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

Preparers:

David B. Sampson, Oregon State University
Owen S. Hamel, Northwest Fisheries Science Center
Katelyn Bosley, Northwest Fisheries Science Center
John Budrick, California Department of Fish and Wildlife
Lee Cronin-Fine, University of Washington
Lisa K. Hillier, Washington Department of Fish and Wildlife
Kristen E. Hinton, Washington Department of Fish and Wildlife
Melissa J. Krigbaum, University of Washington
Stacey Miller, Northwest Fisheries Science Center
Kristin M. Privitera-Johnson, University of Washington
Kirsten L. Ramey, California Department of Fish and Wildlife
Brett T. Rodomsky, Oregon Department of Fish and Wildlife
Laura K. Solinger, Humboldt State University
Alison D. Whitman, Oregon Department of Fish and Wildlife

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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 and 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. Because of their poor flesh quality, there are limited markets for arrowtooth flounder 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.

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

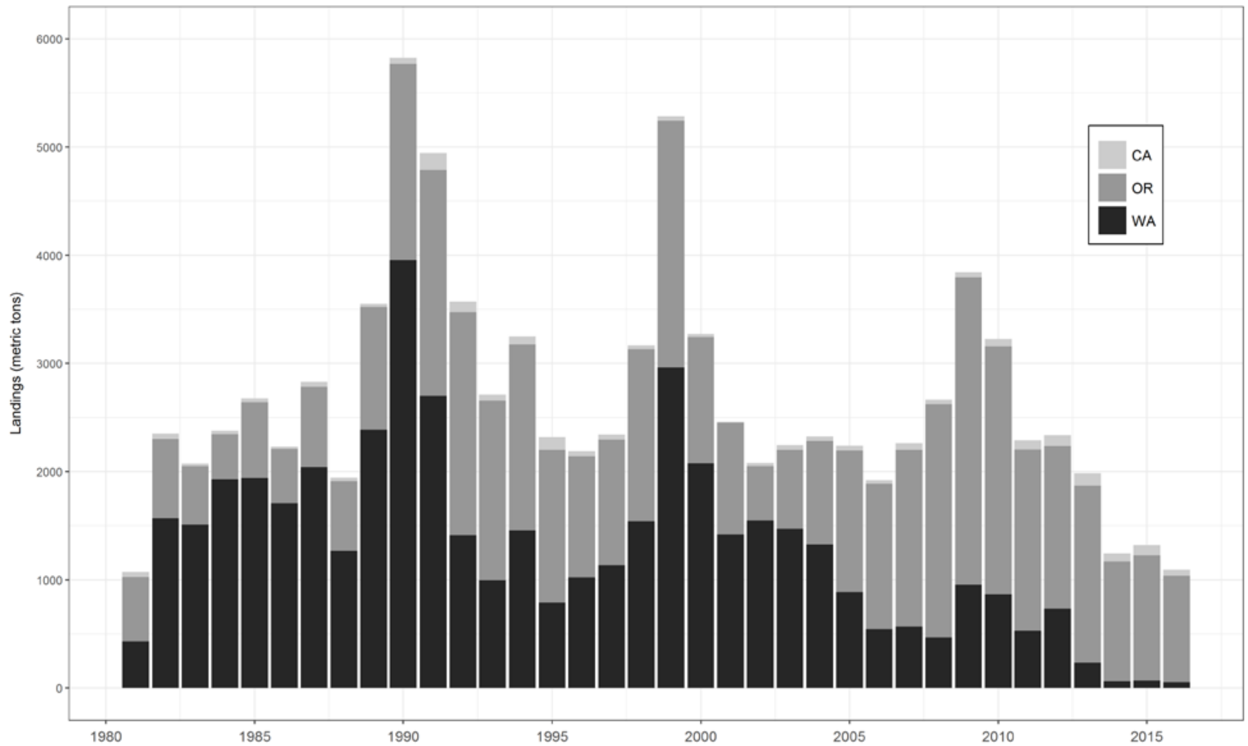

Figure a. Landings of arrowtooth flounder by state, 1981 to 2016.

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 in 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 great 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: the Triennial shelf survey (1980-2001); 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 include 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 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 29.6 thousand mt, the second lowest value in the series. Since 2010 the spawning biomass has been increasing steadily and is estimated to be almost 57 thousand 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, 2007-2016.

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%

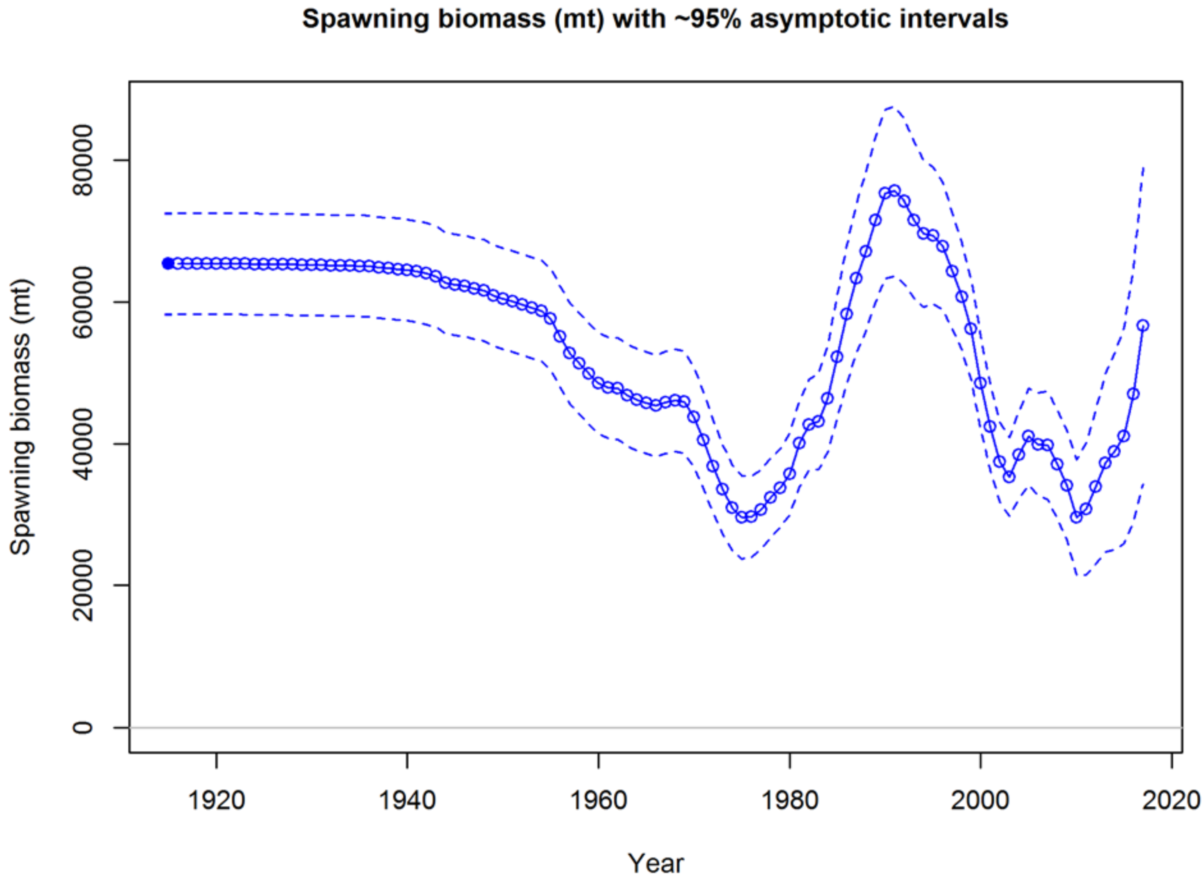

Figure b. Estimated spawning biomass of arrowtooth flounder, 1916-2016.

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, 2007-2016

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

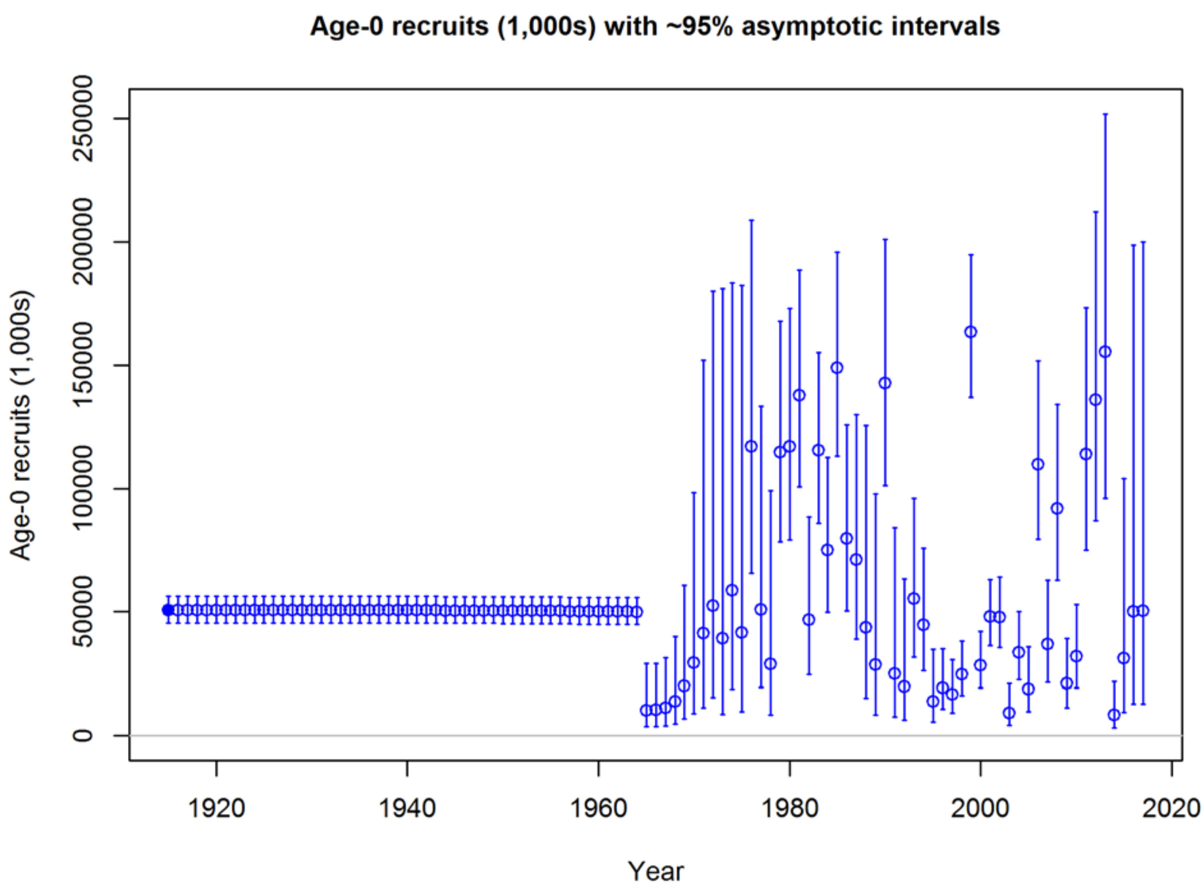

Figure c. Estimated recruitment of arrowtooth flounder, 1916-2016.

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%

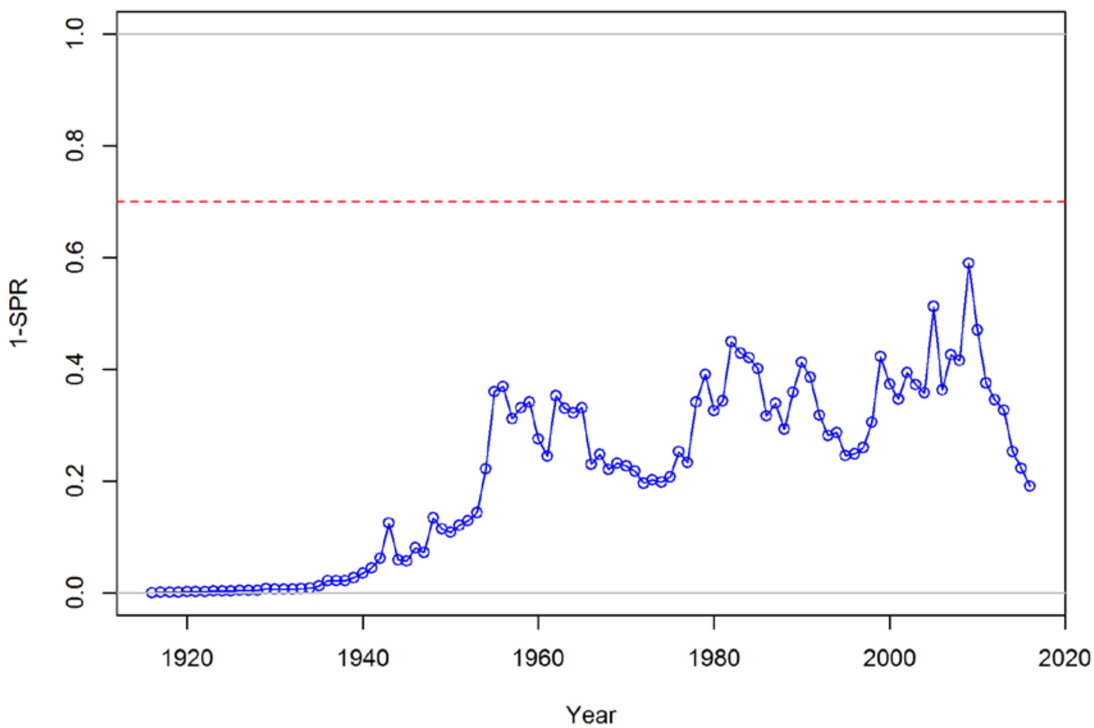

Figure d. Times series of estimated spawning potential ratio (SPR) rates.

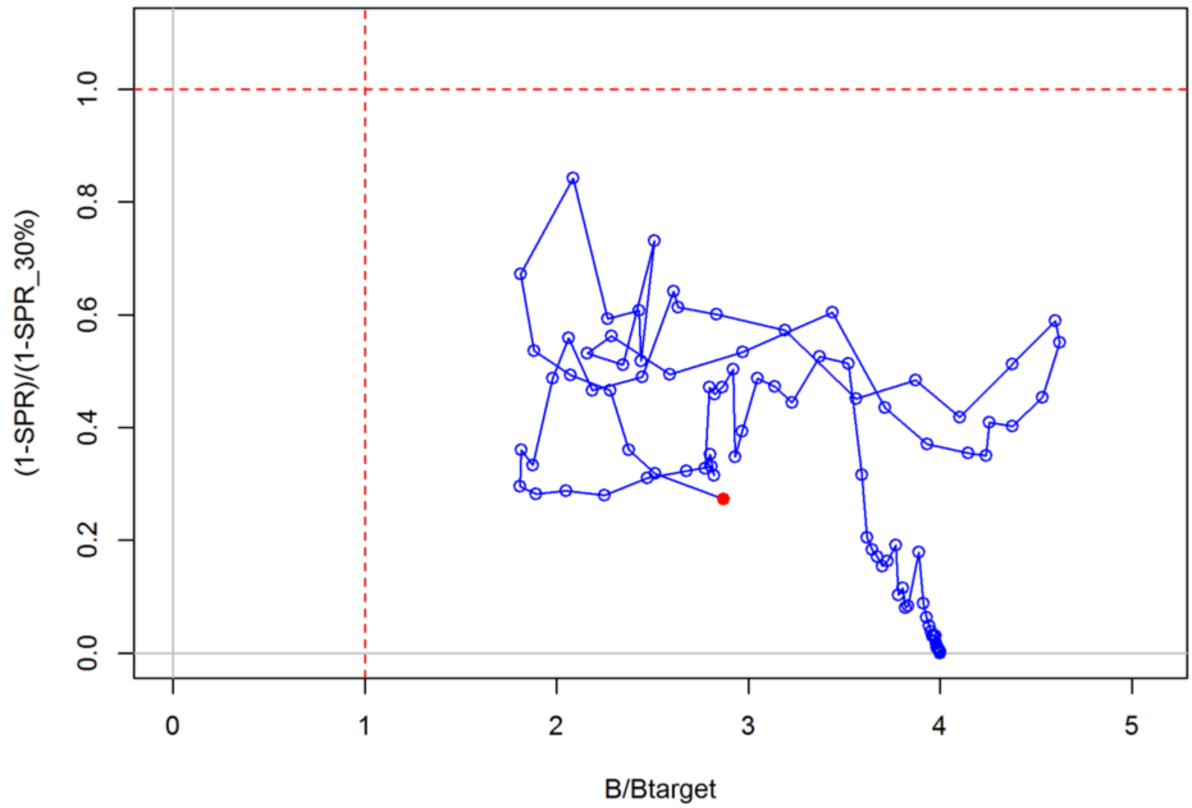

Figure e. Phase plot of the relative depletion (biomass status) versus the relative spawning potential ratio (SPR) rate (exploitation status). The red point represents the ending year of the assessed period, 2016.

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 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 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.

Table e. 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%

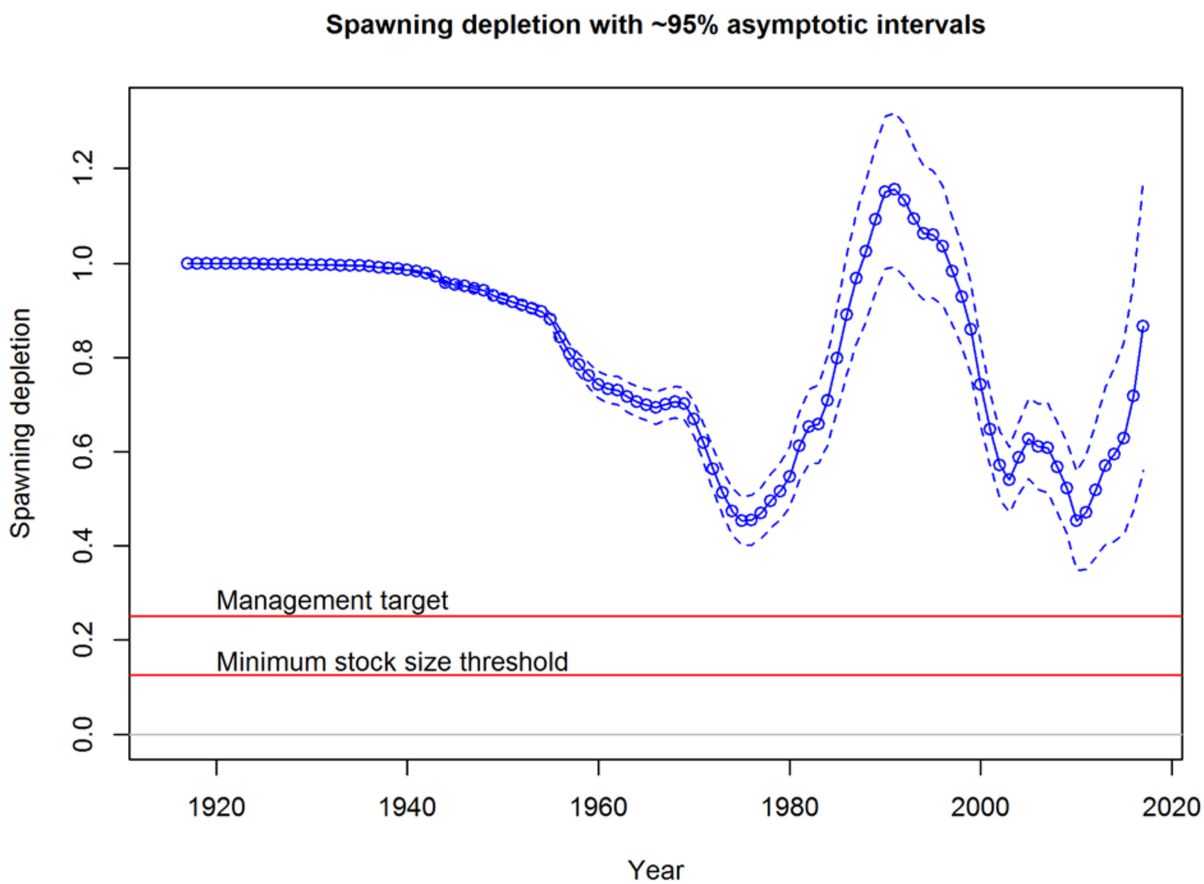

Figure f. Estimated relative depletion for arrowtooth flounder.

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 FMSY proxy of F30%, a BMSY target of B25%, and a minimum stock size threshold (MSST) of B12.5% (half of BMSY). Fishing mortality rates (measured in terms of SPR) have been below the current F-target for flatfish of SPR30% 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 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 **
2000	5800	-	-	3597	4910
2001	5800	-	-	2705	3849
2002	5800	-	-	3086	4256
2003	5800	-	-	3006	3640
2004	5800	-	5800	2597	3447
2005	5800	-	5800	2456	6564
2006	5800	-	5800	2085	3653
2007	5800	-	5800	2473	4716
2008	5800	-	5800	2804	4365
2009	11267	-	11267	4277	7936
2010	10112	-	10112	3620	4513
2011	18211	-	15174	2482	3059
2012	14460	12049	12049	2452	2893
2013	7391	6157	6157	2335	2901
2014	6912	5758	5758	1639	2197
2015	6599	5497	5497	1609	2038
2016	6396	5328	3241	1341	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 assessement does not represent the official 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.

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 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. Although it's 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.

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 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, male *M* = 0.21), (2) the base case (female *M* = 0.216, male *M* = 0.30), and (3) the high state (female *M* = 0.31, male *M* = 0.43). 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 0.45 and a category 1 stock designation. 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 upon the assumptions that P*=0.45 and σ=0.36 for a category 1 designation, and the ACLs are taken in 2017 (13,804mt) and 2018 (13,743mt).

			State of nature					
			Low $M_{female} = 0.15$ $M_{male} = 0.21$		Base case $M_{female} = 0.216$ $M_{male} = 0.30$		High $M_{female} = 0.31$ $M_{male} = 0.43$	
Relative probability of ln(SB_2013)			0.25		0.5		0.25	
Management decision	Year	Catch (mt)	Spawning biomass (mt)	Depletion	Spawning biomass (mt)	Depletion	Spawning biomass (mt)	Depletion
ABC catches from "Low" state of nature	2019	8,103	35,586	0.68	52,226	0.80	124,842	0.68
	2020	7,728	32,491	0.62	48,580	0.74	118,797	0.64
	2021	7,033	28,859	0.55	44,745	0.68	117,510	0.64
	2022	6,263	25,559	0.49	41,676	0.64	120,398	0.65
	2023	5,587	22,884	0.44	39,491	0.60	125,275	0.68
	2024	5,061	20,852	0.40	38,087	0.58	130,821	0.71
	2025	4,673	19,368	0.37	37,291	0.57	136,330	0.74
	2026	4,395	18,303	0.35	36,933	0.56	141,443	0.77
	2027	4,197	17,543	0.33	36,874	0.56	146,002	0.79
	2028	4,054	16,997	0.32	37,008	0.57	149,964	0.81
Base Case ABC catches	2019	17,873	35,586	0.68	52,226	0.80	124,842	0.68
	2020	14,632	25,124	0.48	40,700	0.62	111,344	0.60
	2021	11,697	16,550	0.31	31,930	0.49	105,796	0.57
	2022	9,575	10,459	0.20	26,382	0.40	106,846	0.58
	2023	8,305	6,455	0.12	23,277	0.36	111,299	0.60
	2024	7,630	3,861	0.07	21,666	0.33	117,034	0.63
	2025	7,281	2,122*	0.04*	20,835	0.32	122,864	0.67
	2026	7,090	0	0	20,366	0.31	128,226	0.70
	2027	6,969	0	0	20,053	0.31	132,924	0.72
	2028	6,880	0	0	19,813	0.30	136,946	0.74
ABC catches from "High" state of nature	2019	65,934	35,586	0.68	52,226	0.80	124,842	0.68
	2020	41,117	0	0	3,194	0.05	73,971	0.40
	2021	29,796	0	0	0	0	54,540	0.30
	2022	26,736	0	0	0	0	51,249	0.28
	2023	27,127	0	0	0	0	52,964	0.29
	2024	27,973	0	0	0	0	54,686	0.30
	2025	28,342	0	0	0	0	55,210	0.30
	2026	28,279	0	0	0	0	54,869	0.30
	2027	28,046	0	0	0	0	54,300	0.29
	2028	27,842	0	0	0	0	53,894	0.29

* The model removed 7,489 mt in 2024 (98% of the 7,630 mt in the forecast for that year).

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. *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.
3. *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.
4. *Evaluation of stock boundaries and the feasibility of a bilateral assessment with Canadian scientists*. This could perhaps be accomplished through the Technical Subcommittee (TSC) of the US Canada groundfish working group.
5. *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.
6. *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.
7. *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.

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) forklength (FL), arrowtooth flounder females grow quite a bit 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, halibut, coastal sharks, orcas, toothed whales, and harbor seals have all been found to be predators of juvenile arrowtooth. The larger of these predators are also likely to consume adult arrowtooth 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

There is not much 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. 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

Along the US West Coast arrowtooth flounder has been caught by trawl fleets for decades. 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) 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 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 in 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 kept arrowtooth flounder landings in fluctuation (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.

In this update assessment we assume 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 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.

For the bycatch estimates in the 2007 assessment a 13% discard ratio was applied to the coastwide landings of Dover, English and petrale soles for the years 1956-2006. 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.

Beginning in 2000, the Council established trip limits for arrowtooth flounder, placed restrictions on the use of large footropes, and in 2001 began using areas 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 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 markets conditions for arrowtooth flounder. In 2011, NOAA Fisheries implemented the West Coast Groundfish Trawl Individual Fishing Quota (IFQ) program, 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 et al. 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 FMSY proxy of F30%, a BMSY target of B25%, and a minimum stock size threshold (MSST) of B12.5% (half of BMSY). Fishing mortality rates (measured in terms of SPR) have been below the current F-target for flatfish of SPR30% 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 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

In the Eastern Bering Sea and the Aleutian Islands (BSAI), arrowtooth flounder is managed as a single stock 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, 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, the percentage of arrowtooth flounder retained in catches has increased and remained high in 2015 (84%) and 2016 (83%) (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 by the use of a length-age (growth) matrix. Estimates of total catch, trawl survey biomass estimates and standard error from the eastern Bering Sea shelf, eastern Bering Sea slope and Aleutian Islands surveys, 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 for females and 0.35 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

In the Gulf of Alaska (GOA), arrowtooth flounder are managed as a single stock. 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. Beginning 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 for females and 0.35 for males in the model, and weight at age data was 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). Arrowtooth flounder biomass estimates 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 survey, 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. The 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 beginning of 2015 to be 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. For years prior to 1978 the Washington landings reconstruction project had not yet been able to apportion landings of arrowtooth flounder 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. In that series the non-zero landings of arrowtooth flounder 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), but for the years 1956-1980 they are reasonably well correlated ($r = 0.703$). 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 Oregon 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 pulled from WaFT (accessed 04/12/17; K. Hinton, WDFW) for trips that landed arrowtooth flounder, as well as trips that did not land arrowtooth, 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 and discard fleets*.

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 (ref) 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. The ratios were 0.1194 for English sole and 0.1297 for petrale sole.

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 1981-1968, 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.

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 and discard fleets.*

California landings and discards

The California landings reconstruction (Ralston et al. 2010), which was completed since the 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).

While arrowtooth flounder are caught in limited amounts by the recreational and commercial fixed-gear fisheries, the trawl fishery is the primary source of both landings and discards.

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 and discard fleets*.

Discard fractions and discard ratios

As explained above in the section *Important features of current fishery and relevant history of fishery*, this update assessment apportions the catches of arrowtooth flounder to three fleets. 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 (by O.Hamel) 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, NMFS / 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 6.

Methods used for estimating discards by the fillet and discard fleets

We used similar methods for all three states to estimate the annual discards by the fillet and discard fleets. 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 a 9.0% discard fraction for all three states to derive the state-specific discards of arrowtooth flounder by the fillet fleet and the following 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.

There are some slight inconsistencies in how we developed the estimated discards for each state’s discard fleet. 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.

Compositional data from the fisheries

Commercial biological data from Oregon, Washington 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 6. 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 separate 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 (NMFS / 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 7). 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, 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 8.

The AFSC Triennial survey was conducted every third year from 1977 – 2001. Details of the methods and data from the AFSC Triennial shelf survey are described in the 2007 assessment document (Kaplan & 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. 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. 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 50m 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 FRAM 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 9. 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 10).

Due to the high occurrence of zero-catch hauls in all the surveys, indices were developed using a Delta-GLM approach, which 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 & Helser 2007).

Since the 2007 assessment was conducted there have been significant developments in the methods available to derive biomass indices based on trawl survey data. 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 variable 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) model differs from the method used in the 2007 assessment to develop the biomass index for the NWFSC shelf-slope survey, the geostatistical model 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 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 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	23976	0.25	25796	0.16	3.66
2004	19571	0.27	14756	0.18	-14.03
2005	22603	0.28	21640	0.16	-2.18
2006	22551	0.30	22516	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 were reduced using the VAST approach. 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 9. The predicted biomass values by stratum and overall are given in Table 7.

Visual inspection of the Q-Q plot indicated a slight deviation from the assumed distribution for positive catch rates (Figure 11). 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 12).

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 8). 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 each stratum and weighed by numbers of fish in each stratum to determine the annual length compositions.

Estimates of swept-area biomass and abundance for the revised NWFSC slope-shelf survey are provided in Table 9.

Survey age-at-length composition series

Four additional years of age-composition data (2013 - 2016) were included with 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, 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 8.

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 (nls) 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. 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 13. 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 updates assessment. The 2007 assessment used *M* values of 0.166 yr^{-1} for females and 0.274 yr^{-1} for males.

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, personal communication).

Maturity.

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

$$Proportion\ Mature = 1\ /\ (\ 1 + \exp(\ Slope\ *(\ Length - Inflection\ )))$$

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 in 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 14).

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

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

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 15).

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 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. The only other stock assessment for arrowtooth flounder off the US West Coast was Rickey (1993), which 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 develop estimated biomass trajectories or evaluate stock status.

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 state's 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 and discard fleets*.

The state's reconstructions did not develop "high and low values to set bounds for the exploration for 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 do not currently exist except 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 FRAM 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 put into 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%; the estimate of 2006 spawning biomass increasing by an additional 0.44%. The changes are almost imperceptible in Figure 16. Additional details are provided in Table 10.

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 metric tons 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 and discard fleets) and a revised biomass index for the FRAM 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 FRAM 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 10, noting changes in the assessment results at each step. Also during this phase of the bridging process we updated the natural mortality coefficients, the coefficients for the length-weight relationships, and turned on a feature that estimates an "*extra_SD*" parameter for each of the survey catchability coefficients. These *extra_SD* parameters allow for extra variability in the survey process that is not accounted for by the survey biomass standard errors 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 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 16. 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 added new data elements as appropriate for the years 2007 through 2016 and also made some needed adjustments to the model dimensions. We also added an *extra_SD* parameter for the NWFSC slope-shelf survey, 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 11 the model was once again iteratively retuned. Also, an additional round of model tuning was required after a new version of the Stock Synthesis software was released on 05/09/2017. Some of the steps created large changes in the assessment model's estimates of the spawning biomass trajectory, as illustrated in Figure 17.

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 applied, 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 and discard fleets*. The selection curves for the fishing fleets were entirely length-based and all were assumed to be asymptotic in shape. Because there are no length-composition data for the mink-food fleet, it was not possible for the model to estimate selection curve parameters 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 or the parameter values chosen by the 2007 STAT.

There are four surveys in the model: (1) the Triennial Shelf Survey (1980-2001); (2) the AFSC slope survey (1997, 1999-2001); (3) the NWFSC slope survey (1999-2002); and the NWFSC slope-shelf survey (2003-2016). The biomass indices for surveys (1) through (3) had no additional years of data available and were taken directly from the 2007 assessment without modification. The index for the NWFSC slope-shelf survey was updated as described above in the section *Survey biomass indices*. 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 more 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 8 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 in the assessment model were the maximum length parameter and von Bertalanffy growth coefficient, both of which were separate 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.

Recruitment is modeled using a Beverton-Holt stock-recruit curve with steepness fixed at 0.902, as in the 2007 assessment. The sigma-R parameter that controls recruitment variability was fixed at 0.8, as in the 2007 assessment. The update assessment model begins in 1916 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 included added 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 12, along with the 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 18 and the corresponding values of unfished spawning biomass are shown in Figure 19.

We attempted to estimate the *Female_M and Female_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 20) indicated that the data available to the assessment model provide little information regarding the value of steepness.

Likelihood profile on ln(R0)

The likelihood profile over the ln(R0) parameter (Figure 21 and Table 13) indicated tensions among the likelihood components, with the length compositions (and the survey biomass indices, to a lesser extent) tending to force ln(R0) away from lower values and the age-at-length compositions tending to force ln(R0) 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.

Residual plots

The framework underlying the Stock Synthesis approach to stock assessments makes key 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 going into 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 22 and 23 provide comparison plots of the survey biomass index observations with the values predicted by the base model. Figures 24 to 33 are plots of the observed and predicted length-compositions by year and fleet, and include bubble-pots of the residuals for the fits to the length-composition data. Figure 34 shows the observed and predicted compositions aggregated across all the years for which data are available. Figures 35 – 40 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.

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 41) and, 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 and their associated standard errors are given in Table 14. 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 estimated growth curves are shown in Figure 42. 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 a restructuring of the length composition data and other 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 43. The estimated stock-recruitment curve and estimated (recruitment, spawning biomass) points are shown in Figure 44. 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 45 indicates that the base model was fully tuned with regard to the spawner-recruit bias adjustments.

Table 15 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 46 - 49.

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 29.6 thousand mt, the second lowest value in the series. Since 2010 the spawning biomass has been increasing steadily and is estimated to be almost 57 thousand 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. As explained above in the sections *Discard fractions and discard ratios* and *Methods used for estimating discards by the fillet and discard fleets*, 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). 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 discards and catches (landings plus discards). The alternative catch scenarios are compared to the base model catch series in Figure 50. The alternative catch series had only a modest influence on the biomass trajectory compared to the sensitivity to other fixed elements of the model (e.g., natural mortality).

Sensitivity to weighting method

In the base model we used the McAllister-Ianelli method for iteratively tuning the input effective N values that influence how much weight is applied to any composition observation. Because there is concern that this method may give undue weight to compositions at the expense of goodness-of-fit to the survey biomass indices, STATs have been encouraged to use the alternative composition weighting approach developed in Francis (2011). 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. The resulting biomass trajectories, which are shown in Figure 51, were fairly sensitive to the choice of weighting method.

Parameter uncertainty

Table 14 provides the values for the main estimated parameter and their standard errors.

Retrospective analysis,

A five-year retrospective analysis was conducted in which the last year of the data series are 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 52.

Historical analysis

Figure 17, 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%

Harvest projections and decision table

The decision table (Table 16) 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, male M = 0.21), (2) the base case (female M = 0.216, male M = 0.30), and (3) the high state (female M = 0.31, male M = 0.43). 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 0.45 and a category

1 stock designation. 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 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 and much less abundant off northern California and essentially absent farther south. Such regional differences in abundance could lead to localized over-fishing. However, 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 the near or medium term, at least from the perspective of the status of the arrowtooth flounder stock.

*N. Research needs (should be prioritized)

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. *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.
3. *Research to provide information on survey catchability*. The absolute scale of the stock is still quite uncertain. The calculated catachability associated with the NWFSC trawl survey ranges from 0.2 to 0.8 across the three states of nature.
4. *Evaluation of stock boundaries and the feasibility of a bilateral assessment with Canadian scientists*. This could perhaps be accomplished through the Technical Subcommittee (TSC) of the US Canada groundfish working group.
5. *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.

6. *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.
7. *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

Also, numerous R4SS output files were placed in a compressed folder called:
"plots-arrowtooth_2017-BASE

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	

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	4010 South	Arrowtoothflounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 North	Arrowtoothflounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 South	Arrowtoothflounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtoothflounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	3800 South	Arrowtoothflounder, limited entry trawl, 10000 lbs per 2 months
1/1/2007	4010 North	Arrowtoothflounder, limited entry trawl, large and small footrope gear, 100000 lbs per 2 months
1/1/2007	4010 North	Arrowtoothflounder, limited entry trawl, selective flatfish trawl, 90000 lbs per 2 months
1/1/2007	4010 North	Arrowtoothflounder, limited entry trawl, multiple bottom trawl gear, 90000 lbs per 2 months
3/1/2007	3800 South	Oth flatfish including english sole and starry flounder, arrowtooth flounder, and petrale sole, limited entry trawl, 110000 lbs per 2 months no more than 30000 lbs per 2 months may be petrale sole
5/1/2007	3800 South	Oth flatfish including english sole and starry flounder, arrowtooth flounder, and petrale sole, limited entry trawl, 110000 lbs per 2 months no more than 25000 lbs per 2 months may be petrale sole
5/1/2007	3800 South	Arrowtooth flounder, limited entry trawl, arrowtooth included in other flatfish limits
5/1/2007	4010 North	Arrowtooth flounder, limited entry trawl, multiple bottom trawl gear, arrowtooth flounder included in other flatfish limits
5/1/2007	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, selective flatfish trawl, 70000 lbs per 2 months including arrowtooth flounder, no more than 15000 lbs per 2 months may be petrale sole
5/1/2007	4010 North	Arrowtooth flounder, limited entry trawl, selective flatfish trawl, arrowtooth flounder included in other flatfish limits
5/1/2007	4010 North	Arrowtooth flounder, limited entry trawl, large and small footrope gear, arrowtooth flounder included in other flatfish limits

5/1/2007	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 70000 lbs per 2 months including arrowtooth flounder, no more than 15000 lbs per 2 months may be petrale sole
5/1/2007	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 70000 lbs per 2 months including arrowtooth flounder, no more than 15000 lbs per 2 months may be petrale sole
9/1/2007	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 70000 lbs per 2 months including arrowtooth flounder, no more than 15000 lbs per 2 months may be petrale sole
9/1/2007	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 30000 lbs per 2 months including arrowtooth flounder, no more than 8000 lbs per 2 months may be petrale sole
9/1/2007	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, selective flatfish trawl, 70000 lbs per 2 months including arrowtooth, no more than 15000 lbs per 2 months may be petrale sole
9/1/2007	3800 South	Other flatfish including english sole and starry flounder, arrowtooth flounder, and petrale sole, limited entry trawl, 150000 lbs per 2 months no more than 30000 lbs per 2 months may be petrale sole
11/1/2007	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, selective flatfish trawl, 30000 lbs per 2 months including arrowtooth flounder, no more than 8000 lbs per 2 months may be petrale sole
11/1/2007	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, large and small footrope gear, 150000 lbs per 2 months including arrowtooth flounder
11/1/2007	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 30000 lbs per 2 months including arrowtooth flounder, no more than 8000 lbs per 2 months may be petrale sole
1/1/2008	4010 North	Arrowtooth flounder, limited entry trawl, large and small footrope gear, 150000 lbs per 2 months
1/1/2008	4010 North	Arrowtooth flounder, limited entry trawl, selective flatfish trawl, 10000 lbs per 2 months
1/1/2008	4010 North	Arrowtooth flounder, limited entry trawl, multiple bottom trawl gear, 10000 lbs per 2 months
1/1/2008	4010 South	Arrowtooth flounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 North	Arrowtooth flounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 South	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 South	Arrowtooth flounder, limited entry trawl, 10000 lbs per 2 months
3/1/2008	4010 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 30000 lbs per 2 months may be petrale sole
5/1/2008	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, selective flatfish trawl, 50000 lbs per 2 months including arrowtooth flounder, no more than 18000 lbs per 2 months may be petrale sole
5/1/2008	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 50000 lbs per 2 months including arrowtooth flounder, no more than 18000 lbs per 2 months may be petrale sole
5/1/2008	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 50000 lbs per 2 months including arrowtooth flounder, no more than 18000 lbs per 2 months may be petrale sole
7/1/2008	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 80000 lbs per 2 months including arrowtooth flounder, no more than 18000 lbs per 2 months may be petrale sole
7/1/2008	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 80000 lbs per 2 months including arrowtooth flounder, no more than 18000 lbs per 2 months may be petrale sole
7/1/2008	4010 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	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, selective flatfish trawl, 80000 lbs per 2 months including arrowtooth flounder, no more than 16000 lbs per 2 months may be petrale sole
9/1/2008	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 80000 lbs per 2 months including arrowtooth flounder, no more than 16000 lbs per 2 months may be petrale sole
9/1/2008	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 80000 lbs per 2 months including arrowtooth flounder, no more than 16000 lbs per 2 months may be petrale sole
11/1/2008	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 80000 lbs per 2 months including arrowtooth flounder. Other flounder, no more than 10000 lbs per 2 months may be petrale sole
11/1/2008	4010 North	Petrale sole, limited entry trawl, selective flatfish trawl, 80000 lbs per 2 months including arrowtooth flounder, no more than 10000 lbs per 2 months may be petrale sole

11/1/2008	4010 North	Other flatfish including english sole and starry flounder, limited entry trawl, selective flatfish trawl, 80000 lbs per 2 months including arrowtooth flounder, no more than 10000 lbs per 2 months may be petrale sole
11/1/2008	4010 South	Oth flatfish including english sole and starry flounder, arrowtooth flounder, and petrale sole, limited entry trawl, 110000 lbs per 2 months
1/1/2009	4010 South	Arrowtooth flounder, limited entry trawl, 10000 lbs per 2 months
1/1/2009	4010 North	Arrowtooth flounder, limited entry trawl, large and small footrope gear, 150000 lbs per 2 months
1/1/2009	4010 North	Arrowtooth flounder, limited entry trawl, selective flatfish trawl, 90000 lbs per 2 months
1/1/2009	4010 North	Arrowtooth flounder, limited entry trawl, multiple bottom trawl gear, 90000 lbs per 2 months
1/1/2009	4010 North	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 South	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtooth flounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 South	Arrowtooth flounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 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 30000 lbs per 2 months may be petrale sole
10/28/2009	4010 North	Arrowtooth flounder, limited entry trawl, large and small footrope gear, 180000 lbs per 2 months
11/1/2009	4010 South	Other flatfish including english sole and starry flounder, arrowtooth flounder, and petrale sole, limited entry trawl, 110000 lbs per 2 months
1/1/2010	4010 North	Arrowtooth flounder, limited entry trawl, multiple bottom trawl gear, 90000 lbs per 2 months
1/1/2010	4010 South	Arrowtooth flounder, limited entry trawl, 10000 lbs per 2 months
1/1/2010	4010 North	Arrowtooth flounder, limited entry trawl, large and small footrope gear, 150000 lbs per 2 months
1/1/2010	4010 North	Arrowtooth flounder, limited entry trawl, selective flatfish trawl, 90000 lbs per 2 months

1/1/2010	4010 South	Arrowtooth flounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 North	Arrowtooth flounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 South	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 60000 lbs per 2 months including arrowtooth flounder, no more than 6300 lbs per 2 months may be petrale sole
9/1/2010	4010 North	Other flatfish, limited entry trawl, multiple bottom trawl gear, 70000 lbs per 2 months including arrowtooth flounder, no more than 6300 lbs per 2 months may be petrale sole
9/1/2010	4010 North	Arrowtooth flounder, limited entry trawl, multiple bottom trawl gear, 100000 lbs per 2 months
9/1/2010	4010 South	Arrowtooth flounder, limited entry trawl, 12000 lbs per 2 months
9/1/2010	4010 North	Arrowtooth flounder, limited entry trawl, selective flatfish trawl, 100000 lbs per 2 months
9/1/2010	4010 North	Arrowtooth flounder, limited entry trawl, large and small footrope gear, 180000 lbs per 2 months
1/1/2011	All	West Coast Groundfish Trawl IFQ Program implemented
1/1/2011	4010 North	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 South	Arrowtooth flounder,limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtooth flounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 South	Arrowtooth flounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 South	Arrowtooth flounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 South	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 North	Arrowtooth flounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 North	Arrowtooth flounder, open access gears, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 North	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 South	Arrowtooth flounder, limited entry fixed gear, 5000 lbs per month, south of 4200 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	4010 South	Arrowtooth flounder, open access gear, 3000 lbs per month, no more than 300 lbs of which may be species other than pacific sanddabs, south of 4200 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	4010 North	Non-trawl, , limited entry, arrowtooth flounder, 5000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2014	4010 South	Non-trawl, limited entry, arrowtooth flounder, 5000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2014	4010 North	Non-trawl, open access, arrowtooth flounder, 3000 lbs per month, no more than 300 lbs may be species other than pacific sanddabs
1/1/2014	4010 South	Non-trawl, open access, arrowtooth flounder, 3000 lbs per month of which no more than 300 lbs may be species other than pacific sanddabs
1/1/2015	4010 North	Non-trawl, limited entry, arrowtooth flounder, 5000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2015	4010 South	Non-trawl, limited entry, arrowtooth flounder, 5000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2015	4010 North	Non-trawl, open access, arrowtooth flounder, 3000 lbs per month, no more than 300 lbs may be species other than pacific sanddabs

1/1/2015	4010 South	Non-trawl, open access, arrowtooth flounder, 3000 lbs per month of which no more than 300 lbs may be species other than pacific sanddabs
1/1/2016	4010 North	Non-trawl, limited entry, arrowtooth flounder, 5000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2016	4010 South	Non-trawl, limited entry, arrowtooth flounder, 5000 lbs per month, with a gear restriction allowing fishing inside RCA
1/1/2016	4010 North	Non-trawl, open access, arrowtooth flounder, 3000 lbs per month, no more than 300 lbs may be species other than pacific sanddabs
1/1/2016	4010 South	Non-trawl, open access, arrowtooth flounder, 3000 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	-	-	3564	4830
1995	5800	-	-	2546	3807
1996	5800	-	-	2407	3769
1997	5800	-	-	2571	3850
1998	5800	-	-	3481	4571
1999	5800	-	-	5802	6989
2000	5800	-	-	3597	4910
2001	5800	-	-	2705	3849
2002	5800	-	-	3086	4256
2003	5800	-	-	3006	3640
2004	5800	-	5800	2597	3447
2005	5800	-	5800	2456	6564
2006	5800	-	5800	2085	3653
2007	5800	-	5800	2473	4716
2008	5800	-	5800	2804	4365
2009	11267	-	11267	4277	7936
2010	10112	-	10112	3620	4513
2011	18211	-	15174	2482	3059
2012	14460	12049	12049	2452	2893
2013	7391	6157	6157	2335	2901
2014	6912	5758	5758	1639	2197
2015	6599	5497	5497	1609	2038
2016	6396	5328	3241	1341	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 assessement 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.*

	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. 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 7. 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 8. 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 9. 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	N Hauls	N +Hauls	Biomass-mt	N Fish-1000s	N Hauls	N +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

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 10. Stepwise construction of a bridge from the 2007 assessment model to the 2017 update model.

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 FRAM 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 FRAM slope/shelf length-comp data (thru 2006).	59178.3	-26.3%	0.2%	35425.7	-41.6%	-4.8%
K	Updated the FRAM slope/shelf age@L comps (thru 2006).	59350.1	-26.1%	0.3%	35844.5	-40.9%	1.2%
L	Updated the FRAM 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	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 11. Stepwise construction of a bridge from the 2007 assessment model to the 2017 update model.

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

Step	Description	SB[0]	%change from S2.0	Step %change	SB[2006]	%change from S2.0	Step %change
	Start from the 2007 assessment model (SS version 2.0g)	80313.5			60633.4		
P	Tuned input effective Ns for length-comps (Flts 2,3,6) and SR bias adjustments	71608.4	-10.8%		66006.5	8.9%	
Q	Add new data for 2007 thru 2016	59030.4	-26.5%	-17.6%	72355.3	19.3%	9.6%

		SB[0]	%change from S2.0	Step %change	SB[2016]	%change from Q	Step %change
Q	Add new data for 2007 thru 2016	59030.4	-26.5%	-17.6%	72355.3		
R	Tune input effective Ns for length-comps (Flts 2,3,6) and SR bias adjustments	50151.9	-37.6%	-15.0%	77778.8	7.5%	7.5%
S	Fixed bad fleet ID for FRAM slope/shelf age-at-length comps; retune the leng-comps	51479.4	-35.9%	2.6%	77427.9	7.0%	-0.5%
T	Include extra_se in FRAM slope/shelf survey and tune its comp-data	44986.0	-44.0%	-12.6%	34500.9	-52.3%	-55.4%
U	Extra_SE 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 12. Base model parameters and their constraints.

Parameter description	Est / Fixed	Low Bnd	High Bnd
Natural mortality, females	Fixed	0.01	0.8
Length at age-1, females	Fixed	5	25
Length at age-30, females	Est	40	90
VB growth coefficient, females	Est	0.05	0.25
CV length at age-1, females	Fixed	0.05	0.25
CV length at age-30, females	Fixed	0.05	0.25
Weight-length alpha, females	Fixed	0	0.5
Weight-length beta, females	Fixed	0	5
Length at 50% maturity, females	Fixed	0	50
Maturity-length slope coefficient, females	Fixed	-1	1
Eggs/kg intercept, females	Fixed	0	1
Eggs/kg slope, females	Fixed	0	1
Natural mortality, males	Fixed	0.01	0.8
Length at age-1, males	Fixed	5	25
Length at age-30, males	Est	30	70
VB growth coefficient, males	Est	0.05	0.5
CV length at age-1, males	Fixed	0.05	0.25
CV length at age-30, males	Fixed	0.05	0.25
Weight-length alpha, males	Fixed	0	0.5
Weight-length beta, males	Fixed	0	5
Fraction female at birth	Fixed	0.000001	0.999999
Spawner-recruit parameters			
loge(R0)	Est	5	25
steepness	Fixed	0.2	1
sigma R	Fixed	0	2
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	15	46
Width of top, Mink- food fleet	Fixed	-6	6

Parameter description	Est / Fixed	Low Bnd	High Bnd
Ascending width, Mink-food fleet	Fixed	-1	10
Descending width, Mink-food fleet	Fixed	-5	9
Final selection, Mink-food fleet	Fixed	-10	10
Inital selection, Mink-food fleet	Fixed	0	50
Length at peak selection, Fillet fleet	Fixed	15	79
Width of top, Fillet fleet	Fixed	-6	6
Ascending width, Fillet fleet	Est	-1	10
Descending width, Fillet fleet	Fixed	-5	9
Final selection, Fillet fleet	Fixed	-10	10
Inital selection, Fillet fleet	Fixed	0	50
Length at male dogleg, Fillet fleet	Fixed	15	79
ln(Rel. selection) at Lmin, Fillet fleet	Fixed	-3	0
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	-6	4
Ascending width, Discard fleet	Est	-1	9
Descending width, Discard fleet	Fixed	-1	9
Final selection, Discard fleet	Fixed	-5	9
Inital selection, Discard fleet	Fixed	-5	9
Length at peak selection, NWFSC slope-shelf survey	Est	15	79
Width of top, NWFSC slope-shelf survey	Fixed	-6	6
Ascending width, NWFSC slope-shelf survey	Est	-1	10
Descending width, NWFSC slope-shelf survey	Fixed	-5	9
Final selection, NWFSC slope-shelf survey	Fixed	-10	10
Inital selection, NWFSC slope-shelf survey	Fixed	0	50
Length at male dogleg, NWFSC shelf-slope survey	Fixed	15	79
ln(Rel. selection) at Lmin, NWFSC shelf-slope survey	Fixed	-3	0
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	-6	4
Ascending width, Triennial survey	Est	-1	9
Descending width, Triennial survey	Fixed	-1	9
Final selection, Triennial survey	Fixed	-5	9
Inital selection, Triennial survey	Fixed	-5	9
Length at male dogleg, Triennial survey	Fixed	15	79
ln(Rel. selection) at Lmin, Triennial survey	Fixed	-3	0
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	-6	4

Parameter description	Est / Fixed	Low Bnd	High Bnd
Ascending width, AFSC slope survey	Est	-1	9
Descending width, AFSC slope survey	Fixed	-1	9
Final selection, AFSC slope survey	Fixed	-5	9
Inital selection, AFSC slope survey	Fixed	-5	9
Length at male dogleg, AFSC slope survey	Fixed	15	79
ln(Rel. selection) at Lmin, AFSC slope survey	Fixed	-3	0
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 13. Likelihood profile over parameter ln(R0).

ln(R0) =	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.FRAM_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	122983.0

Table 14. Likelihood components for the base model and estimated parameters and their standard errors.

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
Management 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 15. 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%

Year	Total biomass (mt)	Age-3+ biomass (mt)	Spawning biomass (mt)	Age-0 Recruits (1000s)	Depletion % of Bzero	F rate
1953	84,993	81,789	59,198	50,343	90.4%	1.84%
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%

Year	Total biomass (mt)	Age-3+ biomass (mt)	Spawning biomass (mt)	Age-0 Recruits (1000s)	Depletion % of Bzero	F rate
1992	109,145	103,881	74,146	19,769	113.3%	5.50%
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 16. 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=0.36 for a category 1 designation, and the ACLs are taken in 2017 (13,804mt) and 2018 (13,743mt).

			State of nature					
			Low $M_{female} = 0.15$ $M_{male} = 0.21$		Base case $M_{female} = 0.216$ $M_{male} = 0.30$		High $M_{female} = 0.31$ $M_{male} = 0.43$	
Relative probability of ln(SB_2013)			0.25		0.5		0.25	
Management decision	Year	Catch (mt)	Spawning biomass (mt)	Depletion	Spawning biomass (mt)	Depletion	Spawning biomass (mt)	Depletion
ABC catches from “Low” state of nature	2019	8,103	35,586	0.68	52,226	0.80	124,842	0.68
	2020	7,728	32,491	0.62	48,580	0.74	118,797	0.64
	2021	7,033	28,859	0.55	44,745	0.68	117,510	0.64
	2022	6,263	25,559	0.49	41,676	0.64	120,398	0.65
	2023	5,587	22,884	0.44	39,491	0.60	125,275	0.68
	2024	5,061	20,852	0.40	38,087	0.58	130,821	0.71
	2025	4,673	19,368	0.37	37,291	0.57	136,330	0.74
	2026	4,395	18,303	0.35	36,933	0.56	141,443	0.77
	2027	4,197	17,543	0.33	36,874	0.56	146,002	0.79
	2028	4,054	16,997	0.32	37,008	0.57	149,964	0.81
Base Case ABC catches	2019	17,873	35,586	0.68	52,226	0.80	124,842	0.68
	2020	14,632	25,124	0.48	40,700	0.62	111,344	0.60
	2021	11,697	16,550	0.31	31,930	0.49	105,796	0.57
	2022	9,575	10,459	0.20	26,382	0.40	106,846	0.58
	2023	8,305	6,455	0.12	23,277	0.36	111,299	0.60
	2024	7,630	3,861	0.07	21,666	0.33	117,034	0.63
	2025	7,281	2,122*	0.04*	20,835	0.32	122,864	0.67
	2026	7,090	0	0	20,366	0.31	128,226	0.70
	2027	6,969	0	0	20,053	0.31	132,924	0.72
	2028	6,880	0	0	19,813	0.30	136,946	0.74
ABC catches from “High” state of nature	2019	65,934	35,586	0.68	52,226	0.80	124,842	0.68
	2020	41,117	0	0	3,194	0.05	73,971	0.40
	2021	29,796	0	0	0	0	54,540	0.30
	2022	26,736	0	0	0	0	51,249	0.28
	2023	27,127	0	0	0	0	52,964	0.29
	2024	27,973	0	0	0	0	54,686	0.30
	2025	28,342	0	0	0	0	55,210	0.30
	2026	28,279	0	0	0	0	54,869	0.30
	2027	28,046	0	0	0	0	54,300	0.29
	2028	27,842	0	0	0	0	53,894	0.29

Figures

Figure 1. Map of the US West Coast.

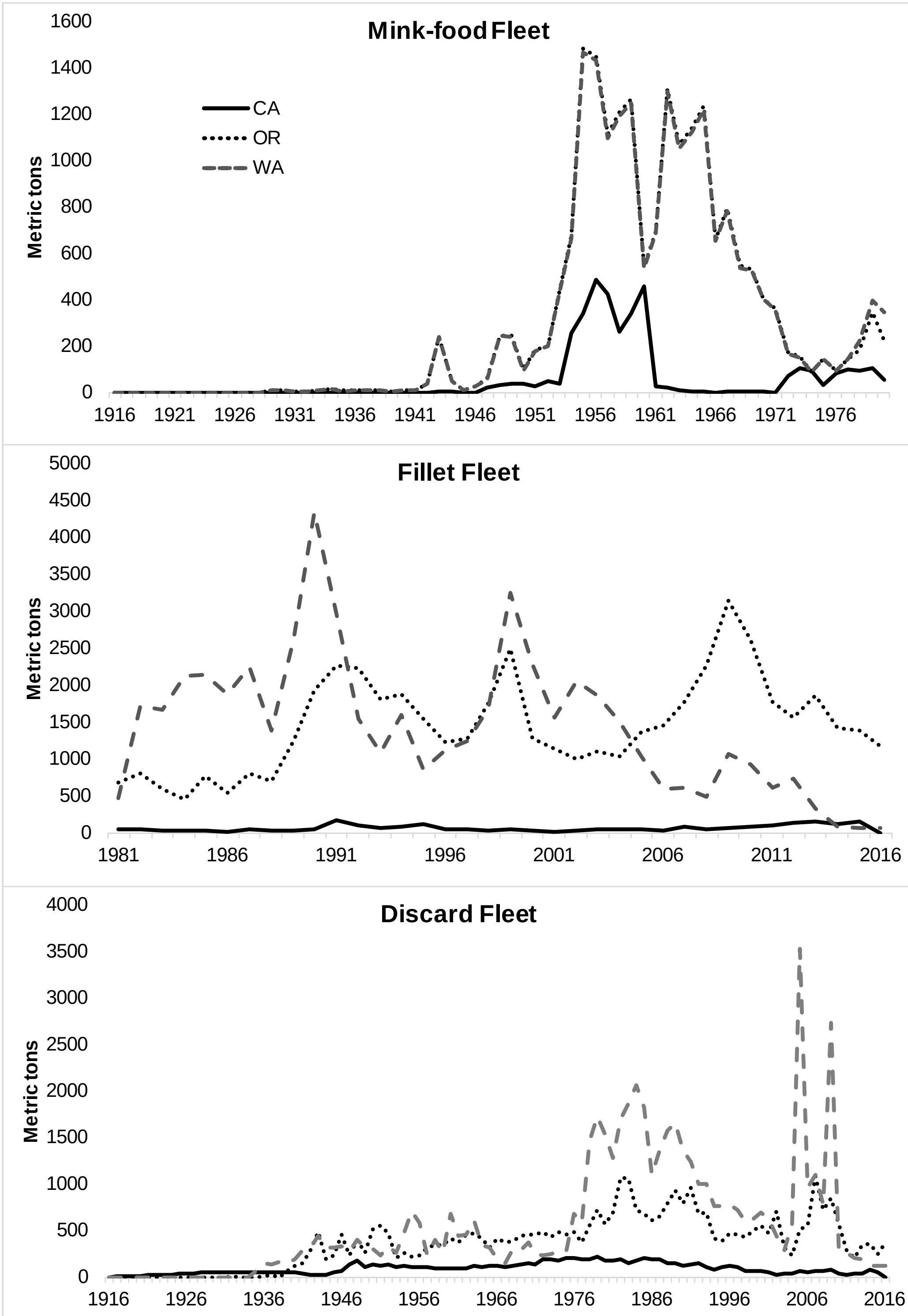


Figure 2. Reconstructed catch series of arrowtooth flounder by state for the A. mink-food, B. fillet, and C. discard fleets.

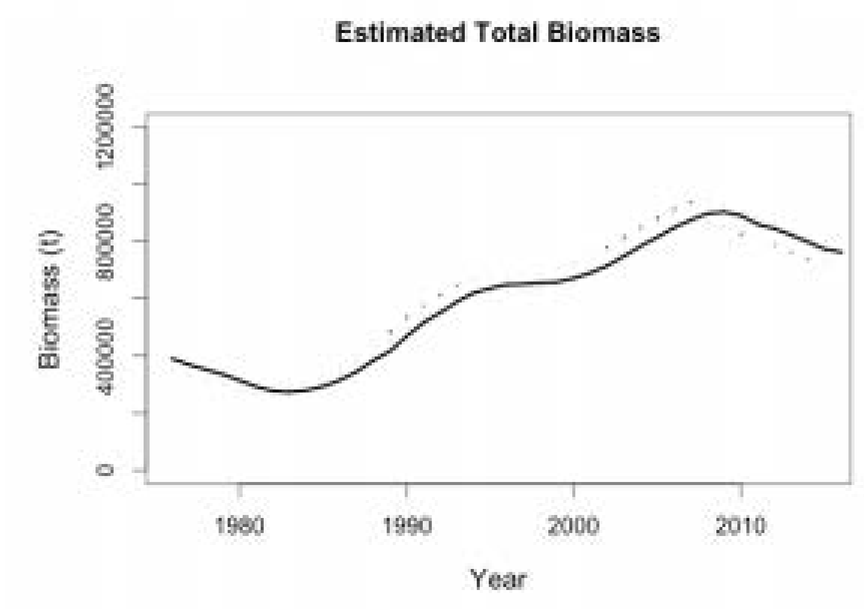


Figure 3. Estimated biomass trends for arrowtooth flounder in the Bering Sea, from Spies, et al. (2016).

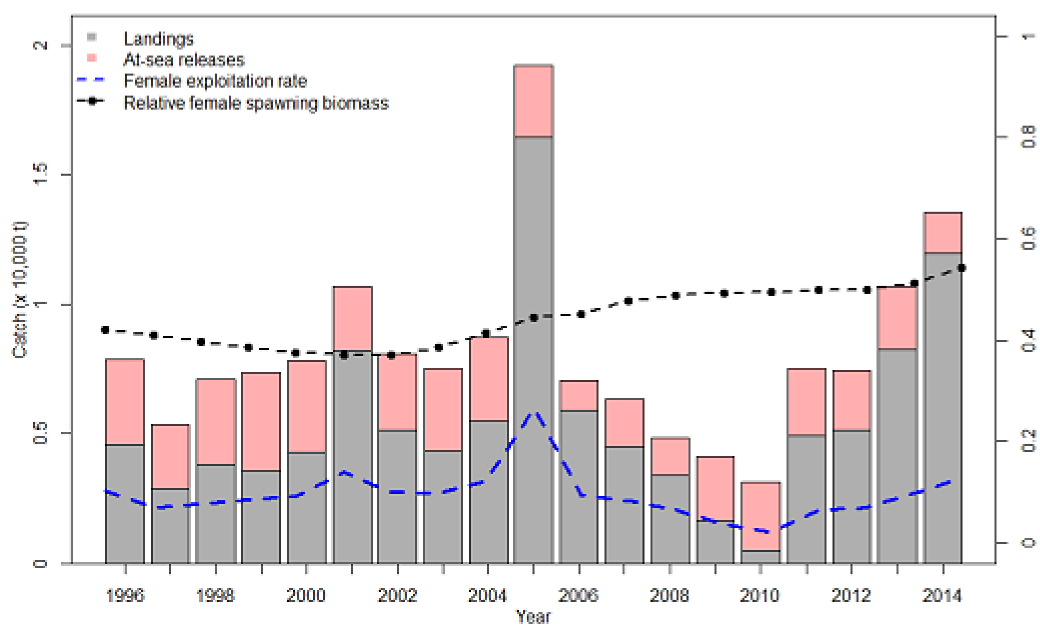


Figure 4. Estimated catches and biomass trends for arrowtooth flounder off British Columbia, from DFO (2015).

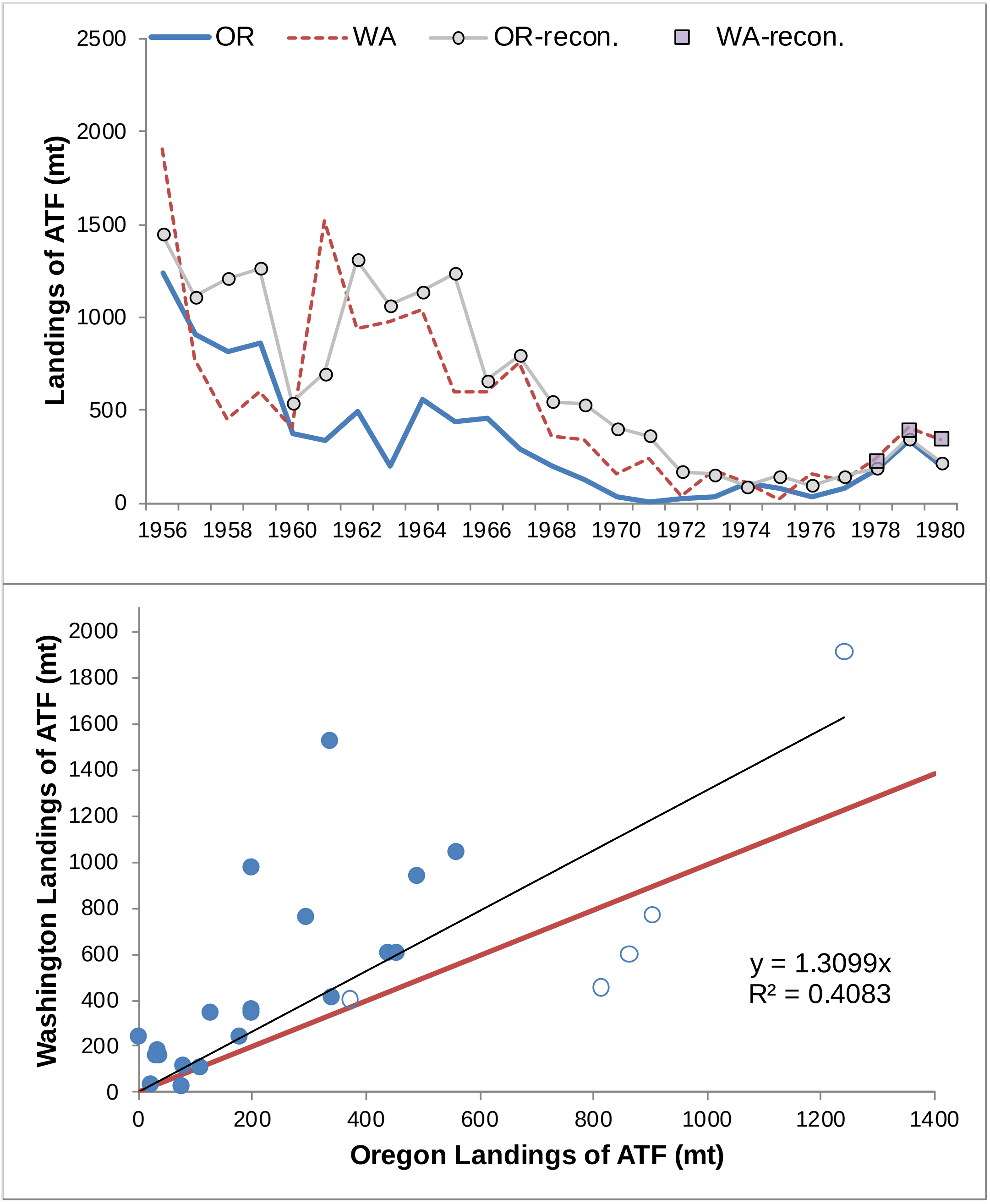


Figure 5. Washington versus Oregon historical landings of arrowtooth flounder (ATF) as reported in the 2007 stock assessment. The points shown as open circles in the lower panel (for the years 1956-1960) were used to derive the WA:OR ratio (0.988, shown as the thicker line) that was applied to the reconstructed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

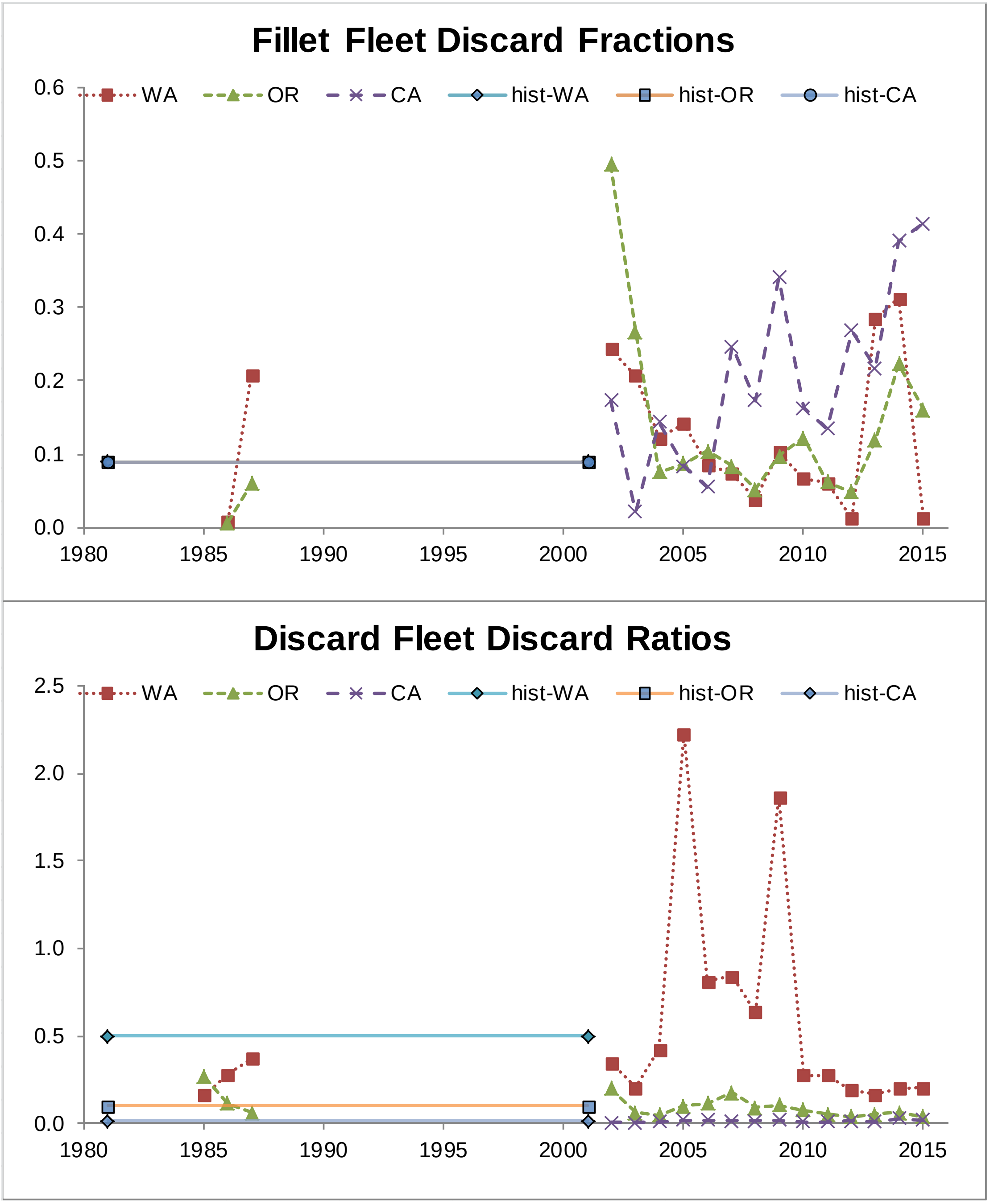


Figure 6. Estimated arrowtooth flounder discard fractions and discard ratios. Details are provided in the section *Discard fractions and discard ratios.*

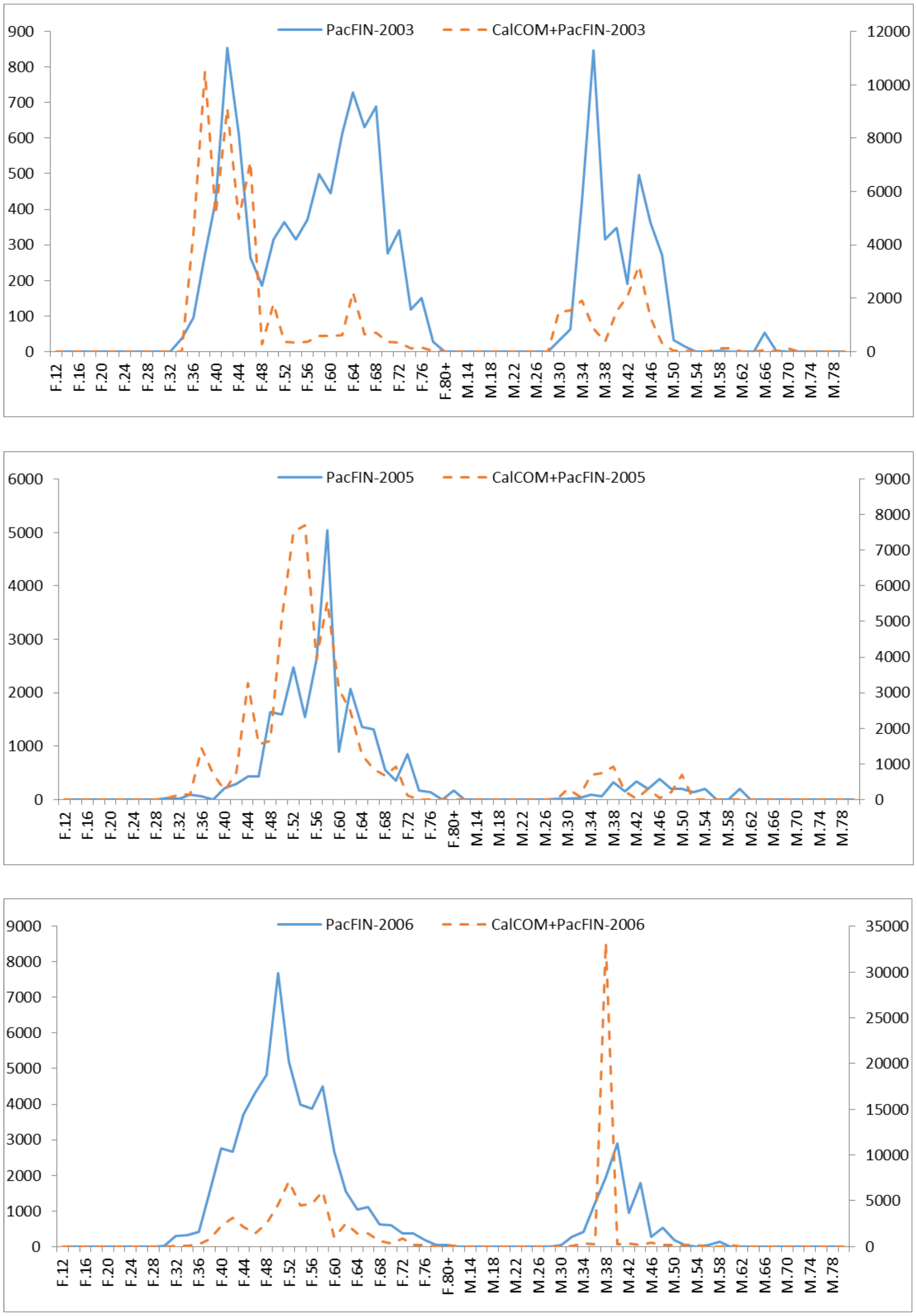


Figure 7. Example comparisons of length-compositions based exclusively on the PacFIN Utilities software expansion of coastwide biological data from the PacFIN BDS versus compositions based on PacFIN Utilities software expansion of OR & WA biological data from the PacFIN BDS plus a separate expansion 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.

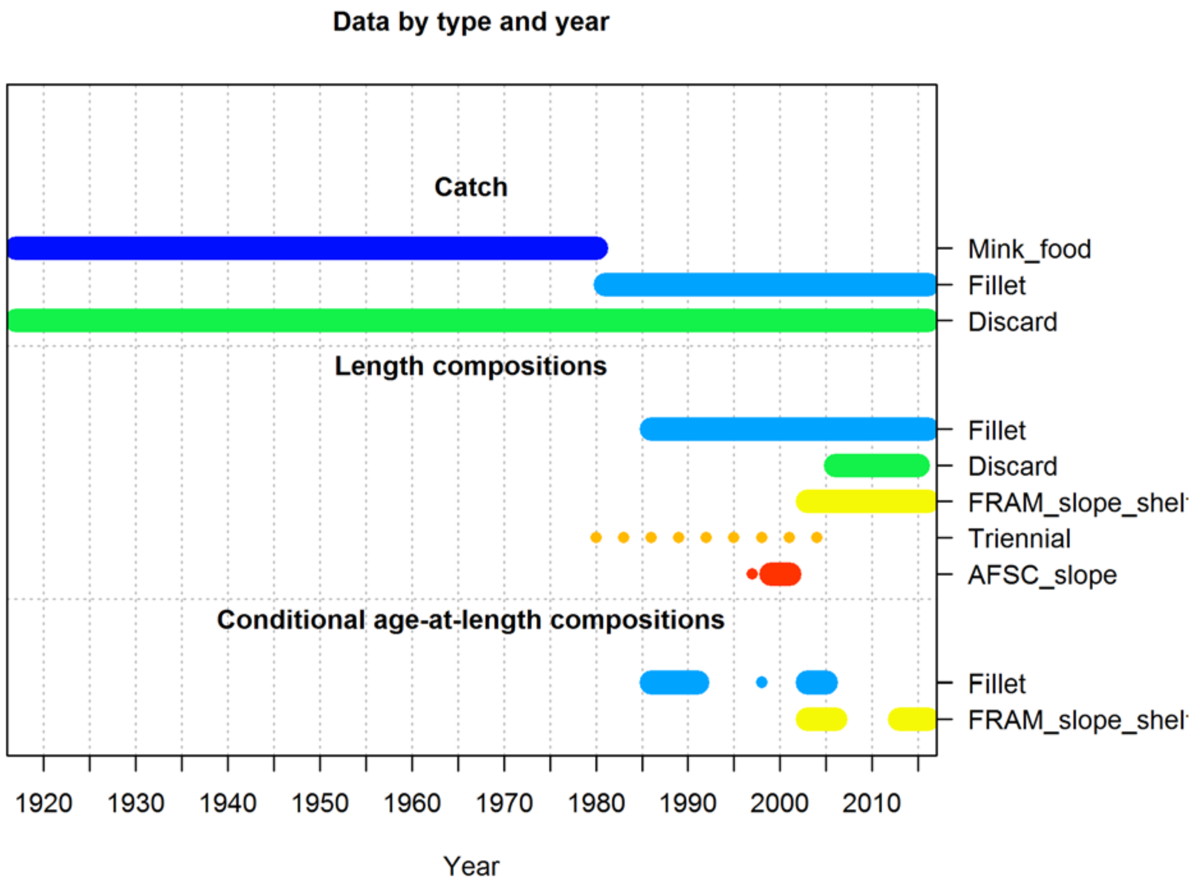


Figure 8. Diagram of the data sources used in the assessment model and their temporal coverages.

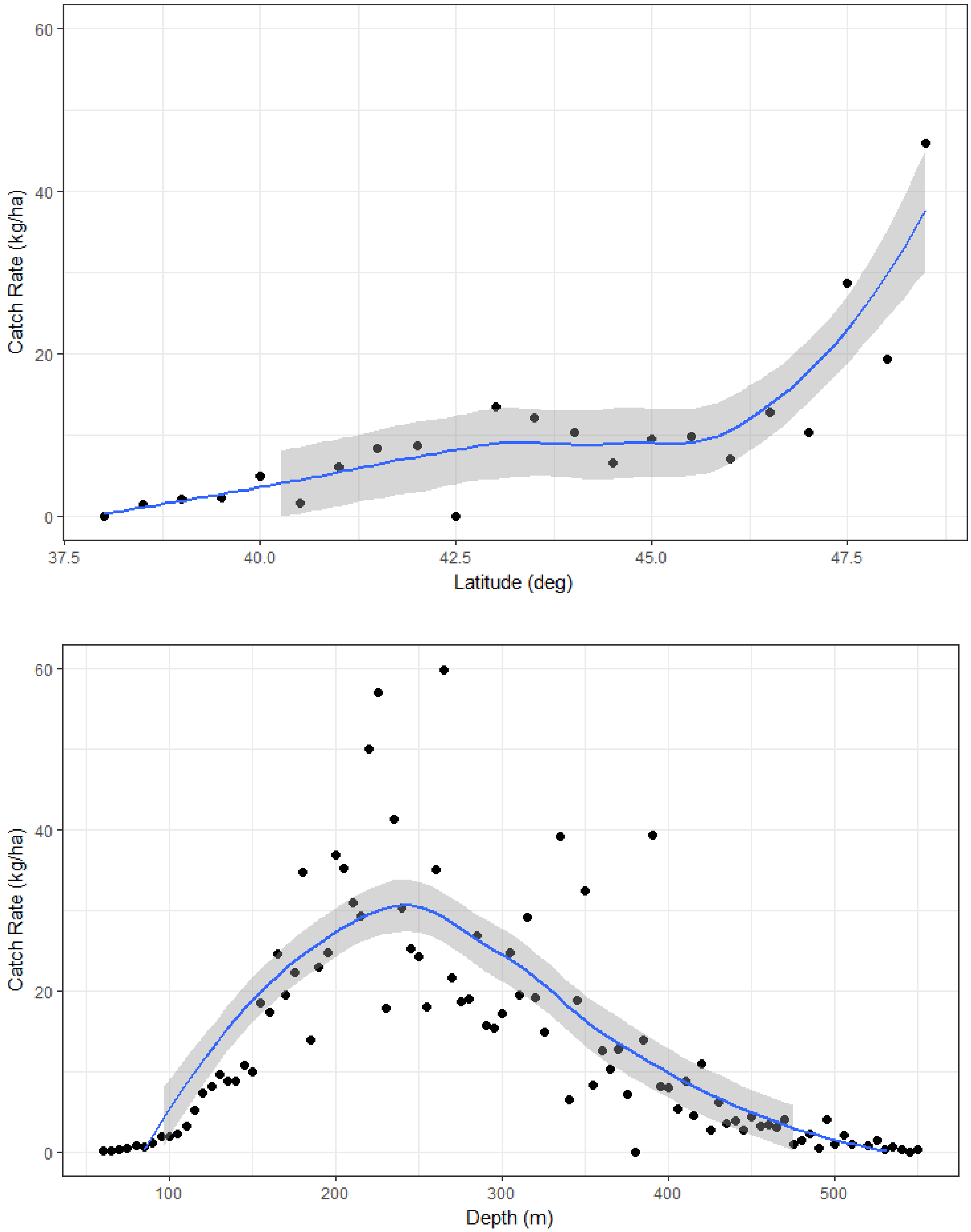


Figure 9. Catch densities by latitude (upper panel) and depth (lower panel) for the NWFSC slope-shelf survey, 2003-2016.

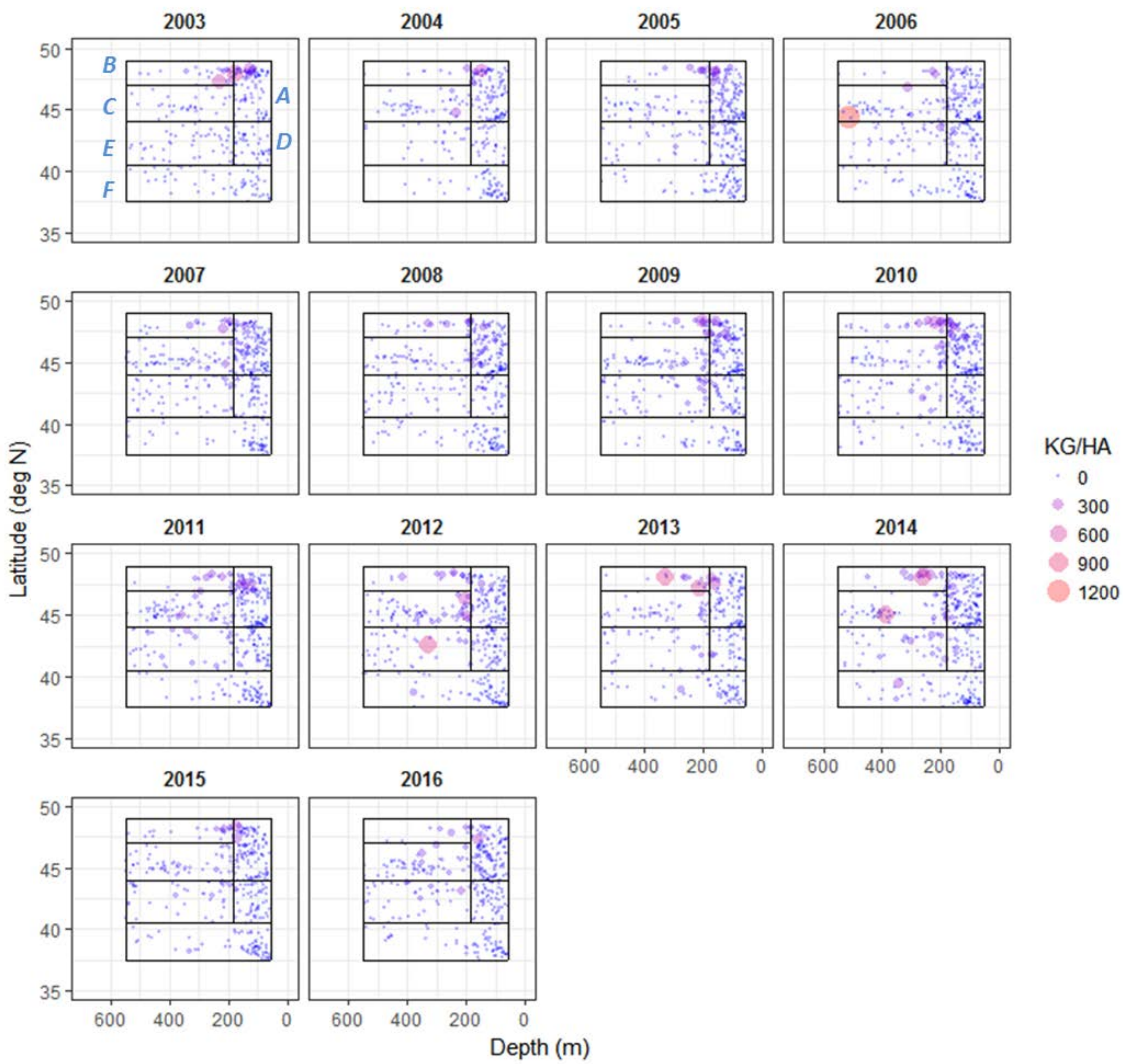


Figure 10. Stratum boundaries for the NWFSC slope-shelf survey as applied in the current assessment. The dots indicate the haul locations in terms of their latitude and depth, with the coloration and magnitude of the dots indicating the biomass density for each haul. The stratum labels (A-F), which are used elsewhere in this document, are shown in the upper left panel.

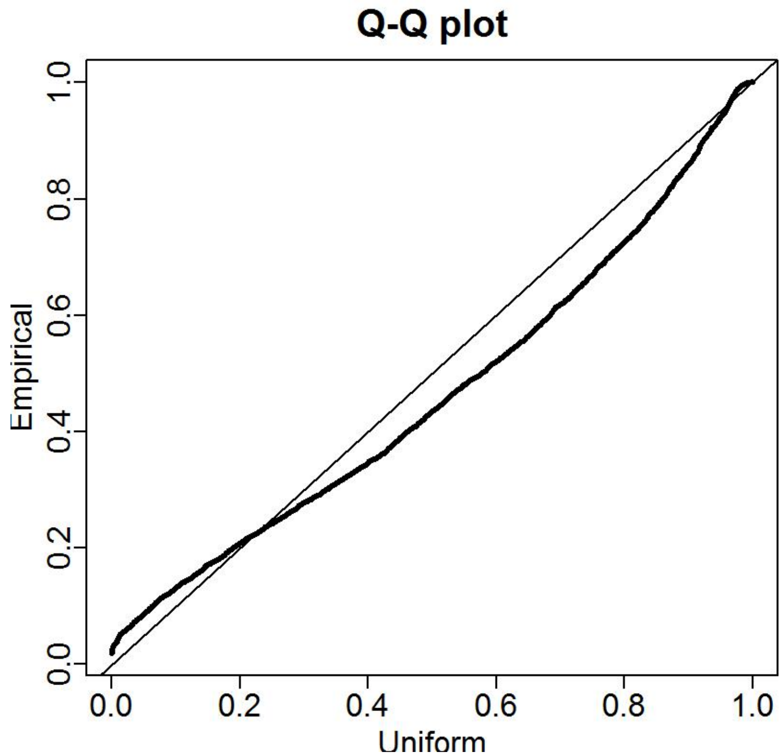


Figure 11. The Q-Q diagnostic plot obtained from application of the VAST model to the NWFSC slope-shelf data for 2003-2016.

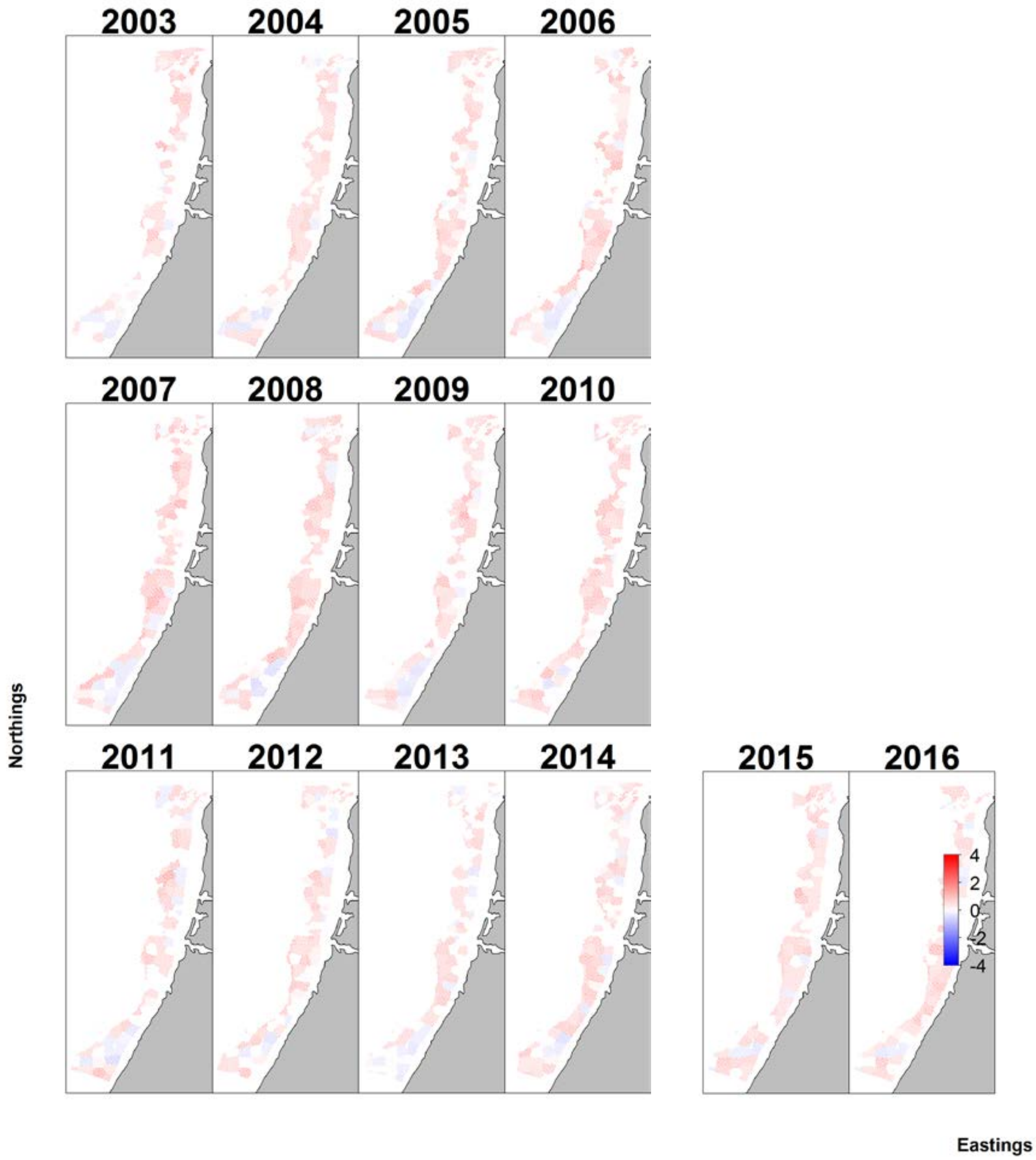


Figure 12. Maps of the Pearson residuals from the application of the VAST model to the NWFSC slope-shelf data for 2003-2016.

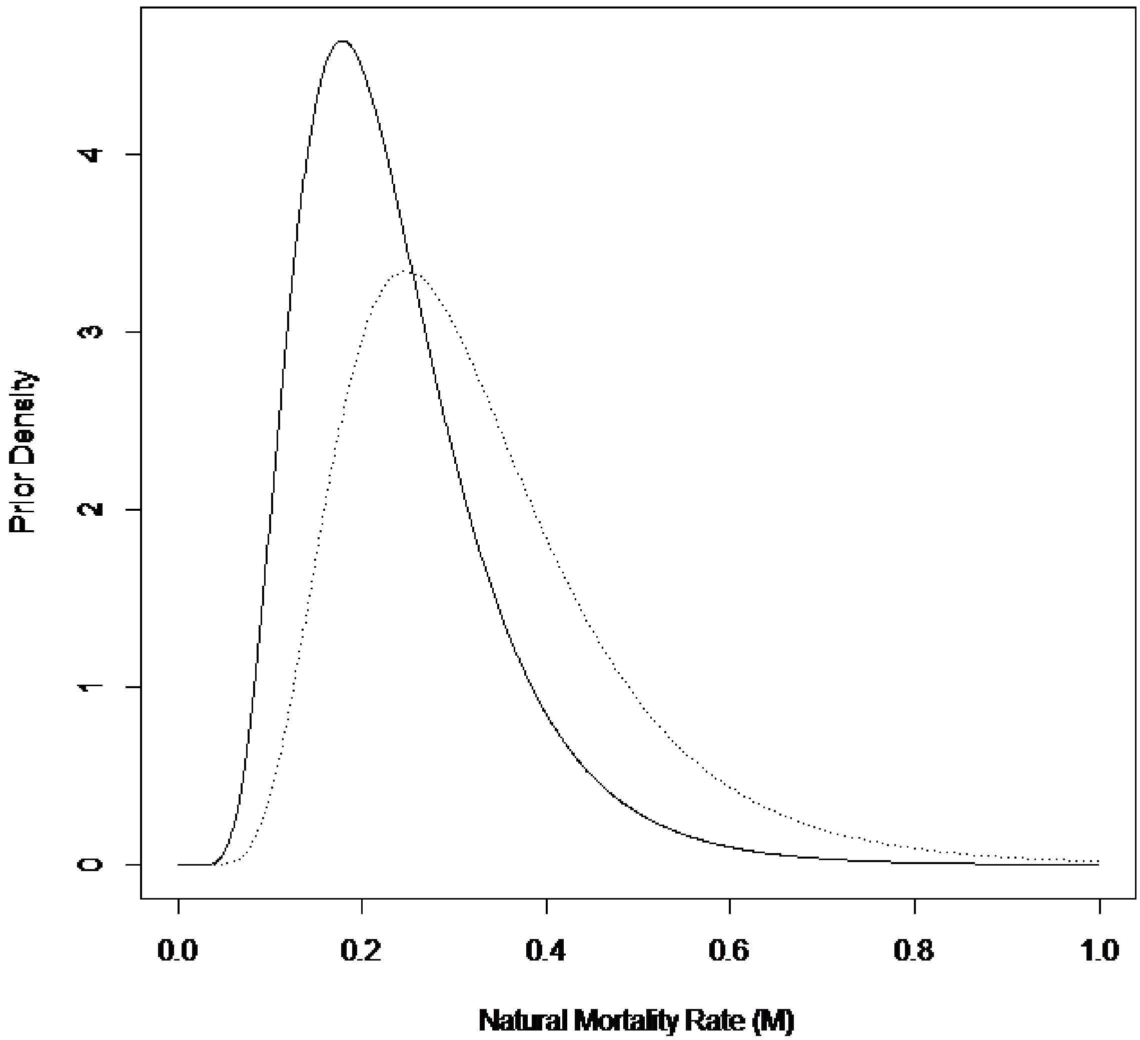
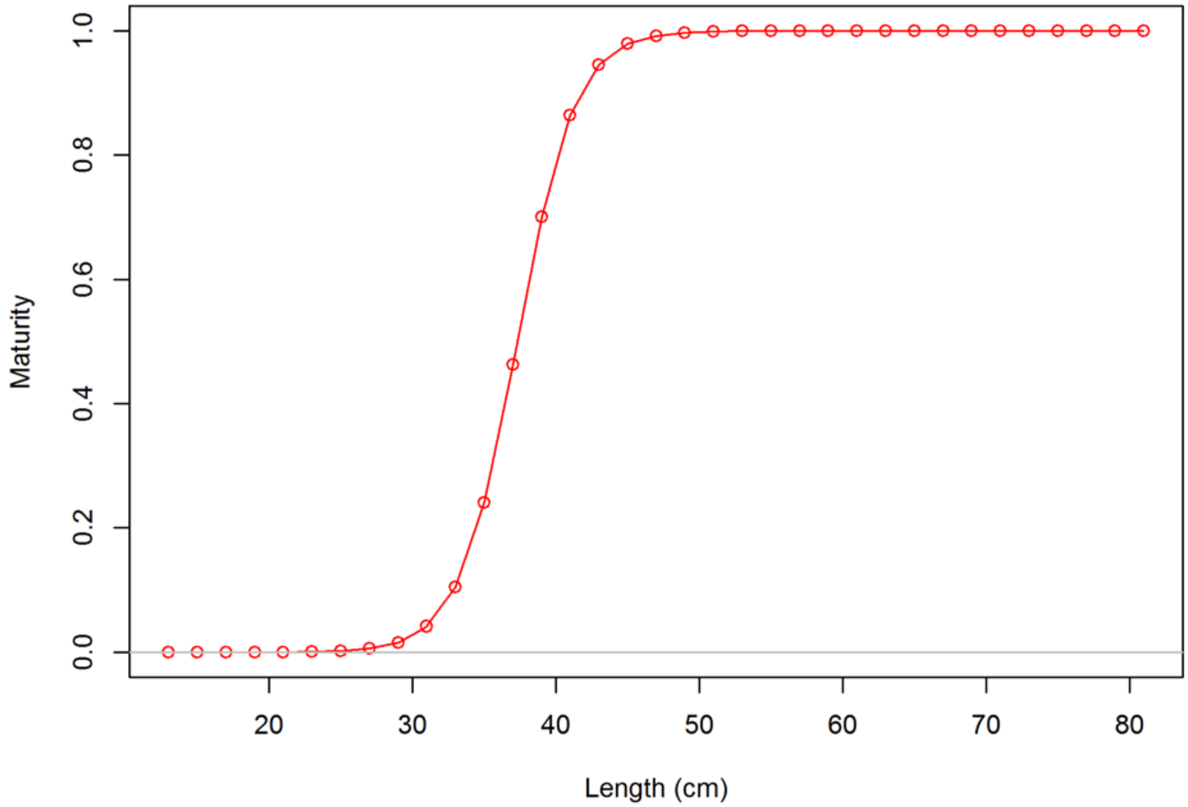


Figure 13. Prior distributions for natural mortality (*M*) for female and male arrowtooth flounder based on the prior developed by Owen Hamel (NMFS, NFWSC) and observed maximum ages of arrowtooth flounder (25 years for females; 18 for males).

Figure 14. 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.

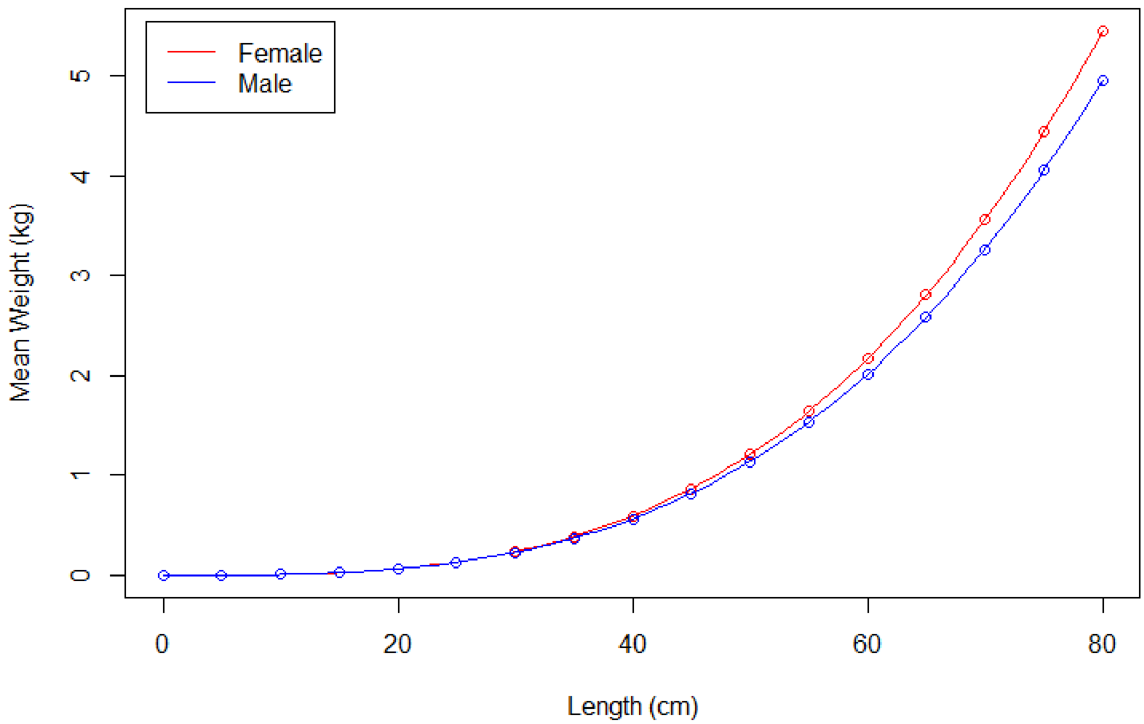


Figure 15. The revised length-weight relationship for female and male arrowtooth flounder that is used in this update assessment. The curve was derived from data collected during the NWFSC slope-shelf surveys during 2003-2015.

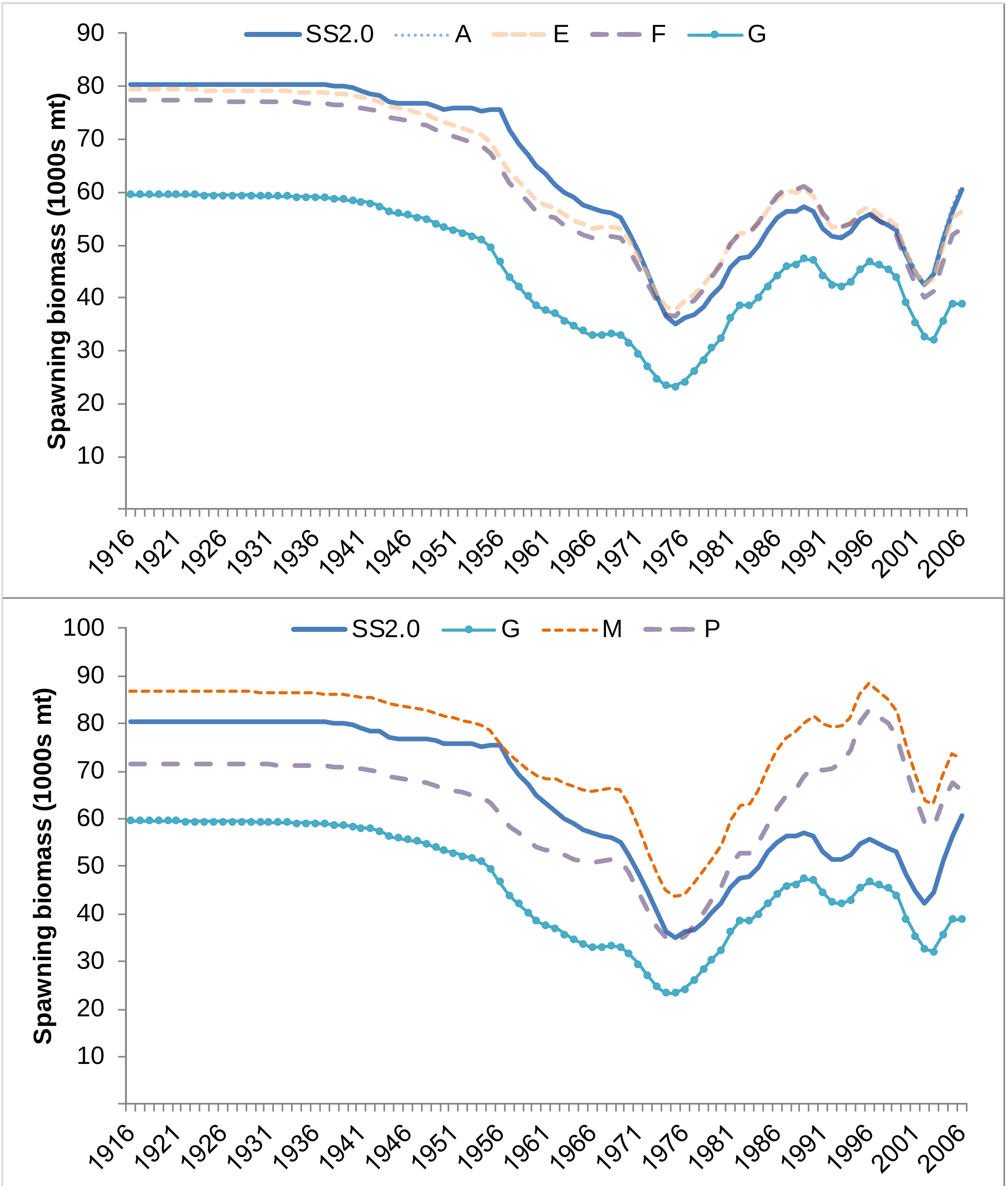


Figure 16. Changing estimates of spawning biomass during the stepwise process of bridging from the 2007 assessment base model to the 2017 update base model. Part 1: Updating the data through 2006.

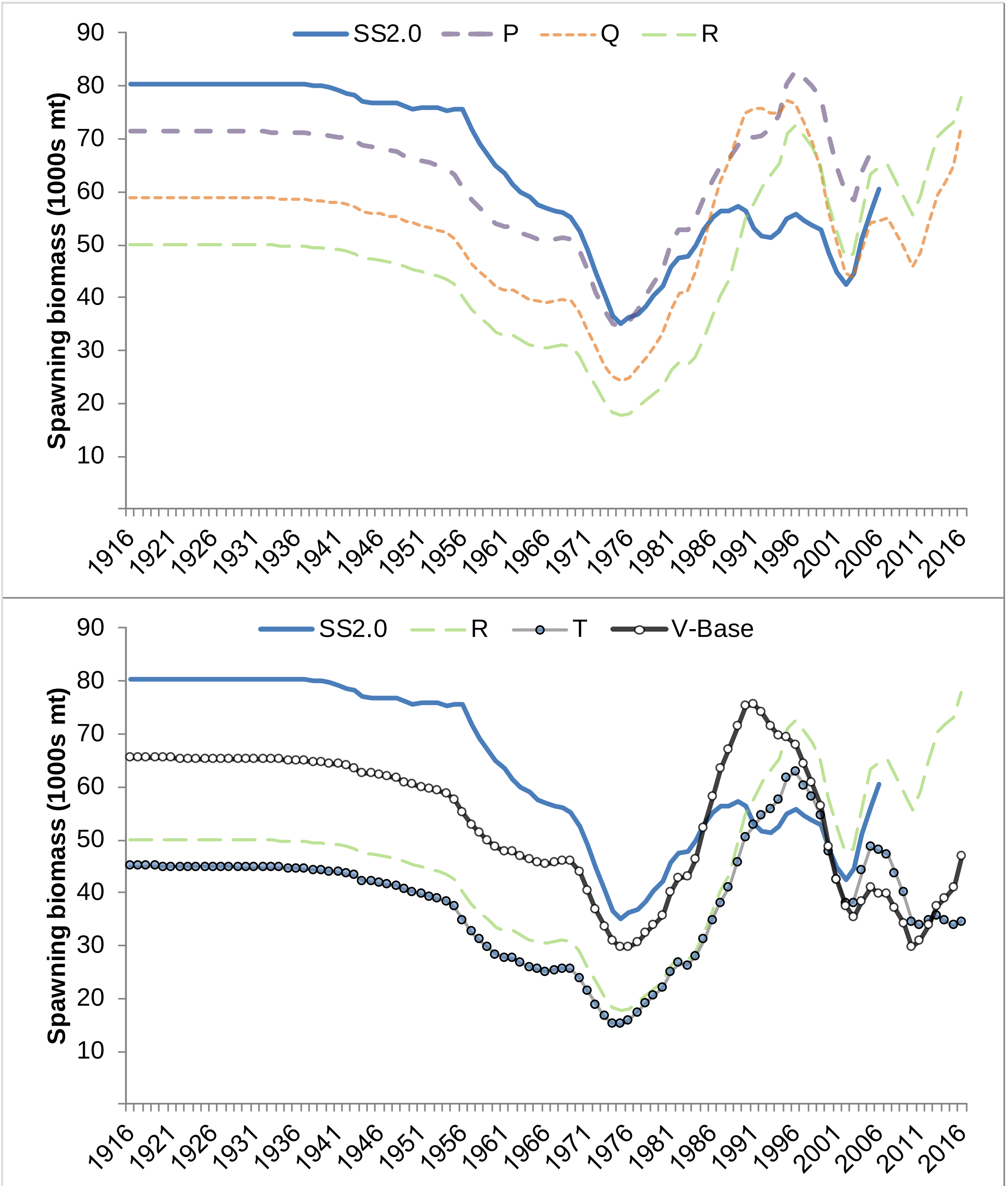


Figure 17. Changing estimates of spawning biomass during the stepwise process of bridging from the 2007 assessment base model to the 2017 update base model. Part 2: Adding data through 2016 and model tuning.

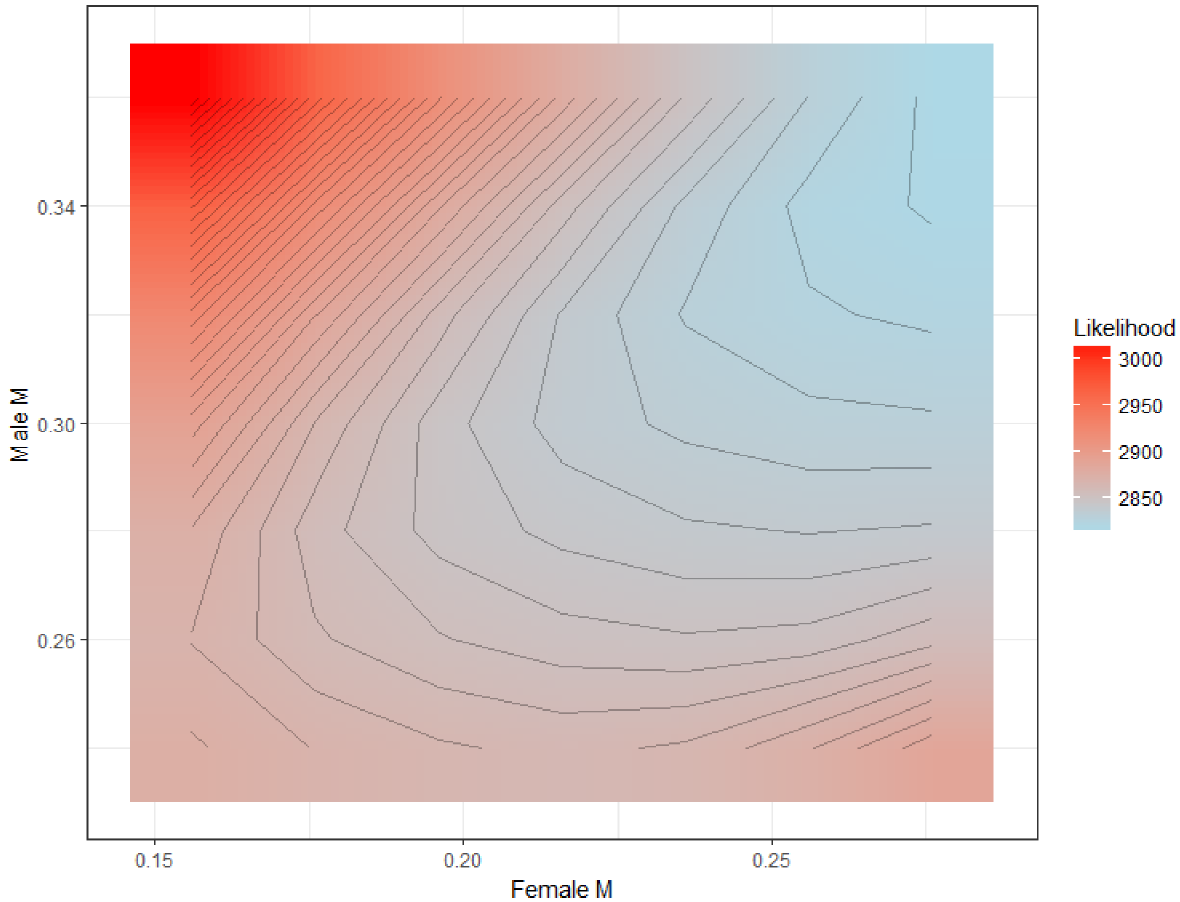


Figure 18. Likelihood surface plot as a function of the *Female_M* and *Male_M* parameters. The values in the base model were 0.216 yr^{-1} for *Female_M* and 0.300 yr^{-1} for *Male_M*.

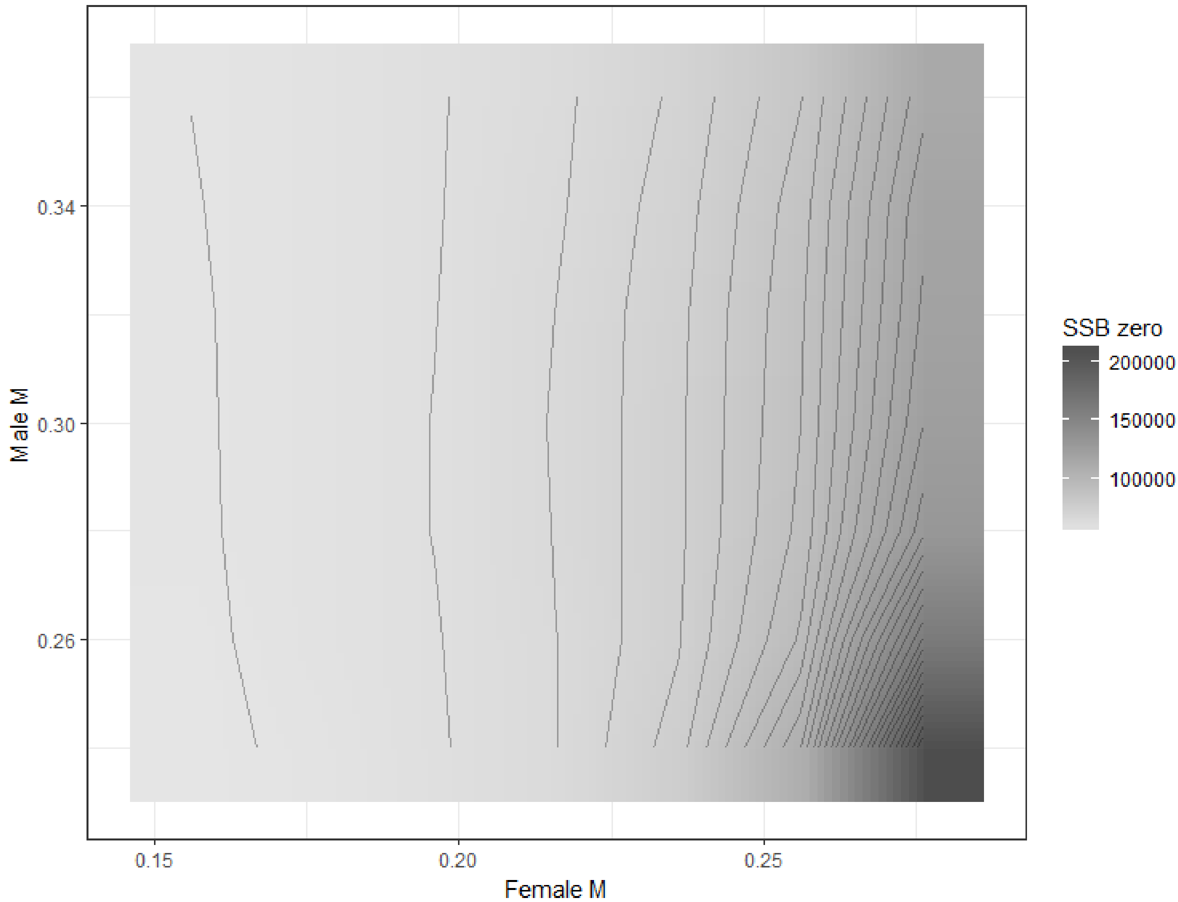


Figure 19. Estimates of unfished spawning biomass corresponding to the –ln(likelihood) surface shown in Figure 18.

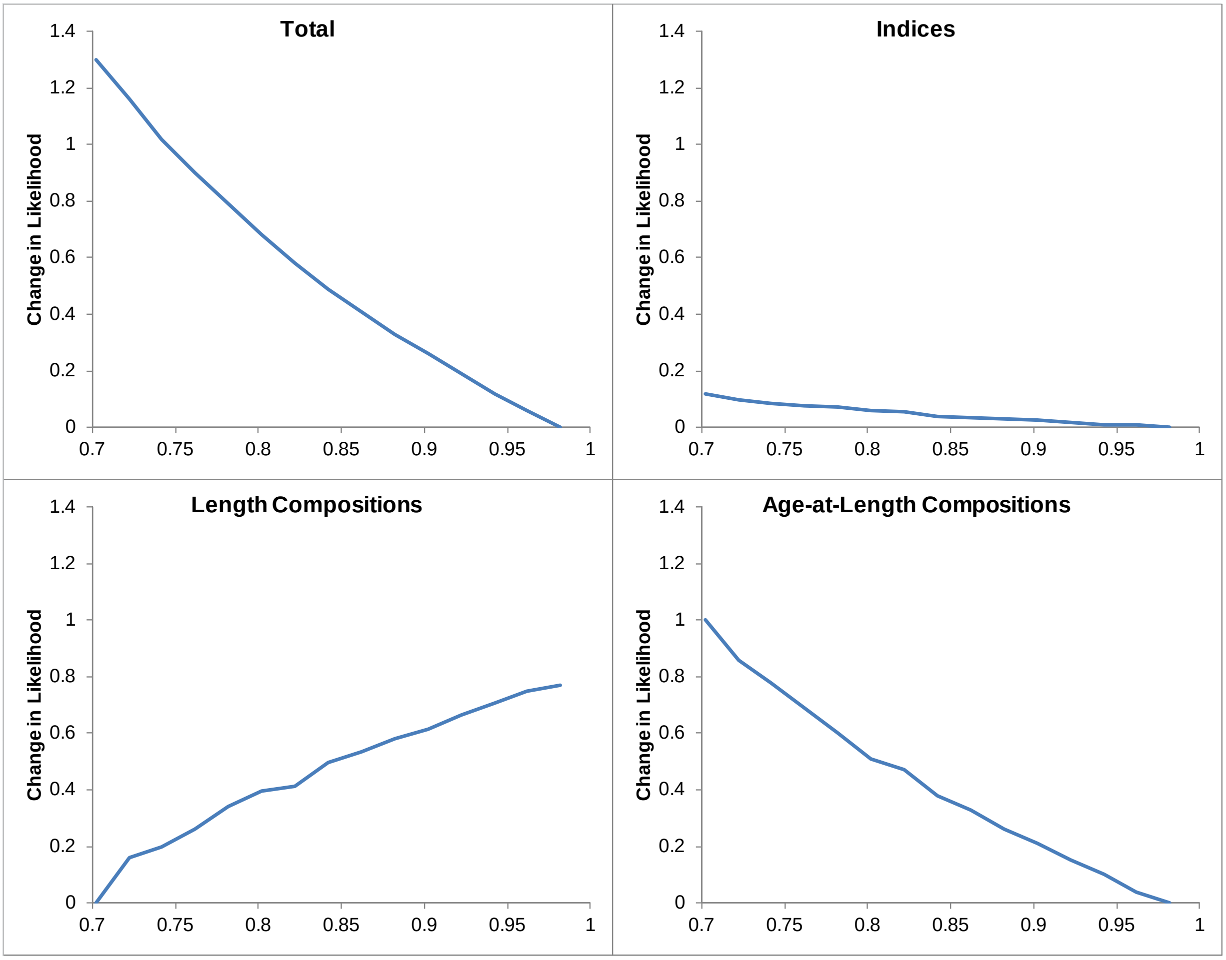


Figure 20. Likelihood profile over the spawner-recruit steepness parameter. For the base model this parameter was fixed at 0.902.

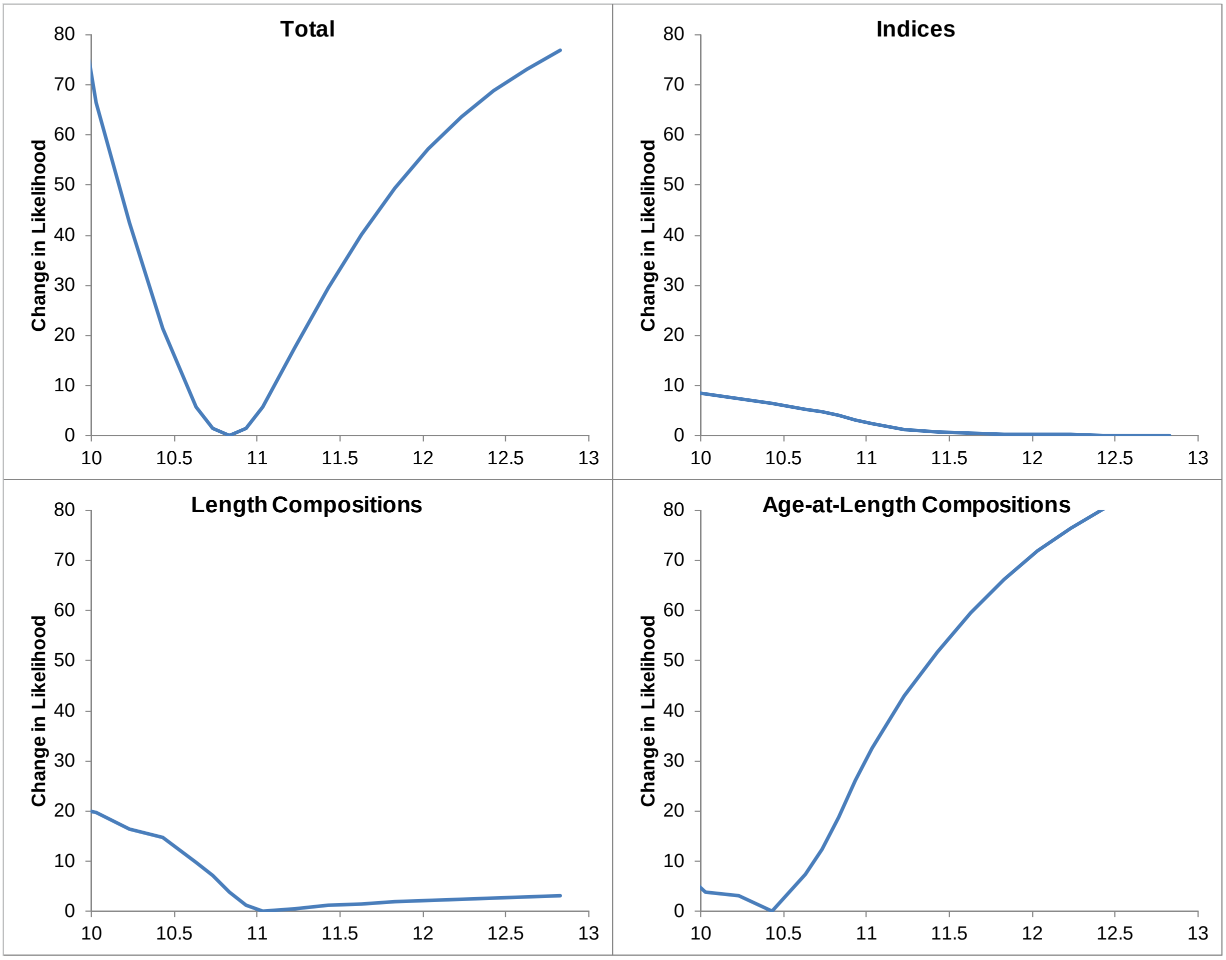
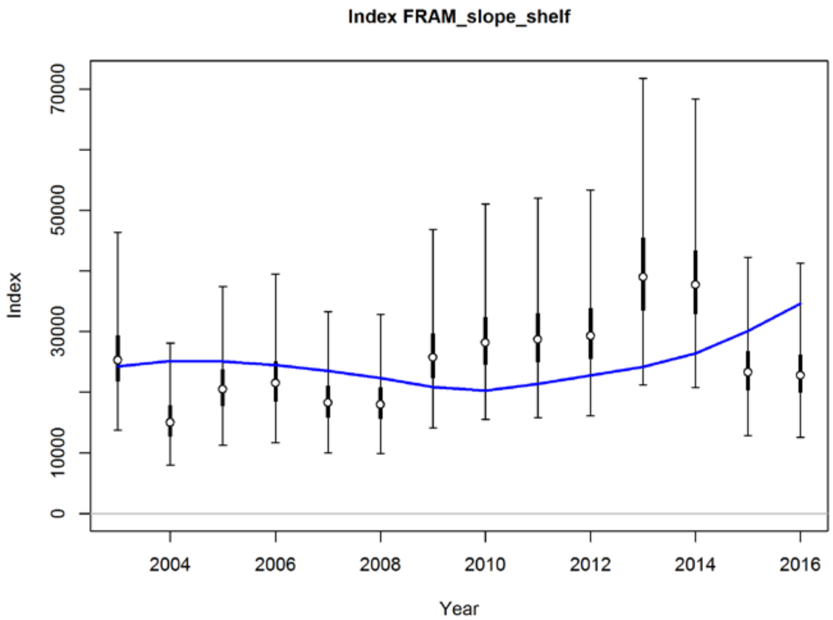
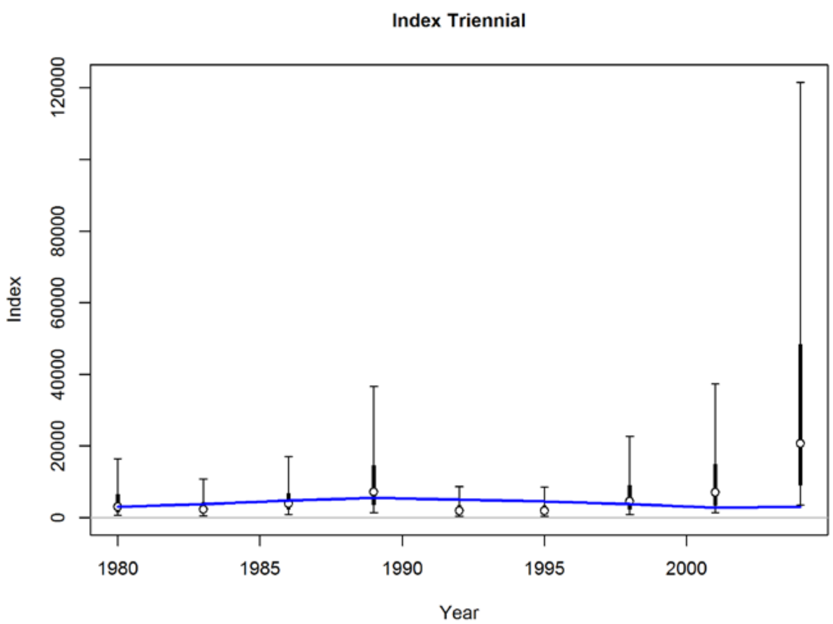


Figure 21. Likelihood profile over the ln(R0) parameter. The base model estimated a value of 10.8295 for this parameter.





<u>Figure 22. Observed and predicted values for the NWFSC (FRAM) slope-shelf survey biomass index and the Triennial survey biomass index.</u>

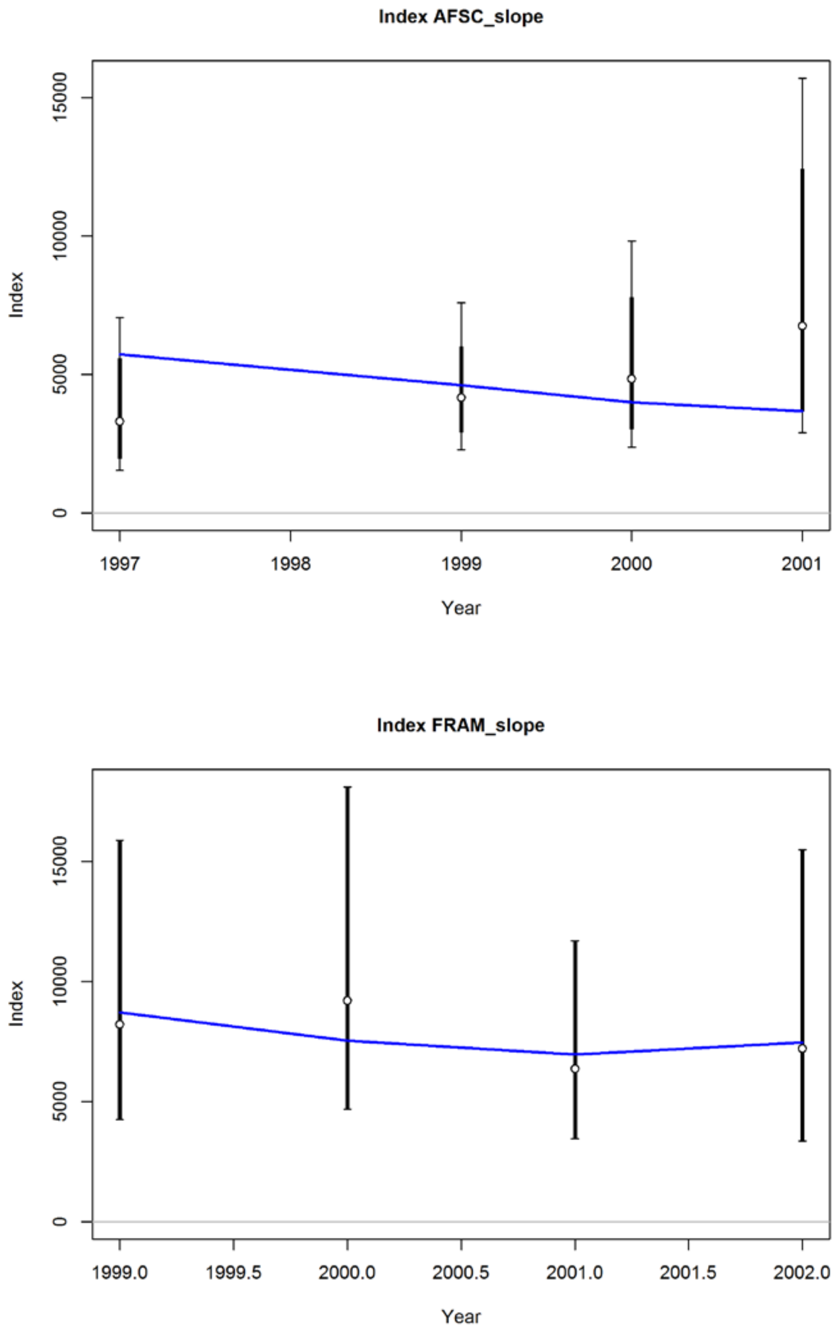
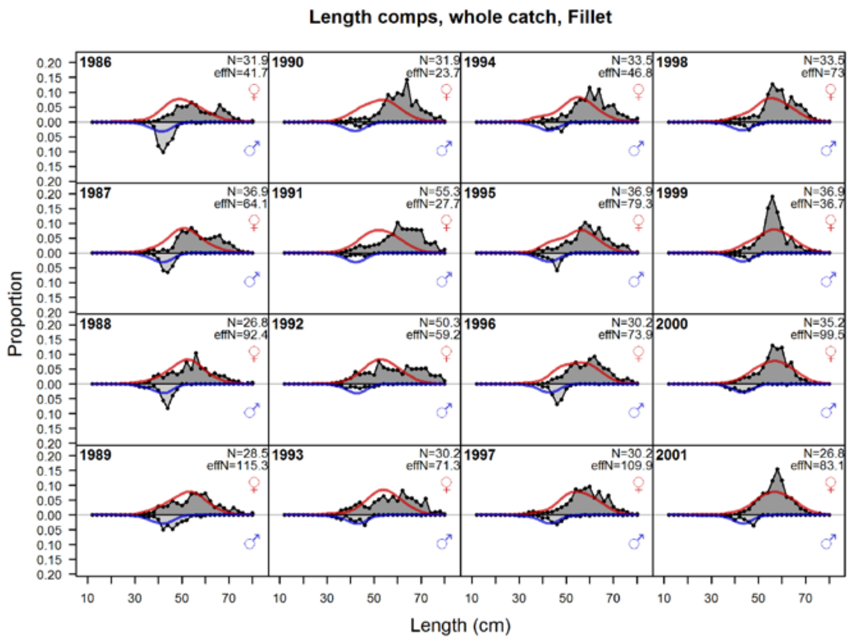


Figure 23. Observed and predicted values for the AFSC slope survey biomass index and the NWFSC (FRAM) slope survey biomass index.



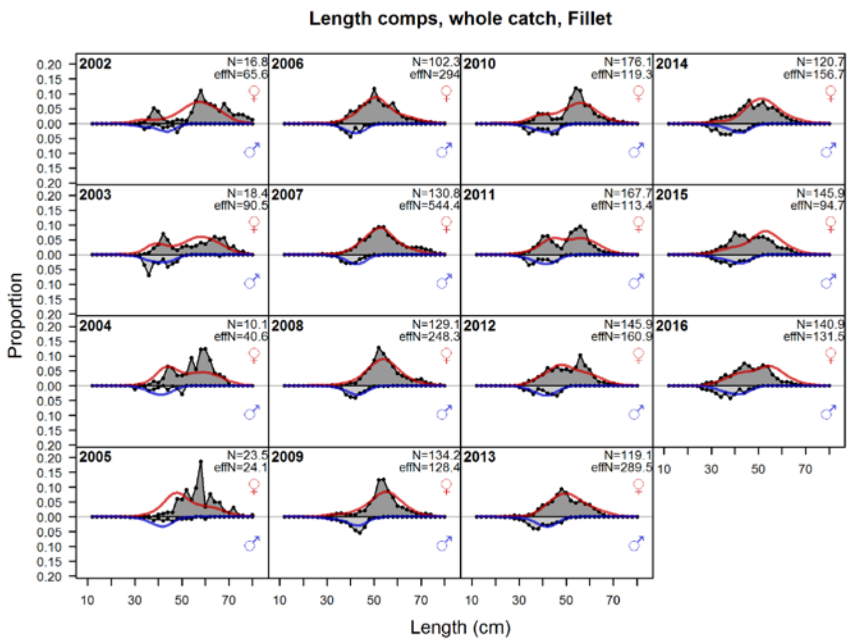


Figure 24. Observed and predicted length-compositions for the fillet fleet.

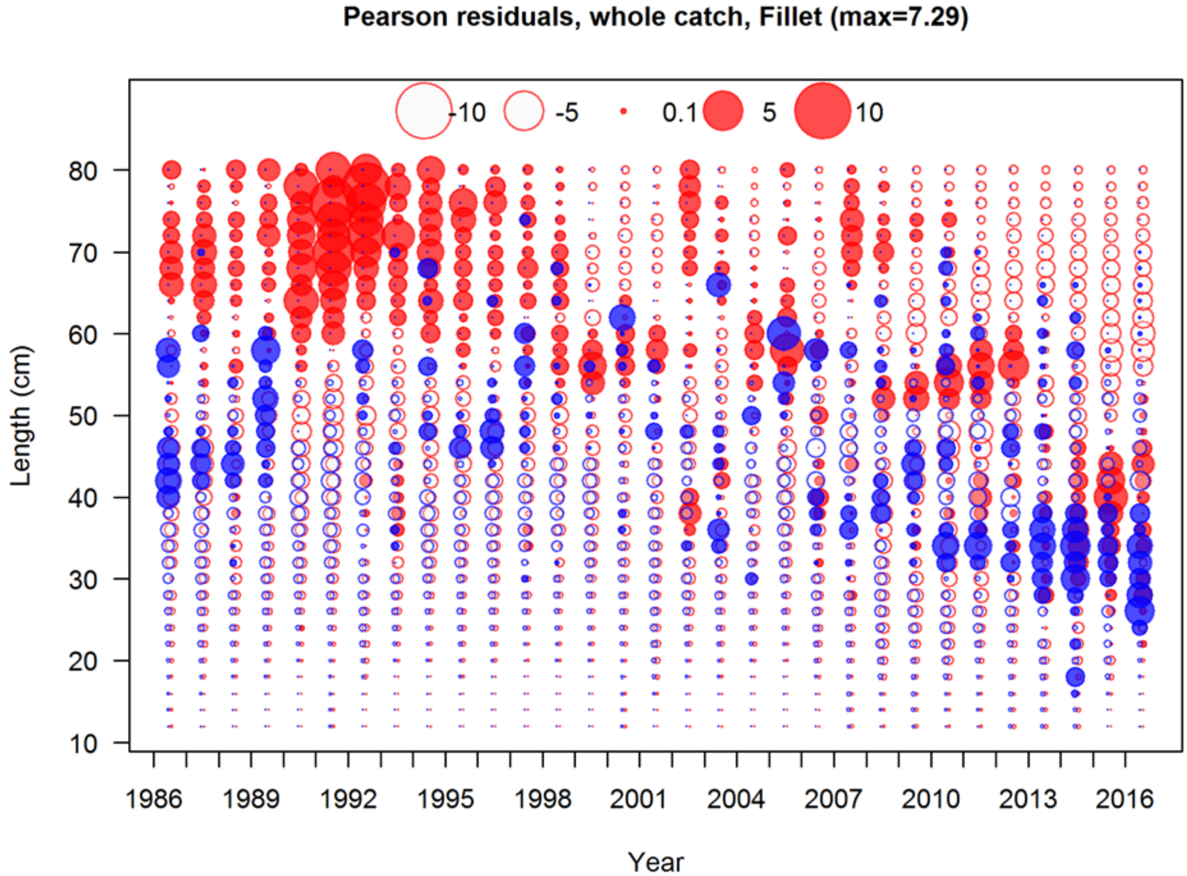


Figure 25. Residual bubble plot for the length-compositions from the fillet fleet.

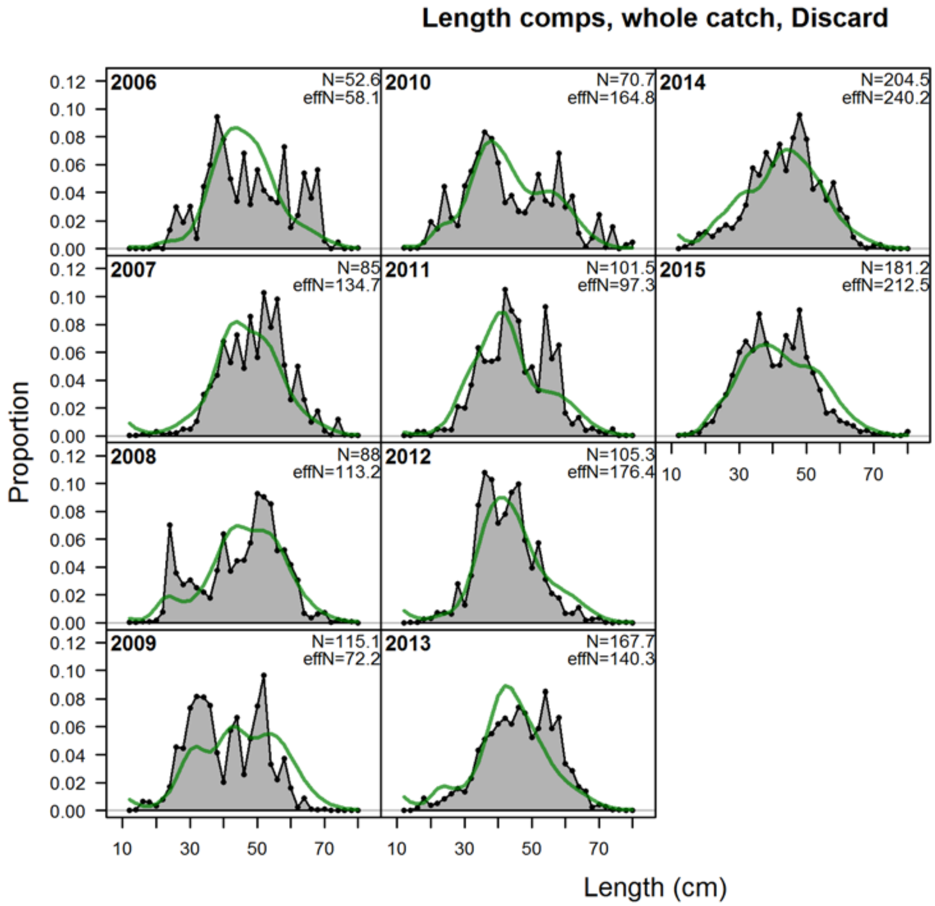


Figure 26. Observed and predicted length-compositions for the discard fleet.

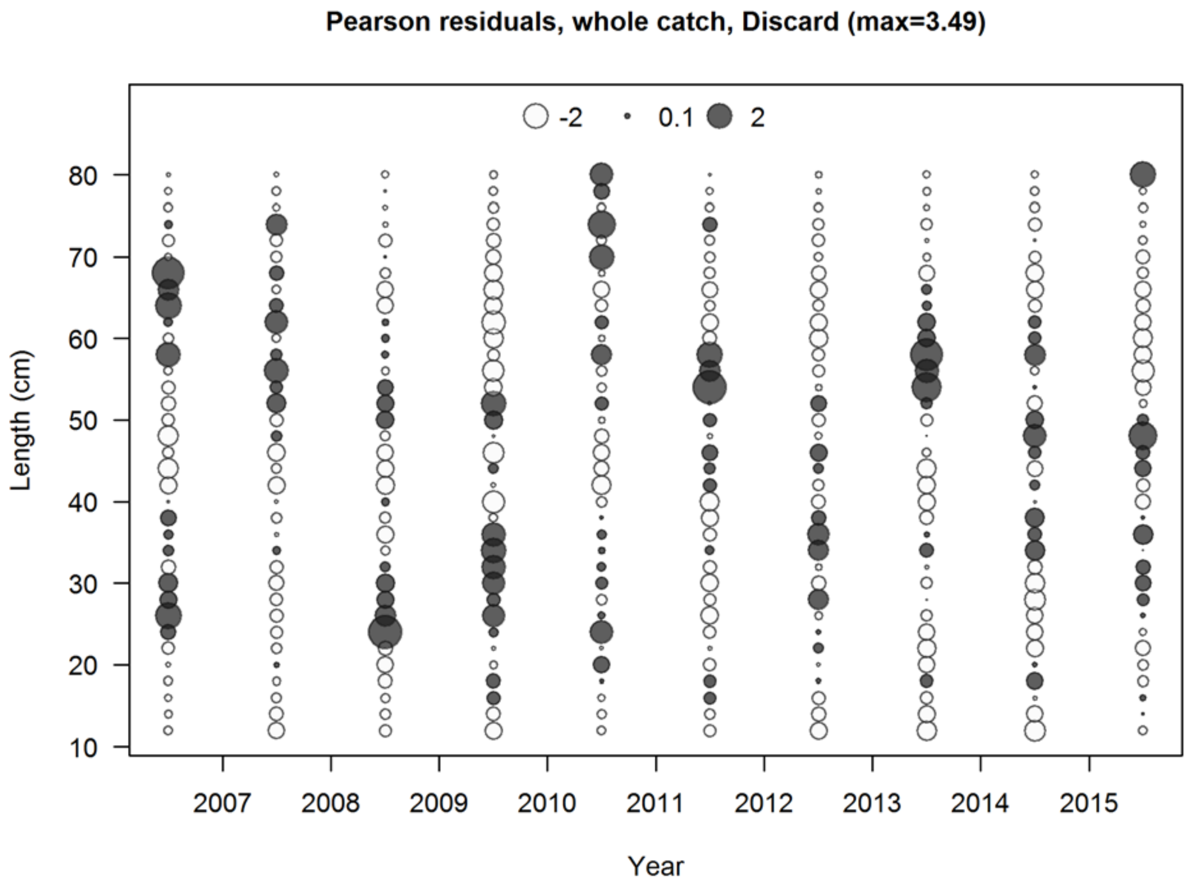


Figure 27. Residual bubble plot for the length-compositions from the discard fleet.

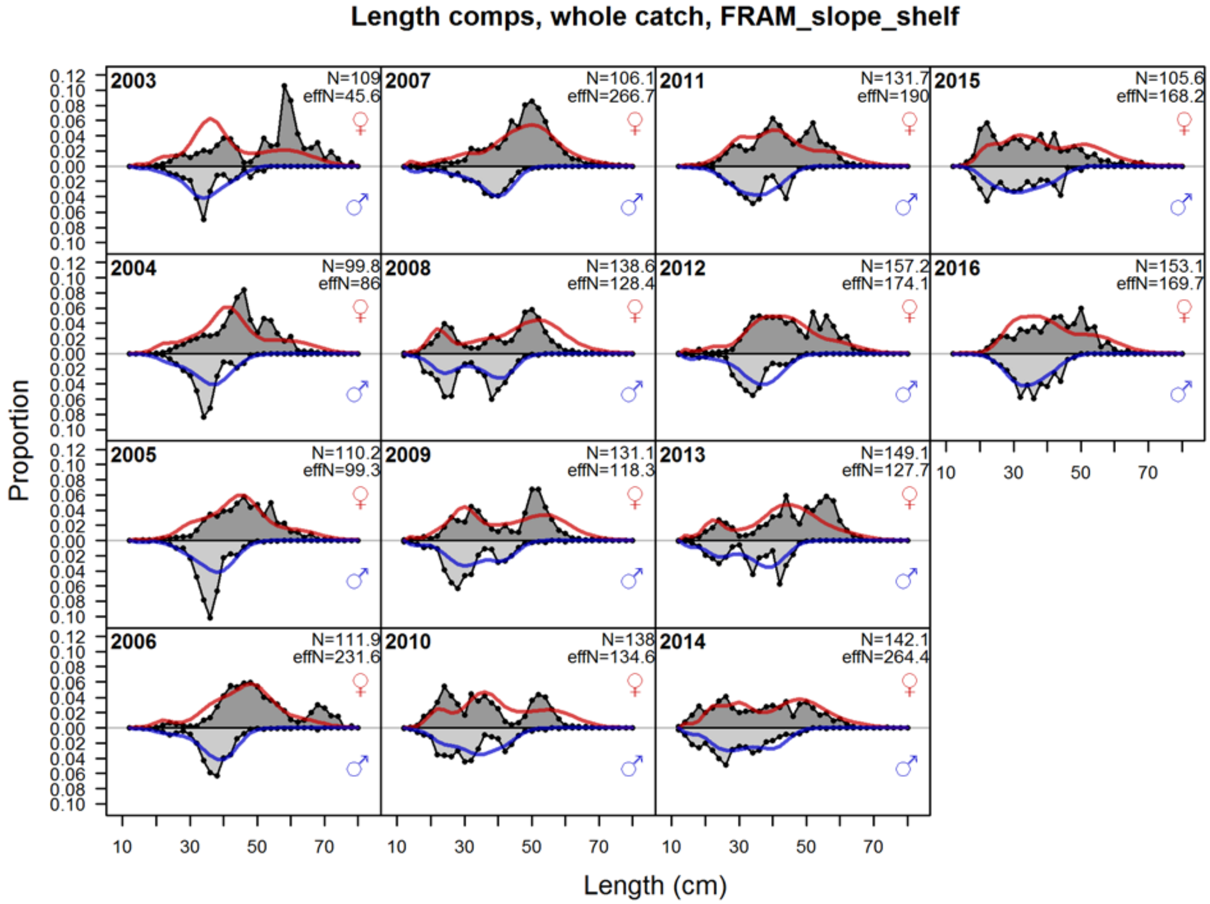


Figure 28. Observed and predicted length-compositions for the NWFSC (FRAM) slope-shelf survey.

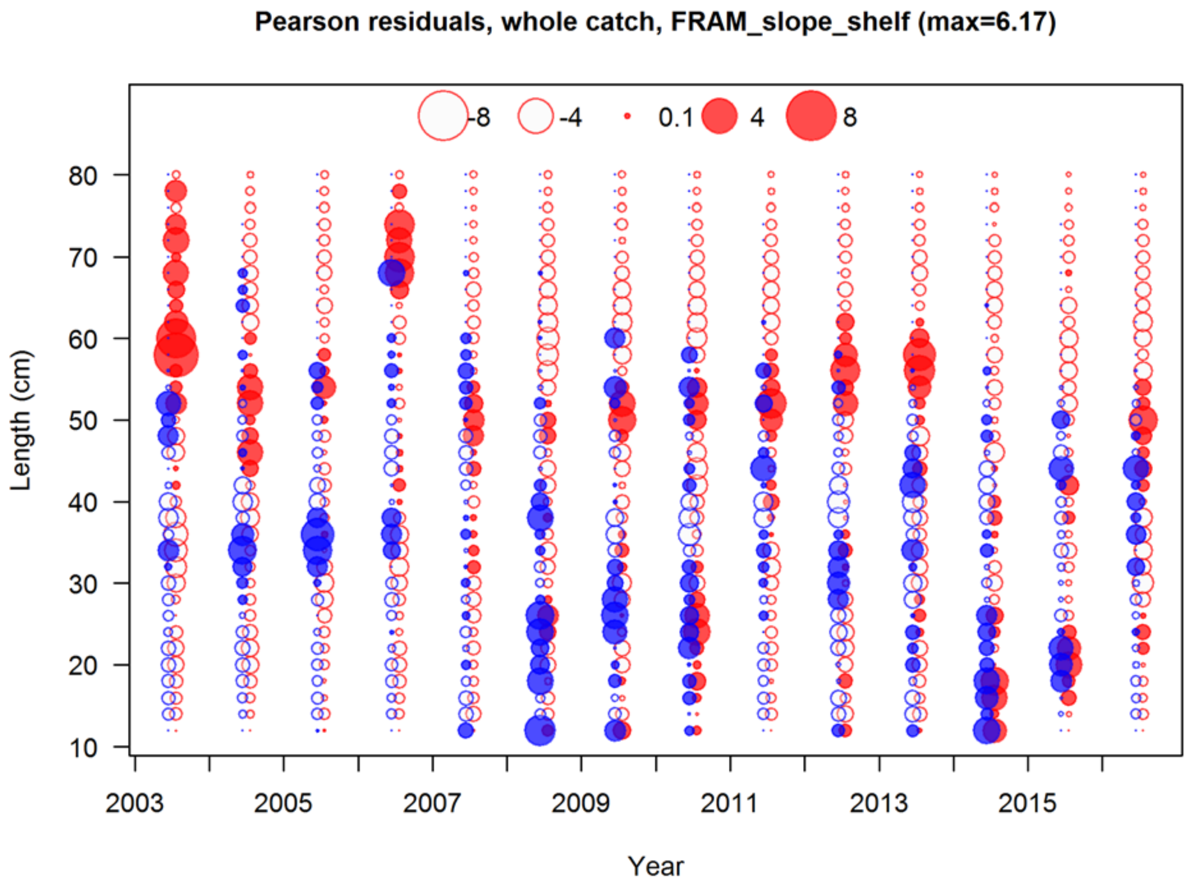


Figure 29. Residual bubble plot for the length-compositions from the NWFSC (FRAM) slope-shelf survey.

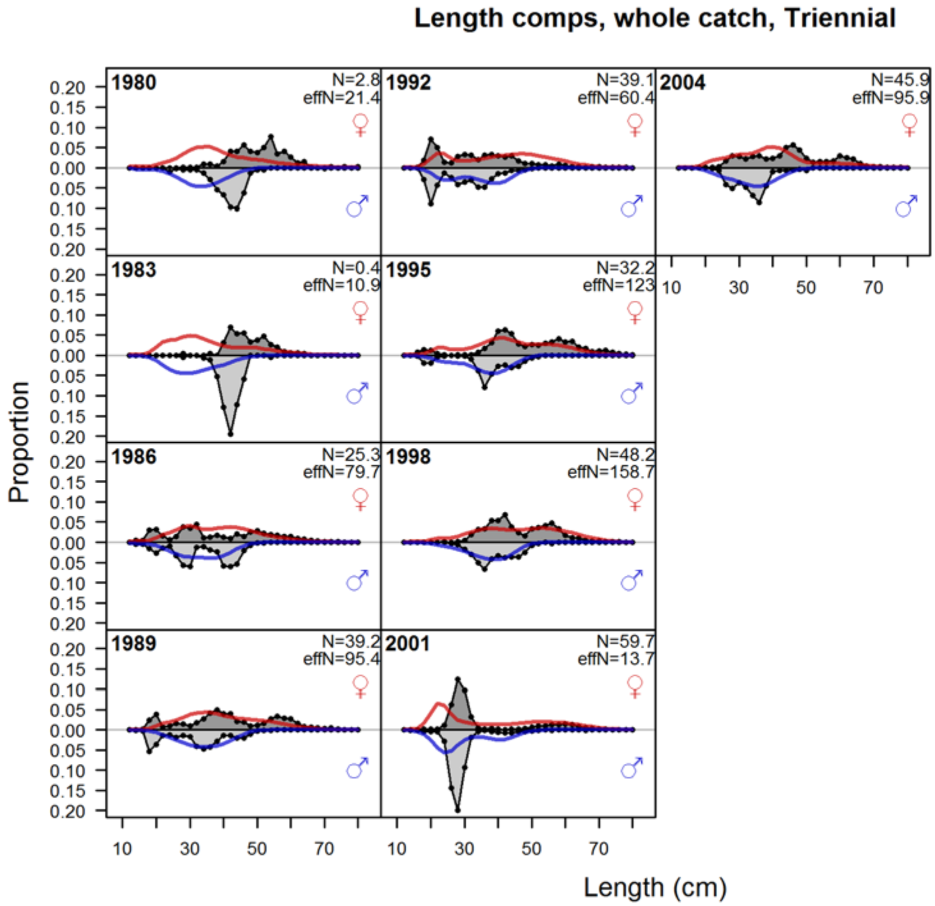


Figure 30. Observed and predicted length-compositions for the Triennial shelf survey.

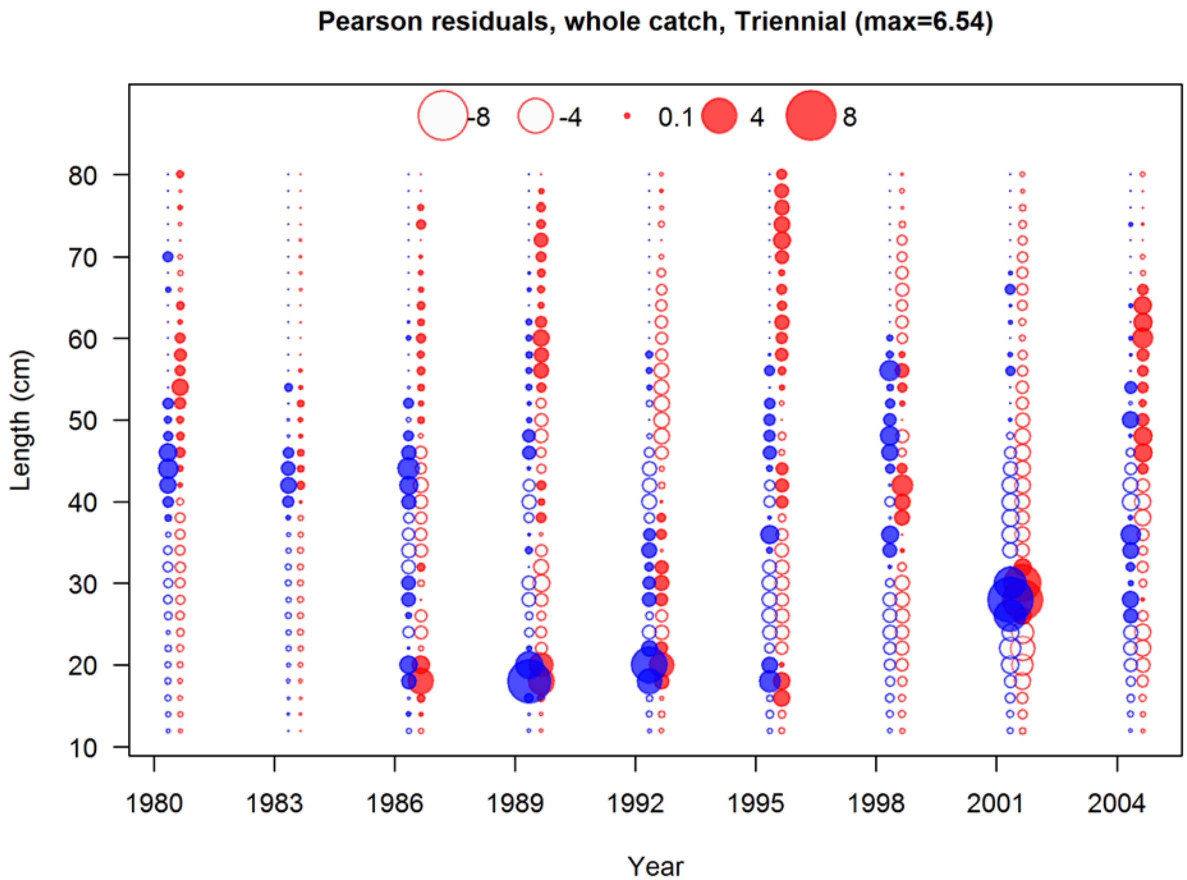


Figure 31. Residual bubble plot for the length-compositions from the Triennial shelf survey.

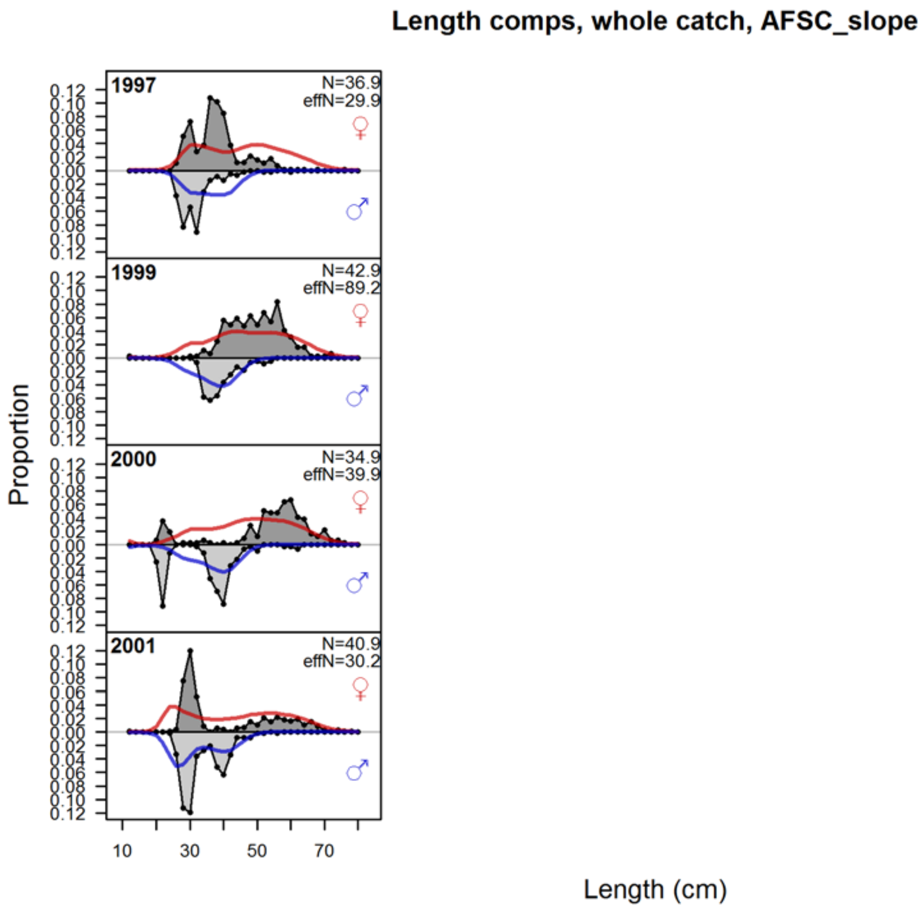


Figure 32. Observed and predicted length-compositions for the AFSC slope survey.

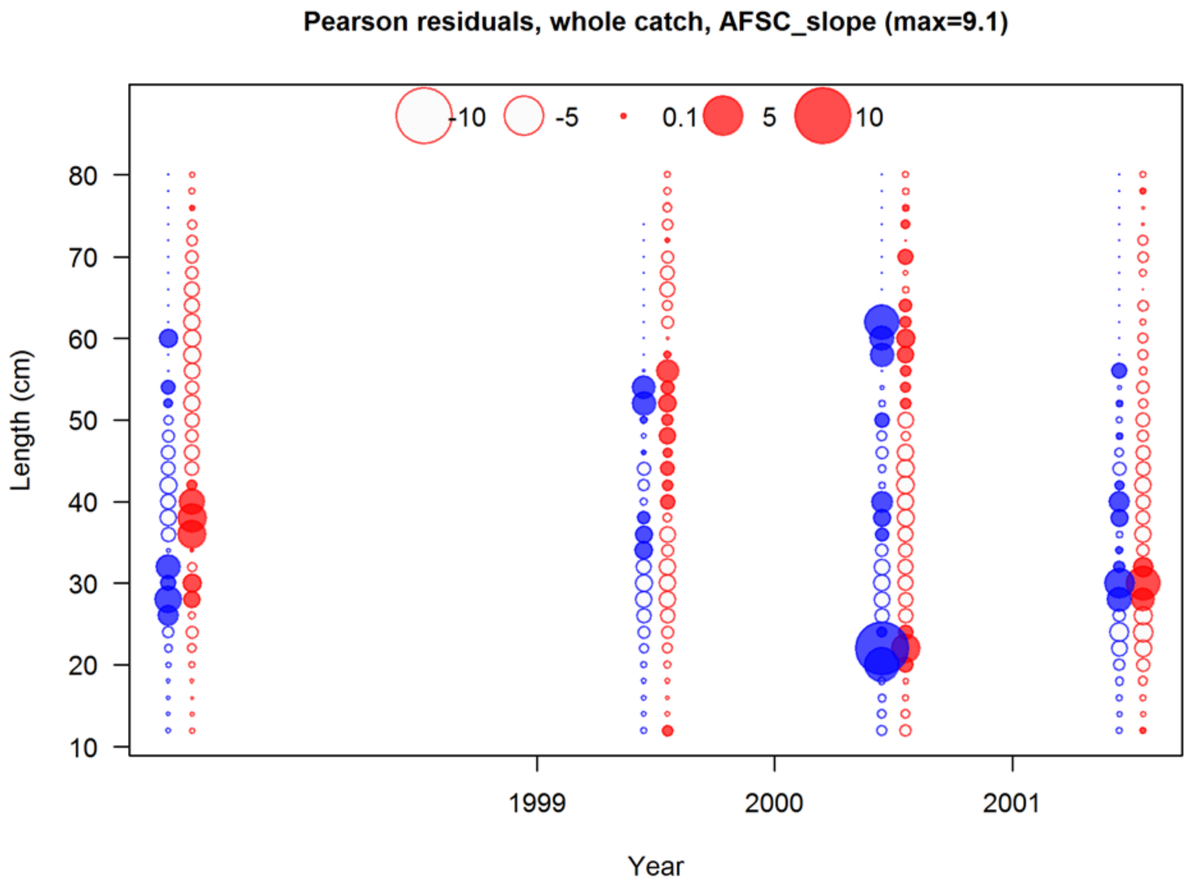


Figure 33. Residual bubble plot for the length-compositions from the AFSC slope survey.

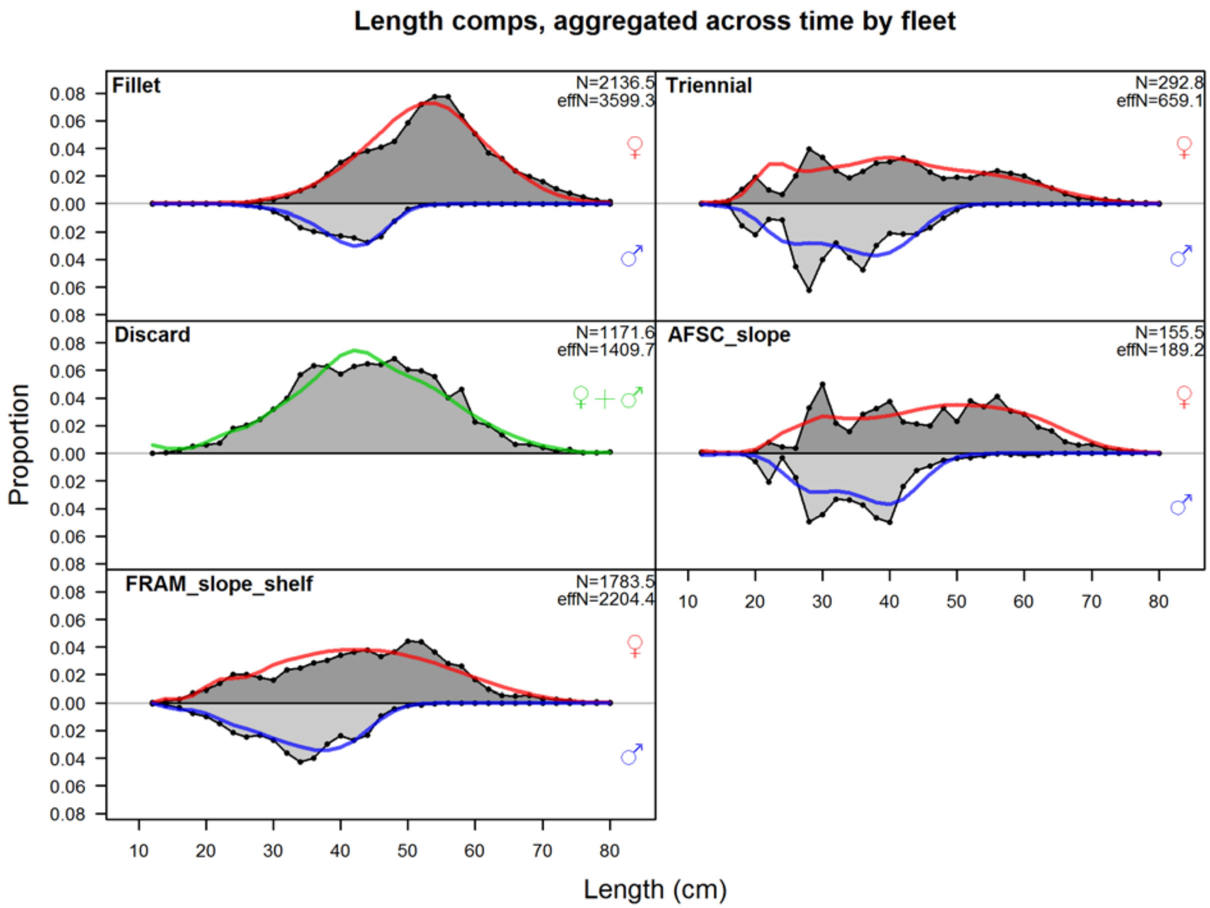


Figure 34. Aggregated observed and predicted length-compositions for the fleets and surveys with length data.

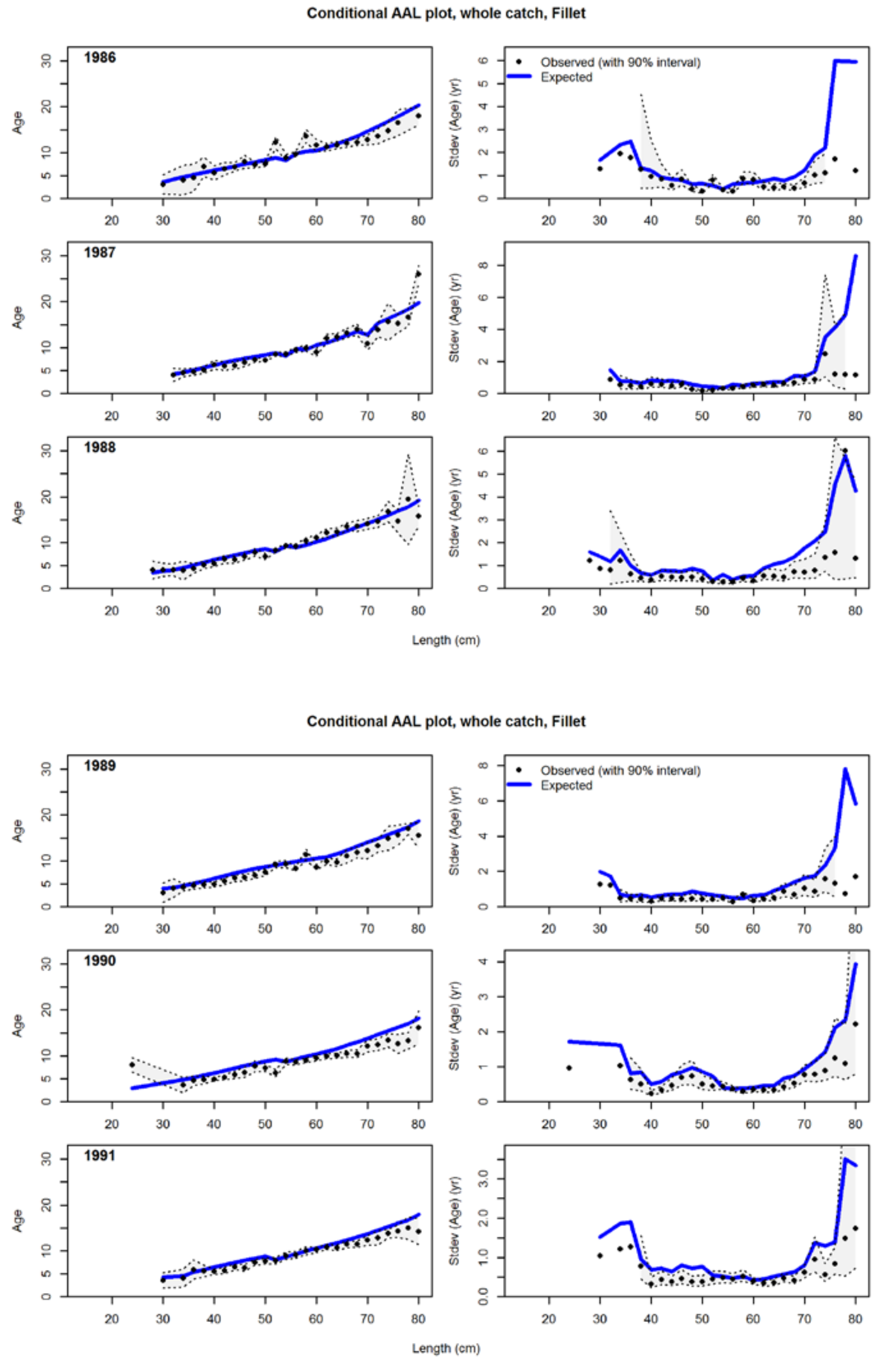
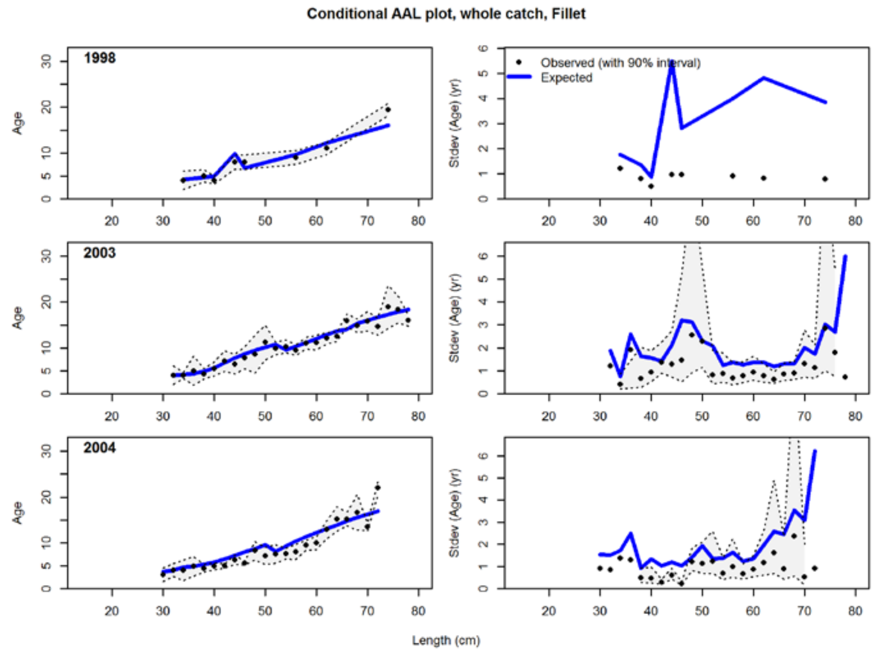


Figure 35. Conditional age-at-length diagnostic plot for the fillet fleet.



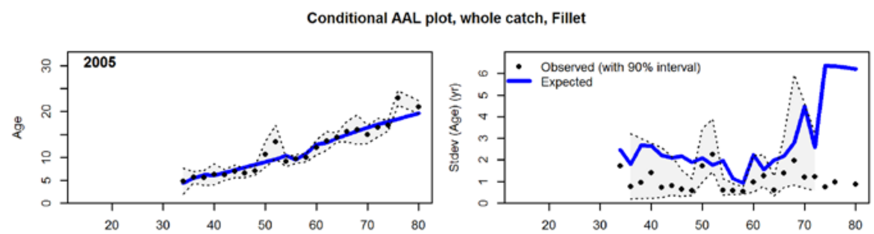
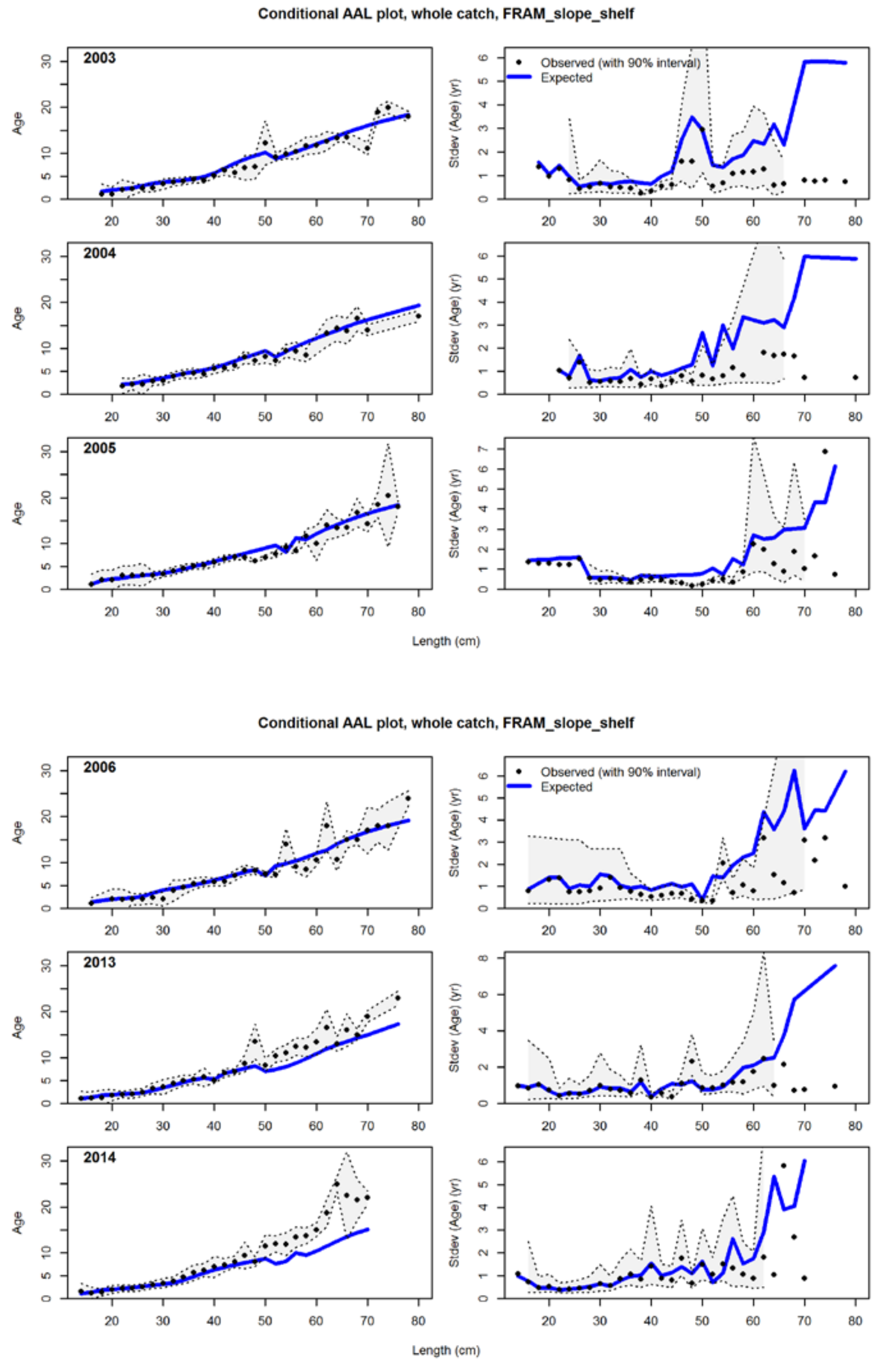


Figure 36. Conditional age-at-length diagnostic plot for the fillet fleet.



<u>Figure 37. Conditional age-at-length diagnostic plot for the NWFSC (FRAM) slope-shelf survey.</u>

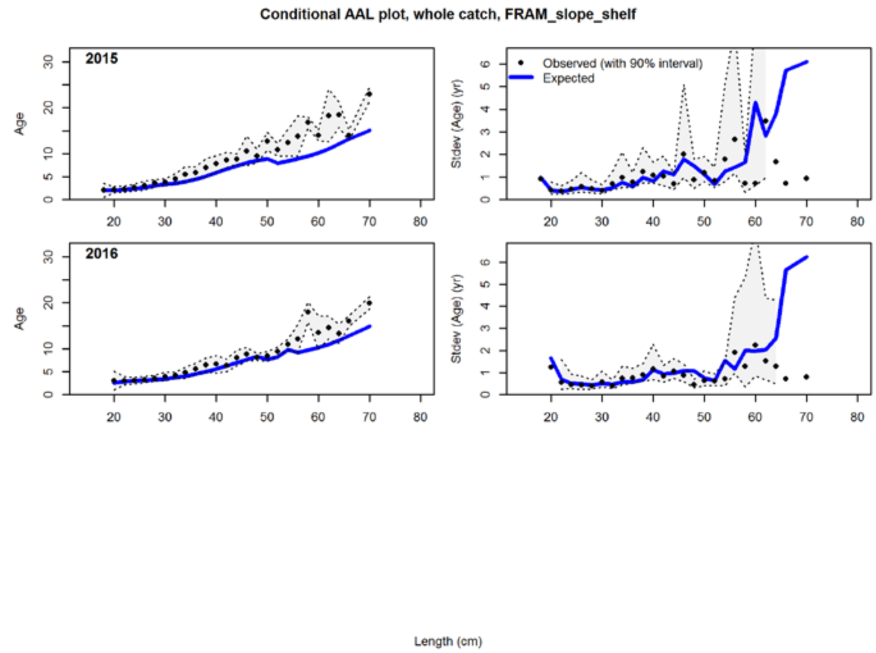


Figure 38. Conditional age-at-length diagnostic plot for the NWFSC (FRAM) slope-shelf survey.

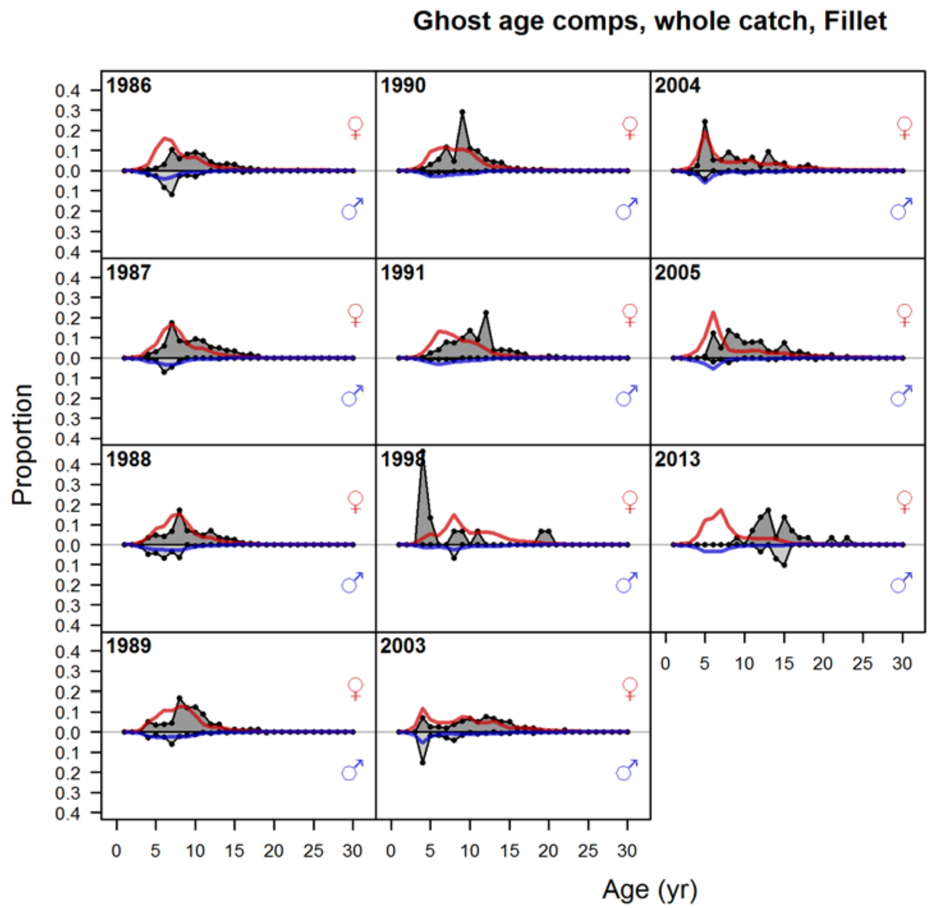


Figure 39. Observed and predicted marginal age-compositions for the fillet fleet. These data do not contribute to the likelihood in the model. They were included to aid visual inspection.

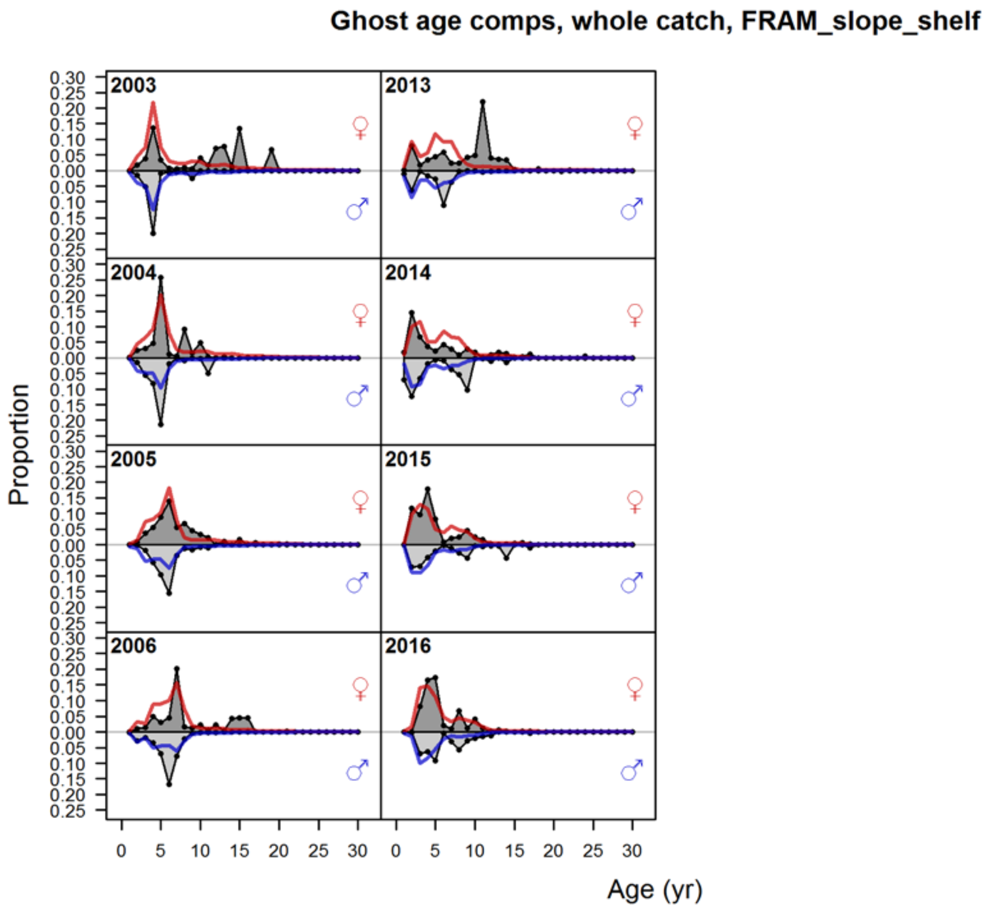


Figure 40. Observed and predicted marginal age-compositions for the NWFSC (FRAM) slope-shelf survey. These data do not contribute to the likelihood in the model. They were included to aid visual inspection.

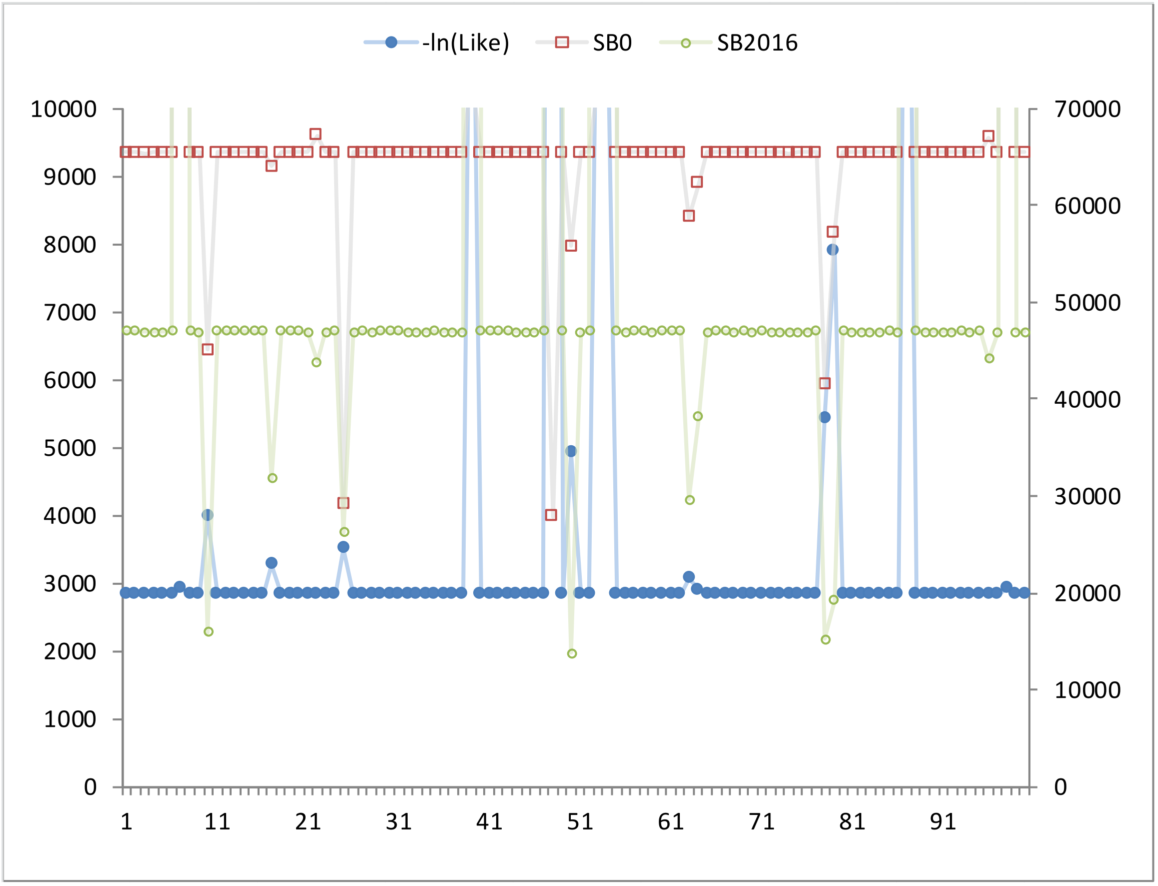


Figure 41. Exploration of the convergence of the base model using 100 runs of the model that had “jittered” initial parameter values.

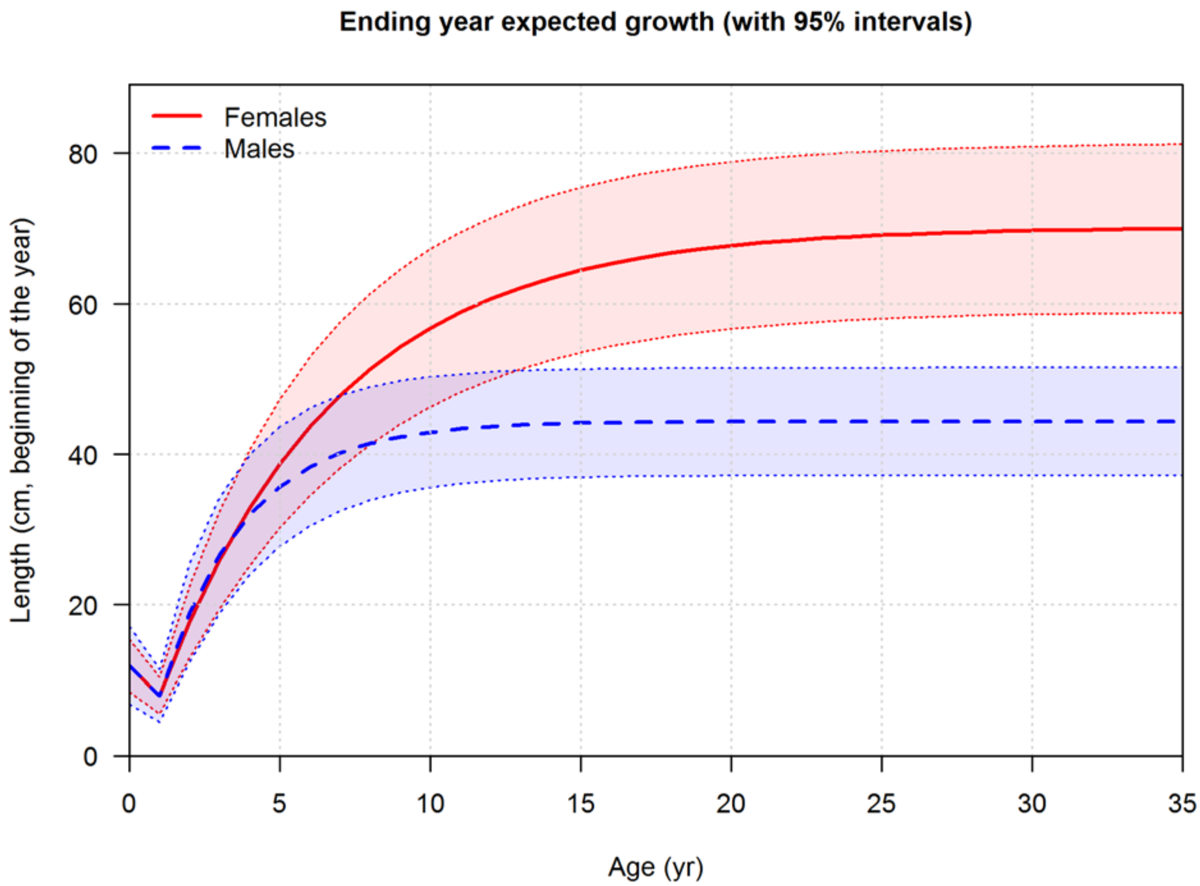


Figure 42. Estimated growth curves from the base model.

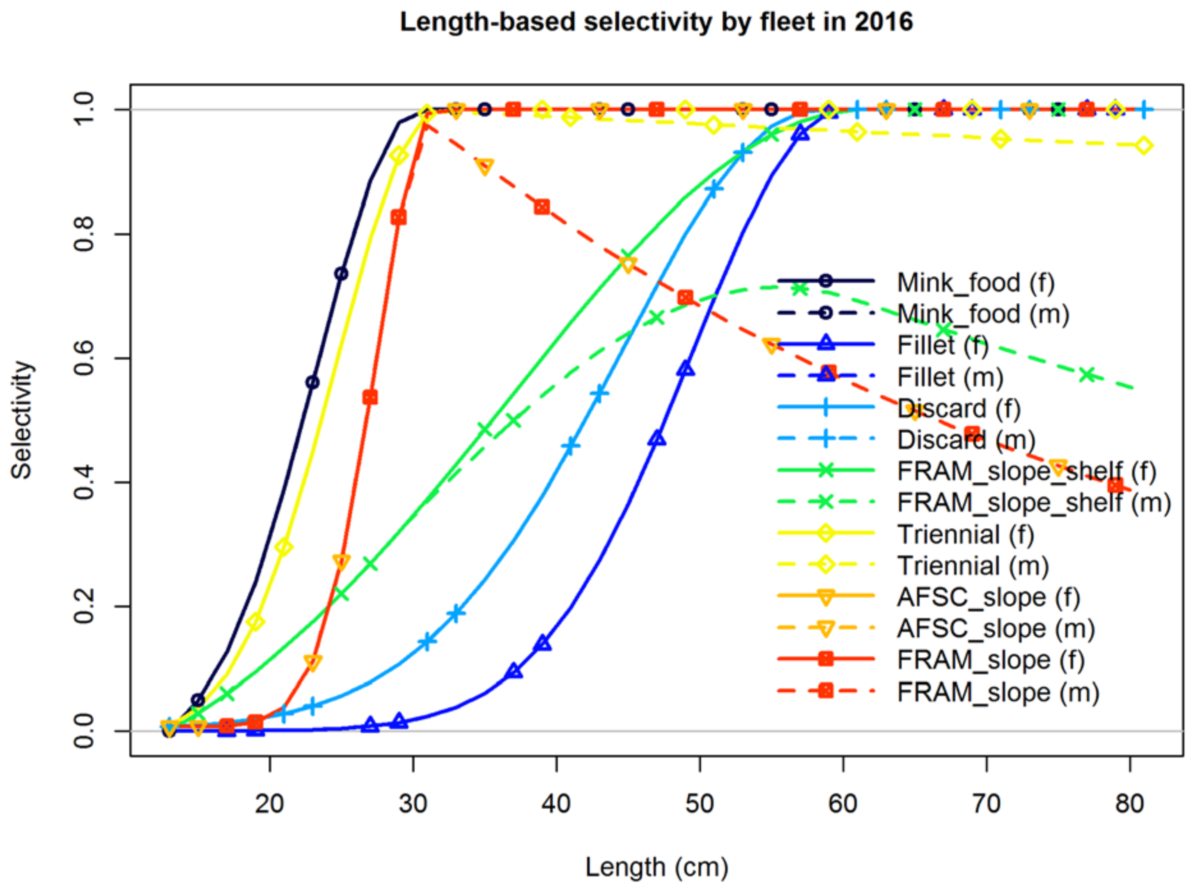


Figure 43. Estimated length selection curves for the fishing fleets and surveys.

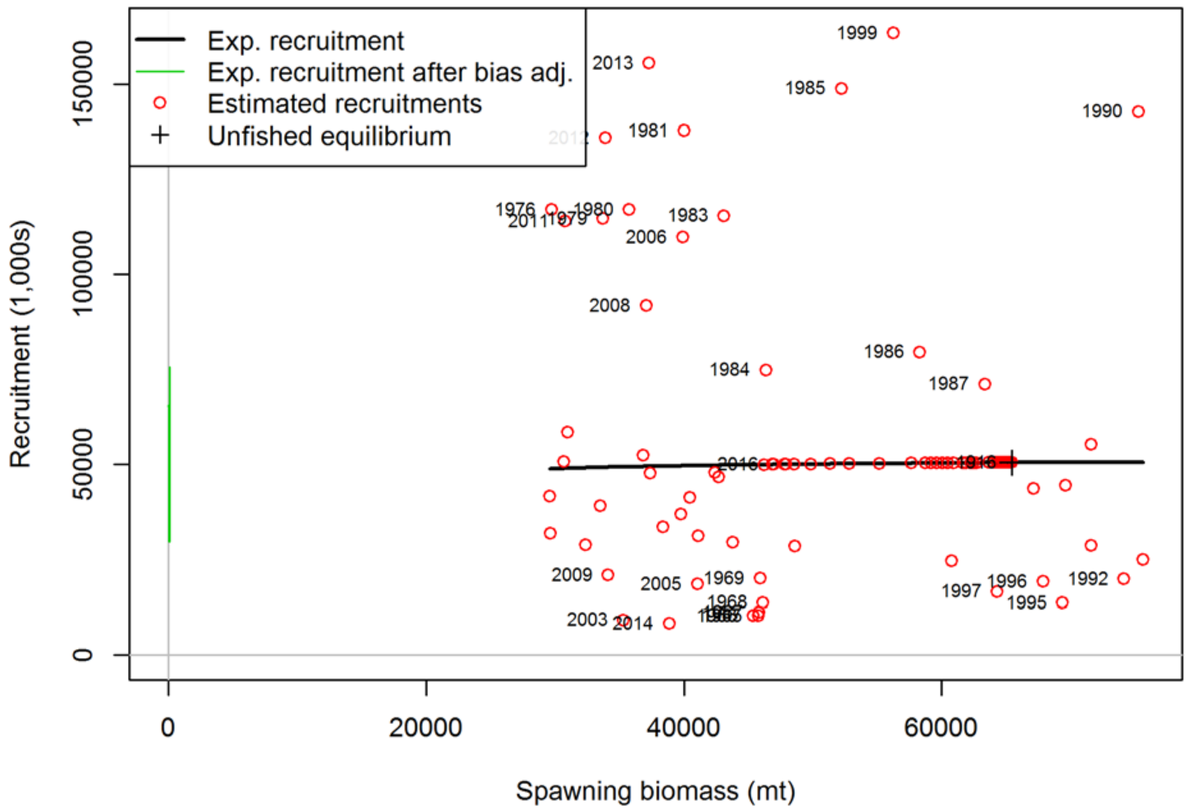


Figure 44. Base model spawner-recruit curve and points indicating the estimates of recruitment and the spawning biomass that produced those recruits.

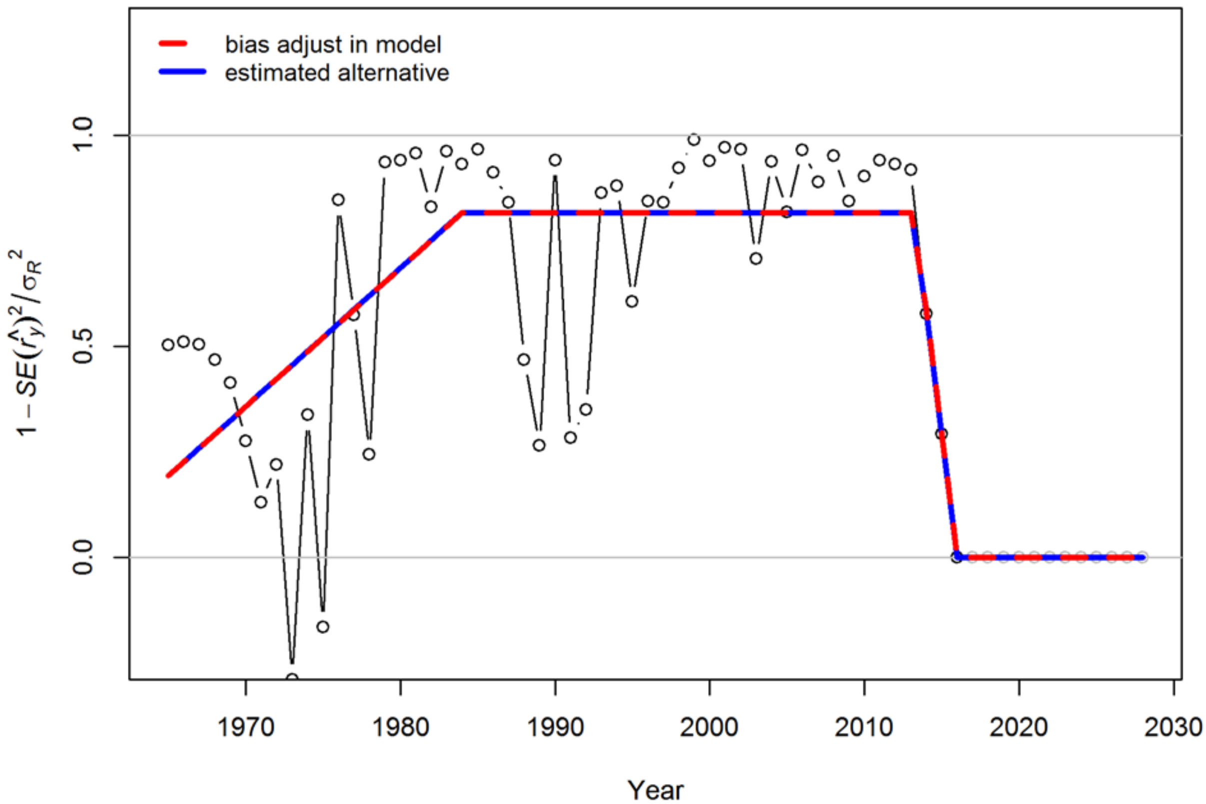


Figure 45. Recruitment bias-adjustments applied to the estimated annual recruitment deviations.

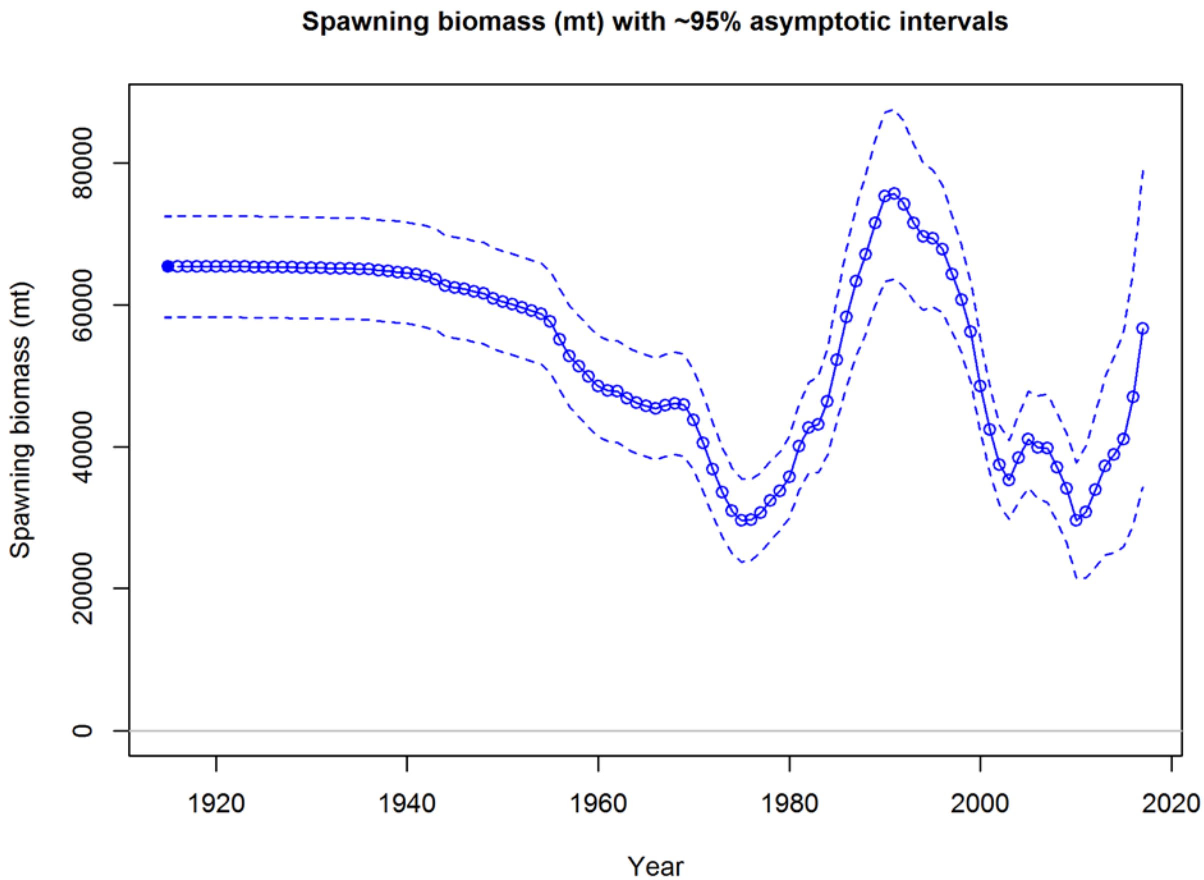


Figure 46. Base model estimated trajectory for spawning biomass.

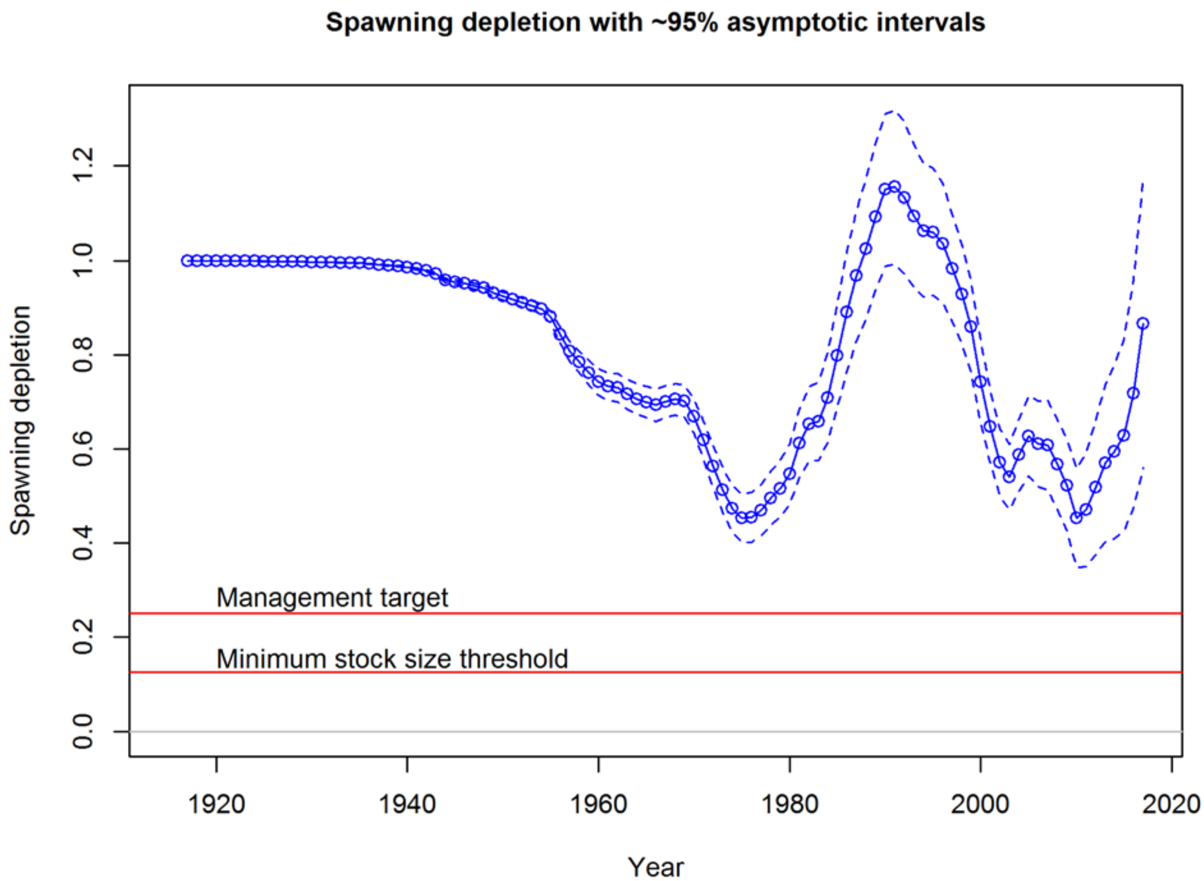


Figure 47. Base model estimated trajectory for depletion (spawning biomass / unfished spawning biomass).

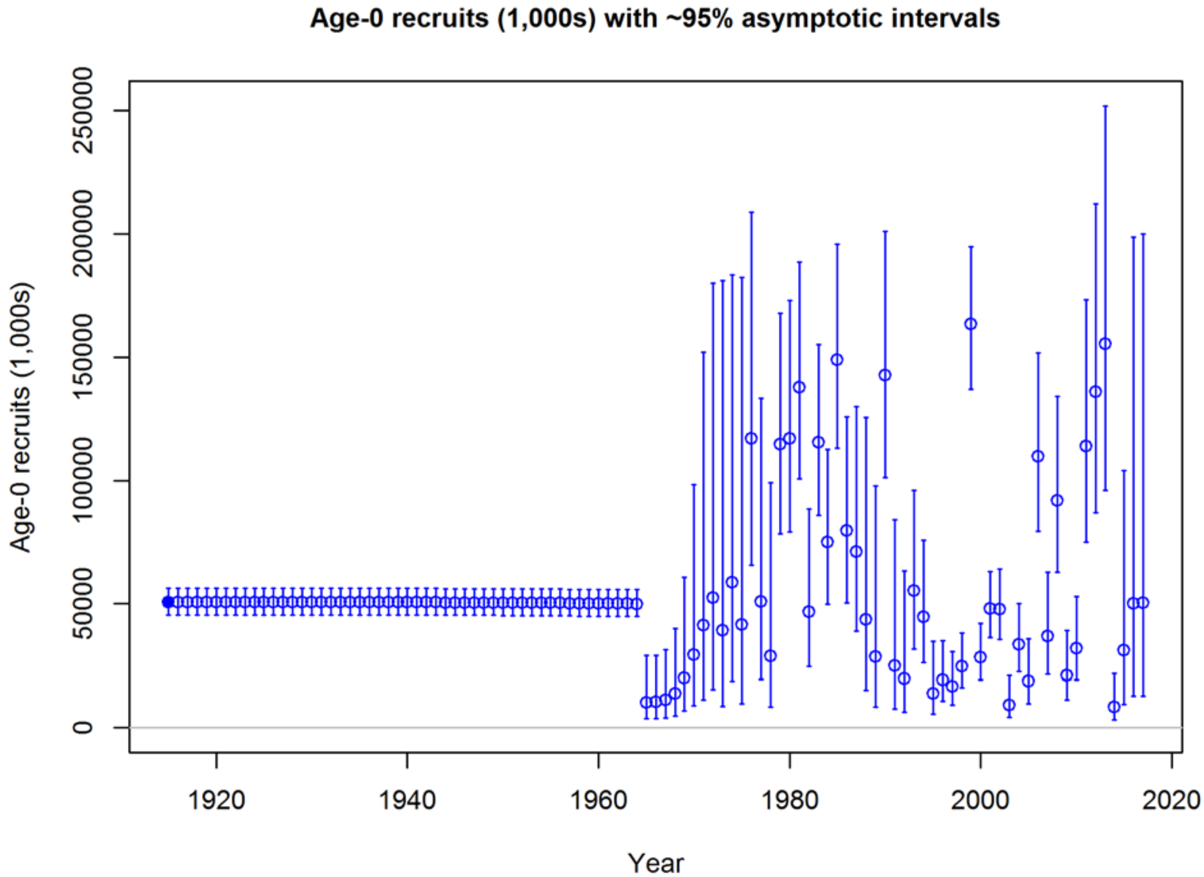


Figure 48. Base model estimated trajectory for age-0 recruitment.

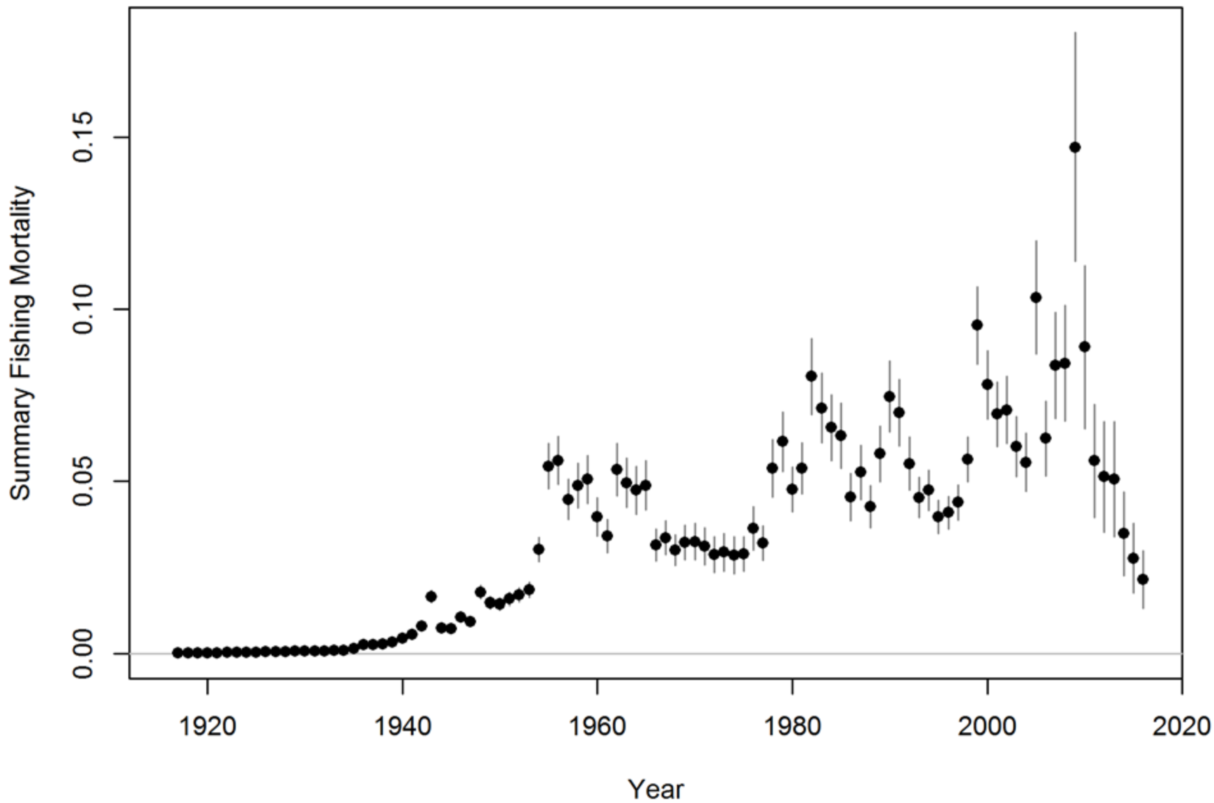


Figure 49. Base model estimated trajectory for exploitation.

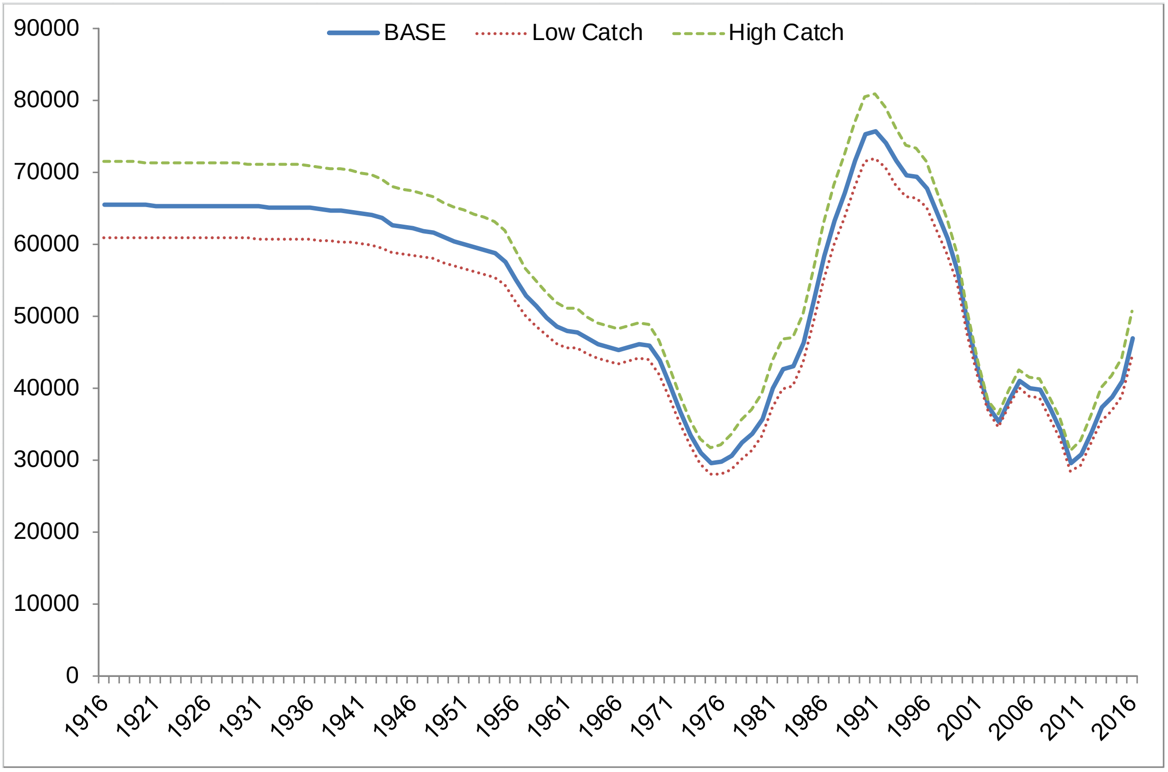


Figure 50. Comparison of base model spawning biomass trajectory with ones based on low and high alternative catch series.

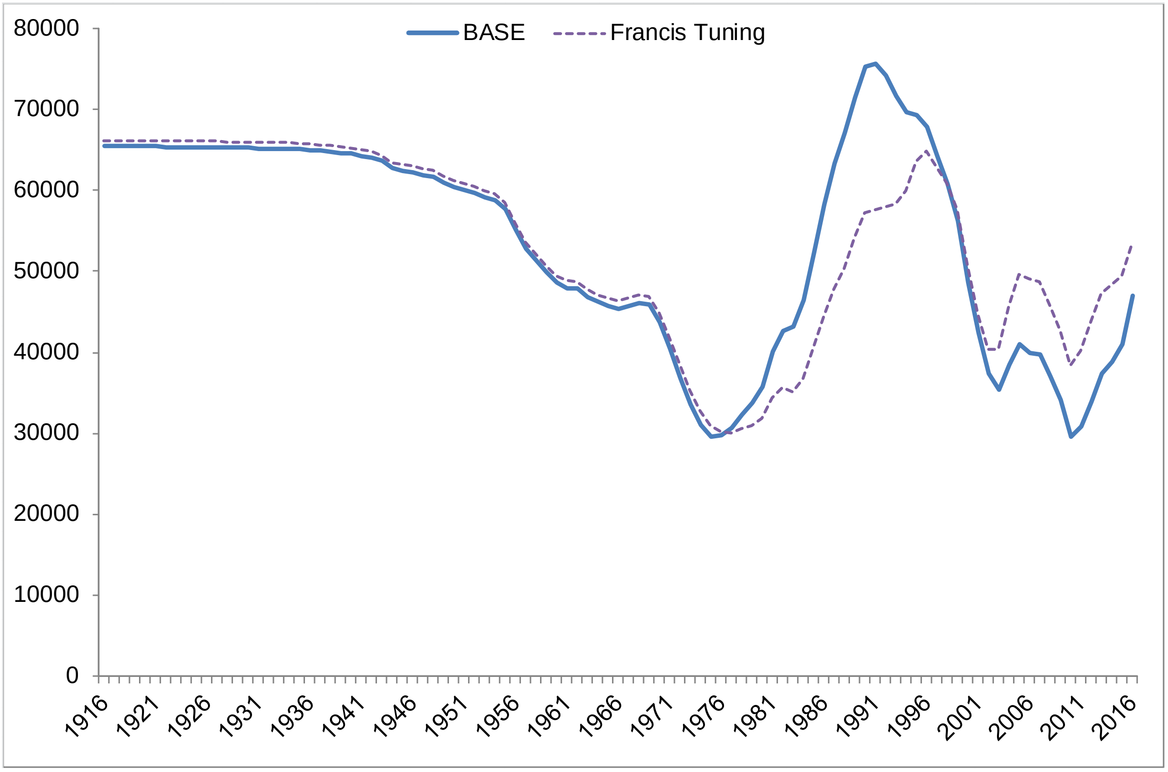


Figure 51. Comparison of spawning biomass trajectory from the base model with an alternative model that had the length-composition data series tuned using the Francis method. The base model was tuned using the McAllister-ianelli method for all composition data series.

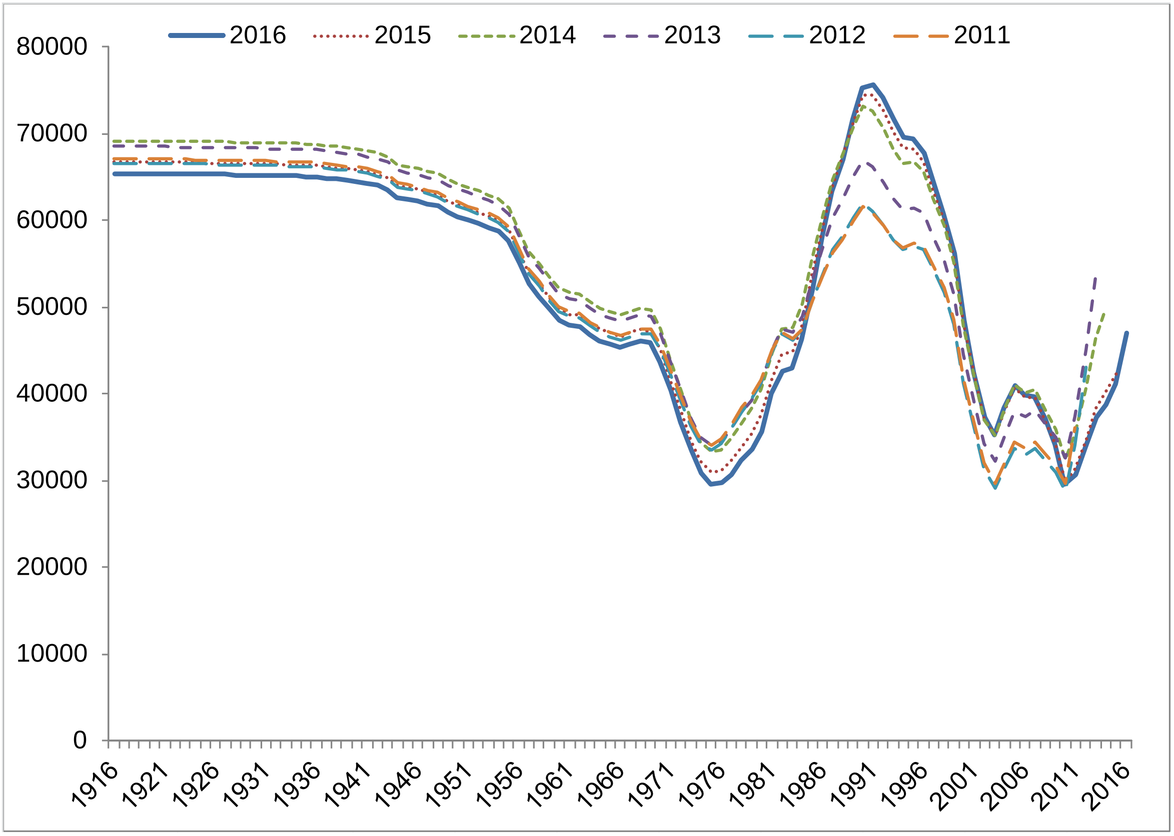


Figure 52. Retrospective analysis for the base model.