Yellowfin Sole model for Plan Team consideration for the Yellowfin Sole Stock in the Bering Sea and Aleutian Islands

Ingrid Spies and James Ianelli
Alaska Fisheries Science Center, National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE., Seattle, WA 98115-6349
31 August, 2020

Executive summary

This document presents a new model for consideration for the 2020 BSAI Yellowfin Sole stock assessment. The data used to explore models are the same as those used in the 2019 assessment.

Relative to the 2018 assessment, the models include the following data updates.

1. The 2019 NMFS eastern Bering Sea shelf bottom-trawl survey biomass estimates and standard error were included.
2. The 2018 fishery age composition was added.
3. The 2018 survey age composition was included.
4. Estimates of the retained and discarded portions of the 2018 catch were added.
5. The estimate of the total catch made through the end of 2020 was used.

Two models are presented here:

1. Model 18.1a: The accepted model used in the 2018 assessment is referred to as Model 18.1a. Model 18.1a used the same natural mortality for males and females, M=0.12.
2. Model 18.2: This second model uses a fixed value for female natural mortality (M=0.12) and allows male natural mortality to be estimated within the model. Model 18.2 is the preferred model.

Data

The data used in these models include estimates of total catch, bottom trawl survey biomass estimates and their attendant 95% confidence intervals, catch-at-age from the fishery, and population age composition estimates from the bottom trawl survey. Weight-at-age and proportion mature-at-age are also available from studies conducted during the bottom trawl surveys. Further information on the data used here can be found in the 2019 Yellowfin Sole stock assessment (Spies et al. 2019a).

Data source	Year
Fishery catch	1954 - 2019
Fishery age composition	1964 - 2018
Fishery weight-at-age	Avg. weight at age from 2008-2018 used for 2008-2019
Survey biomass and standard error	1982 - 2019
bottom temperature	1982 - 2019
Survey age composition	1979 - 2018
Annual length-at-age and weight-at-age from surveys	1979 - 2018
Age at maturity	Combined 1992 and 2012 samples

Responses to SSC and Plan Team Comments Specific to this Assessment

In their December 2019 minutes the SSC concurred with the Plan Team's recommendation to use Model 18.1a for management in 2020, as Model 18.2 had not received thorough review.

In response we have prepared this update.

The SSC requested the authors clarify and justify why natural mortality is estimated in the model for males, rather than for females or both sexes, and whether the value previously used for both sexes combined (M=0.12) is appropriate for a single sex.

Examining the sex-specific differences in natural mortality, M, was a first step towards revisiting assumptions about natural mortality in Yellowfin Sole. Sex-specific natural mortality is a common feature for flatfish that is currently used in NPFMC arrowtooth flounder stock assessment models (Wilderbuer and Turnock 2009; Spies et al. 2018; Spies et al. 2019a). Skewed sex ratio in Yellowfin Sole and research on other flatfish species provides evidence for higher natural mortality for males than females (Nichol et al. 1998; Wilderbuer and Turnock 2009). In Model 18.2, natural mortality is fixed for females, rather than males, because the high proportion of females allows for a better understanding of female natural mortality than male. Natural mortality was estimated at M = 0.12 by minimizing residual variance (Bakkala and Wespestad 1984) and by profiling over a range of values in the stock assessment model using data up to 1992 (Wilderbuer 1992). Female M was estimated from 0.10 to 0.33 and from 0.16 to 0.51 for males (Wilderbuer and Turnock 2009), and a single estimate of female M was 0.10 (Gunderson et al. 2003). We acknowledge that other parameterizations may provide a better fit to the data, but the assumptions in Model 18.2 were made based on the best available information. Future model configurations will to continue to explore split sex natural mortality for Yellowfin Sole.

The SSC appreciates the authors' initial response concerning the variability in the proportion of the yellowfin sole stock that occurs in the Northern Bering Sea. As described in the 2018 SSC minutes, the SSC suggests the application of the VAST model to estimate the proportion of yellowfin sole in the NBS over time, as well as an examination of other available data sources, in particular the ADF&G survey in Norton Sound that has been conducted triennially since 1978 and annually since 2017. The SSC continues to encourage the authors to consider approaches for including the substantial biomass of NBS yellowfin sole in the model, with the expectation that NBS surveys will be conducted regularly in the future.

Authors plan to consider addition of Northern Bering Sea survey data for the December document as an exploratory analysis.

The SSC suggest the authors consider estimating a single selectivity curve for both sexes since the sex-specific selectivities are so similar.

This will be considered for the December document.

The SSC requests the authors include an explanation of why the model fit to the survey and the model estimated biomass trends diverge, including what model-estimated process explains the change, whether the process is biologically plausible, and whether this model estimated process could potentially explain the retrospective pattern.

This will be investigated in future analyses.

The SSC acknowledges the past work that has been done to resolve the retrospective pattern and recognizes that the models with the best fit are different than those that with the best retrospective pattern. However, the SSC remains concerned about the large retrospective pattern and requests the authors continue to investigate this as they are able.

This will continue to be investigated.

The SSC recommends the authors revisit the fixed values of natural mortality, as the document states the data from which these values are based are from the 1990s.

Examining the sex-specific differences in M was a first step towards revisiting assumptions about natural mortality. Further explorations are planned.

The SSC also noted a number of editorial matters which we were grateful to receive and note that they were corrected for the posted final version.

Description of Models

The general model structure is as described in the 2019 Yellowfin Sole stock assessment (Spies et al. 2019b). The accepted model used in the 2019 assessment is referred to as Model 18.1a. Model 18.1a used the same natural mortality for males and females, M=0.12. A second model is also considered in this assessment (Model 18.2) that uses a fixed value for female natural mortality (M=0.12) and allows male natural mortality to be estimated within the model. This was included in some cases for comparison, but is not explicitly compared here, as comparison of Model 18.2 with Model 18.1a was sufficient to understand differences among the two models.

Parameters Estimated Outside the Assessment Model

Natural mortality (M) was initially estimated by a least squares analysis where catch at age data were fitted to Japanese pair trawl effort data while varying the catchability coefficient (q) and M simultaneously. The best fit to the data (the point where the residual variance was minimized) occurred at a value of M=0.12 (Bakkala and Wespestad 1984). This was also the value which provided the best fit to the observable population characteristics when M was profiled over a range of values in the stock assessment model using data up to 1992 (Wilderbuer 1992).

Parameters Estimated Inside the Assessment Model

There were 452 parameters estimated by Model 18.2, and 453 parameters estimated by Model 18.1a. The number of key parameters are presented below:

Fishing mortality	Selectivity	Survey catchability	Year-class strength	Spawner-recruit	M
67	272	4	106	2	1 or 2

In each year, seven additional parameters are generally added to the model; another year of fishery data and the entry of another year class into the observed population, four more sex-specific fishery selectivity parameters, and an additional catchability parameter. Either 1 or two parameters were incorporated for male natural mortality, depending on the model.

Results (Model Evaluation)

Two models are presented in this document. Model 18.1a was the accepted model used in the 2019 assessment. The second model, Model 18.2, fixed female natural mortality at M=0.12 as in previous years, but allowed the model to freely estimate male natural mortality. The model estimated male natural mortality to be higher than female natural mortality (0.135), which is in common with known life history parameters of other

Alaska flatfish. In Arrowtooth Flounder, higher natural mortality is assumed for males and is consistent with their skewed sex ratio (Wilderbuer and Turnock 2009). Higher natural mortality for male flatfish has been assumed to flatfish from other regions as well (Maunder and Wong 2011).

The two models differed slightly in several parameter estimates. The trend in survey catchability was similar for Model 18.1a and Model 18.2, but catchability was lower with Model 18.2 (Figure 1). The sex ratio estimate changed slightly in Model 18.2. The proportion female was estimated to be slightly lower in Model 18.1a than Model 18.2, as higher male natural mortality increased the estimated number of males in the population (Figure 2). Female spawning biomass did not change significantly among Model 18.1a and 18.2, but was slightly higher for Model 18.2 (Table 1). A similar pattern was noted for total (age 2+) biomass (Table 2). Recruitment estimates were also higher in Model 18.2, likely due to the higher natural mortality applied to males (Table 3). Overall, the total negative log likelihod was lower for Model 18.2, and provided a better fit to the survey and fishery ages, as well as an improvement to the fit to survey catchability, with the total negative log likelihood reduced from 1,424 in Model 18.1a to 1,356 in Model 18.2 (Table 4, Figure 3, Figure 4, Figure 5, Figure 6).

Table 5 indicates that the ABC values from Model 18.2 for 2020 would be 33,428 t (13%) higher than the 2020 value projected by Model 18.1a. This is due to the higher biomass estimate resulting from an increased value of male natural mortality in Model 18.2. Model 18.2 also provided a slightly better fit to survey biomass, but this effect was primarily noticeable during the years 1988-1995. Overall Model 18.2 provided very little change in the fit to survey biomass (Figure 7).

Given the uncertainty of the productivity of Yellowfin Sole at low spawning stock sizes, and because the AFSC policy for reference point time-series selection is to use the post 1977 regime shift values unless there is a compelling reason to do otherwise, the productivity of Yellowfin Sole in these models were estimated by fitting the 1977-2013 spawner-recruit data (Ricker 1958). The resulting stock recruitment curves are very similar for Models 18.1a and 18.2 (Figure 8 and Figure 9).

Posterior distributions of several key parameters in the model capture variability in posterior distributions of parameter estimates and differences between Model 18.2 and Model 18.1a (Figure 10). Model 18.2 resulted in higher estimates for B_{MSY}, total and age 6 biomass and female spawning biomass and recruitment, but similar values to Model 18.1a for F_{MSY}. The posterior distribution for female spawning biomass is above the Model 18.2 estimate for B_{MSY} (Figure 10).

The full-selection fishing mortality, F, has averaged 0.0717 over the period 2014-2018 (Table 6). Model estimated survey selectivities (Figure 11) show very little difference between Model 18.2 and 18.1a. Both models indicate that both sexes of Yellowfin Sole are 50% selected by the fishery at about age 9 and nearly fully selected by age 13, with annual variability.

A within-model retrospective analysis was included for Model 18.1a and Model 18.2. In this analysis, retrospective female spawning biomass was calculated by sequentially dropping data one year at a time and then comparing the peeled estimate to the reference stock assessment model used in the assessment (Figure 12, Figure 13). Mohn's rho was -0.219 using Model 18.2 and -0.254 under Model 18.1a; thus the preferred model resulted in a less negative value. Visually, Model 18.2 shows a similar retrospective pattern to Model 18.1a, although both patterns showed a lower level of spawning biomass than the current year's data in earlier retrospective years (Figure 12, Figure 13). The difference in female spawning biomass was negative for all years, except for the most recent. Model 18.2 improved the retrospective pattern for differences in female spawning biomass (Figure 14,Figure 15).

There is a large amount of variability in the annual survey biomass of Yellowfin Sole due to the temperature-influenced availability to the survey. This large variability can contribute to undesirable retrospective patterns since earlier years do not fit the same highly variable information as the current year. In particular, retrospective model runs are outside the confidence intervals of the assessment model spawning biomass trajectory for approximately 17 years from 1986-2019.

In 2017 the Plan Team recommended that the assessment continue to explore the retrospective patterns in relation to M and q by profiling over a range of combinations of M and q and recording the resulting values of Mohn's rho and also total likelihood. Profiling over M and q was performed in the 2018 assessment. The best retrospective patterns did not occur at corresponding best model fit values. The retrospective technique may not always be the best tool for model selection, at least for BSAI Yellowfin Sole as there is tension between model fit and good retrospective pattern over the range of parameterization examined.

Given the higher total log likelihood, improved Mohn's rho, and other results discussed above, Model 18.2 is the preferred model for estimating the Yellowfin Sole stock size and management quantities for the 2021 fishing season.

Literature Cited

Bakkala, R. G. and V. Wespestad. 1984. Yellowfin sole. In R. G. Bakkala and L. resources of the eastern Bering Sea and Aleutian Islands region in 1983, p. 37-60. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-53.

Gunderson, D. R., M. Zimmerman, D. G. Nichol, and K. Pearson. 2003. Indirect estimates of natural mortality rate for arrowtooth flounder (*Atheresthes stomias*) and darkblotched rockfish (*Sebastes crameri*). U.S. National Marine Fisheries Service Fishery Bulletin 101:175–182.

Maunder, M.N. and Wong, R.A., 2011. Approaches for estimating natural mortality: application to summer flounder (*Paralichthys dentatus*) in the US mid-Atlantic. Fisheries Research, 111(1-2), pp.92-99.

Nichol, D.G., 1998. Annual and between-sex variability of yellowfin sole, Pleuronectes aspe. Fishery Bulletin, 96, pp.547-561.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Bd. Can., (119) 300 p.

Spies, I. Thomas K. Wilderbuer, Daniel G. Nichol, Jerry Hoff, and Wayne Palsson 2018. Assessment of the arrowtooth flounder stock in the Eastern Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2019. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, AK 99510.

Spies, I., Ianelli, J,. and Palsson, W. 2019a. Assessment of the arrowtooth flounder stock in the Eastern Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2020. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, AK 99510.

Spies, I., Wilderbuer, T., Nichol, D., and J. Ianelli. 2019b. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2020. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, AK 99510.

Wilderbuer, T. K. 1992. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1993. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Wilderbuer, T.K. and Turnock, B.J., 2009. Sex-specific natural mortality of arrowtooth flounder in Alaska: Implications of a skewed sex ratio on exploitation and management. North American Journal of Fisheries Management, 29(2), pp.306-322.

Wilderbuer, T., Nichol, D., and J. Ianelli. 2018. Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2019, chapter 4. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, AK 99510.

Tables

Table 1: Model estimates of Yellowfin Sole female spawning biomass (FSB) in metric tons (t) and upper (HCI) and lower (LCI) 95% confidence intervals from the 2019 stock assessment, including Models 18.1a and 18.2.

	Model 18.2			Model 18.1a		
	FSB (t)	LCI	HCI	FSB (t)	LCI	HCI
1954	995,657	769,574	1,288,160	915,908	681,608	1,230,750
1955	1,005,490	789,513	1,280,540	924,390	697,057	1,225,860
1956	996,743	794,331	1,250,730	915,709	698,802	1,199,940
1957	972,387	785,412	1,203,870	892,677	688,253	1,157,820
1958	935,656	764,916	1,144,510	858,483	667,585	1,103,970
1959	859,116	708,274	1,042,080	786,931	612,923	1,010,340
1960	672,609	551,965	819,622	611,836	462,609	809,201
1961	369,438	283,114	482,084	332,534	211,227	523,505
1962	47,947	19,142	120,097	106,089	65,650	171,437
1963	12,714	4,771	33,878	104,083	81,245	133,341
1964	26,218	13,232	51,950	136,253	115,305	161,008
1965	51,391	32,679	80,816	160,204	133,762	191,874
1966	91,133	67,413	123,200	189,954	152,418	236,735
1967	125,614	101,748	155,079	196,192	155,342	247,784
1968	147,229	123,776	175,127	190,858	155,387	234,427
1969	152,238	125,818	184,205	177,685	149,722	210,871
1970	119,798	101,361	141,589	130,348	110,822	153,314
1971	94,236	79,963	111,058	105,971	91,610	122,584
1972	65,770	52,544	82,324	84,733	71,684	100,158
1973	70,963	57,243	87,972	84,596	70,778	101,111
1974	85,064	70,287	102,948	92,645	77,890	110,195
1975	137,410	117,002	161,378	144,943	125,229	167,761
1976	205,495	179,989	234,615	205,625	181,712	232,684
1977	310,577	277,551	347,533	298,276	268,485	331,374
1978	446,372	404,443	492,648	414,956	378,919	454,421
1979	590,091	538,349	646,806	533,330	490,830	579,510
1980	751,446	689,177	819,341	665,236	615,936	718,482
1981	903,580	831,201	982,262	787,055	731,300	847,059
1982	991,653	914,034	1,075,860	855,370	796,724	918,333
1983	1,117,680	1,032,420	1,209,970	958,019	894,705	1,025,810
1984	1,219,120	1,127,810	1,317,820	1,038,760	971,990	1,110,110
1985	1,284,230	1,186,900	1,389,550	1,086,830	1,016,460	1,162,060
1986	1,278,870	1,178,860	1,387,360	1,073,790	1,002,040	1,150,670
1987	1,280,870	1,177,260	1,393,600	1,067,490	993,463	1,147,040
1988	1,219,480	1,117,080	1,331,280	1,009,630	936,584	1,088,360
1989	1,194,240	1,090,210	1,308,200	982,484	908,353	1,062,660
1990	1,209,630	1,103,960	1,325,420	993,667	918,508	1,074,980
1991	1,306,040	1,194,900	1,427,520	1,075,380	996,596	1,160,400
1992	1,405,300	1,288,080	1,533,200	1,158,760	1,075,940	1,247,950
1993	1,450,280	1,328,810	1,582,850	1,194,580	1,108,800	1,287,000
1994	1,455,350	1,333,270	1,588,610	1,197,910	1,111,740	1,290,750
1995	1,456,660	1,333,240	1,591,510	1,197,290	1,110,120	1,291,310
1996	1,378,410	1,259,580	1,508,450	1,130,460	1,046,460	1,221,210
1997	1,336,920	1,219,640	1,465,470	1,094,160	1,011,180	1,183,940
1998	1,261,720	1,148,330	1,386,300	1,029,730	949,397	1,116,860
1999	1,251,930	1,139,090	1,375,950	1,021,800	941,711	1,108,690

2000	1,235,910	1,124,180	1,358,750	1,008,730	929,270	1,094,970
2001	1,230,060	1,119,290	1,351,790	1,004,900	926,005	1,090,520
2002	1,227,310	1,117,240	1,348,210	1,003,480	924,975	1,088,640
2003	1,236,510	1,126,800	1,356,910	1,012,930	934,586	1,097,850
2004	1,271,980	1,160,670	1,393,960	1,044,610	965,010	1,130,770
2005	1,290,030	1,178,040	1,412,670	1,061,350	981,126	1,148,130
2006	1,314,510	1,200,540	1,439,300	1,082,770	1,000,930	1,171,300
2007	1,320,870	1,205,670	1,447,070	1,088,570	1,005,600	1,178,380
2008	1,292,010	1,177,360	1,417,830	1,064,230	981,334	1,154,130
2009	1,249,410	1,136,430	1,373,620	1,028,460	946,482	1,117,530
2010	1,218,970	1,107,310	1,341,890	1,003,630	922,322	1,092,110
2011	1,189,640	1,079,340	1,311,210	980,254	899,636	1,068,100
2012	1,166,410	1,056,180	1,288,160	961,340	880,409	1,049,710
2013	1,151,250	1,039,910	1,274,520	948,637	866,480	1,038,580
2014	1,098,520	987,916	1,221,500	902,784	820,721	993,052
2015	1,084,640	971,738	1,210,670	889,934	805,619	983,072
2016	1,080,390	964,790	1,209,840	885,570	798,685	981,906
2017	1,052,650	936,257	1,183,510	861,185	773,144	959,251
2018	1,049,380	929,804	1,184,330	857,537	766,402	959,508
2019	1,062,990	938,252	1,204,310	868,914	773,040	976,678

Table 2: Model estimates of Yellowfin Sole age 2+ total biomass (t) from the 2019 stock assessment, Model 18.1a and 18.2, and upper (HCI) and lower (LCI) 95% confidence intervals.

	Model 18.2			Model 18.1a		
	Biomass (t)	LCI	HCI	Biomass (t)	LCI	HCI
1954	2,568,990	2,261,130	2,918,770	2,359,740	1,955,750	2,847,180
1955	2,521,590	2,243,160	2,834,590	2,324,790	1,937,740	2,789,140
1956	2,467,720	2,222,200	2,740,360	2,278,250	1,910,280	2,717,100
1957	2,407,370	2,197,530	2,637,240	2,224,760	1,880,870	2,631,520
1958	2,361,270	2,188,490	2,547,690	2,192,360	1,885,180	2,549,600
1959	2,312,040	2,174,940	2,457,780	2,168,120	1,916,640	2,452,590
1960	2,131,950	2,025,970	2,243,480	2,023,930	1,846,440	2,218,480
1961	1,689,120	1,612,230	1,769,680	1,625,110	1,529,600	1,726,570
1962	1,178,470	1,127,240	1,232,040	1,165,070	1,104,040	1,229,470
1963	834,849	801,795	869,266	856,721	798,872	918,760
1964	875,678	842,106	910,590	892,087	835,008	953,068
1965	869,728	835,979	904,840	871,860	823,676	922,862
1966	917,105	881,419	954,236	910,892	866,697	957,340
1967	905,579	868,346	944,408	890,782	850,522	932,947
1968	834,485	796,394	874,398	810,474	773,850	848,831
1969	876,087	833,236	921,142	842,478	803,553	883,289
1970	860,596	812,394	911,658	813,400	771,733	857,316
1971	946,723	889,263	1,007,900	877,193	829,253	927,905
1972	1,044,350	975,549	1,118,010	948,707	892,805	1,008,110
1973	1,336,300	1,251,820	1,426,480	1,204,100	1,136,520	1,275,690
1974	1,627,450	1,526,230	1,735,380	1,455,610	1,375,370	1,540,520
1975	2,020,490	1,898,200	2,150,660	1,818,000	1,721,540	1,919,870
1976	2,372,970	2,231,510	2,523,400	2,130,460	2,019,580	2,247,430
1977	2,726,000	2,566,260	2,895,680	2,446,750	2,322,030	2,578,170
1978	3,060,000	2,883,160	3,247,680	2,747,860	2,610,160	2,892,820
1979	3,250,100	3,059,280	3,452,820	2,913,470	2,765,080	3,069,820
1980	3,457,650	3,254,370	3,673,620	3,101,040	2,942,950	3,267,620
1981	3,643,470	3,429,750	3,870,510	3,272,130	3,105,780	3,447,400
1982	3,772,620	3,552,940	4,005,880	3,389,530	3,219,080	3,569,000
1983	3,745,370	3,524,650	3,979,910	3,368,250	3,196,490	3,549,230
1984	4,004,910	3,769,040	4,255,550	3,599,900	3,416,940	3,792,660
1985	4,025,010	3,782,030	4,283,600	3,612,740	3,424,030	3,811,840
1986	3,720,010	3,484,860	3,971,040	3,325,240	3,142,480	3,518,620
1987	3,697,540	3,455,790	3,956,200	3,288,910	3,101,640	3,487,480
1988	3,591,380	3,350,870	3,849,150	3,193,860	3,006,750	3,392,620
1989	3,671,410	3,419,140	3,942,300	3,256,370	3,060,110	3,465,220
1990	3,520,210	3,273,140	3,785,940	3,121,530	2,928,590	3,327,170
1991	3,647,290	3,393,130	3,920,500	3,243,910	3,044,680	3,456,190
1992	3,885,910	3,617,680	4,174,040	3,457,530	3,247,420	3,681,230
1993	3,928,940	3,654,340	4,224,170	3,495,440	3,279,860	3,725,190
1994	3,973,900	3,696,330	4,272,320	3,541,210	3,322,590	3,774,210
1995	3,715,600	3,449,220	4,002,560	3,311,170	3,100,250	3,536,450
1996	3,619,500	3,357,900	3,901,480	3,228,210	3,020,380	3,450,340
1997	3,646,800	3,381,440	3,932,970	3,247,110	3,036,380	3,472,460
1998	3,340,330	3,089,200	3,611,880	2,968,760	2,768,670	3,183,300
1999	3,128,930	2,889,430	3,388,280	2,780,490	2,588,980	2,986,160
2000	3,179,720	2,939,640	3,439,410	2,830,550	2,638,460	3,036,620
2001	3,088,090	2,853,750	3,341,670	2,754,160	2,565,850	2,956,290

2002	3,128,070	2,893,370	3,381,810	2,795,920	2,607,030	2,998,500
2003	3,361,730	3,113,910	3,629,280	3,012,930	2,813,120	3,226,930
2004	3,593,780	3,331,950	3,876,180	3,224,900	3,013,720	3,450,880
2005	3,700,510	3,432,350	3,989,610	3,329,620	3,112,580	3,561,800
2006	3,669,130	3,400,990	3,958,400	3,302,880	3,085,410	3,535,670
2007	3,659,630	3,388,970	3,951,900	3,298,260	3,077,900	3,534,400
2008	3,491,070	3,226,920	3,776,840	3,147,840	2,931,750	3,379,860
2009	3,287,460	3,031,620	3,564,880	2,964,890	2,754,640	3,191,180
2010	3,318,660	3,057,880	3,601,680	2,994,290	2,779,520	3,225,650
2011	3,322,390	3,057,270	3,610,500	3,000,600	2,781,360	3,237,110
2012	3,269,470	3,001,140	3,561,790	2,950,040	2,727,470	3,190,780
2013	3,178,900	2,909,820	3,472,860	2,865,350	2,641,370	3,108,340
2014	2,922,880	2,664,870	3,205,860	2,640,920	2,424,100	2,877,140
2015	2,915,360	2,647,620	3,210,180	2,633,840	2,407,360	2,881,630
2016	3,056,080	2,764,880	3,377,950	2,757,750	2,510,290	3,029,600
2017	2,965,470	2,667,900	3,296,230	2,676,210	2,421,520	2,957,690
2018	3,048,260	2,718,210	3,418,380	2,753,560	2,468,250	3,071,850
2019	3,090,480	2,721,980	3,508,860	2,792,240	2,470,490	3,155,900

Table 3: Model estimates of age 1 recruitment (in billions of fish), 1954-2019, with 95% lower and upper confidence intervals (LCI, HCI) for Model 18.1a and 18.2.

Year	Model 18.1a			Model 18.2		
	Recruitment	LCI	HCI	Recruitment	LCI	HCI
1954	1.511	1.117	1.904	2.301	1.598	3.005
1955	1.264	0.958	1.571	1.613	0.775	2.451
1956	1.181	0.857	1.505	1.067	0.564	1.569
1957	4.735	2.339	7.132	3.507	2.677	4.336
1958	3.247	0.978	5.515	2.528	2.129	2.928
1959	2.127	1.153	3.101	1.946	1.667	2.225
1960	1.811	1.381	2.241	1.842	1.585	2.100
1961	1.008	0.812	1.204	1.067	0.872	1.263
1962	1.900	1.647	2.153	2.039	1.769	2.310
1963	0.995	0.809	1.181	1.048	0.851	1.245
1964	0.920	0.746	1.095	0.956	0.771	1.140
1965	1.192	0.988	1.396	1.279	1.059	1.500
1966	1.217	0.998	1.436	1.359	1.111	1.608
1967	2.550	2.205	2.894	2.878	2.471	3.285
1968	3.894	3.446	4.341	4.484	3.943	5.025
1969	3.986	3.523	4.449	4.633	4.073	5.193
1970	5.256	4.718	5.794	6.121	5.462	6.781
1971	5.843	5.278	6.407	6.807	6.111	7.503
1972	4.594	4.109	5.080	5.350	4.756	5.944
1973	3.183	2.796	3.570	3.702	3.235	4.169
1974	4.281	3.840	4.722	4.969	4.431	5.508
1975	5.029	4.558	5.500	5.824	5.245	6.403
1976	3.308	2.939	3.677	3.820	3.375	4.265
1977	4.165	3.746	4.584	4.800	4.291	5.308
1978	2.728	2.400	3.057	3.141	2.748	3.533
1979	1.743	1.486	2.001	2.009	1.705	2.312
1980	3.374	3.010	3.737	3.900	3.459	4.341
1981	2.517	2.208	2.826	2.926	2.552	3.299
1982	7.294	6.716	7.872	8.507	7.768	9.246
1983	1.350	1.129	1.572	1.575	1.310	1.839
1984	6.040	5.530	6.550	7.039	6.394	7.685
1985	2.089	1.815	2.363	2.435	2.104	2.766
1986	1.605	1.370	1.839	1.868	1.587	2.149
1987	2.193	1.919	2.467	2.550	2.219	2.881
1988	3.007	2.680	3.333	3.497	3.097	3.897
1989	3.008	2.683	3.334	3.500	3.100	3.899
1990	1.504	1.284	1.724	1.750	1.486	2.014
1991	1.692	1.455	1.928	1.973	1.688	2.258
1992	3.757	3.376	4.138	4.392	3.918	4.865
1993	2.243	1.961	2.525	2.625	2.281	2.969
1994	1.893	1.636	2.151	2.214	1.902	2.525
1995	1.906	1.647	2.164	2.224	1.911	2.536
1996	4.700	4.256	5.144	5.473	4.920	6.027
1997	2.031	1.763	2.298	2.360	2.038	2.682
1998	1.685	1.446	1.924	1.953	1.667	2.238
1999	2.065	1.801	2.329	2.382	2.066	2.699
2000	2.893	2.571	3.214	3.332	2.943	3.720
2001	1.873	1.620	2.125	2.158	1.857	2.459

2002	2.538	2.231	2.846	2.926	2.556	3.296
2003	2.448	2.141	2.755	2.822	2.454	3.191
2004	3.816	3.400	4.232	4.403	3.897	4.910
2005	1.689	1.429	1.949	1.953	1.643	2.262
2006	1.931	1.633	2.228	2.234	1.880	2.588
2007	2.400	2.038	2.762	2.777	2.346	3.209
2008	2.226	1.859	2.592	2.574	2.140	3.008
2009	2.597	2.162	3.031	3.003	2.487	3.519
2010	3.702	3.083	4.321	4.280	3.547	5.013
2011	1.262	0.920	1.605	1.458	1.058	1.857
2012	0.672	0.403	0.942	0.776	0.464	1.088
2013	1.759	1.184	2.333	2.034	1.365	2.703
2014	2.649	1.631	3.667	3.075	1.887	4.263
2015	3.932	1.903	5.962	4.538	2.187	6.889
2016	3.050	0.091	6.009	3.465	0.101	6.829
2017	2.160	-0.651	4.971	2.437	-0.732	5.607
2018	2.366	-0.914	5.647	2.672	-1.031	6.375
2019	2.389	-0.951	5.729	2.699	-1.075	6.473

Table 4: Comparison of likelihood values for survey and fishery age, selectivity, survey biomass, recruitment, catchability, and total likelihood for Models 18.1a and 18.2.

Likelihood component	Model 18.1a	Model 18.2
Survey age	589.18	560.25
Fishery age	651.62	609.64
Selectivity	63.4	62.81
Survey biomass	91.98	95.08
Recruitment	26.9	28.25
Catchability	0.0083	0.0069
Total	1423.09	1356.03

Table 5: Comparison of reference points for Model 18.2 and 18.1a. Values are in metric tons (t).

	Model 18.2		Model 18.1a	
Quantity	2020	2021	2020	2021
M (natural mortality rate)	0.12, 0.135	0.12, 0.135	0.12	0.12
Tier	1a	1a	1a	1a
Projected total (age 6+) biomass (t)	2,726,370	2,733,120	2,466,130	2,472,760
Projected female spawning biomass (t)	1,051,050	1,005,310	859,256	820,588
$B_{100\%}$	1,501,510	1,501,510	1,275,940	1,275,940
$B_{MSY\%}$	542,791	542,791	467,194	467,194
F_{OFL}	0.118	0.118	0.117	0.117
$maxF_{ABC}$	0.109	0.109	0.106	0.106
F_{ABC}	0.109	0.109	0.106	0.106
OFL	321,794	322,591	289,512	290,290
$maxABC$	296,060	296,793	262,632	263,337
ABC	296,060	296,793	262,632	263,337
Status	2018	2019	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Projections for Model 18.1a and 18.2 were based on estimated catches of 118,642 t in 2019 and 137,230 used in place of maximum ABC for 2020.

Table 6: Model estimates of Yellowfin Sole full selection fishing mortality (F) and exploitation rate (catch/total biomass).

	Model 18.2		Model 18.1a	
	Full selection F	Catch/Total Biomass	Full selection F	Catch/Total Biomass
1954	0.006	0.005	0.007	0.005
1955	0.008	0.006	0.008	0.006
1956	0.013	0.010	0.014	0.011
1957	0.013	0.010	0.014	0.011
1958	0.026	0.019	0.028	0.020
1959	0.123	0.080	0.130	0.085
1960	0.411	0.214	0.435	0.225
1961	0.967	0.328	1.083	0.341
1962	4.874	0.357	3.984	0.361
1963	0.319	0.103	1.317	0.100
1964	0.277	0.127	0.309	0.125
1965	0.236	0.062	0.252	0.062
1966	0.436	0.112	0.471	0.112
1967	0.593	0.179	0.622	0.182
1968	0.464	0.101	0.569	0.104
1969	0.654	0.191	0.679	0.198
1970	0.679	0.155	0.742	0.164
1971	0.891	0.169	0.626	0.183
1972	0.287	0.046	0.331	0.050
1973	0.445	0.059	0.452	0.065
1974	0.130	0.026	0.150	0.029
1975	0.118	0.032	0.129	0.036
1976	0.115	0.024	0.124	0.026
1977	0.053	0.021	0.057	0.024
1978	0.103	0.045	0.113	0.050
1979	0.060	0.030	0.065	0.034
1980	0.066	0.025	0.074	0.028
1981	0.052	0.027	0.058	0.030
1982	0.039	0.025	0.043	0.028
1983	0.041	0.029	0.045	0.032
1984	0.063	0.040	0.069	0.044
1985	0.093	0.056	0.103	0.063
1986	0.085	0.056	0.095	0.063
1987	0.084	0.049	0.093	0.055
1988	0.105	0.062	0.118	0.070
1989	0.078	0.042	0.088	0.047
1990	0.034	0.023	0.038	0.026
1991	0.039	0.026	0.043	0.029
1992	0.063	0.041	0.070	0.046
1993	0.047	0.027	0.052	0.030
1994	0.056	0.036	0.063	0.041
1995	0.049	0.034	0.054	0.038
1996	0.053	0.036	0.059	0.040
1997	0.078	0.050	0.087	0.056
1998	0.045	0.030	0.050	0.034
1999	0.034	0.022	0.038	0.024
2000	0.042	0.026	0.047	0.030
2001	0.031	0.021	0.035	0.023

2002	0.035	0.023	0.039	0.026
2003	0.034	0.022	0.037	0.025
2004	0.031	0.019	0.034	0.021
2005	0.042	0.026	0.046	0.028
2006	0.039	0.027	0.043	0.030
2007	0.054	0.033	0.059	0.037
2008	0.061	0.043	0.067	0.047
2009	0.046	0.033	0.051	0.036
2010	0.050	0.036	0.054	0.040
2011	0.064	0.045	0.070	0.050
2012	0.063	0.045	0.068	0.050
2013	0.078	0.052	0.085	0.058
2014	0.077	0.054	0.084	0.059
2015	0.071	0.044	0.078	0.048
2016	0.074	0.044	0.081	0.049
2017	0.068	0.045	0.076	0.049
2018	0.069	0.043	0.075	0.048
2019	0.062	0.038	0.068	0.042

Figures

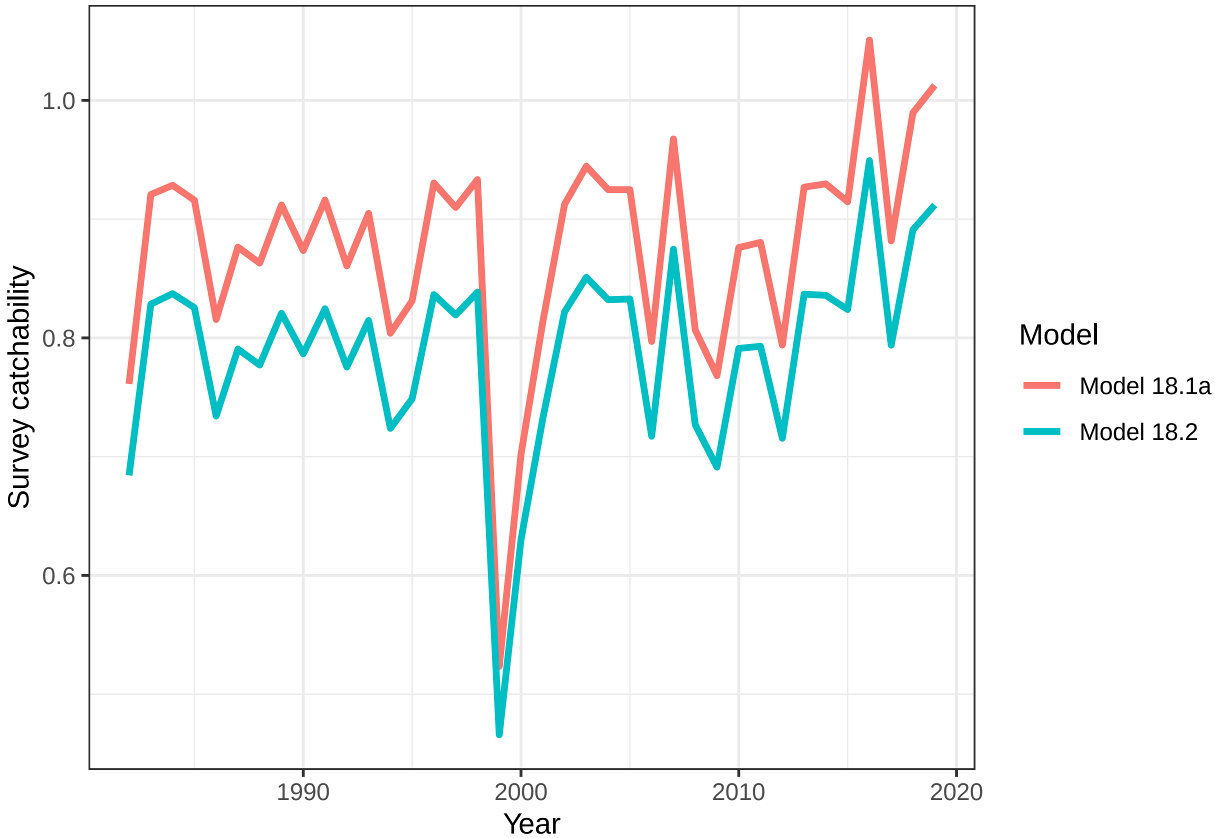

Figure 1: Survey catchability for Model 18.1a and 18.2, 1982-2019.

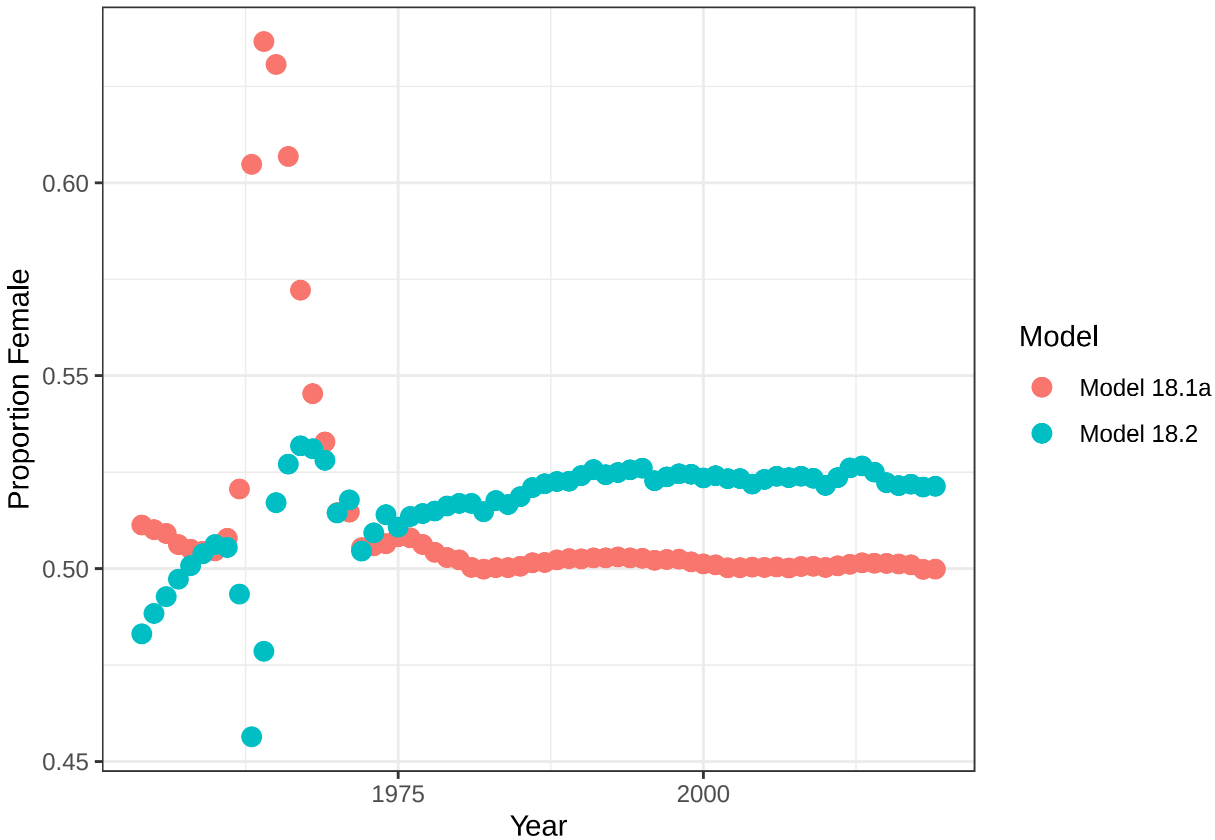

Figure 2: Model estimates of the proportion of female Yellowfin Sole in the population, 1982-2019.

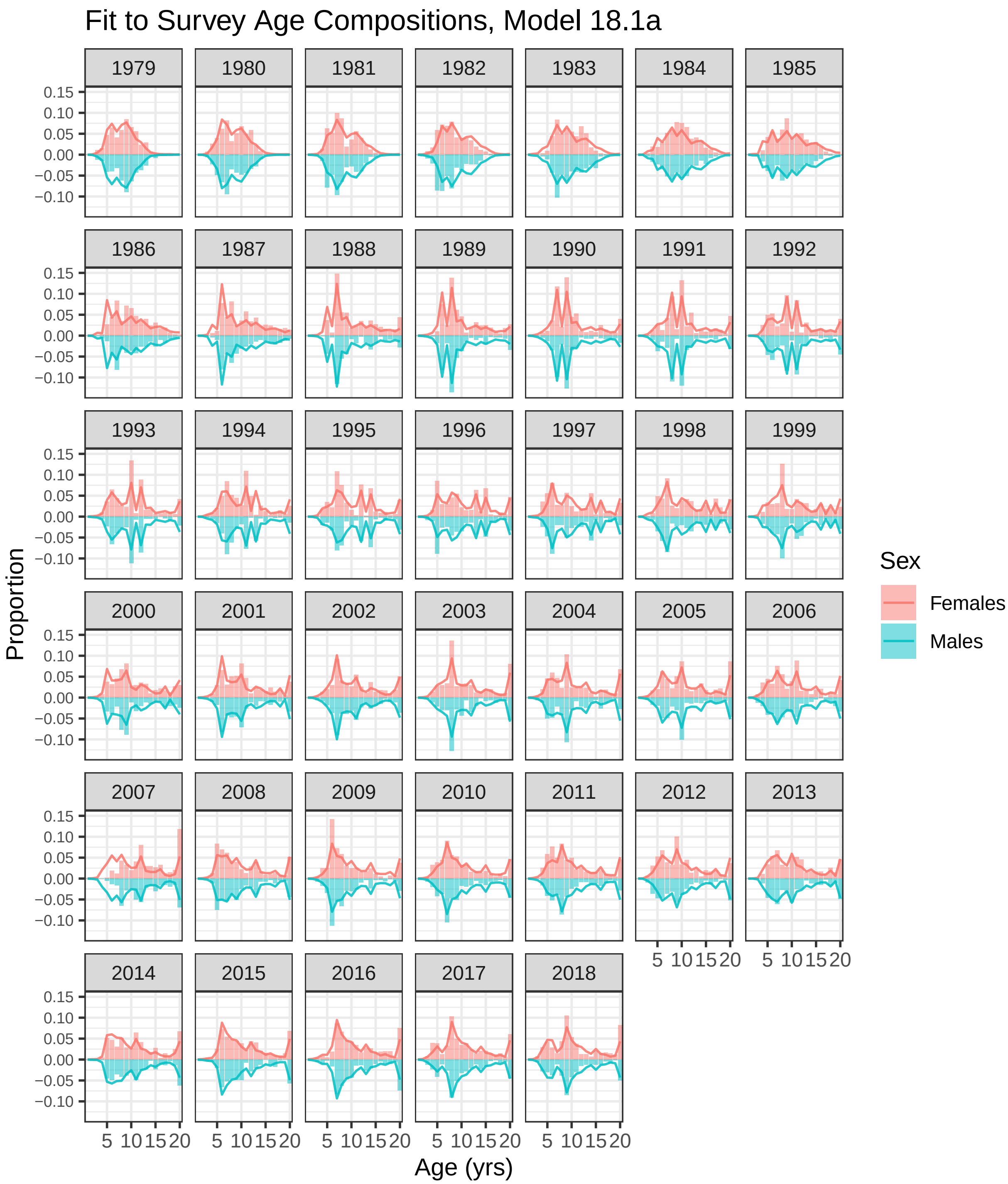

Figure 3: Model 18.1a fit to the time-series of survey age composition, by sex, 1979-2018.

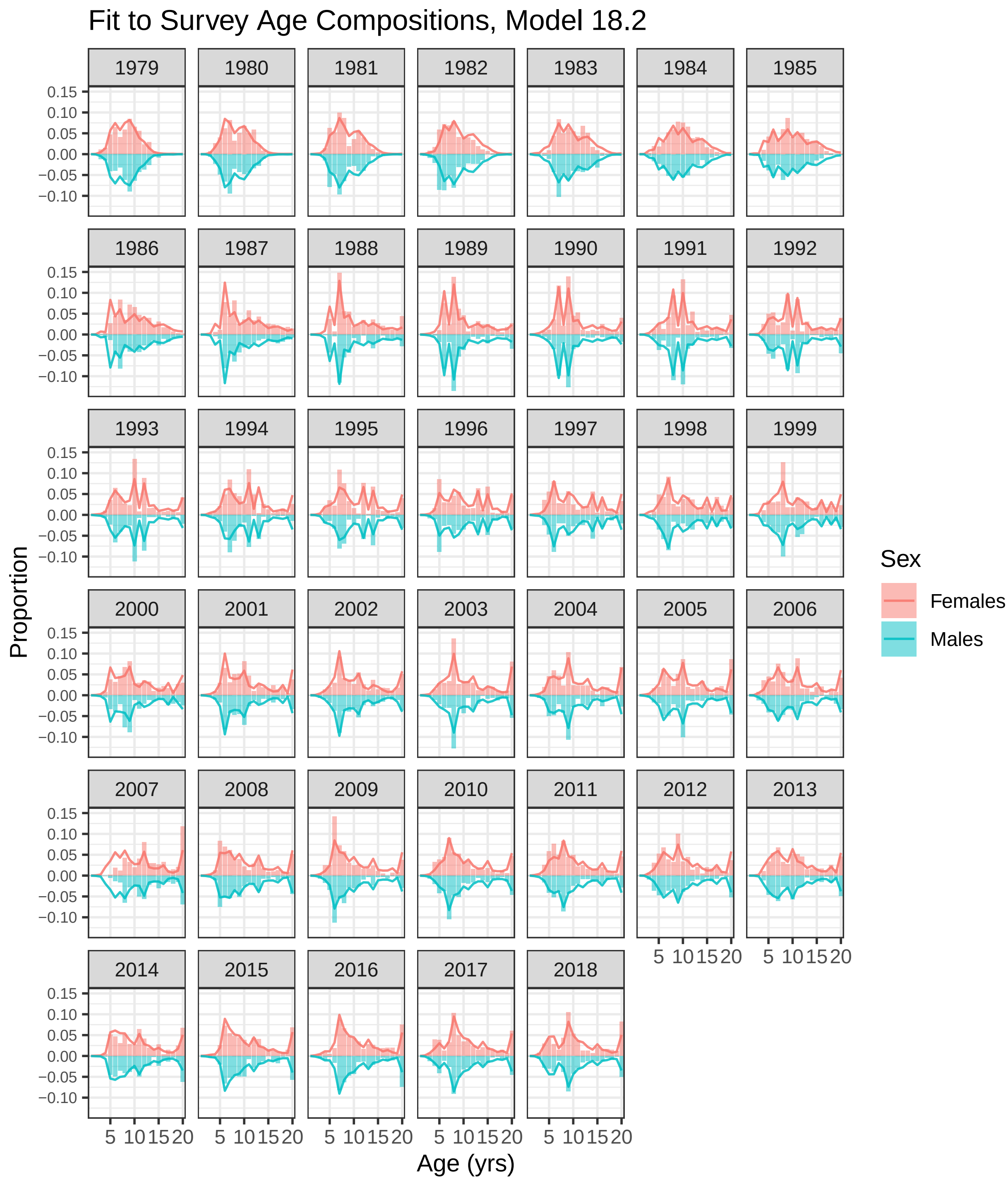

Figure 4: Model 18.2 fit to the time-series of survey age composition, by sex, 1979-2018.

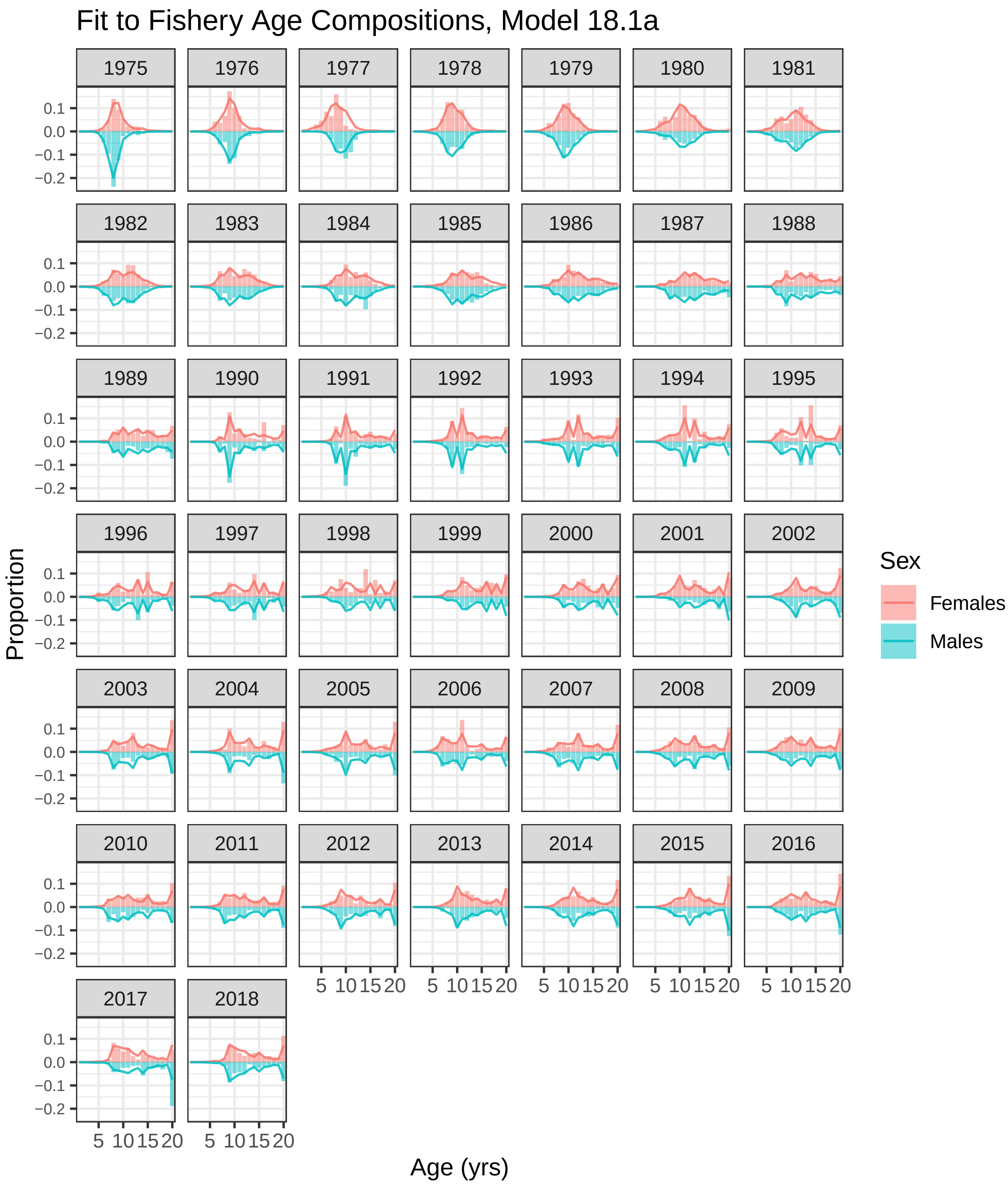

Figure 5: Model 18.1a fit to the time-series of fishery age composition, by sex, 1975-2018.

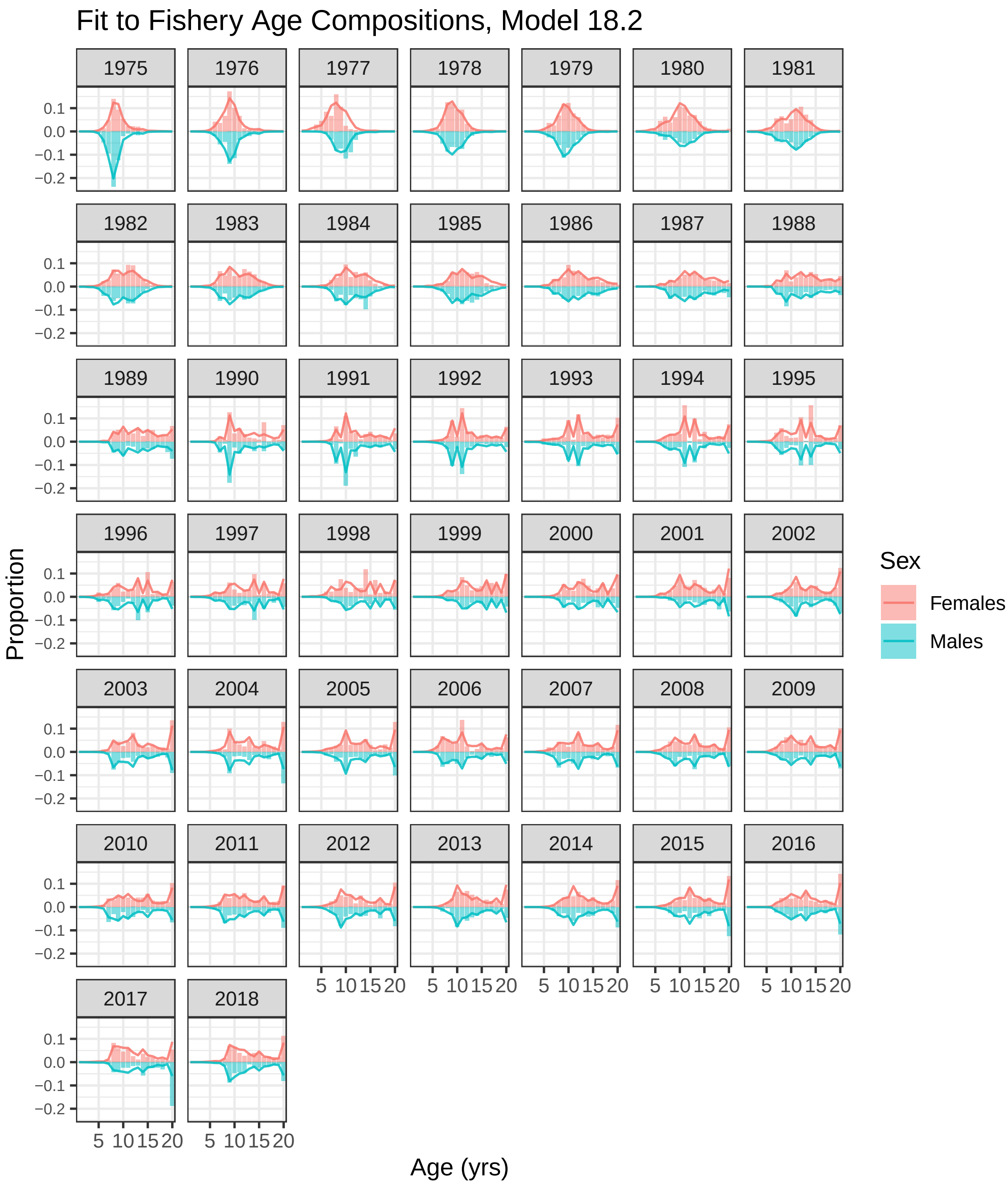

Figure 6: Model 18.2 fit to the time-series of fishery age composition, by sex, 1975-2018.

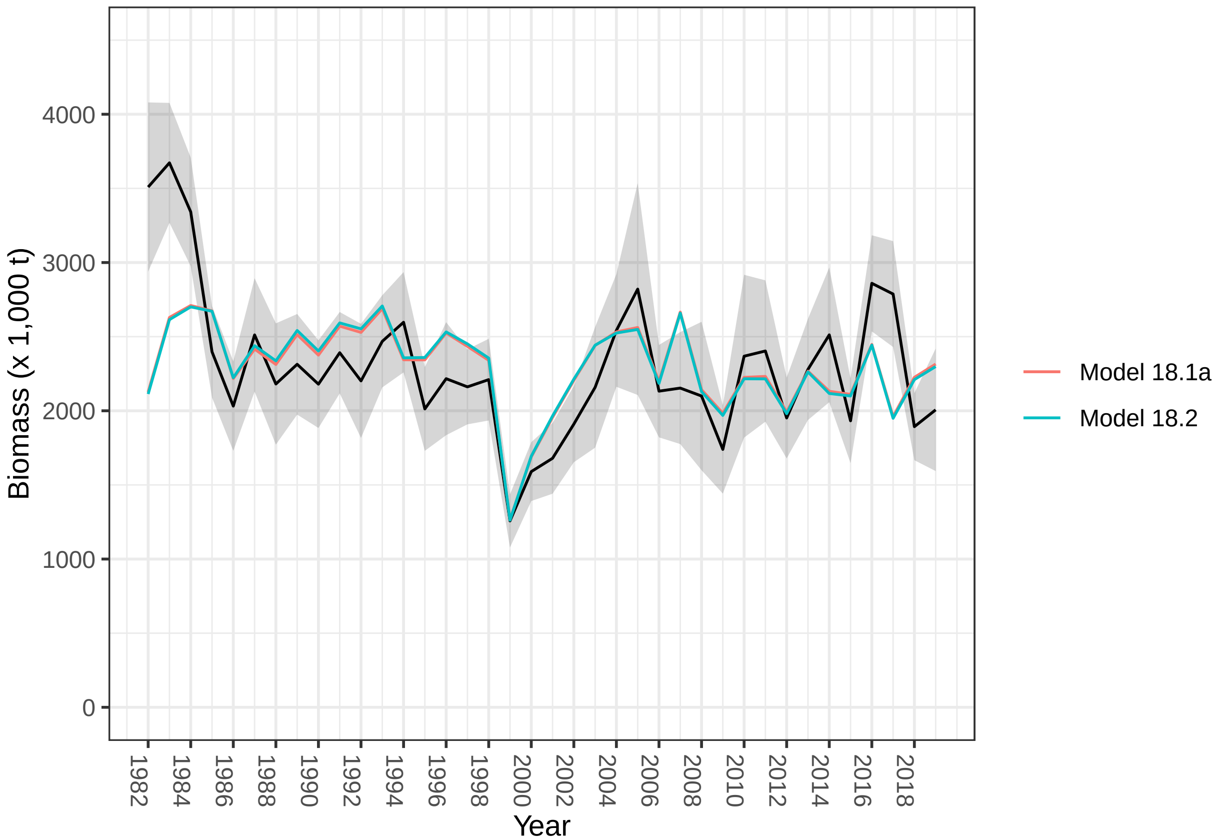

Figure 7: NMFS eastern Bering Sea survey biomass estimates (black line), with 95% confidence intervals and Model 18.1a and Model 18.2 fit to survey biomass estimates, from 1982-2019.

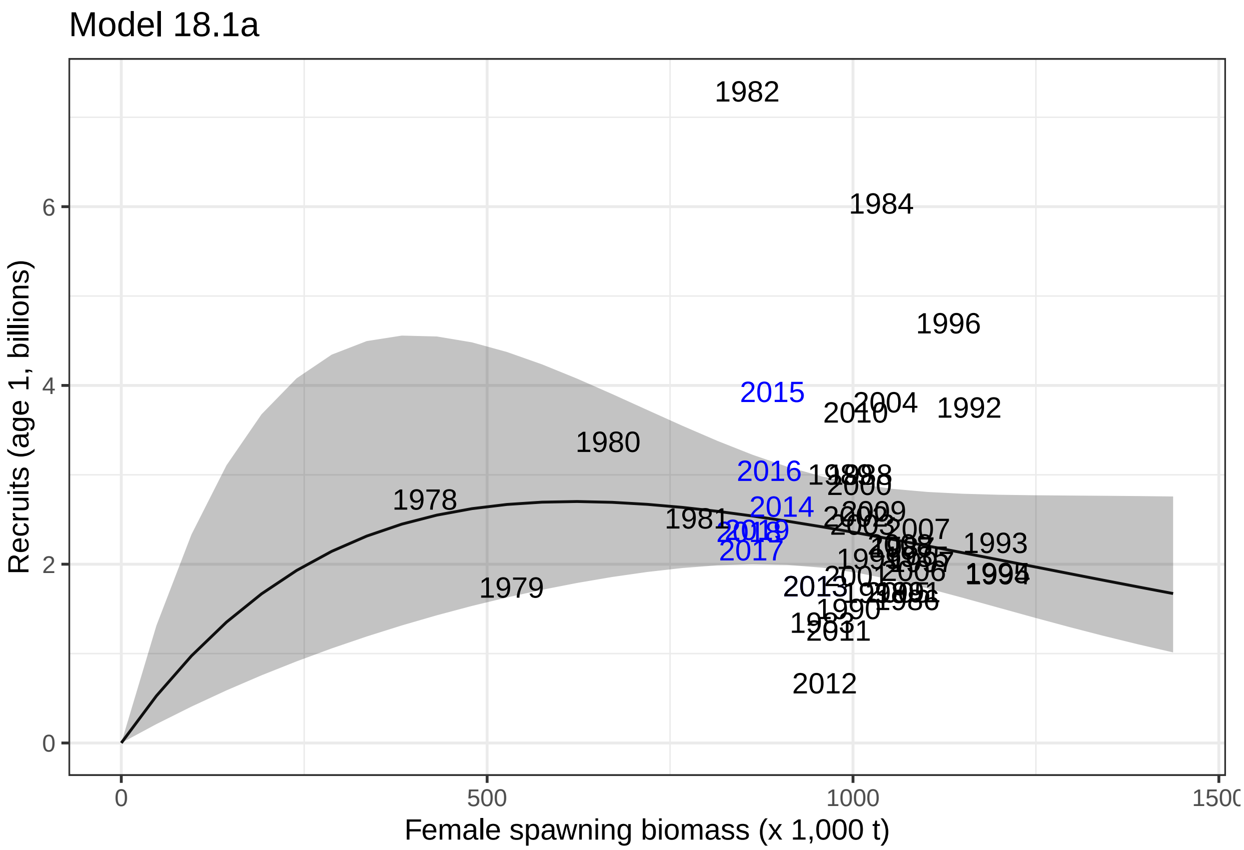

Figure 8: Ricker stock recruitment curve for Model 18.1a with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2013. Years in black indicate data used to fit the model.

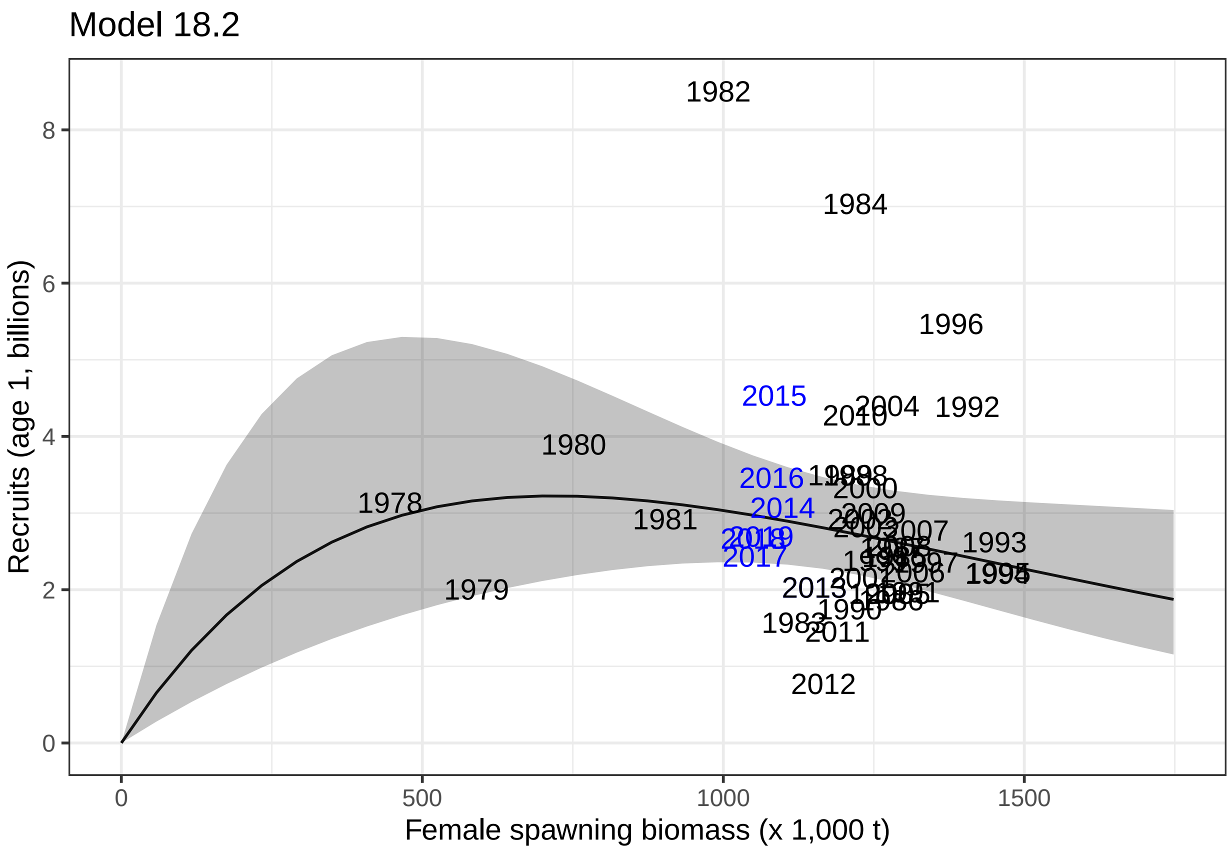

Figure 9: Ricker stock recruitment curve for Model 18.2 with 95% confidence intervals (shaded region) fit to female spawning biomass and recruitment data from 1978-2013. Years in black indicate data used to fit the model.

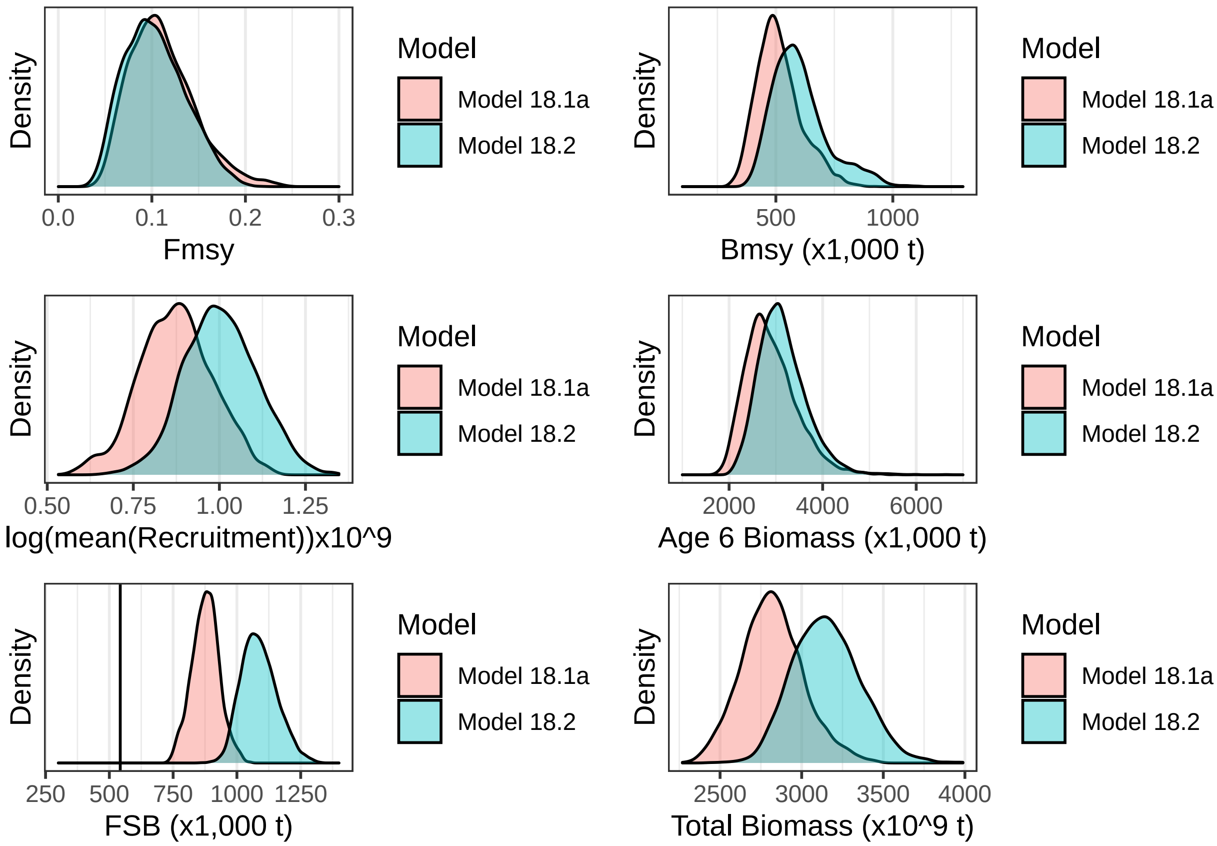

Figure 10: MCMC posterior distributions for Fmsy, Bmsy, log(mean(Recruitment)), Age 6 biomass, female spawning biomass (FSB) for 2019, and total biomass for 2019.

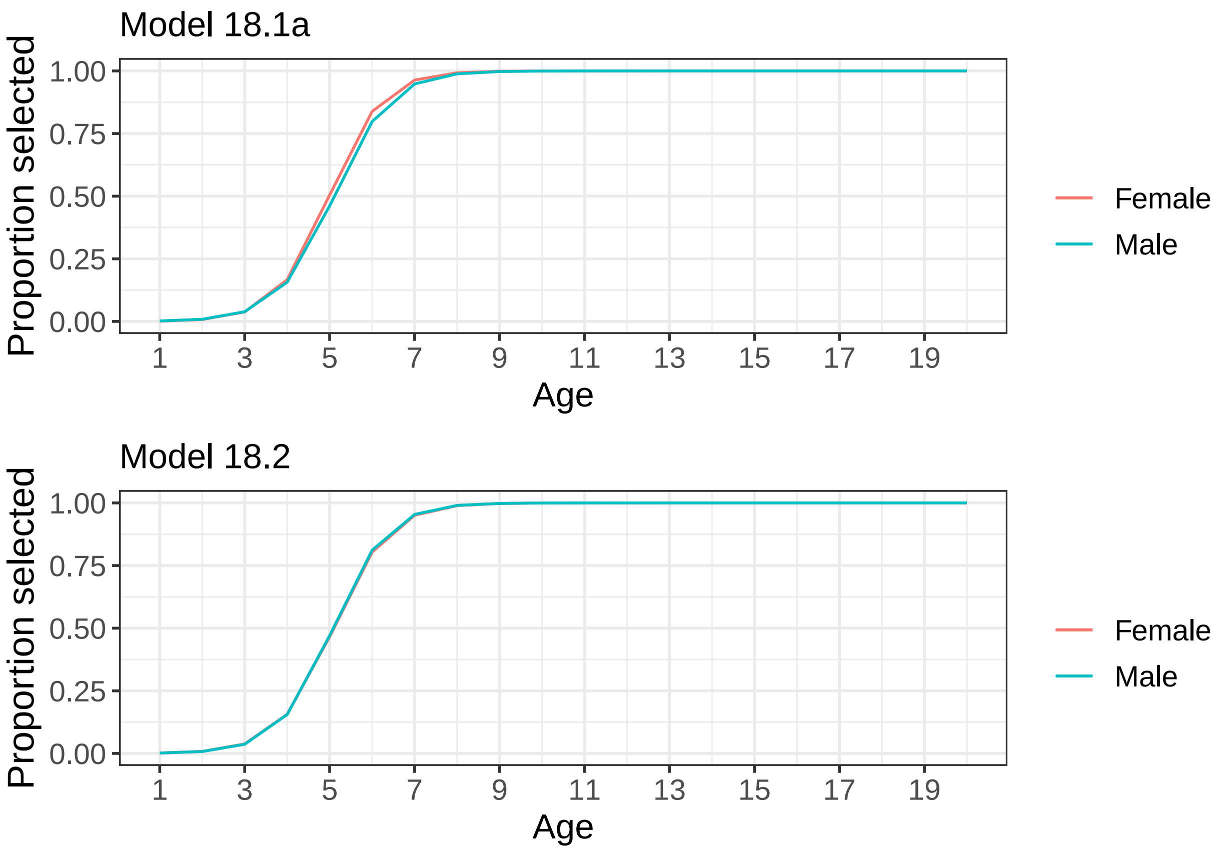

Figure 11: Estimate of survey selectivity for males and females, Model 18.1a upper panel, Model 18.2 lower panel.

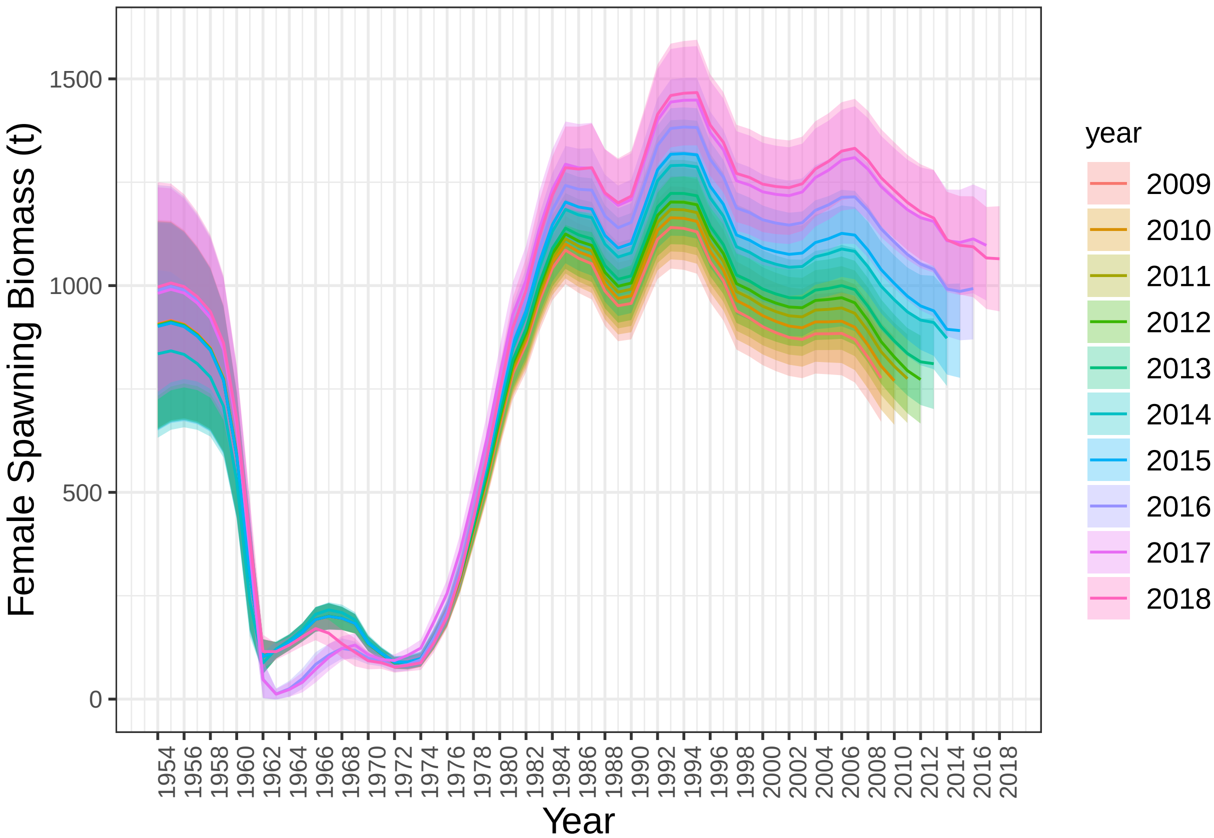

Figure 12: Retrospective plot of female spawning biomass. The preferred model with data through 2019 is shown, and data was sequentially removed through 2009, based on Model 18.2.

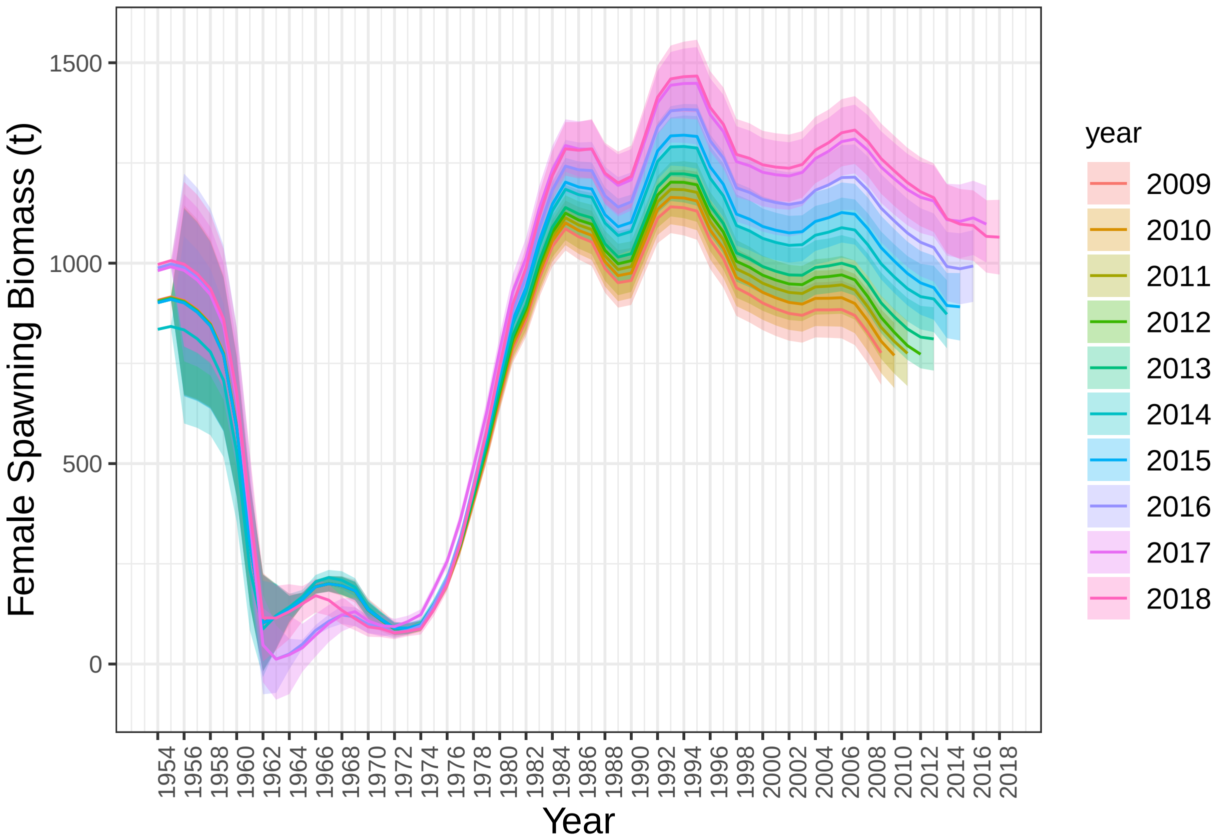

Figure 13: Retrospective plot of female spawning biomass. The preferred model with data through 2019 is shown, and data was sequentially removed through 2009, based on Model 18.1a.

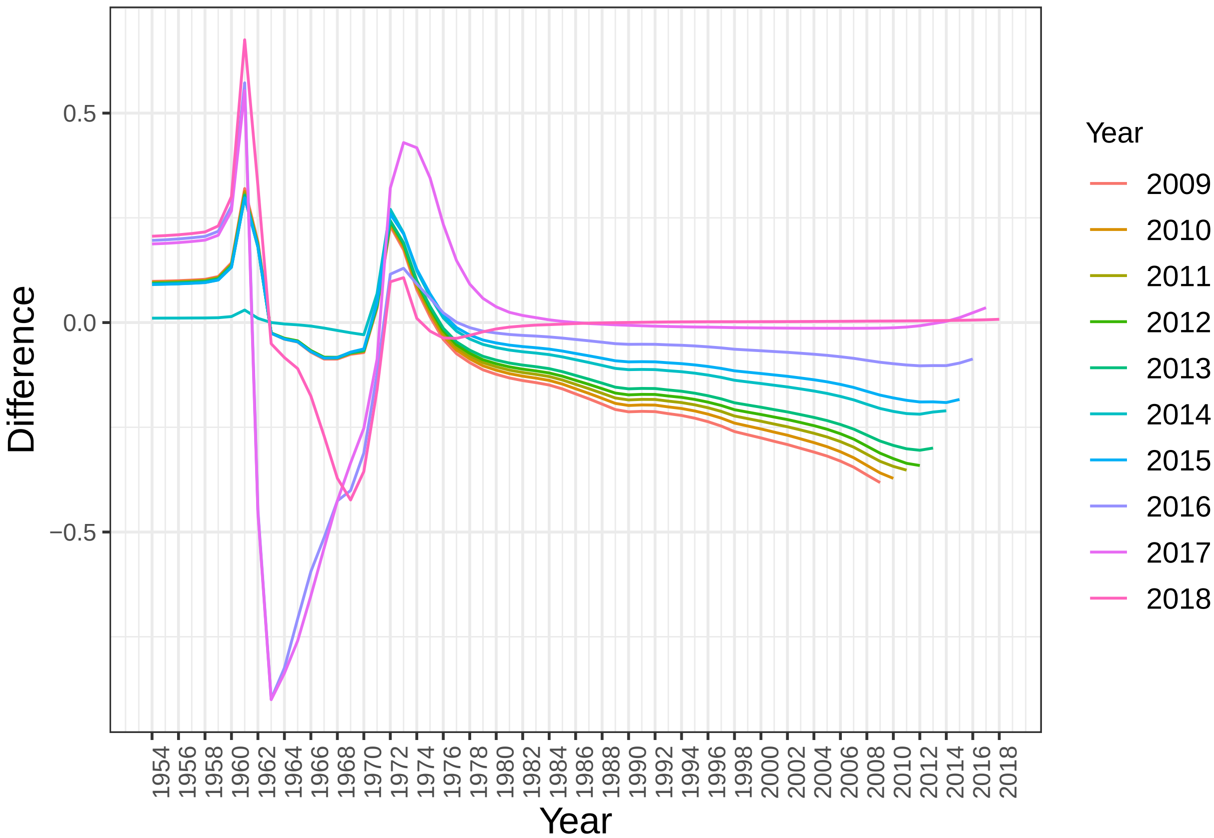

Figure 14: Relative differences in estimates of spawning biomass between the 2019 model and the retrospective model run for years 2018 through 2009, based on 18.2.

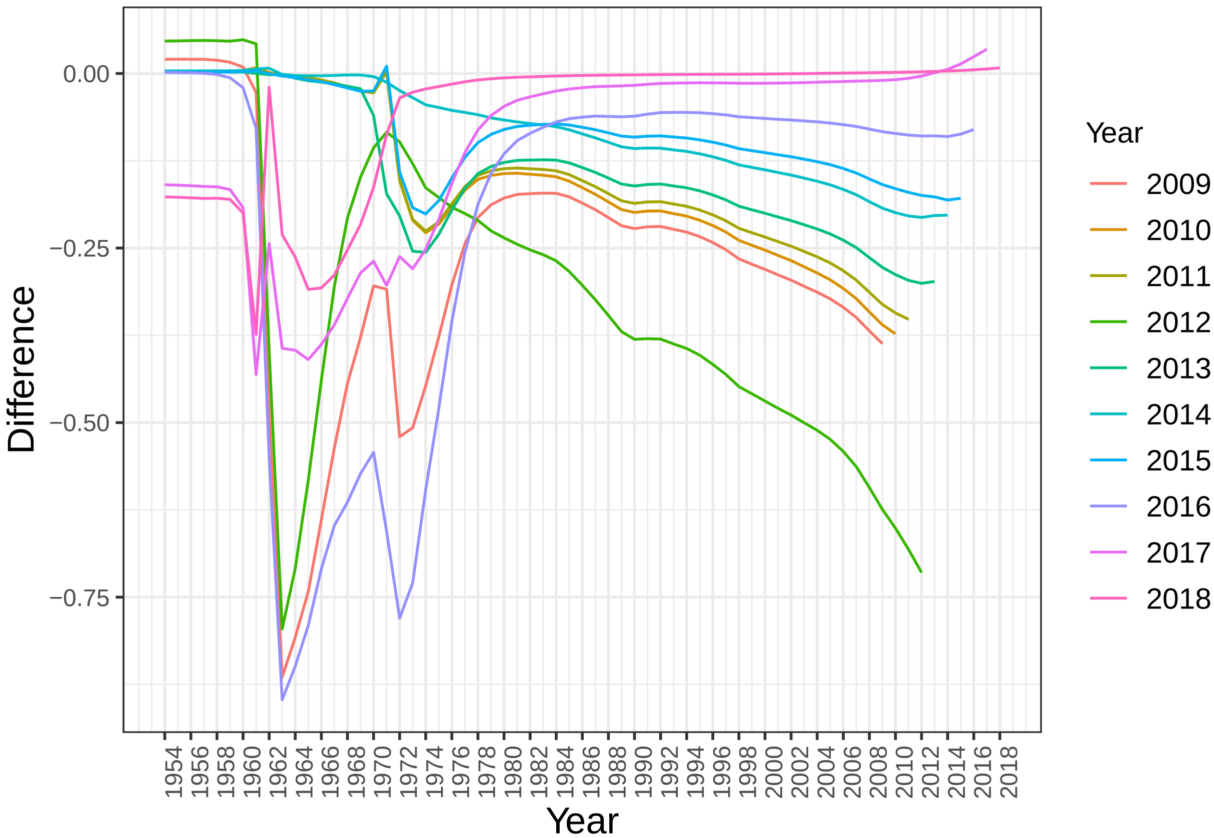

Figure 15: Relative differences in estimates of spawning biomass between the 2019 model and the retrospective model run for years 2018 through 2009, based on 18.1a.