temporal coverages.



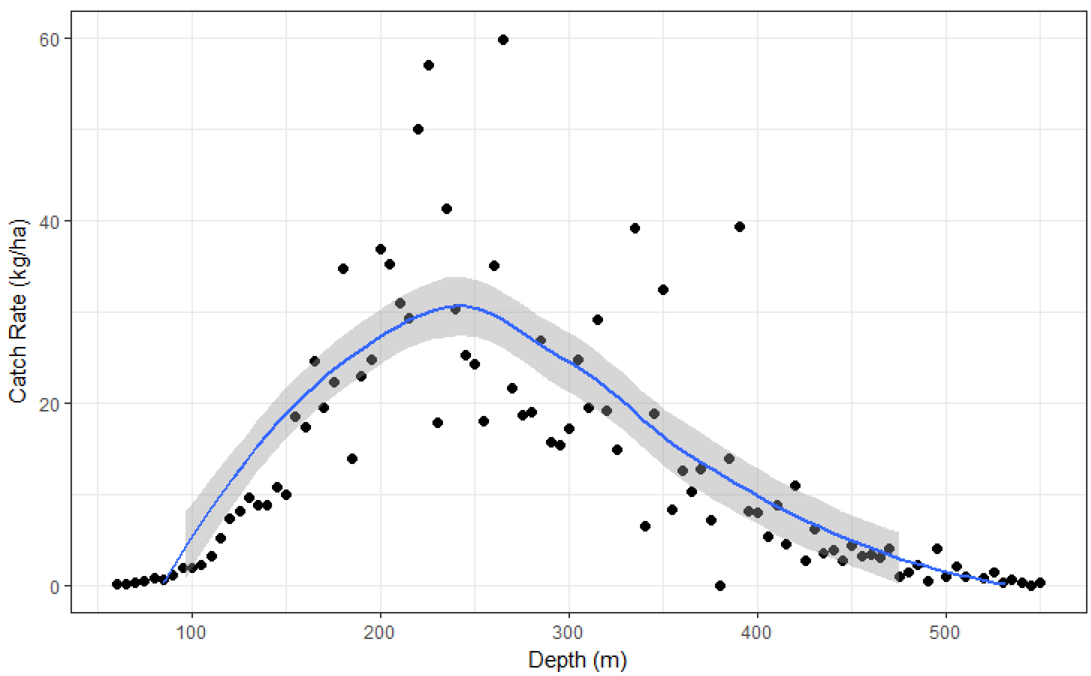


Figure 11. Catch densities by latitude (upper panel) and depth (lower panel) for the NWFSC slope-shelf survey, 2003-2016.

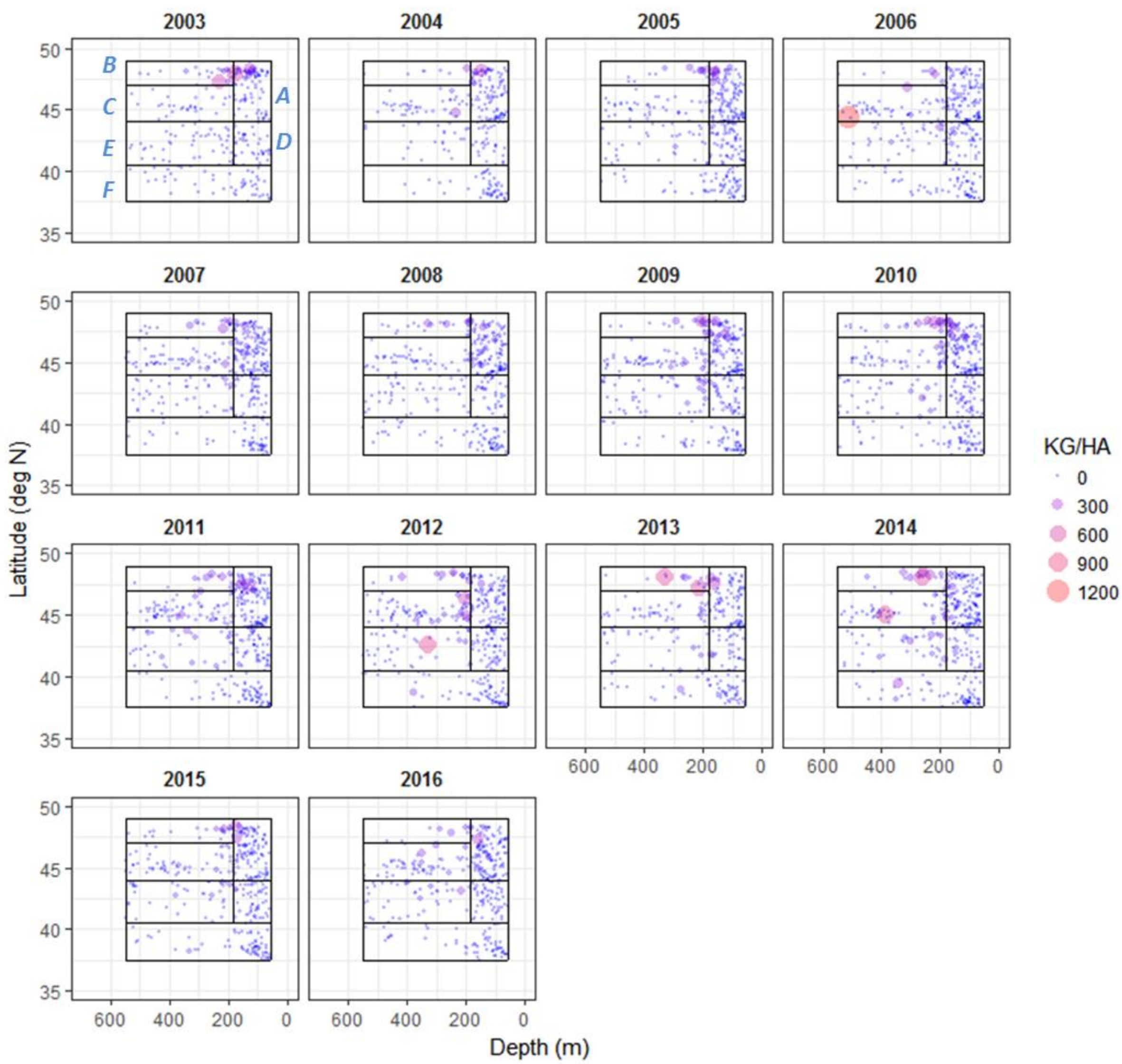


Figure 12. Stratum boundaries for the NWFSC slope-shelf survey as applied in the current assessment. The dots indicate the haul locations in terms of their latitude and depth, with the coloration and magnitude of the dots indicating the biomass density for each haul. The stratum labels (A-F), which are used elsewhere in this document, are shown in the upper left panel.

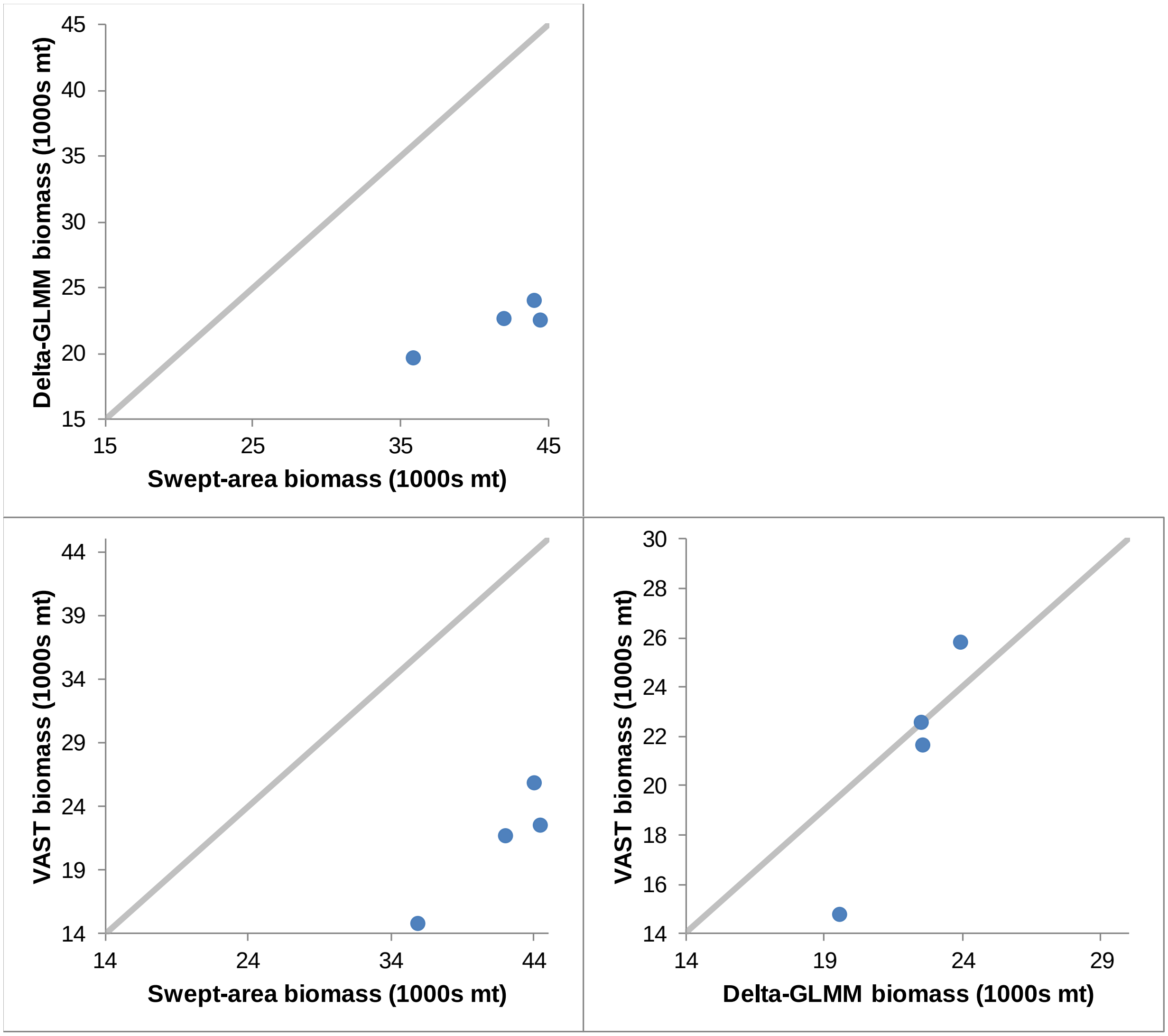


Figure 13. Scatterplot comparisons of the three methods used to derive the NWFSC slope-shelf biomass index.

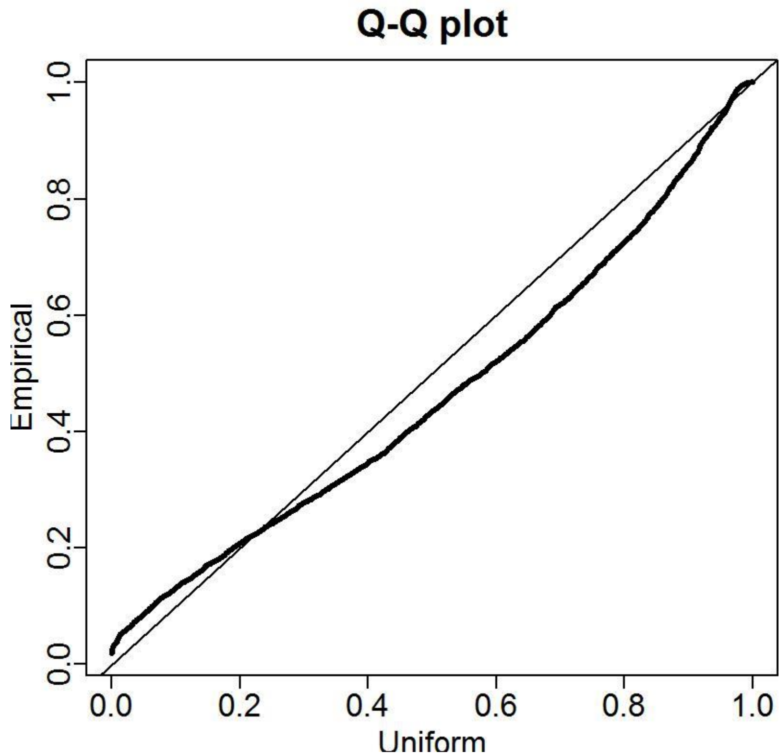


Figure 14. The Q-Q diagnostic plot obtained from application of the VAST model to the NWFSC slope-shelf data for 2003-2016.

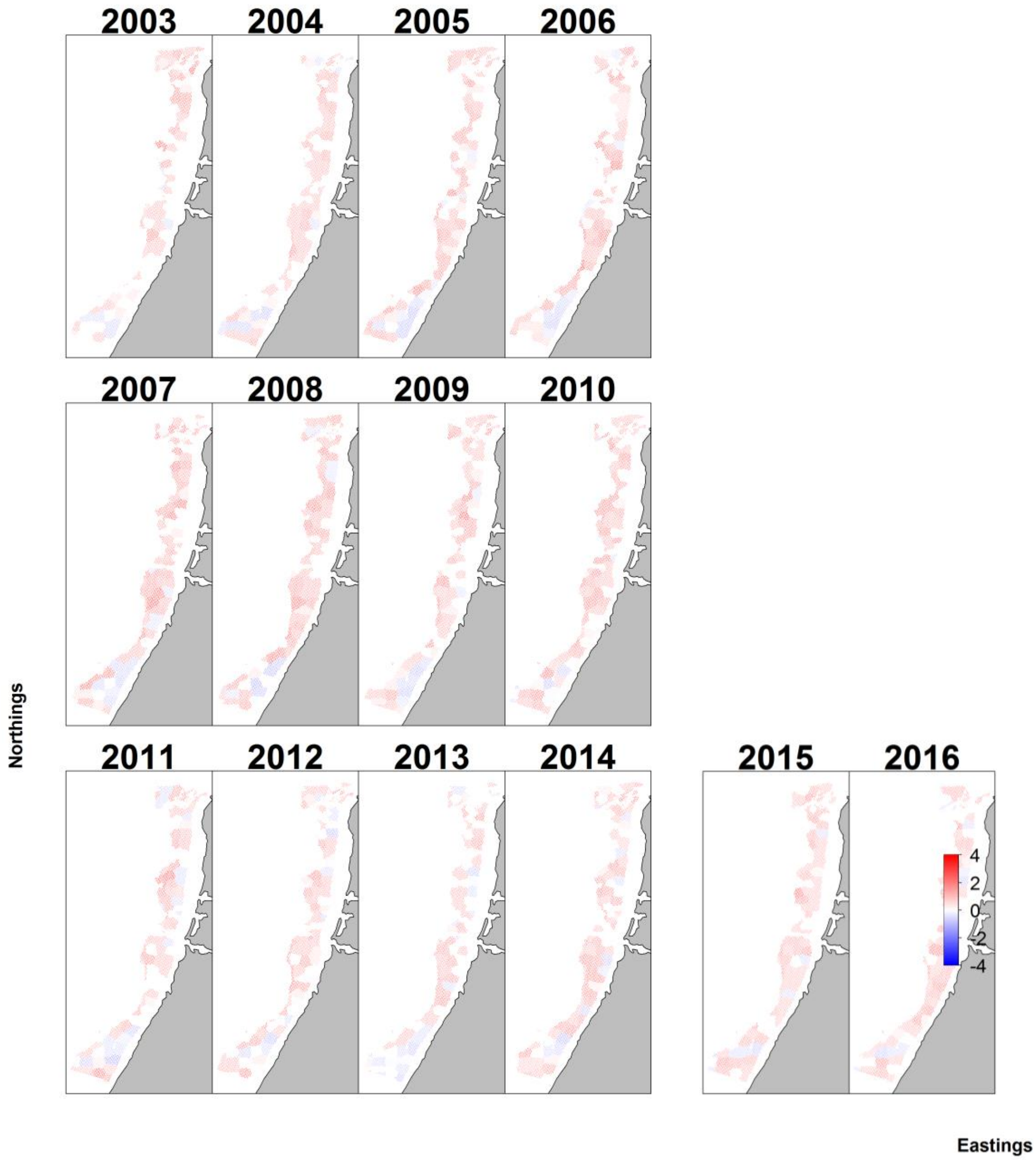


Figure 15. Maps of the Pearson residuals from the application of the VAST model to the NWFSC slope-shelf data for 2003-2016.

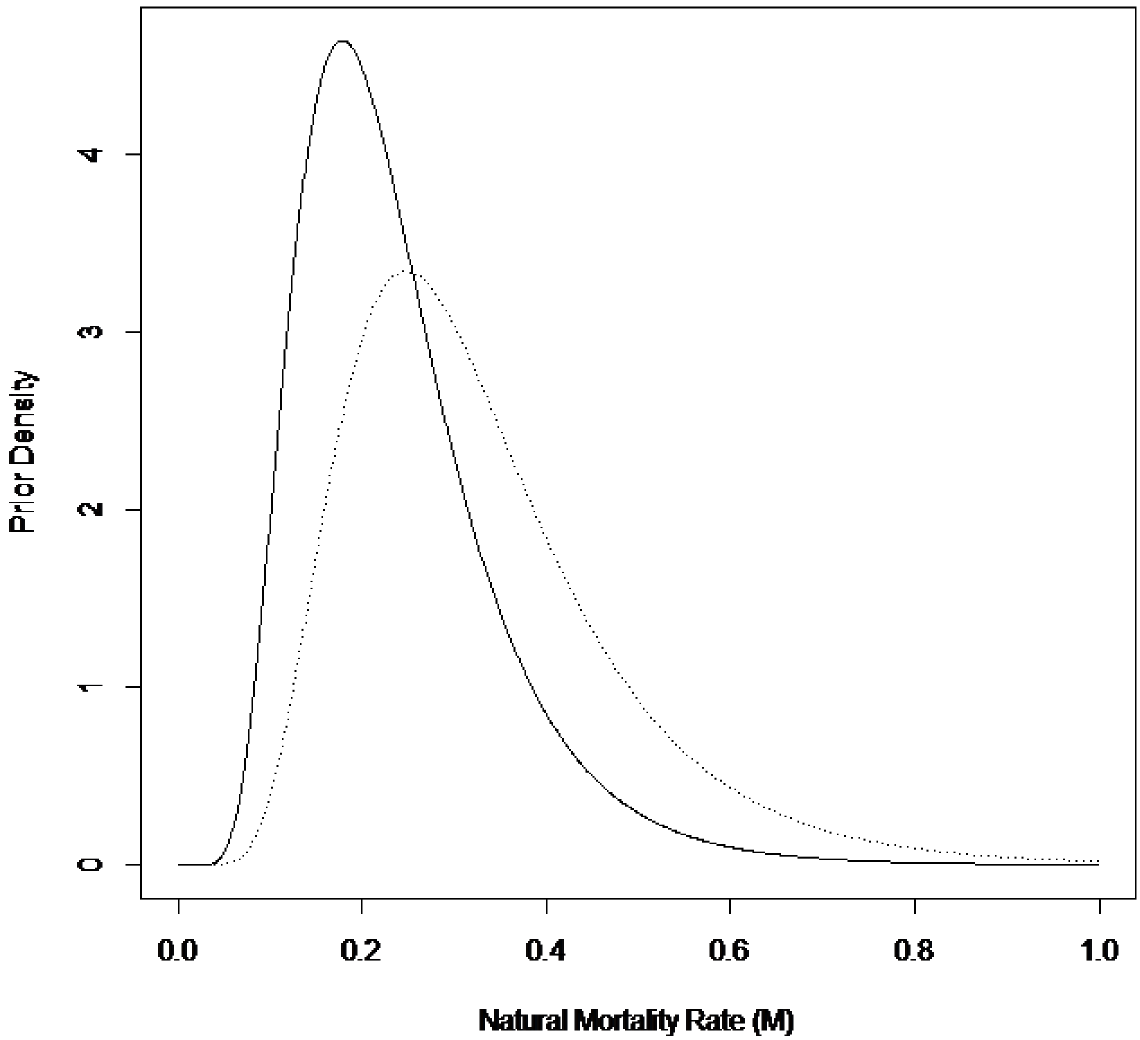


Figure 16. Prior distributions for natural mortality (*M*) for female and male Arrowtooth Flounder based on the prior developed by Owen Hamel (NMFS, NFWSC) and observed maximum ages of Arrowtooth Flounder (25 years for females; 18 years for males).

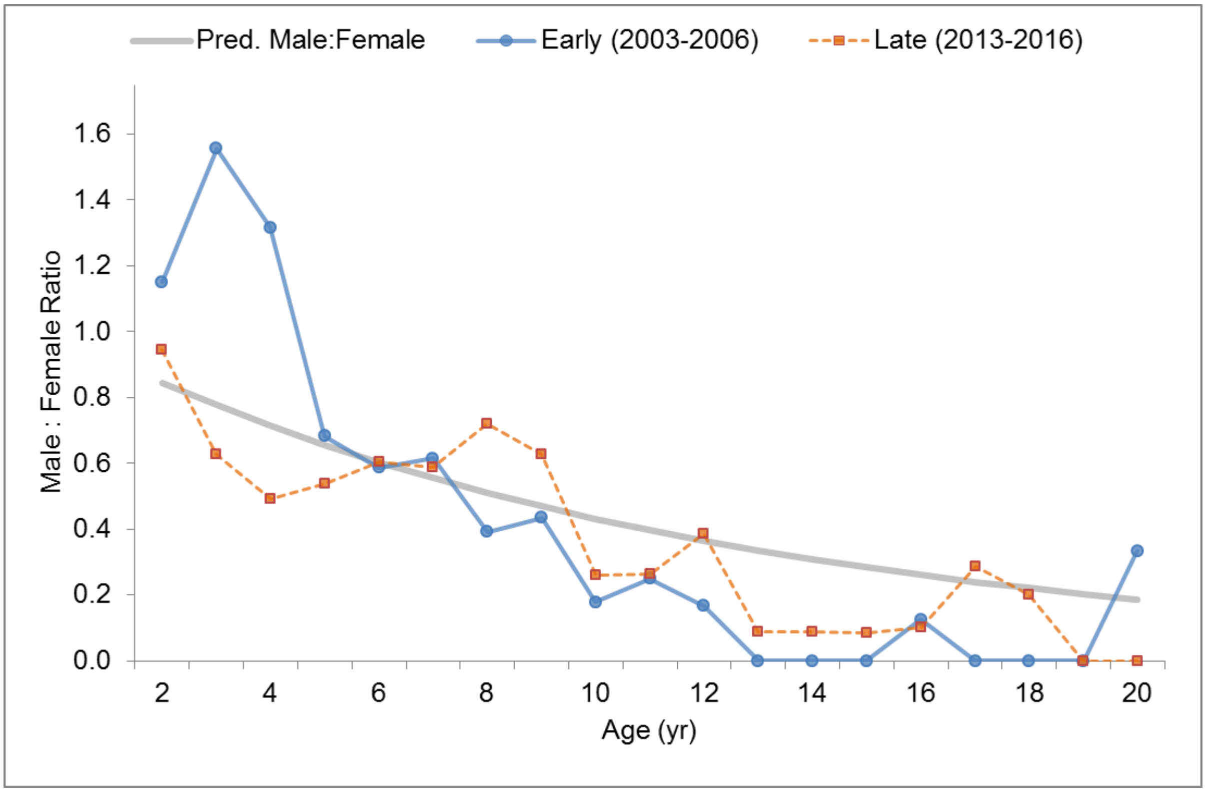


Figure 17. Predicted and observed male-to-female sex ratios for Arrowtooth Flounder. The predicted curve is based on the assumed 50:50 sex ratio at birth and assumed natural mortality rates of 0.166 yr^{-1} for females and 0.274 yr^{-1} for males. The observed sex ratios are based on the NWFSC slope-shelf age-composition data that are available for 2003-2006 (the early period) and 2013-2016 (the late period).

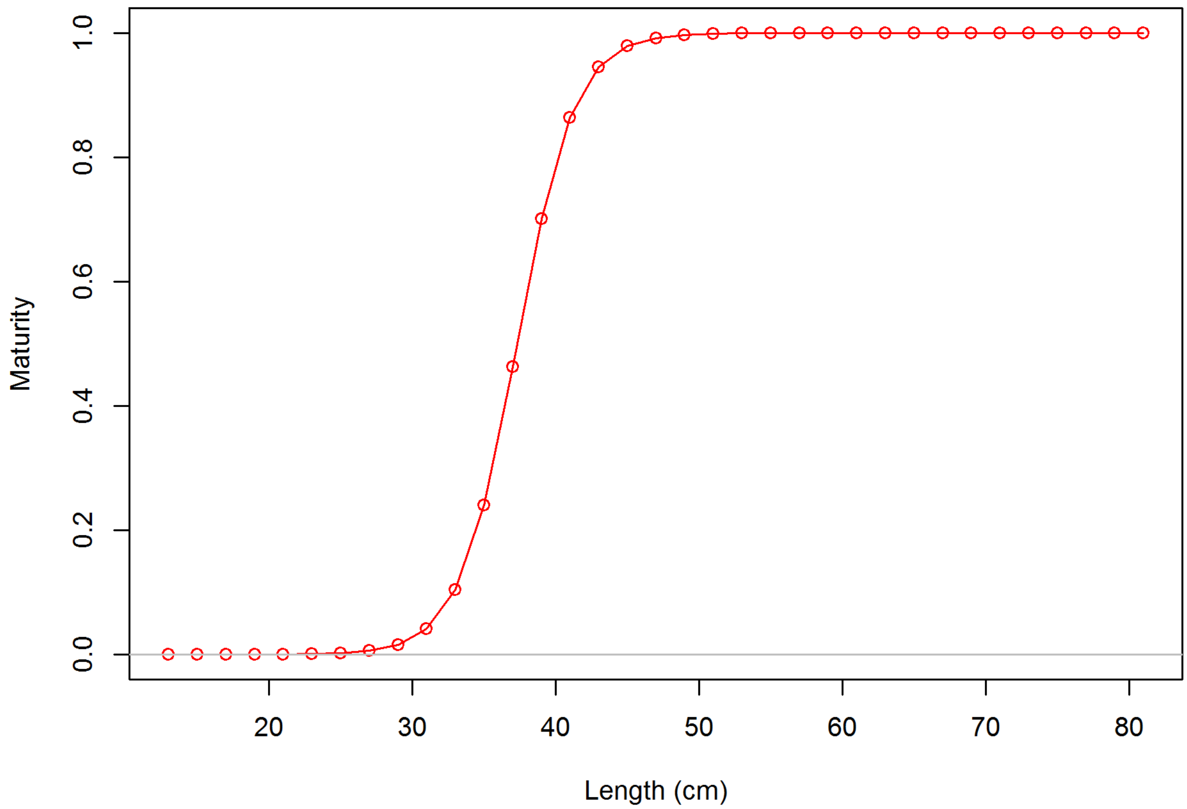


Figure 18. The maturity versus length relationship for Arrowtooth Flounder used in the assessment model. The relationship was originally developed by Rickey (1993) and also was used in the 2007 assessment for Arrowtooth Flounder.

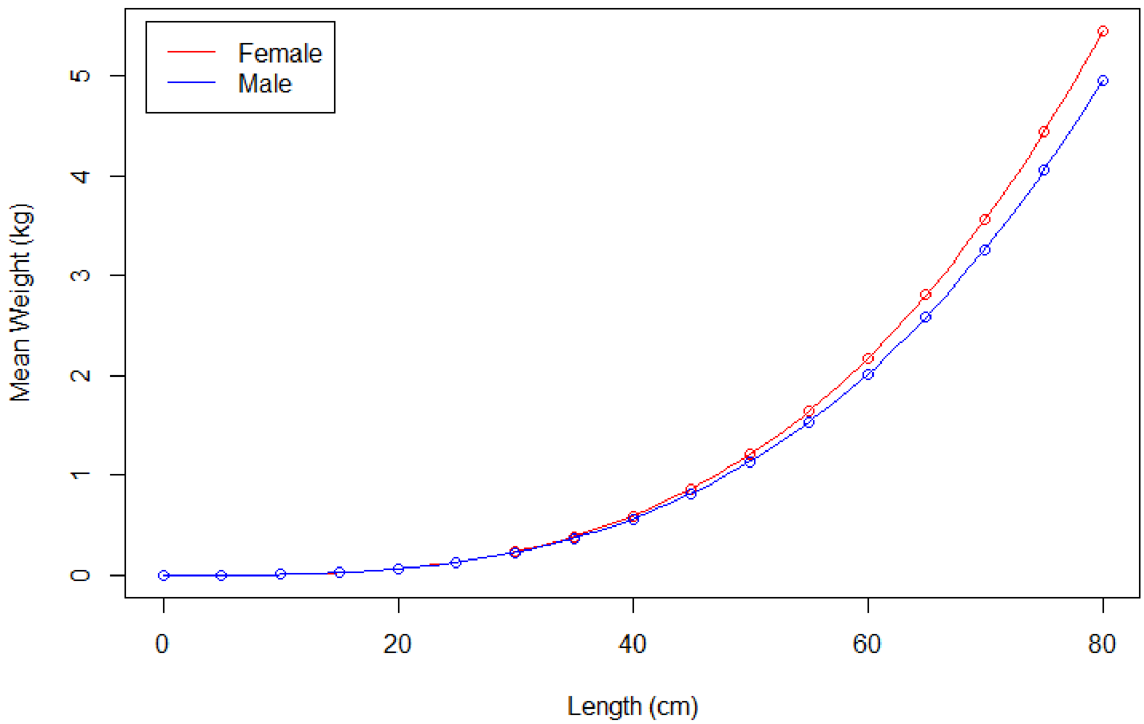


Figure 19. The revised length-weight relationship for female and male Arrowtooth Flounder that is used in this update assessment. The curve was derived from data collected during the NWFSC slope-shelf surveys during 2003-2015.

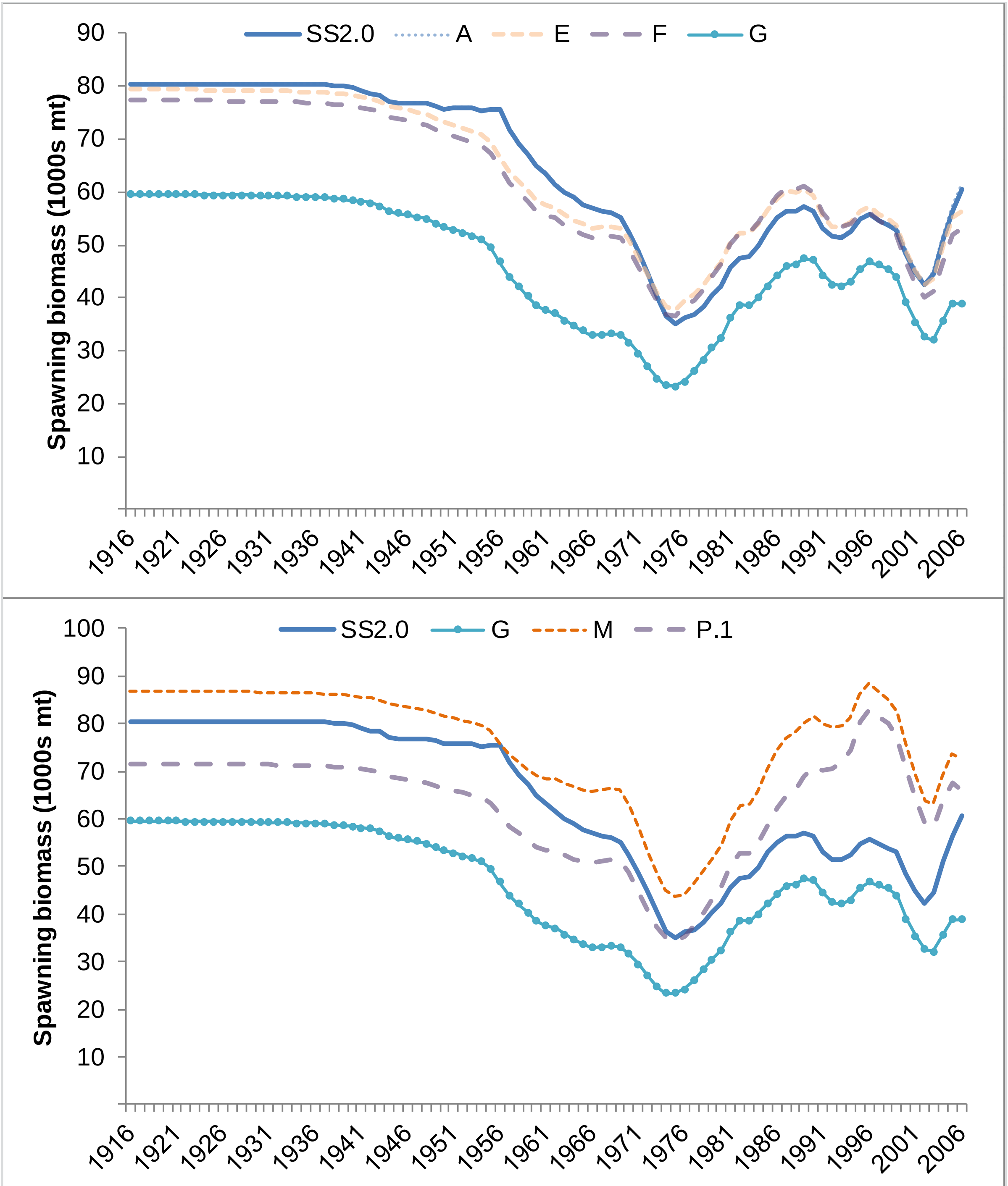


Figure 20. Changing estimates of spawning biomass during the stepwise process of bridging from the 2007 assessment base model to the 2017 update base model. Part 1: Updating the data through 2006. The model designators (e.g., A, E, F, …) are described in Table 11.

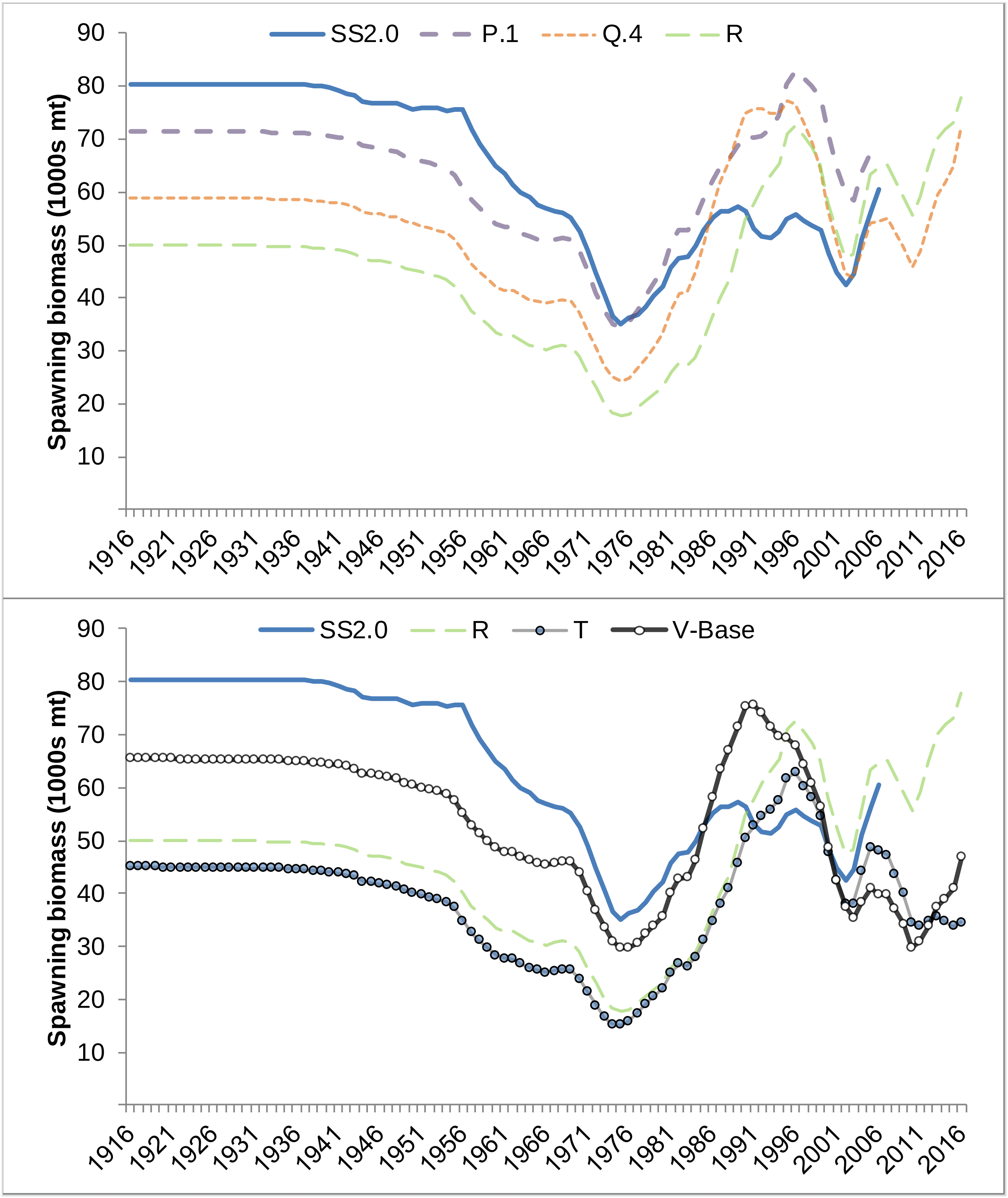


Figure 21. Changing estimates of spawning biomass during the stepwise process of bridging from the 2007 assessment base model to the 2017 update base model. Part 2: Adding data through 2016 and model tuning. The model designators (e.g., P.1, R, T) are described in Table 12.

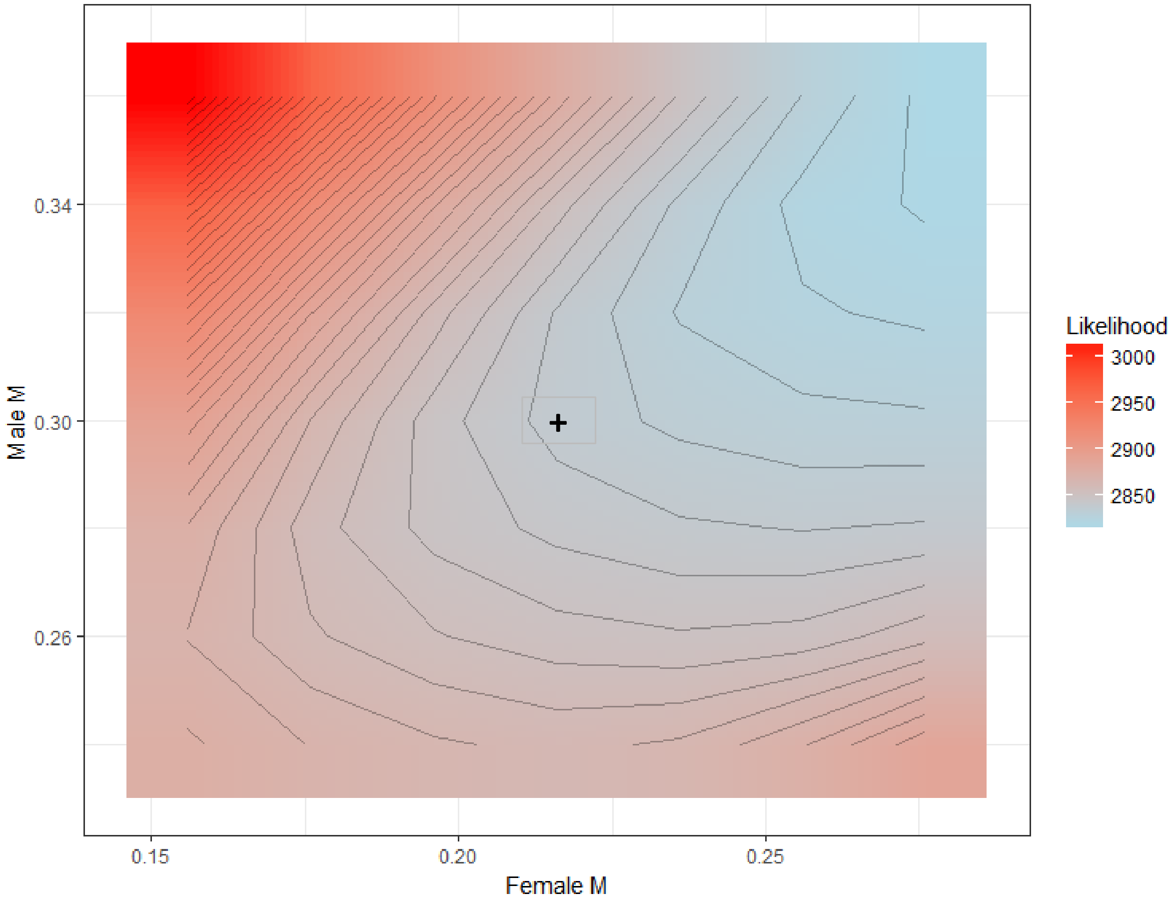


Figure 22. Likelihood surface plot as a function of the *Female_M* and *Male_M* parameters. The values in the base model were 0.216 yr^{-1} for *Female_M* and 0.300 yr^{-1} for *Male_M*, indicated by the black + sign.

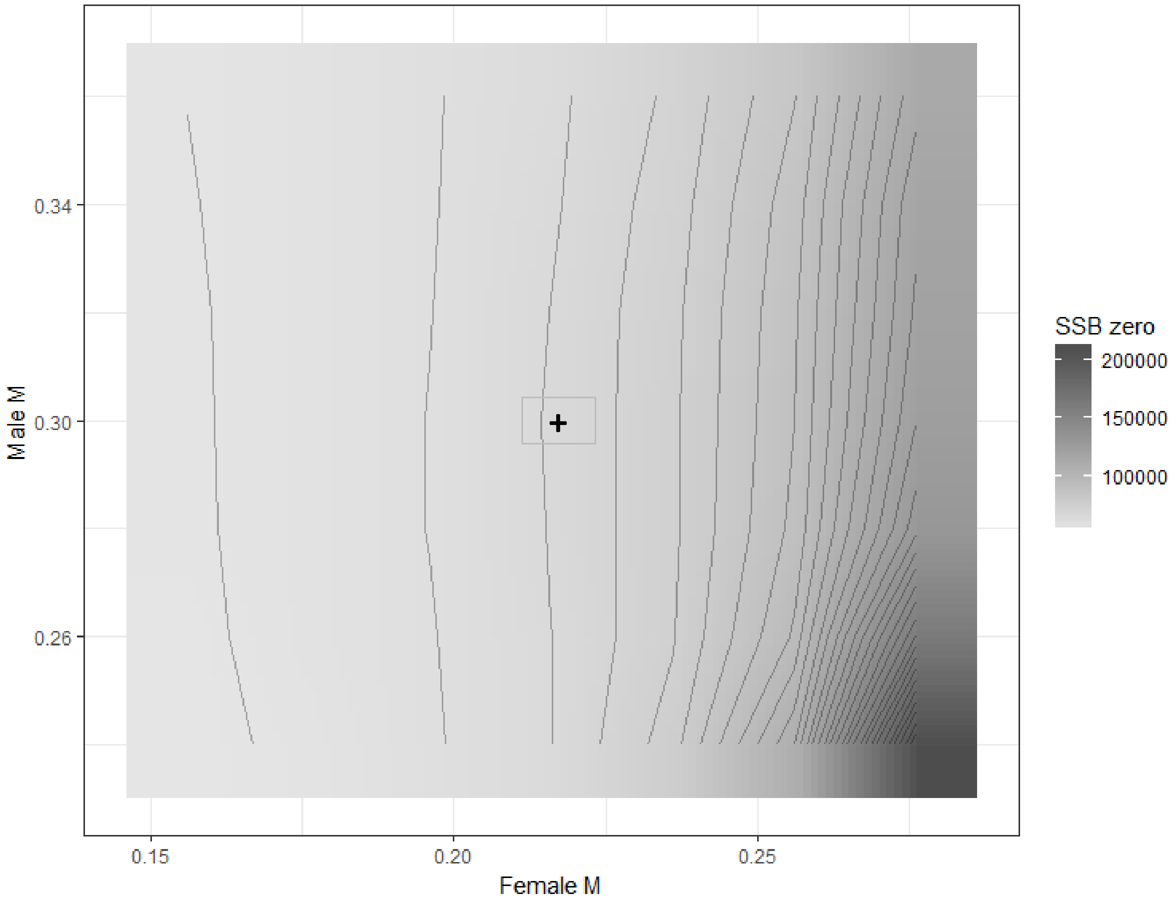


Figure 23. Estimates of unfished spawning biomass corresponding to the –ln(likelihood) surface shown in Figure 22. The values in the base model were 0.216 yr^{-1} for *Female_M* and 0.300 yr^{-1} for *Male_M*, indicated by the black **+** sign.

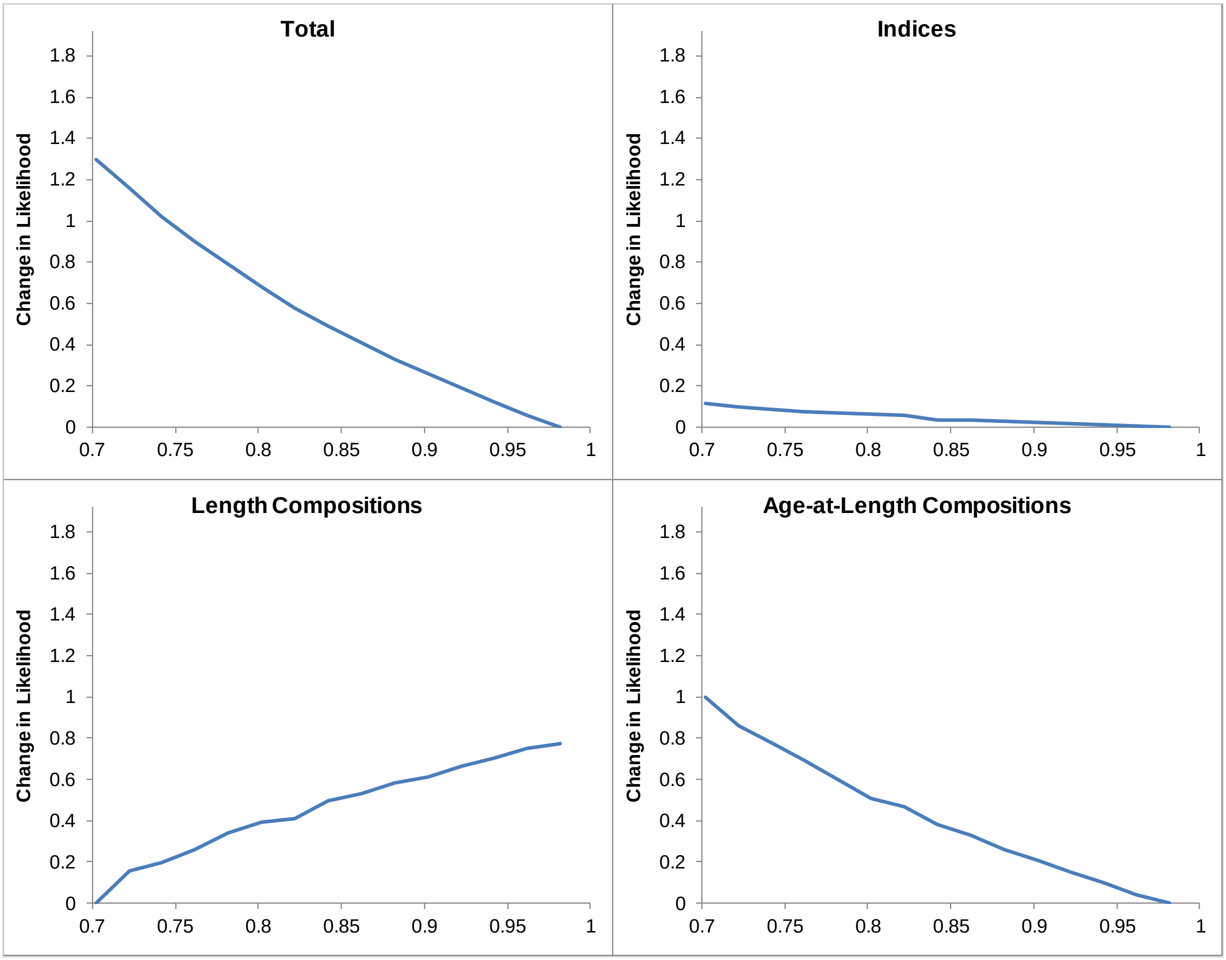


Figure 24. Likelihood profile over the spawner-recruit steepness parameter. For the base model this parameter was fixed at 0.902.

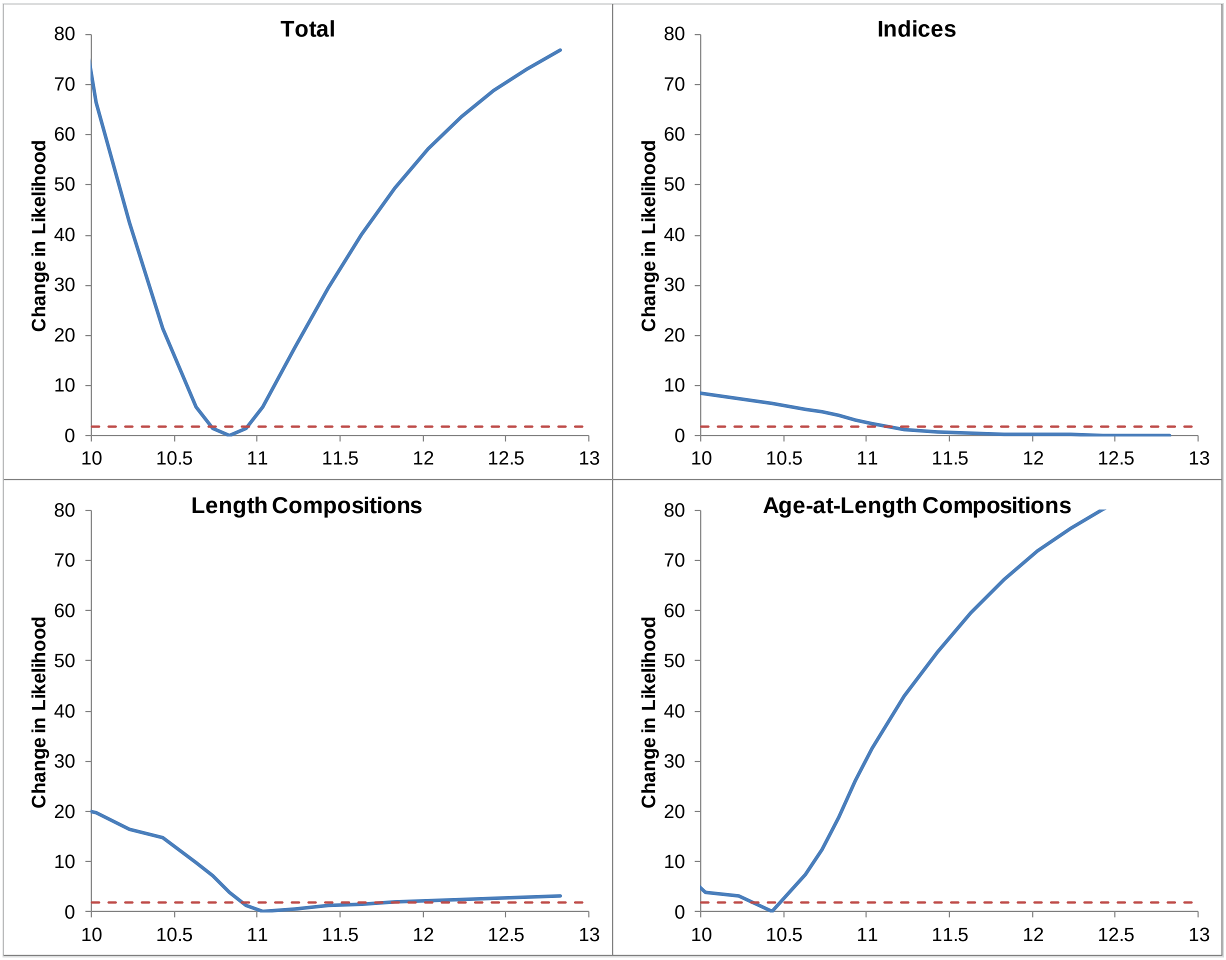


Figure 25. Likelihood profile over the ln(R0) parameter. The base model estimated a value of 10.8295 for this parameter. The intersection of the profiles with the dashed horizontal lines (at 1.92 log-likelihood units) indicate the approximate 95% confidence limits for ln(R0).

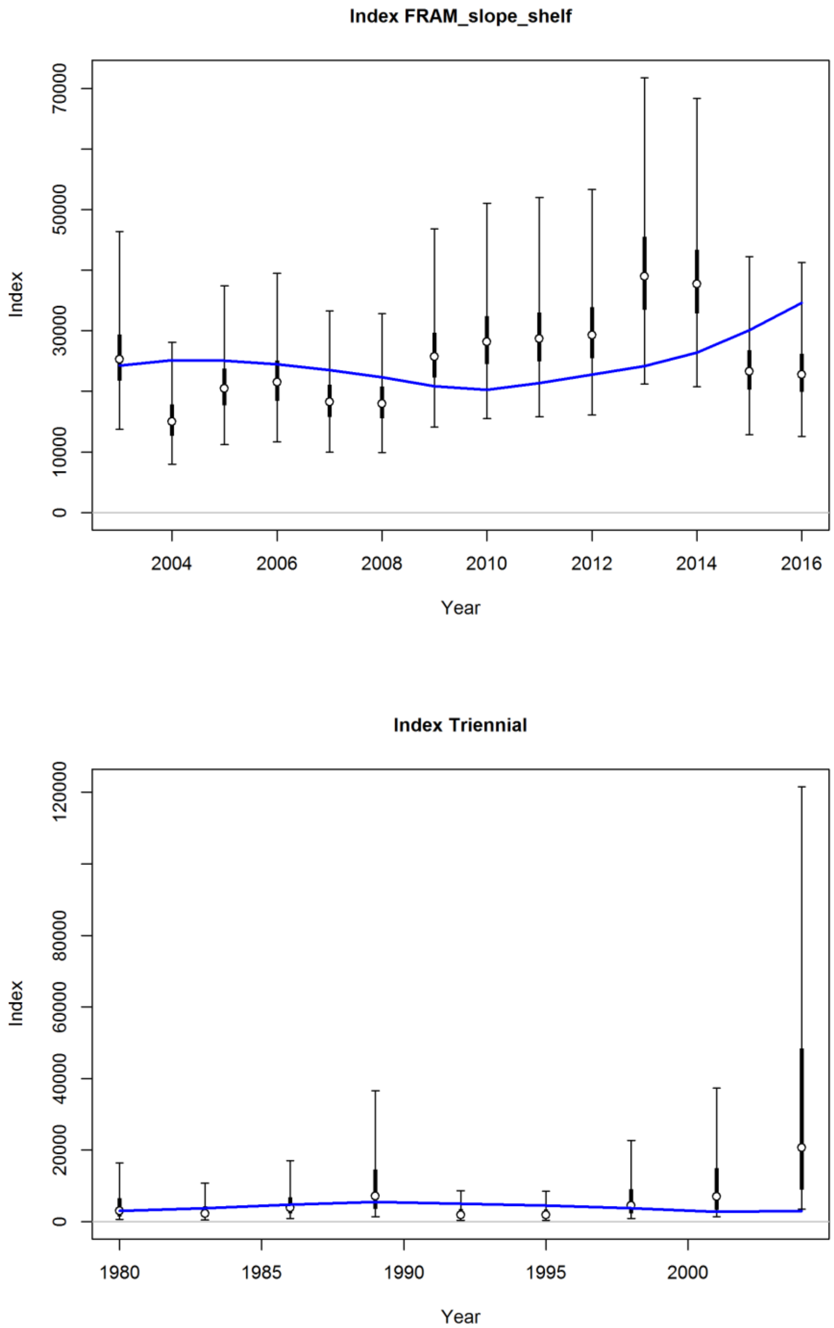


Figure 26. Observed and model-predicted values for the NWFSC (labeled as FRAM in the plot title in the upper panel) slope-shelf survey biomass index and the Triennial survey biomass index.

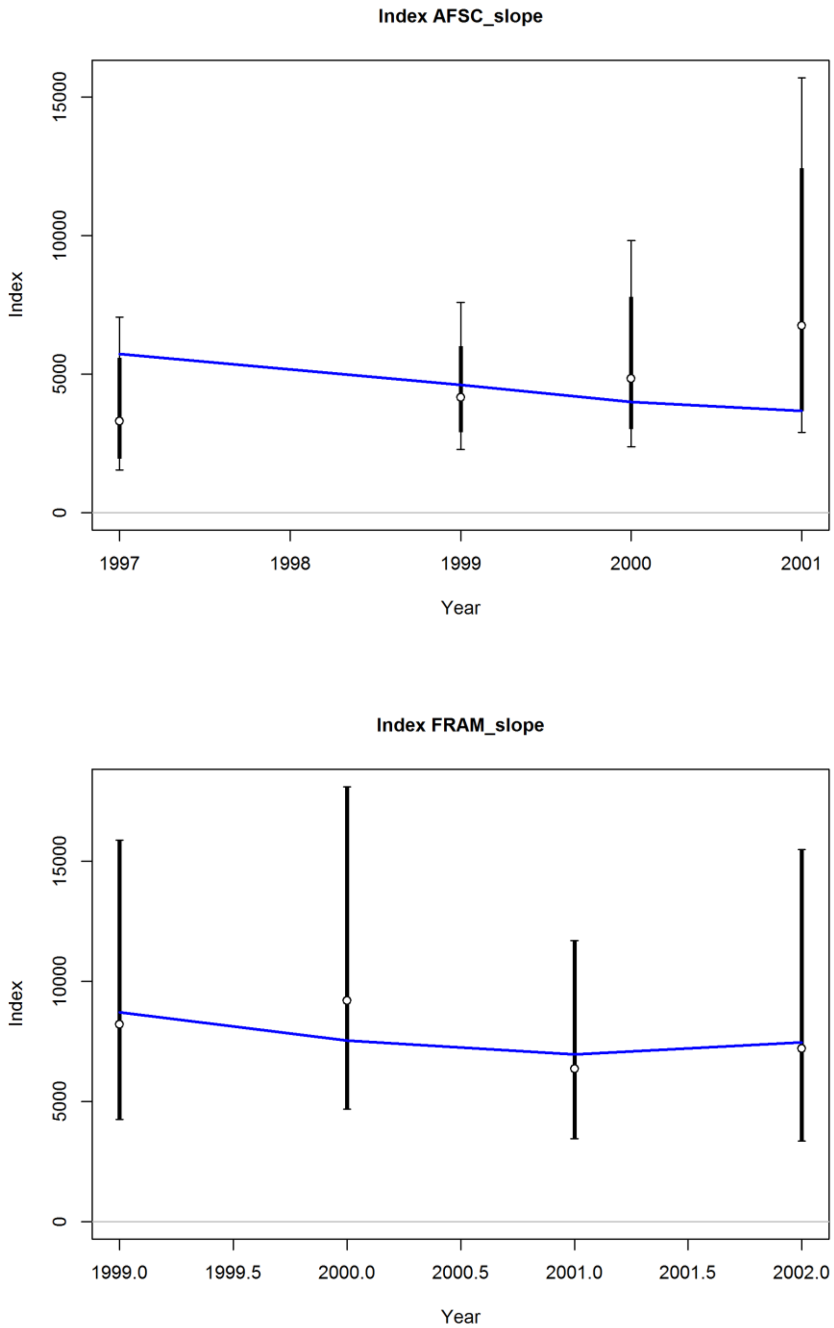
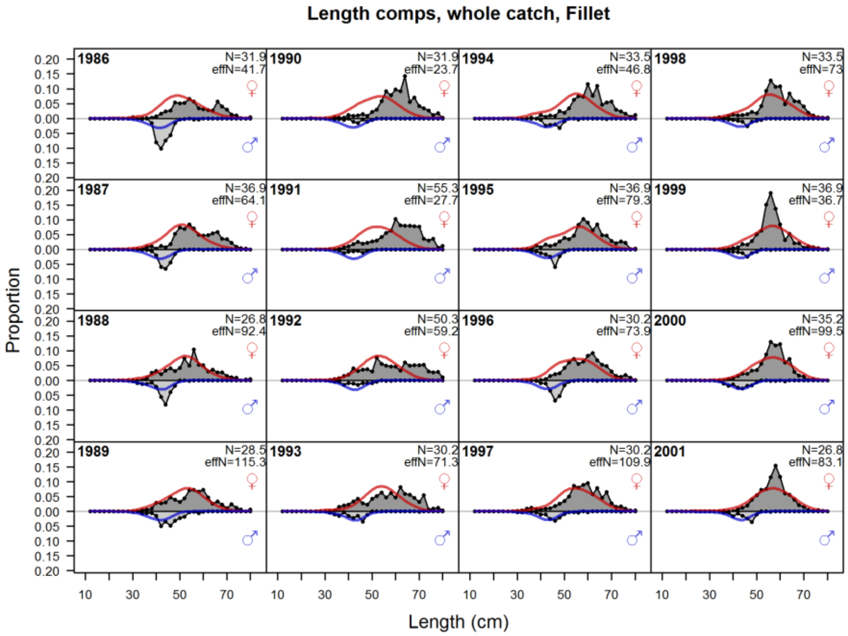


Figure 27. Observed and model-predicted values for the AFSC slope survey biomass index and the NWFSC (FRAM) slope survey biomass index.



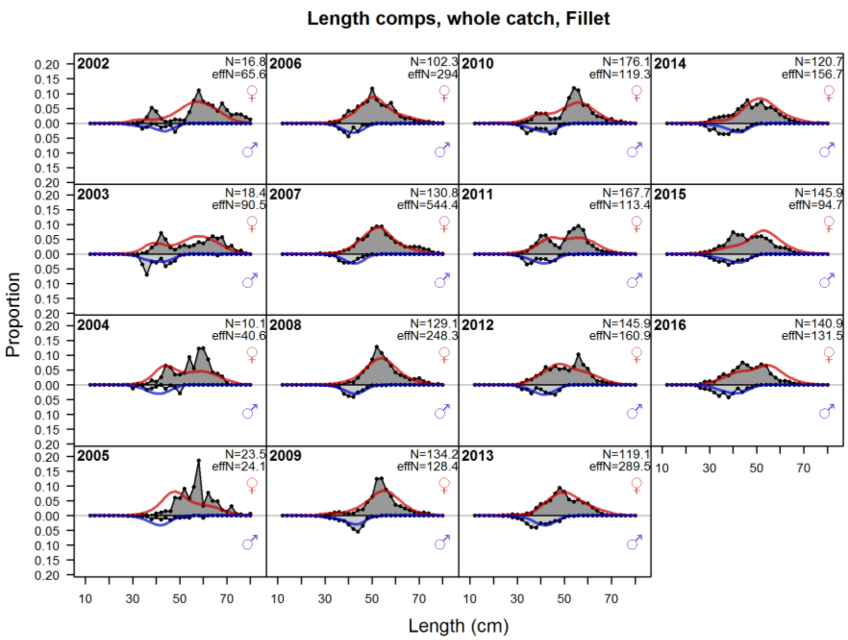


Figure 28. Observed and model-predicted length-compositions for the fillet fleet.

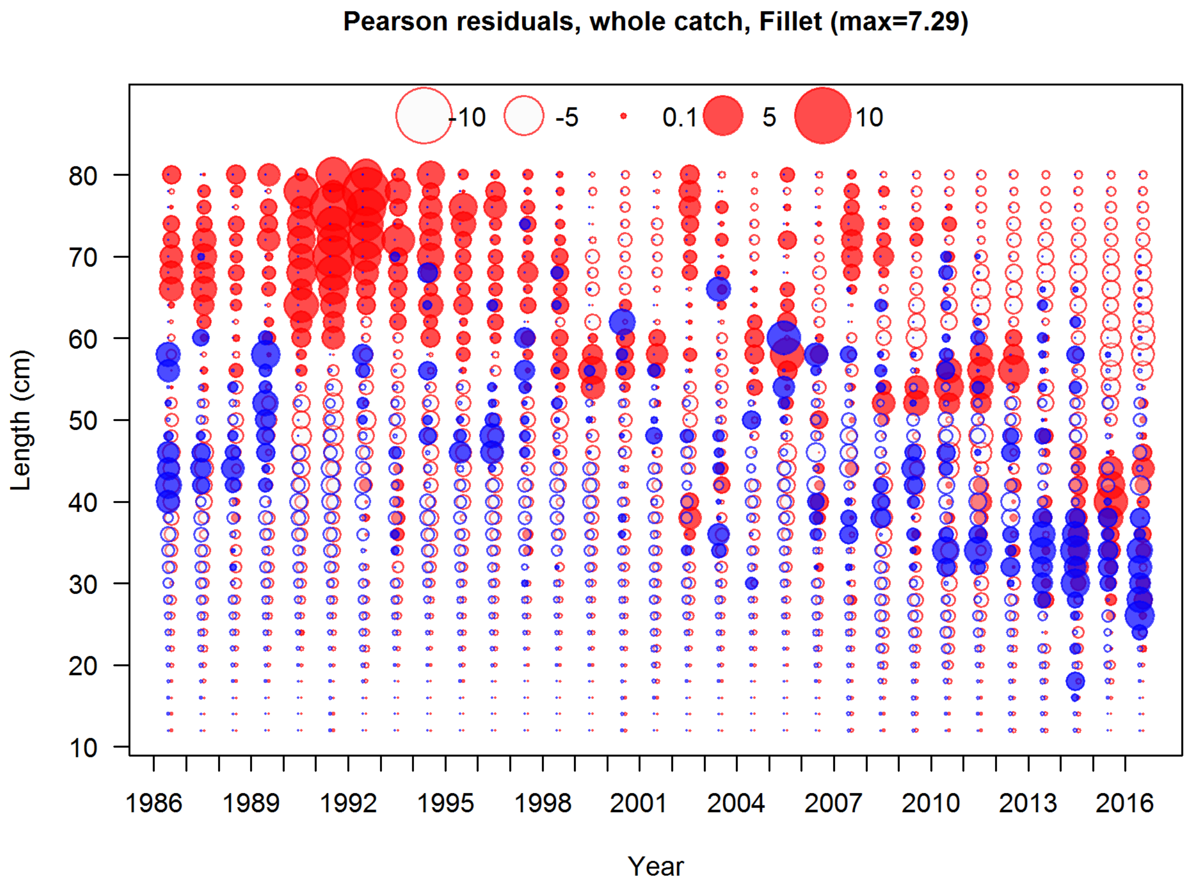


Figure 29. Residual bubble plot for the length-compositions from the fillet fleet.

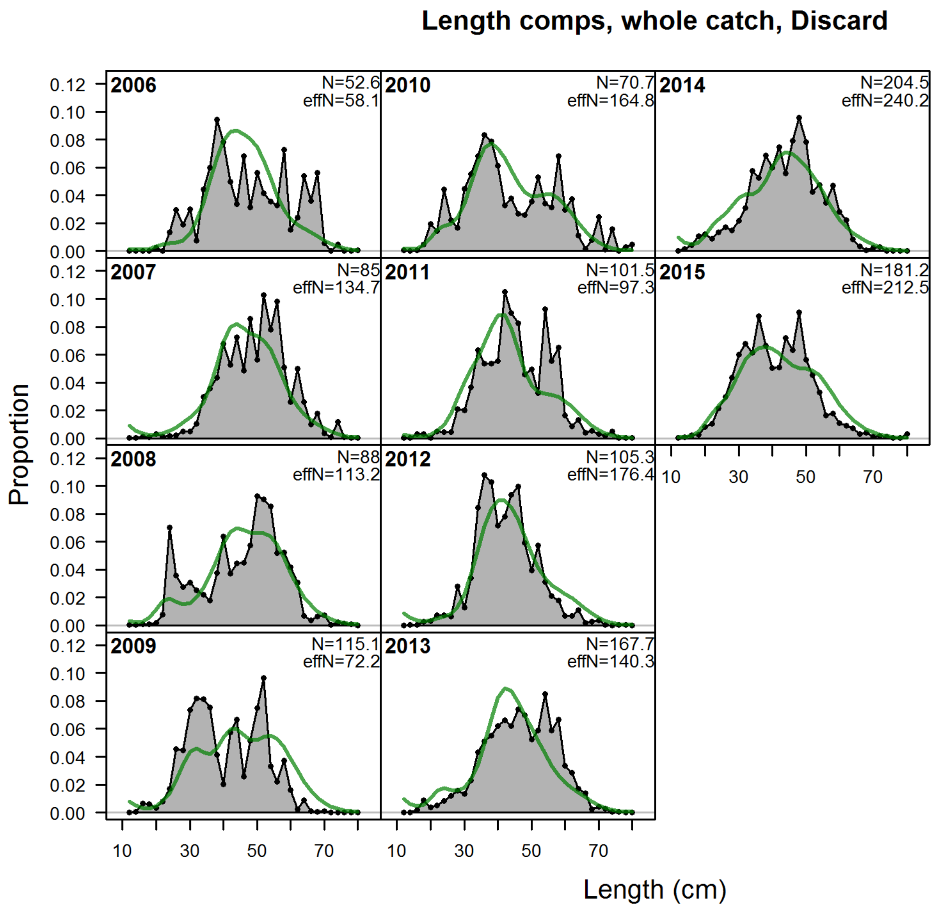


Figure 30. Observed and predicted length-compositions for the “discard fleet”.

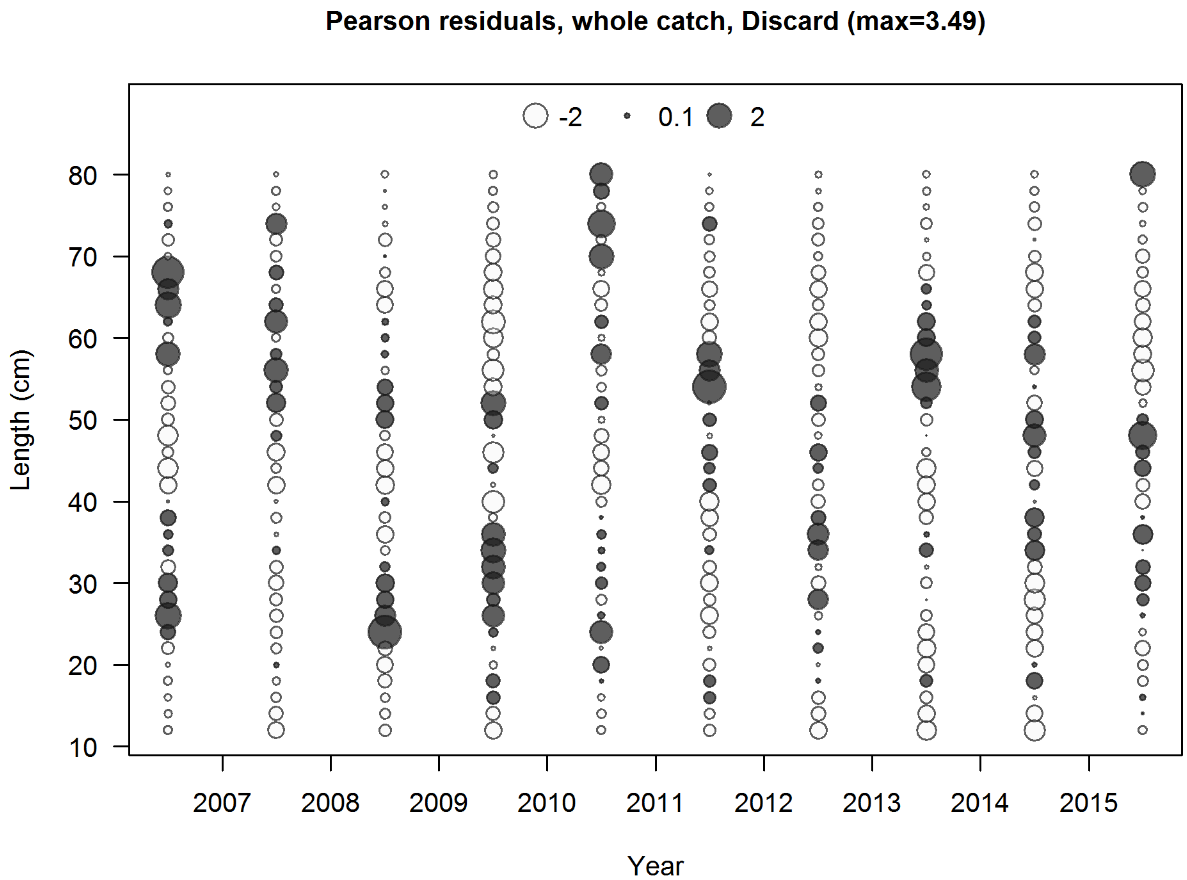


Figure 31. Residual bubble plot for the length-compositions from the "discard fleet".

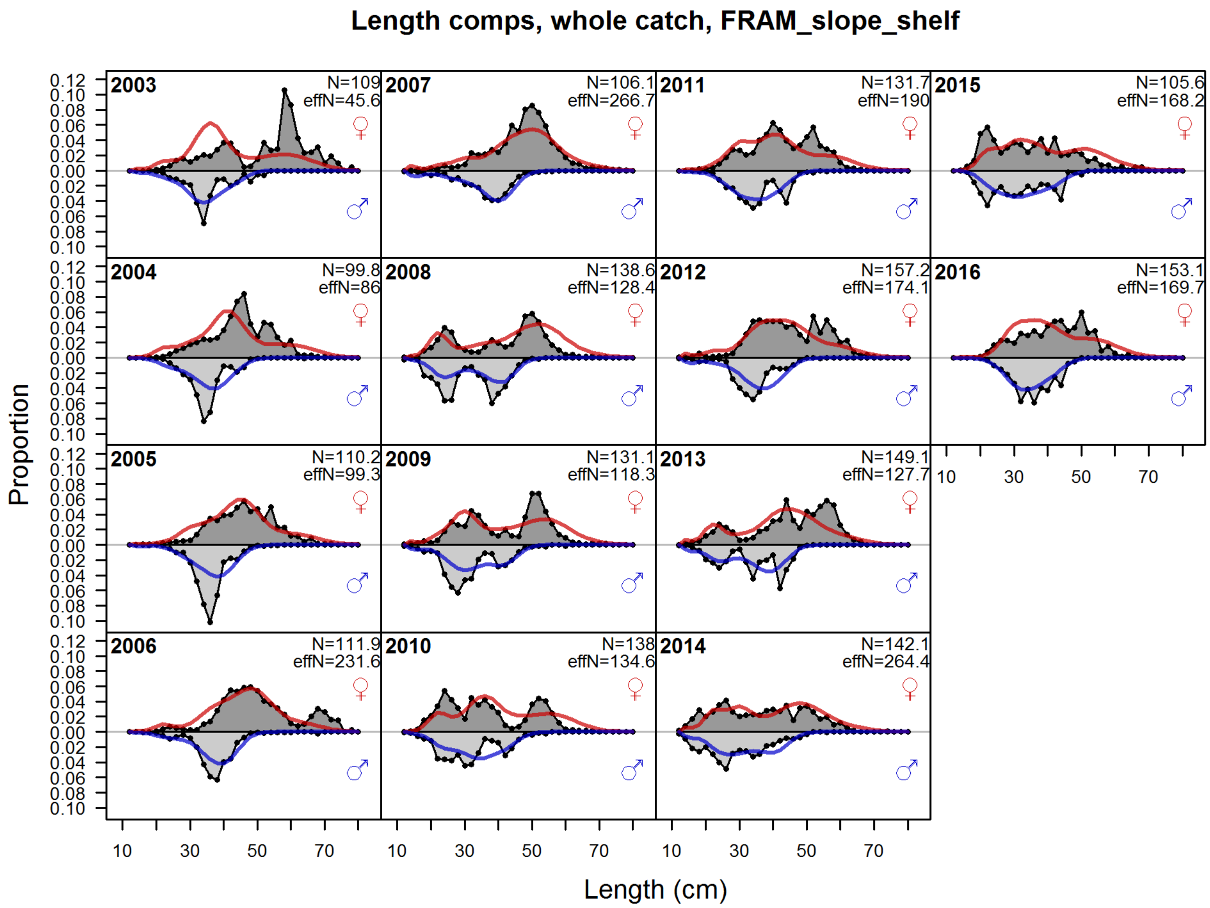


Figure 32. Observed and model-predicted length-compositions for the NWFSC (FRAM) slope-shelf survey.

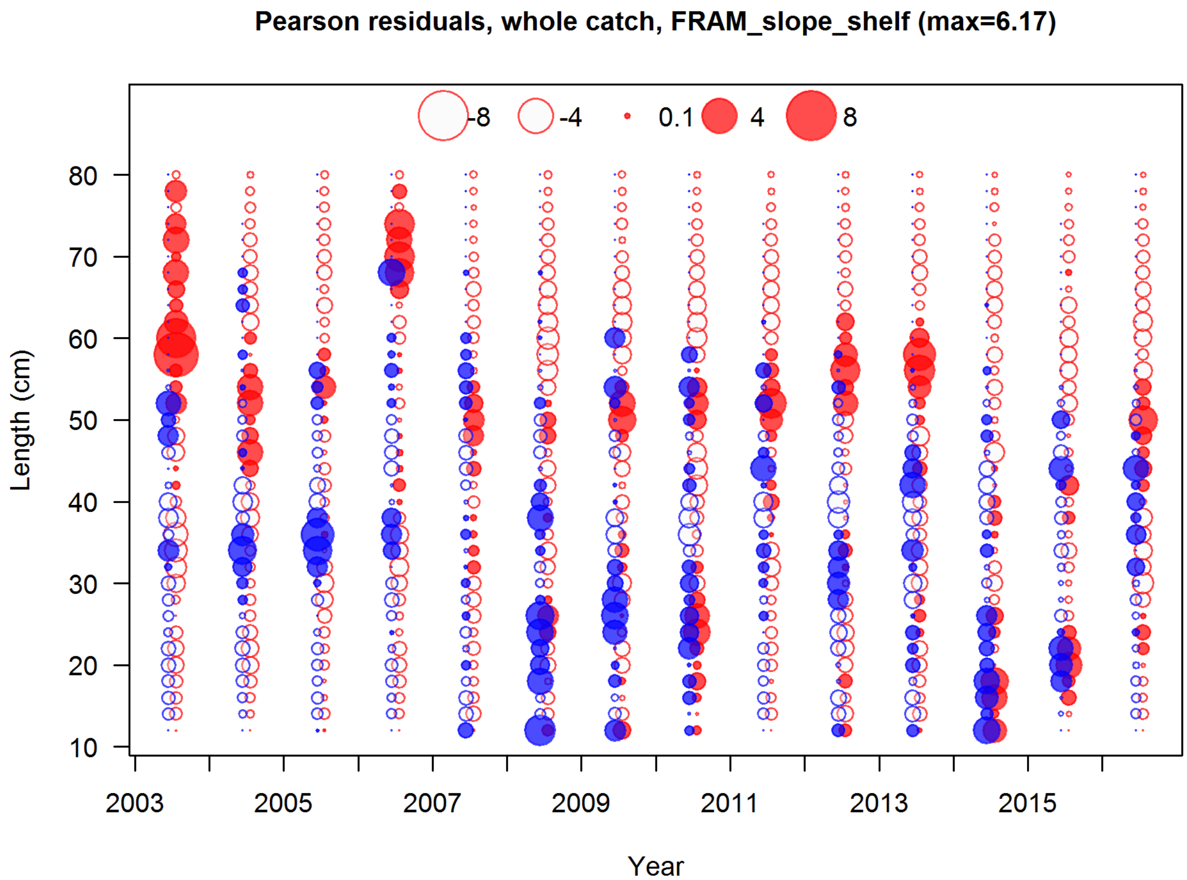


Figure 33. Residual bubble plot for the length-compositions from the NWFSC (FRAM) slope-shelf survey.

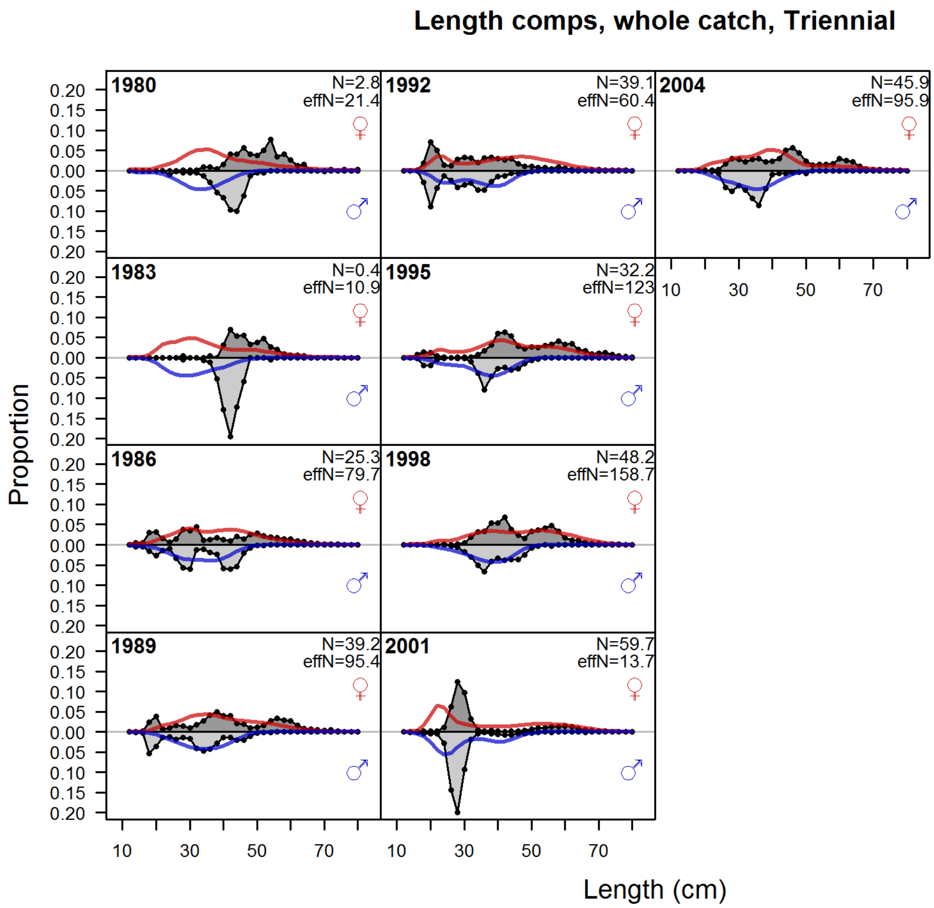


Figure 34. Observed and model-predicted length-compositions for the Triennial shelf survey.

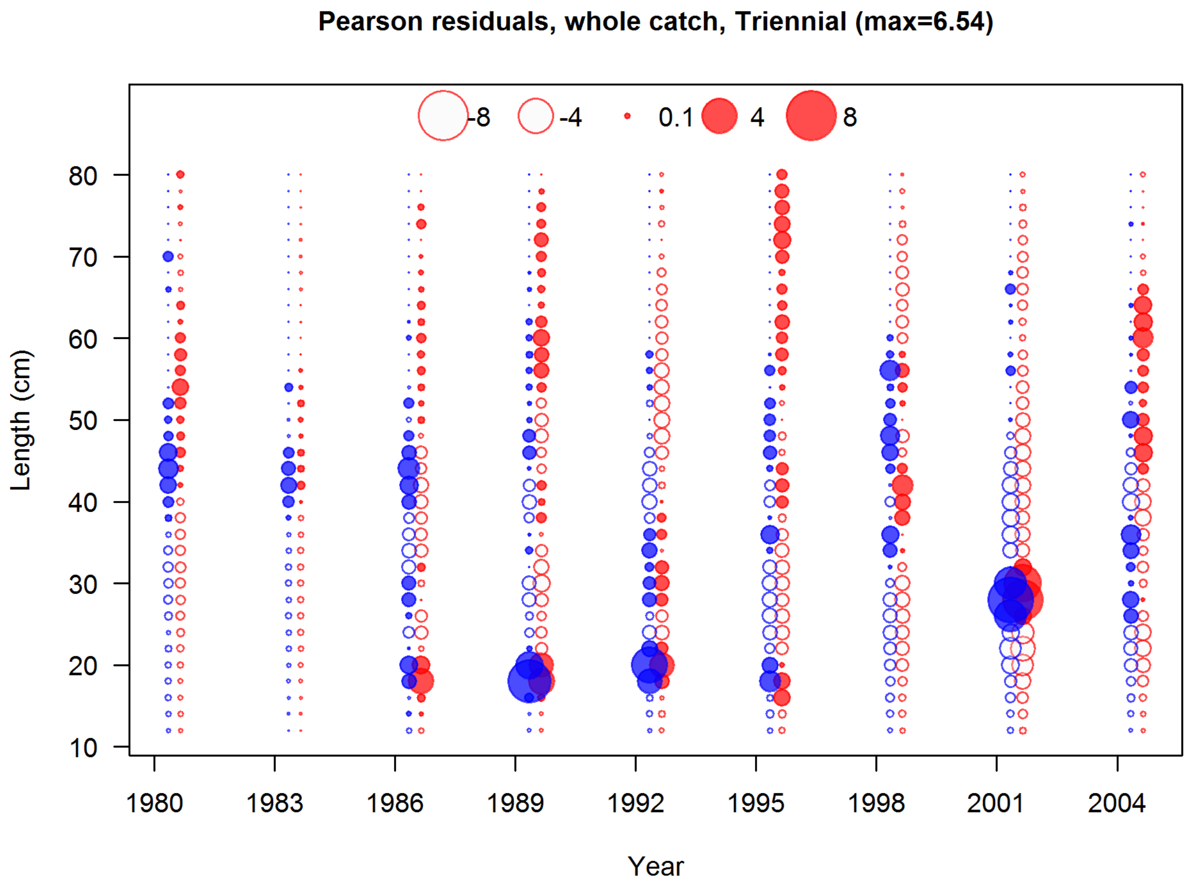


Figure 35. Residual bubble plot for the length-compositions from the Triennial shelf survey.

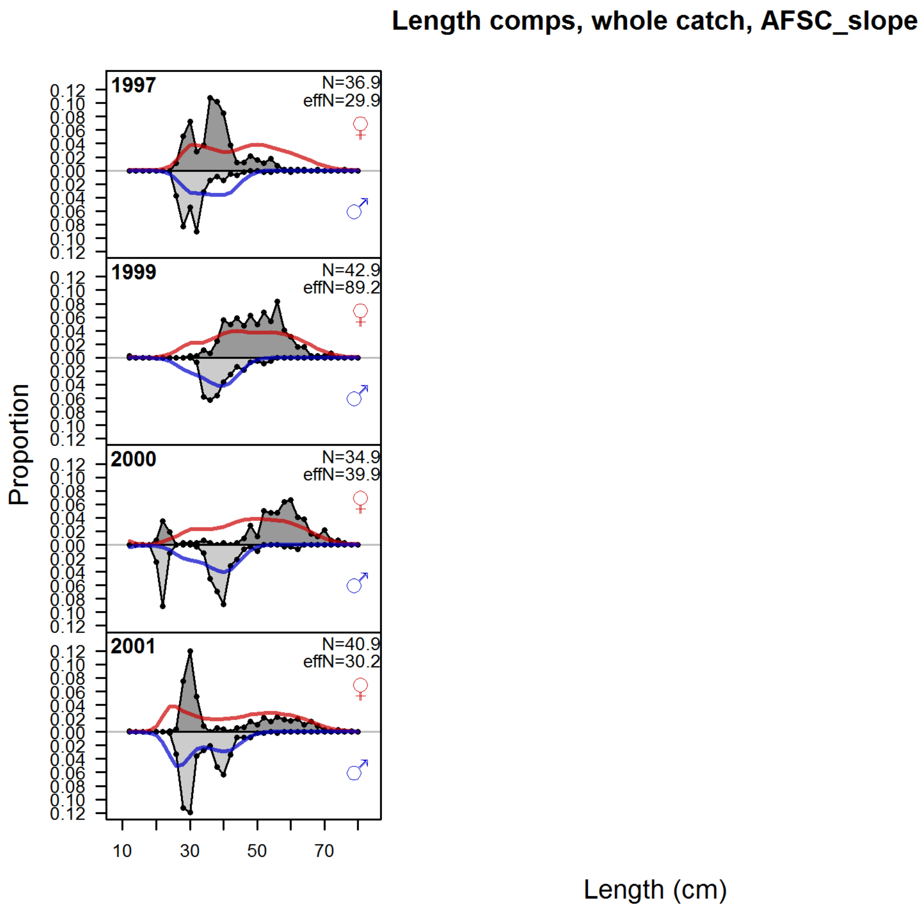


Figure 36. Observed and model-predicted length-compositions for the AFSC slope survey.

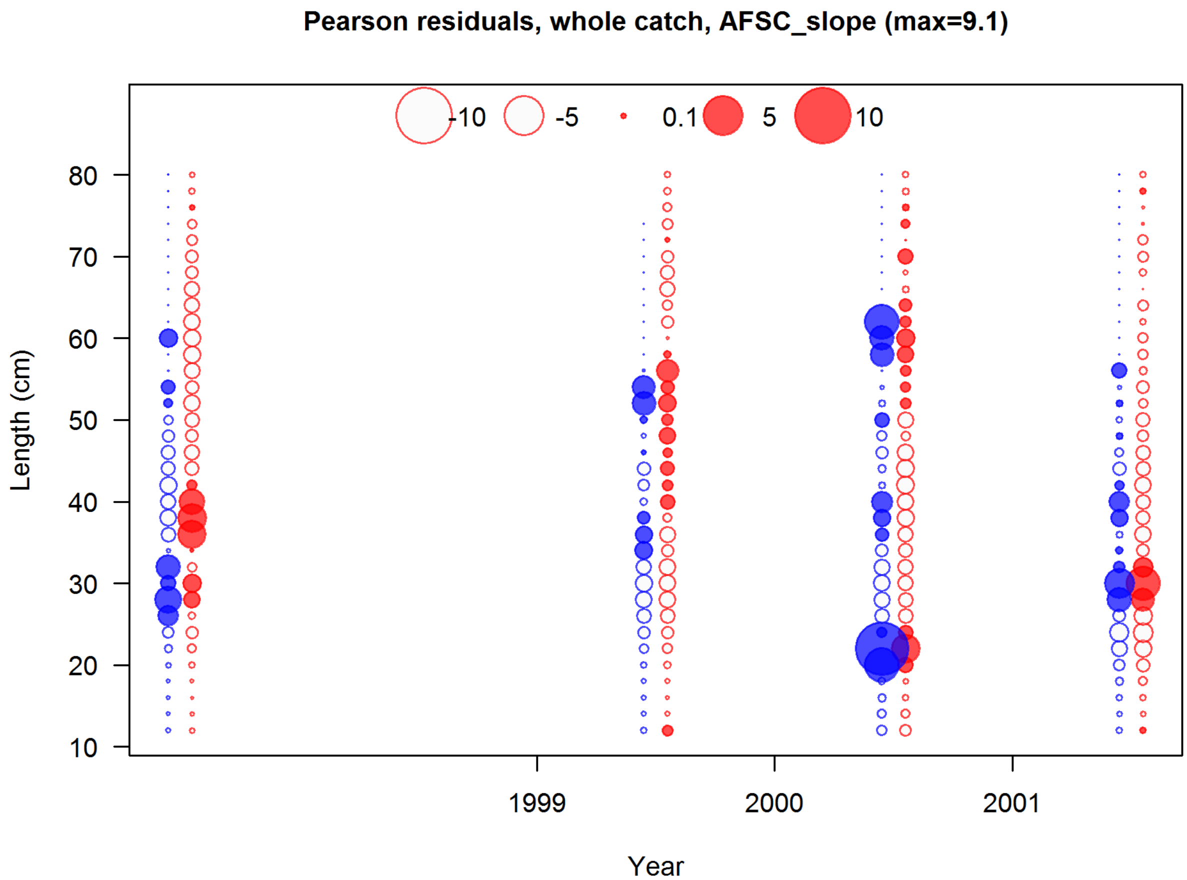


Figure 37. Residual bubble plot for the length-compositions from the AFSC slope survey.

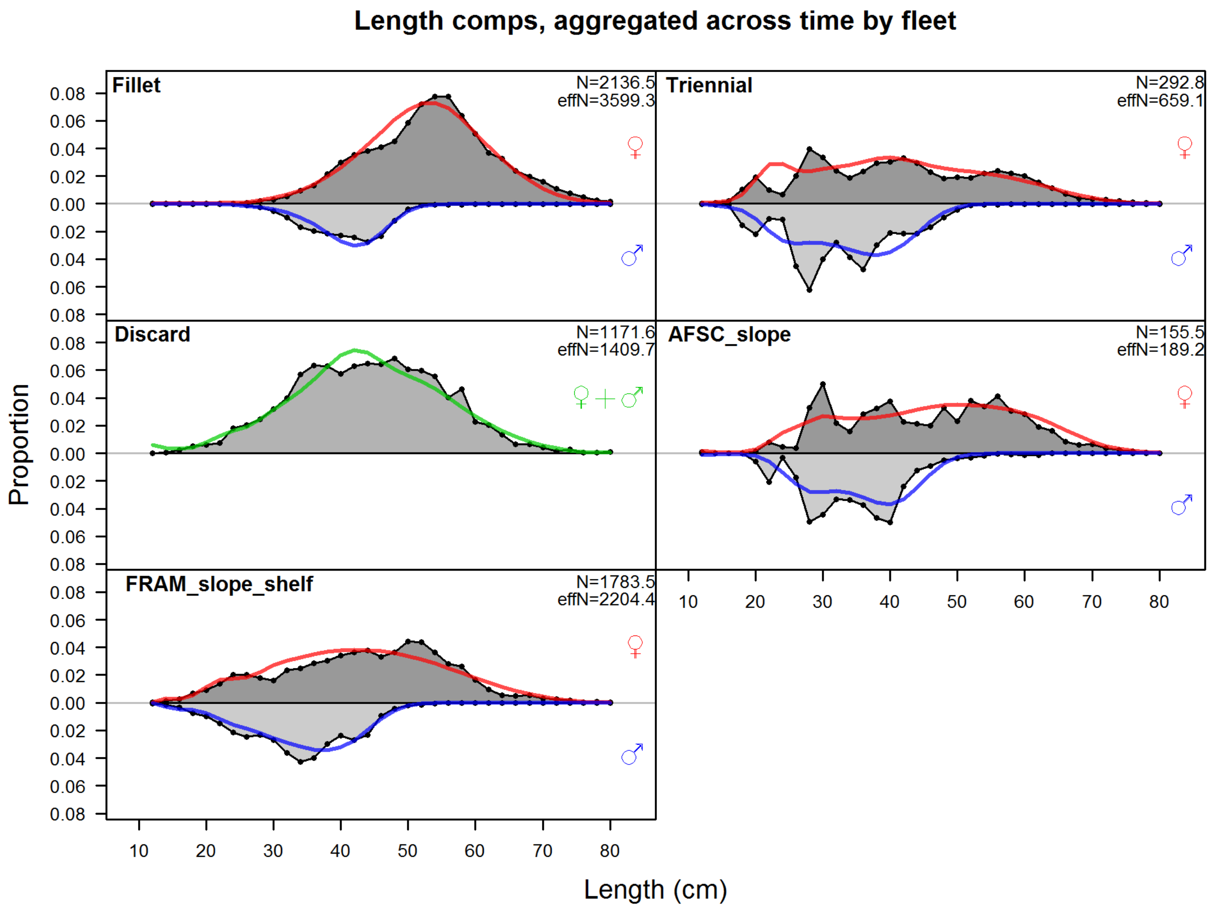


Figure 38. Aggregated observed and model-predicted length-compositions for the fleets and surveys with length data.

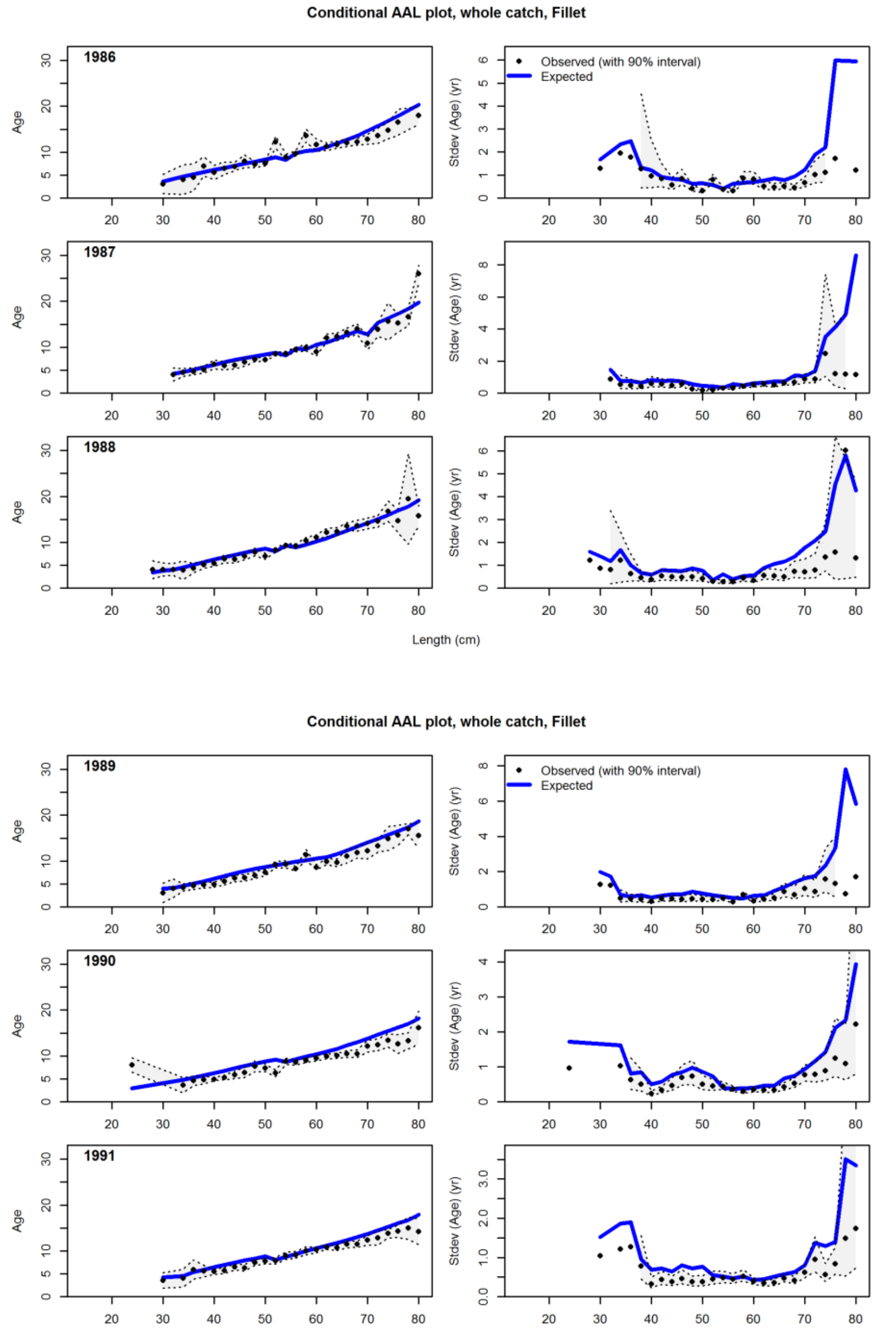
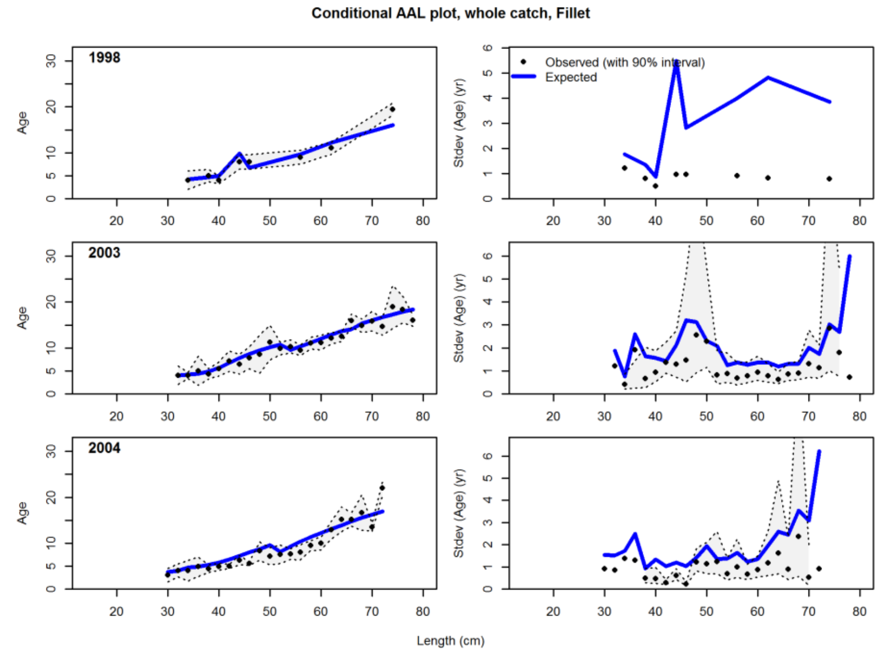


Figure 39. Conditional age-at-length diagnostic plot for the fillet fleet.



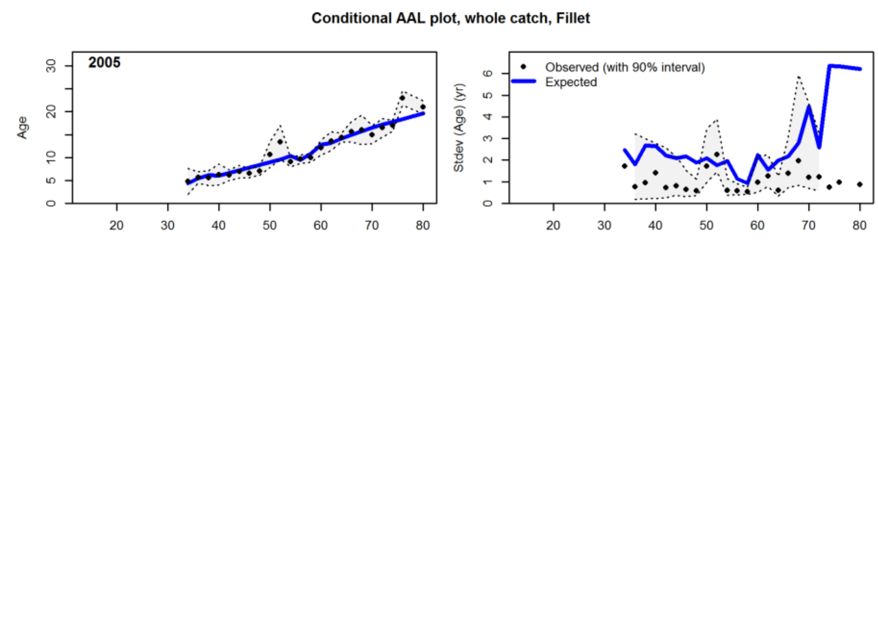
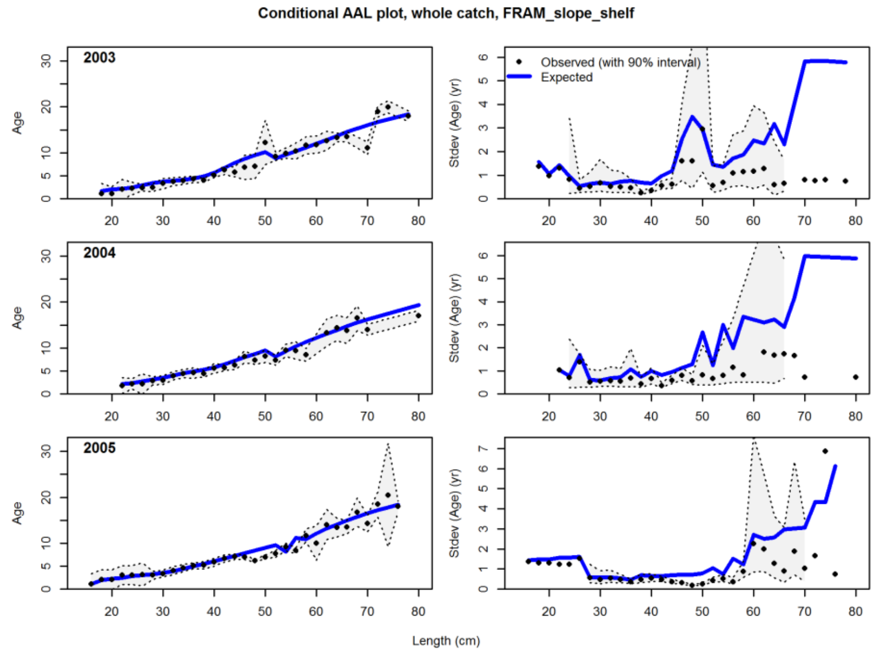


Figure 40. Conditional age-at-length diagnostic plot for the fillet fleet.



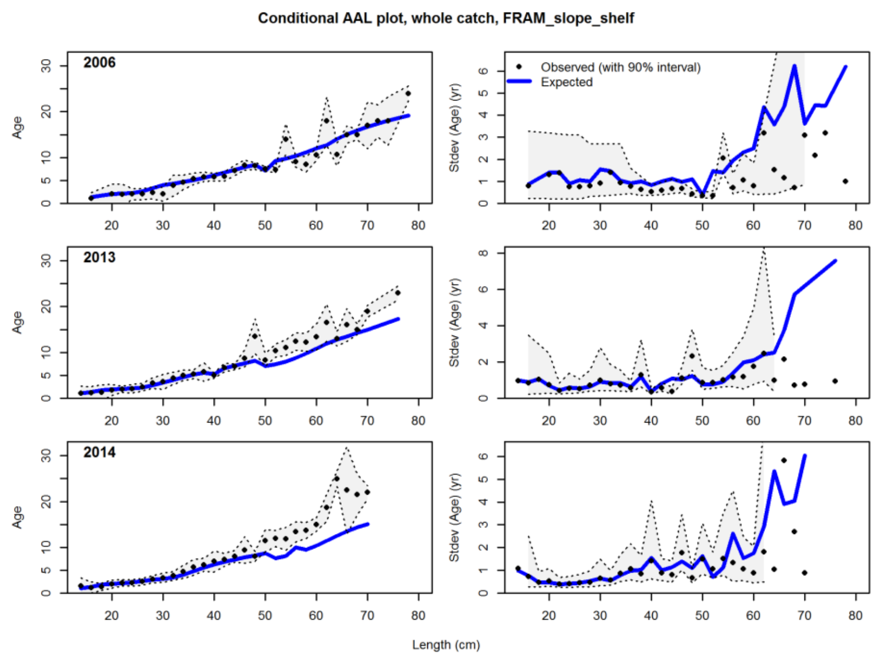


Figure 41. Conditional age-at-length diagnostic plot for the NWFSC (FRAM) slope-shelf survey.

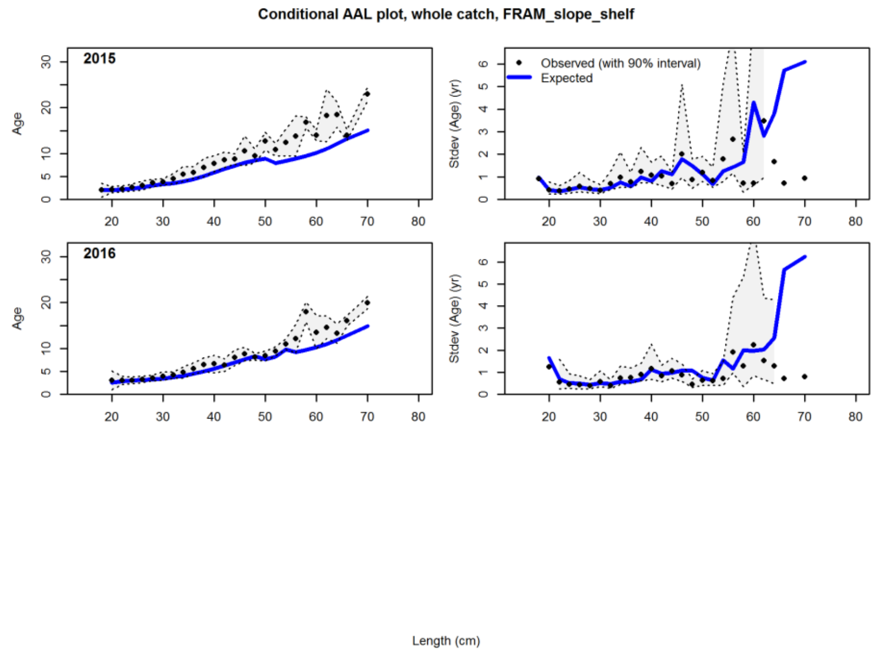


Figure 42. Conditional age-at-length diagnostic plot for the NWFSC (FRAM) slope-shelf survey.

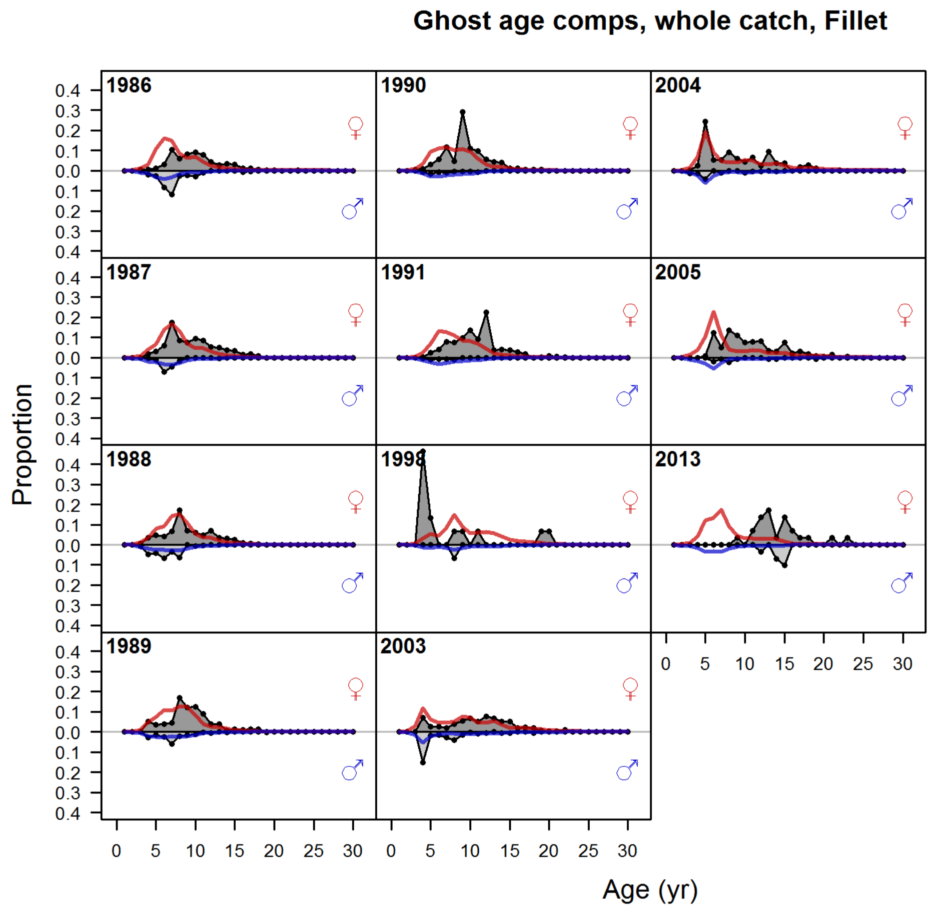


Figure 43. Observed and model-predicted marginal age-compositions for the fillet fleet. These data do not contribute to the likelihood in the model. They were included to aid visual inspection.

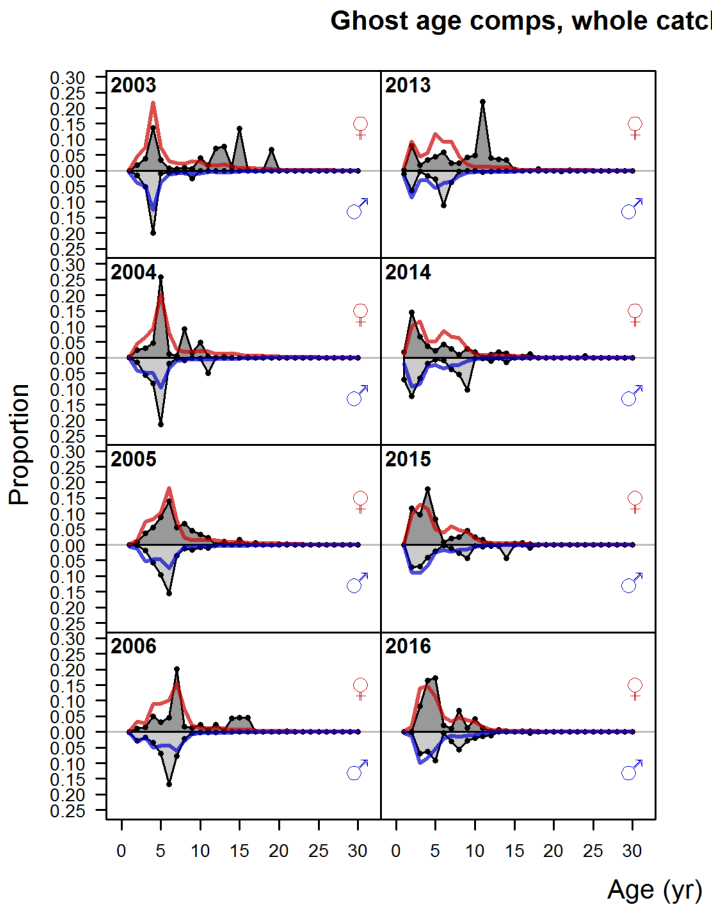


Figure 44. Observed and model-predicted marginal age-compositions for the NWFSC (FRAM) slope-shelf survey. These data do not contribute to the likelihood in the model. They were included to aid visual inspection.

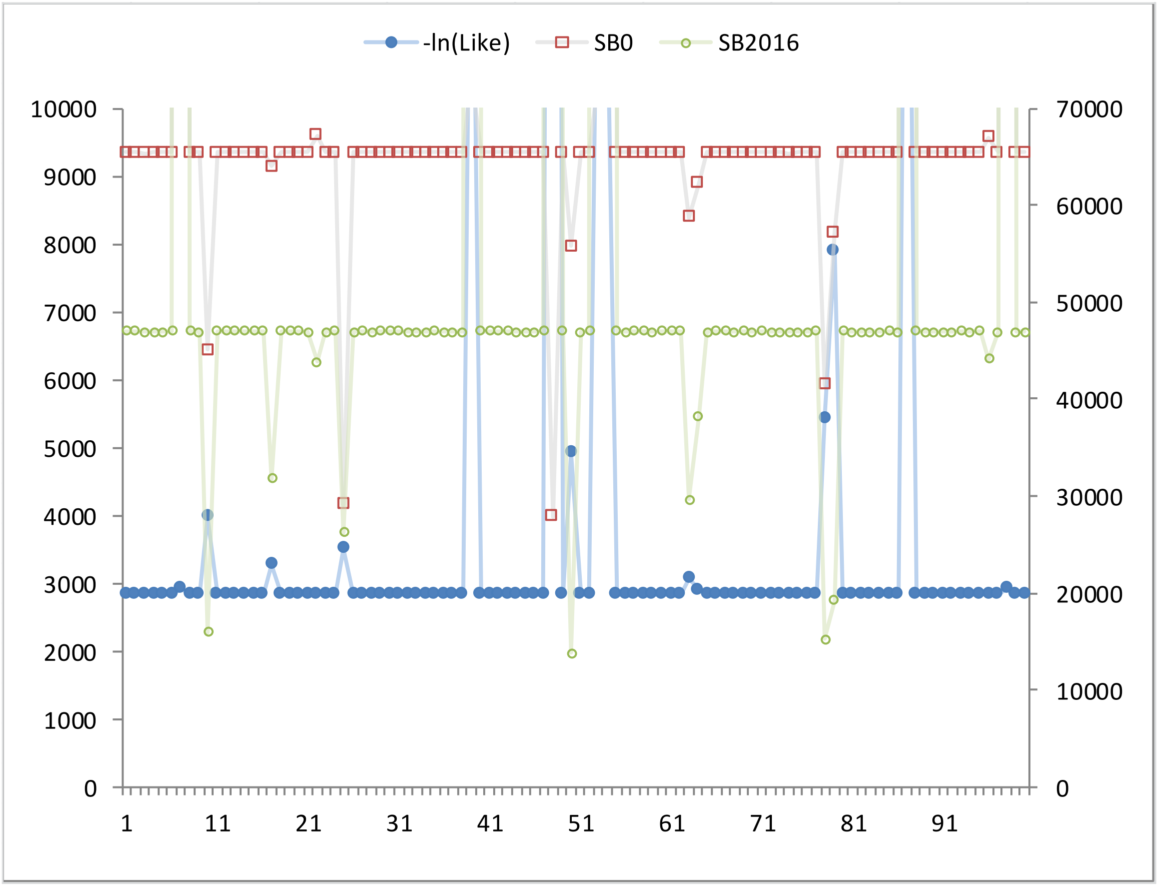


Figure 45. Exploration of the convergence of the base model using 100 runs of the model that had "jittered" initial parameter values.

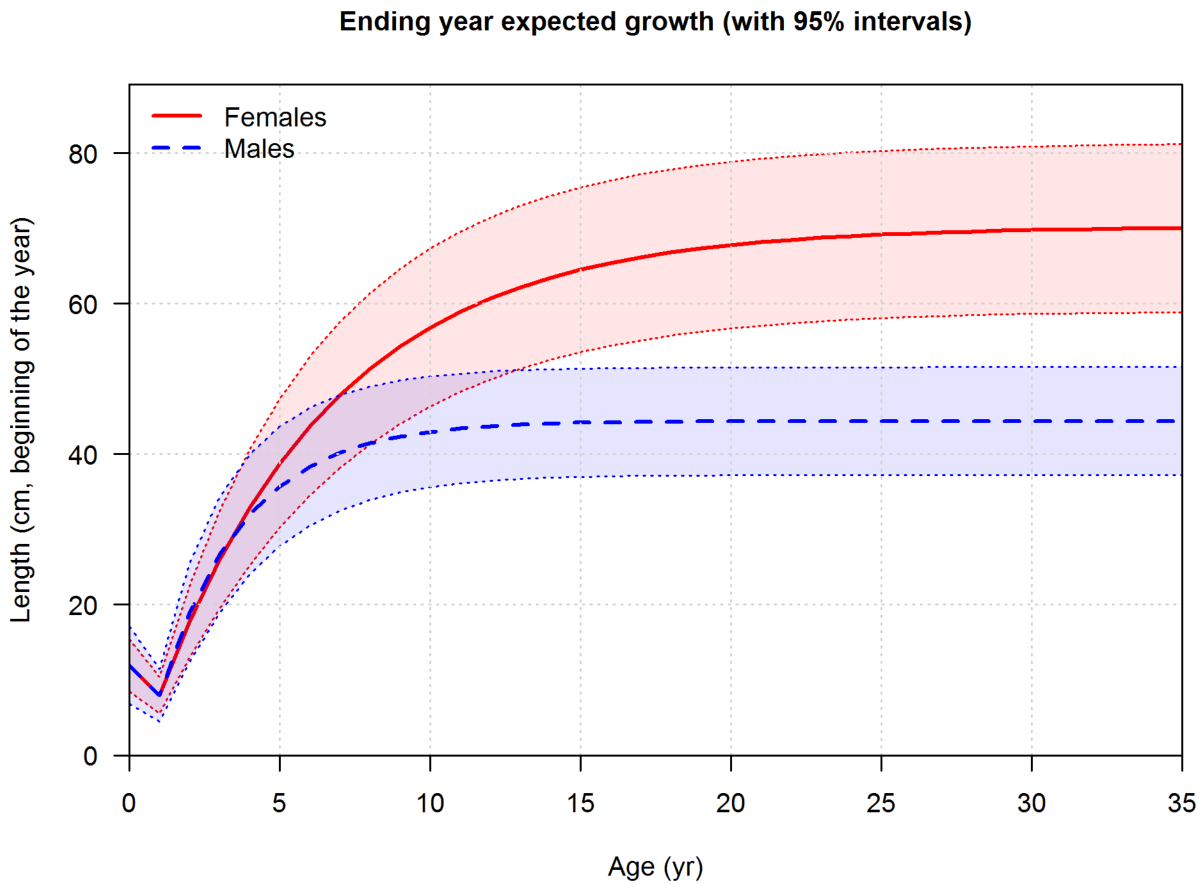


Figure 46. Estimated growth curves from the base model.

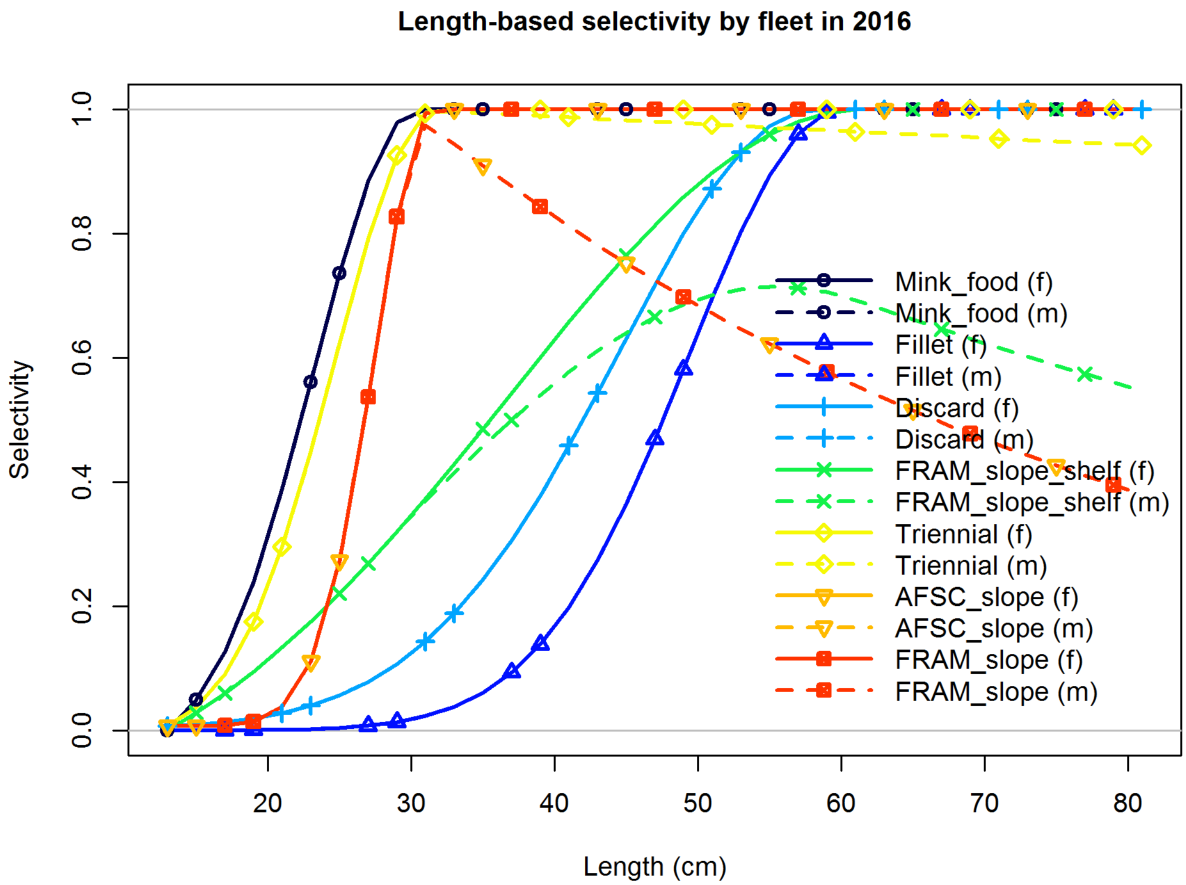


Figure 47. Estimated length selection curves for the fishing fleets and surveys.

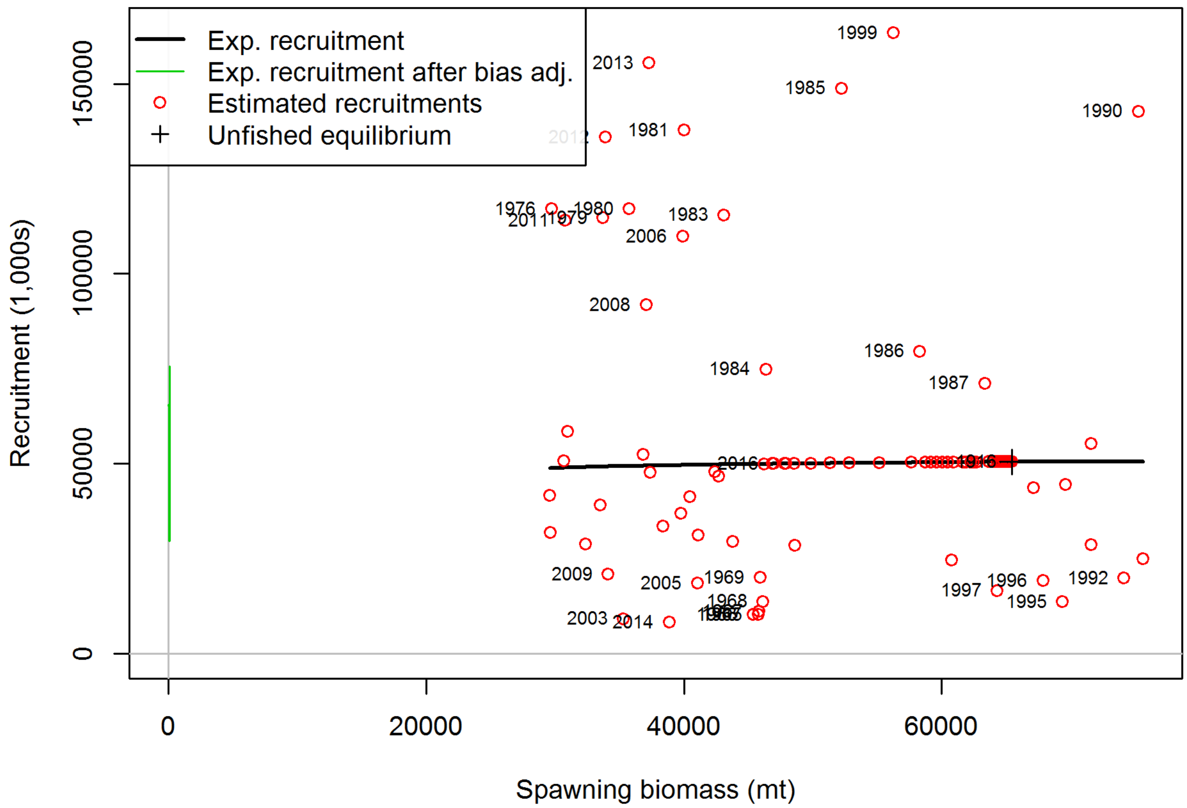


Figure 48. Base model spawner-recruit curve and points indicating the estimates of recruitment and the spawning biomass that produced those recruits.

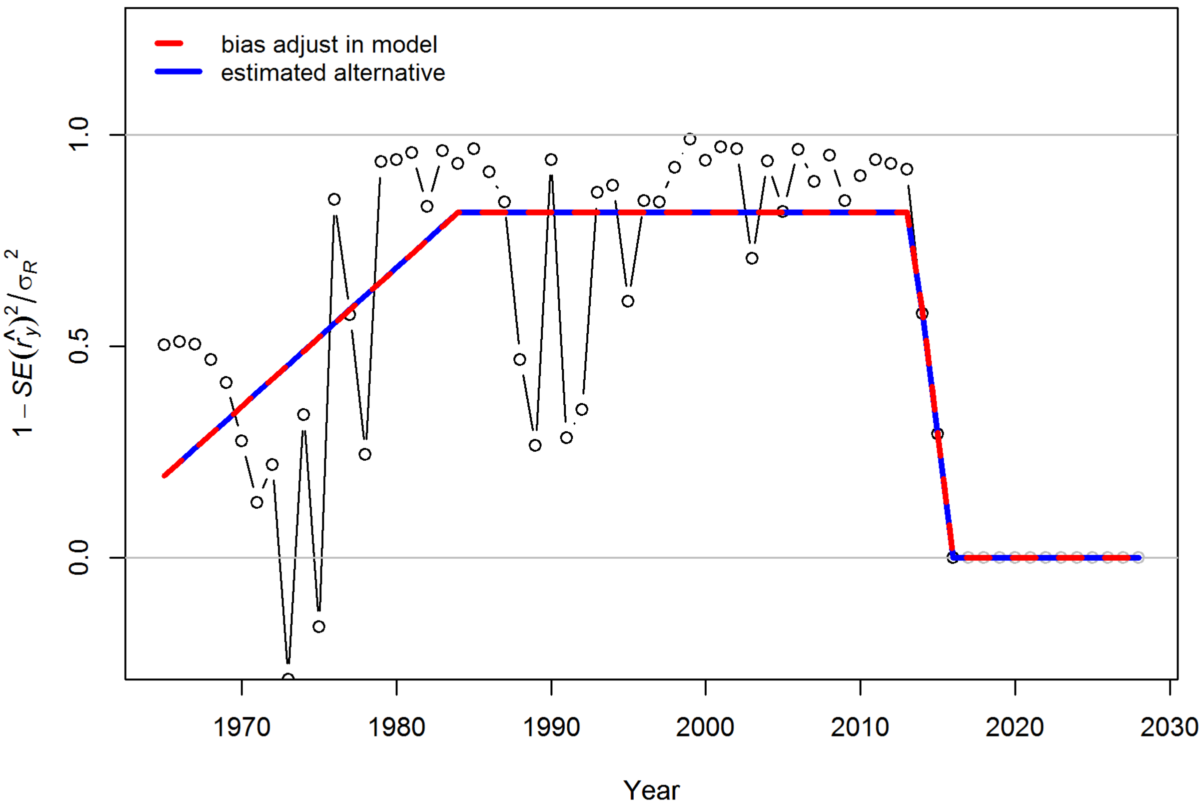


Figure 49. Recruitment bias-adjustments applied to the estimated annual recruitment deviations.

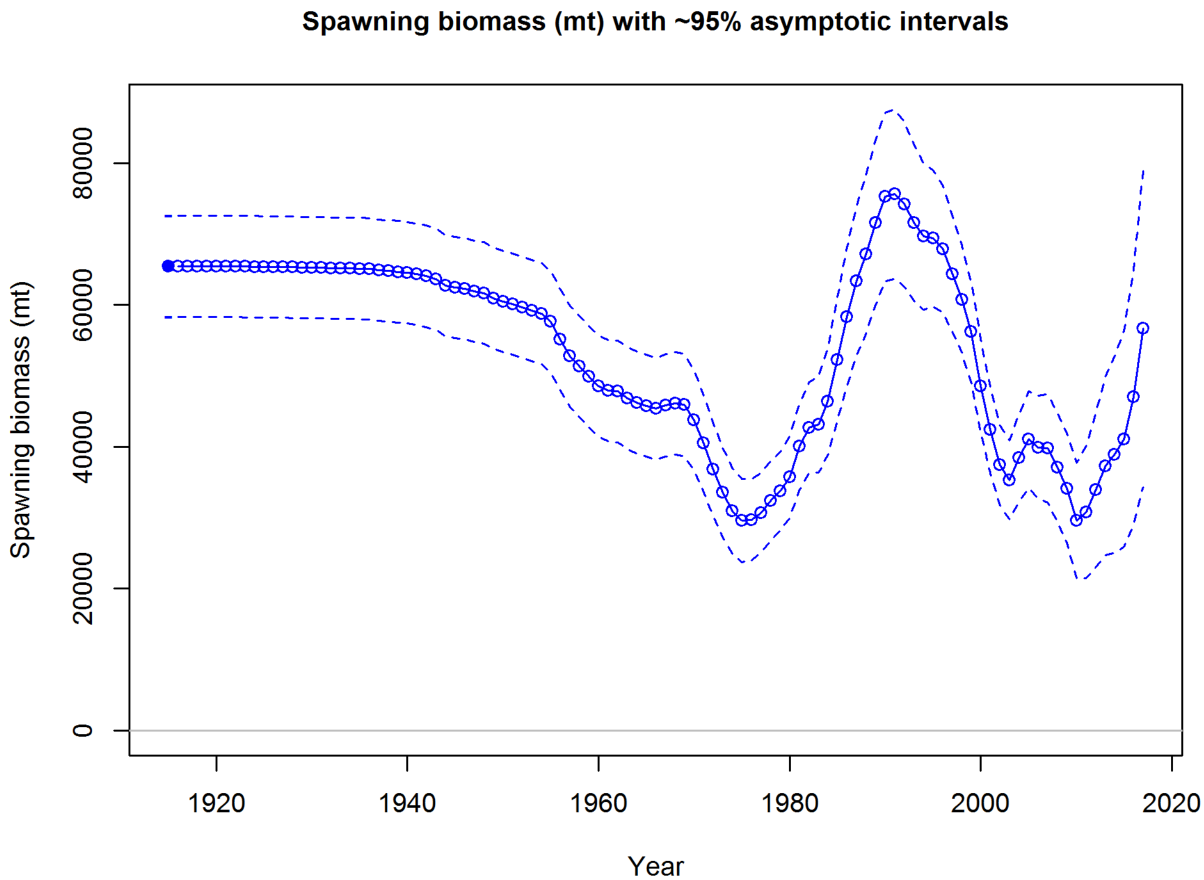


Figure 50. Base model estimated trajectory for spawning biomass.

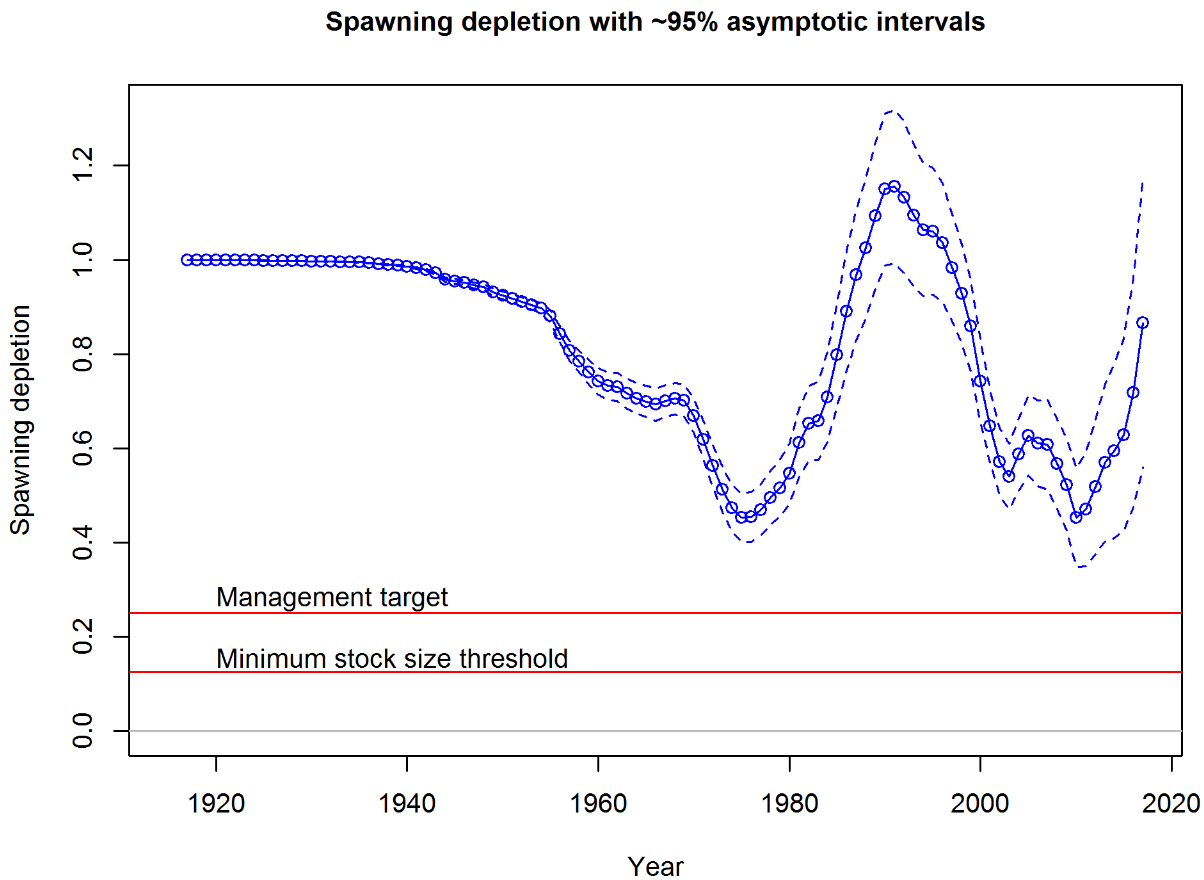


Figure 51. Base model estimated trajectory for depletion (spawning biomass / unfished spawning biomass).

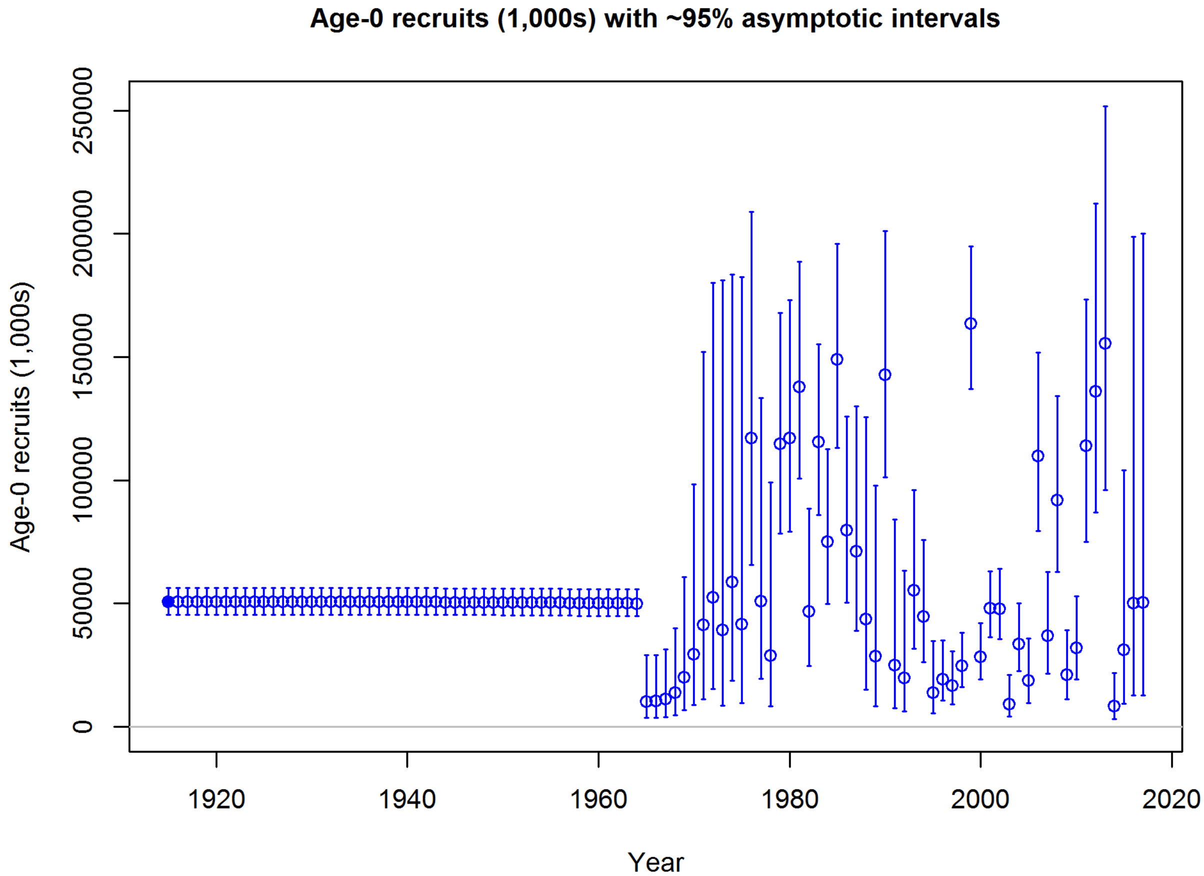


Figure 52. Base model estimated trajectory for age-0 recruitment.

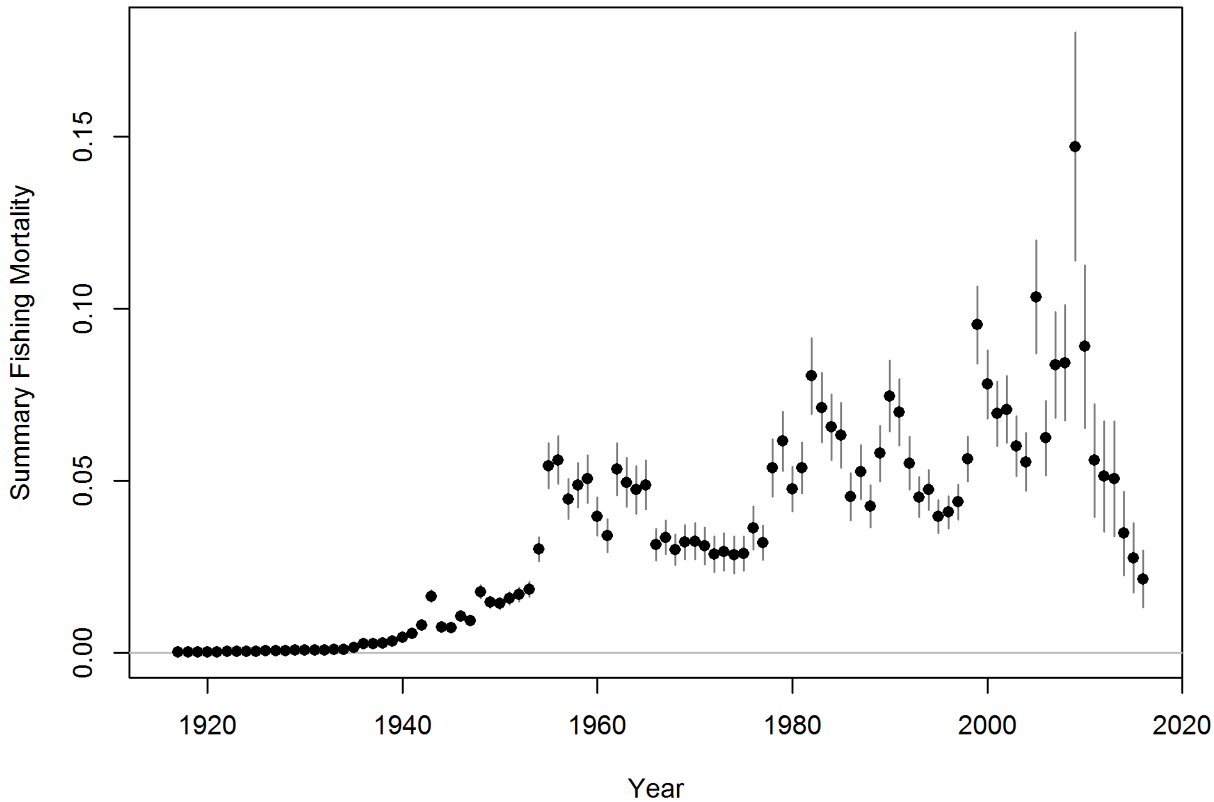


Figure 53. Base model estimated trajectory for exploitation.

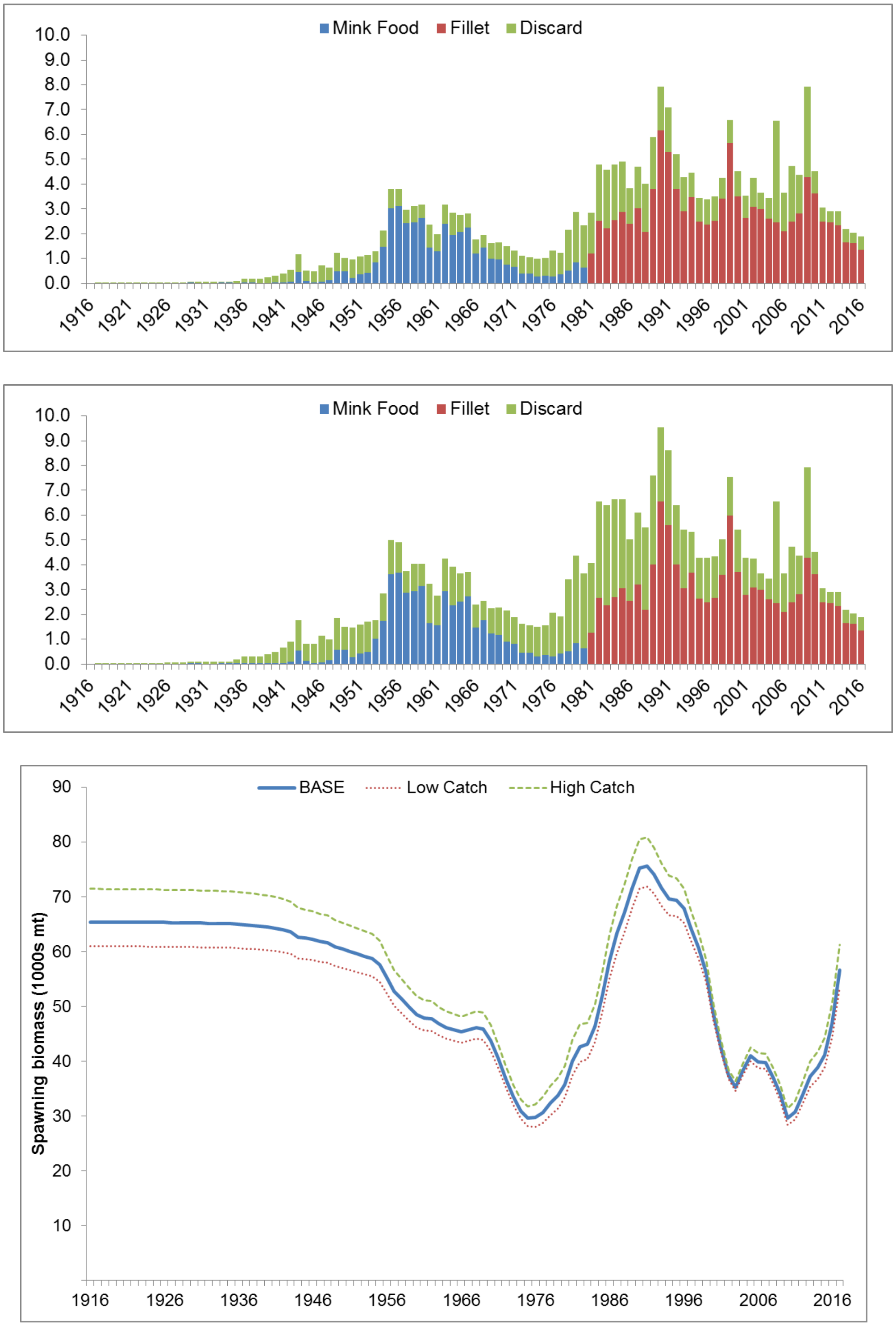


Figure 54. Low (upper panel) and high (middle panel) alternative historical catch series and comparison of the base model spawning biomass trajectory with ones based on low and high alternative catch series (lower panel).

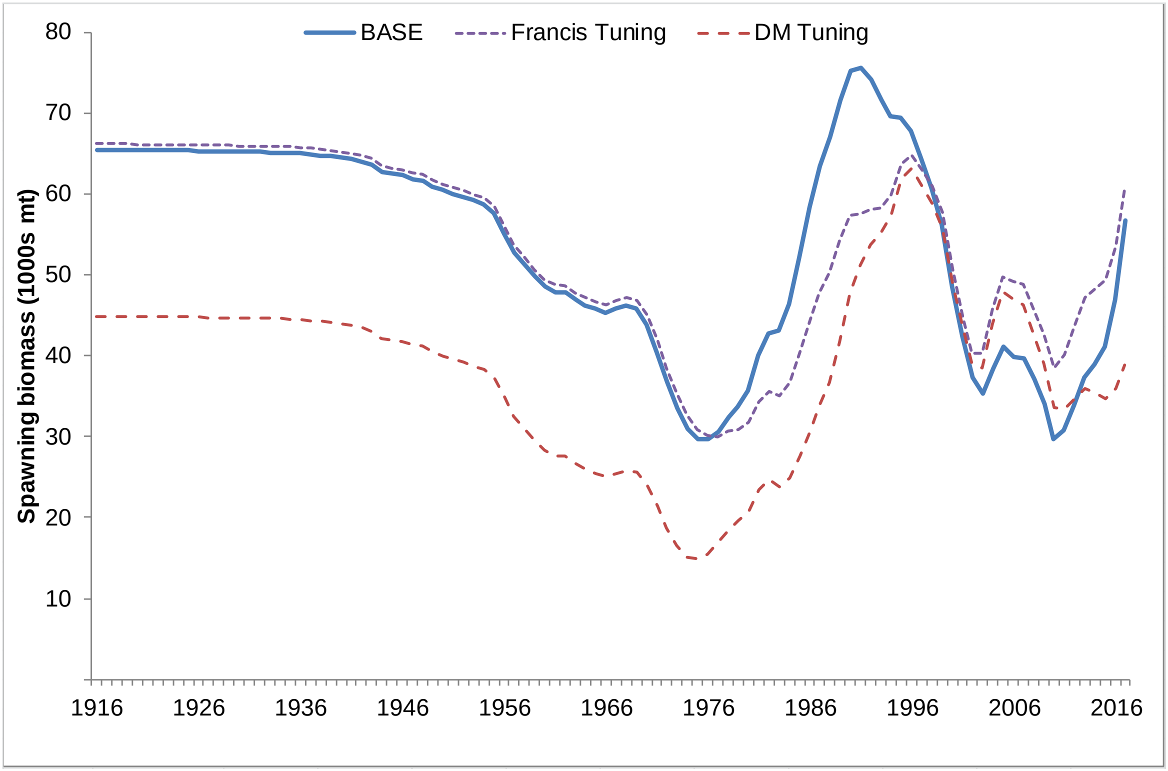


Figure 55. Comparison of spawning biomass trajectory from the base model with an alternative model that had the length-composition data series tuned using the Francis method and using Dirichlet multinomial (DM) weighting for all composition data series. The base model was tuned using the McAllister-Ianelli method for all composition data series.

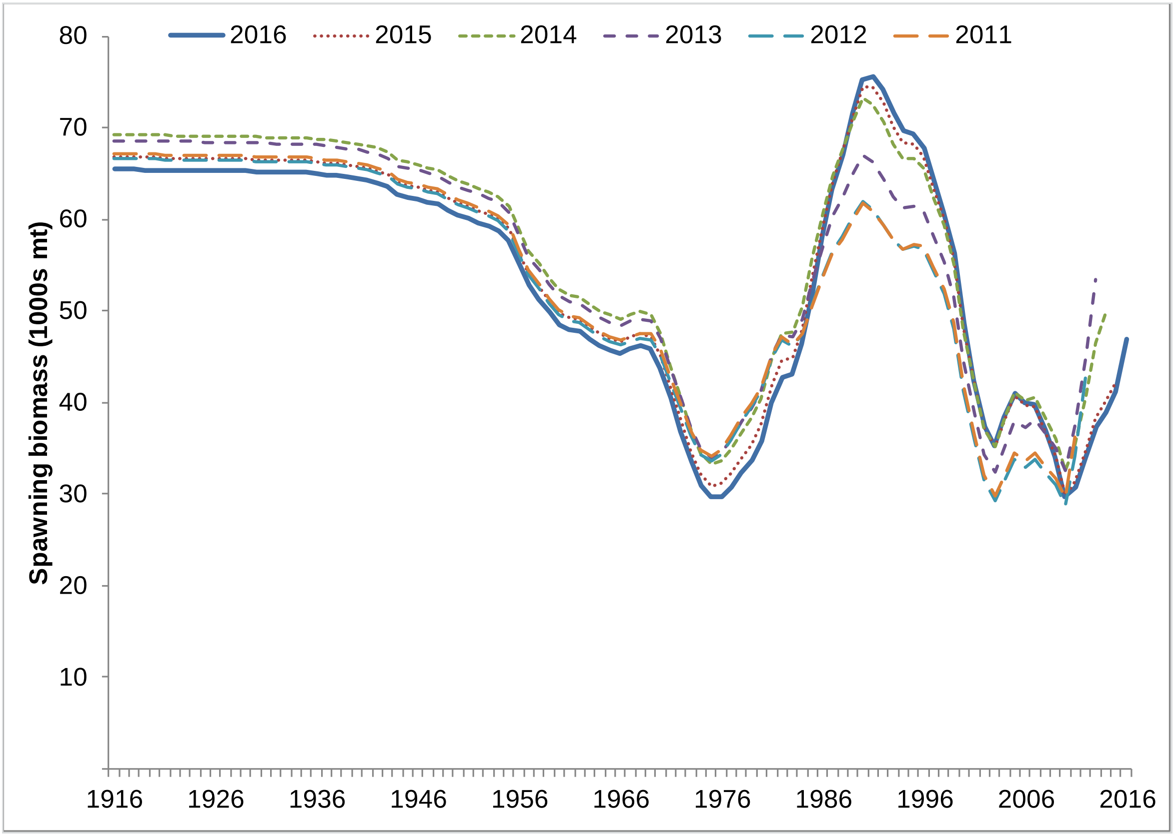


Figure 56. Retrospective analysis for the base model, in which the data from each ending year are sequentially removed from the model, one year at a time. The strong retrospective pattern evident in the figure is described in the main text.

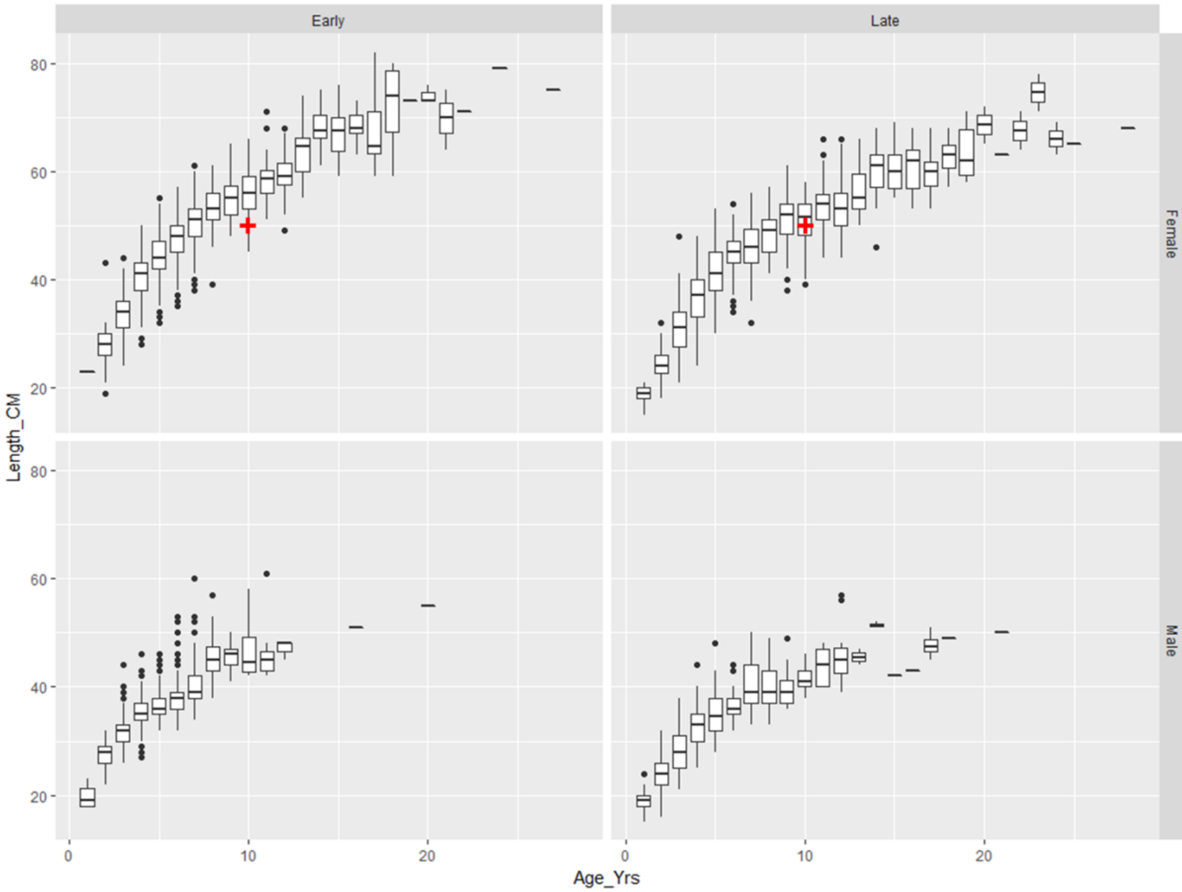


Figure 57. Comparison of lengths-at-age of Arrowtooth Flounder from the NWFSC slope-shelf, which were available for two periods, early (2003-2006) and late (2013-2016). The red crosses on the two upper panels mark the reference point (age=10, length=50).

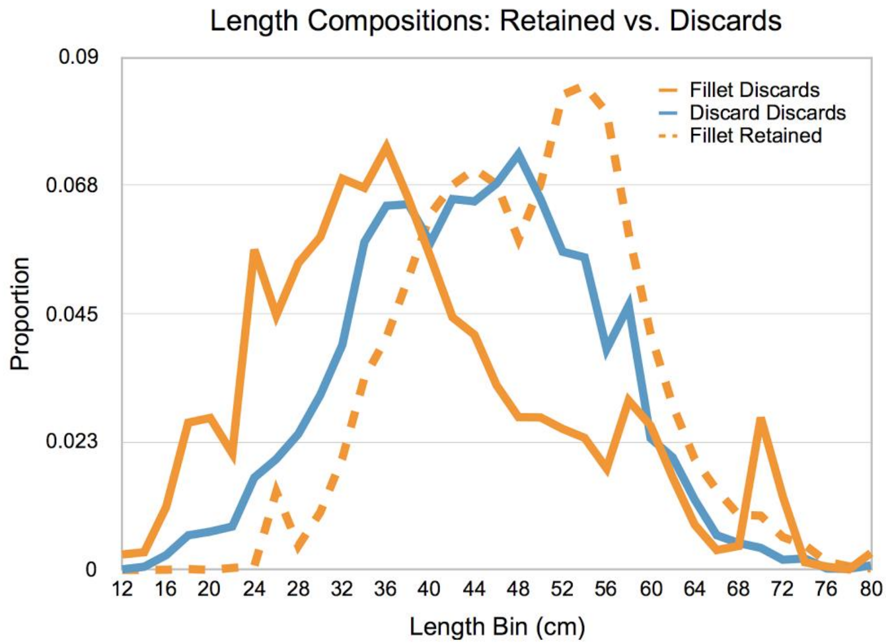


Figure 58. Length-compositions of Arrowtooth Flounder that were discarded and retained by the fillet fleet versus those discarded by the “discard fleet”.

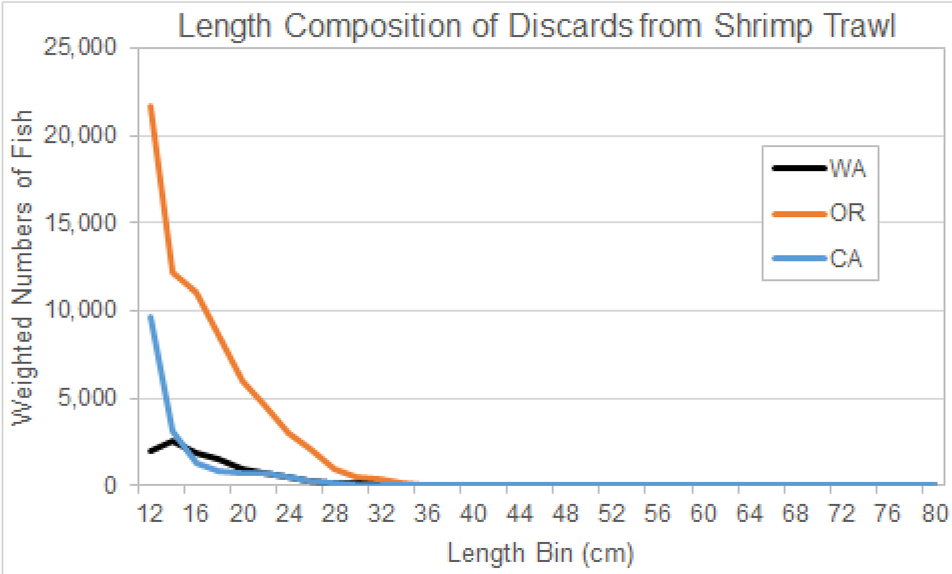


Figure 59. Length-compositions of Arrowtooth Flounder that were caught and discarded in the shrimp fishery, by state.