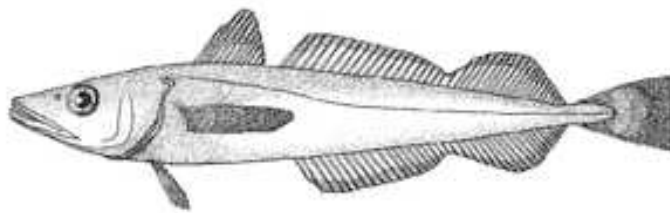


# **Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2018**



Joint Technical Committee of the Pacific Hake/Whiting Agreement  
Between the Governments of the United States and Canada

March 2<sup>nd</sup>, 2018

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This document reports the collaborative efforts of the official U.S. and Canadian members of the Joint Technical Committee, and others that contributed significantly.

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## ONE-PAGE SUMMARY

- The stock assessment model for 2018 is similar in structure to the 2017 model. It is fit to an acoustic survey index of abundance, annual commercial catch data, and age-composition data from the survey and commercial fisheries.
- Updates to the data include: the biomass estimate and age-composition data from the acoustic survey conducted in 2017, fishery catch and age-composition data from 2017, weight-at-age data for 2017, and calculation of a new age-based maturity ogive.
- The model was updated to include a new non-iterative approach for weighting age-composition data.
- Coastwide catch in 2017 was the largest on record at 440,944 t, out of a Total Allowable Catch (adjusted for carryovers) of 597,500 t. Attainment in the U.S. was 80.2% of its quota; in Canada it was 55.6%.
- The stock is estimated to have been at relatively high levels since 2013 due to large estimated 2010 and 2014 cohorts.
- The median estimate of the 2018 relative spawning biomass (female spawning biomass at the start of 2018 divided by that at unfished equilibrium,  $B_0$ ) is 66.7% but is highly uncertain (with 95% credible interval from 32.7% to 136.1%).
- The median estimate of female spawning biomass at the start of 2018 is 1.357 million t (with 95% credible interval from 0.610 to 3.161 million t). This is a decrease from the 2017 median of 1.469 million t (though its 95% credible interval is 0.766–3.086 million t).
- The model estimates that the joint probability of being both above the target relative fishing intensity in 2017 and below the  $B_{40\%}$  (40% of  $B_0$ ) reference point at the start of 2018 is less than 6%.
- Based on the default harvest rule, the estimated median catch limit for 2018 is 725,984 t (with 95% credible interval from 270,948 to 1,881,590 t).
- As in the past, projections are highly uncertain due to uncertainty in estimates of recruitment for recent years. Projections were conducted across a range of catch levels.
- Projections setting the 2018 and 2019 catch equal to the 2017 Total Allowable Catch of 597,500 t show the estimated median relative spawning biomass decreasing from 67% in 2018 to 59% in 2019 and 50% in 2020. However, due to uncertainty there is an estimated 36% chance of the spawning biomass falling below 40% of  $B_0$  in 2020. There is an estimated 73% chance of the spawning biomass declining from 2018 to 2019, and a 82% chance of it declining from 2019 to 2020 under this constant level of catch.

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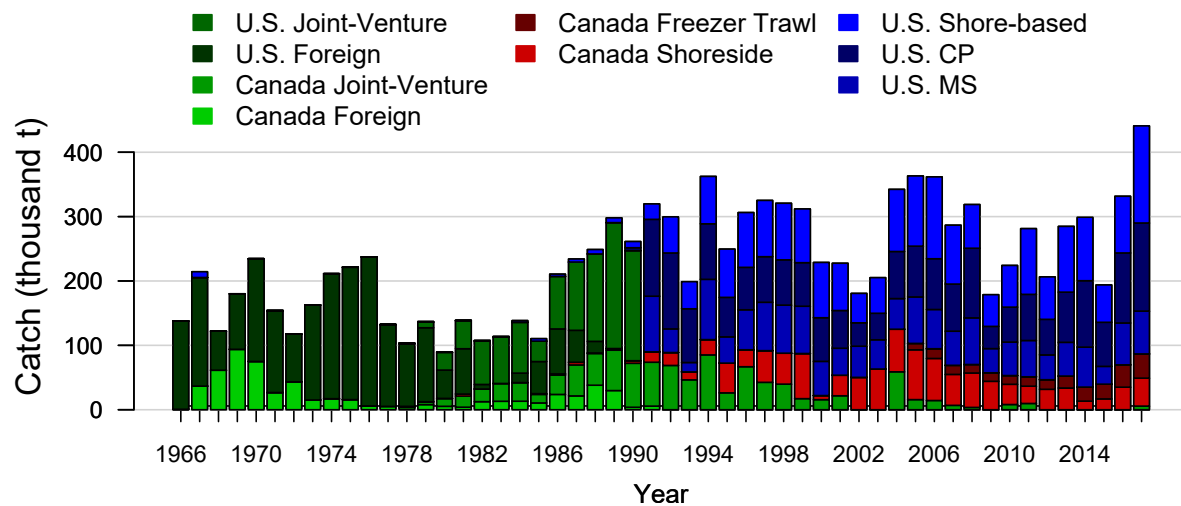
## EXECUTIVE SUMMARY

### STOCK

This assessment reports the status of the coastal Pacific Hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the United States and Canada at the start of 2018. This stock exhibits seasonal migratory behavior, ranging from offshore and generally southern waters during the winter spawning season to coastal areas between northern California and northern British Columbia during the spring, summer and fall when the fishery is conducted. In years with warmer water the stock tends to move farther to the north during the summer. Older hake tend to migrate farther north than younger fish in all years, with catches in the Canadian zone typically consisting of fish greater than four years old. Separate, and much smaller, populations of hake occurring in the major inlets of the northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California, are not included in this analysis.

### CATCHES

Coast-wide fishery Pacific Hake landings averaged 230,250 t from 1966 to 2017, with a low of 89,930 t in 1980 and a peak of 440,944 t in 2017 (Figure a). Prior to 1966, total removals were negligible compared to the modern fishery. Over the early period, 1966–1990, most removals were from foreign or joint-venture fisheries. Over all years, the fishery in U.S. waters averaged 174,349 t, or 75.7% of the average total landings, while catch from Canadian waters averaged 55,901 t. Over the last 10 years, 2008–2017 (Table a), the average coastwide catch was 276,288 t



**Figure a.** Total Pacific Hake catch used in the assessment by sector, 1966–2017. U.S. tribal catches are included in the sectors where they are represented.

**Table a.** Recent commercial fishery catch (t). Tribal catches are included in the sector totals. Research catch includes landed catch associated with certain research-related activities. Catch associated with surveys and discarded bycatch in fisheries not targeting hake are not currently included in the model.

Year	US Mother- ship	US Catcher- processor	US Shore- based	US Research	US Total	CAN Joint- Venture	CAN Shore- side	CAN Freezer Trawlers	CAN Total	Total
2006	60,926	78,864	127,165	0	266,955	14,319	65,289	15,136	94,744	361,699
2007	52,977	73,263	91,441	0	217,682	6,780	48,075	14,121	68,976	286,658
2008	72,440	108,195	67,861	0	248,496	3,592	53,444	13,214	70,251	318,746
2009	37,550	34,552	49,222	0	121,324	0	44,136	13,223	57,359	178,683
2010	52,022	54,284	64,736	0	171,043	8,081	31,418	13,573	53,072	224,115
2011	56,394	71,678	102,146	1,042	231,261	9,717	26,827	14,593	51,137	282,398
2012	38,512	55,264	65,919	448	160,144	0	31,718	14,909	46,627	206,771
2013	52,447	77,950	102,143	1,018	233,558	0	33,665	18,584	52,249	285,807
2014	62,102	103,203	98,640	197	264,141	0	13,326	21,787	35,113	299,254
2015	27,661	68,484	58,011	0	154,156	0	16,775	22,903	39,678	193,834
2016	65,036	108,786	88,023	745	262,590	0	35,012	34,729	69,740	332,330
2017	66,428	136,960	150,843	0	354,231	5,608	43,427	37,679	86,713	440,944

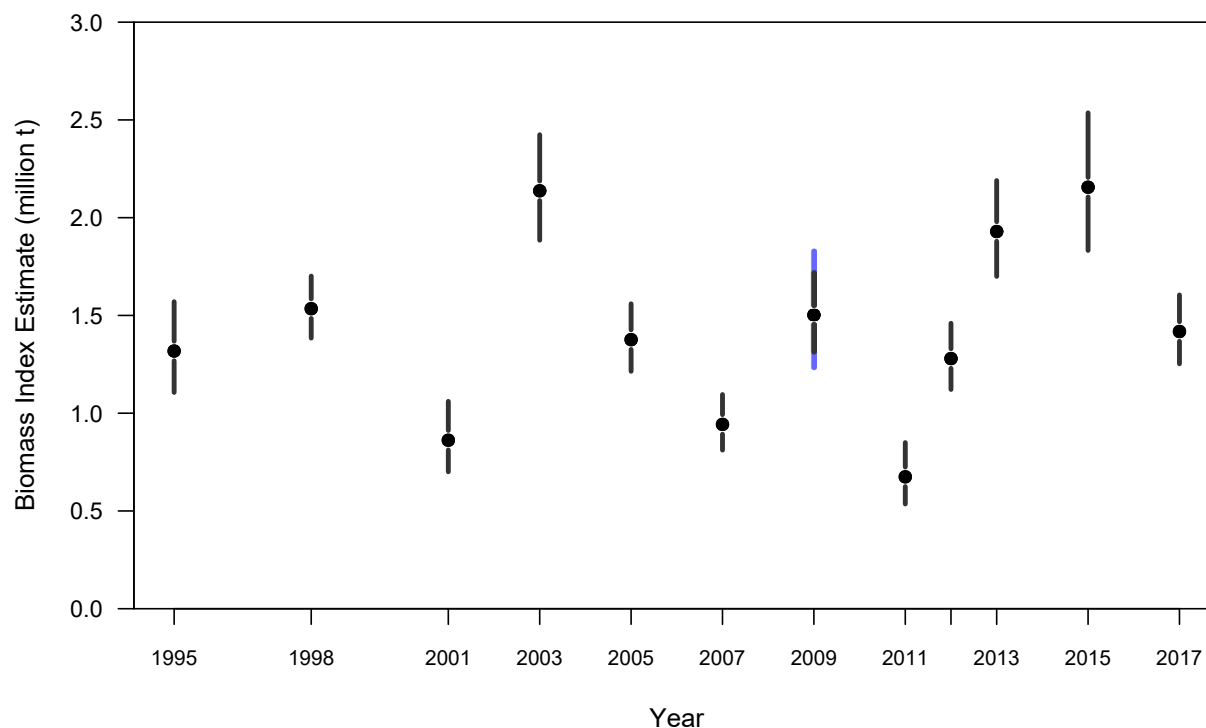
with U.S. and Canadian catches averaging 220,094 t and 56,194 t, respectively. The coastwide catch in 2017 was 440,944 t, out of a total allowable catch (TAC, adjusted for carryovers) of 597,500 t. Attainment in the U.S. was 80.2% of its quota; in Canada it was 55.6%.

In this stock assessment, the terms catch and landings are used interchangeably. Estimates of discard within the target fishery are included, but discarding of Pacific Hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings in recent years. During the last five years, catches have been above the long-term average catch (230,250 t) in 2013, 2014, 2016 and 2017, and below it in 2015. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal (through 2017) from that cohort estimated at approximately 1.29 million t. Through 2017, the total catch of the 2010 year class is estimated to be about 0.88 million t.

## DATA AND ASSESSMENT

The biomass index and age composition from the acoustic survey conducted in 2017 have been added to the survey time series (Figure b). A new age-based maturity ogive was developed for this assessment, replacing the previous ogive that was based on estimates of maturity-at-length from 1997 and weight-at-length from 2011. Further new data for this 2018 assessment, that were not in the 2017 assessment, are the 2017 fishery catch and fishery age compositions, and the mean weight-at-age for 2017.

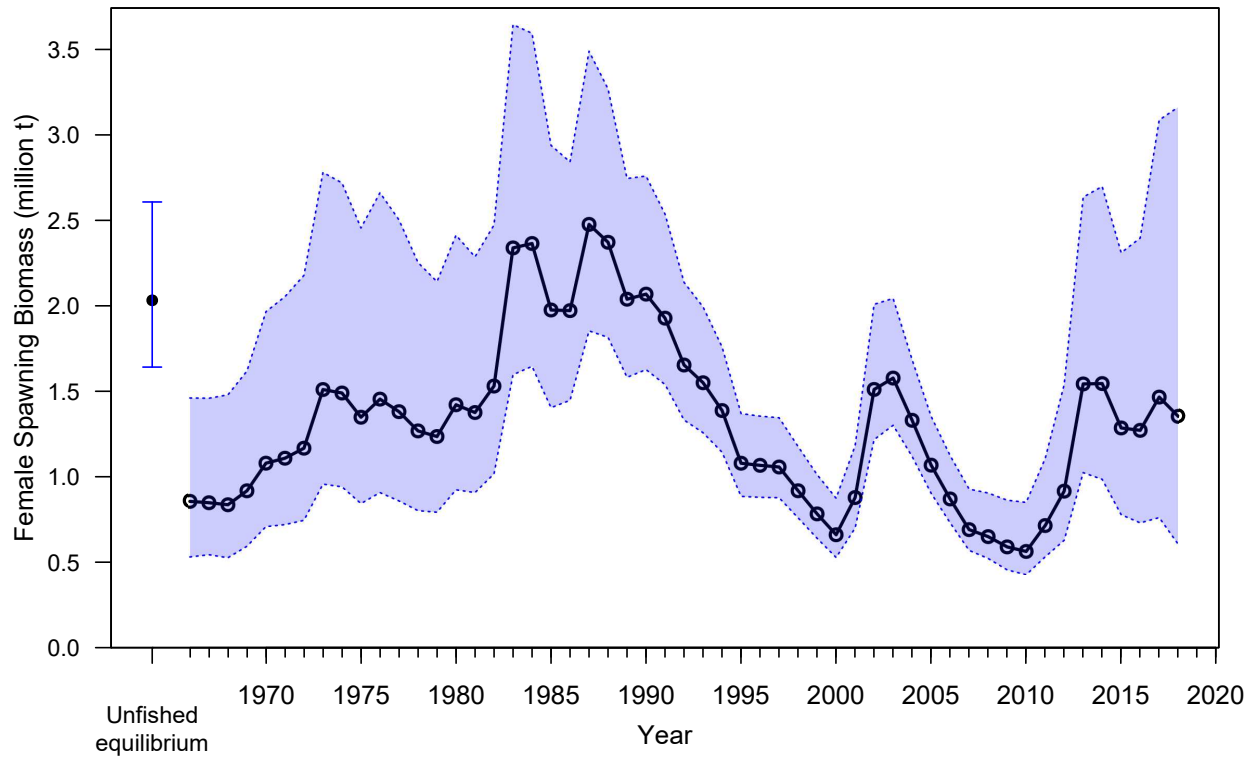
This Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2017), acoustic survey biomass indices (Figure b) and age-compositions (1995–2017), as well as fishery age-compositions (1975–2017). The 2011 survey index value was the lowest in the time series, and was followed by the index increasing in 2012, 2013, and 2015, and then declining in 2017. Age-composition data from the aggregated fisheries and the acoustic survey contribute to the assessment model’s ability to resolve strong and weak cohorts.



**Figure b.** Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2017) in addition to squid/hake apportionment uncertainty (2009, in blue).

The assessment uses a Bayesian estimation approach, sensitivity analyses, and retrospective investigations to evaluate the potential consequences of parameter uncertainty, alternative structural models, and historical performance of the assessment model, respectively. The Bayesian approach combines prior knowledge about natural mortality, stock-recruitment steepness (a parameter for stock productivity) and several other parameters, with likelihoods for acoustic survey biomass indices, acoustic survey age-composition data, and fishery age-composition data. Integrating the joint posterior distribution over model parameters (via the Markov Chain Monte Carlo algorithm) provides probabilistic inferences about uncertain model parameters and forecasts derived from those parameters. Sensitivity analyses are used to identify alternative structural models that may also be consistent with the data. Retrospective analyses identify possible poor performance of the assessment model with respect to future predictions. Past assessments have conducted closed-loop simulations which provide insights into how alternative combinations of survey frequency, assessment model selectivity assumptions, and harvest control rules affect expected management outcomes given repeated application of these procedures over the long-term. The results of past closed-loop simulations influence the decisions made for this assessment.

This 2018 assessment retains the structural form of the base assessment model from 2017 as well as many of the previous elements as configured in Stock Synthesis. Analyses conducted in 2014 showed that allowing for time-varying (rather than fixed) selectivity reduced the magnitude of extreme cohort strength estimates. In closed-loop simulations, management based upon assessment

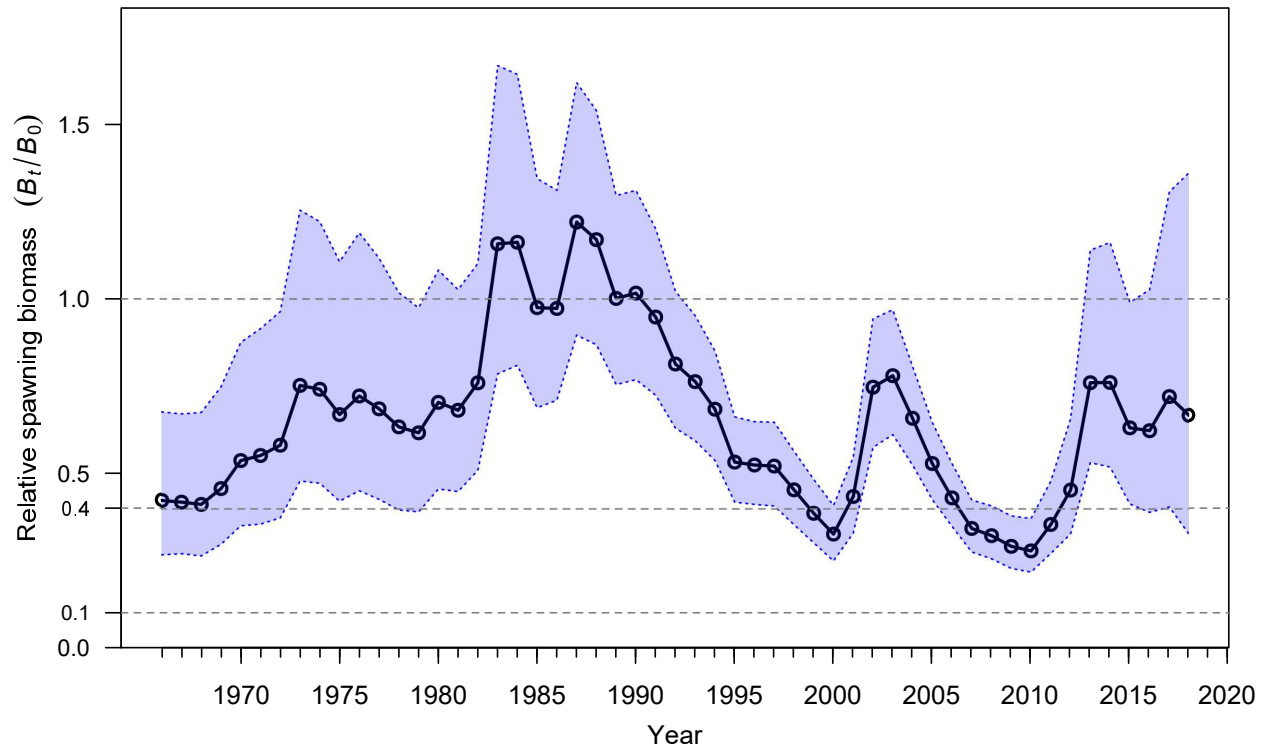


**Figure c.** Median of the posterior distribution for beginning of the year female spawning biomass through 2018 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

models allowing for time-varying fishery selectivity led to higher median average catch, lower risk of falling below 10% of unfished biomass ( $B_0$ ), smaller probability of fishery closures, and lower inter-annual variability in catch compared to assessment models which force time-invariant fishery selectivity. Even a small degree of flexibility in the assessment model fishery selectivity could reduce the effects of errors caused by assuming selectivity is constant over time. Therefore, we retain time-varying selectivity in this assessment, albeit with a new parameterization due to a change in Stock Synthesis. The assumed variability of the annual deviations in selectivity was increased in the 2017 assessment because the settings used in previous assessments resulted in an extremely large estimate of the 2014 year class without adequate basis (i.e., based upon quite limited data). We retained the equivalent assumed variability here. We also included a new approach for automatically weighting composition data.

## STOCK BIOMASS

The base stock assessment model indicates that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near (and above) unfished equilibrium (Figures c and d). The model estimates that it was below the unfished equilibrium in the 1960s, at the start of the assessment model, due to lower than average recruitment. The stock is estimated to have increased rapidly to near unfished equilibrium after two or more large recruitments in the early 1980s, and



**Figure d.** Median (solid line) of the posterior distribution for relative spawning biomass ( $B_t/B_0$ ) through 2018 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the very large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.568 million t in 2010. The assessment model estimates that median spawning biomass then peaked again in 2013 and 2014 due to a very large 2010 year class and an above-average 2008 year class. The subsequent decline is from the 2010 year class surpassing the age at which gains in weight from growth are greater than the loss in weight from natural mortality. The 2014 year class is estimated to be large, though not as large as the 1999 and 2010 year classes, which, combined with the fishing mortality on these cohorts, has resulted in a relatively constant biomass since 2013.

The median estimate of the 2018 relative spawning biomass (spawning biomass at the start of 2018 divided by that at unfished equilibrium,  $B_0$ ) is 66.7%. However, the uncertainty is large, with a 95% posterior credibility interval from 32.7% to 136.1% (Table b). The median estimate of the 2018 spawning biomass is 1.357 million t (with a 95% posterior credibility interval from 0.610 to 3.161 million t). The estimate of the 2017 female spawning biomass is 1.469 (0.766–3.086) million t. This is a lower median than the 2.129 (0.763–7.445) million t estimated in the 2017 assessment, though the credibility interval lies within that from the 2017 assessment.

**Table b.** Recent trends in estimated beginning of the year female spawning biomass (thousand t) and spawning biomass level relative to estimated unfished equilibrium.

Year	Spawning Biomass (thousand t)			Relative spawning Biomass ( $B_t/B_0$ )		
	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile
2009	460.6	594.8	867.3	23.0%	29.3%	38.0%
2010	432.4	568.3	854.5	21.9%	28.0%	37.2%
2011	536.6	719.3	1,110.0	27.3%	35.6%	47.9%
2012	633.3	920.0	1,541.7	32.8%	45.4%	65.7%
2013	1,028.0	1,545.7	2,635.7	53.2%	76.1%	113.9%
2014	989.0	1,547.9	2,698.1	52.0%	76.1%	116.1%
2015	782.6	1,288.9	2,311.2	41.4%	63.2%	99.0%
2016	735.1	1,275.0	2,397.1	39.0%	62.4%	102.6%
2017	765.8	1,469.0	3,085.6	40.6%	72.1%	130.6%
2018	610.1	1,356.5	3,160.8	32.7%	66.7%	136.1%

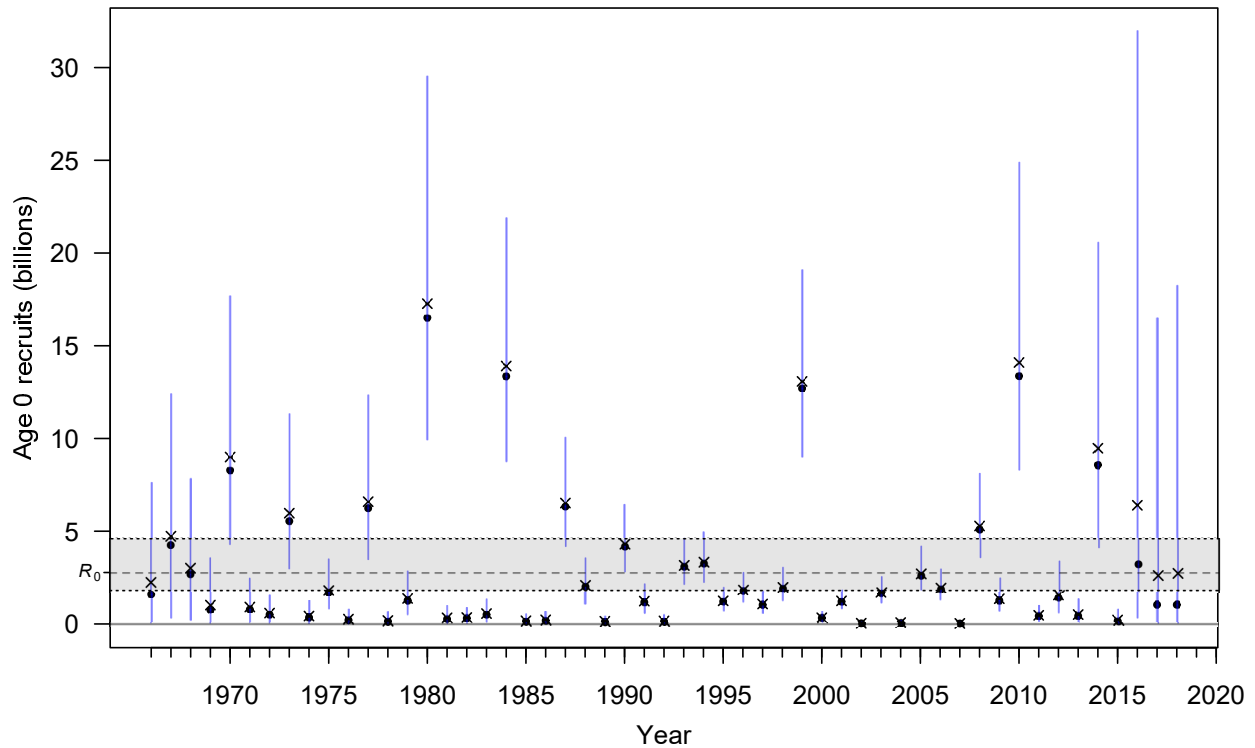
**Table c.** Estimates of recent recruitment (millions of age-0) and recruitment deviations, where deviations below (above) zero indicate recruitment below (above) that estimated from the stock-recruit relationship.

Year	Absolute recruitment (millions)			Recruitment deviations		
	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile
2008	3,607.8	5,096.0	8,117.0	1.481	1.715	1.988
2009	734.9	1,274.2	2,490.3	-0.097	0.353	0.815
2010	8,282.3	13,368.6	24,883.0	2.403	2.703	3.043
2011	153.9	427.0	998.1	-1.711	-0.798	-0.099
2012	628.2	1,415.6	3,395.2	-0.253	0.381	1.047
2013	110.8	431.6	1,327.2	-2.134	-0.890	0.070
2014	4,137.1	8,582.7	20,561.7	1.543	2.123	2.786
2015	20.9	154.6	785.6	-3.828	-1.878	-0.413
2016	360.9	3,235.8	31,932.6	-0.912	1.185	3.341
2017	62.3	1,036.5	16,490.6	-2.714	0.025	2.709

## RECRUITMENT

The new data available for this assessment do not significantly change the pattern of recruitment estimated in recent assessments. Pacific Hake appear to have low average recruitment with occasional large year-classes (Table c and Figure e). Very large year classes in 1980, 1984, and 1999 supported much of the commercial catch from the 1980s to the mid-2000s. From 2000 to 2007 estimated recruitment was at some of the lowest values in the time series, but this was followed by a relatively large 2008 year class. The current assessment estimates a very strong 2010 year class





**Figure e.** Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment ( $R_0$ ) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

comprising 71% of the coast-wide commercial catch in 2013, 65% of the 2014 catch, 71% of the 2015 catch and 33% of the 2016 catch. The smaller proportion of the 2010 year class in the 2016 catch is due to the large influx of the 2014 year class (47% of the 2016 catch was age-2 fish from the 2014 year class, which was similar to the proportion of age-2 fish, 41%, from the 2010 year class in 2012). The median of the estimated size of the 2010 year class is the second highest in the time series (after that for 1980). The model currently estimates smaller-than-average 2011, 2012, 2013, and 2015 year classes (median recruitment below the mean of all median recruitments). The 2014 year class is likely larger than average yet has only a 4.8% chance of being larger than the 2010 year class. There is no information in the data to estimate the sizes of the 2017 and 2018 year classes. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable prior to model age-3 (observed at age-2).

## DEFAULT HARVEST POLICY

The default  $F_{\text{SPR}=40\%}$ -40:10 harvest policy prescribes the maximum rate of fishing mortality to equal  $F_{\text{SPR}=40\%}$ . This rate gives a spawning potential ratio (SPR) of 40%, meaning that the spawning biomass per recruit with  $F_{\text{SPR}=40\%}$  is 40% of that without fishing. If spawning biomass is below  $B_{40\%}$  (40% of  $B_0$ ), the policy reduces the TAC linearly until it equals zero at  $B_{10\%}$  (10% of  $B_0$ ).



**Table d.** Recent estimates of relative fishing intensity,  $(1 - \text{SPR})/(1 - \text{SPR}_{40\%})$ , and exploitation fraction (catch divided by age-2+ biomass).

Year	Relative fishing intensity			Exploitation fraction		
	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile
2008	0.753	0.973	1.179	0.137	0.192	0.239
2009	0.582	0.801	1.012	0.099	0.144	0.186
2010	0.689	0.943	1.206	0.090	0.134	0.176
2011	0.631	0.908	1.159	0.113	0.177	0.238
2012	0.446	0.706	0.965	0.039	0.066	0.097
2013	0.446	0.681	0.897	0.048	0.082	0.124
2014	0.447	0.695	0.962	0.047	0.084	0.132
2015	0.273	0.486	0.754	0.040	0.073	0.119
2016	0.444	0.740	1.062	0.051	0.102	0.179
2017	0.556	0.862	1.178	0.066	0.142	0.271

Relative fishing intensity for fishing rate  $F$  is  $(1 - \text{SPR}(F))/(1 - \text{SPR}_{40\%})$ , where  $\text{SPR}_{40\%}$  is the target SPR of 40%.

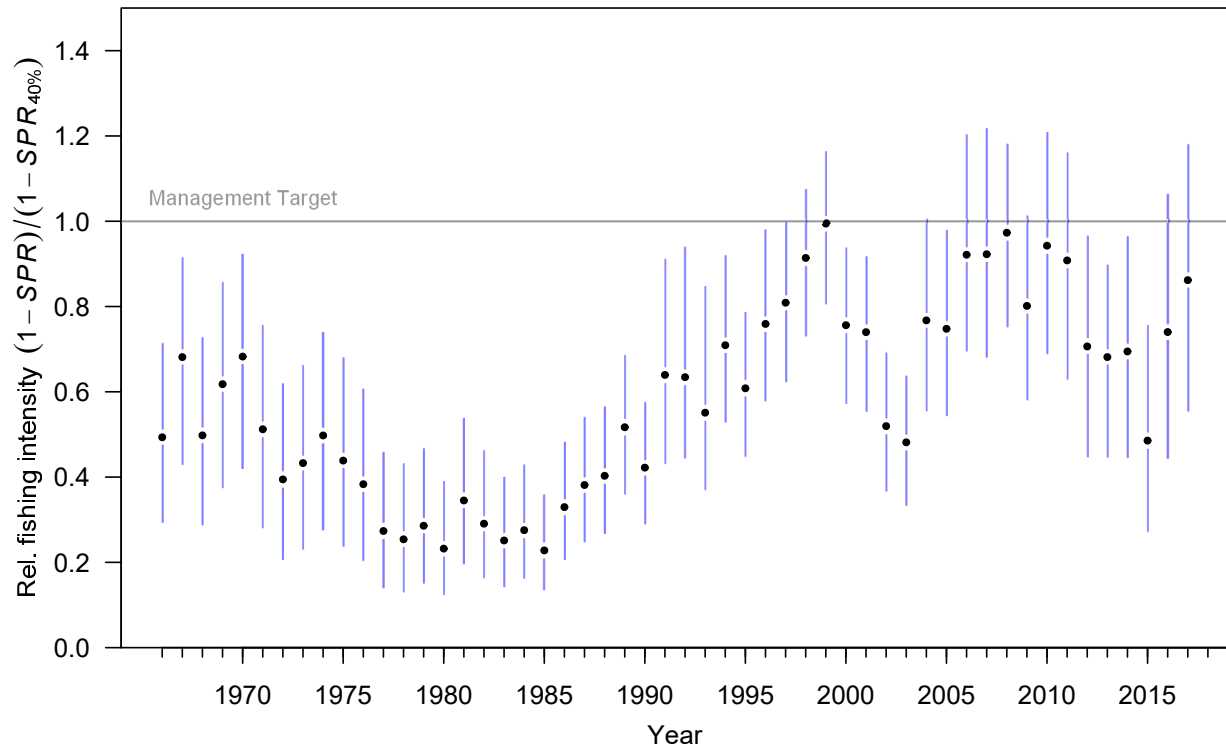
## EXPLOITATION STATUS

Median relative fishing intensity on the stock is estimated to have been below the target of 1.0 for all years (see Table d for recent years, and Figure f). Median exploitation fraction (catch divided by biomass of fish of age-2 and above) peaked in 1999, and then reached even higher values in 2006 and 2008 (Table d and Figure g). Note that in previous assessments exploitation fraction was defined in terms of fish age-3 and above, but we revised the definition this year because age-2 fish are often caught by the fishery. Median relative fishing intensity is estimated to have declined from 94.3% in 2010 to 86.2% in 2017, while the exploitation fraction has increased from 0.13 in 2010 to 0.14 in 2017. There is a considerable amount of uncertainty around estimates of relative fishing intensity, with the 95% posterior credibility interval reaching above the SPR management target for 2017 (Figure f).

## MANAGEMENT PERFORMANCE

Over the last decade (2008–2017), the mean coast-wide utilization rate (proportion of catch target removed) has been 75.7% (Table e). Over the last five years (2013 to 2017), the mean utilization rates differed between the United States (73.8%) and Canada (46.0%). Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

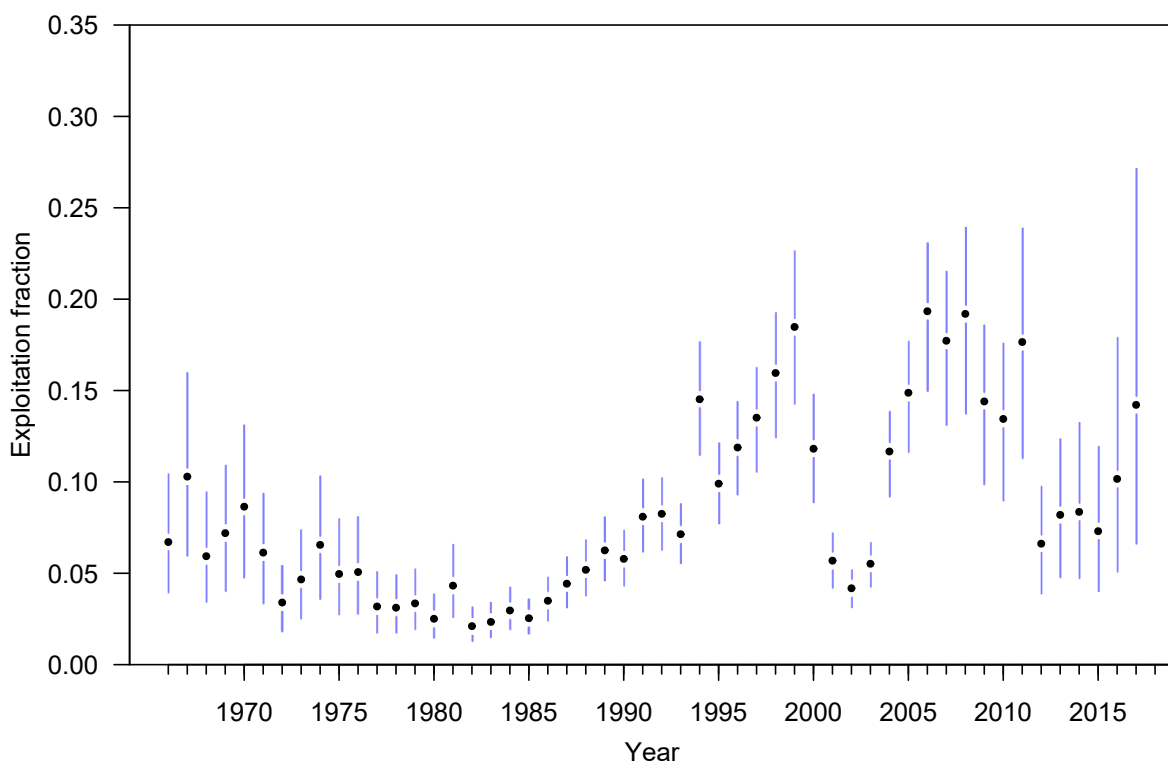
The median relative fishing intensity was below target in all years (Figure f). The median female spawning biomass was above the  $B_{40\%}$  reference point in all years except 1999–2000 and 2007–



**Figure f.** Trend in median relative fishing intensity (relative to the SPR management target) through 2017 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

**Table e.** Recent trends in Pacific Hake landings and management decisions.

Year	US landings (t)	Canada landings (t)	Total landings (t)	Coast-wide catch target (t)	US catch target (t)	Canada catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2008	248,496	70,251	318,746	364,842	269,545	95,297	92.2%	73.7%	87.4%
2009	121,324	57,359	178,683	184,000	135,939	48,061	89.2%	119.3%	97.1%
2010	171,043	53,072	224,115	262,500	193,935	68,565	88.2%	77.4%	85.4%
2011	231,261	51,137	282,398	393,751	290,903	102,848	79.5%	49.7%	71.7%
2012	160,144	46,627	206,771	251,809	186,036	65,773	86.1%	70.9%	82.1%
2013	233,558	52,249	285,807	365,112	269,745	95,367	86.6%	54.8%	78.3%
2014	264,141	35,113	299,254	428,000	316,206	111,794	83.5%	31.4%	69.9%
2015	154,156	39,678	193,834	440,000	325,072	114,928	47.4%	34.5%	44.1%
2016	262,590	69,740	332,330	497,500	367,553	129,947	71.4%	53.7%	66.8%
2017	354,231	86,713	440,944	597,500	441,433	156,067	80.2%	55.6%	73.8%



**Figure g.** Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2017 with 95% posterior credibility intervals.

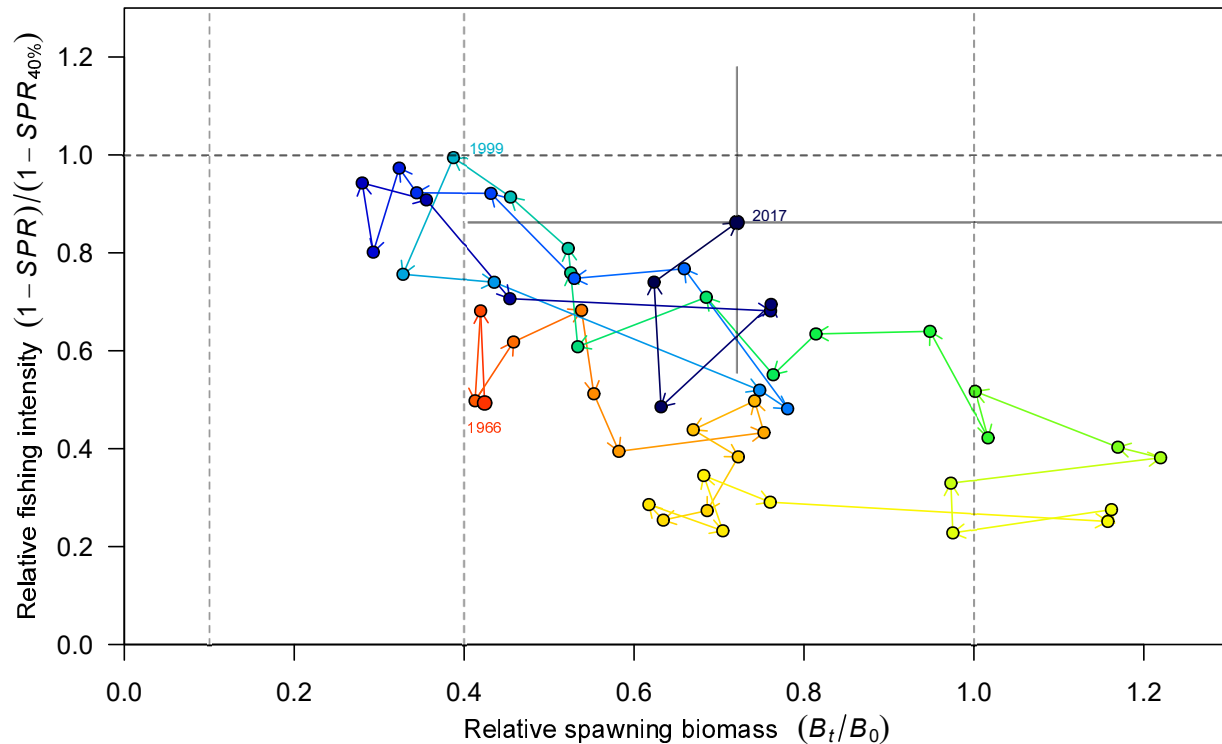
2011 (Figure d).

The joint history of the medians of relative spawning biomass and relative fishing intensity shows that the median relative fishing intensity has never been above the target of 1.0 when the female spawning biomass is below the reference point of  $B_{40\%}$  (Figure h). Between 2007 and 2011, median relative fishing intensity ranged from 80% to 97% and median relative spawning biomass between 0.28 and 0.36. Biomass has risen from the 2010 low with the 2008, 2010 and 2014 recruitments, and median relative spawning biomass has been above the reference point of 40% since 2012.

While there is large uncertainty in the 2017 estimates of relative fishing intensity and relative spawning biomass, the model estimates a 5.7% joint probability of being both above the target relative fishing intensity in 2017 and below the  $B_{40\%}$  relative spawning biomass level at the start of 2018.

## REFERENCE POINTS

Estimates of the 2018 base model reference points with posterior credibility intervals are in Table f. The estimates are slightly different than those in the 2017 assessment, with lower sustainable yields and reference points estimated in this assessment (except for SPR at  $B_{40\%}$  and SPR at MSY).



**Figure h.** Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2017 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

## UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

Measures of uncertainty in the base model underestimate the total uncertainty in the current stock status and projections because they do not account for possible alternative structural models for hake population dynamics and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distributions. To address such structural uncertainties, we performed sensitivity analyses to investigate a range of alternative models, and present the key sensitivity analyses in the main document.

The Pacific Hake stock displays a very high recruitment variability relative to other west coast groundfish stocks, resulting in large and rapid biomass changes. This leads to a dynamic fishery that potentially targets strong cohorts resulting in time-varying fishery selectivity. This volatility results in a high level of uncertainty in estimates of current stock status and stock projections because, with limited data to estimate incoming recruitment, the cohorts are fished before the assessment can accurately determine how big the cohort is (i.e., cohort strength is not well known until it is at least age-3).

In a 2015 Joint Management Committee (JMC) meeting, the JTC presented results from closed-loop simulations to evaluate the effect of including potential age-1 indices on management outcomes. It was found that fitting to an unbiased age-1 survey results in lower catch, lower probabil-

**Table f.** Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2017 averages for mean size-at-age and selectivity-at-age.

Quantity	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile
Unfished female spawning biomass ( $B_0$ , thousand t)	1,641	2,032	2,608
Unfished recruitment ( $R_0$ , millions)	1,828	2,773	4,607
<b>Reference points (equilibrium) based on <math>F_{\text{SPR}=40\%}</math></b>			
Female spawning biomass at $F_{\text{SPR}=40\%}$ (thousand t)	538	730	929
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	16.0%	18.3%	20.6%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	243	340	484
<b>Reference points (equilibrium) based on <math>B_{40\%}</math> (40% of <math>B_0</math>)</b>			
Female spawning biomass ( $B_{40\%}$ , thousand t)	657	813	1,043
SPR at $B_{40\%}$	40.6%	43.5%	50.6%
Exploitation fraction resulting in $B_{40\%}$	12.8%	16.1%	19.0%
Yield at $B_{40\%}$ (thousand t)	242	332	474
<b>Reference points (equilibrium) based on estimated MSY</b>			
Female spawning biomass ( $B_{\text{MSY}}$ , thousand t)	377	518	795
SPR at MSY	22.5%	29.9%	45.3%
Exploitation fraction corresponding to SPR at MSY	15.4%	25.5%	34.5%
MSY (thousand t)	250	358	528

ity that spawning biomass falls below 10% of  $B_0$ , and a lower average annual variability in catch. However, comparable results in terms of catch could be achieved with a more precise age-2+ survey or alternative harvest control rules. The simulations assumed an age-1 survey design with consistent, effective, and numerous sampling, which may not be the case for the existing age-1 index. The age-1 index is not included in the base model but is included in a sensitivity run.

## FORECAST DECISION TABLES

The catch limit for 2018 based on the default  $F_{\text{SPR}=40\%}$ –40:10 harvest policy has a median of 725,984 t with a wide range of uncertainty, the 95% credibility interval being 270,948–1,881,590 t.

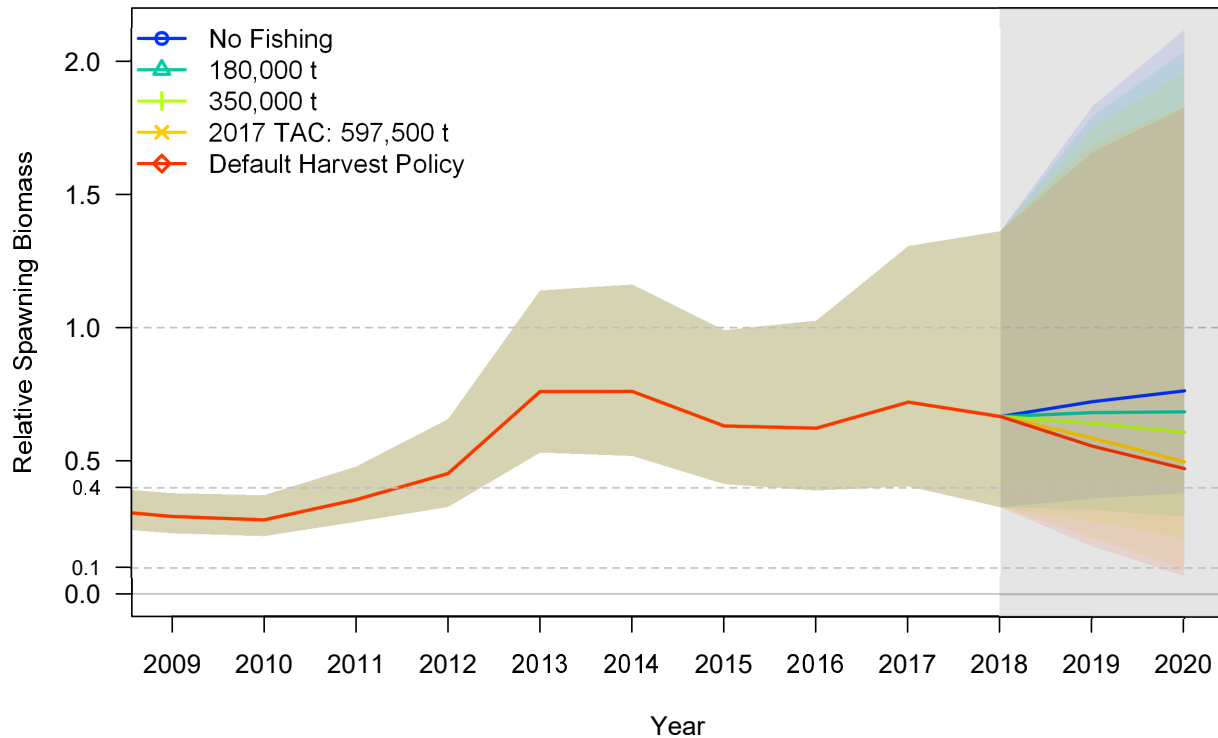
Decision tables give the projected population status (relative spawning biomass) and the relative fishing intensity under different catch alternatives for the base model (Tables g and h). The tables are organized such that the projected outcome for each potential catch level and year (each row) can be evaluated across the quantiles (columns) of the posterior distribution. Table g shows projected relative spawning biomass outcomes and Table h shows projected fishing intensity outcomes relative to the target fishing intensity (based on SPR – see table legend). Figure i shows the projected biomass for several catch alternatives.

**Table g.** Forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e), including catch from 2017 (row d) and the TAC from 2017 (row e), the catch values that result in a median relative fishing intensity of 100% (row f), the median values estimated via the default harvest policy ( $F_{SPR=40\%}-40:10$ ) for the base model (row g), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2018 and 2019 (row h). Catch in 2020 does not impact the beginning of the year biomass in 2020.

Within model quantile Management Action			5%	25%	50%	75%	95%
Year Catch (t)			Beginning of year relative spawning biomass				
a:	2018	0	38%	54%	67%	83%	119%
	2019	0	40%	58%	72%	93%	152%
	2020	0	42%	60%	76%	101%	172%
b:	2018	180,000	38%	54%	67%	83%	119%
	2019	180,000	36%	53%	68%	89%	148%
	2020	180,000	33%	52%	68%	93%	165%
c:	2018	350,000	38%	54%	67%	83%	119%
	2019	350,000	32%	49%	64%	86%	145%
	2020	350,000	26%	44%	61%	86%	158%
d:	2018	440,000	38%	54%	67%	83%	119%
	2017	2019 440,000	30%	48%	62%	84%	143%
	catch	2020 440,000	21%	40%	57%	83%	155%
e:	2018	597,500	38%	54%	67%	83%	119%
	2017	2019 597,500	26%	44%	59%	80%	140%
	TAC	2020 597,500	14%	33%	50%	76%	148%
f:	2018	639,000	38%	54%	67%	83%	119%
	FI=	2019 554,000	25%	43%	58%	79%	139%
	100%	2020 509,000	14%	34%	50%	76%	148%
g:	2018	725,984	38%	54%	67%	83%	119%
	default	2019 600,991	23%	41%	56%	77%	137%
	HR	2020 538,263	11%	31%	47%	73%	146%
h:	2018	626,954	38%	54%	67%	83%	119%
	C2018=	2019 626,954	25%	43%	58%	80%	139%
	C2019	2020 556,786	13%	32%	49%	75%	147%

**Table h.** Forecast quantiles of Pacific Hake relative fishing intensity  $(1-SPR)/(1-SPR_{40\%})$  for the 2018–2020 catch alternatives presented in Table g. Values greater than 100% indicate relative fishing intensities greater than the  $F_{SPR=40\%}$  harvest policy calculated using baseline selectivity.

Within model quantile Management Action			5%	25%	50%	75%	95%
Year Catch (t)			Relative fishing intensity				
a:	2018	0	0%	0%	0%	0%	0%
	2019	0	0%	0%	0%	0%	0%
	2020	0	0%	0%	0%	0%	0%
b:	2018	180,000	27%	39%	49%	59%	77%
	2019	180,000	23%	37%	47%	58%	79%
	2020	180,000	21%	34%	45%	56%	77%
c:	2018	350,000	45%	62%	75%	86%	106%
	2019	350,000	41%	61%	76%	90%	113%
	2020	350,000	38%	59%	75%	91%	119%
d:	2018	440,000	53%	71%	84%	96%	115%
2017	2019	440,000	49%	71%	87%	101%	124%
catch	2020	440,000	45%	70%	88%	105%	134%
e:	2018	597,500	65%	84%	97%	109%	126%
2017	2019	597,500	62%	86%	103%	117%	140%
TAC	2020	597,500	58%	87%	107%	125%	160%
f:	2018	639,000	68%	87%	100%	112%	129%
FI=	2019	554,000	59%	83%	100%	115%	139%
100%	2020	509,000	52%	80%	100%	119%	154%
g:	2018	725,984	73%	93%	105%	117%	133%
default	2019	600,991	62%	88%	105%	120%	144%
HR	2020	538,263	54%	84%	105%	125%	163%
h:	2018	626,954	67%	86%	99%	111%	128%
C2018=	2019	626,954	63%	88%	105%	120%	142%
C2019	2020	556,786	55%	84%	105%	124%	160%



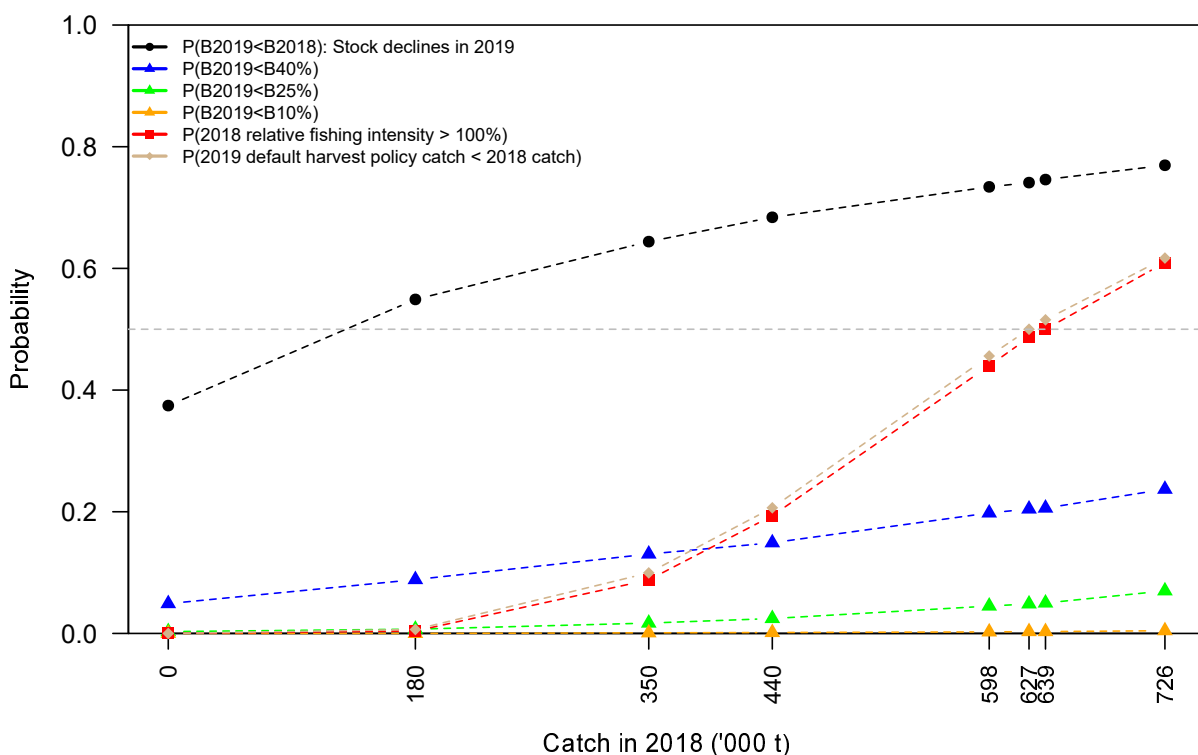
**Figure i.** Time series of estimated relative spawning biomass to 2018 from the base model, and forecast trajectories to 2020 for several management actions defined in Table g (grey region), with 95% posterior credibility intervals.

A relative fishing intensity above 100% indicates fishing greater than the  $F_{\text{SPR}=40\%}$  default harvest rate catch limit. This can happen for the median relative fishing intensity in projected years because the  $F_{\text{SPR}=40\%}$  default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of fishing in excess of the default harvest policy. Alternative catch levels where median relative fishing intensity is 100% for three years of projections are provided for comparison (scenario f: FI=100%).

Management metrics that were identified as important to the JMC and the Advisory Panel (AP) in 2012 are presented for projections to 2019 and 2020 (Tables i and j and Figures j and k). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from these results for intermediate catch values. Figure i shows the predicted relative spawning biomass trajectory through 2020 for several of these management actions. With zero catch for the next two years, the biomass has a 37% probability of decreasing from 2018 to 2019, and a 35% probability of decreasing from 2019 to 2020.

The probability of the spawning biomass decreasing from 2018 to 2019 is less than 50% for only the 0 t catch level (Table i and Figure j). The highest probability of decrease is 77%, which is for the default harvest policy (row g in Table i). The predicted probability of the spawning biomass

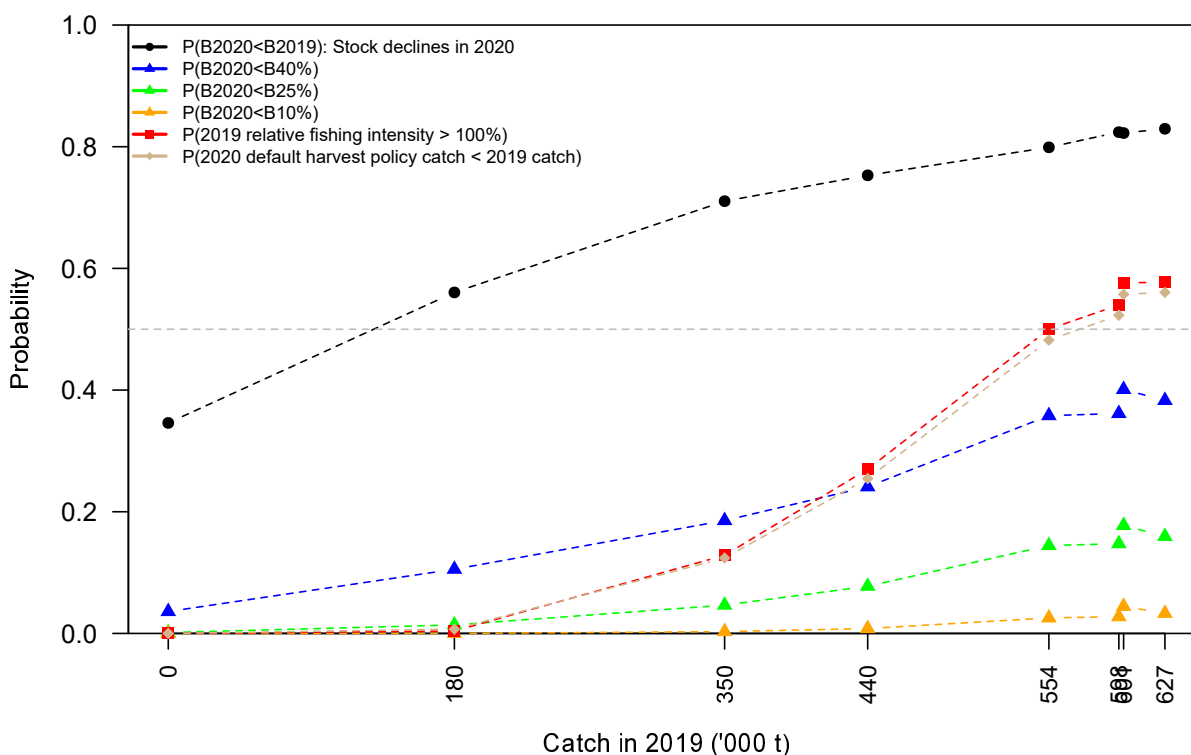




**Figure j.** Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (catch options explained in Table g) as listed in Table i. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

**Table i.** Probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (catch options explained in Table g).

Catch in 2018	Probability B <sub>2019</sub> <B <sub>2018</sub>	Probability B <sub>2019</sub> <B <sub>40%</sub>	Probability B <sub>2019</sub> <B <sub>25%</sub>	Probability B <sub>2019</sub> <B <sub>10%</sub>	Probability 2018 relative fishing intensity >100%	Probability 2019 default harvest policy catch <2018 catch
a: 0	37%	5%	0%	0%	0%	0%
b: 180,000	55%	9%	1%	0%	0%	1%
c: 350,000	64%	13%	2%	0%	9%	10%
d: 440,000	68%	15%	2%	0%	19%	21%
e: 597,500	73%	20%	4%	0%	44%	46%
f: 639,000	75%	21%	5%	0%	50%	52%
g: 725,984	77%	24%	7%	0%	61%	62%
h: 626,954	74%	20%	5%	0%	49%	50%



**Figure k.** Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (including associated 2018 catch; catch options explained in Table g) as listed in Table j. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

**Table j.** Probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options, given the 2018 catch level shown in Table i (catch options explained in Table g).

Catch in 2019	Probability $B_{2020} < B_{2019}$	Probability $B_{2020} < B_{40\%}$	Probability $B_{2020} < B_{25\%}$	Probability $B_{2020} < B_{10\%}$	Probability 2019 relative fishing intensity >100%	Probability 2020 default harvest policy catch <2019 catch
a: 0	35%	4%	0%	0%	0%	0%
b: 180,000	56%	11%	1%	0%	0%	1%
c: 350,000	71%	19%	5%	0%	13%	12%
d: 440,000	75%	24%	8%	1%	27%	25%
e: 597,500	82%	36%	15%	3%	54%	52%
f: 554,000	80%	36%	14%	3%	50%	48%
g: 600,991	82%	40%	18%	4%	58%	56%
h: 626,954	83%	38%	16%	3%	58%	56%

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dropping below  $B_{10\%}$  at the start of 2019 is less than 1% and the maximum probability of dropping below  $B_{40\%}$  is 24% for all catches explored (Table i and Figure j). The model estimated below-average recruitment for the 2011, 2012, 2013, and 2015 cohorts, but above-average 2014 and 2016 cohorts that may result in increases to the spawning biomass as they mature and increase in weight.

During the 2018 Scientific Review Group (SRG) meeting, the SRG requested an alternative run. This alternative run includes the following changes from the base model, related to fecundity:

- add time-varying fecundity by multiplying the weight-at-age matrix (rather than an overall mean weight-at-age vector as in the base model) and the new maturity ogive to get annual estimates of fecundity from 1975-2017;
- set equilibrium and 1966-1974 fecundity (where empirical data are not available) to the product of maturity and mean weight-at-age over 1975-1979;
- set forecast-year fecundity (including 2017 due to current configurations in Stock Synthesis) weight-at-age to the product of maturity and mean weight-at-age over 2015-2017.

Decision tables, reference points, probabilities associated with alternative forecast catch levels, and comparisons to the base model are presented for the alternative run in Appendix A. The difference between the results is predominantly due to the assumptions about equilibrium weight-at-age.

An inconsistency in this alternative run is that the the mean weight-at-age across all years is still used for the calculation of stock biomass in the years outside the range with empirical data (1975-2017), rather than the short-term averages (1975-1979 or 2015-2017). A brief examination of the sensitivity of the alternative run to removing this inconsistency showed relatively little change in results.

## RESEARCH AND DATA NEEDS

There are many research projects that could improve the stock assessment for Pacific Hake and lead to improved biological understanding and decision-making. The top three are:

1. Continue investigation of links between hake biomass and its spatial distribution, and how these vary with ocean conditions and ecosystem variables such as temperature and prey availability. These investigations have the potential to improve the scenarios considered in future management strategy evaluation (MSE) work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.
2. Continue development of the MSE to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery, and compare potential methods to address them. Incorporate the feedback from JMC/AP/SRG/MSE Advisory Panels into operating model development.

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3. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength, directionality of survey and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others. Continue to work with acousticians and survey personnel from the NWFSC and DFO to determine an optimal design for the Joint U.S./Canada acoustic survey. Develop automation and methods to allow for the availability of biomass and age composition estimates to the JTC in a timely manner after a survey is completed.

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# 1 INTRODUCTION

The Joint US-Canada Agreement for Pacific Hake (called the Agreement) was signed in 2003, went into force in 2008 and was implemented in 2010. The committees defined by the Agreement were first formed in 2011, and 2012 was the first year for which the process defined by the Agreement was followed. This is the seventh annual stock assessment conducted under the Agreement process.

Under the Agreement, Pacific Hake (*Merluccius productus*, also referred to as Pacific whiting) stock assessments are to be prepared by the Joint Technical Committee (JTC) comprised of both U.S. and Canadian scientists, and reviewed by the Scientific Review Group (SRG), consisting of representatives from both nations. Additionally, the Agreement calls for both of these bodies to include scientists nominated by an Advisory Panel (AP) of fishery stakeholders.

The data sources for this assessment include an acoustic survey, annual fishery catch, as well as survey and fishery age-composition data. The assessment depends primarily upon the acoustic survey biomass index time-series for information on the scale of the current hake stock. Age-composition data from the aggregated fishery and the acoustic survey provide additional information allowing the model to resolve strong and weak cohorts. The catch is an important source of information in contributing to changes in abundance and providing a lower bound on the available population biomass in each year.

This assessment is fully Bayesian, with the base model incorporating prior information on several key parameters (including natural mortality,  $M$ , and steepness of the stock-recruit relationship,  $h$ ) and integrating over parameter uncertainty to provide results that can be probabilistically interpreted. From a range of alternate models investigated by the JTC, a subset of sensitivity analyses are also reported in order to provide a broad qualitative comparison of structural uncertainty with respect to the base case. These sensitivity analyses are thoroughly described in this assessment document. The structural assumptions of this 2018 base model, implemented using version 3.30 of the Stock Synthesis software (Methot and Wetzel, 2013), are effectively the same as the 2017 base model (Berger et al., 2017), though we incorporate new approaches for weighting composition data and for parameterizing time-varying selectivity.

## 1.1 STOCK STRUCTURE AND LIFE HISTORY

Pacific Hake is a semi-pelagic schooling species distributed along the west coast of North America, generally ranging in latitude from 25°N to 55°N (see Figure 1 for an overview map). It is among 18 species of hake from four genera (being the majority of the family Merlucciidae), which are found in both hemispheres of the Atlantic and Pacific Oceans (Alheit and Pitcher, 1995; Lloris et al., 2005). The coastal stock of Pacific Hake is currently the most abundant groundfish population in the California Current system. Smaller populations of this species occur in the major inlets of the Northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California. Genetic studies indicate that the Strait of Georgia and the Puget Sound populations are genetically distinct from the coastal population (Iwamoto et al., 2004; King et al., 2012). Genetic differences

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have also been found between the coastal population and hake off the west coast of Baja California (Vrooman and Paloma, 1977). The coastal stock is also distinguished from the inshore populations by larger size-at-age and seasonal migratory behavior.

The coastal stock of Pacific Hake typically ranges from the waters off southern California to northern British Columbia and rarely into southern Alaska, with the northern boundary related to fluctuations in annual migration. In spring, adult Pacific Hake migrate onshore and northward to feed along the continental shelf and slope from northern California to Vancouver Island. In summer, Pacific Hake often form extensive mid-water aggregations in association with the continental shelf break, with highest densities located over bottom depths of 200-300 m (Dorn and Methot, 1991, 1992).

Older Pacific Hake exhibit the greatest northern migration each season, with two- and three-year old fish rarely observed in Canadian waters north of southern Vancouver Island. During El Niño events (warm ocean conditions, such as 1998 and 2015), a larger proportion of the stock migrates into Canadian waters (Figure 2), apparently due to intensified northward transport during the period of active migration (Dorn, 1995; Agostini et al., 2006). In contrast, La Niña conditions (colder water, such as in 2001) result in a southward shift in the stock's distribution, with a much smaller proportion of the population found in Canadian waters, as seen in the 2001 survey (Figure 2). The distribution of age-1 fish also changes between years (Figure 3). The research on links between migration of different age classes and environmental variables is anticipated to be updated in the years ahead to take advantage of the data that have been collected in the years since the previous analyses were conducted.

Additional information on the stock structure for Pacific Hake is available in the 2013 Pacific Hake stock assessment document (Hicks et al., 2013).

## **1.2 ECOSYSTEM CONSIDERATIONS**

Pacific Hake are important to ecosystem dynamics in the Eastern Pacific due to their relatively large total biomass and potentially large role as both prey and predator in the Eastern Pacific Ocean. A more detailed description of ecosystem considerations is given in the 2013 Pacific Hake stock assessment (Hicks et al., 2013). Recent research has developed an index of abundance for Humboldt Squid and suggested links between squid and hake abundance (Stewart et al., 2014) and has evaluated hake distribution, recruitment and growth patterns in relation to oceanographic conditions for assessment and management (Ressler et al., 2007; Hamel et al., 2015). The 2015 Pacific Hake stock assessment document presented a sensitivity analysis where hake mortality was linked to the Humboldt Squid index (Taylor et al., 2015). This sensitivity was not repeated in this assessment, although further research on this topic is needed. Ongoing research investigating abiotic (environmental conditions) and biotic (e.g., euphausiid distribution and abundance) drivers of hake distribution could provide insight into how the hake population is linked with broader ecosystem considerations.

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### 1.3 MANAGEMENT OF PACIFIC HAKE

Since implementation of the Magnuson-Stevens Fishery Conservation and Management Act in the U.S. and the declaration of a 200 mile fishery conservation zone in the U.S. and Canada in the late 1970s, annual quotas (or catch targets) have been used to limit the catch of Pacific Hake in both country's zones. Scientists from both countries historically collaborated through the Technical Subcommittee of the Canada-U.S. Groundfish Committee (TSC), and there were informal agreements on the adoption of annual fishing policies. During the 1990s, however, disagreements between the U.S. and Canada on the allotment of the catch limits between U.S. and Canadian fisheries led to quota overruns; 1991-1992 national quotas summed to 128% of the coast-wide limit, while the 1993-1999 combined quotas were an average of 107% of the limit. The Agreement between the U.S. and Canada establishes U.S. and Canadian shares of the coast-wide allowable biological catch at 73.88% and 26.12%, respectively, and this distribution has been adhered to since ratification of the Agreement.

Throughout the last decade, the total coast-wide catch has tracked harvest targets reasonably well. Since 1999, catch targets have been determined using an  $F_{SPR=40\%}$  default harvest rate with a 40:10 adjustment. This decreases the catch linearly from the catch target at a relative spawning biomass of 40% and above, to zero catch at relative spawning biomass values of 10% or less (called the default harvest policy in the Agreement). Further considerations have often resulted in catch targets to be set lower than the recommended catch limit. In the last decade, total catch has never exceeded the quota, although retrospectively, as estimated in this assessment, harvest rates in some of those years approached the  $F_{SPR=40\%}$  target. Overall, management appears to be effective at maintaining a sustainable stock size, in spite of uncertain stock assessments and a highly dynamic population. However, management has been precautionary in years when very large quotas were determined from the stock assessment.

#### 1.3.1 Management of Pacific Hake in the United States

In the U.S. zone, participants in the directed fishery are required to use pelagic trawls with a codend mesh of at least 7.5 cm (3 inches). Regulations also restrict the area and season of fishing to reduce the bycatch of Chinook salmon and several depleted rockfish stocks (though some rockfish stocks have rebuilt in recent years). The at-sea fisheries begin on May 15, but processing and night fishing (midnight to one hour after official sunrise) are prohibited south of 42°N latitude (the Oregon-California border). Shore-based fishing is allowed after April 15 south of 40°30'N latitude, but only a small amount of the shore-based allocation is released prior to the opening of the main shore-based fishery (May 15). The current allocation agreement, effective since 1997, divides the U.S. non-tribal harvest among catcher-processors (34%), motherships (24%), and the shore-based fleet (42%). Since 2011, the non-tribal U.S. fishery has been fully rationalized with allocations in the form of Individual Fishing Quotas (IFQs) to the shore-based sector and group shares to cooperatives in the at-sea mothership and catcher-processor sectors. Starting in 1996, the Makah Indian Tribe has also conducted a fishery with a specified allocation in its "usual and accustomed fishing area".



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Shortly after the 1997 allocation agreement was approved by the Pacific Marine Fisheries Commission (PMFC), fishing companies owning catcher-processor (CP) vessels with U.S. west coast groundfish permits established the Pacific Whiting Conservation Cooperative (PWCC). The primary role of the PWCC is to distribute the CP allocation among its members in order to achieve greater efficiency and product quality, as well as promoting reductions in waste and bycatch rates relative to the former “derby” fishery in which all vessels competed for a fleet-wide quota. The mothership fleet (MS) has also formed a co-operative where bycatch allocations are pooled and shared among the vessels. The individual cooperatives have internal systems of in-season monitoring and spatial closures to avoid and reduce bycatch of salmon and rockfish. The shore-based fishery is managed with IFQs.

### **1.3.2 Management of Pacific Hake in Canada**

Canadian groundfish managers distribute their portion (26.12%) of the Total Allowable Catch (TAC) as quota to individual license holders. In 2017, Canadian hake fishermen were allocated a TAC of 156,067 t, including 17,239 t of uncaught carryover fish from 2016. Canadian priority lies with the domestic fishery, but when there is determined to be an excess of fish for which there is not enough domestic processing capacity, fisheries managers give consideration to a Joint Venture fishery in which foreign processor vessels are allowed to accept codends from Canadian catcher vessels while at sea. There was a Joint Venture fishery conducted in 2017.

In 2017, all Canadian Pacific Hake trips remained subject to 100% observer coverage, by either electronic monitoring for the shoreside component of the domestic fishery or on-board observer for the freezer trawler component. All shoreside hake landings were also subject to 100% verification by the groundfish Dockside Monitoring Program (DMP). Retention of all catch, with the exception of prohibited species, was mandatory. The retention of groundfish other than Sablefish, Mackerel, Walleye Pollock, and Pacific Halibut on non-observed but electronically monitored, dedicated Pacific Hake trips, was not allowed to exceed 10% of the landed catch weight. The bycatch allowance for Walleye Pollock was 30% of the total landed weight.

## **1.4 FISHERIES**

The fishery for the coastal population of Pacific Hake occurs along the coasts of northern California, Oregon, Washington, and British Columbia primarily during May-November. The fishery is conducted with mid-water trawls. Foreign fleets dominated the fishery until 1991, when domestic fleets began taking the majority of the catch. Catches were occasionally greater than 200,000 t prior to 1986, and since then they have been greater than 200,000 t for all except four years. A more detailed description of the history of the fishery is provided by Hicks et al. (2013).



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### 1.4.1 Overview of the fisheries in 2017

The Joint Management Committee (JMC) determined an adjusted (for carryovers) coast-wide catch target of 597,500 t for 2017, with a U.S. allocation of 441,433 t (73.88%) and a Canadian allocation of 156,067 t (26.12%). The historical catch of Pacific Hake for 1966–2017 by nation and fishery sector is shown in Figure 5 and Tables 1, 2 and 3. Table 4 shows recent catches in relation to targets (see Section 3.4.2). A review of the 2017 fishery now follows.

#### United States

The U.S. adjusted allocation (i.e. adjusted for carryovers) of 441,433 t was further divided among the research, tribal, catcher-processor, mothership, and shore-based sectors. After the tribal allocation of 17.5% (77,251 t), and a 1,500 t allocation for research catch and bycatch in non-groundfish fisheries, the 2017 non-tribal U.S. catch limit of 362,682 t was allocated to the catcher-processor (34%), mothership (24%), and shore-based (42%) commercial sectors. Reallocation of 41,000 t of tribal quota to non-tribal sectors on September 15 resulted in final quotas for the catcher-processor (CP), mothership (MS), and shore-based (Shore) sectors of 137,252 t, 96,884 t, and 169,547 t, respectively.

The midwater fishery for Pacific Hake began on May 15 for the shorebased and at-sea fisheries. In earlier years, the shore-based midwater fishery began on June 15 north of 42°N latitude, but could fish for hake between 40°30'N and 42°N latitudes starting on April 1. Beginning in 2015, the shorebased fishery has been allowed to fish north of 40°30'N latitude starting May 15, and could fish south of 40°30'N latitude starting on April 15. Regulations do not allow at-sea processing south of 42°N latitude at any time during the year.

The overall catch of Pacific Hake in U.S. waters was substantially greater than in 2016, reaching the highest values ever recorded (Table 1). Throughout 2017, catches were considerably higher than in 2016 (Figure 7). Initial database extractions reported small amounts of hake catch by tribal fisheries in 2017. However, the U.S. advisory panel report on the 2017 fishery (Appendix D) indicated a tribal catch of 6,012 t. Through discussions with the Washington Department of Fish and Wildlife and a U.S. advisory panel member, the Joint Technical Committee was made aware of missing fish tickets in the regional (PacFIN) database. These discrepancies were not resolved until late in the assessment preparation process, thereby precluding an update to the overall catch this year (see Section 2.1.1). However, this amount of catch is small relative to the total catch, and a sensitivity to the inclusion of this catch in the 2017 base model resulted in negligible influence on model results. The catcher-processor, mothership, and shore-based fleets caught 99.8%, 68.6%, and 89.0% of their final reallocated quotas, respectively. Overall, 87,202 t (19.8%) of the total U.S. adjusted TAC was not caught. For further details see the report from the U.S. Advisory Panel (Appendix D).

In both U.S. at-sea sectors (CP and MS) the most common cohorts in the spring fishery were age-7 and age-3 fish associated with the 2010 and 2014 year-classes, but by the fall, both sectors were catching a majority of age-3 fish. In total, 44% of the CP catch was age-3 and 33% was age-7

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(proportions by numbers here and below; Table 6). For the MS sector, the total for the year was 47% age-3 and 33% age-7 (Table 7). These totals were based on samples from 273 and 536 hauls, respectively, in each sector (Table 5). Age-samples from 110 shoreside trips showed an even higher proportion of age-7 fish than the at-sea sectors, at 44%, with 35% of the shoreside samples coming from the 2014 year class (Table 8). Age-5 fish from the 2012 year-class were the third largest proportion in the shoreside and CP sectors (4–5%), and age-1 was the third largest (6%) in the MS sector.

The at-sea fishery maintained relatively high catch rates throughout the year (Figure 7), averaging around 30 t/hr in the spring (May–June) and 20 t/hr in the fall (September–November). Relative to last year, both the spring and fall fisheries saw a considerable increase in catch rates. The median fishing depth for the at-sea fleets was shallower than in the past 10 years (Figure 6). During July and August, some operators in the at-sea fishery continued to fish hake, forgoing the usual summer opportunities in Alaskan waters. The shorebased fishery had the largest monthly catches during June, July, and August. Due to high catch-rates throughout the year for all U.S. fleets, as compared to recent years, the U.S. utilization rate continued to increase from recent years from 47% in 2015 to 71% in 2016 to 79% in 2017, even with the increases in TAC over that period.

## **Canada**

The 2017 Canadian Pacific Hake domestic fishery removed 86,713 t from Canadian waters, which was 55.6% of the Canadian TAC of 156,067 t.

The shoreside component, made up of vessels landing fresh round product onshore, landed 43,427 t. The freezer trawler component, which freezes headed and gutted product while at sea, landed 37,679 t. For the first time since 2011 there was a Joint Venture fishery (running from 21 August to 19 September), delivering 5,608 t to a Dutch vessel.

Fishing started in April, in the southern area off Vancouver Island. A majority of the Canadian production was HGT (headed, gutted and tail off), by both shoreside and freezer vessels, with a very small amount of mince and whole round produced shoreside. The Canadian hake shoreside TAC was harvested by freezer vessels and vessels that delivered fresh fish to shoreside plants.

Fish were continuously present throughout the season along the shelf break and on the shelf off the west coast of Vancouver Island. Similarly to 2016, there appeared to be a larger hake biomass in Canada compared to previous years, which is one reason why overall fleet participation was up from 2016. For further details see the report from the Canadian Advisory Panel (Appendix C).

The most abundant year classes (by numbers) in the Canadian Freezer trawler catch were age 7 at 47.4%, age 8 at 14.3%, age 9 at 9.4%, and age 3 at 7.8%. The most abundant year classes in the Canadian Shoreside catch were age 7 at 46.4%, age 8 at 14.8%, age 6 at 7.9%, and age 1 at 7.7%.

For an overview of Canadian catch by year and fleet, see Table 2. For some years there was no

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Joint Venture fishery operating in Canada, as reflected by the relevant zeros in Table 2.

## 2 DATA

Fishery-dependent and fishery-independent data sources used in the 2018 assessment (Figure 4) include:

- Total catch from all U.S. and Canadian target fisheries (1966–2017; Tables 1–3).
- Age compositions composed of data from the U.S. fishery (1975–2017) and the Canadian fishery (1990–2017). The last 10 years of these data are shown in Tables 6–10, and the aggregated data for all years shown in Table 11.
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012, 2013, 2015 and 2017; Tables 12 and 13).
- Mean observed weight-at-age from fishery and survey catches (1975–2017; Figure 13).

The assessment model also used biological relationships derived from external analysis of auxiliary data. These include:

- Ageing-error matrices based on cross-read and double-blind-read otoliths.
- Proportion of female hake maturity by age, as developed from histological analyses of ovary samples collected in recent years (Table 16 and Figure 12).

Some data sources were not included in the base model, but have been explored or used for sensitivity analyses, or were included in previous stock assessments but not in this one. Data sources not discussed here have either been discussed at past Pacific Hake assessment review meetings or are discussed in more detail in the 2013 stock assessment document (Hicks et al., 2013). Some of these additional data sources are:

- Fishery and acoustic survey length composition information.
- Fishery and acoustic survey age-at-length composition information.
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1977, 1980, 1983, 1986, 1989 and 1992).
- Bottom trawl surveys in the U.S. and Canada (various years and spatial coverage from 1977–2017).
- NWFSC/SWFSC/PWCC coast-wide juvenile hake and rockfish surveys (2001–2017).

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- Bycatch of Pacific Hake in the trawl fishery for Pink Shrimp off the coast of Oregon, 2004, 2005, 2007 and 2008.
  - Historical biological samples collected in Canada prior to 1990, but currently not available in electronic form.
  - Historical biological samples collected in the U.S. prior to 1975, but currently not available in electronic form or too incomplete to allow analysis with methods consistent with more current sampling programs.
  - CalCOFI larval hake production index, 1951-2006. The data source was previously explored and rejected as a potential index of hake spawning stock biomass, and has not been revisited since the 2008 stock assessment.
  - Joint-U.S. and Canada acoustic survey index of age-1 Pacific Hake.
  - NWFSC winter 2016 and 2017 acoustic research surveys of spawning Pacific Hake.

## **2.1 FISHERY-DEPENDENT DATA**

### **2.1.1 Total catch**

The catch of Pacific Hake for 1966–2017 by nation and fishery sector is shown in Figure 5 and Tables 1, 2 and 3. Catches in U.S. waters prior to 1978 are available only by year from Bailey et al. (1982) and historical assessment documents. Canadian catches prior to 1989 are also unavailable in disaggregated form. For more recent catches, haul or trip-level information was available to partition the removals by month during the hake fishing season, and estimate bycatch rates from observer information at this temporal resolution. This has allowed a more detailed investigation of shifts in fishery timing (see Figure 5 in Taylor et al. 2014). The U.S. shore-based landings are from the Pacific Fishery Information Network (PacFIN). Foreign and joint-venture catches for 1981–1990 and domestic at-sea catches for 1991–2017 are estimated from the AFSC and, subsequently, the NWFSC at-sea hake observer programs stored in the NORPAC (North Pacific Groundfish and Halibut Observer) database. Canadian Joint-Venture catches from 1989 are from the Groundfish Biological (GFBio) database, the shore-based landings from 1989 to 1995 are from the Groundfish Catch (GFCatch) database, from 1996 to March 31, 2007 from the Pacific Harvest Trawl (PacHarvTrawl) database, and from April 1, 2007 to present from the Fisheries Operations System (FOS) database. Discards are negligible relative to the total fishery catch. The vessels in the U.S. shore-based fishery carry observers and are required to retain all catch and bycatch for sampling by plant observers. All catches from U.S. at-sea vessels, Canadian Joint-Venture vessels, and Canadian freezer trawlers are monitored by at-sea observers. Observers use volume/density methods to estimate total catch. Canadian shoreside landings are recorded by dockside monitors using total catch weights provided by processing plants.

Three independent issues in the calculation of total catch were identified late in the assessment

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process and could not be included in the base model. These were explored in a sensitivity analysis described in Section 3.8. The impact of these changes was very small. The first issue was an error in the code that extracts and calculates the catch for Canadian fisheries. The Joint Venture catch was erroneously being added to the Shoreside catch, resulting in the values being added to the total catch twice. This error was for each of the five years within the past decade when the JV fishery took place: 2007, 2008, 2010, 2011, and 2017. Second, several fish-ticket discrepancies were identified related to total tribal catch levels. Fish tickets recorded by the Makah Indian Tribe, the Washington Department of Fish and Wildlife, and as archived in the PacFIN database did not match, resulting in an underestimate of total catch in 2016 (1,677 t, change of 0.5%) and 2017 (6,172 t, change of 1.4%). Improving the tracking and archival of tribal fish tickets has been identified as a future data need (Section 4) to ensure consistent and accurate accounting of total removals. Third, small changes to the pre-2017 catch in the U.S. fisheries were inadvertently left out of the “Update data from years prior to 2017” bridging step described in Section 3.4.1. The total net effect of these changes from 2007 to 2017 was 15,798 t, which is around 0.5% of the total catch of over 3,000,000 t.

### **2.1.2 Fishery biological data**

Biological information from the U.S. at-sea commercial Pacific Hake fishery was extracted from the NORPAC database. This included length, weight, and age information from the foreign and joint-venture fisheries from 1975–1990, and from the domestic at-sea fishery from 1991–2017. Specifically, these data include sex-specific length and age data which observers collect by selecting fish randomly from each haul for biological data collection and otolith extraction. Biological samples from the U.S. shore-based fishery from 1991–2017 were collected by port samplers located where there are substantial landings of Pacific Hake: primarily Eureka, Newport, Astoria, and Westport. Port samplers routinely take one sample per offload (or trip) consisting of 100 randomly selected fish for individual length and weight, and from these 20 are randomly subsampled for otolith extraction.

The Canadian domestic fishery is subject to 100% observer coverage on the four freezer trawler vessels *Viking Enterprise*, *Osprey #1*, *Northern Alliance*, and *Raw Spirit*, which together make up a large portion of the Canadian catch (43.5% in 2017). The Joint-Venture fishery has 100% observer coverage on their processing vessels, which in 2017 made up 6.5% of the Canadian catch. On observed freezer trawler trips, otoliths (for ageing) and lengths are sampled from Pacific Hake caught for each haul of the trip. The sampled weight from which biological information is collected must be inferred from length-weight relationships. For electronically observed shoreside trips, port samplers obtain biological data from the landed catch. Observed domestic haul-level information is then aggregated to the trip level to be consistent with the unobserved trips that are sampled in ports.

For the Canadian Joint-Venture fishery, an observer aboard the factory ship estimates the codend weight by measuring the diameter of the codend and doing a spherical volume calculation for each delivery from a companion catcher boat. Length samples are collected every second day of fishing operations, and otoliths are collected once a week. Length and age samples are taken randomly

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from a given codend. Since the weight of the sample from which biological information is taken is not recorded, sample weight must be inferred from a length-weight relationship applied to all lengths taken and summed over each haul.

The sampling unit for the shore-based fisheries is the trip, while the haul is the primary unit for the at-sea fisheries. Since detailed haul-level information is not recorded on trip landings documentation in the shore-based fishery, and hauls sampled in the at-sea fishery cannot be aggregated to a comparable trip level, there is no least common denominator for aggregating at-sea and shore-based fishery samples. As a result, initial sample sizes are simply the summed hauls and trips for fishery biological data. The magnitude of this sampling among sectors and over time is presented in Table 5.

Biological data were analyzed based on the sampling protocols used to collect them, and expanded to estimate the corresponding statistic from the entire landed catch by fishery and year when sampling occurred. A description of the analytical steps for expanding the age compositions can be found in recent stock assessment documents (Hicks et al., 2013; Taylor et al., 2014).

The aggregate fishery age-composition data (1975–2017) confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999 (Figure 8 and Table 11). The more recent age-composition data consisted of high proportions of 2008 and 2010 year classes in the 2012 fishery, and the 2010 year class from 2013 to 2017 fisheries (Figure 8 and Table 11). In 2016 and 2017, the 2010 and 2014 cohorts showed up as significant proportions (Figure 8 and Tables 6–11). In 2016, the 2014 cohort was the largest in all three U.S. fleets (Tables 6–8) while the 2010 cohort was largest in both Canadian fleets (Tables 9 and 10). In 2017, the 2014 cohort was the largest in the two at-sea U.S. fleets and the 2010 cohort was largest in both Canadian fleets and the U.S. shoreside fleet. The 2010 cohort was the largest (40%) and the 2014 cohort second largest (33%) for the aggregated data (Table 11).

We caution that proportion-at-age data contains information about the relative numbers-at-age, and these can be affected by changing recruitment, selectivity or fishing mortality, making these data difficult to interpret on their own. For example, the above-average 2005 and 2006 year classes declined in proportion in the 2011 fishery samples, but have persisted in small proportions since that time in the fishery catch, although are much reduced recently due to mortality and the overwhelming 2008 and 2010 cohorts. The assessment model is fit to these data to estimate the absolute sizes of incoming cohorts, which become more precise after they have been observed several times (i.e., encountered by the fishery and survey over several years).

Both the weight- and length-at-age information suggest that hake growth has changed markedly over time (see Figure 7 in Stewart et al. 2011). This is particularly evident in the frequency of larger fish ( $> 55$  cm) before 1990 and a shift to much smaller fish in more recent years. The treatment of weight- and length-at-age are described in more detail in sections 2.3.3 and 2.3.4 below. Although length composition data are not fit explicitly in the base assessment models presented here, the presence of the 2008 and 2010 year classes have been clearly observed in length data from both of the U.S. fishery sectors, and the 2014 year class was apparent in 2017.



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### 2.1.3 Catch per unit effort

Calculation of a reliable fishery catch-per-unit-effort (CPUE) metric is particularly problematic for Pacific Hake and it has never been used as a tuning index for assessment of this stock. There are many reasons that fishery CPUE would not index the abundance of Pacific Hake, which are discussed in the 2013 stock assessment (Hicks et al., 2013).

## 2.2 FISHERY-INDEPENDENT DATA

An acoustic survey of age 2+ hake was included in this assessment, while bottom trawl and pre-recruit sources were not used. An age-1 index derived from acoustic survey data was explored as a sensitivity to the base model. See Hicks et al. (2013) for a more thorough description and history of these fishery-independent data sources.

### 2.2.1 Acoustic survey

The joint biennial U.S. and Canadian integrated acoustic and trawl survey has been the primary fishery-independent tool used to assess the distribution, abundance and biology of coastal Pacific Hake along the west coasts of the United States and Canada. A detailed history of the acoustic survey is given by Stewart et al. (2011). The acoustic surveys performed in 1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012, 2013, 2015 and 2017 were used in this assessment (Table 13). The acoustic survey samples transects representing all waters off the coasts of the U.S. and Canada thought to contain all portions of the Pacific Hake stock age-2 and older. Age-0 and age-1 hake have been historically excluded from the survey efforts, due to largely different schooling behavior relative to older hake, concerns about different catchability by the trawl gear, and differences in expected location during the summer months when the survey takes place. Observations of age-1 hake are recorded during the survey, and an age-1 index is estimated (described below), but is only included in a sensitivity analysis.

Distributions of hake backscatter plotted for each acoustic survey since 1995 illustrate the variable spatial patterns of age-2+ hake across years (Figure 2). This variability is due in part to changes in the composition of the (age-2+) population (older Pacific Hake tend to migrate farther north), and partly due to environmental and/or climatic factors. The 1998 acoustic survey is notable because it shows an extremely northward distribution that is thought to be related to the strong 1997-1998 El Niño. In contrast, the distribution of hake during the 2001 survey was compressed into the lower latitudes off the coast of Oregon and Northern California. In 2003, 2005 and 2007 the distribution of Pacific Hake did not show an unusual coast-wide pattern, but in 2009, 2011, 2012, and 2013 the majority of the hake distribution was again found in U.S. waters, which is more likely due to age-composition than the environment, although 2013 showed some warmer than average sea-surface temperatures. In 2015, sea-surface temperatures were warmer again, resulting in a northern shift in the overall hake distribution. The distribution of Pacific Hake in 2017 was more latitudinally uniform than observed in recent years. This is likely a result of having large proportions of two cohorts (2010 and 2014 year-classes) in 2017 as opposed to many other years when a single cohort is dominant in the observed samples (Figure 2), in addition to prevailing

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environmental conditions.

During the acoustic surveys, mid-water trawls are made opportunistically to determine the species composition of observed acoustic sign and to obtain the length data necessary to scale the acoustic backscatter into biomass (see Table 13 for the number of trawls in each survey year). Biological samples collected from these trawls were post-stratified, based on similarity in size composition, and the composite length frequency was used to characterize the hake size distribution along each transect and to predict the expected backscattering cross section for hake based on the fish size-target strength (TS) relationship. Any potential biases that might be caused by factors such as alternative TS relationships are partially accounted for in catchability, but variability in the estimated survey biomass due to uncertainty in target strength is not explicitly accounted for in the assessment.

Acoustic survey data from 1995 onward have been analyzed using the kriging geostatistical technique, which accounts for spatial correlation to provide an estimate of total biomass as well as an estimate of the year-specific sampling variability due to patchiness of hake schools and irregular transects (Petitgas, 1993; Rivoirard et al., 2000; Mello and Rose, 2005; Simmonds and MacLennan, 2006). Advantages to the kriging approach are discussed in the 2013 stock assessment (Hicks et al., 2013).

For the 2016 assessment (Grandin et al., 2016), the data from all surveys since 1998 were scrutinized and reanalyzed using consistent assumptions. The same analytical procedure was carried out during the reanalysis of 1995 survey data (Berger et al., 2017) and during the preparation of 2017 survey data. These include:

- fixing the minimum and maximum number of points used to calculate the value in a cell at  $k_{\min}=3$  and  $k_{\max}=10$ ;
- standardizing the search radius to be three times the length scale that is estimated from the variogram;
- when extrapolating biomass beyond the end of a transect, using a function that decays with distance from the end of the transect;
- correcting spurious off-transect zeros that were erroneously generated in previous exportation of data; and
- re-analyzing data using an updated version of the EchoPro software with consistent data input files.

Thus, a full time-series of consistently analyzed survey biomass (Table 13 and Figures 9 and 10) and age compositions (Figure 8 and Table 12) are being input into the assessment model.

Results from research done in 2010 and 2014 on representativeness of the biological data (i.e. repeated trawls at different depths and spatial locations on the same aggregation of hake) and sensitivity analyses of stratified data showed that trawl sampling and post-stratification is only a small



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source of variability among all of the sources of variability inherent to the acoustic analysis (see Stewart et al. 2011).

Estimated age-2+ biomass in the survey increased steadily over the four surveys conducted in 2011-2013 and 2015. The 2017 survey biomass index declined from the 2015 index to 1.42 million metric tons, which is 0.66 times the 2015 index (Table 13 and Figure 9). The 2017 survey age composition was made up of 26.0% age-7 fish from the 2010 year-class and 52.7% age-3 fish from the 2014 year-class.

The acoustic survey biomass index included in the base model (Table 13) includes an estimate of biomass outside the survey area that is expected to be present due to the occurrence of fish at or near the western end of some survey transects. The method of extrapolation was refined for the 2016 assessment (Grandin et al., 2016) and supported by the SRG.

The acoustic survey data in this assessment do not include age-1 fish, although a separate age-1 index has been explored in the past. The age-1 index is used in this stock assessment as a sensitivity because more time is needed to develop and investigate the index, the uncertainty of each estimate is unknown, and the survey is not specifically designed to representatively survey age-1 hake. Given the design changes that have occurred over time, the index was not included in the base model. However, the estimates that have been provided seem to track the estimated recruitment reasonably well (Figure 11). The 2013 stock assessment provides a more detailed description of the age-1 index (Hicks et al., 2013).

## **2.2.2 Other fishery-independent data**

Fishery-independent data from the Alaska Fisheries Science Center (AFSC) bottom trawl survey, the Northwest Fishery Science Center (NWFSC) bottom trawl survey, the NWFSC and Pacific Whiting Conservation Cooperative (PWCC) pre-recruit survey, or any other DFO surveys were not used in this assessment. More information on these data sources is given in the 2013 stock assessment (Hicks et al., 2013).

## **2.3 EXTERNALLY ANALYZED DATA**

### **2.3.1 Maturity and fecundity**

The maturity and fecundity relationships were updated for the 2018 base model. Previously, fecundity was based on the product of the maturity-at-length reported by Dorn and Saunders (1997) and the weight-at-length estimated in 2011. These values were converted to fecundity-at-age using a parametric growth curve estimated in 2011 from a model that included length data.

For this assessment, a new age-based maturity ogive (Table 16 and Figure 12) was developed using histological estimates of functional maturity from 1,947 ovaries that were associated with age estimates. These samples were collected from the acoustic survey, winter and summer acoustic

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research trips, from the U.S. At-Sea Hake Observer Program (A-SHOP) observers aboard commercial Catcher-Processor vessels, and from the U.S. West Coast bottom trawl survey.

An additional 87 samples with age and maturity estimates from south of Point Conception, California (34.44°N) were examined and found to exhibit the same differences in the age dimension that were previously reported for length-based relationships (Figure 11 in Berger et al. 2017), with the fish from South of Point Conception maturing at earlier ages and smaller sizes. These fish were excluded from the maturity estimates.

The new age-based maturity ogive was multiplied by the mean weight-at-age averaged across all years to get a new estimate of fecundity-at-age. Samples from ages 15 and above were pooled for both the maturity and weight-at-age estimation due to limited sample sizes, and the age 15+ estimates were applied to ages 15-20 for purposes of modeling the population dynamics (Figure 12).

Some fish at almost every age were found to be functionally immature based on the histological criteria, which is a combination of “skip spawners” that will not be spawning in the upcoming year and senescent fish that appear to no longer have viable ovaries.

Tissue samples for genetic analyses have been collected from many of the same fish from which ovaries were sampled – this may help determine whether the fish south of 34.44°N are from the same stock as the rest of the population.

### **2.3.2 Ageing error**

The large inventory of Pacific Hake age determinations includes many duplicate reads of the same otolith, either by more than one laboratory, or by more than one age-reader within a lab. Recent stock assessments have utilized the cross- and double-reads approach to generate an ageing error vector describing the imprecision and bias in the observation process as a function of fish age. New data and analysis were used in the 2009 assessment to address an additional process influencing the ageing of hake: cohort-specific ageing error related to the relative strength of a year-class. This process reflects a tendency for uncertain age determinations to be assigned to predominant year classes. The result is that the presence of strong year classes is inflated in the age data while neighboring year-classes are under-represented relative to what would be observed if ageing error were consistent at age across cohorts.

To account for these observation errors in the model, year-specific ageing-error matrices (defined via vectors of standard deviations of observed age at true age) are applied, where the standard deviations of strong year classes are reduced by a constant proportion. For the 2009 and 2010 assessments this proportion was determined empirically by comparing double-read error rates for strong year classes with rates for other year classes. In 2010, a blind double-read study was conducted using otoliths collected across the years 2003-2009. One read was conducted by a reader who was aware of the year of collection, and therefore of the age of the strong year classes in each sample, while the other read was performed by a reader without knowledge of the year of

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collection, and therefore with little or no information to indicate which ages would be more prevalent. The resulting data were analyzed via an optimization routine to estimate both ageing error and the cohort effect. The resultant ageing error was similar to the ageing error derived from the 2008 analysis. The application of the cohort-specific ageing error was similar between assessments since 2011, with the ageing-error standard deviation reduced by a factor of 0.55 for the largest cohorts: 1980, 1984, 1999, 2010, and 2014. In the 2014 base model (Taylor et al., 2014), the 2008 cohort was also included in this set, but current estimates show this year-class to be enough less than the four largest that a reduction in ageing was not included for the 2008 year class in the 2015-2017 assessments (Taylor et al., 2015; Grandin et al., 2016; Berger et al., 2017) or this 2018 assessment. Also, the model presented here does not include the reduction in ageing error for age-1 fish under the assumption that they never represent a large enough proportion of the samples to cause the cohort-effect. A sensitivity analysis without any cohort ageing error is provided in Section 3.8.

### **2.3.3 Weight-at-age**

A matrix of empirically derived population weight-at-age by year is used in the current assessment model to translate numbers-at-age directly to biomass-at-age (Figure 13). Mean weight-at-age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2017 (Figure 13). Past investigations into calculating weight-at-age for the fishery and survey independently showed little impact on model results. Ages 15 and above for each year were pooled and assumed to have the same weight. The combinations of age and year with no observations were assumed to change linearly over time between observations at any given age. Mean weights were assumed to remain constant prior to the first observation and after the last observation within the range of years in the matrix. The number of samples is generally proportional to the amount of catch, so the combinations of year and age with no samples should have relatively little importance in the overall estimates of the population dynamics. The use of empirical weight-at-age is a convenient method to capture the variability in both the weight-at-length relationship within and among years, as well as the variability in length-at-age, without requiring parametric models to represent these relationships. However, this method requires the assumption that observed values are not biased by strong selectivity at length or weight and that the spatial and temporal patterns of the data sources provide a representative view of the underlying population. Simulations performed by Kuriyama et al. (2016) showed that, in general, using empirical weight-at-age when many observations are available resulted in more accurate estimates of spawning biomass.

For purposes of forecasting, the mean weights at each age in the forecast were set equal to the mean across all years – they therefore match the equilibrium and reference point calculations. Mean weight has been declining for most ages over the past few years, but did increase slightly in 2017 from recent lows in 2016.

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### 2.3.4 Length-at-age

In the 2011 assessment model (Stewart et al., 2011) and in models used for management prior to the 2006 stock assessment, temporal variability in length-at-age was included in stock assessments via the calculation of empirical weight-at-age. In the 2006 and subsequent assessments that attempted to estimate the parameters describing a parametric growth curve, strong patterns have been identified in the observed data indicating sexually dimorphic and temporally variable growth. In aggregate, these patterns result in a greater amount of process error for length-at-age than is easily accommodated with parametric growth models, and attempts to explicitly model size-at-age dynamics (including use of both year-specific and cohort-specific growth) have not been very successful for hake. Models have had great difficulty in making predictions that mimic the observed data. This was particularly evident in the residuals to the length-frequency data from models prior to 2011. We have not revisited the potential avenues for explicitly modeling variability in length- and weight-at-age in this model, but retain the empirical approach to weight-at-age used since 2011 and described above, which models this variability implicitly.

## 2.4 ESTIMATED PARAMETERS AND PRIOR PROBABILITY DISTRIBUTIONS

The estimated parameters and prior probability distributions used in this stock assessment are reported in Table 17. Several important distributions are discussed in detail below.

### 2.4.1 Natural Mortality

Since the 2011 assessment, and again this year, a combination of the informative prior for natural mortality used in previous Canadian assessments and results from analyses using Hoenig's (1983) method support the use of a log-normal distribution with a median of 0.2 and a logarithmic standard deviation of 0.1. Historical treatment of natural mortality,  $M$ , is discussed in the 2013 stock assessment (Hicks et al., 2013). Sensitivity to this prior has been evaluated extensively in many previous hake assessments (e.g., Hicks et al. 2013) and is repeated here (see Section 3.8). Alternative prior distributions for  $M$  typically have a significant impact on the model results, but in the absence of new information on  $M$ , there has been little option to update the prior.

### 2.4.2 Steepness

The prior for the steepness parameter of the stock-recruitment function is based on the median (0.79) and the 20th (0.67) and 80th (0.87) percentiles from Myers et al.'s (1999) meta-analysis of the family Gadidae, and has been used in U.S. assessments since 2007. This prior has a beta distribution with parameters 9.76 and 2.80, which translate to a mean of 0.777 and a log-standard deviation of 0.113. Sensitivities to the variance on the prior on steepness were evaluated in the 2012 and 2013 assessments (Stewart et al., 2012; Hicks et al., 2013). Sensitivities to the mean of the prior are explored in this assessment (see Section 3.8).

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### 2.4.3 Variability on fishery selectivity deviations

Time-varying fishery selectivity was introduced in the 2014 assessment (Taylor et al., 2014) and is modeled with yearly deviations applied to the selectivity-at-age parameters. A penalty function in the form of a normal distribution is applied to each deviation to keep the deviation from straying far from zero, unless the data are overwhelming. The amount of deviation from zero is controlled by a fixed standard deviation,  $\phi$  (explained further below).

The 2017 assessment (Berger et al., 2017) increased the value of  $\phi$  from the previously-used value of 0.03 to 0.20 for a variety of reasons, including reports of unusual ocean conditions in recent years and good performance of the more flexible selectivity in past management strategy evaluations (Taylor et al., 2014). However, the most compelling reason for the change was that the large catch of age-2 fish in 2016 caused the model with less flexible selectivity ( $\phi = 0.03$ ) to produce implausible estimates of 2014 recruitment, values about three times larger than the very large 1999 and 2010 cohorts. This was inconsistent with the qualitative comparison to the age-1 index, and the fishery age-composition was not believed to be sufficiently reliable to support such a large estimate. The original basis for the  $\phi = 0.03$  value was a method of treating the deviations as random effects and integrating over them using the Laplace method, as described by Thorson et al. (2014). Repeating that approach has continued to produce similarly low values for  $\phi$ .

A new parameterization for the selectivity deviations was explored this year, based on the recent work of Xu et al. (under review), in an effort to produce a more objective way to determine the degree of flexibility. However, further testing of this approach was believed necessary before making the change and so it was only used for a sensitivity analysis (see Section 3.8).

Further details on the time-varying selectivity function are provided.

For each age  $a \geq A_{\min}$ , where  $A_{\min}$  is the minimum age for which selectivity is allowed to be non-zero, there is an incremental selectivity parameter,  $p_a$ , for the fishery (for which  $A_{\min} = 1$ ). There is also an equivalent  $p_a$  for the survey (for which  $A_{\min} = 2$ ), but to keep the notation simple we do not distinguish them here because the following calculations are the same for the survey and the fishery. The selectivity at age  $a$  is computed as

$$S_a = \exp(S'_a - S'_{\max}), \quad (1)$$

where

$$S'_a = \sum_{i=A_{\min}}^a p_i \quad (2)$$

and

$$S'_{\max} = \max\{S'_a\}. \quad (3)$$

Selectivity is fixed at  $S_a = 0$  for  $a < A_{\min}$ .

This formulation has the properties that the maximum selectivity equals 1, positive values of  $p_a$  are associated with increasing selectivity between ages  $a - 1$  and  $a$ , and negative values are associated

with decreasing selectivity between those ages. Beyond the maximum age for which selectivity is estimated (6 in the base model for both the fishery and the survey),  $p_a = 0$  gives constant selectivity beyond the last estimated value. The condition that maximum selectivity equals 1 results in one fewer degree of freedom than the number of estimated  $p_a$ . Therefore,  $p_{A_{\min}} = 0$  can be set for the fishery and for the survey.

The implementation of time-varying selectivity in the assessments from 2014 to 2017 used an option available in Stock Synthesis 3.24 whereby annual deviations to the selectivity parameters were applied after the following logistic transformation (which is not available in Stock Synthesis 3.30) to keep the time-varying parameters within a set of bounds.

Given bounds  $p_{\text{low}}$  and  $p_{\text{high}}$  such that  $p_{\text{low}} \leq p_a \leq p_{\text{high}}$ , the base parameters  $p_a$  are transformed into  $\tilde{p}_a$  via the equation

$$\tilde{p}_a = -\frac{1}{2} \log \left( \frac{p_{\text{high}} - p_{\text{low}} + 2 \times 10^{-7}}{p_a - p_{\text{low}} + 10^{-7}} - 1 \right) \quad (4)$$

where the small constants in the numerator and denominator are included to ensure that  $\tilde{p}_a$  is finite even when  $p_a$  is on a bound.

The deviations are applied in this transformed space as

$$\tilde{p}_{ay} = \tilde{p}_a + \epsilon'_{ay} \quad (5)$$

where the  $\epsilon'_{ay}$  are additional parameters estimated in the model.

The resulting value is then back-transformed into the standard parameter space via

$$p_{ay} = p_{\text{low}} + \frac{p_{\text{high}} - p_{\text{low}}}{1 + \exp(-2\tilde{p}_{ay})} \quad (6)$$

In Stock Synthesis 3.30, this logistic transformation is no longer available, so the deviations are applied directly to the base parameter:

$$p_{ay} = p_a + \epsilon_{ay} \quad (7)$$

where the  $\epsilon_{ay}$  are the parameter deviations estimated in the model. These deviations are included in an additional likelihood component with negative log-likelihood proportional to

$$-\log(L) \propto \frac{1}{2} \sum_{a=A_{\min}}^6 \sum_{y=1991}^{2017} \frac{\epsilon_{ay}^2}{\Phi^2}, \quad (8)$$

where  $\Phi$  is the standard deviation of the normal penalty function. Note that there is such a log-likelihood component for both the fishery and the survey selectivities.

The logistic transformation proved unnecessary as the bounds on the selectivity parameters were somewhat arbitrary, and none of the deviations led to parameters approaching these bounds. To



calculate a value of  $\Phi$  to apply in the standard parameter space that corresponds to the  $\phi = 0.20$  use in the transformed parameter space in the 2017 assessment (Berger et al., 2017), the derivative of (6) with respect to  $\tilde{p}_{ay}$  was calculated, with  $p_{\text{low}} = -5$  and  $p_{\text{high}} = 9$  for the bounds. The resulting value of 7 at the mid-point between the bounds is an approximation to the relative impact of a deviation in the logistic parameter space to one in the standard parameter space. The resulting value of  $\Phi = 1.40$  approximates the value of  $\phi = 0.20$  used in the transformed parameter space in the 2017 assessment.

#### 2.4.4 Age composition likelihood

The base model includes a change in the likelihood and data-weighting method applied to the age composition data. The 2017 assessment (Berger et al., 2017), like those before it, used a multinomial likelihood and the tuning method of McAllister and Ianelli (1997) for weighting the age compositions. This tuning method involves iteratively adjusting a multiplier of the input sample sizes until they are roughly equal to the harmonic mean of the effective sample sizes, where the effective sample size is dependent on how well the model expectation matches the observed values. For this assessment, a new Dirichlet-Multinomial (D-M) likelihood was adopted, as proposed by Thorson et al. (2017) and tested by them on a simplified version of the 2015 Pacific Hake model (Taylor et al., 2015). The primary benefit of the D-M approach is that instead of manually iterating the sample size multiplier, an estimated parameter,  $\theta$ , serves to automatically adjust the weight given to the composition data. This increases efficiency of the assessment process, removes the subjective choice of how many iterations are required in the previous approach, and also ensures that the results of model sensitivities, retrospective analyses, and likelihood profiles will all be automatically tuned, rather than having the age compositions given the same weight as the base model. Note that the following description holds for both the survey data and the fishery data, but, again, for simplicity we do not make the distinction here (other than to note that we consequently estimate  $\theta_{\text{surv}}$  for the survey data and  $\theta_{\text{fish}}$  for the fishery data).

The likelihood function is given by equation (10) of Thorson et al. (2017), and is

$$L(\boldsymbol{\pi}, \theta | \tilde{\boldsymbol{\pi}}, n) = \frac{\Gamma(n+1)}{\prod_{a=1}^{A_{\max}} \Gamma(n\tilde{\pi}_a + 1)} \frac{\Gamma(\theta n)}{\Gamma(n + \theta n)} \prod_{a=1}^{A_{\max}} \frac{\Gamma(n\tilde{\pi}_a + \theta n\pi_a)}{\Gamma(\theta n\pi_a)} \quad (9)$$

where  $\tilde{\pi}_a$  is the observed proportion at age  $a$ ,  $\pi_a$  is the corresponding expected proportion at age  $a$  estimated by the model,  $\tilde{\boldsymbol{\pi}}$  and  $\boldsymbol{\pi}$  designate the vectors of these proportions,  $A_{\max}$  is the maximum age in the model, and  $n$  is the input sample size. The parameter  $\theta$  is defined as a linear scaling parameter such that  $\theta n$  is the variance-inflation parameter of the Dirichlet-Multinomial distribution (see Thorson et al. 2017).

The effective sample size associated with this likelihood is given by

$$n_{\text{eff}} = \frac{1}{1 + \theta} + \frac{n\theta}{1 + \theta} \quad (10)$$

The input samples sizes used in this assessment, which are based on the number of trips or hauls, are large enough that the  $1/(1 + \theta)$  term is insignificant compared to the  $n\theta/(1 + \theta)$  term, which

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means that  $\theta/(1 + \theta)$  can be compared to the sample size multipliers used in the McAllister-Ianelli data weighting method.

See Thorson et al. (2017) for the derivation of the likelihood and more details on the hake-based simulation study used to test it. The implementation of the D-M likelihood in Stock Synthesis has  $\log \theta$  as the estimated parameter in order to ensure that  $\theta$  remains positive.



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## 3 ASSESSMENT

### 3.1 MODELING HISTORY

In spite of the relatively short history of fishing, Pacific Hake have surely been subject to a larger number of stock assessments than any marine species off the west coast of the U.S. and Canada. These assessments have included a large variety of age-structured models. Initially, a cohort analysis tuned to fishery CPUE was used (Francis et al., 1982). Later, the cohort analysis was tuned to NMFS triennial acoustic survey estimates of absolute abundance at age (Hollowed et al., 1988). Since 1989, stock-synthesis models using fishery catch-at-age data and acoustic survey estimates of population biomass and age composition have been the primary assessment method (Berger et al., 2017).

While the general form of the age-structured assessment has remained similar since 1991, management procedures have been modified in a variety of ways. There have been alternative data choices, post-data collection processing routines, different data weighting schemes, many structural assumptions for the stock assessment model, and alternative control rules.

Data processing, choices, and weighting have been modified several times in historical hake assessments. For example, acoustic data processing has been modified over the years through modifications to target strength calculations (Dorn and Saunders, 1997) or the introduction of kriging (Stewart and Hamel, 2010). While survey data have been the key index for abundance since 1988, surveys that have been used have varied considerably. The AFSC/NWFSC triennial bottom trawl survey was used from 1988 before being discarded from the 2009 assessment (by Hamel and Stewart 2009). Acoustic surveys from the years prior to 1995 were used for assessments in the early 1990s, but Stewart et al. (2011) reviewed these early surveys and deemed that sampling had been insufficient to be comparable with more recent data. Various recruitment indices have also been considered, but subsequently rejected (Helser et al., 2002, 2005; Stewart and Hamel, 2010). Even where data have been consistently used, the weighting of these data in the statistical likelihood has changed through the use of various emphasis factors (e.g. Dorn 1994; Dorn et al. 1999); the use of a multinomial sample size on age-composition (Dorn et al., 1999; Helser et al., 2002, 2005; Stewart et al., 2011); and assumptions regarding survey variance. The list of changes discussed above is for illustrative purposes only; it is only a small fraction of the different data choices analysts have made and that reviewers have required.

The structure of assessment models has perhaps had the largest number of changes. In terms of spatial models, analysts have considered spatially explicit forms (Dorn, 1994, 1997), spatially implicit forms (Helser et al., 2006) and single-area models (Stewart et al., 2012). Predicted recruitment has been modeled by sampling historical recruitment (e.g., Dorn 1994; Helser et al. 2005), using a stock-recruitment relationship parameterized using maximum sustainable yield (MSY) and the fishing mortality rate ( $F_{\text{MSY}}$ ) estimated to produce the MSY (Martell, 2010), and using several alternative steepness priors (Stewart et al., 2012; Hicks et al., 2013). Selectivity has also been modeled in several ways: it has been invariant (Stewart et al., 2012; Hicks et al., 2013), time-varying with (Helser et al., 2002) and without (Dorn, 1994; Dorn and Saunders, 1997; Stewart et al., 2012; Hicks et al., 2013) a random walk and alternative levels of allowable deviation through time (Hicks

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et al., 2013; Berger et al., 2017), age-based (Dorn, 1994; Dorn and Saunders, 1997; Stewart et al., 2012; Hicks et al., 2013) and length-based (Helser and Martell, 2007).

Several harvest control rules have been explored for providing catch limits from these stock assessments. Pacific Hake stock assessments have presented decision makers with constant  $F$ , variable  $F$  and hybrid control rules:  $F_{\text{SPR}=35\%}$ ,  $F_{\text{SPR}=40\%}$ ,  $F_{\text{SPR}=40\%}-40:10$ ,  $F_{\text{SPR}=45\%}$ ,  $F_{\text{SPR}=45\%}-40:10$  and  $F_{\text{SPR}=50\%}$  (e.g., Dorn 1996; Hicks et al. 2013). The above is only a small fraction of the number of management procedures that have actually been investigated. There have been many other combinations of data, assessment models and harvest control rules. In addition to the cases examined in the assessment documents, there have been many more requested at review panel meetings.

While there have been many changes to Pacific Hake management procedures, each one has been considered carefully. Available data have changed over the years, and there have been many advances in the discipline of fisheries science. In some ways, the latter has evolved considerably over the course of the historical hake fishery: new statistical techniques and software have evolved (e.g. Bayesian vs. maximum likelihood methods), and the scientific literature has suggested potentially important biological dynamics to consider (e.g. explicit modeling of length-at-age). Policies requiring the application of specific control rules have also changed such as the United States' National Standards Guidelines in 2002 and the  $F_{\text{SPR}=40\%}-40:10$  harvest control rule in The Agreement (see Glossary in Appendix B). Analysts making changes to Pacific Hake management procedures have been trying to improve the caliber and relevance of the assessments by responding to new scientific developments, policy requirements, and different or new insights during the peer review process. Until the process for a Management Strategy Evaluation (MSE) began, initiated in 2013 (Hicks et al., 2013) and now being revisited in 2018, none of these management procedure changes were evaluated by simulation and quantitatively compared with performance measures.

### 3.2 DESCRIPTION OF BASE MODEL

The 2018 base model is predominantly an update of the base model in the 2017 stock assessment. Stock Synthesis (Methot and Wetzel, 2013) version 3.30 was used for the first time this year, which is a significant update to the software version (3.24U) used in the previous assessment (Berger et al., 2017). In addition to the new version of Stock Synthesis, the largest changes between the 2017 and 2018 stock assessments are the addition of another year of acoustic survey and fishery data, a new maturity ogive, a new approach for weighting composition data, and a modification of the parameterization for time-varying selectivity.

The 2018 base model includes an acoustic data time series from 1995 to 2017, where estimates of abundance from the survey followed the same procedures as in 2017 (Berger et al., 2017). An updated maturity ogive was estimated and incorporated into the 2018 base model (see Section 2.3.1). The Dirichlet-Multinomial (D-M) likelihood approach (Thorson et al., 2017) was used to estimate the weights associated with age-composition data, rather than iteratively tuning the sample size multiplier as in previous assessments (see Section 2.4.4). Time-varying fishery selectivity is retained in the 2018 base model with the magnitude of the allowable deviations effectively unchanged from the  $\phi = 0.20$  used in the 2017 base model to an equivalent value of  $\Phi = 1.4$  (see

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Section 2.4.3). Otherwise, the general parameterization of selectivity was retained, although additional parameters were required to estimate an additional year of deviations. The acoustic survey selectivity is assumed to not change over time. Selectivity curves were modeled as non-parametric functions estimating age-specific values for each age beginning at age 2 for the acoustic survey (because age-1 fish are mainly excluded from the sampling design) and age-1 for the fishery until a maximum age of 6 (all fish 6 and older have the same selectivity).

Prior probability distributions remained unchanged from 2017 and fixed values are used for several parameters. For the base model, the instantaneous rate of natural mortality ( $M$ ) is estimated with a lognormal prior having a median of 0.20 and a standard deviation (in log-space) of 0.1 (see Section 2.4.1). The stock-recruitment function is a Beverton-Holt parameterization, with the log of the mean unexploited recruitment freely estimated. This assessment uses the same Beta-distributed prior for stock-recruit steepness ( $h$ ), based on Myers et al. (1999), that has been applied since 2011 (Stewart et al., 2011, 2012; Hicks et al., 2013; Taylor et al., 2014, 2015; Grandin et al., 2016; Berger et al., 2017). Year-specific recruitment deviations were estimated from 1966-2017 as well as the years 2018, 2019, and 2020 for purposes of forecasting. The standard deviation,  $\sigma_r$ , of recruitment variability, serving as both a recruitment deviation constraint and bias-correction term, is fixed at a value of 1.4 in this assessment. This value is based on consistency with the observed variability in the time series of recruitment deviation estimates, and is the same as assumed in assessments from 2013 to 2017. Survey catchability was set at the median unbiased estimate calculated analytically as per Ludwig and Walters (1981). Maturity and fecundity relationships are assumed to be time-invariant and fixed values were updated using the new maturity ogive discussed earlier.

Statistical likelihood functions used for data fitting are typical of many stock assessments. The acoustic survey index of abundance was fit via a log-normal likelihood function, using the observed (and extra 2009) sampling variability, estimated via kriging, as year-specific weighting. An additional constant and additive standard deviation on the log-scale component is included, which was freely estimated to accommodate unaccounted-for sources of process and observation error. A Dirichlet-Multinomial (D-M) likelihood was applied to age-composition data, with input sample sizes equal to the sum of the number of trips or hauls actually sampled across all fishing fleets or the number of trawl sets in the research surveys (see Section 2.4.4). A weighting parameter for the fishery and the survey age compositions was specified and then estimated in the model fitting procedure to allow for additional sources of process and observation error. This process resulted in automatically tuned input sample sizes. Tuning quantities did not change in assessments from 2012 to 2015, however additional tuning was required in 2016 and 2017 given the updated acoustic survey index composition data and refinements to fishery composition data. Tuning quantities changed again this year with the addition of the new D-M data weighting (tuning) approach.

Uncertainty of estimated quantities was calculated via Markov Chain Monte Carlo (MCMC) simulations. The bounds of 95% credibility intervals were calculated as the 2.5% quantile and the 97.5% quantile of posterior distributions from the MCMC simulations, to give equal-tailed intervals. The Stock Synthesis input files for the based model are given in Appendices F-J.

Calculations and figures from Stock Synthesis output were performed using R version 3.4.3 (2017-11-30) (R Core Team, 2017) and many R packages (in particular *r4ss* and *xtable*). The use of R,

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knitr, L<sup>A</sup>T<sub>E</sub>X and GitHub immensely facilitated the collaborative writing of this document.

For this assessment document, we have slightly refined the Glossary (Appendix B), adding an explicit definition of spawning biomass per recruit.

### 3.3 RESPONSE TO 2017 SCIENTIFIC REVIEW GROUP (SRG) REVIEW

The Scientific Review Group (SRG) meeting was held from February 14–16, 2017, at the Morris J. Wosk Centre for Dialogue, Vancouver, BC, Canada.

The following are the Assessment Recommendations from the 2017 SRG report, as listed from highest to lowest priority, and associated responses from the JTC:

- In the current assessment, the change from  $\phi = 0.03$  to  $\phi = 0.2$  has a large effect on fisheries selectivity in all years, as well as on the estimate of 2017 female spawning biomass. The SRG is concerned about the broad-reaching impact of this change, intended to reduce an anomalously high 2014 recruitment estimate informed solely by fishery catch-at-age data. As discussed above, the SRG recommends continued work on evaluating the impact of flexibility in time-varying selectivity and a more objective way of determining an appropriate value of  $\phi$  (or other parameterizations of time-varying selectivity) for future assessments.

*Response – The JTC has conducted several analyses in response to this request including evaluating alternative  $\phi$  values in sensitivity trials and exploring an alternative “semi-parametric” parameterization of the approach to specifying time-varying selectivity, all described in Section 3.8. Although the semi-parametric option shows promise, no considered alternative was a clear improvement over the status-quo parameterization with the larger  $\phi$  value (previously  $\phi = 0.2$  but now converted to  $\Phi = 1.4$  after removing a logistic transformation as described in Section 3.4.1). The data from 2017 suggest that the 2014 cohort was more in line with the estimates from the model with more (rather than less) flexible fishery selectivity (larger  $\phi$ ), providing support for maintaining that flexibility for this year.*

- The next priority for 2018 is processing the archived ovary collections of Pacific Hake, and re-estimating the maturity schedule based on histological techniques. Three issues are of particular interest: addressing the question of different maturity schedules north and south of Point Conception ( $34.5^\circ$  N); bringing the stock assessment up to date given that the current assessment is based on information more than 20 years old from Dorn and Saunders (1997); and assessing whether maturity is more dependent upon age or upon weight. If maturity is more dependent on weight, then the assessment model would need revisions to obtain maturity-at-age from the empirical weight-at-age-and-year matrices, resulting in variable proportions of mature fish-at-age in each year.

*Response – The JTC worked with the Northwest Fisheries Science Center (NWFSC) to estimate a new functional maturity ogive included in the base model which is based on histological examination of 1,947 ovary samples with ages from north of  $34.44^\circ$  N, as discussed in sections 2.3.1, 3.4, and 3.8. A thorough analysis of whether maturity is more dependent*

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*upon age or upon weight has not yet been completed although the greatest variability in weight occurs at older ages which are mostly mature. Models were explored that assumed fecundity-at-age varied over time in proportion to mean weight-at-age, but the impact of that alternative assumption was small due to the weak link between recruitment and spawning biomass and the lack of information about weight-at-age in the unfished equilibrium. Further analysis of the relationships between fecundity, age, and weight would depend upon collecting whole ovaries rather than ovary samples. The difference in maturity between fish sampled north and south of Point Conception is strongly evident when considering maturity-at-age as well as maturity-at-length, and NWFSC is seeking to conduct genetic analyses that could test whether the southern samples are from a distinct stock.*

- The SRG notes that MCMC convergence diagnostics for the 2017 base model pointed towards the need for a longer MCMC chain (24 million rather than 12 million in length) in the 2017 assessment. We recommend that for the 2018 assessment, the JTC investigate running longer MCMC chains, into retaining a higher number of samples than the current 999 samples for greater precision, and look into more efficient methods of obtaining Bayesian posteriors if available (e.g., Monnahan et al. 2017).

*Response – The JTC ran multiple MCMC algorithms in response to this request, including alternative chain lengths (12 million and 24 million), sample lengths (1,200, 999 saved after burn-in; and 2,400, 2,000 saved after burn-in), and chains. In addition to standard single chain MCMC convergence diagnostics, we also evaluated multi-chain diagnostics (Gelman-Rubin) that compare within-chain and among-chain variances to further diagnose convergence. The R package ‘adnuts’ has recently been incorporated into the new 12.0 version of ADMB, and we expect to further explore more efficient methods for obtaining Bayesian posteriors once Stock Synthesis has been compiled and fully tested with this new version.*

- The list of sensitivity tests presented in the 2017 assessment covers the major axes of uncertainty and should be continued in future assessments, including the sensitivity tests for alternative values for  $\sigma_r$  (which sets variability around the theoretical recruitment model) of 1.0 and 2.0. The SRG requests that future assessments, beginning with 2018, include the following key sensitivity tests: natural mortality, stock-recruit steepness ( $h$ ),  $\sigma_r$ , inclusion of the age-1 index, and exploring the degree of flexibility in time-varying selectivity or the  $\phi$  parameter, as well as any others the JTC deems appropriate.

*Response – The 2018 assessment includes all of the key sensitivities that the SRG requested. Many other sensitivity model runs were conducted during the development of the base model and to explore different than base model assumptions, including sources of data, model structural assumptions, and parameterizations. The main sensitivity runs, including those related to time-varying selectivity, are discussed further under Section 3.8.*

- The SRG supports continued development of an age-1 index from the acoustic survey, and recommends continuing to run sensitivity tests in future assessments fitted to the current provisional age-1 index. This index is most important in years where auxiliary information



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is needed to assess the likelihood of small or large recruitment events that are influential in projections, but highly uncertain.

*Response – The 2018 assessment includes a sensitivity model run that incorporates the acoustic survey age-1 index (see Figures 3, 47, and 48). The age-1 index time series was extended to include the age-1 estimate for 2017. The age-1 index is used in this stock assessment as a sensitivity because the survey is not specifically designed to survey age-1 hake and uncertainty associated with each estimate is unknown.*

- Current biological evidence does not support including Pacific Hake south of Point Conception (34.5° N) in the assessment. The SRG encourages ongoing collection and analysis of genetic material in both Canadian and US waters to resolve stock structure in the California Current.

*Response – The JTC continues to support this recommendation.*

- The following two recommendations are to fulfill requests for specific information by the AP representatives:
  - A table providing exploitation rates by age and year be added to future assessment documents.
  - A table in future assessment documents reporting on the model estimates of the annual weight of each cohorts that is caught, dies from natural mortality, and lives, by year.

*Response – The exploitation rates by age and year were included in the final version of the 2017 assessment (Berger et al., 2017) as Table 22. We also presented estimated biomass-at-age at the beginning of each year (Table 21), and catch-at-age in numbers (Table 23) and biomass (Table 24) for each year. We included the requested estimated fate of cohorts for the strongest cohorts only (Table 25) to restrict the length of the assessment document. Tables that include the fate of other cohorts can be accommodated upon request. These tables are included in this 2018 assessment as Tables 22, 21, 23, 24 and 25, respectively.*

## 3.4 MODELING RESULTS

### 3.4.1 Changes from 2017

A set of ‘bridging’ models was constructed to evaluate the component-specific effects of all changes from the 2017 base model to the 2018 base model.

In short, these included the following

- Update the Stock Synthesis modeling software from version 3.24 to version 3.30.
- Update data from years prior to 2017.

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- Add 2017 total catch.
  - Add 2017 survey biomass estimate.
  - Add 2017 survey age composition.
  - Add 2017 fishery ages and update associated settings related to recruitment.
  - Tune the model (apply the McAllister-Ianelli data-weighting method).
  - Switch to Dirichlet-Multinomial likelihood for age compositions.
  - Update the estimates of maturity and fecundity.

In general, these changes mimic the steps routinely applied, with a few exceptions requiring additional explanation. Stock Synthesis (SS) version 3.30 includes a large number of new features and behind-the-scenes changes which are described in detail in Methot et al. (2018). It has been extensively tested prior to release and used in 2017 for at least six stock assessments for species managed under the Pacific Fishery Management Council.

One change between the two Stock Synthesis versions with significance for this assessment is a change in the options for how time-varying parameters are represented. In SS 3.24, time-varying parameters could have a logistic transformation applied to ensure that adjusted parameter values stay within certain bounds. The parameter deviations were applied in a logistic space and the resulting values were transformed back into the normal parameter space. This option was not included in SS version 3.30 because it was found to make interpretation of the parameter values more difficult and appropriate adjustment of parameter bounds made the transformation unnecessary. Recent hake assessments used the logistic transformation for the time-varying selectivity parameters, so the conversion of the 2017 assessment to the newer software required an adaptation to account for this option no longer being available. In particular, the  $\phi$  parameter controlling the flexibility of the variability associated with fishery selectivity (which was increased from  $\phi = 0.03$  in the 2016 assessment to  $\phi = 0.20$  in the 2017 assessment) no longer had the same effect when applied in the standard instead of logistic parameter space. An analysis of the transformation, described in Section 2.4.3, estimated that the  $\phi = 0.20$  applied in the logistic parameter space in the 2017 assessment could be converted to  $\Phi = 1.40$  applied in the standard parameter space. Exploration of higher and lower  $\Phi$  values confirmed that the model with  $\Phi = 1.40$  provided the best approximation to the 2017 base model as measured by both the resulting pattern of fishery selectivity over time and the estimated time series of spawning biomass. Overall, the results of the switch to SS 3.30 had only subtle impacts on the model results (Figure 14).

The bridging step “Update data from years prior to 2017” was primarily a change to the fishery ages, where a few additional samples from previous years, especially from the end of 2016 that were not available in time for the 2017 assessment were now included. These changes were small enough that they had little impact on the model results (Figure 14).

The addition of 2017 catch allowed the ending year of the model to be extended to 2018, but the



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estimates for 2018 remaining highly uncertain (Figure 15) in the absence of additional information about recent recruitment. The change with the biggest impact was the addition of the 2017 survey biomass estimate, which reduced the estimated size of the 2014 year class, bringing down the estimated spawning biomass at the end of the time series as well as reducing the uncertainty. The addition of the age compositions for the survey and fishery had relatively little additional impact on the biomass estimates, indicating that the observed ages were consistent with the model estimates without those data (Figure 15).

The addition of the fishery ages in “Add 2017 fishery ages and updated associated settings related to recruitment” combined multiple elements that should be associated with each other. The assessment model separates the main vector of recruitment deviations from those applied in the forecast, because the deviations in the ‘main’ period are modeled as summing to zero to ensure that they are equally balanced around the stock-recruit relationship. If forecast deviations were included in this vector, this zero-sum constraint would have the potential to cause those forecast deviations to differ from zero, even in the absence of any data for the forecast years. The addition of the 2017 fishery data, which included small numbers of age-1 fish from the 2016 cohort, meant that it was now necessary to shift the endpoint of the main vector of recruitment deviations to include 2016. The settings related to avoiding bias in recruitment estimation, based on the method proposed by Methot and Taylor (2011), were also shifted by 1 year as part of this same bridging step, to account for the addition of information about recruitment for the 2016 cohort. Finally, this bridging step also shifted the ending year of the deviations in the selectivity parameters from 2016 to 2017 since there was now fishery data in 2017.

The bridging steps “Tune the model (apply the McAllister-Ianelli data-weighting method)” and “Switch to Dirichlet-Multinomial likelihood for age compositions” were not sequential, but rather alternative data-weighting approaches that produced similar results (Figure 16). The Dirichlet-Multinomial method represents a replacement of the status-quo McAllister-Ianelli data-weighting method as described in Section 2.4.4. The choice to switch to the new likelihood was based on practical considerations, but the overall model results showed little impact of the switch.

The final bridging step “Update the estimates of maturity and fecundity” represents an update to the estimated fecundity-at-age as discussed in Section 2.3.1. This caused a visible change in the time series of spawning biomass (Figure 16) as the fecundity of all cohorts were different and the less smooth maturity ogive leads to larger variability in the time series of spawning biomass. The new fecundity has a larger increase from age 2 to age 3 than that used previously (Figure 12), causing a more abrupt increase in spawning biomass in years where large cohorts reach age 3, such as 1983, 1987, 2002, and 2013. These increases are followed by faster declines in spawning biomass when the cohorts reach age 5 as the updated fecundity shows a smaller increase from age 4 to 5 than that used previously, such that the loss due to mortality is greater in comparison. The estimated decline in fecundity due to senescence and skip spawning from age 13 onward also reduces the estimates of spawning biomass at the initial equilibrium and in the early part of the time series where there were more old individuals than in the following years with higher fishing intensity. In spite of these changes to the estimated spawning biomass, this bridging step had little impact on recruitment, since the stock-recruit relationship indicates a relatively weak link between spawning biomass and recruitment (see below).

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### 3.4.2 Assessment model results

#### Model Fit

For the base model, the MCMC chain length was increased from the 12 million in the 2017 assessment (Berger et al., 2017) to a chain length of 24 million. The first 4,000,000 values were discarded to eliminate ‘burn-in’ effects and each 10,000th value thereafter was retained, resulting in 2,000 samples from the posterior distributions for model parameters and derived quantities. Initial MCMC explorations indicated that  $\log \theta_{\text{surv}}$ , the log of the  $\theta$  parameter associated with the survey data in the Dirichlet-Multinomial (D-M) weighting, was not being sampled efficiently due to many samples occurring in a part of the parameter space where the effective sample size multiplier,  $\theta_{\text{surv}}/(1 + \theta_{\text{surv}})$ , is between 0.99 and 1.0. In this area, the input sample sizes are given full weight and the likelihood surface is almost completely flat with respect to this parameter. Therefore, to improve MCMC convergence,  $\log \theta_{\text{surv}}$  was fixed at the MLE estimate of 2.427, corresponding to a weight of  $\theta_{\text{surv}}/(1 + \theta_{\text{surv}}) = 0.919$ . The D-M parameter for the fishery weights was well sampled by the MCMC, with a median estimate of  $\log \theta_{\text{fish}} = -0.562$  and an associated median weight of  $\theta_{\text{fish}}/(1 + \theta_{\text{fish}}) = 0.363$ .

Stationarity of the posterior distribution for model parameters was re-assessed via a suite of standard single-chain and multi-chain diagnostic tests. The objective function, as well as all estimated parameters and derived quantities, showed good mixing during the chain, no evidence for lack of convergence, and low autocorrelation (results for some key parameters are shown in Figures 17 and 18). Correlation-corrected effective sample sizes were sufficient to summarize the posterior distributions and neither the Geweke nor the Heidelberger and Welch statistics for these parameters exceeded critical values more frequently than expected via random chance (Figure 19). The Gelman-Rubin multi-chain diagnostic test, which compares within-chain variance to among-chain variance, further indicated that convergence was adequately achieved (Figure 20). Correlations among key parameters were generally low, with the exception of natural mortality,  $M$ , and the logarithm of the unexploited equilibrium recruitment level,  $\log R_0$ , (Figure 21). Derived quantities for recruitment in 2008 and 2010 as well as the relationship between relative spawning biomass in 2018 with both the catch from default harvest rule in 2018 and the recruitment in 2014 being highly correlated, as to be expected given the dependencies among these quantities (Figure 21). An examination of deviations in recruitment (log-scale differences between estimated and expected recruitment values) from recent years (Figure 22) indicates the highest correlation (0.74) between the 2008 and 2010 recruitment deviations. This continues to be likely caused by the relative proportion of these two cohorts being better informed by recent age-composition data than the absolute magnitude of these recruitments.

The base model fit to the acoustic survey biomass index (Figures 10 and 23) remains similar to the 2017 base model up through 2013. The addition of the 2017 survey biomass estimate resulted in a downward shift in the fit to the 2015 survey data point and a leveling off of the biomass trend over recent years (Figure 15). The 2001 data point continues to be well below any model predictions that were evaluated, and no direct cause for this is known. The survey did begin earlier that year than all other surveys between 1995 and 2009 (Table 13), which may explain some portion of

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the anomaly, along with El Niño conditions and age structure. The 2009 index is much higher than any predicted value observed during model evaluation. The uncertainty of this point (both modeled and actual) is also higher than in other years, due to the presence of large numbers of Humboldt Squid during the survey. Humboldt Squid have similar Target Strength to hake which could introduce bias in the biomass estimate for that year, and which also likely influenced hake population dynamics through predation in that year.

The MLE and median posterior density estimate underfit the 2015 survey index and overfit the 2017 survey index. This is likely due to fishery data suggesting slightly different population dynamics than the survey in recent years. This phenomenon can arise when the fishery gets a prominent signal about age-1 fish, as it did in 2015, whereas the survey contains information on age-2 and older fish.

Fits to the age-composition data continue to show close correspondence to the dominant cohorts observed in the data and also the identification of small cohorts, where the data give a consistent signal (Figure 24). Because of the time-varying fishery selectivity, the fit to commercial age-composition data is particularly good, although models with time-invariant selectivity used in previous years also fit the age compositions well. The 2017 age composition was dominated by age-3 fish from the 2014 year-class (33% of the catch in the fishery) and age-7 fish from the 2010 year-class (40% of the catch in the fishery). Age composition from the 2015 acoustic survey also indicated that the 2010 year-class was large (59% of the catch for that year). The 2017 acoustic survey was the first time the survey was able to sample the 2014 year-class, and it confirmed that the 2014 year-class (53% of the catch for that year) was indicated above average. The pattern for the 2010 year-class was expected given the strength of that cohort from the fishery composition data from 2012 onward, and thus are fit well by the model. Combined, the 2015, 2016, and 2017 fishery age composition data and the 2017 acoustic survey age composition data suggest that 2014 was likely a strong recruitment year, and the model was able to adequately fit to these observations (Figure 24). Residual patterns to the fishery and survey age data do not show patterns that would indicate systematic bias in model predictions (Figure 25). The MLEs for numbers, biomass, exploitation rate and catch (in numbers and in biomass) for each age class in each year are given in Tables 20-24. For the major cohorts, the resulting age-specific catch, natural mortality and surviving biomasses are given in Table 25.

Posterior distributions for both steepness and natural mortality are strongly influenced by priors (Figure 26). The posterior for steepness was not updated much by the data, as expected given the low sensitivity to steepness values found in previous hake assessments. The natural mortality parameter, on the other hand, is shifted to the right of the prior distribution and the prior may be constraining the posterior distribution from shifting further. Broadening the prior distribution by increasing the prior standard deviation for the natural mortality parameter is examined in sensitivity runs (see Section 3.8). Other parameters showed updating from non-informative priors to stationary posterior distributions.

The 2018 base model specified a similar level of variation (standard deviation of  $\Phi = 1.4$ ) associated with time-varying fishery selectivity to that of  $\phi = 0.20$  in the 2017 base model, effectively allowing the model flexibility (i.e., a lower penalty on the overall likelihood) to fit to data that

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suggests high variability among years for each age. This level of variation led to results that were consistent with the 2017 acoustic survey biomass estimate and gave reasonable fits to the fishery age composition data, while maintaining that there is considerable uncertainty associated with spatial changes in fish availability (due to movement) and recent variability in oceanographic conditions. Estimated selectivity deviations from 2010 to 2012 are the largest in recent years (Figures 27 and 28). The median selectivity peaks at age 4 in 2010 and 2012 and at age 3 in 2011 suggesting targeting of the younger cohorts in those years. This pattern is consistent with the 2008 cohort appearing strong in the fishery age compositions initially, but decreasing in prominence from 2013 onward (Figures 24 and 58). Fishery selectivity on age-2 fish was at its highest in 2016. The selectivity of age-3 fish by the fishery in 2017 (2014 cohort) was similar to that for the 1999 and 2010 large cohorts (age-3 in 2002 and 2013, respectively; Figure 28). Even though the survey selectivity is time invariant, the posterior shows a broad band of uncertainty between ages 2 and 5 (Figure 29). The decline in survey selectivity between ages 3 and 4 may be an artifact of the interaction between large cohorts and the biennial timing of recent surveys, with the 1999 cohort occurring in the survey at ages 2 and 4 but not 3 while the 2010 and 2014 cohorts occurred at ages 3 and 5 but not age 4. Fishery selectivity is likewise very uncertain (Figures 28 and 29), but in spite of this uncertainty, changes in year-to-year patterns in the estimates are still evident, particularly for age-3 and age-4 fish, though these patterns might also reflect time-varying mortality processes.

## Stock biomass

The base stock assessment model indicates that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium (Figures 30 and 31 and Tables 18 and 19). The model estimates that it was below the unfished equilibrium in the 1960s and 1970s due to lower than average recruitment. The stock is estimated to have increased rapidly to near unfished equilibrium after two or more large recruitments in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.568 million t in 2010. The assessment model estimates that spawning biomass declined slightly from 2014 to 2015 after five years of increases from 2009 to 2014. These estimated increases were the result of a large 2010 cohort and an above-average 2008 cohort, and the decline in 2015 and 2016 is from the 2010 cohort surpassing the age at which gains in weight from growth are greater than the loss in weight from natural mortality. The model estimates an increase from 2016 to 2017 due to the large 2014 year class, which is estimated to be the fifth highest recruitment in the time series, and a slight decrease from 2017 to 2018 due, in part, to the model fit of the acoustic survey index (Figure 15).

The median estimate of the 2018 relative spawning biomass (female spawning biomass at the start of 2018 divided by that at unfished equilibrium,  $B_0$ ) is 66.7% but is highly uncertain (with a 95% posterior credibility interval from 32.7% to 136.1%; see Tables 18 and 19). The median estimate of the female spawning biomass at the start of 2018 is 1.357 million t (with a 95% posterior credibility

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interval from 0.610 to 3.161 million t).

The estimated 2017 female spawning biomass is 1.469 (0.766-3.086) million t. In the 2017 assessment, the equivalent estimate of 2017 female spawning biomass was 2.129 (0.763-7.445) million t. Thus the 2018-estimated median is smaller than the 2017-estimated median, while the 2018 credible interval remains within the 2017 interval. The additional data in the 2018 assessment has reduced the uncertainty of the 2017 biomass, and decreased the median partly due to the impact of the survey biomass estimate.

## **Recruitment**

The new data available for this assessment do not significantly change the estimated patterns of recruitment. Pacific Hake appear to have low average recruitment with occasional large year-classes (Figures 32 and 33, Tables 18 and 19). Very large year classes in 1980, 1984, and 1999 supported much of the commercial catch from the 1980s to the mid-2000s. From 2000 to 2007, estimated recruitment was at some of the lowest values in the time-series followed by a moderately large 2008 year class. The current assessment continues to estimate a very strong 2010 year class (Figure 35) comprising 71% of the coast-wide commercial catch in 2013, 65% of the 2014 catch, 71% of the 2015 catch, 33% of the 2016 catch, and 40% of the 2017 catch. The current assessment also estimates a strong 2014 year class (Figure 35) comprising 50% of the 2016 catch and 33% of the 2017 catch. Although the absolute size of the 2014 year class remains highly uncertain, at least more so than cohorts that have been observed for more years, two years of fishery data and one year of survey data suggest that it is one of the higher estimates in the time series.

The extra data in the 2018 assessment has reduced the median estimate of the 2014 year class to 8.583 billion fish (Table 18), from the 12.105 billion estimated in the 2017 assessment (Table 18 of Berger et al. 2017). Yet the 2014 year class remains the fifth largest estimated recruitment, albeit with large uncertainty (Table 19 and Figure 32).

The model currently estimates small 2011, 2013, and 2015 year classes (median recruitment below the mean of all median recruitments) and a slightly above average 2012 year class. There is little or no information in the data to estimate the sizes of the 2017 and 2018 year classes. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable prior to at least age-3 (Hicks et al., 2013).

The estimated recruitments with uncertainty for each predicted point and the overall stock recruit relationship are provided in Figure 34. Extremely large variability about the expectation and about the joint uncertainty of individual recruitment and spawning biomass pairs are evident in this plot. High and low recruitments have been produced throughout the range of observed spawning biomass (Figure 34). The standard deviation of the time series of median recruitment deviation estimates for the years 1970-2015, which are informed by the age compositions, is 1.67. This value is consistent with the base model value of 1.4.



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## Exploitation status

Median relative fishing intensity on the stock is estimated to have been below the  $SPR_{40\%}$  for all years (Figure 36 and Tables 18 and 19). It should be noted, however, that the median relative fishing intensity was close to the target in 2008 and 2010, but harvest in those years did not exceed the catch limits that were specified, based on the best available science and harvest control rules in place at the time. Exploitation fraction (catch divided by biomass of fish of age-2 and above) has shown relatively similar patterns (Figure 37 and Tables 18 and 19). Although similar patterns, the exploitation fraction does not necessarily correspond to fishing intensity because fishing intensity more directly accounts for the age-structure of both the population and the catch. Median relative fishing intensity is estimated to have declined from 94.3% in 2010 to 48.6% in 2015, after which it increased to 86.2% in 2017. The exploitation fraction has decreased from 0.18 in 2011 to 0.07 in 2015 and then increased to 0.14 in 2017. Although there is a considerable amount of imprecision around these recent estimates due to uncertainty in recruitment and spawning biomass, the 95% posterior credibility interval of relative fishing intensity was below the  $SPR$  management target from 2012 through 2015 (Figure 36). The median estimates for 2016 and 2017 are below the management target, however the 95% posterior credibility intervals do include the target level.

## Management performance

Over the last decade (2008–2017), the mean coast-wide utilization rate (i.e., landings/quota) has been 75.7% and catches have been below coast-wide targets (Table 4). From 2013 to 2017, the mean utilization rates differed between the United States (73.8%) and Canada (46.0%). In 2015, the utilization rate for the fishery was the lowest in the previous decade (44.1%) due, in part, to difficulties locating aggregations of fish and possibly economic reasons. In years previous to 2015, the underutilization in the United States was mostly a result of unrealized catch in the tribal apportionment, while reports from stakeholders in Canada suggested that hake were less aggregated in Canada and availability had declined. In 2016, the utilization rate increased but remained below pre-2015 levels, despite the total 2016 catch being one of the highest in recent years. This is in large part due to increasing catch targets as biomass continues to increase. The utilization rate in 2017 continued to increase from the 2015 low in both the United States and Canada. Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

The median relative fishing intensity was below target in all years throughout the time series (Figure 36). The female spawning biomass was above target all years except from 1999–2000 and from 2007–2011 (Figure 38).

The joint history of biomass and  $F$ -based target reference points shows that before 2007, median relative fishing intensity was below target and female spawning biomass was mostly above  $B_{40\%}$  (Figure 38). Between 2007 and 2011, however, median relative fishing intensity ranged from 80% to 97% and median relative spawning biomass between 0.28 and 0.36. Biomass has risen recently with the 2008, 2010, and 2014 recruitments and, correspondingly, relative fishing intensity fell well below targets. Relative spawning biomass has been above the target since 2012. While there is

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large uncertainty in the 2017 estimates of relative fishing intensity and relative spawning biomass, the model predicts a less than 6% joint probability of being both above the target relative fishing intensity in 2017 and below the  $B_{40\%}$  relative spawning biomass level at the start of 2018.

### 3.5 MODEL UNCERTAINTY

The base assessment model integrates over the substantial uncertainty associated with several important model parameters including: acoustic survey catchability ( $q$ ), the magnitude of the stock (via the  $R_0$  parameter for equilibrium recruitment), productivity of the stock (via the steepness parameter,  $h$ , of the stock-recruitment relationship), the rate of natural mortality ( $M$ ), annual selectivity for key ages, and recruitment deviations. The uncertainty portrayed by the posterior distribution is a better representation of the uncertainty when compared to asymptotic approximations about the maximum likelihood estimates (MLE) because it allows for asymmetry (Figure 26; also see Stewart et al. (2012) for further discussion and examples). Table 26 shows that most key derived quantities from the posterior distribution are larger than their respective MLEs (e.g., median biomass, recruitment, and relative spawning biomass), however some parameter estimates (e.g., steepness and catchability) are smaller. Figure 39 shows the MLE and Bayesian (from MCMC) estimates as well as the skewed uncertainty in the posterior distributions for spawning biomass and recruitment for each year. Median estimates of spawning biomass and recruitment from the posterior distribution are slightly larger than their respective MLEs, but the 95% credibility (posterior median) and confidence (MLE) intervals considerably overlap.

Uncertainty measures in the base model underestimate the total uncertainty in the current stock status and projections because they do not account for alternative structural models for hake population dynamics and fishery processes (e.g., recruitment, selectivity, or spatial fleet or population structure), the effects of alternative data-weighting choices, and the scientific basis for prior probability distributions. To address structural uncertainties, the JTC investigated a range of alternative models, and we present the key sensitivity analyses along with a suite of other informative sensitivity analyses in the main document.

The Pacific Hake stock displays a very high degree of recruitment variability, perhaps the largest of any west coast groundfish stock, resulting in large and rapid biomass changes. This volatility, coupled with a dynamic fishery that potentially targets strong cohorts (resulting in time-varying selectivity), and little data to inform incoming recruitment until the cohort is at least age-2, will in most circumstances continue to result in highly uncertain estimates of current stock status and even less-certain projections of the stock trajectory.

The JTC continues to be committed to advancing MSE analyses, through further internal technical developments and by coordinating research with other scientists in the region engaging in similar research. In particular, the JTC aspires to advance MSE research in 2018 by collaborating with the Treaty MSE Working Group and a post-doctoral scientist dedicated to developing MSE models. Incorporating feedback from JMC/AP/SRG/MSE Working Group will ensure that the operating model is able to provide insight into the important questions defined by these groups. Specifically, the development of MSE tools to evaluate major sources of uncertainty relating to data, model



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structure and the harvest policy for this fishery and compare potential methods to address them remains an important goal. If a spatially, seasonally explicit operating model is needed, then research should focus on how best to model these dynamics in order to capture seasonal effects and potential climate forcing influences in the simulations. Further, investigations into the impact of making incorrect assumptions about the underlying recruitment process is central to the adequate characterization of uncertainty when applied to proposed management procedures.

### 3.6 REFERENCE POINTS

We report estimates of the base reference points (e.g., relative to  $F_{\text{SPR}=40\%}$ ,  $B_{40\%}$ ,  $B_{\text{MSY}}$ , and  $\text{MSY}$ ) with posterior credibility intervals in Table 27. Only those based on  $F_{\text{SPR}=40\%}$  explicitly relate to target reference points per the treaty Agreement (see Section 1.3 and Appendix B). The estimates are slightly different than the estimates in the 2017 assessment with smaller equilibrium yields, spawning biomass, and recruitments (particularly for the 2014 year class) estimated in this assessment.

As part of the DFO Sustainable Fisheries Framework, DFO (2009) suggested a provisional limit reference point of  $0.4B_{\text{MSY}}$  and an upper stock reference point of  $0.8B_{\text{MSY}}$ . We note that the probabilities of the female spawning biomass at the start of 2018 being above these points are both 100% – i.e. the stock is estimated to be in the provisional ‘healthy zone’.

### 3.7 MODEL PROJECTIONS

The median catch limit for 2018 based on the default  $F_{\text{SPR}=40\%}$ –40:10 harvest policy is 725,984 t, but has a wide range of uncertainty (Figure 40), with the 2.5% to 97.5% range being 270,948–1,881,590 t.

Decision tables give projected population status (relative spawning biomass) and relative fishing intensity under different catch alternatives for the base model (Tables 28 and 29). The tables are organized such that the projected outcome for each potential catch level and year (each row) can be evaluated across the quantiles (columns) of the posterior distribution. Table 28 shows projected relative spawning biomass outcomes, and Table 29 shows projected fishing intensity outcomes relative to the 100% target (based on SPR; see table legend).

Relative fishing intensity exceeding 100% indicates fishing in excess of the  $F_{\text{SPR}=40\%}$  default harvest rate catch limit. This can happen for the median relative fishing intensity in 2018, 2019 and 2020 because the  $F_{\text{SPR}=40\%}$  default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of overfishing. An alternative catch level where median relative fishing intensity is 100% is provided for comparison (catch alternative e: FI=100%).

Management metrics that were first identified as important to the Joint Management Committee

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(JMC) and the Advisory Panel (AP) in 2012 are presented for projections to 2019 and 2020 (Tables 30 and 31). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values. Figure 41 shows the predicted relative spawning biomass trajectory through 2020 for several of these management actions. With zero catch for the next two years, the biomass has a probability of 37% of decreasing from 2018 to 2019 (Table 30 and Figure 42), and a probability of 35% of decreasing from 2019 to 2020 (Table 31 and Figure 43).

The spawning biomass is predicted to decrease from 2018 to 2019 with a greater than 50% probability for catch levels investigated above 0 t (Table 30 and Figure 42). The model predicts high biomass levels and the predicted probability of the spawning biomass dropping below  $B_{10\%}$  ( $0.1B_0$ ) in 2019 is less than 1% and the probability of dropping below  $B_{40\%}$  is less than 24% for all catches explored (Table 30). It should be noted that the natural mortality rate has overtaken the growth rate for the 2010 year class and the model estimated below average recruitment for the 2011 and 2013 cohorts, but the above average predicted 2014 year class will result in an increase to the spawning biomass as it enters maturity. The probability that the 2019 spawning biomass will be less than the 2018 spawning biomass ranges from 37% to 74% depending on the catch level (Table 30 and Figure 42).

The age composition (in numbers) of the catch in 2018 is projected to be 42% age-4 fish from the 2014 year-class and 23% age-8 fish from the 2010 year-class (Figure 44). However, those estimates are highly uncertain with the 95% credibility interval for the age-4 fraction spanning 19%–62%. Due to the lower average weight at age 4 vs. 8, the expected proportion of the 2018 catch by weight is expected to be more similar between these two cohorts, at 38% and 31%, respectively.

With respect to the DFO provisional reference points, even with the largest 2018 catch of 725,984 t given in Table 30, the stock is expected to be in the healthy zone at the start of 2019 with a probability of 96%.

### 3.8 SENSITIVITY ANALYSES

Sensitivity analyses were conducted to investigate influence of data inputs and structural uncertainty of the base model by investigating how changes to the model affected the estimated values and derived quantities. For expediency, all sensitivity analyses compared MLE estimates rather than MCMC posteriors. Therefore, the values reported below are not directly comparable to the base model MCMC values reported elsewhere. For a comparison of the base model MCMC and MLE estimates, see Tables 32 and 33. The sensitivities include the following:

1. Consideration of a higher standard deviation on the prior distribution for natural mortality;
2. Consideration of alternative values for steepness;
3. Assume higher/lower variation about the stock-recruitment curve ( $\sigma_r$ );

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4. Include the age-1 survey index as an additional source of information;
  5. Assume no cohort-based ageing error (i.e., time invariant ageing error);
  6. Use of the McAllister-Ianelli method for data-weighting;
  7. Use of an alternative method for aggregating the age compositions from the U.S. fishery (weighting by the catch within each month)
  8. Consideration of an alternative catch stream which addresses a few issues related to the annual catch in recent years.
  9. Consideration of alternative maximum age assumptions for estimating selectivity;
  10. Consideration of alternative standard deviations for time-varying selectivity; and
  11. Consideration of an alternative parameterization for time-varying selectivity.

In general, none of the sensitivities resulted in any significant departure from the main population dynamics of the base model; all models showed large estimated increases in spawning biomass in recent years that continues to be driven by the large 2010 cohort and the 2014 cohort. The overall scale of the population was impacted by various alternative assumptions, and the highly uncertain size of the 2016 cohort was more variable across sensitivity analyses than earlier cohorts which have been observed in more years.

Several key underlying structural model assumptions were identified that have persisted across many previous hake assessments, and thus warrant revisiting periodically as a set of reference sensitivity examinations to new base models. Those identified here (as noted above) include the specification of natural mortality, the level of variation assumed about the stock-recruitment relationship ( $\sigma_r$ ), and the resiliency of the stock in terms of recruitment (steepness).

The standard deviation of the prior distribution on natural mortality was increased from the base model value of 0.1 to 0.2 and 0.3. Maximum likelihood estimates of natural mortality increased from 0.214 for the base model (prior standard deviation of 0.1) to 0.253 for the sensitivity run with the prior standard deviation set to 0.3 (Table 32). In addition to allowing a higher estimated value for natural mortality, the broader prior in  $M$  also increased the overall scale of the population, the estimated stock status relative to  $B_0$ , and the uncertainty in spawning biomass on both absolute and relative scales (Table 32 and Figures 45 and 46).

The mean of the prior distribution on steepness was decreased from 0.777 (base) to 0.5, and, separately, steepness was fixed at 1.0. The decrease in the mean of the prior resulted in a change in the maximum likelihood estimate of steepness from 0.862 to 0.600 (Table 32). However, neither steepness sensitivity had a strong impact on the overall model results (Figures 45 and 46). The small influence of steepness on model results is related to the relatively large  $\sigma_r$  value which allows the recruitments to deviate far from the underlying stock-recruit relationship (Figure 34).

The value of  $\sigma_r$  was changed from a value of 1.4 (base) to alternative high (1.8) and low (1.0) states.

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The low value,  $\sigma_r = 1.0$ , resulted in a model where the standard deviation of the MLE estimates of recruitment deviations in the period with the most informative data was 1.45, suggesting that the data were inconsistent with the lower value of  $\sigma_r$ . The high value,  $\sigma_r = 1.8$ , resulted in a model with a more consistent standard deviation for the estimated recruitment deviations, at 1.74. However, the high  $\sigma_r$  model had a larger difference between the unfished equilibrium and the initial year of the model (Table 32 and Figures 45 and 46). The method of Methot and Taylor (2011) considers a combination of the variability among the estimated deviations and the uncertainty around the estimates using the formula

$$\sigma_r^2 = \text{Var}(\hat{r}) + \overline{\text{SE}(\hat{r}_y)}^2, \quad (11)$$

where  $\text{Var}(\hat{r})$  is the variance among deviations and  $\text{SE}(\hat{r}_y)$  is the standard error of each estimate. It produced a suggested  $\sigma_r$  of 1.52, which was similar to the base-model value of 1.4.

The sensitivity of the base model to the inclusion of the age-1 survey index provides an additional source of information about the recruitment of different year classes (see discussion in Section 2.2.1), which can be particularly useful for the most recent years when little information on cohort strength is otherwise available. Compared to the base model, estimates of spawning biomass throughout most of the time series are similar, but do diverge near the end of the time series (Table 33; Figures 47 and 48; 2018 estimates are 56.4% of unfished biomass for the base model and 67.4% for the age-1 index model). This change is likely due to the base model underfitting the age-1 index estimates of the size of the 2014 and 2016 cohorts (Figure 11). These changes are subtle, however since the base model generally tracks the trends in the age-1 index well.

The impact of assuming a time-invariant ageing error vector instead of a cohort-based ageing error matrix (as in the base model) was evaluated. The largest changes to model results are associated with estimates of equilibrium unfished biomass and thus relative spawning biomass (Table 32). These differences stem from the population model being restricted in the time-invariant case to fitting age-composition data with a stationary level of measurement error associated with each age.

As noted in the description of assessment changes in Section 3.4.1, the base model used a new Dirichlet-Multinomial likelihood which includes two additional estimated parameters that automatically weight each of the fishery and survey age compositions. This produced higher weights on the age compositions but generally very similar results to the McAllister-Ianelli method used in previous assessments, whereby the input sample sizes are iteratively adjusted by a multiplier to make the arithmetic mean of the input sample size approximately equal to the harmonic mean of the effective sample sizes.

The influence of an alternative approach for calculating the 2017 fishery age composition was also explored. In most years, nearly all the available Pacific Hake otoliths caught in U.S. waters are aged and then used, along with data from Canada, to develop an annual age composition for the fishery (see Section 2.1.2). High catch levels in 2017, resulting from high estimates of abundance and associated TACs, and it being a survey year has led to an increase in the total number of otoliths sampled for ageing. For 2017, nearly 77% (2,369 out of 3,090) of the U.S. at-sea sectors otoliths were aged in time for this assessment (typically greater than 95% are aged). Recently,

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the seasonality of catch-at-age has become even more apparent with the large 2010 and 2014 cohorts, resulting in younger individuals being caught in larger proportions later in the year. This can lead to bias when the unread otoliths are also from later in the year when aggregating to a single annual age composition. In response, the JTC calculated a monthly catch weighted annual composition for the U.S. at-sea sectors, and then combined that with the compositions from other sectors following standard procedures (Hicks et al., 2013; Taylor et al., 2014). The result was minor differences in the overall fishery age composition (Table 32): less than a 0.4% change for all ages except the 2014 cohort (increase 2.1%) and the 2010 cohort (decrease 1.0%). These relatively minor differences also had little to no influence on estimates of spawning biomass (Figure 47) or stock status (Figure 48) in 2018. Nonetheless, otolith subsampling protocols should be developed to account for seasonality in catch-at-age. Such protocols are especially critical during survey years or years of high abundance when large sample sizes are expected or when ageing laboratory resources are limited.

The “Consideration of an alternative catch stream” sensitivity analysis explores the combined impact of the three independent issues in the calculation of total catch that were identified late in the assessment process (as described at the end of Section 2.1.1). The average change in catch for the period in question, 2007 to 2017, was 0.5% which was too small to make a noticeable impact in the time series of spawning biomass (Figures 47 and 48).

Three types of alternative setups for selectivity were explored in sensitivity analyses: alternative assumptions about the age beyond which selectivity is assumed constant, alternative values of the  $\Phi$  parameter controlling the degree of flexibility of annual variation in the fishery selectivity, and an alternative “semi-parametric” parameterization of the time-varying selectivity. The methods and results of each will be described in turn.

Fishery and survey selectivity in the base model is modeled as changing from each age to the next up to age 6 beyond which it is assumed constant. Three alternative maximum selectivity age values (5, 7, and 10) were considered to investigate the asymptotic properties of fishery and survey selectivity patterns and the impact maximum selectivity age has on model behavior. For each alternative option all of the ages with estimated fishery selectivity had annual deviations estimated for the corresponding parameters. Thus, a change from age-6 to age-7 as the maximum selectivity age was associated with 29 additional parameters, 1 each for the additional age in the fishery and the selectivity and 27 deviations for the years 1991 to 2017.

The estimated population trends throughout the time series are similar, irrespective of maximum selectivity age (Figures 49-51). However, absolute levels of spawning biomass are different, particularly for the age-10 case. Under all alternatives, the base model pattern of a decline in survey selectivity between ages 3 and 4 remained, and was either increased or repeated at additional ages (Figure 49). As noted in Section 3.4.2, a potential cause of this zig-zag pattern is the interaction of the biennial timing for much of the survey history with large cohorts. The 1999 cohort made up the majority of the observed ages in the survey when they were age 2, 4, 6, and 8, while the 2010 and 2014 cohorts have primarily been observed when they were age 3, 5, or 7. Thus, any differences in the dynamics of these cohorts that are not represented in the model, such as differences in natural mortality, would lead to a shift in selectivity between the even- and odd-numbered ages. The



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choice of age 6 as the maximum was retained in the base model as it was more flexible than the choice of age 5 while those with higher ages produces less plausible patterns of selectivity.

The consideration of alternative standard deviations ( $\Phi$ ) for time-varying selectivity is discussed earlier in Section 2.4.3. In short, low values of the parameter  $\Phi$  controlling the flexibility in time-varying selectivity resulted in potentially implausibly high estimates recent recruitments. The values of the related  $\phi$  explored in the 2017 assessment (Berger et al., 2017) were 0.03, 0.10, and 0.30, as alternatives to the 0.20 used in the base model. As discussed in Section 2.4.3, the change to the new version of Stock Synthesis required appropriate values of  $\Phi$ , with  $\Phi = 7\phi$  resulting in approximately equivalent dynamics. Thus, the base model value is  $\Phi = 1.40$ , and alternatives explored as sensitivity analyses were 0.21, 0.70, and 2.10. The addition of the 2017 fishery age compositions and the 2017 survey biomass estimate and age compositions led to more precise estimates of the 2014 recruitment, regardless of the value of  $\Phi$ . However, the 2016 recruitment, which is only informed by the 2017 fishery age composition, is strongly linked to the choice of  $\Phi$ , where the model with the smallest  $\Phi$  at 0.21 (equivalent to  $\phi = 0.03$  in the previous setup) estimates the 2016 recruitment deviation as the highest in the time series (Figure 50) and provides the worst fit to the recent survey biomass estimates (Figure 51).

The alternative “semi-parametric” setup for selectivity based on the work of Xu et al. (under review) differs from the status-quo approach in that the deviations are applied to the resulting selectivity estimates, not to the original parameters, and the resulting selectivity ogive is no longer constrained between 0 and 1 (Figure 52). That is, the deviations are no longer applied as shown in equation (7), but as exponential multipliers on the baseline selectivity

$$S_{ay} = S_a \cdot \exp(\varepsilon_{ay}) \quad (12)$$

where the  $S_{ay}$  are derived as described in equations (1)-(3), the  $\varepsilon_{ay}$  are the selectivity deviations,  $\sigma_s$  is the parameter which controls the variability in the deviations (equivalent to  $\Phi$  in the base model parameterization), and the likelihood contribution for the  $\varepsilon_{ay}$  parameters is from treating the deviations as normal random variables with standard deviation  $\sigma_s$ ,  $N(0, \sigma_s)$ .

This alternative parameterization was expected to reduce correlation among the deviation parameters, because a positive deviation at a younger age no longer leads to a rescaling of the selectivity pattern at all ages. Indeed, there are only 2 pairs of parameters with correlations above 0.7 or below -0.7 in the semi-parametric model that most closely matched the based model ( $M$  and  $\log(R_0)$  were positively correlated, and the deviation for selectivity at age 1 in 2017 was negatively correlated with 2016 recruitment). This is in contrast to the base model, which had 36 parameter pairs with correlations above 0.7 or below -0.7, of which 34 of the pairs were between two of the selectivity deviations. The Laplace method of Thorson et al. (2014) also provided an estimate of the variance parameter for the semi-parametric selectivity, at  $\sigma_s = 0.695$ , which provided more plausible results than when this method was applied to the status-quo selectivity setup.

However, the model with  $\sigma_s = 0.695$  had higher estimates of 2016 and worse fits to the recent survey biomass estimates (Figures 53-56). Increasing  $\sigma_s$  to 1.0 provided the additional flexibility required to give more plausible estimates of this cohort that has only been observed as age-1 in the 2017 fishery. However, relying on the subjective choice of  $\sigma_s = 1.0$  removed one of the potential

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benefits of the semi-parametric approach. Given that an MCMC chain of 24-million samples has been adequate to overcome the inefficient sampling caused by high parameter correlations in the status-quo approach, the parameter selectivity was kept as before for this assessment, with the hopes that the semi-parametric setup could be further explored in the year ahead for potential inclusion in a future hake assessment.

Any additional sensitivity runs arising from the Scientific Review Group meeting to be held from 26th February to 1st March 2018 will be documented in Appendix A and briefly summarized here.

### 3.9 RETROSPECTIVE ANALYSES

Retrospective analyses were performed by iteratively removing the terminal years' data and estimating the parameters under the assumptions of the base model. Models with 3, 4, or 5 years of data removed had information available regarding the high 2010 year class, but did not yet have information on the 2014 year class (Figure 57). Models with 1 and 2 years of data removed were just beginning to receive data on age-2 and age-1, respectively, individuals to predict the size of the 2014 year class. The base model now has three years of data to estimate the size of the 2014 cohort, and the uncertainty around this estimate, while still large, has been considerably reduced compared to one year ago (Figure 57).

Overall, there is little retrospective change to the relative spawning biomass trajectory up to the mid-2000s, and most retrospective change occurs in the final years of the retrospective model. Retrospective estimates over the last 5 years have been predominantly positively biased. In the last 4 years, the stock assessment has retrospectively overestimated the status in the terminal year, which is likely related to the dynamics introduced by the large 2010 and 2014 cohorts and the high observed survey biomass index in 2009.

Figure 58 shows the retrospective patterns of estimated recruitment deviations for various cohorts. The magnitude of the deviation is not well estimated until several ( $\sim 4$ -7) years of fishery catch-at-age data and survey age-composition data have been collected on the cohort. Very strong and weak cohorts tend to be identified in the model at a younger age than intermediate cohorts. For example, the strong 2010 cohort has been fairly well determined in the model by age-3 and the weak 2007 cohort by age 5. Estimated recruitment deviations for the 2014 cohort appear to be similar to other large cohorts (1999, 2008, and 2010), though with the extra year of data in this year's assessment the 2014 cohort appears to maybe be more similar to the 2008 cohort rather than the 1999 and 2010 cohorts (which are the largest). The variability among cohort estimates relative to their estimated size in the base model (Figure 59) further indicates that the estimates can start to improve as early as age-3, but some may not stabilize until the cohort approaches an age upward of 7 years old. This illustrates that multiple observations of each cohort are needed in order to more accurately determine their recruitment strength.

A comparison of the actual assessment models used in each year since 1991 is shown in Figure 60. There have been substantial differences in model structural assumptions and thus results submitted



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each year, which can clearly be seen by looking at the spawning biomass trajectories. The variability between models, especially early on in the time series, is larger than the uncertainty (95% credibility interval) reported in any single model in recent years. One important avenue that was investigated between 2004 and 2007 was the inclusion of several different, but fixed, survey catchability ( $q$ ) values followed by a span of years (2008 to present) where it was freely estimated by the model. In all years prior to 2004, survey catchability was fixed at 1.0. The fixing of survey catchability had the effect of driving the estimate of initial biomass upward, which in turn scaled the entire biomass trajectory up, leading to higher estimates of relative spawning biomass than in more recent assessments. The median estimates of spawning biomass for recent years have declined in the 2018 assessment relative to recent assessments. Although the model structure has remained relatively consistent in recent years, the 2017 acoustic survey biomass estimate was lower than what previous models would have predicted. The uncertainty interval associated with the 2018 assessment brackets the majority of the historical estimates.

## **4 RESEARCH AND DATA NEEDS**

### **4.1 RESEARCH AND DATA NEEDS FOR THE FUTURE**

There are many research projects that could improve the stock assessment for Pacific Hake. The following prioritized list of topics will lead to improved biological understanding and decision-making:

1. Continue investigation of links between hake biomass and its spatial distribution, and how these vary with ocean conditions and ecosystem variables such as temperature and prey availability. These investigations have the potential to improve the scenarios considered in future management strategy evaluation (MSE) work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.
2. Continue development of the MSE to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery, and compare potential methods to address them. Incorporate the feedback from JMC/AP/SRG/MSE Advisory Panels into operating model development.
3. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength, directionality of survey and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others. Continue to work with acousticians and survey personnel from the NWFSC and DFO to determine an optimal design for the Joint U.S./Canada acoustic survey. Develop automation and methods to allow for the availability of biomass

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and age composition estimates to the JTC in a timely manner after a survey is completed.

4. Continue to explore and develop statistical methods to parameterize time-varying fishery selectivity in the assessment and with regard to forecasting.
5. Continue to investigate fecundity and maturity, including trying to understand links between fecundity and size, age, weight, and batch spawning.
6. Explore the use of genetics and other methods to explore potential stock differences north and south of Point Conception that may be related to the observed differences in maturity.
7. Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific Hake, including investigations into the winter acoustic surveys.
8. Continue to investigate alternative ways to model and forecast recruitment, given the uncertainty present.
9. Improve the characterization and accounting of research and tribal catch that is reported to standard databases to improve data tracking and avoid double counting.
10. Update ageing error calculations given new information from recent double reads. Conduct further exploration of ageing imprecision and the effects of large cohorts via simulation and blind source age-reading of samples with differing underlying age distributions – with and without dominant year classes.
11. Conduct further exploration into potential biases that could arise by aggregating age composition information across fishing sectors using an annual time step when less than 100% of sampled otoliths are aged. As needed, develop protocols for ageing laboratories to subsample the otoliths available for a given year to ensure the resulting age composition accounts for seasonal differences in catch-at-age and is representative of the annual catch.
12. Continue to collect and analyze life-history data, including weight, maturity and fecundity for Pacific Hake. Explore possible relationships among these life history traits including time-varying changes as well as with body growth and population density. Currently available information is limited and outdated. Continue to explore the possibility of using additional data types (such as length data) within the stock assessment.
13. Maintain the flexibility to undertake annual acoustic surveys for Pacific Hake under pressing circumstances in which uncertainty in the hake stock assessment presents a potential risk to or underutilization of the stock.
14. Evaluate the quantity and quality of historical biological data (prior to 1989 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use as age-composition and weight-at-age data, and/or any historical indications of abundance fluctuations.
15. Consider alternative methods for refining existing prior distributions for natural mortality ( $M$ ), including the use of meta-analytic methods.

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16. Explore the potential to use acoustic data collected from commercial fishing vessels to study hake distributions, schooling patterns, and other questions of interest. This could be similar to the “acoustic vessels of opportunity” program on fishing vessels targeting Pollock in Alaska.

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## 7 TABLES

**Table 1.** Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2017. Tribal catches are included in the sector totals. Research Catch includes landed catch associated with research-related activities. Catch associated with surveys and discarded bycatch in fisheries not targeting hake is not currently included in the model.

Year	Foreign	JV	Mothership	Catcher-Processor	Shore-based	Research	Total
1966	137,000	0	0	0	0	0	137,000
1967	168,700	0	0	0	8,960	0	177,660
1968	60,660	0	0	0	160	0	60,820
1969	86,190	0	0	0	90	0	86,280
1970	159,510	0	0	0	70	0	159,580
1971	126,490	0	0	0	1,430	0	127,920
1972	74,090	0	0	0	40	0	74,130
1973	147,440	0	0	0	70	0	147,510
1974	194,110	0	0	0	0	0	194,110
1975	205,650	0	0	0	0	0	205,650
1976	231,330	0	0	0	220	0	231,550
1977	127,010	0	0	0	490	0	127,500
1978	96,827	860	0	0	690	0	98,377
1979	114,910	8,830	0	0	940	0	124,680
1980	44,023	27,537	0	0	790	0	72,350
1981	70,365	43,557	0	0	838	0	114,760
1982	7,089	67,465	0	0	1,027	0	75,581
1983	0	72,100	0	0	1,051	0	73,151
1984	14,772	78,889	0	0	2,721	0	96,382
1985	49,853	31,692	0	0	3,894	0	85,439
1986	69,861	81,640	0	0	3,465	0	154,966
1987	49,656	105,997	0	0	4,795	0	160,448
1988	18,041	135,781	0	0	6,867	0	160,690
1989	0	195,636	0	0	7,414	0	203,050
1990	0	170,972	0	4,537	9,632	0	185,142
1991	0	0	86,408	119,411	23,970	0	229,789
1992	0	0	36,721	117,981	56,127	0	210,829
1993	0	0	14,558	83,466	42,108	0	140,132
1994	0	0	93,610	86,251	73,616	0	253,477
1995	0	0	40,805	61,357	74,962	0	177,124
1996	0	0	62,098	65,933	85,128	0	213,159
1997	0	0	75,128	70,832	87,416	0	233,376
1998	0	0	74,686	70,377	87,856	0	232,920
1999	0	0	73,440	67,655	83,470	0	224,565
2000	0	0	53,110	67,805	85,854	0	206,770
2001	0	0	41,901	58,628	73,412	0	173,940
2002	0	0	48,404	36,342	45,708	0	130,453
2003	0	0	45,396	41,214	55,335	0	141,945
2004	0	0	47,561	73,176	96,503	0	217,240
2005	0	0	72,178	78,890	109,052	0	260,120
2006	0	0	60,926	78,864	127,165	0	266,955
2007	0	0	52,977	73,263	91,441	0	217,682
2008	0	0	72,440	108,195	67,861	0	248,496
2009	0	0	37,550	34,552	49,222	0	121,324
2010	0	0	52,022	54,284	64,736	0	171,043
2011	0	0	56,394	71,678	102,146	1,042	231,261
2012	0	0	38,512	55,264	65,919	448	160,144
2013	0	0	52,447	77,950	102,143	1,018	233,558

2014	0	0	62,102	103,203	98,640	197	264,141
2015	0	0	27,661	68,484	58,011	0	154,156
2016	0	0	65,036	108,786	88,023	745	262,590
2017	0	0	66,428	136,960	150,843	0	354,231

**Table 2.** Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2017.

Year	Foreign	JV	Shoreside	Freezer-trawl	Total
1966	700	0	0	0	700
1967	36,710	0	0	0	36,710
1968	61,360	0	0	0	61,360
1969	93,850	0	0	0	93,850
1970	75,010	0	0	0	75,010
1971	26,700	0	0	0	26,700
1972	43,410	0	0	0	43,410
1973	15,130	0	0	0	15,130
1974	17,150	0	0	0	17,150
1975	15,700	0	0	0	15,700
1976	5,970	0	0	0	5,970
1977	5,190	0	0	0	5,190
1978	3,450	1,810	0	0	5,260
1979	7,900	4,230	300	0	12,430
1980	5,270	12,210	100	0	17,580
1981	3,920	17,160	3,280	0	24,360
1982	12,480	19,680	0	0	32,160
1983	13,120	27,660	0	0	40,780
1984	13,200	28,910	0	0	42,110
1985	10,530	13,240	1,190	0	24,960
1986	23,740	30,140	1,770	0	55,650
1987	21,450	48,080	4,170	0	73,700
1988	38,080	49,240	830	0	88,150
1989	29,750	62,718	2,562	0	95,029
1990	3,810	68,314	4,021	0	76,144
1991	5,610	68,133	16,174	0	89,917
1992	0	68,779	20,043	0	88,822
1993	0	46,422	12,352	0	58,773
1994	0	85,154	23,776	0	108,930
1995	0	26,191	46,181	0	72,372
1996	0	66,779	26,360	0	93,139
1997	0	42,544	49,227	0	91,771
1998	0	39,728	48,074	0	87,802
1999	0	17,201	70,121	0	87,322
2000	0	15,625	6,382	0	22,007
2001	0	21,650	31,935	0	53,585
2002	0	0	50,244	0	50,244
2003	0	0	63,217	0	63,217
2004	0	58,892	66,175	0	125,067
2005	0	15,695	77,335	9,985	103,014
2006	0	14,319	65,289	15,136	94,744
2007	0	6,780	48,075	14,121	68,976
2008	0	3,592	53,444	13,214	70,251
2009	0	0	44,136	13,223	57,359
2010	0	8,081	31,418	13,573	53,072

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2011	0	9,717	26,827	14,593	51,137
2012	0	0	31,718	14,909	46,627
2013	0	0	33,665	18,584	52,249
2014	0	0	13,326	21,787	35,113
2015	0	0	16,775	22,903	39,678
2016	0	0	35,012	34,729	69,740
2017	0	5,608	43,427	37,679	86,713

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**Table 3.** Total U.S., Canadian and coastwide catches of Pacific Hake (t) from 1966-2017. The percentage of the total catch from each country's waters is also given.

<b>Year</b>	<b>Total U.S.</b>	<b>Total Canada</b>	<b>Total coastwide</b>	<b>Percent U.S.</b>	<b>Percent Canada</b>
1966	137,000	700	137,700	99.5	0.5
1967	177,660	36,710	214,370	82.9	17.1
1968	60,820	61,360	122,180	49.8	50.2
1969	86,280	93,850	180,130	47.9	52.1
1970	159,580	75,010	234,590	68.0	32.0
1971	127,920	26,700	154,620	82.7	17.3
1972	74,130	43,410	117,540	63.1	36.9
1973	147,510	15,130	162,640	90.7	9.3
1974	194,110	17,150	211,260	91.9	8.1
1975	205,650	15,700	221,350	92.9	7.1
1976	231,550	5,970	237,520	97.5	2.5
1977	127,500	5,190	132,690	96.1	3.9
1978	98,377	5,260	103,637	94.9	5.1
1979	124,680	12,430	137,110	90.9	9.1
1980	72,350	17,580	89,930	80.5	19.5
1981	114,760	24,360	139,120	82.5	17.5
1982	75,581	32,160	107,741	70.2	29.8
1983	73,151	40,780	113,931	64.2	35.8
1984	96,382	42,110	138,492	69.6	30.4
1985	85,439	24,960	110,399	77.4	22.6
1986	154,966	55,650	210,616	73.6	26.4
1987	160,448	73,700	234,148	68.5	31.5
1988	160,690	88,150	248,840	64.6	35.4
1989	203,050	95,029	298,079	68.1	31.9
1990	185,142	76,144	261,286	70.9	29.1
1991	229,789	89,917	319,705	71.9	28.1
1992	210,829	88,822	299,650	70.4	29.6
1993	140,132	58,773	198,905	70.5	29.5
1994	253,477	108,930	362,407	69.9	30.1
1995	177,124	72,372	249,495	71.0	29.0
1996	213,159	93,139	306,299	69.6	30.4
1997	233,376	91,771	325,147	71.8	28.2
1998	232,920	87,802	320,722	72.6	27.4
1999	224,565	87,322	311,887	72.0	28.0
2000	206,770	22,007	228,777	90.4	9.6
2001	173,940	53,585	227,525	76.4	23.6
2002	130,453	50,244	180,697	72.2	27.8
2003	141,945	63,217	205,162	69.2	30.8
2004	217,240	125,067	342,307	63.5	36.5
2005	260,120	103,014	363,135	71.6	28.4

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2006	266,955	94,744	361,699	73.8	26.2
2007	217,682	68,976	286,658	75.9	24.1
2008	248,496	70,251	318,746	78.0	22.0
2009	121,324	57,359	178,683	67.9	32.1
2010	171,043	53,072	224,115	76.3	23.7
2011	231,261	51,137	282,398	81.9	18.1
2012	160,144	46,627	206,771	77.5	22.5
2013	233,558	52,249	285,807	81.7	18.3
2014	264,141	35,113	299,254	88.3	11.7
2015	154,156	39,678	193,834	79.5	20.5
2016	262,590	69,740	332,330	79.0	21.0
2017	354,231	86,713	440,944	80.3	19.7

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**Table 4.** Recent trends in Pacific Hake landings and management decisions.

Year	US landings (t)	Canada landings (t)	Total landings (t)	Coast-wide catch target (t)	US catch target (t)	Canada catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2008	248,496	70,251	318,746	364,842	269,545	95,297	92.2%	73.7%	87.4%
2009	121,324	57,359	178,683	184,000	135,939	48,061	89.2%	119.3%	97.1%
2010	171,043	53,072	224,115	262,500	193,935	68,565	88.2%	77.4%	85.4%
2011	231,261	51,137	282,398	393,751	290,903	102,848	79.5%	49.7%	71.7%
2012	160,144	46,627	206,771	251,809	186,036	65,773	86.1%	70.9%	82.1%
2013	233,558	52,249	285,807	365,112	269,745	95,367	86.6%	54.8%	78.3%
2014	264,141	35,113	299,254	428,000	316,206	111,794	83.5%	31.4%	69.9%
2015	154,156	39,678	193,834	440,000	325,072	114,928	47.4%	34.5%	44.1%
2016	262,590	69,740	332,330	497,500	367,553	129,947	71.4%	53.7%	66.8%
2017	354,231	86,713	440,944	597,500	441,433	156,067	80.2%	55.6%	73.8%

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**Table 5.** Annual summary of U.S. and Canadian fishery sampling included in this stock assessment. Canadian, foreign, joint-venture and at-sea sectors are in number of hauls sampled for age-composition, the shore-based sector is in number of trips. A dash (–) indicates there was no catch to sample. A number indicates how many samples from the catch were taken. The number of fish with otoliths sampled per haul has varied over time but is typically small (current protocols for the U.S. At-Sea sectors is 2 fish per haul).

Year	U.S.						Canada			
	Foreign (hauls)	Joint- Venture (hauls)	Mother- ship (hauls)	Combined Mother- ship Catcher- processor (hauls)	Catcher- processor (hauls)	Shore- based (trips)	Foreign (hauls)	Joint- Venture (hauls)	Shoreside (trips)	Freezer Trawlers (hauls)
1975	13	–	–	–	–	0	0	–	–	–
1976	142	–	–	–	–	0	0	–	–	–
1977	320	–	–	–	–	0	0	–	–	–
1978	336	5	–	–	–	0	0	0	–	–
1979	99	17	–	–	–	0	0	0	0	–
1980	191	30	–	–	–	0	0	0	0	–
1981	113	41	–	–	–	0	0	0	0	–
1982	52	118	–	–	–	0	0	0	–	–
1983	–	117	–	–	–	0	0	0	–	–
1984	49	74	–	–	–	0	0	0	–	–
1985	37	19	–	–	–	0	0	0	0	–
1986	88	32	–	–	–	0	0	0	0	–
1987	22	34	–	–	–	0	0	0	0	–
1988	39	42	–	–	–	0	0	3	0	–
1989	–	77	–	–	–	0	0	3	0	–
1990	–	143	–	0	–	15	0	5	0	–
1991	–	–	–	116	–	26	0	18	0	–
1992	–	–	–	164	–	46	–	33	0	–
1993	–	–	–	108	–	36	–	25	3	–
1994	–	–	–	143	–	50	–	41	1	–
1995	–	–	–	61	–	51	–	35	3	–
1996	–	–	–	123	–	35	–	28	1	–
1997	–	–	–	127	–	65	–	27	1	–
1998	–	–	–	149	–	64	–	21	9	–
1999	–	–	–	389	–	80	–	14	26	–
2000	–	–	–	413	–	91	–	25	1	–
2001	–	–	–	429	–	82	–	28	1	–
2002	–	–	–	342	–	71	–	–	36	–
2003	–	–	–	358	–	78	–	–	20	–
2004	–	–	–	381	–	72	–	20	28	–
2005	–	–	–	499	–	58	–	11	31	14
2006	–	–	–	549	–	83	–	21	21	46
2007	–	–	–	524	–	68	–	1	7	29
2008	–	–	324	–	356	63	–	0	20	31
2009	–	–	316	–	278	66	–	–	7	19
2010	–	–	443	–	331	75	–	0	8	17
2011	–	–	481	–	506	81	–	2	4	7
2012	–	–	299	–	332	76	–	–	43	101
2013	–	–	409	–	474	96	–	–	10	105
2014	–	–	400	–	557	68	–	–	26	79
2015	–	–	203	–	431	84	–	–	6	74
2016	–	–	502	–	671	62	–	–	75	116
2017	–	–	273	–	536	110	–	–	62	54

**Table 6.** Recent age proportion data used in the assessment for the U.S. Catcher-processor fleet. Proportions are calculated from numbers of individuals in each age group. Age 15 is an accumulator group.

Year	Number of fish	Number of hauls	Age (% of total for each year)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2008	1,757	356	0.16	9.78	40.43	1.99	12.57	1.13	4.25	3.37	23.59	1.35	0.52	0.50	0.03	0.29	0.04
2009	1,323	278	0.96	0.86	33.18	42.88	1.96	8.04	0.91	1.28	0.58	7.83	1.09	0.07	0.13	0.22	0.00
2010	976	331	0.00	13.91	8.30	41.94	29.31	1.27	1.42	0.06	0.34	0.18	2.81	0.32	0.00	0.09	0.05
2011	1,185	506	6.92	16.79	53.03	1.83	9.12	7.22	1.47	0.69	0.36	0.33	0.04	1.79	0.23	0.09	0.09
2012	981	332	0.00	50.41	9.94	23.82	2.95	5.30	2.72	1.64	0.79	0.28	0.47	0.49	0.56	0.33	0.31
2013	1,402	474	0.10	0.51	72.04	7.12	13.80	1.50	1.19	1.44	0.84	0.36	0.24	0.10	0.07	0.44	0.24
2014	1,652	557	0.00	4.13	5.17	71.41	5.98	8.89	0.89	2.03	0.89	0.44	0.09	0.00	0.00	0.09	0.00
2015	1,263	431	3.49	1.66	7.55	3.45	76.45	3.20	2.16	0.33	0.77	0.52	0.00	0.12	0.12	0.00	0.15
2016	1,995	671	0.40	52.87	2.37	5.57	2.23	31.31	1.56	2.06	0.73	0.20	0.44	0.20	0.00	0.04	0.00
2017	1,578	536	1.98	0.74	43.98	2.54	5.17	3.51	33.03	3.69	2.52	1.54	0.28	0.70	0.22	0.00	0.10

**Table 7.** Recent age proportion data used in the assessment for the U.S. Mothership fleet. Proportions are calculated from numbers of individuals in each age group. Age 15 is an accumulator group.

Year	Number of fish	Number of hauls	Age (% of total for each year)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2008	1,580	324	1.21	8.59	38.53	3.48	14.88	0.72	2.73	3.33	22.75	2.03	0.48	0.73	0.25	0.08	0.19
2009	1,187	316	2.03	0.69	30.42	23.69	3.94	10.17	0.87	3.04	2.07	19.81	1.90	0.27	0.63	0.27	0.19
2010	1,305	443	0.00	41.59	1.35	36.69	12.81	1.32	1.89	0.38	0.21	0.95	2.27	0.39	0.04	0.12	0.00
2011	1,153	481	4.12	15.25	72.04	2.68	3.56	1.60	0.20	0.11	0.10	0.03	0.11	0.11	0.03	0.03	0.02
2012	884	299	0.70	76.44	5.88	13.09	1.34	0.84	0.87	0.32	0.07	0.00	0.09	0.04	0.10	0.07	0.12
2013	1,215	409	0.00	1.19	83.16	4.52	7.51	0.25	0.96	1.18	0.13	0.19	0.15	0.05	0.23	0.35	0.14
2014	1,184	400	0.00	5.09	3.74	74.13	4.49	7.85	0.98	1.37	0.95	0.56	0.12	0.08	0.00	0.14	0.50
2015	601	203	1.82	0.65	10.41	4.78	71.41	4.00	4.13	1.07	0.63	0.83	0.29	0.00	0.00	0.00	0.00
2016	1,495	502	0.53	59.25	1.45	5.10	2.44	26.82	1.54	1.92	0.38	0.32	0.09	0.15	0.00	0.00	0.00
2017	789	273	5.89	0.86	46.80	2.30	3.55	1.21	33.12	2.21	2.03	0.61	0.06	0.91	0.25	0.21	0.00

**Table 8.** Recent age proportion data used in the assessment for the U.S. Shoreside fleet. Proportions are calculated from numbers of individuals in each age group. Age 15 is an accumulator group.

Year	Number of trips	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2008	63	1.88	13.86	26.09	2.32	21.71	1.34	3.85	2.87	21.99	1.99	0.99	0.42	0.22	0.23	0.24
2009	66	0.00	0.28	44.84	28.34	2.22	8.98	0.51	1.81	1.68	8.50	1.21	0.59	0.58	0.08	0.38
2010	75	0.09	32.90	1.93	37.37	16.30	1.64	2.96	0.14	0.66	1.01	3.87	0.70	0.14	0.00	0.31
2011	81	0.05	2.70	86.98	3.42	3.00	1.68	0.41	0.54	0.36	0.16	0.00	0.56	0.09	0.00	0.05
2012	76	0.00	22.91	18.92	51.10	1.52	2.39	1.18	0.66	0.29	0.07	0.00	0.33	0.23	0.20	0.22
2013	96	0.00	0.37	79.28	5.93	9.78	0.67	1.38	1.02	0.36	0.37	0.13	0.04	0.09	0.31	0.27
2014	68	0.00	2.18	3.00	63.95	8.41	15.20	1.32	2.44	1.70	0.64	0.23	0.00	0.20	0.20	0.51
2015	84	5.98	1.33	7.43	4.92	67.34	4.06	5.08	0.78	1.06	1.28	0.24	0.17	0.00	0.00	0.32
2016	62	0.13	63.79	1.39	3.61	1.67	22.84	1.84	2.70	0.87	0.35	0.30	0.19	0.17	0.05	0.09
2017	110	3.28	0.51	35.46	2.54	3.65	2.44	44.25	2.57	2.10	1.42	0.64	0.52	0.29	0.12	0.22

**Table 9.** Recent age proportion data used in the assessment for the Canadian Shoreside fleet. Proportions are calculated from numbers of individuals in each age group. Age 15 is an accumulator group.

Year	Number of trips	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2008	20	0.00	3.66	3.73	1.89	9.02	0.93	3.52	3.16	54.29	9.74	3.66	1.50	2.12	0.77	2.00
2009	7	0.00	0.43	8.94	18.11	5.72	16.43	3.32	3.10	5.38	28.73	5.27	2.51	0.66	0.62	0.79
2010	8	0.00	0.07	0.93	10.17	37.58	7.52	8.66	1.60	0.91	1.76	25.57	3.07	1.90	0.15	0.14
2011	4	0.00	0.00	63.89	2.88	12.59	8.98	2.82	3.10	0.23	1.91	0.24	2.63	0.25	0.47	0.01
2012	43	0.00	0.84	11.28	54.04	5.31	13.06	5.41	2.21	1.56	0.81	1.08	0.21	2.52	0.29	1.38
2013	10	0.00	0.00	1.36	4.69	4.33	2.25	26.17	7.99	4.57	14.15	0.51	2.90	4.36	24.83	1.87
2014	26	0.00	0.00	0.19	14.90	12.60	23.94	8.96	14.68	8.90	1.88	4.40	0.56	0.46	0.90	7.62
2015	6	2.79	0.00	1.12	2.64	63.49	8.13	11.52	1.31	5.60	1.85	0.00	0.53	0.00	0.34	0.68
2016	70	0.00	4.70	0.19	2.66	2.43	70.55	9.30	8.59	0.65	0.41	0.10	0.15	0.12	0.00	0.15
2017	62	7.69	0.38	7.46	1.70	3.15	7.91	46.37	14.79	6.21	1.37	1.02	1.21	0.16	0.09	0.48

**Table 10.** Recent age proportion data used in the assessment for the Canadian Freezer Trawler fleet. Proportions are calculated from numbers of individuals in each age group. Age 15 is an accumulator group.

Year	Number of hauls	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2008	31	0.00	18.23	17.89	1.92	7.64	0.53	2.65	2.07	36.58	5.57	2.26	1.70	1.62	0.68	0.66
2009	19	0.00	0.19	22.55	13.89	4.22	11.81	1.56	2.56	2.08	30.23	6.52	1.67	1.89	0.47	0.35
2010	17	0.00	4.31	4.28	31.23	25.64	6.09	4.07	2.02	2.57	3.16	11.26	3.40	0.62	0.66	0.69
2011	7	0.00	0.00	5.34	1.36	23.81	28.49	10.97	4.06	1.02	1.77	2.26	15.45	1.89	1.19	2.38
2012	101	0.00	0.05	2.91	25.29	6.27	29.04	13.76	3.48	3.83	1.04	1.31	1.79	8.21	1.94	1.08
2013	105	0.00	0.00	2.78	5.88	18.17	5.88	18.86	13.09	5.47	5.56	2.06	2.72	4.15	11.62	3.76
2014	79	0.00	0.00	0.98	13.30	10.07	24.66	5.37	14.15	7.62	4.75	3.16	1.43	1.93	2.07	10.50
2015	74	0.00	0.28	2.59	2.67	58.81	12.33	11.60	3.19	3.83	2.23	0.81	0.64	0.15	0.25	0.62
2016	111	0.17	5.14	2.06	4.40	6.98	56.82	9.20	8.08	2.18	2.38	1.30	0.56	0.15	0.12	0.46
2017	54	0.00	0.00	7.76	2.69	4.63	5.40	47.38	14.27	9.37	2.93	3.06	1.34	0.22	0.26	0.68

**Table 11.** Aggregated fishery age proportion data used in the base model. Proportions are calculated from numbers of individuals in each age group where the contributions from each sector are weighted by the catch in that sector. Sample sizes are sum of hauls and trips from individual sectors (shown in preceding tables) as described in Section 2.1.2. Age 15 is an accumulator group for purposes of comparing observed and expected proportions.

Year	Number of samples	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1975	13	4.61	33.85	7.43	1.25	25.40	5.55	8.03	10.54	0.95	0.60	0.87	0.45	0.00	0.48	0.00
1976	142	0.08	1.34	14.47	6.74	4.10	24.58	9.77	8.90	12.10	5.43	4.30	4.08	1.07	2.36	0.69
1977	320	0.00	8.45	3.68	27.47	3.59	9.11	22.68	7.60	6.54	4.02	3.55	2.31	0.57	0.31	0.12
1978	341	0.47	1.11	6.51	6.31	26.42	6.09	8.87	21.50	9.78	4.71	4.68	2.34	0.52	0.35	0.34
1979	116	0.00	6.49	10.24	9.38	5.72	17.67	10.26	17.37	12.76	4.18	2.88	0.96	1.65	0.00	0.45
1980	221	0.15	0.54	30.09	1.86	4.49	8.17	11.23	5.01	8.94	11.07	9.46	2.63	3.79	1.52	1.07
1981	154	19.49	4.03	1.40	26.73	3.90	5.55	3.38	14.67	3.77	3.19	10.19	2.31	0.50	0.16	0.72
1982	170	0.00	32.05	3.52	0.49	27.35	1.53	3.68	3.89	11.76	3.27	3.61	7.65	0.24	0.30	0.66
1983	117	0.00	0.00	34.14	4.00	1.82	23.46	5.13	5.65	5.30	9.38	3.91	3.13	2.26	1.13	0.69
1984	123	0.00	0.00	1.39	61.90	3.62	3.85	16.78	2.85	1.51	1.24	3.34	0.92	0.59	1.44	0.56
1985	57	0.92	0.11	0.35	7.24	66.75	8.41	5.60	7.11	2.04	0.53	0.65	0.25	0.00	0.00	0.03
1986	120	0.00	15.34	5.38	0.53	0.76	43.64	6.90	8.15	8.26	2.19	2.82	1.83	3.13	0.46	0.61
1987	56	0.00	0.00	29.58	2.90	0.14	1.01	53.26	0.40	1.25	7.09	0.00	0.74	1.86	1.76	0.00
1988	84	0.00	0.66	0.06	32.35	0.98	1.45	0.66	45.96	1.34	0.83	10.50	0.79	0.05	0.06	4.30
1989	80	0.00	5.62	2.43	0.29	50.21	1.26	0.29	0.08	35.19	1.80	0.40	2.32	0.08	0.00	0.04
1990	163	0.00	5.19	20.56	1.88	0.59	31.35	0.51	0.20	0.04	31.90	0.30	0.07	6.41	0.00	0.99
1991	160	0.00	3.46	20.37	19.63	2.52	0.79	28.26	1.18	0.14	0.18	18.69	0.42	0.00	3.61	0.74
1992	243	0.46	4.24	4.30	13.05	18.59	2.27	1.04	33.93	0.77	0.08	0.34	18.05	0.41	0.04	2.43
1993	172	0.00	1.05	23.24	3.26	12.98	15.67	1.50	0.81	27.42	0.67	0.09	0.12	12.00	0.05	1.13
1994	235	0.00	0.04	2.83	21.39	1.27	12.63	18.69	1.57	0.57	29.91	0.26	0.28	0.02	9.63	0.91
1995	147	0.62	1.28	0.47	6.31	28.97	1.15	8.05	20.27	1.58	0.22	22.42	0.44	0.45	0.04	7.73
1996	186	0.00	18.28	16.24	1.51	7.74	18.14	1.00	4.91	10.98	0.58	0.35	15.72	0.01	0.11	4.44
1997	220	0.00	0.74	29.48	24.95	1.47	7.84	12.49	1.80	3.98	6.67	1.28	0.22	6.08	0.73	2.28
1998	243	0.02	4.79	20.35	20.29	26.60	2.87	5.40	9.31	0.92	1.56	3.90	0.35	0.09	2.94	0.63
1999	509	0.06	10.24	20.36	17.98	20.06	13.20	2.69	3.93	4.01	0.99	1.54	2.14	0.39	0.33	2.07
2000	530	1.00	4.22	10.94	14.29	12.88	21.06	13.12	6.55	4.65	2.51	2.07	2.31	1.29	0.72	2.41
2001	540	0.00	17.34	16.25	14.25	15.68	8.56	12.10	5.99	1.78	2.23	1.81	0.70	1.42	0.68	1.21
2002	449	0.00	0.03	50.64	14.93	9.69	5.72	4.44	6.58	3.55	0.87	0.84	1.04	0.24	0.47	0.95
2003	456	0.00	0.10	1.40	67.90	11.64	3.34	4.99	3.19	3.14	2.11	0.87	0.44	0.53	0.12	0.23
2004	501	0.00	0.02	5.31	6.07	68.29	8.15	2.19	4.15	2.51	1.28	1.08	0.35	0.27	0.16	0.17
2005	613	0.02	0.57	0.46	6.56	5.38	68.72	7.95	2.36	2.91	2.21	1.18	1.09	0.25	0.09	0.25
2006	720	0.33	2.81	10.44	1.67	8.57	4.88	59.04	5.28	1.72	2.38	1.13	1.02	0.43	0.14	0.19
2007	629	0.76	11.29	3.73	15.45	1.59	6.85	3.84	44.12	5.19	1.72	2.29	1.78	0.51	0.19	0.69
2008	794	0.76	9.85	30.60	2.40	14.42	1.03	3.63	3.16	28.00	3.04	1.14	0.73	0.49	0.31	0.43
2009	686	0.64	0.52	30.63	27.55	3.36	10.70	1.30	2.26	2.29	16.19	2.48	0.87	0.59	0.28	0.34
2010	874	0.03	25.29	3.35	34.80	21.56	2.37	3.01	0.44	0.58	0.98	6.09	0.93	0.31	0.10	0.16
2011	1,081	2.64	8.50	70.84	2.65	6.42	4.45	1.15	0.82	0.29	0.39	0.12	1.35	0.17	0.11	0.11
2012	851	0.18	40.95	11.56	32.99	2.49	5.08	2.52	1.13	0.66	0.23	0.33	0.35	0.87	0.28	0.38
2013	1,094	0.03	0.54	70.31	5.91	10.47	1.12	3.41	2.06	0.91	1.37	0.26	0.33	0.53	2.28	0.46
2014	1,130	0.00	3.31	3.73	64.30	6.93	12.17	1.59	3.14	1.83	0.82	0.47	0.12	0.19	0.28	1.13
2015	798	3.59	1.14	6.88	3.95	70.02	4.94	5.09	0.96	1.55	1.09	0.20	0.21	0.06	0.05	0.27
2016	1,426	0.30	49.63	1.69	4.58	2.52	33.17	2.85	3.23	0.80	0.46	0.37	0.21	0.07	0.04	0.07
2017	762	3.04	0.53	32.69	2.45	4.26	3.81	40.49	5.60	3.44	1.59	0.77	0.75	0.24	0.08	0.25

**Table 12.** Survey age proportion data used in the base model. Proportions are calculated from numbers of individuals in each age group. Age 15 is an accumulator group.

Year	Number of samples	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1995	69	0.00	20.48	3.26	1.06	19.33	1.03	4.03	16.37	1.44	0.72	24.86	0.24	1.67	0.21	5.32
1998	105	0.00	6.83	8.03	17.03	17.25	1.77	11.37	10.79	1.73	4.19	7.60	1.27	0.34	9.74	2.06
2001	57	0.00	50.61	10.95	15.12	7.86	3.64	3.84	2.60	1.30	1.34	0.65	0.68	0.87	0.15	0.39
2003	71	0.00	23.06	1.63	43.40	13.07	2.71	5.14	3.43	1.82	2.44	1.44	0.49	0.43	0.42	0.52
2005	47	0.00	19.07	1.23	5.10	4.78	50.66	6.99	2.50	3.99	2.45	1.71	0.74	0.48	0.14	0.16
2007	69	0.00	28.29	2.16	11.64	1.38	5.01	3.25	38.64	3.92	1.94	1.70	0.83	0.77	0.34	0.12
2009	72	0.00	0.55	29.34	40.22	2.29	8.22	1.25	1.79	1.93	8.32	3.63	1.44	0.28	0.48	0.26
2011	46	0.00	27.62	56.32	3.71	2.64	2.94	0.70	0.78	0.38	0.66	0.97	2.10	0.76	0.31	0.11
2012	94	0.00	62.12	9.78	16.70	2.26	2.92	1.94	1.01	0.50	0.23	0.27	0.66	0.98	0.51	0.12
2013	67	0.00	2.17	74.98	5.63	8.68	0.95	2.20	2.59	0.71	0.35	0.10	0.13	0.36	0.77	0.38
2015	78	0.00	7.45	9.19	4.38	58.99	4.88	7.53	1.69	1.68	1.64	0.95	0.16	0.29	0.24	0.92
2017	59	0.00	0.49	52.72	2.80	3.70	3.31	26.02	4.13	2.91	1.14	0.91	0.87	0.42	0.33	0.25



**Table 13.** Summary of the acoustic surveys from 1995 to 2017.

Year	Start date	End date	Vessels	Biomass index (million t)	Sampling CV	Number of hauls with bio. samples
1995	01-Jul	01-Sep	Miller Freeman Ricker	1.318	0.089	69
1998	06-Jul	27-Aug	Miller Freeman Ricker	1.534	0.053	105
2001	15-Jun	18-Aug	Miller Freeman Ricker	0.862	0.106	57
2003	29-Jun	01-Sep	Ricker	2.138	0.064	71
2005	20-Jun	19-Aug	Miller Freeman	1.376	0.064	47
2007	20-Jun	21-Aug	Miller Freeman	0.943	0.077	69
2009	30-Jun	07-Sep	Miller Freeman Ricker	1.502	0.010	72
2011	26-Jun	10-Sep	Bell Shimada Ricker	0.675	0.118	46
2012	23-Jun	07-Sep	Bell Shimada Ricker	1.279	0.067	94
2013	13-Jun	11-Sep	F/V Forum Star Bell Shimada Ricker	1.929	0.065	67
2015	15-Jun	14-Sep	Bell Shimada Ricker	2.156	0.083	78
2017	22-Jun	13-Sep	Bell Shimada Nordic Pearl	1.418	0.063	70

**Table 14.** Biomass indices from the acoustic survey (million t) used in this assessment.

Year	Biomass estimate (million t)	Sampling CV
1995	1.318	8.9%
1998	1.569	4.8%
2001	0.862	10.6%
2003	2.138	6.4%
2005	1.376	6.4%
2007	0.943	7.7%
2009	1.502	10.0%
2011	0.675	11.8%
2012	1.279	6.7%
2013	1.929	6.5%
2015	2.156	8.3%
2017	1.418	6.3%

**Table 15.** Number of Pacific Hake ovaries collected for histological analysis with maturity determined from different years and different sources.

Year	NWFSC Trawl Survey	Acoustic survey/Research (Summer)	Acoustic survey/Research (Winter)	U.S. At-Sea Hake Observer Program (Spring)	U.S. At-Sea Hake Observer Program (Fall)	Total
2009	263	0	0	0	0	<b>263</b>
2012	71	199	0	0	0	<b>270</b>
2013	70	254	0	104	103	<b>531</b>
2014	276	0	0	105	142	<b>523</b>
2015	293	193	0	98	112	<b>696</b>
2016	277	26	309	100	162	<b>874</b>
2017	109	65	134	93	113	<b>514</b>
<b>Total</b>	<b>1,359</b>	<b>737</b>	<b>443</b>	<b>500</b>	<b>632</b>	<b>3,671</b>

**Table 16.** Information on maturity and fecundity used in this assessment as shown in Figure 12. The sample sizes refer to the subset of samples in Table 15 for which age readings and histological estimates of maturity have been completed. The mean weight (kg) is based on a much larger set of samples. The new fecundity estimate is the product of the maturity and mean weight values while the old fecundity was the result of an older length-based maturity estimate converted to ages. The values reported for ages 15 and above (with the exception of the old fecundity) represent the average across all samples in this range.

Age	Number of samples	Old fecundity	New fecundity	Maturity ogive	Mean weight
0	0	0.000	0.000	0.000	0.017
1	122	0.000	0.000	0.000	0.092
2	276	0.100	0.065	0.261	0.249
3	348	0.254	0.318	0.839	0.379
4	333	0.399	0.465	0.961	0.484
5	299	0.518	0.490	0.920	0.533
6	221	0.613	0.539	0.928	0.581
7	81	0.690	0.599	0.926	0.647
8	70	0.751	0.688	0.957	0.718
9	36	0.801	0.744	0.944	0.788
10	51	0.841	0.843	0.980	0.859
11	26	0.872	0.895	0.962	0.931
12	18	0.898	0.970	1.000	0.970
13	24	0.918	1.021	0.958	1.066
14	22	0.934	0.963	0.955	1.009
15	8	0.947	0.930	0.900	1.034
16	9	0.957	0.930	0.900	1.034
17	2	0.965	0.930	0.900	1.034
18	1	0.971	0.930	0.900	1.034
19	0	0.976	0.930	0.900	1.034
20	0	0.983	0.930	0.900	1.034

**Table 17.** Summary of estimated model parameters and priors in the base model. The Beta prior is parameterized with a mean and standard deviation. The Lognormal distribution is parameterized with the median and standard deviation in log space.

Parameter	Number estimated	Bounds (low, high)	Prior (Mean, SD) single value = fixed
<b><u>Stock Dynamics</u></b>			
Log( $R_0$ )	1	(13,17)	Uniform
Steepness ( $h$ )	1	(0.2,1)	Beta(0.78,0.11)
Recruitment variability ( $\sigma_r$ )	–	–	1.4
Log recruitment deviations: 1946–2017	72	(-6,6)	Lognormal(0, $\sigma_r$ )
Natural mortality ( $M$ )	1	(0.05,0.4)	Lognormal(0.20,1.11)
<b><u>Catchability and selectivity</u></b>			
<b><i>Acoustic Survey</i></b>			
Catchability ( $q$ )	1	–	Analytic solution
Additional value for survey log(SE)	–	(0.05,1.2)	Uniform
Non-parametric age-based selectivity: ages 3–6	4	(-5,9)	Uniform
<b><i>Fishery</i></b>			
Non-parametric age-based selectivity: ages 2–6	5	(-5,9)	Uniform
Selectivity deviations (1991–2017, ages 2–6)	135	–	Normal(0,1.4)
<b><u>Data weighting</u></b>			
Dirichlet-Multinomial likelihood (log( $\theta$ ))	2	(-5,20)	Uniform

**Table 18.** Time-series of median posterior population estimates from the base model. Relative spawning biomass is spawning biomass relative to the unfished equilibrium ( $B_0$ ). Total biomass includes females and males of all ages ages 0 and above. Age-2+ biomass includes females and males ages 2 and above. Exploitation fraction is total catch divided by total age-2+ biomass. Relative fishing intensity is  $(1-SPR)/(1-SPR_{40\%})$ .

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Total biomass (thousand t)	Age-2+ biomass (thousand t)	Age-0 recruits (millions)	Relative fishing intensity	Exploitation fraction
1966	860	42.4%	2,242	2,053	1,605	49.3%	6.7%
1967	853	41.9%	2,311	2,084	4,262	68.1%	10.3%
1968	841	41.3%	2,429	2,059	2,702	49.8%	5.9%
1969	922	45.8%	2,735	2,503	752	61.8%	7.2%
1970	1,083	53.8%	2,918	2,714	8,291	68.3%	8.6%
1971	1,112	55.3%	3,136	2,522	779	51.2%	6.1%
1972	1,171	58.2%	3,533	3,459	504	39.5%	3.4%
1973	1,513	75.3%	3,616	3,488	5,545	43.3%	4.7%
1974	1,493	74.2%	3,633	3,223	347	49.8%	6.6%
1975	1,352	67.0%	4,603	4,461	1,696	43.9%	5.0%
1976	1,457	72.3%	4,831	4,689	208	38.3%	5.1%
1977	1,384	68.6%	4,526	4,168	6,238	27.4%	3.2%
1978	1,272	63.4%	3,699	3,326	134	25.4%	3.1%
1979	1,239	61.7%	4,165	4,092	1,271	28.6%	3.4%
1980	1,424	70.4%	4,431	3,582	16,514	23.2%	2.5%
1981	1,379	68.2%	4,653	3,218	265	34.5%	4.3%
1982	1,533	76.0%	5,155	5,114	304	29.1%	2.1%
1983	2,339	115.8%	4,925	4,876	501	25.1%	2.3%
1984	2,365	116.2%	5,164	4,674	13,356	27.5%	3.0%
1985	1,977	97.5%	6,218	4,347	137	22.8%	2.5%
1986	1,974	97.3%	6,051	6,026	182	33.0%	3.5%
1987	2,477	122.0%	5,455	5,287	6,327	38.1%	4.4%
1988	2,372	116.9%	5,534	4,796	2,032	40.3%	5.2%
1989	2,040	100.2%	4,994	4,767	118	51.7%	6.3%
1990	2,070	101.7%	4,598	4,513	4,182	42.2%	5.8%
1991	1,930	94.8%	4,414	3,949	1,176	64.0%	8.1%
1992	1,656	81.4%	3,772	3,631	132	63.4%	8.3%
1993	1,553	76.4%	2,850	2,787	3,104	55.1%	7.1%
1994	1,391	68.5%	2,843	2,496	3,272	70.9%	14.5%
1995	1,083	53.4%	2,820	2,520	1,210	60.8%	9.9%
1996	1,071	52.5%	2,698	2,578	1,798	75.9%	11.9%
1997	1,061	52.2%	2,557	2,406	1,032	80.9%	13.5%
1998	922	45.5%	2,108	2,010	1,920	91.4%	16.0%
1999	787	38.7%	2,089	1,688	12,700	99.4%	18.5%
2000	666	32.8%	3,865	1,937	320	75.6%	11.8%
2001	883	43.5%	4,031	3,999	1,207	74.0%	5.7%
2002	1,514	74.8%	4,398	4,324	33	52.0%	4.2%
2003	1,580	78.1%	3,744	3,717	1,664	48.1%	5.5%
2004	1,334	65.9%	3,084	2,935	63	76.8%	11.7%
2005	1,072	53.0%	2,488	2,441	2,622	74.8%	14.9%
2006	875	43.1%	2,173	1,871	1,886	92.1%	19.3%
2007	696	34.4%	1,723	1,656	24	92.3%	17.7%
2008	655	32.4%	1,755	1,677	5,096	97.3%	19.2%
2009	595	29.3%	1,524	1,231	1,274	80.1%	14.4%
2010	568	28.0%	2,019	1,716	13,369	94.3%	13.4%
2011	719	35.6%	2,558	1,652	427	90.8%	17.7%
2012	920	45.4%	3,176	3,111	1,416	70.6%	6.6%
2013	1,546	76.1%	3,645	3,484	432	68.1%	8.2%
2014	1,548	76.1%	3,739	3,574	8,583	69.5%	8.4%
2015	1,289	63.2%	3,139	2,611	155	48.6%	7.3%
2016	1,275	62.4%	3,345	3,242	3,236	74.0%	10.2%
2017	1,469	72.1%	3,658	3,098	1,036	86.2%	14.2%
2018	1,357	66.7%	3,557	3,337	1,035	–	–

**Table 19.** Time-series of 95% posterior credibility intervals for the quantities shown in Table 18.

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Total biomass (thousand t)	Age-2+ biomass (thousand t)	Age-0 recruits (millions)	(1-SPR) / (1-SPR <sub>40%</sub> )	Exploitation fraction
1966	536-1,464	26.9- 67.7%	1,513-3,773	1,320-3,486	78- 7,587	29.6- 71.3%	3.9-10.4%
1967	549-1,462	27.2- 67.2%	1,555-3,901	1,345-3,588	333-12,364	43.0- 91.4%	6.0-15.9%
1968	531-1,482	26.6- 67.6%	1,614-4,263	1,292-3,582	211- 7,829	28.9- 72.6%	3.4- 9.5%
1969	598-1,621	29.9- 74.9%	1,811-4,864	1,651-4,500	66- 3,568	37.7- 85.6%	4.0-10.9%
1970	713-1,967	35.2- 87.6%	1,910-5,317	1,790-4,911	4,310-17,663	42.2- 92.3%	4.8-13.1%
1971	725-2,055	35.7- 91.5%	2,002-5,856	1,651-4,605	94- 2,479	28.2- 75.5%	3.4- 9.4%
1972	750-2,180	37.4- 96.4%	2,225-6,560	2,185-6,462	73- 1,561	20.9- 61.9%	1.8- 5.4%
1973	961-2,780	48.0-125.4%	2,282-6,673	2,204-6,440	3,007-11,312	23.2- 66.0%	2.5- 7.4%
1974	945-2,719	47.3-122.1%	2,282-6,674	2,050-5,881	47- 1,233	27.7- 73.8%	3.6-10.3%
1975	848-2,456	42.2-110.6%	2,864-8,393	2,775-8,135	834- 3,509	24.0- 68.0%	2.7- 8.0%
1976	912-2,661	45.2-118.9%	3,025-8,890	2,935-8,518	26- 786	20.5- 60.7%	2.8- 8.1%
1977	863-2,503	42.7-111.6%	2,805-8,169	2,608-7,547	3,503-12,304	14.0- 45.7%	1.8- 5.1%
1978	806-2,254	39.7-101.8%	2,325-6,523	2,105-5,900	19- 628	13.2- 43.1%	1.8- 4.9%
1979	797-2,143	39.2- 97.5%	2,660-7,171	2,620-7,054	517- 2,862	15.2- 46.7%	1.9- 5.2%
1980	928-2,414	45.7-108.2%	2,859-7,418	2,328-6,089	9,953-29,510	12.5- 38.8%	1.5- 3.9%
1981	912-2,287	45.0-102.7%	3,062-7,639	2,114-5,317	38- 985	19.7- 53.6%	2.6- 6.6%
1982	1,021-2,473	51.0-110.1%	3,448-8,248	3,415-8,178	53- 867	16.6- 46.2%	1.3- 3.2%
1983	1,600-3,642	78.6-166.7%	3,376-7,667	3,348-7,587	107- 1,321	14.5- 39.9%	1.5- 3.4%
1984	1,648-3,592	81.0-164.2%	3,614-7,814	3,274-7,125	8,788-21,885	16.5- 42.8%	1.9- 4.2%
1985	1,407-2,938	68.9-134.4%	4,452-9,236	3,088-6,444	21- 506	13.7- 35.7%	1.7- 3.6%
1986	1,450-2,841	71.1-131.1%	4,440-8,750	4,424-8,711	28- 640	20.8- 48.2%	2.4- 4.8%
1987	1,855-3,487	89.7-161.8%	4,083-7,705	3,964-7,453	4,204-10,052	24.8- 53.9%	3.1- 5.9%
1988	1,818-3,267	86.9-153.8%	4,222-7,679	3,667-6,594	1,108- 3,566	27.0- 56.3%	3.8- 6.8%
1989	1,584-2,744	75.5-129.6%	3,877-6,810	3,687-6,462	21- 422	36.0- 68.5%	4.6- 8.1%
1990	1,629-2,759	76.9-131.0%	3,619-6,164	3,555-6,052	2,844- 6,421	29.1- 57.4%	4.3- 7.4%
1991	1,542-2,536	72.5-120.1%	3,521-5,850	3,150-5,160	567- 2,173	43.3- 91.1%	6.2-10.2%
1992	1,335-2,138	63.1-102.2%	3,027-4,953	2,931-4,756	21- 477	44.5- 93.9%	6.3-10.2%
1993	1,261-1,995	59.5- 95.2%	2,309-3,698	2,259-3,593	2,172- 4,619	37.2- 84.6%	5.5- 8.8%
1994	1,147-1,762	53.8- 85.2%	2,327-3,652	2,055-3,162	2,281- 4,938	53.0- 91.9%	11.5-17.6%
1995	890-1,373	41.9- 66.3%	2,303-3,641	2,059-3,242	742- 1,985	44.9- 78.5%	7.7-12.1%
1996	884-1,358	41.3- 64.9%	2,225-3,454	2,129-3,290	1,207- 2,785	58.0- 97.9%	9.3-14.4%
1997	882-1,348	40.8- 64.8%	2,113-3,264	2,002-3,071	611- 1,785	62.5- 99.8%	10.6-16.2%
1998	764-1,180	35.5- 56.5%	1,744-2,717	1,667-2,579	1,257- 3,060	73.1-107.4%	12.4-19.2%
1999	645-1,016	30.3- 48.4%	1,692-2,768	1,379-2,185	9,059-19,080	80.8-116.3%	14.3-22.6%
2000	533- 879	25.1- 41.0%	3,015-5,320	1,547-2,576	99- 662	57.4- 93.6%	8.9-14.8%
2001	705-1,185	33.1- 54.8%	3,191-5,449	3,162-5,404	844- 1,841	55.6- 91.6%	4.2- 7.2%
2002	1,221-2,010	57.6- 94.3%	3,543-5,849	3,482-5,734	7- 109	36.8- 69.1%	3.2- 5.2%
2003	1,304-2,045	61.2- 96.9%	3,093-4,850	3,072-4,811	1,177- 2,560	33.5- 63.6%	4.3- 6.7%
2004	1,122-1,687	52.6- 80.8%	2,584-3,918	2,472-3,723	11- 195	55.6-100.4%	9.2-13.8%
2005	908-1,357	42.7- 64.8%	2,089-3,188	2,056-3,114	1,870- 4,194	54.6- 97.8%	11.7-17.7%
2006	735-1,127	35.0- 53.0%	1,809-2,880	1,570-2,413	1,333- 2,970	69.5-120.1%	15.0-23.0%
2007	574- 932	27.7- 42.5%	1,416-2,323	1,363-2,236	5- 90	68.2-121.7%	13.1-21.5%
2008	527- 909	25.7- 40.9%	1,405-2,481	1,346-2,342	3,608- 8,117	75.3-117.9%	13.7-23.9%
2009	461- 867	23.0- 38.0%	1,170-2,238	954-1,793	735- 2,490	58.2-101.2%	9.9-18.6%
2010	432- 855	21.9- 37.2%	1,516-3,124	1,313-2,576	8,282-24,883	68.9-120.6%	9.0-17.6%
2011	537-1,110	27.3- 47.9%	1,827-4,184	1,224-2,579	154- 998	63.1-115.9%	11.3-23.8%
2012	633-1,542	32.8- 65.7%	2,146-5,384	2,115-5,287	628- 3,395	44.6- 96.5%	3.9- 9.7%
2013	1,028-2,636	53.2-113.9%	2,408-6,298	2,312-5,966	111- 1,327	44.6- 89.7%	4.8-12.4%
2014	989-2,698	52.0-116.1%	2,356-6,652	2,260-6,347	4,137-20,562	44.7- 96.2%	4.7-13.2%
2015	783-2,311	41.4- 99.0%	1,873-5,779	1,599-4,725	21- 786	27.3- 75.4%	4.0-11.9%
2016	735-2,397	39.0-102.6%	1,912-6,674	1,841-6,461	361-31,933	44.4-106.2%	5.1-17.9%
2017	766-3,086	40.6-130.6%	1,891-8,670	1,623-6,635	62-16,491	55.6-117.8%	6.6-27.1%
2018	610-3,161	32.7-136.1%	1,612-9,640	1,485-8,987	68-18,220	—	—

**Table 20.** Estimated numbers-at-age at the beginning of the year from the base model (MLE; million).

Year	Age															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1966	1,572	1,387	792	499	341	247	194	162	140	122	107	94	83	72	63	284
1967	3,317	1,270	1,119	630	387	260	185	139	116	100	88	77	68	59	52	249
1968	2,281	2,679	1,023	879	474	282	184	121	91	76	66	57	50	44	39	198
1969	751	1,842	2,161	812	680	359	210	131	86	65	54	47	41	36	32	168
1970	6,189	607	1,485	1,702	616	500	258	141	88	58	44	36	31	27	24	134
1971	715	4,998	489	1,163	1,272	443	350	166	90	56	37	28	23	20	18	101
1972	415	577	4,030	387	895	956	328	245	116	63	40	26	20	16	14	83
1973	4,138	335	466	3,213	303	689	727	240	180	85	46	29	19	14	12	71
1974	304	3,342	270	370	2,499	231	519	526	174	130	62	34	21	14	10	60
1975	1,286	246	2,695	214	286	1,884	171	365	370	122	92	43	24	15	10	50
1976	175	1,039	198	2,143	167	218	1,418	124	264	267	88	66	31	17	11	43
1977	4,850	141	838	158	1,676	128	166	1,042	91	194	196	65	48	23	13	39
1978	111	3,916	114	671	125	1,313	100	126	791	69	147	149	49	37	17	39
1979	1,015	89	3,161	91	532	98	1,024	76	96	604	53	112	114	38	28	43
1980	13,723	820	72	2,531	72	416	76	776	58	73	458	40	85	86	28	54
1981	205	11,083	661	58	2,010	57	326	59	596	44	56	352	31	65	66	64
1982	219	165	8,943	528	45	1,559	44	243	44	444	33	42	262	23	49	97
1983	404	177	133	7,161	418	36	1,210	33	184	33	336	25	32	199	17	110
1984	11,107	327	143	107	5,680	328	28	927	25	141	25	258	19	24	152	98
1985	107	8,970	264	114	85	4,455	256	21	706	19	107	19	196	15	18	190
1986	153	86	7,240	212	91	67	3,499	198	16	545	15	83	15	152	11	161
1987	5,239	124	70	5,792	167	71	52	2,633	149	12	410	11	62	11	114	130
1988	1,794	4,231	100	56	4,544	129	54	38	1,951	110	9	304	8	46	8	181
1989	121	1,449	3,413	80	44	3,504	98	40	28	1,437	81	7	224	6	34	139
1990	3,506	98	1,169	2,709	62	33	2,610	70	28	20	1,019	58	5	159	4	123
1991	1,103	2,832	79	931	2,116	47	25	1,912	51	21	15	746	42	3	116	93
1992	127	890	2,284	61	640	1,587	35	18	1,378	37	15	11	538	30	3	151
1993	2,678	103	718	1,817	44	451	1,179	24	13	957	26	10	7	374	21	107
1994	2,831	2,162	83	575	1,372	32	321	853	18	9	693	19	8	5	271	92
1995	1,112	2,286	1,745	66	452	970	22	200	532	11	6	432	12	5	3	226
1996	1,574	898	1,845	1,400	52	349	673	15	132	350	7	4	284	8	3	151
1997	880	1,271	723	1,398	1,033	39	254	416	9	81	216	4	2	176	5	95
1998	1,653	711	1,026	578	974	695	27	157	257	6	50	134	3	1	108	62
1999	10,926	1,335	573	806	362	670	404	17	97	158	3	31	82	2	1	105
2000	320	8,824	1,076	416	528	204	418	242	10	58	95	2	19	49	1	63
2001	1,019	259	7,123	857	304	380	137	258	149	6	36	59	1	11	30	40
2002	29	823	209	5,701	637	202	255	89	168	97	4	23	38	1	7	46
2003	1,412	24	665	168	4,478	471	142	182	64	120	69	3	17	27	1	38
2004	77	1,140	19	535	133	3,404	340	101	130	45	86	50	2	12	19	28
2005	2,176	62	920	15	401	81	2,380	226	67	86	30	57	33	1	8	31
2006	1,641	1,757	50	738	12	280	48	1,523	145	43	55	19	36	21	1	25
2007	21	1,325	1,416	36	524	8	166	28	906	86	26	33	11	22	13	15
2008	4,201	17	1,068	1,086	24	340	5	95	16	520	49	15	19	7	12	16
2009	1,048	3,393	14	818	704	16	196	3	50	9	274	26	8	10	3	15
2010	10,382	846	2,738	11	574	478	12	121	2	31	5	169	16	5	6	11
2011	378	8,384	683	2,097	8	296	284	7	78	1	20	3	110	10	3	11
2012	1,093	305	6,752	532	1,140	5	193	193	5	53	1	14	2	75	7	10
2013	407	883	246	5,251	384	731	3	135	135	4	37	1	10	2	52	12
2014	6,560	329	712	196	3,826	279	518	2	86	86	2	24	0	6	1	41
2015	150	5,298	265	559	141	2,758	197	337	1	56	56	1	15	0	4	27
2016	2,251	122	4,265	211	424	104	1,971	144	247	1	41	41	1	11	0	23
2017	2,064	1,818	97	3,041	159	299	72	1,319	97	165	1	27	27	1	8	15
2018	2,045	1,667	1,444	74	2,192	111	201	39	716	53	90	0	15	15	0	12



**Table 21.** Estimated biomass-at-age at the beginning of the year from the base model (MLE; thousand metric tons).

Year	Age																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	27	127	197	189	165	131	113	105	100	96	92	88	80	77	64	56	49	41	35	30	82
1967	56	116	278	239	187	138	108	90	84	79	75	72	66	63	52	47	41	35	30	25	80
1968	39	245	255	333	229	150	107	79	66	60	57	53	49	47	39	35	31	27	23	20	69
1969	13	169	538	308	329	191	122	85	62	51	47	44	40	38	32	29	25	22	19	16	63
1970	105	56	370	645	298	267	150	91	63	46	37	34	30	29	24	22	19	17	15	13	53
1971	12	458	122	441	616	236	204	107	65	44	32	26	23	21	18	16	14	12	11	9	42
1972	7	53	1,003	147	433	510	191	159	83	50	34	24	19	17	14	13	11	10	9	8	36
1973	70	31	116	1,218	147	367	423	156	129	67	40	27	19	15	12	11	9	8	7	6	32
1974	5	306	67	140	1,210	123	302	340	125	102	53	31	20	15	10	9	8	7	6	5	28
1975	71	39	805	78	175	1,188	135	319	358	111	89	73	35	28	19	20	17	14	13	11	62
1976	10	102	47	1,070	86	151	1,140	113	318	356	128	109	56	32	21	19	14	12	10	9	52
1977	267	12	337	77	989	85	124	862	89	214	242	85	68	40	26	17	11	9	7	6	36
1978	6	284	15	315	66	791	64	93	666	68	162	185	65	55	30	22	14	9	7	6	34
1979	49	7	762	24	310	67	786	68	88	627	63	140	174	58	50	26	14	9	6	4	26
1980	620	66	15	1,146	28	204	39	508	41	64	486	46	110	112	36	30	14	8	5	3	16
1981	9	1,190	141	20	1,058	22	171	32	445	32	46	366	34	88	99	27	20	9	5	3	13
1982	8	20	2,204	176	14	857	17	128	25	338	23	36	280	20	50	58	19	14	7	4	12
1983	14	23	18	2,442	154	12	629	17	114	23	296	23	33	205	23	55	55	18	14	6	15
1984	357	43	23	27	2,490	135	12	544	15	95	18	245	22	25	195	25	53	54	18	13	21
1985	3	1,561	61	31	37	2,449	140	13	526	13	78	17	171	14	12	130	11	24	24	8	15
1986	4	13	2,013	61	28	25	1,899	113	10	448	14	98	18	208	19	23	144	13	27	27	26
1987	116	18	10	2,195	46	20	19	1,520	89	8	313	11	58	14	137	12	15	95	8	18	35
1988	34	592	19	18	2,140	48	20	20	1,263	76	7	280	9	47	12	123	9	12	73	6	40
1989	2	201	934	24	13	1,799	43	16	15	900	54	4	196	4	28	7	70	5	7	41	27
1990	55	13	285	950	24	17	1,426	42	19	11	785	48	10	188	4	35	6	65	5	6	63
1991	17	387	22	344	973	24	14	1,129	37	18	16	536	27	4	140	8	42	8	77	6	82
1992	2	121	529	21	303	846	20	11	883	24	9	8	396	26	2	86	2	13	2	24	27
1993	42	13	179	615	17	205	582	12	6	526	13	13	8	229	13	1	40	1	6	1	24
1994	44	258	25	208	613	14	169	486	11	5	439	9	5	4	190	11	1	31	1	5	20
1995	17	253	468	23	220	520	15	125	351	8	4	321	9	4	2	135	8	1	21	1	16
1996	24	90	531	558	25	185	380	10	78	223	4	3	192	6	5	2	83	5	0	13	10
1997	13	115	257	604	509	21	139	243	5	49	137	4	1	125	3	2	1	60	3	0	17
1998	25	57	215	205	491	360	15	101	156	4	41	96	2	1	81	2	1	1	34	2	10
1999	166	181	143	278	154	353	225	10	59	111	2	25	62	1	1	55	1	1	0	21	7
2000	5	1,676	346	197	304	134	300	176	8	49	77	2	16	46	1	0	37	1	0	0	20
2001	15	13	2,042	415	198	252	102	222	128	5	35	57	1	12	30	1	0	24	1	0	13
2002	0	62	75	2,608	386	165	193	75	164	91	4	23	38	1	8	21	0	0	17	0	9
2003	21	2	170	73	2,340	277	107	126	48	99	53	3	15	22	1	5	14	0	0	11	7
2004	1	123	4	233	64	1,811	220	71	86	32	69	43	2	12	17	0	3	9	0	0	12
2005	32	7	239	6	204	44	1,352	143	44	61	24	46	27	1	9	13	0	2	7	0	8
2006	24	233	19	337	6	161	28	911	95	30	40	14	28	14	1	5	8	0	2	4	5
2007	0	59	322	14	280	4	101	18	586	61	20	25	9	19	10	0	3	4	0	1	5
2008	62	2	261	443	13	217	3	65	12	375	37	12	16	5	11	6	0	1	2	0	3
2009	16	226	3	281	332	10	131	2	37	7	210	21	8	8	3	7	4	0	1	2	2
2010	154	92	637	3	249	254	8	101	2	32	5	148	14	5	4	2	4	2	0	1	2
2011	6	708	168	675	3	152	169	5	67	1	20	4	116	11	3	4	1	2	1	0	2
2012	16	39	1,448	188	467	2	127	133	4	48	1	13	2	74	7	2	3	1	2	1	1
2013	6	115	71	1,888	180	373	2	97	98	3	37	1	12	2	56	5	2	2	1	1	2
2014	97	34	291	92	1,835	149	297	1	57	62	2	28	0	6	1	35	3	1	1	0	2
2015	2	402	66	218	63	1,298	109	201	1	39	40	1	15	0	4	1	27	3	1	1	2
2016	33	20	1,040	81	176	46	914	74	128	1	27	29	1	9	0	5	1	25	2	1	3
2017	31	248	28	1,199	74	150	38	712	55	102	0	19	21	1	6	0	2	0	10	1	1
2018	35	153	359	28	1,061	59	117	25	515	41	77	0	14	16	0	4	0	1	0	6	1

**Table 22.** Estimated exploitation-rate-at-age (catch-at-age divided by biomass-at-age at the beginning of the year) for each year from the base model (MLE; percentage of age class removed by fishing).

Year	Age																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0.00	0.12	1.41	3.53	5.17	6.37	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03
1967	0.00	0.21	2.48	6.14	8.94	10.95	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98
1968	0.00	0.13	1.52	3.81	5.58	6.87	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80
1969	0.00	0.19	2.21	5.49	8.00	9.81	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28	15.28
1970	0.00	0.23	2.73	6.75	9.82	12.01	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56	18.56
1971	0.00	0.14	1.70	4.23	6.20	7.62	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95	11.95
1972	0.00	0.10	1.16	2.90	4.27	5.26	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31	8.31
1973	0.00	0.11	1.33	3.33	4.89	6.02	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49	9.49
1974	0.00	0.14	1.64	4.09	5.98	7.36	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55
1975	0.00	0.11	1.36	3.39	4.98	6.13	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67
1976	0.00	0.10	1.14	2.85	4.19	5.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16	8.16
1977	0.00	0.06	0.74	1.86	2.74	3.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38
1978	0.00	0.06	0.67	1.68	2.48	3.06	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
1979	0.00	0.06	0.77	1.93	2.85	3.51	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59
1980	0.00	0.05	0.60	1.50	2.22	2.74	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37
1981	0.00	0.08	0.97	2.44	3.58	4.42	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01	7.01
1982	0.00	0.06	0.76	1.92	2.83	3.50	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56	5.56
1983	0.00	0.05	0.64	1.60	2.36	2.91	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64	4.64
1984	0.00	0.06	0.70	1.76	2.59	3.20	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09	5.09
1985	0.00	0.05	0.54	1.36	2.01	2.48	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
1986	0.00	0.07	0.85	2.14	3.15	3.88	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17
1987	0.00	0.09	1.03	2.58	3.80	4.68	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42
1988	0.00	0.09	1.10	2.77	4.06	5.01	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93
1989	0.00	0.13	1.55	3.88	5.69	6.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99
1990	0.00	0.10	1.17	2.94	4.32	5.32	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41	8.41
1991	0.00	0.13	3.54	13.51	6.47	7.56	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67	9.67
1992	0.00	0.12	1.36	9.84	11.51	7.21	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66	12.66
1993	0.00	0.07	0.79	5.85	9.24	10.71	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36
1994	0.00	0.06	0.85	2.44	11.26	11.70	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64	20.64
1995	0.00	0.07	0.59	1.97	4.02	12.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74	16.74
1996	0.00	0.24	5.53	7.79	7.96	8.71	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22	21.22
1997	0.00	0.07	0.90	12.46	15.08	11.32	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33	21.33
1998	0.00	0.15	2.48	20.42	13.39	25.44	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31	21.31
1999	0.00	0.17	9.11	17.09	27.44	20.61	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37	23.37
2000	0.00	0.04	1.22	8.72	9.79	15.23	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32	21.32
2001	0.00	0.06	0.80	7.20	15.91	15.38	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55	17.55
2002	0.00	0.03	0.38	2.47	7.72	11.92	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32	10.32
2003	0.00	0.02	0.26	1.59	5.30	9.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46	10.46
2004	0.00	0.09	1.61	6.61	22.60	12.13	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07
2005	0.00	0.05	0.63	3.56	12.24	24.51	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76	18.76
2006	0.00	0.22	10.20	10.87	16.66	24.08	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88	23.88
2007	0.00	0.16	4.54	17.32	17.67	17.41	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23	26.23
2008	0.00	0.41	4.64	17.85	13.06	26.05	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44	31.44
2009	0.00	0.08	1.85	11.90	14.33	11.07	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34	21.34
2010	0.00	0.09	4.64	13.17	32.72	23.98	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80	17.80
2011	0.00	0.25	3.10	29.64	18.09	17.31	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22	14.22
2012	0.00	0.24	3.34	9.76	18.63	12.43	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35	12.35
2013	0.00	0.07	1.07	8.83	9.02	11.05	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99	18.99
2014	0.00	0.12	2.64	9.77	9.70	11.22	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56	17.56
2015	0.00	0.27	1.33	5.49	7.87	10.38	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35
2016	0.00	0.95	10.57	6.25	11.37	12.86	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46	15.46
2017	0.00	1.48	5.11	9.69	12.29	15.06	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71	29.71

**Table 23.** Estimated catch-at-age in numbers for each year from the base model (MLE; thousands).

Year	Age																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0	1,639	11,171	17,596	17,660	15,706	19,466	16,257	14,013	12,239	10,742	9,453	8,289	7,261	6,334	5,478	4,711	4,024	3,416	2,882	7,975
1967	0	2,649	27,712	38,662	34,619	28,459	31,439	23,658	19,759	17,032	14,876	13,056	11,490	10,075	8,824	7,698	6,658	5,726	4,891	4,152	13,196
1968	0	3,424	15,597	33,472	26,454	19,339	19,911	13,112	9,867	8,240	7,103	6,204	5,445	4,792	4,202	3,680	3,211	2,777	2,388	2,040	7,235
1969	0	3,422	47,702	44,550	54,390	35,225	32,093	20,024	13,186	9,923	8,287	7,143	6,239	5,476	4,819	4,226	3,701	3,229	2,793	2,401	9,327
1970	0	1,397	40,545	114,968	60,500	60,078	47,945	26,161	16,323	10,749	8,089	6,755	5,823	5,086	4,464	3,928	3,445	3,017	2,632	2,276	9,561
1971	0	7,118	8,296	49,246	78,832	33,777	41,843	19,816	10,813	6,746	4,443	3,343	2,792	2,407	2,102	1,845	1,624	1,424	1,247	1,088	4,892
1972	0	560	46,698	11,247	38,181	50,272	27,240	20,389	9,656	5,269	3,287	2,165	1,629	1,361	1,173	1,024	899	791	694	608	2,914
1973	0	374	6,198	107,035	14,798	41,446	69,032	22,809	17,073	8,085	4,412	2,753	1,813	1,364	1,139	982	858	753	662	581	2,949
1974	0	4,589	4,427	15,139	149,545	17,012	59,945	60,705	20,058	15,013	7,110	3,880	2,421	1,594	1,200	1,002	864	754	662	583	3,104
1975	0	279	36,561	7,279	14,225	115,523	16,575	35,328	35,776	11,821	8,848	4,190	2,286	1,427	939	707	590	509	444	390	2,173
1976	0	988	2,253	61,058	6,975	11,240	115,679	10,087	21,499	21,772	7,194	5,385	2,550	1,391	868	572	430	359	310	270	1,560
1977	0	87	6,192	2,937	45,886	4,337	8,922	56,012	4,884	10,410	10,542	3,483	2,607	1,235	674	420	277	208	174	150	886
1978	0	2,186	762	11,293	3,100	40,200	4,866	6,146	38,585	3,365	7,171	7,262	2,399	1,796	851	464	290	191	143	120	714
1979	0	57	24,294	1,766	15,138	3,449	57,212	4,257	5,377	33,760	2,944	6,274	6,354	2,099	1,571	744	406	253	167	126	729
1980	0	408	430	38,062	1,602	11,397	3,328	33,883	2,521	3,185	19,994	1,743	3,716	3,763	1,243	931	441	240	150	99	506
1981	0	8,993	6,421	1,409	72,025	2,515	22,827	4,103	41,772	3,108	3,926	24,649	2,149	4,581	4,639	1,533	1,147	543	296	185	746
1982	0	106	68,370	10,159	1,286	54,480	2,429	13,488	2,425	24,682	1,837	2,320	14,565	1,270	2,707	2,741	906	678	321	175	550
1983	0	94	848	114,494	9,844	1,035	56,134	1,536	8,531	1,533	15,611	1,162	1,467	9,212	803	1,712	1,734	573	429	203	459
1984	0	191	999	1,882	147,188	10,512	1,415	47,215	1,292	7,175	1,290	13,130	977	1,234	7,748	676	1,440	1,458	482	361	557
1985	0	4,045	1,424	1,559	1,702	110,590	10,134	838	27,972	766	4,251	764	7,779	579	731	4,590	400	853	864	285	543
1986	0	61	61,581	4,520	2,864	2,598	215,733	12,180	1,007	33,619	920	5,109	918	9,349	696	879	5,517	481	1,025	1,038	996
1987	0	107	719	149,681	6,337	3,324	3,838	195,363	11,030	912	30,444	833	4,627	832	8,467	630	796	4,996	436	929	1,842
1988	0	3,904	1,100	1,541	184,653	6,463	4,306	3,038	154,652	8,732	722	24,100	660	3,663	658	6,702	499	630	3,955	345	2,194
1989	0	1,888	53,034	3,089	2,480	245,091	10,818	4,400	3,104	158,015	8,921	738	24,624	674	3,742	673	6,848	510	644	4,041	2,594
1990	0	96	13,702	79,597	2,655	1,755	219,422	5,867	2,386	1,683	85,687	4,838	400	13,353	365	2,029	365	3,713	276	349	3,598
1991	0	3,706	2,788	125,864	136,834	3,575	2,424	184,815	4,941	2,010	1,418	72,172	4,075	337	11,247	308	1,709	307	3,128	233	3,324
1992	0	1,042	30,950	6,013	73,656	114,347	4,430	2,289	174,489	4,665	1,897	1,339	68,140	3,847	318	10,619	291	1,614	290	2,953	3,358
1993	0	69	5,656	106,225	4,064	48,255	110,376	2,275	1,175	89,601	2,396	974	687	34,990	1,976	163	5,453	149	829	149	3,241
1994	0	1,395	703	14,034	154,429	3,731	66,213	176,133	3,630	1,876	142,982	3,823	1,555	1,097	55,836	3,152	261	8,701	238	1,322	5,409
1995	0	1,693	10,253	1,312	18,168	123,568	3,753	33,479	89,057	1,835	948	72,295	1,933	786	555	28,232	1,594	132	4,400	120	3,404
1996	0	2,130	102,097	109,030	4,178	30,356	142,761	3,130	27,923	74,279	1,531	791	60,299	1,612	656	463	23,547	1,329	110	3,670	2,939
1997	0	880	6,481	174,232	155,787	4,376	54,252	88,697	1,945	17,349	46,149	951	491	37,463	1,002	407	287	14,630	826	68	4,106
1998	0	1,099	25,491	118,092	130,321	176,840	5,818	33,445	54,680	1,199	10,695	28,450	586	303	23,096	617	251	177	9,019	509	2,573
1999	0	2,206	52,235	137,687	99,216	137,993	94,327	3,939	22,642	37,017	812	7,240	19,260	397	205	15,635	418	170	120	6,106	2,087
2000	0	3,772	13,126	36,281	51,680	30,996	89,054	51,570	2,153	12,378	20,238	444	3,958	10,530	217	112	8,548	229	93	66	4,479
2001	0	166	56,945	61,732	48,303	58,437	23,991	45,248	26,202	1,094	6,289	10,283	225	2,011	5,350	110	57	4,343	116	47	2,309
2002	0	257	803	140,709	49,202	24,078	26,266	9,176	17,307	10,022	418	2,406	3,933	86	769	2,046	42	22	1,661	44	901
2003	0	5	1,702	2,662	237,130	44,528	14,818	19,052	6,656	12,554	7,270	304	1,745	2,853	63	558	1,484	31	16	1,205	686
2004	0	1,061	305	35,408	30,090	413,069	54,658	16,247	20,890	7,299	13,766	7,971	333	1,913	3,128	69	612	1,628	34	17	2,073
2005	0	33	5,782	536	49,013	19,775	446,343	42,362	12,592	16,191	5,657	10,669	6,178	258	1,483	2,424	53	474	1,261	26	1,620
2006	0	3,875	5,133	80,179	1,946	67,350	11,351	363,761	34,524	10,262	13,195	4,610	8,695	5,035	210	1,209	1,976	43	386	1,028	1,342
2007	0	2,139	64,209	6,241	92,579	1,339	43,478	7,411	237,496	22,540	6,700	8,615	3,010	5,677	3,287	137	789	1,290	28	252	1,547
2008	0	70	49,593	193,778	3,073	88,688	1,577	29,900	5,097	163,328	15,501	4,608	5,925	2,070	3,904	2,261	94	543	887	19	1,238
2009	0	2,729	256	97,399	100,880	1,799	41,797	565	10,712	1,826	58,515	5,554	1,651	2,123	742	1,399	810	34	194	318	450
2010	0	781	126,957	1,442	187,742	114,645	2,049	21,516	291	5,515	940	30,123	2,859	850	1,093	382	720	417	17	100	395
2011	0	21,145	21,169	621,633	1,366	51,271	40,356	1,061	11,143	151	2,856	487	15,600	1,481	440	566	198	373	216	9	257
2012	0	740	225,403	51,954	212,373	606	23,884	23,849	627	6,585	89	1,688	288	9,219	875	260	334	117	220	128	157
2013	0	632	2,638	463,456	34,601	80,749	645	25,616	25,578	673	7,063	95	1,810	309	9,888	938	279	359	125	236	305
2014	0	404	18,827	19,155	371,169	31,269	90,982	381	15,108	15,086	397	4,166	56	1,068	182	5,832	553	165	212	74	319
2015	0	14,548	3,528	30,676	11,117	286,175	16,460	28,148	118	4,674	4,667	123	1,289	17	330	56	1,804	171	51	65	122
2016	0	1,159	450,672	13,196	48,175	13,383	304,678	22,334	38,192	160	6,342	6,333	167	1,749	24	448	76	2,448	232	69	254
2017	0	26,																			

**Table 24.** Estimated catch-at-age in biomass for each year from the base model (MLE; metric tons).

Year	Age																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0	150	2,781	6,669	8,549	8,370	11,315	10,520	10,067	9,639	9,232	8,798	8,037	7,738	6,392	5,662	4,869	4,159	3,531	2,979	8,243
1967	0	243	6,897	14,653	16,759	15,166	18,276	15,309	14,195	13,412	12,784	12,152	11,139	10,738	8,905	7,957	6,882	5,918	5,055	4,291	13,639
1968	0	314	3,882	12,686	12,806	10,306	11,574	8,485	7,088	6,489	6,104	5,774	5,279	5,107	4,240	3,804	3,318	2,870	2,468	2,108	7,478
1969	0	313	11,873	16,884	26,330	18,772	18,656	12,957	9,473	7,814	7,122	6,648	6,049	5,836	4,863	4,368	3,825	3,337	2,886	2,482	9,640
1970	0	128	10,092	43,573	29,288	32,016	27,870	16,929	11,726	8,465	6,951	6,287	5,645	5,421	4,505	4,060	3,560	3,118	2,720	2,353	9,882
1971	0	652	2,065	18,664	38,163	18,000	24,323	12,823	7,768	5,313	3,818	3,111	2,707	2,565	2,121	1,907	1,678	1,472	1,289	1,124	5,057
1972	0	51	11,623	4,263	18,484	26,790	15,834	13,194	6,937	4,149	2,825	2,015	1,579	1,450	1,183	1,059	929	818	717	628	3,012
1973	0	34	1,543	40,566	7,164	22,087	40,128	14,760	12,265	6,367	3,791	2,562	1,757	1,454	1,150	1,015	886	778	685	600	3,048
1974	0	420	1,102	5,738	72,395	9,065	34,846	39,282	14,409	11,823	6,110	3,611	2,347	1,699	1,210	1,035	893	780	684	602	3,208
1975	0	44	10,921	2,663	8,739	72,849	13,050	30,869	34,624	10,727	8,582	7,095	3,430	2,710	1,837	1,940	1,620	1,397	1,220	1,071	5,963
1976	0	97	531	30,468	3,619	7,796	92,983	9,245	25,934	29,033	10,427	8,888	4,607	2,586	1,698	1,569	1,181	986	850	742	4,280
1977	0	7	2,489	1,434	27,082	2,884	6,681	46,333	4,776	11,505	13,010	4,580	3,657	2,162	1,415	929	612	460	384	331	1,958
1978	0	158	97	5,307	1,644	24,225	3,110	4,546	32,496	3,301	7,886	9,048	3,190	2,661	1,482	1,084	676	445	335	280	1,667
1979	0	4	5,855	457	8,812	2,369	43,922	3,793	4,908	35,006	3,529	7,832	9,738	3,258	2,821	1,475	805	502	331	249	1,445
1980	0	33	91	17,238	628	5,589	1,719	22,207	1,799	2,783	21,246	2,026	4,793	4,892	1,579	1,299	615	336	209	138	707
1981	0	966	1,372	482	37,914	989	11,993	2,241	31,179	2,239	3,232	25,667	2,362	6,161	6,925	1,859	1,392	659	360	224	905
1982	0	12	16,853	3,389	398	29,942	961	7,115	1,365	18,773	1,256	1,981	15,541	1,117	2,757	3,205	1,059	793	375	205	643
1983	0	12	115	39,042	3,636	339	29,190	772	5,271	1,083	13,738	1,080	1,519	9,497	1,062	2,538	2,570	849	636	301	680
1984	0	25	164	469	64,527	4,323	616	27,725	750	4,849	904	12,491	1,110	1,266	9,923	1,270	2,707	2,742	906	678	1,046
1985	0	704	327	418	751	60,780	5,548	504	20,845	531	3,074	656	6,766	547	494	5,149	449	957	969	320	610
1986	0	10	17,120	1,314	866	970	117,057	6,967	647	27,598	865	6,059	1,093	12,843	1,169	1,418	8,905	777	1,655	1,676	1,608
1987	0	16	100	56,729	1,765	954	1,390	112,822	6,590	581	23,254	818	4,280	1,032	10,186	892	1,127	7,073	617	1,315	2,608
1988	0	547	206	491	86,990	2,384	1,607	1,568	100,075	6,011	519	22,199	721	3,745	955	9,743	725	916	5,749	501	3,189
1989	0	262	14,515	941	727	125,830	4,745	1,788	1,604	98,965	5,898	445	21,566	451	3,099	758	7,714	574	725	4,552	2,921
1990	0	13	3,336	27,907	1,037	897	119,848	3,565	1,593	892	65,953	4,021	880	15,819	372	2,977	535	5,447	405	512	5,277
1991	0	507	768	46,532	62,916	1,837	1,318	109,170	3,563	1,708	1,559	51,856	2,609	343	13,554	733	4,073	732	7,453	555	7,921
1992	0	141	7,168	2,088	34,935	60,993	2,577	1,421	111,778	3,046	1,201	966	50,110	3,270	310	10,907	299	1,658	298	3,033	3,450
1993	0	9	1,406	35,947	1,609	21,903	54,471	1,141	574	49,200	1,222	1,231	705	21,466	1,184	112	3,735	102	568	102	2,220
1994	0	166	211	5,089	69,014	1,669	34,841	100,396	2,257	1,050	90,665	1,854	1,009	801	39,158	2,350	194	6,487	178	986	4,033
1995	0	188	2,750	449	8,859	66,319	2,442	20,921	58,751	1,387	633	53,824	1,546	715	377	22,608	1,276	106	3,523	96	2,726
1996	0	214	29,363	43,416	1,953	16,140	80,674	2,037	16,634	47,257	926	593	40,738	1,307	974	347	17,682	998	83	2,755	2,207
1997	0	80	2,304	75,303	76,819	2,396	29,583	51,737	1,139	10,532	29,143	821	292	26,666	663	354	250	12,718	718	59	3,569
1998	0	88	5,330	41,793	65,695	91,462	3,153	21,445	33,350	812	8,640	20,410	475	234	17,345	493	200	141	7,196	406	2,053
1999	0	298	13,069	47,571	42,177	72,653	52,531	2,256	13,850	26,023	540	5,784	14,549	349	151	12,800	342	139	98	4,999	1,709
2000	0	716	4,221	17,157	29,799	20,451	63,905	37,538	1,623	10,371	16,512	391	3,386	9,889	190	105	7,980	213	87	61	4,182
2001	0	8	16,326	29,897	31,528	38,831	17,919	39,044	22,416	963	6,057	10,067	227	2,111	5,311	108	56	4,242	113	46	2,255
2002	0	19	288	64,374	29,807	19,647	19,912	7,789	16,911	9,343	384	2,399	3,890	80	865	2,164	45	23	1,756	47	953
2003	0	1	434	1,159	123,900	26,205	11,215	13,175	4,972	10,352	5,592	270	1,617	2,252	53	556	1,479	30	16	1,201	684
2004	0	115	61	15,438	14,464	219,711	35,407	11,484	13,744	5,178	11,081	6,840	257	1,857	2,700	61	548	1,458	30	16	1,858
2005	0	4	1,505	231	24,928	10,665	253,612	26,840	8,248	11,377	4,504	8,646	5,010	196	1,698	2,346	51	459	1,221	25	1,568
2006	0	513	1,966	36,682	1,039	38,659	6,709	217,493	22,648	7,181	9,578	3,328	6,741	3,313	135	1,154	1,887	41	369	982	1,281
2007	0	95	14,588	2,357	49,548	741	26,404	4,690	153,779	15,902	5,175	6,571	2,449	4,940	2,633	119	686	1,122	25	219	1,346
2008	0	9	12,101	79,042	1,730	56,450	1,082	20,386	3,618	117,776	11,607	3,720	5,026	1,605	3,449	1,884	79	452	739	16	1,031
2009	0	182	63	33,418	47,535	1,146	28,012	392	7,995	1,502	44,904	4,520	1,675	1,805	711	1,445	837	35	201	328	465
2010	0	85	29,530	421	81,330	60,785	1,349	17,964	315	5,667	901	26,397	2,437	956	787	344	650	376	16	90	357
2011	0	1,785	5,201	200,104	528	26,363	24,012	716	9,510	140	2,793	523	16,518	1,522	465	521	182	344	199	8	236
2012	0	95	48,349	18,371	86,946	296	15,673	16,473	488	5,974	86	1,627	277	9,117	868	245	315	110	208	120	148
2013	0	82	758	166,612	16,252	41,214	404	18,354	18,698	559	7,055	103	2,227	345	10,562	990	294	378	132	249	322
2014	0	42	7,681	8,976	178,050	16,766	52,233	236	9,957	10,823	276	4,851	57	1,013	176	6,170	586	174	224	78	338
2015	0	1,104	872	11,979	4,942	134,731	9,104	16,742	79	3,215	3,351	102	1,227	18	360	70	2,254	214	64	82	152
2016	0	192	109,919	5,056	20,036	5,897	141,310	11,482	19,722	82	4,110	4,558	99	1,356	34	708	121	3,868	367	109	401
2017	0	3,676	1,406	116,194	9,100	22,669	11,307	211,585	16,357	30,163	125	5,592	6,106	161	1,792	28	523	89	2,858	271	377

**Table 25.** For the strong cohorts, calculations of what happens to the biomass at each age. Start Biomass is the biomass at the beginning of the year, Catch Weight is the catch for the cohort for the year, M is the biomass attributed to natural mortality, and Surviving Biomass is what survives to the end of the year. Surviving Biomass does not equal the Start Biomass in the following year because the empirical weights-at-age change between years (for 2018 the mean weights-at-age are used). Estimated quantities are MLEs.

Age	1999 cohort				2010 cohort				2014 cohort			
	Start Biomass 000s t	Catch Weight 000s t	M 000s t	Surviving Biomass 000s t	Start Biomass 000s t	Catch Weight 000s t	M 000s t	Surviving Biomass 000s t	Start Biomass 000s t	Catch Weight 000s t	M 000s t	Surviving Biomass 000s t
0	166.1	0.0	32.0	134.1	153.7	0.0	29.6	124.1	97.1	0.0	18.7	78.4
1	1,675.6	0.7	322.3	1,352.6	707.6	1.8	136.0	569.9	402.1	1.1	77.2	323.7
2	2,042.1	16.3	391.2	1,634.5	1,448.4	48.3	273.7	1,126.4	1,040.3	109.9	188.6	741.8
3	2,608.3	64.4	495.2	2,048.7	1,887.8	166.6	345.8	1,375.4	1,198.6	116.2	218.4	864.0
4	2,339.8	123.9	437.3	1,778.6	1,835.3	178.0	334.4	1,322.8	1,061.3			
5	1,810.6	219.7	325.2	1,265.7	1,298.3	134.7	235.6	927.9				
6	1,352.1	253.6	233.1	865.4	914.1	141.3	160.9	611.9				
7	910.6	217.5	151.7	541.4	712.2	211.6	113.9	386.7				
8	586.3	153.8	96.1	336.4	514.6							
9	374.7	117.8	59.2	197.7								
10	210.4	44.9	35.7	129.8								
11	148.3	26.4	25.7	96.2								
12	116.2	16.5	20.6	79.1								
13	73.8	9.1	13.2	51.5								
14	55.6	10.6	9.6	35.5								
15	35.1	6.2	6.1	22.9								
16	27.0	2.3	5.0	19.8								
17	25.0	3.9	4.4	16.8								
18	9.6	2.9	1.5	5.2								
19	5.9											
20												

**Table 26.** Select parameters, derived quantities, and reference point estimates for the base model MLE and posterior median (MCMC) estimates with an additional comparison to posterior median estimates from the previous (2017) base model.

	MLE	Posterior median	Posterior median from 2017 base model
<b>Parameters</b>			
Natural mortality ( $M$ )	0.214	0.230	0.229
Unfished recruitment ( $R_0$ (millions))	2,108	2,773	3,170
Steepness ( $h$ )	0.862	0.812	0.815
Additional acoustic survey SD	0.257	0.305	0.310
Catchability ( $q$ )	1.136	0.961	0.940
<b>Derived Quantities</b>			
2008 recruitment (millions)	4,201	5,096	5,556
2010 recruitment (millions)	10,382	13,369	15,808
2014 recruitment (millions)	6,560	8,583	12,105
Unfished female spawning biomass ( $B_0$ (thousand t))	1,750	2,032	2,362
2009 relative spawning biomass	29.5%	29.3%	24.2%
2018 relative spawning biomass	56.4%	62.4%	—
2017 relative fishing intensity: $(1-SPR)/(1-SPR_{40\%})$	95.8%	86.2%	101.2%
Female spawning biomass at $F_{SPR=40\%}$ ( $B_{SPR=40\%}$ , thousand t)	656	730	836
<b>Reference Points (equilibrium) based on <math>F_{SPR=40\%}</math></b>			
SPR at $F_{SPR=40\%}$	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	18.3%	22.2%
Yield at $B_{SPR=40\%}$ (thousand t)	288	340	380

**Table 27.** Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2017 averages for mean weight-at-age and baseline selectivity.

Quantity	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile
Unfished female spawning biomass ( $B_0$ , thousand t)	1,641	2,032	2,608
Unfished recruitment ( $R_0$ , millions)	1,828	2,773	4,607
<b>Reference points (equilibrium) based on <math>F_{SPR=40\%}</math></b>			
Female spawning biomass at $F_{SPR=40\%}$ (thousand t)	538	730	929
SPR at $F_{SPR=40\%}$	—	40%	—
Exploitation fraction corresponding to $F_{SPR=40\%}$	16.0%	18.3%	20.6%
Yield associated with $F_{SPR=40\%}$ (thousand t)	243	340	484
<b>Reference points (equilibrium) based on <math>B_{40\%}</math> (40% of <math>B_0</math>)</b>			
Female spawning biomass ( $B_{40\%}$ , thousand t)	657	813	1,043
SPR at $B_{40\%}$	40.6%	43.5%	50.6%
Exploitation fraction resulting in $B_{40\%}$	12.8%	16.1%	19.0%
Yield at $B_{40\%}$ (thousand t)	242	332	474
<b>Reference points (equilibrium) based on estimated MSY</b>			
Female spawning biomass ( $B_{MSY}$ , thousand t)	377	518	795
SPR at MSY	22.5%	29.9%	45.3%
Exploitation fraction corresponding to SPR at MSY	15.4%	25.5%	34.5%
MSY (thousand t)	250	358	528

**Table 28.** Decision table of forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Quantiles from the base model are shown for various harvest alternatives (rows) based on: constant catch levels (rows a, b, c, d, e), including the catch from 2017 (row d) and the TAC from 2017 (row e), the catch values that result in a median relative fishing intensity of 100% (row f), the median values estimated via the default harvest policy ( $F_{SPR=40\%}-40:10$ ) using the base model (row g), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2018 and 2019 (row h). Catch in 2020 does not impact the beginning of the year biomass in 2020.

Within model quantile Management Action			5%	25%	50%	75%	95%
Year Catch (t)			Beginning of year relative spawning biomass				
a:	2018	0	38%	54%	67%	83%	119%
	2019	0	40%	58%	72%	93%	152%
	2020	0	42%	60%	76%	101%	172%
b:	2018	180,000	38%	54%	67%	83%	119%
	2019	180,000	36%	53%	68%	89%	148%
	2020	180,000	33%	52%	68%	93%	165%
c:	2018	350,000	38%	54%	67%	83%	119%
	2019	350,000	32%	49%	64%	86%	145%
	2020	350,000	26%	44%	61%	86%	158%
d:	2018	440,000	38%	54%	67%	83%	119%
	2017 catch	2019 440,000	30%	48%	62%	84%	143%
	2020	440,000	21%	40%	57%	83%	155%
e:	2018	597,500	38%	54%	67%	83%	119%
	2017 TAC	2019 597,500	26%	44%	59%	80%	140%
	2020	597,500	14%	33%	50%	76%	148%
f:	2018	639,000	38%	54%	67%	83%	119%
	FI= 100%	2019 554,000	25%	43%	58%	79%	139%
	2020	509,000	14%	34%	50%	76%	148%
g: default HR	2018	725,984	38%	54%	67%	83%	119%
	2019	600,991	23%	41%	56%	77%	137%
	2020	538,263	11%	31%	47%	73%	146%
h: C2018= C2019	2018	626,954	38%	54%	67%	83%	119%
	2019	626,954	25%	43%	58%	80%	139%
	2020	556,786	13%	32%	49%	75%	147%



**Table 29.** Decision table of forecast quantiles of Pacific Hake relative fishing intensity  $(1-SPR)/(1-SPR_{40\%})$  for the 2018–2020 catch alternatives presented in Table 28. Values greater than 100% indicate fishing intensities greater than the  $F_{40\%}$  harvest policy calculated using baseline selectivity.

Within model quantile Management Action			5%	25%	50%	75%	95%
Year Catch (t)			Relative fishing intensity				
a:	2018	0	0%	0%	0%	0%	0%
	2019	0	0%	0%	0%	0%	0%
	2020	0	0%	0%	0%	0%	0%
b:	2018	180,000	27%	39%	49%	59%	77%
	2019	180,000	23%	37%	47%	58%	79%
	2020	180,000	21%	34%	45%	56%	77%
c:	2018	350,000	45%	62%	75%	86%	106%
	2019	350,000	41%	61%	76%	90%	113%
	2020	350,000	38%	59%	75%	91%	119%
d:	2018	440,000	53%	71%	84%	96%	115%
2017	2019	440,000	49%	71%	87%	101%	124%
catch	2020	440,000	45%	70%	88%	105%	134%
e:	2018	597,500	65%	84%	97%	109%	126%
2017	2019	597,500	62%	86%	103%	117%	140%
TAC	2020	597,500	58%	87%	107%	125%	160%
f:	2018	639,000	68%	87%	100%	112%	129%
FI=	2019	554,000	59%	83%	100%	115%	139%
100%	2020	509,000	52%	80%	100%	119%	154%
g:	2018	725,984	73%	93%	105%	117%	133%
default	2019	600,991	62%	88%	105%	120%	144%
HR	2020	538,263	54%	84%	105%	125%	163%
h:	2018	626,954	67%	86%	99%	111%	128%
C2018=	2019	626,954	63%	88%	105%	120%	142%
C2019	2020	556,786	55%	84%	105%	124%	160%

**Table 30.** Probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (catch options explained in Table 28).

<b>Catch in 2018</b>	<b>Probability B<sub>2019</sub>&lt;B<sub>2018</sub></b>	<b>Probability B<sub>2019</sub>&lt;B<sub>40%</sub></b>	<b>Probability B<sub>2019</sub>&lt;B<sub>25%</sub></b>	<b>Probability B<sub>2019</sub>&lt;B<sub>10%</sub></b>	<b>Probability 2018 relative fishing intensity &gt;100%</b>	<b>Probability 2019 default harvest policy catch &lt;2018 catch</b>
a: 0	37%	5%	0%	0%	0%	0%
b: 180,000	55%	9%	1%	0%	0%	1%
c: 350,000	64%	13%	2%	0%	9%	10%
d: 440,000	68%	15%	2%	0%	19%	21%
e: 597,500	73%	20%	4%	0%	44%	46%
f: 639,000	75%	21%	5%	0%	50%	52%
g: 725,984	77%	24%	7%	0%	61%	62%
h: 626,954	74%	20%	5%	0%	49%	50%

**Table 31.** Probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options, given the 2018 catch level shown in Table 30 (catch options explained in Table 28).

<b>Catch in 2019</b>	<b>Probability B<sub>2020</sub>&lt;B<sub>2019</sub></b>	<b>Probability B<sub>2020</sub>&lt;B<sub>40%</sub></b>	<b>Probability B<sub>2020</sub>&lt;B<sub>25%</sub></b>	<b>Probability B<sub>2020</sub>&lt;B<sub>10%</sub></b>	<b>Probability 2019 relative fishing intensity &gt;100%</b>	<b>Probability 2020 default harvest policy catch &lt;2019 catch</b>
a: 0	35%	4%	0%	0%	0%	0%
b: 180,000	56%	11%	1%	0%	0%	1%
c: 350,000	71%	19%	5%	0%	13%	12%
d: 440,000	75%	24%	8%	1%	27%	25%
e: 597,500	82%	36%	15%	3%	54%	52%
f: 554,000	80%	36%	14%	3%	50%	48%
g: 600,991	82%	40%	18%	4%	58%	56%
h: 626,954	83%	38%	16%	3%	58%	56%

**Table 32.** Maximum likelihood estimates (MLE) of select parameters, derived quantities, reference points, and negative log likelihoods for the base model and some sensitivity runs (described in Section 3.8).

	Base model	Steepness Mean Prior Low (0.5)	Steepness Fix 1.0	Sigma R 1.0	Sigma R 1.8	Natural Mortality (SD=0.2)	Natural Mortality (SD=0.3)	Add Age 1 Index	Ageing Error (cohort invariant)	Harmonic Mean Data Weighting	U.S. Comps Weighted by Month	Alternative catch stream
<b>Parameters</b>												
Natural mortality ( $M$ )	0.214	0.220	0.212	0.212	0.216	0.238	0.253	0.214	0.210	0.215	0.214	0.214
$R_0$ (millions)	2,108	2,448	2,021	1,503	3,569	2,730	3,214	2,157	2,225	2,462	2,104	2,102
Steepness ( $h$ )	0.862	0.600	–	0.853	0.883	0.853	0.848	0.862	0.837	0.861	0.862	0.862
Additional acoustic survey SD	0.257	0.258	0.257	0.255	0.258	0.256	0.256	0.258	0.224	0.252	0.258	0.257
Additional age-1 index SD	–	–	–	–	–	–	–	0.195	–	–	–	–
<b>Derived Quantities</b>												
2008 recruitment (millions)	4,201	4,396	4,155	4,160	4,284	5,068	5,718	4,367	4,583	4,306	4,189	4,154
2010 recruitment (millions)	10,382	10,921	10,254	10,282	10,616	13,028	15,049	11,152	12,469	10,701	10,385	10,375
2014 recruitment (millions)	6,560	6,793	6,504	6,383	6,735	8,113	9,292	7,780	6,857	6,430	6,602	6,529
$B_0$ (thousand t)	1,750	1,919	1,702	1,263	2,893	1,850	1,944	1,789	1,910	2,018	1,748	1,746
2009 relative spawning biomass	29.5%	27.8%	30.1%	41.0%	18.0%	31.7%	32.8%	29.7%	32.7%	25.3%	29.6%	29.4%
2018 relative spawning biomass	56.4%	51.9%	57.8%	77.3%	34.6%	62.4%	65.7%	67.4%	61.3%	49.0%	56.6%	56.1%
<b>Reference Points based on <math>F_{SPR=40\%}</math></b>												
2017 rel. fishing intensity: $(1-SPR)/(1-SPR_{40\%})$	95.8%	93.9%	96.3%	95.3%	95.3%	84.4%	77.5%	90.3%	89.2%	95.2%	95.9%	96.1%
Female spawning biomass ( $B_{F_{40\%}}$ ; thousand t)	656	538	681	471	1,098	690	723	671	706	756	655	654
$SPR_{MSY}$ -proxy	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	17.7%	17.2%	17.2%	17.4%	18.7%	19.6%	17.3%	16.9%	17.4%	17.3%	17.3%
Yield at $B_{F_{40\%}}$ (thousand t)	288	243	296	205	488	337	375	295	301	335	287	287
<b>Negative log likelihoods</b>												
Total	700.43	701.98	710.13	711.11	700.38	699.98	699.69	702.89	978.06	226.22	700.41	700.45
Survey	-6.83	-6.81	-6.84	-6.91	-6.79	-6.86	-6.87	-5.36	-8.05	-7.00	-6.82	-6.83
Survey age compositions	83.01	83.01	83.01	83.98	82.54	83.13	83.18	83.06	109.93	37.08	83.05	83.03
Fishery age compositions	517.07	517.06	517.07	523.38	514.57	517.29	517.42	517.99	777.01	104.11	516.97	517.05
Recruitment	47.52	48.34	47.28	50.44	50.73	46.52	46.08	48.15	44.47	39.44	47.56	47.52
Parameter priors	0.19	0.88	10.15	0.13	0.37	0.34	0.25	0.19	0.04	0.24	0.19	0.19
Parameter deviations	59.47	59.50	59.47	60.09	58.97	59.56	59.63	58.86	54.66	52.34	59.47	59.48

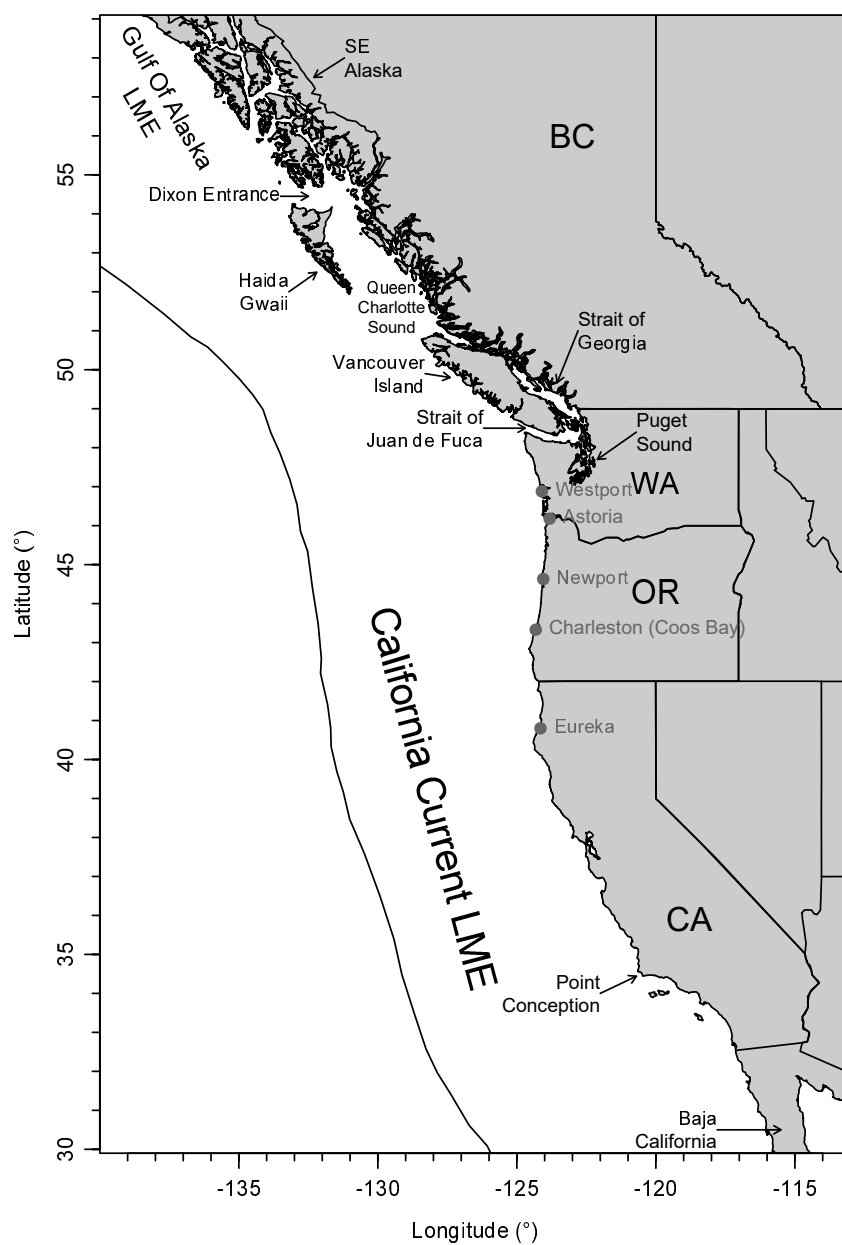
**Table 33.** Maximum likelihood estimates (MLE) of select parameters, derived quantities, reference points, and negative log likelihoods for the base model and further sensitivity runs (described in Section 3.8).

	Base model	Max. age selectivity 5	Max. age selectivity 7	Max. age selectivity 10	Phi t.v. selectivity (0.21)	Phi t.v. selectivity (0.70)	Phi t.v. selectivity (2.10)	Semi-Parametric t.v. selectivity (0.695)	Semi-Parametric t.v. selectivity (1.0)
<b>Parameters</b>									
Natural mortality ( $M$ )	0.214	0.216	0.207	0.205	0.214	0.212	0.214	0.215	0.216
$R_0$ (millions)	2,108	2,192	1,887	1,830	2,326	2,107	2,116	2,286	2,219
Steepness ( $h$ )	0.862	0.858	0.865	0.860	0.864	0.863	0.861	0.863	0.863
Additional acoustic survey SD	0.257	0.240	0.257	0.232	0.285	0.263	0.256	0.277	0.261
<b>Derived Quantities</b>									
2008 recruitment (millions)	4,201	4,192	3,938	4,560	4,283	4,133	4,233	4,275	4,216
2010 recruitment (millions)	10,382	10,765	8,995	10,325	10,548	10,055	10,536	10,943	10,526
2014 recruitment (millions)	6,560	5,934	6,058	6,452	9,478	6,618	6,564	9,444	7,190
$B_0$ (thousand t)	1,750	1,782	1,665	1,631	1,926	1,773	1,744	1,872	1,812
2009 relative spawning biomass	29.5%	30.6%	28.8%	29.4%	25.7%	28.6%	29.9%	26.9%	28.4%
2018 relative spawning biomass	56.4%	50.8%	51.9%	65.3%	90.7%	58.7%	56.6%	77.5%	60.4%
<b>Reference Points based on <math>F_{SPR=40\%}</math></b>									
2017 rel. fishing intensity: $(1-SPR)/(1-SPR_{40\%})$	95.8%	99.7%	99.7%	94.8%	91.7%	98.1%	94.1%	91.3%	92.0%
Female spawning biomass ( $B_{F_{40\%}}$ ; thousand t)	656	666	625	611	723	665	654	703	680
$SPR_{MSY-proxy}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	17.4%	17.0%	16.9%	17.4%	17.2%	17.3%	17.4%	17.4%
Yield at $B_{F_{40\%}}$ (thousand t)	288	295	267	261	319	291	287	311	301
<b>Negative log likelihoods</b>									
Total	700.43	715.96	683.05	674.31	526.22	629.32	744.88	780.50	790.35
Survey	-6.83	-7.40	-6.79	-7.71	-5.91	-6.62	-6.89	-6.18	-6.70
Survey age compositions	83.01	86.91	77.68	72.02	82.61	83.13	82.92	81.90	82.49
Fishery age compositions	517.07	540.09	493.31	460.47	577.34	533.41	510.30	548.45	521.34
Recruitment	47.52	46.87	47.80	48.07	49.85	48.78	47.05	48.81	47.35
Parameter priors	0.19	0.26	0.03	0.00	0.21	0.15	0.22	0.25	0.26
Parameter deviations	59.47	49.22	71.03	101.46	-177.88	-29.53	111.29	107.28	145.61

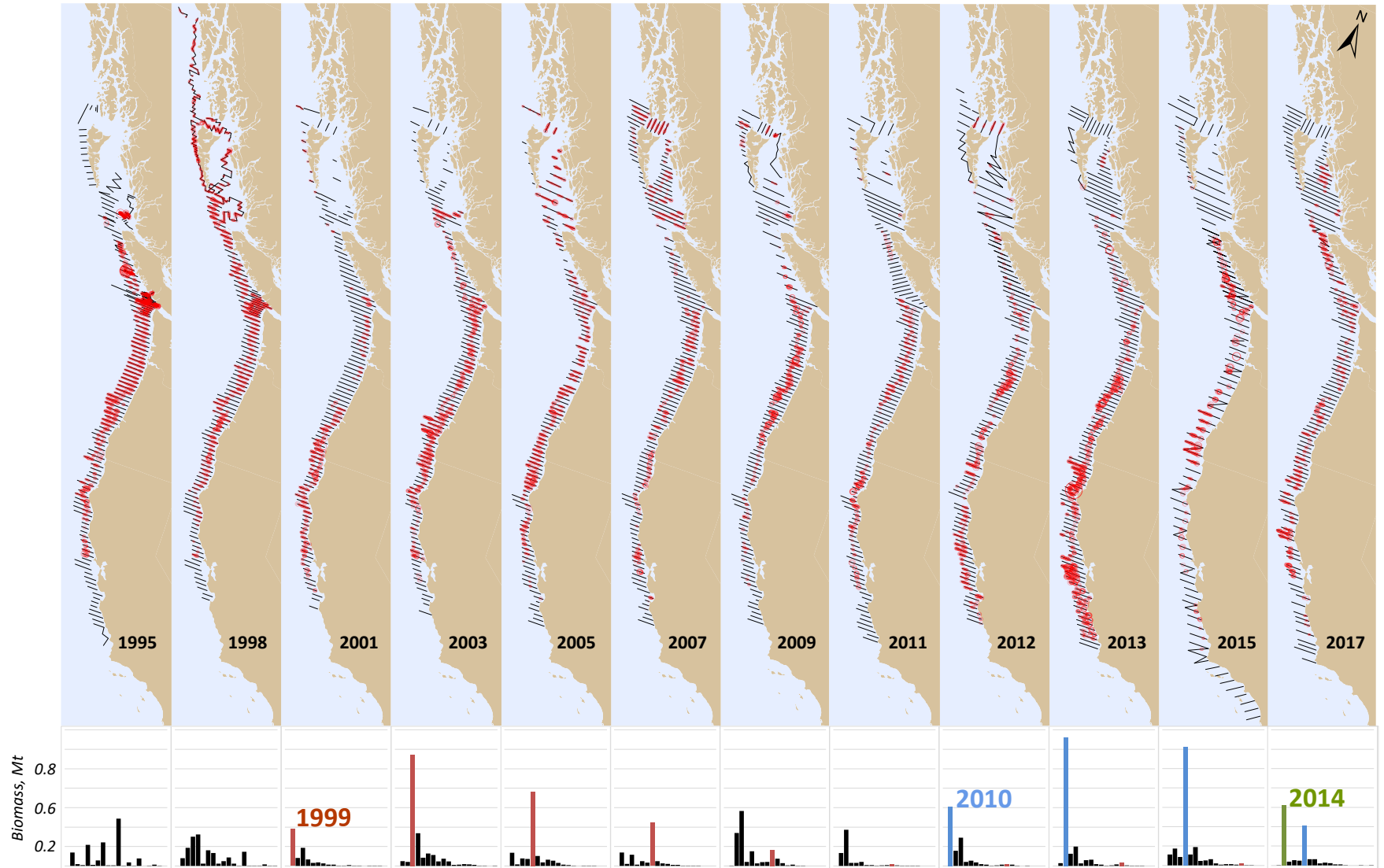
**Table 34.** Select parameters, derived quantities, reference point estimates, and negative log likelihoods for retrospective analyses using the base model. Some values are implied since they occur after the ending year of the respective retrospective analysis.

	2018 Base model SS 3.30	-1 year	-2 years	-3 years	-4 years	-5 years
<b>Parameters</b>						
Natural mortality ( $M$ )	0.214	0.214	0.214	0.212	0.212	0.213
$R_0$ (millions)	2,108	2,199	2,203	2,037	2,047	2,071
Steepness ( $h$ )	0.862	0.863	0.863	0.862	0.863	0.865
Additional acoustic survey SD	0.257	0.254	0.253	0.262	0.287	0.349
<b>Derived Quantities</b>						
2008 recruitment (millions)	4,201	4,385	4,435	4,365	5,114	5,653
2010 recruitment (millions)	10,382	11,657	11,462	10,609	11,017	8,825
2014 recruitment (millions)	6,560	9,065	3,630	637	864	867
$B_0$ (thousand t)	1,750	1,814	1,826	1,719	1,717	1,724
2009 relative spawning biomass	29.5%	29.5%	30.2%	31.0%	27.4%	24.0%
2018 relative spawning biomass	56.4%	74.5%	47.0%	27.6%	31.2%	25.5%
<b>Reference Points based on <math>F_{SPR=40\%}</math></b>						
2017 rel. fishing intensity: $(1-SPR)/(1-SPR_{40\%})$	95.8%	86.9%	97.0%	109.4%	106.5%	113.0%
Female spawning biomass ( $B_{F_{40\%}}$ ; thousand t)	656	681	685	645	644	648
$SPR_{MSY-proxy}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	17.3%	17.3%	17.2%	17.2%	17.3%
Yield at $B_{F_{40\%}}$ (thousand t)	288	300	301	280	281	284
<b>Negative log likelihoods</b>						
Total	700.43	691.74	683.75	672.16	660.47	643.38
Survey	-6.83	-6.33	-6.38	-5.52	-4.83	-2.93
Survey age compositions	83.01	82.07	81.71	78.72	75.91	71.60
Fishery age compositions	517.07	510.63	504.26	496.79	487.39	473.65
Recruitment	47.52	46.71	45.48	44.78	44.89	44.42
Parameter priors	0.19	0.22	0.20	0.13	0.16	0.19
Parameter deviations	59.47	58.44	58.48	57.26	56.95	56.44

## 8 FIGURES

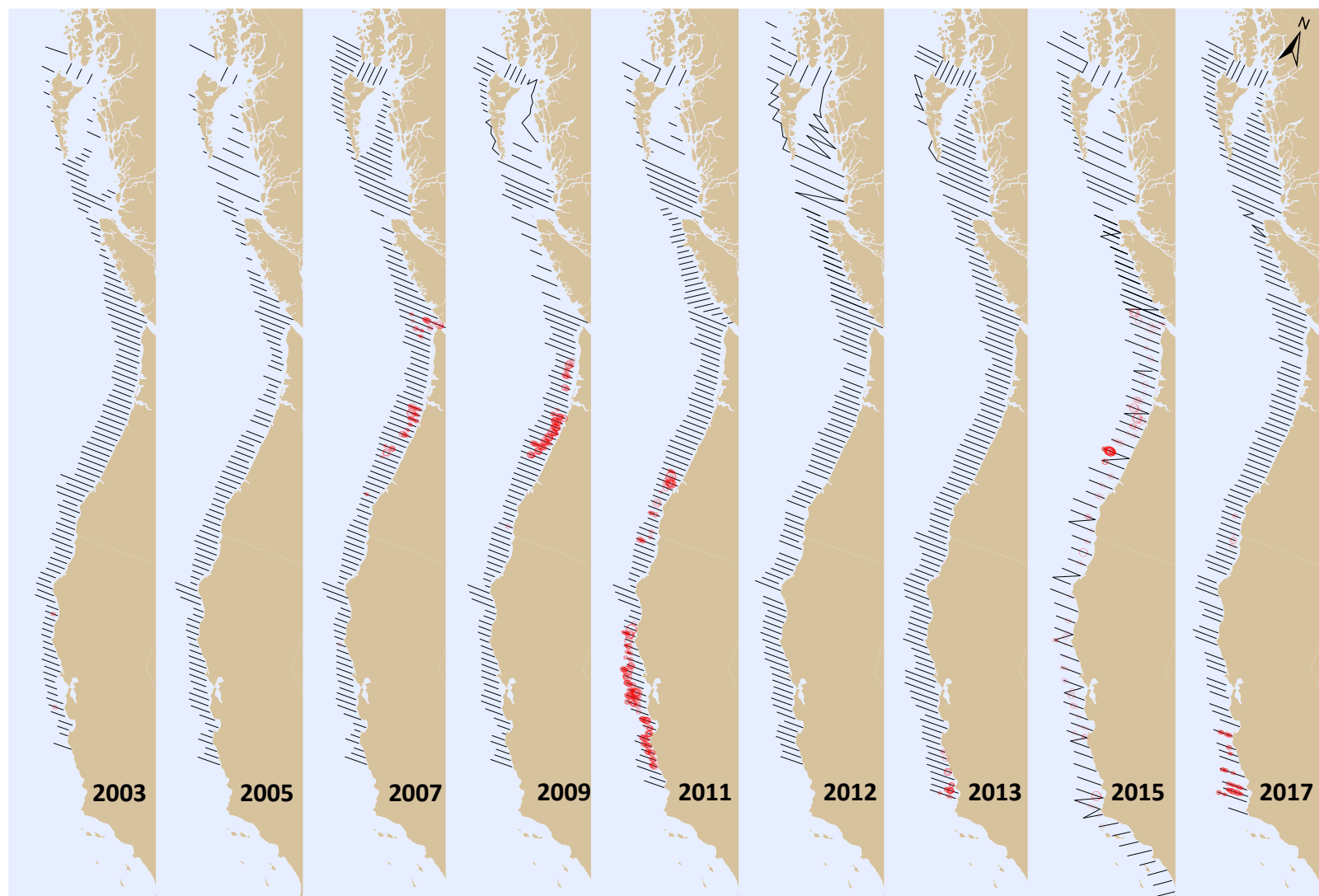


**Figure 1.** Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.

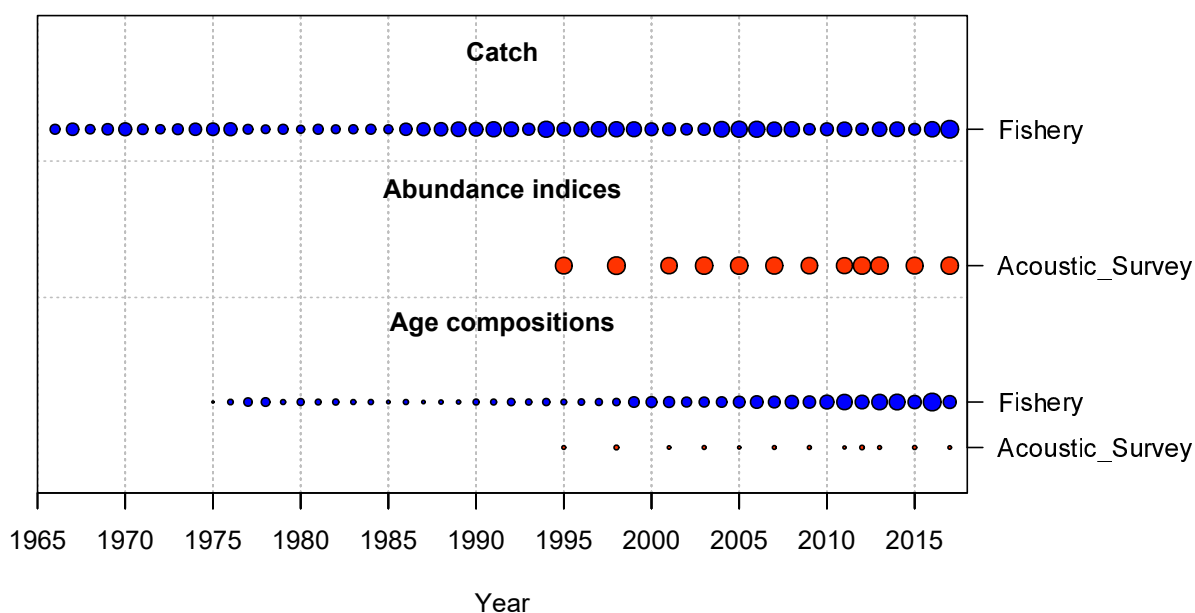


**Figure 2.** Spatial distribution of acoustic backscatter attributable to age-2 and older Pacific Hake from joint US-Canada acoustic surveys 1995–2017. Area of the circle is roughly proportional to observed backscatter. Histograms show survey-estimated biomass for ages 2 to 20, with major cohorts highlighted in color. Figure produced by Julia Clemons (NOAA).

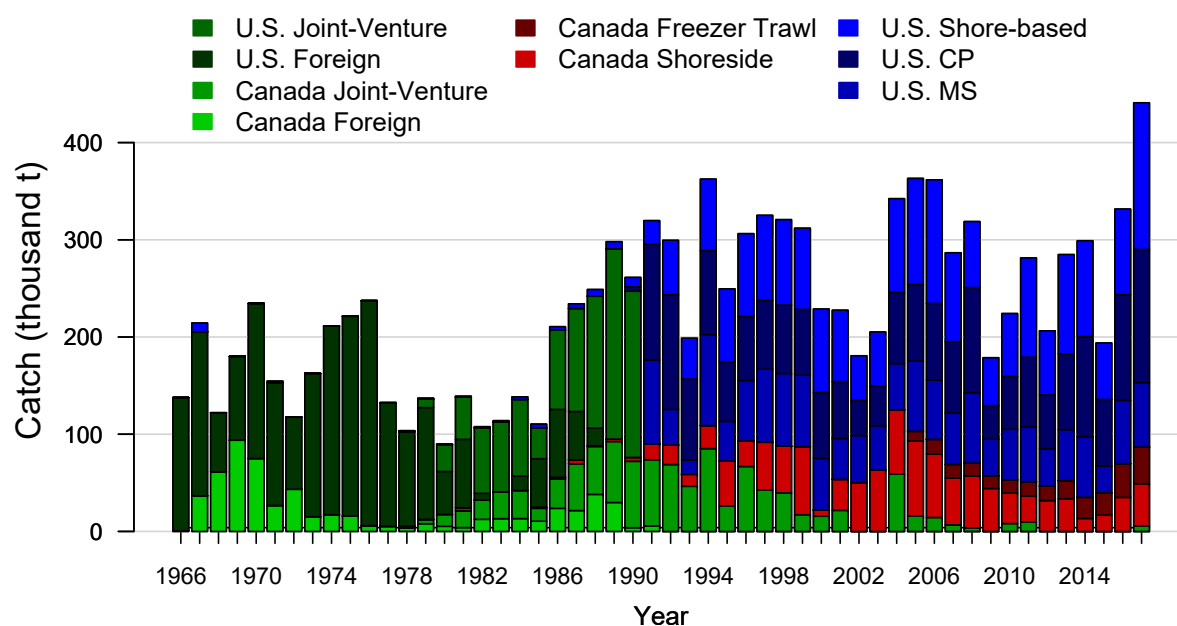




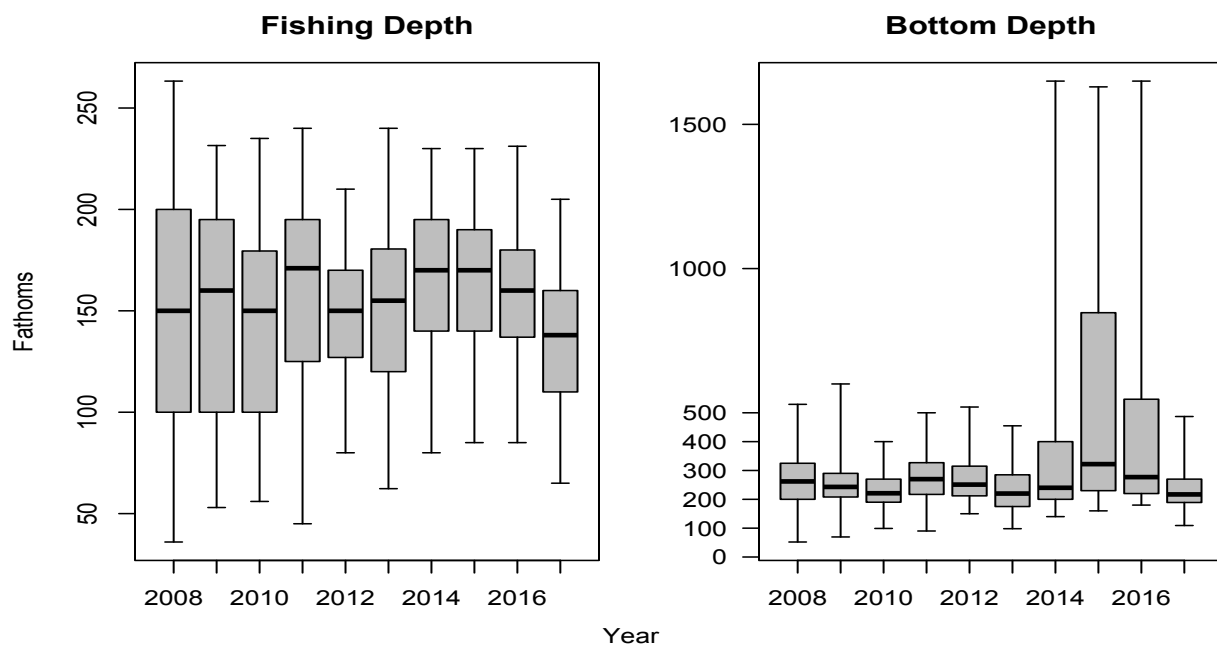
**Figure 3.** Spatial distribution of acoustic backscatter attributable to age-1 Pacific Hake from joint US-Canada acoustic surveys 2003 –2017. Age-1 Pacific Hake are not fully sampled during the acoustic survey and were not explicitly considered during establishment of the survey sampling design. The area of the circle is roughly proportional to observed backscatter. Figure produced by Julia Clemons (NOAA).



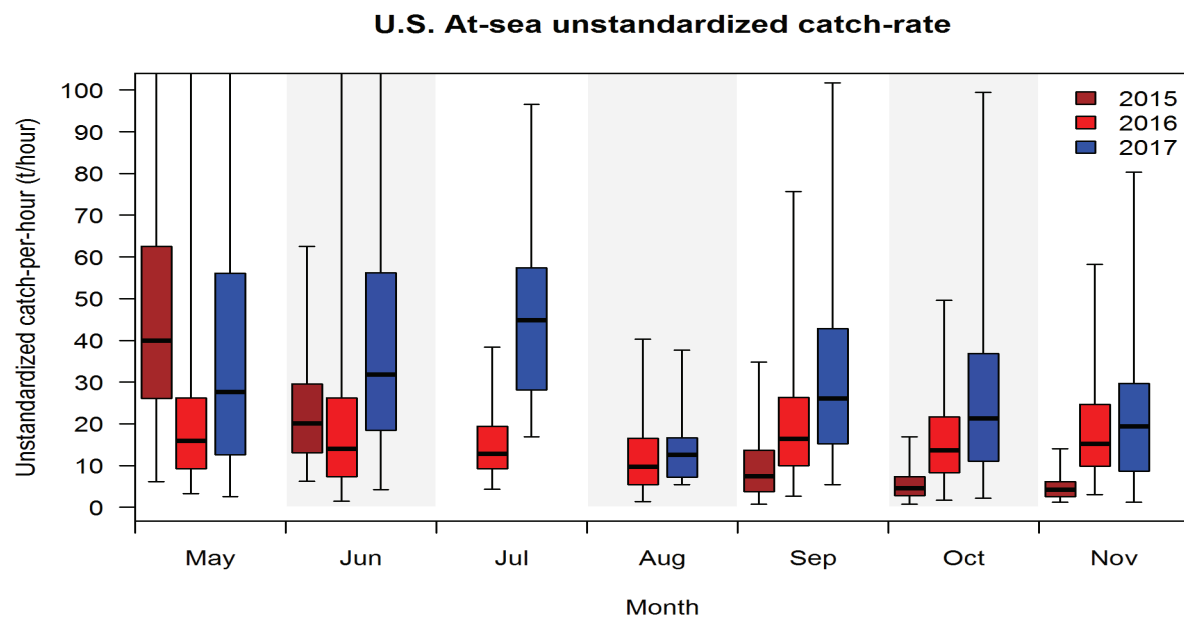
**Figure 4.** Overview of data used in this assessment, 1966–2017. Circle areas are proportional to the precision within the data type.



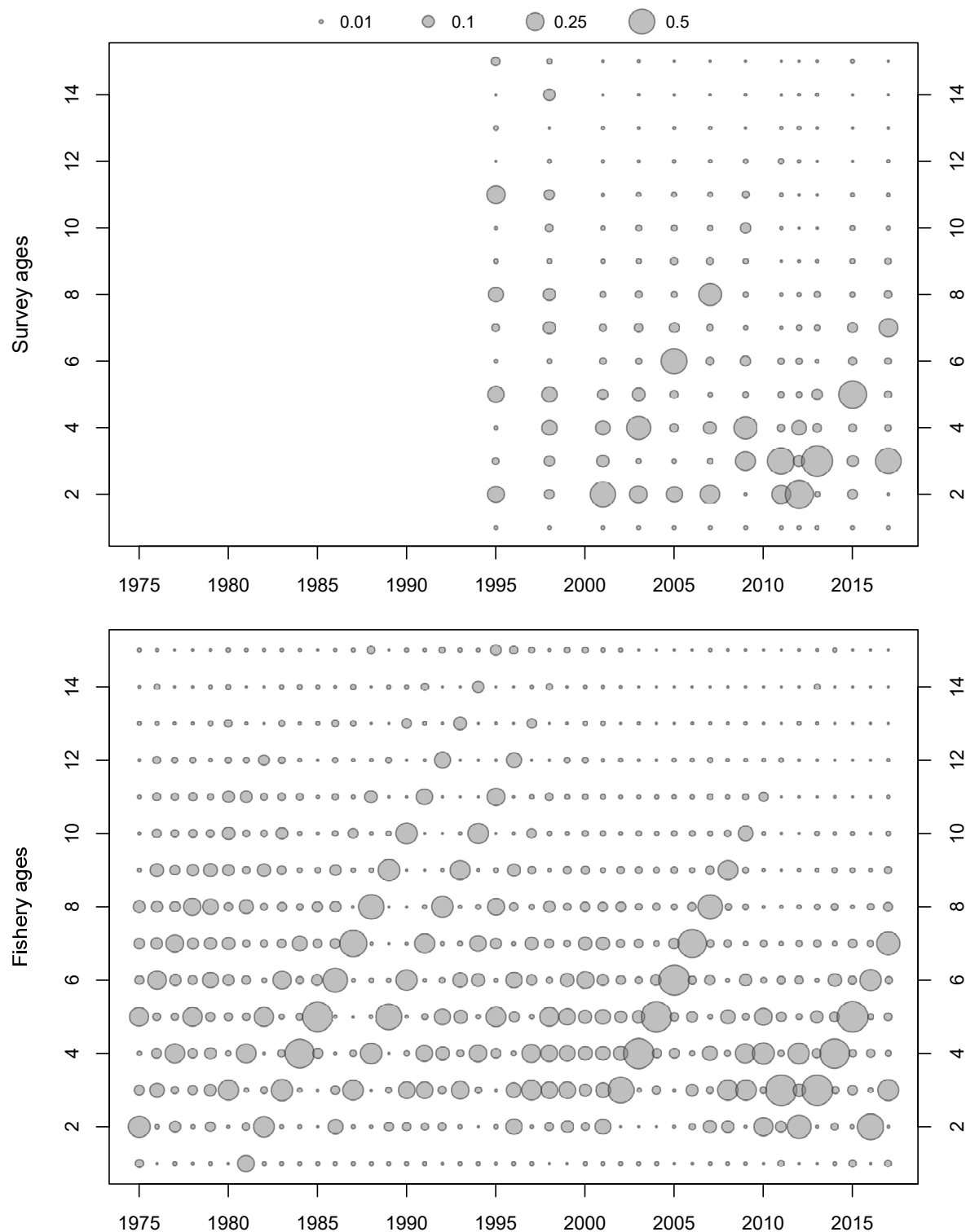
**Figure 5.** Total Pacific Hake catch used in the assessment by sector, 1966–2017. U.S. tribal catches are included in the appropriate sector.



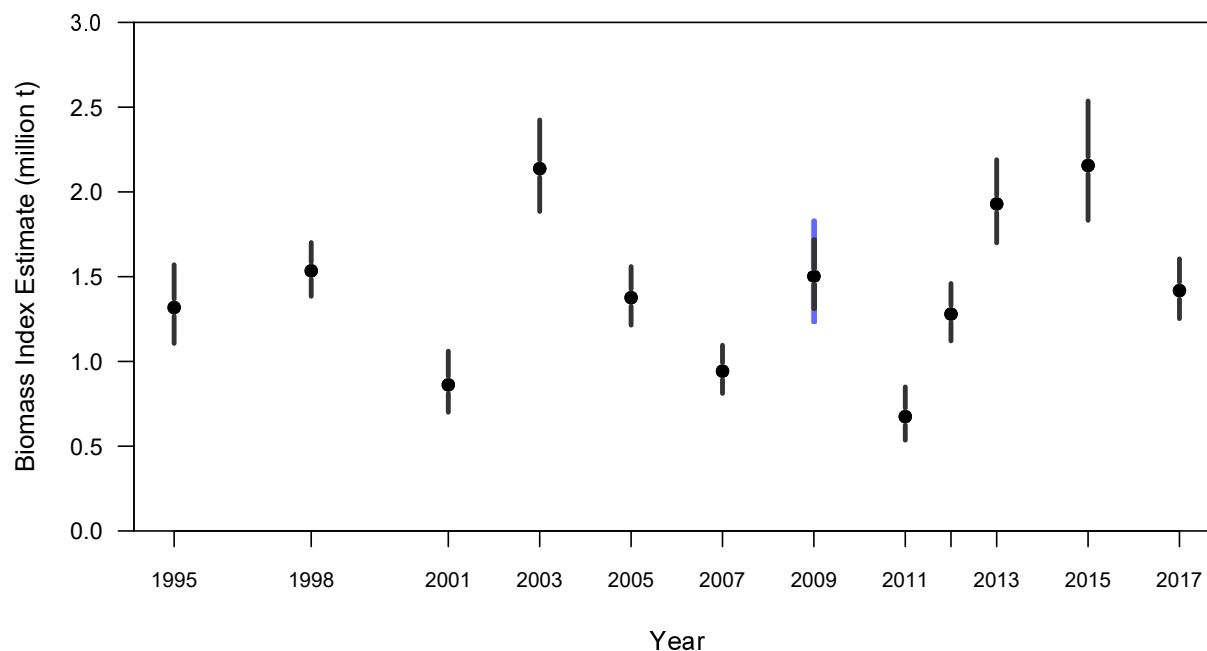
**Figure 6.** Distribution of fishing depths (left) and bottom depths (right), in fathoms, of Pacific Hake catches in the U.S. at-sea fleet from 2008–2017.



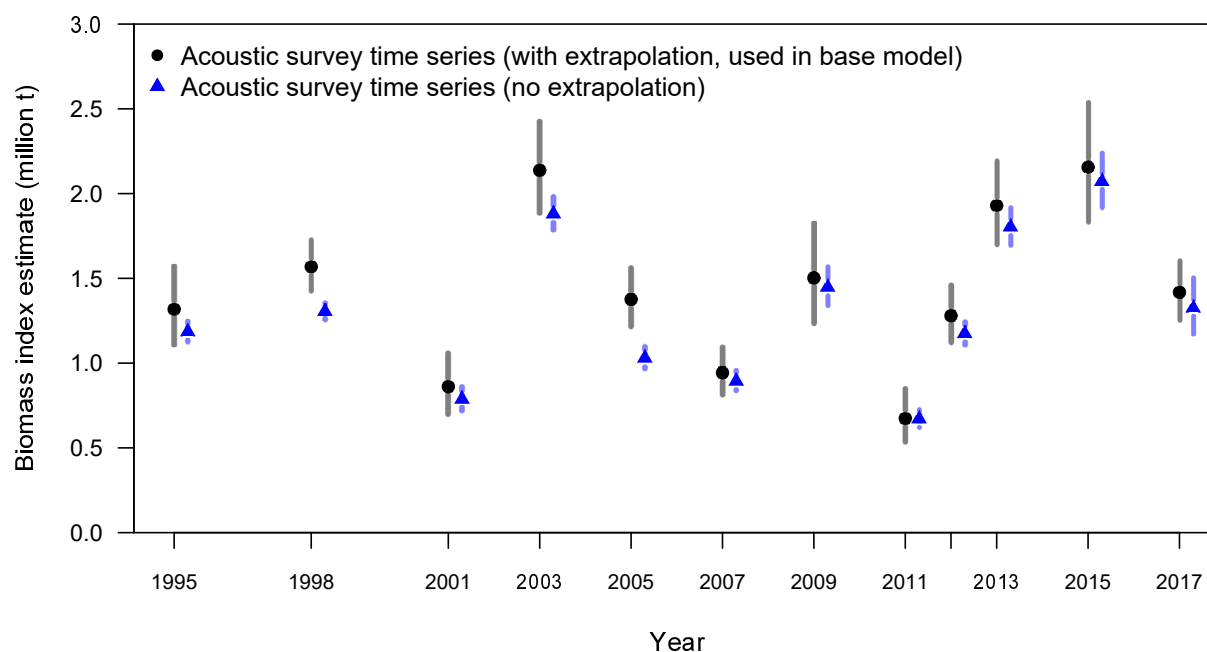
**Figure 7.** Unstandardized (raw) catch-rates (t/hr) of Pacific Hake catches by tow in the U.S. at-sea fleet in 2017.



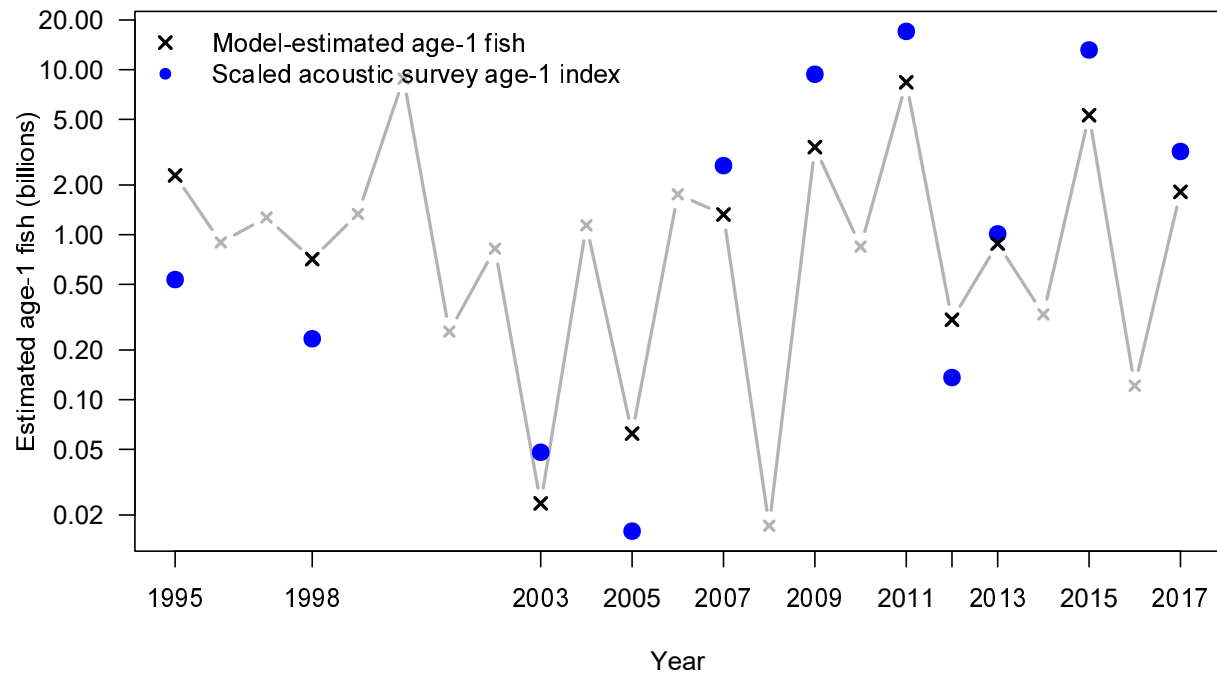
**Figure 8.** Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2017. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble in the survey data is 0.75 for age 3 in 2013 and in the fishery is 0.71 for age 3 in 2011.



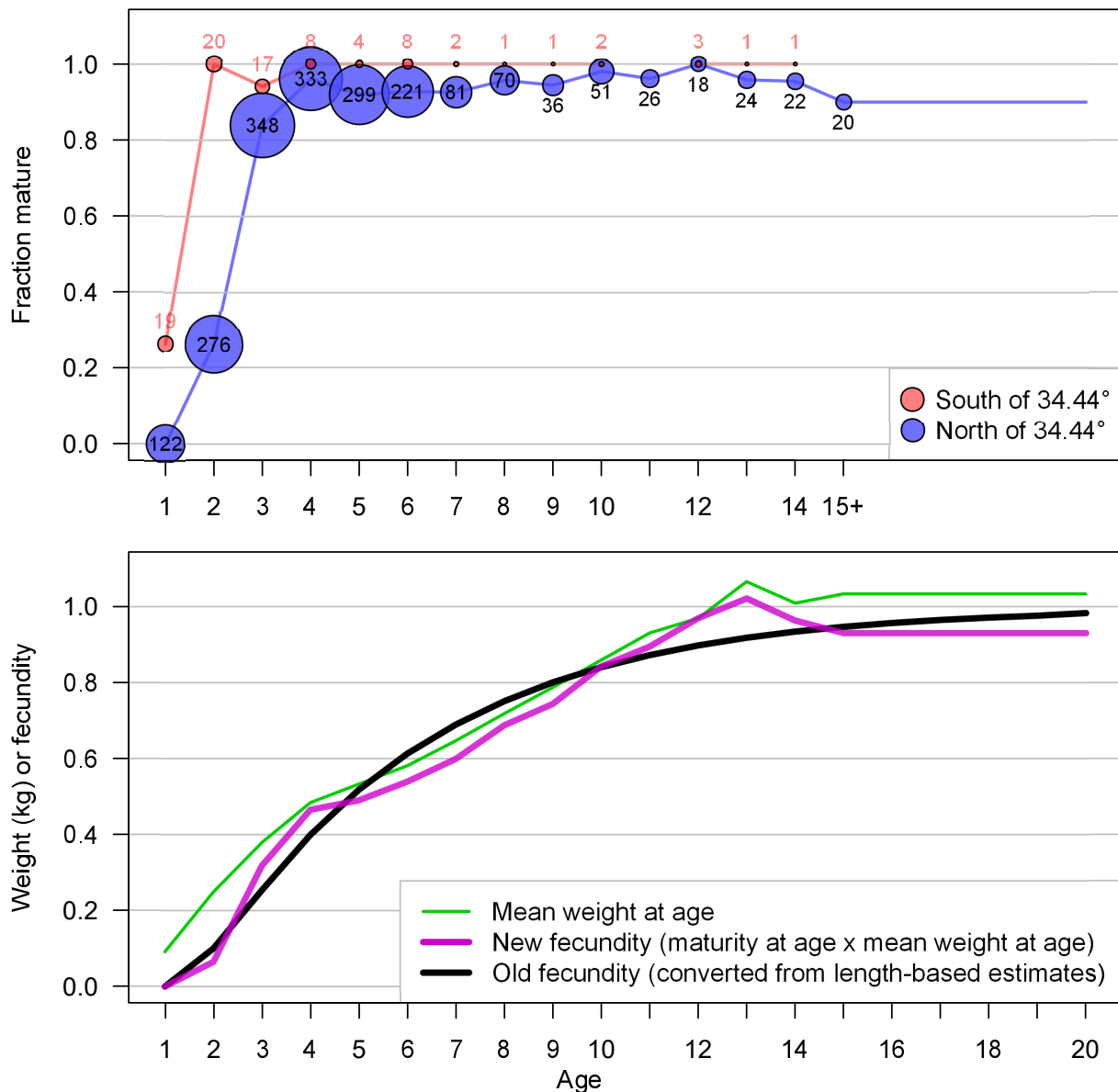
**Figure 9.** Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals (black bars) are based on sampling variability; blue bars for 2009 include additional uncertainty due to squid/hake apportionment.



**Figure 10.** Acoustic survey biomass indices with and without extrapolation (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (and squid/hake apportionment uncertainty in 2009). See Table 14 for values used in the base model

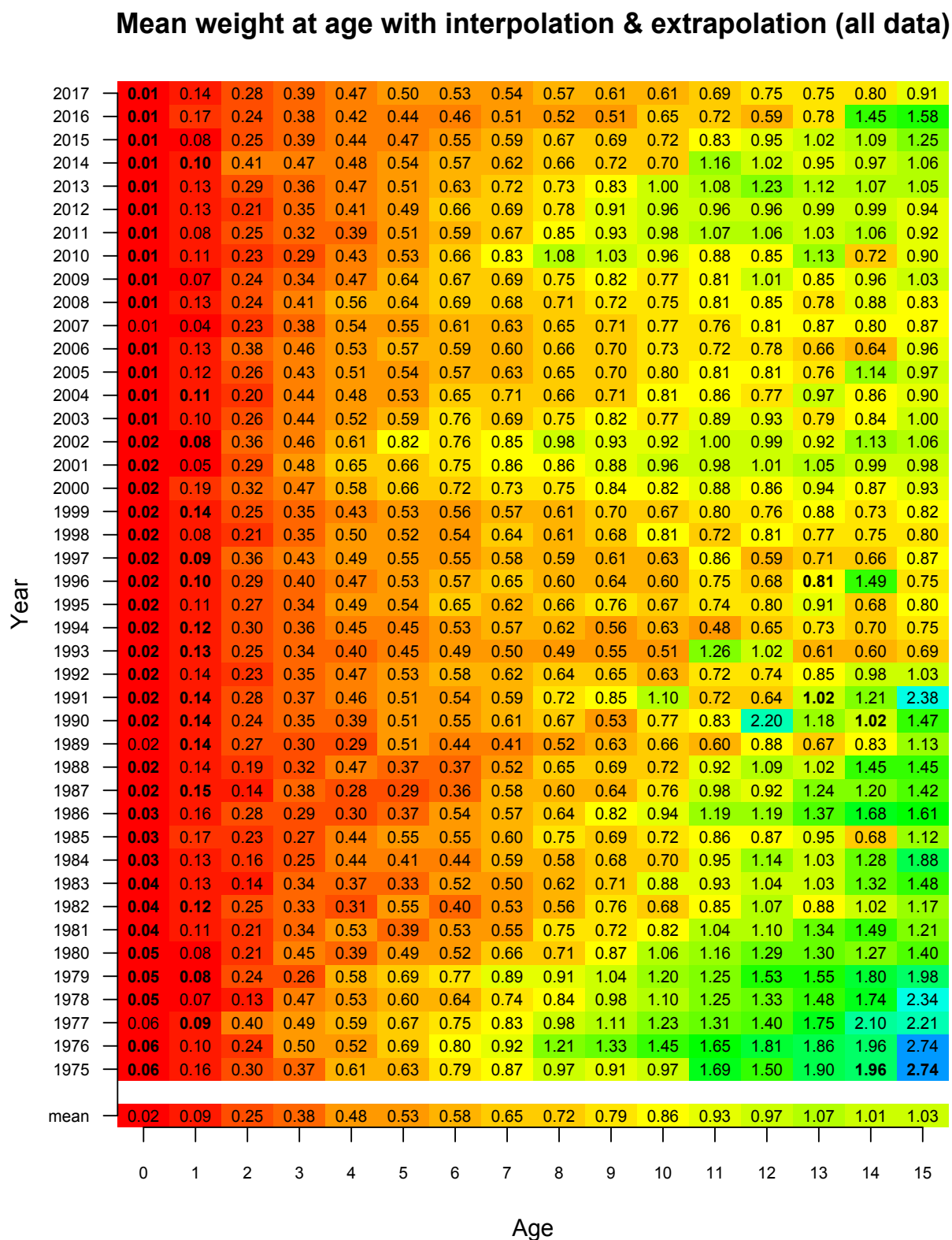


**Figure 11.** Preliminary acoustic survey age-1 index overlaid on estimated numbers of age-1 fish (MLE from the base model).

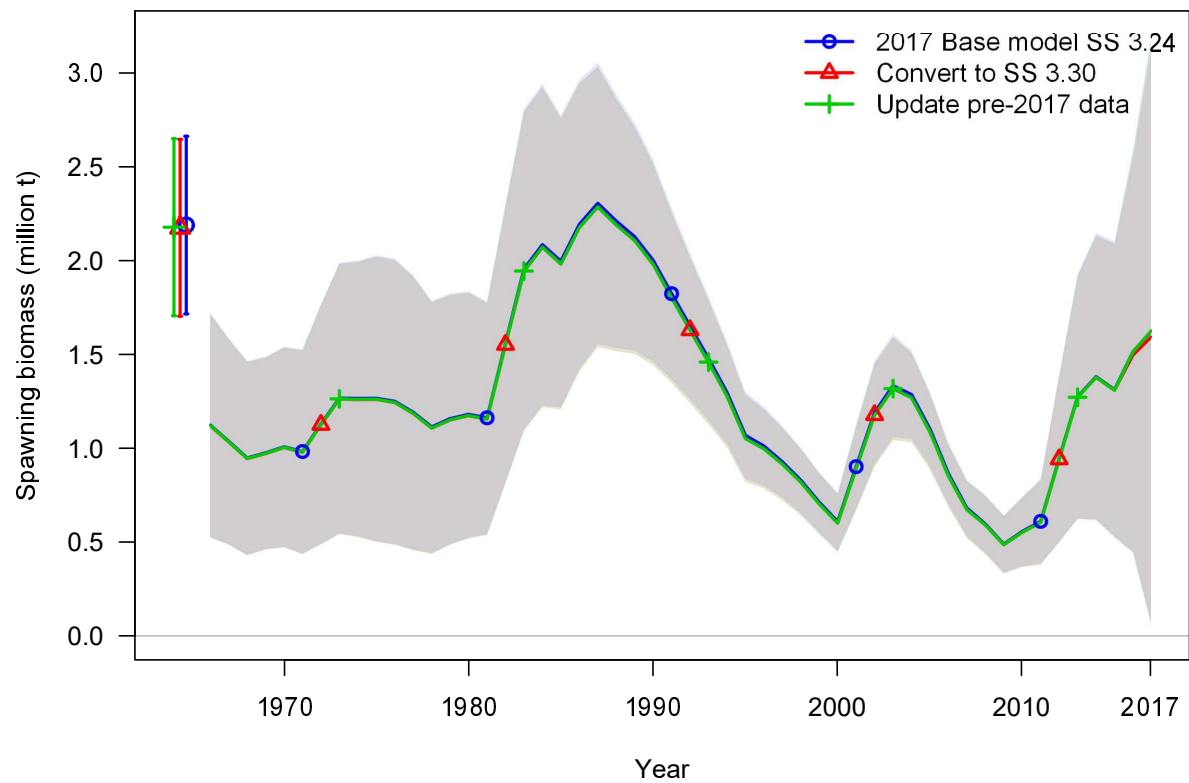


**Figure 12.** Fraction of fish that are mature at each age north and south of 34.44°N (upper panel) and comparison of old and new fecundity relationships (lower panel). The old fecundity relationship (black line in lower plot) was a product of the maturity-at-length reported by Dorn and Saunders (1997) and the weight-at-length estimated in 2011, converted to age using a parametric growth curve estimated in 2011. The new fecundity relationship (purple line) is the product of the mean weight-at-age averaged across all years (green line) and the maturity-at-age for the samples collected from North of 34.44°N (blue line in upper plot).

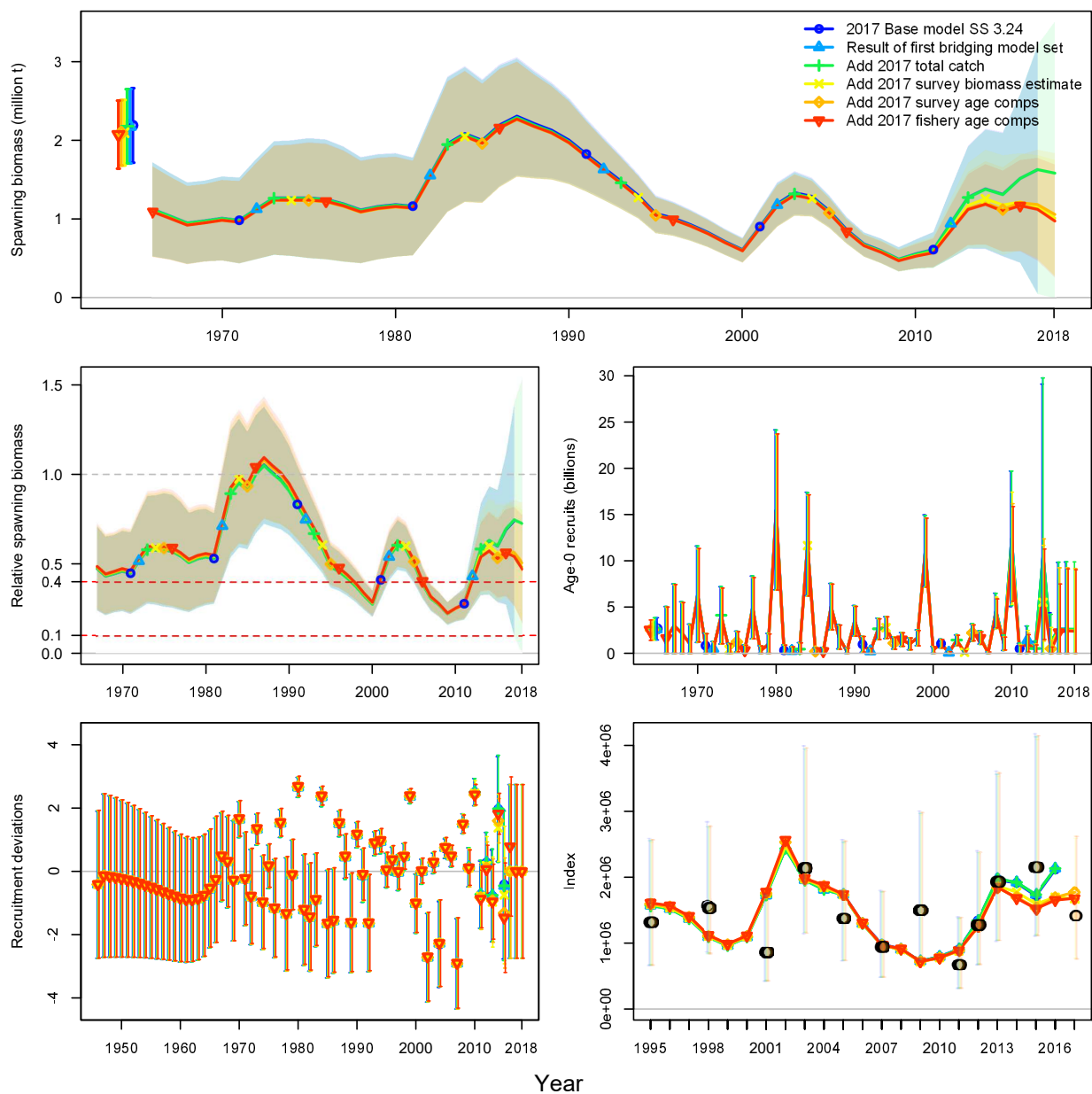




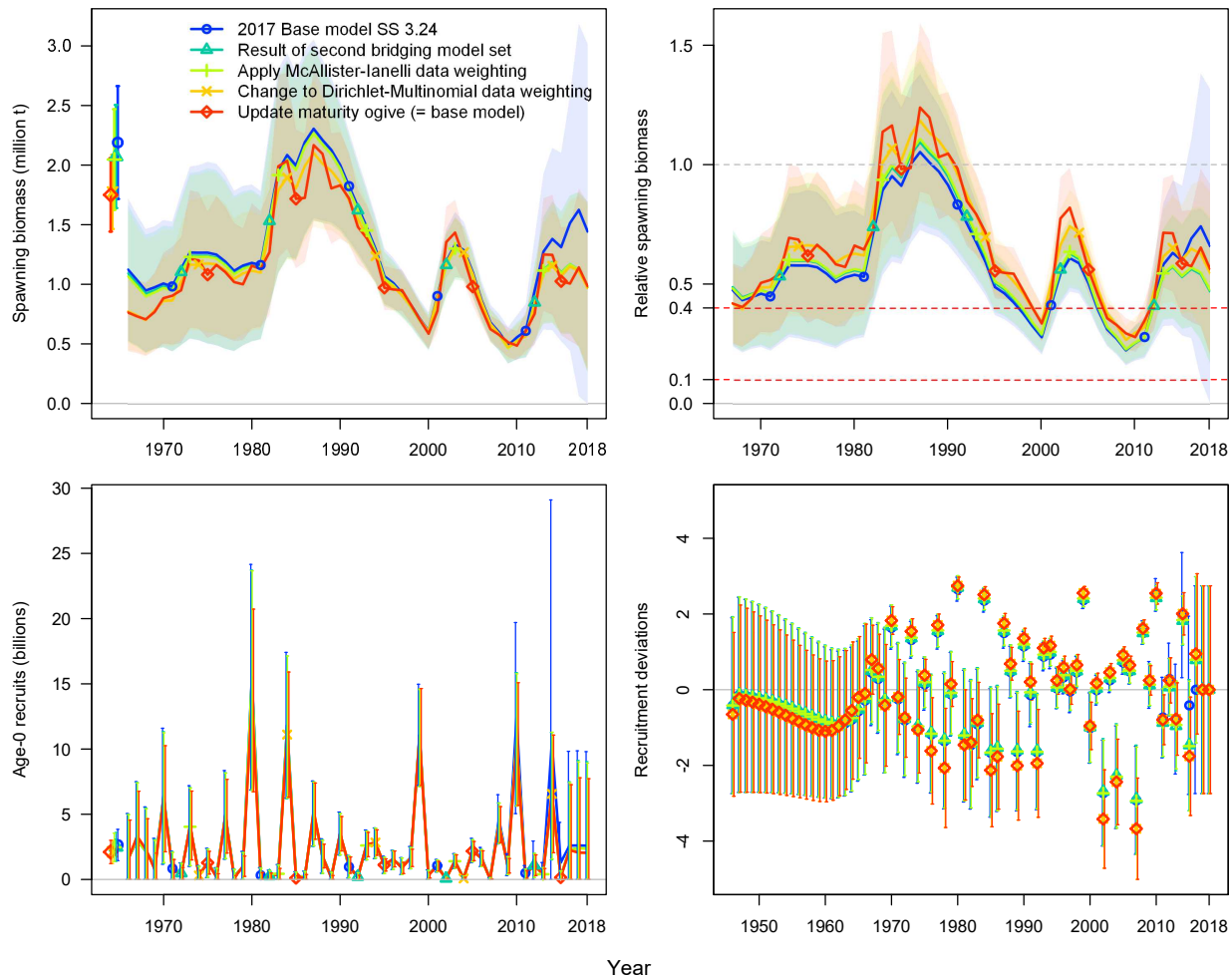
**Figure 13.** Empirical weight-at-age (kg) used in the assessment (numbers, with colors given by the scale at the bottom). Numbers shown in bold were interpolated or extrapolated from adjacent areas.



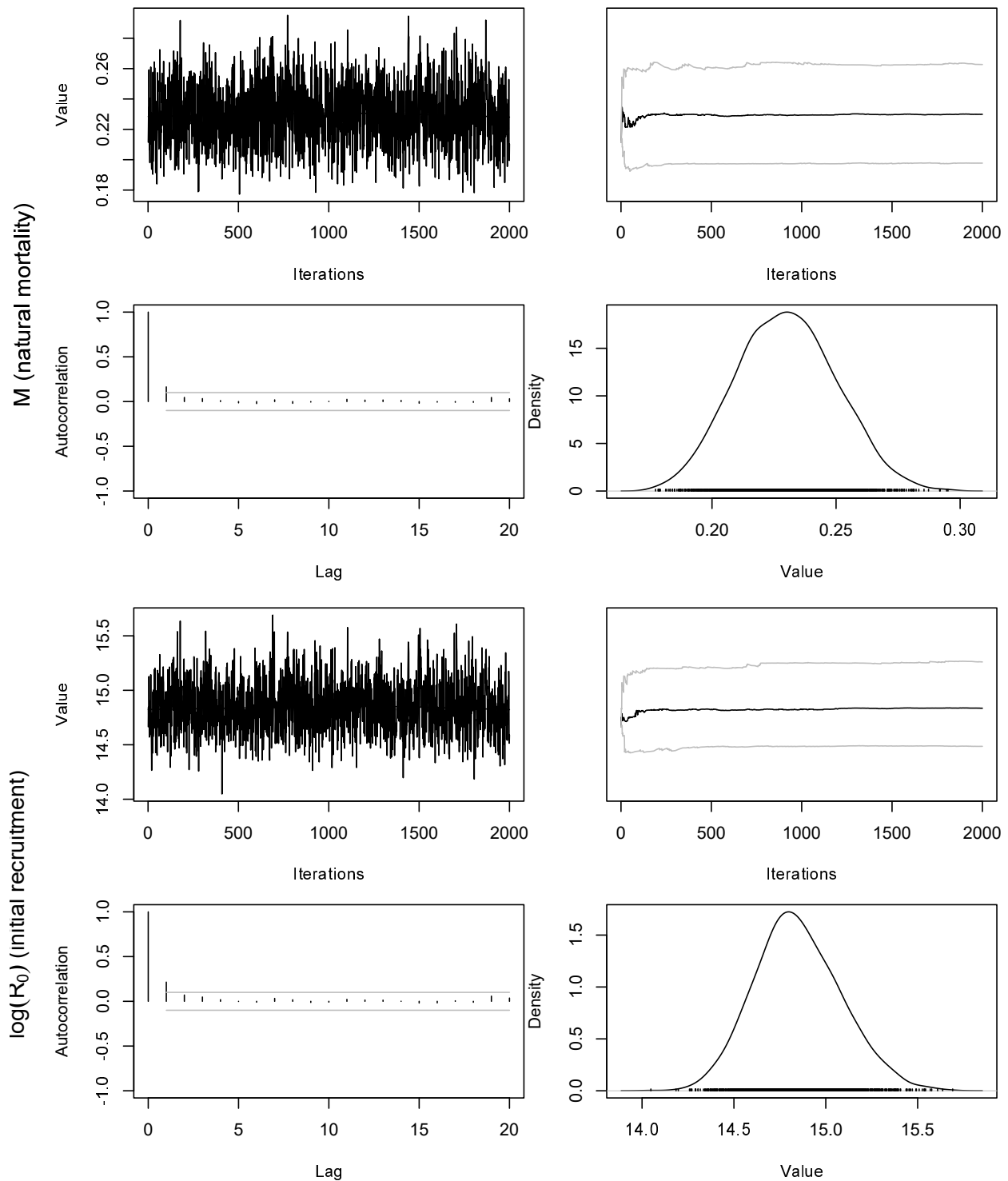
**Figure 14.** Bridging models showing the 2017 base model and the results of converting that model to Stock Synthesis version 3.30 and then updating the pre-2017 data. The points disconnected from the time-series on the left side show the unfished equilibrium spawning biomass estimates.



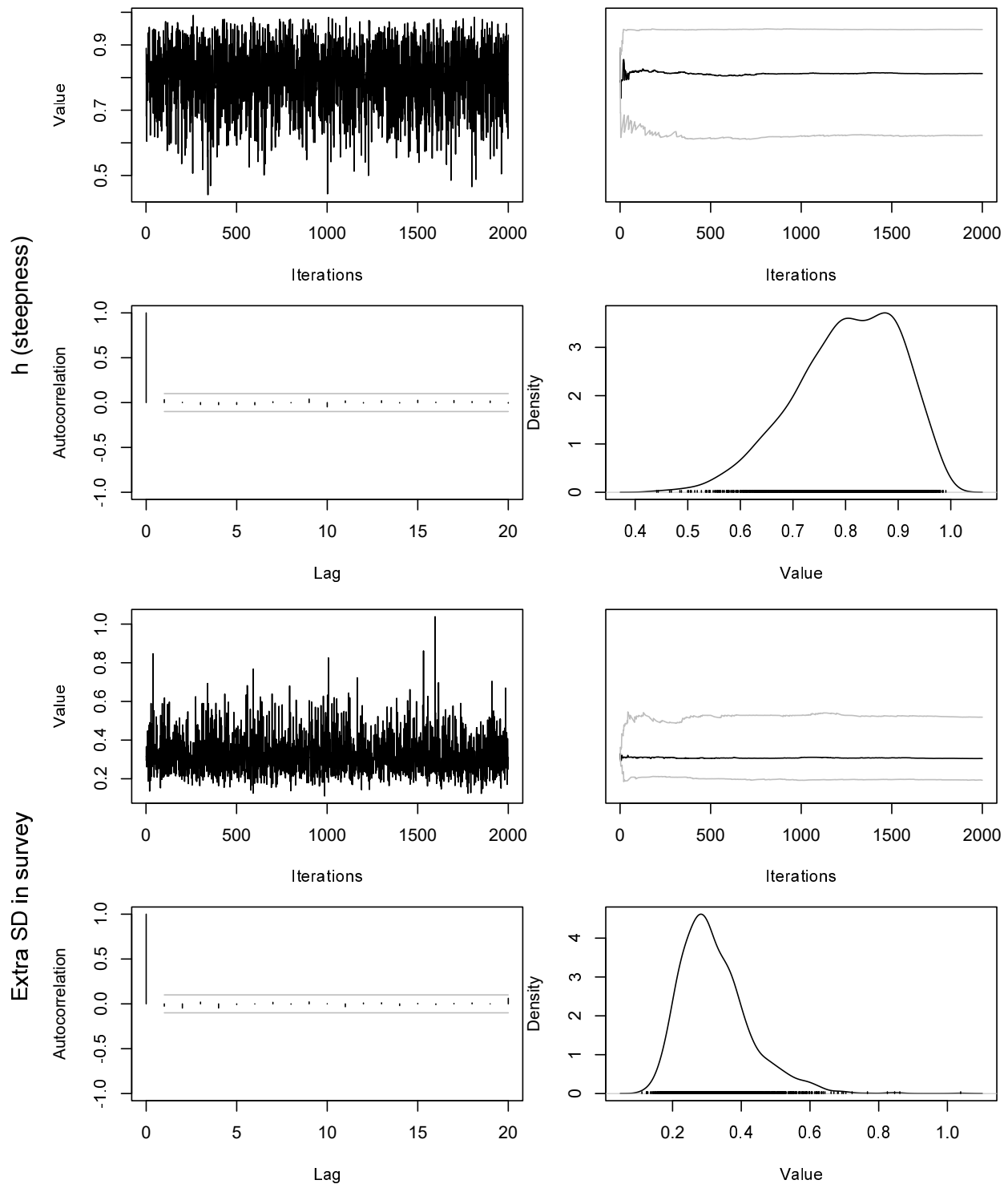
**Figure 15.** Bridging models showing the difference between the 2017 base model, the result of the first set of changes shown in Figure 14 above, and the sequential addition of the new survey and fishery data. Spawning biomass (upper panel), relative spawning biomass (spawning biomass in each year relative to the unfished equilibrium spawning biomass, middle left), absolute recruitment (middle right), recruitment deviations (lower left), and survey index (lower right) are shown.



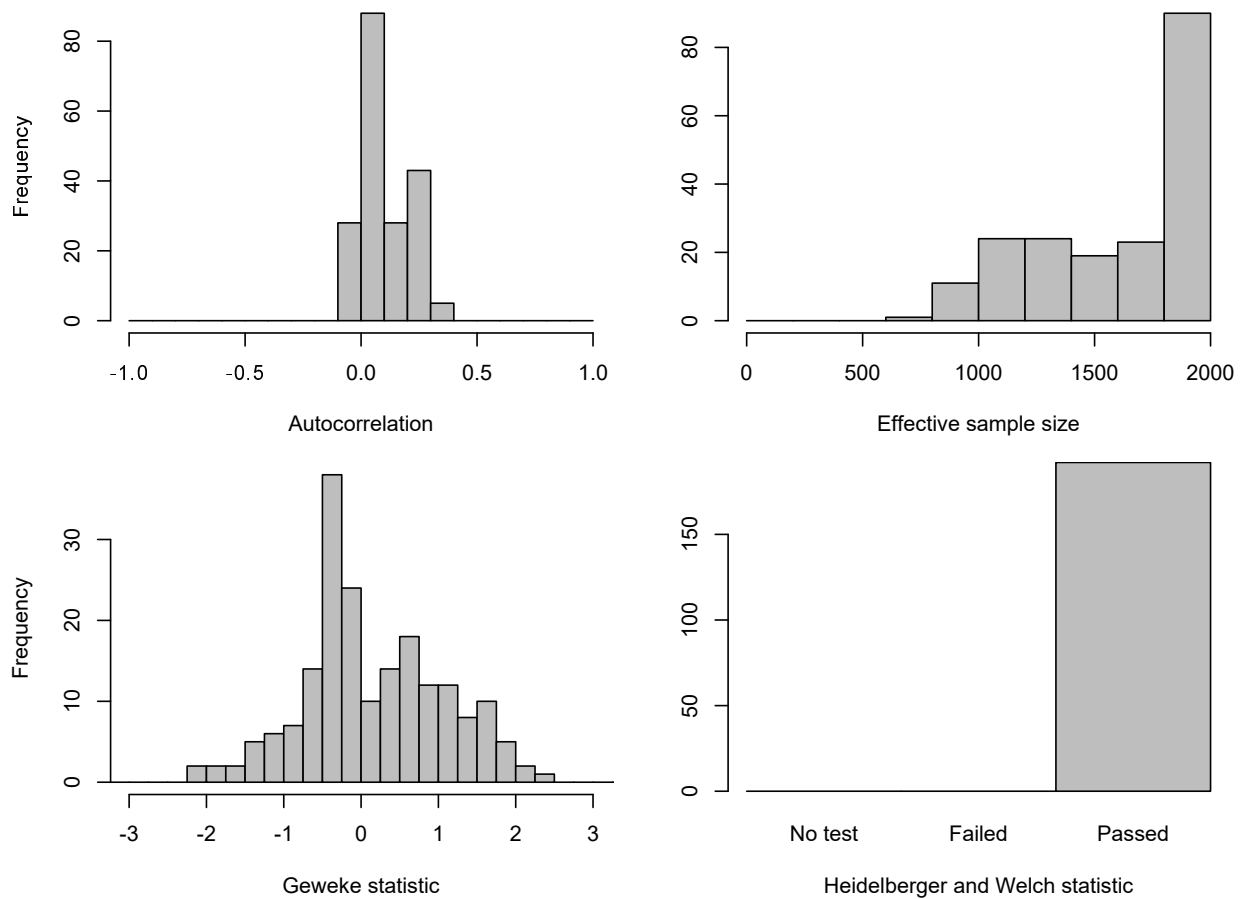
**Figure 16.** Bridging models showing the difference between the 2017 base model, the result of the second set of changes shown in Figure 15 above, the result of tuning the model using the McAllister-Ianelli data-weighting method, the change to the new Dirichlet-Multinomial data-weighting method, and the update of the maturity ogive. That last step is the final change to arrive at the 2018 base model (shown by the red line in the plots). Spawning biomass (upper left panel), relative spawning biomass (spawning biomass in each year relative to the unfished equilibrium spawning biomass, upper right), absolute recruitment (lower left), and recruitment deviations (lower right) are shown.



**Figure 17.** Summary of MCMC diagnostics for natural mortality (upper panels) and  $\log(R_0)$  (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower left sub-panel indicates the autocorrelation present in the chain at different lag times (i.e., distance between samples in the chain), and the lower right sub-panel shows the distribution of the values in the chain (i.e., the marginal density from a smoothed histogram of values in the trace plot).

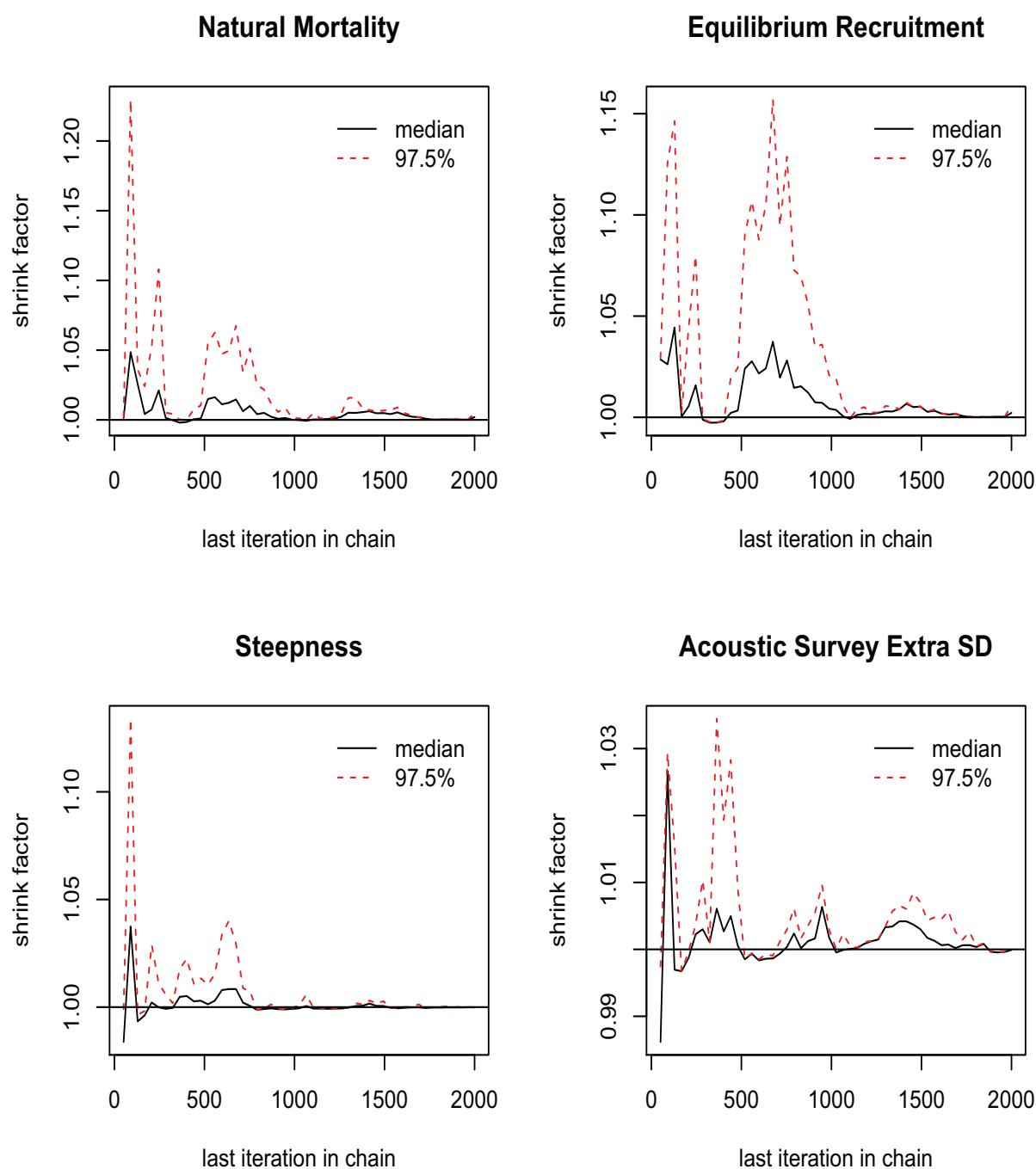


**Figure 18.** Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower left sub-panel indicates the autocorrelation present in the chain at different lag times (i.e., distance between samples in the chain), and the lower right sub-panel shows the distribution of the values in the chain (i.e., the marginal density from a smoothed histogram of values in the trace plot).

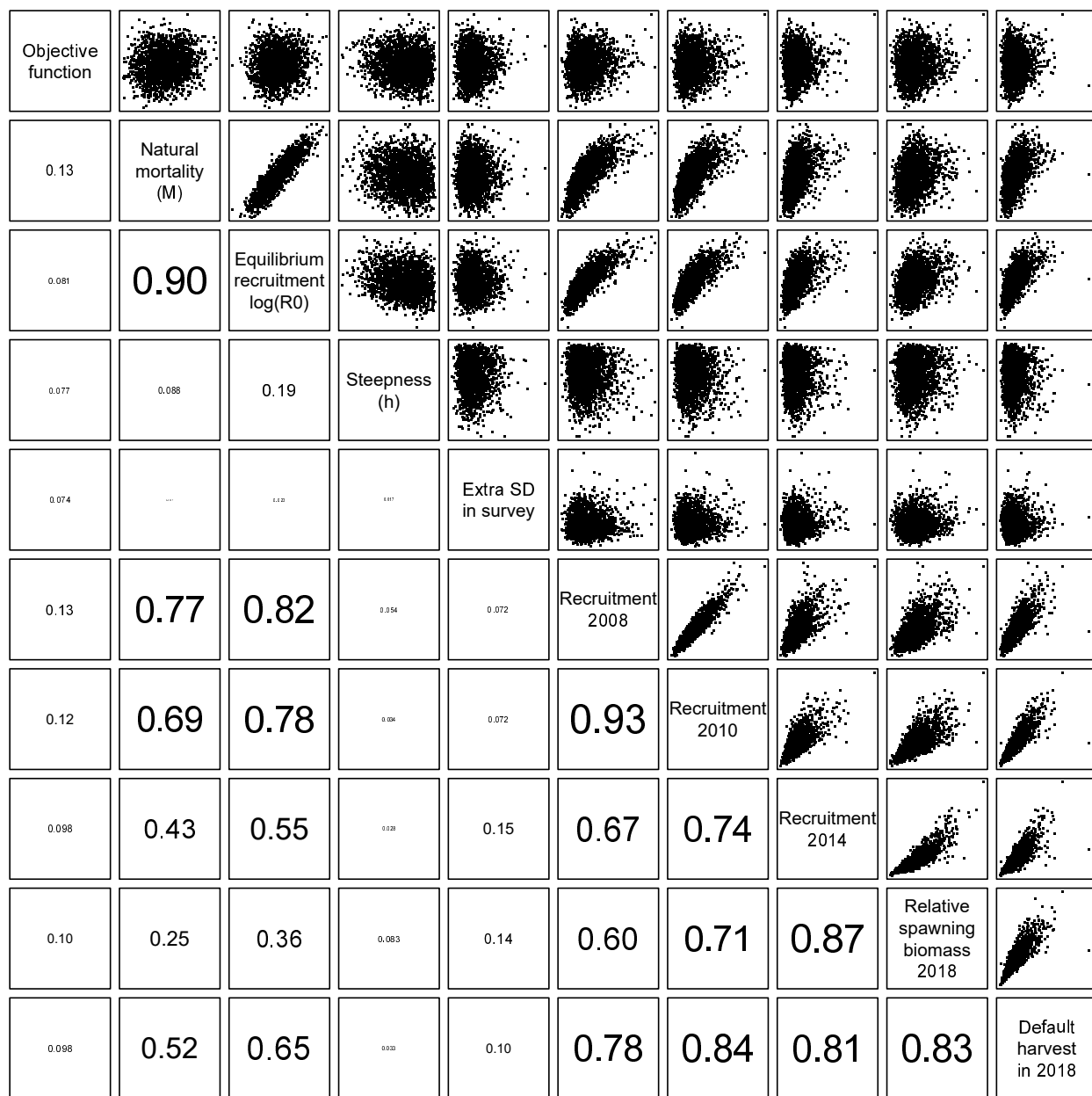


**Figure 19.** Summary histograms of MCMC diagnostics for all base model parameters together with the derived time series of spawning biomass and relative spawning biomass. The level of autocorrelation in the chain (distribution across lag times, i.e. distance between samples in the chain, shown in the top left panel) influences the effective sample size (top right panel) used to estimate posterior distributions. The Geweke statistic (lower left panel) tests for equality between means located in the first part of the chain against means in the last part of the chain. The Heidelberg and Welch statistic (lower right panel) tests if the sampled values come from a stationary distribution by comparing different sections of the chain.

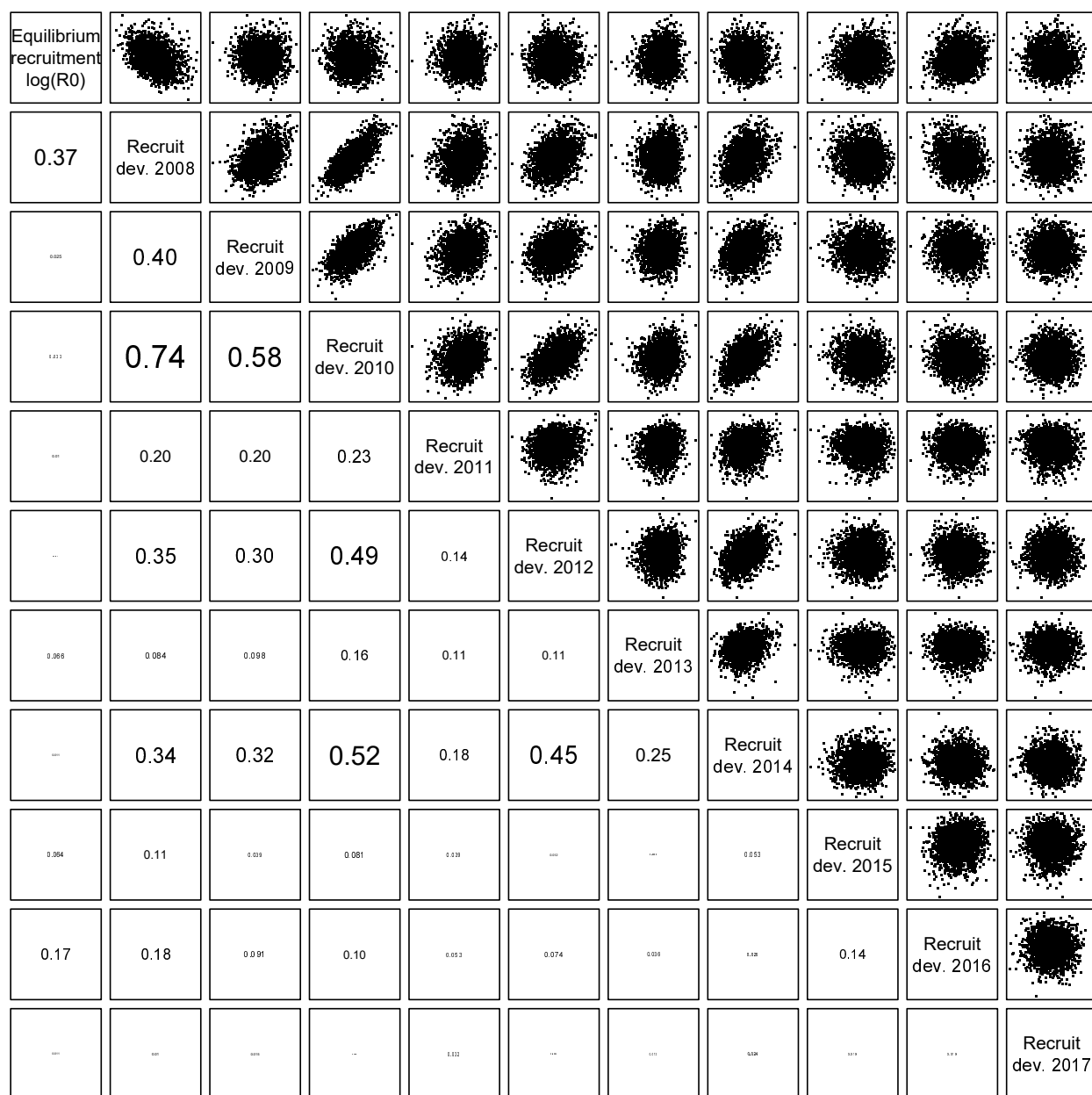




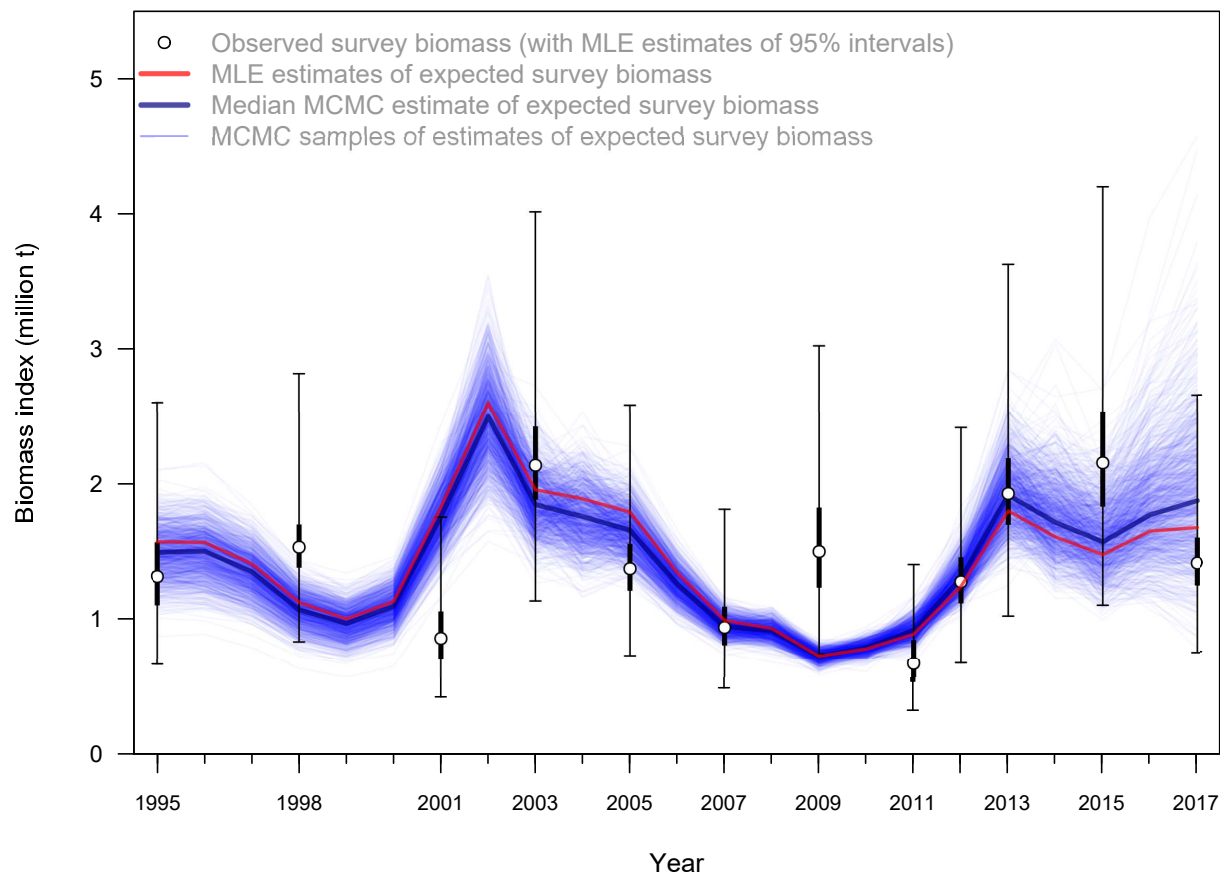
**Figure 20.** Gelman-Rubin plot showing the development of the scale-reduction (shrink factor) across the chain length for key posterior parameter distributions. A factor close to 1 indicates that between chain variance and within chain variance are equal. Values much greater than 1.1 indicate a notable difference between chains and the possible lack of achieving a converged stationary posterior distribution.



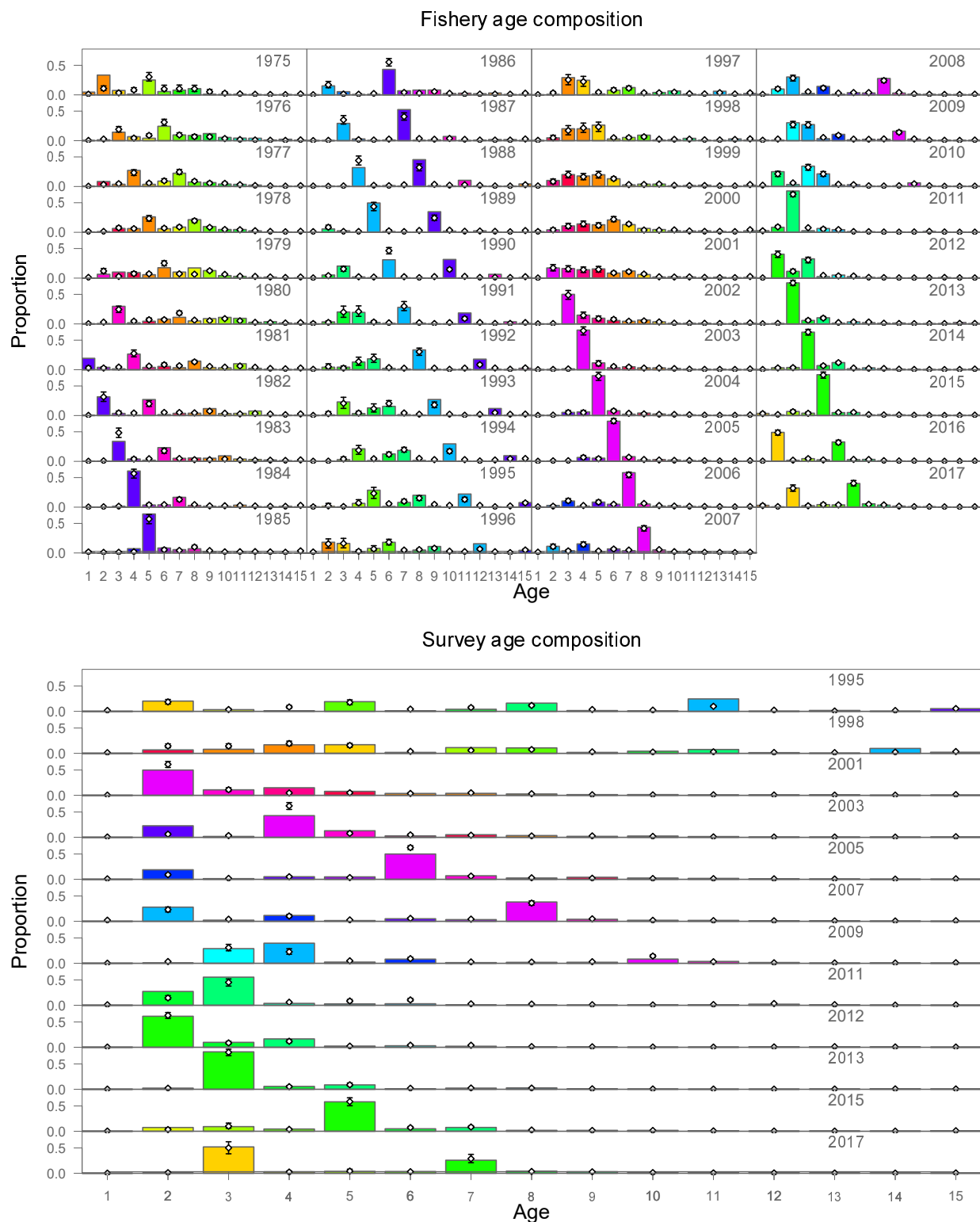
**Figure 21.** Posterior correlations among key base-model parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.



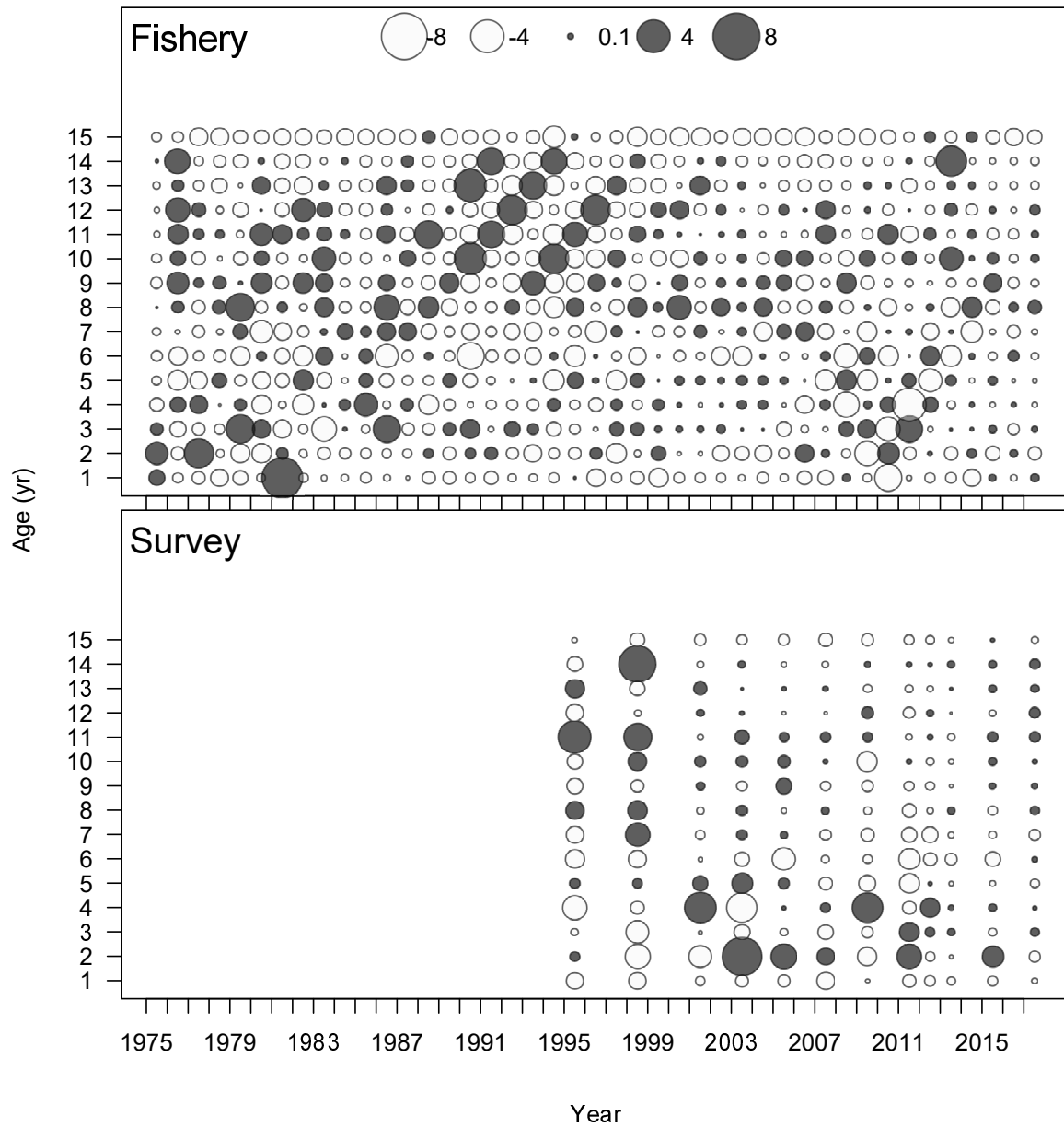
**Figure 22.** Posterior correlations among recruitment deviations from recent years. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.



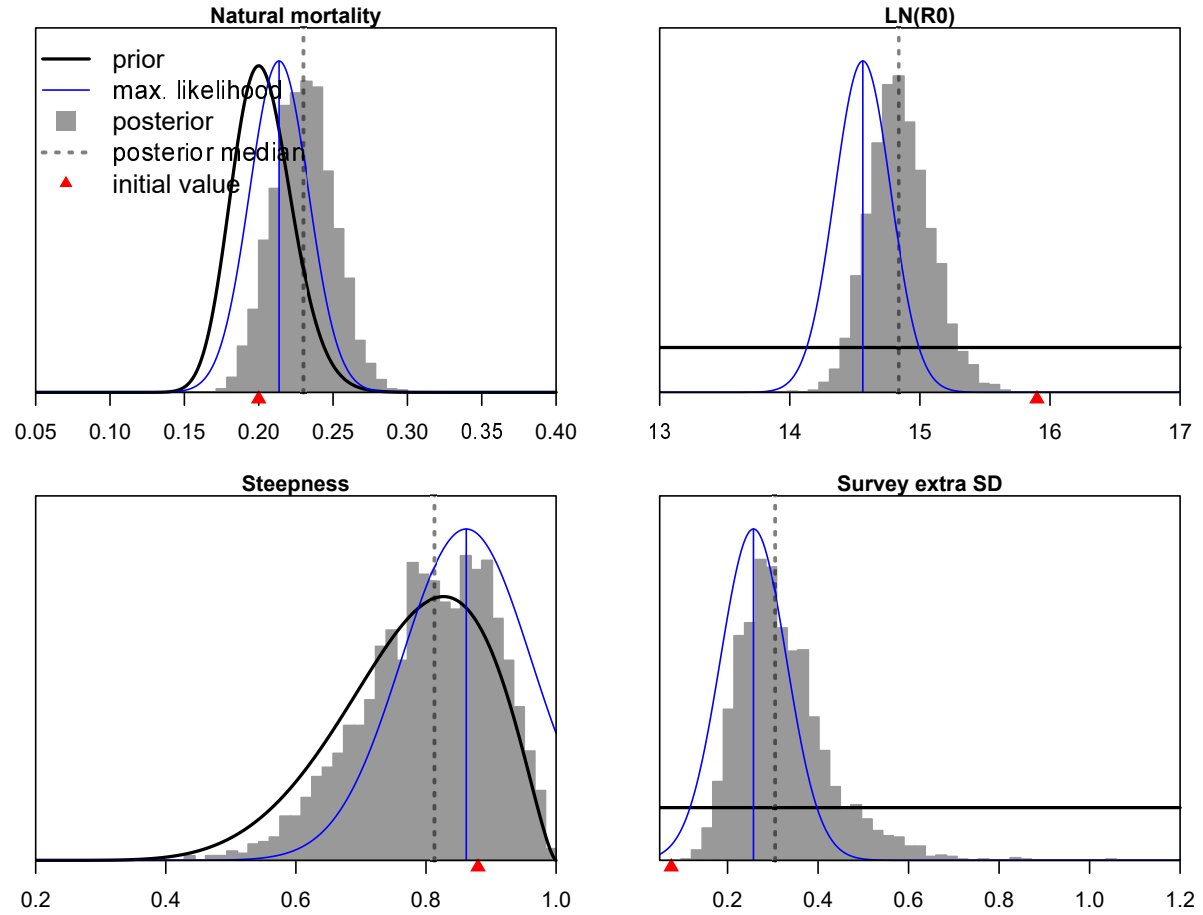
**Figure 23.** Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker bars on uncertainty intervals around observed survey points indicate 95% log-normal uncertainty intervals estimated by the kriging method. Longer bars indicate 95% uncertainty intervals with the MLE estimate of additional uncertainty.



**Figure 24.** Base model fit to the observed fishery (top) and acoustic survey (bottom) age composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% credibility intervals from the MCMC calculations.

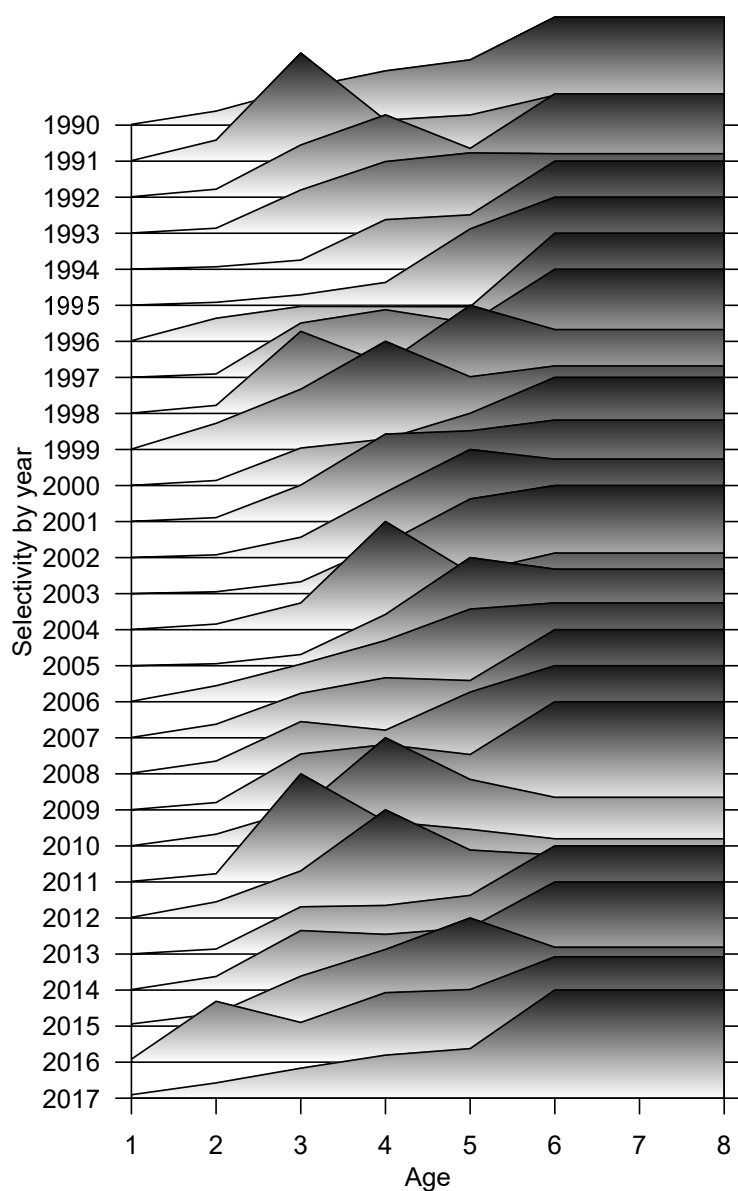


**Figure 25.** Pearson residuals for base model MLE fits to the age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

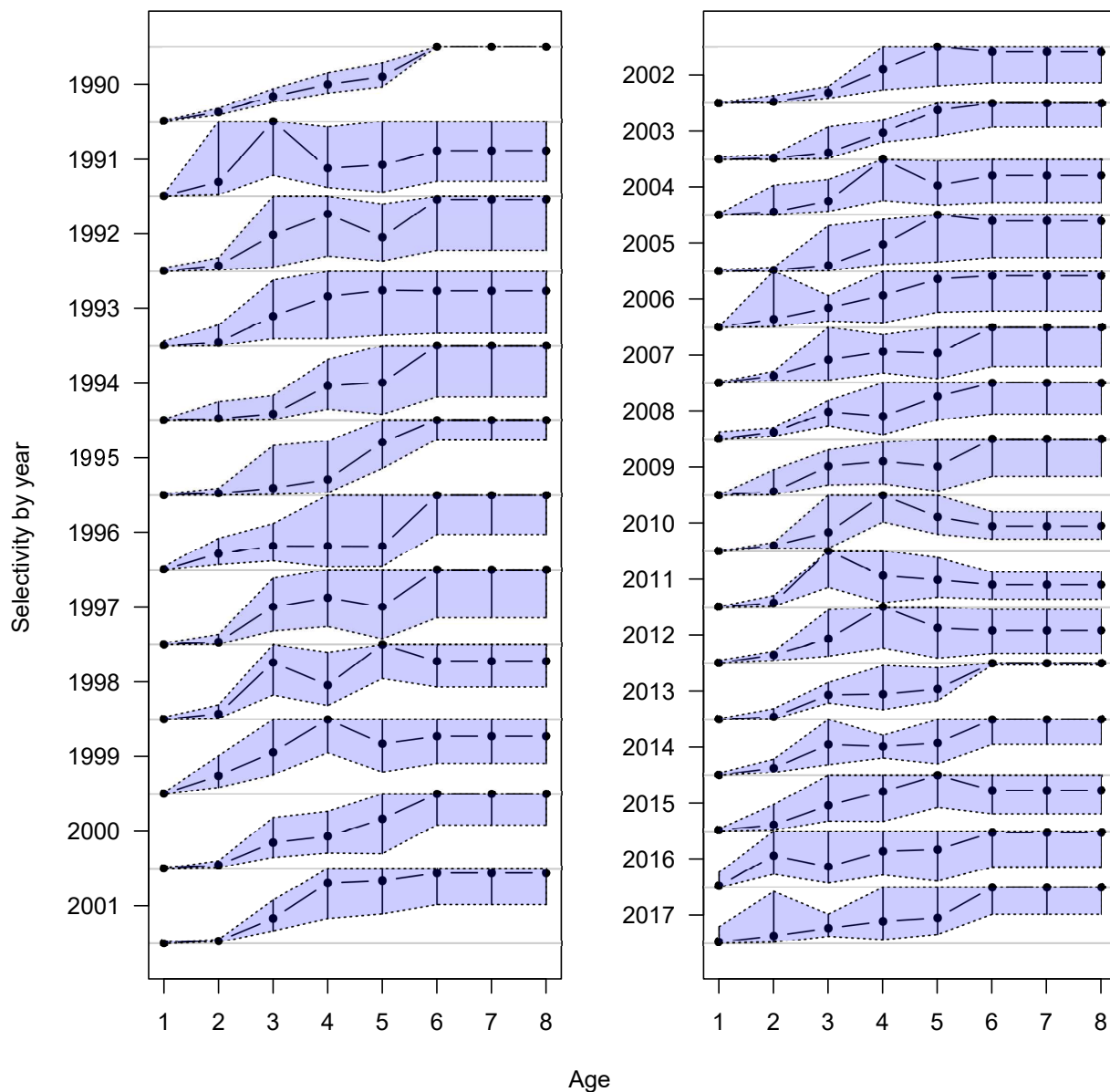


**Figure 26.** Prior (black lines) and posterior (gray histograms) distributions for key parameters in the base model. The parameters are: natural mortality ( $M$ ), equilibrium log recruitment  $\log(R_0)$ , steepness ( $h$ ), and the additional process-error standard deviation for the acoustic survey. The maximum likelihood estimates and associated symmetric uncertainty intervals are also shown (blue lines).

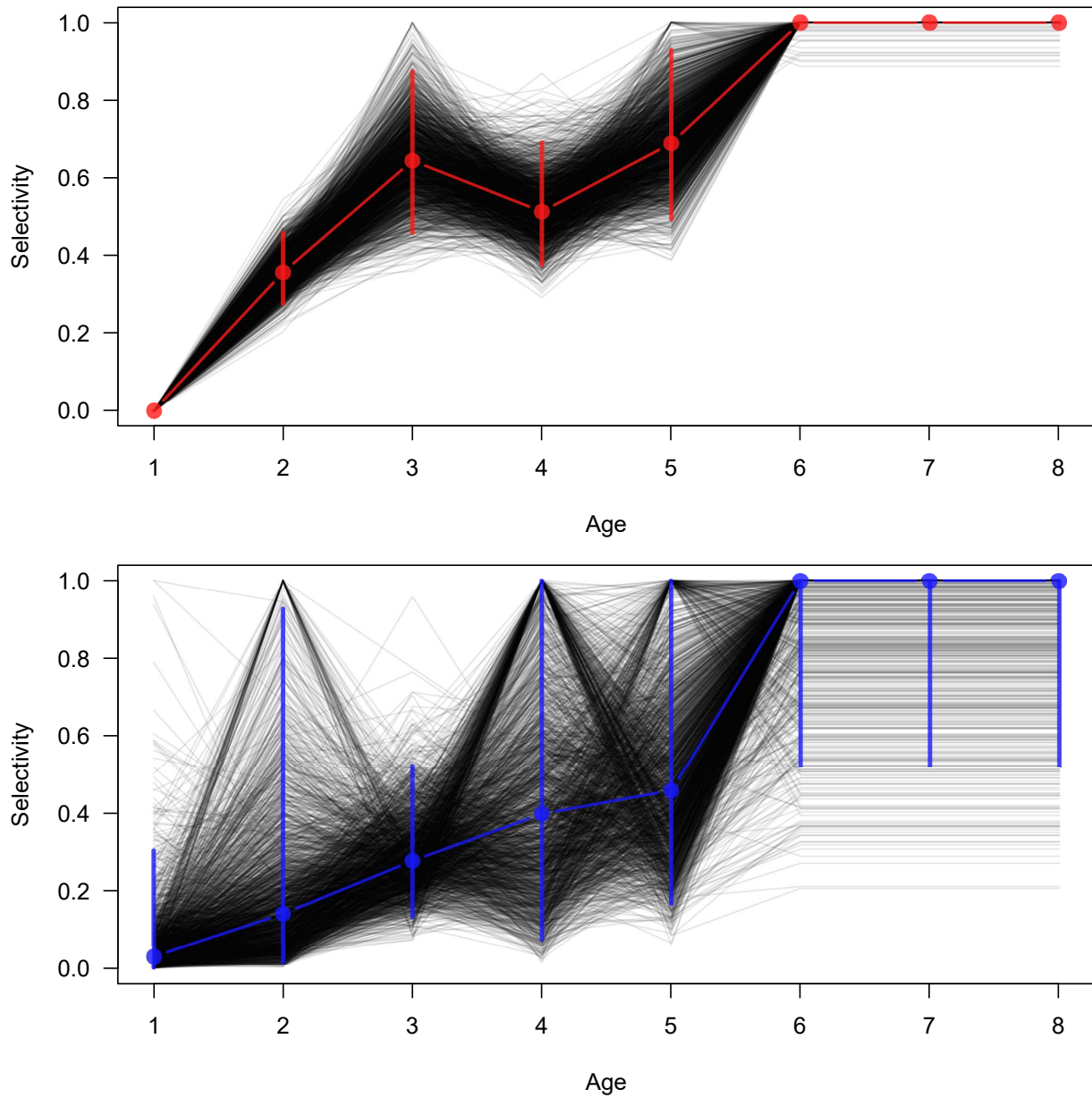




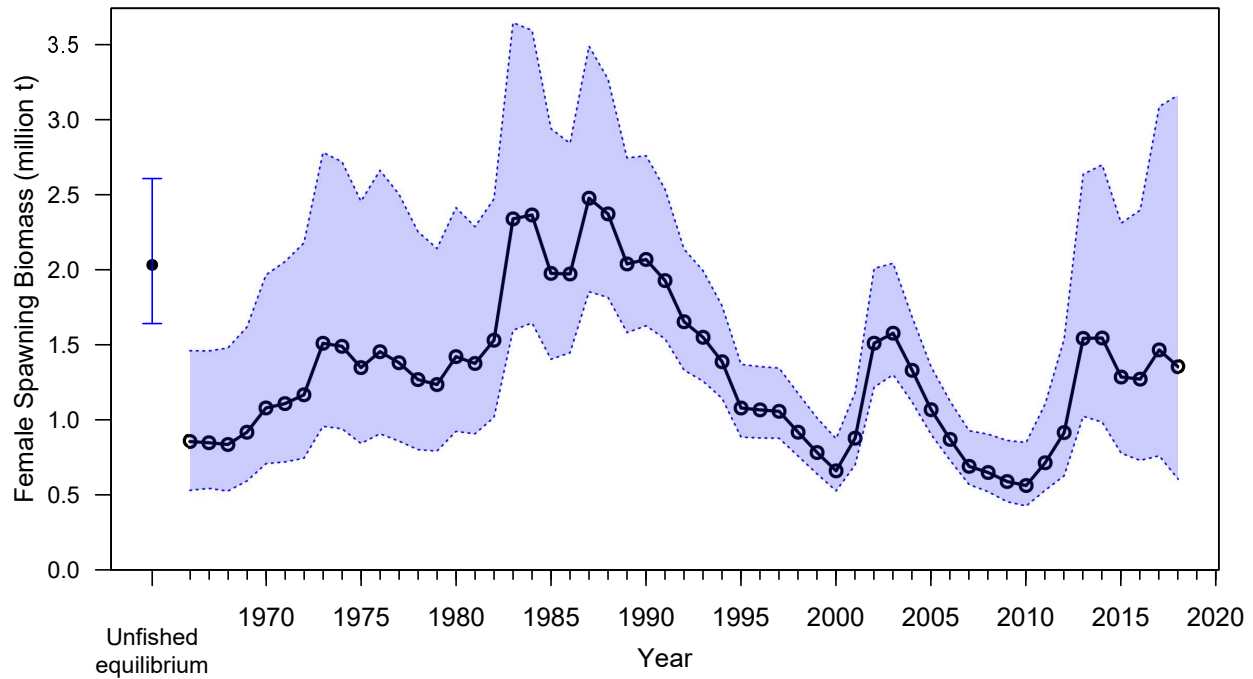
**Figure 27.** Mountains plot of median fishery selectivity in each year for the base model. Range of selectivity is 0 to 1 in each year.



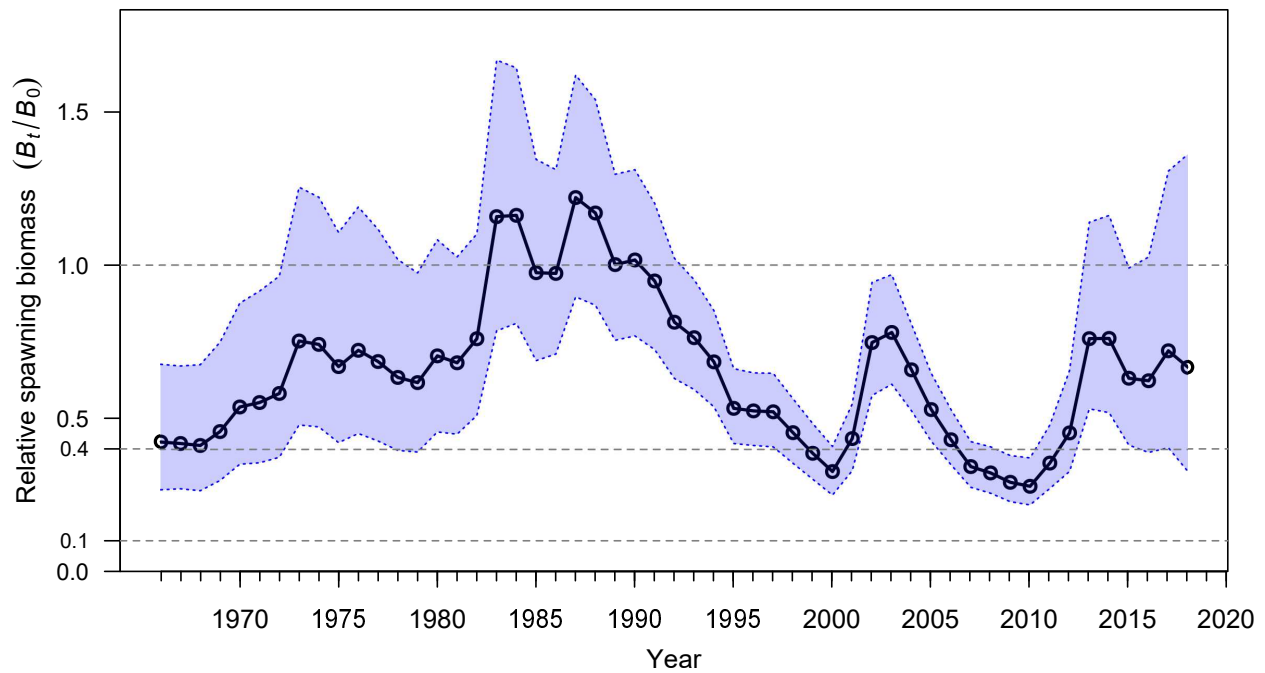
**Figure 28.** Fishery selectivity sampled from posterior probability distribution by year for the base model. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared for all years from 1966 to 1990.



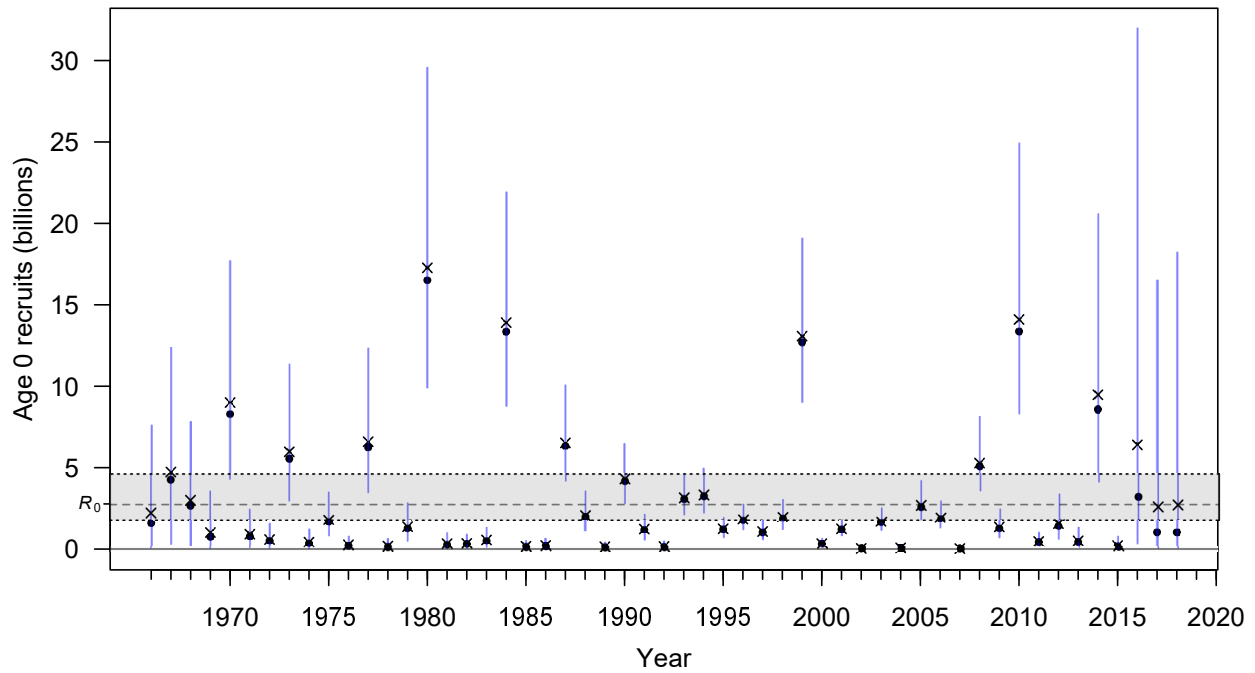
**Figure 29.** Estimated acoustic (top – for all years) and fishery selectivities (bottom – for 2017 only) from the posterior distribution for the base model.



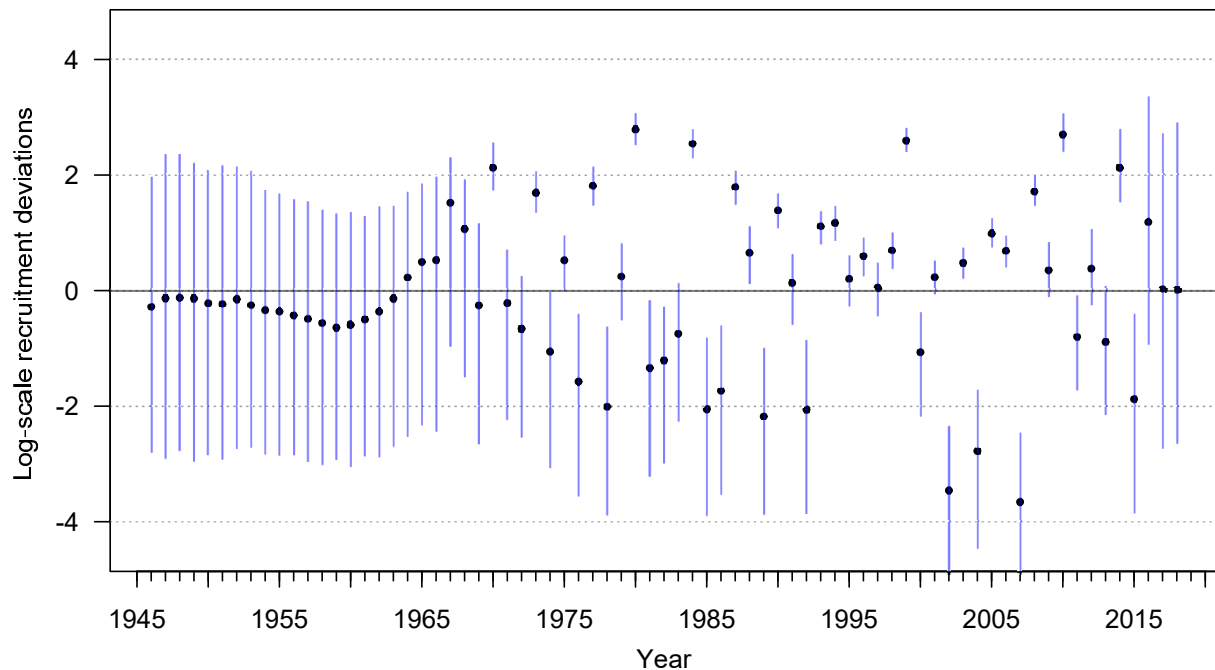
**Figure 30.** Median of the posterior distribution for female spawning biomass at the start of each year ( $B_t$ ) for the base model up to 2018 (solid line) with 95% posterior credibility intervals (shaded area).



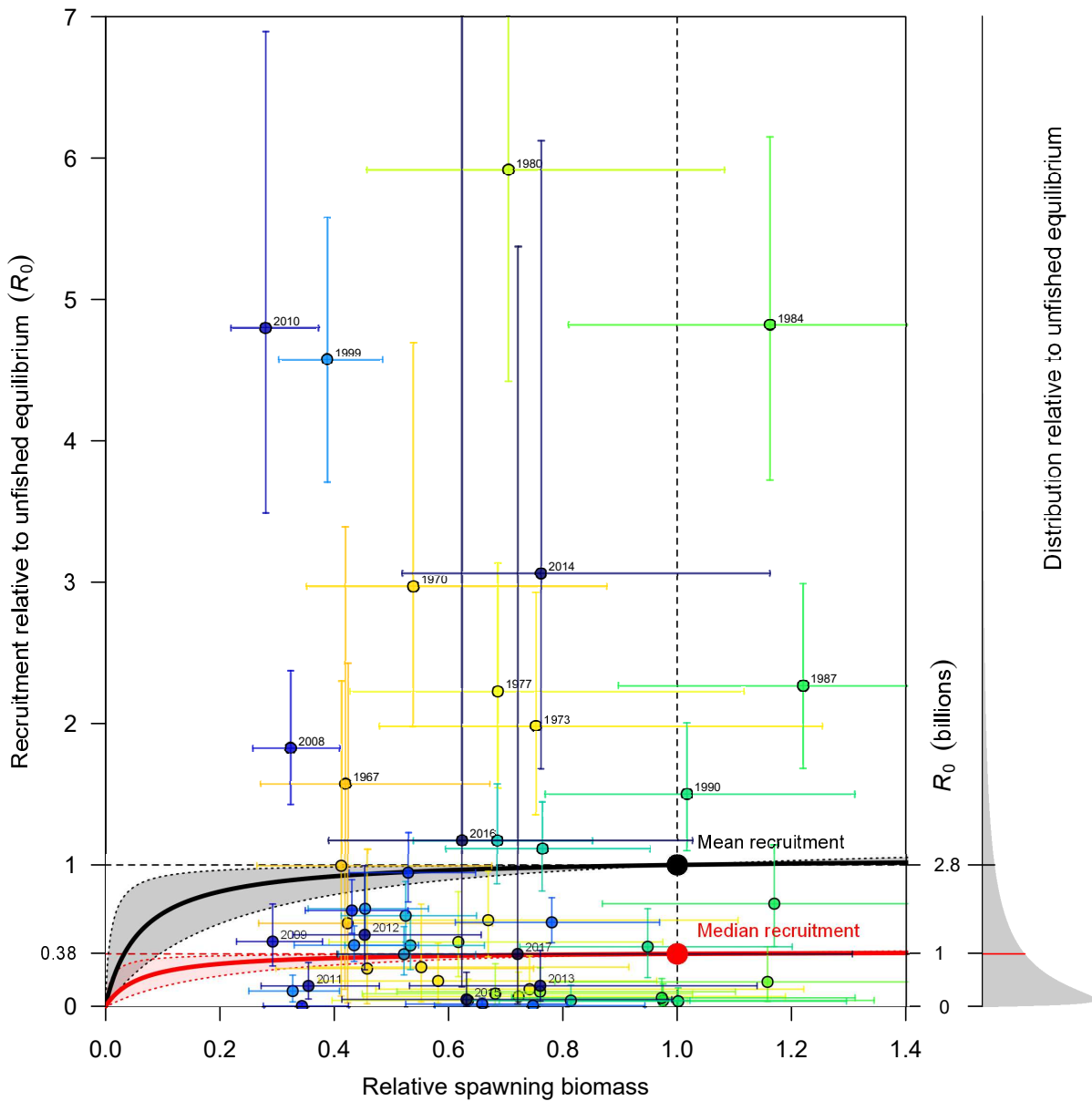
**Figure 31.** Median (solid line) of the posterior distribution for relative spawning biomass ( $B_t/B_0$ ) for the base model through 2018 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.



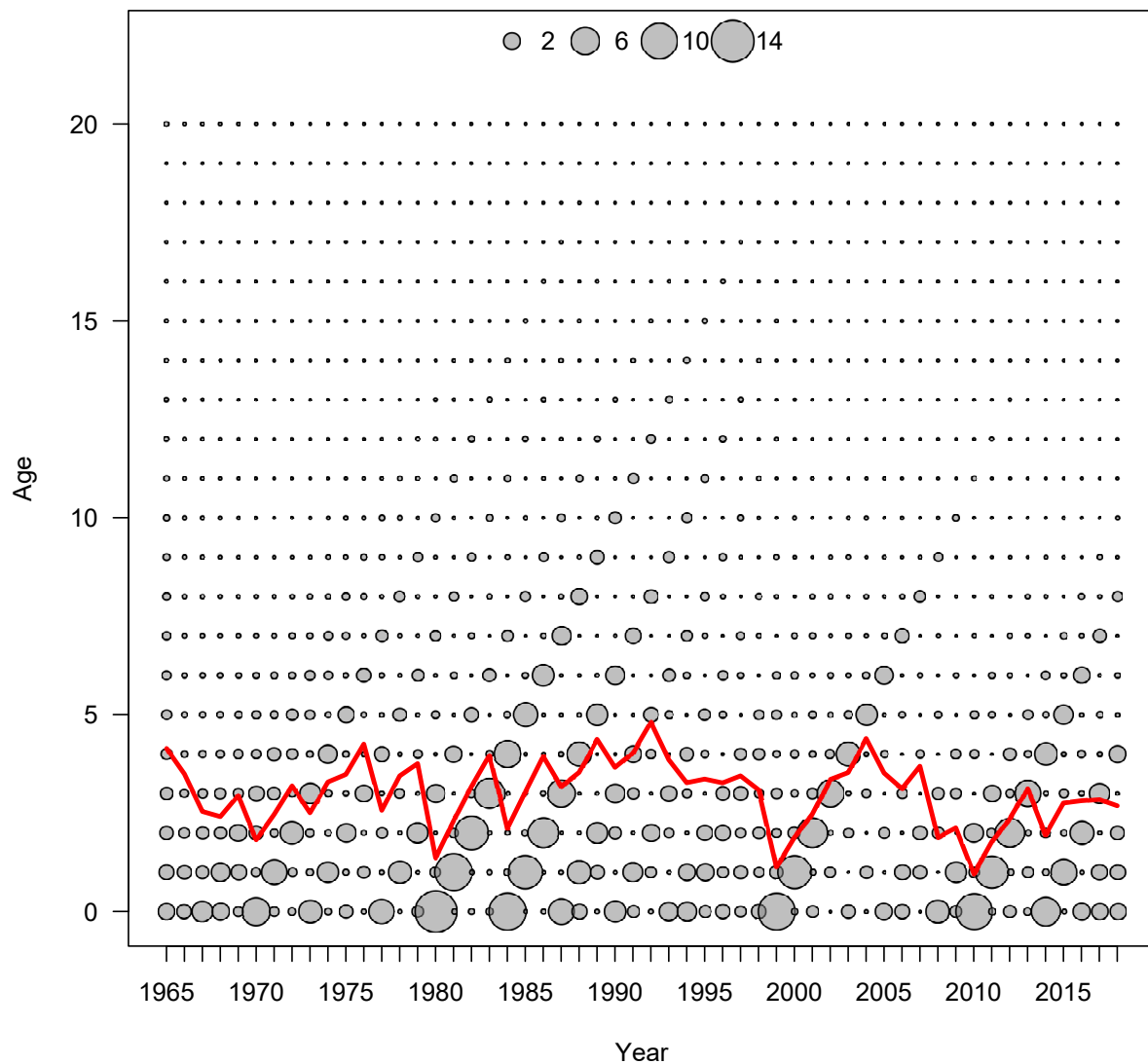
**Figure 32.** Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment ( $R_0$ ) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.



**Figure 33.** Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model. Deviations for the years 1970–2016 are constrained to sum to zero while deviations outside this range are represented as separate values that do not have that constraint.

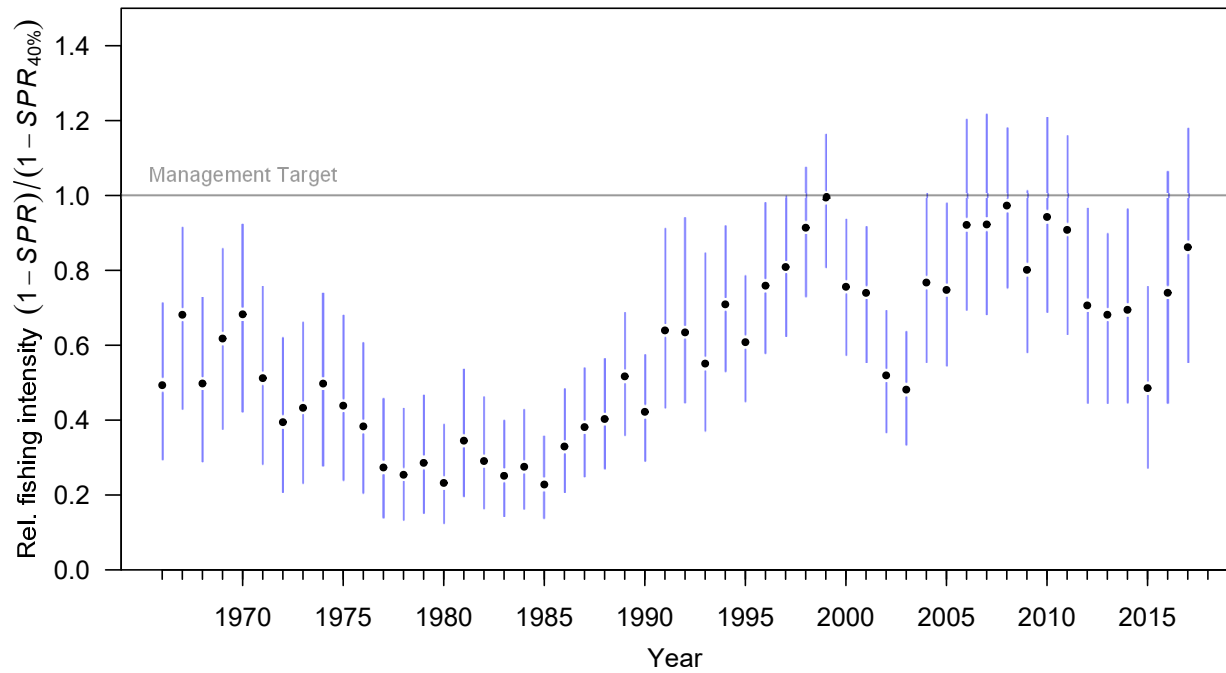


**Figure 34.** Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (mean) and the red line the central tendency after bias correcting for the log-normal distribution (median). Shading around stock-recruit curves indicates uncertainty in shape associated with distribution of the steepness parameter ( $h$ ). The gray polygon on the right indicates the expected distribution of recruitments relative to the unfished equilibrium.

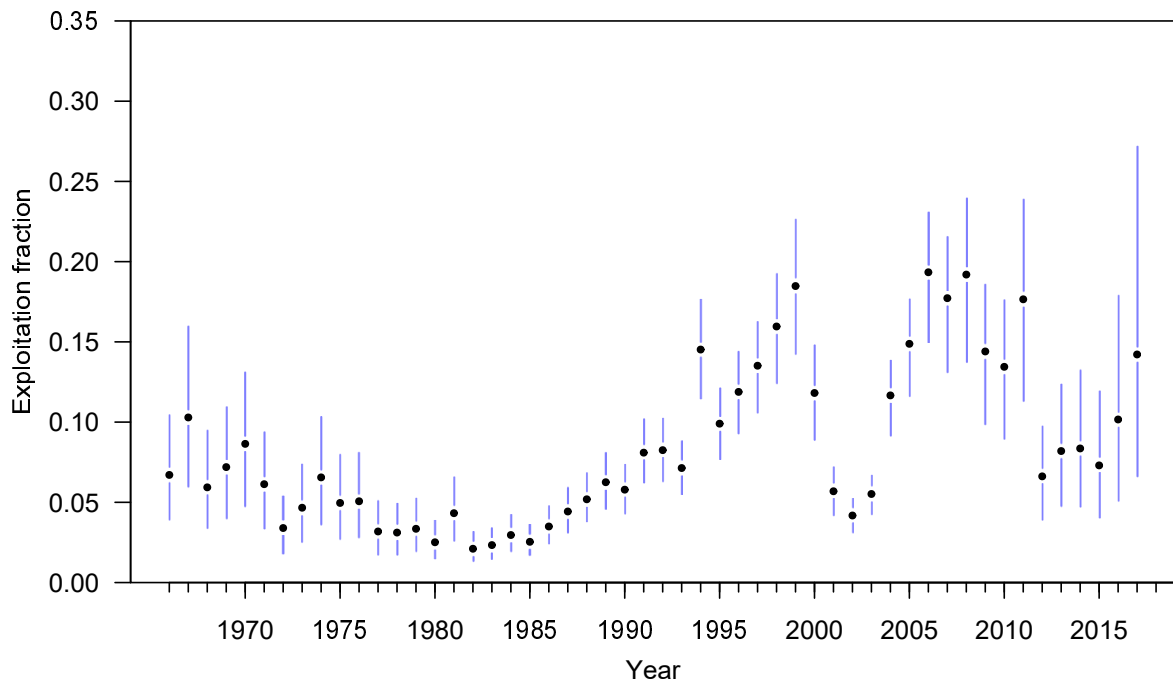


**Figure 35.** Bubble plot of maximum likelihood (MLE) estimates of population numbers at age at the beginning of each year, where diagonals follow each year-class through time. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish (with the largest bubble representing 13.7 billion age-0 recruits in 1980). See Table 20 for values.

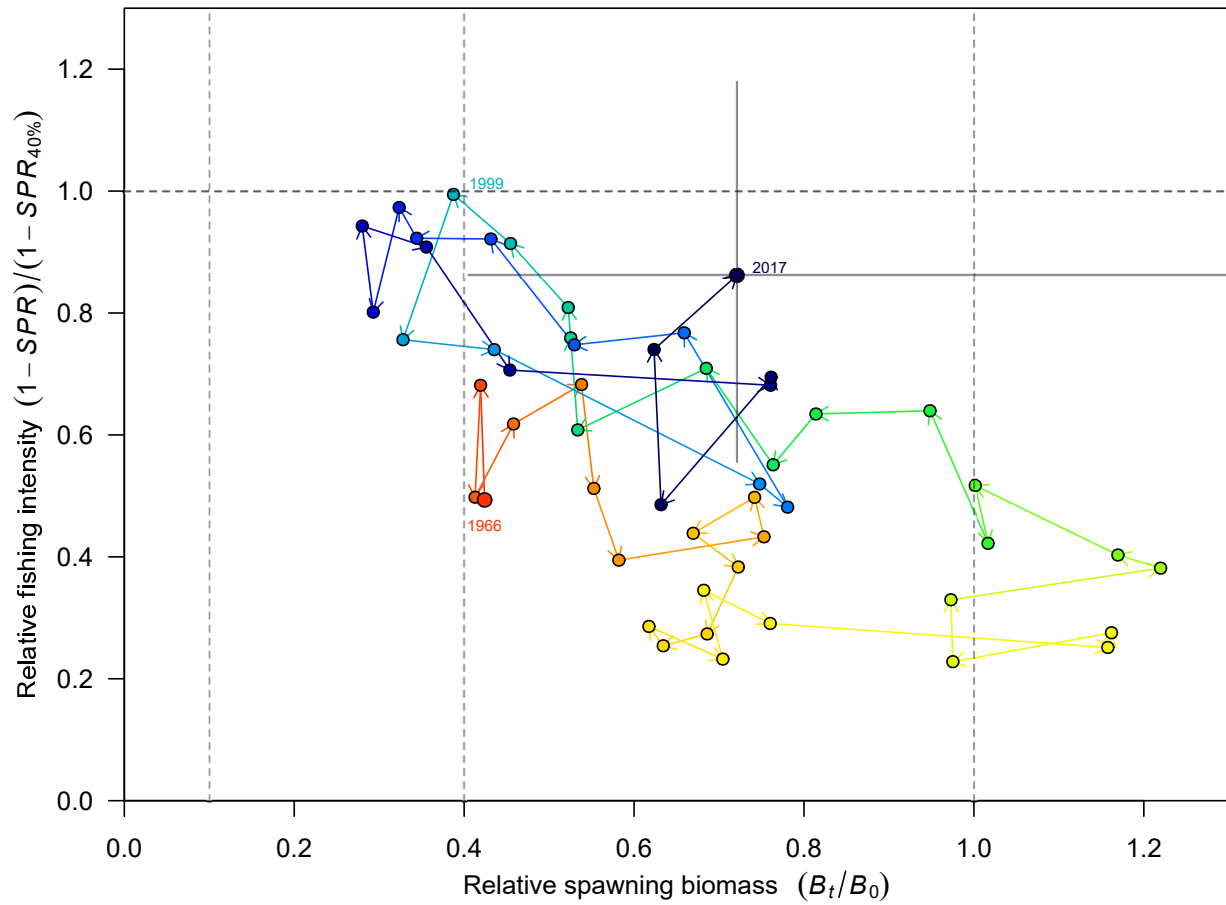




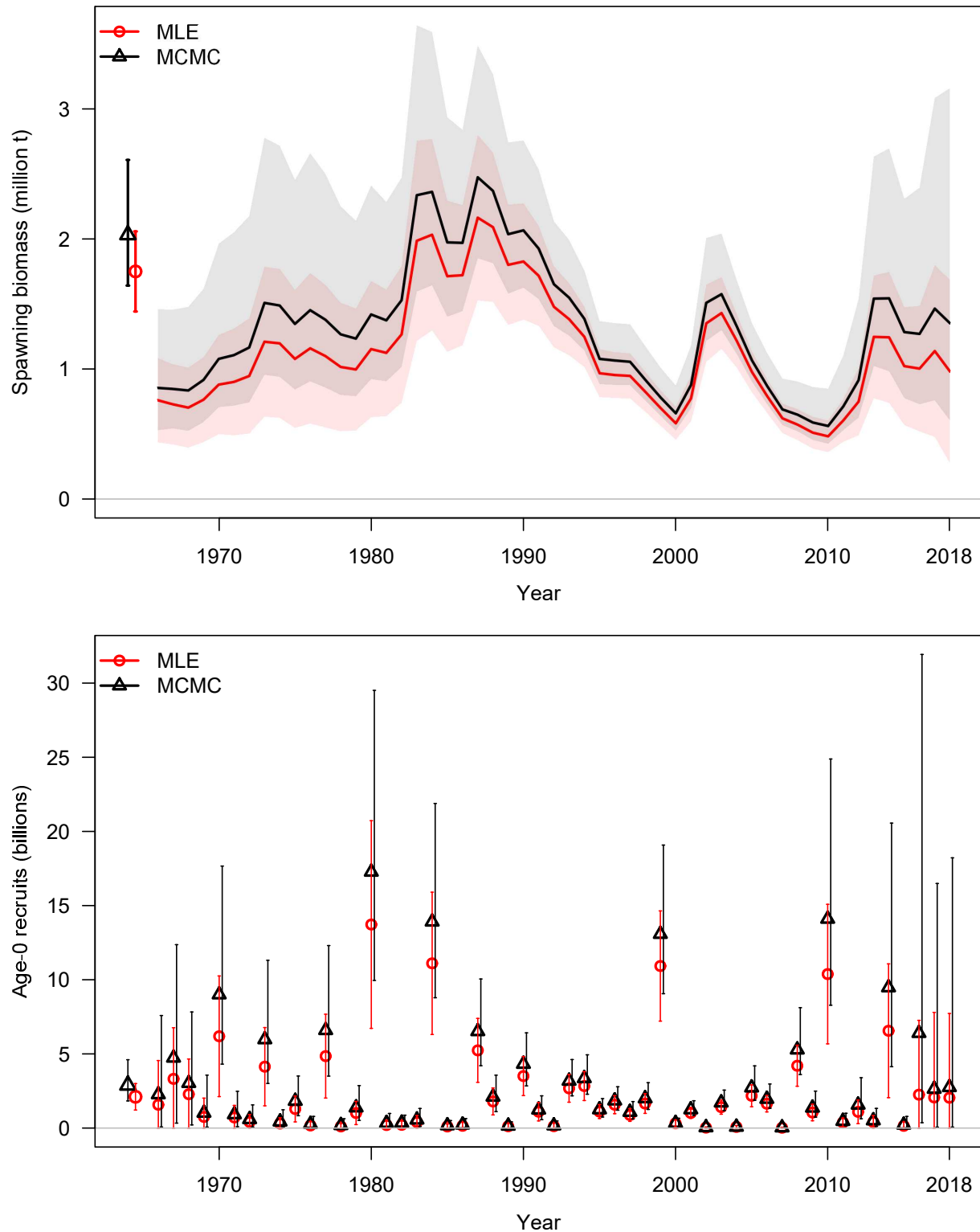
**Figure 36.** Trend in median fishing intensity (relative to the SPR management target) through 2017 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.



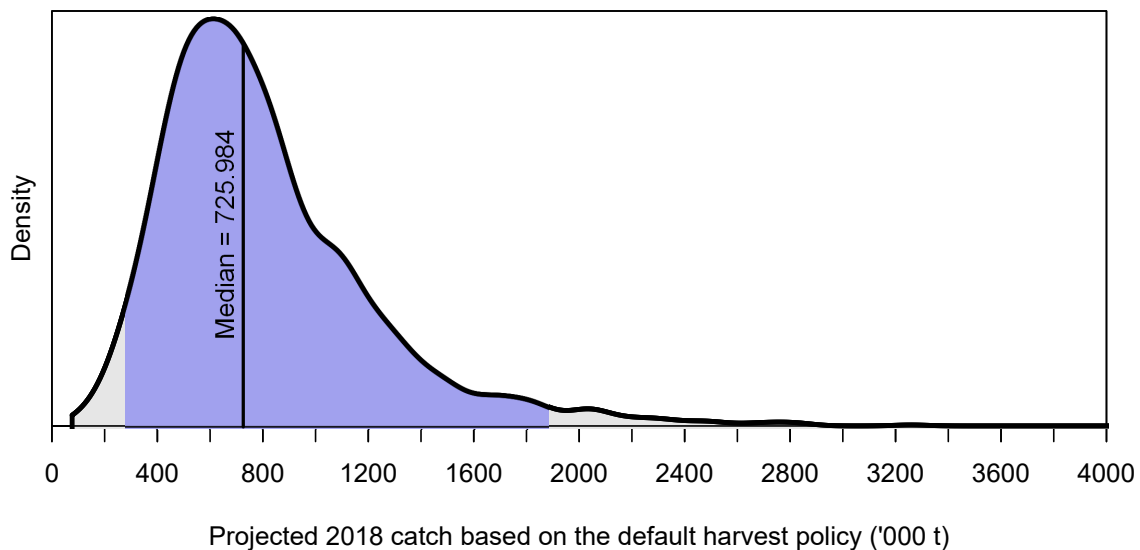
**Figure 37.** Trend in median exploitation fraction (catch divided by biomass of fish of age-2 and above) through 2017 with 95% posterior credibility intervals.



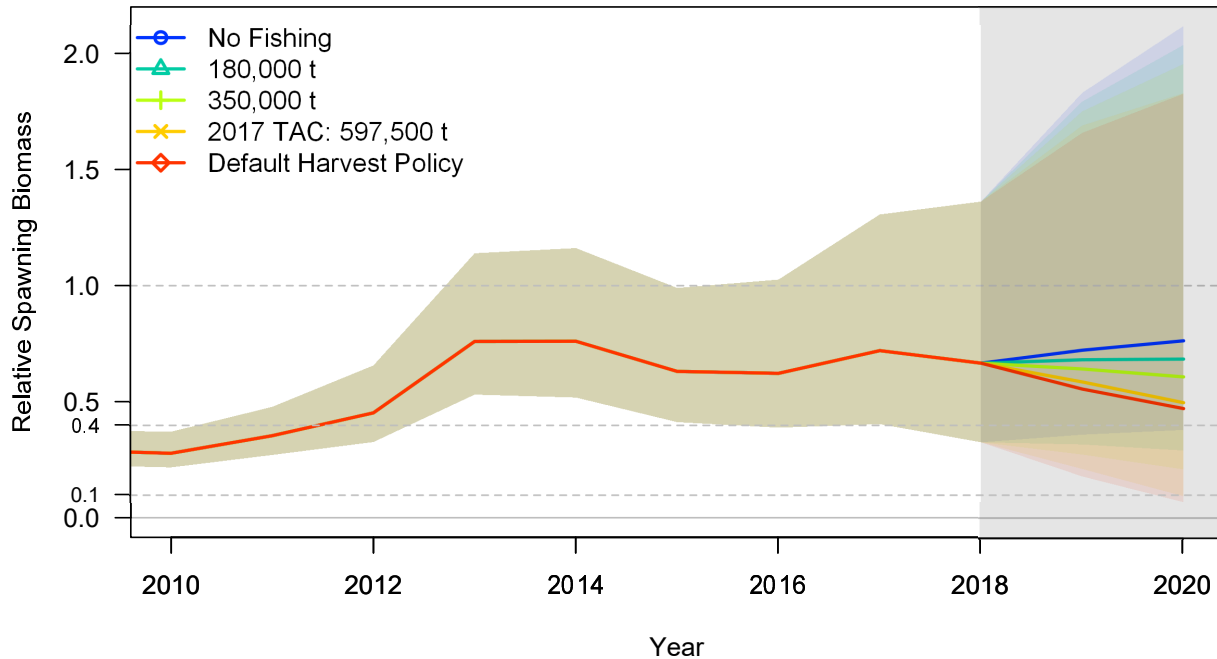
**Figure 38.** Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake. Start and end years are labeled, as is the year with the highest relative fishing intensity. Gray bars span the 95% credibility intervals for 2017 relative fishing intensity (vertical) and relative spawning biomass (horizontal).



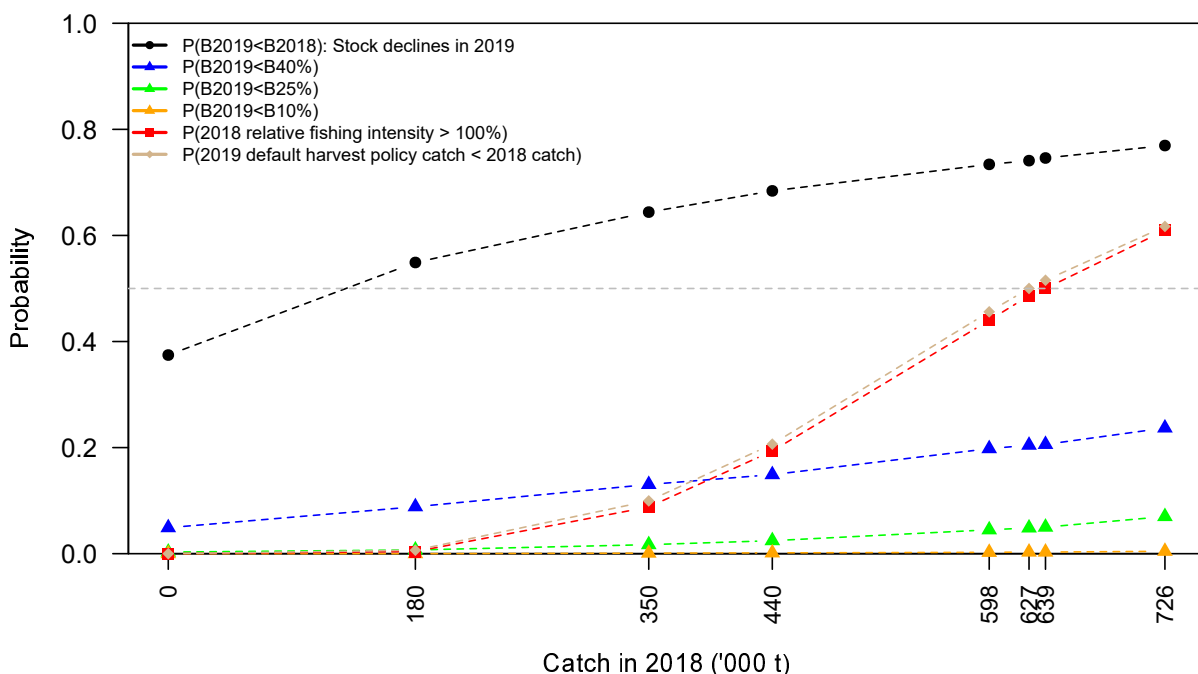
**Figure 39.** A comparison of maximum likelihood estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the posterior distribution with 95% credibility intervals (black). The posterior median is shown for spawning biomass while the posterior mean recruitment is displayed in the lower panel to be more comparable to the MLE value.



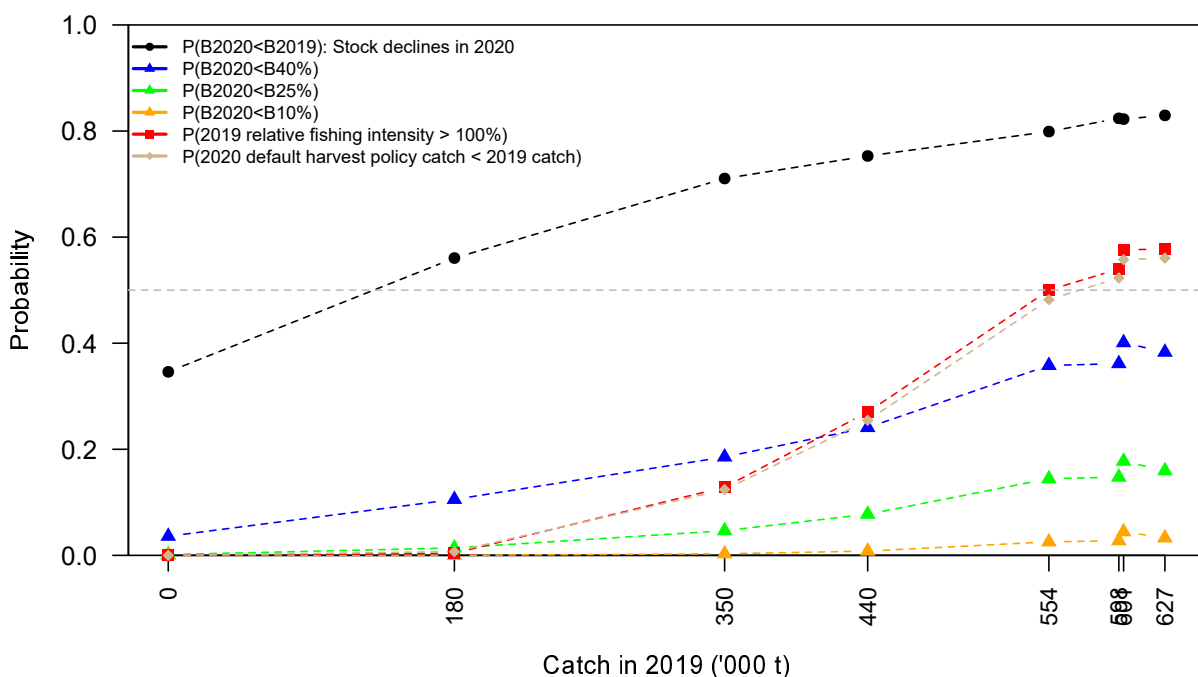
**Figure 40.** The posterior distribution of the default 2018 catch limit calculated using the default harvest policy ( $F_{\text{SPR}=40\%}-40:10$ ). The median is 725,984 t (vertical line), with the dark shaded area ranging from the 2.5% quantile to the 97.5% quantile, covering the range 270,948–1,881,590 t.



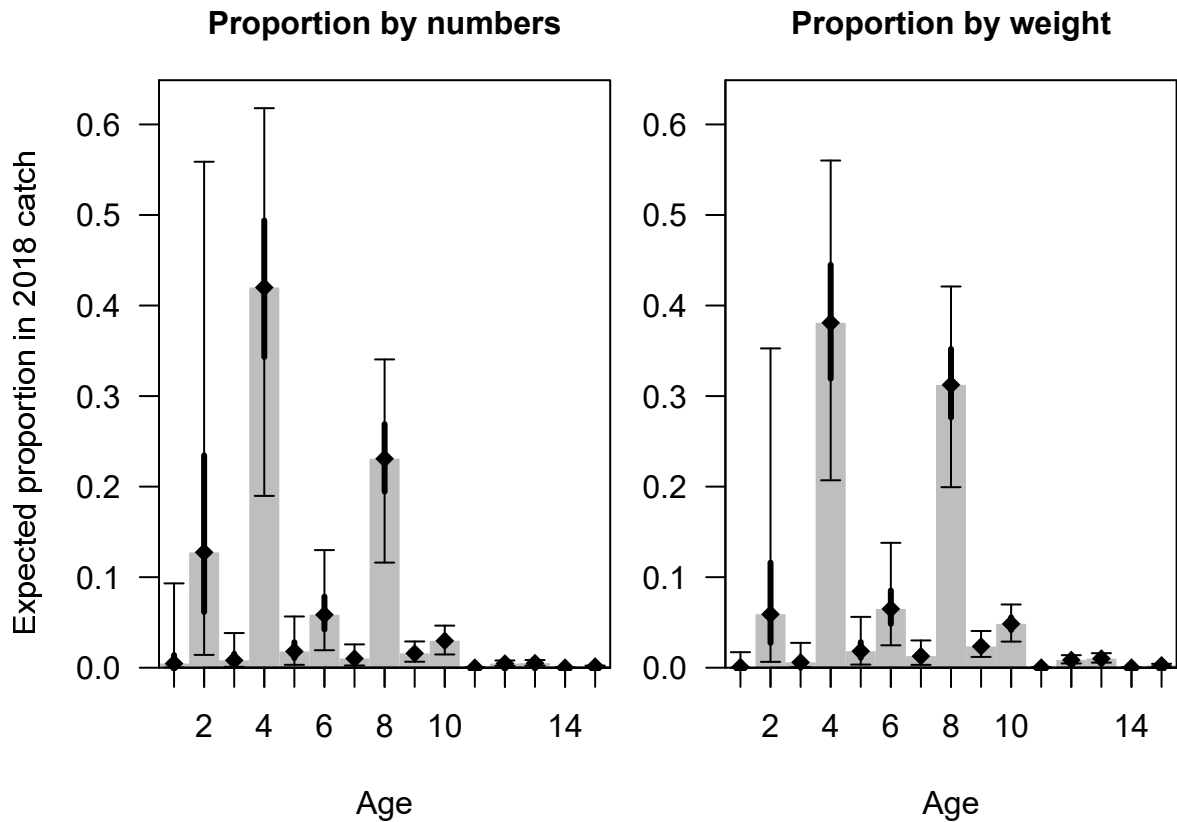
**Figure 41.** Time series of relative spawning biomass at the start of each year until 2018 as estimated from the base model, and forecast trajectories to the start of 2020 for several management options from the decision table (grey region), with 95% posterior credibility intervals. The 2018 catch of 725,984 t was calculated using the default harvest policy, as defined in the Agreement.



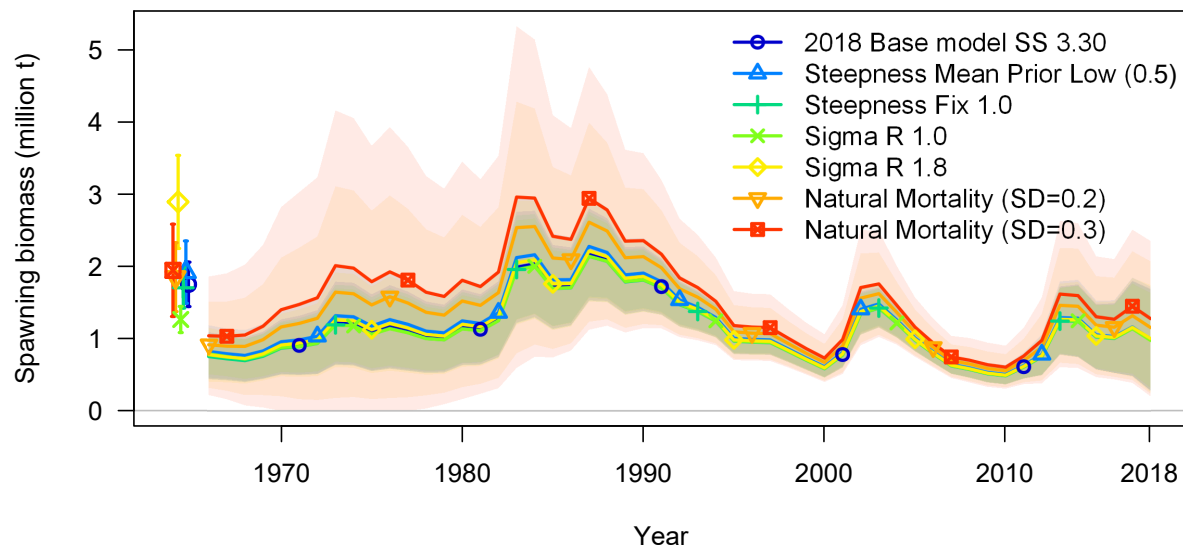
**Figure 42.** Graphical representation of the base model results presented in Table 30 for various catches in 2018. The symbols indicate points that were computed directly from model output and lines interpolate between the points.



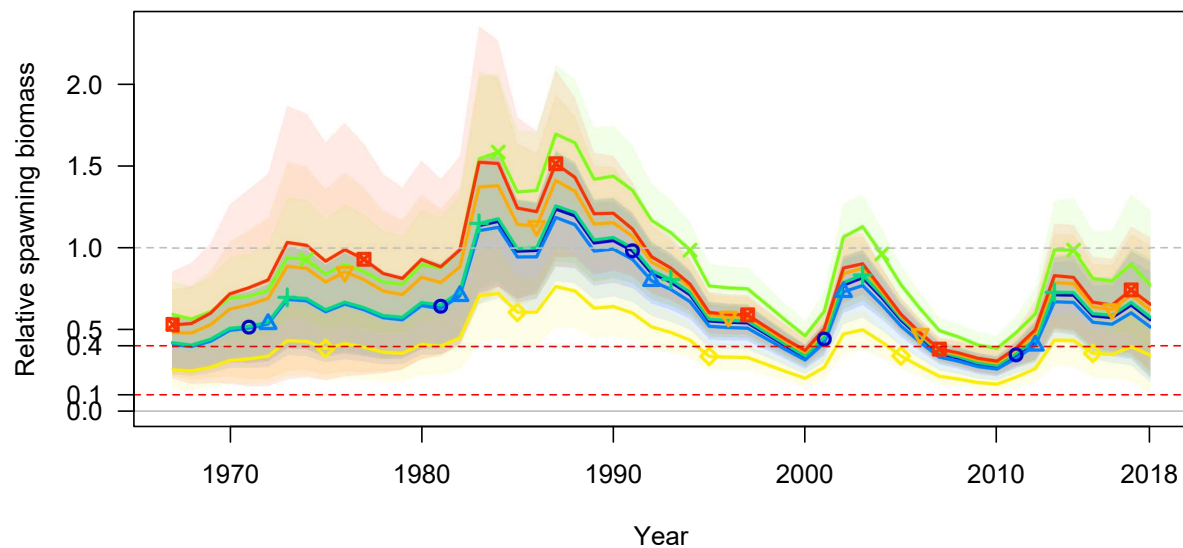
**Figure 43.** Graphical representation of the base model results presented in Table 31 for catch in 2019, given the 2018 catch level shown in Table 30. The symbols indicate points that were computed directly from model output and lines interpolate between the points.



**Figure 44.** Forecast age compositions in numbers and in weight for the 2018 fishery catch (combined across all sectors in both countries). Gray bars show median estimates. Thick black lines show 50% credibility intervals and thin black lines show 95% credibility intervals. These estimates are based on the posterior distribution for selectivity averaged across the most recent five years and the distribution for expected numbers at age at the start of 2018 (see Table 20 for the MLEs for numbers-at-age for all years). The panel on the right is scaled based on the weight at each age averaged across all years.

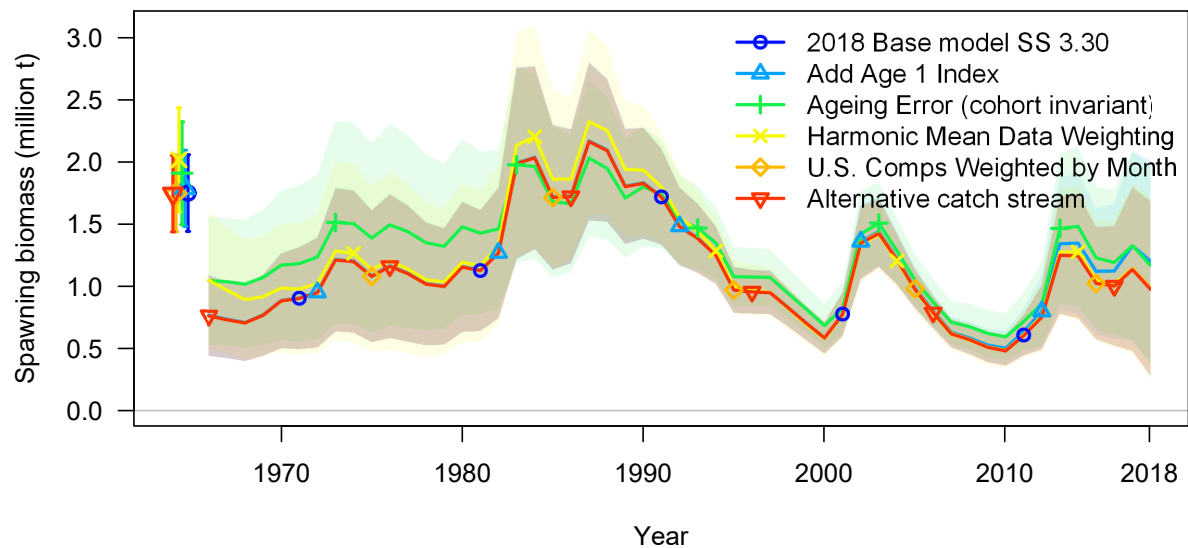


**Figure 45.** Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, lower (1.0) and higher (1.8) levels of sigma-R, and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3.

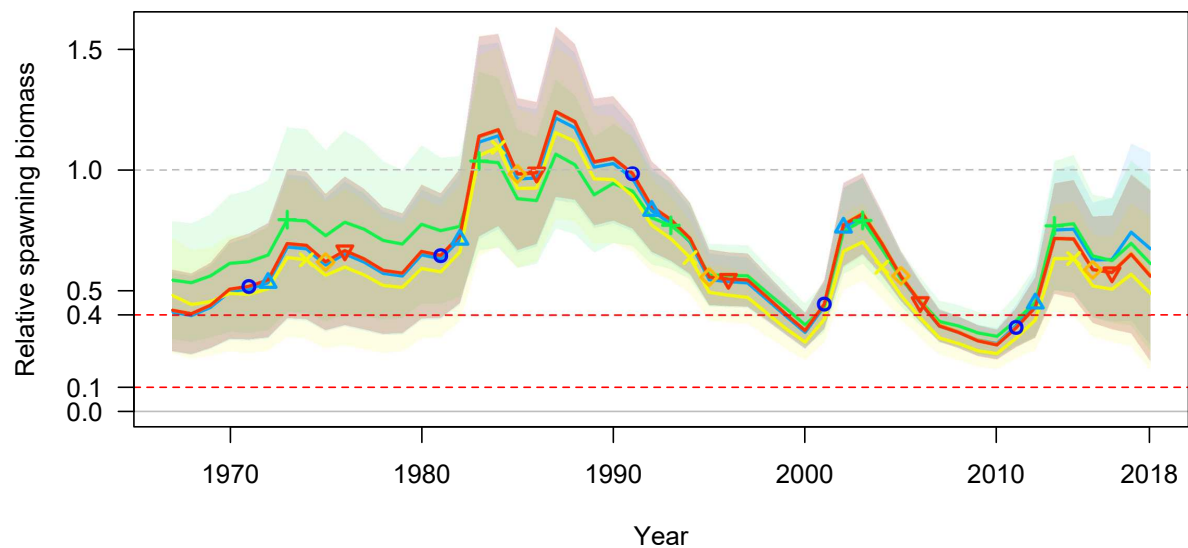


**Figure 46.** Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, lower (1.0) and higher (1.8) levels of sigma-R, and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3. See Figure 45 for legend.

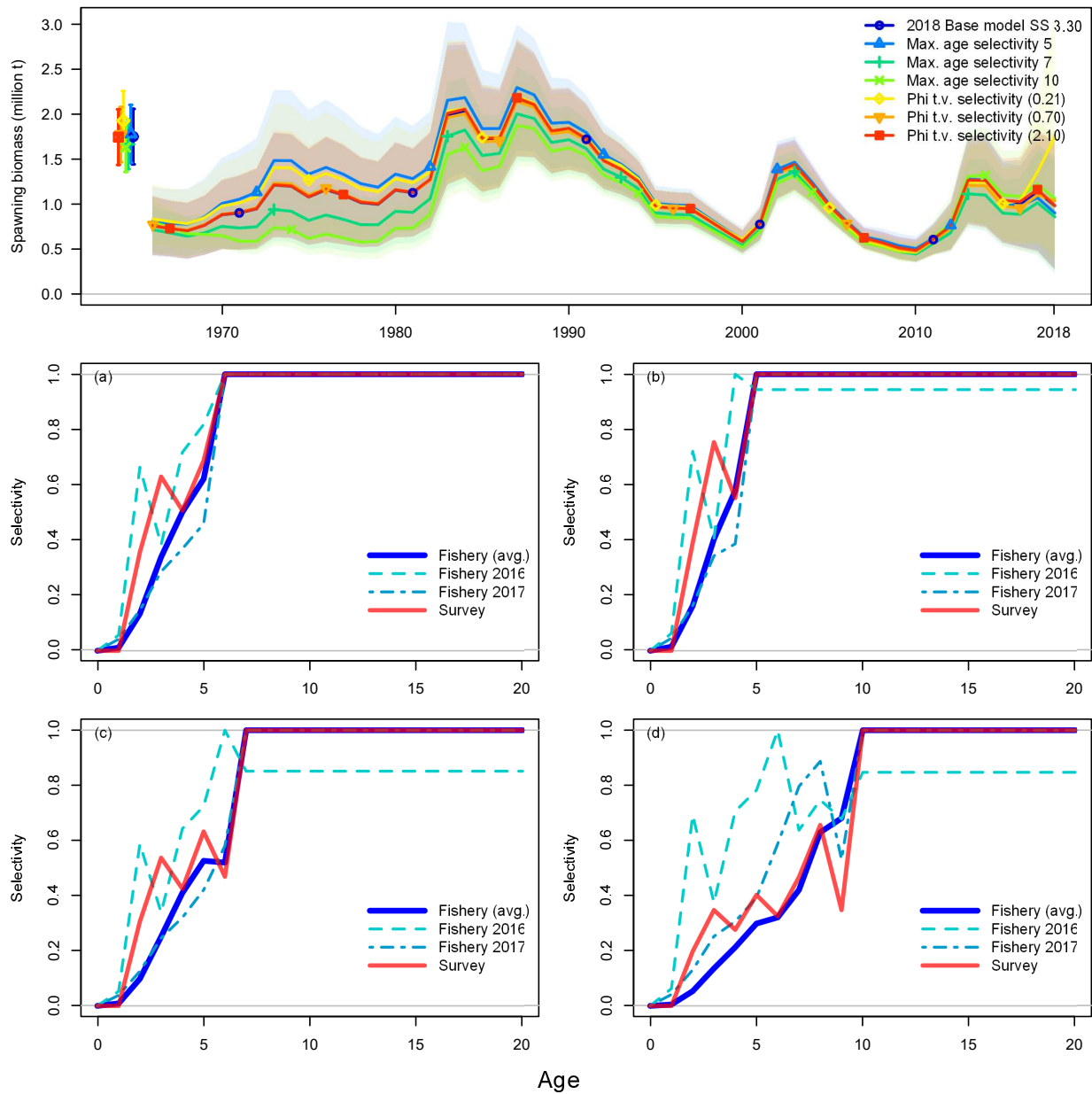




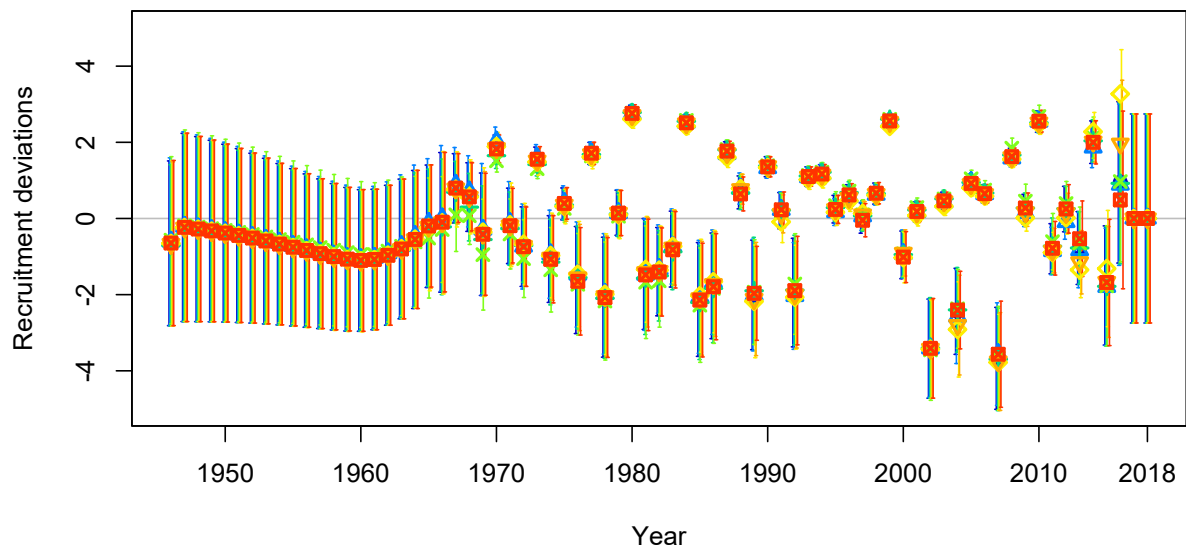
**Figure 47.** Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs that represent changes in data: adding an age-1 index of abundance, incorporating ageing error that is cohort invariant, using the harmonic mean approach to weight composition data, accounting for seasonal age sampling in the aggregation of age composition information, and removing catch which was double-counted for the Canadian JV fishery and adding U.S. tribal catch which was missed for 2016 and 2017.



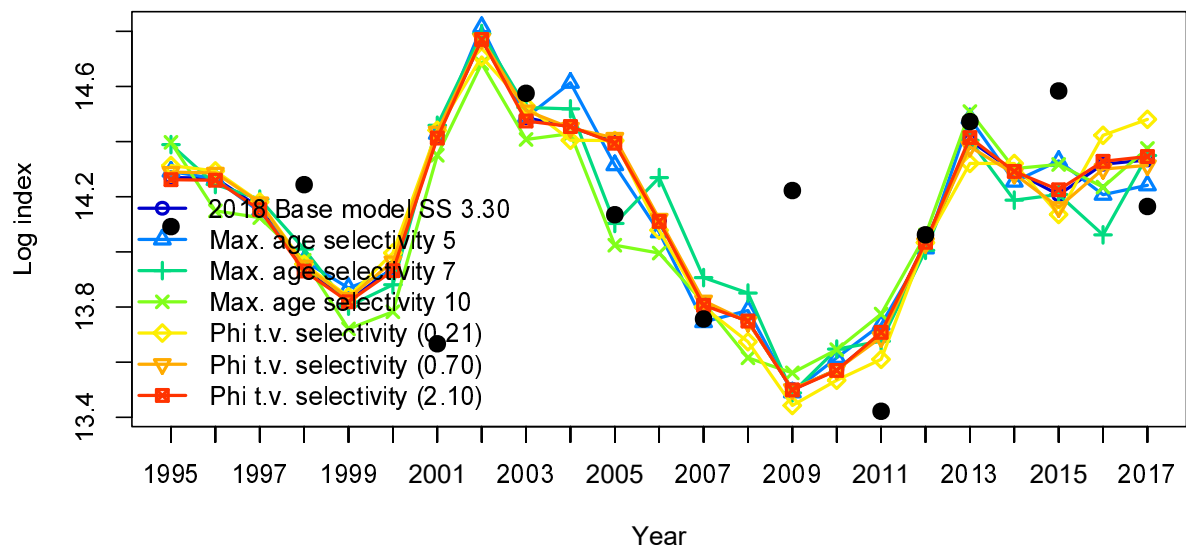
**Figure 48.** Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs that represent changes in data. See Figure 47 for sensitivity descriptions.



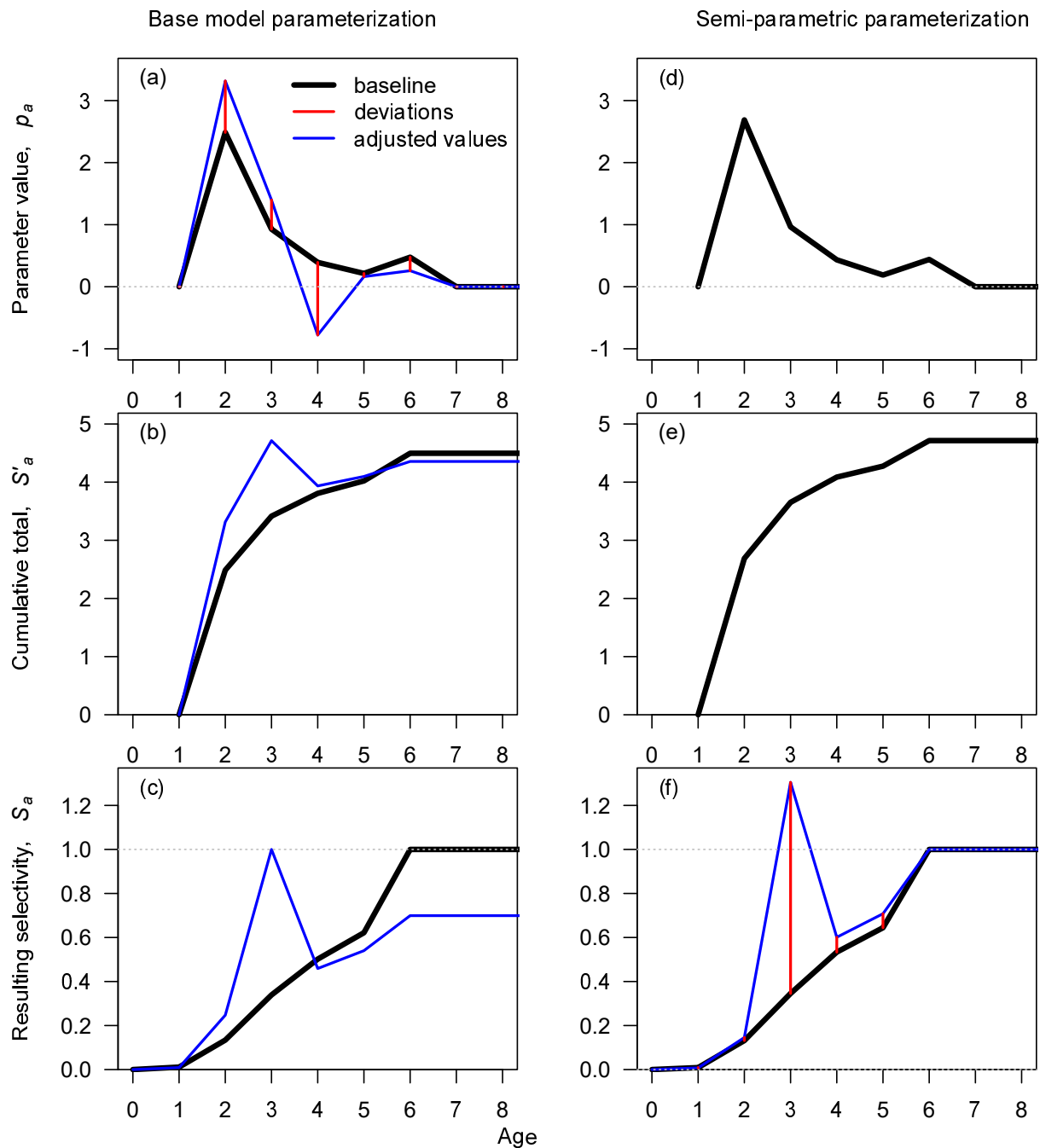
**Figure 49.** Top panel shows maximum likelihood estimates of spawning biomass and selectivity for the base model and alternative sensitivity runs representing changes in the age of maximum selectivity from the value of 6 in the base model and the standard deviation ( $\Phi$ ) associated with time-varying selectivity. Lower panels show baseline selectivity for both fleets and time-varying fishery selectivity for the two most recent years for a) Base model, b) Max. age selectivity 5, c) Max. age selectivity 7, and d) Max. age selectivity 10.



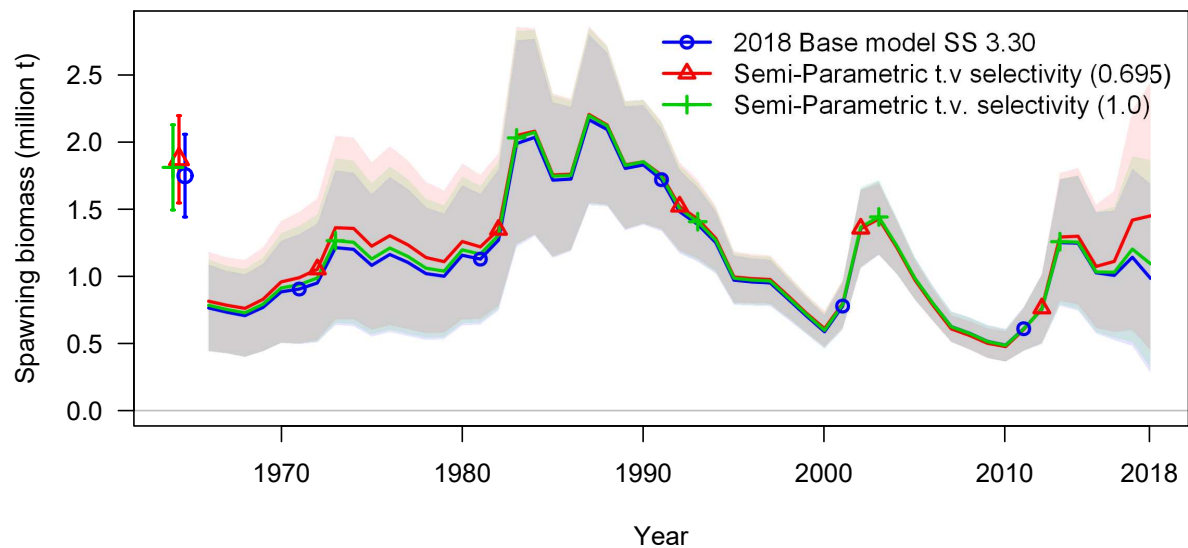
**Figure 50.** Maximum likelihood estimates of recruitment deviations for the base model and alternative sensitivity runs (refer to the legend below) representing changes in the age of maximum selectivity from the value of 6 in the base model and the standard deviation ( $\Phi$ ) associated with time-varying selectivity.



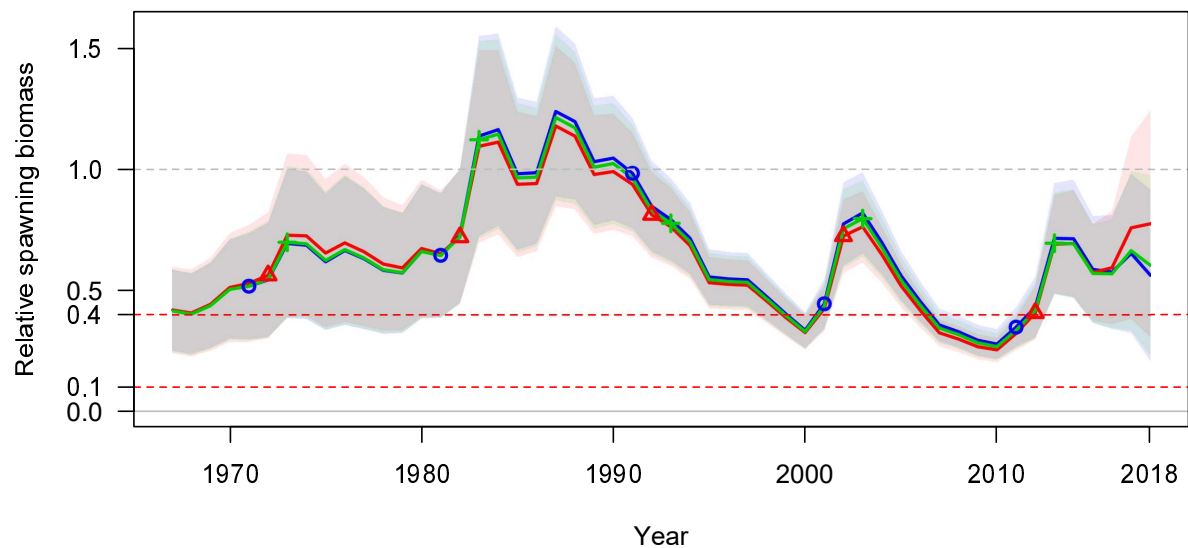
**Figure 51.** Maximum likelihood estimates of the fit to the survey biomass index for the base model and alternative sensitivity runs representing changes in the age of maximum selectivity from the value of 6 in the base model and the standard deviation ( $\Phi$ ) associated with time-varying selectivity.



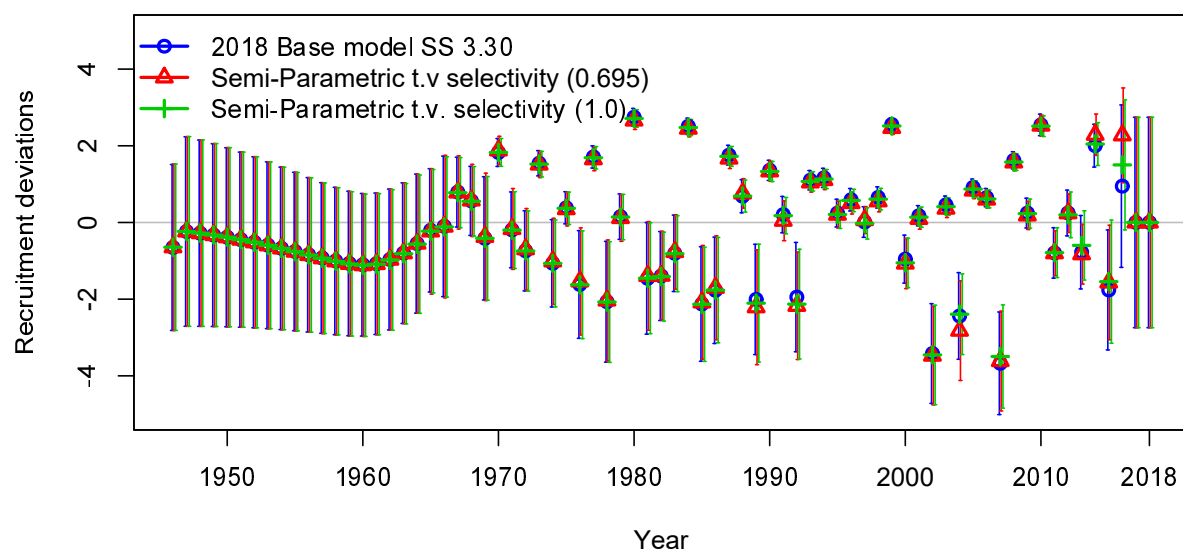
**Figure 52.** Illustration of parameterization of time-varying selectivity as represented in the base model (left) and the semi-parametric approach used in sensitivity analyses (right). Panels show transformation from estimated parameters (a) to cumulative sum up to each age (b) and the resulting selectivity after exponential transformation and rescaling to have maximum 1.0 (c), as described by equations (1) through (3). In the base model, the deviations (red lines) are applied to the baseline parameters, resulting in a new set of parameters which are transformed in the same way, as shown in the blue lines in (a) through (c). In the alternative approach, the deviations are applied as exponential offsets to the resulting selectivity (f).



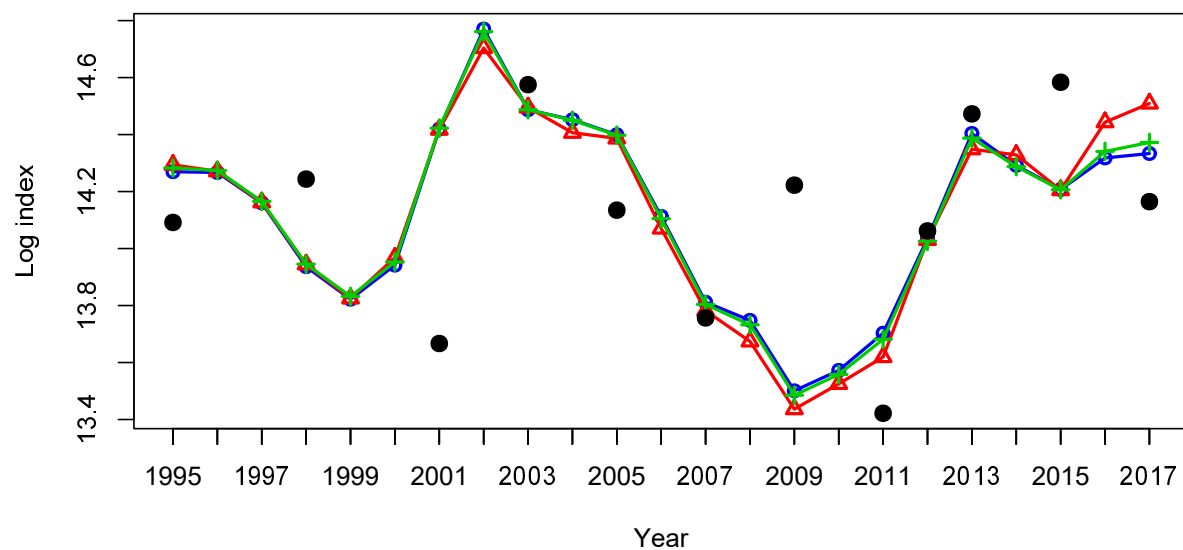
**Figure 53.** Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing the use of a semi-parametric approach for implementing time-varying selectivity ( $\sigma$ -S).



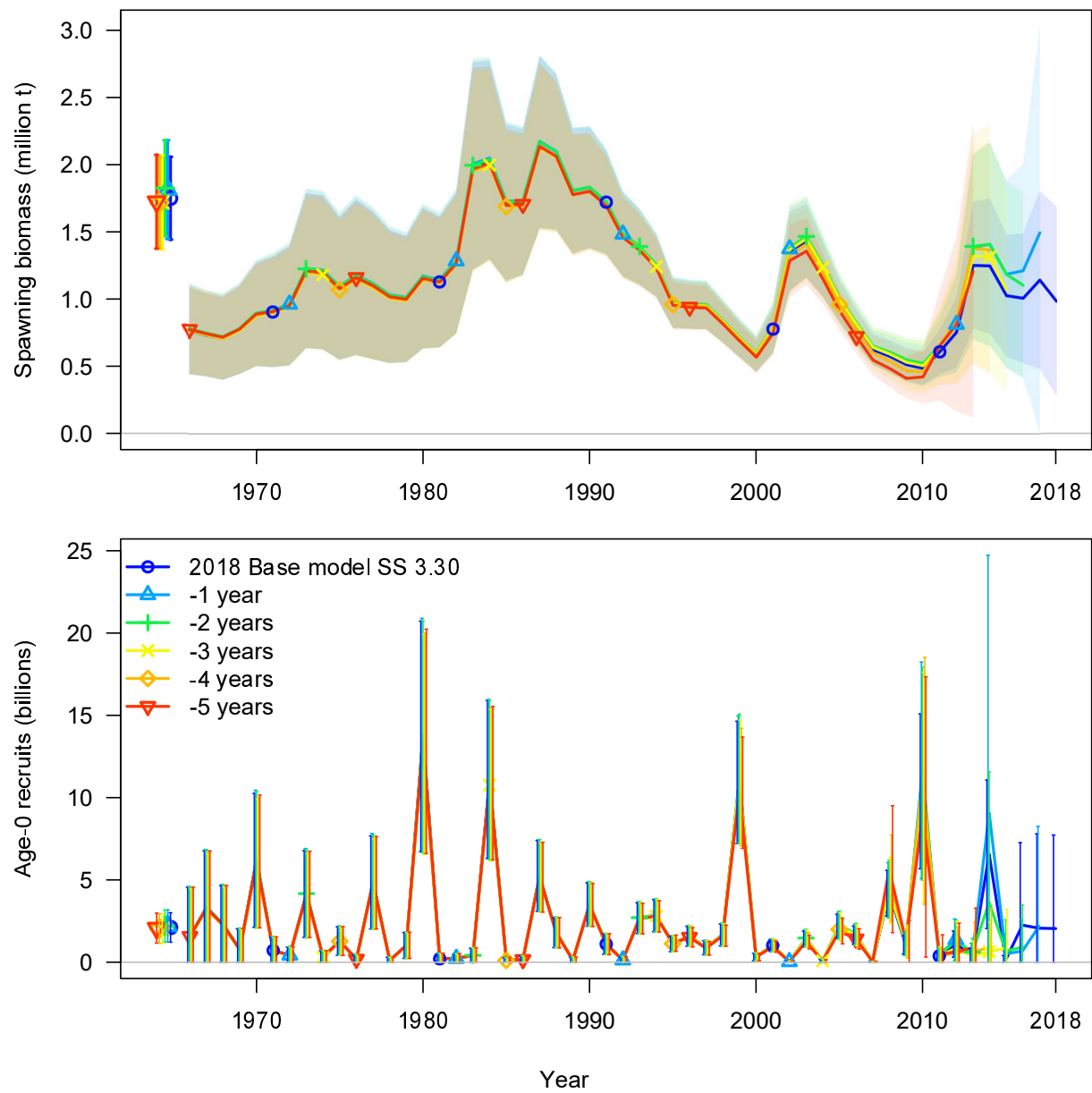
**Figure 54.** Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing the use of a semi-parametric approach for implementing time-varying selectivity ( $\sigma$ -S). See Figure 53 for legend.



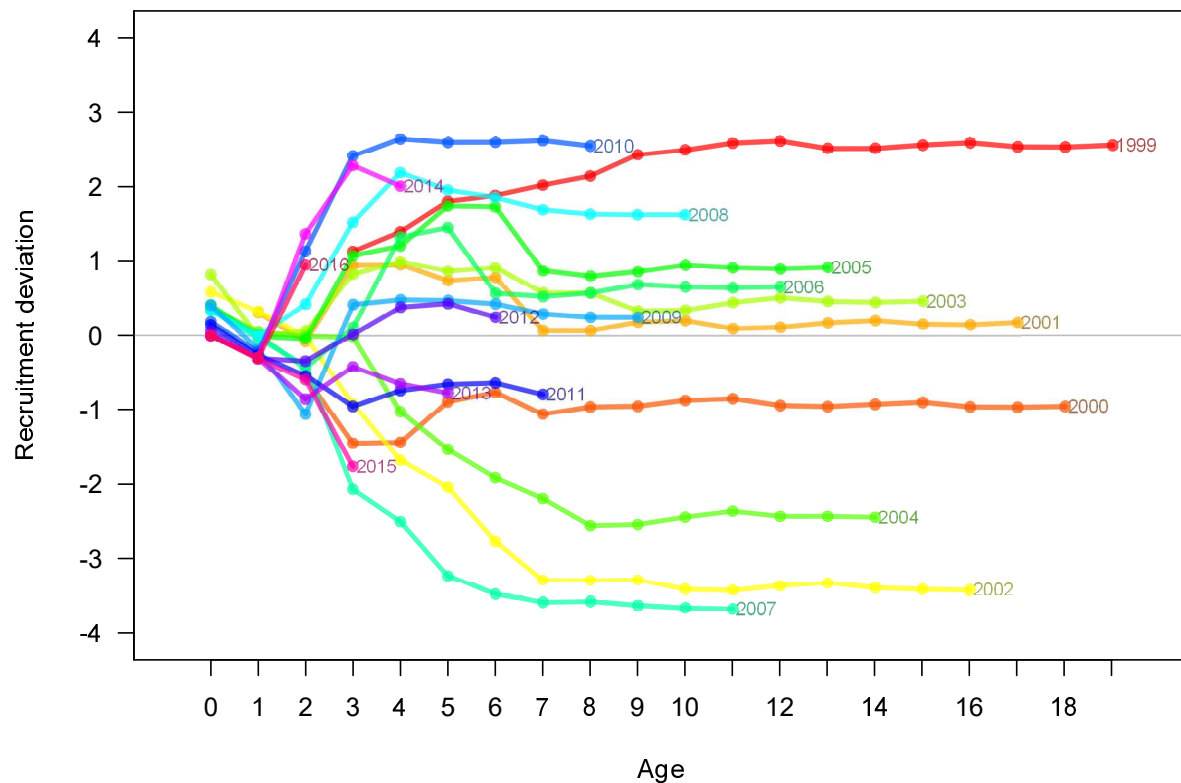
**Figure 55.** Maximum likelihood estimates of recruitment deviations for the base model and alternative sensitivity runs representing the use of a semi-parametric approach for implementing time-varying selectivity (sigma-S). See Figure 53 for legend.



**Figure 56.** Maximum likelihood estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs representing the use of a semi-parametric approach for implementing time-varying selectivity (sigma-S). See Figure 53 for legend.

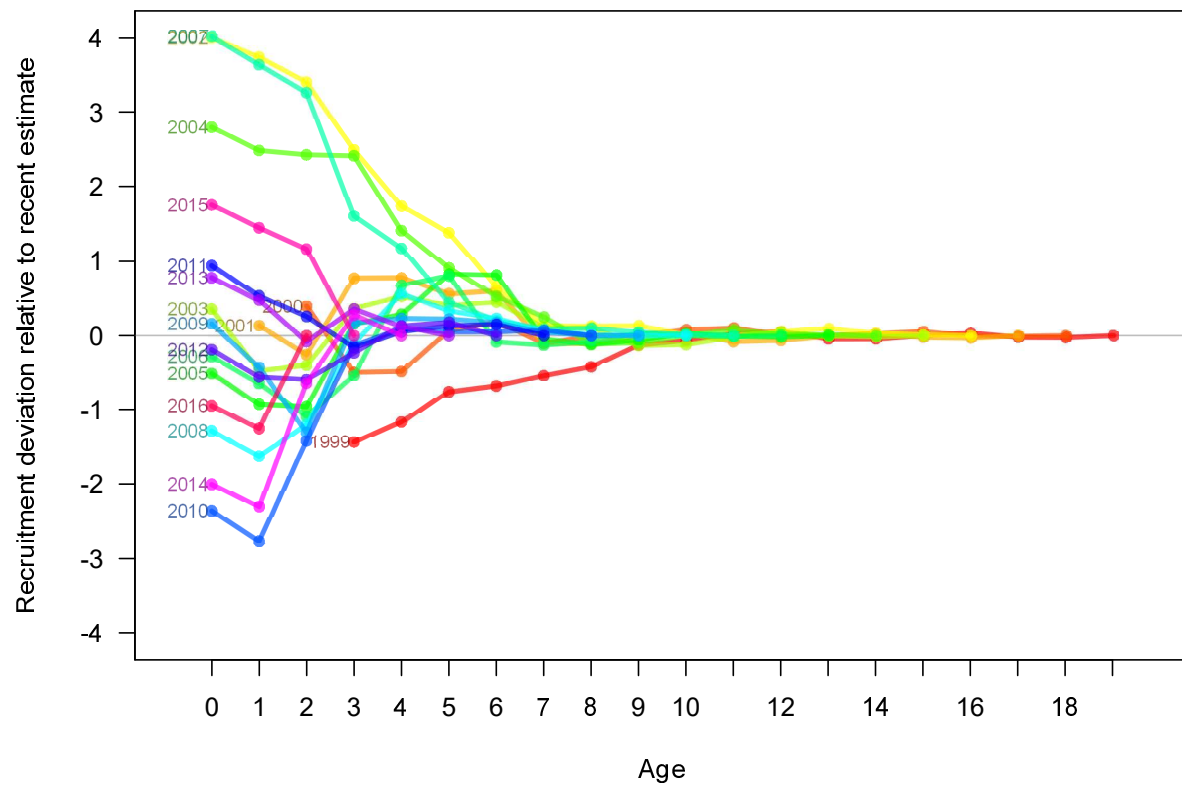


**Figure 57.** Estimates of spawning biomass at the start of each year (top) and recruitment (bottom) for the base model and retrospective runs (based on MLE model runs).

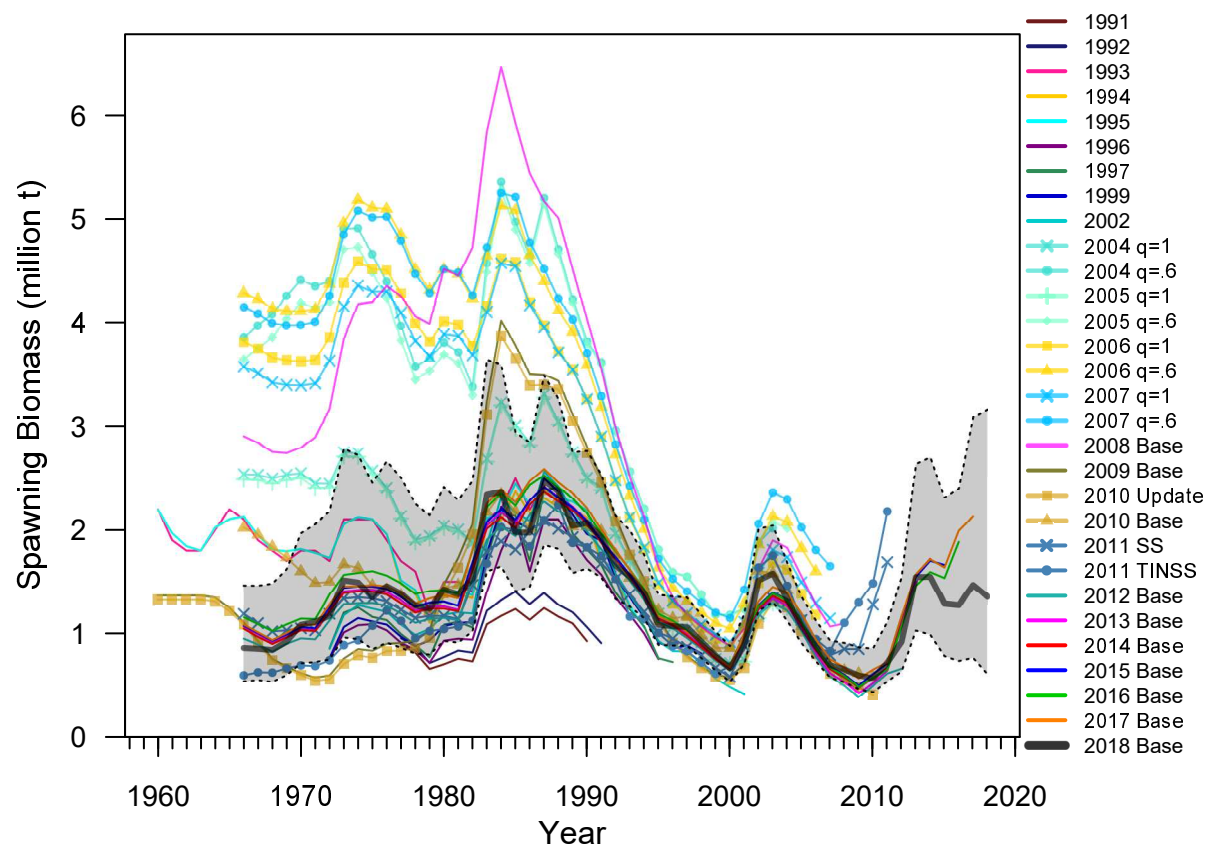


**Figure 58.** Retrospective analysis of recruitment deviations from maximum likelihood estimate (MLE) models over the last 17 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for cohorts from 1999 to 2016, with cohort birth year marked at the right of each color-coded line. Values are estimated by models using data available only up to the year in which each cohort was a given age.





**Figure 59.** Retrospective recruitment estimates shown in Figure 58 scaled relative to the most recent estimate of the strength of each cohort.



**Figure 60.** Summary of historical Pacific Hake assessment estimates of spawning biomass. Estimates are MLEs or MCMC medians depending on the model structure. Shading represents the approximate 95% confidence range from the 2018 base model.

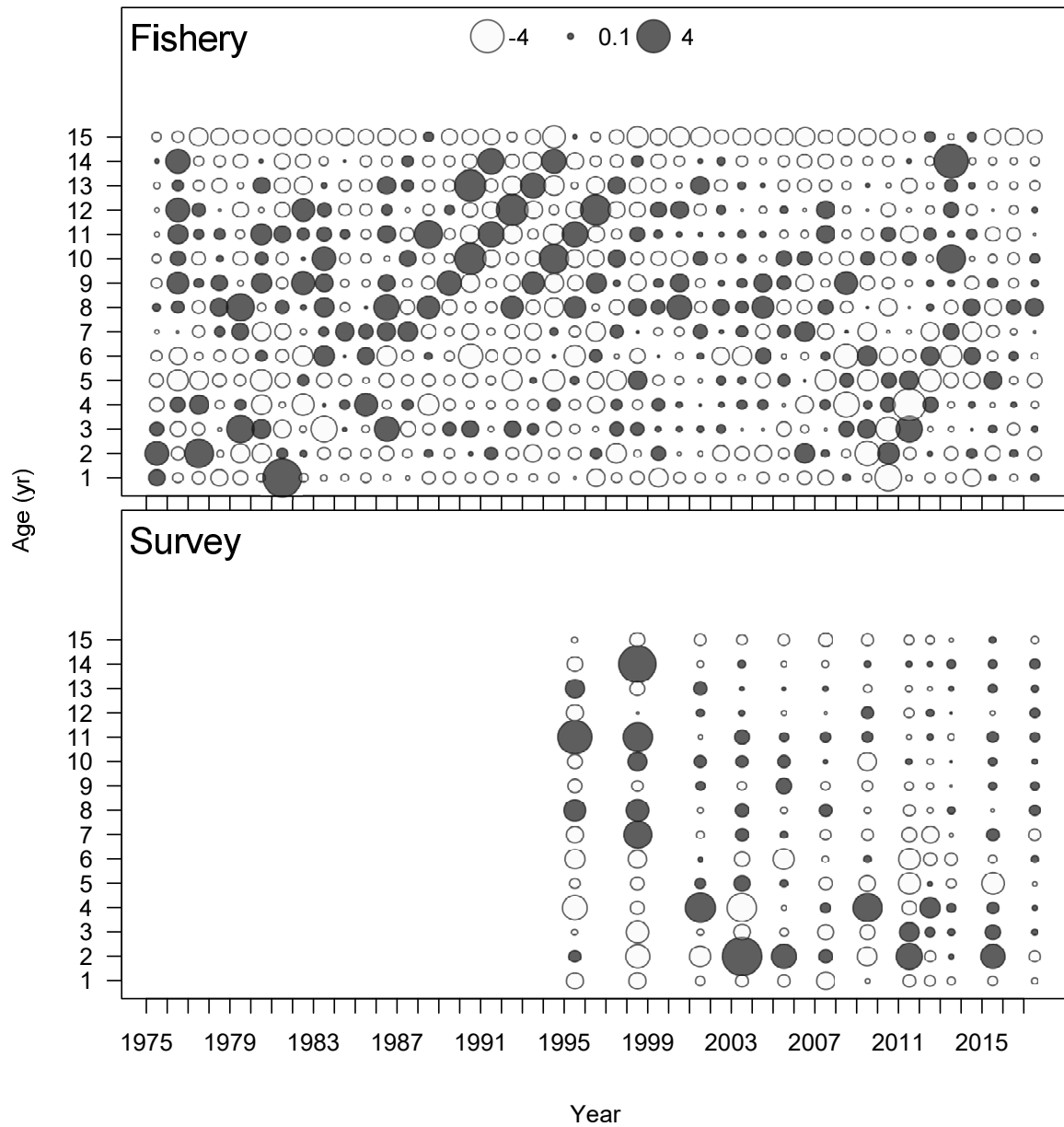
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## **A SCIENTIFIC REVIEW GROUP (SRG) REQUESTS FROM 2018 MEETING**

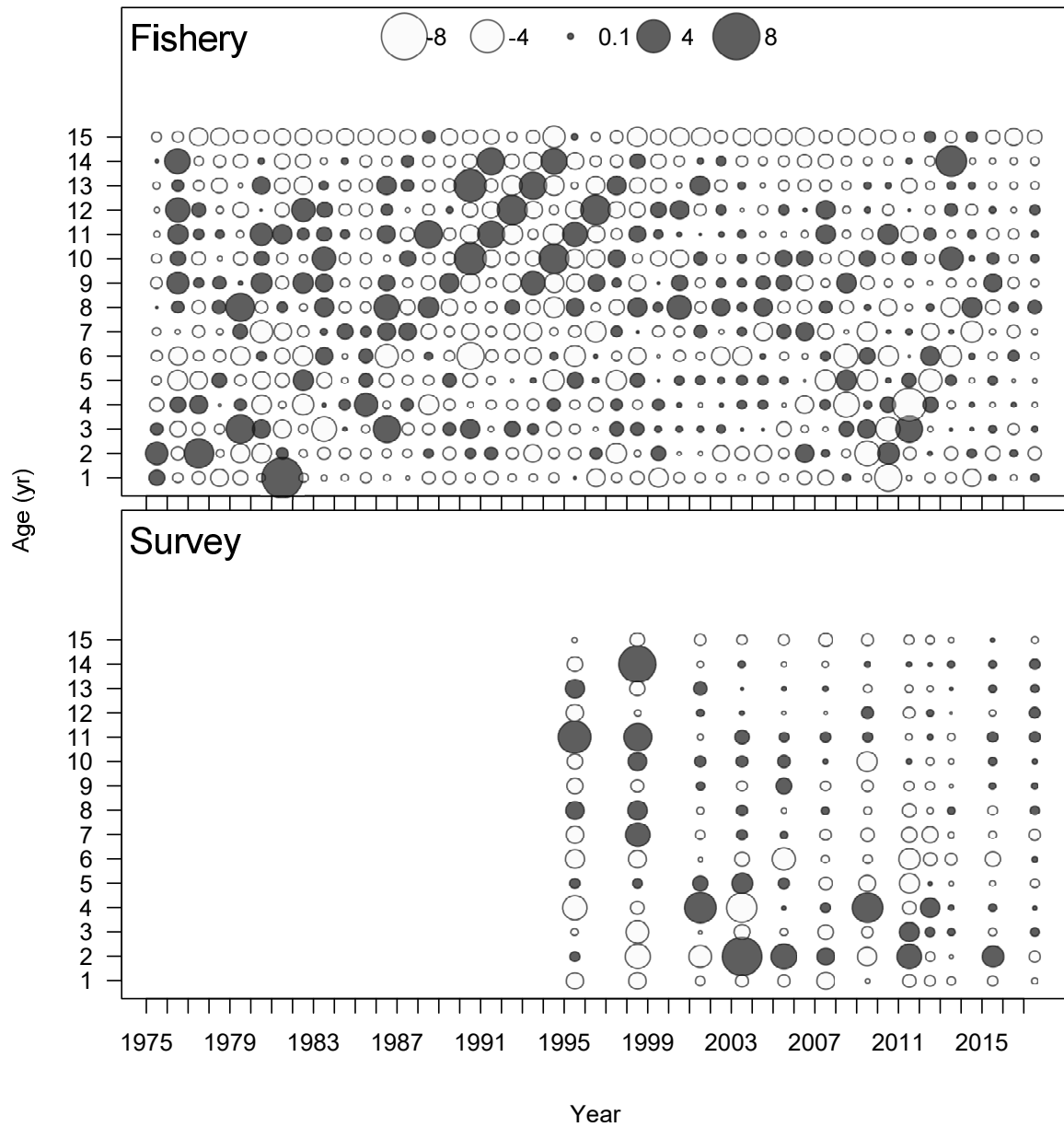
This appendix contains results requested at the Scientific Review Group meeting held from 26th February to 1st March 2018 in Lynnwood, WA, USA.

### **A.1 RESIDUALS FOR SENSITIVITY RUNS WITH DIFFERENT MAXIMUM AGE OF SELECTIVITY**

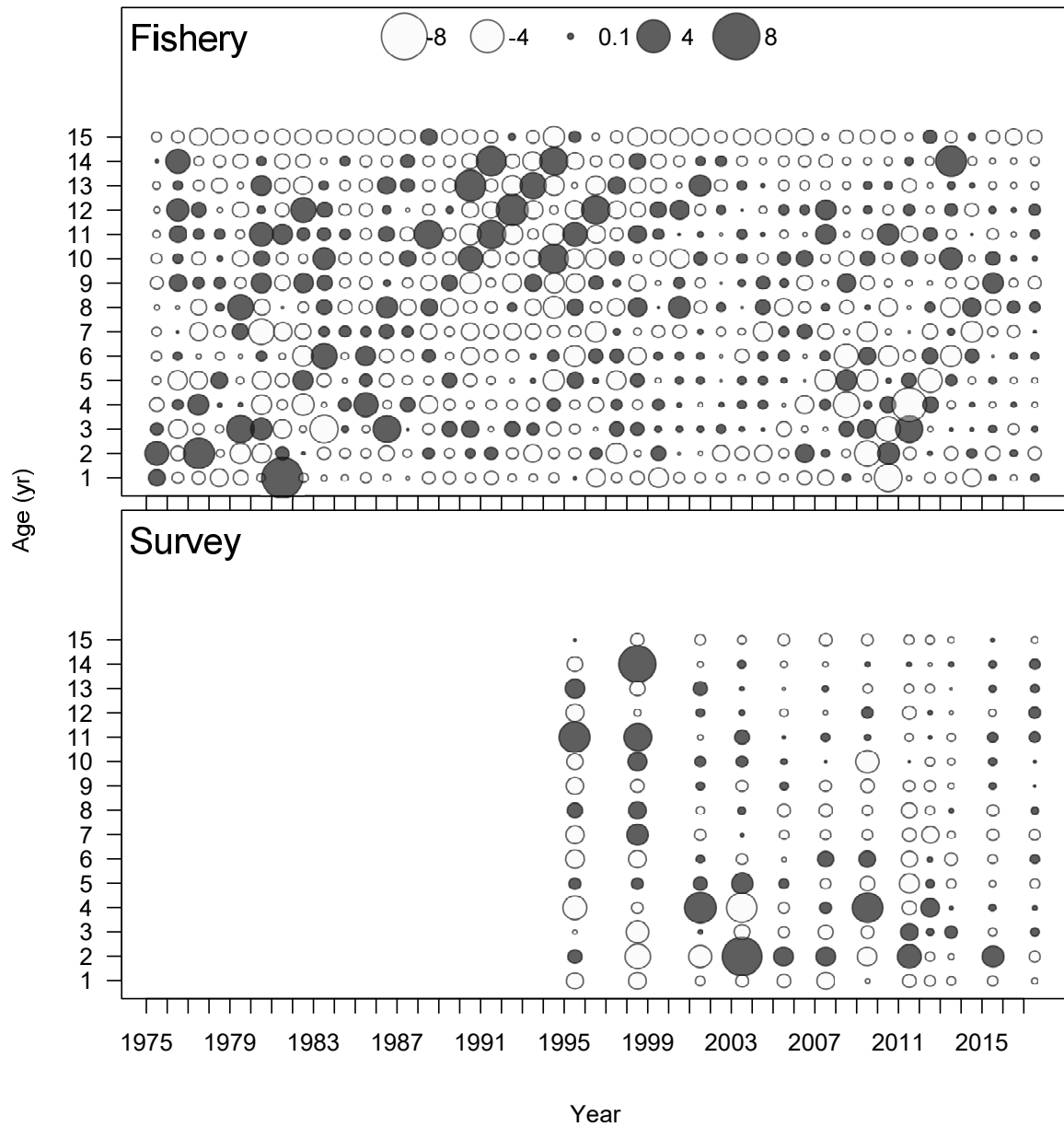
Figures A.1-A.4 show the Pearson residual plots of the age composition data for different values of maximum age of selectivity, as per the sensitivity analyses in the main text.



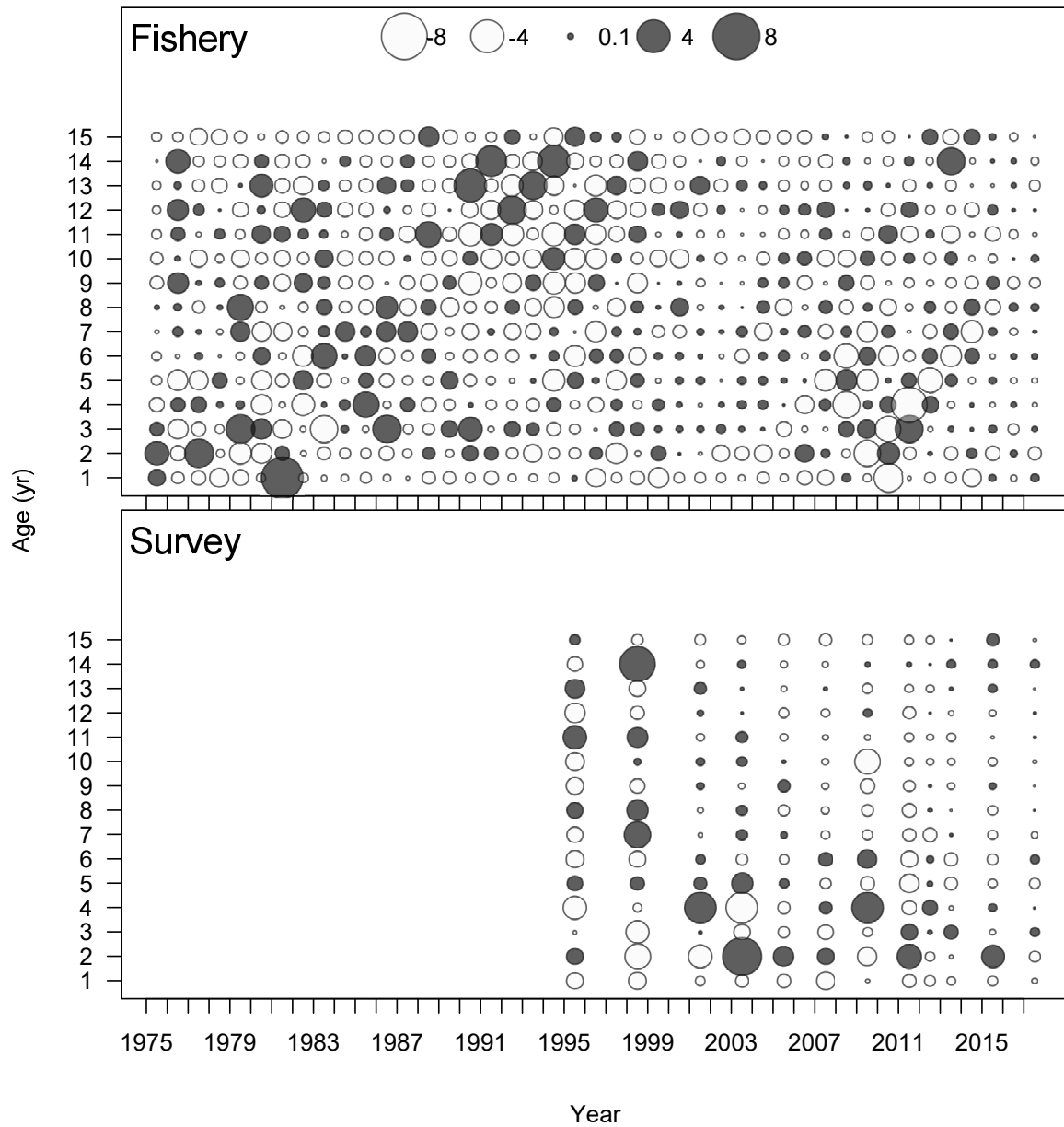
**Figure A.1.** Pearson residuals for model with maximum age of selectivity set to 5, showing MLE fits to the age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). Bubbles in Figures A.1-A.4 are the same scale, even though the legends are different.



**Figure A.2.** Pearson residuals for base model for which maximum age of selectivity is set to 6, showing MLE fits to the age composition data (copy of Figure 25). Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).



**Figure A.3.** Pearson residuals for model with maximum age of selectivity set to 7, showing MLE fits to the age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).



**Figure A.4.** Pearson residuals for model with maximum age of selectivity set to 10, showing MLE fits to the age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

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## A.2 ALTERNATIVE TIME-VARYING FECUNDITY RUN

During the 2018 Scientific Review Group (SRG) meeting, the SRG requested an additional model run. This alternative run includes changes related to fecundity, as described in the Executive Summary. For this alternative run the following figures and tables are the equivalent to those presented earlier for the base model run.

For the alternative run there is an estimated 47.8% probability of being below  $B_{40\%}$  at the start of 2018 and a 18.4% probability that the 2017 fishing intensity was above the target. There is an estimated 16.4% joint probability of being both above the target relative fishing intensity in 2017 and below the  $B_{40\%}$  relative spawning biomass level at the start of 2018.

Tables A.1-A.7 provide information on this alternative run including time series tables, reference points, decision tables, and risk tables. Figures A.1-A.3 illustrate the forecast depletion and risk probabilities in those tables.

Figures A.4-A.7 compare results from the alternative run to those of the based model run.



**Table A.1.** Time series of median posterior population estimates from the alternative time-varying fecundity run. Relative spawning biomass is spawning biomass relative to the unfished equilibrium ( $B_0$ ). Total biomass includes females and males of all ages ages 0 and above. Age-2+ biomass includes females and males ages 2 and above. Exploitation fraction is total catch divided by total age-2+ biomass. Relative fishing intensity is  $(1-SPR)/(1-SPR_{40\%})$ .

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Total biomass (thousand t)	Age-2+ biomass (thousand t)	Age-0 recruits (millions)	Relative fishing intensity	Exploitation fraction
1966	1,301	43.5%	2,304	2,118	1,775	56.1%	6.5%
1967	1,253	42.1%	2,368	2,138	4,317	75.3%	10.0%
1968	1,203	40.3%	2,475	2,125	2,829	56.3%	5.7%
1969	1,290	43.4%	2,796	2,554	728	69.0%	7.1%
1970	1,450	48.8%	2,988	2,777	8,443	76.1%	8.4%
1971	1,479	49.9%	3,215	2,592	805	57.9%	6.0%
1972	1,548	52.4%	3,613	3,537	537	44.9%	3.3%
1973	1,958	66.4%	3,702	3,563	5,714	49.1%	4.6%
1974	1,937	65.9%	3,712	3,289	363	56.6%	6.4%
1975	1,757	59.7%	4,696	4,556	1,710	52.9%	4.9%
1976	2,165	73.5%	4,962	4,803	223	46.1%	4.9%
1977	1,875	63.2%	4,660	4,290	6,388	30.9%	3.1%
1978	1,582	53.4%	3,809	3,417	153	30.5%	3.0%
1979	1,653	55.6%	4,285	4,200	1,294	32.9%	3.3%
1980	1,655	55.7%	4,522	3,672	16,845	25.5%	2.4%
1981	1,511	50.6%	4,748	3,296	271	37.0%	4.2%
1982	1,543	51.8%	5,244	5,201	302	31.3%	2.1%
1983	2,186	73.7%	5,005	4,957	532	29.6%	2.3%
1984	2,245	75.9%	5,258	4,751	13,848	34.5%	2.9%
1985	2,018	68.2%	6,322	4,402	144	23.2%	2.5%
1986	2,040	68.8%	6,148	6,117	189	40.8%	3.4%
1987	2,381	80.5%	5,540	5,369	6,510	45.6%	4.4%
1988	2,315	78.2%	5,635	4,869	2,090	46.0%	5.1%
1989	1,880	63.6%	5,079	4,846	121	53.4%	6.2%
1990	1,994	67.5%	4,661	4,577	4,262	47.7%	5.7%
1991	1,854	62.8%	4,481	3,993	1,209	71.2%	8.0%
1992	1,529	51.9%	3,825	3,685	137	61.0%	8.1%
1993	1,222	41.3%	2,884	2,820	3,112	52.0%	7.1%
1994	1,180	39.9%	2,874	2,529	3,306	63.0%	14.3%
1995	1,013	34.2%	2,850	2,540	1,211	54.7%	9.8%
1996	987	33.2%	2,721	2,599	1,828	69.7%	11.8%
1997	1,020	34.5%	2,574	2,425	1,064	71.7%	13.4%
1998	864	29.2%	2,125	2,027	1,952	87.0%	15.8%
1999	724	24.6%	2,110	1,705	12,895	96.2%	18.3%
2000	775	26.2%	3,915	1,957	315	68.2%	11.7%
2001	1,085	36.8%	4,079	4,045	1,251	68.1%	5.6%
2002	1,886	64.0%	4,450	4,376	34	47.0%	4.1%
2003	1,720	58.3%	3,786	3,755	1,678	43.9%	5.5%
2004	1,359	46.1%	3,109	2,964	62	72.3%	11.5%
2005	1,057	35.9%	2,508	2,461	2,669	69.4%	14.8%
2006	854	29.1%	2,195	1,885	1,896	82.9%	19.2%
2007	665	22.6%	1,739	1,673	24	87.8%	17.5%
2008	668	22.7%	1,770	1,691	5,175	90.3%	19.0%
2009	575	19.6%	1,532	1,241	1,308	78.7%	14.3%
2010	558	19.0%	2,052	1,733	13,579	96.6%	13.3%
2011	679	23.1%	2,586	1,674	426	93.0%	17.4%
2012	849	28.9%	3,208	3,138	1,476	71.5%	6.6%
2013	1,506	51.1%	3,674	3,522	451	69.1%	8.1%
2014	1,570	53.3%	3,767	3,588	8,799	65.1%	8.3%
2015	1,178	39.9%	3,176	2,634	153	49.4%	7.2%
2016	1,077	36.1%	3,401	3,300	3,395	76.4%	10.0%
2017	1,368	46.0%	3,788	3,162	1,054	85.4%	13.9%
2018	1,210	40.7%	3,705	3,458	1,064	–	–

**Table A.2.** Time series of 95% posterior credibility intervals for the quantities shown in Table A.1 for the alternative time-varying fecundity run.

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Total biomass (thousand t)	Age-2+ biomass (thousand t)	Age-0 recruits (millions)	(1-SPR) / (1-SPR <sub>40%</sub> )	Exploitation fraction
1966	808-2,246	27.1- 70.8%	1,512-4,047	1,309-3,726	92- 8,331	32.6- 80.5%	3.7-10.5%
1967	787-2,172	26.3- 67.5%	1,577-4,178	1,380-3,826	245-12,853	46.9-100.8%	5.6-15.5%
1968	767-2,127	25.5- 65.8%	1,636-4,459	1,335-3,851	342- 9,359	31.5- 81.7%	3.2- 9.2%
1969	846-2,275	27.8- 71.7%	1,851-5,052	1,665-4,564	61- 3,322	41.3- 94.5%	3.9-10.8%
1970	943-2,609	31.5- 82.2%	1,949-5,643	1,832-5,170	4,478-19,508	46.0-102.1%	4.5-12.8%
1971	951-2,753	31.1- 86.9%	2,031-6,298	1,652-4,992	100- 2,673	31.7- 84.9%	3.1- 9.4%
1972	988-2,975	32.7- 92.3%	2,266-7,192	2,219-7,097	77- 1,802	22.7- 70.0%	1.7- 5.3%
1973	1,241-3,848	41.0-117.3%	2,356-7,290	2,268-7,029	3,097-12,864	25.5- 75.1%	2.3- 7.2%
1974	1,254-3,749	40.6-115.2%	2,349-7,272	2,127-6,357	52- 1,292	29.5- 83.2%	3.3- 9.9%
1975	1,115-3,353	36.3-104.5%	2,956-9,113	2,845-8,757	864- 3,810	27.3- 80.2%	2.5- 7.8%
1976	1,365-4,097	44.4-128.0%	3,123-9,380	3,028-9,070	33- 868	23.7- 71.7%	2.6- 7.8%
1977	1,165-3,488	38.2-109.3%	2,897-8,706	2,667-7,970	3,592-13,081	15.0- 51.8%	1.7- 5.0%
1978	996-2,884	33.0- 89.7%	2,379-6,889	2,141-6,237	19- 651	14.8- 50.8%	1.7- 4.8%
1979	1,052-2,931	34.6- 91.0%	2,734-7,632	2,692-7,460	545- 2,983	17.1- 53.4%	1.8- 5.1%
1980	1,077-2,916	35.2- 90.7%	2,904-8,020	2,383-6,497	10,089-31,385	13.1- 41.9%	1.4- 3.8%
1981	990-2,606	32.6- 80.2%	3,090-8,229	2,156-5,671	32- 1,022	19.9- 57.9%	2.5- 6.5%
1982	1,027-2,595	33.7- 79.8%	3,476-8,823	3,449-8,743	54- 903	16.8- 49.9%	1.2- 3.1%
1983	1,486-3,567	48.5-111.1%	3,405-8,151	3,377-8,091	113- 1,383	16.3- 47.0%	1.4- 3.4%
1984	1,567-3,570	50.6-111.7%	3,663-8,314	3,315-7,544	8,885-23,744	19.3- 53.3%	1.8- 4.2%
1985	1,435-3,100	46.3- 98.2%	4,467-9,874	3,121-6,790	20- 598	13.2- 36.5%	1.6- 3.5%
1986	1,488-3,040	48.2- 96.1%	4,484-9,294	4,453-9,242	32- 669	25.2- 58.8%	2.3- 4.7%
1987	1,777-3,506	56.6-112.1%	4,116-8,158	4,004-7,900	4,221-10,497	28.6- 64.3%	3.0- 5.8%
1988	1,762-3,323	55.5-106.7%	4,267-8,091	3,694-7,004	1,120- 3,551	29.3- 64.4%	3.6- 6.7%
1989	1,450-2,632	45.5- 85.4%	3,921-7,142	3,729-6,811	20- 439	35.6- 72.1%	4.4- 8.0%
1990	1,556-2,758	48.9- 89.7%	3,653-6,454	3,589-6,327	2,896- 6,758	31.4- 64.6%	4.1- 7.3%
1991	1,487-2,509	46.3- 82.3%	3,583-6,107	3,201-5,398	578- 2,298	47.9- 99.3%	5.9-10.0%
1992	1,242-2,037	38.5- 67.6%	3,080-5,157	2,978-4,927	20- 459	40.1- 90.6%	6.1-10.1%
1993	996-1,611	30.8- 53.5%	2,349-3,838	2,301-3,744	2,157- 4,738	34.0- 83.1%	5.3- 8.6%
1994	978-1,529	29.7- 51.1%	2,357-3,779	2,090-3,286	2,350- 5,089	44.1- 84.5%	11.0-17.3%
1995	833-1,319	25.6- 43.8%	2,329-3,762	2,080-3,343	740- 1,983	39.5- 71.1%	7.5-12.0%
1996	816-1,285	25.1- 42.8%	2,240-3,557	2,143-3,391	1,196- 2,905	51.3- 91.1%	9.0-14.3%
1997	847-1,323	25.9- 44.2%	2,128-3,358	2,014-3,159	632- 1,922	52.8- 90.2%	10.3-16.1%
1998	714-1,121	21.8- 37.3%	1,743-2,796	1,663-2,655	1,289- 3,144	68.0-103.7%	12.1-19.3%
1999	589- 951	18.1- 31.4%	1,685-2,850	1,388-2,254	9,250-19,948	75.2-112.8%	13.8-22.5%
2000	616-1,038	19.1- 33.8%	3,028-5,509	1,557-2,649	109- 676	49.8- 85.7%	8.6-14.7%
2001	859-1,471	26.8- 47.2%	3,204-5,619	3,179-5,580	849- 1,920	49.7- 85.2%	4.1- 7.2%
2002	1,513-2,535	47.1- 82.0%	3,559-5,998	3,497-5,883	7- 118	32.6- 62.9%	3.1- 5.2%
2003	1,408-2,252	43.6- 73.6%	3,097-4,975	3,076-4,932	1,185- 2,623	29.8- 59.1%	4.2- 6.7%
2004	1,140-1,742	35.0- 57.1%	2,598-4,008	2,486-3,794	12- 199	51.7- 96.6%	9.0-13.8%
2005	891-1,351	27.4- 44.2%	2,100-3,255	2,066-3,187	1,889- 4,401	50.1- 92.5%	11.4-17.6%
2006	714-1,117	22.1- 35.8%	1,811-2,929	1,571-2,463	1,328- 3,064	60.7-111.5%	14.7-23.0%
2007	543- 895	17.0- 28.4%	1,413-2,371	1,361-2,279	4- 89	63.4-116.6%	12.9-21.6%
2008	533- 942	17.0- 29.4%	1,418-2,525	1,357-2,396	3,638- 8,671	67.8-110.8%	13.4-23.7%
2009	445- 848	14.2- 25.9%	1,185-2,298	964-1,827	748- 2,539	56.0-100.3%	9.7-18.4%
2010	425- 853	13.8- 25.6%	1,534-3,237	1,324-2,649	8,459-25,615	71.5-123.3%	8.7-17.4%
2011	504-1,069	16.6- 31.9%	1,832-4,301	1,240-2,664	157- 1,060	63.8-118.9%	10.9-23.5%
2012	588-1,443	19.6- 42.7%	2,174-5,522	2,136-5,412	667- 3,361	45.4- 98.5%	3.8- 9.6%
2013	1,005-2,612	33.6- 77.5%	2,434-6,430	2,328-6,103	125- 1,420	44.5- 91.6%	4.7-12.3%
2014	1,007-2,785	34.0- 83.2%	2,396-6,770	2,296-6,399	4,329-20,710	40.6- 90.6%	4.7-13.0%
2015	724-2,174	24.5- 64.7%	1,925-5,873	1,627-4,900	21- 748	27.0- 75.5%	3.9-11.7%
2016	631-2,028	21.4- 60.0%	1,960-6,795	1,907-6,459	321-28,452	46.1-107.8%	5.1-17.3%
2017	728-2,779	25.2- 83.7%	1,921-8,328	1,672-6,542	67-16,759	54.0-118.8%	6.7-26.3%
2018	548-2,774	19.5- 80.2%	1,596-9,241	1,489-8,646	70-15,429	—	—

**Table A.3.** For the alternative run, summary of median and 95% credibility intervals of equilibrium reference points. Equilibrium reference points were computed using 1966–2017 averages for mean size-at-age and selectivity-at-age.

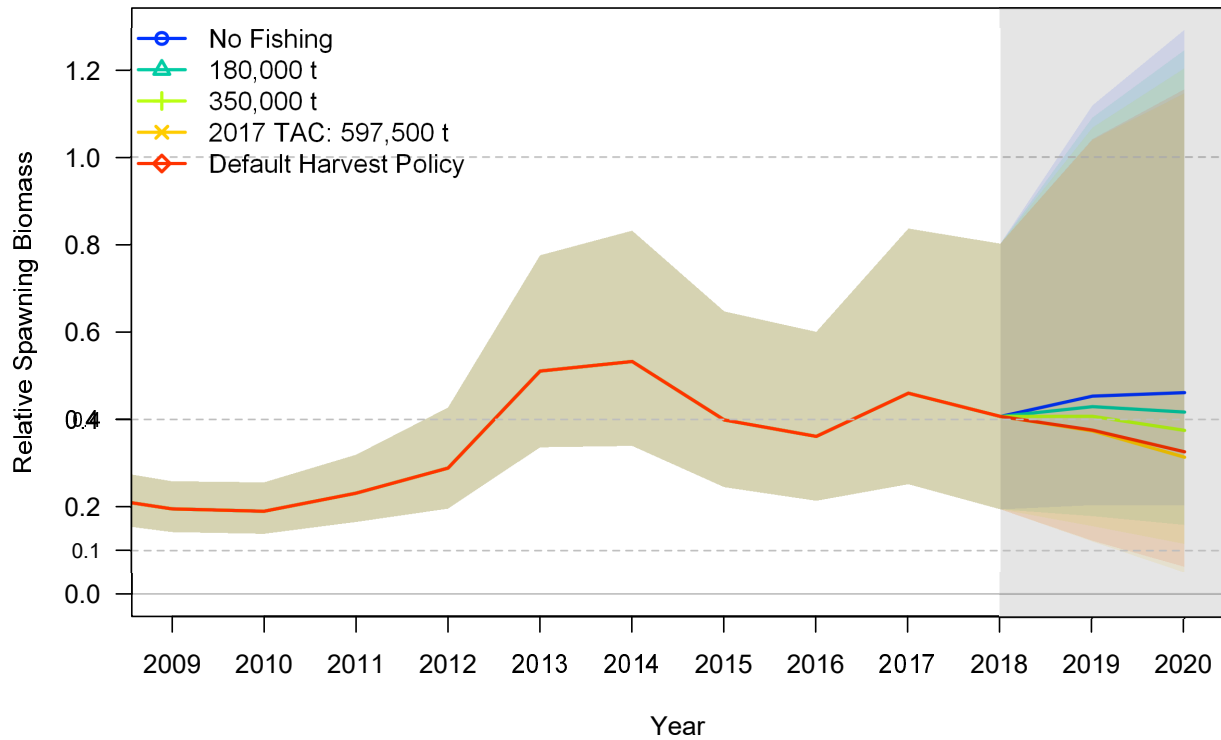
Quantity	2.5 <sup>th</sup> percentile	Median	97.5 <sup>th</sup> percentile
Unfished female spawning biomass ( $B_0$ , thousand t)	2,416	2,989	3,919
Unfished recruitment ( $R_0$ , millions)	1,906	2,938	5,051
<b>Reference points (equilibrium) based on <math>F_{\text{SPR}=40\%}</math></b>			
Female spawning biomass at $F_{\text{SPR}=40\%}$ (thousand t)	867	1,082	1,348
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	13.2%	15.4%	18.1%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	252	335	487
<b>Reference points (equilibrium) based on <math>B_{40\%}</math> (40% of <math>B_0</math>)</b>			
Female spawning biomass ( $B_{40\%}$ , thousand t)	966	1,196	1,568
SPR at $B_{40\%}$	40.6%	43.0%	49.4%
Exploitation fraction resulting in $B_{40\%}$	11.0%	13.8%	16.5%
Yield at $B_{40\%}$ (thousand t)	246	325	469
<b>Reference points (equilibrium) based on estimated MSY</b>			
Female spawning biomass ( $B_{\text{MSY}}$ , thousand t)	515	677	1,111
SPR at MSY	22.2%	26.0%	40.9%
Exploitation fraction corresponding to SPR at MSY	15.0%	25.3%	31.2%
MSY (thousand t)	271	369	537

**Table A.4.** For the alternative run, forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e), including catch from 2017 (row d) and the TAC from 2017 (row e), the catch values that result in a median relative fishing intensity of 100% (row f), the median values estimated via the default harvest policy ( $F_{SPR=40\%}-40:10$ ) (row g), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2018 and 2019 (row h). Catch in 2020 does not impact the beginning of the year biomass in 2020.

Within model quantile Management Action			5%	25%	50%	75%	95%
Year Catch (t)			Beginning of year relative spawning biomass				
a:	2018	0	22%	32%	41%	51%	72%
	2019	0	23%	35%	45%	60%	94%
	2020	0	24%	35%	46%	62%	106%
b:	2018	180,000	22%	32%	41%	51%	72%
	2019	180,000	21%	33%	43%	58%	91%
	2020	180,000	19%	31%	42%	58%	102%
c:	2018	350,000	22%	32%	41%	51%	72%
	2019	350,000	19%	30%	41%	55%	89%
	2020	350,000	15%	26%	37%	54%	98%
d:	2018	440,000	22%	32%	41%	51%	72%
	2017	2019 440,000	18%	29%	39%	54%	87%
	catch	2020 440,000	12%	24%	35%	51%	96%
e:	2018	597,500	22%	32%	41%	51%	72%
	2017	2019 597,500	15%	27%	37%	52%	85%
	TAC	2020 597,500	8%	20%	31%	48%	92%
f:	2018	668,000	22%	32%	41%	51%	72%
	FI=	2019 582,000	14%	26%	36%	51%	85%
	100%	2020 535,000	8%	19%	31%	47%	91%
g:	2018	583,970	22%	32%	41%	51%	72%
	default	2019 517,889	15%	27%	38%	52%	86%
	HR	2020 473,043	9%	21%	33%	49%	93%
h:	2018	531,342	22%	32%	41%	51%	72%
	C2018=	2019 531,342	16%	28%	38%	53%	86%
	C2019	2020 477,594	10%	22%	33%	49%	94%

**Table A.5.** For the alternative run, forecast quantiles of Pacific Hake relative fishing intensity  $(1-SPR)/(1-SPR_{40\%})$  for the 2018–2020 catch alternatives presented in Table A.4. Values greater than 100% indicate relative fishing intensities greater than the  $F_{SPR=40\%}$  harvest policy calculated using baseline selectivity.

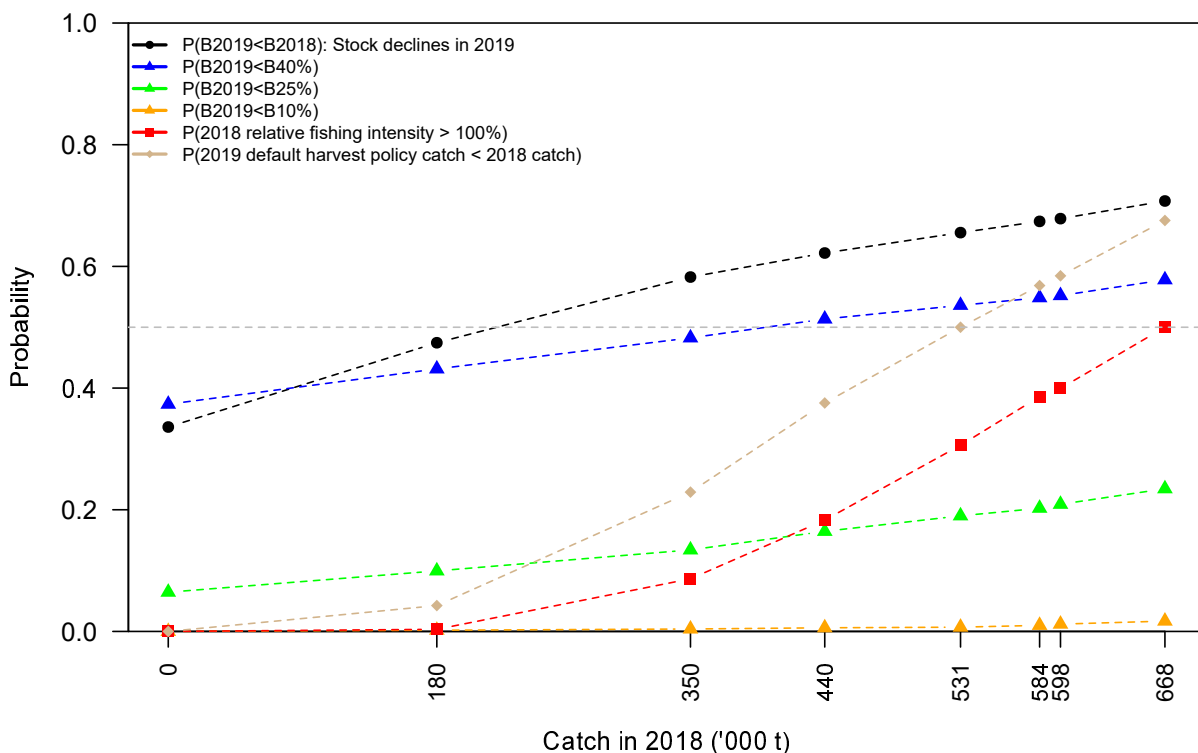
Within model quantile Management Action			5%	25%	50%	75%	95%
Year Catch (t)			Relative fishing intensity				
a:	2018	0	0%	0%	0%	0%	0%
	2019	0	0%	0%	0%	0%	0%
	2020	0	0%	0%	0%	0%	0%
b:	2018	180,000	27%	39%	49%	59%	79%
	2019	180,000	25%	37%	47%	59%	79%
	2020	180,000	22%	34%	45%	57%	78%
c:	2018	350,000	45%	61%	74%	86%	106%
	2019	350,000	43%	61%	74%	89%	111%
	2020	350,000	39%	59%	74%	91%	117%
d:	2018	440,000	53%	70%	83%	95%	114%
2017	2019	440,000	51%	70%	85%	100%	122%
catch	2020	440,000	47%	69%	86%	104%	133%
e:	2018	597,500	64%	83%	96%	107%	126%
2017	2019	597,500	63%	84%	100%	115%	138%
TAC	2020	597,500	60%	85%	104%	124%	159%
f:	2018	668,000	68%	87%	100%	112%	129%
FI=	2019	582,000	62%	84%	100%	116%	140%
100%	2020	535,000	56%	81%	100%	121%	158%
g:	2018	583,970	63%	82%	95%	106%	125%
default	2019	517,889	58%	79%	94%	110%	133%
HR	2020	473,043	51%	75%	93%	112%	146%
h:	2018	531,342	60%	78%	91%	103%	121%
C2018=	2019	531,342	58%	79%	94%	110%	132%
C2019	2020	477,594	51%	75%	93%	112%	144%



**Figure A.1.** For the alternative run, time series of estimated relative spawning biomass to 2018 and forecast trajectories to 2020 for several management actions defined in Table A.4 (grey region), with 95% posterior credibility intervals.

**Table A.6.** For the alternative run, probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (catch options explained in Table A.4).

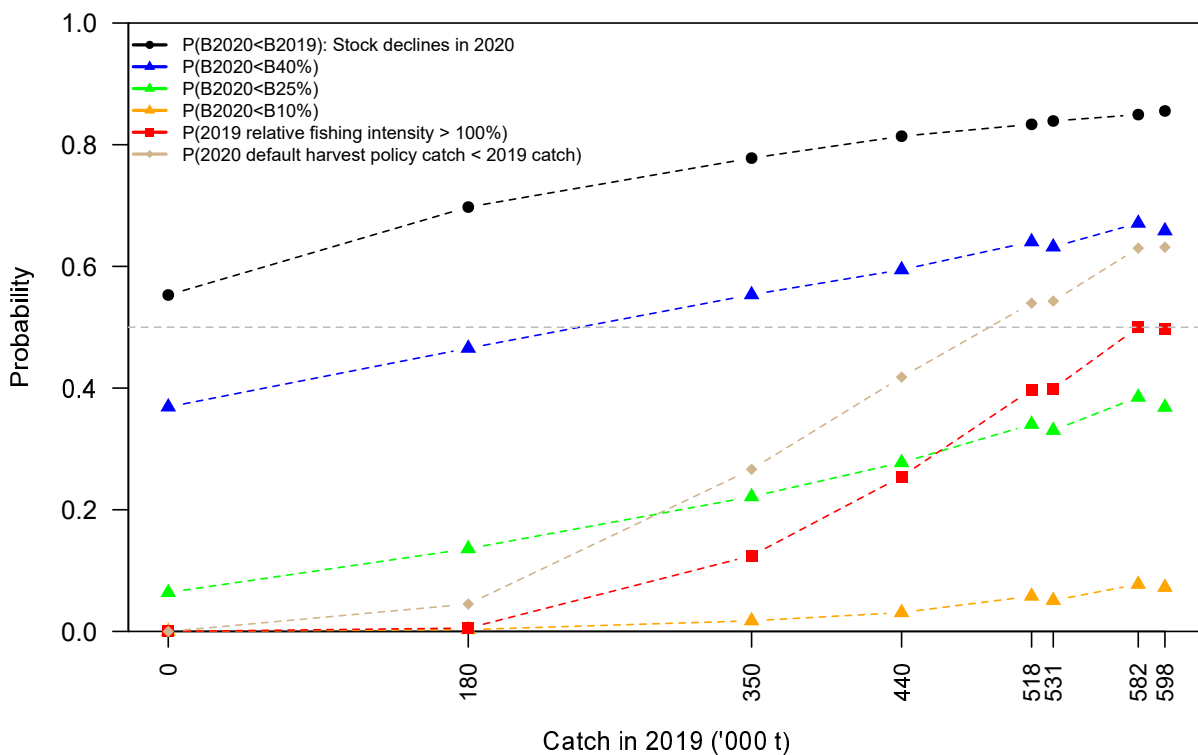
Catch in 2018	Probability $B_{2019} < B_{2018}$	Probability $B_{2019} < B_{40\%}$	Probability $B_{2019} < B_{25\%}$	Probability $B_{2019} < B_{10\%}$	Probability 2018 relative fishing intensity >100%	Probability 2019 default harvest policy catch <2018 catch
a: 0	34%	37%	6%	0%	0%	0%
b: 180,000	47%	43%	10%	0%	0%	4%
c: 350,000	58%	48%	13%	0%	9%	23%
d: 440,000	62%	51%	16%	1%	18%	38%
e: 597,500	68%	55%	21%	1%	40%	58%
f: 668,000	71%	58%	23%	2%	50%	68%
g: 583,970	67%	55%	20%	1%	39%	57%
h: 531,342	66%	54%	19%	1%	31%	50%



**Figure A.2.** For the alternative run, graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (catch options explained in Table A.4) as listed in Table A.6. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

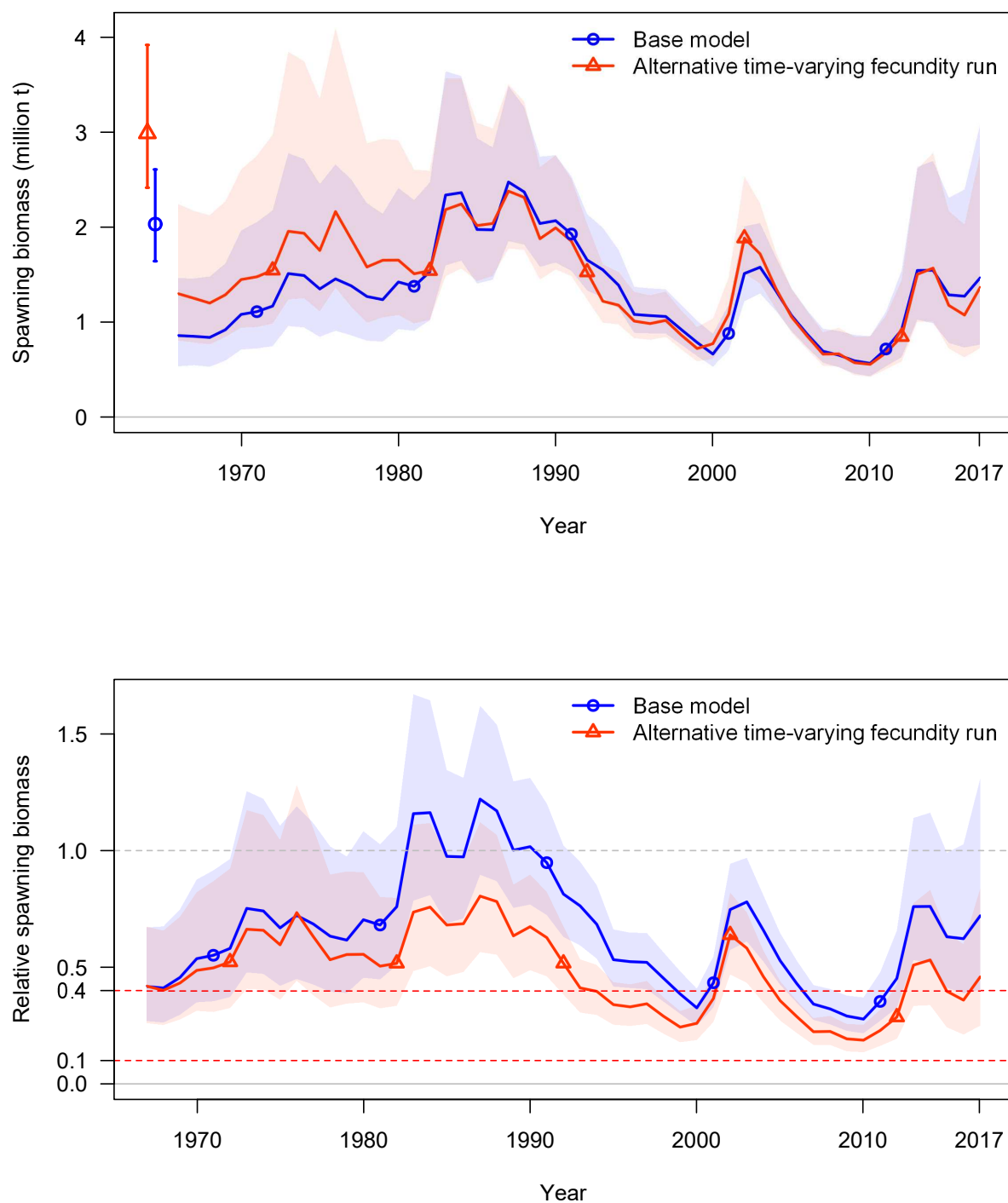
**Table A.7.** For the alternative run, probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options, given the 2018 catch level shown in Table A.6 (catch options explained in Table A.4).

Catch in 2019	Probability B <sub>2020</sub> <B <sub>2019</sub>	Probability B <sub>2020</sub> <B <sub>40%</sub>	Probability B <sub>2020</sub> <B <sub>25%</sub>	Probability B <sub>2020</sub> <B <sub>10%</sub>	Probability 2019 relative fishing intensity >100%	Probability 2020 default harvest policy catch <2019 catch
a: 0	55%	37%	6%	0%	0%	0%
b: 180,000	70%	47%	14%	0%	1%	4%
c: 350,000	78%	55%	22%	2%	12%	27%
d: 440,000	81%	59%	28%	3%	25%	42%
e: 597,500	86%	66%	37%	7%	50%	63%
f: 582,000	85%	67%	38%	8%	50%	63%
g: 517,889	83%	64%	34%	6%	40%	54%
h: 531,342	84%	63%	33%	5%	40%	54%

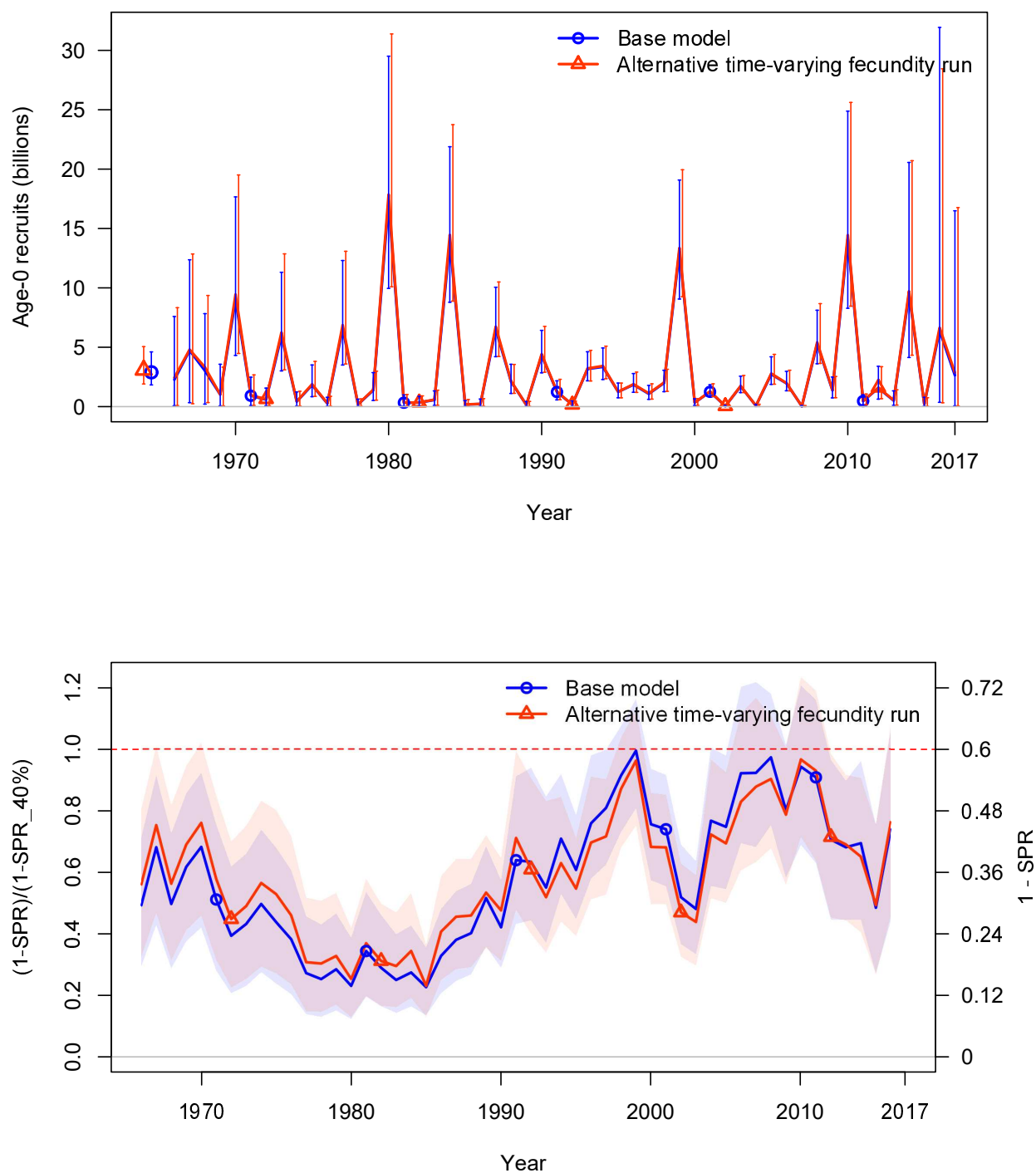


**Figure A.3.** For the alternative run, graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (including associated 2018 catch; catch options explained in Table A.4) as listed in Table A.7. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

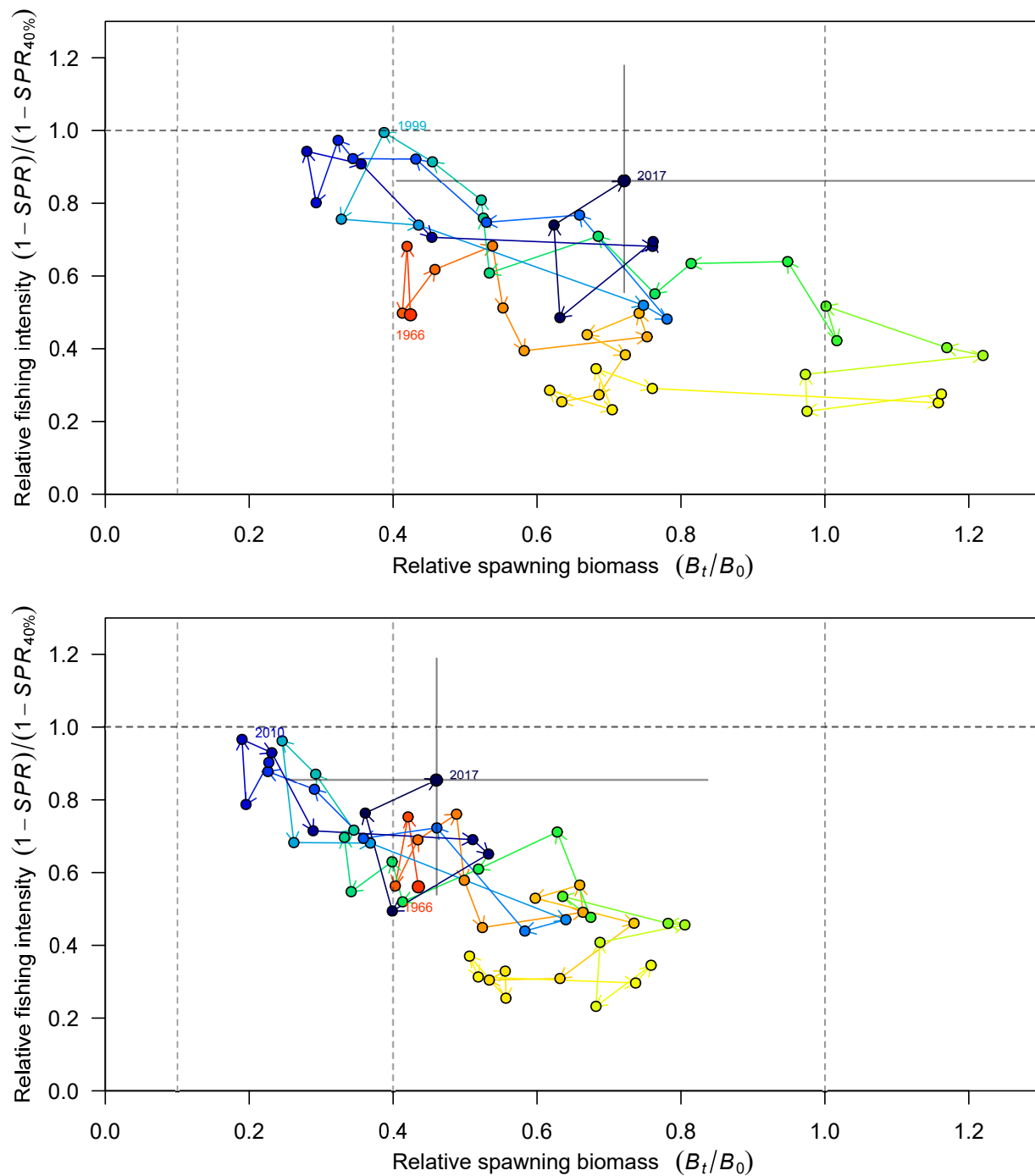




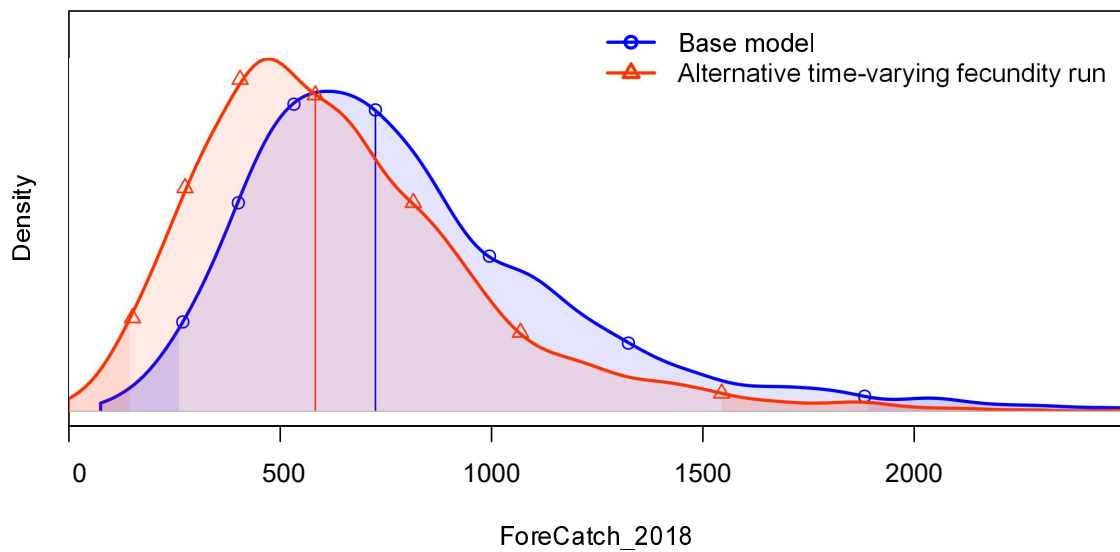
**Figure A.4.** A comparison of MCMC posterior median estimates and 95% credibility intervals of spawning biomass (upper panel) and relative spawning biomass (lower panel) for the base model (blue line) and the alternative time-varying fecundity run (red line). Relative spawning biomass (depletion) at the start of 2018 is estimated to be 67% for the base model and 41% for the alternative run.



**Figure A.5.** A comparison of MCMC posterior median estimates and 95% credibility intervals of recruitment (upper panel) and relative fishing intensity (lower panel) for the base model (blue line) and the alternative time-varying fecundity run (red line).



**Figure A.6.** For the base model (top) and alternative run (bottom), estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999 or 2010). Gray bars span the 95% credibility intervals for 2017 relative fishing intensity (vertical) and relative spawning biomass (horizontal).



**Figure A.7.** Posterior estimates of 2018 default harvest control rule catch for the base model and the alternative time-varying fecundity run.

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## B GLOSSARY OF TERMS AND ACRONYMS USED IN THIS DOCUMENT

40:10 adjustment: a reduction in the overall total allowable catch that is triggered when the female spawning biomass falls below 40% of its unfished equilibrium level. This adjustment reduces the total allowable catch on a straight-line basis from the 40% level such that the total allowable catch would equal zero when the biomass is at 10% of its unfished equilibrium level. This is one component of the default harvest policy (see below).

ABC: Acceptable biological catch. See below.

Acceptable biological catch (ABC): The acceptable biological catch is a scientific calculation of the sustainable harvest level of a fishery used historically to set the upper limit for fishery removals by the Pacific Fishery Management Council. It is calculated by applying the estimated (or proxy) harvest rate that produces maximum sustainable yield (MSY, see below) to the estimated exploitable stock biomass (the portion of the fish population that can be harvested). For Pacific Hake/whiting, the calculation of the acceptable biological catch and application of the 40:10 adjustment is now replaced with the default harvest rate and the Total Allowable Catch.

Adjusted: A term used to describe Total Allowable Catch or allocations that account for carryovers of uncaught catch from previous years (see Carryover below).

Advisory Panel (AP): The advisory panel on Pacific Hake/whiting established by the Agreement.

Agreement (“Treaty”): The Agreement between the government of the United States and the government of Canada on Pacific Hake/whiting, signed at Seattle, Washington, on November 21, 2003, and entered into force June 25, 2008.

AFSC: Alaska Fisheries Science Center (National Marine Fisheries Service).

$B_0$ : The unfished equilibrium female spawning biomass.

$B_{10\%}$ : The level of female spawning biomass corresponding to 10% of unfished equilibrium female spawning biomass, i.e.  $B_{10\%} = 0.1B_0$ . This is the level below which the calculated TAC is set to 0, based on the 40:10 adjustment (see above).

$B_{40\%}$ : The level of female spawning biomass corresponding to 40% of unfished equilibrium female spawning biomass, i.e.  $B_{40\%} = 0.4B_0$ . This is the level below which the calculated TAC is decreased from the value associated with  $F_{SPR=40\%}$ , based on the 40:10 adjustment (see above).

$B_{MSY}$ : The estimated female spawning biomass which theoretically would produce the maximum sustainable yield (MSY) under equilibrium fishing conditions (constant fishing and av-

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erage recruitment in every year). Also see  $B_{40\%}$  (above).

**Backscatter:** The scattering by a target back in the direction of an acoustic source. Specifically, the Nautical Area Scattering Coefficient (a measure of scattering per area) is frequently referred to as backscatter.

**California Current Ecosystem:** The waters of the continental shelf and slope off the west coast of North America, commonly referring to the area from central California to southern British Columbia.

**Carryover:** If at the end of the year, there are unharvested allocations, then there are provisions for an amount of these fish to be carried over into the next year's allocation process. The Agreement states that "[I]f, in any year, a Party's catch is less than its individual TAC, an amount equal to the shortfall shall be added to its individual TAC in the following year, unless otherwise recommended by the JMC. Adjustments under this sub-paragraph shall in no case exceed 15 percent of a Party's unadjusted individual TAC for the year in which the shortfall occurred."

**Catchability ( $q$ ):** The parameter defining the proportionality between a relative index of stock abundance (often a fishery-independent survey) and the estimated stock abundance available to that survey (as modified by selectivity) in the assessment model.

**Catch-per-unit-effort (CPUE):** A raw or (frequently) standardized and model-based metric of fishing success based on the catch and relative effort expended to generate that catch. Catch-per-unit-effort is often used as an index of stock abundance in the absence of fishery-independent indices and/or where the two are believed to be proportional.

**Catch target:** A general term used to describe the catch value used for management. Depending on the context, this may be a limit rather than a target, and may be equal to a TAC, an ABC, the median result of applying the default harvest policy, or some other number. The JTC welcomes input from the JMC on the best terminology to use for these quantities.

**Closed-loop simulation:** A subset of an MSE that iteratively simulates a population using an operating model, generates data from that population and passes it to an estimation model, uses the estimation model and a management strategy to provide management advice, which then feeds back into the operating model to simulate an additional fixed set of time before repeating this process.

**Cohort:** A group of fish born in the same year. Also see recruitment and year-class.

**Constant catch:** A catch scenario used for forecasting in which the same catch is used in successive years.

**CPUE:** Catch-per-unit-effort (see above).

**CV:** Coefficient of variation. A measure of uncertainty defined as the standard deviation (SD, see

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below) divided by the mean.

Default harvest policy (rate): The application of  $F_{\text{SPR}=40\%}$  (see below) with the 40:10 adjustment (see above). Having considered any advice provided by the JTC, SRG or AP, the JMC may recommend a different harvest rate if the scientific evidence demonstrates that a different rate is necessary to sustain the offshore Pacific Hake/whiting resource.

Depletion: Term used for relative spawning biomass (see below) prior to the 2015 stock assessment. “Relative depletion” was also used.

DFO: Department of Fisheries and Oceans (Canada). See Fisheries and Oceans Canada.

El Niño: Abnormally warm ocean climate conditions in the California Current Ecosystem (see above) as a result of broad changes in the Eastern Pacific Ocean across the eastern coast of Latin America (centered on Peru) often around the end of the calendar year.

Exploitation fraction: A metric of fishing intensity that represents the total annual catch divided by the estimated population biomass over a range of ages assumed to be vulnerable to the fishery (set to ages 2+ in this assessments; note that in previous assessments it was 3+). This value is not equivalent to the instantaneous rate of fishing mortality (see below) or the spawning potential ratio (SPR, see below).

$F$ : Instantaneous rate of fishing mortality (or fishing mortality rate); see below.

$F_{\text{SPR}=40\%}$ : The rate of fishing mortality estimated to give a spawning potential ratio (SPR, see below) of 40%. Therefore, by definition this satisfies

$$0.4 = \frac{\text{spawning biomass per recruit with } F_{\text{SPR}=40\%}}{\text{spawning biomass per recruit with no fishing}}, \quad (\text{B.1})$$

and  $\text{SPR}(F_{\text{SPR}=40\%}) = 40\%$ . The 40% value is specified in the Agreement.

$F_{\text{SPR}=40\%}$ –40:10 harvest policy: The default harvest policy (see above).

Female spawning biomass: The biomass of mature female fish at the beginning of the year. Sometimes abbreviated to spawning biomass.

Fisheries and Oceans Canada: Federal organization which delivers programs and services that support sustainable use and development of Canada’s waterways and aquatic resources.

Fishing intensity: A measure of the magnitude of fishing, defined for a fishing rate  $F$  as:

$$\text{fishing intensity for } F = 1 - \text{SPR}(F), \quad (\text{B.2})$$

where  $\text{SPR}(F)$  is the spawning potential ratio for the value of  $F$ . Often given as a percentage. Relative fishing intensity is the fishing intensity relative to that at the SPR target fishing rate  $F_{\text{SPR}=40\%}$ , where  $F_{\text{SPR}=40\%}$  is the  $F$  that gives an SPR of 40% such

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that, by definition,  $\text{SPR}(F_{\text{SPR}=40\%}) = 40\%$  (the target spawning ratio). Therefore

$$\text{relative fishing intensity for } F = \frac{1 - \text{SPR}(F)}{1 - \text{SPR}(F_{\text{SPR}=40\%})} \quad (\text{B.3})$$

$$= \frac{1 - \text{SPR}(F)}{1 - 0.4} \quad (\text{B.4})$$

$$= \frac{1 - \text{SPR}(F)}{0.6}, \quad (\text{B.5})$$

as shown in Figure B.1. For brevity we use  $\text{SPR}_{40\%} = \text{SPR}(F_{\text{SPR}=40\%})$  in the text. Although this simply equals 40%, it can be helpful to explicitly write:

$$\text{relative fishing intensity for } F = \frac{1 - \text{SPR}(F)}{1 - \text{SPR}_{40\%}}. \quad (\text{B.6})$$

The calculation of relative fishing intensity is shown graphically in Figure B.2.

**Fishing mortality rate, or instantaneous rate of fishing mortality ( $F$ ):** A metric of fishing intensity that is usually reported in relation to the most highly selected ages(s) or length(s), or occasionally as an average over an age range that is vulnerable to the fishery. Because it is an instantaneous rate operating simultaneously with natural mortality, it is not equivalent to exploitation fraction (or percent annual removal; see above) or the spawning potential ratio (SPR, see below).

**$F_{\text{MSY}}$ :** The rate of fishing mortality estimated to produce the maximum sustainable yield (MSY) from the stock.

**Harvest strategy:** A formal system for managing a fishery that includes the elements shown in Figure A.1 of Taylor et al. (2015).

**Harvest control rule:** A process for determining an ABC from a stock assessment. Also see default harvest policy (above).

**Joint Management Committee (JMC):** The joint management committee established by the Agreement.

**Joint Technical Committee (JTC):** The joint technical committee established by the Agreement. The full formal name is “Joint Technical Committee of the Pacific Hake/whiting Agreement Between the Governments of the United States and Canada”.

**Logistic transformation:** A mathematical transformation used to translate between numbers bounded within some range to numbers on the real line ( $-\infty$  to  $+\infty$ ).

**Magnuson-Stevens Fishery Conservation and Management Act:** The MSFCMA, sometimes known as the “Magnuson-Stevens Act”, established the 200-mile fishery conservation zone, the regional fishery management council system, and other provisions of U.S. marine fishery law.



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Management Strategy Evaluation (MSE): A formal process for evaluating Harvest Strategies (see above).

Markov-Chain Monte-Carlo (MCMC): A numerical method used to sample from the posterior distribution (see below) of parameters and derived quantities in a Bayesian analysis. It is more computationally intensive than the maximum likelihood estimate (see below), but provides a more accurate depiction of parameter uncertainty. See Stewart et al. (2013) for a discussion of issues related to differences between MCMC and MLE.

Maximum likelihood estimate (MLE): A method used to estimate a single value for each of the parameters and derived quantities. It is less computationally intensive than MCMC methods (see below), but parameter uncertainty is less well determined.

Maximum sustainable yield (MSY): An estimate of the largest sustainable annual catch that can be continuously taken over a long period of time from a stock under equilibrium ecological and environmental conditions.

MCMC: Markov-Chain Monte-Carlo (see above).

MLE: Maximum likelihood estimate (see above).

MSE: Management Strategy Evaluation (see above).

MSY: Maximum sustainable yield (see above).

t: Metric ton(s). A unit of mass (often referred to as weight) equal to 1,000 kilograms or 2,204.62 pounds. Previous stock assessments used the abbreviation “mt” (metric tons).

NA: Not available.

National Marine Fisheries Service: See NOAA Fisheries below.

NMFS: National Marine Fisheries Service. See NOAA Fisheries below.

NOAA Fisheries: The division of the United States National Oceanic and Atmospheric Administration (NOAA) responsible for conservation and management of offshore fisheries (and inland salmon). This is also known as the National Marine Fisheries Service (NMFS), and both names are commonly used at this time.

NORPAC: North Pacific Database Program. A database storing U.S. fishery observer data collected at sea.

NWFSC : Northwest Fisheries Science Center. A NOAA Fisheries Science Center located primarily in Seattle, Washington, but also in Newport, Oregon and other locations.

Operating Model (OM): A model used to simulate data for use in the MSE (see above). The operating model includes components for the stock and fishery dynamics, as well as the

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simulation of the data sampling process, potentially including observation error. Cases in the MSE represent alternative configurations of the operating model.

OM: Operating Model (see above).

PacFIN: Pacific Coast Fisheries Information Network. A database that provides a central repository for commercial fishery information from Washington, Oregon, and California.

PBS: Pacific Biological Station of Fisheries and Oceans Canada (DFO, see above), located in Nanaimo, British Columbia.

Pacific Fishery Management Council (PFMC): The U.S. organization under which historical stock assessments for Pacific Hake/whiting were conducted.

Pacific Hake: Common name for *Merluccius productus*, the species whose offshore stock in the waters of the United States and Canada is subject of this assessment.

Pacific Whiting: an alternative name for Pacific Hake commonly used in the United States.

Posterior distribution: The probability distribution for parameters or derived quantities from a Bayesian model representing the result of the prior probability distributions (see below) being updated by the observed data via the likelihood equation. For stock assessments, posterior distributions are approximated via numerical methods; one frequently employed method is MCMC (see above).

Prior distribution: Probability distribution for a parameter in a Bayesian analysis that represents the information available before evaluating the observed data via the likelihood equation. For some parameters, noninformative priors can be constructed which allow the data to dominate the posterior distribution (see above). For other parameters, informative priors can be constructed based on auxiliary information and/or expert knowledge or opinions.

$q$ : Catchability (see above).

$R_0$ : Estimated annual recruitment at unfished equilibrium.

Recruits/recruitment: the estimated number of new members in a fish population born in the same age. In this assessment, recruitment is reported at age 0. See also cohort and year-class.

Recruitment deviation: The offset of the recruitment in a given year relative to the stock-recruit function; values occur on a logarithmic scale and are relative to the expected recruitment at a given spawning biomass (see below).

Relative fishing intensity: See definition of fishing intensity.

Relative spawning biomass: The ratio of the beginning-of-the-year female spawning biomass to

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the unfished equilibrium female spawning biomass ( $B_0$ , see above). Thus, lower values are associated with fewer mature female fish. This term was introduced in the 2015 stock assessment as a replacement for “depletion” (see above) which was a source of some confusion.

Scientific Review Group (SRG): The scientific review group established by the Agreement.

Scientific and Statistical Committee (SSC): The scientific advisory committee to the PFM. The Magnuson-Stevens Act requires that each council maintain an SSC to assist in gathering and analyzing statistical, biological, ecological, economic, social, and other scientific information that is relevant to the management of council fisheries.

SD: Standard deviation. A measure of variability within a sample.

Simulation: A model evaluation under a particular state of nature, including combinations of parameters controlling stock productivity, stock status, and the time series of recruitment deviations. In this assessment, there are 2,000 simulations used to characterize alternative states of nature, each of which are based on a sample from the posterior distribution of the parameters, as calculated using MCMC, for a particular model (e.g., the base model).

Spawning biomass: Abbreviated term for female spawning biomass (see above).

Spawning biomass per recruit: The expected lifetime contribution of an age-0 recruit, calculated as the sum across all ages of the product of spawning biomass at each age and the probability of surviving to that age. See Figure B.2 for a graphical demonstration of the calculation of this value, which is found in both numerator and denominator of the Spawning potential ratio (SPR, see below).

Spawning potential ratio (SPR): The ratio of the spawning biomass per recruit under a given level of fishing to the estimated spawning biomass per recruit in the absence of fishing; i.e. for fishing mortality rate  $F$

$$\text{SPR}(F) = \frac{\text{spawning biomass per recruit with } F}{\text{spawning biomass per recruit with no fishing}}. \quad (\text{B.7})$$

Often expressed as a percentage, it achieves a value of 100% in the absence of fishing and declines toward zero as fishing intensity increases. See Figure B.2 for a graphical demonstration of the calculation of SPR.

SPR: Spawning potential ratio (see above).

SPR<sub>40%</sub>: See target spawning potential ratio.

SS: Stock Synthesis (see below).

Steepness ( $h$ ): A stock-recruit relationship parameter representing the proportion of  $R_0$  expected (on average) when the female spawning biomass is reduced to 20% of  $B_0$  (i.e., when

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relative spawning biomass is equal to 20%).

Stock Synthesis (SS): The age-structured stock assessment model applied in this stock assessment.

Target spawning potential ratio ( $SPR_{40\%}$ ): The spawning potential ratio of 40%, where the 40% relates to the default harvest rate of  $F_{SPR=40\%}$  specified in the Agreement. Even under equilibrium conditions,  $F_{SPR=40\%}$  would not necessarily result in a spawning biomass of  $B_{40\%}$  because  $F_{SPR=40\%}$  is defined in terms of the spawning potential ratio which depends on the spawning biomass *per recruit*.

Target strength (TS): The amount of backscatter from an individual acoustic target.

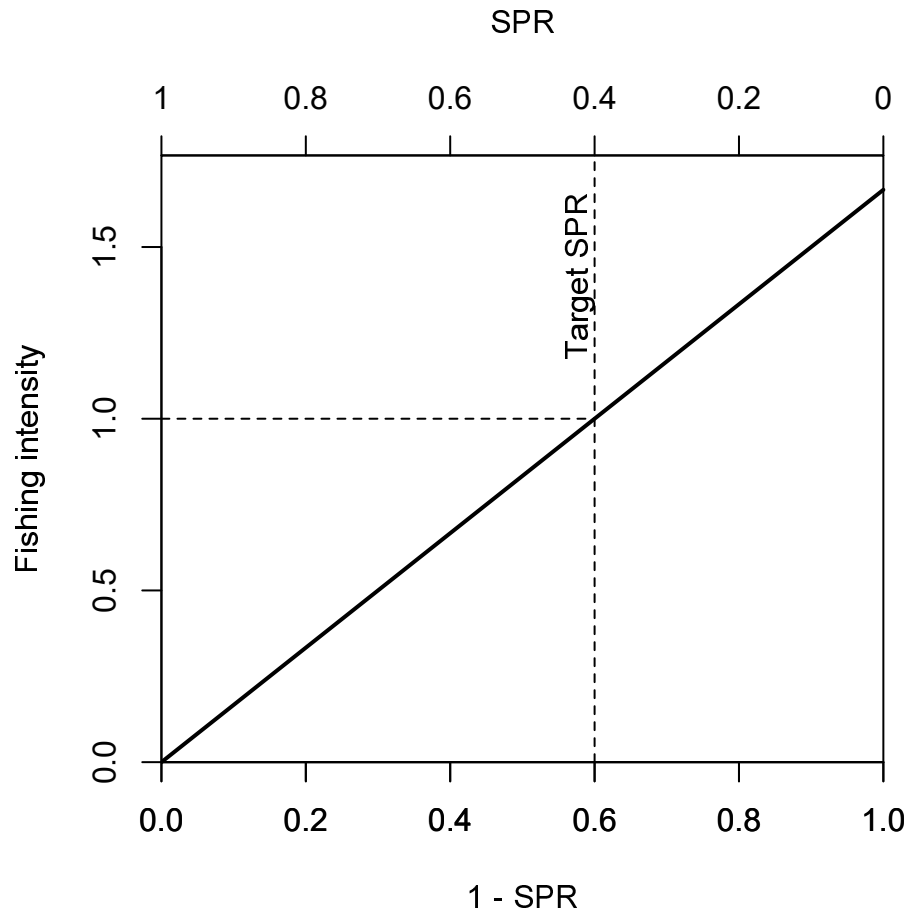
TAC: Total allowable catch (see below).

Total allowable catch (TAC): The maximum fishery removal under the terms of the Agreement.

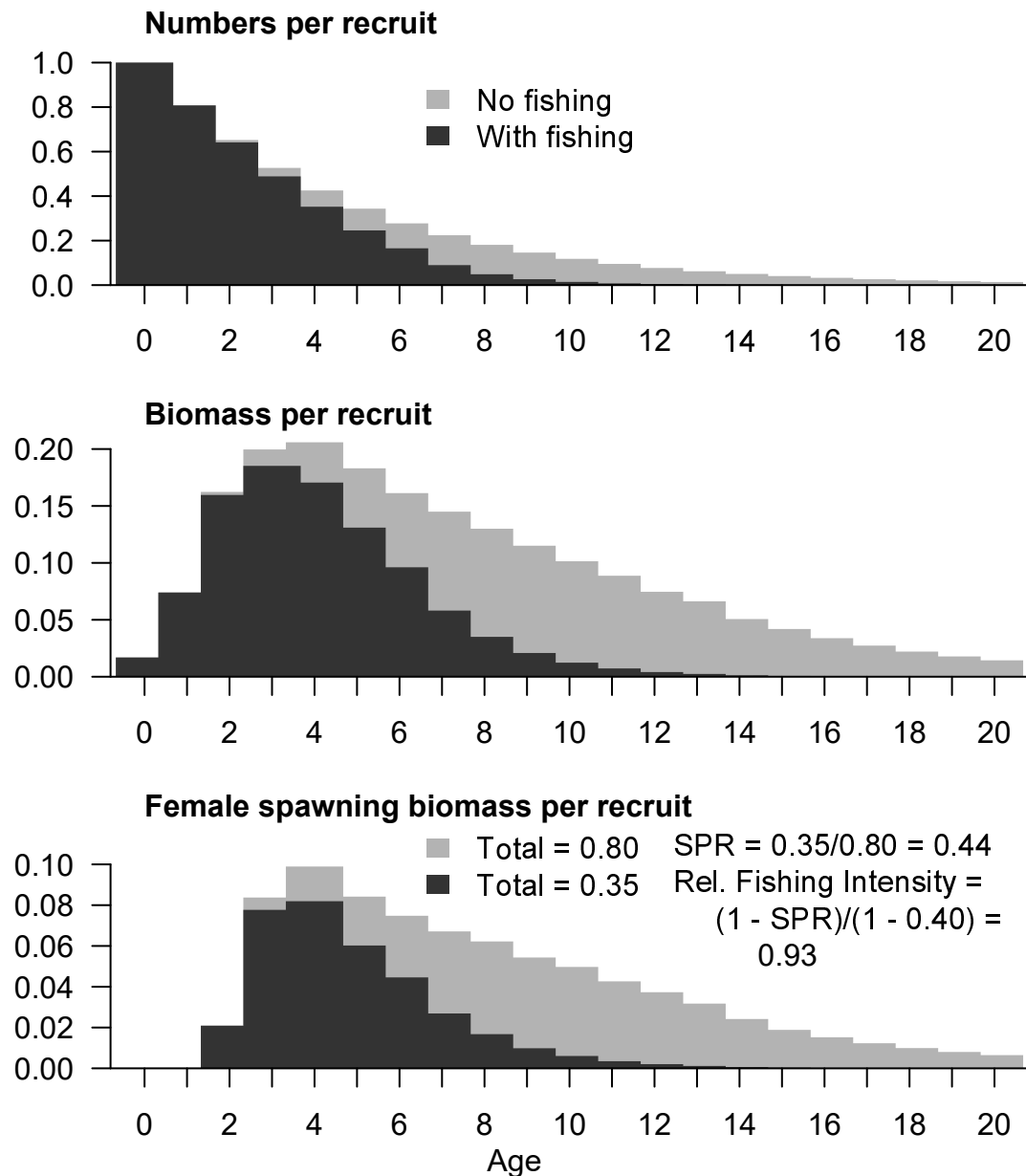
U.S./Canadian allocation: The division of the total allowable catch of 73.88% as the United States' share and 26.12% as Canada's share.

Vulnerable biomass: The demographic portion of the stock available for harvest by the fishery.

Year-class: A group of fish born in the same year. See also 'cohort' and 'recruitment'.



**Figure B.1.** Fishing intensity as a function of SPR (top axis) and 1-SPR (bottom axis); given the target SPR of 40%, the bold line is simply  $1/0.6$ , as shown in equation (B.5).



**Figure B.2.** Illustration of the spawning potential ratio (SPR) calculation based on the combination of maturity and fecundity used in the model, using the maximum likelihood estimates of natural mortality, selectivity, and fishing mortality in the final year of the base model.

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## C REPORT OF THE 2017 PACIFIC HAKE FISHERY IN CANADA

**Prepared by the Canadian Advisory Panel and submitted for inclusion in this assessment document on February 7th, 2018.**

The 2017 Offshore Pacific adjusted Total Allowable Catch (TAC) for Canada was 156,067 mt, consisting of an allowable catch of 138,828 mt and a carry over from the 2016 fishery of 17,239 mt. As of December 14, the total 2017 catch of Offshore Pacific Hake by Canadian vessels was 87,366.93 mt which equates to 56% of the adjusted TAC. For the first time since 2011 there was a Joint Venture (JV) fishery in Pacific Canada. The JV fishery ran from August 21 to September 19 and a total of 5,825.25 mt of hake was delivered to the Dutch registered vessel *Annelies Ilena*.

Fishing in the Canadian zone started in mid-April with the last delivery occurring on November 24, 2017. Freezer vessels started first with shoreside deliveries and processing commencing in early April. The early fishery was in the southern area off Vancouver Island. The size of the fish was generally around 550-600 grams round. There were not a lot of really large fish (800 grams and larger) early in the year. There was a small amount of them late in September. In August the fleet ran into small fish (300-400 grams) near the Canada/US border.

A majority of the Canadian production was HGT (headed, gutted and tail off), by both shoreside and freezer vessels, with a very small amount of mince and whole round produced shoreside. The Canadian hake shoreside TAC is harvested by freezer vessels and vessels delivering fresh to shoreside plants. Overall fleet participation was up from 2016 due to good hake abundance and availability close to the processing facility in Ucluelet, the addition of a Joint Venture fishery, closure to the West coast Vancouver Island shrimp trawl fishery, and more stable market conditions throughout the season.

The Canadian hake fleet believes the 2017 hake fishery was positive, with fish present continuously along the shelf break and on the shelf off the West Coast of Vancouver Island throughout the season. Similar to 2016, there appeared to be a larger hake biomass in Canada compared to previous years. Bycatch was seldom a problem throughout the year, except for incidence of high Pacific Ocean Perch catch early in the year and significant juvenile Sablefish interceptions early in the summer.

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## D REPORT OF THE 2017 PACIFIC HAKE FISHERY IN THE UNITED STATES

**Prepared by the United States Advisory Panel and submitted for the Canada/US Joint Management Committee's and the Joint Technical Committee's consideration on February 6, 2018.**

The Mothership (MS), Catcher Processor (CP), and Shoreside (SS) sectors of the U.S. fishery started on May 15. With limited exception, the U.S. fishery followed historic patterns related to fishing effort. One major mothership processor did not participate in the spring fishery, but did participate with limited effort in the fall fishery. There was little activity in the CP and MS sectors during July and August because the vessels left to participate in the Alaska pollock fishery during that time period. The SS sector was active throughout the summer and experienced steady fishing throughout. All three sectors participated during the fall with fishing continuing steadily through November and with limited fishing in the CP and MS fisheries in early December. Although overall effort and therefore total catch was lower than normal in the MS sector, catching and processing efforts across all non-Tribal sectors was higher than recent years and generally more consistent with historic effort levels. Like 2016, a limited Tribal fishery occurred in 2017, which was limited by processing capacity, not fish abundance or availability in the Tribal usual and accustomed fishing area.

**Table D.1.** 2017 US Catch Summary (does not include 1,500 mt research and incidental catch set-aside)

	SS	CP	MS	Tribal	Total
<b>Init. Alloc. (5/15)</b>	152,326	123,312	87,044	77,251	439,933
<b>Rev. Alloc. (9/14)</b>	169,546	137,252	96,884	36,251	439,933
<b>Catch</b>	144,396	136,960	66,427	6,012	353,796
<b>Remaining</b>	25,150	291	30,457	30,239	86,137
<b>% Util Init. Alloc.</b>	95%	111%	76%	0.08%	
<b>% Util Rev. Alloc.</b>	85%	100%	69%	17%	80%

As in the past, concerns of bycatch and efforts to reduce interaction with these constraining species dominated fishing effort and practices. For example, various voluntary management measures encouraged fishing north of 44 degrees North, and some sectors endeavored to fish in deep water and only during daylight hours.

Product forms in the 2017 US hake fishery included surimi, mince, fillet, HGT, and fishmeal products. For the at-sea sectors, surimi continued to be the predominant product in response to improved market conditions. HGT continued to dominate production in the SS fishery although surimi production was also increased.

All sectors experienced excellent catch per unit of fishing effort (CPUE), with reports that fishing was ‘the best they can remember’, ‘the best in the last 8-10 years’, etc. CPUE’s remained high throughout the season with no early summer ‘lull’ often experienced in early July. An abundance of fish was still available in the north, even as late as December. Similarly, all sectors reported encountering an abundance of larger fish than seen in recent years while also seeing significant



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amounts of smaller fish throughout the coast shoreward of 50 fathoms and in particular to the south of the Columbia River. Reports noted the presence of huge schools of six inch hake in waters off Washington inside of 100 fathoms, particularly during the spring. An abundance of sub-200 gram fish was also reported to the south of the Columbia River and in Oregon, particularly in the shallower depths. Reports from fishermen and processors confirm two different year classes in the catch across sectors, presumably the 2010 and 2014 year classes. As a general rule, the fish were larger to the north and trending smaller to the south. Average fish sizes were reported to be ‘the best we have seen in years’ with two distinct sizes focused around 400 and 600 grams. Good fishing was spread spatially along the entire coast. Unlike seasons in the recent past, SS catcher vessels did not need to travel far from their shoreside plants to catch and deliver their hake.

Bycatch concerns continued to dominate the US fishery with high encounters of Pacific Ocean perch (POP) and widow rockfish north of the Columbia River, and widow rockfish and dark-blotched rockfish to the South. Efforts by the fleet to minimize incidental catch of Klamath River-area Chinook limited fishing in Oregon south of 44 degrees North latitude. As has been reported, there has been a strong rebuilding of several rockfish species that, by regulation, constrain the MS and CP sectors. In 2017, there were several large ‘lightning strike’ encounters in both sectors that significantly disrupted typical fishing patterns in both sectors, necessitating movement from good fishing areas off of Washington into more southerly waters. For example, the 1st Pool of the MS sector was shut down on May 29th due to exceeding the POP amount set by the MS CoOp for that 1st pool. Similarly, the CP sector also experienced chronic encounters with rebuilt and plentiful hard cap rockfish species. One CP company ceased their spring hake fishing prematurely because of encounters with POP. For both at-sea sectors, POP encounters pushed fishing south in order to reduce bycatch. The result was that fleets left larger fish and better CPUE and fished on smaller fish with lower CPUE but less constraining species bycatch. While the rebuilding of the various constraining rockfish species is encouraging, their increased abundance has had significant impact on the hake harvest rates and selectivity in all non-Tribal sectors. In sum, avoidance of rockfish and salmon continued to dominate harvest strategies in the U.S. fishery.

Ocean conditions appear to have returned closer to ‘normal’. Water temperatures showed more consistent historic patterns. Hake appeared to move South to North and then again South in a more consistent historic pattern. Rockfish species were more widely dispersed (North-South and Shallow-Deep) than recent years. Two anomalies were reported by harvesters in the spring fishery. The first was unusually high encounters with juvenile black cod north of the Columbia River. The second anomaly was large concentrations of pyrosomes encountered throughout the coast, reportedly from Oregon all the way to the US/Canada border, occasionally so dense that they clogged trawls, especially impacting the ability of smaller vessels to fish in certain areas.

Overall, the 2017 U.S. fishery was extremely successful. Harvests reached historic highs. Fish size and quality were good and the market supported these increased catches. Observations of fishermen along with the fishery data support that the management of the hake stock continue to result in a healthy, diverse and abundant stock.

## E ESTIMATED PARAMETERS IN THE BASE ASSESSMENT MODEL

**Table E.1.** Medians of estimated parameters for the base model.

Parameter	Posterior median
NatM_p_1_Fem_GP_1	0.2299
SR_LN.R0.	14.8354
SR_BH_steep	0.8122
Q_extraSD_Acoustic_Survey.2.	0.3048
ln.EffN_mult_1	-0.5619
Early_InitAge_20	-0.2779
Early_InitAge_19	-0.1323
Early_InitAge_18	-0.1227
Early_InitAge_17	-0.1369
Early_InitAge_16	-0.2216
Early_InitAge_15	-0.2361
Early_InitAge_14	-0.1492
Early_InitAge_13	-0.2527
Early_InitAge_12	-0.3399
Early_InitAge_11	-0.3623
Early_InitAge_10	-0.4276
Early_InitAge_9	-0.4902
Early_InitAge_8	-0.5601
Early_InitAge_7	-0.6397
Early_InitAge_6	-0.5936
Early_InitAge_5	-0.5002
Early_InitAge_4	-0.3634
Early_InitAge_3	-0.1386
Early_InitAge_2	0.2263
Early_InitAge_1	0.4970
Early_RecrDev_1966	0.5261
Early_RecrDev_1967	1.5203
Early_RecrDev_1968	1.0659
Early_RecrDev_1969	-0.2556
Main_RecrDev_1970	2.1265
Main_RecrDev_1971	-0.2185
Main_RecrDev_1972	-0.6585
Main_RecrDev_1973	1.6911
Main_RecrDev_1974	-1.0572
Main_RecrDev_1975	0.5233
Main_RecrDev_1976	-1.5741
Main_RecrDev_1977	1.8132
Main_RecrDev_1978	-2.0099
Main_RecrDev_1979	0.2425
Main_RecrDev_1980	2.7852
Main_RecrDev_1981	-1.3383
Main_RecrDev_1982	-1.2073
Main_RecrDev_1983	-0.7454
Main_RecrDev_1984	2.5445
Main_RecrDev_1985	-2.0532
Main_RecrDev_1986	-1.7333
Main_RecrDev_1987	1.7890
Main_RecrDev_1988	0.6539
Main_RecrDev_1989	-2.1783
Main_RecrDev_1990	1.3874
Main_RecrDev_1991	0.1312
Main_RecrDev_1992	-2.0583
Main_RecrDev_1993	1.1089
Main_RecrDev_1994	1.1702
Main_RecrDev_1995	0.2027
Main_RecrDev_1996	0.6000
Main_RecrDev_1997	0.0526
Main_RecrDev_1998	0.6923
Main_RecrDev_1999	2.5964

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**Table E.1.** Medians of estimated parameters for the base model.

Parameter	Posterior median
Main_RecrDev_2000	-1.0658
Main_RecrDev_2001	0.2319
Main_RecrDev_2002	-3.4592
Main_RecrDev_2003	0.4830
Main_RecrDev_2004	-2.7760
Main_RecrDev_2005	0.9850
Main_RecrDev_2006	0.6845
Main_RecrDev_2007	-3.6576
Main_RecrDev_2008	1.7151
Main_RecrDev_2009	0.3531
Main_RecrDev_2010	2.7031
Main_RecrDev_2011	-0.7975
Main_RecrDev_2012	0.3814
Main_RecrDev_2013	-0.8901
Main_RecrDev_2014	2.1233
Main_RecrDev_2015	-1.8784
Main_RecrDev_2016	1.1849
Late_RecrDev_2017	0.0252
ForeRecr_2018	0.0125
ForeRecr_2019	0.0632
ForeRecr_2020	-0.0275
AgeSel_P3_Fishery.1.	2.8476
AgeSel_P4_Fishery.1.	0.9730
AgeSel_P5_Fishery.1.	0.3861
AgeSel_P6_Fishery.1.	0.1775
AgeSel_P7_Fishery.1.	0.5048
AgeSel_P4_Acoustic_Survey.2.	0.5919
AgeSel_P5_Acoustic_Survey.2.	-0.2258
AgeSel_P6_Acoustic_Survey.2.	0.2876
AgeSel_P7_Acoustic_Survey.2.	0.3728
AgeSel_P3_Fishery.1._DEVadd_1991	0.5603
AgeSel_P3_Fishery.1._DEVadd_1992	0.0029
AgeSel_P3_Fishery.1._DEVadd_1993	-0.0397
AgeSel_P3_Fishery.1._DEVadd_1994	0.1155
AgeSel_P3_Fishery.1._DEVadd_1995	-0.1800
AgeSel_P3_Fishery.1._DEVadd_1996	0.4931
AgeSel_P3_Fishery.1._DEVadd_1997	0.1311
AgeSel_P3_Fishery.1._DEVadd_1998	0.2197
AgeSel_P3_Fishery.1._DEVadd_1999	0.9937
AgeSel_P3_Fishery.1._DEVadd_2000	0.4772
AgeSel_P3_Fishery.1._DEVadd_2001	0.0308
AgeSel_P3_Fishery.1._DEVadd_2002	0.0953
AgeSel_P3_Fishery.1._DEVadd_2003	-0.0059
AgeSel_P3_Fishery.1._DEVadd_2004	0.2931
AgeSel_P3_Fishery.1._DEVadd_2005	0.0505
AgeSel_P3_Fishery.1._DEVadd_2006	0.5577
AgeSel_P3_Fishery.1._DEVadd_2007	0.5612
AgeSel_P3_Fishery.1._DEVadd_2008	-0.0382
AgeSel_P3_Fishery.1._DEVadd_2009	0.4445
AgeSel_P3_Fishery.1._DEVadd_2010	0.9733
AgeSel_P3_Fishery.1._DEVadd_2011	-0.1699
AgeSel_P3_Fishery.1._DEVadd_2012	0.1822
AgeSel_P3_Fishery.1._DEVadd_2013	0.2215
AgeSel_P3_Fishery.1._DEVadd_2014	0.3428
AgeSel_P3_Fishery.1._DEVadd_2015	-0.7978
AgeSel_P3_Fishery.1._DEVadd_2016	0.0871
AgeSel_P3_Fishery.1._DEVadd_2017	-0.9672
AgeSel_P4_Fishery.1._DEVadd_1991	0.3661
AgeSel_P4_Fishery.1._DEVadd_1992	0.5541
AgeSel_P4_Fishery.1._DEVadd_1993	0.7739
AgeSel_P4_Fishery.1._DEVadd_1994	0.1901

Continued on next page

**Table E.1.** Medians of estimated parameters for the base model.

Parameter	Posterior median
AgeSel_P4_Fishery.1._DEVadd_1995	0.2387
AgeSel_P4_Fishery.1._DEVadd_1996	-0.4089
AgeSel_P4_Fishery.1._DEVadd_1997	1.2548
AgeSel_P4_Fishery.1._DEVadd_1998	0.9249
AgeSel_P4_Fishery.1._DEVadd_1999	-0.1038
AgeSel_P4_Fishery.1._DEVadd_2000	0.7567
AgeSel_P4_Fishery.1._DEVadd_2001	0.9024
AgeSel_P4_Fishery.1._DEVadd_2002	0.7430
AgeSel_P4_Fishery.1._DEVadd_2003	0.6327
AgeSel_P4_Fishery.1._DEVadd_2004	0.4132
AgeSel_P4_Fishery.1._DEVadd_2005	0.6021
AgeSel_P4_Fishery.1._DEVadd_2006	-0.1124
AgeSel_P4_Fishery.1._DEVadd_2007	0.1641
AgeSel_P4_Fishery.1._DEVadd_2008	0.3071
AgeSel_P4_Fishery.1._DEVadd_2009	0.7245
AgeSel_P4_Fishery.1._DEVadd_2010	0.0993
AgeSel_P4_Fishery.1._DEVadd_2011	1.0706
AgeSel_P4_Fishery.1._DEVadd_2012	0.1092
AgeSel_P4_Fishery.1._DEVadd_2013	0.9114
AgeSel_P4_Fishery.1._DEVadd_2014	0.3536
AgeSel_P4_Fishery.1._DEVadd_2015	0.2897
AgeSel_P4_Fishery.1._DEVadd_2016	-1.0009
AgeSel_P4_Fishery.1._DEVadd_2017	-0.2030
AgeSel_P5_Fishery.1._DEVadd_1991	-0.8457
AgeSel_P5_Fishery.1._DEVadd_1992	0.0512
AgeSel_P5_Fishery.1._DEVadd_1993	0.0123
AgeSel_P5_Fishery.1._DEVadd_1994	0.8948
AgeSel_P5_Fishery.1._DEVadd_1995	0.2579
AgeSel_P5_Fishery.1._DEVadd_1996	-0.2966
AgeSel_P5_Fishery.1._DEVadd_1997	-0.1152
AgeSel_P5_Fishery.1._DEVadd_1998	-0.6098
AgeSel_P5_Fishery.1._DEVadd_1999	0.1099
AgeSel_P5_Fishery.1._DEVadd_2000	-0.1247
AgeSel_P5_Fishery.1._DEVadd_2001	0.3057
AgeSel_P5_Fishery.1._DEVadd_2002	0.5441
AgeSel_P5_Fishery.1._DEVadd_2003	0.7235
AgeSel_P5_Fishery.1._DEVadd_2004	0.6745
AgeSel_P5_Fishery.1._DEVadd_2005	0.7449
AgeSel_P5_Fishery.1._DEVadd_2006	0.0271
AgeSel_P5_Fishery.1._DEVadd_2007	-0.0649
AgeSel_P5_Fishery.1._DEVadd_2008	-0.4263
AgeSel_P5_Fishery.1._DEVadd_2009	-0.1685
AgeSel_P5_Fishery.1._DEVadd_2010	0.4718
AgeSel_P5_Fishery.1._DEVadd_2011	-0.6933
AgeSel_P5_Fishery.1._DEVadd_2012	0.2273
AgeSel_P5_Fishery.1._DEVadd_2013	-0.2611
AgeSel_P5_Fishery.1._DEVadd_2014	-0.3174
AgeSel_P5_Fishery.1._DEVadd_2015	-0.0402
AgeSel_P5_Fishery.1._DEVadd_2016	0.1111
AgeSel_P5_Fishery.1._DEVadd_2017	-0.0549
AgeSel_P6_Fishery.1._DEVadd_1991	-0.0930
AgeSel_P6_Fishery.1._DEVadd_1992	-0.4495
AgeSel_P6_Fishery.1._DEVadd_1993	-0.0298
AgeSel_P6_Fishery.1._DEVadd_1994	-0.1071
AgeSel_P6_Fishery.1._DEVadd_1995	0.7222
AgeSel_P6_Fishery.1._DEVadd_1996	-0.1618
AgeSel_P6_Fishery.1._DEVadd_1997	-0.3228
AgeSel_P6_Fishery.1._DEVadd_1998	0.3778
AgeSel_P6_Fishery.1._DEVadd_1999	-0.3981
AgeSel_P6_Fishery.1._DEVadd_2000	0.1470
AgeSel_P6_Fishery.1._DEVadd_2001	-0.0958

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**Table E.1.** Medians of estimated parameters for the base model.

Parameter	Posterior median
AgeSel_P6_Fishery.1._DEVadd_2002	0.1204
AgeSel_P6_Fishery.1._DEVadd_2003	0.2693
AgeSel_P6_Fishery.1._DEVadd_2004	-0.5698
AgeSel_P6_Fishery.1._DEVadd_2005	0.2768
AgeSel_P6_Fishery.1._DEVadd_2006	0.1821
AgeSel_P6_Fishery.1._DEVadd_2007	-0.1871
AgeSel_P6_Fishery.1._DEVadd_2008	0.3371
AgeSel_P6_Fishery.1._DEVadd_2009	-0.2911
AgeSel_P6_Fishery.1._DEVadd_2010	-0.4557
AgeSel_P6_Fishery.1._DEVadd_2011	-0.1789
AgeSel_P6_Fishery.1._DEVadd_2012	-0.4517
AgeSel_P6_Fishery.1._DEVadd_2013	0.0155
AgeSel_P6_Fishery.1._DEVadd_2014	-0.0552
AgeSel_P6_Fishery.1._DEVadd_2015	0.0992
AgeSel_P6_Fishery.1._DEVadd_2016	-0.1401
AgeSel_P6_Fishery.1._DEVadd_2017	0.0038
AgeSel_P7_Fishery.1._DEVadd_1991	-0.0610
AgeSel_P7_Fishery.1._DEVadd_1992	0.0694
AgeSel_P7_Fishery.1._DEVadd_1993	-0.3766
AgeSel_P7_Fishery.1._DEVadd_1994	0.1347
AgeSel_P7_Fishery.1._DEVadd_1995	-0.1151
AgeSel_P7_Fishery.1._DEVadd_1996	0.4194
AgeSel_P7_Fishery.1._DEVadd_1997	0.1220
AgeSel_P7_Fishery.1._DEVadd_1998	-0.4950
AgeSel_P7_Fishery.1._DEVadd_1999	-0.2575
AgeSel_P7_Fishery.1._DEVadd_2000	-0.0579
AgeSel_P7_Fishery.1._DEVadd_2001	-0.2880
AgeSel_P7_Fishery.1._DEVadd_2002	-0.3893
AgeSel_P7_Fishery.1._DEVadd_2003	-0.2695
AgeSel_P7_Fishery.1._DEVadd_2004	-0.1724
AgeSel_P7_Fishery.1._DEVadd_2005	-0.4179
AgeSel_P7_Fishery.1._DEVadd_2006	-0.3334
AgeSel_P7_Fishery.1._DEVadd_2007	0.0293
AgeSel_P7_Fishery.1._DEVadd_2008	-0.1862
AgeSel_P7_Fishery.1._DEVadd_2009	0.1218
AgeSel_P7_Fishery.1._DEVadd_2010	-0.5888
AgeSel_P7_Fishery.1._DEVadd_2011	-0.5139
AgeSel_P7_Fishery.1._DEVadd_2012	-0.3527
AgeSel_P7_Fishery.1._DEVadd_2013	0.0754
AgeSel_P7_Fishery.1._DEVadd_2014	0.0053
AgeSel_P7_Fishery.1._DEVadd_2015	-0.5342
AgeSel_P7_Fishery.1._DEVadd_2016	-0.1281
AgeSel_P7_Fishery.1._DEVadd_2017	0.1763

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## F STOCK SYNTHESIS DATA FILE

```

../models/2018.40_base_model/2018hake_data.ss
#C 2018 Hake data file
1966 #_StartYr
2017 #_EndYr
1 #_Nseas
  12 #_months/season
2 #_Nsubseasons (even number, minimum is 2)
1 #_spawn_month
1 #_Ngenders
20 #_Nages=accumulator age
1 #_Nareas
2 #_Nfleets (including surveys)
#_fleet_type: 1=catch fleet; 2=bycatch only fleet; 3=survey; 4=ignore
#_survey_timing: -1=for use of catch-at-age to override the month value
  associated with a datum
#_fleet_area: area the fleet/survey operates in
#_units of catch: 1=bio; 2=num (ignored for surveys; their units read
  later)
#_catch_mult: 0=no; 1=yes
#_rows are fleets
#_fleet_type timing area units need_catch_mult fleetname
  1      -1      1      1      0      Fishery # 1
  3      0.5     1      2      0      Acoustic_Survey # 2
#_Catch data: yr, seas, fleet, catch, catch_se
#_catch_se: standard error of log(catch)
#_NOTE: catch data is ignored for survey fleets

#Year Seas Fleet Catch Catch_SE
-999 1 1 0 0.01 # equilibrium catch prior to initial year
#
1966 1 1 137700 0.01
1967 1 1 214370 0.01
1968 1 1 122180 0.01
1969 1 1 180130 0.01
1970 1 1 234590 0.01
1971 1 1 154620 0.01
1972 1 1 117540 0.01
1973 1 1 162640 0.01
1974 1 1 211260 0.01
1975 1 1 221350 0.01
1976 1 1 237520 0.01
1977 1 1 132690 0.01
1978 1 1 103637 0.01
1979 1 1 137110 0.01
1980 1 1 89930 0.01
1981 1 1 139120 0.01
1982 1 1 107741 0.01
1983 1 1 113931 0.01
1984 1 1 138492 0.01
1985 1 1 110399 0.01
1986 1 1 210616 0.01

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1987  1    1    234148  0.01
1988  1    1    248840  0.01
1989  1    1    298079  0.01
1990  1    1    261286  0.01
1991  1    1    319705  0.01
1992  1    1    299650  0.01
1993  1    1    198905  0.01
1994  1    1    362407  0.01
1995  1    1    249495  0.01
1996  1    1    306299  0.01
1997  1    1    325147  0.01
1998  1    1    320722  0.01
1999  1    1    311887  0.01
2000  1    1    228777  0.01
2001  1    1    227525  0.01
2002  1    1    180697  0.01
2003  1    1    205162  0.01
2004  1    1    342307  0.01
2005  1    1    363135  0.01
2006  1    1    361699  0.01
2007  1    1    293389  0.01
2008  1    1    321802  0.01
2009  1    1    177171  0.01
2010  1    1    230755  0.01
2011  1    1    291670  0.01
2012  1    1    205787  0.01
2013  1    1    285591  0.01
2014  1    1    298705  0.01
2015  1    1    190663  0.01
2016  1    1    329427  0.01
2017  1    1    440380  0.01
#
-9999 0 0 0 0 # end input of catch data
#
#_CPUE_and_surveyabundance_observations
#_Units:  0=numbers; 1=biomass; 2=F; >=30 for special types
#_Errtype:  -1=normal; 0=lognormal; >0=T
#_SD_Report: 0=no sdreport; 1=enable sdreport
#_Fleet Units Errtype SD_Report
1 1 0 0 # Fishery
2 1 0 0 # Acoustic_Survey
# Year  month    fleet    obs      se(log)
1995    7        2    1318035  0.0893
1996    7       -2        1        1    # dummy observation
1997    7       -2        1        1    # dummy observation
1998    7        2    1534604  0.0526
1999    7       -2        1        1    # dummy observation
2000    7       -2        1        1    # dummy observation
2001    7        2    861744    0.1059
2002    7       -2        1        1    # dummy observation
2003    7        2    2137528  0.0642
2004    7       -2        1        1    # dummy observation
2005    7        2    1376099  0.0638
2006    7       -2        1        1    # dummy observation

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2007      7      2      942721      0.0766
2008      7     -2       1         1      # dummy observation
2009      7      2     1502273     0.0995
2010      7     -2       1         1      # dummy observation
2011      7      2     674617     0.1177
2012      7      2     1279421     0.0673
2013      7      2     1929235     0.0646
2014      7     -2       1         1      # dummy observation
2015      7      2     2155853     0.0829 # note: "revised in early 2016
      from 0.092 to 0.0829"
2016      7     -2       1         1      # dummy observation
2017      7      2     1417811     0.0632

-9999 1 1 1 1 # terminator for survey observations
#
0 #_N_fleets_with_discard
#_discard_units (1=same_as_catchunits(bio/num); 2=fraction; 3=numbers)
#_discard_errtype: >0 for DF of T-dist(read CV below); 0 for normal with
      CV; -1 for normal with se; -2 for lognormal; -3 for trunc normal with
      CV
# note, only have units and errtype for fleets with discard
#_Fleet units errtype
# -9999 0 0 0.0 0.0 # terminator for discard data
#
0 #_use meanbodysize_data (0/1)
#_COND_30 #_DF_for_meanbodysize_T-distribution_like
# note: use positive partition value for mean body wt, negative
      partition for mean body length
#_yr month fleet part obs stderr
# -9999 0 0 0 0 0 # terminator for mean body size data
#
# set up population length bin structure (note - irrelevant if not using
      size data and using empirical wtatage
2 # length bin method: 1=use databins; 2=generate from binwidth,min,max
      below; 3=read vector
2 # binwidth for population size comp
10 # minimum size in the population (lower edge of first bin and size at
      age 0.00)
70 # maximum size in the population (lower edge of last bin)
1 # use length composition data (0/1)
#_mintailcomp: upper and lower distribution for females and males
      separately are accumulated until exceeding this level.
#_addtocomp: after accumulation of tails; this value added to all bins
#_males and females treated as combined gender below this bin number
#_compressbins: accumulate upper tail by this number of bins; acts
      simultaneous with mintailcomp; set=0 for no forced accumulation
#_Comp_Error: 0=multinomial, 1=dirichlet
#_Comp_Error2: parm number for dirichlet
#_minsamplesize: minimum sample size; set to 1 to match 3.24, minimum
      value is 0.001
#_mintailcomp addtocomp combM+F CompressBns CompError ParmSelect
      minsamplesize
-1      0.001      0      0      0      0      0.001
      #_fleet:1_Fishery

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-1          0.001      0      0      0      0      0.001
#_fleet:2_Acoustic_Survey
# sex codes: 0=combined; 1=use female only; 2=use male only; 3=use both
  as joint sexxlength distribution
# partition codes: (0=combined; 1=discard; 2=retained
26 #_N_LengthBins; then enter lower edge of each length bin
  20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66
  68 70
#_yr month fleet sex part Nsamp datavector(female-male)
-9999 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
#
15 #_N_age_bins
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
45 #_N_ageerror_definitions
#age0      age1      age2      age3      age4      age5      age6
      age7      age8      age9      age10     age11     age12
      age13     age14     age15     age16     age17     age18
      age19     age20     yr      def      comment
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 1973    def1      'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
      2.934     3.388     # 1973    def1      'SD of age. '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 1974    def2      'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
      2.934     3.388     # 1974    def2      'SD of age. '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 1975    def3      'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
      2.934     3.388     # 1975    def3      'SD of age. '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 1976    def4      'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
      2.934     3.388     # 1976    def4      'SD of age. '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 1977    def5      'Expected ages '

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0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1977      def5        'SD of age. '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
      7.5          8.5          9.5          10.5         11.5         12.5
      13.5         14.5         15.5         16.5         17.5         18.5
      19.5         20.5         # 1978      def6        'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1978      def6        'SD of age. '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
      7.5          8.5          9.5          10.5         11.5         12.5
      13.5         14.5         15.5         16.5         17.5         18.5
      19.5         20.5         # 1979      def7        'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1979      def7        'SD of age. '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
      7.5          8.5          9.5          10.5         11.5         12.5
      13.5         14.5         15.5         16.5         17.5         18.5
      19.5         20.5         # 1980      def8        'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1980      def8        'SD of age. '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
      7.5          8.5          9.5          10.5         11.5         12.5
      13.5         14.5         15.5         16.5         17.5         18.5
      19.5         20.5         # 1981      def9        'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1981      def9        'SD of age. '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
      7.5          8.5          9.5          10.5         11.5         12.5
      13.5         14.5         15.5         16.5         17.5         18.5
      19.5         20.5         # 1982      def10       'Expected ages '
0.329242    0.329242    0.19080435 0.368632    0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1982      def10       'SD of age.
0.55*age2 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
      7.5          8.5          9.5          10.5         11.5         12.5
      13.5         14.5         15.5         16.5         17.5         18.5
      19.5         20.5         # 1983      def11       'Expected ages '
0.329242    0.329242    0.346917    0.2027476  0.395312    0.42809
0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
0.996322    1.1665      1.37557    1.63244    1.858        2.172        2.53
      2.934      3.388      # 1983      def11       'SD of age.
0.55*age3 '

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0.5      1.5      2.5      3.5      4.5      5.5      6.5
          7.5      8.5      9.5      10.5     11.5     12.5
          13.5     14.5     15.5     16.5     17.5     18.5
          19.5     20.5     # 1984     def12     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.2174216  0.42809
          0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
          0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
          2.934     3.388     # 1984     def12     'SD of age.
          0.55*age4 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
          7.5      8.5      9.5      10.5     11.5     12.5
          13.5     14.5     15.5     16.5     17.5     18.5
          19.5     20.5     # 1985     def13     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.2354495
          0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
          0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
          2.934     3.388     # 1985     def13     'SD of age.
          0.55*age5 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
          7.5      8.5      9.5      10.5     11.5     12.5
          13.5     14.5     15.5     16.5     17.5     18.5
          19.5     20.5     # 1986     def14     'Expected ages '
0.329242  0.329242  0.19080435 0.368632  0.395312  0.42809
          0.2575991 0.517841  0.57863  0.653316  0.745076  0.857813
          0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
          2.934     3.388     # 1986     def14     'SD of age.
          0.55*age2, 0.55*age6 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
          7.5      8.5      9.5      10.5     11.5     12.5
          13.5     14.5     15.5     16.5     17.5     18.5
          19.5     20.5     # 1987     def15     'Expected ages '
0.329242  0.329242  0.346917  0.2027476 0.395312  0.42809
          0.468362  0.28481255 0.57863  0.653316  0.745076  0.857813
          0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
          2.934     3.388     # 1987     def15     'SD of age.
          0.55*age3, 0.55*age7 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
          7.5      8.5      9.5      10.5     11.5     12.5
          13.5     14.5     15.5     16.5     17.5     18.5
          19.5     20.5     # 1988     def16     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.2174216  0.42809
          0.468362  0.517841  0.3182465 0.653316  0.745076  0.857813
          0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
          2.934     3.388     # 1988     def16     'SD of age.
          0.55*age4, 0.55*age8 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
          7.5      8.5      9.5      10.5     11.5     12.5
          13.5     14.5     15.5     16.5     17.5     18.5
          19.5     20.5     # 1989     def17     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.2354495
          0.468362  0.517841  0.57863  0.3593238 0.745076  0.857813
          0.996322  1.1665   1.37557  1.63244  1.858     2.172     2.53
          2.934     3.388     # 1989     def17     'SD of age.
          0.55*age5, 0.55*age9 '

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0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 1990         def18         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.2575991    0.517841    0.57863    0.653316    0.4097918    0.857813
          0.996322    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 1990         def18         'SD of age.
          0.55*age6, 0.55*age10 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 1991         def19         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.28481255 0.57863    0.653316    0.745076    0.47179715
          0.996322    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 1991         def19         'SD of age.
          0.55*age7, 0.55*age11 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 1992         def20         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.3182465 0.653316    0.745076    0.857813
          0.5479771    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 1992         def20         'SD of age.
          0.55*age8, 0.55*age12 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 1993         def21         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.3593238 0.745076    0.857813
          0.996322    0.641575    1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 1993         def21         'SD of age.
          0.55*age9, 0.55*age13 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 1994         def22         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.4097918    0.857813
          0.996322    1.1665     0.7565635 1.63244    1.858         2.172         2.53
          2.934         3.388         # 1994         def22         'SD of age.
          0.55*age10, 0.55*age14 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 1995         def23         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.745076    0.47179715
          0.996322    1.1665     1.37557    0.897842    1.858         2.172         2.53
          2.934         3.388         # 1995         def23         'SD of age.
          0.55*age11, 0.55*age15 '

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0.5      1.5      2.5      3.5      4.5      5.5      6.5
        7.5      8.5      9.5      10.5     11.5     12.5
        13.5     14.5     15.5     16.5     17.5     18.5
        19.5     20.5     # 1996     def24     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
        0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
        0.5479771 1.1665    1.37557  1.63244  1.0219    2.172      2.53
        2.934     3.388     # 1996     def24     'SD of age.
        0.55*age12, 0.55*age16 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
        7.5      8.5      9.5      10.5     11.5     12.5
        13.5     14.5     15.5     16.5     17.5     18.5
        19.5     20.5     # 1997     def25     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
        0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
        0.996322  0.641575  1.37557  1.63244  1.858     1.1946    2.53
        2.934     3.388     # 1997     def25     'SD of age.
        0.55*age13, 0.55*age17 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
        7.5      8.5      9.5      10.5     11.5     12.5
        13.5     14.5     15.5     16.5     17.5     18.5
        19.5     20.5     # 1998     def26     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
        0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
        0.996322  1.1665    0.7565635 1.63244  1.858     2.172
        1.3915    2.934     3.388     # 1998     def26     'SD of age.
        0.55*age14, 0.55*age18 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
        7.5      8.5      9.5      10.5     11.5     12.5
        13.5     14.5     15.5     16.5     17.5     18.5
        19.5     20.5     # 1999     def27     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
        0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
        0.996322  1.1665    1.37557  0.897842 1.858     2.172      2.53
        1.6137    3.388     # 1999     def27     'SD of age.
        0.55*age15, 0.55*age19 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
        7.5      8.5      9.5      10.5     11.5     12.5
        13.5     14.5     15.5     16.5     17.5     18.5
        19.5     20.5     # 2000     def28     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
        0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
        0.996322  1.1665    1.37557  1.63244  1.0219    2.172      2.53
        2.934     1.8634    # 2000     def28     'SD of age.
        0.55*age16, 0.55*age20 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
        7.5      8.5      9.5      10.5     11.5     12.5
        13.5     14.5     15.5     16.5     17.5     18.5
        19.5     20.5     # 2001     def29     'Expected ages '
0.329242  0.329242  0.19080435 0.368632  0.395312  0.42809
        0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
        0.996322  1.1665    1.37557  1.63244  1.858     1.1946    2.53
        2.934     3.388     # 2001     def29     'SD of age.
        0.55*age2, 0.55*age17 '

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0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 2002     def30     'Expected ages '
0.329242  0.329242  0.346917  0.2027476  0.395312  0.42809
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172
      1.3915    2.934    3.388    # 2002     def30     'SD of age.
      0.55*age3, 0.55*age18 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 2003     def31     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.2174216  0.42809
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172      2.53
      1.6137    3.388    # 2003     def31     'SD of age.
      0.55*age4, 0.55*age19 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 2004     def32     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.2354495
      0.468362  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172      2.53
      2.934     1.8634   # 2004     def32     'SD of age.
      0.55*age5, 0.55*age20 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 2005     def33     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.2575991  0.517841  0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172      2.53
      2.934     3.388    # 2005     def33     'SD of age.
      0.55*age6 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 2006     def34     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.468362  0.28481255 0.57863  0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172      2.53
      2.934     3.388    # 2006     def34     'SD of age.
      0.55*age7 '
0.5      1.5      2.5      3.5      4.5      5.5      6.5
      7.5      8.5      9.5      10.5     11.5     12.5
      13.5     14.5     15.5     16.5     17.5     18.5
      19.5     20.5     # 2007     def35     'Expected ages '
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
      0.468362  0.517841  0.3182465 0.653316  0.745076  0.857813
      0.996322  1.1665   1.37557  1.63244  1.858     2.172      2.53
      2.934     3.388    # 2007     def35     'SD of age.
      0.55*age8 '

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0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2008         def36         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.3593238    0.745076    0.857813
          0.996322    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 2008         def36         'SD of age.
          0.55*age9 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2009         def37         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.4097918    0.857813
          0.996322    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 2009         def37         'SD of age.
          0.55*age10 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2010         def38         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.745076    0.47179715
          0.996322    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 2010         def38         'SD of age.
          0.55*age11 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2011         def39         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
          0.5479771    1.1665     1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 2011         def39         'SD of age.
          0.55*age12 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2012         def40         'Expected ages '
0.329242    0.329242    0.19080435 0.368632    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
          0.996322    0.641575    1.37557    1.63244    1.858         2.172         2.53
          2.934         3.388         # 2012         def40         'SD of age.
          0.55*age2, 0.55*age13 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2013         def41         'Expected ages '
0.329242    0.329242    0.346917    0.2027476    0.395312    0.42809
          0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
          0.996322    1.1665     0.7565635 1.63244    1.858         2.172         2.53
          2.934         3.388         # 2013         def41         'SD of age.
          0.55*age3, 0.55*age14 '

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0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2014         def42         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.2174216    0.42809
          0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
          0.996322    1.1665     1.37557    0.897842    1.858         2.172         2.53
          2.934         3.388         # 2014         def42         'SD of age.
          0.55*age4, 0.55*age15 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2015         def43         'Expected ages '
0.329242    0.329242    0.346917    0.368632    0.395312    0.2354495
          0.468362    0.517841    0.57863    0.653316    0.745076    0.857813
          0.996322    1.1665     1.37557    1.63244    1.0219         2.172         2.53
          2.934         3.388         # 2015         def43         'SD of age.
          0.55*age5, 0.55*age16 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2016         def44         'Expected ages '
0.329242    0.329242    0.19080435 0.368632    0.395312    0.42809
          0.2575991    0.517841    0.57863    0.653316    0.745076    0.857813
          0.996322    1.1665     1.37557    1.63244    1.858         1.1946         2.53
          2.934         3.388         # 2016         def44         'SD of age.
          0.55*age2, 0.55*age6, 0.55*age17 '
0.5          1.5          2.5          3.5          4.5          5.5          6.5
          7.5          8.5          9.5          10.5         11.5         12.5
          13.5         14.5         15.5         16.5         17.5         18.5
          19.5         20.5         # 2017         def45         'Expected ages '
0.329242    0.329242    0.346917    0.2027476  0.395312    0.42809
          0.468362    0.28481255 0.57863    0.653316    0.745076    0.857813
          0.996322    1.1665     1.37557    1.63244    1.858         2.172
          1.3915     2.934         3.388         # 2017         def45         'SD of age.
          0.55*age3, 0.55*age7, 0.55*age18 '

#_mintailcomp: upper and lower distribution for females and males
separately are accumulated until exceeding this level.
#_addtocomp: after accumulation of tails; this value added to all bins
#_males and females treated as combined gender below this bin number
#_compressbins: accumulate upper tail by this number of bins; acts
simultaneous with mintailcomp; set=0 for no forced accumulation
#_Comp_Error: 0=multinomial, 1=dirichlet
#_Comp_Error2: parm number for dirichlet
#_minsamplesize: minimum sample size; set to 1 to match 3.24, minimum
value is 0.001
#_mintailcomp addtocomp combM+F CompressBns CompError ParmSelect
minsamplesize
-1          0.001         0         0         1         1         0.001
#_fleet:1_Fishery
-1          0.001         0         0         1         2         0.001
#_fleet:2_Acoustic_Survey
1 #_Lbin_method_for_Age_Data: 1=poplenbins; 2=datalenbins; 3=lengths

```

---



# sex codes: 0=combined; 1=use female only; 2=use male only; 3=use both  
as joint sexxlength distribution  
# partition codes: (0=combined; 1=discard; 2=retained

# Acoustic survey ages

#year	Month	Fleet	Sex	Partition	AgeErr	LbinLo	LbinHi	nTrips	a1	a2
		a3	a4	a5	a6	a7	a8	a9	a10	
		a11	a12	a13	a14	a15				
1995	7	2	0	0	23	-1	-1	69	0	
		20.48	3.26	1.06	19.33	1.03	4.03	16.37	1.44	0.72
		24.86	0.24	1.67	0.21	5.32				
1998	7	2	0	0	26	-1	-1	105	0	
		6.83	8.03	17.03	17.25	1.77	11.37	10.79	1.73	4.19
		7.60	1.27	0.34	9.74	2.06				
2001	7	2	0	0	29	-1	-1	57	0	
		50.62	10.95	15.12	7.86	3.64	3.84	2.60	1.30	1.34
		0.65	0.68	0.87	0.15	0.39				
2003	7	2	0	0	31	-1	-1	71	0	
		23.06	1.63	43.40	13.07	2.71	5.14	3.43	1.82	2.44
		1.44	0.49	0.43	0.42	0.52				
2005	7	2	0	0	33	-1	-1	47	0	
		19.07	1.23	5.10	4.78	50.67	6.99	2.50	3.99	2.45
		1.71	0.74	0.48	0.14	0.16				
2007	7	2	0	0	35	-1	-1	69	0	
		28.29	2.16	11.64	1.38	5.01	3.25	38.64	3.92	1.94
		1.70	0.83	0.77	0.34	0.12				
2009	7	2	0	0	37	-1	-1	72	0	
		0.55	29.33	40.21	2.29	8.22	1.25	1.79	1.93	8.32
		3.63	1.44	0.28	0.48	0.26				
2011	7	2	0	0	39	-1	-1	46	0	
		27.62	56.32	3.71	2.64	2.94	0.70	0.78	0.38	0.66
		0.97	2.10	0.76	0.31	0.11				
2012	7	2	0	0	40	-1	-1	94	0	
		62.12	9.78	16.70	2.26	2.92	1.94	1.01	0.50	0.23
		0.27	0.66	0.98	0.51	0.12				
2013	7	2	0	0	41	-1	-1	67	0	
		2.17	74.97	5.63	8.68	0.95	2.20	2.59	0.71	0.35
		0.10	0.13	0.36	0.77	0.38				
2015	7	2	0	0	43	-1	-1	78	0	
		7.45	9.19	4.38	58.98	4.88	7.53	1.69	1.68	1.64
		0.95	0.16	0.29	0.24	0.92				
2017	7	2	0	0	45	-1	-1	59	0	
		0.49	52.73	2.80	3.70	3.31	26.02	4.13	2.91	1.14
		0.91	0.87	0.42	0.33	0.25				

#Aggregate marginal fishery age comps

#year	Month	Fleet	Sex	Partition	AgeErr	LbinLo	LbinHi	nTrips		
		a1	a2	a3	a4	a5	a6	a7	a8	a9
		a10	a11	a12	a13	a14	a15			
1975	7	1	0	0	3	-1	-1	13		
		4.608	33.846	7.432	1.248	25.397	5.546	8.031	10.537	
		0.953	0.603	0.871	0.451	0.000	0.476	0.000		
1976	7	1	0	0	4	-1	-1	142		

---

	0.085	1.337	14.474	6.742	4.097	24.582	9.766	8.899
	12.099	5.431	4.303	4.075	1.068	2.355	0.687	
1977	7	1	0	0	5	-1	-1	320
	0.000	8.448	3.683	27.473	3.594	9.106	22.682	7.599
	6.544	4.016	3.550	2.308	0.572	0.308	0.119	
1978	7	1	0	0	6	-1	-1	341
	0.472	1.110	6.511	6.310	26.416	6.091	8.868	21.505
	9.776	4.711	4.680	2.339	0.522	0.353	0.337	
1979	7	1	0	0	7	-1	-1	116
	0.000	6.492	10.241	9.382	5.721	17.666	10.256	17.370
	12.762	4.180	2.876	0.963	1.645	0.000	0.445	
1980	7	1	0	0	8	-1	-1	221
	0.148	0.544	30.087	1.855	4.488	8.166	11.227	5.012
	8.941	11.075	9.460	2.628	3.785	1.516	1.068	
1981	7	1	0	0	9	-1	-1	154
	19.492	4.031	1.403	26.726	3.901	5.547	3.376	14.675
	3.769	3.195	10.186	2.313	0.504	0.163	0.720	
1982	7	1	0	0	10	-1	-1	170
	0.000	32.050	3.521	0.486	27.347	1.526	3.680	3.894
	11.764	3.268	3.611	7.645	0.241	0.302	0.664	
1983	7	1	0	0	11	-1	-1	117
	0.000	0.000	34.144	3.997	1.825	23.458	5.126	5.647
	5.300	9.383	3.910	3.128	2.259	1.130	0.695	
1984	7	1	0	0	12	-1	-1	123
	0.000	0.000	1.393	61.904	3.625	3.849	16.778	2.853
	1.509	1.239	3.342	0.923	0.586	1.439	0.561	
1985	7	1	0	0	13	-1	-1	57
	0.925	0.111	0.348	7.241	66.754	8.407	5.605	7.106
	2.042	0.530	0.654	0.246	0.000	0.000	0.032	
1986	7	1	0	0	14	-1	-1	120
	0.000	15.341	5.384	0.527	0.761	43.638	6.898	8.154
	8.260	2.189	2.817	1.834	3.133	0.457	0.609	
1987	7	1	0	0	15	-1	-1	56
	0.000	0.000	29.583	2.904	0.135	1.013	53.260	0.404
	1.250	7.091	0.000	0.744	1.859	1.757	0.000	
1988	7	1	0	0	16	-1	-1	84
	0.000	0.657	0.065	32.348	0.980	1.451	0.656	45.959
	1.343	0.835	10.498	0.791	0.054	0.064	4.301	
1989	7	1	0	0	17	-1	-1	80
	0.000	5.616	2.431	0.288	50.206	1.257	0.292	0.084
	35.192	1.802	0.395	2.316	0.084	0.000	0.037	
1990	7	1	0	0	18	-1	-1	163
	0.000	5.194	20.559	1.885	0.592	31.349	0.512	0.200
	0.043	31.901	0.296	0.067	6.411	0.000	0.992	
1991	7	1	0	0	19	-1	-1	160
	0.000	3.464	20.372	19.632	2.522	0.790	28.260	1.177
	0.145	0.181	18.688	0.423	0.000	3.606	0.741	
1992	7	1	0	0	20	-1	-1	243
	0.461	4.238	4.304	13.052	18.594	2.272	1.044	33.927
	0.767	0.078	0.340	18.049	0.413	0.037	2.426	
1993	7	1	0	0	21	-1	-1	172
	0.000	1.051	23.240	3.260	12.980	15.666	1.500	0.810
	27.421	0.674	0.089	0.120	12.004	0.054	1.129	
1994	7	1	0	0	22	-1	-1	235

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		0.000	0.037	2.832	21.390	1.265	12.628	18.687	1.571
		0.573	29.906	0.262	0.282	0.022	9.634	0.909	
1995	7	1	0	0	23	-1	-1	147	
		0.619	1.281	0.467	6.309	28.973	1.152	8.051	20.271
		1.576	0.222	22.422	0.435	0.451	0.037	7.734	
1996	7	1	0	0	24	-1	-1	186	
		0.000	18.282	16.242	1.506	7.743	18.140	1.002	4.908
		10.981	0.576	0.347	15.716	0.009	0.108	4.439	
1997	7	1	0	0	25	-1	-1	220	
		0.000	0.737	29.476	24.952	1.468	7.838	12.488	1.798
		3.977	6.671	1.284	0.216	6.079	0.733	2.282	
1998	7	1	0	0	26	-1	-1	243	
		0.015	4.786	20.351	20.288	26.596	2.869	5.399	9.310
		0.917	1.557	3.899	0.352	0.092	2.940	0.627	
1999	7	1	0	0	27	-1	-1	509	
		0.062	10.245	20.364	17.981	20.061	13.198	2.688	3.930
		4.008	0.989	1.542	2.140	0.392	0.334	2.066	
2000	7	1	0	0	28	-1	-1	530	
		0.996	4.218	10.935	14.285	12.880	21.063	13.115	6.548
		4.648	2.509	2.070	2.306	1.292	0.720	2.414	
2001	7	1	0	0	29	-1	-1	540	
		0.000	17.338	16.247	14.250	15.685	8.559	12.100	5.989
		1.778	2.232	1.810	0.698	1.421	0.685	1.209	
2002	7	1	0	0	30	-1	-1	449	
		0.000	0.033	50.642	14.934	9.687	5.719	4.438	6.580
		3.546	0.871	0.845	1.036	0.242	0.475	0.953	
2003	7	1	0	0	31	-1	-1	456	
		0.000	0.105	1.397	67.898	11.643	3.339	4.987	3.191
		3.136	2.106	0.874	0.435	0.533	0.125	0.231	
2004	7	1	0	0	32	-1	-1	501	
		0.000	0.022	5.310	6.067	68.288	8.152	2.187	4.155
		2.512	1.281	1.079	0.350	0.268	0.160	0.170	
2005	7	1	0	0	33	-1	-1	613	
		0.018	0.569	0.464	6.562	5.381	68.724	7.953	2.358
		2.909	2.207	1.177	1.090	0.250	0.090	0.248	
2006	7	1	0	0	34	-1	-1	720	
		0.326	2.808	10.444	1.673	8.567	4.879	59.039	5.275
		1.715	2.376	1.133	1.015	0.426	0.135	0.188	
2007	7	1	0	0	35	-1	-1	629	
		0.760	11.292	3.731	15.451	1.594	6.852	3.836	44.123
		5.186	1.721	2.286	1.781	0.506	0.187	0.693	
2008	7	1	0	0	36	-1	-1	794	
		0.758	9.855	30.597	2.403	14.421	1.027	3.628	3.165
		28.005	3.037	1.142	0.731	0.491	0.313	0.428	
2009	7	1	0	0	37	-1	-1	686	
		0.637	0.519	30.633	27.553	3.355	10.702	1.305	2.258
		2.289	16.187	2.484	0.866	0.591	0.281	0.340	
2010	7	1	0	0	38	-1	-1	874	
		0.028	25.291	3.351	34.805	21.560	2.368	3.010	0.445
		0.579	0.975	6.088	0.930	0.309	0.104	0.157	
2011	7	1	0	0	39	-1	-1	1081	
		2.637	8.499	70.841	2.650	6.417	4.449	1.146	0.820
		0.294	0.391	0.118	1.348	0.171	0.110	0.108	
2012	7	1	0	0	40	-1	-1	851	

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		0.181	40.946	11.557	32.994	2.489	5.085	2.516	1.132
		0.659	0.231	0.329	0.347	0.869	0.283	0.383	
2013	7	1	0	0	41	-1	-1		1094
		0.030	0.544	70.309	5.906	10.474	1.123	3.414	2.059
		0.906	1.366	0.264	0.332	0.530	2.280	0.462	
2014	7	1	0	0	42	-1	-1		1130
		0.000	3.314	3.731	64.297	6.927	12.170	1.587	3.141
		1.827	0.822	0.466	0.118	0.191	0.279	1.131	
2015	7	1	0	0	43	-1	-1		798
		3.591	1.136	6.883	3.946	70.024	4.940	5.089	0.958
		1.550	1.087	0.202	0.205	0.061	0.054	0.273	
2016	7	1	0	0	44	-1	-1		1426
		0.300	49.629	1.690	4.581	2.517	33.171	2.853	3.234
		0.804	0.459	0.366	0.213	0.071	0.039	0.073	
2017	7	1	0	0	45	-1	-1		762
		3.039	0.534	32.691	2.450	4.259	3.810	40.489	5.603
		3.438	1.594	0.769	0.752	0.242	0.083	0.246	
-9999	0	0	0	0	0	0	0	0	0

```

#
0 #_Use_MeanSize-at-Age_obs (0/1)
#
0 #_N_environ_variables
#Yr Variable Value
#
0 # N sizefreq methods to read
#
0 # do tags (0/1)
#
0 # morphcomp data(0/1)
# Nobs, Nmorphs, mincomp
# yr, seas, type, partition, Nsamp, datavector_by_Nmorphs
#
0 # Do dataread for selectivity priors(0/1)
# Yr, Seas, Fleet, Age/Size, Bin, selex_prior, prior_sd
# feature not yet implemented
#
999

```

---

## G STOCK SYNTHESIS CONTROL FILE

```
../models/2018.40_base_model/2018hake_control.ss
#C 2018 Hake control file
1 # 0 means do not read wtatage.ss; 1 means read and use wtatage.ss and
  also read and use growth parameters
1 #_N_Growth_Patterns
1 #_N_platoons_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond 1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
2 # recr_dist_method for parameters: 2=main effects for GP, Settle
  timing, Area; 3=each Settle entity; 4=none when N_GP*Nsettle*pop==1
1 # not yet implemented; Future usage: Spawner-Recruitment: 1=global;
  2=by area
1 # number of recruitment settlement assignments
0 # unused option
#GPattern month area age (for each settlement assignment)
1 1 1 0
#
#_Cond 0 # N_movement_definitions goes here if Nareas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not
  integer) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1,
  source=1 dest=2, age1=4, age2=10
#
0 #_Nblock_Patterns
#
# controls for all timevary parameters
1 #_env/block/dev_adjust_method for all time-vary parms (1=warn relative
  to base parm bounds; 3=no bound check)
# autogen
1 1 1 1 1 # autogen: 1st element for biology, 2nd for SR, 3rd for Q, 4th
  reserved, 5th for selex
# where: 0 = autogen all time-varying parms; 1 = read each time-varying
  parm line; 2 = read then autogen if parm min== -12345
#
#
# setup for M, growth, maturity, fecundity, recruitment distribution,
  movement
#
0 #_natM_type:_0=1Parm;
  1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
  #_no additional input for selected M option; read 1P per morph
1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2;
  3=age_specific_K; 4=not implemented
1 #_Age(post-settlement)_for_L1;linear growth below this
20 #_Growth_Age_for_L2 (999 to use as Linf)
-999 #_exponential decay for growth above maxage (fixed at 0.2 in 3.24;
  value should approx initial Z; -999 replicates 3.24)
0 #_placeholder for future growth feature
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern: 0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4
```

```

logSD=F(A)
5 #_maturity_option: 1=length logistic; 2=age logistic; 3=read
  age-maturity matrix by growth_pattern; 4=read age-fecundity;
  5=disabled; 6=read length-maturity
#_Age_Fecundity by growth pattern from wt-at-age.ss now invoked by read
  bodywt flag
2 #_First_Mature_Age
1 #_fecundity_option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b;
  (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism_option: 0=none; 1=female-to-male age-specific fxn;
  -1=male-to-female age-specific fxn
1 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from
  female-GP1, 3=like SS2 V1.x)
#
#_growth_parms
#_L0      HI      INIT      PRIOR      PR_SD      PR_type PHASE      env_var devlink
      devminyr devmaxyr dev_PH Block  Block_Fxn
0.05      0.4      0.2      -1.60944 0.1      3      4      0      0      0
      0      0      0      0      #      NatM_p_1_Fem_GP_1
2      15      5      32      99      0      -5      0      0      0
      0      0      0      0      #      L_at_Amin_Fem_GP_1
45      60      53.2      50      99      0      -3      0      0      0
      0      0      0      0      #      L_at_Amax_Fem_GP_1
0.2      0.4      0.3      0.3      99      0      -3      0      0      0
      0      0      0      0      #      VonBert_K_Fem_GP_1
0.03      0.16      0.066      0.1      99      0      -5      0      0      0
      0      0      0      0      #      CV_young_Fem_GP_1
0.03      0.16      0.062      0.1      99      0      -5      0      0      0
      0      0      0      0      #      CV_old_Fem_GP_1
-3      3      7E-06      7E-06      99      0      -50      0      0      0
      0      0      0      0      #      Wtlen_1_Fem
-3      3      2.9624      2.9624      99      0      -50      0      0      0
      0      0      0      0      #      Wtlen_2_Fem
-3      43      36.89      36.89      99      0      -50      0      0      0
      0      0      0      0      #      Mat50%_Fem
-3      3      -0.48      -0.48      99      0      -50      0      0      0
      0      0      0      0      #      Mat_slope_Fem
-3      3      1      1      99      0      -50      0      0      0
      0      0      0      0      #      Eggs/kg_inter_Fem
-3      3      0      0      99      0      -50      0      0      0
      0      0      0      0      #      Eggs/kg_slope_wt_Fem
0      2      1      1      99      0      -50      0      0      0
      0      0      0      0      #      RecrDist_GP_1
0      2      1      1      99      0      -50      0      0      0
      0      0      0      0      #      RecrDist_Area_1
0      2      1      1      99      0      -50      0      0      0
      0      0      0      0      #      RecrDist_timing_1
1      1      1      1      1      0      -1      0      0      0
      0      0      0      0      #      CohortGrowDev
0.00001 0.99999 0.5      0.5      0.5      0      -99      0      0      0
      0      0      0      0      #      FracFemale_GP_1
#
#_no timevary MG parameters
#

```

---

```

#_seasonal_effects_on_biology_parms
0 0 0 0 0 0 0 0 0
    #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_ L0 HI INIT PRIOR PR_SD PR_type PHASE
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Spawner-Recruitment
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop;
    7=survival_3Parm; 8=Shepard_3Parm
0 # 0/1 to use steepness in initial equ recruitment calculation
0 # future feature: 0/1 to make realized sigmaR a function of SR
    curvature
#_
    L0          HI          INIT          PRIOR          PR_SD
    PR_type     PHASE     env-var    use_dev    dev_mnyr    dev_mxyr
    dev_PH      Block    Blk_Fxn #   parm_name
        13          17          15.9          15          99
            0          1          0          0          0
        0          0          0 # SR_LN(R0)
        0.2          1          0.88          0.777          0.113
            2          4          0          0          0
        0          0          0 # SR_BH_steep
            1          1.6          1.4          1.1          99
            0          -6          0          0          0
        0          0          0 # SR_sigmaR
        -5          5          0          0          99
            0          -50          0          0          0
        0          0          0 # SR_regime
            0          2          0          1          99
            0          -50          0          0          0
            0          0          0 # SR_autocorr
1 #do_recdev: 0=none; 1=devvector; 2=simple deviations
1970 # first year of main recr_devs; early devs can preceed this era
2016 # last year of main recr_devs; forecast devs start in following year
1 #_recdev phase
1 # (0/1) to read 13 advanced options
1946 #_recdev_early_start (0=none; neg value makes relative to
    recdev_start)
3 #_recdev_early_phase
5 #_forecast_recruitment phase (incl. late recr) (0 value resets to
    maxphase+1)
1 #_lambda for Fcast_recrr_like occurring before endyr+1
1965 #_last_early_yr_nobias_adj_in_MPD
1971 #_first_yr_fullbias_adj_in_MPD
2016 #_last_yr_fullbias_adj_in_MPD
2017 #_first_recent_yr_nobias_adj_in_MPD
0.87 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for
    all estimated recdevs)
0 #_period of cycles in recruitment (N parms read below)
-6 #min rec_dev
6 #max rec_dev
0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles

```

---

---

```

# read specified recr devs
#_Yr Input_value
#
# all recruitment deviations
# 1946E 1947E 1948E 1949E 1950E 1951E 1952E 1953E 1954E 1955E 1956E
  1957E 1958E 1959E 1960E 1961E 1962E 1963E 1964E 1965E 1966E 1967E
  1968E 1969E 1970R 1971R 1972R 1973R 1974R 1975R 1976R 1977R 1978R
  1979R 1980R 1981R 1982R 1983R 1984R 1985R 1986R 1987R 1988R 1989R
  1990R 1991R 1992R 1993R 1994R 1995R 1996R 1997R 1998R 1999R 2000R
  2001R 2002R 2003R 2004R 2005R 2006R 2007R 2008R 2009R 2010R 2011R
  2012R 2013R 2014R 2015F 2016F 2017F 2018F 2019F
# 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0
# implementation error by year in forecast: 0 0 0
#
#Fishing Mortality info
0.1 # F ballpark
-1999 # F ballpark year (neg value to disable)
3 # F_Method: 1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
1.5 # max F or harvest rate, depends on F_Method
# no additional F input needed for Fmethod 1
# if Fmethod=2; read overall start F value; overall phase; N detailed
  inputs to read
# if Fmethod=3; read N iterations for tuning for Fmethod 3
5 # iterations for hybrid F
#
#_initial_F_parms; count = 0
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
#2019 2037
# F rates by fleet
# Yr: 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978
  1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992
  1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
  2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
# seas: 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
# Fishery 0.00933897 0.0146642 0.00853273 0.012888 0.0174513 0.0121336
  0.00976528 0.0143888 0.0200448 0.0140502 0.0147779 0.00984755
  0.00884188 0.0123284 0.010776 0.0189597 0.01714 0.0176621 0.020617
  0.0190307 0.0328569 0.0448643 0.046737 0.0665674 0.0490229 0.0548243
  0.0667206 0.0519506 0.0926444 0.0606975 0.0759137 0.0805482 0.086194
  0.0869669 0.0517765 0.0478408 0.0356577 0.0466746 0.0834855 0.0900341
  0.0883171 0.0785301 0.0810821 0.0455776 0.0573031 0.074574 0.0532697
  0.0685086 0.0705113 0.0503989 0.0892282 0.159745 0.163071 0.167658
#
#_Q_setup for fleets with cpue or survey data
#_1: link type: (1=simple q, 1 parm; 2=mirror simple q, 1 mirrored parm;
  3=q and power, 2 parm)
#_2: extra input for link, i.e. mirror fleet
#_3: 0/1 to select extra sd parameter
#_4: 0/1 for biasadj or not
#_5: 0/1 to float
#_ fleet link link_info extra_se biasadj float # fleetname

```

---



---

```

                2          1          0          1          0          1  #
    Acoustic_Survey
-9999 0 0 0 0 0
#
#_Q_parms(if_any);Qunits_are_ln(q)
#NOTE: the first parameter lines below (for LnQ_base_Acoustic_Survey(2)),
    is
#    automatically replaced by an analytical estimate since float=1 in
    Q_setup above
#_
    LO          HI          INIT          PRIOR          PR_SD
    PR_type     PHASE     env-var     use_dev     dev_mnyr     dev_mxyr
    dev_PH      Block     Blk_Fxn #   parm_name
        -15          15      -1.0376          0          1
            0          -1          0          0          0
            0          0          0 #   LnQ_base_Acoustic_Survey(2)
        0.05          1.2      0.0755          0.0755          0.1
            0          4          0          0          0
            0          0          0 #   Q_extraSD_Acoustic_Survey(2)
#_no timevary Q parameters
#
#_size_selex_patterns
#Pattern:_0; parm=0; selex=1.0 for all sizes
#Pattern:_1; parm=2; logistic; with 95% width specification
#Pattern:_5; parm=2; mirror another size selex; PARMS pick the min-max
    bin to mirror
#Pattern:_15; parm=0; mirror another age or length selex
#Pattern:_6; parm=2+special; non-parm len selex
#Pattern:_43; parm=2+special+2; like 6, with 2 additional param for
    scaling (average over bin range)
#Pattern:_8; parm=8; New doublelogistic with smooth transitions and
    constant above Linf option
#Pattern:_9; parm=6; simple 4-parm double logistic with starting length;
    parm 5 is first length; parm 6=1 does desc as offset
#Pattern:_21; parm=2+special; non-parm len selex, read as pairs of size,
    then selex
#Pattern:_22; parm=4; double_normal as in CASAL
#Pattern:_23; parm=6; double_normal where final value is directly equal
    to sp(6) so can be >1.0
#Pattern:_24; parm=6; double_normal with sel(minL) and sel(maxL), using
    joiners
#Pattern:_25; parm=3; exponential-logistic in size
#Pattern:_27; parm=3+special; cubic spline
#Pattern:_42; parm=2+special+3; // like 27, with 2 additional param for
    scaling (average over bin range)
#_discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_
#_Pattern Discard Male Special
    0 0 0 0 # 1 Fishery
    0 0 0 0 # 2 Acoustic_Survey
#
#_age_selex_types
#Pattern:_0; parm=0; selex=1.0 for ages 0 to maxage
#Pattern:_10; parm=0; selex=1.0 for ages 1 to maxage
#Pattern:_11; parm=2; selex=1.0 for specified min-max age
#Pattern:_12; parm=2; age logistic

```

---

```

#Pattern:_13; parm=8; age double logistic
#Pattern:_14; parm=nages+1; age empirical
#Pattern:_15; parm=0; mirror another age or length selex
#Pattern:_16; parm=2; Coleraine - Gaussian
#Pattern:_17; parm=nages+1; empirical as random walk N parameters to
    read can be overridden by setting special to non-zero
#Pattern:_41; parm=2+nages+1; // like 17, with 2 additional param for
    scaling (average over bin range)
#Pattern:_18; parm=8; double logistic - smooth transition
#Pattern:_19; parm=6; simple 4-param double logistic with starting age
#Pattern:_20; parm=6; double_normal,using joiners
#Pattern:_26; parm=3; exponential-logistic in age
#Pattern:_27; parm=3+special; cubic spline in age
#Pattern:_42; parm=2+nages+1; // cubic spline; with 2 additional param
    for scaling (average over bin range)
#_Pattern Discard Male Special
    17 0 0 20 # 1 Fishery
    17 0 0 20 # 2 Acoustic_Survey

```

```

#
#_      LO      HI      INIT      PRIOR      PR_SD
      PR_type  PHASE  env-var  use_dev  dev_mnyr  dev_mxyr
      dev_PH   Block  Blk_Fxn  #   parm_name
      -1002      3      -1000      -1      0.01
          0      -2          0          0          0          0
          0          0          0 #   AgeSel_P1_Fishery(1)
          -1          1          0          -1      0.01
          0      -2          0          0          0          0
          0          0          0 #   AgeSel_P2_Fishery(1)
          -5          9          2.8          -1      0.01
          0          2          0          2      1991      2017
          5          0          0 #   AgeSel_P3_Fishery(1)
          -5          9          0.1          -1      0.01
          0          2          0          2      1991      2017
          5          0          0 #   AgeSel_P4_Fishery(1)
          -5          9          0.1          -1      0.01
          0          2          0          2      1991      2017
          5          0          0 #   AgeSel_P5_Fishery(1)
          -5          9          0.1          -1      0.01
          0          2          0          2      1991      2017
          5          0          0 #   AgeSel_P6_Fishery(1)
          -5          9          0          -1      0.01
          0          2          0          2      1991      2017
          5          0          0 #   AgeSel_P7_Fishery(1)
          -5          9          0          -1      0.01
          0          -2          0          0          0          0
          0          0          0 #   AgeSel_P8_Fishery(1)
          -5          9          0          -1      0.01
          0          -2          0          0          0          0
          0          0          0 #   AgeSel_P9_Fishery(1)
          -5          9          0          -1      0.01
          0          -2          0          0          0          0
          0          0          0 #   AgeSel_P10_Fishery(1)
          -5          9          0          -1      0.01
          0          -2          0          0          0          0

```

---

0	0	0	#	AgeSel_P11_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P12_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P13_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P14_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P15_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P16_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P17_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P18_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P19_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P20_Fishery(1)	
-5	9	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P21_Fishery(1)	
-1002	3	0		-1000	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P1_Acoustic_Survey(2)	
-1002	3	0		-1000	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P2_Acoustic_Survey(2)	
-1	1	0		0	-1
0	-2	0		0	0
0	0	0	#	AgeSel_P3_Acoustic_Survey(2)	
-5	9	0		0.1	-1
0	2	0		0	0
0	0	0	#	AgeSel_P4_Acoustic_Survey(2)	
-5	9	0		0.1	-1
0	2	0		0	0
0	0	0	#	AgeSel_P5_Acoustic_Survey(2)	
-5	9	0		0	-1
0	2	0		0	0
0	0	0	#	AgeSel_P6_Acoustic_Survey(2)	
-5	9	0		0	-1
0	2	0		0	0
0	0	0	#	AgeSel_P7_Acoustic_Survey(2)	
-5	9	0		0	-1
0	-2	0		0	0

---

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```

0      0      0 # AgeSel_P8_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P9_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P10_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P11_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P12_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P13_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P14_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P15_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P16_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P17_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P18_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P19_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P20_Acoustic_Survey(2)
-5      9      0      0      -1      0.01
0      -2      0      0      0      0
0      0      0 # AgeSel_P21_Acoustic_Survey(2)
# Dirichlet-Multinomial parameters controlling age-comp weights
-5      20      .5      0      99
0      2      0      0      0
0      0      0 # ln(EffN_mult)_1
-5      20      .5      0      99
0      2      0      0      0
0      0      0 # ln(EffN_mult)_2
# timevary selex parameters
# value of 1.40 for "dev_se" parameters (a.k.a phi) is converted from 0.20
# in 2017 hake assessment using slope of parameter transformation
#_      LO      HI      INIT      PRIOR      PR_SD
      PR_type      PHASE #      parm_name
0.0001      2      1.40      0.5      0.5
      -1      -5 # AgeSel_P3_Fishery(1)_dev_se

```

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```

-0.99      0.99      0      0      0.5
-1      -6 # AgeSel_P3_Fishery(1)_dev_autocorr
0.0001      2      1.40      0.5      0.5
-1      -5 # AgeSel_P4_Fishery(1)_dev_se
-0.99      0.99      0      0      0.5
-1      -6 # AgeSel_P4_Fishery(1)_dev_autocorr
0.0001      2      1.40      0.5      0.5
-1      -5 # AgeSel_P5_Fishery(1)_dev_se
-0.99      0.99      0      0      0.5
-1      -6 # AgeSel_P5_Fishery(1)_dev_autocorr
0.0001      2      1.40      0.5      0.5
-1      -5 # AgeSel_P6_Fishery(1)_dev_se
-0.99      0.99      0      0      0.5
-1      -6 # AgeSel_P6_Fishery(1)_dev_autocorr
0.0001      2      1.40      0.5      0.5
-1      -5 # AgeSel_P7_Fishery(1)_dev_se
-0.99      0.99      0      0      0.5
-1      -6 # AgeSel_P7_Fishery(1)_dev_autocorr
# info on dev vectors created for selex parms are reported with other
# devs after tag parameter section
#
0 # use 2D_AR1 selectivity(0/1): experimental feature
#_no 2D_AR1 selex offset used
#
# Tag loss and Tag reporting parameters go next
0 # TG_custom: 0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0 #_placeholder if no parameters
#
# deviation vectors for timevary parameters
# base base first block block env env dev dev dev dev dev
# type index parm trend pattern link var vectr link _mnyr mxyr dev
# phase dev_vector
# 5 3 1 0 0 2 0 1 2 1991 2017
4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
# 5 4 3 0 0 2 0 2 2 1991 2017
4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
# 5 5 5 0 0 2 0 3 2 1991 2017
4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
# 5 6 7 0 0 2 0 4 2 1991 2017
4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
# 5 7 9 0 0 2 0 5 2 1991 2017
4 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
#
# Input variance adjustments factors:

```

---

---

```

#_1=add_to_survey_CV
#_2=add_to_discard_stddev
#_3=add_to_bodywt_CV
#_4=mult_by_lencomp_N
#_5=mult_by_agecomp_N
#_6=mult_by_size-at-age_N
#_7=mult_by_generalized_sizecomp
### values below no longer needed thanks to new Dirichelt-Multinomial
    likelihood
### with additional parameters defined above
## #_Factor   Fleet   Value
##          5       1     0.15
##          5       2     0.45
-9999   1     0 # terminator
#
1 #_maxlambdaphase
1 #_sd_offset; must be 1 if any growthCV, sigmaR, or survey extraSD is an
    estimated parameter
# read 0 changes to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq;
    7=sizeage; 8=catch; 9=init_equ_catch;
# 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp;
    15=Tag-comp; 16=Tag-negbin; 17=F_ballpark
#like_comp fleet  phase  value  sizefreq_method
-9999   1   1   1   1   # terminator
#
# lambdas (for info only; columns are phases)
# 0 #_CPUE/survey:_1
# 1 #_CPUE/survey:_2
# 1 #_agecomp:_1
# 1 #_agecomp:_2
# 1 #_init_equ_catch
# 1 #_recruitments
# 1 #_parameter-priors
# 1 #_parameter-dev-vectors
# 1 #_crashPenLambda
# 0 # F_ballpark_lambda
1 # (0/1) read specs for more stddev reporting
  2 2 -1 15 1 1 1 -1 1 # selex type, len/age, year, N selex bins, Growth
    pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 # vector with selex std bin picks
    (-1 in first bin to self-generate)
  -1 # vector with growth std bin picks (-1 in first bin to self-generate)
  20 # vector with NatAge std bin picks (-1 in first bin to self-generate)
999

```

---

## H STOCK SYNTHESIS STARTER FILE

```
../models/2018.40_base_model/starter.ss
#C 2018 Hake starter file
2018hake_data.SS
2018hake_control.SS
0 # 0=use init values in control file; 1=use ss.par
1 # run display detail (0,1,2)
1 # detailed age-structured reports in REPORT.SS0 (0=low,1=high,2=low for
  data-limited)
0 # write detailed checkup.sso file (0,1)
0 # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all;
  3=every_iter,all_parms; 4=every,active)
0 # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
1 # Include prior_like for non-estimated parameters (0,1)
0 # Use Soft Boundaries to aid convergence (0,1) (recommended)
1 # Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd
  and higher are bootstrap
25 # Turn off estimation for parameters entering after this phase
400 # MCeval burn interval
1 # MCeval thin interval
0 # jitter initial parm value by this fraction
-1 # min yr for sdreport outputs (-1 for styr)
-2 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
#vector of year values

1e-05 # final convergence criteria (e.g. 1.0e-04)
0 # retrospective year relative to end year (e.g. -4)
2 # min age for calc of summary biomass
1 # Depletion basis: denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel
  X*B_styr
1 # Fraction (X) for Depletion denominator (e.g. 0.4)
1 # SPR_report_basis: 0=skip; 1=(1-SPR)/(1-SPR_tgt);
  2=(1-SPR)/(1-SPR_MSY); 3=(1-SPR)/(1-SPR_Btarget); 4=rawSPR
1 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num);
  3=sum(Frates); 4=true F for range of ages
#COND 10 15 #_min and max age over which average F will be calculated
  with F_reporting=4
0 # F_report_basis: 0=raw_F_report; 1=F/Fspr; 2=F/Fmsy ; 3=F/Ftgt
3 # MCMC output detail (0=default; 1=obj func components; 2=expanded;
  3=make output subdir for each MCMC vector)
0 # ALK tolerance (example 0.0001)
3.30 # check value for end of file and for version control
```

---

## I STOCK SYNTHESIS FORECAST FILE

```
../models/2018.40_base_model/forecast.ss
#C 2018 Hake forecast file
# for all year entries except rebuilder; enter either: actual year, -999
  for styrr, 0 for endyr, neg number for rel. endyr
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy; 2=calc F_spr,F0.1,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt) or F0.1; 4=set
  to F(endyr)
0.4 # SPR target (e.g. 0.40)
0.4 # Biomass target (e.g. 0.40)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF,
  end_relF, beg_recr_dist, end_recr_dist, beg_SRparm, end_SRparm (enter
  actual year, or values of 0 or -integer to be rel. endyr)
-999 -999 -999 -999 -999 -999 -999 0 -999 0
2 #Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast
  below
#
1 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt) or F0.1; 4=Ave F (uses
  first-last relF yrs); 5=input annual F scalar
3 # N forecast years
1 # F scalar (only used for Do_Forecast==5)
#_Fcast_years: beg_selex, end_selex, beg_relF, end_relF, beg_recruits,
  end_recruits (enter actual year, or values of 0 or -integer to be
  rel. endyr)
-4 0 -4 0 -999 0
0 # Forecast selectivity (0=fcast selex is mean from year range; 1=fcast
  selectivity from annual time-vary parms)
1 # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0.4 # Control rule Biomass level for constant F (as frac of Bzero, e.g.
  0.40); (Must be > the no F level below)
0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
1 # Control rule target as fraction of Flimit (e.g. 0.75)
3 #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch
  with allocations applied)
3 #_First forecast loop with stochastic recruitment
0 #_Forecast recruitment: 0= spawn_recr; 1=value*spawn_recr_fxn;
  2=value*VirginRecr; 3=recent mean)
1 # value is ignored
0 #_Forecast loop control #5 (reserved for future bells&whistles)
2020 #FirstYear for caps and allocations (should be after years with
  fixed inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>0.0
  to cause active impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
1999 # Rebuilder: first year catch could have been set to zero
  (Ydecl)(-1 to set to 1999)
2002 # Rebuilder: year for current age structure (Yinit) (-1 to set to
  endyear+1)
1 # fleet relative F: 1=use first-last alloc year; 2=read seas, fleet,
  alloc list below
# Note that fleet allocation is used directly as average F if
  Do_Forecast=4
```



---

```

2 # basis for fcast catch tuning and for fcast catch caps and allocation
  (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
# Conditional input if relative F choice = 2
# enter list of:  season,  fleet, relF; if used, terminate with
  season=-9999
# 1 1 1
# enter list of: fleet number, max annual catch for fleets with a max;
  terminate with fleet=-9999
-9999 -1
# enter list of area ID and max annual catch; terminate with area=-9999
-9999 -1
# enter list of fleet number and allocation group assignment, if any;
  terminate with fleet=-9999
-9999 -1
#_if N allocation groups >0, list year, allocation fraction for each group
# list sequentially because read values fill to end of N forecast
# terminate with -9999 in year field
# no allocation groups
2 # basis for input Fcast catch: -1=read basis with each obs; 2=dead
  catch; 3=retained catch; 99=input Hrate(F)
#enter list of Fcast catches; terminate with line having year=-9999
#_Yr Seas Fleet Catch(or_F)
-9999 1 1 0
#
999 # verify end of input

```

## J STOCK SYNTHESIS WEIGHT-AT-AGE FILE

```

../models/2018.40_base_model/wtatage.ss

#C 2018 Hake weight-at-age file
# empirical weight-at-age Stock Synthesis input file for hake
# modified from file created by code in the R script:
  wtatage_calculations.R
# original creation date: 2018-01-11 16:39:23,
# modification date: 2018-01-29
#####
20 # Maximum age

#Maturity x Fecundity: Fleet = -2
# new values added in 2018 based on age-based maturity * avg weight-at-age
#_#Yr seas gender GP bseas fleet a0 a1 a2 a3 a4 a5 a6
      a7 a8 a9 a10 a11 a12 a13 a14 a15 a16
      a17 a18 a19 a20
-1940 1 1 1 1 -2 0 0 0.0649 0.318 0.4652 0.4901 0.5392
      0.5992 0.6876 0.7437 0.8425 0.8949 0.9695 1.021 0.9632 0.9302 0.9302
      0.9302 0.9302 0.9302 0.9302

#All matrices below use the same values, pooled across all data sources

#Weight at age for population in middle of the year: Fleet = -1
#_#Yr seas gender GP bseas fleet a0 a1 a2 a3 a4
      a5 a6 a7 a8 a9 a10 a11 a12 a13 a14
      a15 a16 a17 a18 a19 a20
-1940 1 1 1 1 -1 0.0169 0.0916 0.2489 0.3790 0.4841
      0.5329 0.5813 0.6471 0.7184 0.7875 0.8594 0.9307 0.9695 1.0658 1.0091
      1.0336 1.0336 1.0336 1.0336 1.0336 1.0336
1975 1 1 1 1 -1 0.0550 0.1575 0.2987 0.3658 0.6143
      0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555
      2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
1976 1 1 1 1 -1 0.0550 0.0986 0.2359 0.4990 0.5188
      0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507 1.8066 1.8588 1.9555
      2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
1977 1 1 1 1 -1 0.0550 0.0855 0.4020 0.4882 0.5902
      0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148 1.4027 1.7511 2.1005
      2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
1978 1 1 1 1 -1 0.0517 0.0725 0.1275 0.4699 0.5302
      0.6026 0.6392 0.7397 0.8422 0.9811 1.0997 1.2459 1.3295 1.4814 1.7419
      2.3353 2.3353 2.3353 2.3353 2.3353 2.3353
1979 1 1 1 1 -1 0.0484 0.0763 0.2410 0.2587 0.5821
      0.6868 0.7677 0.8909 0.9128 1.0369 1.1987 1.2482 1.5326 1.5520 1.7950
      1.9817 1.9817 1.9817 1.9817 1.9817 1.9817
1980 1 1 1 1 -1 0.0452 0.0800 0.2125 0.4529 0.3922
      0.4904 0.5166 0.6554 0.7136 0.8740 1.0626 1.1623 1.2898 1.3001 1.2699
      1.3961 1.3961 1.3961 1.3961 1.3961 1.3961
1981 1 1 1 1 -1 0.0419 0.1074 0.2137 0.3422 0.5264
      0.3933 0.5254 0.5462 0.7464 0.7204 0.8231 1.0413 1.0989 1.3449 1.4926
      1.2128 1.2128 1.2128 1.2128 1.2128 1.2128
1982 1 1 1 1 -1 0.0386 0.1181 0.2465 0.3336 0.3097
      0.5496 0.3956 0.5275 0.5629 0.7606 0.6837 0.8539 1.0670 0.8793 1.0186

```

Appendix J – Weight-at-age file

```
#Weight at age for population at beginning of the year: Fleet = 0
```

---

#_#Yr	seas	gender	GP	bseas	fleet	a0	a1	a2	a3	a4
a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	
a15	a16	a17	a18	a19	a20					
-1940	1	1	1	1	0	0.0169	0.0916	0.2489	0.3790	0.4841
0.5329	0.5813	0.6471	0.7184	0.7875	0.8594	0.9307	0.9695	1.0658	1.0091	
1.0336	1.0336	1.0336	1.0336	1.0336	1.0336	1.0336				
1975	1	1	1	1	0	0.0550	0.1575	0.2987	0.3658	0.6143
0.6306	0.7873	0.8738	0.9678	0.9075	0.9700	1.6933	1.5000	1.9000	1.9555	
2.7445	2.7445	2.7445	2.7445	2.7445	2.7445	2.7445				
1976	1	1	1	1	0	0.0550	0.0986	0.2359	0.4990	0.5188
0.6936	0.8038	0.9165	1.2063	1.3335	1.4495	1.6507	1.8066	1.8588	1.9555	
2.7445	2.7445	2.7445	2.7445	2.7445	2.7445	2.7445				
1977	1	1	1	1	0	0.0550	0.0855	0.4020	0.4882	0.5902
0.6650	0.7489	0.8272	0.9779	1.1052	1.2341	1.3148	1.4027	1.7511	2.1005	
2.2094	2.2094	2.2094	2.2094	2.2094	2.2094	2.2094				
1978	1	1	1	1	0	0.0517	0.0725	0.1275	0.4699	0.5302
0.6026	0.6392	0.7397	0.8422	0.9811	1.0997	1.2459	1.3295	1.4814	1.7419	
2.3353	2.3353	2.3353	2.3353	2.3353	2.3353	2.3353				
1979	1	1	1	1	0	0.0484	0.0763	0.2410	0.2587	0.5821
0.6868	0.7677	0.8909	0.9128	1.0369	1.1987	1.2482	1.5326	1.5520	1.7950	
1.9817	1.9817	1.9817	1.9817	1.9817	1.9817	1.9817				
1980	1	1	1	1	0	0.0452	0.0800	0.2125	0.4529	0.3922
0.4904	0.5166	0.6554	0.7136	0.8740	1.0626	1.1623	1.2898	1.3001	1.2699	
1.3961	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961				
1981	1	1	1	1	0	0.0419	0.1074	0.2137	0.3422	0.5264
0.3933	0.5254	0.5462	0.7464	0.7204	0.8231	1.0413	1.0989	1.3449	1.4926	
1.2128	1.2128	1.2128	1.2128	1.2128	1.2128	1.2128				
1982	1	1	1	1	0	0.0386	0.1181	0.2465	0.3336	0.3097
0.5496	0.3956	0.5275	0.5629	0.7606	0.6837	0.8539	1.0670	0.8793	1.0186	
1.1693	1.1693	1.1693	1.1693	1.1693	1.1693	1.1693				
1983	1	1	1	1	0	0.0353	0.1287	0.1357	0.3410	0.3694
0.3277	0.5200	0.5028	0.6179	0.7060	0.8800	0.9299	1.0356	1.0310	1.3217	
1.4823	1.4823	1.4823	1.4823	1.4823	1.4823	1.4823				
1984	1	1	1	1	0	0.0321	0.1315	0.1642	0.2493	0.4384
0.4113	0.4352	0.5872	0.5802	0.6758	0.7010	0.9513	1.1364	1.0258	1.2807	
1.8800	1.8800	1.8800	1.8800	1.8800	1.8800	1.8800				
1985	1	1	1	1	0	0.0288	0.1740	0.2297	0.2679	0.4414
0.5496	0.5474	0.6017	0.7452	0.6933	0.7231	0.8584	0.8698	0.9458	0.6759	
1.1217	1.1217	1.1217	1.1217	1.1217	1.1217	1.1217				
1986	1	1	1	1	0	0.0255	0.1555	0.2780	0.2906	0.3024
0.3735	0.5426	0.5720	0.6421	0.8209	0.9403	1.1860	1.1900	1.3737	1.6800	
1.6142	1.6142	1.6142	1.6142	1.6142	1.6142	1.6142				
1987	1	1	1	1	0	0.0222	0.1478	0.1388	0.3790	0.2786
0.2870	0.3621	0.5775	0.5975	0.6369	0.7638	0.9820	0.9250	1.2407	1.2031	
1.4157	1.4157	1.4157	1.4157	1.4157	1.4157	1.4157				
1988	1	1	1	1	0	0.0190	0.1400	0.1870	0.3189	0.4711
0.3689	0.3731	0.5163	0.6471	0.6884	0.7183	0.9211	1.0924	1.0225	1.4500	
1.4537	1.4537	1.4537	1.4537	1.4537	1.4537	1.4537				
1989	1	1	1	1	0	0.0157	0.1389	0.2737	0.3047	0.2931
0.5134	0.4386	0.4064	0.5167	0.6263	0.6611	0.6027	0.8758	0.6686	0.8282	
1.1264	1.1264	1.1264	1.1264	1.1264	1.1264	1.1264				
1990	1	1	1	1	0	0.0156	0.1378	0.2435	0.3506	0.3906
0.5111	0.5462	0.6076	0.6678	0.5300	0.7697	0.8312	2.2000	1.1847	1.0166	
1.4668	1.4668	1.4668	1.4668	1.4668	1.4668	1.4668				

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1991	1	1	1	1	0	0.0156	0.1367	0.2754	0.3697	0.4598
	0.5138	0.5437	0.5907	0.7210	0.8497	1.0997	0.7185	0.6403	1.0174	1.2051
	2.3828	2.3828	2.3828	2.3828	2.3828	2.3828				
1992	1	1	1	1	0	0.0155	0.1356	0.2316	0.3473	0.4743
	0.5334	0.5817	0.6210	0.6406	0.6530	0.6330	0.7217	0.7354	0.8501	0.9750
	1.0272	1.0272	1.0272	1.0272	1.0272	1.0272				
1993	1	1	1	1	0	0.0155	0.1274	0.2486	0.3384	0.3960
	0.4539	0.4935	0.5017	0.4880	0.5491	0.5100	1.2630	1.0250	0.6135	0.5995
	0.6850	0.6850	0.6850	0.6850	0.6850	0.6850				
1994	1	1	1	1	0	0.0154	0.1191	0.3000	0.3626	0.4469
	0.4473	0.5262	0.5700	0.6218	0.5598	0.6341	0.4850	0.6491	0.7300	0.7013
	0.7455	0.7455	0.7455	0.7455	0.7455	0.7455				
1995	1	1	1	1	0	0.0154	0.1108	0.2682	0.3418	0.4876
	0.5367	0.6506	0.6249	0.6597	0.7560	0.6670	0.7445	0.7998	0.9101	0.6804
	0.8008	0.8008	0.8008	0.8008	0.8008	0.8008				
1996	1	1	1	1	0	0.0153	0.1007	0.2876	0.3982	0.4674
	0.5317	0.5651	0.6509	0.5957	0.6362	0.6049	0.7500	0.6756	0.8109	1.4853
	0.7509	0.7509	0.7509	0.7509	0.7509	0.7509				
1997	1	1	1	1	0	0.0153	0.0906	0.3555	0.4322	0.4931
	0.5476	0.5453	0.5833	0.5855	0.6071	0.6315	0.8633	0.5946	0.7118	0.6618
	0.8693	0.8693	0.8693	0.8693	0.8693	0.8693				
1998	1	1	1	1	0	0.0152	0.0805	0.2091	0.3539	0.5041
	0.5172	0.5420	0.6412	0.6099	0.6769	0.8078	0.7174	0.8100	0.7733	0.7510
	0.7979	0.7979	0.7979	0.7979	0.7979	0.7979				
1999	1	1	1	1	0	0.0152	0.1352	0.2502	0.3455	0.4251
	0.5265	0.5569	0.5727	0.6117	0.7030	0.6650	0.7989	0.7554	0.8787	0.7348
	0.8187	0.8187	0.8187	0.8187	0.8187	0.8187				
2000	1	1	1	1	0	0.0151	0.1899	0.3216	0.4729	0.5766
	0.6598	0.7176	0.7279	0.7539	0.8378	0.8159	0.8814	0.8554	0.9391	0.8744
	0.9336	0.9336	0.9336	0.9336	0.9336	0.9336				
2001	1	1	1	1	0	0.0151	0.0512	0.2867	0.4843	0.6527
	0.6645	0.7469	0.8629	0.8555	0.8802	0.9630	0.9790	1.0054	1.0494	0.9927
	0.9768	0.9768	0.9768	0.9768	0.9768	0.9768				
2002	1	1	1	1	0	0.0150	0.0756	0.3583	0.4575	0.6058
	0.8160	0.7581	0.8488	0.9771	0.9322	0.9176	0.9974	0.9890	0.9236	1.1250
	1.0573	1.0573	1.0573	1.0573	1.0573	1.0573				
2003	1	1	1	1	0	0.0150	0.1000	0.2551	0.4355	0.5225
	0.5885	0.7569	0.6915	0.7469	0.8246	0.7692	0.8887	0.9266	0.7894	0.8414
	0.9965	0.9965	0.9965	0.9965	0.9965	0.9965				
2004	1	1	1	1	0	0.0149	0.1081	0.2000	0.4360	0.4807
	0.5319	0.6478	0.7068	0.6579	0.7094	0.8050	0.8581	0.7715	0.9704	0.8631
	0.8959	0.8959	0.8959	0.8959	0.8959	0.8959				
2005	1	1	1	1	0	0.0149	0.1162	0.2603	0.4311	0.5086
	0.5393	0.5682	0.6336	0.6550	0.7027	0.7962	0.8104	0.8109	0.7602	1.1449
	0.9678	0.9678	0.9678	0.9678	0.9678	0.9678				
2006	1	1	1	1	0	0.0148	0.1324	0.3831	0.4575	0.5341
	0.5740	0.5910	0.5979	0.6560	0.6997	0.7259	0.7220	0.7753	0.6580	0.6399
	0.9550	0.9550	0.9550	0.9550	0.9550	0.9550				
2007	1	1	1	1	0	0.0148	0.0445	0.2272	0.3776	0.5352
	0.5530	0.6073	0.6328	0.6475	0.7055	0.7723	0.7627	0.8137	0.8702	0.8008
	0.8698	0.8698	0.8698	0.8698	0.8698	0.8698				
2008	1	1	1	1	0	0.0148	0.1346	0.2440	0.4079	0.5630
	0.6365	0.6865	0.6818	0.7098	0.7211	0.7488	0.8073	0.8483	0.7755	0.8834
	0.8332	0.8332	0.8332	0.8332	0.8332	0.8332				

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2009	1	1	1	1	0	0.0148	0.0667	0.2448	0.3431	0.4712
	0.6371	0.6702	0.6942	0.7463	0.8226	0.7674	0.8139	1.0147	0.8503	0.9582
	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334				
2010	1	1	1	1	0	0.0148	0.1089	0.2326	0.2918	0.4332
	0.5302	0.6582	0.8349	1.0828	1.0276	0.9582	0.8763	0.8524	1.1253	0.7200
	0.9021	0.9021	0.9021	0.9021	0.9021	0.9021				
2011	1	1	1	1	0	0.0148	0.0844	0.2457	0.3219	0.3867
	0.5142	0.5950	0.6746	0.8534	0.9294	0.9780	1.0749	1.0588	1.0279	1.0557
	0.9212	0.9212	0.9212	0.9212	0.9212	0.9212				
2012	1	1	1	1	0	0.0148	0.1290	0.2145	0.3536	0.4094
	0.4889	0.6562	0.6907	0.7775	0.9072	0.9633	0.9639	0.9639	0.9889	0.9924
	0.9425	0.9425	0.9425	0.9425	0.9425	0.9425				
2013	1	1	1	1	0	0.0148	0.1297	0.2874	0.3595	0.4697
	0.5104	0.6260	0.7165	0.7310	0.8313	0.9989	1.0752	1.2303	1.1187	1.0682
	1.0545	1.0545	1.0545	1.0545	1.0545	1.0545				
2014	1	1	1	1	0	0.0148	0.1028	0.4080	0.4686	0.4797
	0.5362	0.5741	0.6198	0.6590	0.7174	0.6950	1.1645	1.0150	0.9491	0.9674
	1.0579	1.0579	1.0579	1.0579	1.0579	1.0579				
2015	1	1	1	1	0	0.0148	0.0759	0.2471	0.3905	0.4445
	0.4708	0.5531	0.5948	0.6749	0.6879	0.7179	0.8337	0.9523	1.0185	1.0893
	1.2493	1.2493	1.2493	1.2493	1.2493	1.2493				
2016	1	1	1	1	0	0.0148	0.1653	0.2439	0.3831	0.4159
	0.4406	0.4638	0.5141	0.5164	0.5127	0.6480	0.7198	0.5948	0.7756	1.4510
	1.5802	1.5802	1.5802	1.5802	1.5802	1.5802				
2017	1	1	1	1	0	0.0148	0.1363	0.2835	0.3941	0.4668
	0.5033	0.5280	0.5398	0.5693	0.6139	0.6080	0.6853	0.7494	0.7510	0.7966
	0.9076	0.9076	0.9076	0.9076	0.9076	0.9076				

#Weight at age for Fishery: Fleet = 1

#_#Yr	seas	gender	GP	bseas	fleet	a0	a1	a2	a3	a4
a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	
a15	a16	a17	a18	a19	a20					
-1940	1	1	1	1	1	0.0169	0.0916	0.2489	0.3790	0.4841
	0.5329	0.5813	0.6471	0.7184	0.7875	0.8594	0.9307	0.9695	1.0658	1.0091
	1.0336	1.0336	1.0336	1.0336	1.0336	1.0336				
1975	1	1	1	1	1	0.0550	0.1575	0.2987	0.3658	0.6143
	0.6306	0.7873	0.8738	0.9678	0.9075	0.9700	1.6933	1.5000	1.9000	1.9555
	2.7445	2.7445	2.7445	2.7445	2.7445	2.7445				
1976	1	1	1	1	1	0.0550	0.0986	0.2359	0.4990	0.5188
	0.6936	0.8038	0.9165	1.2063	1.3335	1.4495	1.6507	1.8066	1.8588	1.9555
	2.7445	2.7445	2.7445	2.7445	2.7445	2.7445				
1977	1	1	1	1	1	0.0550	0.0855	0.4020	0.4882	0.5902
	0.6650	0.7489	0.8272	0.9779	1.1052	1.2341	1.3148	1.4027	1.7511	2.1005
	2.2094	2.2094	2.2094	2.2094	2.2094	2.2094				
1978	1	1	1	1	1	0.0517	0.0725	0.1275	0.4699	0.5302
	0.6026	0.6392	0.7397	0.8422	0.9811	1.0997	1.2459	1.3295	1.4814	1.7419
	2.3353	2.3353	2.3353	2.3353	2.3353	2.3353				
1979	1	1	1	1	1	0.0484	0.0763	0.2410	0.2587	0.5821
	0.6868	0.7677	0.8909	0.9128	1.0369	1.1987	1.2482	1.5326	1.5520	1.7950
	1.9817	1.9817	1.9817	1.9817	1.9817	1.9817				
1980	1	1	1	1	1	0.0452	0.0800	0.2125	0.4529	0.3922
	0.4904	0.5166	0.6554	0.7136	0.8740	1.0626	1.1623	1.2898	1.3001	1.2699
	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961				
1981	1	1	1	1	1	0.0419	0.1074	0.2137	0.3422	0.5264

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	0.3933	0.5254	0.5462	0.7464	0.7204	0.8231	1.0413	1.0989	1.3449	1.4926
	1.2128	1.2128	1.2128	1.2128	1.2128	1.2128				
1982	1		1	1	1	0.0386	0.1181	0.2465	0.3336	0.3097
	0.5496	0.3956	0.5275	0.5629	0.7606	0.6837	0.8539	1.0670	0.8793	1.0186
	1.1693	1.1693	1.1693	1.1693	1.1693	1.1693				
1983	1		1	1	1	0.0353	0.1287	0.1357	0.3410	0.3694
	0.3277	0.5200	0.5028	0.6179	0.7060	0.8800	0.9299	1.0356	1.0310	1.3217
	1.4823	1.4823	1.4823	1.4823	1.4823	1.4823				
1984	1		1	1	1	0.0321	0.1315	0.1642	0.2493	0.4384
	0.4113	0.4352	0.5872	0.5802	0.6758	0.7010	0.9513	1.1364	1.0258	1.2807
	1.8800	1.8800	1.8800	1.8800	1.8800	1.8800				
1985	1		1	1	1	0.0288	0.1740	0.2297	0.2679	0.4414
	0.5496	0.5474	0.6017	0.7452	0.6933	0.7231	0.8584	0.8698	0.9458	0.6759
	1.1217	1.1217	1.1217	1.1217	1.1217	1.1217				
1986	1		1	1	1	0.0255	0.1555	0.2780	0.2906	0.3024
	0.3735	0.5426	0.5720	0.6421	0.8209	0.9403	1.1860	1.1900	1.3737	1.6800
	1.6142	1.6142	1.6142	1.6142	1.6142	1.6142				
1987	1		1	1	1	0.0222	0.1478	0.1388	0.3790	0.2786
	0.2870	0.3621	0.5775	0.5975	0.6369	0.7638	0.9820	0.9250	1.2407	1.2031
	1.4157	1.4157	1.4157	1.4157	1.4157	1.4157				
1988	1		1	1	1	0.0190	0.1400	0.1870	0.3189	0.4711
	0.3689	0.3731	0.5163	0.6471	0.6884	0.7183	0.9211	1.0924	1.0225	1.4500
	1.4537	1.4537	1.4537	1.4537	1.4537	1.4537				
1989	1		1	1	1	0.0157	0.1389	0.2737	0.3047	0.2931
	0.5134	0.4386	0.4064	0.5167	0.6263	0.6611	0.6027	0.8758	0.6686	0.8282
	1.1264	1.1264	1.1264	1.1264	1.1264	1.1264				
1990	1		1	1	1	0.0156	0.1378	0.2435	0.3506	0.3906
	0.5111	0.5462	0.6076	0.6678	0.5300	0.7697	0.8312	2.2000	1.1847	1.0166
	1.4668	1.4668	1.4668	1.4668	1.4668	1.4668				
1991	1		1	1	1	0.0156	0.1367	0.2754	0.3697	0.4598
	0.5138	0.5437	0.5907	0.7210	0.8497	1.0997	0.7185	0.6403	1.0174	1.2051
	2.3828	2.3828	2.3828	2.3828	2.3828	2.3828				
1992	1		1	1	1	0.0155	0.1356	0.2316	0.3473	0.4743
	0.5334	0.5817	0.6210	0.6406	0.6530	0.6330	0.7217	0.7354	0.8501	0.9750
	1.0272	1.0272	1.0272	1.0272	1.0272	1.0272				
1993	1		1	1	1	0.0155	0.1274	0.2486	0.3384	0.3960
	0.4539	0.4935	0.5017	0.4880	0.5491	0.5100	1.2630	1.0250	0.6135	0.5995
	0.6850	0.6850	0.6850	0.6850	0.6850	0.6850				
1994	1		1	1	1	0.0154	0.1191	0.3000	0.3626	0.4469
	0.4473	0.5262	0.5700	0.6218	0.5598	0.6341	0.4850	0.6491	0.7300	0.7013
	0.7455	0.7455	0.7455	0.7455	0.7455	0.7455				
1995	1		1	1	1	0.0154	0.1108	0.2682	0.3418	0.4876
	0.5367	0.6506	0.6249	0.6597	0.7560	0.6670	0.7445	0.7998	0.9101	0.6804
	0.8008	0.8008	0.8008	0.8008	0.8008	0.8008				
1996	1		1	1	1	0.0153	0.1007	0.2876	0.3982	0.4674
	0.5317	0.5651	0.6509	0.5957	0.6362	0.6049	0.7500	0.6756	0.8109	1.4853
	0.7509	0.7509	0.7509	0.7509	0.7509	0.7509				
1997	1		1	1	1	0.0153	0.0906	0.3555	0.4322	0.4931
	0.5476	0.5453	0.5833	0.5855	0.6071	0.6315	0.8633	0.5946	0.7118	0.6618
	0.8693	0.8693	0.8693	0.8693	0.8693	0.8693				
1998	1		1	1	1	0.0152	0.0805	0.2091	0.3539	0.5041
	0.5172	0.5420	0.6412	0.6099	0.6769	0.8078	0.7174	0.8100	0.7733	0.7510
	0.7979	0.7979	0.7979	0.7979	0.7979	0.7979				
1999	1		1	1	1	0.0152	0.1352	0.2502	0.3455	0.4251

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	0.5265	0.5569	0.5727	0.6117	0.7030	0.6650	0.7989	0.7554	0.8787	0.7348
	0.8187	0.8187	0.8187	0.8187	0.8187	0.8187				
2000	1	1	1	1	1	0.0151	0.1899	0.3216	0.4729	0.5766
	0.6598	0.7176	0.7279	0.7539	0.8378	0.8159	0.8814	0.8554	0.9391	0.8744
	0.9336	0.9336	0.9336	0.9336	0.9336	0.9336				
2001	1	1	1	1	1	0.0151	0.0512	0.2867	0.4843	0.6527
	0.6645	0.7469	0.8629	0.8555	0.8802	0.9630	0.9790	1.0054	1.0494	0.9927
	0.9768	0.9768	0.9768	0.9768	0.9768	0.9768				
2002	1	1	1	1	1	0.0150	0.0756	0.3583	0.4575	0.6058
	0.8160	0.7581	0.8488	0.9771	0.9322	0.9176	0.9974	0.9890	0.9236	1.1250
	1.0573	1.0573	1.0573	1.0573	1.0573	1.0573				
2003	1	1	1	1	1	0.0150	0.1000	0.2551	0.4355	0.5225
	0.5885	0.7569	0.6915	0.7469	0.8246	0.7692	0.8887	0.9266	0.7894	0.8414
	0.9965	0.9965	0.9965	0.9965	0.9965	0.9965				
2004	1	1	1	1	1	0.0149	0.1081	0.2000	0.4360	0.4807
	0.5319	0.6478	0.7068	0.6579	0.7094	0.8050	0.8581	0.7715	0.9704	0.8631
	0.8959	0.8959	0.8959	0.8959	0.8959	0.8959				
2005	1	1	1	1	1	0.0149	0.1162	0.2603	0.4311	0.5086
	0.5393	0.5682	0.6336	0.6550	0.7027	0.7962	0.8104	0.8109	0.7602	1.1449
	0.9678	0.9678	0.9678	0.9678	0.9678	0.9678				
2006	1	1	1	1	1	0.0148	0.1324	0.3831	0.4575	0.5341
	0.5740	0.5910	0.5979	0.6560	0.6997	0.7259	0.7220	0.7753	0.6580	0.6399
	0.9550	0.9550	0.9550	0.9550	0.9550	0.9550				
2007	1	1	1	1	1	0.0148	0.0445	0.2272	0.3776	0.5352
	0.5530	0.6073	0.6328	0.6475	0.7055	0.7723	0.7627	0.8137	0.8702	0.8008
	0.8698	0.8698	0.8698	0.8698	0.8698	0.8698				
2008	1	1	1	1	1	0.0148	0.1346	0.2440	0.4079	0.5630
	0.6365	0.6865	0.6818	0.7098	0.7211	0.7488	0.8073	0.8483	0.7755	0.8834
	0.8332	0.8332	0.8332	0.8332	0.8332	0.8332				
2009	1	1	1	1	1	0.0148	0.0667	0.2448	0.3431	0.4712
	0.6371	0.6702	0.6942	0.7463	0.8226	0.7674	0.8139	1.0147	0.8503	0.9582
	1.0334	1.0334	1.0334	1.0334	1.0334	1.0334				
2010	1	1	1	1	1	0.0148	0.1089	0.2326	0.2918	0.4332
	0.5302	0.6582	0.8349	1.0828	1.0276	0.9582	0.8763	0.8524	1.1253	0.7200
	0.9021	0.9021	0.9021	0.9021	0.9021	0.9021				
2011	1	1	1	1	1	0.0148	0.0844	0.2457	0.3219	0.3867
	0.5142	0.5950	0.6746	0.8534	0.9294	0.9780	1.0749	1.0588	1.0279	1.0557
	0.9212	0.9212	0.9212	0.9212	0.9212	0.9212				
2012	1	1	1	1	1	0.0148	0.1290	0.2145	0.3536	0.4094
	0.4889	0.6562	0.6907	0.7775	0.9072	0.9633	0.9639	0.9639	0.9889	0.9924
	0.9425	0.9425	0.9425	0.9425	0.9425	0.9425				
2013	1	1	1	1	1	0.0148	0.1297	0.2874	0.3595	0.4697
	0.5104	0.6260	0.7165	0.7310	0.8313	0.9989	1.0752	1.2303	1.1187	1.0682
	1.0545	1.0545	1.0545	1.0545	1.0545	1.0545				
2014	1	1	1	1	1	0.0148	0.1028	0.4080	0.4686	0.4797
	0.5362	0.5741	0.6198	0.6590	0.7174	0.6950	1.1645	1.0150	0.9491	0.9674
	1.0579	1.0579	1.0579	1.0579	1.0579	1.0579				
2015	1	1	1	1	1	0.0148	0.0759	0.2471	0.3905	0.4445
	0.4708	0.5531	0.5948	0.6749	0.6879	0.7179	0.8337	0.9523	1.0185	1.0893
	1.2493	1.2493	1.2493	1.2493	1.2493	1.2493				
2016	1	1	1	1	1	0.0148	0.1653	0.2439	0.3831	0.4159
	0.4406	0.4638	0.5141	0.5164	0.5127	0.6480	0.7198	0.5948	0.7756	1.4510
	1.5802	1.5802	1.5802	1.5802	1.5802	1.5802				
2017	1	1	1	1	1	0.0148	0.1363	0.2835	0.3941	0.4668

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0.5033 0.5280 0.5398 0.5693 0.6139 0.6080 0.6853 0.7494 0.7510 0.7966  
0.9076 0.9076 0.9076 0.9076 0.9076 0.9076

#Weight at age for Survey: Fleet = 2

#_#Yr	seas	gender	GP	bseas	fleet	a0	a1	a2	a3	a4
a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	
a15	a16	a17	a18	a19	a20					
-1940	1	1	1	1	2	0.0169	0.0916	0.2489	0.3790	0.4841
0.5329	0.5813	0.6471	0.7184	0.7875	0.8594	0.9307	0.9695	1.0658	1.0091	
1.0336	1.0336	1.0336	1.0336	1.0336	1.0336	1.0336				
1975	1	1	1	1	2	0.0550	0.1575	0.2987	0.3658	0.6143
0.6306	0.7873	0.8738	0.9678	0.9075	0.9700	1.6933	1.5000	1.9000	1.9555	
2.7445	2.7445	2.7445	2.7445	2.7445	2.7445	2.7445				
1976	1	1	1	1	2	0.0550	0.0986	0.2359	0.4990	0.5188
0.6936	0.8038	0.9165	1.2063	1.3335	1.4495	1.6507	1.8066	1.8588	1.9555	
2.7445	2.7445	2.7445	2.7445	2.7445	2.7445	2.7445				
1977	1	1	1	1	2	0.0550	0.0855	0.4020	0.4882	0.5902
0.6650	0.7489	0.8272	0.9779	1.1052	1.2341	1.3148	1.4027	1.7511	2.1005	
2.2094	2.2094	2.2094	2.2094	2.2094	2.2094	2.2094				
1978	1	1	1	1	2	0.0517	0.0725	0.1275	0.4699	0.5302
0.6026	0.6392	0.7397	0.8422	0.9811	1.0997	1.2459	1.3295	1.4814	1.7419	
2.3353	2.3353	2.3353	2.3353	2.3353	2.3353	2.3353				
1979	1	1	1	1	2	0.0484	0.0763	0.2410	0.2587	0.5821
0.6868	0.7677	0.8909	0.9128	1.0369	1.1987	1.2482	1.5326	1.5520	1.7950	
1.9817	1.9817	1.9817	1.9817	1.9817	1.9817	1.9817				
1980	1	1	1	1	2	0.0452	0.0800	0.2125	0.4529	0.3922
0.4904	0.5166	0.6554	0.7136	0.8740	1.0626	1.1623	1.2898	1.3001	1.2699	
1.3961	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961				
1981	1	1	1	1	2	0.0419	0.1074	0.2137	0.3422	0.5264
0.3933	0.5254	0.5462	0.7464	0.7204	0.8231	1.0413	1.0989	1.3449	1.4926	
1.2128	1.2128	1.2128	1.2128	1.2128	1.2128	1.2128				
1982	1	1	1	1	2	0.0386	0.1181	0.2465	0.3336	0.3097
0.5496	0.3956	0.5275	0.5629	0.7606	0.6837	0.8539	1.0670	0.8793	1.0186	
1.1693	1.1693	1.1693	1.1693	1.1693	1.1693	1.1693				
1983	1	1	1	1	2	0.0353	0.1287	0.1357	0.3410	0.3694
0.3277	0.5200	0.5028	0.6179	0.7060	0.8800	0.9299	1.0356	1.0310	1.3217	
1.4823	1.4823	1.4823	1.4823	1.4823	1.4823	1.4823				
1984	1	1	1	1	2	0.0321	0.1315	0.1642	0.2493	0.4384
0.4113	0.4352	0.5872	0.5802	0.6758	0.7010	0.9513	1.1364	1.0258	1.2807	
1.8800	1.8800	1.8800	1.8800	1.8800	1.8800	1.8800				
1985	1	1	1	1	2	0.0288	0.1740	0.2297	0.2679	0.4414
0.5496	0.5474	0.6017	0.7452	0.6933	0.7231	0.8584	0.8698	0.9458	0.6759	
1.1217	1.1217	1.1217	1.1217	1.1217	1.1217	1.1217				
1986	1	1	1	1	2	0.0255	0.1555	0.2780	0.2906	0.3024
0.3735	0.5426	0.5720	0.6421	0.8209	0.9403	1.1860	1.1900	1.3737	1.6800	
1.6142	1.6142	1.6142	1.6142	1.6142	1.6142	1.6142				
1987	1	1	1	1	2	0.0222	0.1478	0.1388	0.3790	0.2786
0.2870	0.3621	0.5775	0.5975	0.6369	0.7638	0.9820	0.9250	1.2407	1.2031	
1.4157	1.4157	1.4157	1.4157	1.4157	1.4157	1.4157				
1988	1	1	1	1	2	0.0190	0.1400	0.1870	0.3189	0.4711
0.3689	0.3731	0.5163	0.6471	0.6884	0.7183	0.9211	1.0924	1.0225	1.4500	
1.4537	1.4537	1.4537	1.4537	1.4537	1.4537	1.4537				
1989	1	1	1	1	2	0.0157	0.1389	0.2737	0.3047	0.2931
0.5134	0.4386	0.4064	0.5167	0.6263	0.6611	0.6027	0.8758	0.6686	0.8282	



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    0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008      1          1 1      1      2 0.0148 0.1346 0.2440 0.4079 0.5630
    0.6365 0.6865 0.6818 0.7098 0.7211 0.7488 0.8073 0.8483 0.7755 0.8834
    0.8332 0.8332 0.8332 0.8332 0.8332 0.8332
2009      1          1 1      1      2 0.0148 0.0667 0.2448 0.3431 0.4712
    0.6371 0.6702 0.6942 0.7463 0.8226 0.7674 0.8139 1.0147 0.8503 0.9582
    1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
2010      1          1 1      1      2 0.0148 0.1089 0.2326 0.2918 0.4332
    0.5302 0.6582 0.8349 1.0828 1.0276 0.9582 0.8763 0.8524 1.1253 0.7200
    0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
2011      1          1 1      1      2 0.0148 0.0844 0.2457 0.3219 0.3867
    0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
    0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
2012      1          1 1      1      2 0.0148 0.1290 0.2145 0.3536 0.4094
    0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
    0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
2013      1          1 1      1      2 0.0148 0.1297 0.2874 0.3595 0.4697
    0.5104 0.6260 0.7165 0.7310 0.8313 0.9989 1.0752 1.2303 1.1187 1.0682
    1.0545 1.0545 1.0545 1.0545 1.0545 1.0545
2014      1          1 1      1      2 0.0148 0.1028 0.4080 0.4686 0.4797
    0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
    1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
2015      1          1 1      1      2 0.0148 0.0759 0.2471 0.3905 0.4445
    0.4708 0.5531 0.5948 0.6749 0.6879 0.7179 0.8337 0.9523 1.0185 1.0893
    1.2493 1.2493 1.2493 1.2493 1.2493 1.2493
2016      1          1 1      1      2 0.0148 0.1653 0.2439 0.3831 0.4159
    0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
    1.5802 1.5802 1.5802 1.5802 1.5802 1.5802
2017      1          1 1      1      2 0.0148 0.1363 0.2835 0.3941 0.4668
    0.5033 0.5280 0.5398 0.5693 0.6139 0.6080 0.6853 0.7494 0.7510 0.7966
    0.9076 0.9076 0.9076 0.9076 0.9076 0.9076
# End of wtatage.ss file

-9999      1          1 1      1      2 0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0

```