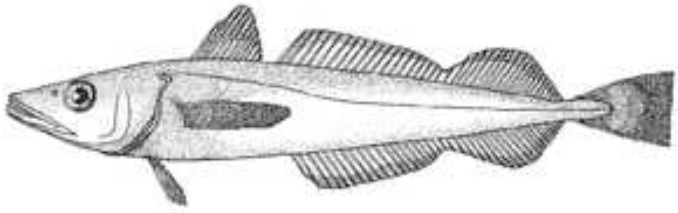
Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2019



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

February 25th, 2019

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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APPENDICES

ONE-PAGE SUMMARY

- The stock assessment model for 2019 is similar in structure to the 2018 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.

- The only structural change from 2018 is the inclusion of time-varying (rather than constant) fecundity. This is achieved by using a single maturity-at-age curve multiplied by yearly weight-at-age data to produce the fecundity-at-age for each year.

- Updates to the data include: minor changes to historical (pre-2018) catch, age composition, and weight-at-age data; addition of 2018 fishery catch and age-composition data; and addition of 2018 weight-at-age data.

- Coastwide catch in 2018 was the second largest on record at 410,443 t [t represents metric tons], out of a Total Allowable Catch (adjusted for carryovers) of 597,500 t. Attainment in the U.S. was 71.4% of its quota (down 9% from last year); in Canada it was 61.1% (up 6% from last year).

- The stock is estimated to have been at a minimum of 51% of B_0 since 2013 due to large estimated 2010 and 2014 cohorts.

- The median estimate of the 2019 relative spawning biomass (female spawning biomass at the start of 2019 divided by that at unfished equilibrium, B_0) is 64.1% but is highly uncertain (with 95% credible interval from 26.3% to 156.7%). The median estimate of female spawning biomass at the start of 2019 is 1.312 million t (with 95% credible interval from 0.471 to 3.601 million t). This is a decrease from the 2018 median of 1.346 million t (though its 95% credible interval is 0.616–2.943 million t).

- The estimated joint probability of being both above the target relative fishing intensity in 2018 and below the $B_{40\%}$ (40% of B_0) reference point at the start of 2019 is 10.3%.

- Based on the default harvest rule, the estimated median catch limit for 2019 is 725,593 t (with 95% credible interval from 214,763 to 2,106,509 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 2019 and 2020 catch equal to the 2018 Total Allowable Catch of 597,500 t show the estimated median relative spawning biomass decreasing from 64% in 2019 to 61% in 2020 and 53% in 2021. However, due to uncertainty there is an estimated 34% chance of the spawning biomass falling below $B_{40\%}$ in 2021. There is an estimated 68% chance of the spawning biomass declining from 2019 to 2020, and an 84% chance of it declining from 2020 to 2021 under this constant level of catch.

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 2019. 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 233,645 t from 1966 to 2018, with a low of 89,930 t in 1980 and a peak of 440,942 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 catch in U.S. waters averaged 176,999 t, or 75.8% of the average total catch, while catch from Canadian waters averaged 56,646 t. Over the last 10 years, 2009–2018 (Table a), the average coastwide catch was 285,434 t with U.S. and

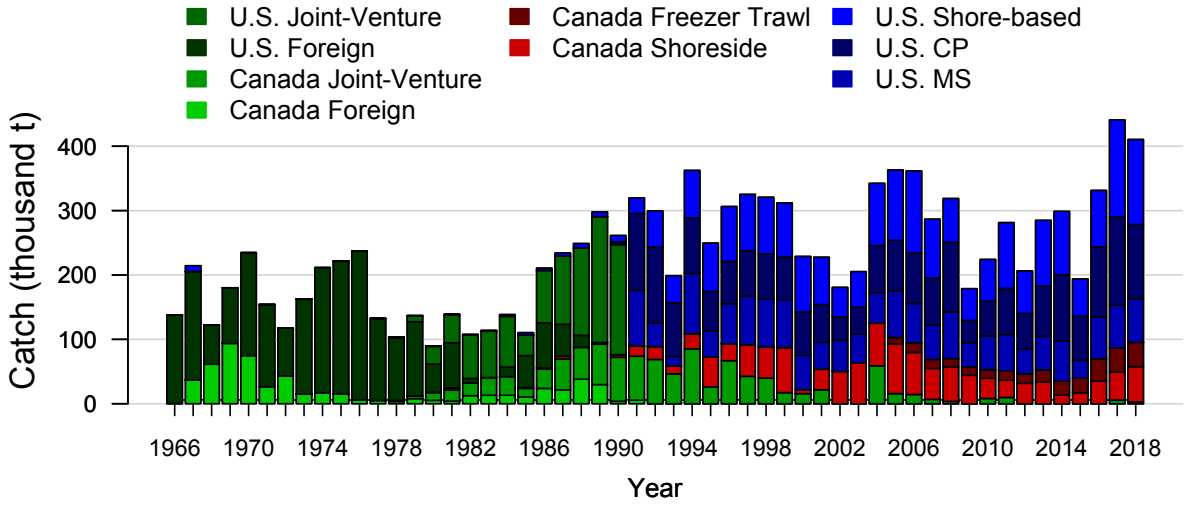

Figure a. Total Pacific Hake catch used in the assessment by sector, 1966–2018. U.S. tribal catches are included in the sectors where they are represented. CP is catcher-processor and MS is mothership.

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	52,470	77,950	102,143	1,018	233,581	0	33,665	18,584	52,249	285,830
2014	62,102	103,203	98,640	197	264,141	0	13,326	21,787	35,113	299,254
2015	27,665	68,484	58,011	0	154,160	0	16,775	22,903	39,678	193,838
2016	65,036	108,786	87,760	745	262,327	0	35,012	34,729	69,740	332,067
2017	66,428	136,960	150,841	0	354,229	5,608	43,427	37,679	86,713	440,942
2018	67,129	116,073	131,829	0	315,031	2,724	54,447	38,241	95,412	410,443

Canadian catches averaging 226,724 t and 58,710 t, respectively. The coastwide catch in 2018 was 410,443 t, out of a total allowable catch (TAC, adjusted for carryovers) of 597,500 t. Attainment in the U.S. was 71.4% of its quota; in Canada it was 61.1%.

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, including those that do not target hake, 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 (233,645 t) in 2014, 2016, 2017 and 2018, 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 2018) from that cohort estimated at approximately 1.29 million t. Through 2018, the total catch of the 2010 and 2014 year classes is estimated to be about 1.00 million t and 0.37 million t, respectively.

DATA AND ASSESSMENT

This Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2018), acoustic survey biomass indices (Figure b) and age-compositions (1995–2017), as well as fishery age-compositions (1975–2018). 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.

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 in-

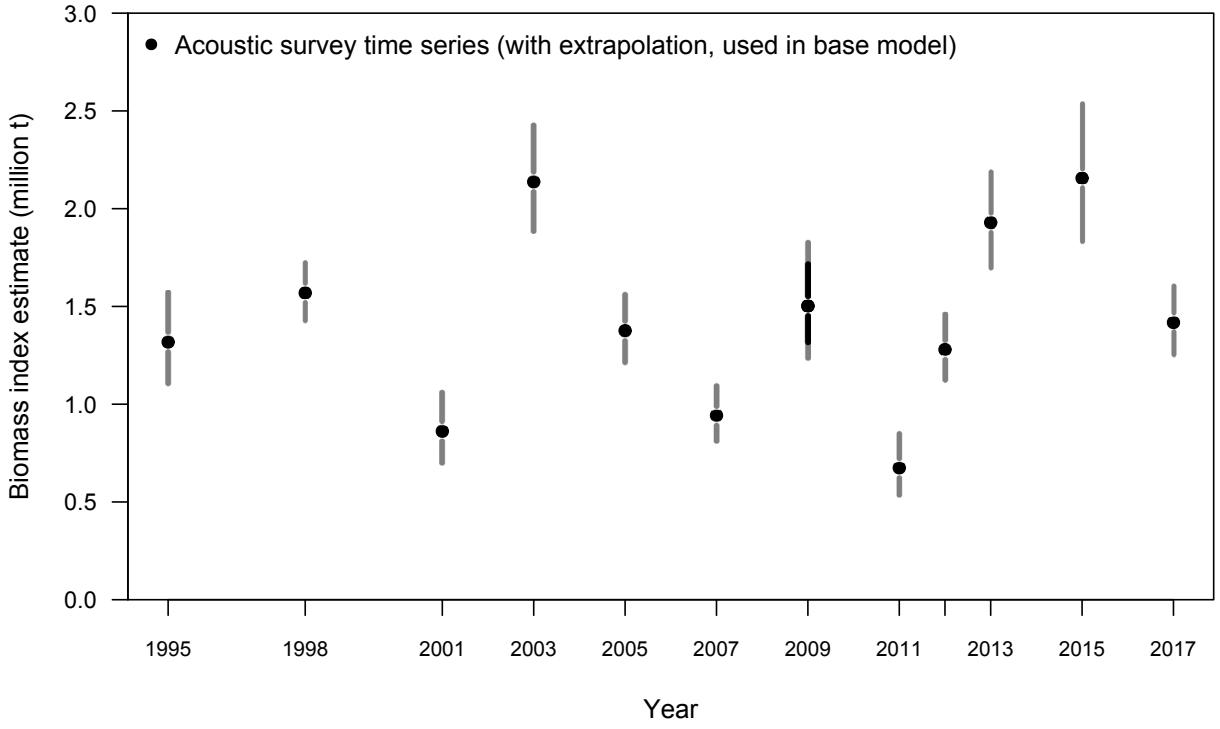

Figure b. Acoustic survey biomass index (millions of tons). Approximate 95% confidence intervals (gray bars) are based on sampling variability; black bar for 2009 does not include additional uncertainty due to squid/hake apportionment.

dices, 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 model assumptions 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 (and ongoing) closed-loop simulations influenced the decisions made for this assessment.

The 2019 assessment retains most of the structural form of the base assessment model from 2018 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 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,

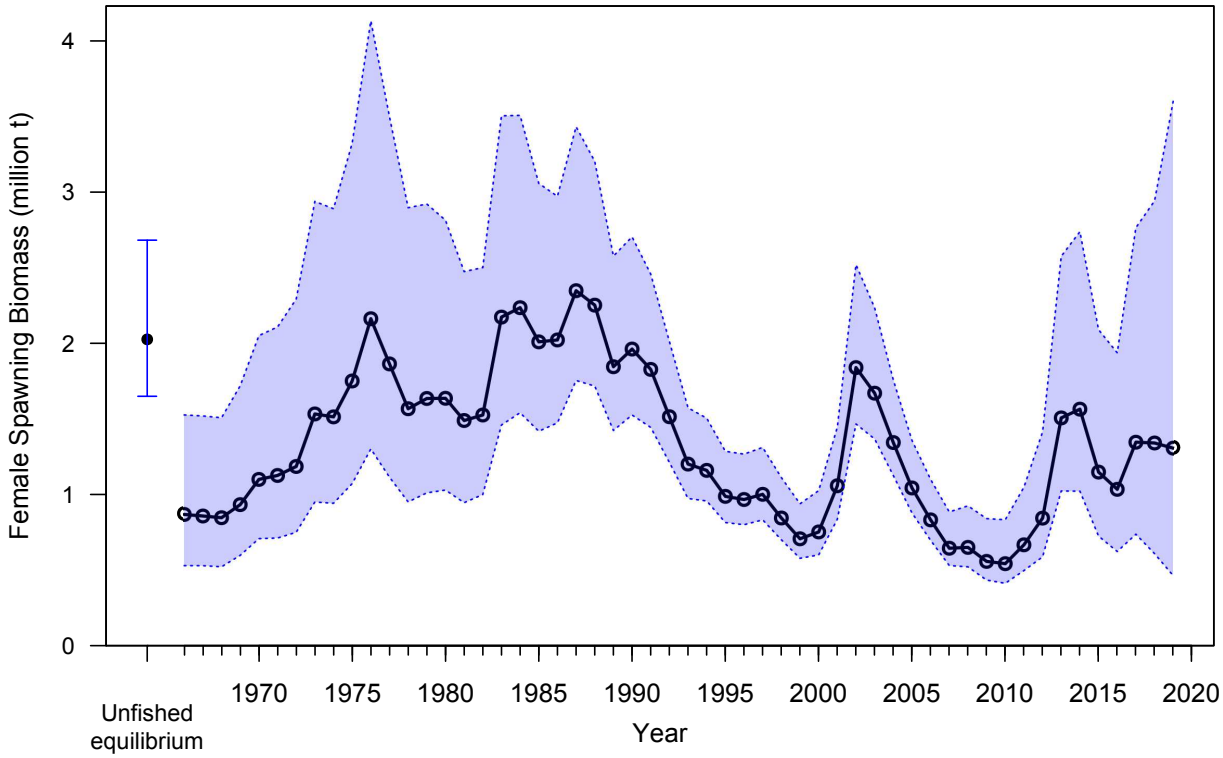

Figure c. Median of the posterior distribution for beginning of the year female spawning biomass (B_t in year t) through 2019 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

we retain time-varying selectivity in this assessment, continuing with the new parameterization introduced in the 2018 assessment and retaining the equivalent level of assumed variability. We apply the Dirichlet-Multinomial approach to weighting composition data again this year and provide sensitivities to alternative data-weighting approaches. For 2019, we incorporate time-varying fecundity into the assessment model, whereas previously it was time-invariant.

The 35-day 2018/2019 U.S. government shutdown considerably delayed delivery of U.S. age data and reduced the JTC's time available to collectively complete the 2019 assessment. As a result, many planned supplementary and exploratory analyses could not be completed, including some developed for response to 2018 SRG requests, although many sensitivity runs (including new ones related to time-varying fecundity) were completed.

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 in the mid-1970s and then again after two large recruitments

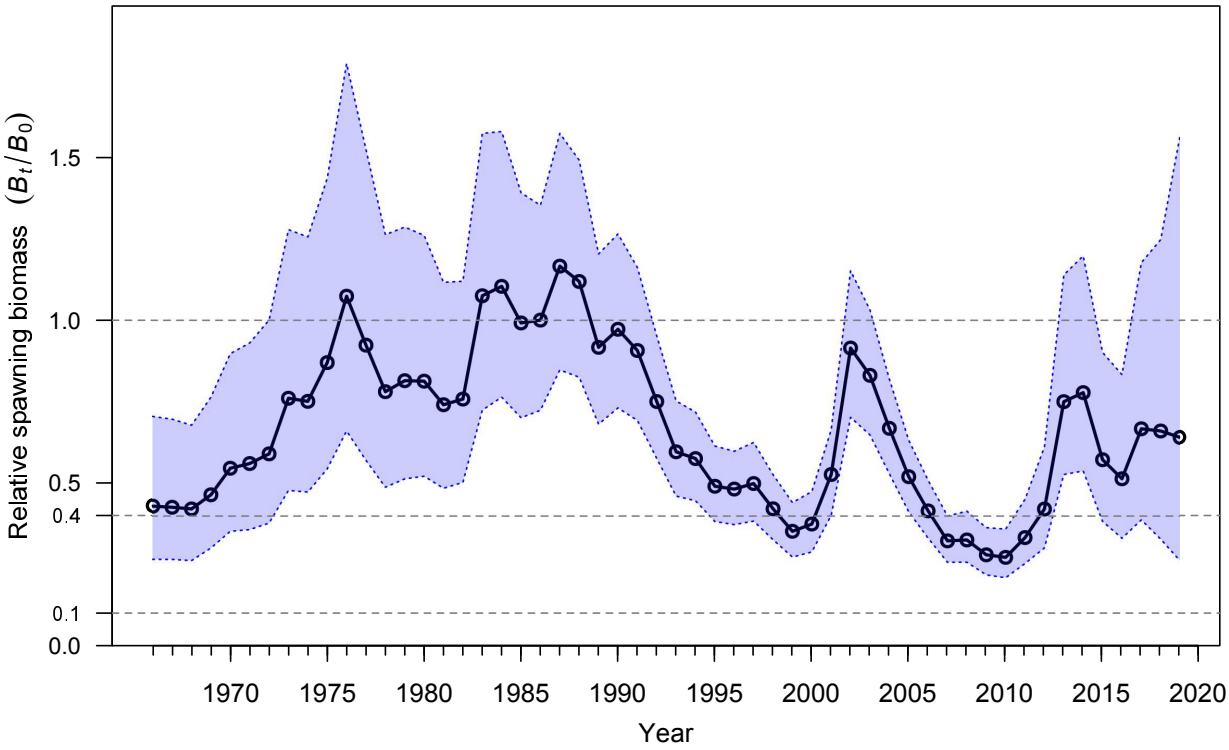

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2019 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 1999. This long period of decline was followed by a brief increase to a peak in 2002 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 0.550 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 from 2014 to 2016 is primarily from the 2010 year class surpassing the age at which gains in weight from growth are greater than the loss in weight from 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 and an above-average estimate of the 2016 year class, has resulted in a relatively constant biomass since 2017.

The median estimate of the 2019 relative spawning biomass (spawning biomass at the start of 2019 divided by that at unfished equilibrium, B_0) is 64.1%. However, the uncertainty is large, with a 95% posterior credibility interval from 26.3% to 156.7% (Table b). The median estimate of the 2019 spawning biomass is 1.312 million t (with a 95% posterior credibility interval from 0.471 to 3.601 million t). The estimate of the 2018 female spawning biomass is 1.346 (0.616–2.943) million t. This is a slightly lower median than the 1.357 (0.610-3.161) million t estimated in the 2018 assessment, though the credibility interval lies within that from the 2018 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)		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2010	420.1	549.6	839.5	21.1%	27.3%	36.0%
2011	503.9	673.9	1,054.0	25.5%	33.4%	45.2%
2012	594.6	850.0	1,419.5	30.3%	42.2%	61.2%
2013	1,029.1	1,511.1	2,577.6	52.7%	75.1%	113.9%
2014	1,027.6	1,568.9	2,739.6	53.8%	77.8%	119.7%
2015	731.4	1,153.8	2,093.2	38.4%	57.3%	90.2%
2016	629.9	1,040.1	1,940.7	33.2%	51.4%	83.4%
2017	743.7	1,350.9	2,766.3	38.8%	66.8%	117.7%
2018	615.8	1,345.7	2,942.6	32.9%	66.1%	124.8%
2019	470.6	1,311.7	3,601.2	26.3%	64.1%	156.7%

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		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2009	735.3	1,297.3	2,543.2	-0.053	0.374	0.822
2010	8,605.8	13,583.1	25,331.8	2.453	2.730	3.076
2011	153.1	390.2	925.6	-1.659	-0.857	-0.176
2012	586.1	1,114.1	2,366.8	-0.329	0.152	0.678
2013	120.0	374.8	1,167.6	-2.088	-1.011	-0.054
2014	4,182.6	8,467.4	19,352.0	1.565	2.100	2.728
2015	14.2	85.4	463.0	-4.151	-2.440	-0.969
2016	746.1	3,895.2	26,085.3	-0.124	1.365	3.087
2017	215.4	2,177.4	21,018.1	-1.470	0.764	2.917
2018	60.6	1,002.5	15,086.4	-2.759	-0.018	2.734

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 recruitment with occasional large year-classes (Table c and Figure e). Very large year classes in 1980, 1984, and 1999 supported

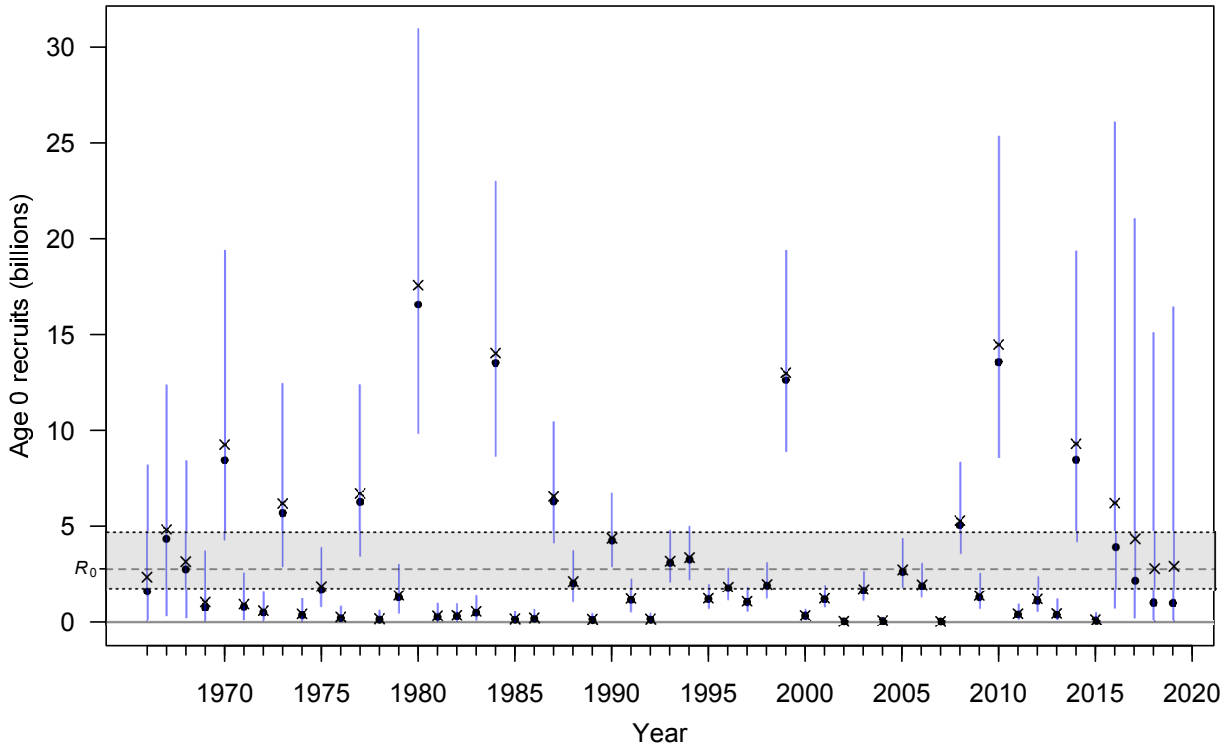

Figure e. Medians (solid circles) and means ($\times$) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line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

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 an above average 2008 year class. The current assessment continues to estimate a very strong 2010 year class comprising 64% of the coast-wide commercial catch in 2014, 33% of the 2016 catch, and 24% of the catch in 2018. The smaller proportion of the 2010 year class in the 2016 catch is due to the large influx of the 2014 year class (50% 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 3.0% chance of being larger than the 2010 year class. The 2016 year class is estimated to be above average but remains highly uncertain, and 2017 is highly uncertain. There is no information in the data to estimate the sizes of the 2018 and 2019 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).

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

Year	Relative fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2009	0.567	0.798	1.025	0.098	0.146	0.187
2010	0.703	0.966	1.246	0.086	0.131	0.171
2011	0.627	0.914	1.179	0.109	0.170	0.229
2012	0.469	0.725	0.987	0.038	0.066	0.095
2013	0.448	0.697	0.917	0.047	0.081	0.120
2014	0.416	0.671	0.921	0.048	0.086	0.131
2015	0.299	0.528	0.799	0.042	0.076	0.120
2016	0.487	0.799	1.111	0.054	0.105	0.176
2017	0.517	0.837	1.192	0.070	0.144	0.262
2018	0.459	0.818	1.310	0.043	0.116	0.270

DEFAULT HARVEST POLICY

The default $F_{SPR=40\%}$–40:10 harvest policy prescribes the maximum rate of fishing mortality to equal $F_{SPR=40\%}$. This rate gives a spawning potential ratio (SPR) of 40%, meaning that the spawning biomass per recruit with $F_{SPR=40\%}$ 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). Relative fishing intensity for fishing rate F is $(1-\text{SPR}(F))/(1-\text{SPR}_{40\%})$, where SPR$_{40\%}$ is the target SPR of 40%; it is reported here interchangeably as a decimal proportion or a percentage.

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 (Figure g). Over the last five years, the exploitation fraction was the highest in 2017 (Table d). Note that in earlier assessments the exploitation fraction was often defined in terms of fish age-3 and above, but with the 2018 assessment the definition age was lowered to age-2 because these fish are often caught by the fishery. Median relative fishing intensity is estimated to have declined from 96.6% in 2010 to 52.8% in 2015 before leveling off near 80% the past few years (2016–2018). The exploitation fraction has increased from a recent low of 0.07 in 2012 to 0.14 in 2017 before decreasing to 0.12 in 2018. 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 (of 1.0) for 2016–2018 (Figure f).

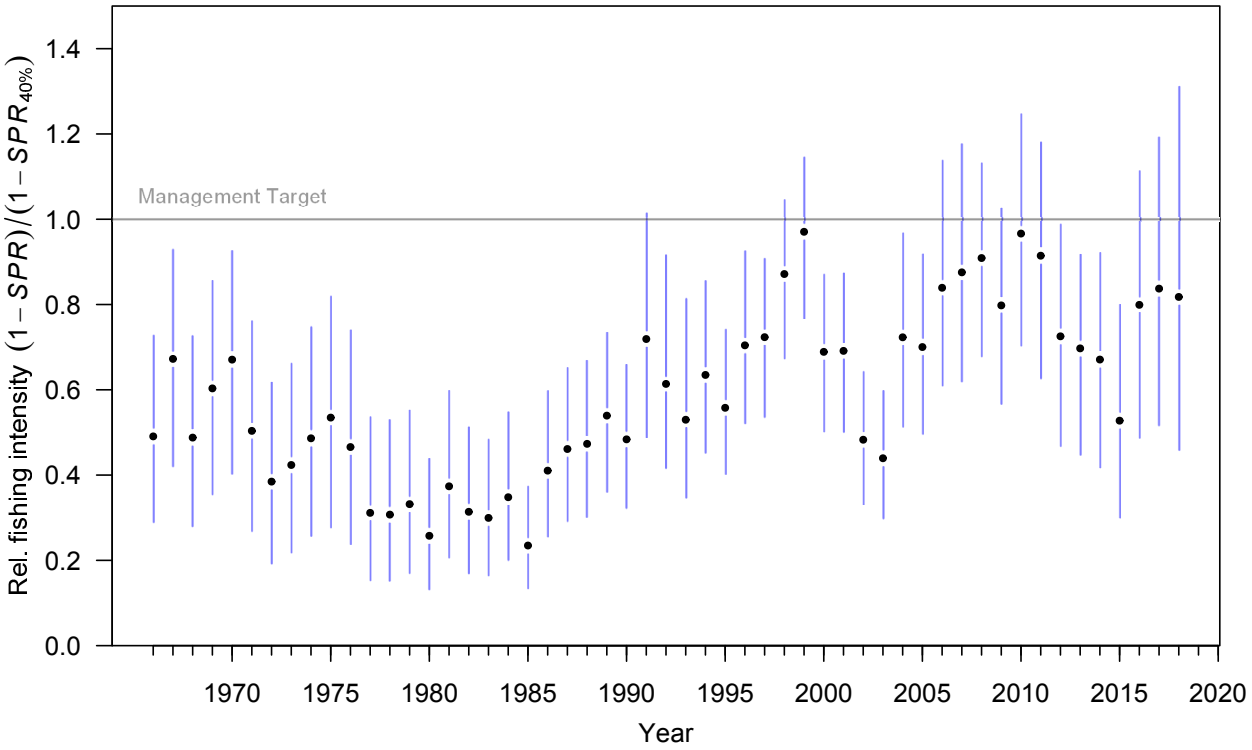

Figure f. Trend in median relative fishing intensity (relative to the SPR management target) through 2018 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

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
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	233,581	52,249	285,830	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	154,160	39,678	193,838	440,000	325,072	114,928	47.4%	34.5%	44.1%
2016	262,327	69,740	332,067	497,500	367,553	129,947	71.4%	53.7%	66.7%
2017	354,229	86,713	440,942	597,500	441,433	156,067	80.2%	55.6%	73.8%
2018	315,031	95,412	410,443	597,500	441,433	156,067	71.4%	61.1%	68.7%

MANAGEMENT PERFORMANCE

Over the last decade (2009–2018), the mean coast-wide utilization rate (proportion of catch target removed) has been 73.8% (Table e). Over the last five years (2014 to 2018), the mean utilization rates were 70.8% for the United States and 47.3% for Canada. Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%, though the fishing intensity was relatively low that year due to the appearance of the 1999 year class.

The median relative fishing intensity was below target in all years (Figure f). The median female

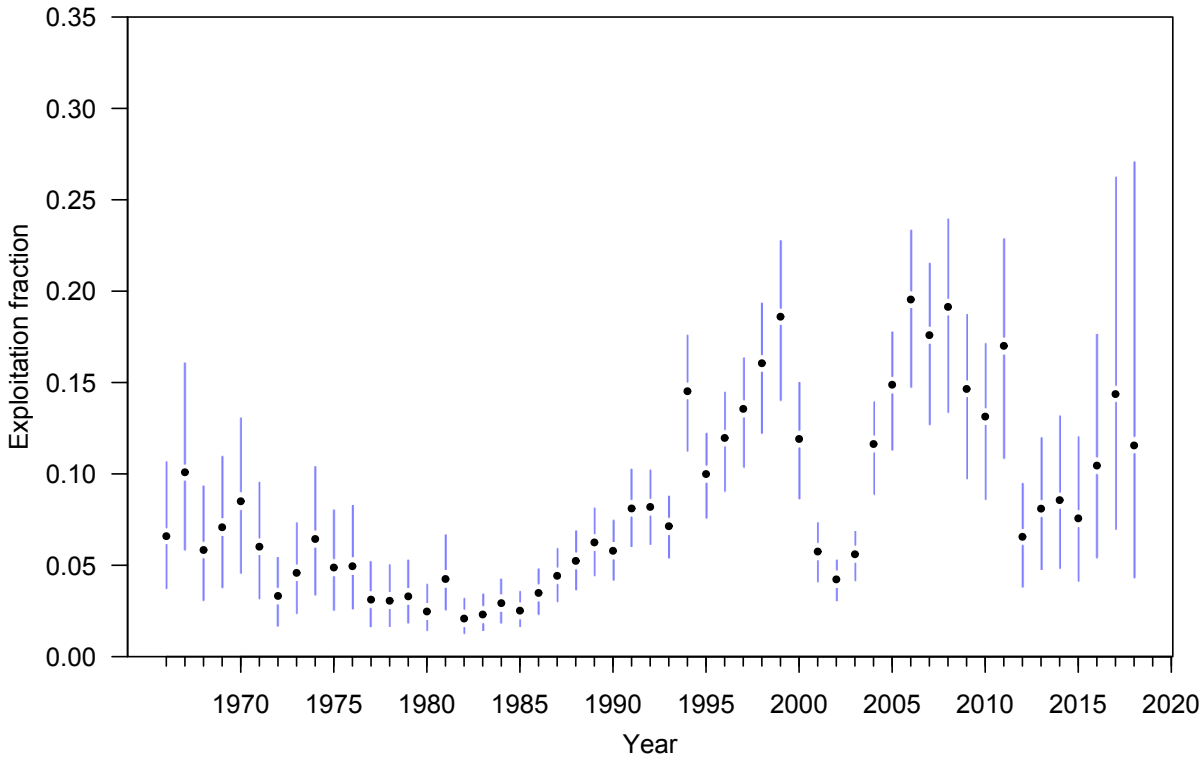

Figure g. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2018 with 95% posterior credibility intervals.

spawning biomass was above the $B_{40\%}$ reference point in all years except 1999-2000 and 2007-2011 (Figure d).

The joint history of the medians for 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). This highlights the highly dynamic nature of the stock due to high variation in recruitment strength. While the target fishing mortality ($F_{SPR=40\%}$) and the target spawning biomass ($B_{40\%}$) result in different population sizes (see Table f), this difference is not, by far, the major driver of the observed dynamics. Between 2007 and 2011, median relative fishing intensity ranged from 80% to 97% and median relative spawning biomass between 0.27 and 0.33. 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 estimates of relative fishing intensity and relative spawning biomass, the model estimates a 10.3% joint probability of being both above the target relative fishing intensity in 2018 and below the $B_{40\%}$ relative spawning biomass level at the start of 2019.

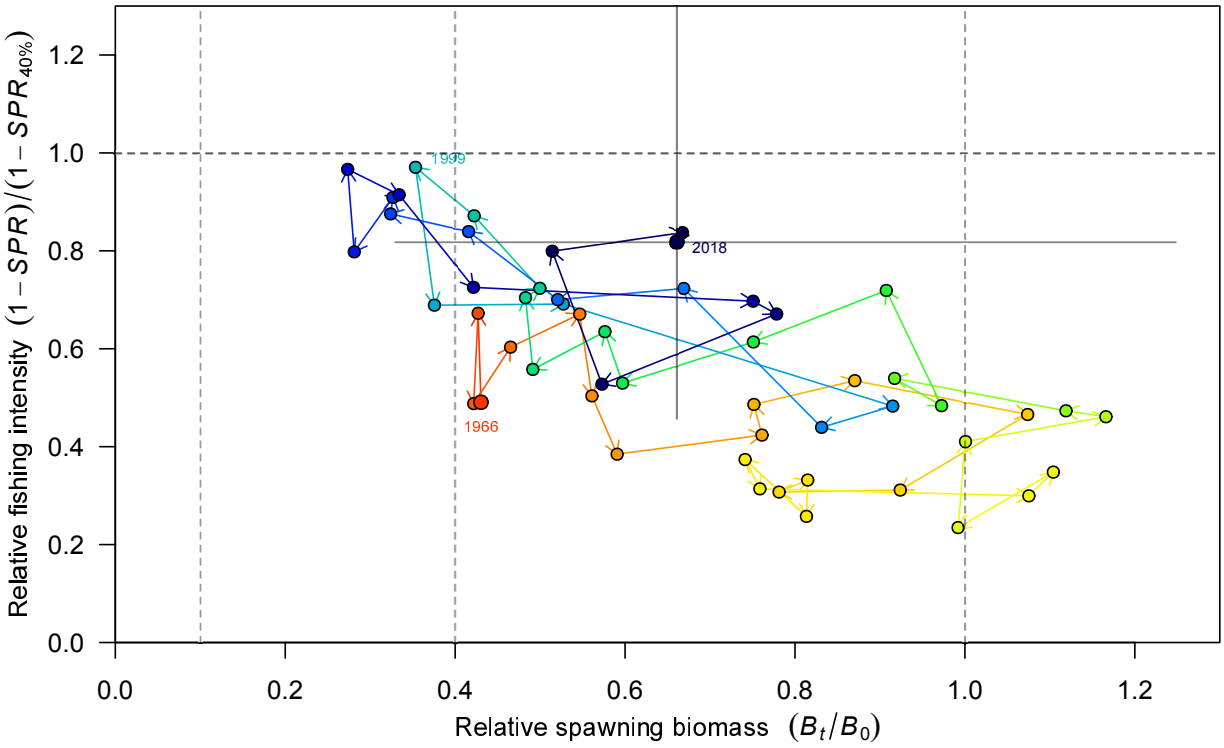

Figure h. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2018 relative fishing intensity (vertical) and relative spawning biomass (horizontal). The points for 2017 and 2018 are nearly on top of one another.

REFERENCE POINTS

Estimates of the 2019 base model reference points with posterior credibility intervals are in Table f. The estimates are slightly different than those in the 2018 assessment, with lower sustainable yields and reference points estimated in this assessment.

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, including those related to the new time-varying fecundity, we performed sensitivity analyses to investigate a range of alternative assumptions, and present the key ones 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

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 1975–2018 averages for mean weight-at-age and selectivity-at-age.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (B_0, thousand t)	1,649	2,026	2,682
Unfished recruitment (R_0, millions)	1,764	2,770	4,657
Reference points (equilibrium) based on $F_{SPR=40\%}$			
Female spawning biomass at $F_{SPR=40\%}$ (thousand t)	533	722	945
SPR at $F_{SPR=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{SPR=40\%}$	16.1%	18.3%	20.8%
Yield associated with $F_{SPR=40\%}$ (thousand t)	242	339	504
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	660	810	1,073
SPR at $B_{40\%}$	40.7%	43.4%	51.6%
Exploitation fraction resulting in $B_{40\%}$	12.5%	16.2%	19.4%
Yield at $B_{40\%}$ (thousand t)	241	329	493
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	373	514	828
SPR at MSY	22.4%	29.6%	46.9%
Exploitation fraction corresponding to SPR at MSY	14.6%	25.8%	34.7%
MSY (thousand t)	249	355	548

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 has been observed by the fishery and survey, typically at minimum 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 probability that spawning biomass falls below 10% of B_0, and a lower average annual variability in catch. However, comparable results in terms of catch may 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.

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, f), including catch similar to 2018 (row d) and the TAC from 2018 (row f), the catch values that result in a median relative fishing intensity of 100% (row g), the median values estimated via the default harvest policy ($F_{SPR=40\%}$–40:10) for the base model (row h), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2019 and 2020 (row i). Catch in 2021 does not impact the beginning of the year biomass in 2021.

Within model quantile Management Action			5%	25%	50%	75%	95%
	Year	Catch (t)	**Beginning of year relative spawning biomass**				
a:	2019	0	31%	48%	64%	85%	133%
	2020	0	35%	54%	73%	98%	163%
	2021	0	37%	56%	75%	102%	173%
b:	2019	180,000	31%	48%	64%	85%	133%
	2020	180,000	31%	50%	69%	94%	159%
	2021	180,000	29%	48%	67%	94%	166%
c:	2019	350,000	31%	48%	64%	85%	133%
	2020	350,000	27%	46%	65%	90%	155%
	2021	350,000	20%	40%	60%	87%	159%
d:	2019	410,000	31%	48%	64%	85%	133%
2018	2020	410,000	25%	44%	63%	89%	154%
catch	2021	410,000	17%	37%	57%	84%	156%
e:	2019	500,000	31%	48%	64%	85%	133%
	2020	500,000	23%	42%	61%	87%	152%
	2021	500,000	13%	33%	53%	81%	153%
f:	2019	597,500	31%	48%	64%	85%	133%
2018	2020	597,500	20%	39%	59%	85%	150%
TAC	2021	597,500	9%	29%	49%	77%	151%
g:	2019	587,419	31%	48%	64%	85%	133%
FI=	2020	556,709	21%	40%	59%	85%	150%
100%	2021	470,962	10%	30%	50%	78%	152%
h:	2019	725,593	31%	48%	64%	85%	133%
default	2020	643,698	17%	36%	56%	82%	147%
HR	2021	517,858	4%	25%	45%	73%	148%
i:	2019	660,812	31%	48%	64%	85%	133%
C2019=	2020	660,812	19%	38%	57%	83%	148%
C2020	2021	526,084	5%	26%	46%	74%	147%

FORECAST DECISION TABLES

The catch limit for 2019 based on the default $F_{SPR=40\%}$–40:10 harvest policy has a median of 725,593 t with a wide range of uncertainty, the 95% credibility interval being 214,763–2,106,509 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 ta-

Table h. Forecast quantiles of Pacific Hake relative fishing intensity (1-SPR)/(1-SPR$_{40\%}$), expressed as a percentage, for the 2019–2021 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:	2019	0	0%	0%	0%	0%	0%
	2020	0	0%	0%	0%	0%	0%
	2021	0	0%	0%	0%	0%	0%
b:	2019	180,000	25%	39%	50%	64%	87%
	2020	180,000	22%	35%	46%	61%	87%
	2021	180,000	20%	34%	47%	63%	90%
c:	2019	350,000	43%	62%	77%	93%	117%
	2020	350,000	38%	59%	75%	94%	123%
	2021	350,000	37%	60%	79%	100%	134%
d:	2019	410,000	48%	69%	84%	100%	124%
2018	2020	410,000	44%	66%	83%	103%	132%
catch	2021	410,000	42%	68%	88%	110%	144%
e:	2019	500,000	56%	78%	93%	109%	132%
	2020	500,000	51%	75%	94%	113%	142%
	2021	500,000	50%	78%	100%	123%	159%
f:	2019	597,500	63%	85%	101%	116%	138%
2018	2020	597,500	58%	84%	103%	123%	151%
TAC	2021	597,500	56%	88%	112%	135%	167%
g:	2019	587,419	62%	85%	100%	115%	137%
FI=	2020	556,709	55%	81%	100%	120%	148%
100%	2021	470,962	48%	77%	100%	125%	163%
h:	2019	725,593	71%	94%	109%	124%	145%
default	2020	643,698	61%	89%	109%	129%	158%
HR	2021	517,858	52%	84%	109%	135%	167%
i:	2019	660,812	67%	90%	105%	120%	141%
C2019=	2020	660,812	62%	90%	109%	129%	156%
C2020	2021	526,084	52%	84%	108%	134%	167%

bles 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.

A relative fishing intensity above 1 (or 100% when shown as a percentage) indicates fishing greater than the $F_{SPR=40\%}$ default harvest rate catch target. This can happen for the median relative fishing intensity in projected years because the $F_{SPR=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity

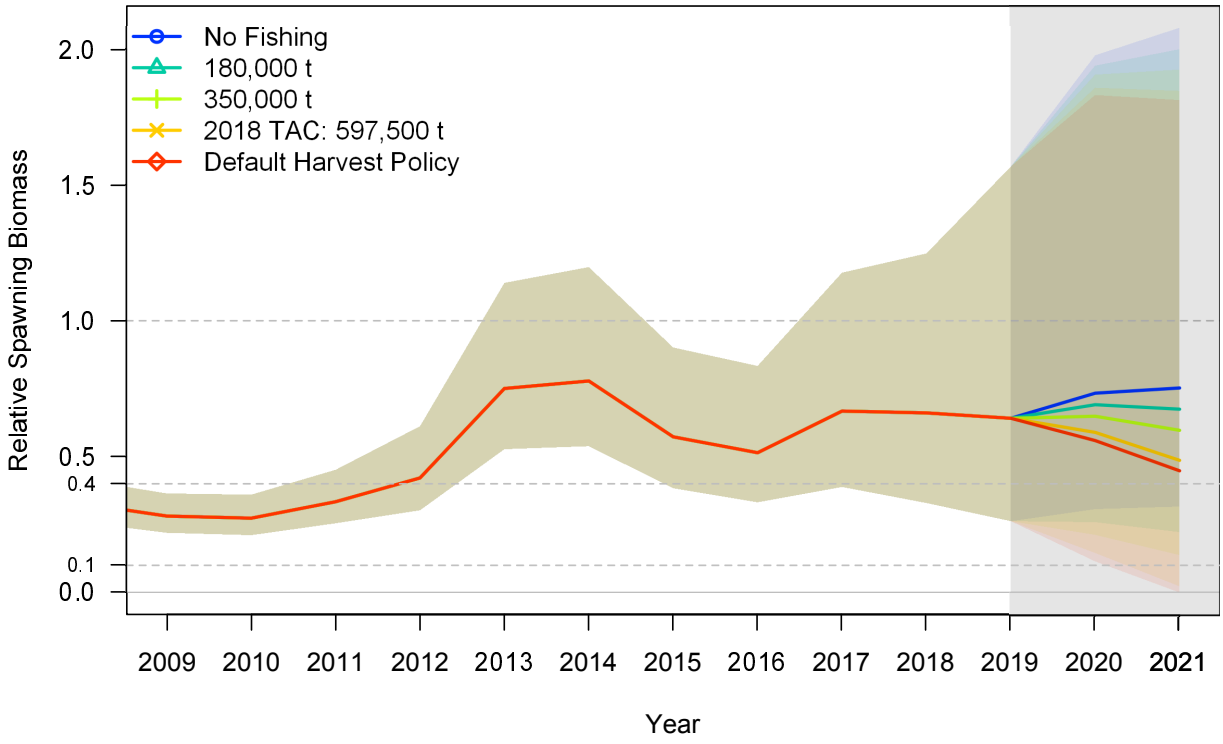

Figure i. Time series of estimated relative spawning biomass to 2019 from the base model, and forecast trajectories to 2021 (grey region) for several management actions defined in Table g, with 95% posterior credibility intervals.

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%).

The addition of time-varying fecundity into the 2019 assessment resulted in the need to clarify which set of fecundity values (defined as weight-at-age multiplied by maturity) would be applied to the forecast period. Ideally, these would be based on a recent average (e.g., a five-year period similar to selectivity). However, Stock Synthesis does not currently have the desired settings to do this appropriately; therefore, the long-term average fecundity-at-age was used.

Management metrics that were identified as important to the JMC and the Advisory Panel (AP) in 2012 are presented for projections to 2020 and 2021 (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 2021 for several of these management actions. With zero catch for the next two years, the biomass has a 17% probability of decreasing from 2019 to 2020 (Table i), and a 53% probability of decreasing from 2020 to 2021 (Table j).

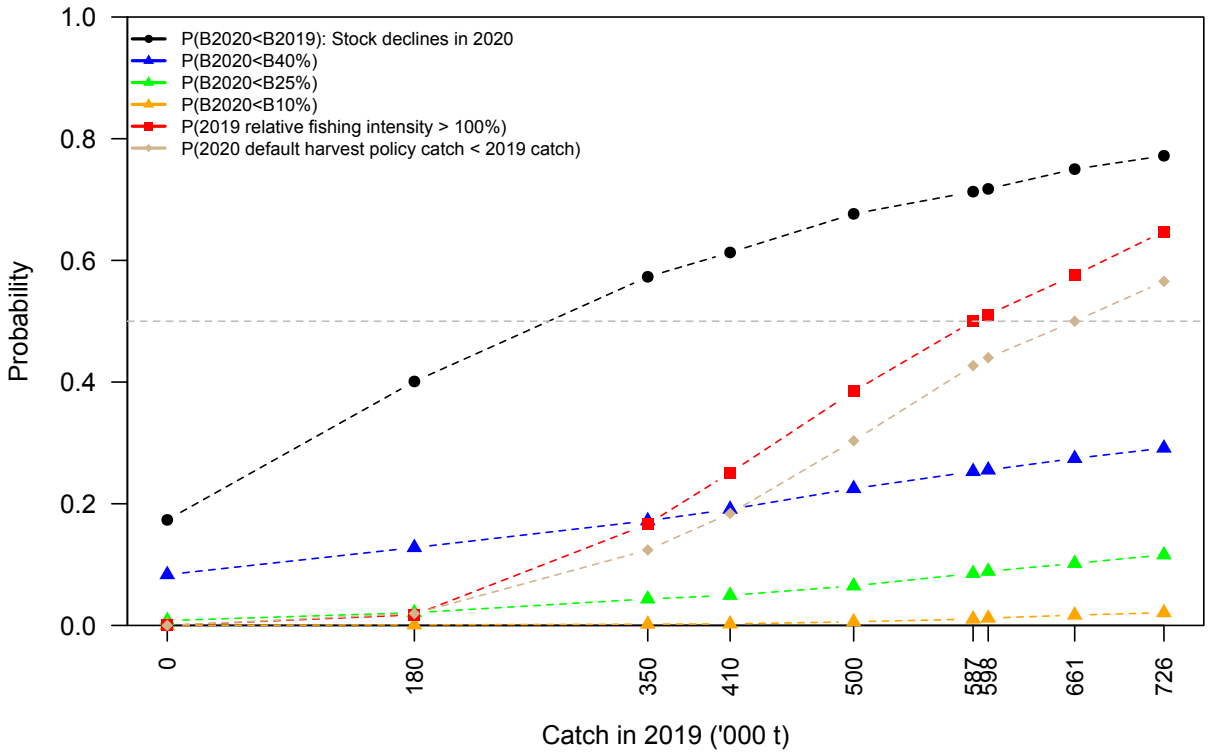

Figure j. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (catch options explained in Table g) as listed in Table i. The symbols indicate points that were computed directly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

Table i. Probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (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	17%	8%	1%	0%	0%	0%
b: 180,000	40%	13%	2%	0%	2%	2%
c: 350,000	57%	17%	4%	0%	17%	12%
d: 410,000	61%	19%	5%	0%	25%	18%
e: 500,000	68%	22%	6%	1%	38%	30%
f: 597,500	72%	26%	9%	1%	51%	44%
g: 587,419	71%	25%	9%	1%	50%	43%
h: 725,593	77%	29%	12%	2%	65%	57%
i: 660,812	75%	27%	10%	2%	58%	50%

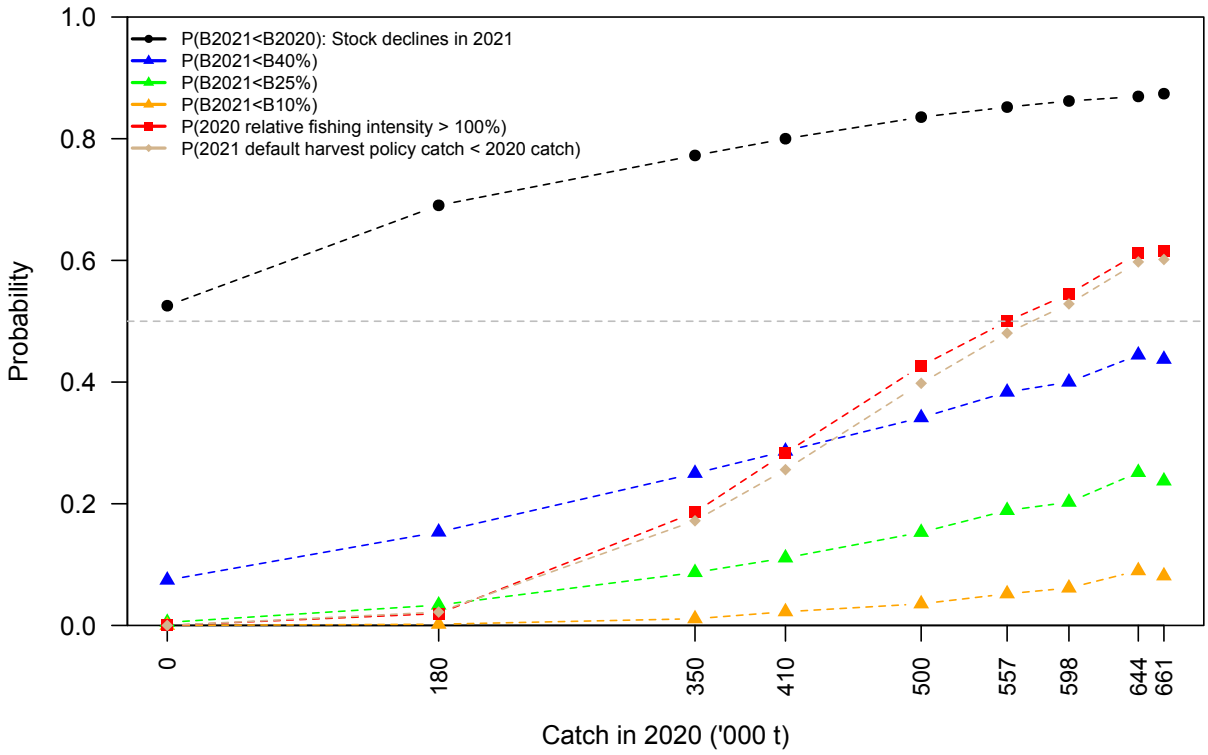

Figure k. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (including associated 2019 catch; catch options explained in Table g) as listed in Table j. The symbols indicate 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 2021 default harvest policy catch for alternative 2020 catch options, given the 2019 catch level shown in Table i (catch options explained in Table g).

Catch in 2020	Probability $B_{2021}<B_{2020}$	Probability $B_{2021}<B_{40\%}$	Probability $B_{2021}<B_{25\%}$	Probability $B_{2021}<B_{10\%}$	Probability 2020 relative fishing intensity >100%	Probability 2021 default harvest policy catch <2020 catch
a: 0	53%	7%	0%	0%	0%	0%
b: 180,000	69%	15%	3%	0%	2%	2%
c: 350,000	77%	25%	9%	1%	19%	17%
d: 410,000	80%	29%	11%	2%	28%	26%
e: 500,000	84%	34%	15%	4%	43%	40%
f: 597,500	86%	40%	20%	6%	55%	53%
g: 556,709	85%	38%	19%	5%	50%	48%
h: 643,698	87%	44%	25%	9%	61%	60%
i: 660,812	87%	44%	24%	8%	62%	60%

The probability of the spawning biomass decreasing from 2019 to 2020 is 50% for some catch level between 180,000 t and 350,000 t (Table i and Figure j). The highest probability of decrease is 77%, which is for the default harvest policy (row g in Table i). For all explored catches, the predicted probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2020 is 2% or less and the maximum probability of dropping below $B_{40\%}$ is 29% (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.

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.

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, including designs that incorporate ecosystem-based factors and other potential target species (e.g., rockfish, euphausiids, and mesopelagics) 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.

1 INTRODUCTION

The Joint U.S.-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 eighth 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 2019 base model, implemented using version 3.30.10 of the Stock Synthesis software (Methot and Wetzel, 2013), are effectively the same as the 2018 base model (Edwards et al., 2018*b*), though we incorporate time-varying fecundity.

The 35-day 2018/2019 U.S. government shutdown considerably delayed delivery of U.S. age data and reduced the JTC's time available to collectively complete the 2019 assessment. As a result, many planned supplementary and exploratory analyses could not be completed, including some developed for response to 2018 SRG requests (see Section 3.3), although most sensitivity runs (including new ones related to time-varying fecundity) were completed. A Glossary of terms appears in Appendix B.

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 Merluccidae), 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, the 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 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 to some extent 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 hake abundance decreased with increasing squid 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 and recruitment could provide insight into how the hake population is linked with broader ecosystem considerations.

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 $F_{\text{SPR=40\%}}$ 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 being 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 $F_{\text{SPR=40\%}}$ 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 using the aforementioned harvest control rule and stock assessment outputs.

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. harvest into tribal (17.5%) and non-tribal (82.5%, with a small set aside for research) compo-

nents. The non-tribal harvest allocation is divided 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". The At-Sea hake observer program has been monitoring fishing vessel activity since 1975, originally monitoring foreign and joint venture vessels. Observer coverage has been 100% on all domestic vessels since 1991.

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 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 2018, Canadian hake fishermen were allocated a TAC of 156,067 t, including 21,197 t of uncaught carryover fish from 2017. 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 2018.

In 2018, 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).

1.4.1 Overview of the fisheries in 2018

The Joint Management Committee (JMC) determined an adjusted (for carryovers) coast-wide catch target of 597,500 t for 2018, 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 1966–2018 by nation and fishery sector is shown in Figure 4 and Tables 1, 2 and 3. Table 4 shows recent catches in relation to targets (see Section 3.4.2). A review of the 2018 fishery now follows by nation.

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 2018 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 40,000 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 136,912 t, 96,644 t, and 169,127 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 slightly less than in 2017, but was the second highest value ever recorded (Table 1). Catch rates were considerably lower in 2018 compared to 2017, despite similar overall catch levels (Figure 5). Tribal landings available at the time of the assessment were 2,423 t. As in recent years, careful consideration was needed to accurately account for tribal landings. The catcher-processor, mothership, and shore-based fleets caught 84.8%, 69.5%, and 77.9% of their final reallocated quotas, respectively. Overall, 126,402 t (28.6%) 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-8 and age-4 fish associated with the 2010 and 2014 year-classes, but by the fall, both sectors were catching a majority of age-2 and age-4 fish. Sampling by sector varied with 492 and 357 hauls from each sector, respectively (Table 5). In total, 33% of the CP catch was age-2, 27% was age-4,

and 20% was age-8 (proportions by numbers here and below; Table 6). For the MS sector, the total for the year was 25% age-2, 28% age-4 and 18% age-8 (Table 7). Age-samples from 80 shoreside trips showed a similar proportion of age-8 fish as the at-sea sectors, at 22%, with 35% of the shoreside samples coming from the 2014 year class and 25% coming from the 2016 year class (Table 8).

The at-sea fishery maintained moderately high catch rates throughout the year (Figure 5), averaging around 20 t/hr in the spring (May–June) and 15 t/hr in the fall (September–November). Relative to last year, both the spring and fall fisheries saw a decline in catch rates. The median fishing depth for the at-sea fleets was shallower again this year than in previous years (Figure 6). During July and August, operators in the at-sea fishery moved to the usual summer fishing grounds in search of opportunities in Alaskan waters. The shorebased fishery had the largest monthly catches during June, July, and August. Due to moderately 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 80% in 2017, before dropping back to 71% in 2018.

Canada

The 2018 Canadian Pacific Hake domestic fishery removed 95,412 t from Canadian waters, which was 61.1% of the Canadian TAC of 156,067 t.

The shoreside component, made up of vessels landing fresh round product onshore, landed 54,447 t. The freezer trawler component, which freezes headed and gutted product while at sea, landed 38,241 t. As for 2017 (which was the first time since 2011), there was a Joint Venture fishery (running from August 21 to September 15), delivering 2,440 t to the Dutch vessel *Margiris*.

Fishing started in April and ended in late November. 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.

Aggregations of hake appeared smaller this year than last, with none found in Queen Charlotte Sound. Avoidance of juvenile Sablefish was an ongoing issue with the fishery this year. 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 8 at 45.5%, age 4 at 17.7%, age 9 at 9.4%, and age 10 at 5.4%. The most abundant year classes in the Canadian Shoreside catch were age 8 at 35.7%, age 4 at 22.2%, age 9 at 12.4%, and age 7 at 5.9%.

For an overview of Canadian catch by year and fleet, see Table 2. For some years there was no 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 this 2019 assessment (Figure 7) include:

- Total catch from all U.S. and Canadian target fisheries (1966–2018; Tables 1–3).
- Age compositions composed of data from the U.S. fishery (1975–2018) and the Canadian fishery (1990–2018). The last 10 years of these data are shown in Tables 6–10, and the aggregated data for all years are 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 (1975-2018; Figure 12) and thus derived fecundity-at-age as well.

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 mature by age, as developed from histological analyses of ovary samples collected in recent years (Table 14 and Figure 11).

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 1977–2018).
- NWFSC/SWFSC/PWCC coast-wide juvenile hake and rockfish surveys (2001–2018).
- 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 1966–2018 by nation and fishery sector is shown in Figure 4 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 1991–2018 are calculated from the AFSC North Pacific Groundfish and Halibut Observer (NORPAC) database, which also stores the NWFSC at-sea hake observer program data. 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 (PacHarv-Trawl) 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.

The three independent issues in the calculation of total catch that were identified late in the 2018 assessment process (Edwards et al., 2018*b*) have been rectified here. Minor updates to catches for years pre-2018 have also been made.

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 1991–2018. 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 1991–2018 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 five freezer trawler vessels *Viking Enterprise*, *Osprey #1*, *Northern Alliance*, *Raw Spirit*, and *Viking Alliance*, which together make up a large portion of the Canadian catch (40.1% in 2018). The Joint-Venture fishery has 100% observer coverage on their processing vessels, which in 2018 made up 2.9% of the Canadian catch. On observed freezer trawler trips, otoliths (for ageing) and lengths are sampled from 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 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 (1975–2018) 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 since then, the proportional representation of the 2010 year class has continued to be high in the fishery (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). Table 11 shows the combined age proportions of all fleets, U.S. and Canadian. For the combined data in 2017, the 2014 cohort was the largest (39%), followed by the 2010 cohort (37%), followed by the 2009 cohort (4%). In 2018, the 2014 cohort was the largest (29%), followed by the 2010 cohort (24%), followed by the 2016 cohort (23%).

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 fluctuated 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 more average-sized 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 and 2018.

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). There was no acoustic survey in 2018. 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 years just prior. 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 environmental conditions. Ongoing research is looking into relationships between environmental conditions and Pacific Hake distribution, which will help to inform the mechanisms behind observations.

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 tech-

nique, 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 (Edwards et al., 2018*b*). 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 Figure 9) 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 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 10). 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, and DFO surveys not already mentioned 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 assessment (Edwards et al., 2018*b*). 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.

In 2018, a new age-based maturity ogive (Table 14 and Figure 11) 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 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 (Table 15).

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.

In the 2018 assessment, the age-based maturity ogive was multiplied by the mean weight-at-age averaged across all years to get a new estimate of time-invariant fecundity-at-age. The 2019 assessment extends this approach to include time-varying fecundity-at-age by using year-specific weight-at-age values (rather than the time-series mean) in the calculation of fecundity. 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 11). The maturity ogive was the same as that used in Edwards et al. (2018*b*) because the U.S. government shutdown delayed delivery of the 2018 histological samples, though note that the ogive used for previous assessments was not updated annually and was that developed by Dorn and Saunders (1997).

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 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 2015-2018

assessments or this 2019 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.

2.3.3 Weight-at-age

A matrix of empirically derived population weight-at-age by year (Figure 12) is used in the current assessment model to translate numbers-at-age directly to biomass-at-age. Mean weight-at-age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2018 (Figure 12). Additional historic weight-at-age data from Canadian fishery and surveys (intermittent years from 1992 onwards) were added in the 2019 assessment, resulting in a 3% increase in total samples from the 2018 assessment. Pre-1975 weight-at-age data available in the PacFIN database was confirmed to be samples collected within Puget Sound and were not included in this assessment. 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 (see Sections 3.3 and 3.8.1 for further details on these assumptions). The number of samples (Figure 13) 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.

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 Tables 16-17. 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).

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, Φ. Further details on the time-varying selectivity function are provided below, as described by Edwards et al. (2018*b*) in detail.

For each age $a \geq A_{\text{min}}$, 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

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

where

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

and

$$S'_{\max} = \max\{S'_a\}. \tag{3}$$

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 uses a set of deviations to control annual changes to the selectivity parameters. The standard deviation associated with these deviations is called Φ. The value for parameter Φ (in standard parameter space) was selected to correspond with the level of variability (in logistic transformed parameter space) used in the 2017 assessment (previously referred to as parameter ϕ under the logistic configuration; see Berger et al. 2017 for further details). In Stock Synthesis 3.30, the logistic transformation was no longer available, so Φ was applied directly to the base parameter. The resulting value of $\Phi = 1.40$ used in 2018 and 2019 assessment approximates the previous value ($\phi = 0.20$) and is calculated by:

$$p_{ay} = p_a + \varepsilon_{ay} \tag{4}$$

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

$$-\log(\mathrm{L}) \propto \frac{1}{2} \sum_{a=A_{\min}}^{6} \sum_{y=1991}^{2018} \frac{\varepsilon_{ay}^2}{\Phi^2}, \tag{5}$$

where Φ 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.

A new parameterization for the selectivity deviations was explored in 2018, based on the work of Xu et al. (2019), 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 so it is only used for a sensitivity analysis (see Section 3.8).

2.4.4 Age composition likelihood

Like the 2018 assessment, this assessment used a Dirichlet-Multinomial (D-M) likelihood (Thorson et al., 2017) to fit the age-composition data. The primary benefit of the D-M approach over the historically used McAllister-Ianelli approach (McAllister and Ianelli, 1997) is that instead of manually iterating the sample size multiplier, an estimated parameter, θ, serves to automatically adjust the weight given to the fishery-composition data (using θ_{fish}) and the survey-composition data (using θ_{surv}). Integration of the data weighting increases the efficiency of the assessment process, removes the subjective choice of how many iterations are required, 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 be given the same weight as the base model. Note that the following description holds for both the survey data and the fishery data, with θ equal to θ_{surv} or θ_{fish}, respectively.

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

$$\mathrm{L}(\boldsymbol{\pi}, \theta | \tilde{\boldsymbol{\pi}}, n) = \frac{\Gamma(n+1)}{\prod_{a=1}^{A_{\max}} \Gamma(n\tilde{\pi}_a + 1)} \frac{\Gamma(\theta n)}{\Gamma(n+\theta n)} \prod_{a=1}^{A_{\max}} \frac{\Gamma(n\tilde{\pi}_a + \theta n \pi_a)}{\Gamma(\theta n \pi_a)} \tag{6}$$

where $\tilde{\pi}_a$ is the observed proportion at age a, π_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 θ is defined as a linear scaling parameter such that θn is the variance-inflation parameter of the D-M distribution.

The effective sample size associated with this likelihood is given by

$$n_{\text{eff}} = \frac{1}{1+\theta} + \frac{n\theta}{1+\theta} \tag{7}$$

The input sample sizes used in this assessment, which are based on the number of trips or hauls, are large enough that the first term is insignificant compared to the second term. Consequently, $\theta/(1+\theta)$ can be compared to the sample size multipliers used in the McAllister-Ianelli data-weighting method (McAllister and Ianelli, 1997) that was used for assessments prior to 2018 (Table 18). In short, the McAllister-Ianelli method involves iteratively adjusting multipliers of the input sample sizes passed to the multinomial likelihoods until they are roughly equal to the harmonic mean of the effective sample sizes. The effective sample size is dependent on how well the model expectation matches the observed values. Typically, this process involves no more than four to five iterations.

Composition data can also be weighted using the Francis method (T2.6 in Table 2 of Francis, 2011), which is based on variability in the observed ages by year. This method, like the McAllister-Ianelli method, is also iterative, where the sample sizes are adjusted such that the fit of the expected compositions should fit within the estimated uncertainty at a rate that is consistent with the variability expected given the effective sample sizes. This method is known to be sensitive to outliers and prone to convergence issues when selectivity is time-varying.

Sensitivity to the D-M method as compared to the McAllister-Ianelli and the Francis methods are presented in Section 3.8.

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 (Edwards et al., 2018*b*).

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. Table 18 summarises the major changes to the model structure in assessments since 2011.

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), a multinomial sample size on age compositions (e.g., Dorn et al. 1999; Helser et al. 2002, 2005; Stewart et al. 2011), internal estimations of effective sample size using the Dirichlet-Multinomial distribution (Edwards et al., 2018*b*), and assumptions regarding year-specific 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 recruit-

ment 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 estimated to produce the MSY (F_{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, 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 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 the following hybrid control rules: $F_{SPR=35\%}$, $F_{SPR=40\%}$, $F_{SPR=40\%}$–40:10, $F_{SPR=45\%}$, $F_{SPR=45\%}$–40:10, and $F_{SPR=50\%}$ (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 $F_{SPR=40\%}$–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 MSE began, initiated in 2013 (Hicks et al., 2013) and currently being revisited, none of these management procedure changes were evaluated by simulation and quantitatively compared with performance measures.

3.2 DESCRIPTION OF BASE MODEL

The 2019 base model is predominantly an update of the base model in the 2018 stock assessment. The statistical-catch-at-age model assumes that the Pacific Hake population is a single coast-wide stock subject to one aggregated fleet with combined male and female population dynamics. Stock Synthesis (Methot and Wetzel, 2013) version 3.30.10 is again used, having been introduced in the previous assessment (Edwards et al., 2018*b*). The largest changes between the 2018 and 2019 stock assessments are the addition of another year of fishery data and the switch from time-invariant to year-specific values for fecundity.

The 2019 base model includes an acoustic data time series from 1995 to 2017. The updated maturity ogive from 2018 was retained (see Section 2.3.1). The Dirichlet-Multinomial (D-M) likelihood approach (Thorson et al., 2017) was again used to estimate the weights associated with age-composition data, rather than iteratively tuning the sample size multiplier as in 2017 and earlier assessments (see Section 2.4.4). Time-varying fishery selectivity is retained in the 2019 base model with the magnitude of the allowable deviations unchanged from the 2018 base model (see Section 2.4.3). 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 2018 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; Edwards et al., 2018*b*). Year-specific recruitment deviations were estimated from 1966–2018 as well as the years 2019, 2020, and 2021 for purposes of forecasting. The standard deviation, σ_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 2018 (Table 18). Survey catchability was set at the median unbiased estimate calculated analytically as per Ludwig and Walters (1981). Maturity is assumed to be time-invariant. Fecundity is defined as weight-at-age multiplied by the maturity ogive and is time-varying across years with empirical weight-at-age data (1975– 2018). For years without data, prior to 1975 and during the forecast period, fecundity is calculated using the long-term mean weight-at-age (see Section 3.3 for more details). Alternative fecundity assumptions are presented through sensitivity analyses (Section 3.8).

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 acous-

tic survey index composition data and refinements to fishery composition data. Tuning quantities changed again in 2018 with the addition of the new D-M data weighting (tuning) approach. Tuning quantities remained relatively consistent from 2018 to 2019.

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 H-L.

Calculations and figures from Stock Synthesis output were performed using R version 3.5.1 (2018-07-02) (R Core Team, 2018) and many R packages (in particular r4ss and xtable). The use of R, knitr, LaTeX and GitHub immensely facilitated the collaborative writing of this document. In particular, having most of the code automatically shared since the 2016 assessment (Grandin et al., 2016) allowed the Canadian JTC members to conduct a preliminary assessment (without the 2018 age data) during the U.S. government shutdown, and ensured the JTC could complete a full assessment in the limited time available. A recent DFO workshop (Edwards et al., 2018*a*) shared such a 'transparent, traceable and transferable' workflow with a wider audience, partly motivated by our ongoing Pacific Hake assessments.

3.3 RESPONSE TO 2018 SCIENTIFIC REVIEW GROUP (SRG) REVIEW

The Scientific Review Group (SRG) meeting was held from February 26 to March 2, 2018 at the Lynnwood Convention Center, Lynnwood, WA, USA.

The following are the 'Assessment Recommendations and Conclusions' from the 2018 SRG report, and associated responses from the JTC:

1. The stock assessment results and stock status are highly sensitive to two aspects of the model:

(i) Weights-at-age: Maturity-at-age was recalculated in the 2018 assessment based on an analysis of ovaries collected during the fishery and survey in recent years to produce an empirical vector of the proportion mature (i.e., that will likely spawn) at each age. Spawning biomass in the base-case model is calculated as the product of numbers-at-age, maturity-at-age, and mean weight-at-age (averaged over all years 1975-2017). The SRG noted that this approach ignores the conspicuous pattern of weights-at-age being much higher in the late 1970s than in recent years. Although the base-case model accounts for this pattern by using annual weights-at-age when calculating total biomass and catches, the variability and pattern in weight-at-age are not included in the calculation of fecundity-at-age and spawning biomass. The SRG considers it more appropriate to calculate spawning biomass using annual weights-at-age for years with data, especially given the higher weights-at-age in the 1970s, and requested a sensitivity to explore the influence of this decision. To conduct this sensitivity an assumption was made that for calculating spawning biomass in 2018 and future projections, average weight-at-age in the most recent 3 years of data be used; and for calculating spawning biomass in the unfished state and years before 1975, the average weight-at-age in the first 5 years of data (1975-1979) be used. [The alternative model maintained the base

model's approach for estimating total biomass prior to 1975 and also in projections (using the weights-at-age averaged over 1975 to 2017). The SRG has requested that the JTC apply calculations for these periods consistent with decisions taken at this meeting when it reports back at the 2019 SRG meeting.] Three hypotheses that might explain the observed changes in weights-at-age: density-dependent growth, environmental drivers, and fishing-induced evolution. **The SRG requests that the JTC examine the historical weights-at-age data, evaluate approaches for parameterizing fecundity-at-age for years without data (pre-1975), and evaluate other methods of deriving biological reference points such as B_0.**

Response – The JTC agreed with the SRG recommendation to calculate spawning biomass and fecundity using annual weight-at-age for years with data, and accordingly included time-varying fecundity in the 2019 base model. Thus, fecundity (calculated as weight-at-age multiplied by maturity) changed from being defined by a single catch-weighted average of weight-at-age applied to all years to being defined by year-specific weight-at-ages covering the time period with data (1975–2018). For periods without data (pre-1975 and post-2018), catch-weighted average weight-at-age was used in the base model. This configuration was based on results from several investigations outlined in the following paragraphs. Alternative fecundity configurations (and thus weight-at-age) for the pre-1975 and forecast period were also used in sensitivity runs (see Sections 3.8.1 and 3.8.2).

Historical weight-at-age data was re-examined to ensure that all relevant data were available to the assessment. Samples from the 1960s in PacFIN that were used in analyses by Christine Stawitz were found to be from Puget Sound, and were therefore correctly excluded from previous (and the current) hake assessments. Weight data from early years was identified as possibly suspect due to inaccurate scales used at that time, especially on foreign vessels. However, a comparison of mean weight-at-age with mean length-at-age showed that those age/year bins with high mean weight also had high mean length, and the method of length measurement likely hasn't changed considerably over time. Ages from the earlier years were likely solely based on surface reads, whereas protocol since the early 2000s has been to use the break and burn method on fish older than about age-2. A comparison between ageing methods was done recently for Petrale Sole, indicating increased bias as fish age when using surface reads, although no such analysis that we are aware of has been done for Pacific Hake. If otoliths from the early years were properly preserved and stored, there may be a chance to conduct research to enumerate any potential biases. Other than standard data updates and the addition of historic weight-at-age data from Canadian fishery and surveys (see Section 2.3.3), no changes were made to weight-at-age data based on these considerations.

Regarding the assumption of pre-1975 weight-at-ages, the JTC conducted an analysis to see whether there was any indication that weights-at-age values were trending through time. A weighted least squares approach was used to fit log weight (kg) data across years 1975-2018, where a separate analysis was done for each age group (age-2 through age-15) and weights were defined as the inverse of the annual sample variance. The resulting slope parameter was used to better understand age-specific long-term trends in weight-at-age. The results of this analysis showed a near zero slope for all ages, with age-13, 14, and 15 being slightly positive and all others being slightly negative (Figure 14), which was not unexpected given the large amount of inter-annual variability in the data. However, estimated slope parameters were sensitive to excluding data from

1975–1980. This, together with the lack of a clear trend of weights-at-age through time, led us to use in the base model the long-term mean (1975–2018) weights-at-age (rather than the short term from 1975–1979) for the pre-1975 time period. Overall inferences were similar when using length instead of weight.

Furthermore, there were small numbers of age samples for the early years (especially 1975) as shown in Figure 13. The few heavy fish in the 15-year-old and older accumulator group from 1976–1979 influence the short-term average for 1975–1979 time period, further justifying use of the long-term mean (1975–2018) for the pre-1975 time period. See Sections 3.8.1 and 3.8.2 for further details. and sensitivity runs that explore these assumptions.

Regarding forecast year weight-at-ages, the JTC used the weighted least squares analysis to also suggest that the assumption of using the long-term mean for weight-at-age in 2019–2021 was reasonable. As documented last year (page 23 of Edwards et al. 2018b), the current configuration of Stock Synthesis (version 3.30.10 as used for this assessment) precludes properly testing other assumptions while using the final year of empirical weight-at-age data. The software required forecast year weights-at-age values to be either (i) set to the same as that for equilibrium conditions, or (ii) set equivalent to the final year of data (2018). For example, we were unable to set future weight-at-age values to be the mean of 2016-2018 without also setting the 2018 weights-at-age to that mean (thereby averaging out the 2018 data). Therefore, we retained the 2018 base model assumption of using the overall 1975-2018 mean for the forecast period. See Section 3.8.1 for further details.

During the 2018 SRG meeting it was further realized that (p23 of Edwards et al. 2018b) "An inconsistency in this alternative run is that 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." This inconsistency has been resolved and does not affect the 2019 base model or sensitivity runs.*

Several alternative weight-at-age (and time-varying fecundity) data configurations were examined through sensitivity analyses. These include (i) time invariant fecundity, (ii) alternative pre-1975 settings, and (iii) alternative forecast period settings. See Section 3.8 for further description and results from sensitivity runs.

Regarding evaluating other methods of deriving biological reference points such as B_0, the JTC expresses interest in using the developing Management Strategy Evaluation to test the impact of making different assumptions about calculating B_0, and other reference points, in the presence of variability in weight-at-age. For example, what if there has been a long-term decline in weight-at-age but it is ignored when setting reference points, or what if weight-at-age varies randomly through time but reference points are set using a non-representative subset of the long-term trend? Recent simulation work by Berger (in press), using Pacific Hake as one example, provided evidence that static reference points, such as those based on unfished equilibrium conditions (B_0), can be misleading when there are directional trends or regime shift changes in the underlying stock

productivity.

(ii) Variance in recruitment deviations (σ_R): The SRG notes the high sensitivity of the model to the variance parameter assumed for recruitment deviations (σ_R, a parameter that is not directly observable). While the spawning biomass trajectories across values of σ_R were very close to one another, the corresponding estimates of R_0 led to widely different estimates of stock status (relative spawning biomass). The JTC presented evidence that supported the value used in the assessment. **The SRG encourages the JTC to explore methods for parameterizing recruitment and/or estimating σ_R that would reduce model sensitivity to the value of this constraint**.

Response – Developing best practices for modeling recruitment variability (σ_R) remains a broad topic of contemporary research. The JTC has outlined several alternative approaches for advancing this research as it applies to Pacific Hake. These are: (a) estimating σ_R in MCMC runs while testing semi-parametric selectivity; (b) estimating recruitment autocorrelation to examine the impact it has on the model and whether it reduces sensitivity to the choice of σ_R; (c) use the Template Model Builder (TMB) code developed by Nis Jacobsen for the Management Strategy Evaluation to explore random effects treatment of recruitment variability (Thorson, in press). The JTC plans to continue to work towards evaluating and testing best practices for modeling recruitment variability. Progression on these research topics was halted during the 2019 assessment season due to unforeseen time constraints imposed on the JTC.

2. The SRG notes that when setting values for other parameters that cannot be estimated directly with confidence, the choice of values should be made using methods that are objective, repeatable, and depend on fits to the observed data rather than on the model's subsequent estimates of biomass or recruitment. One clear example is setting the parameter controlling time-varying fishery selectivity (Φ), with a goal of establishing repeatable steps for setting Φ each year. The SRG recommends that the JTC provide a review of how time-varying selectivity is parameterized and estimated in other assessments.

Response – Although some progress has been made identifying other assessments that specify the variability associated with time-varying selectivity (Φ), a thorough review and comparison of alternative approaches could not be completed in time for the 2019 assessment due to unforeseen time constraints this assessment season.

3. After reviewing the sensitivity analysis for minor corrections to the catch series, the SRG agrees that the assessment results were not significantly affected. **However, the coding and database errors should be rectified as soon as possible.**

Response – These issues were largely rectified during the 2018 meeting, while remaining issues have since been permanently fixed.

4. The new histological analysis of ovaries for maturity, like previous analyses, showed a distinct difference in the percent of hake that are mature at age 2 and age 3 between areas, with a greater proportion mature south of Point Conception (34.47°N). These data suggest that there may be two populations of hake, north and south of this boundary. The SRG also notes that ovaries collected in Canada were not used to update the maturity ogive. The hake found in Canada are generally

older age fish and including samples of these fish in the maturity analysis should improve the robustness of the maturity ogive. **The SRG strongly supports the planned genetic analyses to determine whether there are also genetic differences between these two southern regions and other regions as well. In addition, the SRG notes that Canadian samples should be included in the maturity analysis.**

Response – Regarding genetic difference between regions, Krista Nichols (NWFSC, NOAA) and her staff have started working on this. She says "NWFSC staff have begun a genetic analysis using hake samples collected along the Pacific coast during summer, fall (British Columbia to California) and winter (Oregon and California) and within the Strait of Georgia (British Columbia) during the spring. Prior genetic analyses in Pacific Hake have focused on a smaller geographic range, over a limited seasonal time scale, and used a limited set of genetic markers (Iwamoto et al., 2004, 2015). To improve the power to evaluate genetic stock structure and associations with life history characters important for assessment, thousands of genetic markers in hake are being surveyed using genomic technologies (Baird et al., 2008; Ali et al., 2016). Initial genetics data have been generated for 400 individuals, with planned genetic analysis of close to 2,000 individuals total. This study will examine genetic connectivity between geographic and temporal collections, and evaluate the hypothesis that offshore hake migrate seasonally to Baja and California for spawning in the winter. This work began in December 2018 and is expected to be completed in 2020.

Regarding including the Canadian samples in the maturity analysis, DFO is continuing to assess workload logistics, including the possibility of getting trained by Melissa Head (NWFSC) on the histological methods she used in the recent maturity analysis or alternatively getting samples sent from Canada to Seattle, if appropriate. Presumably, the 2019 survey or fishery would be the earliest time to get any additional Canadian samples.

5. The 2018 assessment diverged from past practice in its approach to determining the data weights applied to the age-composition data. Past assessments used an iterative approach (sometimes referred to as the McAllister-Ianelli approach) to arrive at these weightings. The 2018 assessment incorporates the weightings as estimable parameters, thereby eliminating the need for iterative reweighting. This streamlines the assessment process and the SRG considers it to be a sensible and useful improvement. **However, the SRG requests that the JTC provide thorough documentation of all changes in methods of data weighting.**

Response – Section 2.4.4 includes information on all methods, current and historical, used to weight composition data. Additionally, Table 18 includes a time series of weights used for the fishery and survey age compositions as well as a comparable value derived from the current model that uses the Dirichlet-Multinomial likelihood to estimate weights.

6. The issue of data weighting remains a significant technical challenge for stock assessments (such as the Pacific hake assessment) that integrate information of different forms (e.g., biomass indices and age compositions) from different sources (e.g., different fishing sectors). The SRG notes that the JTC has considered alternative schemes for data weighting such as the Francis (2011) method. **The SRG notes that it would be useful for such explorations to be documented in future assessment reports, and requests that JTC perform a sensitivity analysis for this method in**

future assessments.

Response – Sensitivity analyses were included to compare the use of the Dirichlet-Multinomial likelihood to the McAllister-Ianelli and Francis weighting methods (see Section 3.8). All three methods are described in Section 2.4.4 and historical weightings used in previous assessments can be compared to values estimated in this assessment (Table 18).

A potential issue related to data weighting that should be explored in the next assessment is the JTC's approach to deriving the initial set of data weightings associated with the fishery and survey age-composition observations. Table 5 in the assessment document shows the annual number of at-sea hauls and shore-based trips from which fish ages were incorporated into the age-composition series and the document states that "initial sample sizes are simply the summed hauls and trips". If there are changes in the number of fish associated with each sample unit (haul or trip) over time, one would expect a corresponding change in the information content of an age-composition sample. For example, there may have been more fish per sample in early years than later years, implying that the assessment model should provide a better fit to early samples than to later samples. The approach taken to deriving the initial data weights could account for changes in the number of fish per sampling unit. Alternatively, the Dirichlet multinomial parameter that accounts for variability in the age- composition observations could include a time-varying component to account for changes in the number of fish per sampling unit. **The SRG recommends that the JTC include information in the next assessment on the annual numbers of fish underlying each annual age-composition observation and present an analysis of the potential influence of changes in sampling.**

Response – The number of age (and weight) samples used to develop age compositions over time (1975–2018) are shown in Figure 13. A formal evaluation of the influence temporal fluctuations in the number of fish sampled and aged has on model performance could not be completed in time for the 2019 assessment due to unforeseen time constraints during the assessment season. The JTC plans to complete such an evaluation in preparation for the 2020 stock assessment.

7. **The SRG requests that the estimates of total age-2+ biomass be included in Table 18 of the assessment report in the future.**

Response – This was done for the published version of the 2018 assessment, and will be the standard for the 2019 assessment and beyond.

8. **The SRG recommends that the JTC produce a table showing changes in model structure and parameterization that have been implemented since 2011 as a standard table to be included in the assessment document.**

Response – The 2019 assessment includes Table 18 that summarizes major changes to the model structure and parameterization since 2011. Future assessments will include an updated version of the table as well.

Finally, we note that we have complied with the following request from the 2017 SRG concerning the sensitivity tests to perform in all future assessments:

The SRG requests that future assessments, beginning with 2018, include the following key sensitivity tests: natural mortality, stock-recruit steepness (h), σ_r, inclusion of the age-1 index, and exploring the degree of flexibility in time-varying selectivity or the ϕ parameter, as well as any others the JTC deems appropriate.

3.4 MODELING RESULTS

3.4.1 Changes from 2018

A set of 'bridging' models was constructed to evaluate the component-specific effects of all changes from the 2018 base model to the 2019 base model.

In short, these included the following

- Update catch data from years prior to 2018.
- Update age composition data from years prior to 2018.
- Update weight-at-age data from years prior to 2018
- Add 2018 total catch.
- Add 2018 fishery age composition and weight-at-age data.
- Change fecundity (calculated as weight-at-age multiplied by maturity) from being time-invariant (using a single catch-weighted average of weight-at-age over all years) to time-varying (using year-specific weight-at-age).

In general, these changes mimic the steps routinely applied, with a single exception requiring additional explanation.

The first set of bridging steps were conducted to "Update" data prior to 2018. This primarily included minor adjustments in catch, fishery age composition, and weight-at-age values, where a few additional samples from previous years, especially from the end of 2017 that were not available in time for the 2018 assessment were included. These changes were small enough that they had little impact on the model results (Figure 15).

The addition of 2018 catch allowed the model to be extended to the start of 2019, but the estimates for 2019 remained highly uncertain (Figure 16) in the absence of additional information about recent recruitment. The addition of 2018 fishery age composition information had relatively little additional impact on the biomass estimates, indicating that the observed 2018 ages were consistent with the model estimates without those data (Figure 16). However, the addition of these data did alter recent recruitment estimates, including an increase in the estimated size of the 2016 year class and a reduction in the uncertainty associated with the relative recruitment strength of the 2016 and 2017 year classes.

In addition to fishery ages, this bridging step also included adding 2018 weight-at-age data and updating other associated settings related to recruitment, combining 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 2018 fishery composition data, which included a relatively high proportion of age-1 fish from the 2017 cohort and age-2 fish from the 2016 cohort, meant that it was necessary to shift the endpoint of the main vector of recruitment deviations to include 2017. 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 2017 cohort. Finally, this bridging step also shifted the ending year of the deviations in the selectivity parameters from 2017 to 2018 since there was now fishery data in 2018.

The final bridging step involved changing the structural assumptions about fecundity (discussed further in Sections 2.3.1 and 3.8) and resulted in the 2019 base model (Table 18). The switch from time-invariant to time-varying fecundity resulted in the biggest bridging change to current biomass. Fecundity (calculated as weight-at-age multiplied by maturity) changed from being defined by a single catch-weighted average of weight-at-age applied to all years to being defined by year-specific weight-at-ages covering the time period with data (1975-2018). For periods without data (pre-1975 and post-2018), catch-weighted average weight-at-age was used (however see Section 3.8.1 for discussion on alternatives). The results of this bridging step caused a visible change in the time series of spawning biomass (Figure 16) as the fecundity of all cohorts were different leading to variability in the time series of spawning biomass. 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).

3.4.2 Assessment model results

Model Fit

For the base model, the MCMC chain length was 24 million as it was in the 2018 assessment (Edwards et al., 2018*b*). The first 4,000,000 values were discarded to eliminate 'burn-in' effects and each 10,000th value thereafter was retained, resulting in 2000 samples from the posterior distributions for model parameters and derived quantities. Previous MCMC explorations indicated that $\log \theta_{\text{surv}}$, the log of the θ 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 2.44, corresponding to a weight of $\theta_{\text{surv}}/(1+\theta_{\text{surv}}) = 0.92$. The D-M parameter for the fishery weights was well sampled by the MCMC, with a median estimate of $\log\theta_{\text{fish}} = -0.551$ and an associated median weight of $\theta_{\text{fish}}/(1+\theta_{\text{fish}}) = 0.366$.

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 2019 with the catch from default harvest rule in 2019 were 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 (0.68) between the 2010 and 2012 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 9 and 23) remains similar to the 2018 base model. 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 23). The addition of 2018 fishery data had negligible effect on the fit to survey biomass (Figure 16). 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 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 2018 age composition was dominated by age-2 fish from the 2016 year-class (23% of the catch in the fishery), age-4 fish from the 2014 year-class (29% of the catch in the fishery), and age-8 fish from the 2010 year-class (24% of the catch in the fishery). Age composition from the 2017 acoustic survey also indicated that the 2014 year-class (53% of that catch that year) and the 2010 year-class (26% of the catch for that year) were large. 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 2015–2018 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). The 2016 year-class has yet to be exposed to the acoustic survey, so the strength of this cohort is reliant solely on two years of fishery data and thus remains highly uncertain. 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 19-23. For the major cohorts, the resulting age-specific catch, natural mortality and surviving biomasses are given in Table 24.

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 2019 base model specified the same level of variation (standard deviation of $\Phi = 1.4$) associated with time-varying fishery selectivity as the 2018 base model, effectively allowing the model flexibility (i.e., a lower penalty on the overall likelihood) to fit to data that 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 29). Fishery selectivity on age-2 fish was at its highest in 2016, followed by 2018. 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 30). 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 30), 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 31 and 32 and Tables 25 and 26). 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 2002 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 0.550 million t in 2010. The assessment model estimates that spawning biomass declined slightly from 2014 to 2015 after four years of increases from 2010 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, followed by a period of relatively steady biomass from 2017 to 2019.

The median estimate of the 2019 relative spawning biomass (female spawning biomass at the start of 2019 divided by that at unfished equilibrium, B_0) is 64.1% but is highly uncertain (with a 95% posterior credibility interval from 26.3% to 156.7%; see Tables 25 and 26). The median estimate of the female spawning biomass at the start of 2019 is 1.312 million t (with a 95% posterior credibility interval from 0.471 to 3.601 million t).

The estimated 2018 female spawning biomass is 1.346 (0.616-2.943) million t. In the 2018 assessment, the equivalent estimate of 2018 female spawning biomass was 1.357 (0.610-3.161) million t. The 2019-estimated median is very similar to the 2018-estimated median, while the credible interval has decreased with the addition of another year of fishery data.

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 33 and 34, Tables 25 and 26). 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 70% of the coast-wide commercial catch in 2013, 64% of the 2014 catch, 70% of the 2015 catch, 33% of the 2016 catch, 37% of the 2017 catch, and 24% of the 2018 catch. The current assessment also estimates a strong 2014 year class (Figure 35) comprising 50% of the 2016 catch, 39% of the 2017 catch, and 29% of the 2018 catch. The 2016 cohort also appears to be strong at 23% of the 2018 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, three years of fishery data and one year of survey data suggest that it is one of the higher estimates in the time series. The 2016 year class is estimated to be above average (similar in size to the 2008 year class) from two years of fishery data. The 2016 year class will not be observed in the survey until 2019 as age-3 fish.

The additional data in the 2019 assessment has reduced the median estimate of the 2014 year class to 8.467 billion fish (Table 25), from the 8.583 billion estimated in the 2018 assessment (Table 18 of Edwards et al. 2018*b*). Yet the 2014 year class remains the fifth largest estimated recruitment, albeit with large uncertainty (Table 26 and Figure 33). The median estimate for the 2016 year class is 3.895 billion fish (with a 95% posterior credibility interval from 0.746–26.085 billion fish; Tables 25 and 26).

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 and 2017 year class. The proportion of the age-1 catch (in numbers and biomass) in 2018 (2017 year class) was slightly larger than the age-1 catch in 2017 (2016 year class). There is little or no information in the data to estimate the sizes of the 2018 and 2019 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 36. 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 36). The standard deviation of the time series of median recruitment deviation estimates for the years 1970-2017, which are informed by the age compositions, is 1.67. This value is consistent with the base model value of 1.4.

Exploitation status

Median relative fishing intensity on the stock is estimated to have been below the $SPR_{40\%}$ target for all years (Figure 37 and Tables 25 and 26). It should be noted, however, that the median relative fishing intensity was close to the target in 2008, 2010 and 2011, 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 38 and and Tables 25 and 26). Although displaying 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 96.6% in 2010 to 52.8% in 2015, after which it increased to 81.8% in 2018. The exploitation fraction has decreased from 0.17 in 2011 to 0.08 in 2015 and then increased to 0.14 in 2017 before ending at 0.12 in 2018. 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 37). The median estimates for 2016, 2017, and 2018 are below the management target, however the 95% posterior credibility intervals do include the target level.

Management performance

Over the last decade (2009–2018), the mean coast-wide utilization rate (i.e., landings/quota) has been 73.8% and catches have been below coast-wide targets (Table 4). From 2014 to 2018, the mean utilization rates differed between the United States (70.8%) and Canada (47.3%). 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 rates in 2017 and 2018 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 37). The female spawning biomass was above target all years except from 1999-2000 and from 2007-2011 (Figure 39).

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 39). Between 2007 and 2011, however, median relative fishing intensity ranged from 80% to 97% and median relative spawning biomass between 0.27 and 0.33. 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 large uncertainty in the 2018 estimates of relative fishing intensity and relative spawning biomass, the model estimates a 10.3% joint probability of being both above the target relative fishing intensity in 2018 and below the $B_{40\%}$ relative spawning biomass level at the start of 2019.

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). Note that we use the term MLE even though the priors are involved in the likelihood calculation and so the more accurate term would be the mode of the posterior density. Table 27 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 40 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 overlap considerably.

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.

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, by coordinating research with the Pacific Hake MSE Working Group and other scientists in the region engaging in similar research. Incorporating feedback from JTC/JMC/AP/SRG/MSE Working Group will ensure that constructed operating models will be 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 structure and the harvest policy for this fishery and compare potential methods to address them remains an important goal.

3.6 REFERENCE POINTS

We report estimates of the base reference points (e.g., relative to $F_{\text{SPR}=40\%}$, $B_{40\%}$, B_{MSY}, and MSY) with posterior credibility intervals in Table 28. 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 only very slightly different than the estimates in the 2018 assessment (see also Table 27).

As part of the DFO Sustainable Fisheries Framework, DFO (2009) suggested a provisional limit reference point (below which serious harm is believed to be occurring to the stock) of $0.4B_{\text{MSY}}$ and an upper stock reference point (above which the stock is considered to be healthy) of $0.8B_{\text{MSY}}$. The probabilities of the female spawning biomass at the start of 2019 being above each of these points are $\text{P}(B_{2019} > 0.4B_{\text{MSY}}) = 100\%$ and $\text{P}(B_{2019} > 0.8B_{\text{MSY}}) = 99\%$ such that the stock is estimated to be in the provisional 'healthy zone'.

Reference levels of stock status that are used by the U.S. Pacific Fisheries Management Council (PFMC) include $B_{40\%}$ and Minimum Stock Size Threshold (MSST) = $B_{25\%}$. For 2019, the estimated posterior median stock size for Pacific Hake is above $B_{40\%}$ and well above $B_{25\%}$ at 64.1%.

3.7 MODEL PROJECTIONS

The median catch limit for 2019 based on the default $F_{\text{SPR=40\%}}$–40:10 harvest policy is 725,593 t, but has a wide range of uncertainty (Figure 41), with the 2.5% to 97.5% range being 214,763–2,106,509 t.

Decision tables give projected population status (relative spawning biomass) and relative fishing intensity under different catch alternatives for the base model (Tables 29 and 30). 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 29 shows projected relative spawning biomass outcomes, and Table 30 shows projected fishing intensity outcomes relative to the 100% target (based on SPR; see table legend).

Relative fishing intensity exceeding 1 (or 100% when shown as a percentage) 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 2019, 2020 and 2021 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 (JMC) and the Advisory Panel (AP) in 2012 are presented for projections to 2020 and 2021 (Tables 31 and 32). 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 42 shows the predicted relative spawning biomass trajectory through 2021 for several of these management actions. With zero catch for the next two years, the biomass has a probability of 17% of decreasing from 2019 to 2020 (Table 31 and Figure 43), and a probability of 53% of decreasing from 2020 to 2021 (Table 32 and Figure 44).

The probability of the spawning biomass decreasing from 2019 to 2020 is 50% for some catch

level between 180,000 t and 350,000 t (Table 31 and Figure 43). The model predicts high biomass levels and the predicted probability of the spawning biomass dropping below $B_{10\%}$ ($0.1B_0$) in 2019 is 2% or less and the probability of dropping below $B_{40\%}$ is 29% or less for all catches explored (Table 31). It should be noted that the change in abundance of the 2010 year class is affected more by decreases due to natural mortality than increases from somatic growth and the model estimated below average recruitment for the 2011 and 2013 cohorts, but the above average predicted 2014 and 2016 year classes will result in an increase to the spawning biomass as they enter maturity. The probability that the 2020 spawning biomass will be less than the 2019 spawning biomass ranges from 17% to 77% depending on the catch level (Table 31 and Figure 43).

The age composition (in numbers) of the catch in 2019 is projected to be (using MCMC medians) 22% age-3 fish from the 2016 year-class, 33% age-5 fish from the 2014 year-class and 14% age-9 fish from the 2010 year-class (Figure 45). However, those estimates are highly uncertain with the 95% credibility interval for the age-5 fraction spanning 11%–59%. Due to the lower average weight at age 3 vs. 9, the expected proportion of the 2019 catch by weight is expected to be reversed between the 2016 and 2010 cohorts, at 6% and 22%, respectively.

With respect to the DFO provisional reference points, even with the largest 2019 catch of 725,593 t given in Table 31, at the start of 2020 the stock is expected to be above the cautious zone with a probability of $\mathrm{P}(B_{2020} > 0.4B_{\mathrm{MSY}}) = 98\%$, and in the healthy zone with a probability of $\mathrm{P}(B_{2020} > 0.8B_{\mathrm{MSY}}) = 92\%$.

With respect to PFMC stock size reference points, a level of 2019 catch consistent with the Treaty default harvest control rule (725,593 t) has a 29% estimated probability of the biomass going below $B_{40\%}$ in 2020 (12% probability of going below $B_{25\%}$; Table 31). That probabality decreases to 19% and 5%, respectively, if the catch level stays the same in 2019 as in 2018.

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, almost 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 33 and 34. 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 (σ_r);
4. Include the age-1 survey index as an additional source of information;
5. Use of the McAllister-Ianelli method for data-weighting;

6. Use of the Francis method for data-weighting;

7. Consideration of alternative standard deviations for time-varying selectivity;

8. Consideration of an alternative parameterization for time-varying selectivity; and

9. Consideration of alternative assumptions concerning weight-at-age and fecundity.

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 the early- to mid-2010s 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 recent large cohorts were 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 (σ_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 33). In addition to allowing a higher estimated value for natural mortality, the broader prior on 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 33 and Figures 46 and 47).

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 0.865 to 0.606 (Table 33). However, neither steepness sensitivity analysis had a strong impact on the overall model results (Figures 46 and 47). The small influence of steepness on model results is related to the relatively large σ_r value which allows the recruitments to deviate far from the underlying stock-recruit relationship (Figure 36).

The value of σ_r was changed from a value of 1.4 (base) to alternative high (1.8) and low (1.0) states. 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 1.46, suggesting that the data were inconsistent with the lower value of σ_r. The high value, $\sigma_r = 1.8$, resulted in a model with a more consistent standard deviation for the estimated recruitment deviations, at 1.75. However, the high σ_r model had a larger difference between the spawning biomass at unfished equilibrium and the spawning biomass at the initial year of the model than the low σ_r model (Table 33 and Figures 46 and 47). 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

$$\sigma_r^2 = \text{Var}(\hat{r}) + \overline{\text{SE}(\hat{r}_y)}^2, \tag{8}$$

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 σ_r of 1.53, 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 34; Figures 48 and 49; 2019 estimates are 55.2% of unfished biomass for the base model and 66.9% 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 2012, 2014, and 2016 cohorts (Figure 10). These changes are subtle because the base model generally tracks the trends in the age-1 index well. Including the age-1 index led to worse fits to the last year of the acoustic survey compared to the base model (Figure 50).

The sensitivity of the use of the Dirichlet-Multinomial likelihood, implemented in 2018, which uses two estimated parameters to automatically weight each of the fishery and survey age compositions, was assessed by comparing the weightings to the McAllister-Ianelli and Francis methods. Both alternative methods require manual iterative adjustments to the input sample sizes using a derived multiplier. The McAllister-Ianelli method, which was used in assessments prior to 2018, attempts to make the arithmetic mean of the input sample size approximately equal to the harmonic mean of the effective sample size. The Francis method attempts to make the fit of the expected mean age lie within the uncertainty intervals at a rate which is consistent with variability expected based on the adjusted sample sizes. The Dirichlet-Multinomial method estimated higher weights on the age compositions but generally very similar results to the McAllister-Ianelli method. The McAllister-Ianelli method led to increased uncertainty in estimates of early recruitments compared to other weighting methods (Figure 51). The Francis method increased the weighting of the fishery composition data resulting in a similar time series of biomass, though slightly reduced in scale. As noted in Section 2.4.4, the Francis method is known to be sensitive to outliers and prone to convergence issues when selectivity is time-varying, as it is in this assessment.

The following two types of alternative setups for selectivity were explored in sensitivity analyses: alternative values of the Φ parameter controlling the degree of flexibility of annual variation in the fishery selectivity and an alternative "semi-parametric" parameterization of the time-varying selectivity (Figures 52-55). The methods and results of each will be described in turn.

The consideration of alternative standard deviations (Φ) for time-varying selectivity is discussed earlier in Section 2.4.3. In short, low values of the parameter Φ controlling the flexibility in time-varying selectivity resulted in potentially implausibly high estimates for recent recruitments. 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 Φ. However, the 2016 recruitment, which is only informed by the 2017 and 2018 fishery age compositions, is strongly linked to the choice of Φ, where the model with the smallest Φ at 0.21 estimates the 2016 and 2017 recruitment deviations as the highest in the time series (Figure 54) and provides the worst fit to the recent survey biomass estimates (Figure 55).

The alternative "semi-parametric" setup for selectivity based on the work of Xu et al. (2019) 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 56). That is, the deviations are no longer applied as shown in equation (4), but as exponential multipliers on the baseline selectivity

$$S_{ay} = S_a \cdot \exp(\varepsilon_{ay}) \tag{9}$$

where the S_{ay} are derived as described in equations (1)-(3), the ε_{ay} are the selectivity deviations, σ_s is the parameter which controls the variability in the deviations (equivalent to Φ in the base model parameterization), and the likelihood contribution for the ε_{ay} parameters is from treating the deviations as normal random variables with standard deviation σ_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 7 pairs of parameters with correlations above 0.7 or below -0.7 in the semi-parametric model that most closely matched the base model (M and $\log R_0$ were positively correlated and the deviations for selectivity at ages 1 and 3 in 2017 and 1, 2, and 4 in 2018 were correlated with each other or 2016 or 2017 recruitment). This is in contrast to the base model, which had 38 parameter pairs with correlations above 0.7 or below -0.7, of which 35 of the pairs were between two of the selectivity deviations.

However, the model with $\sigma_s = 0.695$ had higher estimates of 2016 and 2017 recruits and worse fits to the recent survey biomass estimates (Figures 52-55). Increasing σ_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 and age-2 fish in the fishery. However, relying on the subjective choice of $\sigma_s = 1.0$ removed one of the potential 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 assessments.

Sensitivity runs concerning weight-at-age and fecundity are discussed in Sections 3.8.1 and 3.8.2 (Table 35). Any additional sensitivity runs arising from the Scientific Review Group meeting to be held from 19th February to 22nd February 2019 will be documented in Appendix A and briefly summarized here.

3.8.1 Recap of alternative 2018 model run with time-varying fecundity

In 2018 the SRG requested an alternative model run that used time-varying fecundity (Edwards et al., 2018*b*). We have used time-varying fecundity in the 2019 base model, and in three sensitivity

runs with alternative assumptions about the weights-at-age for the years without data. For a given year, fecundity is the (element-wise) product of the maturity ogive and the weight-at-age vector for that year. Thus, the alternative weight-at-age assumptions affect the fecundity. We also tested these four alternative assumptions when using non-time-varying fecundity. The eight combinations are summarised in Table 36, and the four weight-at-age assumptions are shown in the heatmaps in Figures 57–60. The eight runs are first explained in the context of the 2018 assessment, with justification of our base model; results are then given in 3.8.2.

There were four components to the SRG-requested alternative model run that used time-varying fecundity (see p23 of Edwards et al. 2018*b*):

a) "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."

We have done this in the 2019 base model (for the updated time period 1975–2018) because it is more consistent with time-varying weight-at-age than the non-time varying fecundity used in the 2018 base model. The fecundity for the 2018 base model came from multiplying the maturity ogive by an average weight-at-age vector to give age-dependent fecundity that was constant in time. Sensitivity runs 54, 55 and 58 retain the time-varying fecundity of the base model. Sensitivity runs 52, 53, 56 and 57 use non-time-varying fecundity, as per the 2018 base model (Table 36).

b) "Set equilibrium and 1966-1974 fecundity (where empirical data are not available) to the product of maturity and the mean weight-at-age averaged over 1975-1979."

We have not done this in the 2019 base model, as described in Section 3.3, but are using the long-term average (1975-2018) for the equilibrium and 1966-1974 fecundity, as for the 2018 base model. Using the fecundity based on 1975-1979 is examined in sensitivity runs 55, 56, 57 and 58.

c) "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."

We found no compelling evidence to use the short-term mean (2016-2018) for the forecasts, as described in Section 3.3.

Also, the 'current configuration of Stock Synthesis' issue is the requirement that the forecast years' weights-at-age be either (i) the same as the pre-data (pre-1975) years, or (ii) the same as the final year of data (2018). Thus, we cannot set the forecast years' weights-at-age to be the mean of 2016-2018 without setting the 2018 weights-at-age to be this, which seems inappropriate for the base model (but is tested in runs 52, 54, 56 and 58). So, for the 2019 base model we retained the 2018 base model's assumption of using the mean from 1975-2018 for projections (which satisfies the requirement (i) of Stock Synthesis just described).

Similarly, we cannot set the forecast year's weights-at-age to be the mean of 1975-2018 when the pre-1975 weight-at-age is 1975-1979, without setting the 2018 weights-at-age to also be the mean from 2016-2018 (as noted in Section 3.3). This setting is done for model runs 55 and 57, but

precludes run 55 from being a sensible base model because the 2018 weights-at-age are not the true 2018 data (and run 57 does not use time-varying fecundity). Run 53 uses the same weight-at-assumptions as the base model but does not use time-varying fecundity.

d) The inconsistency regarding still using the mean weight-at-age for calculating *stock biomass* is discussed in Section 3.3, and is fully resolved for all runs in 2019.

3.8.2 Fecundity and weight-at-age sensitivities

In 2018, the aforementioned alternative model run was investigated using a full MCMC computation to allow for the presentation of decision tables and projections. For 2019, all eight combinations in Table 36 underwent full MCMC computations. The runs are labeled with run numbers which were used internally by the JTC and are not relevant other than to refer to each run uniquely. The extrapolation of pre-1975 weights-at-age is required because there is catch in the model from 1966 onward but age and weight data were not collected until 1975.

The 2018 base model had the same assumptions as run 53, with one less year of data (Table 36). These assumptions are non-time-varying fecundity, long-term (1975–2018) mean weights-at-age applied for the years 1966–1974, and long-term (1975–2018) mean weights-at-age applied for the years 2019–2021 (Figure 57).

The 2018 alternate model was similarly analogous to run 58 (Table 36), which had time-varying fecundity, short-term (1975–1979) mean weights-at-age applied for the years 1966–1974, and short term (2016–2018) mean weights-at-age applied for the years 2017–2021. Recall the aforementioned configuration issue, that when models use a different set of weights-at-age for the forecast years than for the 1966–1974 period, the last year of data (2018) cannot be included. Instead, the current configuration of Stock Synthesis requires 2018 to be used as a placeholder for the forecasting weights-at-age vector.

This year's base model is a hybrid of the 2018 models, based on the 2018 base model but with the inclusion of time-varying fecundity.

There were five further runs done, overall covering all possible combinations of long- or short-term mean pre-1975 weights-at-age, long- or short-term mean post-2017 weights-at-age, and time-varying fecundity being included or not.

Weights-at-age for runs which use the long-term (1975–2018) mean for both the pre-1975 and post-2018 periods can be seen in Figure 57. This figure includes run 53 and the base model.

Weights-at-age for runs which use the short-term (1975–1979) mean for the pre-1975 period and the long-term (1975–2018) mean for the post-2017 period can be seen in Figure 58. This figure includes runs 55 and 57.

Weights-at-age for runs which use the long-term (1975–2018) mean for the pre-1975 period and the short-term (2016–2018) mean for the post-2017 period can be seen in Figure 59. This figure

includes runs 52 and 57.

Weights-at-age for runs which use the short-term (1975–1979) mean for the pre-1975 period and the short-term (2016–2018) mean for the post-2017 period can be seen in Figure 59. This figure includes runs 56 and 58.

MCMC runs with a chain length of 12,000,000 were done for these sensitivities. The first 2,000,000 values were discarded to eliminate 'burn-in' effects and each 5,000th value thereafter was retained, resulting in 2,000 samples from the posterior distributions for model parameters and derived quantities. Comparisons of both the MLE and median posterior biomass and relative biomass trajectories with 95% credible intervals follow.

The base model and runs 52, 53, and 54 are compared in Figures 61–64. These are the runs which have the pre-1975 weights-at-age being set to the long-term mean from 1975–2018. Runs 52 and 53 show little difference from one another, implying that changing the post-2017 weights-at-age does not have much effect on model outcome. However, they show a noticeable decrease in the estimated spawning biomass (compared to the base model) in and around the 1975 time period (Figures 61 and 62). The peak in biomass for the base model is caused by the weights-at-age in the early part of the time series being significantly higher for older fish and having the fecundity in that time period change accordingly when using time-varying fecundity.

Run 54 also includes time-varying fecundity and exhibits the biomass peak around 1975. Note that it is difficult to see the difference between the base model and run 54 using the MLE plots (because their only difference is in the weight-at-age for 2018 onwards). The MCMC plots allow us to see that the blue and red lines (base model and run 54) follow similar trajectories (Figures 62 and 64).

The base model, and runs 55, 56, 57, and 58 are compared in Figures 65–68. These are the runs which have the pre-1975 weights-at-age being set to the short term mean (1975–2018). Runs 55 and 58 appear to have similar trajectories to one another, as do runs 56 and 57. The difference between these two groups is the inclusion of time-varying fecundity.

Having non-time-varying fecundity and using short-term pre-1975 mean weights-at-age (runs 56 and 57) give an inflated 2019 stock size (Figures 65 and 66), but due to the inflation of the initial biomass give a similar stock status to the base model (Figures 67 and 68).

Runs 55-58 produce an inflated initial biomass, due to the use of a short-term (1975–1979) mean weight-at-age being used for the pre-1975 time period. The weights-at-age for older fish in those early years is significantly higher than the long-term mean as can be seen in Figures 58–60.

MCMC results for runs 53 and 54 including decision tables can be found in Appendices F and G, because these are the closest runs to the 2019 base model.

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 69). Models with 1 and 2 years of data removed were just beginning to receive data on age-3 and age-2, respectively, individuals to to predict the size of the 2014 year class. The base model now has four years of data to estimate the size of the 2014 cohort, and the uncertainty around this estimate has been considerably reduced compared to one year ago (Figure 69).

Overall, there is little retrospective change to the relative spawning biomass trajectory up to the mid-2010s, and most retrospective change occurs in the final years of the retrospective model. Retrospective estimates over the last five years have been predominantly positively biased. In the last four 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 29 shows the retrospective patterns of estimated recruitment deviations for various cohorts. The magnitude of the deviation is not well estimated until several ($\sim$4-9) 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-4 and the weak 2007 cohort by age-6. Estimated recruitment deviations for the 2014 cohort appear to be similar to other large cohorts (1999, 2008, and 2010), though with the extra years of data in this and last 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 70) 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 71. There have been substantial differences in model structural assumptions and thus results submitted 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 2019 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 2019 assessment brackets the majority of the historical estimates.

4 RESEARCH AND DATA NEEDS

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, including designs that incorporate ecosystem-based factors and other potential target species (e.g., rockfish, euphausiids, and mesopelagics) 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.

4. Continue to explore and develop statistical methods to parameterize time-varying fishery selectivity in the assessment and with regard to forecasting. This should include the semi-parametric selectivity approach explored in the 2018 assessment but for which was not explored further this year due to time constraints.

5. Continue to investigate fecundity and maturity, including trying to understand links between fecundity and size, age, weight, and batch spawning.

6. Continue genetic analyses 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. 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.

10. 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.

11. 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.

12. Maintain the flexibility to undertake additional acoustic surveys for Pacific Hake in non-survey years when uncertainty in the hake stock assessment presents a potential risk to or underutilization of the stock.

13. Consider alternative methods for refining existing prior distributions for natural mortality (M), including the use of meta-analytic methods.

14. 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, 1966-2018. 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	52,470	77,950	102,143	1,018	233,581

2014	0	0	62,102	103,203	98,640	197	264,141
2015	0	0	27,665	68,484	58,011	0	154,160
2016	0	0	65,036	108,786	87,760	745	262,327
2017	0	0	66,428	136,960	150,841	0	354,229
2018	0	0	67,129	116,073	131,829	0	315,031

Table 2. Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2018.

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
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
2018	0	2,724	54,447	38,241	95,412

Table 3. Total U.S., Canadian and coastwide catches of Pacific Hake (t) from 1966-2018. The percentage of the total catch from each country's waters is also given.

Year	Total U.S.	Total Canada	Total coastwide	Percent U.S.	Percent Canada
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
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	233,581	52,249	285,830	81.7	18.3
2014	264,141	35,113	299,254	88.3	11.7
2015	154,160	39,678	193,838	79.5	20.5
2016	262,327	69,740	332,067	79.0	21.0
2017	354,229	86,713	440,942	80.3	19.7
2018	315,031	95,412	410,443	76.8	23.2

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
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	233,581	52,249	285,830	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	154,160	39,678	193,838	440,000	325,072	114,928	47.4%	34.5%	44.1%
2016	262,327	69,740	332,067	497,500	367,553	129,947	71.4%	53.7%	66.7%
2017	354,229	86,713	440,942	597,500	441,433	156,067	80.2%	55.6%	73.8%
2018	315,031	95,412	410,443	597,500	441,433	156,067	71.4%	61.1%	68.7%

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 sampled catch. 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).

	U.S.						Canada			
Year	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	76	–	–	75	116
2017	–	–	353	–	684	112	–	–	75	76
2018	–	–	357	–	492	80	–	–	47	83

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
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	2,026	684	1.75	0.87	50.75	2.36	4.99	3.08	28.79	3.01	2.11	1.17	0.25	0.58	0.17	0.00	0.12
2018	976	492	5.49	33.30	1.18	27.39	2.39	2.54	2.56	20.14	2.34	1.51	0.25	0.48	0.32	0.11	0.00

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
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	1,252	423	0.00	5.01	3.50	74.63	4.75	7.51	1.01	1.28	1.00	0.52	0.11	0.08	0.00	0.14	0.47
2015	601	203	1.81	0.65	10.41	4.77	71.42	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	1,054	353	7.78	0.77	51.20	2.21	3.41	1.28	27.73	1.88	1.96	0.49	0.08	0.81	0.19	0.16	0.06
2018	683	357	16.12	24.99	2.00	28.40	0.72	2.12	1.92	18.20	3.20	0.86	0.62	0.38	0.00	0.41	0.07

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
2009	65	0.00	0.30	42.16	27.19	2.52	9.93	0.63	2.25	1.84	9.85	1.46	0.77	0.68	0.10	0.34
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	76	0.11	65.35	1.41	3.27	1.56	22.09	1.60	2.70	0.72	0.29	0.31	0.26	0.14	0.10	0.08
2017	112	3.41	0.73	35.78	2.58	3.67	2.48	43.46	2.53	2.03	1.52	0.67	0.55	0.28	0.12	0.21
2018	80	2.33	24.55	1.99	35.32	1.50	2.88	2.85	21.92	2.91	1.44	0.94	0.62	0.51	0.19	0.06

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
2009	7	0.00	0.43	8.95	18.12	5.71	16.42	3.32	3.10	5.37	28.73	5.27	2.51	0.66	0.62	0.79
2010	8	0.00	0.07	0.93	10.17	37.59	7.52	8.65	1.60	0.91	1.76	25.56	3.07	1.90	0.15	0.14
2011	4	0.00	0.00	63.81	2.88	12.62	9.00	2.83	3.11	0.23	1.91	0.24	2.63	0.25	0.47	0.01
2012	43	0.00	0.84	11.29	54.02	5.30	13.07	5.41	2.21	1.56	0.81	1.09	0.21	2.52	0.29	1.38
2013	10	0.00	0.00	1.36	4.70	4.33	2.26	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	14.91	12.60	23.94	8.97	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	5.61	1.85	0.00	0.53	0.00	0.34	0.68
2016	75	0.00	5.00	0.25	2.77	2.54	69.91	9.18	8.57	0.72	0.44	0.10	0.20	0.14	0.02	0.14
2017	75	6.93	0.33	7.81	1.72	3.00	7.30	48.05	13.30	6.94	1.33	1.25	1.19	0.14	0.15	0.55
2018	47	0.48	5.12	1.94	22.24	1.20	4.50	5.94	35.73	12.37	4.42	2.53	1.17	0.92	1.17	0.26

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
2009	19	0.00	0.19	22.25	13.81	4.23	11.84	1.56	2.58	2.10	30.43	6.57	1.69	1.91	0.48	0.36
2010	17	0.00	4.25	4.24	31.07	25.60	6.09	4.11	2.02	2.59	3.20	11.41	3.43	0.63	0.67	0.70
2011	7	0.00	0.00	5.29	1.35	23.76	28.49	10.97	4.07	1.03	1.77	2.27	15.52	1.90	1.19	2.39
2012	101	0.00	0.05	2.90	25.18	6.26	29.03	13.78	3.49	3.85	1.05	1.31	1.80	8.24	1.95	1.09
2013	105	0.00	0.00	2.77	5.84	18.09	5.89	18.86	13.11	5.48	5.57	2.06	2.73	4.15	11.67	3.77
2014	79	0.00	0.00	0.97	13.25	10.05	24.60	5.36	14.17	7.62	4.77	3.18	1.44	1.93	2.08	10.56
2015	74	0.00	0.28	2.59	2.67	58.75	12.33	11.62	3.20	3.84	2.24	0.81	0.64	0.15	0.25	0.62
2016	116	0.16	4.84	1.96	4.29	6.93	57.54	9.06	8.25	2.07	2.37	1.29	0.53	0.14	0.12	0.44
2017	76	0.00	0.58	7.30	2.42	5.47	5.07	49.97	12.28	9.77	2.37	2.50	1.37	0.21	0.19	0.50
2018	83	0.10	4.67	0.54	17.73	2.61	3.91	5.07	45.54	9.42	5.37	2.52	0.97	0.71	0.61	0.23

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 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	8.16	11.23	5.01	8.94	11.08	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	10.18	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	43.63	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	0.65	0.07	32.28	0.98	1.45	0.66	46.05	1.35	0.84	10.48	0.79	0.05	0.07	4.28
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	7.74
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	29.47	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	4.78	20.34	20.29	26.60	2.87	5.41	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	1.39	67.79	11.66	3.35	5.01	3.20	3.15	2.12	0.88	0.44	0.54	0.13	0.23
2004	501	0.00	0.02	5.34	6.13	68.29	8.11	2.18	4.13	2.51	1.27	1.07	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	1.01	0.43	0.14	0.19
2007	629	0.78	11.52	3.81	15.70	1.59	6.89	3.81	43.95	5.08	1.71	2.20	1.66	0.48	0.19	0.64
2008	794	0.76	9.89	30.84	2.41	14.47	1.03	3.63	3.17	27.78	2.98	1.12	0.72	0.48	0.31	0.41
2009	685	0.64	0.53	29.68	27.19	3.46	11.01	1.35	2.40	2.35	16.67	2.57	0.92	0.62	0.29	0.33
2010	874	0.03	25.92	3.41	35.41	21.16	2.24	2.87	0.42	0.57	0.96	5.61	0.88	0.27	0.10	0.16
2011	1,081	2.71	8.74	71.02	2.64	6.25	4.33	1.10	0.76	0.30	0.35	0.12	1.32	0.17	0.10	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	0.55	70.31	5.90	10.47	1.12	3.41	2.06	0.91	1.37	0.26	0.33	0.53	2.28	0.46
2014	1,153	0.00	3.30	3.68	64.42	6.98	12.08	1.59	3.12	1.83	0.81	0.46	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	1,440	0.29	50.19	1.69	4.47	2.48	32.87	2.77	3.23	0.76	0.44	0.37	0.23	0.06	0.05	0.07
2017	1,300	3.66	0.73	38.55	2.36	4.13	3.10	36.98	4.28	3.07	1.28	0.62	0.72	0.21	0.09	0.21
2018	1,059	5.42	23.44	1.62	28.77	1.68	2.91	3.12	24.17	4.40	2.01	0.98	0.62	0.42	0.35	0.08

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	1.569	0.048	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. Information on maturity and fecundity used in this assessment as shown in Figure 11. 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. Mean fecundity is the product of maturity and mean weight, but note that year-specific fecundities from 1975-2018 were used in the stock assessment. The values reported for ages 15 and above represent the average across all samples in this range.

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

Table 15. Number of Pacific Hake ovaries collected for histological analysis. The maturity ogive was determined from a subset of these samples (up to and including 2017) – see Edwards et al. (2018*b*).

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	**263**
2012	71	199	0	0	0	**270**
2013	70	254	0	104	103	**531**
2014	276	0	0	105	142	**523**
2015	293	193	0	98	112	**696**
2016	277	26	309	100	162	**874**
2017	109	65	134	93	113	**514**
2018	147	64	0	0	0	**211**
Total	**1,506**	**801**	**443**	**500**	**632**	**3,882**

Table 16. Summary of estimated model parameters and priors in the base model. The Beta prior is parameterized with a mean and standard deviation. The Lognormal prior is parameterized with the median and standard deviation in log space.

Parameter	Number estimated	Bounds (low, high)	Prior (Mean, SD) single value = fixed
Stock Dynamics			
Log(R_0)	1	(13,17)	Uniform
Steepness (h)	1	(0.2,1)	Beta(0.78,0.11)
Recruitment variability (σ_r)	–	–	1.4
Log recruitment deviations: 1946–2018	73	(-6,6)	Lognormal(0,σ_r)
Natural mortality (M)	1	(0.05,0.4)	Lognormal(0.20,1.11)
Catchability and selectivity			
Acoustic Survey			
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
Fishery			
Non-parametric age-based selectivity: ages 2–6	5	(-5,9)	Uniform
Selectivity deviations (1991–2018, ages 2–6)	140	–	Normal(0,1.4)
Data weighting			
Dirichlet-Multinomial likelihood (log(θ))	2	(-5,20)	Uniform

Table 17. Select parameters, derived quantities, reference point estimates, and negative log likelihoods for retrospective analyses using the MLE estimates from the base model. Some values are implied since they occur after the ending year of the respective retrospective analysis.

	2019 Base model	-1 year	-2 years	-3 years	-4 years	-5 years
Parameters						
Natural mortality (M)	0.214	0.213	0.214	0.214	0.212	0.212
R_0 (millions)	2,070	2,063	2,185	2,188	2,024	2,035
Steepness (h)	0.865	0.865	0.867	0.867	0.865	0.866
Additional acoustic survey SD	0.260	0.262	0.256	0.255	0.264	0.290
Derived Quantities						
2008 recruitment (millions)	4,162	4,101	4,327	4,379	4,307	5,059
2010 recruitment (millions)	10,500	10,263	11,571	11,374	10,528	10,941
2014 recruitment (millions)	6,380	6,593	9,108	3,612	634	859
B_0 (thousand t)	1,718	1,716	1,800	1,812	1,706	1,704
2009 relative spawning biomass	28.4%	28.2%	28.1%	28.7%	29.5%	26.0%
2019 relative spawning biomass	48.6%	47.4%	57.7%	34.7%	17.3%	20.4%
Reference Points based on $F_{\mathbf{SPR}=40\%}$						
2018 rel. fishing intensity: (1-SPR)/(1-$SPR_{40\%}$)	93.3%	90.1%	78.9%	93.6%	113.7%	109.6%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	645	644	677	681	641	641
$SPR_{MSY\text{-}proxy}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	17.3%	17.4%	17.3%	17.2%	17.3%
Yield at $B_{F_{40\%}}$ (thousand t)	284	284	299	300	280	281
Negative log likelihoods						
Total	713.05	702.48	693.56	685.43	673.86	662.16
Survey	-6.73	-6.67	-6.26	-6.31	-5.46	-4.76
Survey age compositions	83.79	83.07	82.01	81.67	78.69	75.84
Fishery age compositions	525.14	516.79	510.43	503.90	496.44	487.07
Recruitment	48.79	47.99	47.03	45.79	45.10	45.20
Parameter priors	0.19	0.19	0.23	0.21	0.14	0.17
Parameter deviations	61.87	61.10	60.11	60.17	58.95	58.64

Table 18. Annual changes in the modeling framework used to assess Pacific Hake since 2011. The bias adjustment is reported as the maximum used for each assessment. Methods used to weight the age-composition data (Comp Method), i.e., McAllister-Ianelli (MI) and Dirichlet-Multinomial (DM) approaches, are explained in the main text.

Year	Framework	Survey	Bias Adjust	Comp Method	MCMC	Change
2011	SS 3.20, TINSS	yes	0.85	MI (0.10, 0.89)	999	Increased compatibility of SS and TINSS, except for age-composition likelihood
2012	SS 3.23b	yes	0.86	MI (0.12, 0.94)	999	One framework for base model; TINSS changed to CCAM
2013	SS 3.24j	no	0.86	MI (0.12, 0.94)	999	Developed MSE
2014	SS 3.24s	yes	0.86	MI (0.12, 0.94)	999	Time-varying fishery selectivity
2015	SS 3.24u	no	0.87	MI (0.12, 0.94)	999	No major changes
2016	SS 3.24u	yes	0.87	MI (0.11, 0.51)	999	Re-analyzed 1998-2015 acoustic-survey data; Removed 1995 survey data
2017	SS 3.24u	no	0.87	MI (0.14, 0.41)	999	Added 1995 survey data; Increased allowable selectivity variation to 0.20
2018	SS 3.30.10.00	yes	0.87	DM (0.45, 0.92)	2,000	Used DM to weight age compositions; Updated maturity and fecundity; Stopped transforming selectivity parameters
2019	SS 3.30.10.00	no	0.87	DM (0.46, 0.92)	2,000	Change to time-varying fecundity

Table 19. 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	1,567	1,389	788	495	339	245	193	161	139	121	106	93	82	72	62	281
1967	3,320	1,266	1,121	626	384	258	184	138	115	99	87	76	67	59	51	246
1968	2,280	2,681	1,020	880	471	279	183	120	90	75	65	57	50	44	38	195
1969	745	1,842	2,163	810	680	357	208	130	85	64	54	46	40	35	31	165
1970	6,183	602	1,484	1,703	614	500	256	139	87	57	43	36	31	27	24	132
1971	712	4,994	485	1,162	1,272	442	350	164	89	56	37	28	23	20	17	100
1972	412	575	4,027	384	894	957	326	245	115	63	39	26	19	16	14	82
1973	4,133	333	464	3,210	300	688	728	239	180	84	46	29	19	14	12	70
1974	301	3,338	268	369	2,497	229	519	526	173	130	61	33	21	14	10	59
1975	1,285	243	2,692	213	285	1,883	170	365	370	122	91	43	23	15	10	49
1976	173	1,038	196	2,141	165	217	1,417	123	263	267	88	66	31	17	10	42
1977	4,844	139	837	156	1,675	127	165	1,041	90	193	196	64	48	23	12	39
1978	109	3,913	113	671	124	1,311	99	126	790	68	147	149	49	37	17	39
1979	1,011	88	3,158	90	532	97	1,023	76	96	604	52	112	114	37	28	43
1980	13,741	816	71	2,529	71	416	75	775	57	73	457	40	85	86	28	54
1981	202	11,099	659	57	2,009	56	326	58	596	44	56	351	30	65	66	63
1982	216	163	8,956	526	45	1,558	43	243	43	444	33	42	262	23	49	96
1983	399	174	131	7,172	416	35	1,209	33	184	33	336	25	32	198	17	110
1984	11,079	322	141	105	5,690	327	28	926	25	141	25	258	19	24	152	97
1985	105	8,949	260	113	83	4,464	255	21	706	19	107	19	196	15	18	190
1986	150	85	7,224	209	90	66	3,506	197	16	545	15	83	15	152	11	161
1987	5,220	121	69	5,779	165	70	51	2,638	148	12	410	11	62	11	114	129
1988	1,788	4,216	98	55	4,535	127	53	38	1,955	110	9	304	8	46	8	180
1989	119	1,444	3,402	78	43	3,495	97	39	28	1,439	81	7	224	6	34	139
1990	3,500	96	1,165	2,699	60	32	2,604	69	28	20	1,020	57	5	159	4	123
1991	1,095	2,827	78	928	2,109	46	25	1,906	50	20	14	747	42	3	116	93
1992	126	884	2,280	60	637	1,581	34	18	1,374	36	15	10	539	30	2	151
1993	2,666	101	713	1,814	43	449	1,175	24	12	955	25	10	7	374	21	106
1994	2,814	2,153	82	571	1,370	32	320	851	17	9	691	18	7	5	271	92
1995	1,100	2,273	1,738	65	449	968	22	199	530	11	6	430	11	5	3	226
1996	1,562	889	1,835	1,394	52	346	671	15	131	348	7	4	283	7	3	151
1997	870	1,261	716	1,390	1,029	38	253	414	9	81	215	4	2	174	5	95
1998	1,629	703	1,018	572	967	692	27	156	255	6	50	132	3	1	107	61
1999	10,766	1,315	567	799	357	664	401	17	96	157	3	31	82	2	1	104
2000	316	8,695	1,060	411	523	200	413	239	10	57	94	2	18	49	1	63
2001	1,007	255	7,020	845	299	376	134	254	147	6	35	58	1	11	30	39
2002	28	814	206	5,619	627	199	251	87	165	96	4	23	37	1	7	45
2003	1,392	23	657	166	4,412	462	139	179	62	118	68	3	16	27	1	37
2004	76	1,125	19	529	132	3,350	333	99	128	44	84	49	2	12	19	27
2005	2,158	62	907	15	396	79	2,341	221	66	85	29	56	32	1	8	30
2006	1,634	1,743	50	728	11	277	47	1,497	141	42	54	19	36	21	1	24
2007	21	1,320	1,404	36	516	7	163	28	884	84	25	32	11	21	12	15
2008	4,162	17	1,064	1,077	23	335	5	94	16	509	48	14	18	6	12	16
2009	1,057	3,362	14	815	697	16	192	3	50	8	268	25	8	10	3	15
2010	10,500	854	2,713	11	574	474	11	117	2	30	5	163	15	5	6	11
2011	339	8,481	689	2,077	7	296	285	7	76	1	20	3	106	10	3	11
2012	809	274	6,831	537	1,138	5	196	196	5	52	1	14	2	73	7	10
2013	337	653	220	5,314	387	729	3	137	136	4	36	0	9	2	51	11
2014	6,380	272	527	176	3,876	281	516	2	87	87	2	23	0	6	1	40
2015	87	5,153	219	409	125	2,798	199	336	1	57	57	1	15	0	4	27
2016	2,704	70	4,149	174	303	91	1,999	146	246	1	42	42	1	11	0	22
2017	1,469	2,184	56	2,938	128	202	61	1,342	98	165	1	28	28	1	7	15
2018	2,006	1,186	1,733	42	2,058	87	123	35	769	56	95	0	16	16	0	13
2019	1,988	1,620	932	1,208	30	1,450	61	68	19	424	31	52	0	9	9	7

Table 20. Estimated biomass-at-age at the beginning of the year from the base model (MLE; thousand t).

Year	Age																				
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1966	25	126	198	188	164	131	112	104	98	95	91	86	79	76	62	56	48	41	35	29	81
1967	52	115	282	238	187	138	107	89	82	78	74	70	64	62	51	46	40	34	29	25	79
1968	36	243	257	334	229	149	107	78	64	59	56	52	48	46	38	35	30	26	22	19	68
1969	12	167	545	307	330	190	121	84	60	50	46	43	39	37	31	28	25	21	19	16	62
1970	97	54	374	646	298	267	150	90	62	45	37	33	30	29	24	21	19	16	14	12	52
1971	11	452	122	441	618	236	204	106	63	44	31	25	22	21	17	16	14	12	11	9	41
1972	6	52	1,014	146	434	511	190	159	82	49	33	24	19	17	14	12	11	10	8	7	35
1973	65	30	117	1,219	146	367	425	155	127	66	39	26	18	15	12	10	9	8	7	6	31
1974	5	302	68	140	1,213	122	303	340	123	102	52	31	20	14	10	9	8	7	6	5	27
1975	71	38	804	78	175	1,187	134	319	358	110	89	73	35	28	19	20	16	14	12	11	60
1976	9	102	46	1,068	86	151	1,139	112	318	356	127	109	56	31	20	19	14	12	10	9	51
1977	266	12	337	76	988	85	124	861	88	214	242	85	68	40	26	17	11	8	7	6	36
1978	6	284	14	315	66	790	63	93	666	67	161	185	65	54	30	22	14	9	7	6	34
1979	49	7	761	23	310	67	785	67	88	626	63	140	174	58	50	26	14	9	6	4	25
1980	621	65	15	1,145	28	204	39	508	41	64	486	46	110	112	36	30	14	8	5	3	16
1981	8	1,192	141	20	1,057	22	171	32	445	32	46	366	33	88	99	26	20	9	5	3	13
1982	8	19	2,208	176	14	856	17	128	24	337	22	36	279	20	50	58	19	14	7	4	11
1983	14	22	18	2,446	154	12	629	16	114	23	296	23	33	205	23	55	55	18	14	6	14
1984	356	42	23	26	2,495	135	12	544	15	95	18	245	22	25	195	25	53	54	18	13	20
1985	3	1,557	60	30	37	2,453	140	13	526	13	78	16	171	14	12	130	11	24	24	8	15
1986	4	13	2,008	61	27	25	1,902	113	10	447	14	98	18	208	19	23	144	12	27	27	26
1987	116	18	10	2,190	46	20	18	1,524	89	8	313	11	58	14	137	12	15	95	8	18	35
1988	34	590	18	17	2,126	47	19	18	1,225	73	6	279	8	47	8	132	10	12	78	7	43
1989	2	201	931	24	13	1,795	43	16	14	901	53	4	196	4	28	7	70	5	7	41	26
1990	55	13	284	944	24	17	1,424	43	19	10	781	48	10	189	4	35	6	65	5	6	63
1991	17	386	21	343	970	24	13	1,126	36	17	16	537	27	4	140	7	42	7	77	6	82
1992	2	120	528	21	304	851	20	11	885	24	9	8	397	26	2	86	2	13	2	24	27
1993	41	13	177	614	17	204	580	12	6	524	13	13	7	230	13	1	40	1	6	1	24
1994	42	256	25	207	612	14	168	485	11	5	438	9	5	4	190	11	1	31	1	5	19
1995	17	252	466	22	217	519	14	124	348	8	4	319	9	4	2	134	8	1	21	1	16
1996	23	91	528	555	24	184	379	9	78	221	4	3	191	6	5	2	83	5	0	13	10
1997	13	117	254	601	507	21	138	242	5	49	136	4	1	124	3	2	1	59	3	0	17
1998	24	59	214	206	488	358	15	99	155	4	39	94	2	1	80	2	1	1	33	2	10
1999	157	180	142	276	152	350	223	9	59	111	2	24	62	1	1	54	1	1	0	21	7
2000	5	1,651	341	194	301	132	297	174	7	48	77	2	16	46	1	0	37	1	0	0	19
2001	15	13	2,013	409	195	250	100	219	126	5	34	57	1	12	30	1	0	24	1	0	13
2002	0	62	74	2,571	380	162	190	74	161	89	4	23	37	1	8	21	0	0	17	0	9
2003	20	2	168	72	2,305	272	104	123	45	93	52	2	13	21	0	5	13	0	0	10	6
2004	1	122	4	231	64	1,807	224	71	86	32	67	41	2	11	16	0	3	9	0	0	11
2005	30	7	236	6	202	44	1,352	142	44	60	23	45	26	1	8	12	0	2	6	0	8
2006	23	231	19	333	6	159	28	895	93	29	39	14	28	14	1	5	8	0	2	4	5
2007	0	57	306	14	275	4	100	18	580	59	19	24	9	18	10	0	2	4	0	1	5
2008	60	2	260	439	13	213	3	64	11	367	36	12	16	5	11	6	0	1	2	0	3
2009	16	224	3	280	328	10	129	2	37	7	206	21	8	8	3	7	4	0	1	1	2
2010	167	93	631	3	249	251	7	97	2	31	5	143	13	5	4	2	3	2	0	0	2
2011	6	716	169	672	3	152	170	5	65	1	19	4	113	10	3	4	1	2	1	0	2
2012	14	35	1,465	190	466	2	129	135	4	47	1	13	2	72	7	2	2	1	2	1	1
2013	6	85	63	1,910	182	372	2	98	100	3	36	1	12	2	54	5	2	2	1	1	2
2014	121	58	196	81	1,865	152	297	1	58	64	2	26	0	6	1	34	3	1	1	0	2
2015	1	391	54	160	56	1,317	110	200	1	39	41	1	14	0	4	1	26	3	1	1	2
2016	32	12	1,012	67	126	40	931	75	128	1	28	30	1	11	0	4	1	23	2	1	2
2017	12	297	16	1,160	62	105	34	741	57	108	0	20	22	1	6	0	2	0	10	1	1
2018	17	212	618	20	1,049	48	70	22	467	35	64	0	11	14	0	5	0	1	0	7	1
2019	31	147	235	459	15	774	36	44	14	333	26	48	0	9	9	0	2	0	1	0	4

Table 21. 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). Annual exploitation rates for ages 6+ are equivalent because those fish are fully selected.

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	1.45	3.55	5.24	6.45	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15
1967	0.00	0.22	2.54	6.17	9.05	11.09	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17	17.17
1968	0.00	0.13	1.56	3.83	5.65	6.95	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92	10.92
1969	0.00	0.19	2.26	5.49	8.07	9.90	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40
1970	0.00	0.24	2.79	6.76	9.89	12.11	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69	18.69
1971	0.00	0.15	1.73	4.23	6.23	7.67	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01	12.01
1972	0.00	0.10	1.18	2.89	4.28	5.27	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
1973	0.00	0.12	1.35	3.32	4.91	6.05	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53	9.53
1974	0.00	0.14	1.66	4.07	6.00	7.38	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58	11.58
1975	0.00	0.12	1.38	3.38	4.99	6.15	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69
1976	0.00	0.10	1.16	2.84	4.20	5.18	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19	8.19
1977	0.00	0.06	0.75	1.85	2.74	3.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39	5.39
1978	0.00	0.06	0.68	1.68	2.49	3.07	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89
1979	0.00	0.07	0.78	1.92	2.85	3.52	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60
1980	0.00	0.05	0.61	1.50	2.22	2.75	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38
1981	0.00	0.08	0.98	2.42	3.59	4.43	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02	7.02
1982	0.00	0.07	0.77	1.91	2.83	3.50	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55
1983	0.00	0.05	0.65	1.59	2.36	2.92	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65	4.65
1984	0.00	0.06	0.71	1.75	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	0.55	1.35	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	0.86	2.12	3.14	3.88	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16	6.16
1987	0.00	0.09	1.05	2.57	3.81	4.70	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43	7.43
1988	0.00	0.10	1.13	2.78	4.11	5.07	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02	8.02
1989	0.00	0.13	1.57	3.86	5.69	7.01	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00	11.00
1990	0.00	0.10	1.19	2.93	4.33	5.34	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44
1991	0.00	0.13	3.56	13.55	6.48	7.59	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69
1992	0.00	0.12	1.35	9.71	11.51	7.19	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64	12.64
1993	0.00	0.07	0.79	5.85	9.28	10.74	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39	9.39
1994	0.00	0.06	0.85	2.42	11.27	11.73	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71
1995	0.00	0.07	0.59	1.95	4.03	12.83	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87	16.87
1996	0.00	0.24	5.57	7.80	7.99	8.72	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
1997	0.00	0.07	0.90	12.54	15.14	11.37	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45	21.45
1998	0.00	0.16	2.50	20.60	13.48	25.59	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49
1999	0.00	0.17	9.23	17.22	27.76	20.77	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58	23.58
2000	0.00	0.04	1.24	8.83	9.90	15.46	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57	21.57
2001	0.00	0.07	0.81	7.31	16.14	15.57	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82	17.82
2002	0.00	0.03	0.39	2.51	7.85	12.12	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49	10.49
2003	0.00	0.02	0.26	1.59	5.40	9.71	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.77
2004	0.00	0.09	1.61	6.62	22.93	12.18	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13	16.13
2005	0.00	0.05	0.62	3.50	12.19	24.59	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83	18.83
2006	0.00	0.22	10.56	11.00	16.96	24.34	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33	24.33
2007	0.00	0.16	4.55	17.39	17.73	17.28	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98	25.98
2008	0.00	0.42	4.64	17.98	13.10	26.34	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57	31.57
2009	0.00	0.08	1.85	11.56	14.33	11.48	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50	22.50
2010	0.00	0.09	4.71	13.03	32.79	23.03	17.18	17.19	17.19	17.18	17.18	17.19	17.18	17.18	17.19	17.19	17.19	17.19	17.18	17.19	17.19
2011	0.00	0.25	3.17	29.13	17.39	16.26	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54	13.54
2012	0.00	0.25	3.32	9.72	18.75	12.47	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37
2013	0.00	0.09	1.19	8.74	8.95	11.09	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93	18.93
2014	0.00	0.16	3.53	10.80	9.61	11.28	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51	17.51
2015	0.00	0.29	1.62	7.60	9.15	10.40	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47	8.47
2016	0.00	1.11	11.11	7.71	15.81	14.86	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26
2017	0.00	1.58	7.51	12.00	14.45	22.04	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28	26.28
2018	0.00	2.48	12.38	8.43	11.51	11.49	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77	28.77

Table 22. 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	1,708	11,388	17,558	17,735	15,779	19,537	16,326	14,070	12,281	10,776	9,480	8,307	7,271	6,339	5,479	4,709	4,021	3,412	2,877	7,993
1967	0	2,749	28,449	38,630	34,780	28,574	31,510	23,704	19,808	17,072	14,900	13,075	11,502	10,079	8,822	7,691	6,647	5,714	4,879	4,139	13,188
1968	0	3,565	15,934	33,656	26,599	19,412	19,932	13,108	9,861	8,240	7,102	6,199	5,439	4,785	4,193	3,670	3,199	2,765	2,377	2,030	7,208
1969	0	3,547	48,770	44,483	54,909	35,313	32,055	19,959	13,125	9,874	8,251	7,111	6,207	5,446	4,791	4,198	3,675	3,204	2,769	2,380	9,250
1970	0	1,435	41,353	115,092	60,765	60,578	47,910	26,062	16,228	10,672	8,028	6,709	5,782	5,046	4,428	3,895	3,413	2,988	2,605	2,251	9,456
1971	0	7,353	8,378	49,134	79,328	33,861	42,032	19,738	10,738	6,686	4,397	3,307	2,764	2,382	2,079	1,824	1,605	1,406	1,231	1,073	4,823
1972	0	575	47,353	11,094	38,237	50,432	27,176	20,398	9,579	5,211	3,245	2,134	1,605	1,341	1,156	1,009	885	779	682	597	2,862
1973	0	383	6,287	106,682	14,742	41,638	69,352	22,809	17,120	8,040	4,374	2,723	1,791	1,347	1,126	970	847	743	654	573	2,903
1974	0	4,723	4,459	15,024	149,837	16,922	60,029	60,840	20,009	15,019	7,053	3,837	2,389	1,571	1,182	988	851	743	652	573	3,049
1975	0	285	37,087	7,191	14,227	115,858	16,475	35,380	35,858	11,793	8,852	4,157	2,261	1,408	926	697	582	502	438	384	2,135
1976	0	1,018	2,263	60,782	6,948	11,259	116,003	10,034	21,548	21,839	7,182	5,391	2,532	1,377	858	564	424	355	306	267	1,534
1977	0	89	6,283	2,890	45,966	4,319	8,918	56,097	4,852	10,420	10,561	3,473	2,607	1,224	666	415	273	205	171	148	871
1978	0	2,252	764	11,239	3,073	40,314	4,842	6,145	38,654	3,343	7,180	7,277	2,393	1,796	844	459	286	188	141	118	702
1979	0	58	24,625	1,734	15,160	3,419	57,259	4,232	5,371	33,783	2,922	6,275	6,360	2,092	1,570	737	401	250	164	124	717
1980	0	420	433	37,888	1,587	11,441	3,301	33,964	2,510	3,186	20,039	1,733	3,722	3,773	1,241	931	437	238	148	97	498
1981	0	9,272	6,487	1,387	72,090	2,488	22,851	4,062	41,792	3,089	3,920	24,657	2,133	4,580	4,642	1,527	1,146	538	293	182	733
1982	0	107	69,292	10,041	1,273	54,451	2,396	13,473	2,395	24,640	1,821	2,311	14,538	1,257	2,700	2,737	900	676	317	173	540
1983	0	95	848	114,204	9,840	1,029	56,271	1,521	8,554	1,520	15,644	1,156	1,467	9,230	798	1,715	1,738	572	429	201	452
1984	0	193	995	1,840	147,479	10,485	1,402	47,194	1,276	7,174	1,275	13,121	970	1,231	7,742	670	1,438	1,457	479	360	548
1985	0	4,145	1,422	1,522	1,675	110,804	10,092	830	27,938	755	4,247	755	7,767	574	729	4,583	396	851	863	284	538
1986	0	62	62,149	4,422	2,816	2,558	215,904	12,126	997	33,570	908	5,103	907	9,333	690	875	5,507	476	1,023	1,037	987
1987	0	108	717	148,569	6,265	3,282	3,787	196,135	11,016	906	30,496	824	4,636	824	8,479	627	795	5,002	433	929	1,838
1988	0	4,049	1,107	1,522	186,559	6,460	4,290	3,028	156,828	8,808	724	24,385	659	3,707	659	6,779	501	636	4,000	346	2,213
1989	0	1,936	53,564	3,013	2,439	244,883	10,676	4,331	3,057	158,303	8,891	731	24,614	665	3,742	665	6,843	506	642	4,038	2,583
1990	0	98	13,884	79,057	2,616	1,732	219,679	5,806	2,355	1,662	86,095	4,836	398	13,387	362	2,035	362	3,722	275	349	3,601
1991	0	3,714	2,771	125,832	136,781	3,522	2,388	184,798	4,884	1,981	1,398	72,424	4,068	334	11,261	304	1,712	304	3,131	231	3,323
1992	0	1,040	30,726	5,862	73,345	113,716	4,341	2,245	173,712	4,591	1,863	1,315	68,080	3,824	314	10,586	286	1,609	286	2,943	3,341
1993	0	69	5,623	106,185	4,038	48,241	110,358	2,240	1,158	89,639	2,369	961	678	35,131	1,973	162	5,462	148	830	148	3,243
1994	0	1,393	692	13,816	154,454	3,695	66,172	176,117	3,575	1,849	143,051	3,781	1,534	1,083	56,064	3,149	259	8,717	236	1,325	5,410
1995	0	1,701	10,209	1,279	18,089	124,215	3,737	33,580	89,374	1,814	938	72,594	1,919	778	549	28,451	1,598	131	4,424	120	3,418
1996	0	2,134	102,257	108,748	4,134	30,210	143,168	3,104	27,890	74,229	1,507	779	60,292	1,594	646	456	23,629	1,327	109	3,674	2,938
1997	0	883	6,440	174,337	155,809	4,330	54,211	88,878	1,927	17,314	46,081	935	484	37,430	989	401	283	14,669	824	68	4,105
1998	0	1,101	25,432	117,931	130,322	177,053	5,781	33,462	54,860	1,189	10,687	28,444	577	299	23,104	611	248	175	9,055	509	2,576
1999	0	2,200	52,332	137,698	99,122	137,995	94,511	3,905	22,606	37,063	803	7,220	19,216	390	202	15,608	413	167	118	6,117	2,084
2000	0	3,765	13,119	36,278	51,722	30,926	89,154	51,641	2,134	12,352	20,251	439	3,945	10,500	213	110	8,528	225	91	65	4,481
2001	0	167	56,949	61,727	48,322	58,514	23,860	45,306	26,242	1,084	6,277	10,291	223	2,005	5,336	108	56	4,334	115	46	2,310
2002	0	259	803	140,782	49,227	24,080	26,355	9,109	17,296	10,018	414	2,396	3,929	85	765	2,037	41	21	1,654	44	900
2003	0	5	1,703	2,645	238,311	44,915	14,958	19,317	6,676	12,677	7,343	303	1,756	2,880	62	561	1,493	30	16	1,213	691
2004	0	1,049	299	35,038	30,160	407,909	53,761	15,939	20,583	7,114	13,508	7,824	323	1,871	3,068	67	598	1,591	32	17	2,029
2005	0	33	5,670	514	48,255	19,506	440,752	41,631	12,342	15,939	5,509	10,460	6,059	250	1,449	2,376	52	463	1,232	25	1,584
2006	0	3,876	5,268	80,050	1,935	67,328	11,360	364,269	34,406	10,201	13,173	4,553	8,645	5,007	207	1,198	1,964	43	383	1,018	1,330
2007	0	2,110	63,860	6,184	91,541	1,293	42,446	7,165	229,746	21,700	6,434	8,308	2,872	5,452	3,158	131	755	1,238	27	241	1,481
2008	0	70	49,351	193,665	3,039	88,283	1,544	29,708	5,014	160,798	15,188	4,503	5,815	2,010	3,816	2,210	91	529	867	19	1,205
2009	0	2,739	251	94,259	99,893	1,839	43,195	579	11,150	1,882	60,352	5,700	1,690	2,182	754	1,432	830	34	198	325	459
2010	0	779	127,856	1,404	188,249	109,085	1,941	20,022	269	5,168	872	27,974	2,642	783	1,012	350	664	385	16	92	364
2011	0	21,075	21,845	604,858	1,295	48,159	38,619	1,000	10,320	138	2,664	450	14,419	1,362	404	521	180	342	198	8	235
2012	0	688	226,733	52,185	213,454	606	24,268	24,220	627	6,472	87	1,671	282	9,043	854	253	327	113	215	124	152
2013	0	559	2,612	464,435	34,636	80,829	640	25,889	25,838	669	6,905	93	1,782	301	9,647	911	270	349	121	229	295
2014	0	429	18,611	18,957	372,426	31,754	90,384	378	15,288	15,257	395	4,077	55	1,052	178	5,697	538	160	206	71	310
2015	0	14,908	3,561	31,075	11,422	290,931	16,854	28,493	119	4,819	4,810	125	1,285	17	332	56	1,796	170	50	65	120
2016	0	780	461,080	13,393	47,833	13,470	305,069	22,211	37,551	157	6,351	6,339	164	1,694	23	437	74	2,367	224	66	244
2017	0	34,533	4,216	352,508	18,548	44,439	16,075	352,717	25,680	43,416	182	7,343	7,329	190	1,958	26	506	85	2,736	258	358
2018	0	29,420	214,579	3,502	236,844	10,014	35,448	10,088	221,357	16,116	27,247	114	4,609	4,599	119	1,229	16	317	54	1,717	387

Table 23. 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	155	2,869	6,665	8,612	8,426	11,402	10,574	9,986	9,631	9,221	8,758	7,985	7,703	6,337	5,649	4,856	4,146	3,518	2,967	8,241
1967	0	249	7,166	14,664	16,889	15,258	18,389	15,353	14,058	13,388	12,750	12,080	11,056	10,676	8,820	7,930	6,854	5,891	5,030	4,268	13,599
1968	0	323	4,014	12,776	12,916	10,366	11,632	8,490	6,998	6,462	6,077	5,727	5,229	5,068	4,191	3,784	3,299	2,851	2,451	2,093	7,433
1969	0	321	12,285	16,886	26,664	18,857	18,707	12,927	9,315	7,743	7,060	6,570	5,967	5,769	4,790	4,329	3,789	3,303	2,855	2,454	9,538
1970	0	130	10,417	43,689	29,507	32,349	27,960	16,881	11,517	8,369	6,869	6,198	5,558	5,346	4,427	4,016	3,520	3,081	2,686	2,321	9,750
1971	0	665	2,110	18,651	38,522	18,082	24,530	12,785	7,620	5,243	3,762	3,056	2,657	2,523	2,078	1,881	1,655	1,450	1,269	1,107	4,973
1972	0	52	11,928	4,211	18,568	26,930	15,860	13,212	6,798	4,086	2,776	1,971	1,543	1,421	1,156	1,040	913	803	704	616	2,951
1973	0	35	1,584	40,496	7,159	22,235	40,474	14,773	12,150	6,305	3,742	2,516	1,721	1,427	1,125	1,000	873	766	674	591	2,993
1974	0	427	1,123	5,703	72,761	9,036	35,033	39,406	14,201	11,778	6,035	3,545	2,296	1,664	1,181	1,018	878	766	672	591	3,144
1975	0	45	11,078	2,630	8,739	73,060	12,971	30,915	34,704	10,702	8,586	7,039	3,392	2,675	1,811	1,912	1,598	1,377	1,202	1,054	5,860
1976	0	100	534	30,330	3,605	7,809	93,243	9,196	25,993	29,122	10,411	8,899	4,574	2,560	1,677	1,548	1,164	973	839	732	4,211
1977	0	8	2,526	1,411	27,129	2,872	6,679	46,404	4,745	11,516	13,033	4,567	3,657	2,144	1,399	916	603	453	379	326	1,924
1978	0	163	97	5,281	1,629	24,293	3,095	4,545	32,554	3,280	7,896	9,066	3,182	2,661	1,469	1,072	667	439	330	276	1,639
1979	0	4	5,935	449	8,825	2,348	43,958	3,770	4,902	35,030	3,503	7,833	9,747	3,246	2,818	1,461	795	495	325	245	1,420
1980	0	34	92	17,159	622	5,611	1,705	22,260	1,791	2,784	21,294	2,015	4,801	4,905	1,576	1,300	611	332	207	136	696
1981	0	996	1,386	475	37,948	979	12,006	2,218	31,193	2,225	3,226	25,676	2,344	6,160	6,929	1,852	1,390	653	355	221	889
1982	0	13	17,080	3,350	394	29,926	948	7,107	1,348	18,741	1,245	1,973	15,512	1,106	2,751	3,200	1,053	790	371	202	631
1983	0	12	115	38,944	3,635	337	29,261	765	5,286	1,073	13,767	1,075	1,520	9,517	1,055	2,541	2,576	847	636	299	670
1984	0	25	163	459	64,655	4,313	610	27,712	740	4,848	894	12,482	1,102	1,262	9,915	1,259	2,703	2,740	901	676	1,031
1985	0	721	327	408	739	60,898	5,524	499	20,819	524	3,071	648	6,756	543	492	5,141	445	955	968	318	603
1986	0	10	17,277	1,285	852	955	117,150	6,936	640	27,558	853	6,052	1,079	12,821	1,159	1,413	8,889	769	1,651	1,673	1,593
1987	0	16	99	56,308	1,745	942	1,371	113,268	6,582	577	23,293	810	4,288	1,022	10,201	887	1,126	7,082	613	1,315	2,602
1988	0	567	207	459	87,478	2,368	1,529	1,477	98,253	5,883	486	22,392	619	3,800	669	10,610	784	995	6,260	541	3,463
1989	0	269	14,660	918	715	125,723	4,683	1,760	1,579	99,145	5,878	441	21,557	445	3,099	749	7,708	570	723	4,548	2,909
1990	0	13	3,381	27,638	1,021	885	120,099	3,586	1,572	881	65,871	4,019	875	15,905	368	2,985	531	5,459	403	512	5,282
1991	0	508	763	46,520	62,892	1,810	1,298	109,160	3,522	1,684	1,538	52,037	2,605	341	13,571	725	4,079	725	7,460	551	7,917
1992	0	141	7,116	2,036	34,978	61,179	2,552	1,394	111,871	2,998	1,189	949	50,182	3,251	307	10,840	293	1,648	293	3,014	3,421
1993	0	9	1,398	35,933	1,599	21,897	54,462	1,124	565	49,221	1,208	1,214	695	21,553	1,183	111	3,742	101	569	101	2,221
1994	0	166	208	5,010	69,025	1,653	34,819	100,387	2,223	1,035	90,709	1,834	996	790	39,317	2,347	193	6,499	176	988	4,033
1995	0	188	2,738	427	8,746	66,604	2,412	20,873	58,737	1,373	594	53,821	1,542	708	374	22,644	1,272	105	3,521	95	2,720
1996	0	217	29,409	43,303	1,932	16,063	80,904	2,020	16,614	47,224	911	584	40,734	1,292	960	343	17,743	997	82	2,759	2,206
1997	0	82	2,289	75,348	76,829	2,371	29,561	51,843	1,128	10,511	29,100	807	288	26,642	655	349	246	12,752	716	59	3,568
1998	0	92	5,336	42,361	65,813	91,643	3,129	21,228	33,350	798	8,367	20,275	456	231	17,182	485	197	139	7,191	404	2,045
1999	0	301	13,093	47,575	42,137	72,654	52,633	2,237	13,828	26,055	534	5,768	14,516	343	148	12,779	338	137	97	5,008	1,706
2000	0	715	4,219	17,156	29,823	20,405	63,977	37,589	1,609	10,349	16,523	387	3,375	9,860	186	103	7,962	210	85	60	4,183
2001	0	9	16,327	29,894	31,540	38,882	17,821	39,094	22,450	954	6,045	10,075	224	2,104	5,297	106	55	4,233	112	45	2,256
2002	0	20	288	64,408	29,822	19,650	19,979	7,731	16,900	9,339	380	2,390	3,885	79	861	2,154	44	23	1,749	46	951
2003	0	1	434	1,152	124,517	26,433	11,228	13,226	4,900	10,026	5,643	229	1,428	2,273	53	507	1,350	27	14	1,096	625
2004	0	113	61	15,291	14,588	219,985	36,100	11,473	13,867	5,116	10,732	6,644	262	1,755	2,544	58	521	1,386	28	15	1,768
2005	0	4	1,476	224	24,658	10,730	254,578	26,789	8,315	11,374	4,355	8,380	4,918	193	1,555	2,316	50	451	1,201	24	1,544
2006	0	513	2,018	36,623	1,034	38,647	6,714	217,796	22,571	7,137	9,562	3,287	6,702	3,295	132	1,144	1,875	41	365	972	1,270
2007	0	91	13,934	2,365	48,801	722	26,041	4,605	150,621	15,442	4,994	6,224	2,360	4,665	2,477	112	647	1,061	23	207	1,268
2008	0	9	12,042	78,996	1,711	56,192	1,060	20,255	3,559	115,951	11,373	3,635	4,933	1,559	3,371	1,842	76	441	722	16	1,004
2009	0	183	62	32,340	47,070	1,172	28,949	402	8,321	1,548	46,314	4,640	1,715	1,856	723	1,480	857	35	205	336	475
2010	0	85	29,739	410	81,549	57,837	1,278	16,716	291	5,311	836	24,514	2,252	882	728	315	599	347	14	83	328
2011	0	1,779	5,367	195,853	502	24,763	22,978	673	8,803	129	2,602	483	15,271	1,400	426	480	166	315	183	8	216
2012	0	89	48,634	18,453	87,409	296	15,925	16,727	488	5,873	84	1,611	272	8,946	848	239	308	107	202	117	144
2013	0	72	751	166,964	16,269	41,255	401	18,549	18,888	556	6,897	100	2,193	337	10,305	961	285	368	127	241	311
2014	0	91	6,925	8,735	179,211	17,201	52,034	234	10,181	11,223	277	4,617	50	999	191	5,944	561	166	215	74	323
2015	0	1,132	880	12,135	5,077	136,970	9,322	16,948	80	3,315	3,453	104	1,224	18	361	70	2,244	212	63	81	150
2016	0	129	112,457	5,131	19,918	5,940	142,071	11,405	19,459	81	4,203	4,563	97	1,620	33	636	107	3,441	325	96	354
2017	0	4,703	1,195	139,135	8,981	23,197	8,986	194,735	14,876	28,394	110	5,277	5,839	147	1,595	25	480	81	2,599	245	340
2018	0	5,251	76,476	1,644	120,743	5,530	20,280	6,427	134,297	9,966	18,354	76	3,257	3,915	107	1,361	18	351	59	1,901	429

Table 24. 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 2019 the mean weights-at-age are used as per Figure 12). Estimated quantities are MLEs.

	1999 cohort				2010 cohort				2014 cohort			
Age	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	157.2	0.0	30.2	127.0	166.9	0.0	32.1	134.8	120.6	0.0	23.2	97.4
1	1,651.3	0.7	317.5	1,333.1	715.8	1.8	137.5	576.5	391.1	1.1	75.1	314.9
2	2,012.6	16.3	385.3	1,610.9	1,465.2	48.6	276.7	1,139.9	1,011.8	112.5	182.8	716.6
3	2,570.6	64.4	487.7	2,018.6	1,910.4	167.0	349.9	1,393.5	1,159.7	139.1	208.4	812.2
4	2,305.3	124.5	430.4	1,750.5	1,865.3	179.2	339.9	1,346.2	1,049.0	120.7	189.0	739.3
5	1,806.7	220.0	324.3	1,262.5	1,317.1	137.0	238.9	941.2	774.3			
6	1,352.1	254.6	232.9	864.7	931.0	142.1	164.0	624.9				
7	895.1	217.8	148.6	528.7	740.9	194.7	121.4	424.8				
8	579.7	150.6	95.2	333.9	466.8	134.3	75.1	257.4				
9	367.3	116.0	57.9	193.4	332.7							
10	205.8	46.3	34.6	124.9								
11	142.6	24.5	24.8	93.3								
12	112.8	15.3	20.1	77.4								
13	72.3	8.9	13.0	50.4								
14	54.4	10.3	9.4	34.8								
15	34.0	5.9	5.9	22.1								
16	26.5	2.2	4.9	19.4								
17	22.6	3.4	4.0	15.1								
18	9.9	2.6	1.6	5.7								
19	6.6	1.9	0.2	4.5								
20	4.2											

Table 25. 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 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	874	43.0%	2,284	2,089	1,608	49.1%	6.6%
1967	864	42.7%	2,348	2,125	4,320	67.2%	10.1%
1968	853	42.2%	2,465	2,094	2,754	48.8%	5.8%
1969	939	46.5%	2,772	2,544	736	60.3%	7.1%
1970	1,105	54.7%	2,965	2,759	8,446	67.1%	8.5%
1971	1,132	56.1%	3,175	2,570	794	50.4%	6.0%
1972	1,191	59.1%	3,601	3,538	506	38.5%	3.3%
1973	1,537	76.1%	3,675	3,548	5,692	42.4%	4.6%
1974	1,518	75.2%	3,692	3,281	357	48.6%	6.4%
1975	1,755	87.0%	4,688	4,539	1,704	53.5%	4.9%
1976	2,165	107.4%	4,950	4,800	207	46.6%	4.9%
1977	1,867	92.4%	4,614	4,251	6,261	31.1%	3.1%
1978	1,572	78.1%	3,751	3,389	138	30.7%	3.1%
1979	1,639	81.5%	4,236	4,156	1,300	33.2%	3.3%
1980	1,641	81.3%	4,491	3,639	16,569	25.8%	2.5%
1981	1,494	74.1%	4,721	3,274	260	37.4%	4.2%
1982	1,530	75.9%	5,218	5,169	298	31.4%	2.1%
1983	2,176	107.5%	4,988	4,940	493	30.0%	2.3%
1984	2,238	110.4%	5,235	4,730	13,535	34.8%	2.9%
1985	2,013	99.2%	6,247	4,387	137	23.5%	2.5%
1986	2,025	100.1%	6,071	6,043	179	41.0%	3.5%
1987	2,350	116.6%	5,465	5,294	6,287	46.1%	4.4%
1988	2,255	111.9%	5,504	4,749	2,035	47.3%	5.2%
1989	1,849	91.7%	5,004	4,769	120	53.9%	6.3%
1990	1,965	97.2%	4,595	4,512	4,232	48.4%	5.8%
1991	1,831	90.7%	4,426	3,943	1,164	71.9%	8.1%
1992	1,519	75.1%	3,790	3,657	134	61.4%	8.2%
1993	1,207	59.7%	2,849	2,786	3,091	53.0%	7.1%
1994	1,165	57.6%	2,838	2,495	3,259	63.5%	14.5%
1995	994	49.1%	2,807	2,497	1,205	55.8%	10.0%
1996	973	48.3%	2,687	2,560	1,788	70.4%	12.0%
1997	1,007	50.0%	2,547	2,398	1,043	72.3%	13.6%
1998	851	42.2%	2,097	1,998	1,920	87.1%	16.1%
1999	714	35.3%	2,070	1,677	12,633	97.1%	18.6%
2000	759	37.6%	3,823	1,921	318	68.9%	11.9%
2001	1,064	52.7%	3,985	3,956	1,203	69.1%	5.8%
2002	1,843	91.5%	4,350	4,274	32	48.3%	4.2%
2003	1,674	83.1%	3,690	3,662	1,655	43.9%	5.6%
2004	1,349	66.9%	3,088	2,942	61	72.3%	11.6%
2005	1,049	52.1%	2,484	2,440	2,622	70.0%	14.9%
2006	839	41.6%	2,153	1,851	1,886	83.9%	19.5%
2007	651	32.4%	1,693	1,630	25	87.5%	17.6%
2008	657	32.7%	1,742	1,665	5,063	90.9%	19.1%
2009	565	28.1%	1,512	1,220	1,297	79.8%	14.6%
2010	550	27.3%	2,036	1,706	13,583	96.6%	13.1%
2011	674	33.4%	2,580	1,660	390	91.4%	17.0%
2012	850	42.2%	3,213	3,154	1,114	72.5%	6.6%
2013	1,511	75.1%	3,660	3,529	375	69.7%	8.1%
2014	1,569	77.8%	3,719	3,494	8,467	67.1%	8.6%
2015	1,154	57.3%	3,089	2,561	85	52.8%	7.6%
2016	1,040	51.4%	3,267	3,176	3,895	79.9%	10.5%
2017	1,351	66.8%	3,676	3,069	2,177	83.7%	14.4%
2018	1,346	66.1%	4,042	3,551	1,003	81.8%	11.6%
2019	1,312	64.1%	3,493	3,232	983	–	–

Table 26. Time-series of 95% posterior credibility intervals for the quantities shown in Table 25.

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$_{40\%}$)	Exploitation fraction
1966	537-1,531	26.7- 70.5%	1,489- 3,955	1,292-3,679	75- 8,162	29.0- 72.7%	3.7-10.7%
1967	536-1,524	26.7- 69.7%	1,551- 4,092	1,336-3,660	341-12,358	42.1- 92.9%	5.9-16.0%
1968	529-1,512	26.3- 67.9%	1,614- 4,565	1,309-3,930	225- 8,401	28.0- 72.6%	3.1- 9.3%
1969	605-1,723	30.2- 76.4%	1,809- 5,076	1,646-4,724	62- 3,687	35.5- 85.5%	3.8-10.9%
1970	715-2,054	35.3- 89.8%	1,911- 5,617	1,797-5,112	4,271-19,391	40.4- 92.6%	4.6-13.1%
1971	719-2,111	35.9- 93.1%	2,007- 6,214	1,621-4,848	107- 2,558	26.9- 76.1%	3.2- 9.5%
1972	757-2,295	37.8-100.1%	2,227- 6,989	2,183-6,896	78- 1,569	19.4- 61.7%	1.7- 5.4%
1973	956-2,939	47.8-127.8%	2,282- 7,058	2,221-6,790	2,909-12,433	21.8- 66.1%	2.4- 7.3%
1974	948-2,891	47.4-125.6%	2,272- 7,117	2,041-6,238	50- 1,207	25.7- 74.6%	3.4-10.3%
1975	1,078-3,324	54.5-143.5%	2,842- 8,942	2,758-8,695	831- 3,863	27.7- 81.9%	2.5- 8.0%
1976	1,306-4,131	66.1-178.7%	2,968- 9,388	2,887-9,149	30- 828	23.9- 74.0%	2.6- 8.2%
1977	1,120-3,498	57.1-152.4%	2,774- 8,614	2,549-8,011	3,446-12,368	15.4- 53.5%	1.7- 5.2%
1978	957-2,898	48.9-126.3%	2,288- 6,887	2,062-6,255	21- 587	15.2- 53.0%	1.7- 5.0%
1979	1,017-2,922	51.4-128.6%	2,647- 7,462	2,596-7,336	488- 3,007	17.2- 55.2%	1.9- 5.3%
1980	1,035-2,816	52.2-126.0%	2,820- 7,791	2,289-6,221	9,876-30,908	13.3- 43.9%	1.4- 3.9%
1981	952-2,477	48.5-111.6%	3,041- 7,932	2,089-5,435	33- 987	20.7- 59.6%	2.6- 6.7%
1982	1,006-2,503	50.3-112.0%	3,413- 8,573	3,390-8,495	52- 951	17.1- 51.2%	1.3- 3.2%
1983	1,464-3,504	72.5-157.3%	3,374- 8,049	3,329-7,962	95- 1,368	16.5- 48.3%	1.4- 3.4%
1984	1,545-3,507	76.4-157.9%	3,623- 8,177	3,271-7,420	8,673-22,954	20.1- 54.7%	1.9- 4.2%
1985	1,423-3,058	70.1-139.1%	4,457- 9,671	3,105-6,632	20- 534	13.5- 37.4%	1.7- 3.6%
1986	1,479-2,973	72.4-135.3%	4,435- 9,105	4,416-9,034	31- 644	25.6- 59.6%	2.3- 4.8%
1987	1,758-3,432	84.8-157.3%	4,077- 7,999	3,956-7,730	4,127-10,443	29.2- 65.2%	3.0- 5.9%
1988	1,721-3,204	82.6-149.1%	4,167- 7,909	3,623-6,748	1,096- 3,704	30.2- 66.7%	3.7- 6.9%
1989	1,429-2,579	68.2-120.4%	3,847- 7,014	3,667-6,696	18- 435	36.2- 73.4%	4.5- 8.1%
1990	1,530-2,706	73.1-126.5%	3,565- 6,318	3,509-6,206	2,909- 6,684	32.3- 65.7%	4.2- 7.4%
1991	1,448-2,460	69.3-116.2%	3,495- 5,994	3,118-5,289	528- 2,246	48.8-101.4%	6.0-10.3%
1992	1,218-2,015	57.7- 95.2%	3,040- 5,052	2,935-4,852	20- 445	41.5- 91.5%	6.2-10.2%
1993	979-1,578	46.1- 75.3%	2,308- 3,760	2,266-3,683	2,125- 4,766	34.8- 81.3%	5.4- 8.8%
1994	963-1,509	44.7- 71.9%	2,322- 3,725	2,064-3,224	2,237- 4,983	45.3- 85.5%	11.2-17.6%
1995	821-1,291	38.3- 61.5%	2,291- 3,720	2,043-3,278	737- 1,964	40.3- 74.2%	7.6-12.2%
1996	806-1,272	37.4- 59.9%	2,214- 3,534	2,118-3,365	1,177- 2,806	52.1- 92.5%	9.1-14.5%
1997	839-1,317	38.5- 62.6%	2,102- 3,356	1,990-3,136	594- 1,814	53.6- 90.7%	10.4-16.3%
1998	707-1,118	32.7- 52.7%	1,728- 2,760	1,658-2,619	1,238- 3,089	67.3-104.5%	12.2-19.3%
1999	585- 944	27.4- 44.1%	1,664- 2,811	1,372-2,221	8,920-19,386	76.8-114.4%	14.0-22.7%
2000	607-1,031	29.0- 47.5%	2,955- 5,434	1,527-2,647	114- 668	50.2- 86.9%	8.6-15.0%
2001	842-1,450	40.2- 66.5%	3,129- 5,589	3,105-5,545	818- 1,912	50.2- 87.3%	4.1- 7.3%
2002	1,471-2,522	70.3-115.2%	3,481- 5,983	3,419-5,880	7- 114	33.0- 64.3%	3.1- 5.3%
2003	1,372-2,237	64.9-103.2%	3,026- 4,935	3,007-4,896	1,163- 2,639	29.8- 59.6%	4.2- 6.8%
2004	1,131-1,762	53.0- 82.0%	2,572- 4,061	2,464-3,842	12- 208	51.4- 96.7%	8.9-13.9%
2005	884-1,363	41.3- 63.3%	2,079- 3,271	2,045-3,206	1,850- 4,323	49.7- 91.8%	11.3-17.8%
2006	703-1,105	33.2- 51.0%	1,779- 2,913	1,552-2,451	1,320- 3,053	61.0-113.8%	14.8-23.3%
2007	537- 891	25.8- 40.0%	1,383- 2,344	1,332-2,253	5- 92	62.0-117.5%	12.7-21.5%
2008	529- 931	25.9- 41.5%	1,392- 2,506	1,333-2,381	3,582- 8,328	67.9-113.1%	13.4-23.9%
2009	441- 847	22.0- 36.5%	1,171- 2,268	955-1,825	735- 2,543	56.7-102.5%	9.8-18.7%
2010	420- 840	21.1- 36.0%	1,525- 3,171	1,309-2,604	8,606-25,332	70.3-124.6%	8.6-17.1%
2011	504-1,054	25.5- 45.2%	1,851- 4,241	1,235-2,599	153- 926	62.7-117.9%	10.9-22.9%
2012	595-1,420	30.3- 61.2%	2,220- 5,535	2,181-5,386	586- 2,367	46.9- 98.7%	3.8- 9.5%
2013	1,029-2,578	52.7-113.9%	2,462- 6,265	2,388-6,027	120- 1,168	44.8- 91.7%	4.7-12.0%
2014	1,028-2,740	53.8-119.7%	2,426- 6,615	2,276-6,197	4,183-19,352	41.6- 92.1%	4.8-13.1%
2015	731-2,093	38.4- 90.2%	1,925- 5,708	1,615-4,650	14- 463	29.9- 79.9%	4.2-12.0%
2016	630-1,941	33.2- 83.4%	1,936- 6,290	1,885-6,143	746-26,085	48.7-111.1%	5.4-17.6%
2017	744-2,766	38.8-117.7%	1,891- 7,855	1,683-6,282	215-21,018	51.7-119.2%	7.0-26.2%
2018	616-2,943	32.9-124.8%	1,742-11,332	1,518-9,486	61-15,086	45.9-131.0%	4.3-27.0%
2019	471-3,601	26.3-156.7%	1,290-10,020	1,166-9,695	62-16,416	–	–

Table 27. 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 (2018) base model.

	MLE	Posterior median	Posterior median from 2018 base model
Parameters			
Natural mortality (M)	0.214	0.231	0.230
Unfished recruitment (R_0, millions)	2,070	2,770	2,773
Steepness (h)	0.865	0.816	0.812
Additional acoustic survey SD	0.260	0.308	0.305
Catchability (q)	1.141	0.964	0.961
Derived Quantities			
2008 recruitment (millions)	4,162	5,063	5,096
2010 recruitment (millions)	10,500	13,583	13,369
2014 recruitment (millions)	6,380	8,467	8,583
Unfished female spawning biomass (B_0, thousand t)	1,718	2,026	2,032
2009 relative spawning biomass	28.4%	28.1%	29.3%
2019 relative spawning biomass	48.6%	64.1%	–
2018 relative fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	93.3%	81.8%	–
Female spawning biomass at $F_{SPR=40\%}$($B_{SPR=40\%}$, thousand t)	645	722	730
Reference Points (equilibrium) based on $F_{SPR=40\%}$			
SPR at $F_{SPR=40\%}$	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	18.3%	18.3%
Yield at $B_{SPR=40\%}$ (thousand t)	284	339	340

Table 28. Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1975–2018 averages for mean weight-at-age and baseline selectivity.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (B_0, thousand t)	1,649	2,026	2,682
Unfished recruitment (R_0, millions)	1,764	2,770	4,657
Reference points (equilibrium) based on $F_{SPR=40\%}$			
Female spawning biomass at $F_{SPR=40\%}$ (thousand t)	533	722	945
SPR at $F_{SPR=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{SPR=40\%}$	16.1%	18.3%	20.8%
Yield associated with $F_{SPR=40\%}$ (thousand t)	242	339	504
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	660	810	1,073
SPR at $B_{40\%}$	40.7%	43.4%	51.6%
Exploitation fraction resulting in $B_{40\%}$	12.5%	16.2%	19.4%
Yield at $B_{40\%}$ (thousand t)	241	329	493
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	373	514	828
SPR at MSY	22.4%	29.6%	46.9%
Exploitation fraction corresponding to SPR at MSY	14.6%	25.8%	34.7%
MSY (thousand t)	249	355	548

Table 29. 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, f), including catch similar to 2018 (row d) and the TAC from 2018 (row f), the catch values that result in a median relative fishing intensity of 100% (row g), the median values estimated via the default harvest policy ($F_{SPR=40\%}$–40:10) for the base model (row h), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2019 and 2020 (row i). Catch in 2021 does not impact the beginning of the year biomass in 2021.

Within model quantile Management Action			5%	25%	50%	75%	95%
	Year	Catch (t)	**Beginning of year relative spawning biomass**				
a:	2019	0	31%	48%	64%	85%	133%
	2020	0	35%	54%	73%	98%	163%
	2021	0	37%	56%	75%	102%	173%
b:	2019	180,000	31%	48%	64%	85%	133%
	2020	180,000	31%	50%	69%	94%	159%
	2021	180,000	29%	48%	67%	94%	166%
c:	2019	350,000	31%	48%	64%	85%	133%
	2020	350,000	27%	46%	65%	90%	155%
	2021	350,000	20%	40%	60%	87%	159%
d:	2019	410,000	31%	48%	64%	85%	133%
2018	2020	410,000	25%	44%	63%	89%	154%
catch	2021	410,000	17%	37%	57%	84%	156%
e:	2019	500,000	31%	48%	64%	85%	133%
	2020	500,000	23%	42%	61%	87%	152%
	2021	500,000	13%	33%	53%	81%	153%
f:	2019	597,500	31%	48%	64%	85%	133%
2018	2020	597,500	20%	39%	59%	85%	150%
TAC	2021	597,500	9%	29%	49%	77%	151%
g:	2019	587,419	31%	48%	64%	85%	133%
FI=	2020	556,709	21%	40%	59%	85%	150%
100%	2021	470,962	10%	30%	50%	78%	152%
h:	2019	725,593	31%	48%	64%	85%	133%
default	2020	643,698	17%	36%	56%	82%	147%
HR	2021	517,858	4%	25%	45%	73%	148%
i:	2019	660,812	31%	48%	64%	85%	133%
C2019=	2020	660,812	19%	38%	57%	83%	148%
C2020	2021	526,084	5%	26%	46%	74%	147%

Table 30. Decision table of forecast quantiles of Pacific Hake relative fishing intensity (1-SPR)/(1-$SPR_{40\%}$), expressed as a percentage, for the 2019–2021 catch alternatives presented in Table 29. 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:	2019	0	0%	0%	0%	0%	0%
	2020	0	0%	0%	0%	0%	0%
	2021	0	0%	0%	0%	0%	0%
b:	2019	180,000	25%	39%	50%	64%	87%
	2020	180,000	22%	35%	46%	61%	87%
	2021	180,000	20%	34%	47%	63%	90%
c:	2019	350,000	43%	62%	77%	93%	117%
	2020	350,000	38%	59%	75%	94%	123%
	2021	350,000	37%	60%	79%	100%	134%
d:	2019	410,000	48%	69%	84%	100%	124%
2018	2020	410,000	44%	66%	83%	103%	132%
catch	2021	410,000	42%	68%	88%	110%	144%
e:	2019	500,000	56%	78%	93%	109%	132%
	2020	500,000	51%	75%	94%	113%	142%
	2021	500,000	50%	78%	100%	123%	159%
f:	2019	597,500	63%	85%	101%	116%	138%
2018	2020	597,500	58%	84%	103%	123%	151%
TAC	2021	597,500	56%	88%	112%	135%	167%
g:	2019	587,419	62%	85%	100%	115%	137%
FI=	2020	556,709	55%	81%	100%	120%	148%
100%	2021	470,962	48%	77%	100%	125%	163%
h:	2019	725,593	71%	94%	109%	124%	145%
default	2020	643,698	61%	89%	109%	129%	158%
HR	2021	517,858	52%	84%	109%	135%	167%
i:	2019	660,812	67%	90%	105%	120%	141%
C2019=	2020	660,812	62%	90%	109%	129%	156%
C2020	2021	526,084	52%	84%	108%	134%	167%

Table 31. Probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (catch options explained in Table 29).

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	17%	8%	1%	0%	0%	0%
b: 180,000	40%	13%	2%	0%	2%	2%
c: 350,000	57%	17%	4%	0%	17%	12%
d: 410,000	61%	19%	5%	0%	25%	18%
e: 500,000	68%	22%	6%	1%	38%	30%
f: 597,500	72%	26%	9%	1%	51%	44%
g: 587,419	71%	25%	9%	1%	50%	43%
h: 725,593	77%	29%	12%	2%	65%	57%
i: 660,812	75%	27%	10%	2%	58%	50%

Table 32. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options, given the 2019 catch level shown in Table 31 (catch options explained in Table 29).

Catch in 2020	Probability $B_{2021}<B_{2020}$	Probability $B_{2021}<B_{40\%}$	Probability $B_{2021}<B_{25\%}$	Probability $B_{2021}<B_{10\%}$	Probability 2020 relative fishing intensity >100%	Probability 2021 default harvest policy catch <2020 catch
a: 0	53%	7%	0%	0%	0%	0%
b: 180,000	69%	15%	3%	0%	2%	2%
c: 350,000	77%	25%	9%	1%	19%	17%
d: 410,000	80%	29%	11%	2%	28%	26%
e: 500,000	84%	34%	15%	4%	43%	40%
f: 597,500	86%	40%	20%	6%	55%	53%
g: 556,709	85%	38%	19%	5%	50%	48%
h: 643,698	87%	44%	25%	9%	61%	60%
i: 660,812	87%	44%	24%	8%	62%	60%

Table 33. 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	McAllister Ianelli Weighting	Francis Weighting
Parameters										
Natural mortality (M)	0.214	0.220	0.212	0.212	0.217	0.238	0.253	0.214	0.215	0.213
R_0 (millions)	2,070	2,381	1,988	1,474	3,515	2,678	3,153	2,124	2,459	1,933
Steepness (h)	0.865	0.606	–	0.858	0.885	0.856	0.851	0.865	0.864	0.865
Additional acoustic survey SD	0.260	0.260	0.260	0.258	0.261	0.259	0.259	0.261	0.254	0.248
Additional age-1 index SD	–	–	–	–	–	–	–	0.195	–	–
Derived Quantities										
2010 recruitment (millions)	10,500	11,024	10,371	10,477	10,710	13,177	15,231	11,434	10,790	10,495
2014 recruitment (millions)	6,380	6,605	6,324	6,337	6,492	7,872	9,008	7,645	6,181	5,563
2016 recruitment (millions)	2,704	2,606	2,731	2,427	2,944	3,610	4,333	3,385	2,940	2,452
B_0 (thousand t)	1,718	1,869	1,674	1,239	2,844	1,817	1,910	1,757	2,015	1,609
2009 relative spawning biomass	28.4%	26.9%	29.0%	39.5%	17.3%	30.6%	31.6%	28.7%	24.0%	30.0%
2019 relative spawning biomass	48.6%	44.2%	50.1%	66.7%	30.1%	55.4%	59.5%	61.3%	42.5%	44.7%
Reference Points based on $F_{\mathbf{SPR}=40\%}$										
2018 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	93.3%	92.4%	93.6%	93.6%	92.2%	80.2%	72.5%	85.3%	93.4%	98.6%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	645	530	670	464	1,080	679	712	660	756	604
SPR$_{\text{MSY-proxy}}$	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%	17.5%	18.8%	19.6%	17.3%	17.4%	17.3%
Yield at $B_{F_{40\%}}$ (thousand t)	284	240	292	203	482	332	370	291	336	265
Negative log likelihoods										
Total	713.05	714.70	722.72	724.35	712.78	712.61	712.32	715.51	223.48	489.73
Survey	-6.73	-6.71	-6.74	-6.82	-6.69	-6.76	-6.77	-5.27	-6.93	-7.17
Survey age compositions	83.79	83.80	83.78	84.54	83.42	83.86	83.88	83.76	36.94	29.12
Fishery age compositions	525.14	525.13	525.13	531.70	522.51	525.38	525.53	526.11	99.07	352.83
Recruitment	48.79	49.66	48.53	52.09	51.87	47.83	47.42	49.31	40.04	50.33
Parameter priors	0.19	0.91	10.15	0.13	0.38	0.34	0.25	0.21	0.24	0.18
Parameter deviations	61.87	61.92	61.86	62.71	61.29	61.95	62.01	61.39	54.12	64.44

Table 34. 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	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)
Parameters						
Natural mortality (M)	0.214	0.216	0.213	0.214	0.217	0.217
R_0 (millions)	2,070	2,466	2,114	2,072	2,410	2,269
Steepness (h)	0.865	0.870	0.867	0.864	0.867	0.867
Additional acoustic survey SD	0.260	0.273	0.266	0.259	0.274	0.264
Derived Quantities						
2010 recruitment (millions)	10,500	11,095	10,016	10,680	11,502	10,626
2014 recruitment (millions)	6,380	7,694	5,918	6,544	8,864	6,890
2016 recruitment (millions)	2,704	17,716	5,434	2,022	10,810	5,853
B_0 (thousand t)	1,718	2,009	1,768	1,708	1,936	1,830
2009 relative spawning biomass	28.4%	24.0%	27.0%	28.8%	25.2%	26.7%
2019 relative spawning biomass	48.6%	134.2%	60.0%	46.8%	100.3%	64.9%
Reference Points based on $F_{\mathbf{SPR}=40\%}$						
2018 rel. fishing intensity: (1-SPR)/(1-$SPR_{40\%}$)	93.3%	78.7%	91.6%	95.0%	78.6%	82.9%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	645	757	665	641	728	688
$SPR_{MSY\text{-}proxy}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	17.5%	17.3%	17.3%	17.6%	17.5%
Yield at $B_{F_{40\%}}$ (thousand t)	284	338	293	283	327	308
Negative log likelihoods						
Total	713.05	536.60	639.68	758.95	799.49	807.68
Survey	-6.73	-6.31	-6.53	-6.77	-6.30	-6.58
Survey age compositions	83.79	82.38	83.94	83.35	82.23	82.94
Fishery age compositions	525.14	588.65	541.66	518.32	558.89	529.74
Recruitment	48.79	52.62	50.60	48.12	51.27	49.13
Parameter priors	0.19	0.28	0.17	0.22	0.34	0.32
Parameter deviations	61.87	-181.03	-30.18	115.72	113.07	152.14

Table 35. 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	Run 52	Run 53	Run 54	Run 55	Run 56	Run 57	Run 58
Parameters								
Natural mortality (M)	0.214	0.214	0.214	0.214	0.226	0.226	0.226	0.227
R_0 (millions)	2,070	2,073	2,073	2,072	2,377	2,333	2,333	2,378
Steepness (h)	0.865	0.861	0.861	0.865	0.880	0.863	0.863	0.880
Additional acoustic survey SD	0.260	0.259	0.259	0.259	0.259	0.259	0.259	0.259
Derived Quantities								
2010 recruitment (millions)	10,500	10,537	10,532	10,538	11,699	11,640	11,633	11,706
2014 recruitment (millions)	6,380	6,378	6,376	6,376	6,949	6,923	6,921	6,952
2016 recruitment (millions)	2,704	3,125	3,119	3,106	3,355	3,383	3,375	3,363
B_0 (thousand t)	1,718	1,721	1,721	1,719	2,509	2,479	2,479	2,509
2009 relative spawning biomass	28.4%	29.9%	29.9%	28.7%	20.8%	28.4%	28.4%	20.9%
2019 relative spawning biomass	48.6%	49.5%	50.4%	47.1%	36.2%	44.9%	45.9%	33.9%
Reference Points based on $F_{\mathbf{SPR}=40\%}$								
2018 rel. fishing intensity: (1-SPR)/(1-$\text{SPR}_{40\%}$)	93.3%	100.3%	97.2%	96.8%	91.8%	104.6%	101.1%	91.7%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	645	645	645	646	951	930	930	951
$\text{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.3%	17.3%	17.3%	17.3%	15.3%	15.3%	15.3%	15.3%
Yield at $B_{F_{40\%}}$ (thousand t)	284	284	284	284	368	359	358	368
Negative log likelihoods								
Total	713.05	711.33	711.32	711.38	713.29	713.08	713.08	713.29
Survey	-6.73	-6.78	-6.78	-6.78	-6.76	-6.77	-6.77	-6.77
Survey age compositions	83.79	83.70	83.69	83.70	83.74	83.74	83.74	83.74
Fishery age compositions	525.14	524.25	524.25	524.26	524.76	524.75	524.75	524.76
Recruitment	48.79	48.50	48.50	48.53	49.26	49.18	49.17	49.26
Parameter priors	0.19	0.18	0.18	0.20	0.81	0.71	0.71	0.81
Parameter deviations	61.87	61.48	61.48	61.48	61.48	61.47	61.47	61.47

Table 36. Summary of model runs that consider alternative assumptions concerning weight-at-age and time-vary fecundity, plus the two related runs from 2018. Results from the MCMC runs 53 and 54 are given in Appendices F and G. [a]Due to the configuration of Stock Synthesis (noted on page 23 of Edwards et al. 2018*b*), these runs necessitated setting the 2018 (not 2019) weight-at-age onwards to be the mean from 1975-2018. [b]Similarly, for the 2018 alternative run, the 2017 weight-at-age onwards was the mean from 2015-2017. [c]The 2018 onwards weight-at-age was the mean from 1975-2017. See Sections 3.8.1 and 3.8.2 for more details and Figures 57-60 for the various weight-at-age assumptions.

Model run when 2019 onwards weight-at-age is mean from 1975-2018	Model run when 2018 onwards weight-at-age is mean from 2016-2018	Time-varying fecundity?	Pre-1975 weight-at-age is 1975-1979?	Pre-1975 weight-at-age is 1975-2018?
Base model	54	Y		Y
55[a]	58	Y	Y	
53	52			Y
57[a]	56		Y	
2018 base[c]				Y
	2018 alternative[b]	Y	Y	

8 FIGURES

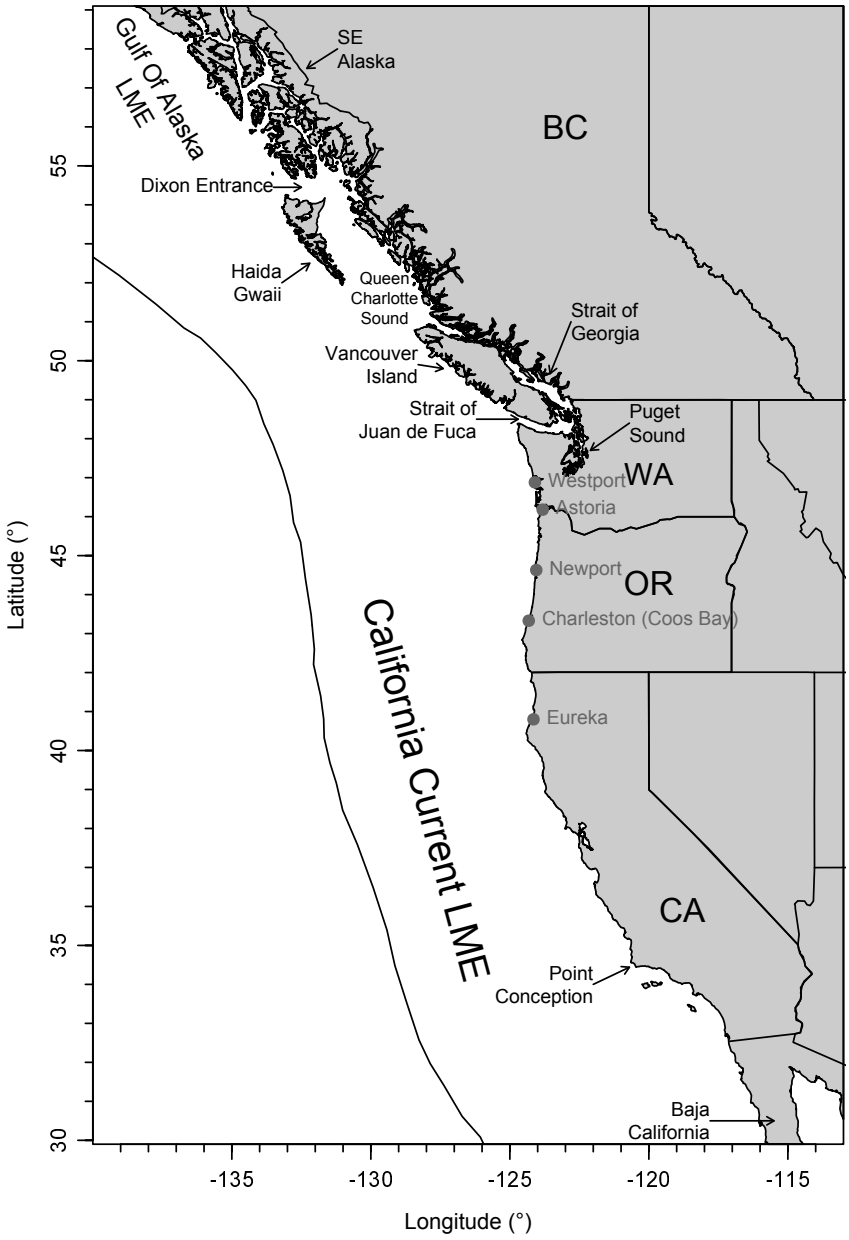

Figure 1. Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.

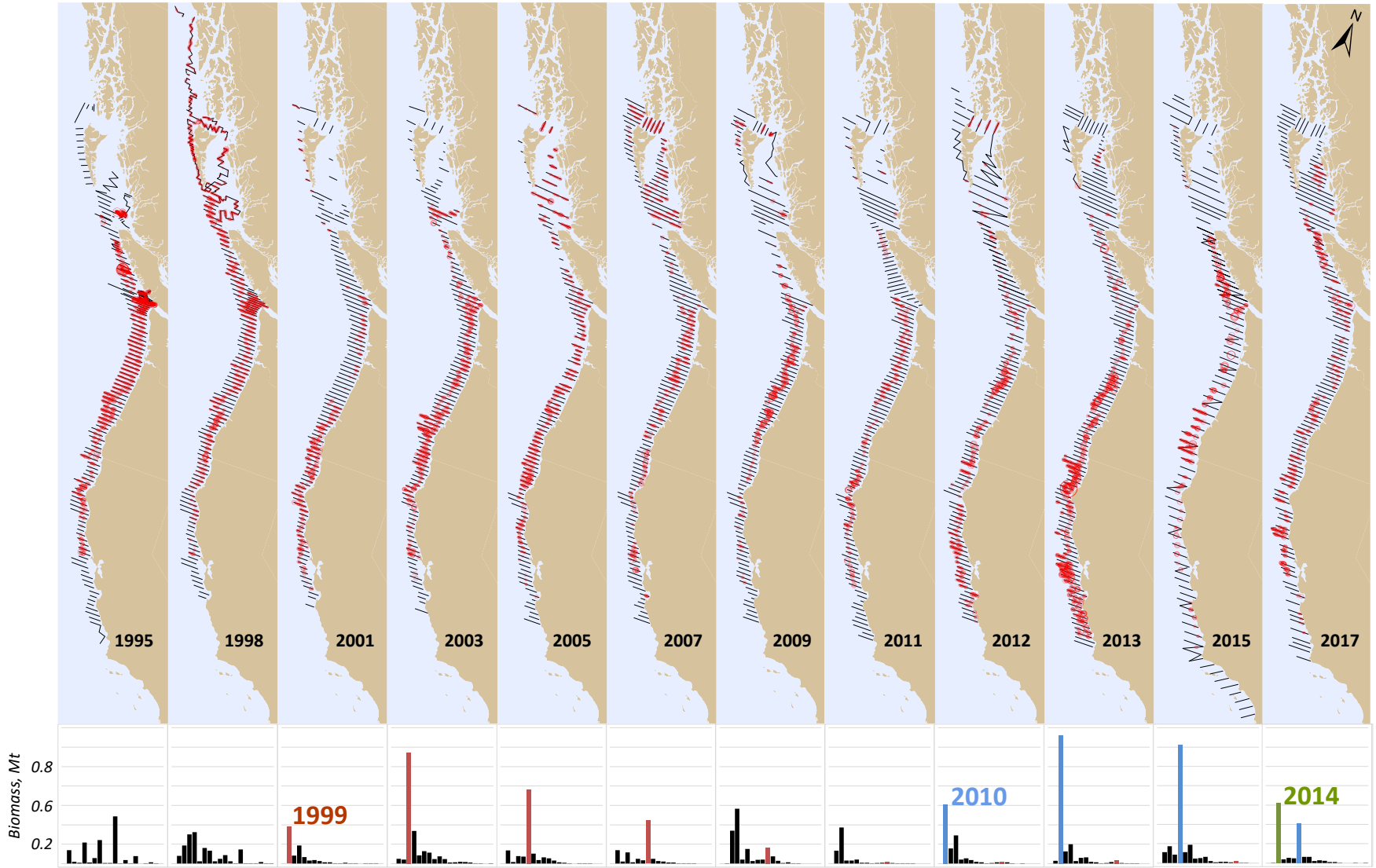

Figure 2. Spatial distribution of acoustic backscatter attributable to age-2 and older Pacific Hake from the Joint U.S. and Canada acoustic surveys 1995–2017. Area of the circle is roughly proportional to observed backscatter. Histograms show survey-estimated biomass for ages 2 to 20, with major cohorts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

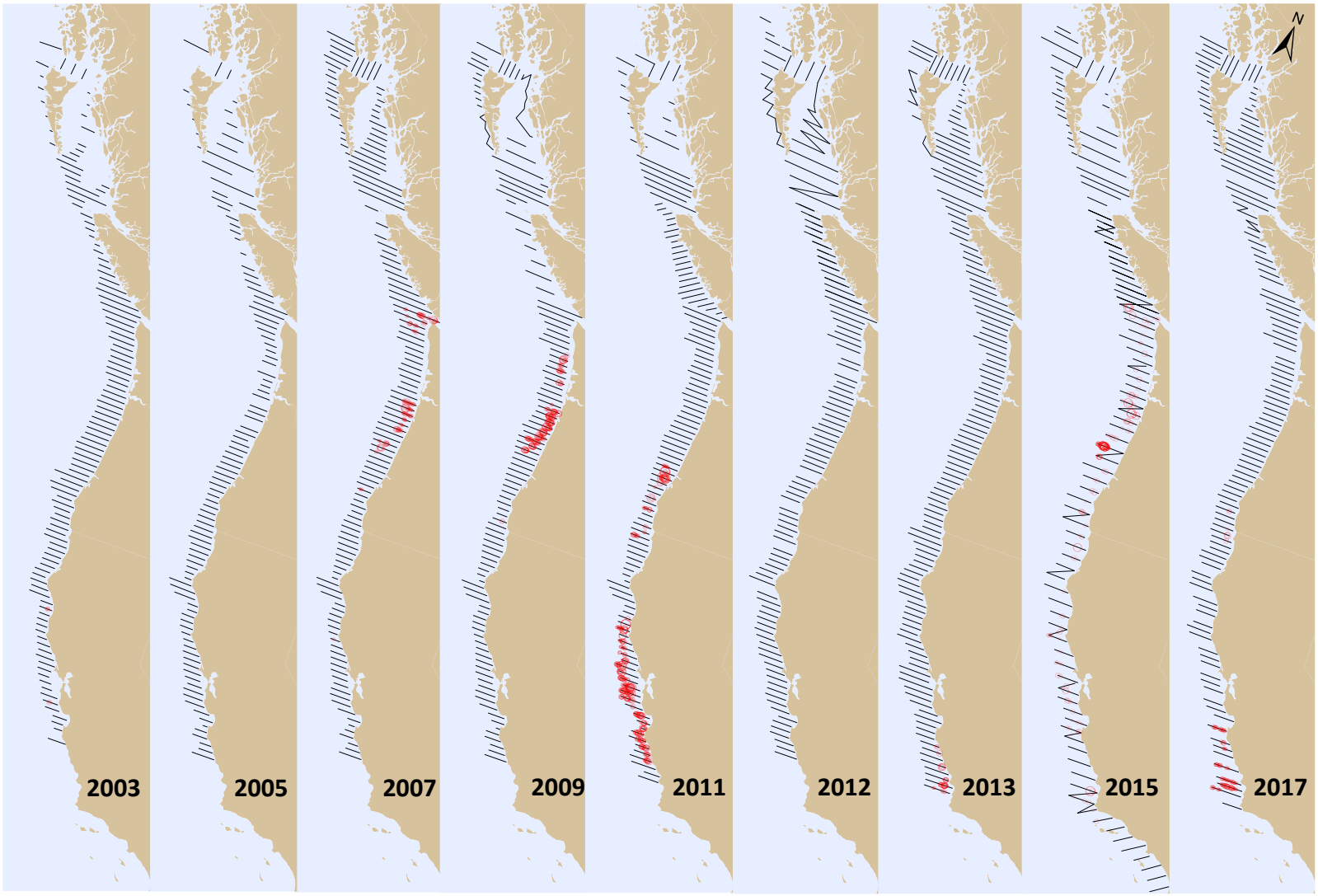

Figure 3. Spatial distribution of acoustic backscatter attributable to age-1 Pacific Hake from the Joint U.S. and Canada acoustic surveys 2003 –2017. Age-1 Pacific Hake are not fully sampled during the acoustic survey and were not explicitly considered during establishment of the survey sampling design.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

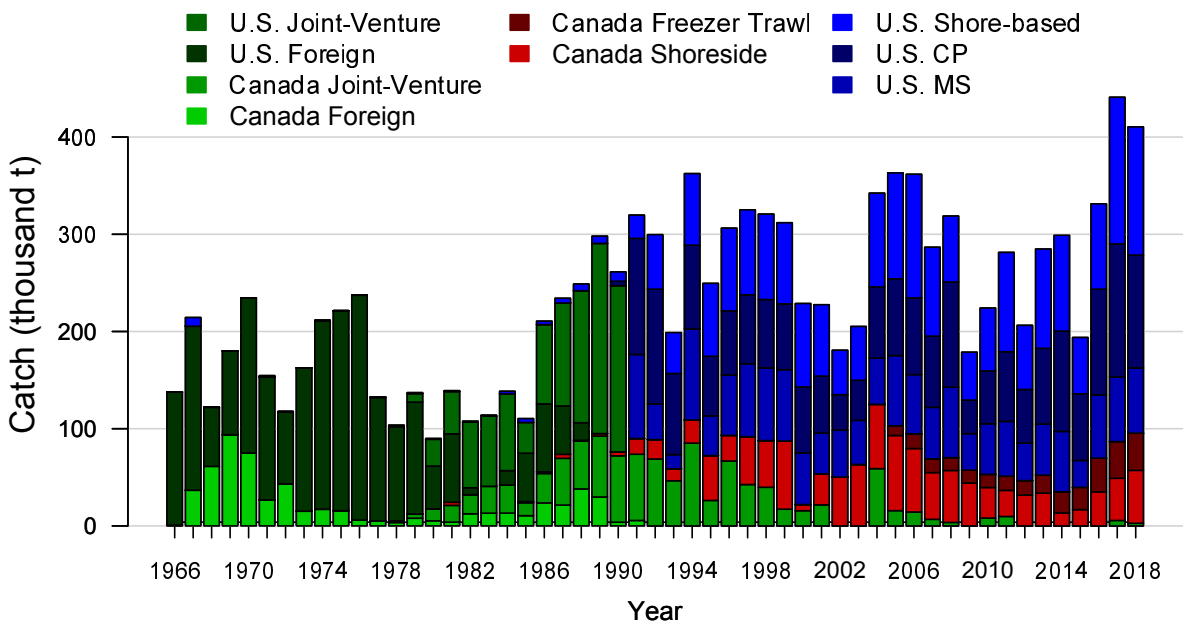

Figure 4. Total Pacific Hake catch used in the assessment by sector, 1966–2018. U.S. tribal catches are included in the appropriate sector.

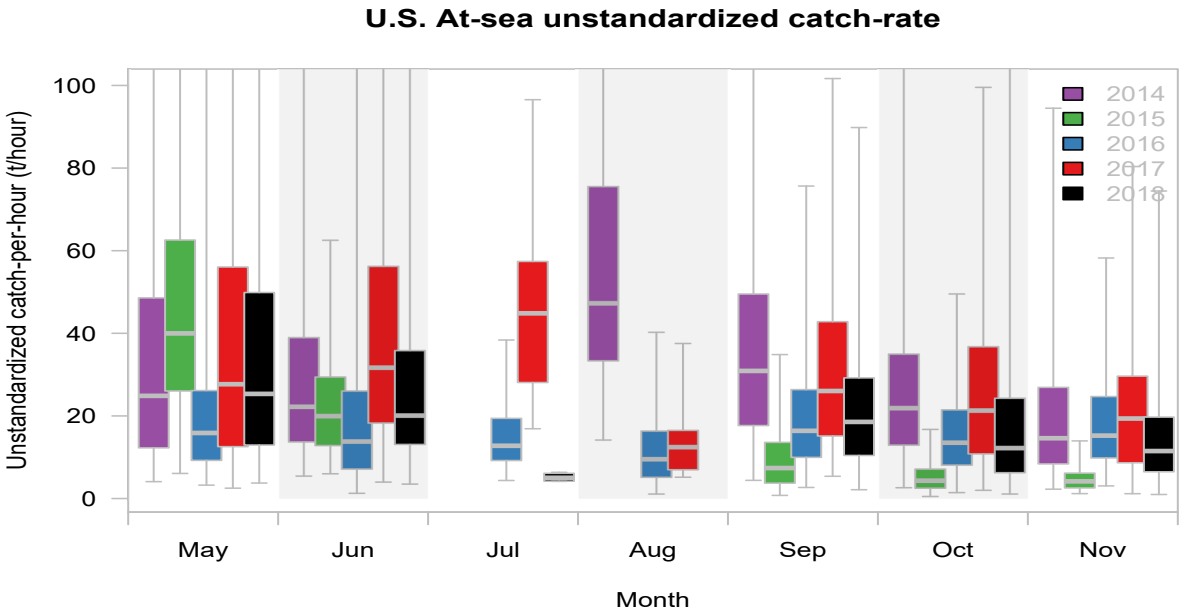

Figure 5. Unstandardized (raw) catch-rates (t/hr) of Pacific Hake catches by tow in the U.S. at-sea fleet from 2014–2018.

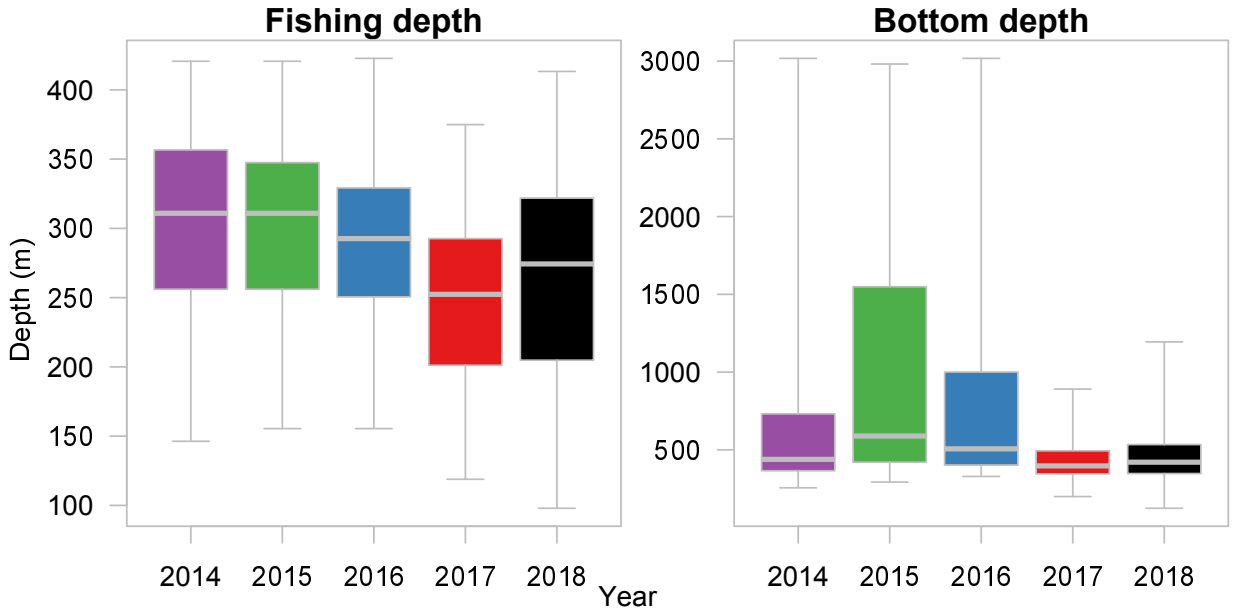

Figure 6. Distribution of fishing depths (left) and bottom depths (right), in meters, of Pacific Hake catches in the U.S. at-sea fleet from 2014–2018.

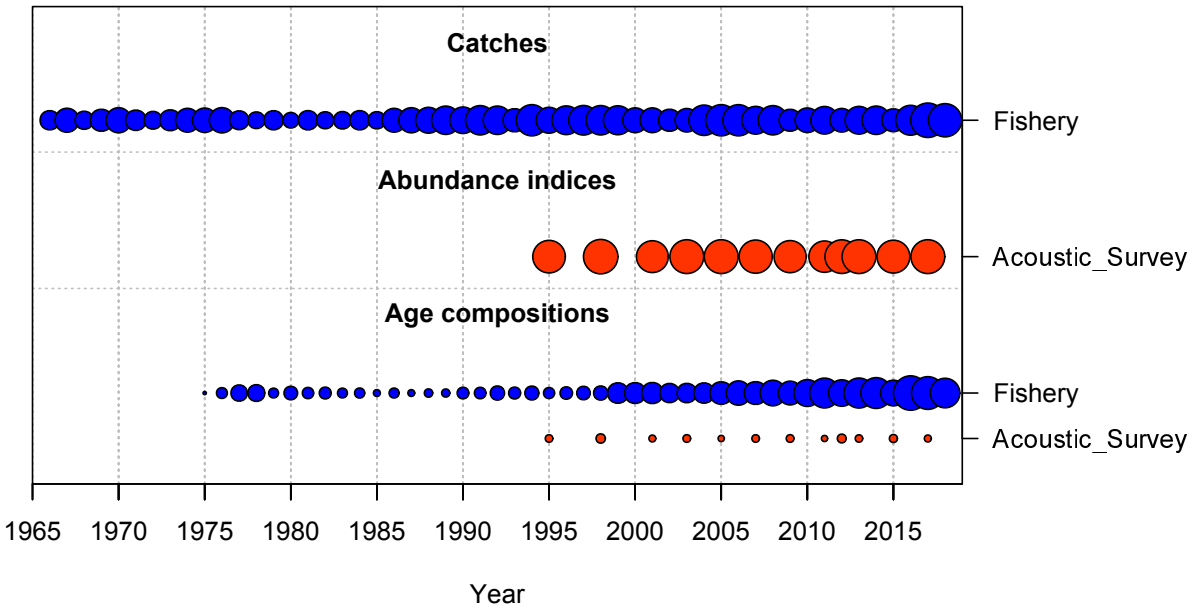

Figure 7. Overview of data used in this assessment, 1966–2018. Circle areas are proportional to the precision within the data type.

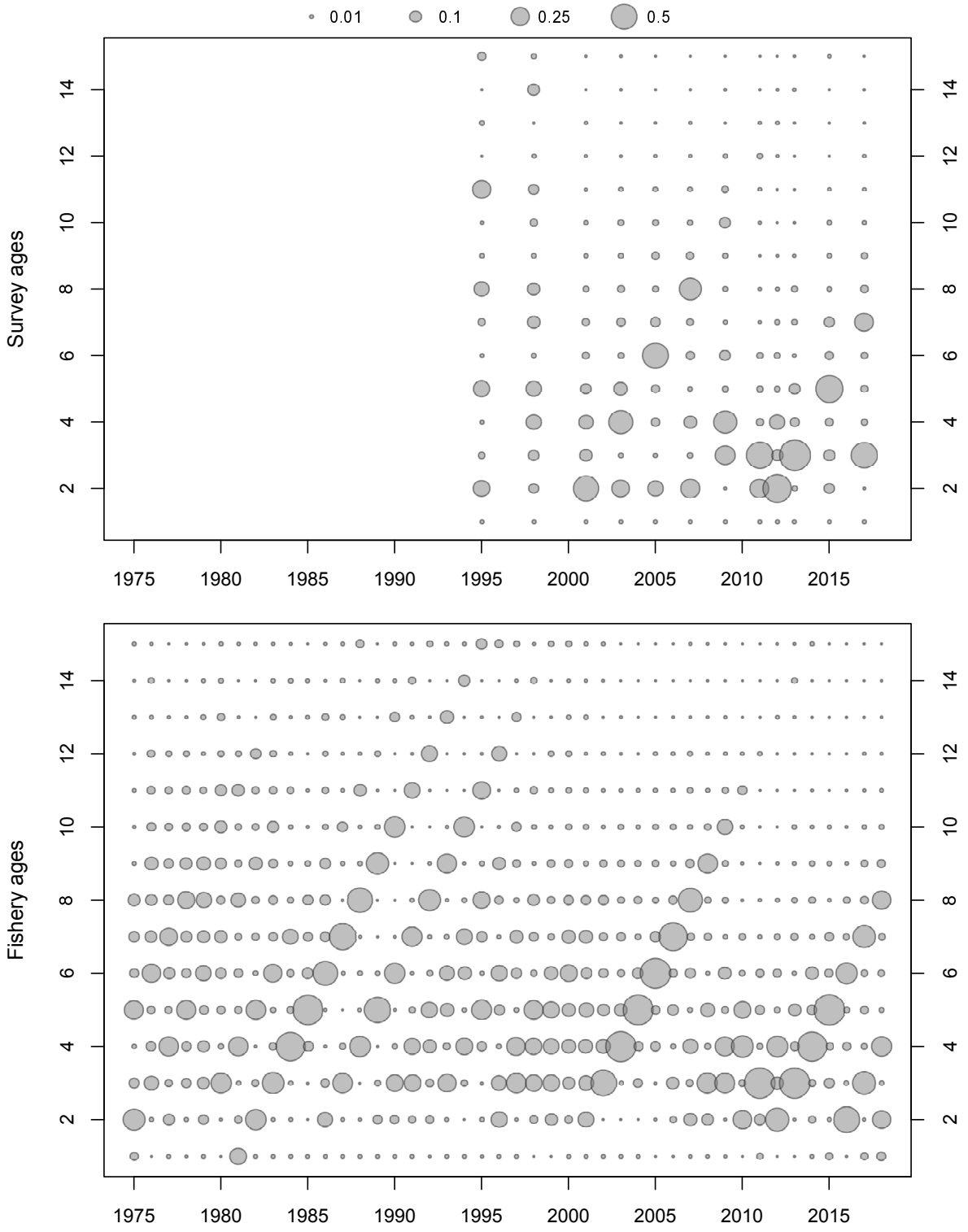

Figure 8. Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2018. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble in the survey data is 0.75 for age 3 in 2013 and in the fishery is 0.71 for age 3 in 2011.

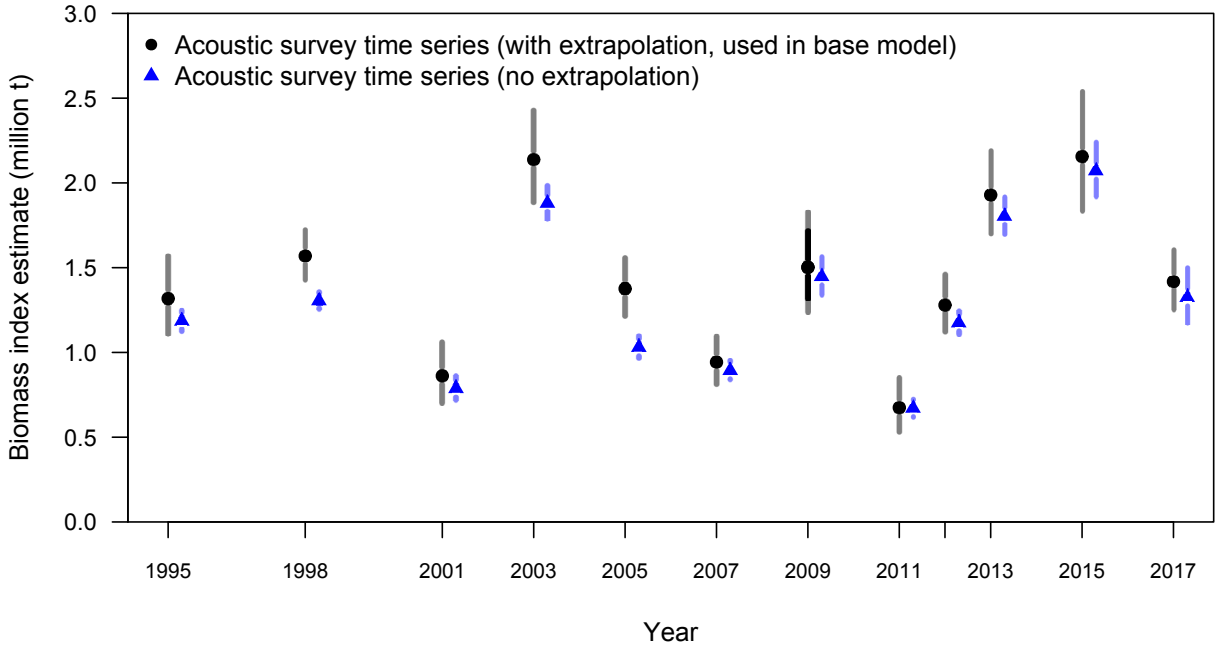

Figure 9. Acoustic survey biomass indices with and without extrapolation (millions of tons). Approximate 95% confidence intervals are based on sampling variability (intervals without squid/hake apportionment uncertainty in 2009 are displayed in black). See Table 13 for values used in the base model.

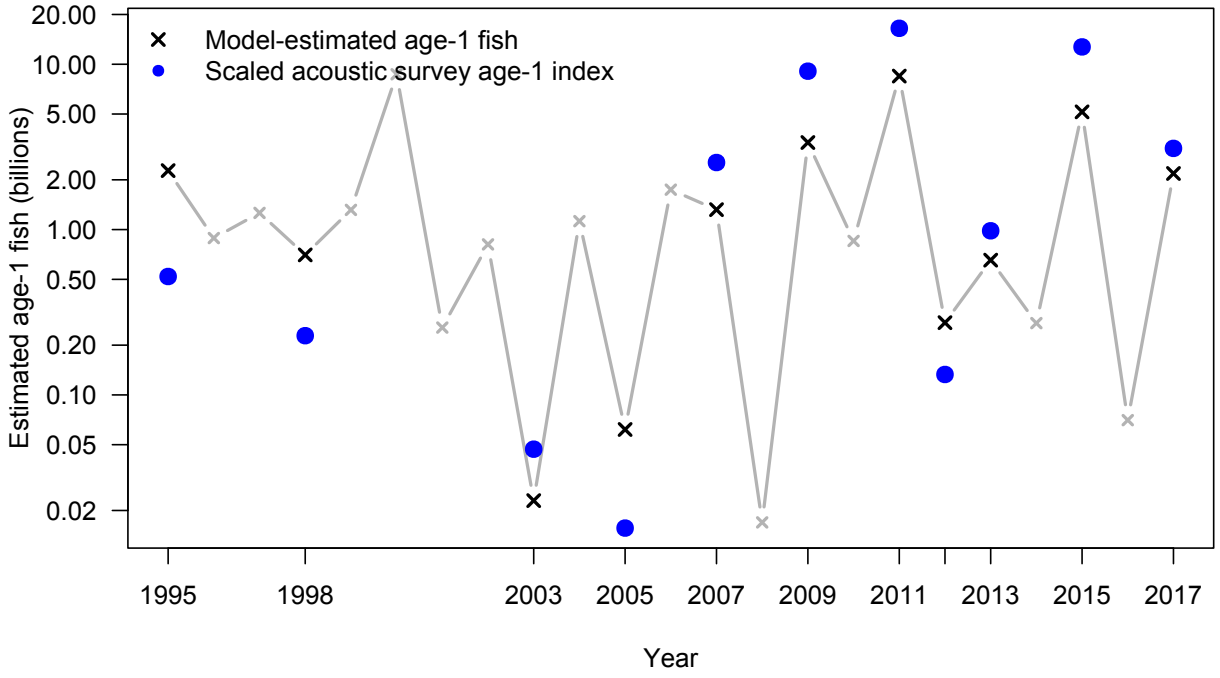

Figure 10. Preliminary acoustic survey age-1 index overlaid on estimated numbers of age-1 fish (MLE from the base model).

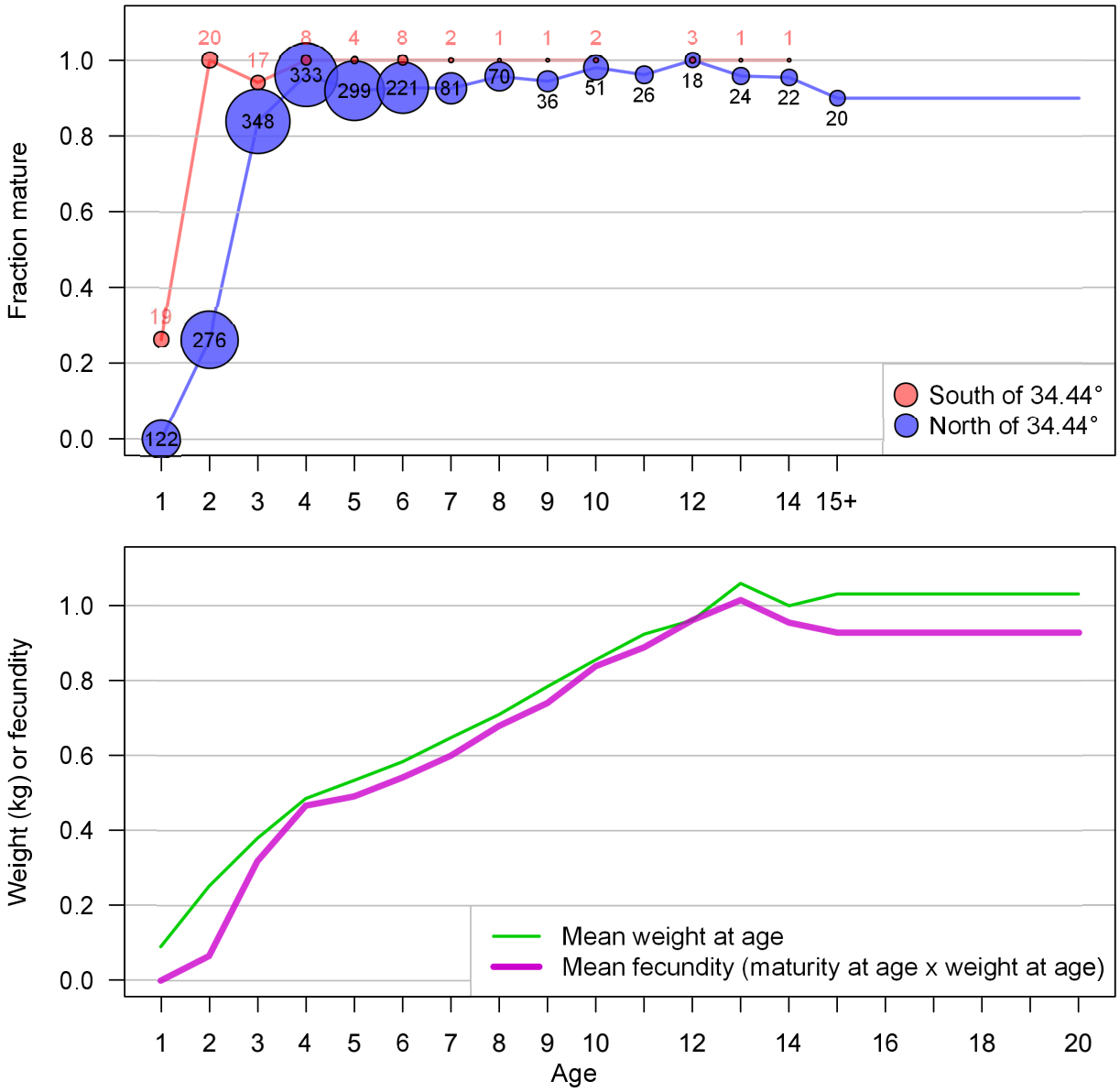

Figure 11. Fraction of fish that are mature at each age north and south of 34.44°N (upper panel) and the fecundity relationship (lower panel). The fecundity relationship (purple line) is the product of the weight-at-age and the maturity-at-age for the samples collected from North of 34.44°N (blue line in upper plot) averaged across 1975 to 2018.

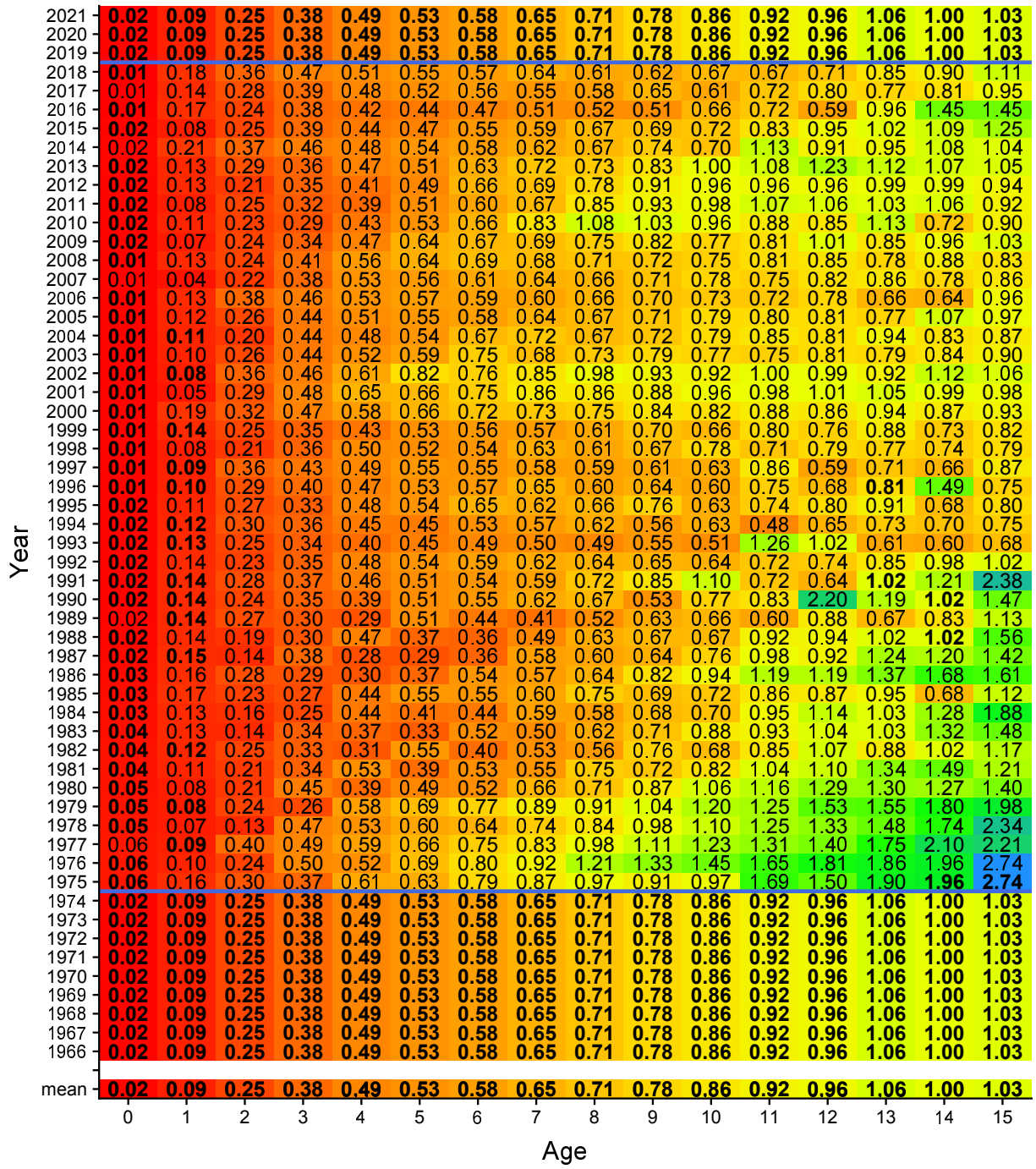

Figure 12. Empirical weight-at-age (kg) values used for the base model (the values match the colors). Data are only available from 1975–2018. Values based on assumptions for the early and late years are shown outside the blue lines (see Table 36); alternative assumptions were tested in sensitivity runs. Bold values between 1975–2018 represent unavailable data such that weights were interpolated or extrapolated from adjacent ages or years. The sample-weighted mean weight-at-age is shown at the bottom.

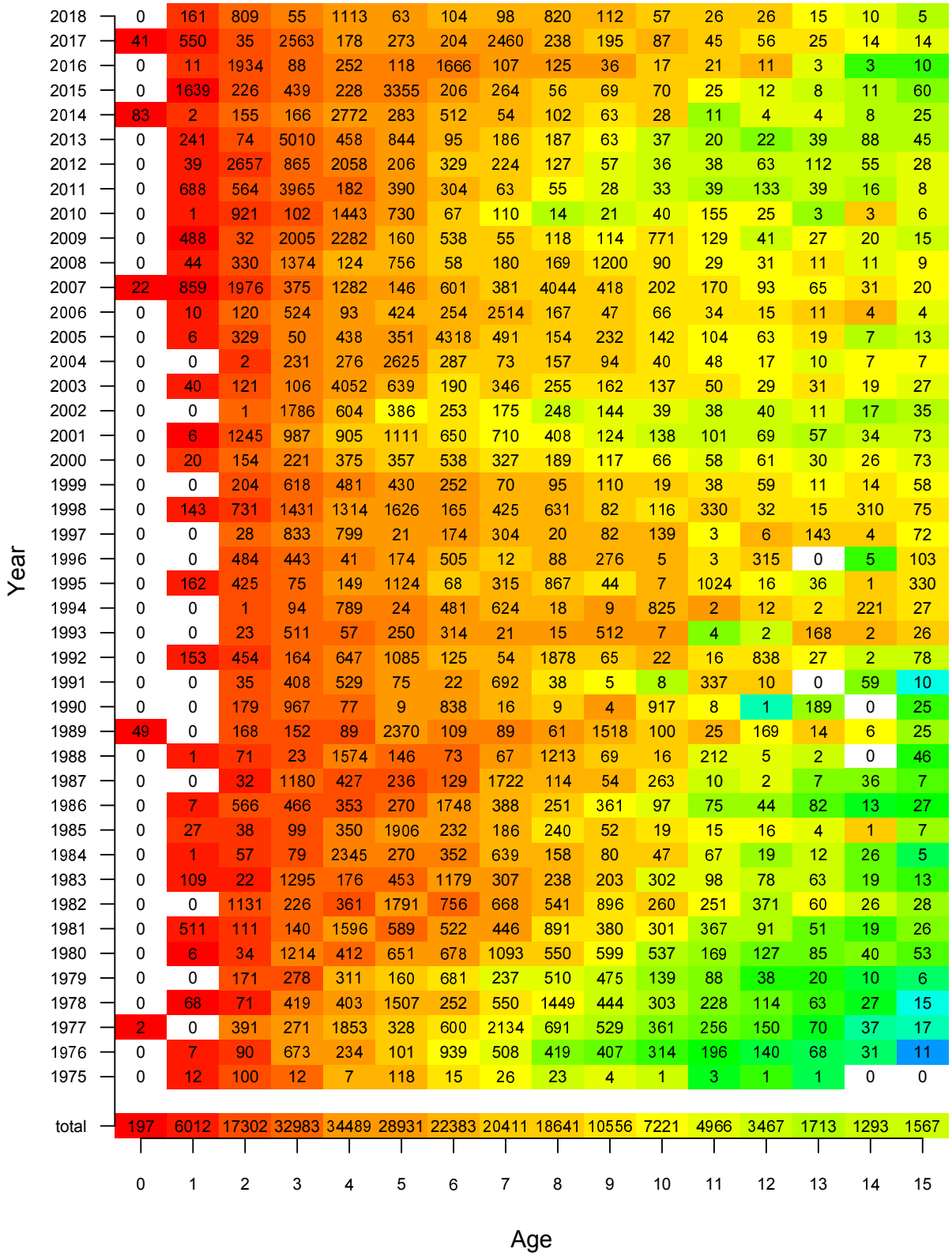

Figure 13. Sample sizes for developing empirical weight-at-age values used in the base model (colors represent empirical weight-at-age data, as shown in Figure 12). Data are available from 1975–2018. The total sample size for each age is shown at the bottom.

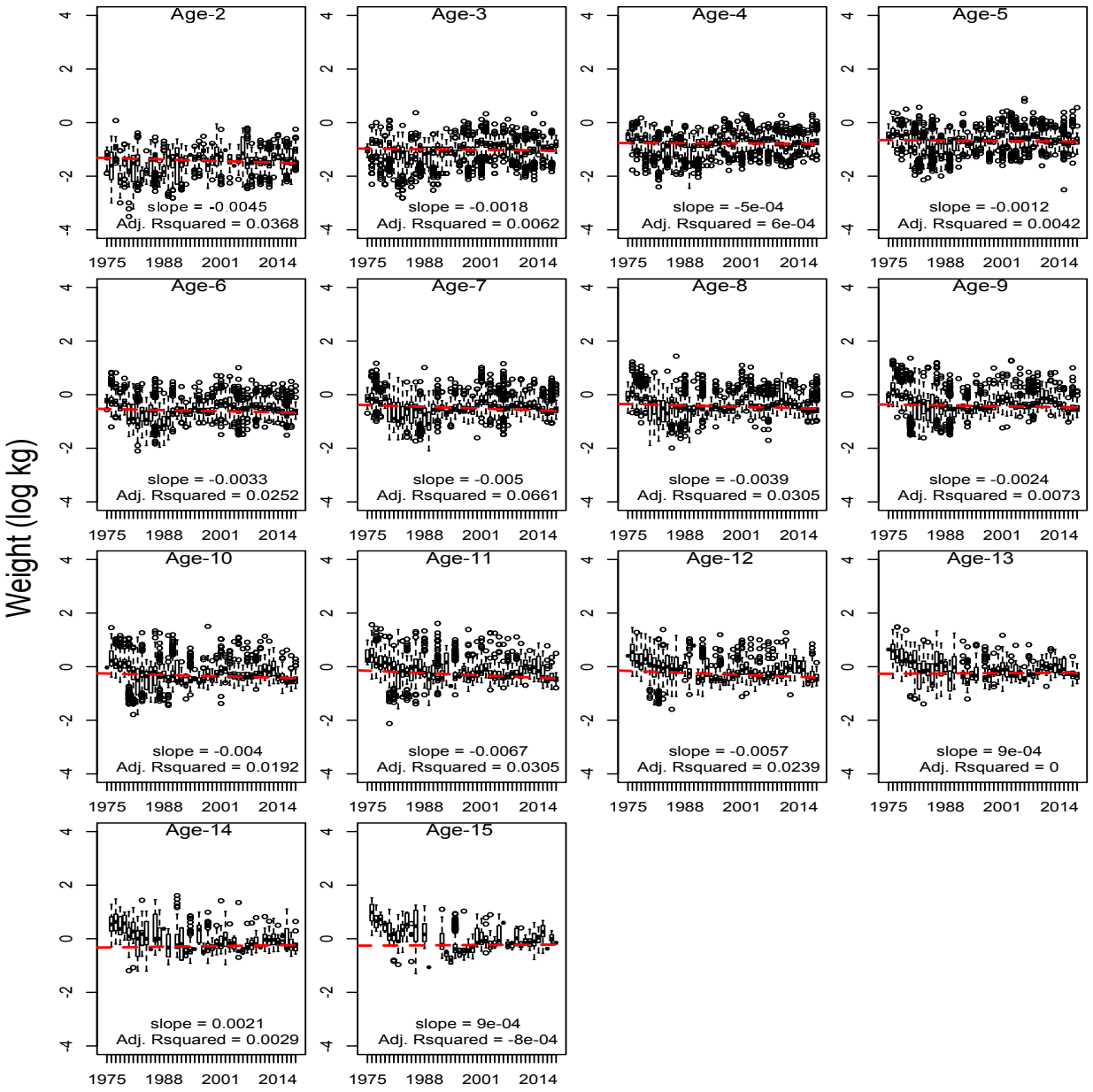

Figure 14. Fit (red lines) to yearly weight-at-age data (standard box plots) by age group (age-2 to age-15; where age-15 is an accumulator group) using weighted least squares. Statistical weights in the regression were based on the inverse of the annual sample variance.

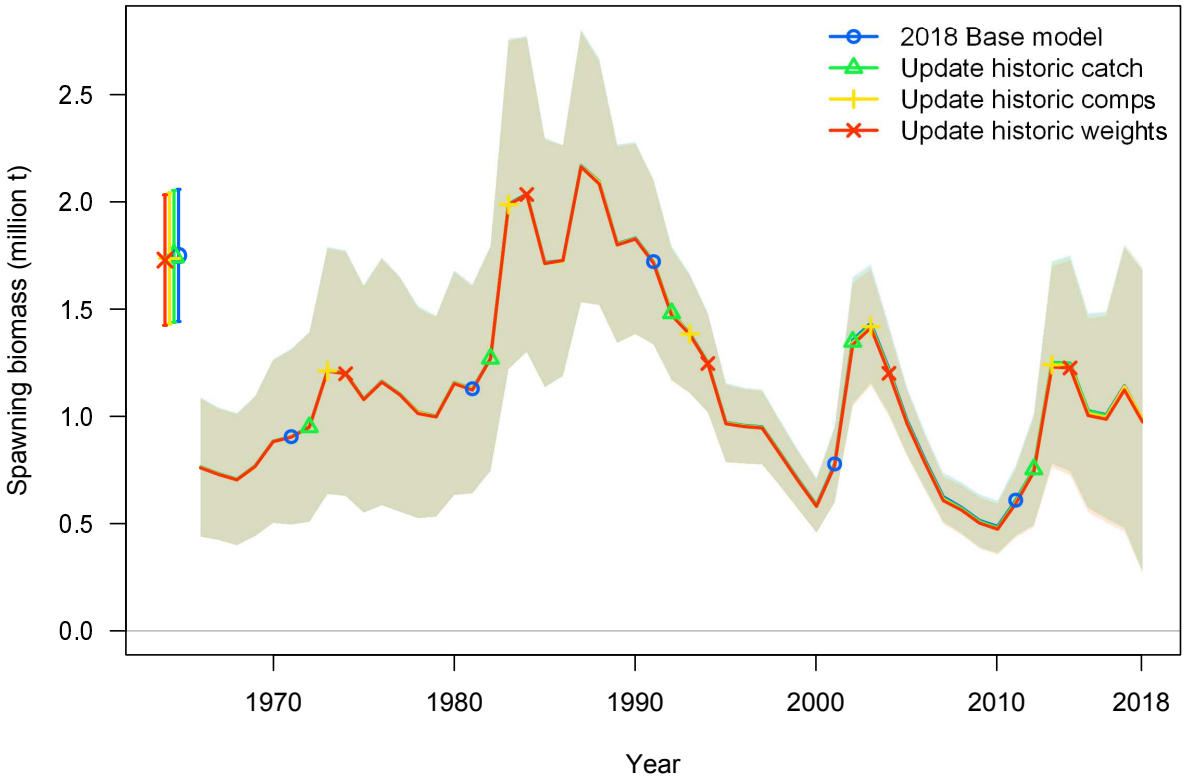

Figure 15. Bridging models showing the 2018 base model and the results of sequentially updating historic catch data, historic age-composition data, and then historic weight-at-age data. The points disconnected from the time-series on the left side show the unfished equilibrium spawning biomass estimates.

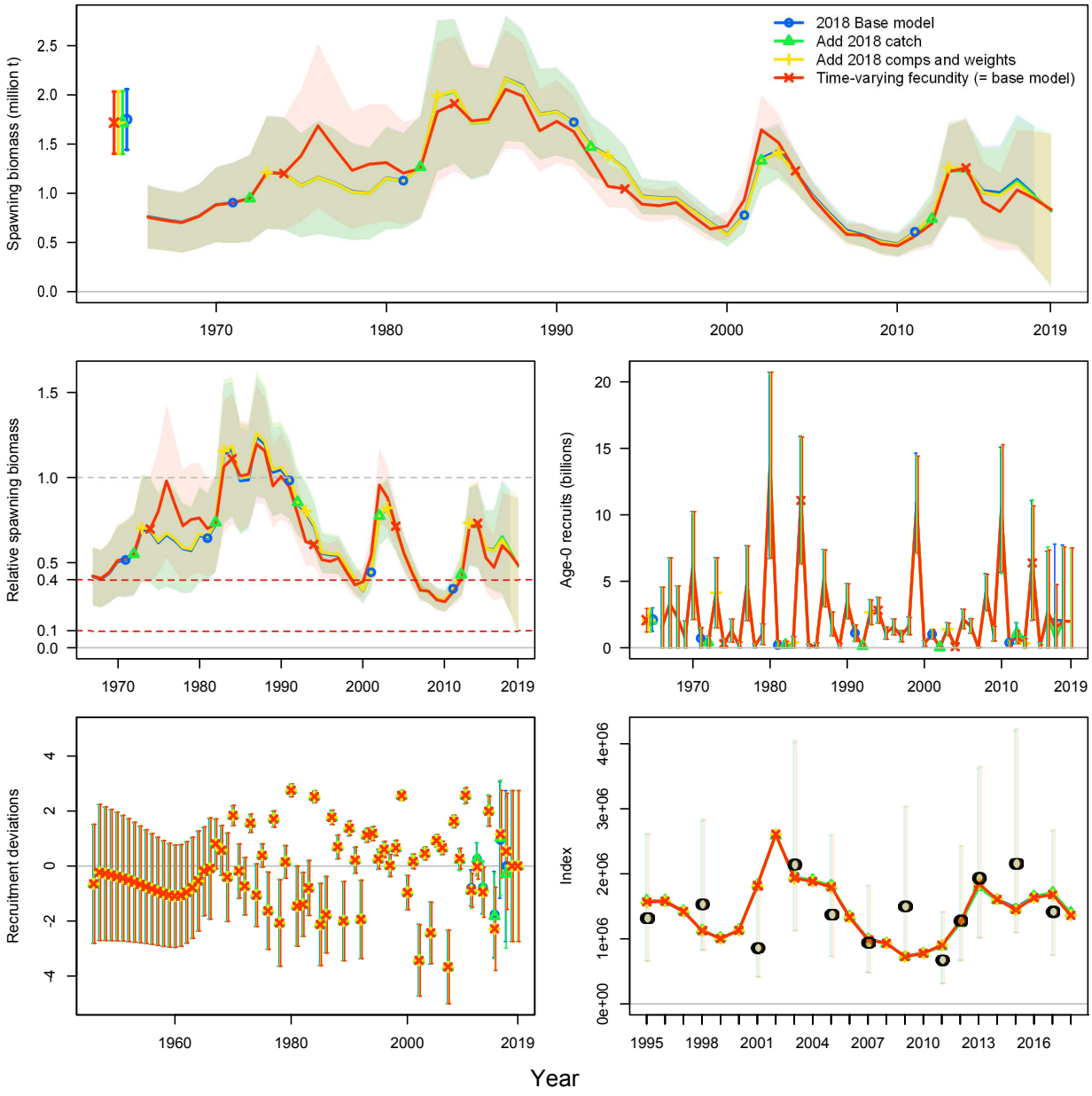

Figure 16. Bridging models showing the 2018 base model and the results of sequentially building upon the base model with updates shown in Figure 15 (i.e., adding the 2018 catch data and 2018 age-composition and weight-at-age data) and then finally changing to time-varying fecundity which became the base model. See Section 3.8 for further details about modeling time-varying fecundity. Panels are 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).

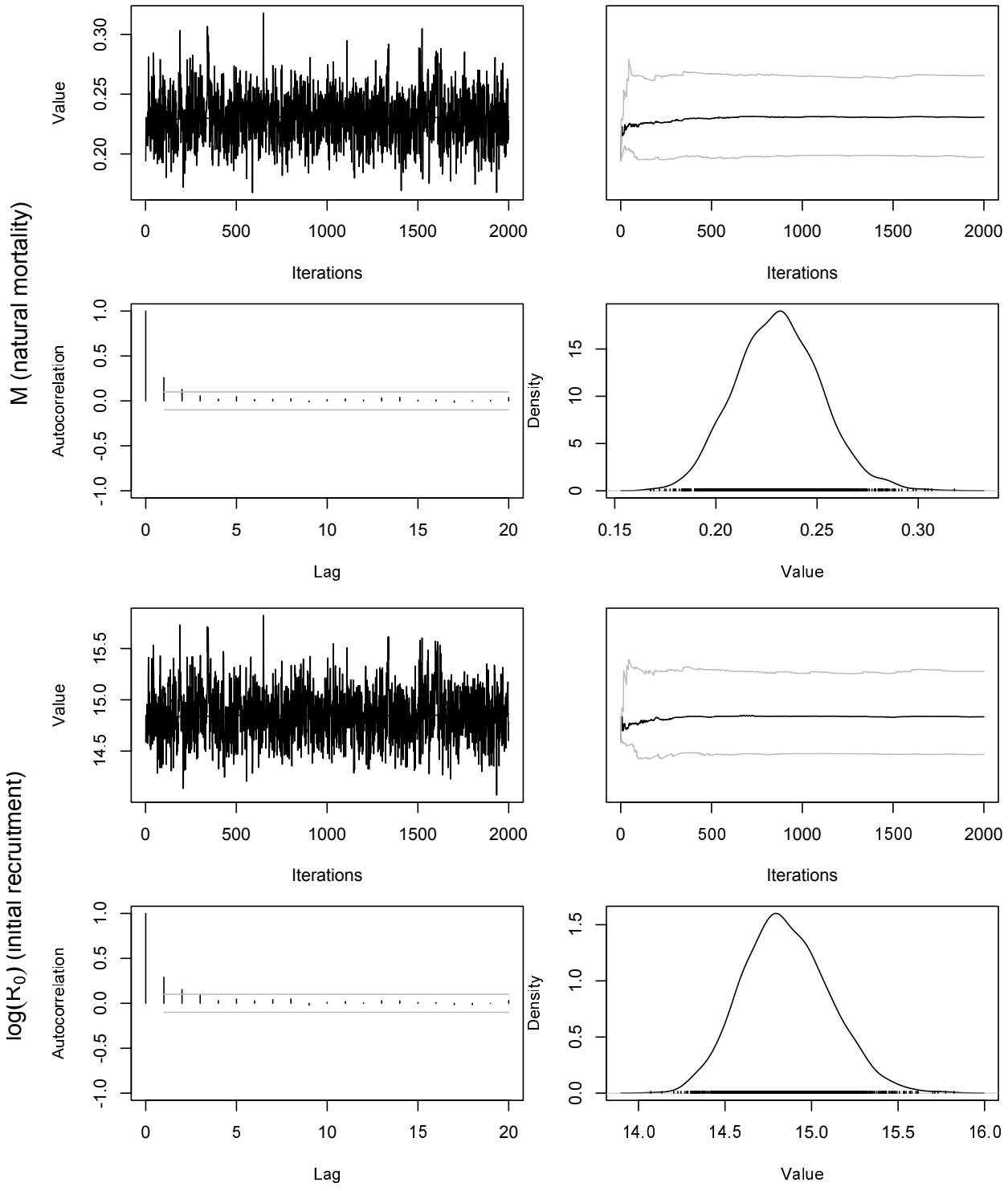

Figure 17. Summary of MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower left 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).

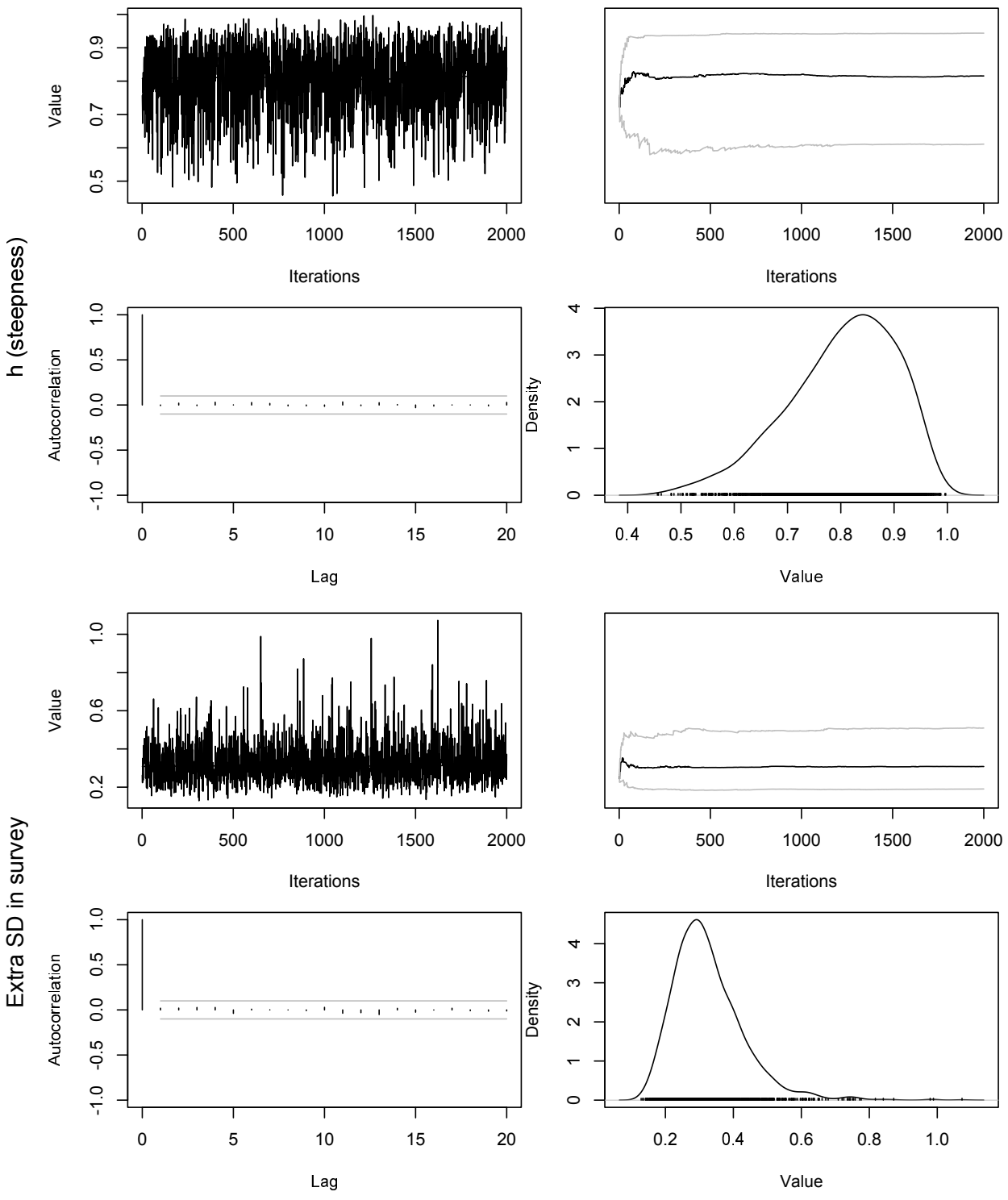

Figure 18. Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th 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).

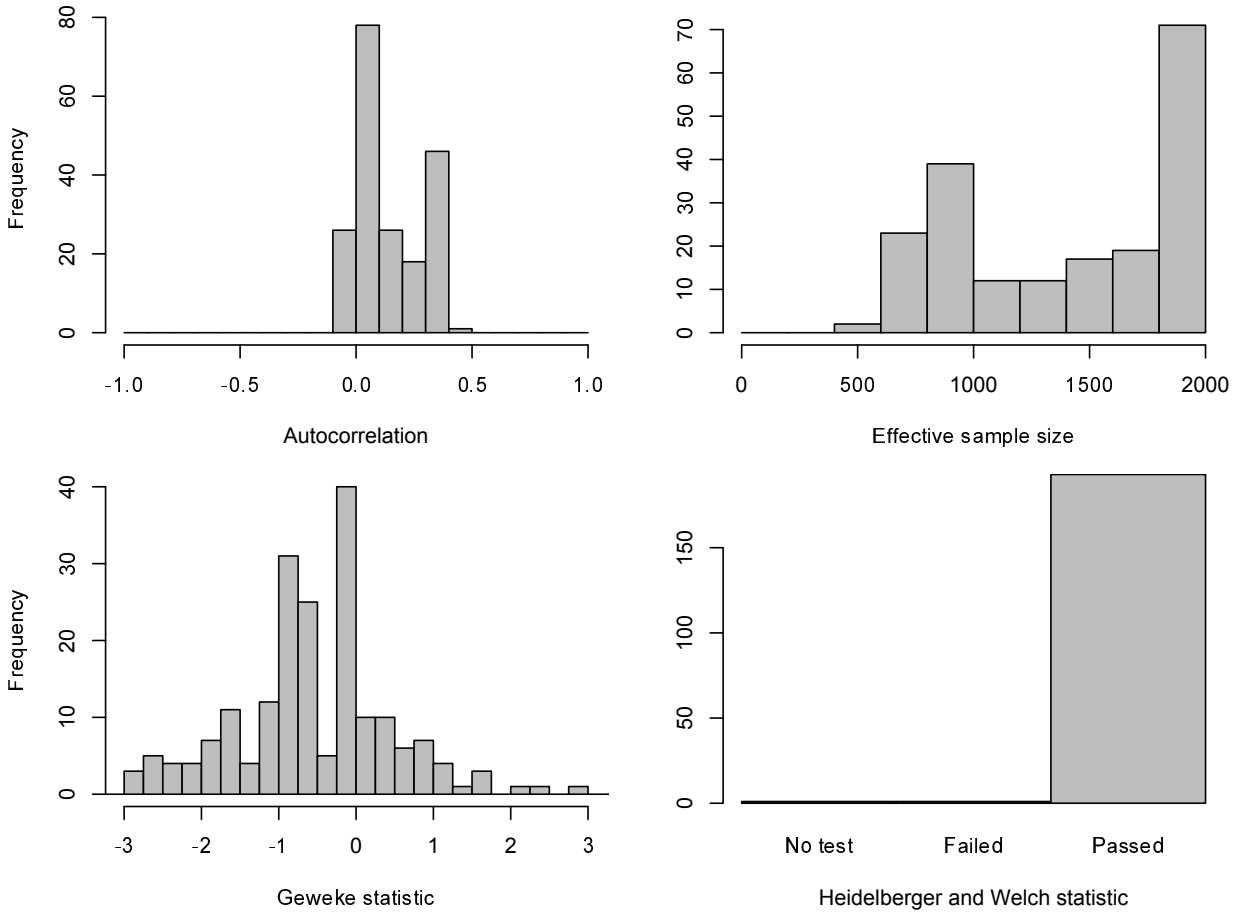

Figure 19. Summary histograms of MCMC diagnostics for all base model parameters together with the derived time series of spawning biomass and relative spawning biomass. The level of autocorrelation in the chain (distribution across lag times, i.e., distance between samples in the chain, shown in the 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 Heidelberger and Welch statistic (lower right panel) tests if the sampled values come from a stationary distribution by comparing different sections of the chain.

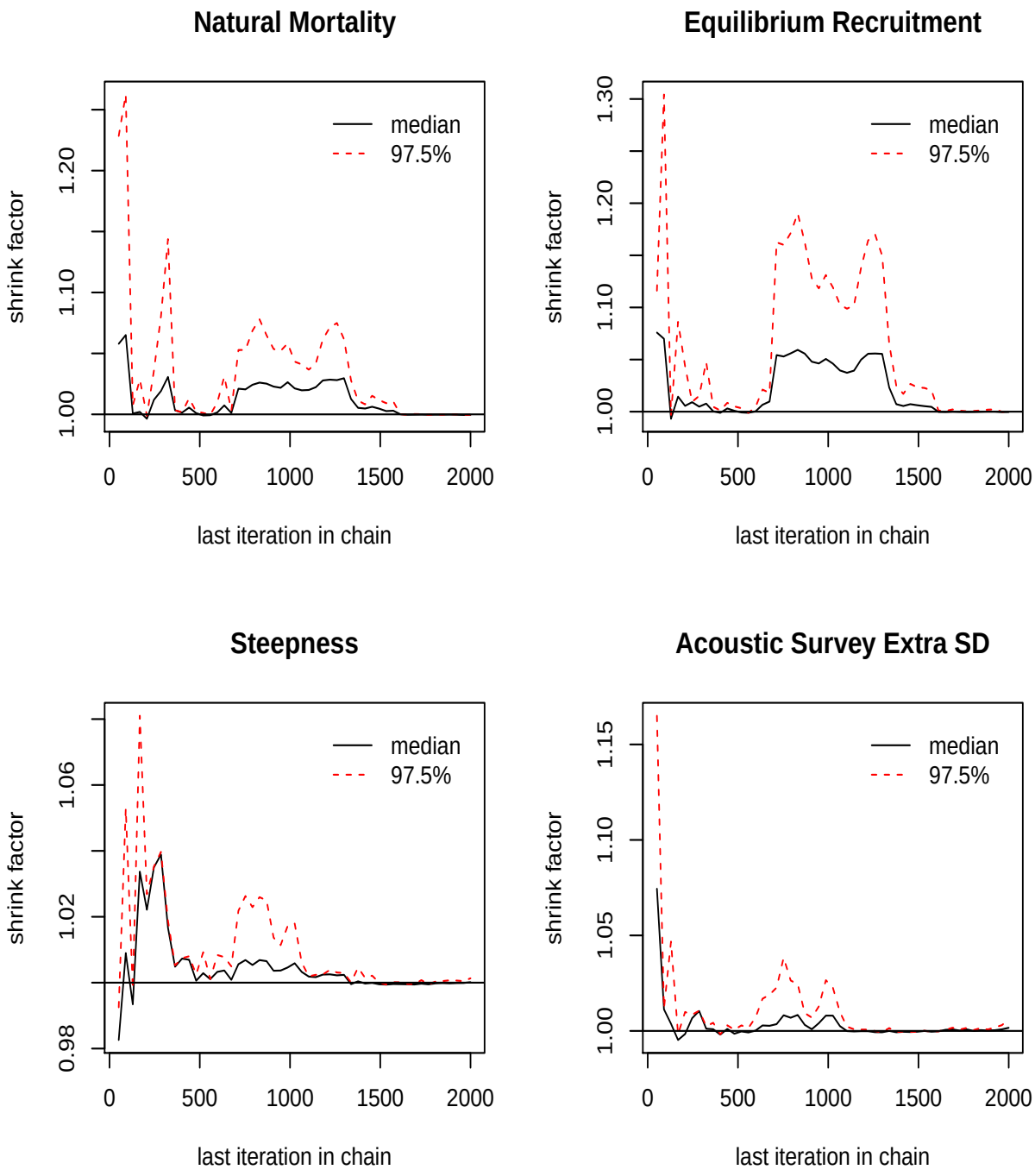

Figure 20. Gelman-Rubin plot showing the development of the scale-reduction (shrink factor) across the chain length for key posterior parameter distributions. A factor close to 1 indicates that between chain variance and within chain variance are equal. Values much greater than 1.1 indicate a notable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

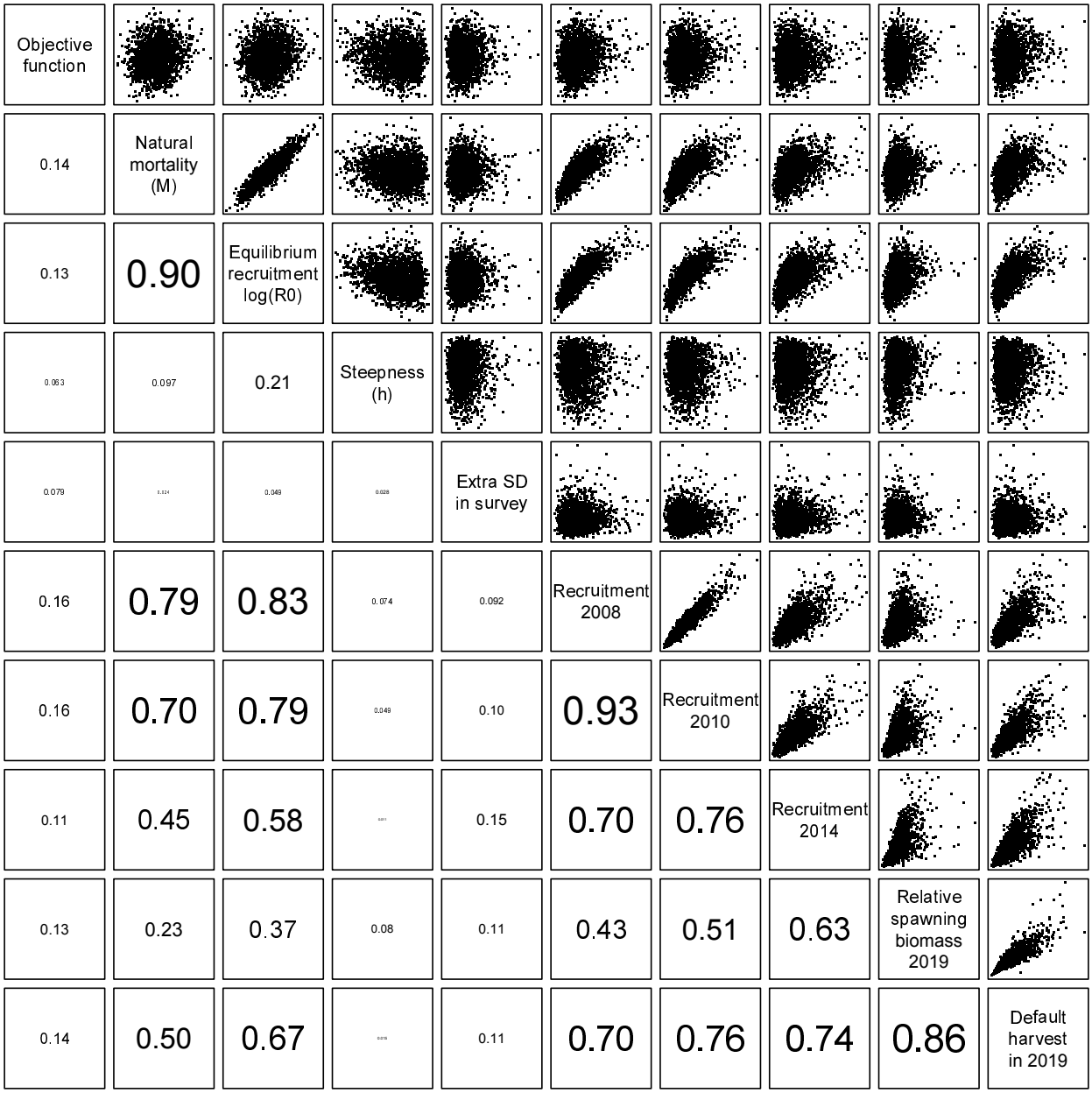

Figure 21. Posterior correlations among key base-model parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

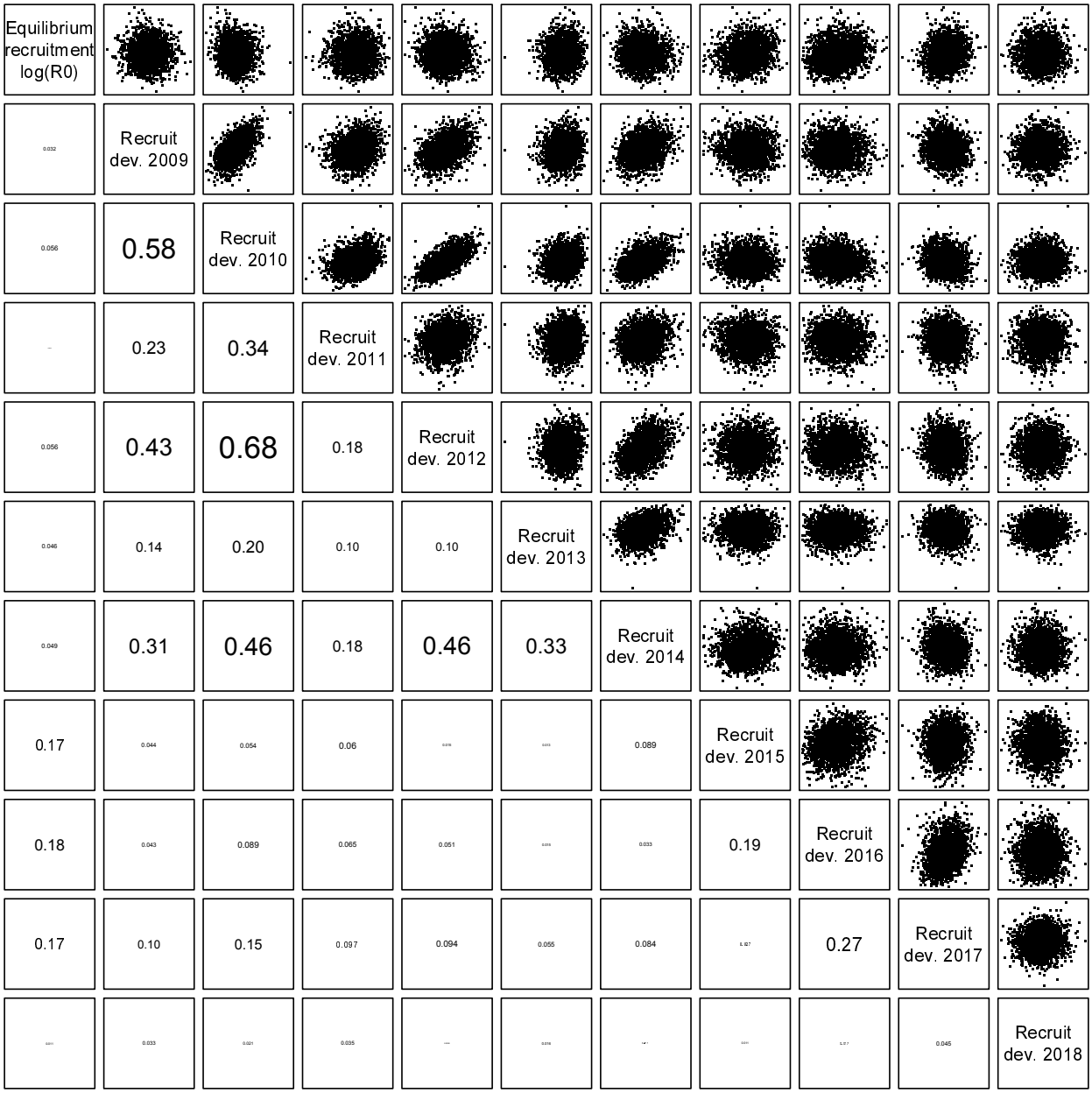

Figure 22. Posterior correlations among recruitment deviations from recent years and equilibrium recruitment. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

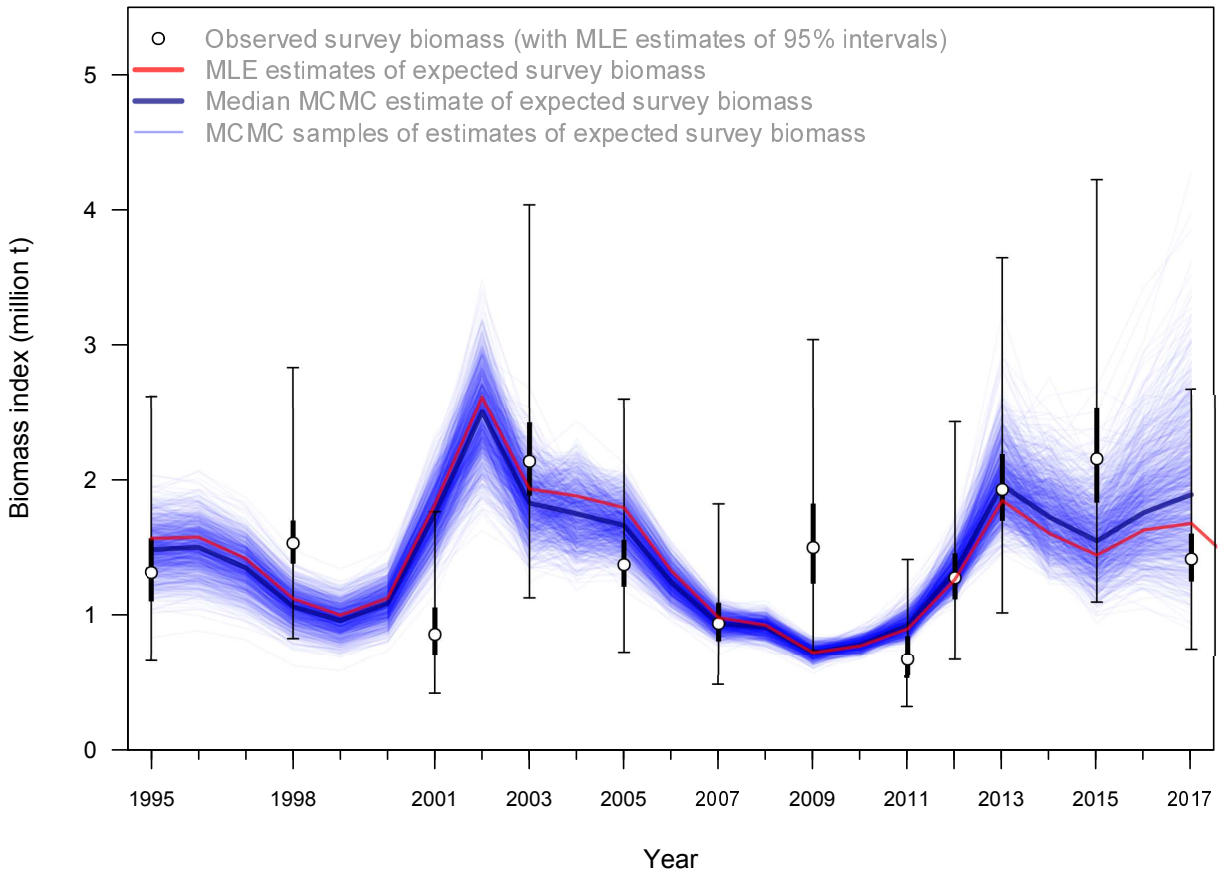

Figure 23. Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker 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.

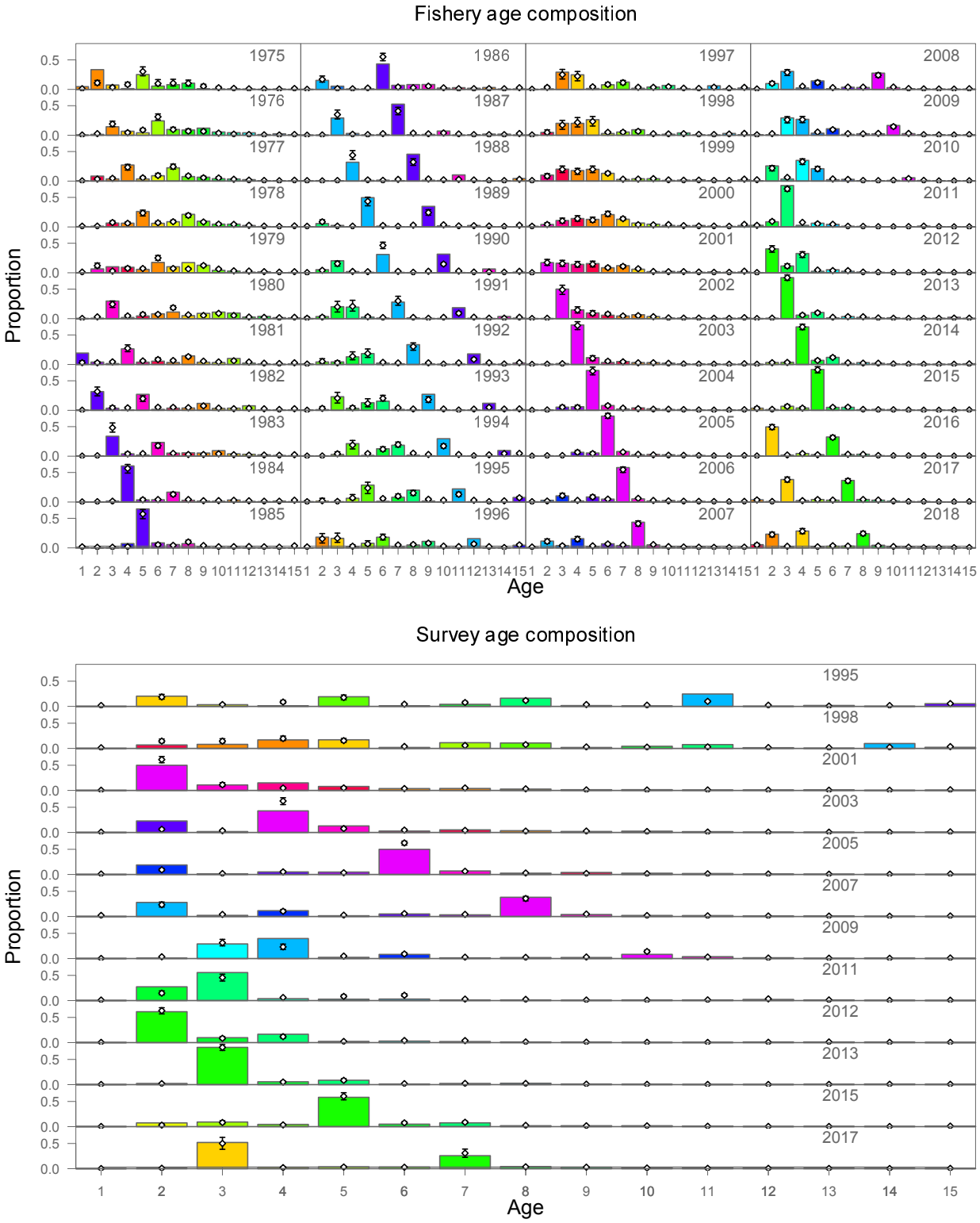

Figure 24. Base model fits to the observed fishery (top) and acoustic survey (bottom) age-composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% credibility intervals from the MCMC calculations.

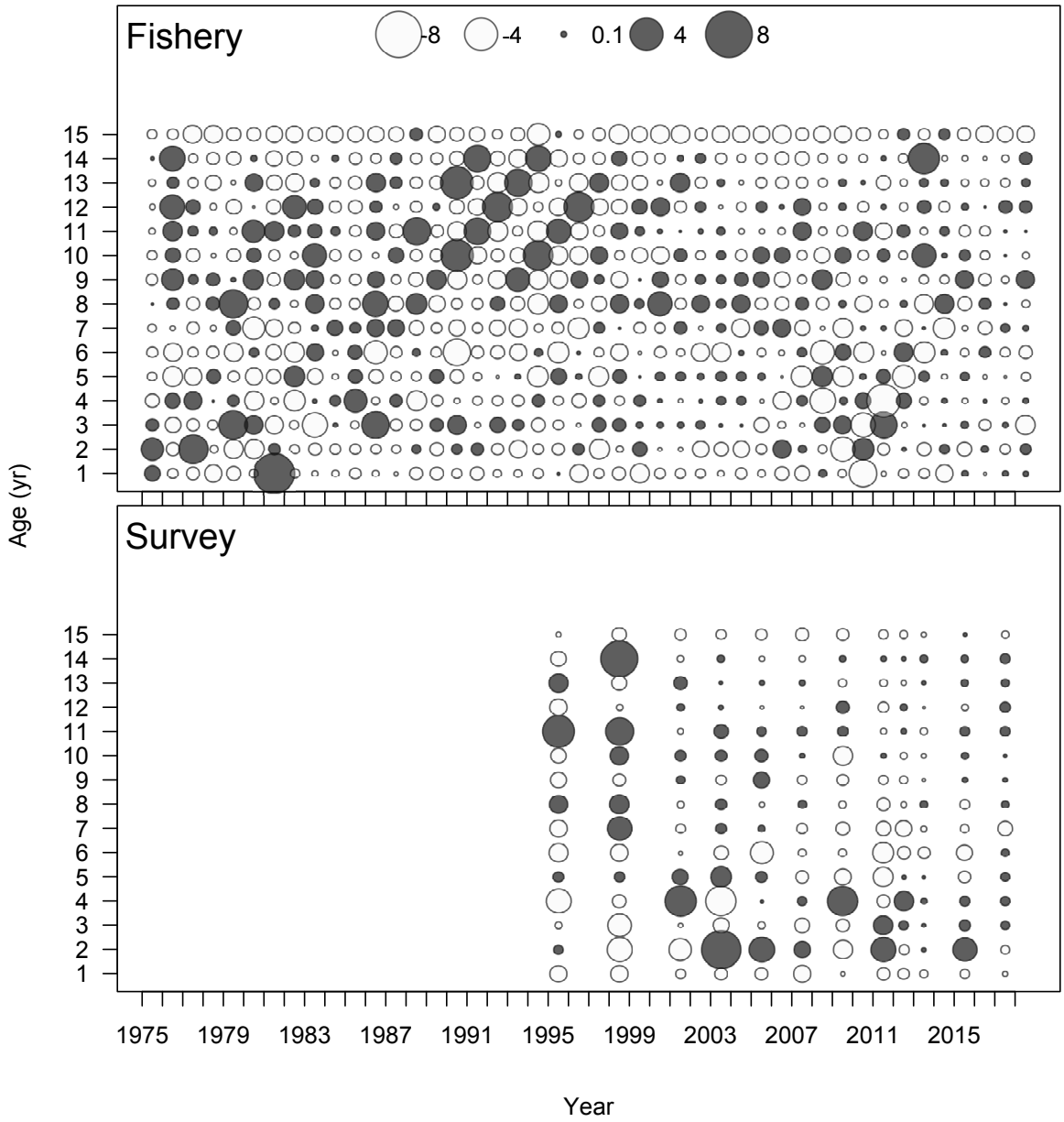

Figure 25. Pearson residuals for base model MLE fits to the age-composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

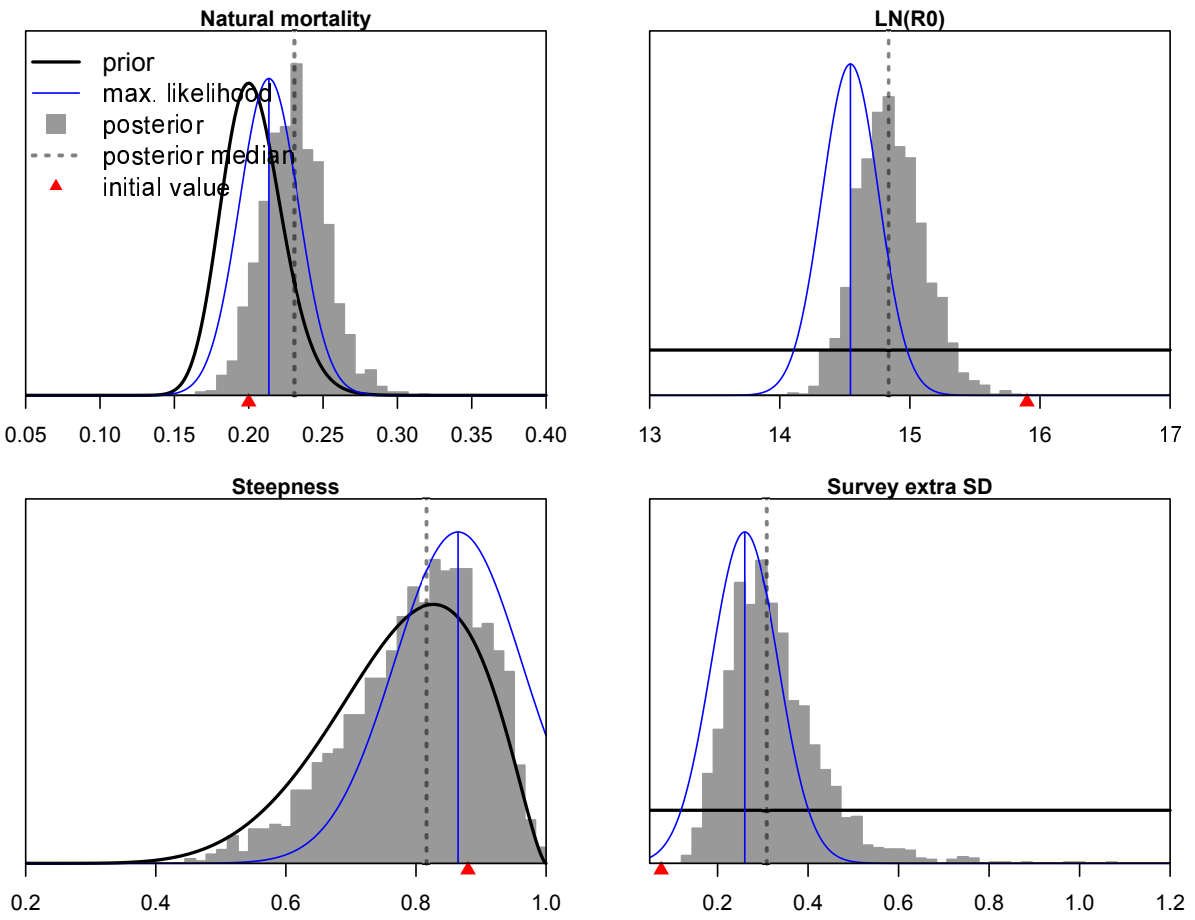

Figure 26. Prior (black lines) and posterior (gray histograms) distributions for key parameters in the base model. The parameters are: natural mortality (M), equilibrium log recruitment $\log(R_0)$, steepness (h), and the additional process-error standard deviation for the acoustic survey. The maximum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

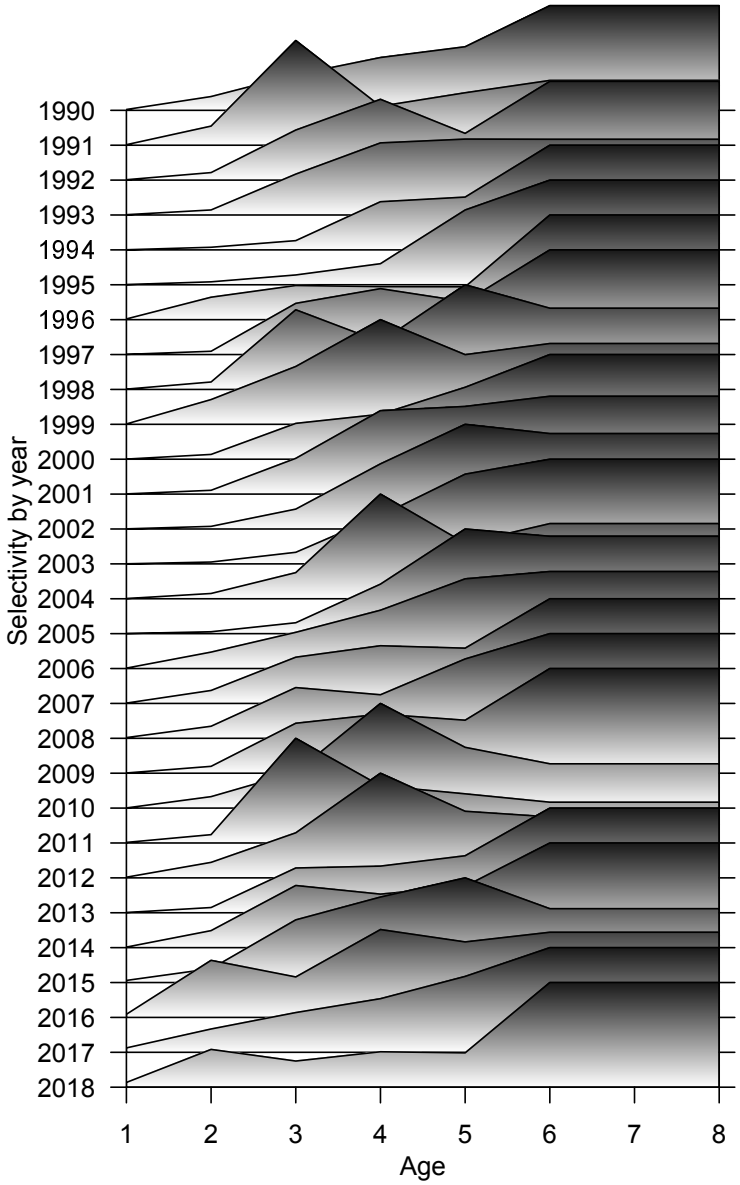

Figure 27. Mountains plot of median fishery selectivity in each year for the base model. Range of selectivity is 0 to 1 in each year.

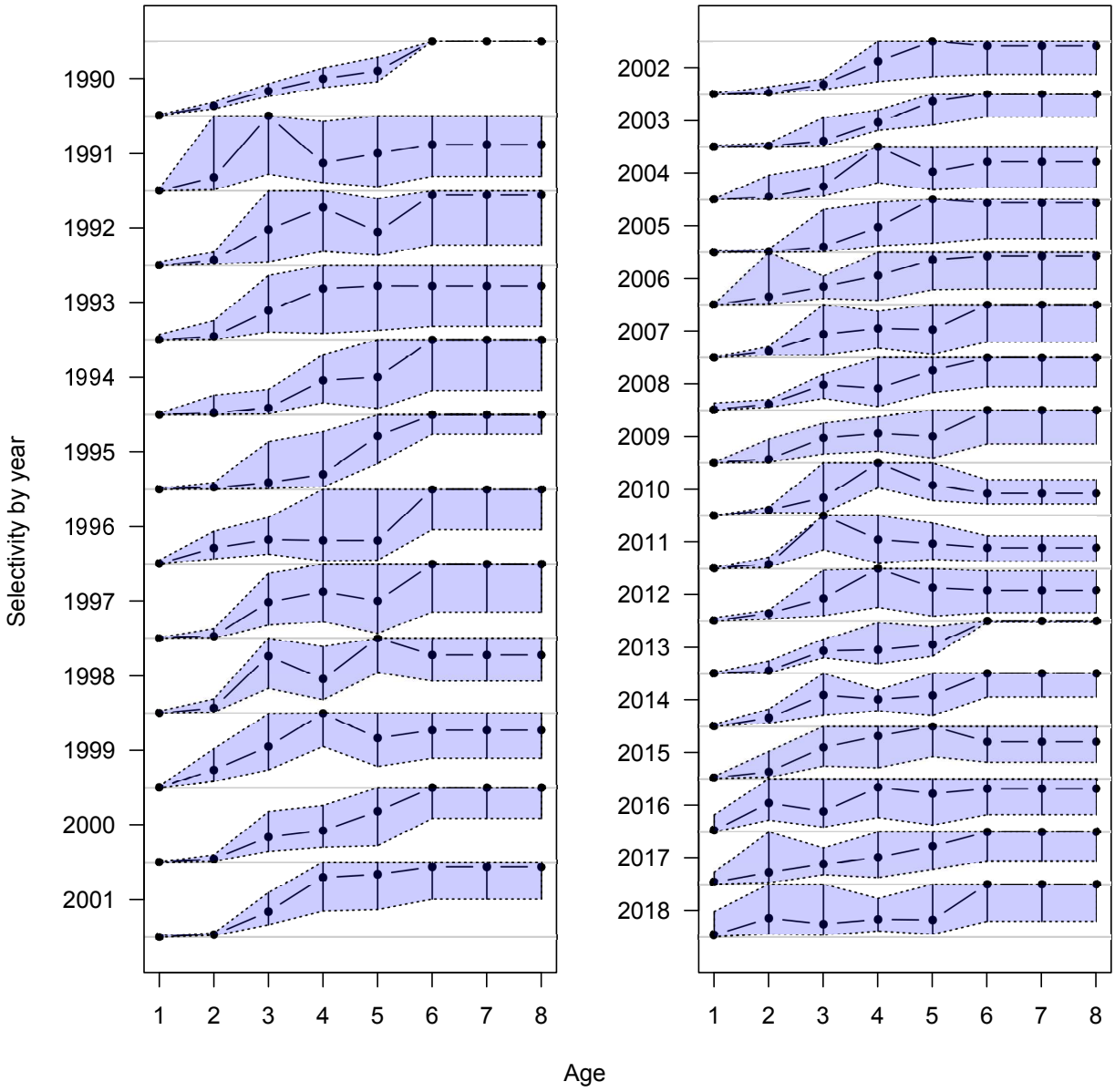

Figure 28. Fishery selectivity sampled from posterior probability distribution by year for the base model. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity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

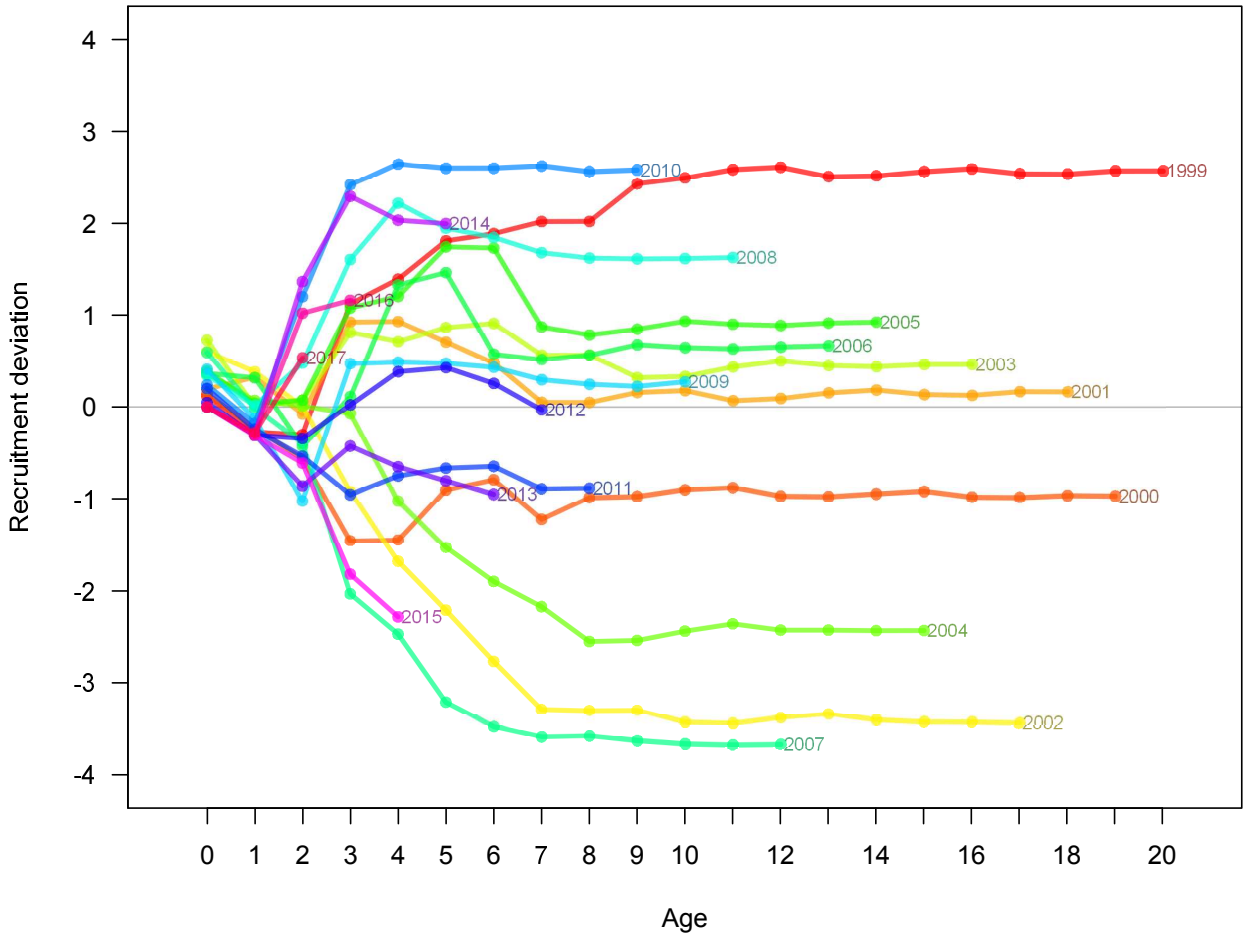

Figure 29. Retrospective analysis of recruitment deviations from MLE models over the last 21 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for cohorts from 1999 to 2017, 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.

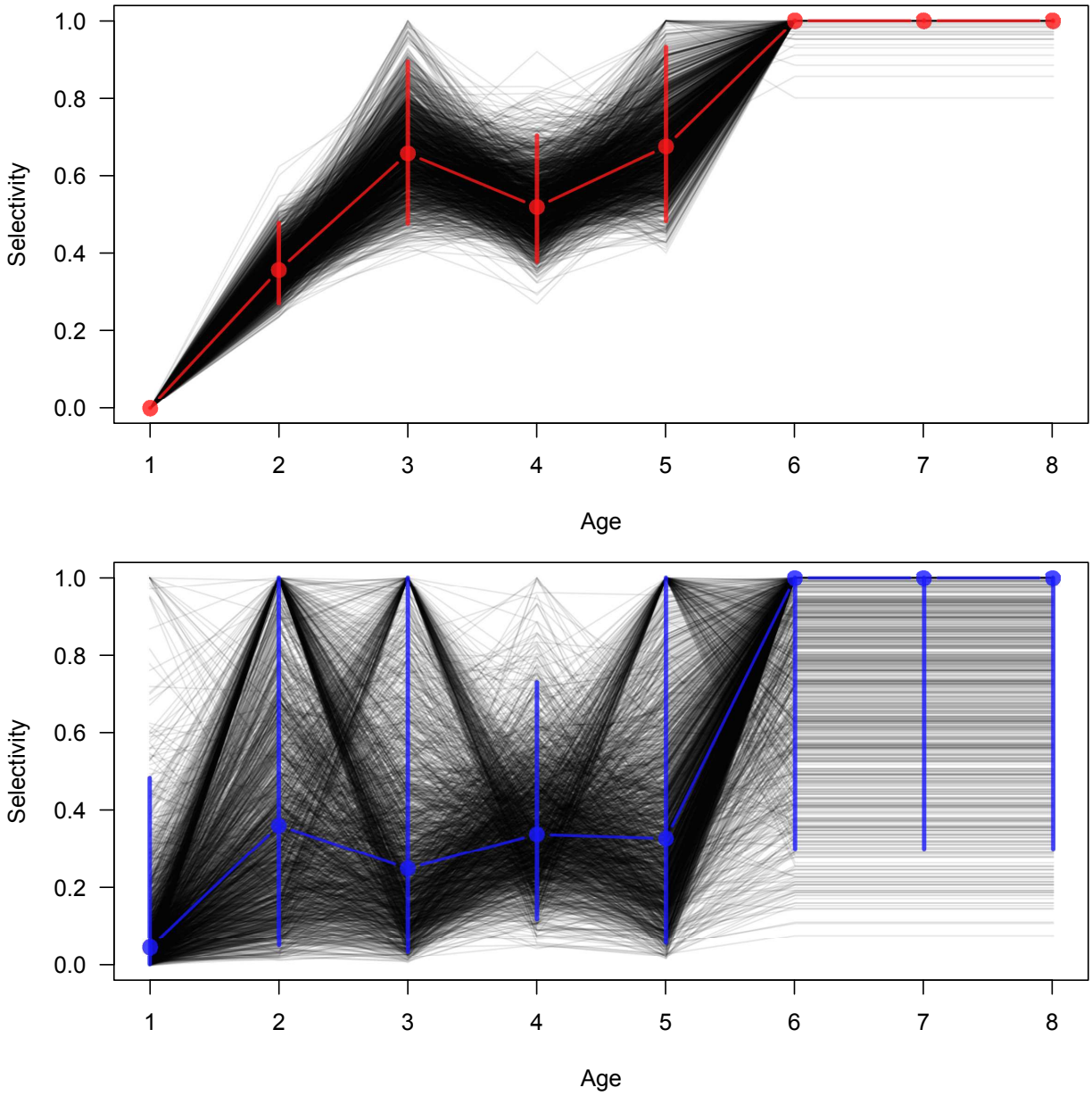

Figure 30. Estimated acoustic (top – for all years) and fishery selectivities (bottom – for 2018 only) from the posterior distribution for the base model.

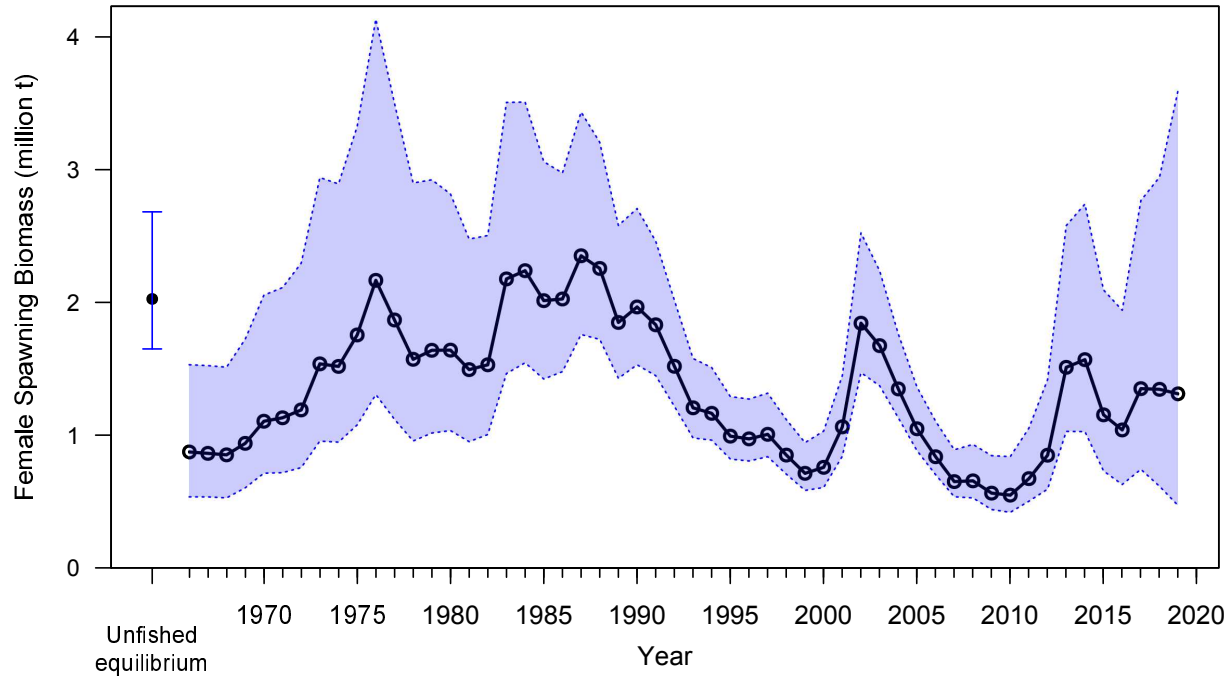

Figure 31. Median of the posterior distribution for female spawning biomass at the start of each year (B_t) for the base model up to 2019 (solid line) with 95% posterior credibility intervals (shaded area).

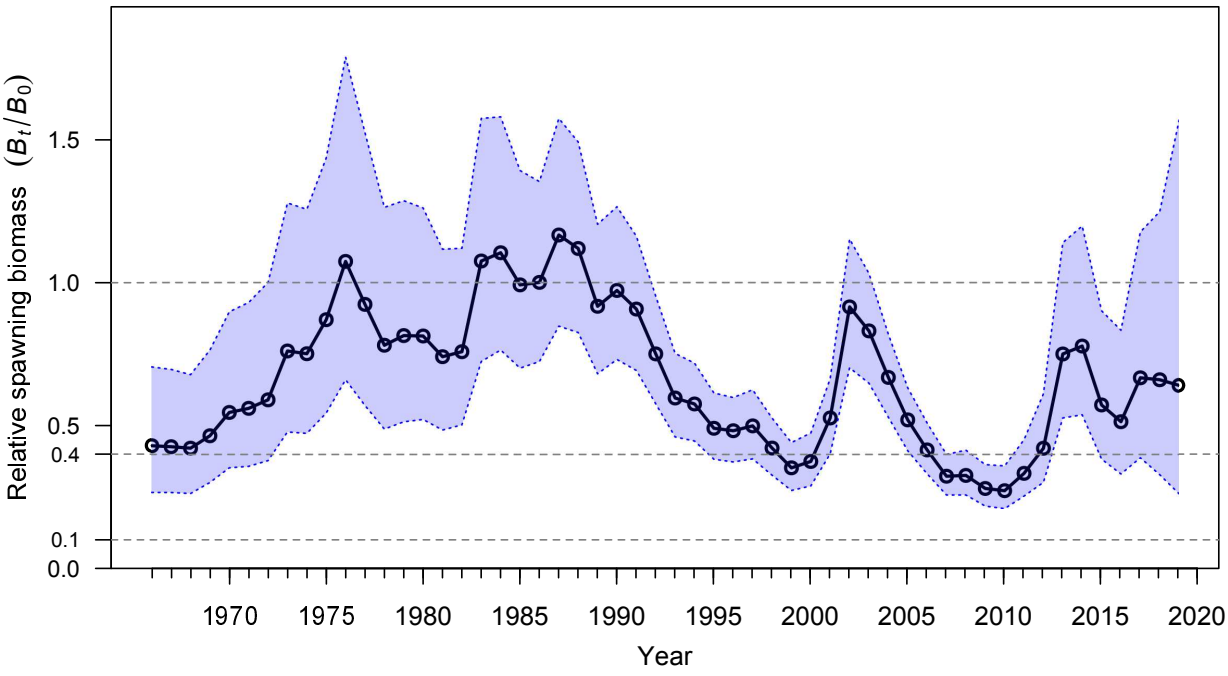

Figure 32. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) for the base model through 2019 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

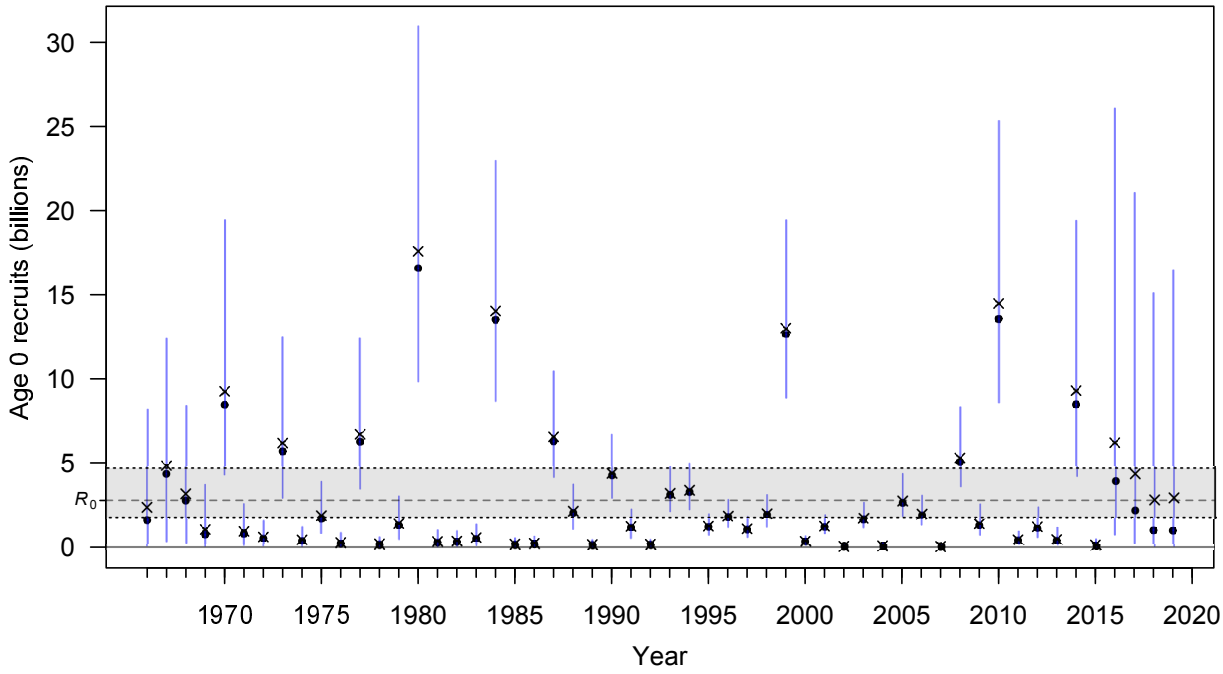

Figure 33. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0 fish) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

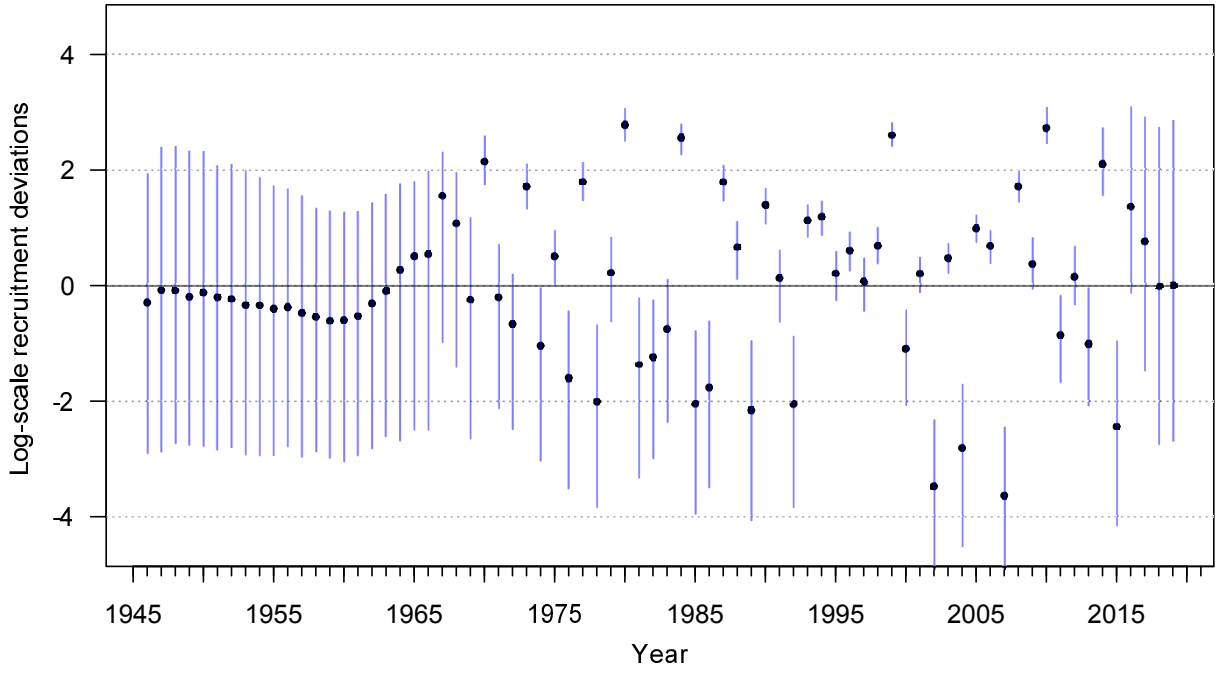

Figure 34. Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model. Deviations for the years 1970–2017 are constrained to sum to zero while deviations outside this range are represented as separate values that do not have that constraint.

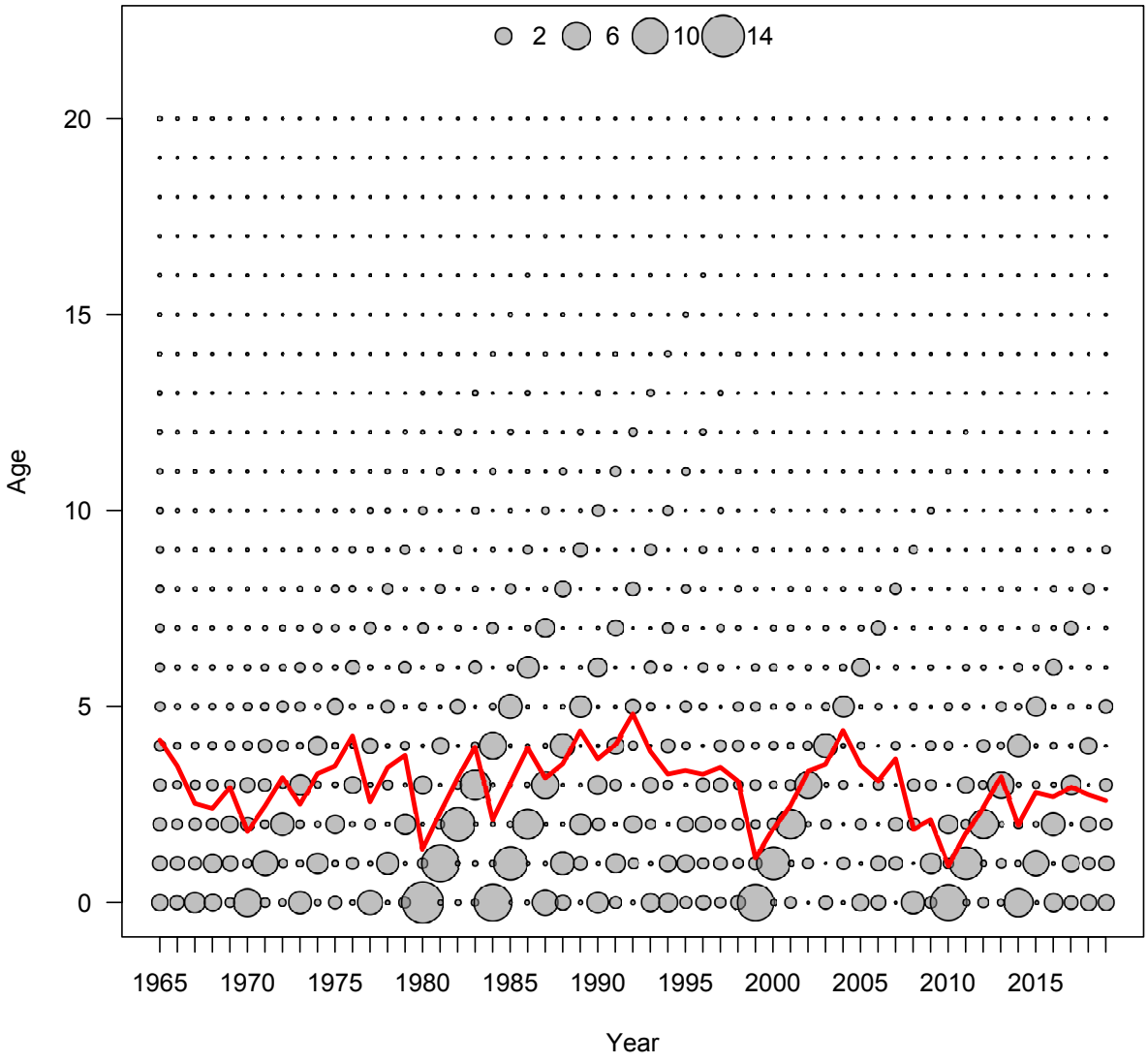

Figure 35. Bubble plot of MLE estimates of population numbers at age at the beginning of each year, where diagonals follow each year-class through time. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish (with the largest bubble representing 13.7 billion age-0 recruits in 1980). See Table 19 for values.

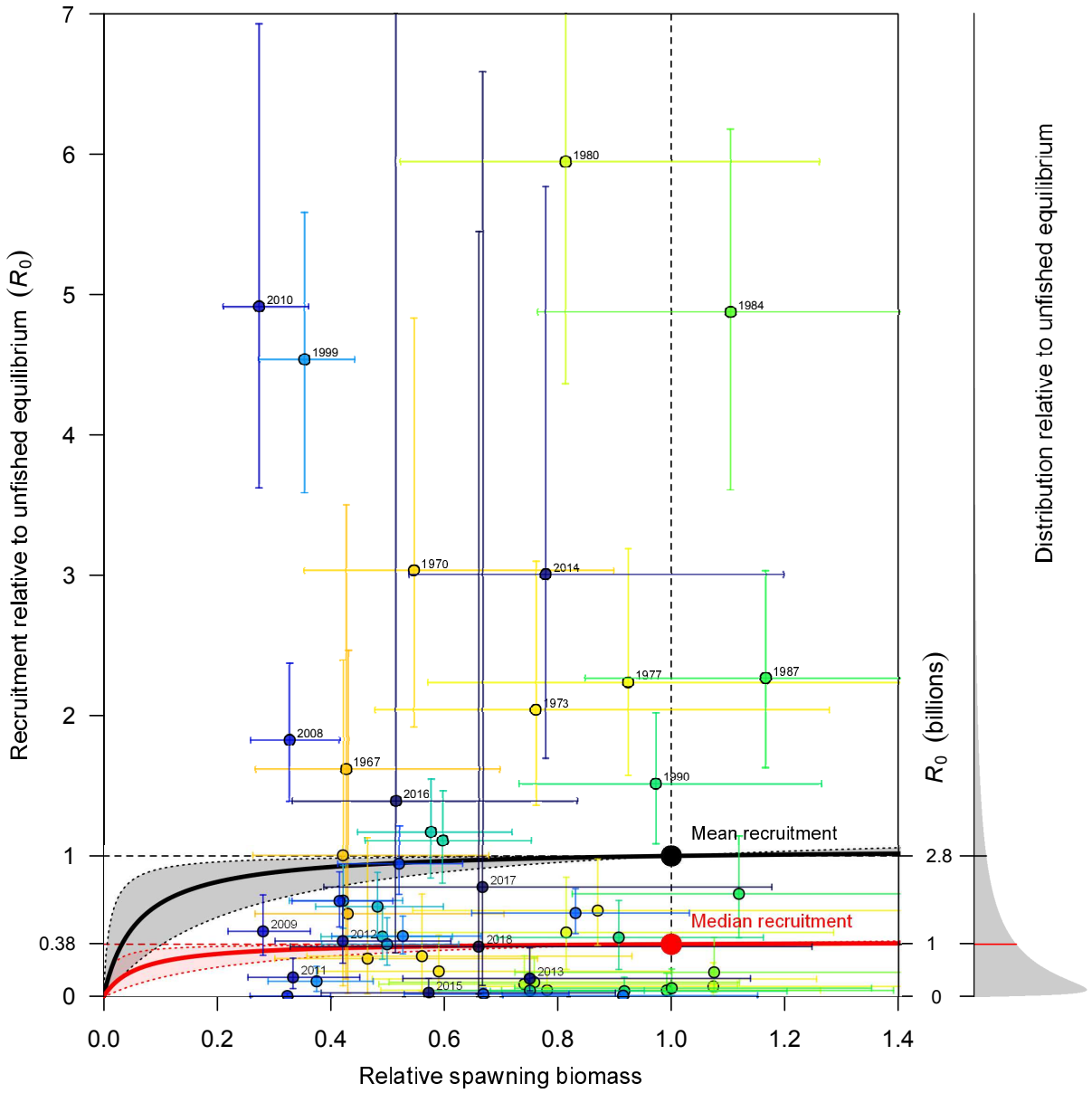

Figure 36. Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (mean) and the red line indicates 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.

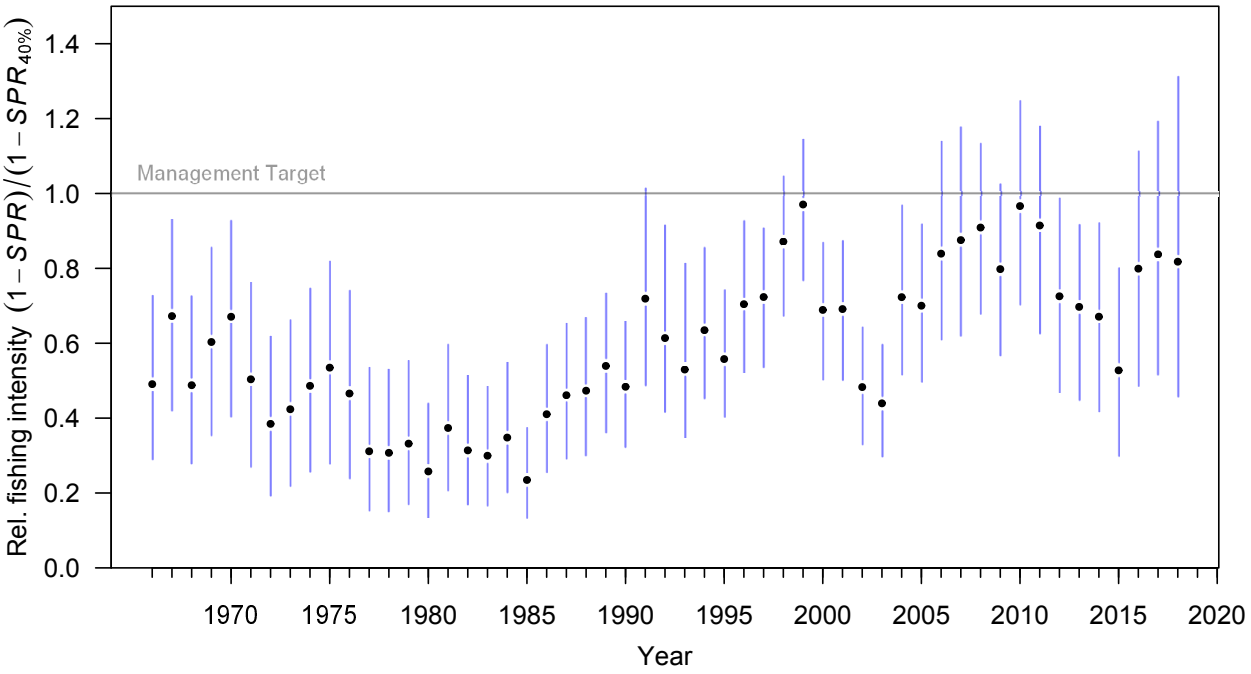

Figure 37. Trend in median fishing intensity (relative to the SPR management target) through 2018 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

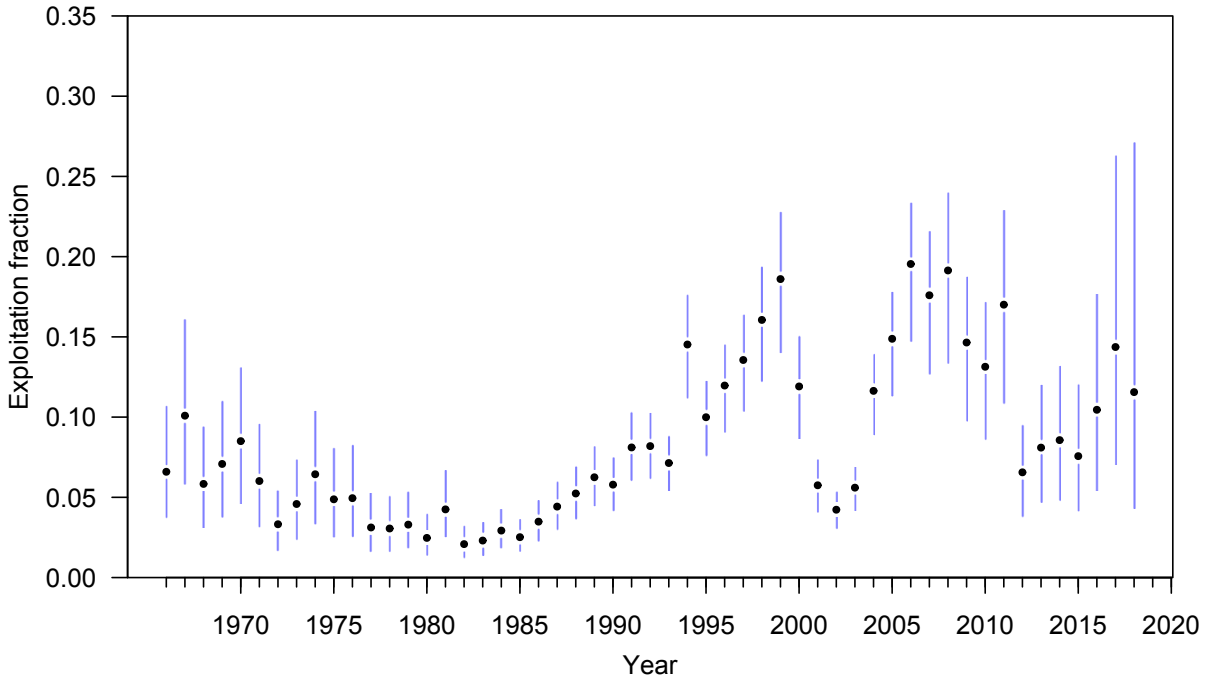

Figure 38. Trend in median exploitation fraction (catch divided by biomass of fish of age-2 and above) through 2018 with 95% posterior credibility intervals.

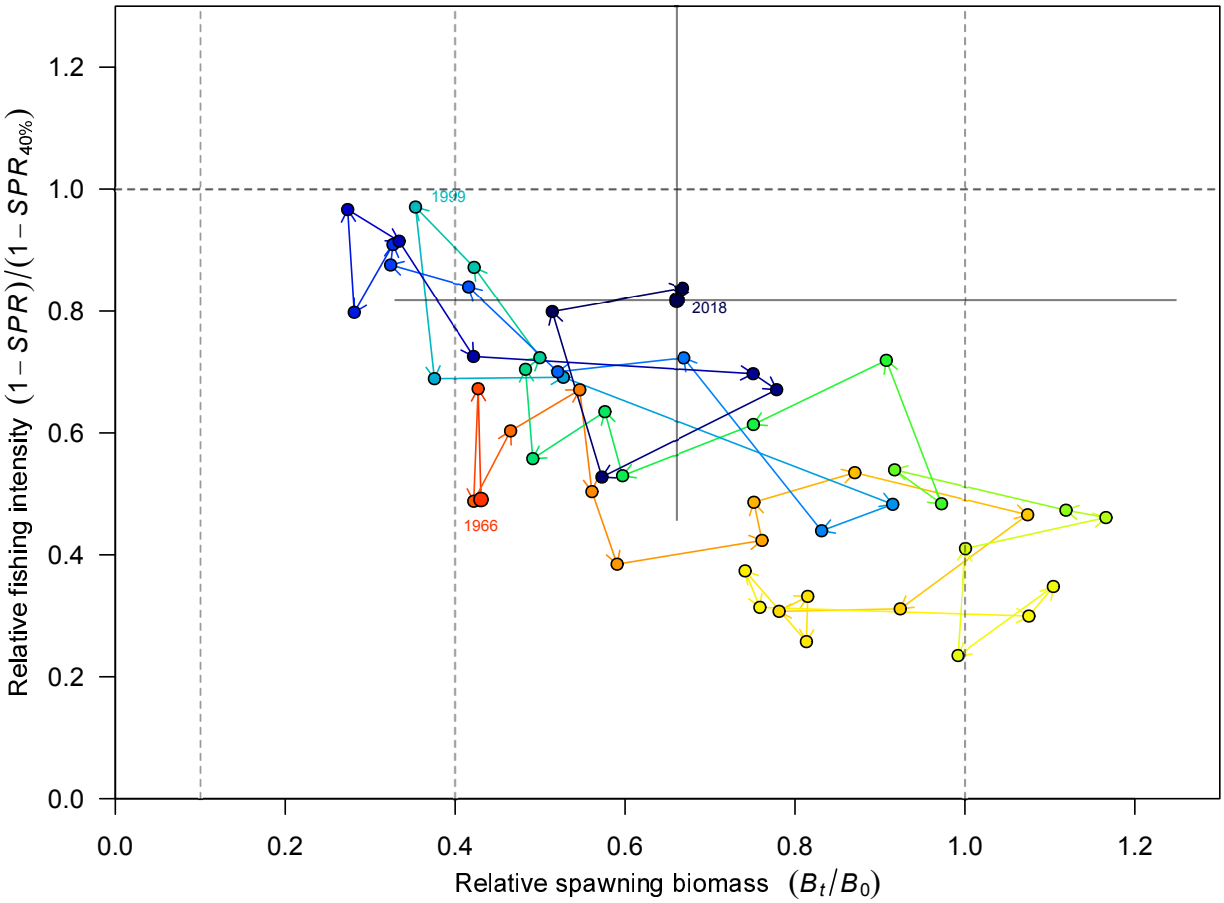

Figure 39. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake. Start and end years are labeled, as is the year with the highest relative fishing intensity. Gray bars span the 95% credibility intervals for 2018 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

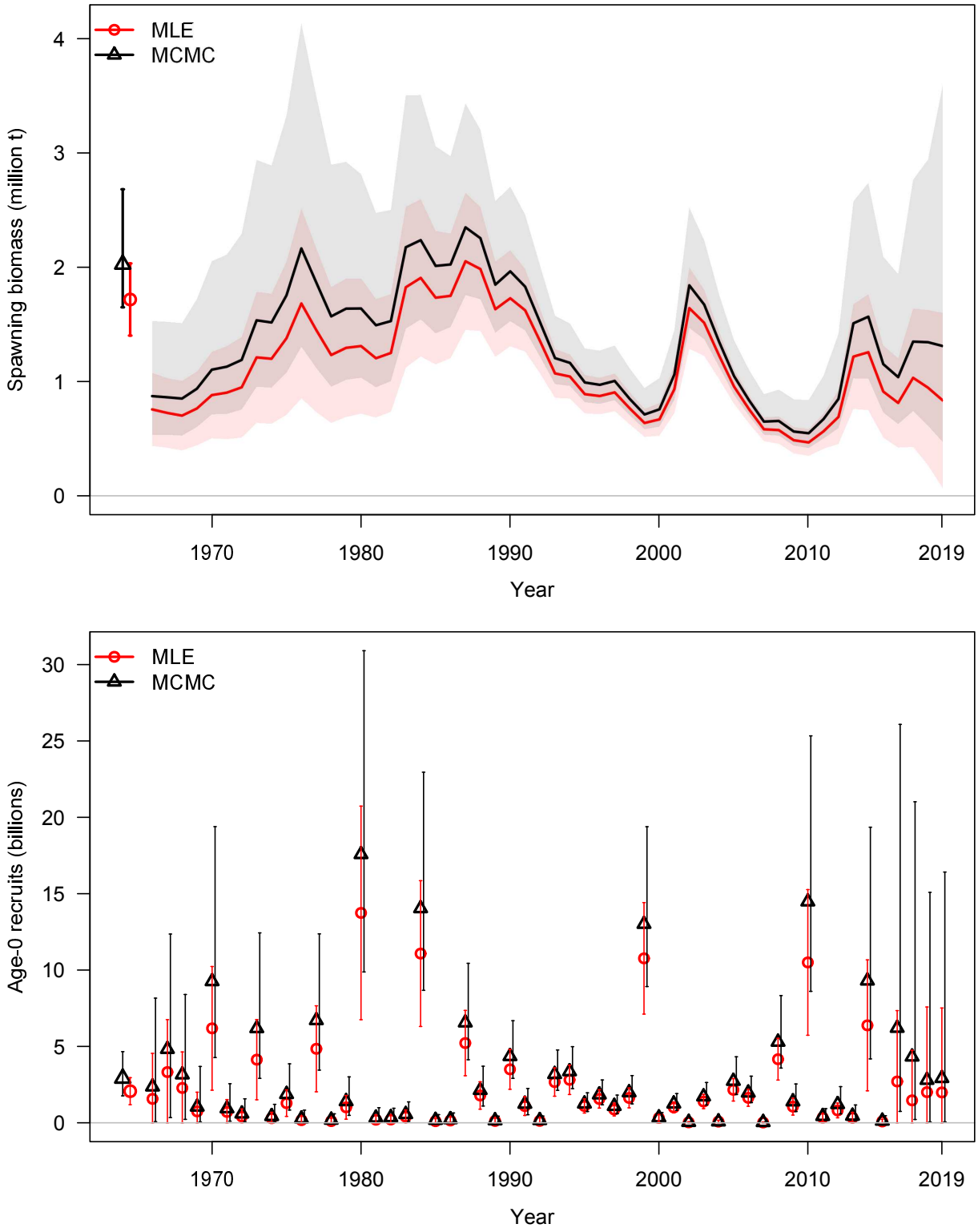

Figure 40. A comparison of maximum likelihood estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the posterior distribution with 95% credibility intervals (black). The posterior median is shown for spawning biomass while the posterior mean recruitment is displayed in the lower panel to be more comparable to the MLE value.

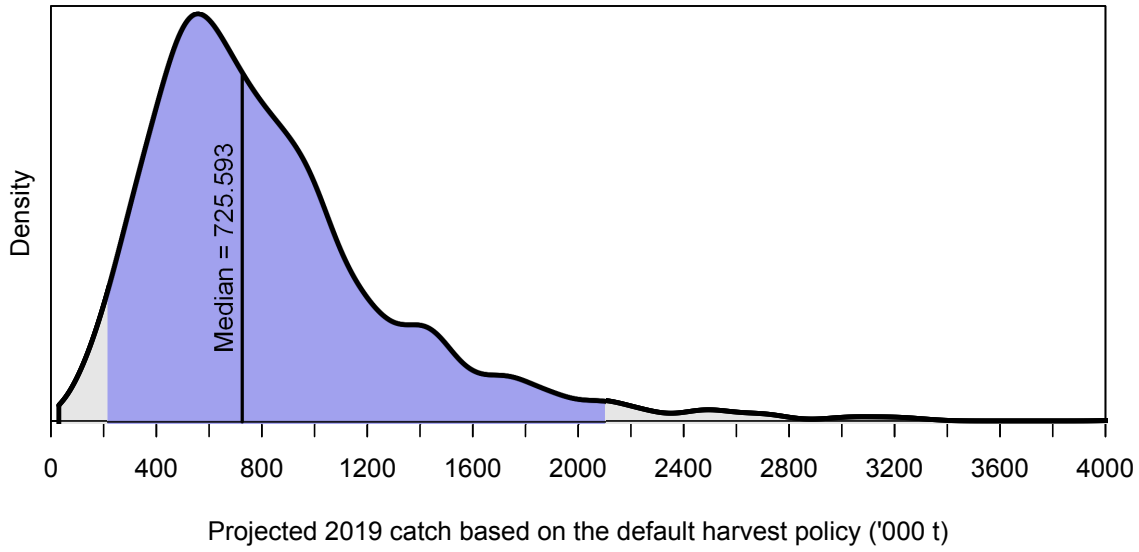

Figure 41. The posterior distribution of the default 2019 catch limit calculated using the default harvest policy ($F_{SPR=40\%}$–40:10). The median is 725,593 t (vertical line), with the dark shaded area ranging from the 2.5% quantile to the 97.5% quantile, covering the range 214,763–2,106,509 t.

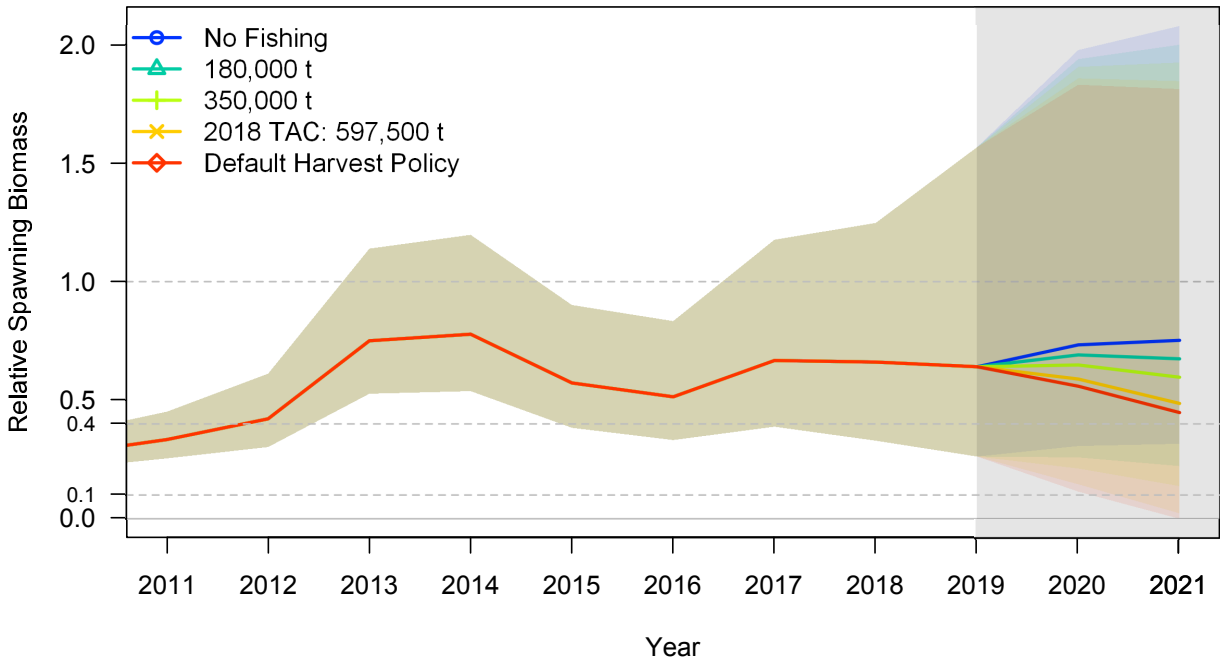

Figure 42. Time series of relative spawning biomass at the start of each year until 2019 as estimated from the base model, and forecast trajectories to the start of 2021 for several management options from the decision table (grey region), with 95% posterior credibility intervals. The 2019 catch of 725,593 t was calculated using the default harvest policy, as defined in the Agreement.

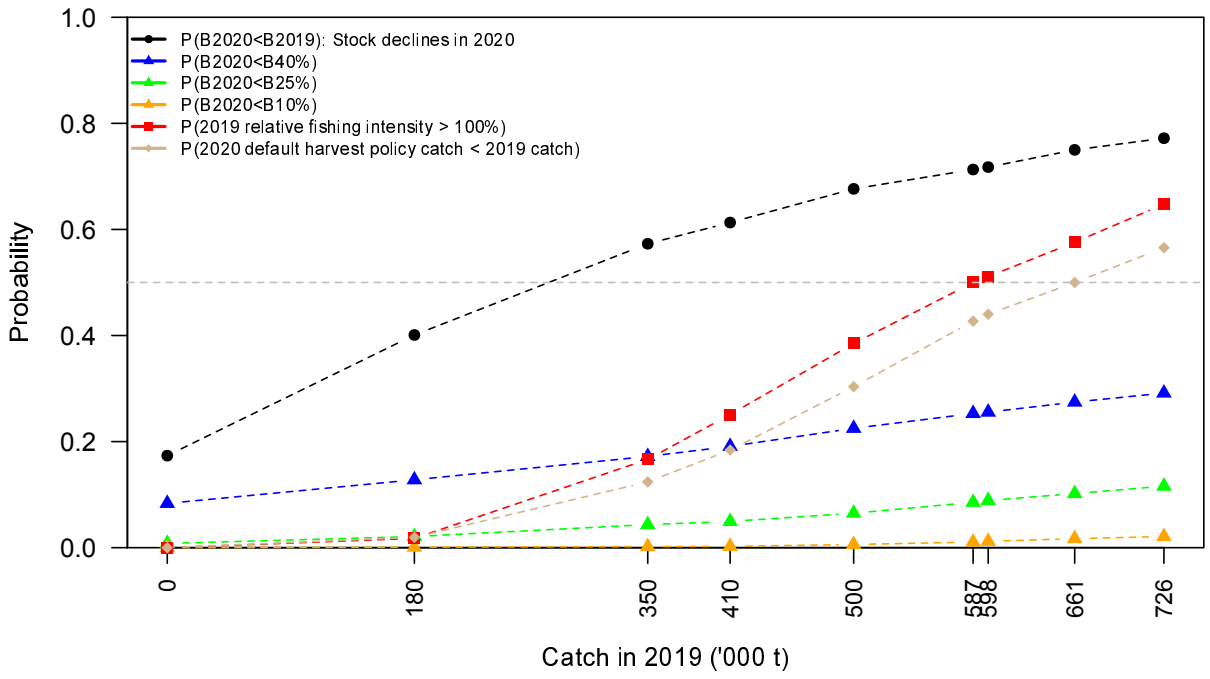

Figure 43. Graphical representation of the base model results presented in Table 31 for various catches in 2019. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

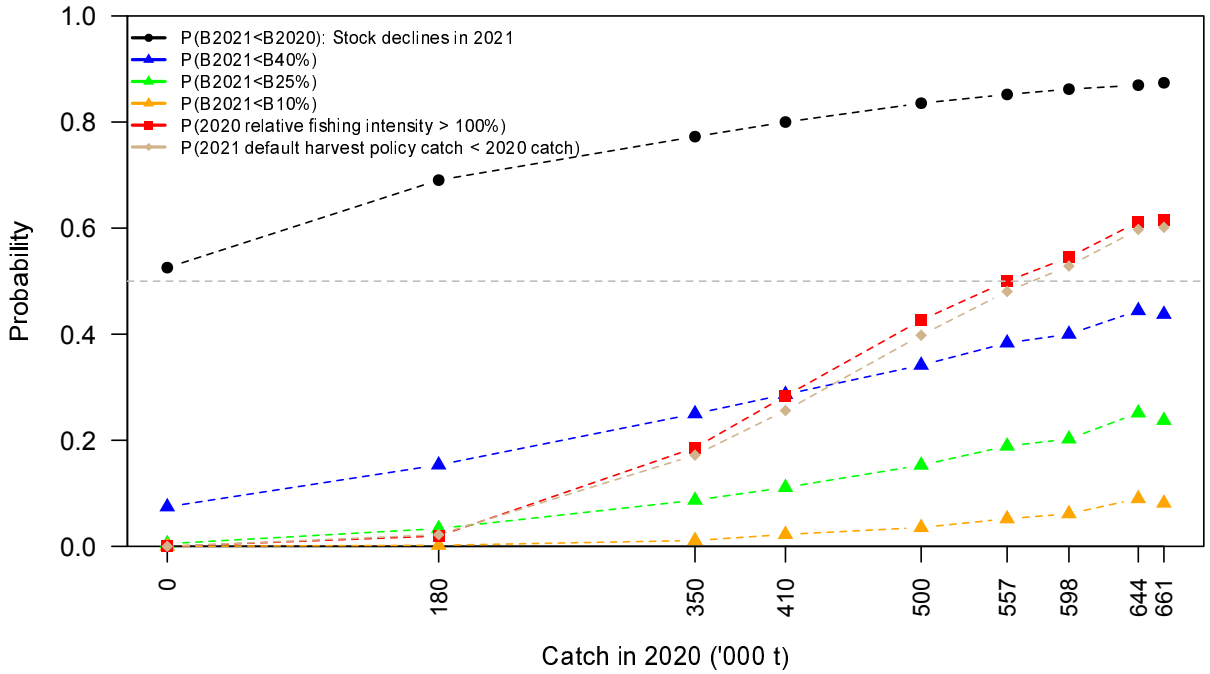

Figure 44. Graphical representation of the base model results presented in Table 32 for catch in 2020, given the 2019 catch level shown in Table 31. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

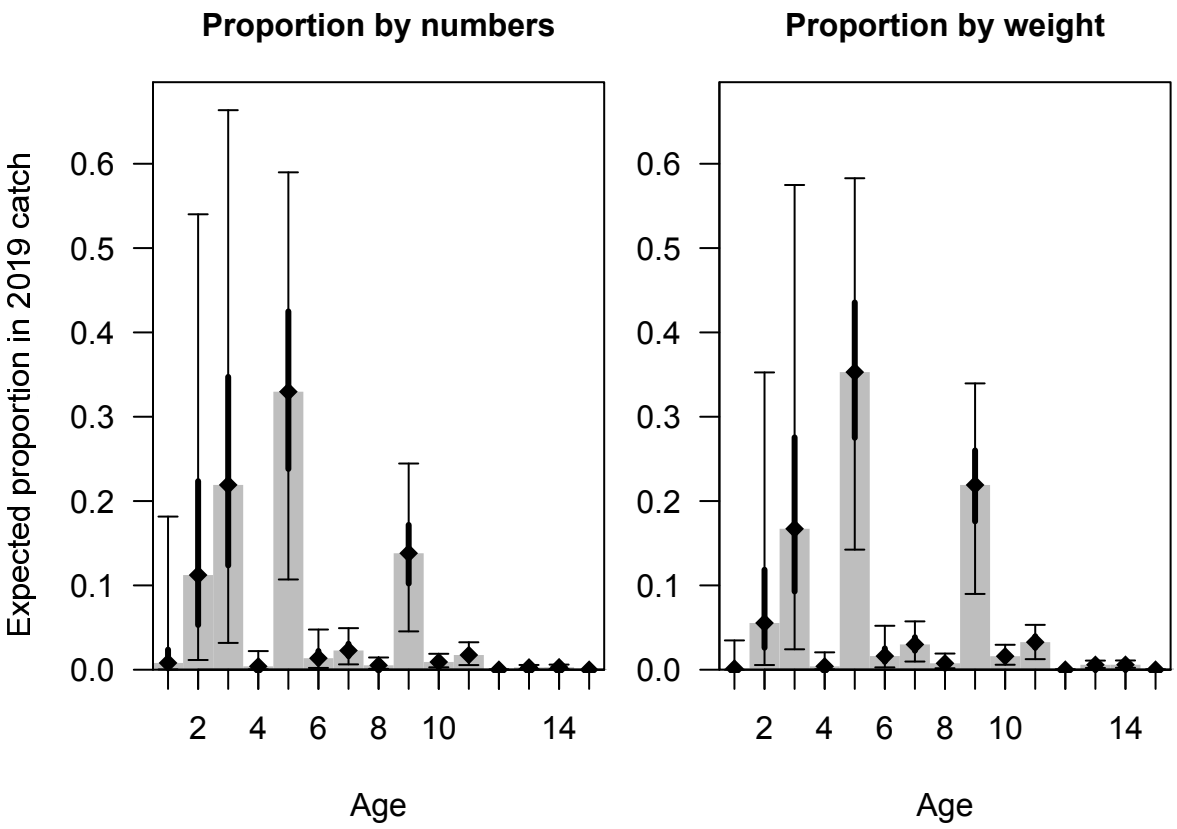

Figure 45. Forecast age compositions in numbers and in weight for the 2019 fishery catch (combined across all sectors in both countries). Gray bars show median estimates. Thick black lines show 50% credibility intervals and thin black lines show 95% credibility intervals. These estimates are based on the posterior distribution for selectivity averaged across the most recent five years and the distribution for expected numbers at age at the start of 2019 (see Table 19 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 1975 to 2018.

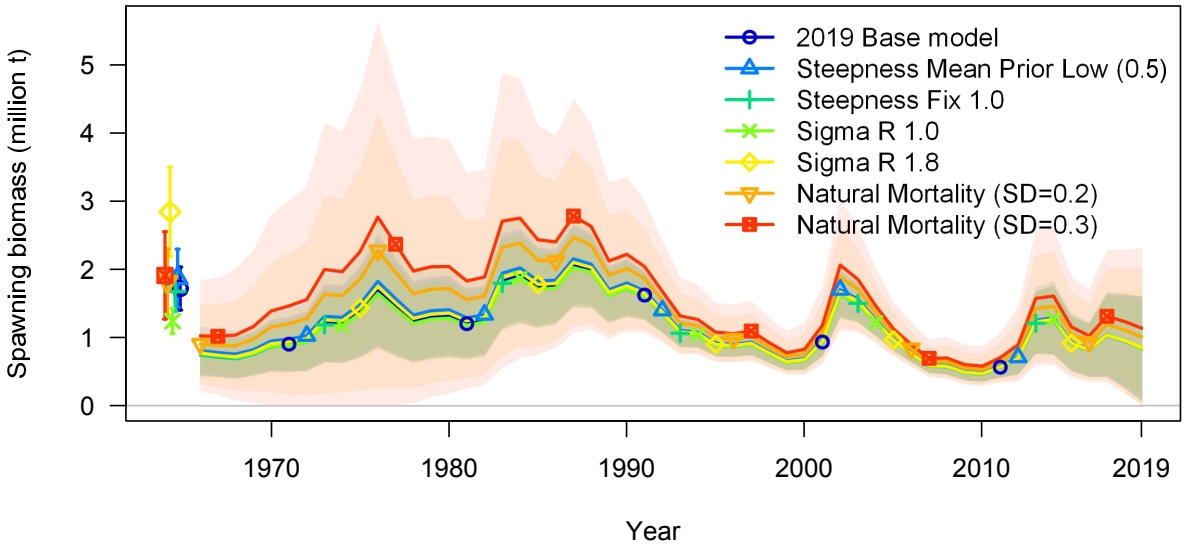

Figure 46. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, lower (1.0) and higher (1.8) levels of variation assumed about the stock-recruitment relationship (σ_r), and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3.

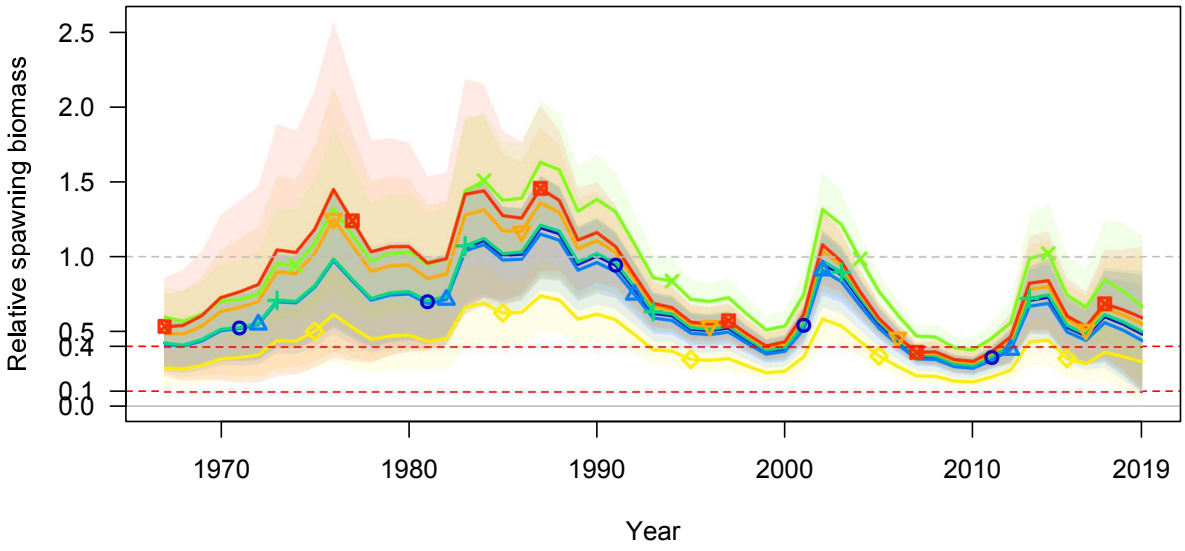

Figure 47. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changing key parameters. See Figure 46 for sensitivity descriptions.

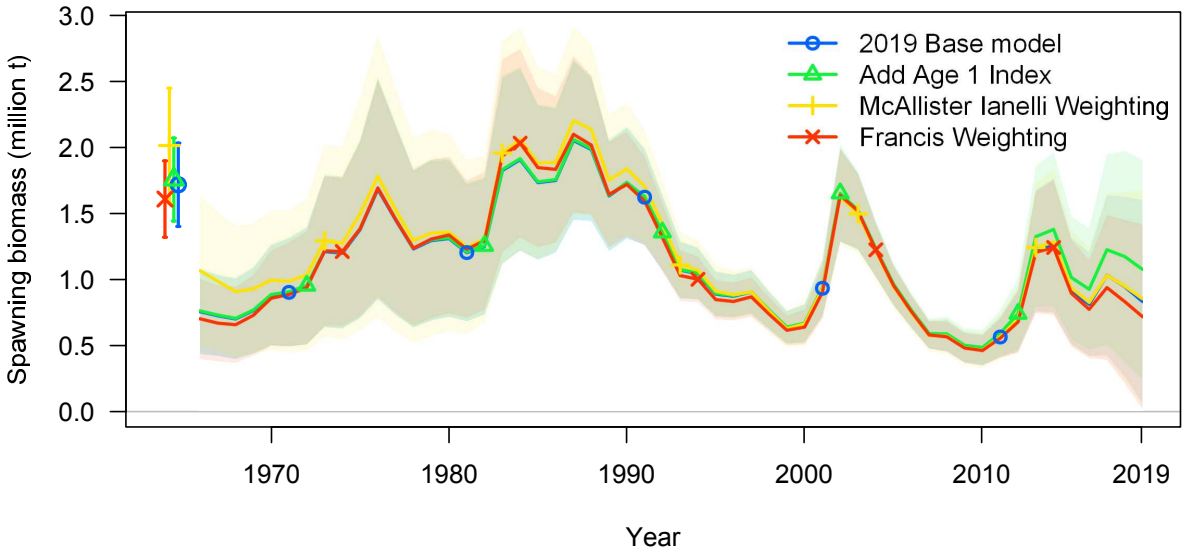

Figure 48. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs that represent the following changes in data: adding an age-1 index of abundance, using the McAllister-Ianelli approach to weight composition data, and using the Francis approach to weight composition data.

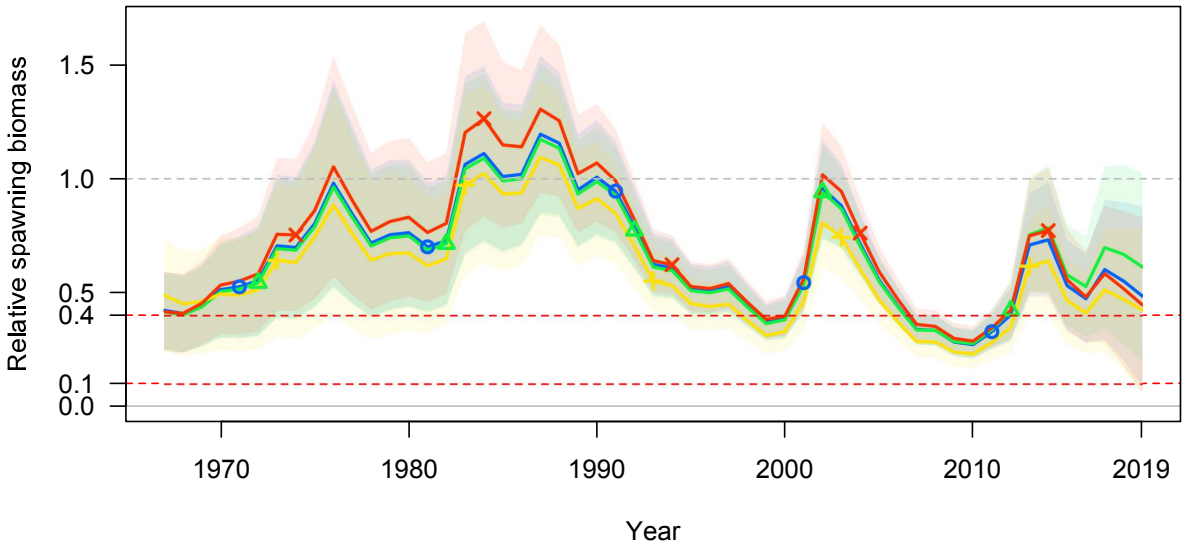

Figure 49. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs that represent changes in data. See Figure 48 for sensitivity descriptions.

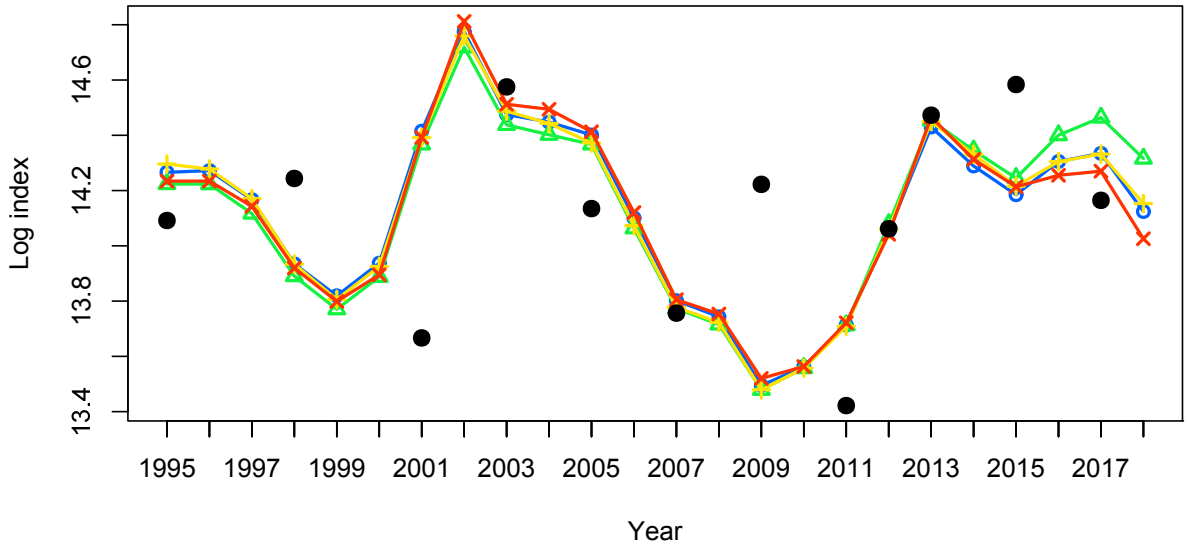

Figure 50. Maximum likelihood estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs that represent changes in data. See Figure 48 for sensitivity descriptions.

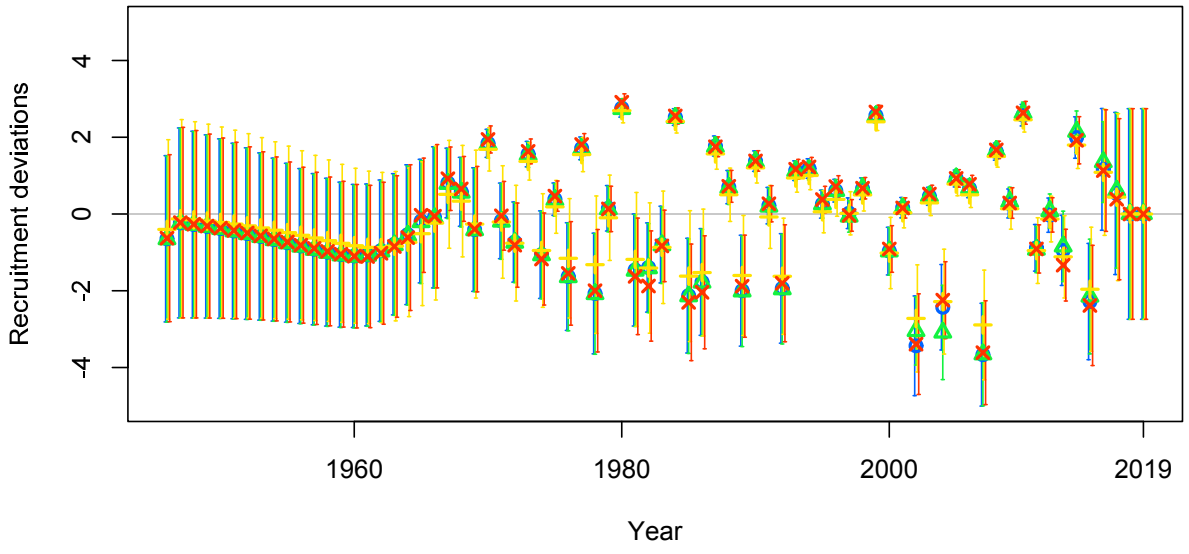

Figure 51. Maximum likelihood estimates of recruitment deviations for the base model and alternative sensitivity runs that represent changes in data. See Figure 48 for sensitivity descriptions.

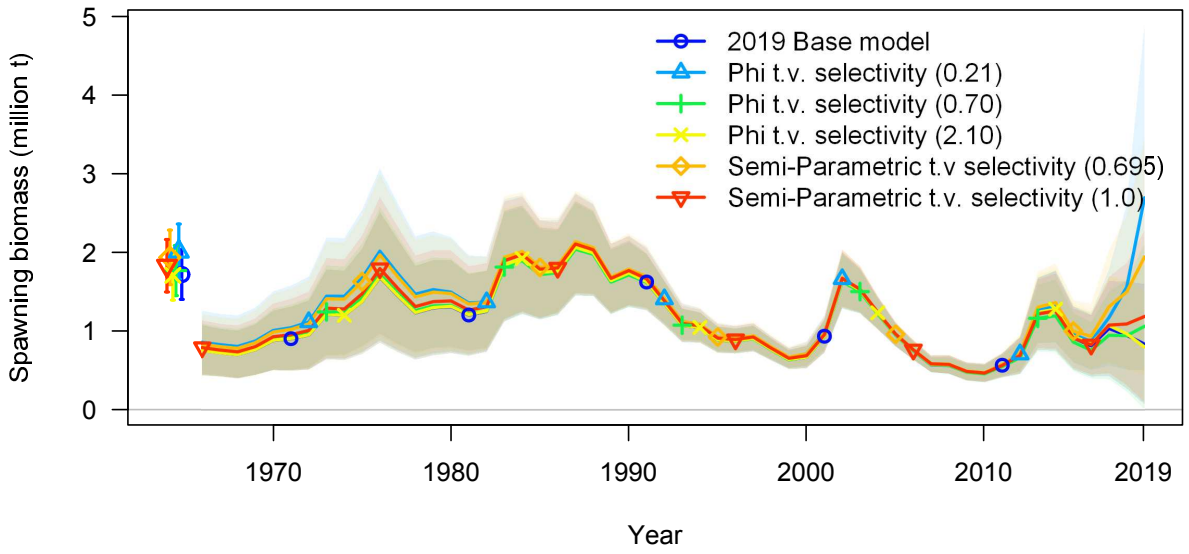

Figure 52. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s).

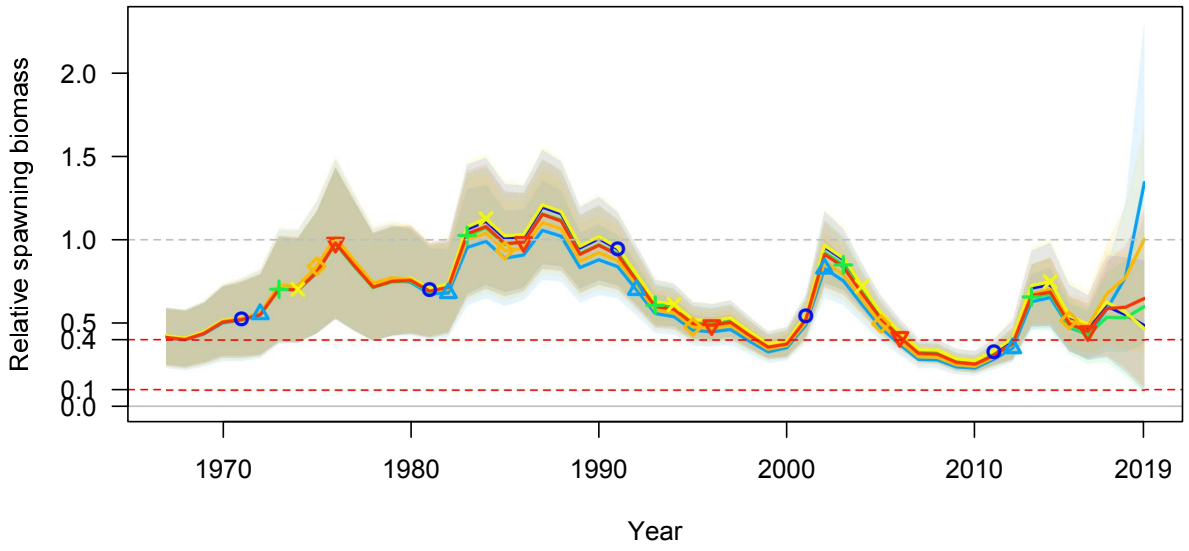

Figure 53. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 52 for legend.

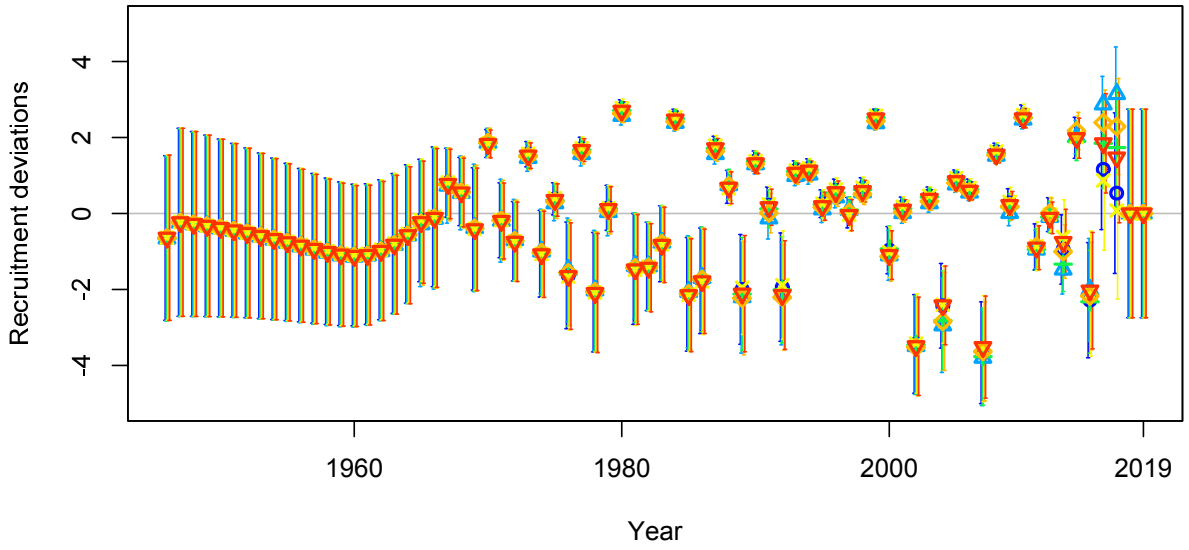

Figure 54. Maximum likelihood estimates of recruitment deviations for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 52 for legend.

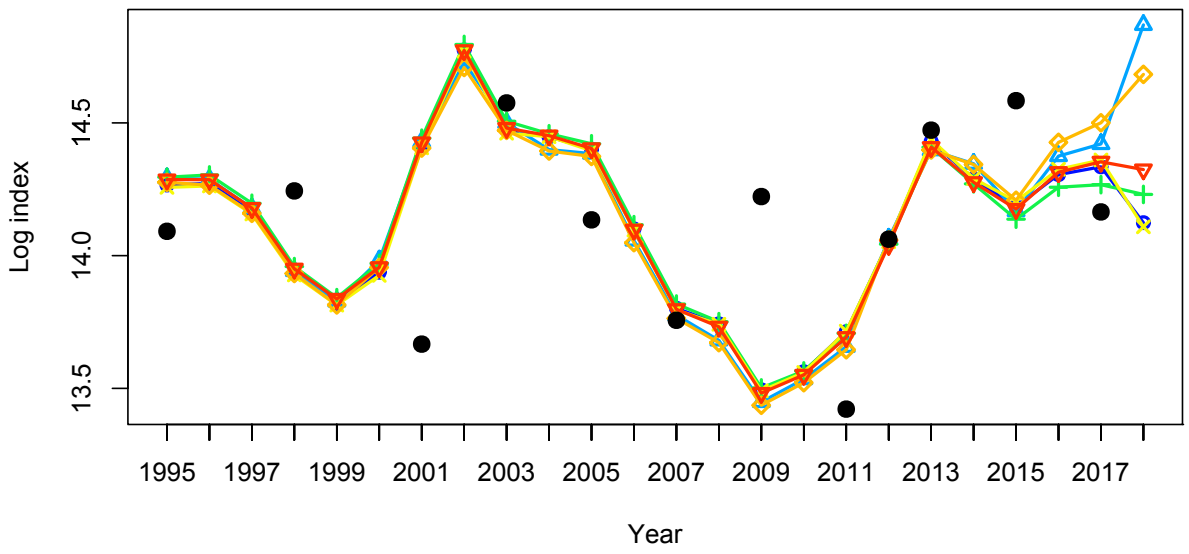

Figure 55. Maximum likelihood estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 52 for legend.

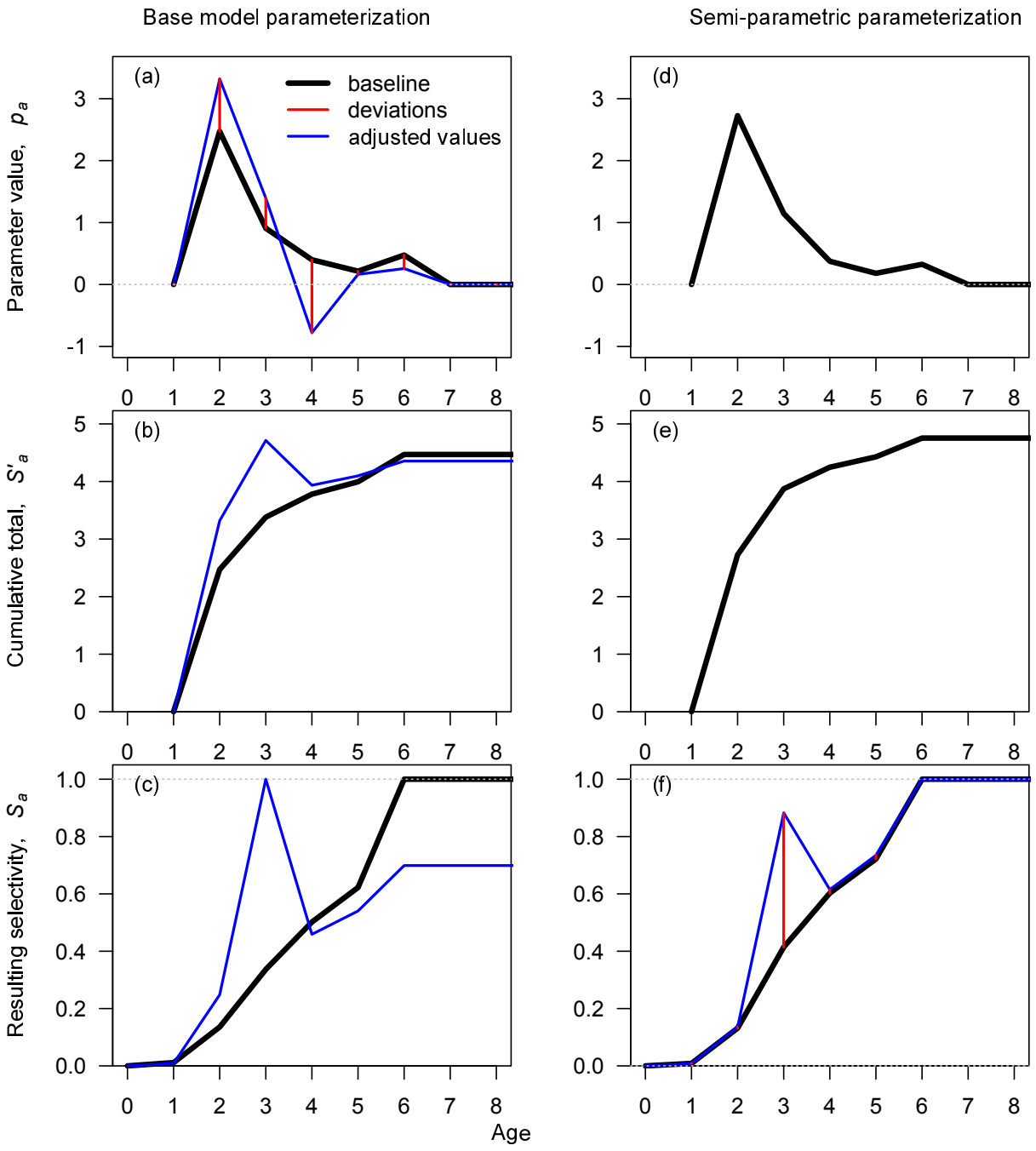

Figure 56. Illustration of parameterization of time-varying selectivity as represented in the base model (left) and the semi-parametric approach used in sensitivity analyses (right). Panels show transformation from estimated parameters (a) to cumulative sum up to each age (b) and the resulting selectivity after exponential transformation and rescaling to have maximum 1.0 (c), as described by equations (1-3). 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).

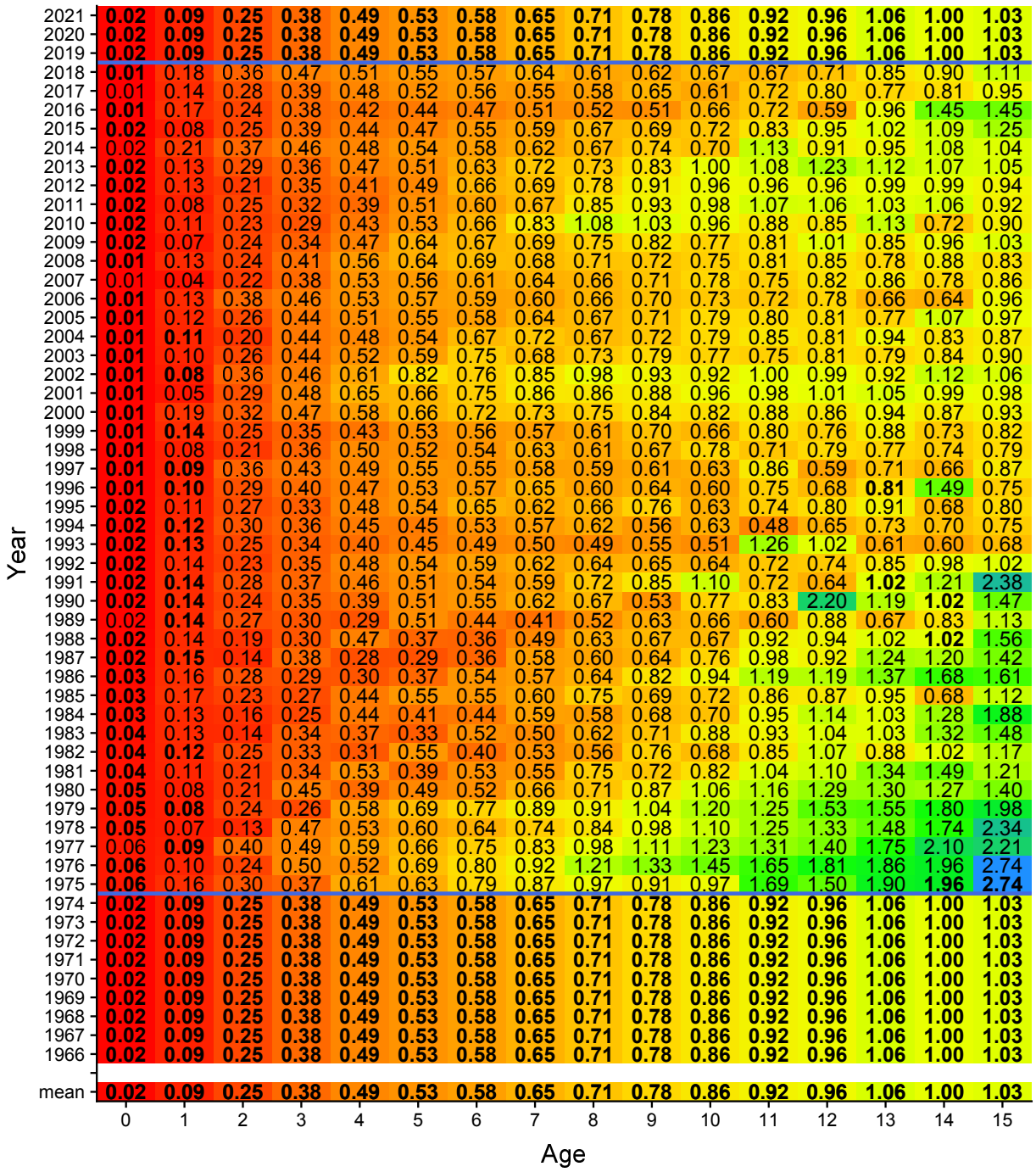

Figure 57. Empirical weight-at-age (kg) values used for sensitivity run 53 and the base model (Figure 12). Data are only available from 1975–2018. Values based on assumptions for the early and late years are shown outside the blue lines (see Table 36). Bold values between the blue lines represent unavailable data and such weights were interpolated or extrapolated from adjacent ages or years. The sample-weighted mean weight-at-age is shown at the bottom.

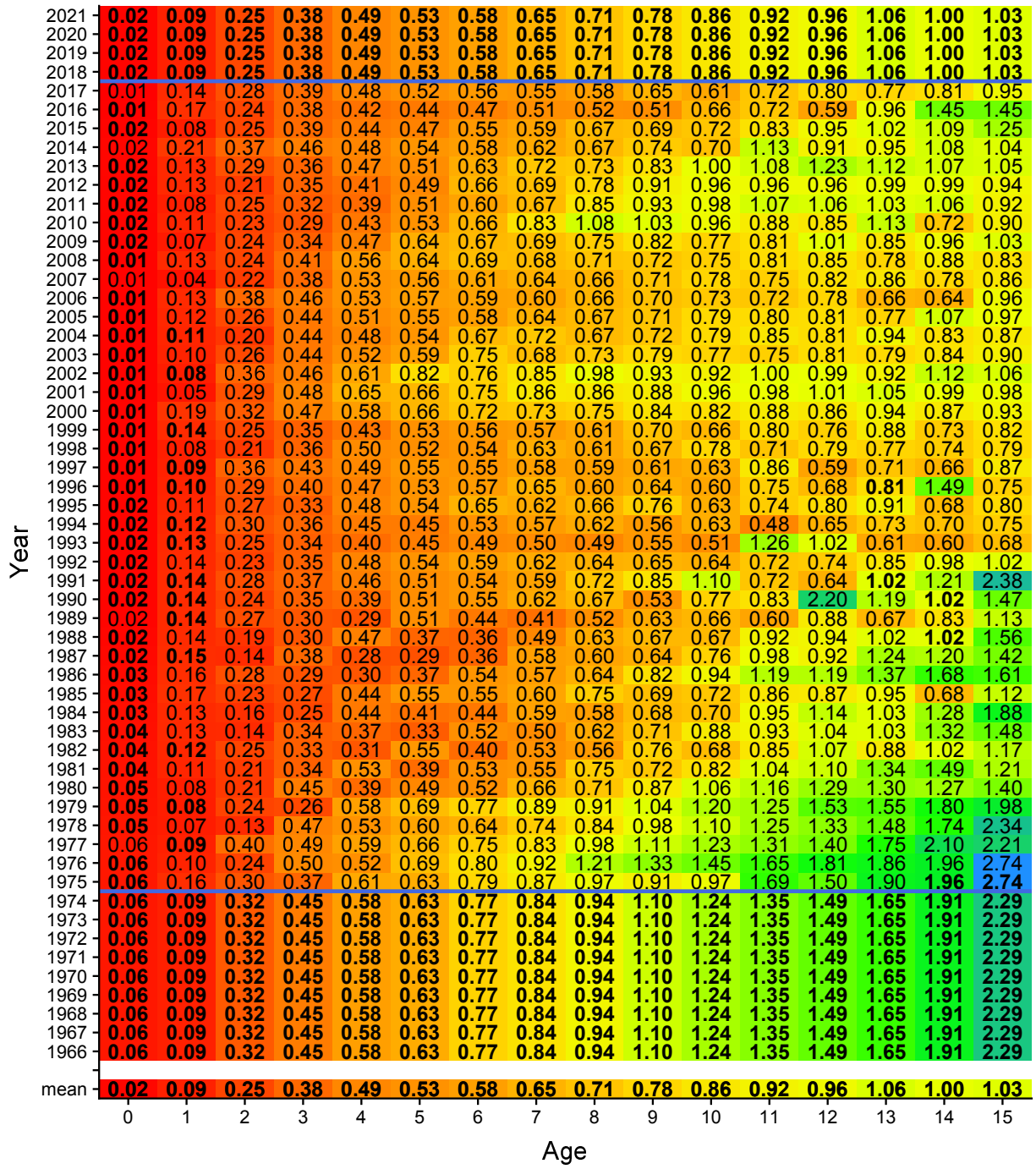

Figure 58. Empirical weight-at-age (kg) values used for sensitivity runs 55 and 57. Details are as in Figure 57. Note the 2018 values have to be assumed (the location of the top blue line is different to Figure 57), as described in Table 36.

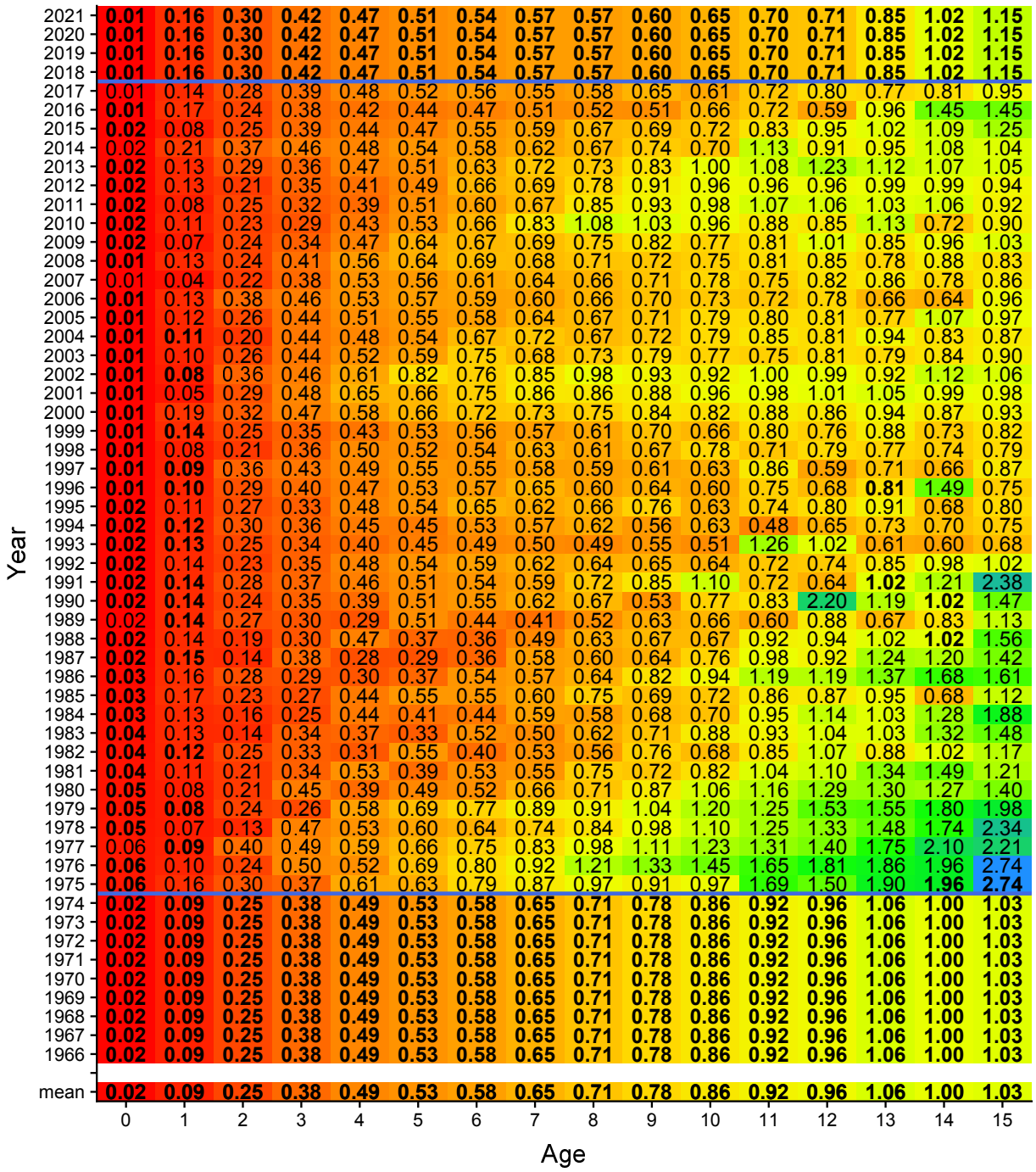

Figure 59. Empirical weight-at-age (kg) values used for sensitivity runs 52 and 54. Details are as in Figure 57. Note the 2018 values have to be assumed (the location of the top blue line is different to Figure 57), as described in Table 36.

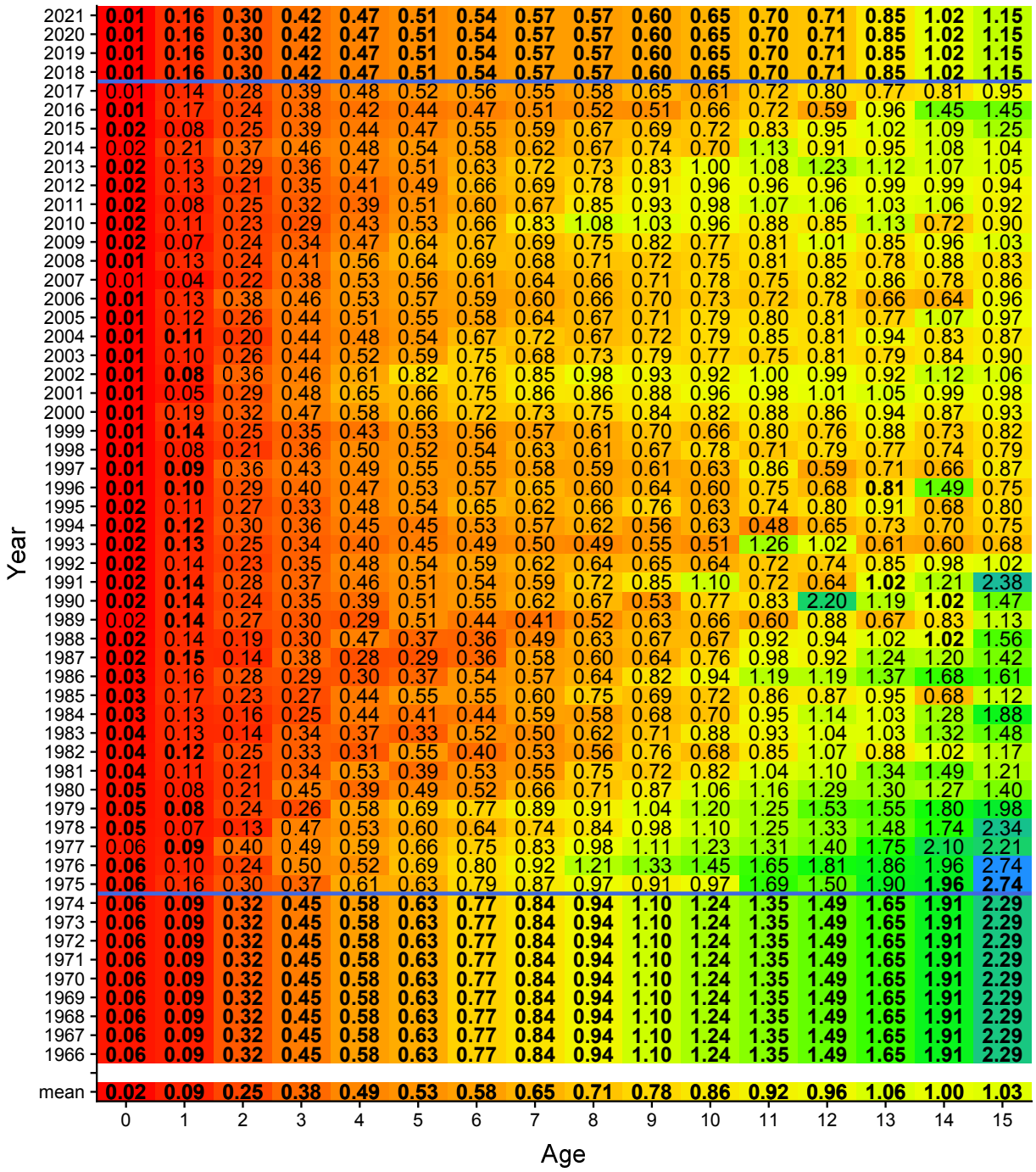

Figure 60. Empirical weight-at-age (kg) used for sensitivity runs 56 and 58. Details are as in Figure 57. Note the 2018 values have to be assumed (the location of the top blue line is different to Figure 57), as described in Table 36.

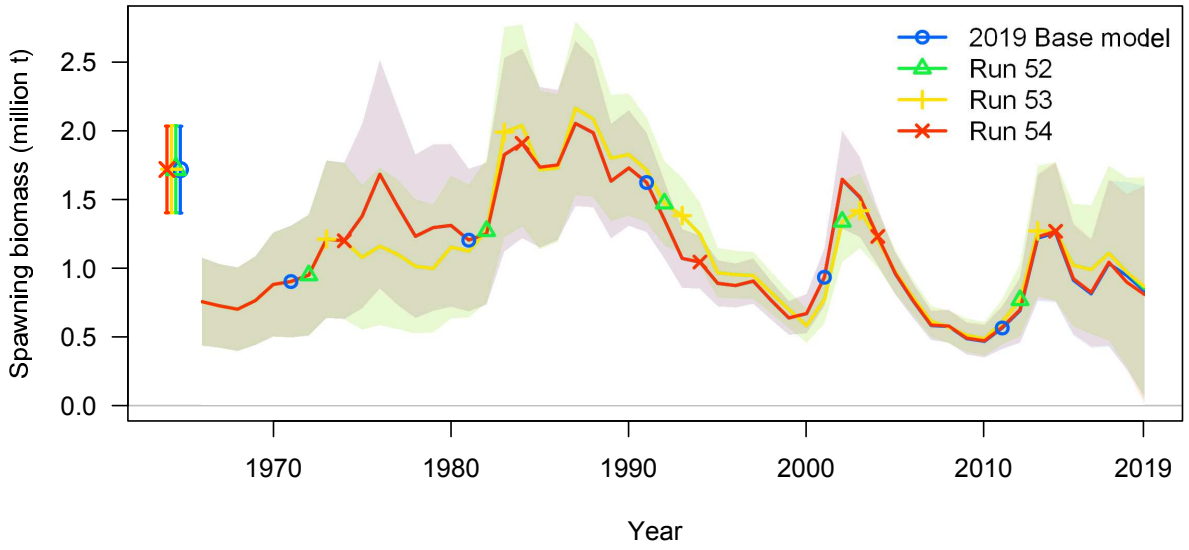

Figure 61. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs 52, 53, and 54 that all set the pre-1975 (1966-1974) weights-at-age to the long term mean (1975–2018). Run 52 has non-time-varying fecundity and the short term mean (2016–2018) as the post-2017 weights-at-age. Run 53 is without time-varying fecundity and with long term (1975–2018) mean as the post-2018 weights-at-age. Run 54 has time-varying fecundity and the short term mean (2016–2018) as the post-2017 weights-at-age. See Table 36 for descriptions of runs.

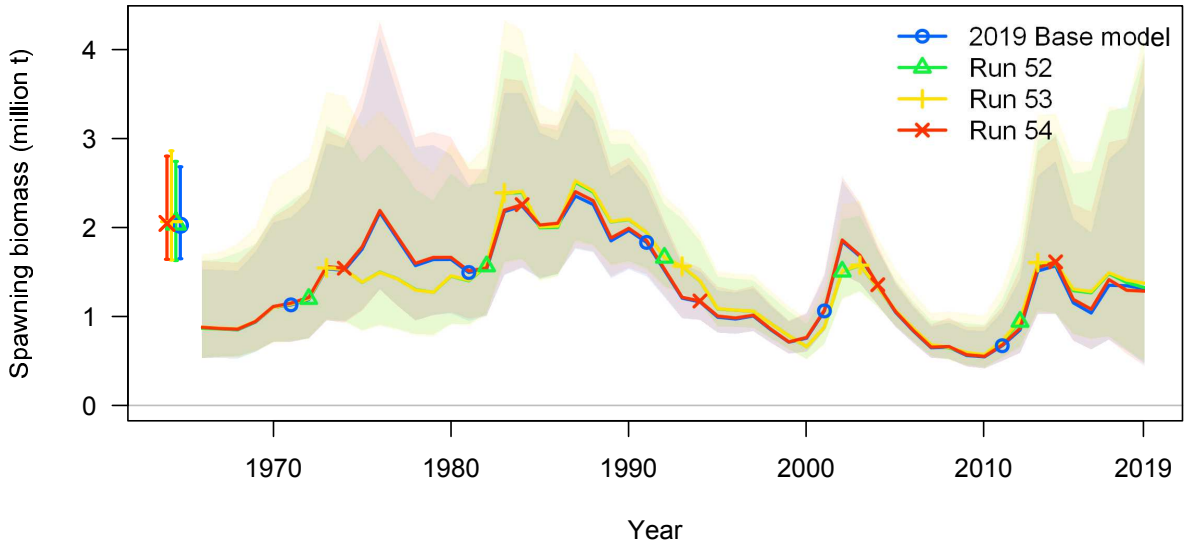

Figure 62. MCMC median posterior estimates with 95% credible interval of spawning biomass for the base model and alternative sensitivity runs 52, 53, and 54. See Figure 61 and Table 36 for descriptions of runs.

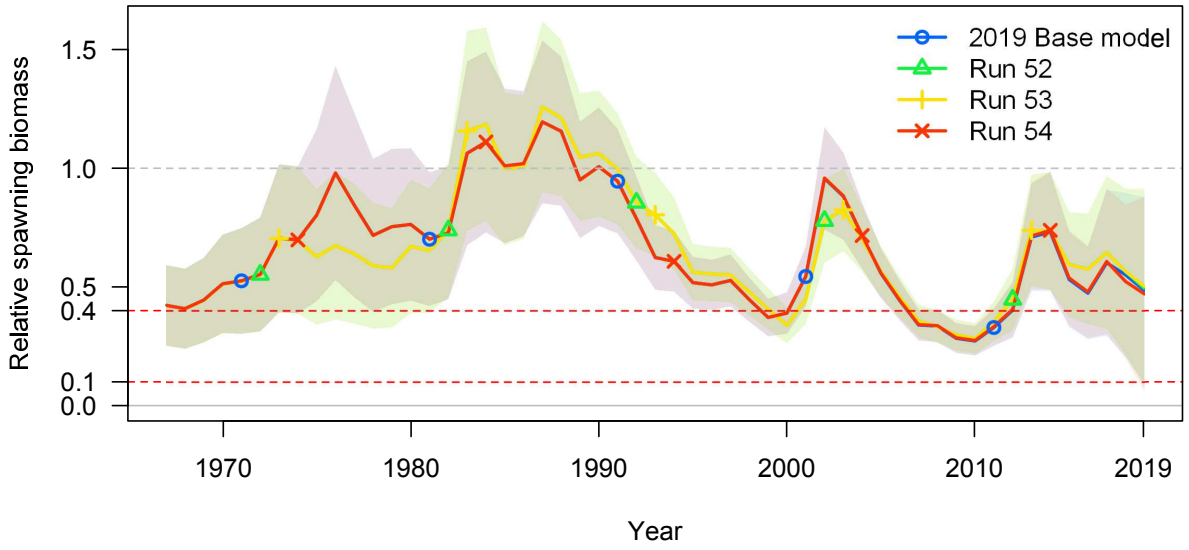

Figure 63. Maximum likelihood estimates of stock status for the base model and alternative sensitivity runs 52, 53, and 54. See Figure 61 and Table 36 for descriptions of runs.

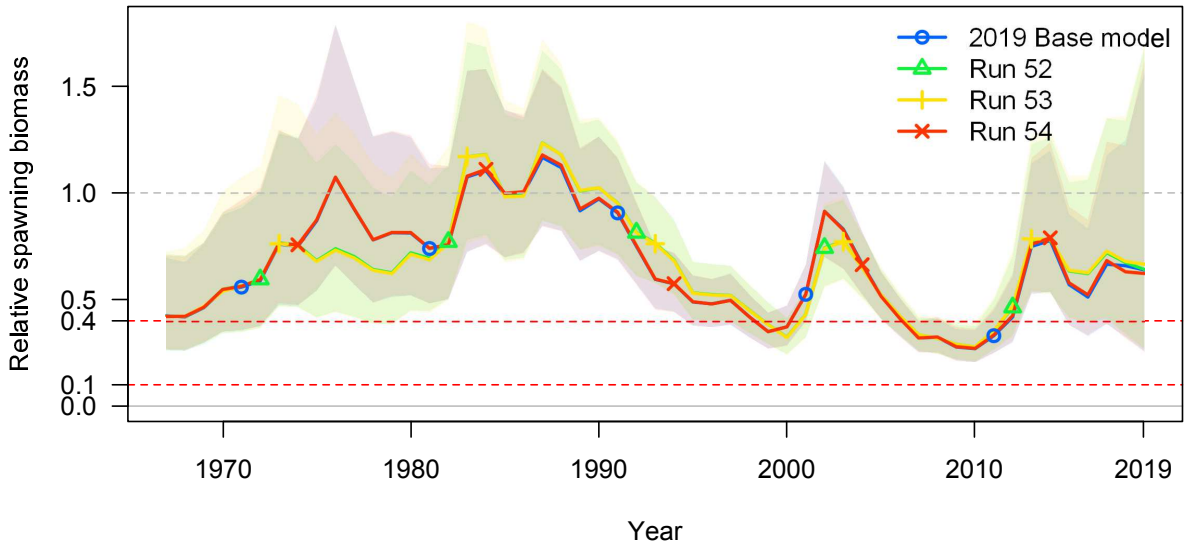

Figure 64. MCMC median posterior estimates with 95% credible interval of stock status for the base model and alternative sensitivity models 52, 53, and 54. See Figure 61 and Table 36 for descriptions of runs.

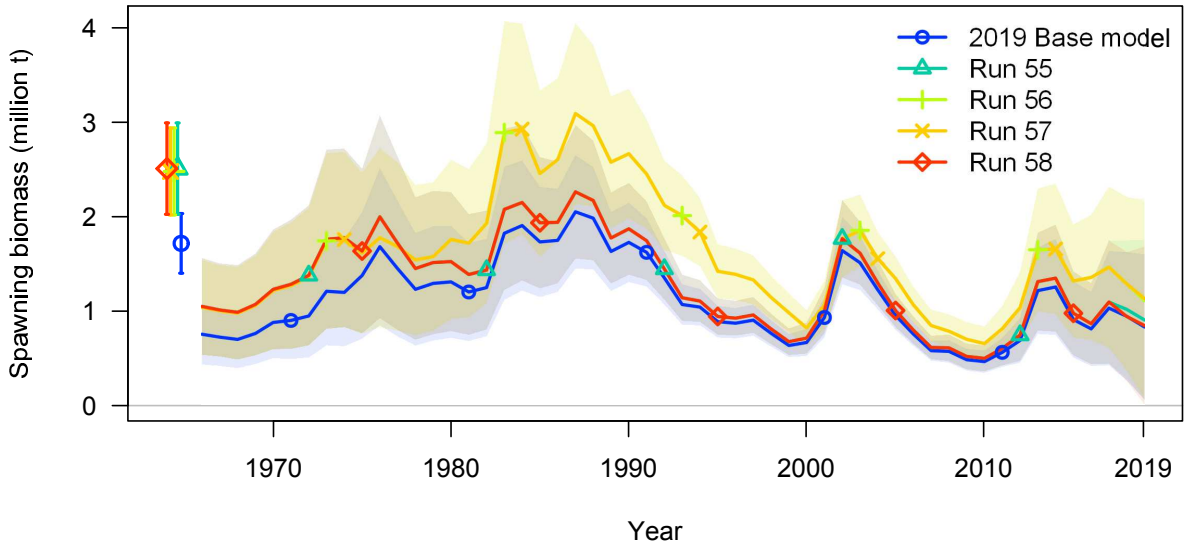

Figure 65. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs 55, 56, 57, and 58 that all set the pre-1975 (1966-1974) weights-at-age to the short term mean (1975–1979). Run 55 has time-varying fecundity and the long term mean (1975–2018) as the post-2017 weights-at-age. Run 56 has non-time-varying fecundity and with short term (2016–2018) mean as the post-2017 weights-at-age. Run 57 has non-time-varying fecundity and the long term mean (1975–2018) as the post-2018 weights-at-age. Run 58 has time-varying fecundity and the short term (2016–2018) mean as the post-2017 weights-at-age. See Table 36 for descriptions of runs.

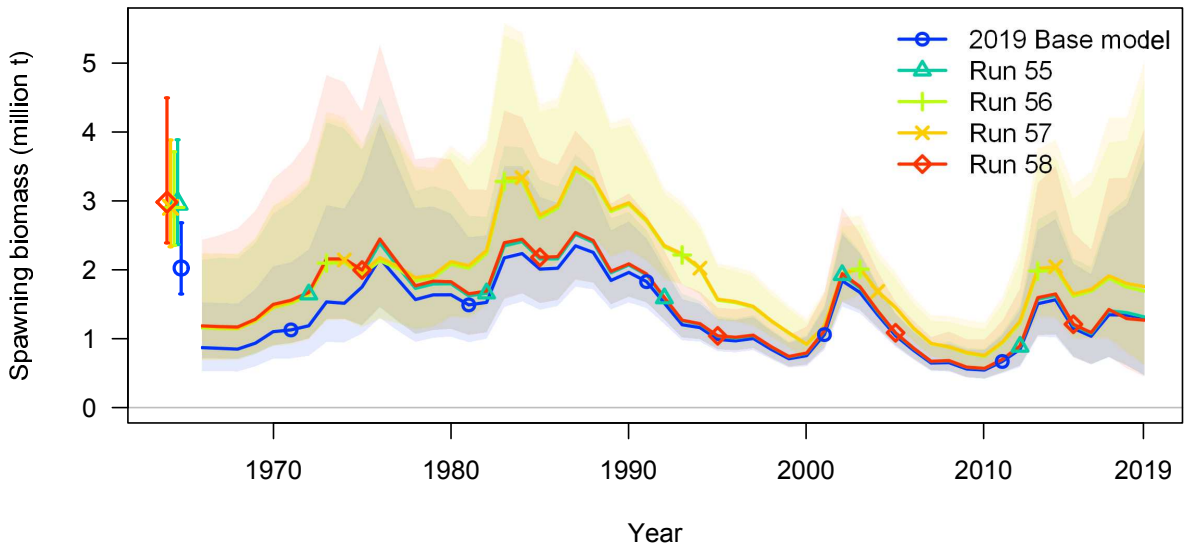

Figure 66. MCMC median posterior estimates with 95% credible interval of spawning biomass for the base model and sensitivity runs 55, 56, 57, and 58. See Figure 65 and Table 36 for descriptions of runs.

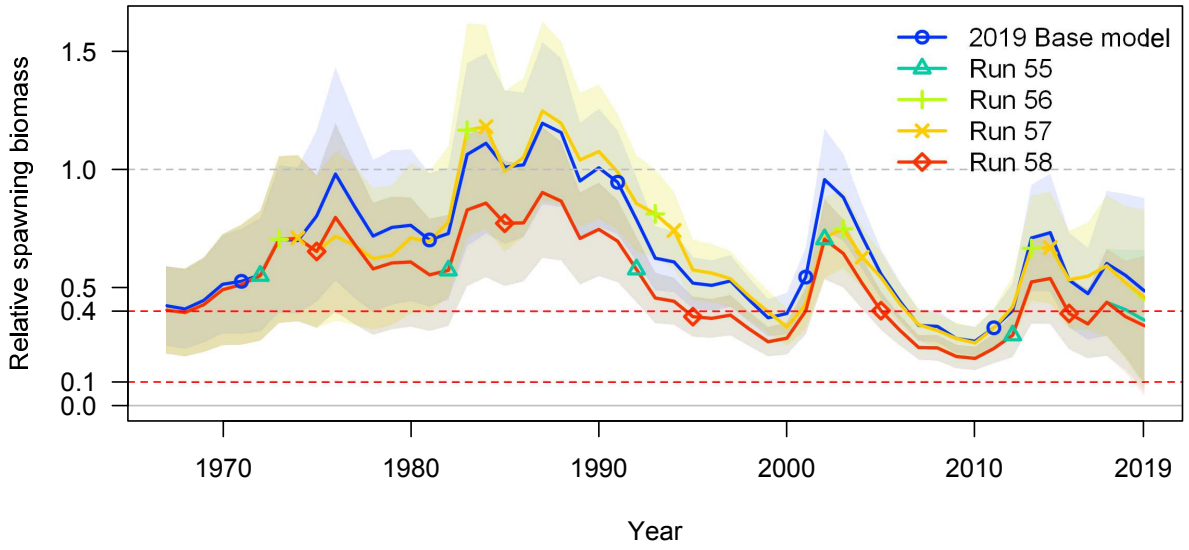

Figure 67. Maximum likelihood estimates of stock status for the base model and alternative sensitivity runs 55, 56, 57, and 58. See Figure 65 and Table 36 for descriptions of runs

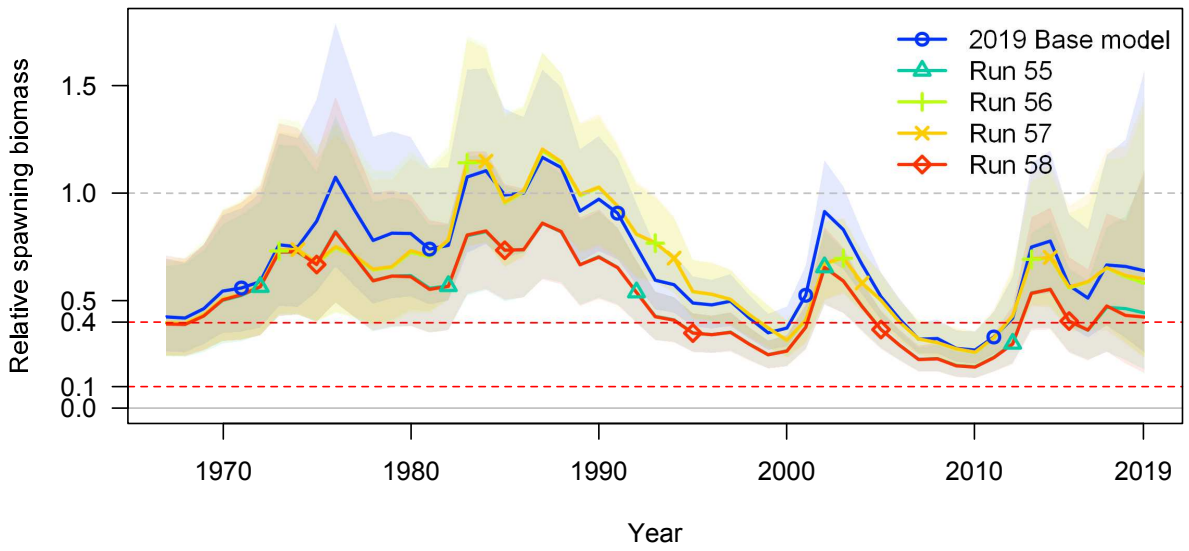

Figure 68. MCMC median posterior estimates with 95% credible interval of stock status for the base model and alternative sensitivity runs 55, 56, 57, and 58. See Figure 65 and Table 36 for descriptions of runs.

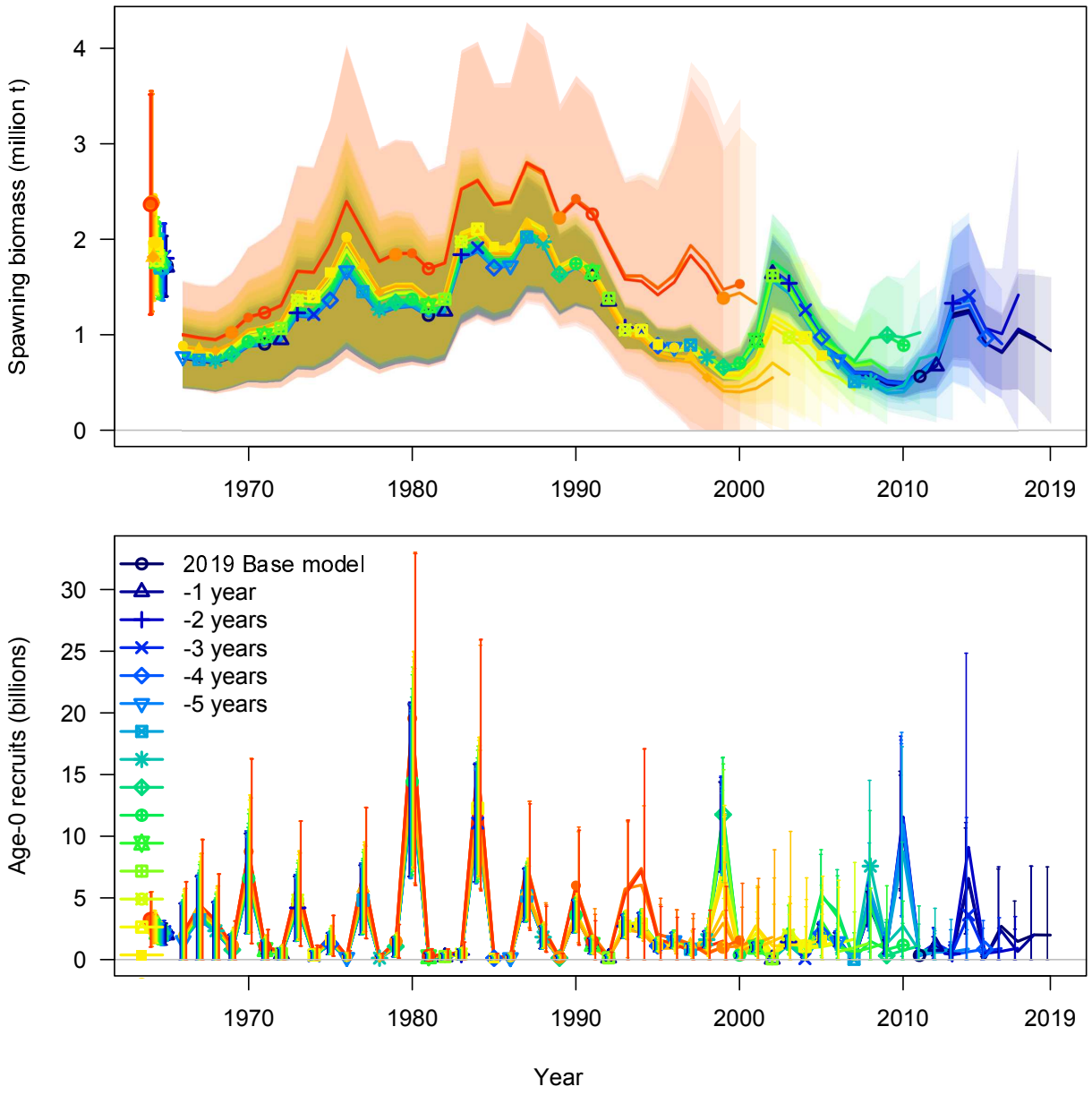

Figure 69. Estimates of spawning biomass at the start of each year (top) and recruitment (bottom) for the base model and retrospective runs (based on MLE model runs).

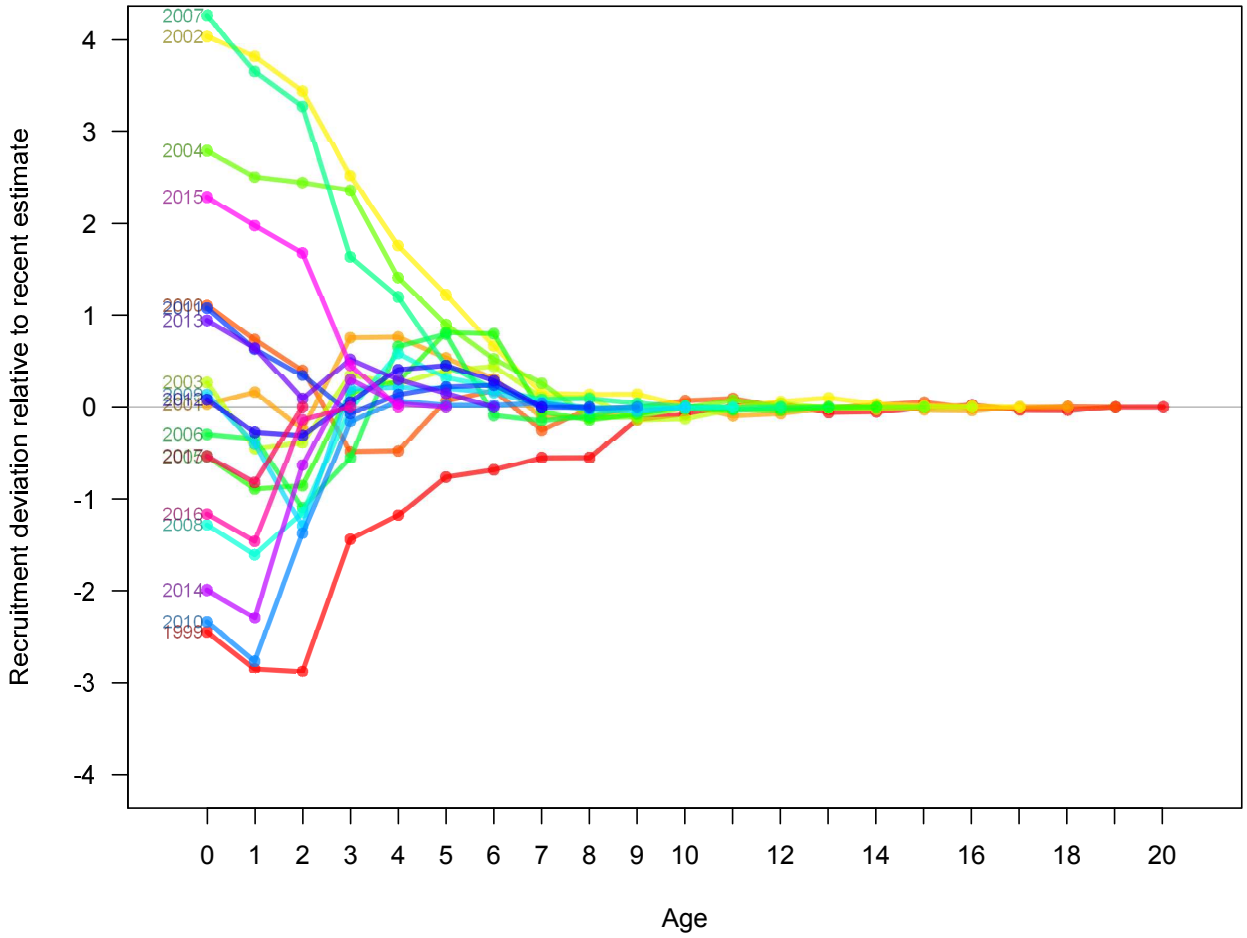

Figure 70. Retrospective recruitment estimates shown in Figure 29 scaled relative to the most recent estimate of the strength of each cohort.

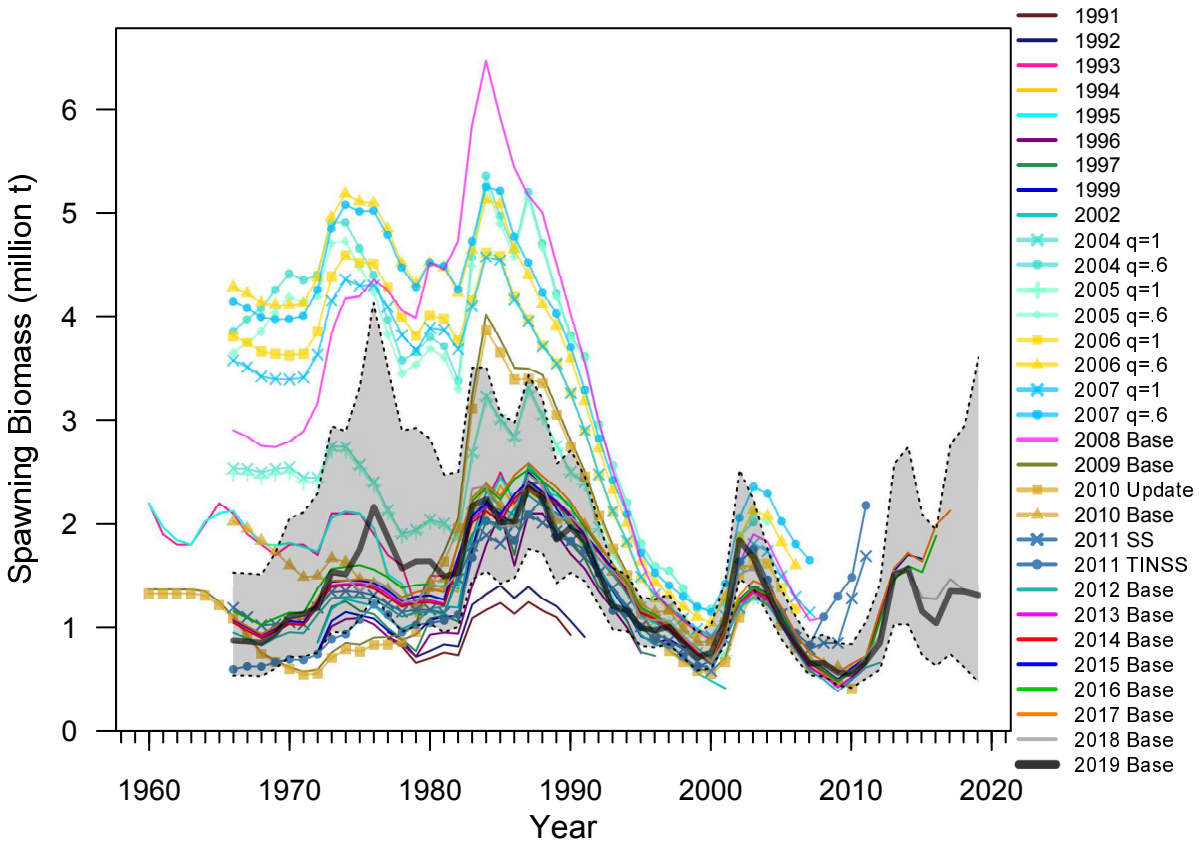

Figure 71. Summary of historical Pacific Hake assessment estimates of spawning biomass. Estimates are MLEs or MCMC medians depending on the model structure. Shading represents the approximate 95% confidence range from the 2019 base model.

A SCIENTIFIC REVIEW GROUP (SRG) REQUESTS FROM 2019 MEETING

This appendix contains results requested at the Scientific Review Group meeting held from 19th February to 22th February, 2019 in Vancouver B.C., Canada.

A.1 ADDITION OF 500,000 T CATCH LEVEL TO FORECASTING

To bridge a large gap in catch levels in the decision tables, the SRG requested the addition of a 500,000 t catch level to the forecasting. This new level was added by the JTC during the meeting, and is included in all relevant tables and figures in this final assessment document.

A.2 CALCULATE RETROSPECTIVES FOR THE SENSITIVITY RUN THAT INCLUDES THE AGE-1 INDEX

The SRG requested the retrospectives be calculated for the sensitivity run that includes the age-1 index in the model. The resulting retrospective cohort plots and associated uncertainty in the recruitment deviations were viewed and discussed, and are shown in Figures A.1 and A.2 and Table A.1.

Investigations into inclusion of the age-1 index will continue in the 2020 assessment, which will include a full MCMC run with an appendix containing forecast decision tables, and other relevant MCMC outputs.

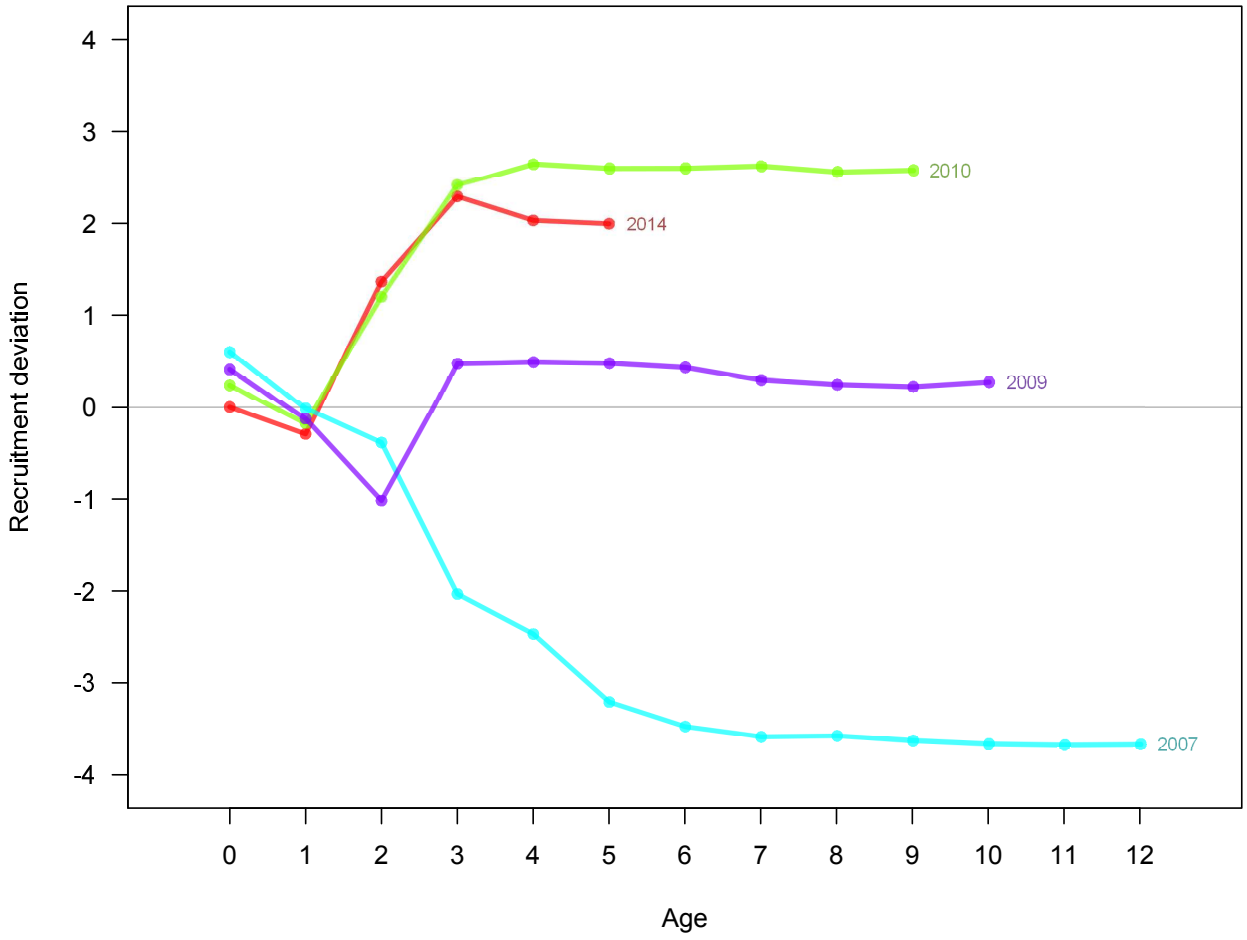

Figure A.1. Retrospective analysis of recruitment deviations for selected cohorts from MLE models associated with the age-1 index sensitivity evaluation over the last 21 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for example cohorts from 2007 to 2014, 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.

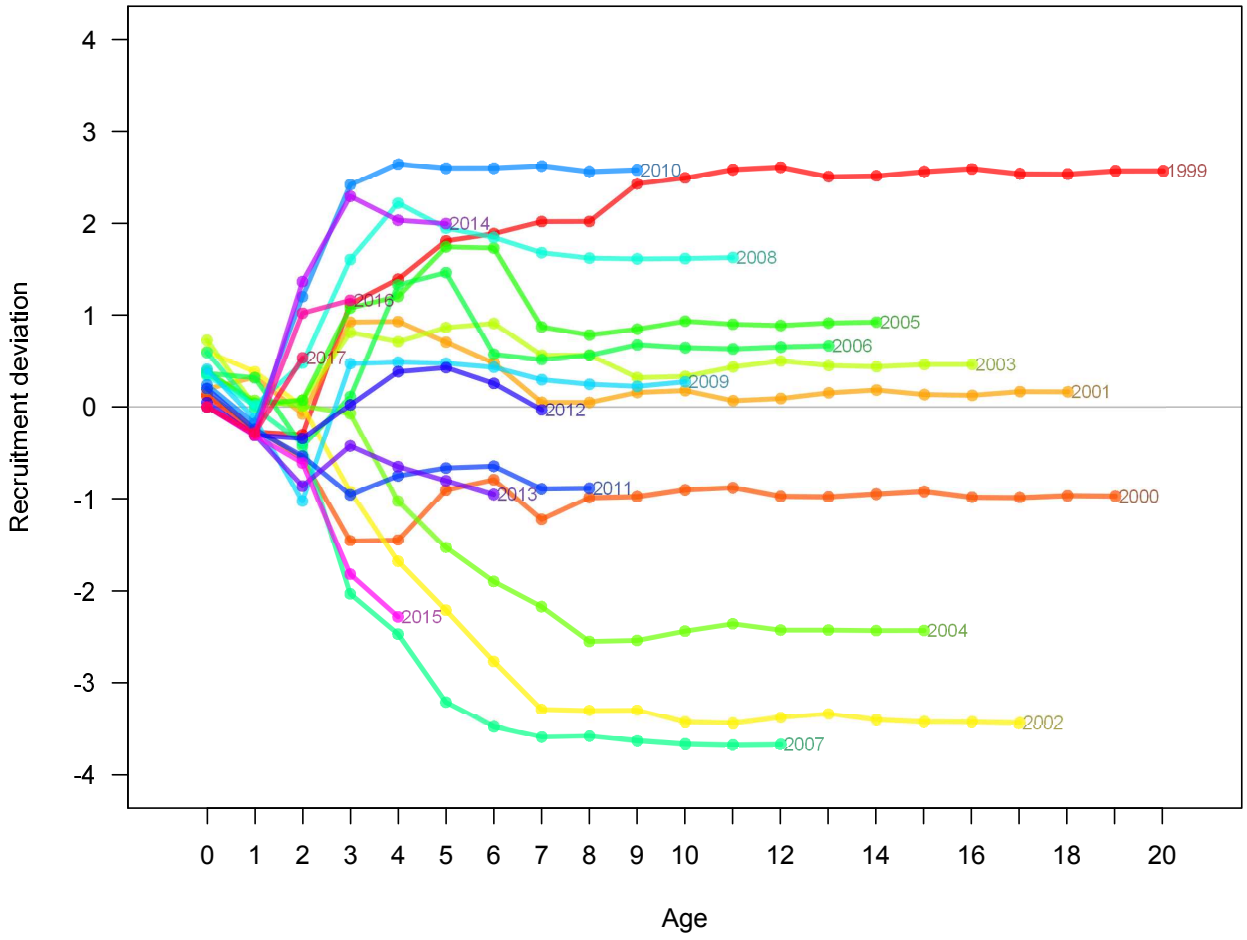

Figure A.2. Retrospective analysis of recruitment deviations for all cohorts from MLE models associated with the age-1 index sensitivity evaluation over the last 21 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for all cohorts from 1999 to 2017, 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.

Table A.1. Estimated recruitment deviations and log standard deviations (approximiate CVs) for age-2 cohorts for the base model and the model which tests the sensitivity to adding the age-1 index. All values are from MLE runs.

	Base model		Age-1 Index	
Cohort	**Value**	**Log(SD)**	**Value**	**Log(SD)**
1999	-0.303	1.144	-0.225	1.141
2000	-0.562	1.187	-0.560	1.187
2001	-0.076	1.315	-0.073	1.329
2002	0.007	1.492	-1.224	0.611
2003	0.073	1.423	0.051	1.417
2004	0.011	1.475	-2.078	0.591
2005	0.074	1.290	-0.435	1.185
2006	-0.425	1.256	1.710	0.553
2007	-0.391	1.211	-0.176	1.314
2008	0.478	1.189	2.454	0.541
2009	-1.021	1.187	-0.827	1.204
2010	1.201	1.286	2.654	0.740
2011	-0.534	1.179	-1.118	0.638
2012	-0.342	1.263	0.308	0.619
2013	-0.857	1.204	-0.802	1.201
2014	1.365	1.061	2.389	0.621
2015	-0.607	1.162	-0.503	1.160
2016	1.022	1.071	1.345	0.595

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 $F_{\mathrm{SPR}=40\%}$, 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-

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

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 is 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

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

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:

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

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

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

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

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

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

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:

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

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_{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.

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

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

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 PFMC. 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

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

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).

$\text{SPR}_{40\%}$: 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

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'.

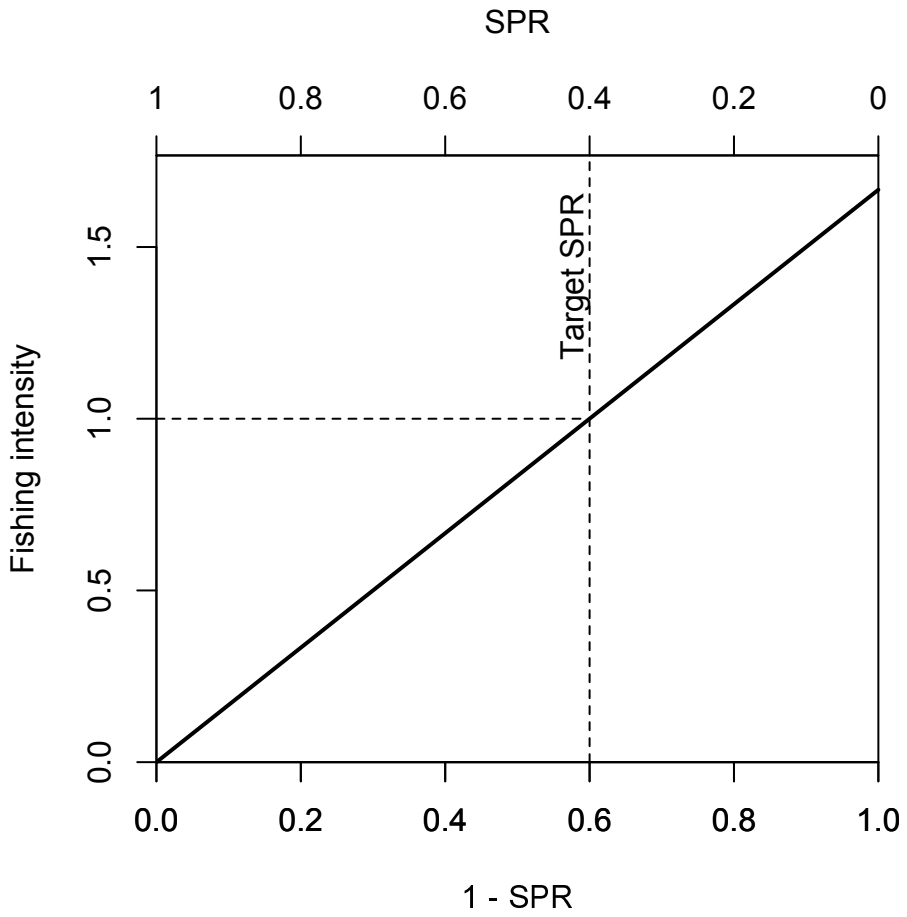

Figure B.1. Fishing intensity as a function of SPR (top axis) and 1-SPR (bottom axis); given the target SPR of 40%, the bold line is simply $1/0.6$, as shown in equation (B.5).

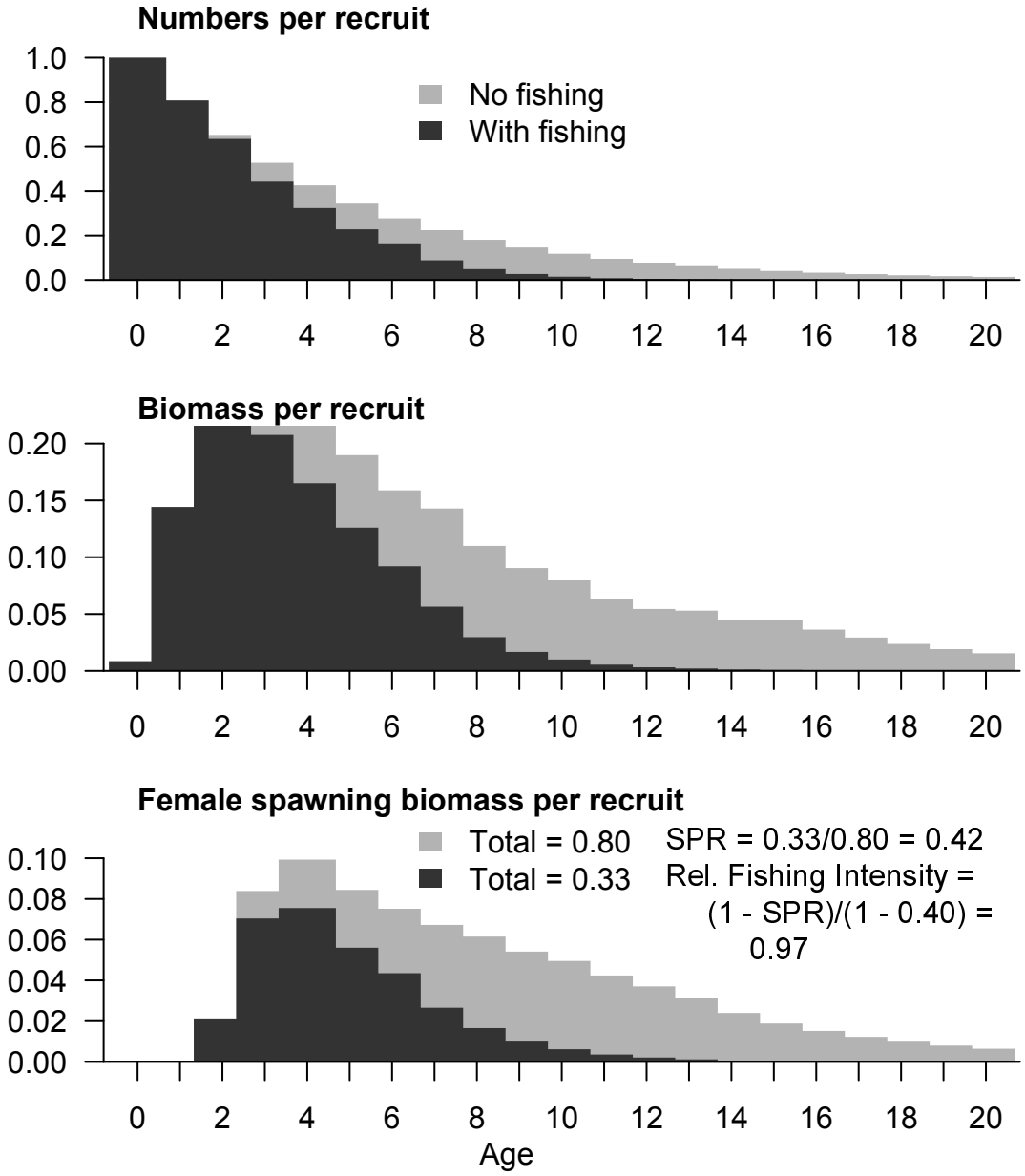

Figure B.2. Illustration of the spawning potential ratio (SPR) calculation based on the combination of maturity and fecundity used in the model, using the maximum likelihood estimates of natural mortality, selectivity, and fishing mortality in the final year of the base model.

C REPORT OF THE 2018 PACIFIC HAKE FISHERY IN CANADA

Prepared by the Canadian Advisory Panel and submitted for inclusion in this assessment document on February 4th, 2019.

The 2018/19 Offshore Pacific TAC for Canada was 135,243 mt. Combined with carryover from the 2017/18 fishery of 20,824 mt, this year's total available harvest was 156,067 mt. As of November 15, this year's total catch of Offshore Pacific hake by Canadian vessels was 91,400 mt which equates to 68% of the Canadian TAC and 59% of the available harvest. For the second year in a row, there was a Joint Venture fishery in Pacific Canada. The JV fishery ran from August 21 to September 15 and a total of 2,439.63 mt of hake was delivered to the Dutch registered vessel Margiris.

Fishing in the Canadian zone started in early April with the last delivery occurring in late November. Freezer vessels started first with shoreside deliveries and processing commencing in mid April. The fishery started off Southern Vancouver Island in Clayoquot Canyon and south down to Barkley Canyon. Through most of the year hake were available in their usual spots on the main edge of Vancouver Island from Nit Nat Canyon to Pisces Canyon. While production was good for most boats this year, operators did notice that the schools of hake were smaller on average than the previous year. In 2018 there weren't significant quantities of hake north of Pisces Canyon and there were no bodies of mature hake seen in Queen Charlotte Sound. The size of the fish was generally similar to the previous year with round sizes ranging from 560 to 860 grams and an average size of 670 grams. There was a very large biomass of juvenile hake off the Goose Bank and Top Knot between 60-90 fathoms depths during June and August.

Avoidance of juvenile sablefish interception was an ongoing problem for the fleet this year. This was also a concern at the start of the 2017 season, but in 2018 it was a continuous issue throughout the year with juvenile sablefish mixed in with mature hake. Fleet avoidance did impair hake harvesting efforts at times. In late August bocaccio rockfish bycatch also started to become a concern (particularly north of Brooks Peninsula) and, while not as problematic as juvenile sablefish, did impact some operations.

A majority of the Canadian production was HGT (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 down slightly from 2017 (32 vessels in 2017 and 29 vessels in 2018), due to a reduced JV fishery.

The Canadian hake fleet believes the 2018 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 2017, there appeared to be a large hake biomass in Canada but the size of the schools were smaller. However, there does appear to be signs of another strong year class.

D REPORT OF THE 2018 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 2, 2019.

The Mothership (MS), Catcher Processor (CP), and Shoreside (SS) sectors of the U.S. Pacific whiting fishery started fishing on May 15 this year. Tribal harvest began on July 5. Consistent with normal operations, harvest continued through the summer in the SS sector; however, both the MS and CP sectors temporarily suspended operations while their vessels participated in the Bering Sea Pollock fishery. Fishing resumed in both offshore sectors in mid-September. Harvesting and processing effort in 2018 was generally consistent with 2017, except that the one MS processor absent in 2017 returned to the fishery.

At the 31 July 2018 JMC meeting in Victoria B.C., it was reported that all sectors were experiencing excellent CPUE early in the season similar to 2017. This year, even more so than last, schools were spread out along the coast from north to south and in both deep and shallow bottom depths. Unlike 2017, where the shallower schools of fish were predominantly small fish, larger fish (2014 and older) have been found in as shallow as 50 fathoms. The abundant schools of whiting encountered inside of 100 fathoms last year, so far have not been reported by the fishermen this year (through July). There have, however, been encounters with sizable schools of 150-200 gram fish both north and south of the Columbia River. Harvest of fish below 250 grams was below 2% early in the season for the offshore sectors. It also was noted at the July meeting that ocean conditions had generally 'returned closer to normal', rockfish species seem to be more widely dispersed (North-South and Shallow-Deep), and that harvesters are again reporting unusually high mid-water encounters with juvenile black cod. Unlike last year where these encounters were limited to the northern areas, it appears that they are spreading to the south as well.

At Sea Sectors

For the at-sea (MS and CP sectors) fishery, bycatch avoidance was again the dominant driver of fishing behavior. Throughout the season and particularly in fall, the MS and CP sectors struggled to find schools of hake that were not mixed with either rockfish, sablefish, Chinook salmon, spiny dogfish, or a combination of all four. Eventually, the fishery shut down early due to bycatch issues.

During the 2018 fishery, hake were spread along the coast from northern WA to southern OR, but more often than not hake schools were mixed with bycatch species. Vessels were forced to move frequently to avoid species of concern. The at-sea sectors voluntarily avoided Chinook salmon and a large year-class of sablefish that was abundant in large concentrations in several areas along the coast. Because exceeding specified amounts of these species would result in fishery closure, these measures, when combined with avoidance of darkblotched rockfish and Pacific Ocean perch, forced the at-sea fleets to move up and down the coast in search of relatively clean schools of hake. Widow rockfish and canary rockfish were also chronically encountered, sometimes in large

amounts.

Early in the season, at-sea fleets encountered fish of 650-700 grams (perhaps from the 2010 year class) to the north, but bycatch events drove them to fish further to the south where catches have been dominated by fish in the 450-500 gram size, presumed to be the 2014 year class. Fish quality during this time was excellent as reported by processors with 'healthy and fat' fish being reported. Like 2017, good early season fishing was reported up and down the coast.

Fishing in the at-sea sectors continued into November, eventually shutting down prematurely due to bycatch issues. Both the MS and CP sectors experienced much higher than normal rockfish bycatch events, especially darkblotched rockfish and Pacific Ocean Perch (POP). In mid-November, a MS catcher vessel had a lightning strike tow with 15 mt of POP. Soon after this event, the MS sector ceased fishing and closed themselves for the remainder of the year. With less than 1.5 mt of POP remaining in the bycatch buffer, the CP sector continued searching for clean fishing for another week up and down the coast, eventually ceasing operations on November 22 when none could be found. As a result of the bycatch constraints, the at-sea sectors stranded large amounts of hake. The CP sector left over 20K mt unharvested and the MS sector left almost 30K mt unharvested.

Shoreside Sectors

The shoreside sector utilized about 76% of its 2018 whiting allocation. Vessels reported a diverse range of fish sizes over the course of this year's fishery, with larger fish found off southern Oregon (Newport) and north of the Columbia River. Smaller fish were consistently reported by vessels fishing off the Willapa area.

Newport OR plants experienced an above average season, with steady production into October and most fish averaging 450-500g or more; boats were usually able to avoid smaller fish. Northern plants (Columbia River) reported that fishing tended to be a little spottier, and pockets of smaller fish (200-300 g) were observed around Willapa and on the shallows (inside of 70 fathom). In areas where fish size was generally smaller (less than 250/300g), the smaller fish were not uniform in size and appear to come from a number of different year classes. Fish size tended to increase again in areas north of Westport WA. The tribal catch of whiting (Makah) consisted of larger fish (400g+).

Bycatch issues are reported to have been less significant for the shoreside sector this year for southern areas of the fishery but problematic at times for the northern areas. Yellowtail rockfish was a dominant bycatch species, and some vessels 'capped out' due to the restrictive vessel cap for yellowtail – this is a substantial concern for vessels that spend part of the year targeting groundfish/rockfish. Additionally, during the summertime fishery, some boats moved off blackcod bycatch encountered off the Willapa towards the Columbia River (in addition to the whiting being smaller in this area).

Tribal Fishery

The 2018 tribal fishery saw significantly more fish on their grounds than 2017 both in spring and in fall. Fish size was better than in recent years. As in the recent past, Tribal harvest was limited

due to processing capacity.

Table D.1. December 31, 2018 PacFin data showed Pacific hake (whiting) harvest in the U.S. fishery as follows:

	U.S. TAC	Shoreside (SS)	Catcher Processor (CP)	Mothership (MS)
Allocation (mt)	441,433	169,127	136,912	96,644
Catch (mt)	312,349	129,180	116,074	67,095
% Utilization	70.80%	76.40%	84.80%	69.40%

Conclusion

In 2018, there was generally good fishing in the U.S. at sea and shoreside fisheries. Fish size was larger on average than in the 2017 fisheries across all sectors. There was good fish abundance, generally spread across the grounds from northern Washington to southern Oregon. Bycatch species of concern dominated harvest behavior and once again resulted in restricted harvest in the U.S. and ultimately a substantial portion of available TAC to be left unharvested.

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	0.2306
SR_LN.R0.	14.8344
SR_BH_steep	0.8157
Q_extraSD_Acoustic_Survey.2.	0.3080
ln.EffN_mult._1	-0.5512
Early_InitAge_20	-0.2943
Early_InitAge_19	-0.0766
Early_InitAge_18	-0.0832
Early_InitAge_17	-0.1944
Early_InitAge_16	-0.1228
Early_InitAge_15	-0.2012
Early_InitAge_14	-0.2364
Early_InitAge_13	-0.3366
Early_InitAge_12	-0.3395
Early_InitAge_11	-0.3995
Early_InitAge_10	-0.3753
Early_InitAge_9	-0.4753
Early_InitAge_8	-0.5424
Early_InitAge_7	-0.6118
Early_InitAge_6	-0.5988
Early_InitAge_5	-0.5250
Early_InitAge_4	-0.3100
Early_InitAge_3	-0.0942
Early_InitAge_2	0.2719
Early_InitAge_1	0.5079
Early_RecrDev_1966	0.5417
Early_RecrDev_1967	1.5511
Early_RecrDev_1968	1.0760
Early_RecrDev_1969	-0.2483
Main_RecrDev_1970	2.1462
Main_RecrDev_1971	-0.2019
Main_RecrDev_1972	-0.6647
Main_RecrDev_1973	1.7150
Main_RecrDev_1974	-1.0404
Main_RecrDev_1975	0.5062
Main_RecrDev_1976	-1.5957
Main_RecrDev_1977	1.7922
Main_RecrDev_1978	-2.0059
Main_RecrDev_1979	0.2202
Main_RecrDev_1980	2.7791
Main_RecrDev_1981	-1.3659
Main_RecrDev_1982	-1.2325
Main_RecrDev_1983	-0.7527
Main_RecrDev_1984	2.5565
Main_RecrDev_1985	-2.0493
Main_RecrDev_1986	-1.7626
Main_RecrDev_1987	1.7899
Main_RecrDev_1988	0.6611
Main_RecrDev_1989	-2.1587
Main_RecrDev_1990	1.3988
Main_RecrDev_1991	0.1291
Main_RecrDev_1992	-2.0526
Main_RecrDev_1993	1.1273
Main_RecrDev_1994	1.1888
Main_RecrDev_1995	0.2079
Main_RecrDev_1996	0.6073
Main_RecrDev_1997	0.0680
Main_RecrDev_1998	0.6885
Main_RecrDev_1999	2.6051

Continued on next page

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

Parameter	Posterior median
Main_RecrDev_2000	-1.0908
Main_RecrDev_2001	0.2038
Main_RecrDev_2002	-3.4746
Main_RecrDev_2003	0.4780
Main_RecrDev_2004	-2.8120
Main_RecrDev_2005	0.9863
Main_RecrDev_2006	0.6851
Main_RecrDev_2007	-3.6337
Main_RecrDev_2008	1.7145
Main_RecrDev_2009	0.3742
Main_RecrDev_2010	2.7303
Main_RecrDev_2011	-0.8573
Main_RecrDev_2012	0.1522
Main_RecrDev_2013	-1.0115
Main_RecrDev_2014	2.1000
Main_RecrDev_2015	-2.4403
Main_RecrDev_2016	1.3651
Main_RecrDev_2017	0.7638
Late_RecrDev_2018	-0.0184
ForeRecr_2019	0.0030
ForeRecr_2020	0.0215
ForeRecr_2021	-0.0272
AgeSel_P3_Fishery.1.	2.7889
AgeSel_P4_Fishery.1.	0.9520
AgeSel_P5_Fishery.1.	0.3925
AgeSel_P6_Fishery.1.	0.1875
AgeSel_P7_Fishery.1.	0.4982
AgeSel_P4_Acoustic_Survey.2.	0.6021
AgeSel_P5_Acoustic_Survey.2.	-0.2259
AgeSel_P6_Acoustic_Survey.2.	0.2608
AgeSel_P7_Acoustic_Survey.2.	0.3920
AgeSel_P3_Fishery.1._DEVadd_1991	0.5812
AgeSel_P3_Fishery.1._DEVadd_1992	0.0952
AgeSel_P3_Fishery.1._DEVadd_1993	-0.0521
AgeSel_P3_Fishery.1._DEVadd_1994	0.1324
AgeSel_P3_Fishery.1._DEVadd_1995	-0.1577
AgeSel_P3_Fishery.1._DEVadd_1996	0.4510
AgeSel_P3_Fishery.1._DEVadd_1997	0.0791
AgeSel_P3_Fishery.1._DEVadd_1998	0.2631
AgeSel_P3_Fishery.1._DEVadd_1999	1.0008
AgeSel_P3_Fishery.1._DEVadd_2000	0.5602
AgeSel_P3_Fishery.1._DEVadd_2001	0.0301
AgeSel_P3_Fishery.1._DEVadd_2002	0.0896
AgeSel_P3_Fishery.1._DEVadd_2003	0.0254
AgeSel_P3_Fishery.1._DEVadd_2004	0.3382
AgeSel_P3_Fishery.1._DEVadd_2005	-0.0179
AgeSel_P3_Fishery.1._DEVadd_2006	0.6404
AgeSel_P3_Fishery.1._DEVadd_2007	0.5573
AgeSel_P3_Fishery.1._DEVadd_2008	-0.0144
AgeSel_P3_Fishery.1._DEVadd_2009	0.4289
AgeSel_P3_Fishery.1._DEVadd_2010	1.0165
AgeSel_P3_Fishery.1._DEVadd_2011	-0.1105
AgeSel_P3_Fishery.1._DEVadd_2012	0.1268
AgeSel_P3_Fishery.1._DEVadd_2013	0.2232
AgeSel_P3_Fishery.1._DEVadd_2014	0.4294
AgeSel_P3_Fishery.1._DEVadd_2015	-0.6453
AgeSel_P3_Fishery.1._DEVadd_2016	0.0777
AgeSel_P3_Fishery.1._DEVadd_2017	-0.7988
AgeSel_P3_Fishery.1._DEVadd_2018	-0.5852
AgeSel_P4_Fishery.1._DEVadd_1991	0.3969
AgeSel_P4_Fishery.1._DEVadd_1992	0.5983

Continued on next page

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

Parameter	Posterior median
AgeSel_P4_Fishery.1._DEVadd_1993	0.7732
AgeSel_P4_Fishery.1._DEVadd_1994	0.2166
AgeSel_P4_Fishery.1._DEVadd_1995	0.2220
AgeSel_P4_Fishery.1._DEVadd_1996	-0.3716
AgeSel_P4_Fishery.1._DEVadd_1997	1.2648
AgeSel_P4_Fishery.1._DEVadd_1998	0.9851
AgeSel_P4_Fishery.1._DEVadd_1999	-0.0899
AgeSel_P4_Fishery.1._DEVadd_2000	0.7562
AgeSel_P4_Fishery.1._DEVadd_2001	0.9288
AgeSel_P4_Fishery.1._DEVadd_2002	0.7374
AgeSel_P4_Fishery.1._DEVadd_2003	0.6784
AgeSel_P4_Fishery.1._DEVadd_2004	0.4751
AgeSel_P4_Fishery.1._DEVadd_2005	0.6377
AgeSel_P4_Fishery.1._DEVadd_2006	-0.1274
AgeSel_P4_Fishery.1._DEVadd_2007	0.2126
AgeSel_P4_Fishery.1._DEVadd_2008	0.3433
AgeSel_P4_Fishery.1._DEVadd_2009	0.7195
AgeSel_P4_Fishery.1._DEVadd_2010	0.1351
AgeSel_P4_Fishery.1._DEVadd_2011	1.0457
AgeSel_P4_Fishery.1._DEVadd_2012	0.1253
AgeSel_P4_Fishery.1._DEVadd_2013	0.8616
AgeSel_P4_Fishery.1._DEVadd_2014	0.2356
AgeSel_P4_Fishery.1._DEVadd_2015	0.3866
AgeSel_P4_Fishery.1._DEVadd_2016	-0.9106
AgeSel_P4_Fishery.1._DEVadd_2017	-0.3059
AgeSel_P4_Fishery.1._DEVadd_2018	-0.9171
AgeSel_P5_Fishery.1._DEVadd_1991	-0.8602
AgeSel_P5_Fishery.1._DEVadd_1992	0.0906
AgeSel_P5_Fishery.1._DEVadd_1993	0.0158
AgeSel_P5_Fishery.1._DEVadd_1994	0.8822
AgeSel_P5_Fishery.1._DEVadd_1995	0.2331
AgeSel_P5_Fishery.1._DEVadd_1996	-0.3415
AgeSel_P5_Fishery.1._DEVadd_1997	-0.1117
AgeSel_P5_Fishery.1._DEVadd_1998	-0.6322
AgeSel_P5_Fishery.1._DEVadd_1999	0.1206
AgeSel_P5_Fishery.1._DEVadd_2000	-0.1237
AgeSel_P5_Fishery.1._DEVadd_2001	0.2880
AgeSel_P5_Fishery.1._DEVadd_2002	0.5497
AgeSel_P5_Fishery.1._DEVadd_2003	0.7351
AgeSel_P5_Fishery.1._DEVadd_2004	0.6607
AgeSel_P5_Fishery.1._DEVadd_2005	0.7248
AgeSel_P5_Fishery.1._DEVadd_2006	0.0111
AgeSel_P5_Fishery.1._DEVadd_2007	-0.1243
AgeSel_P5_Fishery.1._DEVadd_2008	-0.4227
AgeSel_P5_Fishery.1._DEVadd_2009	-0.1544
AgeSel_P5_Fishery.1._DEVadd_2010	0.4780
AgeSel_P5_Fishery.1._DEVadd_2011	-0.7101
AgeSel_P5_Fishery.1._DEVadd_2012	0.2327
AgeSel_P5_Fishery.1._DEVadd_2013	-0.2524
AgeSel_P5_Fishery.1._DEVadd_2014	-0.3703
AgeSel_P5_Fishery.1._DEVadd_2015	-0.1136
AgeSel_P5_Fishery.1._DEVadd_2016	0.1954
AgeSel_P5_Fishery.1._DEVadd_2017	-0.1066
AgeSel_P5_Fishery.1._DEVadd_2018	-0.0489
AgeSel_P6_Fishery.1._DEVadd_1991	-0.0145
AgeSel_P6_Fishery.1._DEVadd_1992	-0.4805
AgeSel_P6_Fishery.1._DEVadd_1993	-0.0470
AgeSel_P6_Fishery.1._DEVadd_1994	-0.1115
AgeSel_P6_Fishery.1._DEVadd_1995	0.7711
AgeSel_P6_Fishery.1._DEVadd_1996	-0.1317
AgeSel_P6_Fishery.1._DEVadd_1997	-0.3376

Continued on next page

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

Parameter	Posterior median
AgeSel_P6_Fishery.1._DEVadd_1998	0.3721
AgeSel_P6_Fishery.1._DEVadd_1999	-0.3994
AgeSel_P6_Fishery.1._DEVadd_2000	0.1680
AgeSel_P6_Fishery.1._DEVadd_2001	-0.1020
AgeSel_P6_Fishery.1._DEVadd_2002	0.1042
AgeSel_P6_Fishery.1._DEVadd_2003	0.2577
AgeSel_P6_Fishery.1._DEVadd_2004	-0.5544
AgeSel_P6_Fishery.1._DEVadd_2005	0.2718
AgeSel_P6_Fishery.1._DEVadd_2006	0.1909
AgeSel_P6_Fishery.1._DEVadd_2007	-0.2099
AgeSel_P6_Fishery.1._DEVadd_2008	0.3175
AgeSel_P6_Fishery.1._DEVadd_2009	-0.2534
AgeSel_P6_Fishery.1._DEVadd_2010	-0.4986
AgeSel_P6_Fishery.1._DEVadd_2011	-0.1775
AgeSel_P6_Fishery.1._DEVadd_2012	-0.4511
AgeSel_P6_Fishery.1._DEVadd_2013	0.0142
AgeSel_P6_Fishery.1._DEVadd_2014	-0.0331
AgeSel_P6_Fishery.1._DEVadd_2015	-0.0028
AgeSel_P6_Fishery.1._DEVadd_2016	-0.2552
AgeSel_P6_Fishery.1._DEVadd_2017	0.0953
AgeSel_P6_Fishery.1._DEVadd_2018	-0.1701
AgeSel_P7_Fishery.1._DEVadd_1991	-0.1369
AgeSel_P7_Fishery.1._DEVadd_1992	0.0782
AgeSel_P7_Fishery.1._DEVadd_1993	-0.3610
AgeSel_P7_Fishery.1._DEVadd_1994	0.1394
AgeSel_P7_Fishery.1._DEVadd_1995	-0.1173
AgeSel_P7_Fishery.1._DEVadd_1996	0.4274
AgeSel_P7_Fishery.1._DEVadd_1997	0.1270
AgeSel_P7_Fishery.1._DEVadd_1998	-0.4983
AgeSel_P7_Fishery.1._DEVadd_1999	-0.2504
AgeSel_P7_Fishery.1._DEVadd_2000	-0.0904
AgeSel_P7_Fishery.1._DEVadd_2001	-0.2768
AgeSel_P7_Fishery.1._DEVadd_2002	-0.3823
AgeSel_P7_Fishery.1._DEVadd_2003	-0.2435
AgeSel_P7_Fishery.1._DEVadd_2004	-0.1615
AgeSel_P7_Fishery.1._DEVadd_2005	-0.3784
AgeSel_P7_Fishery.1._DEVadd_2006	-0.3214
AgeSel_P7_Fishery.1._DEVadd_2007	0.0214
AgeSel_P7_Fishery.1._DEVadd_2008	-0.1814
AgeSel_P7_Fishery.1._DEVadd_2009	0.1305
AgeSel_P7_Fishery.1._DEVadd_2010	-0.5918
AgeSel_P7_Fishery.1._DEVadd_2011	-0.5017
AgeSel_P7_Fishery.1._DEVadd_2012	-0.3437
AgeSel_P7_Fishery.1._DEVadd_2013	0.0755
AgeSel_P7_Fishery.1._DEVadd_2014	-0.0161
AgeSel_P7_Fishery.1._DEVadd_2015	-0.5289
AgeSel_P7_Fishery.1._DEVadd_2016	-0.2266
AgeSel_P7_Fishery.1._DEVadd_2017	-0.1719
AgeSel_P7_Fishery.1._DEVadd_2018	0.3583

F FECUNDITY SENSITIVITY RUN 53

This appendix contains MCMC model results for the fecundity sensitivity, run 53 as described in Sections 3.8.1–3.8.2 and Table 36.

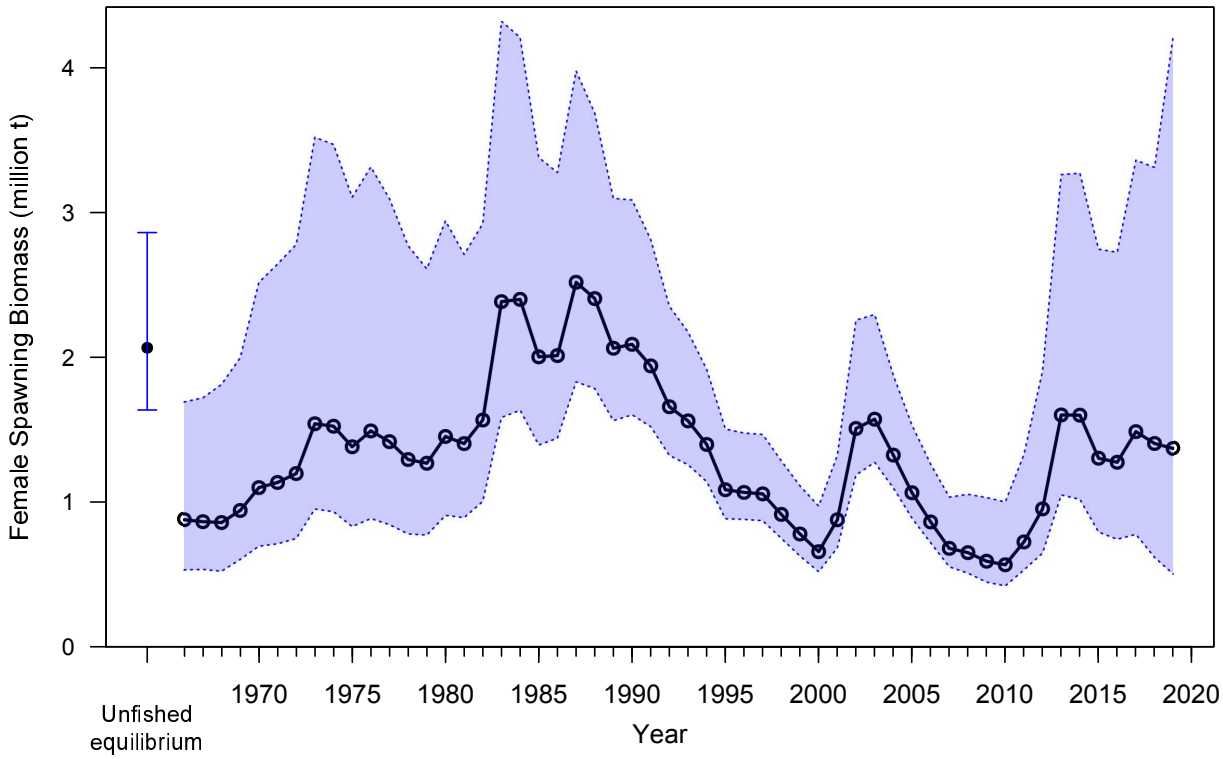

Figure F.1. Median of the posterior distribution for beginning of the year female spawning biomass through 2019 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

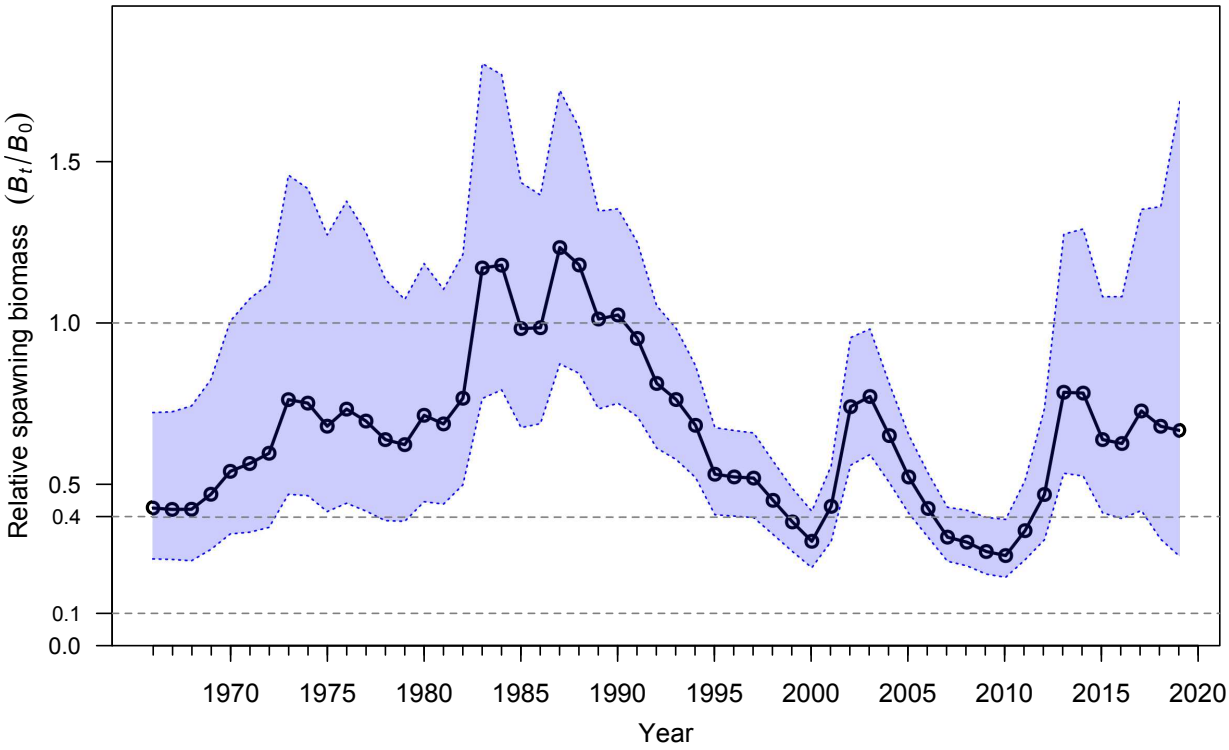

Figure F.2. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2019 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

Table F.1. 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)		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2010	427.2	572.8	1,005.4	21.4%	28.1%	39.3%
2011	537.0	730.1	1,331.9	26.8%	35.8%	51.4%
2012	653.2	958.0	1,910.2	33.0%	47.0%	73.5%
2013	1,053.8	1,605.2	3,261.6	53.6%	78.6%	127.5%
2014	1,023.5	1,603.6	3,271.5	52.7%	78.3%	129.1%
2015	798.1	1,307.3	2,747.9	41.3%	64.0%	108.1%
2016	748.6	1,279.3	2,726.3	39.6%	62.8%	108.2%
2017	782.5	1,490.2	3,361.0	42.0%	72.8%	135.1%
2018	624.0	1,408.7	3,311.1	33.2%	68.1%	136.0%
2019	508.9	1,374.2	4,215.6	27.7%	66.8%	168.9%

Table F.2. 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		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2009	741.8	1,357.7	3,012.6	-0.080	0.389	0.826
2010	8,545.2	14,070.3	32,330.3	2.408	2.740	3.131
2011	149.2	404.2	1,071.5	-1.782	-0.840	-0.150
2012	595.3	1,154.1	2,863.9	-0.351	0.148	0.700
2013	126.0	402.6	1,412.3	-2.097	-0.965	0.049
2014	4,386.9	8,839.7	22,285.5	1.584	2.122	2.777
2015	12.6	89.4	479.6	-4.282	-2.466	-0.975
2016	789.4	4,103.8	28,580.5	-0.159	1.371	3.125
2017	177.6	2,148.3	22,810.4	-1.740	0.706	2.911
2018	68.2	1,107.0	20,378.7	-2.680	0.054	2.768

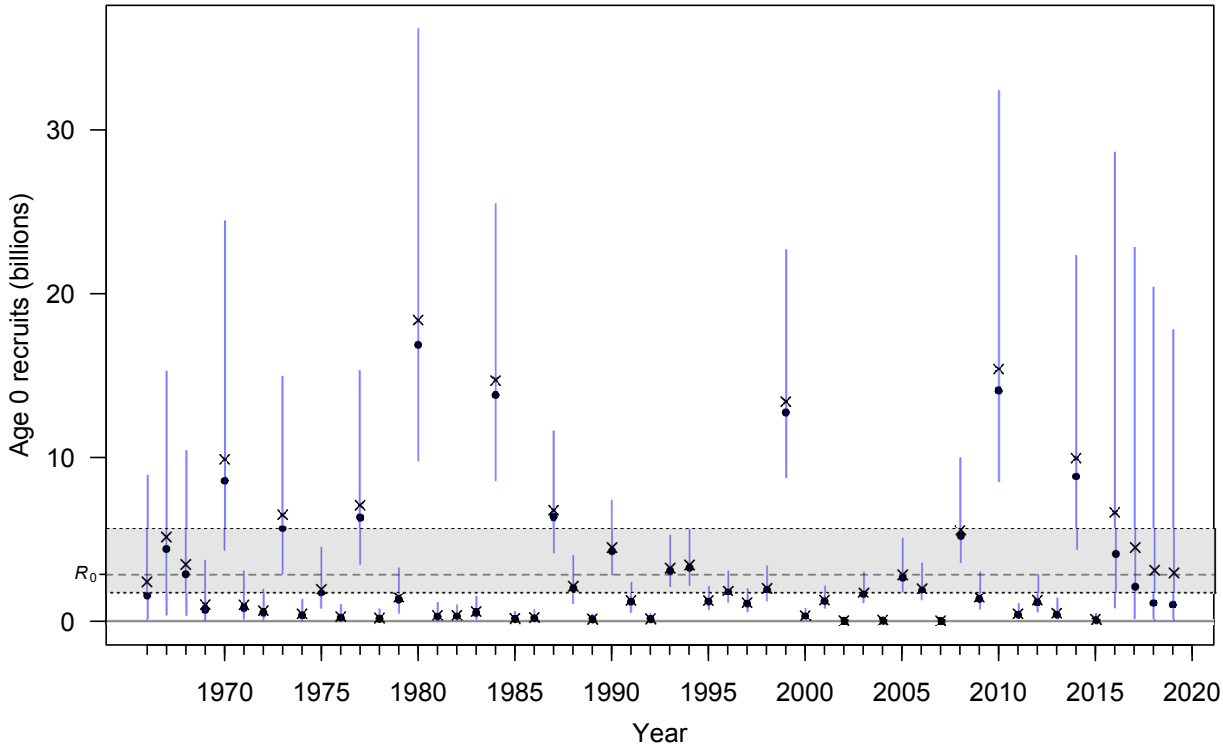

Figure F.3. Medians (solid circles) and means ($\times$) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

Table F.3. Recent estimates of relative fishing intensity, (1-SPR)/(1-$SPR_{40\%}$), and exploitation fraction (catch divided by age-2+ biomass).

Year	Relative fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2009	0.500	0.798	1.029	0.084	0.144	0.190
2010	0.592	0.925	1.200	0.073	0.130	0.172
2011	0.543	0.871	1.148	0.090	0.167	0.229
2012	0.371	0.694	0.971	0.031	0.064	0.096
2013	0.357	0.662	0.894	0.039	0.079	0.121
2014	0.369	0.682	0.957	0.041	0.083	0.131
2015	0.236	0.498	0.775	0.035	0.074	0.121
2016	0.398	0.749	1.085	0.047	0.101	0.177
2017	0.468	0.866	1.222	0.061	0.138	0.268
2018	0.428	0.851	1.338	0.038	0.110	0.256

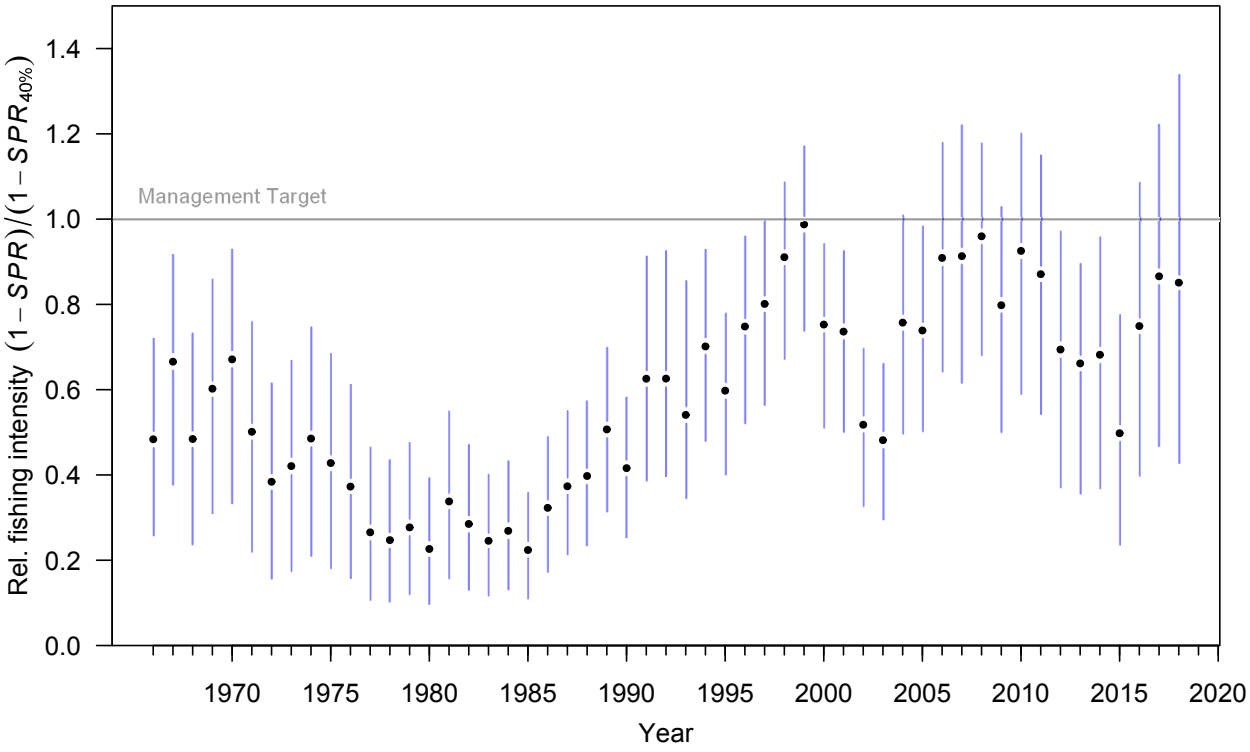

Figure F.4. Trend in median relative fishing intensity (relative to the SPR management target) through 2018 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

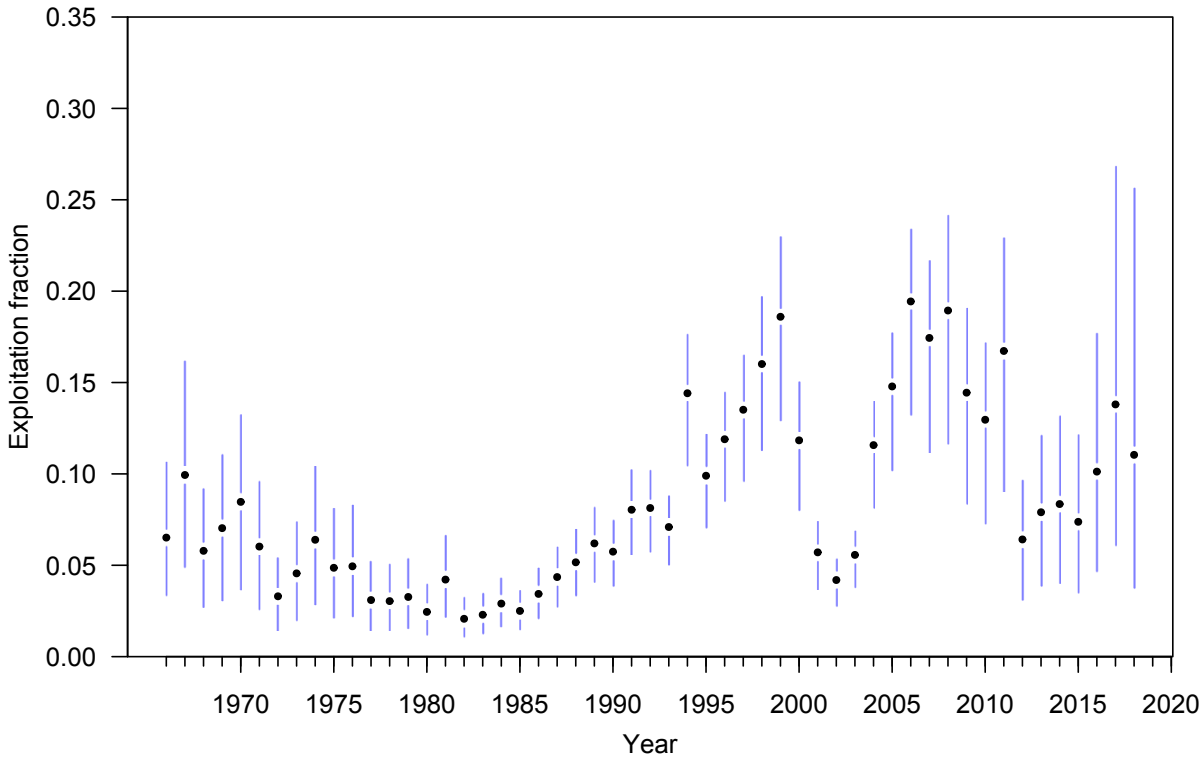

Figure F.5. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2018 with 95% posterior credibility intervals.

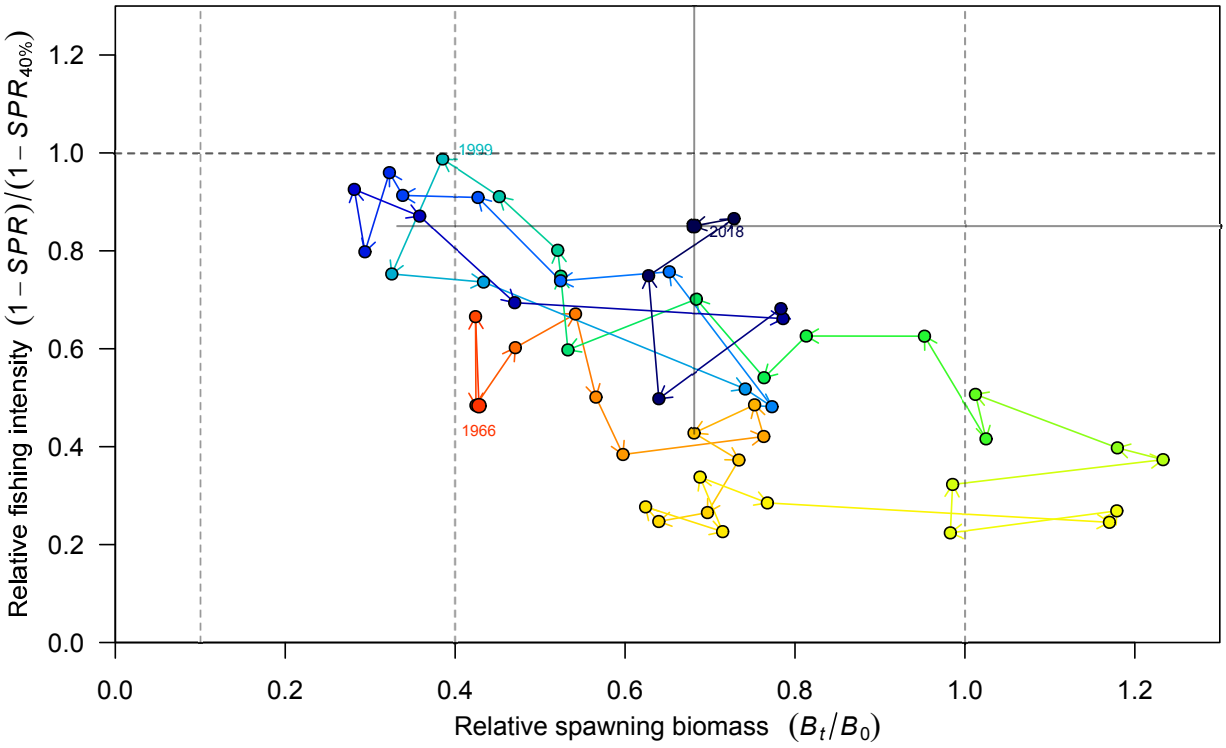

Figure F.6. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2018 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

Table F.4. For the alternative run, summary of median and 95% credibility intervals of equilibrium reference points. Equilibrium reference points were computed using 1966–2018 averages for mean size-at-age and selectivity-at-age.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (B_0, thousand t)	1,636	2,066	2,862
Unfished recruitment (R_0, millions)	1,789	2,864	5,642
Reference points (equilibrium) based on $F_{\mathbf{SPR}=40\%}$			
Female spawning biomass at $F_{\mathrm{SPR}=40\%}$ (thousand t)	534	731	1,012
SPR at $F_{\mathrm{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\mathrm{SPR}=40\%}$	16.0%	18.4%	21.4%
Yield associated with $F_{\mathrm{SPR}=40\%}$ (thousand t)	241	345	568
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	654	826	1,145
SPR at $B_{40\%}$	40.6%	43.5%	51.7%
Exploitation fraction resulting in $B_{40\%}$	12.4%	16.3%	19.7%
Yield at $B_{40\%}$ (thousand t)	241	336	554
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	370	529	857
SPR at MSY	22.4%	29.8%	47.4%
Exploitation fraction corresponding to SPR at MSY	14.5%	25.7%	35.5%
MSY (thousand t)	252	363	614

Table F.5. 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, f), including catch similar to 2018 (row d) and the TAC from 2018 (row f), the catch values that result in a median relative fishing intensity of 100% (row g), the median values estimated via the default harvest policy ($F_{SPR=40\%}$–40:10) for the base model (row h), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2019 and 2020 (row i). Catch in 2021 does not impact the beginning of the year biomass in 2021.

Within model quantile Management Action			5%	25%	50%	75%	95%
	Year	Catch (t)	**Beginning of year relative spawning biomass**				
a:	2019	0	32%	50%	67%	89%	140%
	2020	0	37%	56%	75%	102%	174%
	2021	0	38%	58%	77%	106%	184%
b:	2019	180,000	32%	50%	67%	89%	140%
	2020	180,000	32%	52%	71%	98%	171%
	2021	180,000	30%	49%	68%	98%	176%
c:	2019	350,000	32%	50%	67%	89%	140%
	2020	350,000	28%	48%	67%	94%	167%
	2021	350,000	21%	42%	61%	91%	170%
d:	2019	410,000	32%	50%	67%	89%	140%
2018	2020	410,000	26%	46%	66%	93%	166%
catch	2021	410,000	18%	39%	59%	88%	167%
e:	2019	500,000	32%	50%	67%	89%	140%
	2020	500,000	24%	44%	63%	91%	164%
	2021	500,000	13%	35%	55%	84%	164%
f:	2019	597,500	32%	50%	67%	89%	140%
2018	2020	597,500	22%	42%	61%	88%	161%
TAC	2021	597,500	9%	31%	50%	80%	161%
g:	2019	614,204	32%	50%	67%	89%	140%
FI=	2020	571,591	21%	41%	61%	88%	161%
100%	2021	487,389	9%	31%	51%	80%	161%
h:	2019	769,704	32%	50%	67%	89%	140%
default	2020	669,850	17%	38%	57%	85%	157%
HR	2021	537,218	3%	25%	45%	76%	157%
i:	2019	693,012	32%	50%	67%	89%	140%
C2019=	2020	693,012	19%	39%	59%	86%	159%
C2020	2021	545,694	4%	26%	46%	77%	158%

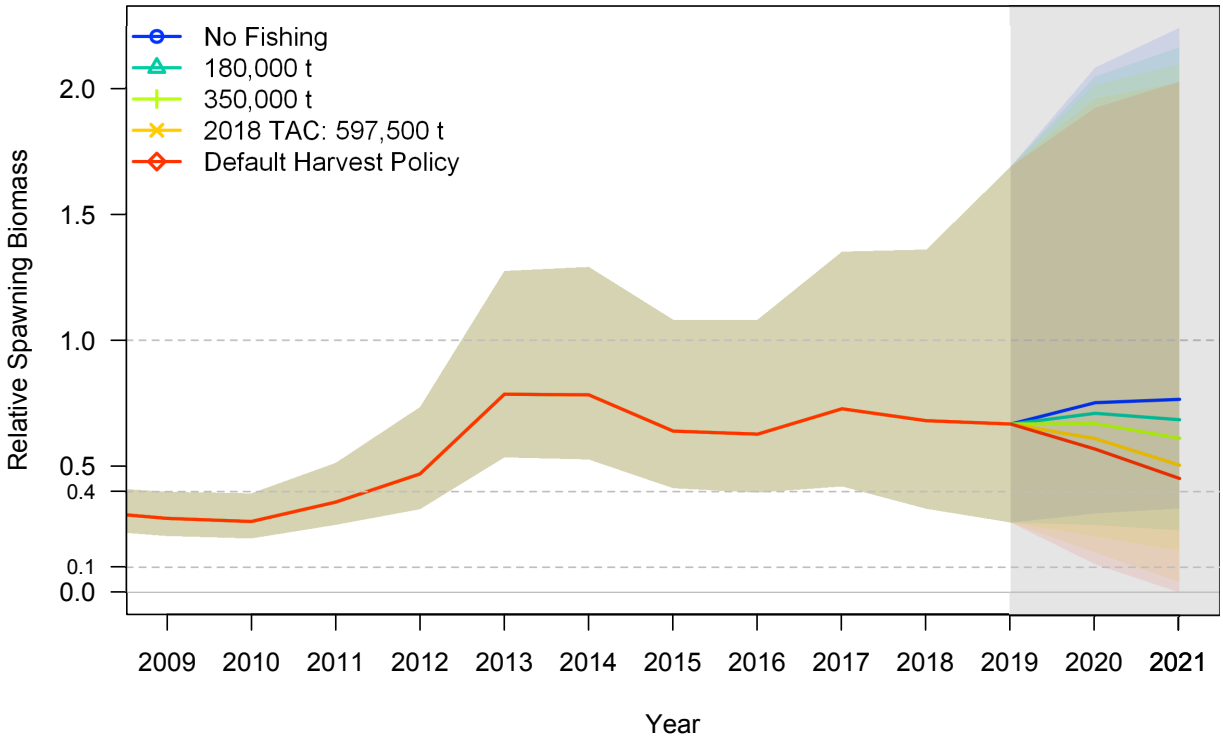

Figure F.7. Time series of estimated relative spawning biomass to 2019 from the base model, and forecast trajectories to 2021 (grey region) for several management actions defined in Table F.5, with 95% posterior credibility intervals.

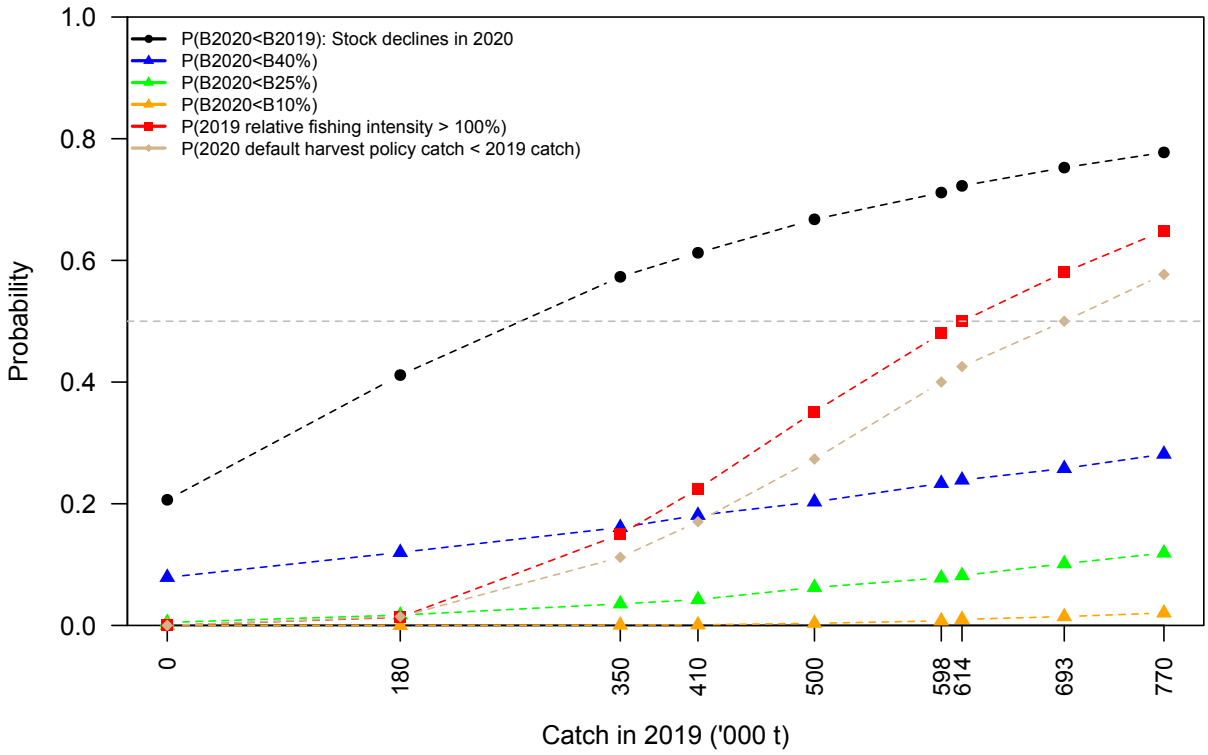

Figure F.8. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (catch options explained in Table F.5) as listed in Table F.6. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table F.6. Probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (catch options explained in Table F.5).

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	21%	8%	0%	0%	0%	0%
b: 180,000	41%	12%	2%	0%	1%	1%
c: 350,000	57%	16%	4%	0%	15%	11%
d: 410,000	61%	18%	4%	0%	22%	17%
e: 500,000	67%	20%	6%	0%	35%	27%
f: 597,500	71%	23%	8%	1%	48%	40%
g: 614,204	72%	24%	8%	1%	50%	43%
h: 769,704	78%	28%	12%	2%	65%	58%
i: 693,012	75%	26%	10%	1%	58%	50%

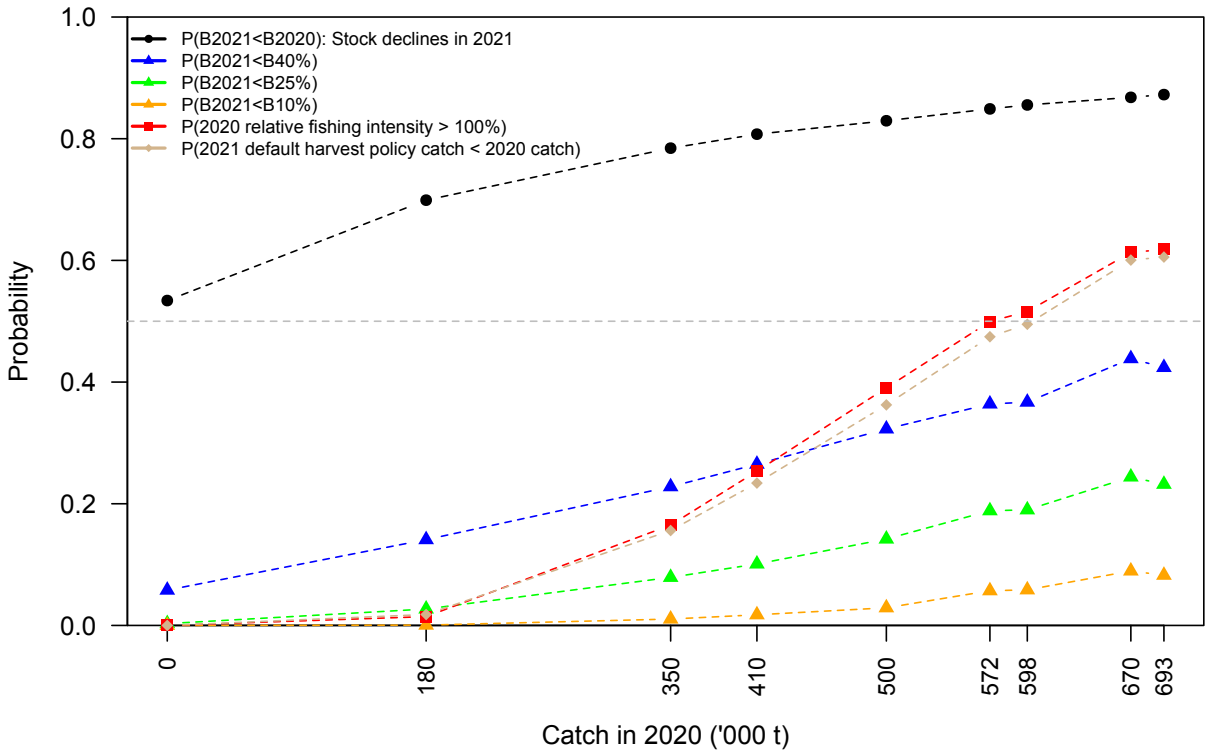

Figure F.9. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (including associated 2019 catch; catch options explained in Table F.5) as listed in Table F.7. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table F.7. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options, given the 2019 catch level shown in Table F.6 (catch options explained in Table F.5).

Catch in 2020	Probability $B_{2021}<B_{2020}$	Probability $B_{2021}<B_{40\%}$	Probability $B_{2021}<B_{25\%}$	Probability $B_{2021}<B_{10\%}$	Probability 2020 relative fishing intensity >100%	Probability 2021 default harvest policy catch <2020 catch
a: 0	53%	6%	0%	0%	0%	0%
b: 180,000	70%	14%	3%	0%	1%	2%
c: 350,000	78%	23%	8%	1%	16%	16%
d: 410,000	81%	26%	10%	2%	25%	23%
e: 500,000	83%	32%	14%	3%	39%	36%
f: 597,500	86%	37%	19%	6%	52%	50%
g: 571,591	85%	36%	19%	6%	50%	47%
h: 669,850	87%	44%	24%	9%	61%	60%
i: 693,012	87%	42%	23%	8%	62%	61%

G FECUNDITY SENSITIVITY RUN 54

This appendix contains MCMC model results for the fecundity sensitivity, run 54 as described in Sections 3.8.1–3.8.2 and Table 36.

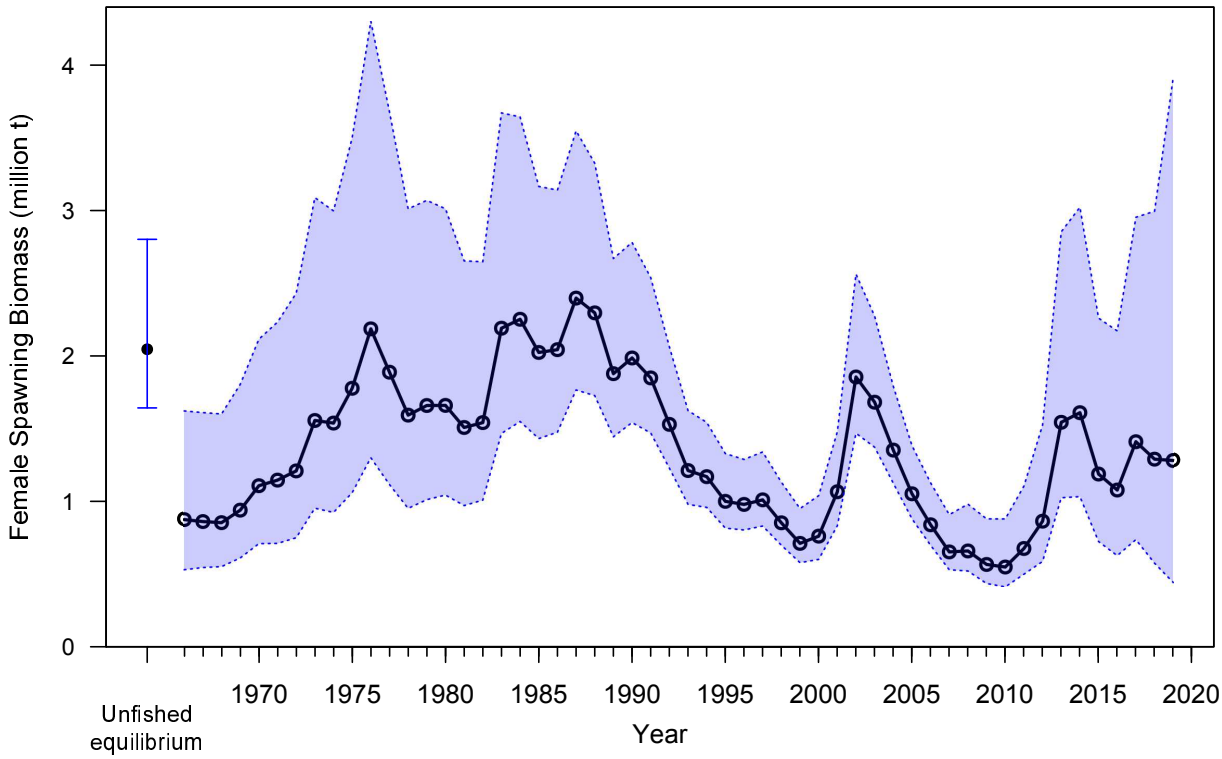

Figure G.1. Median of the posterior distribution for beginning of the year female spawning biomass through 2019 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

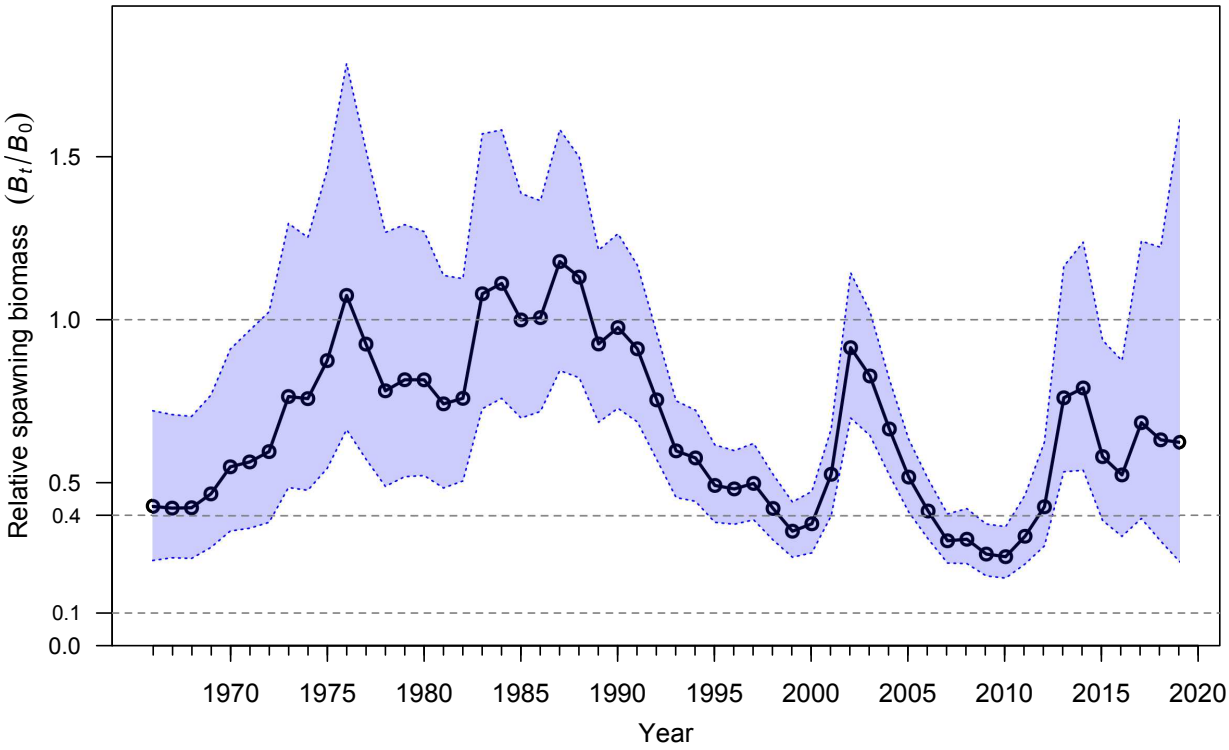

Figure G.2. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2019 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

Table G.1. 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)		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2010	418.3	554.7	884.7	20.9%	27.5%	36.7%
2011	505.2	681.8	1,109.8	25.2%	33.7%	46.3%
2012	593.0	869.1	1,529.7	30.8%	42.7%	62.6%
2013	1,029.7	1,547.4	2,854.1	53.5%	76.1%	116.4%
2014	1,037.5	1,613.3	3,022.6	53.9%	79.1%	123.7%
2015	729.6	1,192.4	2,262.0	38.6%	58.1%	93.7%
2016	632.9	1,082.9	2,174.3	33.7%	52.5%	87.5%
2017	742.6	1,414.2	2,954.0	39.2%	68.5%	124.0%
2018	580.9	1,294.7	2,995.4	32.2%	63.2%	122.2%
2019	448.7	1,285.3	3,912.6	25.8%	62.5%	161.6%

Table G.2. 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		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2009	765.5	1,341.0	2,786.1	-0.076	0.383	0.817
2010	8,683.1	13,947.7	27,787.8	2.420	2.733	3.103
2011	151.2	408.4	993.5	-1.763	-0.840	-0.146
2012	598.8	1,137.6	2,532.4	-0.327	0.152	0.706
2013	118.2	403.2	1,272.9	-2.125	-0.964	-0.006
2014	4,393.9	8,775.4	21,323.3	1.580	2.127	2.755
2015	14.0	90.2	453.8	-4.155	-2.432	-0.989
2016	798.4	4,028.0	25,455.6	-0.122	1.378	3.054
2017	233.0	2,126.1	25,578.2	-1.395	0.708	2.987
2018	68.4	1,051.7	18,357.2	-2.742	-0.013	2.887

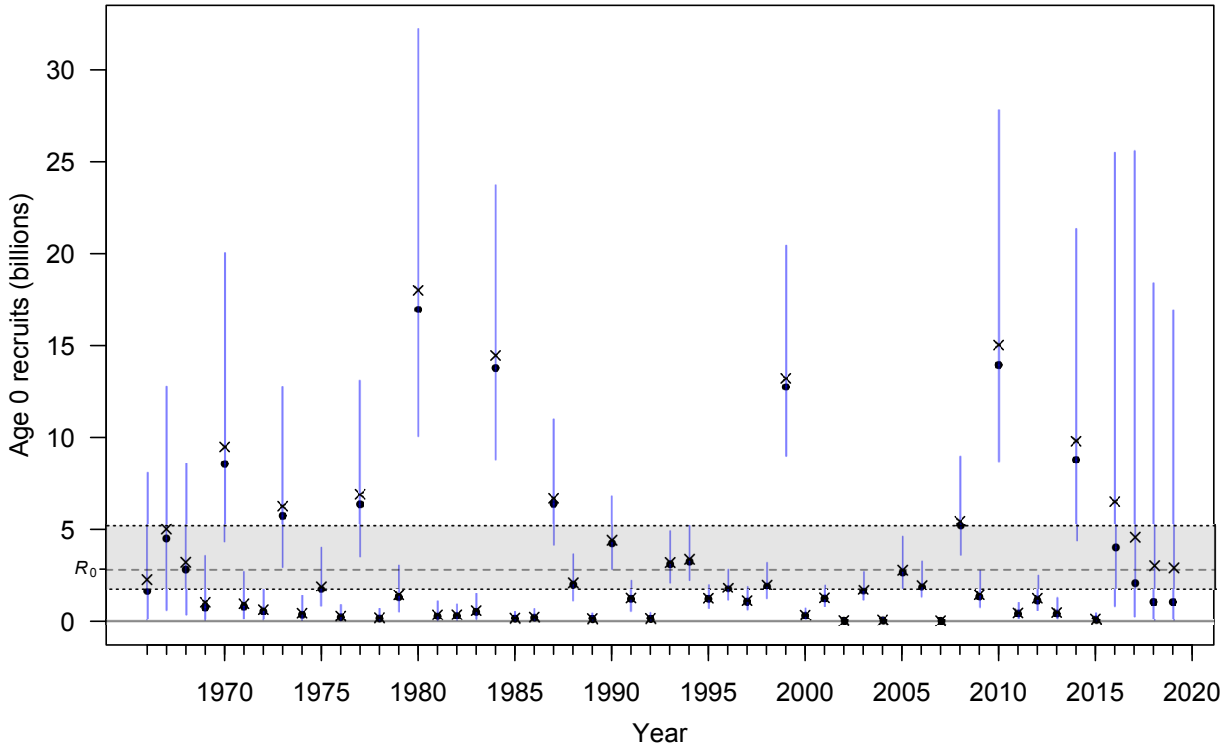

Figure G.3. Medians (solid circles) and means ($\times$) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

Table G.3. Recent estimates of relative fishing intensity, (1-SPR)/(1-$SPR_{40\%}$), and exploitation fraction (catch divided by age-2+ biomass).

Year	Relative fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2009	0.539	0.790	1.009	0.094	0.145	0.188
2010	0.670	0.958	1.233	0.081	0.130	0.172
2011	0.588	0.904	1.192	0.103	0.168	0.229
2012	0.426	0.711	0.996	0.035	0.064	0.095
2013	0.422	0.681	0.907	0.043	0.079	0.119
2014	0.387	0.659	0.920	0.045	0.083	0.130
2015	0.271	0.514	0.787	0.038	0.074	0.120
2016	0.453	0.787	1.087	0.050	0.100	0.175
2017	0.481	0.816	1.172	0.065	0.138	0.263
2018	0.486	0.861	1.341	0.046	0.123	0.278

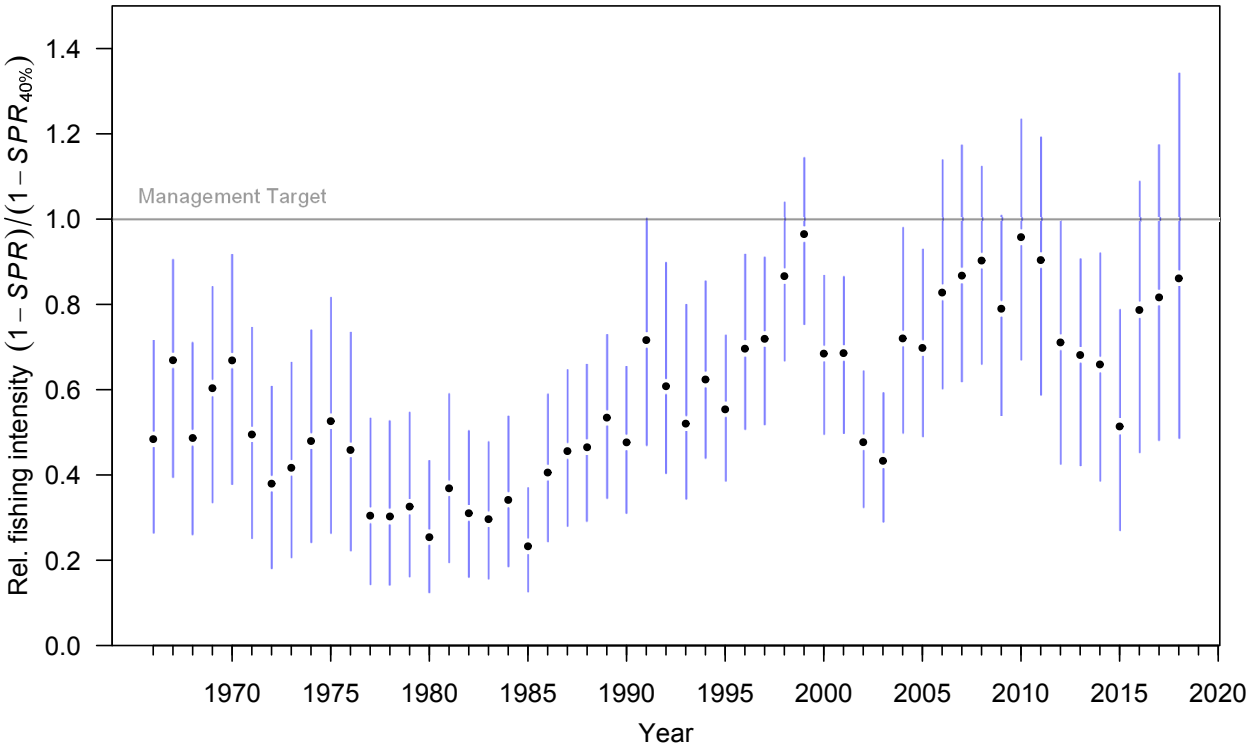

Figure G.4. Trend in median relative fishing intensity (relative to the SPR management target) through 2018 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

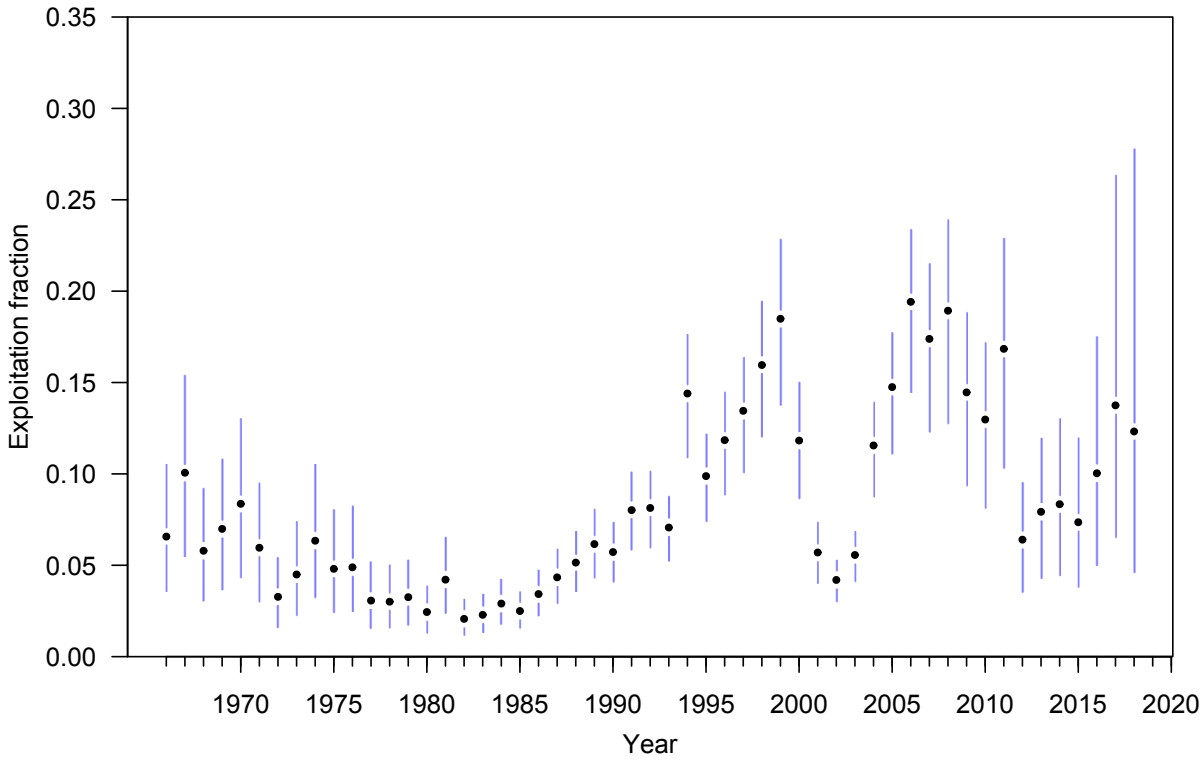

Figure G.5. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2018 with 95% posterior credibility intervals.

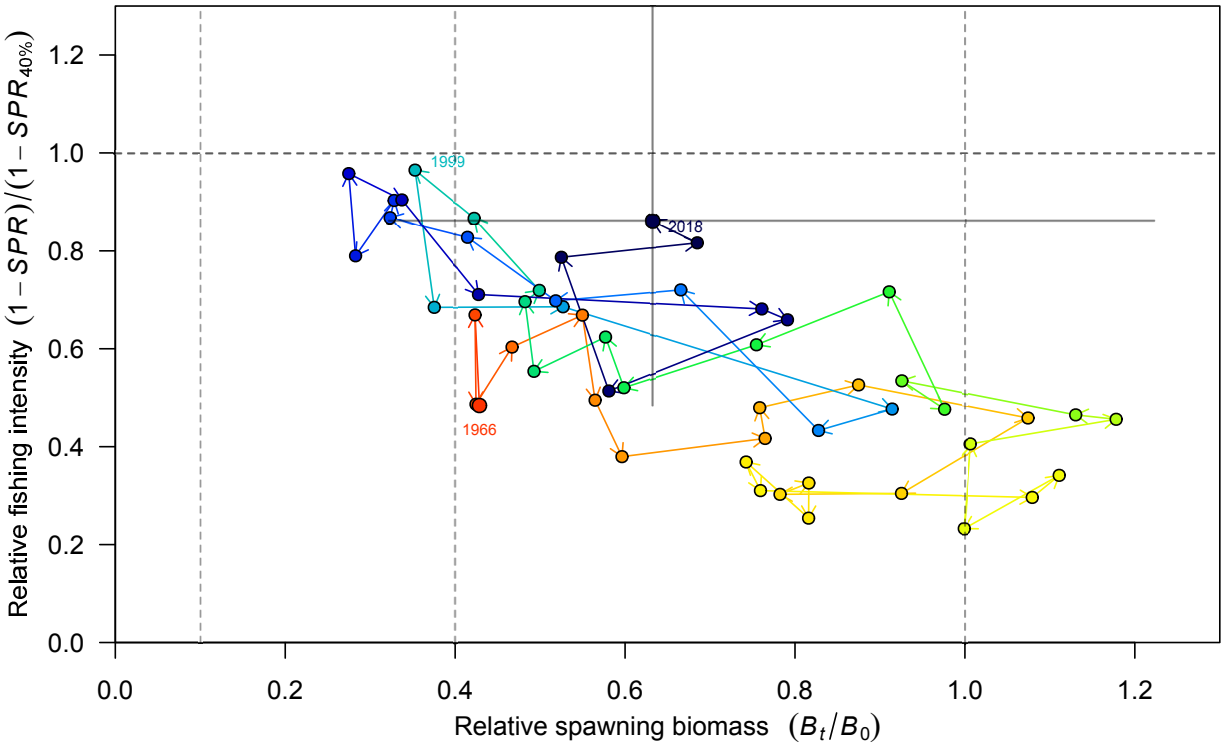

Figure G.6. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2018 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

Table G.4. For the alternative run, summary of median and 95% credibility intervals of equilibrium reference points. Equilibrium reference points were computed using 1966–2018 averages for mean size-at-age and selectivity-at-age.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (B_0, thousand t)	1,643	2,046	2,802
Unfished recruitment (R_0, millions)	1,803	2,836	5,186
Reference points (equilibrium) based on $F_{\mathbf{SPR}=40\%}$			
Female spawning biomass at $F_{\mathrm{SPR}=40\%}$ (thousand t)	553	733	967
SPR at $F_{\mathrm{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\mathrm{SPR}=40\%}$	16.0%	18.4%	21.1%
Yield associated with $F_{\mathrm{SPR}=40\%}$ (thousand t)	243	346	528
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	657	818	1,121
SPR at $B_{40\%}$	40.5%	43.3%	50.4%
Exploitation fraction resulting in $B_{40\%}$	12.9%	16.4%	19.3%
Yield at $B_{40\%}$ (thousand t)	242	338	514
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	368	517	826
SPR at MSY	22.4%	29.3%	44.9%
Exploitation fraction corresponding to SPR at MSY	15.5%	26.1%	34.9%
MSY (thousand t)	252	365	560

Table G.5. 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, f), including catch similar to 2018 (row d) and the TAC from 2018 (row f), the catch values that result in a median relative fishing intensity of 100% (row g), the median values estimated via the default harvest policy ($F_{SPR=40\%}$–40:10) for the base model (row h), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2019 and 2020 (row i). Catch in 2021 does not impact the beginning of the year biomass in 2021.

Within model quantile Management Action			5%	25%	50%	75%	95%
	Year	Catch (t)	**Beginning of year relative spawning biomass**				
a:	2019	0	30%	47%	62%	84%	135%
	2020	0	33%	51%	69%	94%	168%
	2021	0	34%	51%	69%	97%	177%
b:	2019	180,000	30%	47%	62%	84%	135%
	2020	180,000	29%	46%	65%	90%	165%
	2021	180,000	25%	43%	62%	90%	170%
c:	2019	350,000	30%	47%	62%	84%	135%
	2020	350,000	24%	43%	61%	87%	162%
	2021	350,000	18%	36%	55%	83%	164%
d:	2019	410,000	30%	47%	62%	84%	135%
2018	2020	410,000	23%	41%	60%	85%	161%
catch	2021	410,000	15%	34%	52%	81%	161%
e:	2019	500,000	30%	47%	62%	84%	135%
	2020	500,000	21%	39%	58%	83%	159%
	2021	500,000	11%	30%	49%	77%	157%
f:	2019	597,500	30%	47%	62%	84%	135%
2018	2020	597,500	18%	37%	56%	81%	157%
TAC	2021	597,500	7%	26%	45%	73%	156%
g:	2019	634,540	30%	47%	62%	84%	135%
FI=	2020	569,133	17%	36%	55%	81%	156%
100%	2021	464,680	7%	26%	45%	73%	156%
h:	2019	718,572	30%	47%	62%	84%	135%
default	2020	616,636	15%	34%	53%	79%	154%
HR	2021	500,646	4%	23%	42%	71%	153%
i:	2019	637,617	30%	47%	62%	84%	135%
C2019=	2020	637,617	17%	36%	55%	81%	156%
C2020	2021	509,060	5%	24%	43%	72%	155%

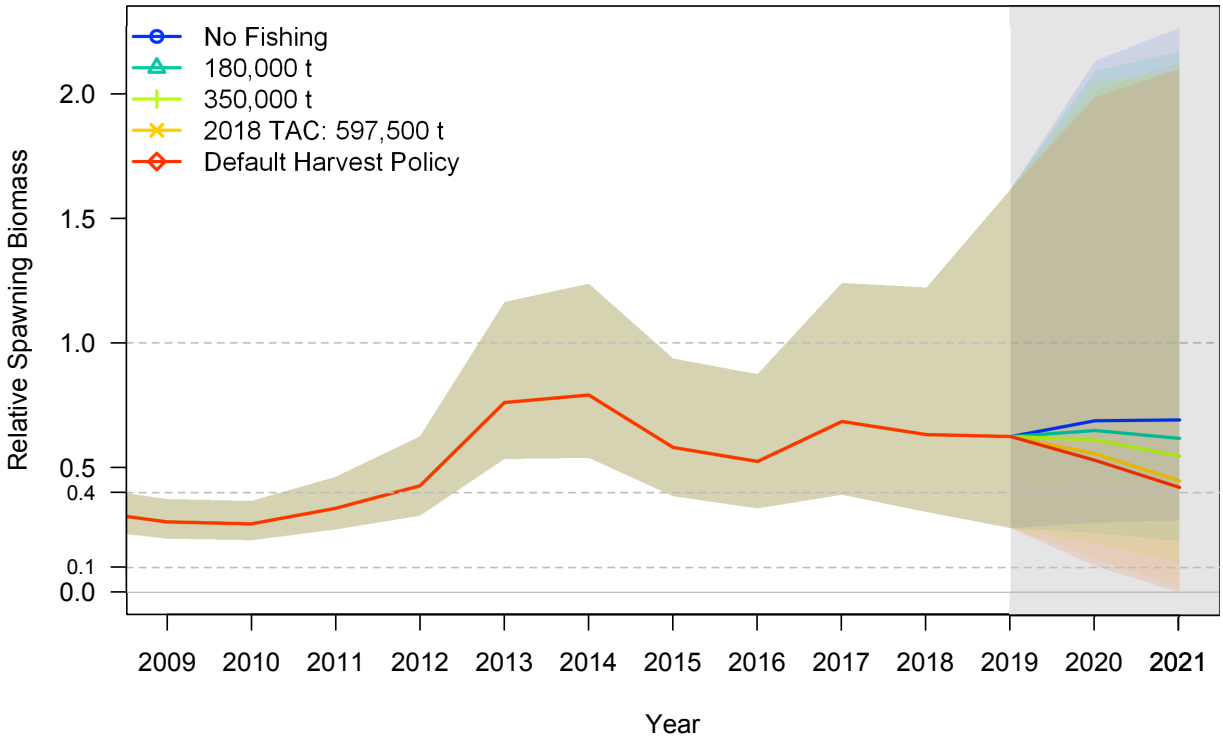

Figure G.7. Time series of estimated relative spawning biomass to 2019 from the base model, and forecast trajectories to 2021 (grey region) for several management actions defined in Table G.5, with 95% posterior credibility intervals.

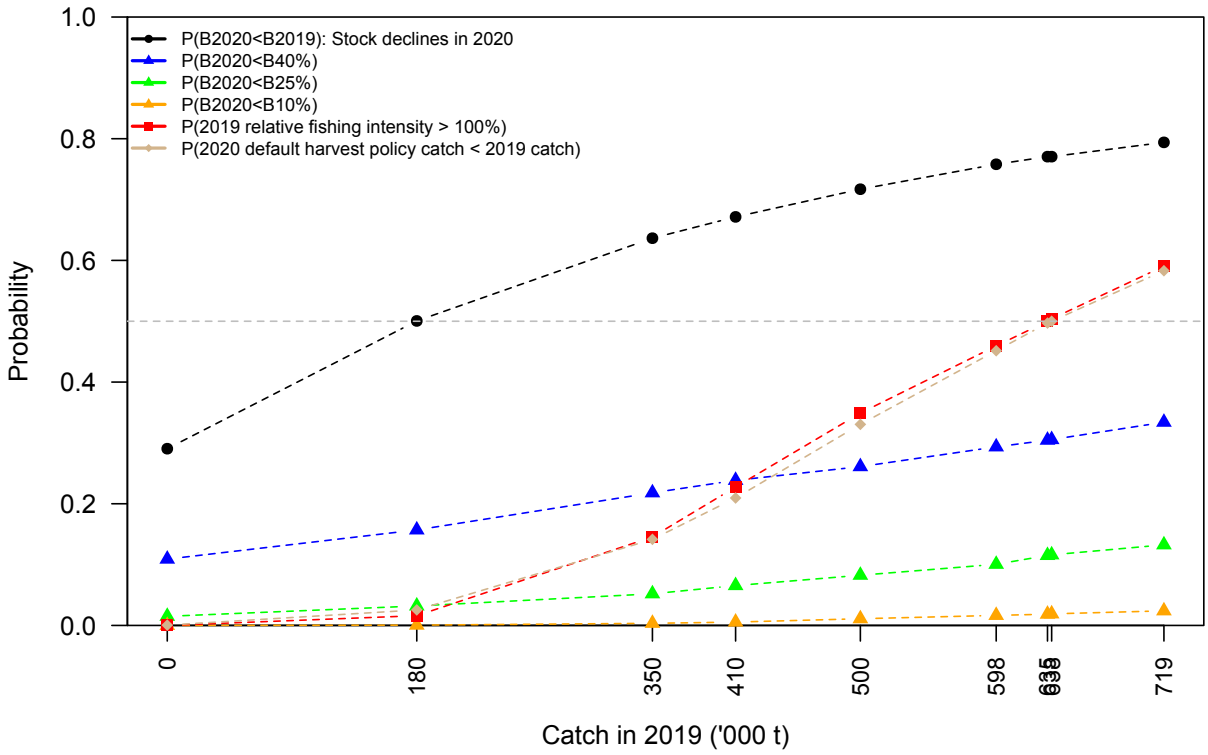

Figure G.8. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (catch options explained in Table G.5) as listed in Table G.6. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table G.6. Probabilities related to spawning biomass, relative fishing intensity, and the 2020 default harvest policy catch for alternative 2019 catch options (catch options explained in Table G.5).

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	29%	11%	2%	0%	0%	0%
b: 180,000	50%	16%	3%	0%	2%	3%
c: 350,000	64%	22%	5%	0%	15%	14%
d: 410,000	67%	24%	7%	1%	23%	21%
e: 500,000	72%	26%	8%	1%	35%	33%
f: 597,500	76%	29%	10%	2%	46%	45%
g: 634,540	77%	30%	12%	2%	50%	50%
h: 718,572	79%	33%	13%	2%	59%	58%
i: 637,617	77%	31%	12%	2%	50%	50%

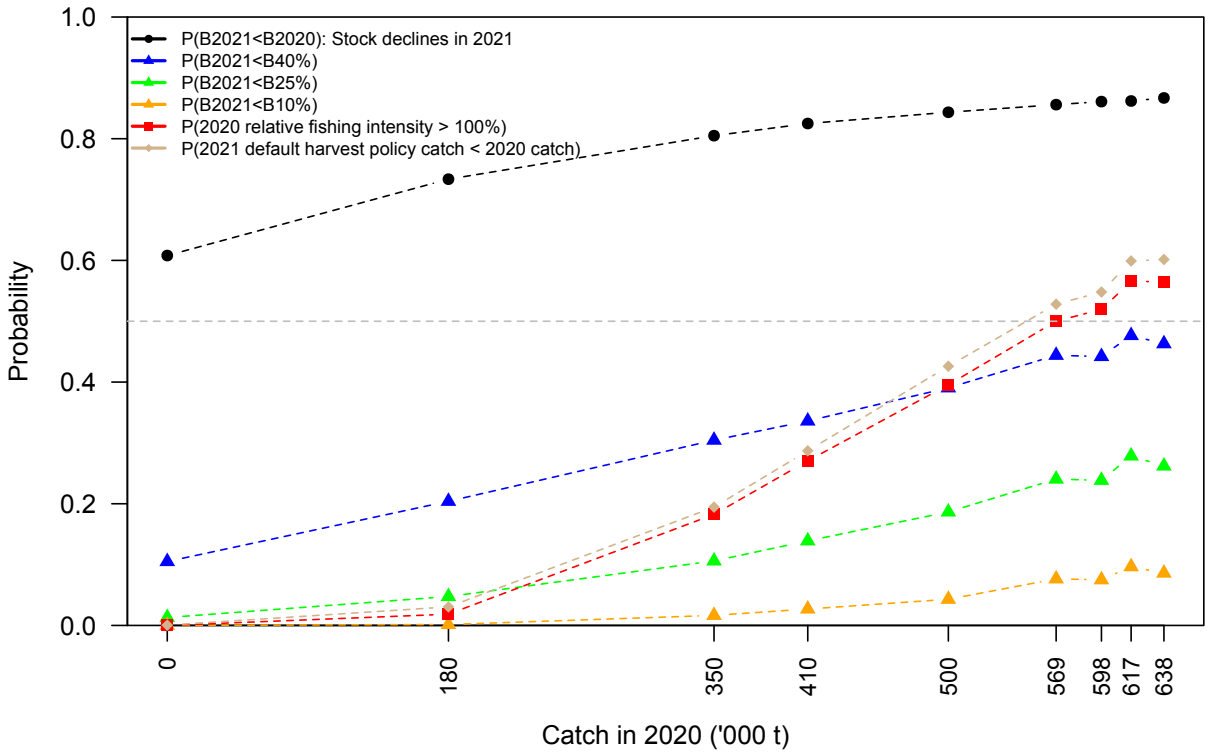

Figure G.9. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (including associated 2019 catch; catch options explained in Table G.5) as listed in Table G.7. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table G.7. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options, given the 2019 catch level shown in Table G.6 (catch options explained in Table G.5).

Catch in 2020	Probability $B_{2021}<B_{2020}$	Probability $B_{2021}<B_{40\%}$	Probability $B_{2021}<B_{25\%}$	Probability $B_{2021}<B_{10\%}$	Probability 2020 relative fishing intensity >100%	Probability 2021 default harvest policy catch <2020 catch
a: 0	61%	10%	1%	0%	0%	0%
b: 180,000	73%	20%	5%	0%	2%	3%
c: 350,000	80%	30%	11%	2%	18%	19%
d: 410,000	82%	34%	14%	3%	27%	29%
e: 500,000	84%	39%	19%	4%	40%	43%
f: 597,500	86%	44%	24%	8%	52%	55%
g: 569,133	86%	44%	24%	8%	50%	53%
h: 616,636	86%	48%	28%	10%	57%	60%
i: 637,617	87%	46%	26%	9%	56%	60%

H STOCK SYNTHESIS DATA FILE

../models/2019.03.00_base/hake_data.ss

```
#C 2019 Hake data file
1966 #_StartYr
2018 #_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 286658 0.01
2008 1 1 318746 0.01
2009 1 1 178683 0.01
2010 1 1 224115 0.01
2011 1 1 282398 0.01
2012 1 1 206771 0.01
2013 1 1 285830 0.01
2014 1 1 299254 0.01
2015 1 1 193838 0.01
2016 1 1 332067 0.01
2017 1 1 440942 0.01
2018 1 1 410443 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
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
2018    7       -2      1         1      # dummy observation
#
-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
-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 0 0 0 0
#
15 #_N_age_bins
 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
46 #_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
```

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          13.5        14.5        15.5        16.5        17.5        18.5
          19.5        20.5        # 1977      def5        '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       # 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
```

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          2.934       3.388       # 1983      def11       'SD of age.
   0.55*age3'
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
```

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          2.934       3.388       # 1989      def17       'SD of age.
   0.55*age5, 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        # 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
```

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         2.934       3.388       # 1995      def23       'SD of age.
   0.55*age11, 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        # 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'
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
```

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          2.934       3.388       # 2007      def35       'SD of age.
   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        # 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
```

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         2.934      3.388      # 2013     def41      'SD of age.
   0.55*age3, 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       # 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'
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       # 2018     def46      '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
         1.6137     3.388      # 2018     def46      'SD of age.
   0.55*age4, 0.55*age8, 0.55*age19'

#_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    8.165    11.227   5.012
   8.941    11.076   9.460    2.628    3.785    1.516    1.068
1981    7        1        0        0        9        -1       -1       154
   19.493   4.030    1.403    26.726   3.901    5.548    3.376    14.675
   3.769    3.195    10.185   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    66.755   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    15.344   5.385    0.527    0.761    43.634   6.897    8.153
   8.260    2.189    2.817    1.834    3.134    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    0.653    0.066    32.276   0.980    1.450    0.664    46.046
   1.351    0.839    10.483   0.789    0.054    0.065    4.283
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   20.560  1.885   0.592   31.348  0.512   0.200
   0.042   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   13.053  18.594  2.271   1.043   33.926
   0.767   0.078   0.340   18.050  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  15.667  1.500   0.810
   27.422  0.674   0.089   0.120   12.004  0.054   1.129
1994    7       1       0       0       22      -1      -1      235
   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   0.468   6.308   28.967  1.152   8.053   20.269
   1.577   0.222   22.424  0.435   0.451   0.037   7.735
1996    7       1       0       0       24      -1      -1      186
   0.000   18.282  16.242  1.506   7.742   18.139  1.002   4.909
   10.981  0.576   0.347   15.717  0.009   0.108   4.439
1997    7       1       0       0       25      -1      -1      220
   0.000   0.737   29.474  24.952  1.469   7.839   12.488  1.798
   3.978   6.671   1.284   0.216   6.080   0.733   2.282
1998    7       1       0       0       26      -1      -1      243
   0.015   4.779   20.335  20.294  26.596  2.868   5.406   9.312
   0.917   1.561   3.901   0.353   0.092   2.942   0.628
1999    7       1       0       0       27      -1      -1      509
   0.062   10.244  20.364  17.982  20.062  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   12.101  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   1.394   67.791  11.664  3.352   5.009   3.203
   3.153   2.119   0.879   0.438   0.536   0.126   0.232
2004    7       1       0       0       32      -1      -1      501
   0.000   0.022   5.343   6.126   68.293  8.115   2.178   4.133
   2.506   1.270   1.073   0.346   0.268   0.158   0.170
2005    7       1       0       0       33      -1      -1      613
   0.018   0.569   0.464   6.561   5.381   68.723  7.954   2.359
   2.908   2.208   1.177   1.091   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   59.037  5.276
   1.716   2.376   1.134   1.015   0.426   0.136   0.188
2007    7       1       0       0       35      -1      -1      629
   0.775   11.522  3.807   15.697  1.589   6.887   3.811   43.947
   5.080   1.713   2.203   1.661   0.482   0.187   0.639
```

```
2008    7       1       0       0       36      -1      -1      794
   0.765   9.891   30.835  2.408   14.475  1.028   3.630   3.167
   27.780  2.977   1.119   0.725   0.477   0.309   0.414
2009    7       1       0       0       37      -1      -1      685
   0.643   0.527   29.679  27.192  3.456   11.007  1.346   2.396
   2.345   16.673  2.572   0.922   0.623   0.290   0.327
2010    7       1       0       0       38      -1      -1      874
   0.029   25.918  3.409   35.410  21.156  2.239   2.872   0.417
   0.572   0.957   5.612   0.878   0.270   0.103   0.158
2011    7       1       0       0       39      -1      -1      1081
   2.713   8.741   71.016  2.642   6.245   4.326   1.101   0.757
   0.296   0.349   0.115   1.317   0.170   0.100   0.112
2012    7       1       0       0       40      -1      -1      851
   0.181   40.950  11.557  32.986  2.489   5.084   2.517   1.133
   0.659   0.232   0.329   0.347   0.871   0.284   0.383
2013    7       1       0       0       41      -1      -1      1094
   0.030   0.545   70.312  5.904   10.470  1.123   3.413   2.059
   0.906   1.366   0.264   0.333   0.530   2.282   0.463
2014    7       1       0       0       42      -1      -1      1153
   0.000   3.299   3.681   64.420  6.979   12.085  1.592   3.120
   1.835   0.815   0.464   0.117   0.191   0.277   1.126
2015    7       1       0       0       43      -1      -1      798
   3.591   1.136   6.883   3.946   70.018  4.940   5.091   0.959
   1.552   1.089   0.202   0.206   0.061   0.054   0.274
2016    7       1       0       0       44      -1      -1      1440
   0.292   50.193  1.693   4.475   2.477   32.871  2.775   3.233
   0.760   0.442   0.369   0.235   0.063   0.054   0.069
2017    7       1       0       0       45      -1      -1      1300
   3.665   0.734   38.551  2.356   4.129   3.104   36.976  4.281
   3.066   1.279   0.623   0.725   0.211   0.094   0.206
2018    7       1       0       0       46      -1      -1      1059
   5.422   23.443  1.625   28.765  1.676   2.907   3.124   24.171
   4.396   2.008   0.984   0.623   0.422   0.352   0.082
-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 #_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
```

I STOCK SYNTHESIS CONTROL FILE

../models/2019.03.00_base/hake_control.ss

```
#C 2019 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 distibution,
   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
#_LO    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 0
   #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_ LO 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
#_          LO            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          0 # SR_LN(R0)
           0.2           1          0.88         0.777         0.113
               2          4          0           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          0 # SR_sigmaR
            -5           5             0             0            99
               0        -50          0           0          0          0
            0          0          0 # SR_regime
             0             2             0             1            99
               0        -50          0           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
2017 # 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_recr_like occurring before endyr+1
 1965 #_last_early_yr_nobias_adj_in_MPD
 1971 #_first_yr_fullbias_adj_in_MPD
 2017 #_last_yr_fullbias_adj_in_MPD
 2018 #_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 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
# 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          0  #  LnQ_base_Acoustic_Survey(2)
          0.05          1.2        0.0755        0.0755          0.1
               0          4          0          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-parm 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        2018
            5          0          0  #  AgeSel_P3_Fishery(1)
            -5             9           0.1            -1          0.01
               0          2          0           2       1991        2018
            5          0          0  #  AgeSel_P4_Fishery(1)
            -5             9           0.1            -1          0.01
               0          2          0           2       1991        2018
            5          0          0  #  AgeSel_P5_Fishery(1)
            -5             9           0.1            -1          0.01
               0          2          0           2       1991        2018
            5          0          0  #  AgeSel_P6_Fishery(1)
            -5             9             0            -1          0.01
               0          2          0           2       1991        2018
            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  #  AgeSel_P11_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P12_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P13_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P14_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P15_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P16_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P17_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P18_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P19_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P20_Fishery(1)
 -5             9             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P21_Fishery(1)
-1002           3         -1000            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P1_Acoustic_Survey(2)
-1002           3         -1000            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P2_Acoustic_Survey(2)
 -1             1             0            -1          0.01
  0            -2             0             0           0
  0             0             0  #  AgeSel_P3_Acoustic_Survey(2)
 -5             9           0.1            -1          0.01
  0             2             0             0           0
  0             0             0  #  AgeSel_P4_Acoustic_Survey(2)
 -5             9           0.1            -1          0.01
  0             2             0             0           0
  0             0             0  #  AgeSel_P5_Acoustic_Survey(2)
 -5             9             0            -1          0.01
  0             2             0             0           0
  0             0             0  #  AgeSel_P6_Acoustic_Survey(2)
 -5             9             0            -1          0.01
  0             2             0             0           0
  0             0             0  #  AgeSel_P7_Acoustic_Survey(2)
```

```
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P8_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P9_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P10_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P11_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P12_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P13_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P14_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P15_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P16_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P17_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P18_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P19_Acoustic_Survey(2)
            -5              9              0            -1          0.01
               0          -2              0             0           0           0
            0             0           0  #  AgeSel_P20_Acoustic_Survey(2)
            -5              9              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           0  #  ln(EffN_mult)_1
            -5             20             .5             0            99
               0           2              0             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
         -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
   phase  dev_vector
#      5     3     1     0     0     2     0     1     2  1991  2018
   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
#      5     4     3     0     0     2     0     2     2  1991  2018
   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
#      5     5     5     0     0     2     0     3     2  1991  2018
   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
#      5     6     7     0     0     2     0     4     2  1991  2018
   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
#      5     7     9     0     0     2     0     5     2  1991  2018
   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
```

```
     #
# 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
```

J STOCK SYNTHESIS STARTER FILE

../models/2019.03.00_base/starter.ss

```
#C Hake starter file
hake_data.SS
hake_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.SSO (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/Fbtgt
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
```

K STOCK SYNTHESIS FORECAST FILE

../models/2019.03.00_base/forecast.ss

```
#C 2018 Hake forecast file
# for all year entries except rebuilder; enter either: actual year, -999
   for styr, 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
```

L STOCK SYNTHESIS WEIGHT-AT-AGE FILE

../models/2019.03.00_base/wtatage.ss

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2019-01-29 14:33:44
#################################################
20 # Maximum age

#Maturity x Fecundity: Fleet = -2
# new values added for 2019 assessment based on age-based maturity *
   weight-at-age for each year
 #_#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
   0.0657459        0.3184844        0.4666616        0.49128
   0.5415808        0.5997702        0.6791829        0.7402848
   0.838586         0.8887918        0.9613   1.0148094
   0.9547135        0.92799 0.92799 0.92799 0.92799 0.92799 0.92799
  1975  1        1       1        1        -2       0        0
   0.0779607        0.3069062        0.5903423        0.580152
   0.7306144        0.8091388        0.9261846        0.85668
   0.9506           1.6289546        1.5      1.8202
   1.8675025        2.47005 2.47005 2.47005 2.47005 2.47005 2.47005
  1976  1        1       1        1        -2       0        0
   0.0615699        0.418661         0.4985668        0.638112
   0.7459264        0.848679         1.1544291        1.258824
   1.42051          1.5879734        1.8066   1.7807304
   1.8675025        2.47005 2.47005 2.47005 2.47005 2.47005 2.47005
  1977  1        1       1        1        -2       0        0
   0.104922         0.4095998        0.5671822        0.6118
   0.6949792        0.7659872        0.9358503        1.0433088
   1.209418         1.2648376        1.4027   1.6775538
   2.0059775        1.98846 1.98846 1.98846 1.98846 1.98846 1.98846
  1978  1        1       1        1        -2       0        0
   0.0332775        0.3942461        0.5095222        0.554392
   0.5931776        0.6849622        0.8059854        0.9261584
   1.077706         1.1985558        1.3295   1.4191812
   1.6635145        2.10177 2.10177 2.10177 2.10177 2.10177 2.10177
  1979  1        1       1        1        -2       0        0
   0.062901         0.2170493        0.5593981        0.631856
   0.7124256        0.8249734        0.8735496        0.9788336
   1.174726         1.2007684        1.5326   1.486816
   1.714225         1.78353 1.78353 1.78353 1.78353 1.78353 1.78353
  1980  1        1       1        1        -2       0        0
   0.0554625        0.3799831        0.3769042        0.451168
   0.4794048        0.6069004        0.6829152        0.825056
   1.041348         1.1181326        1.2898   1.2454958
   1.2127545        1.25649 1.25649 1.25649 1.25649 1.25649 1.25649
```

```
1981  1       1       1       1       -2      0       0
 0.0557757       0.2871058       0.5058704       0.361836
 0.4875712       0.5057812       0.7143048       0.6800576
 0.806638        1.0017306       1.0989  1.2884142
 1.425433        1.09152 1.09152 1.09152 1.09152 1.09152 1.09152
1982  1       1       1       1       -2      0       0
 0.0643365       0.2798904       0.2976217       0.505632
 0.3671168       0.488465        0.5386953       0.7180064
 0.670026        0.8214518       1.067   0.8423694
 0.972763        1.05237 1.05237 1.05237 1.05237 1.05237 1.05237
1983  1       1       1       1       -2      0       0
 0.0354177       0.286099        0.3549934       0.301484
 0.48256         0.4655928       0.5913303       0.666464
 0.8624          0.8945638       1.0356  0.987698
 1.2622235       1.33407 1.33407 1.33407 1.33407 1.33407 1.33407
1984  1       1       1       1       -2      0       0
 0.0428562       0.2091627       0.4213024       0.378396
 0.4038656       0.5437472       0.5552514       0.6379552
 0.68698         0.9151506       1.1364  0.9827164
 1.2230685       1.692   1.692   1.692   1.692   1.692   1.692
1985  1       1       1       1       -2      0       0
 0.0599517       0.2247681       0.4241854       0.505632
 0.5079872       0.5571742       0.7131564       0.6544752
 0.708638        0.8257808       0.8698  0.9060764
 0.6454845       1.00953 1.00953 1.00953 1.00953 1.00953 1.00953
1986  1       1       1       1       -2      0       0
 0.072558        0.2438134       0.2906064       0.34362
 0.5035328       0.529672        0.6144897       0.7749296
 0.921494        1.140932        1.19    1.3160046       1.6044
         1.45278 1.45278 1.45278 1.45278 1.45278 1.45278
1987  1       1       1       1       -2      0       0
 0.0362268       0.317981        0.2677346       0.26404
 0.3360288       0.534765        0.5718075       0.6012336
 0.748524        0.944684        0.925   1.1885906
 1.1489605       1.27413 1.27413 1.27413 1.27413 1.27413 1.27413
1988  1       1       1       1       -2      0       0
 0.048807        0.2532102       0.4506129       0.33718
 0.3307392       0.4517028       0.5995605       0.6304976
 0.657482        0.8834046       0.9388  0.98195
 0.969898        1.4085  1.4085  1.4085  1.4085  1.4085  1.4085
1989  1       1       1       1       -2      0       0
 0.0714357       0.2556433       0.2816691       0.472328
 0.4070208       0.3763264       0.4944819       0.5912272
 0.647878        0.5797974       0.8758  0.6405188
 0.790931        1.01376 1.01376 1.01376 1.01376 1.01376 1.01376
1990  1       1       1       1       -2      0       0
 0.0635535       0.2933144       0.3748861       0.470212
 0.5073376       0.5718976       0.6387018       0.50032
 0.749798        0.7995182       2.2     1.1381998
 0.970853        1.32021 1.32021 1.32021 1.32021 1.32021 1.32021
1991  1       1       1       1       -2      0       0
 0.0718794       0.3101783       0.4418678       0.472696
 0.5045536       0.5469882       0.689997        0.8021168
 1.077706        0.691197        0.6403  0.9762978
```

```
 1.1508705       2.14452 2.14452 2.14452 2.14452 2.14452 2.14452
1992  1       1       1       1       -2      0       0
 0.0604476       0.2913847       0.4583009       0.49496
 0.545664        0.575046        0.616308        0.616432
 0.625534        0.6942754       0.7371  0.8143958
 0.931125        0.9216  0.9216  0.9216  0.9216  0.9216  0.9216
1993  1       1       1       1       -2      0       0
 0.0648846       0.2839176       0.380556        0.417588
 0.457968        0.4645742       0.467016        0.5183504
 0.4998          1.215006        1.025   0.587733
 0.5725225       0.6165  0.6165  0.6165  0.6165  0.6165  0.6165
1994  1       1       1       1       -2      0       0       0.0783
         0.3042214       0.4294709       0.411516
 0.4883136       0.52782         0.5950626       0.5284512
 0.621418        0.46657         0.6491  0.69934
 0.6697415       0.67095 0.67095 0.67095 0.67095 0.67095 0.67095
1995  1       1       1       1       -2      0       0
 0.0700002       0.280226        0.4646435       0.493304
 0.5989312       0.5756016       0.6289404       0.7143248
 0.620536        0.7132268       0.8039  0.8718758
 0.649782        0.71631 0.71631 0.71631 0.71631 0.71631 0.71631
1996  1       1       1       1       -2      0       0
 0.0750636       0.3340898       0.4491714       0.489164
 0.5244128       0.6027334       0.5700849       0.6005728
 0.592802        0.7215          0.6756  0.7768422
 1.4184615       0.67581 0.67581 0.67581 0.67581 0.67581 0.67581
1997  1       1       1       1       -2      0       0
 0.0927855       0.3626158       0.4738691       0.503792
 0.5060384       0.5401358       0.5603235       0.5731024
 0.61887         0.8304946       0.5946  0.6819044
 0.632019        0.78237 0.78237 0.78237 0.78237 0.78237 0.78237
1998  1       1       1       1       -2      0       0
 0.0547578       0.3013688       0.485305        0.476192
 0.5023264       0.5874544       0.5817603       0.6336128
 0.767242        0.6857136       0.7907  0.7408214
 0.7102335       0.71478 0.71478 0.71478 0.71478 0.71478 0.71478
1999  1       1       1       1       -2      0       0
 0.0653022       0.2898745       0.4085211       0.48438
 0.5168032       0.5303202       0.5853969       0.663632
 0.6517          0.7685418       0.7554  0.8417946
 0.701734        0.73683 0.73683 0.73683 0.73683 0.73683 0.73683
2000  1       1       1       1       -2      0       0
 0.0839376       0.3967631       0.5541126       0.607016
 0.6659328       0.6740354       0.7214823       0.7908832
 0.799582        0.8479068       0.8554  0.8996578
 0.835052        0.84024 0.84024 0.84024 0.84024 0.84024 0.84024
2001  1       1       1       1       -2      0       0
 0.0748287       0.4063277       0.6272447       0.61134
 0.6931232       0.7990454       0.8187135       0.8309088
 0.94374         0.941798        1.0054  1.0053252
 0.9480285       0.87912 0.87912 0.87912 0.87912 0.87912 0.87912
2002  1       1       1       1       -2      0       0
 0.0935163       0.3838425       0.5821738       0.75072
 0.7035168       0.7859888       0.9350847       0.8799968
```

```
 0.899248        0.9594988       0.989   0.8848088
 1.074375        0.95157 0.95157 0.95157 0.95157 0.95157 0.95157
2003  1       1       1       1       -2      0       0
 0.0665811       0.3653845       0.5021225       0.54142
 0.6965568       0.6340322       0.7023423       0.7466096
 0.75313         0.7256366       0.8132  0.7562452
 0.803537        0.8136  0.8136  0.8136  0.8136  0.8136  0.8136
2004  1       1       1       1       -2      0       0
 0.0528525       0.3661396       0.4648357       0.496156
 0.623152        0.6665348       0.6447309       0.6788304
 0.77861         0.8169304       0.8105  0.898125
 0.791886        0.78435 0.78435 0.78435 0.78435 0.78435 0.78435
2005  1       1       1       1       -2      0       0
 0.0679383       0.3654684       0.491071        0.506092
 0.5360128       0.595881        0.6447309       0.6736384
 0.77469         0.7706582       0.8117  0.73766
 1.0244285       0.87723 0.87723 0.87723 0.87723 0.87723 0.87723
2006  1       1       1       1       -2      0       0
 0.0999891       0.3838425       0.5132701       0.52808
 0.548448        0.5536554       0.627792        0.6605168
 0.711382        0.694564        0.7753  0.630364
 0.6111045       0.8595  0.8595  0.8595  0.8595  0.8595  0.8595
2007  1       1       1       1       -2      0       0
 0.0569502       0.3208336       0.5123091       0.513912
 0.569328        0.5952328       0.6274092       0.6717504
 0.760676        0.7206342       0.8217  0.819569
 0.749102        0.77067 0.77067 0.77067 0.77067 0.77067 0.77067
2008  1       1       1       1       -2      0       0
 0.063684        0.3422281       0.541043        0.58558
 0.637072        0.6313468       0.6792786       0.6807184
 0.733824        0.7766226       0.8483  0.742929
 0.843647        0.74988 0.74988 0.74988 0.74988 0.74988 0.74988
2009  1       1       1       1       -2      0       0
 0.0638928       0.2878609       0.4528232       0.586132
 0.6219456       0.6428292       0.7142091       0.7765344
 0.752052        0.7829718       1.0147  0.8145874
 0.915081        0.93006 0.93006 0.93006 0.93006 0.93006 0.93006
2010  1       1       1       1       -2      0       0
 0.0607086       0.2448202       0.4163052       0.487784
 0.6108096       0.7731174       1.0362396       0.9700544
 0.939036        0.8430006       0.8524  1.0780374       0.6876
         0.81189 0.81189 0.81189 0.81189 0.81189 0.81189
2011  1       1       1       1       -2      0       0
 0.0641277       0.2716682       0.3723875       0.473064
 0.55216         0.6229202       0.816321        0.8773536
 0.957166        1.0340538       1.0591  0.9847282
 1.0081935       0.82908 0.82908 0.82908 0.82908 0.82908 0.82908
2012  1       1       1       1       -2      0       0
 0.0559845       0.2966704       0.3935295       0.449788
 0.6089536       0.6394956       0.7441632       0.8565856
 0.943348        0.9275604       0.9638  0.9477494
 0.9478375       0.84843 0.84843 0.84843 0.84843 0.84843 0.84843
2013  1       1       1       1       -2      0       0
 0.0750114       0.3016205       0.4513817       0.469568
```

```
   0.580928         0.663479         0.699567         0.7847472
   0.978922         1.0343424        1.2303   1.0717146
   1.020131         0.94905 0.94905 0.94905 0.94905 0.94905 0.94905
  2014  1        1        1        1        -2       0        0
   0.0971181        0.3866112        0.4624332        0.498364
   0.5342496        0.5732866        0.637362         0.6944064
   0.685804         1.0893688        0.9145   0.9092378        1.02758
           0.93906 0.93906 0.93906 0.93906 0.93906 0.93906
  2015  1        1        1        1        -2       0        0
   0.0644931        0.3276295        0.4271645        0.433136
   0.5132768        0.5507848        0.6458793        0.6493776
   0.703542         0.8020194        0.9523   0.975723
   1.0402815        1.12437 1.12437 1.12437 1.12437 1.12437 1.12437
  2016  1        1        1        1        -2       0        0
   0.0636579        0.3214209        0.4001604        0.40572
   0.4321696        0.475501         0.4959174        0.4846496
   0.648466         0.6924476        0.5921   0.9162312
   1.385705         1.30869 1.30869 1.30869 1.30869 1.30869 1.30869
  2017  1        1        1        1        -2       0        0
   0.0739935        0.3311533        0.4653162        0.48024
   0.518752         0.5112446        0.5543901        0.617376
   0.59584          0.6912932        0.7967   0.7422584
   0.777561         0.85473 0.85473 0.85473 0.85473 0.85473 0.85473
  2018  1        1        1        1        -2       0        0
   0.0930204        0.3939105        0.4899178        0.508024
   0.5309088        0.5899546        0.5806119        0.5837696
   0.660128         0.6413654        0.7068   0.8153538
   0.8567305        0.99639 0.99639 0.99639 0.99639 0.99639 0.99639

#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 0.0157 0.0905 0.2519 0.3796 0.4856
   0.5340 0.5836 0.6477 0.7097 0.7842 0.8557 0.9239 0.9613 1.0593 0.9997
   1.0311 1.0311 1.0311 1.0311 1.0311 1.0311
  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
 1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
1983    1      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    -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    -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    -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    -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    -1 0.0190 0.1400 0.1870 0.3018 0.4689
 0.3665 0.3564 0.4878 0.6265 0.6679 0.6709 0.9183 0.9388 1.0250 1.0156
 1.5650 1.5650 1.5650 1.5650 1.5650 1.5650
1989    1      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    -1 0.0156 0.1378 0.2435 0.3496 0.3901
 0.5111 0.5467 0.6176 0.6674 0.5300 0.7651 0.8311 2.2000 1.1881 1.0166
 1.4669 1.4669 1.4669 1.4669 1.4669 1.4669
1991    1      1  1     1    -1 0.0155 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0191 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1      1  1     1    -1 0.0154 0.1356 0.2316 0.3473 0.4769
 0.5380 0.5880 0.6210 0.6440 0.6530 0.6383 0.7217 0.7371 0.8501 0.9750
 1.0240 1.0240 1.0240 1.0240 1.0240 1.0240
1993    1      1  1     1    -1 0.0152 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    -1 0.0151 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    -1 0.0150 0.1108 0.2682 0.3340 0.4835
 0.5362 0.6454 0.6216 0.6572 0.7567 0.6332 0.7414 0.8039 0.9101 0.6804
 0.7959 0.7959 0.7959 0.7959 0.7959 0.7959
1996    1      1  1     1    -1 0.0149 0.1019 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    -1 0.0148 0.0929 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    -1 0.0147 0.0840 0.2098 0.3592 0.5050
 0.5176 0.5413 0.6344 0.6079 0.6712 0.7829 0.7128 0.7907 0.7733 0.7437
```

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 0.7942 0.7942 0.7942 0.7942 0.7942 0.7942
1999    1      1  1     1    -1 0.0146 0.1369 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    -1 0.0145 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 0.0144 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 0.0142 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 0.0141 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7506 0.6847 0.7339 0.7909 0.7685 0.7543 0.8132 0.7894 0.8414
 0.9040 0.9040 0.9040 0.9040 0.9040 0.9040
2004    1      1  1     1    -1 0.0140 0.1081 0.2025 0.4364 0.4837
 0.5393 0.6715 0.7198 0.6737 0.7191 0.7945 0.8492 0.8105 0.9375 0.8292
 0.8715 0.8715 0.8715 0.8715 0.8715 0.8715
2005    1      1  1     1    -1 0.0139 0.1162 0.2603 0.4356 0.5110
 0.5501 0.5776 0.6435 0.6737 0.7136 0.7905 0.8011 0.8117 0.7700 1.0727
 0.9747 0.9747 0.9747 0.9747 0.9747 0.9747
2006    1      1  1     1    -1 0.0138 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 0.0137 0.0429 0.2182 0.3824 0.5331
 0.5586 0.6135 0.6428 0.6556 0.7116 0.7762 0.7491 0.8217 0.8555 0.7844
 0.8563 0.8563 0.8563 0.8563 0.8563 0.8563
2008    1      1  1     1    -1 0.0144 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 0.0152 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 0.0159 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 0.0167 0.0844 0.2457 0.3238 0.3875
 0.5142 0.5950 0.6727 0.8530 0.9294 0.9767 1.0749 1.0591 1.0279 1.0557
 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
2012    1      1  1     1    -1 0.0174 0.1290 0.2145 0.3536 0.4095
 0.4889 0.6562 0.6906 0.7776 0.9074 0.9626 0.9642 0.9638 0.9893 0.9925
 0.9427 0.9427 0.9427 0.9427 0.9427 0.9427
2013    1      1  1     1    -1 0.0182 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 0.0189 0.2120 0.3721 0.4608 0.4812
 0.5417 0.5757 0.6191 0.6660 0.7356 0.6998 1.1324 0.9145 0.9491 1.0760
 1.0434 1.0434 1.0434 1.0434 1.0434 1.0434
2015    1      1  1     1    -1 0.0155 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 0.0120 0.1653 0.2439 0.3831 0.4164
 0.4410 0.4657 0.5135 0.5182 0.5134 0.6617 0.7198 0.5921 0.9564 1.4510
```

```
   1.4541  1.4541  1.4541  1.4541  1.4541  1.4541
  2017     1       1   1      1     -1 0.0085 0.1362 0.2835 0.3947 0.4842
   0.5220  0.5590  0.5521  0.5793  0.6540  0.6080  0.7186  0.7967  0.7748  0.8142
   0.9497  0.9497  0.9497  0.9497  0.9497  0.9497
  2018     1       1   1      1     -1 0.0085 0.1785 0.3564 0.4695 0.5098
   0.5522  0.5721  0.6371  0.6067  0.6184  0.6736  0.6667  0.7068  0.8511  0.8971
   1.1071  1.1071  1.1071  1.1071  1.1071  1.1071

#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 0.0157 0.0905 0.2519 0.3796 0.4856
   0.5340  0.5836  0.6477  0.7097  0.7842  0.8557  0.9239  0.9613  1.0593  0.9997
   1.0311  1.0311  1.0311  1.0311  1.0311  1.0311
  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
  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
  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
  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
  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
  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
  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
  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
  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
  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
  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
  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
  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
```

```
1988    1       1  1     1     0 0.0190 0.1400 0.1870 0.3018 0.4689
 0.3665 0.3564 0.4878 0.6265 0.6679 0.6709 0.9183 0.9388 1.0250 1.0156
 1.5650 1.5650 1.5650 1.5650 1.5650 1.5650
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
1990    1       1  1     1     0 0.0156 0.1378 0.2435 0.3496 0.3901
 0.5111 0.5467 0.6176 0.6674 0.5300 0.7651 0.8311 2.2000 1.1881 1.0166
 1.4669 1.4669 1.4669 1.4669 1.4669 1.4669
1991    1       1  1     1     0 0.0155 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0191 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1       1  1     1     0 0.0154 0.1356 0.2316 0.3473 0.4769
 0.5380 0.5880 0.6210 0.6440 0.6530 0.6383 0.7217 0.7371 0.8501 0.9750
 1.0240 1.0240 1.0240 1.0240 1.0240 1.0240
1993    1       1  1     1     0 0.0152 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 0.0151 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 0.0150 0.1108 0.2682 0.3340 0.4835
 0.5362 0.6454 0.6216 0.6572 0.7567 0.6332 0.7414 0.8039 0.9101 0.6804
 0.7959 0.7959 0.7959 0.7959 0.7959 0.7959
1996    1       1  1     1     0 0.0149 0.1019 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 0.0148 0.0929 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 0.0147 0.0840 0.2098 0.3592 0.5050
 0.5176 0.5413 0.6344 0.6079 0.6712 0.7829 0.7128 0.7907 0.7733 0.7437
 0.7942 0.7942 0.7942 0.7942 0.7942 0.7942
1999    1       1  1     1     0 0.0146 0.1369 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 0.0145 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 0.0144 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 0.0142 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 0.0141 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7506 0.6847 0.7339 0.7909 0.7685 0.7543 0.8132 0.7894 0.8414
 0.9040 0.9040 0.9040 0.9040 0.9040 0.9040
2004    1       1  1     1     0 0.0140 0.1081 0.2025 0.4364 0.4837
 0.5393 0.6715 0.7198 0.6737 0.7191 0.7945 0.8492 0.8105 0.9375 0.8292
 0.8715 0.8715 0.8715 0.8715 0.8715 0.8715
2005    1       1  1     1     0 0.0139 0.1162 0.2603 0.4356 0.5110
 0.5501 0.5776 0.6435 0.6737 0.7136 0.7905 0.8011 0.8117 0.7700 1.0727
 0.9747 0.9747 0.9747 0.9747 0.9747 0.9747
```

```
  2006    1       1  1     1      0 0.0138 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 0.0137 0.0429 0.2182 0.3824 0.5331
   0.5586 0.6135 0.6428 0.6556 0.7116 0.7762 0.7491 0.8217 0.8555 0.7844
   0.8563 0.8563 0.8563 0.8563 0.8563 0.8563
  2008    1       1  1     1      0 0.0144 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      0 0.0152 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 0.0159 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 0.0167 0.0844 0.2457 0.3238 0.3875
   0.5142 0.5950 0.6727 0.8530 0.9294 0.9767 1.0749 1.0591 1.0279 1.0557
   0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1       1  1     1      0 0.0174 0.1290 0.2145 0.3536 0.4095
   0.4889 0.6562 0.6906 0.7776 0.9074 0.9626 0.9642 0.9638 0.9893 0.9925
   0.9427 0.9427 0.9427 0.9427 0.9427 0.9427
  2013    1       1  1     1      0 0.0182 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 0.0189 0.2120 0.3721 0.4608 0.4812
   0.5417 0.5757 0.6191 0.6660 0.7356 0.6998 1.1324 0.9145 0.9491 1.0760
   1.0434 1.0434 1.0434 1.0434 1.0434 1.0434
  2015    1       1  1     1      0 0.0155 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 0.0120 0.1653 0.2439 0.3831 0.4164
   0.4410 0.4657 0.5135 0.5182 0.5134 0.6617 0.7198 0.5921 0.9564 1.4510
   1.4541 1.4541 1.4541 1.4541 1.4541 1.4541
  2017    1       1  1     1      0 0.0085 0.1362 0.2835 0.3947 0.4842
   0.5220 0.5590 0.5521 0.5793 0.6540 0.6080 0.7186 0.7967 0.7748 0.8142
   0.9497 0.9497 0.9497 0.9497 0.9497 0.9497
  2018    1       1  1     1      0 0.0085 0.1785 0.3564 0.4695 0.5098
   0.5522 0.5721 0.6371 0.6067 0.6184 0.6736 0.6667 0.7068 0.8511 0.8971
   1.1071 1.1071 1.1071 1.1071 1.1071 1.1071

#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 0.0157 0.0905 0.2519 0.3796 0.4856
    0.5340 0.5836 0.6477 0.7097 0.7842 0.8557 0.9239 0.9613 1.0593 0.9997
    1.0311 1.0311 1.0311 1.0311 1.0311 1.0311
  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
```

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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
 1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
1983    1       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      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      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      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      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      1 0.0190 0.1400 0.1870 0.3018 0.4689
 0.3665 0.3564 0.4878 0.6265 0.6679 0.6709 0.9183 0.9388 1.0250 1.0156
 1.5650 1.5650 1.5650 1.5650 1.5650 1.5650
1989    1       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      1 0.0156 0.1378 0.2435 0.3496 0.3901
 0.5111 0.5467 0.6176 0.6674 0.5300 0.7651 0.8311 2.2000 1.1881 1.0166
 1.4669 1.4669 1.4669 1.4669 1.4669 1.4669
1991    1       1  1     1      1 0.0155 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0191 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1       1  1     1      1 0.0154 0.1356 0.2316 0.3473 0.4769
 0.5380 0.5880 0.6210 0.6440 0.6530 0.6383 0.7217 0.7371 0.8501 0.9750
 1.0240 1.0240 1.0240 1.0240 1.0240 1.0240
1993    1       1  1     1      1 0.0152 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      1 0.0151 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     1 0.0150 0.1108 0.2682 0.3340 0.4835
 0.5362 0.6454 0.6216 0.6572 0.7567 0.6332 0.7414 0.8039 0.9101 0.6804
 0.7959 0.7959 0.7959 0.7959 0.7959 0.7959
1996    1       1  1     1     1 0.0149 0.1019 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     1 0.0148 0.0929 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     1 0.0147 0.0840 0.2098 0.3592 0.5050
 0.5176 0.5413 0.6344 0.6079 0.6712 0.7829 0.7128 0.7907 0.7733 0.7437
 0.7942 0.7942 0.7942 0.7942 0.7942 0.7942
1999    1       1  1     1     1 0.0146 0.1369 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     1 0.0145 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 0.0144 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 0.0142 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 0.0141 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7506 0.6847 0.7339 0.7909 0.7685 0.7543 0.8132 0.7894 0.8414
 0.9040 0.9040 0.9040 0.9040 0.9040 0.9040
2004    1       1  1     1     1 0.0140 0.1081 0.2025 0.4364 0.4837
 0.5393 0.6715 0.7198 0.6737 0.7191 0.7945 0.8492 0.8105 0.9375 0.8292
 0.8715 0.8715 0.8715 0.8715 0.8715 0.8715
2005    1       1  1     1     1 0.0139 0.1162 0.2603 0.4356 0.5110
 0.5501 0.5776 0.6435 0.6737 0.7136 0.7905 0.8011 0.8117 0.7700 1.0727
 0.9747 0.9747 0.9747 0.9747 0.9747 0.9747
2006    1       1  1     1     1 0.0138 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 0.0137 0.0429 0.2182 0.3824 0.5331
 0.5586 0.6135 0.6428 0.6556 0.7116 0.7762 0.7491 0.8217 0.8555 0.7844
 0.8563 0.8563 0.8563 0.8563 0.8563 0.8563
2008    1       1  1     1     1 0.0144 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 0.0152 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 0.0159 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 0.0167 0.0844 0.2457 0.3238 0.3875
 0.5142 0.5950 0.6727 0.8530 0.9294 0.9767 1.0749 1.0591 1.0279 1.0557
 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
2012    1       1  1     1     1 0.0174 0.1290 0.2145 0.3536 0.4095
 0.4889 0.6562 0.6906 0.7776 0.9074 0.9626 0.9642 0.9638 0.9893 0.9925
 0.9427 0.9427 0.9427 0.9427 0.9427 0.9427
```

```
  2013    1       1  1     1      1 0.0182 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 0.0189 0.2120 0.3721 0.4608 0.4812
    0.5417 0.5757 0.6191 0.6660 0.7356 0.6998 1.1324 0.9145 0.9491 1.0760
    1.0434 1.0434 1.0434 1.0434 1.0434 1.0434
  2015    1       1  1     1      1 0.0155 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 0.0120 0.1653 0.2439 0.3831 0.4164
    0.4410 0.4657 0.5135 0.5182 0.5134 0.6617 0.7198 0.5921 0.9564 1.4510
    1.4541 1.4541 1.4541 1.4541 1.4541 1.4541
  2017    1       1  1     1      1 0.0085 0.1362 0.2835 0.3947 0.4842
    0.5220 0.5590 0.5521 0.5793 0.6540 0.6080 0.7186 0.7967 0.7748 0.8142
    0.9497 0.9497 0.9497 0.9497 0.9497 0.9497
  2018    1       1  1     1      1 0.0085 0.1785 0.3564 0.4695 0.5098
    0.5522 0.5721 0.6371 0.6067 0.6184 0.6736 0.6667 0.7068 0.8511 0.8971
    1.1071 1.1071 1.1071 1.1071 1.1071 1.1071

#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 0.0157 0.0905 0.2519 0.3796 0.4856
    0.5340 0.5836 0.6477 0.7097 0.7842 0.8557 0.9239 0.9613 1.0593 0.9997
    1.0311 1.0311 1.0311 1.0311 1.0311 1.0311
  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
  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
  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
  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
  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
  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
  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
  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
  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
```

```
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
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
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
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
1988    1       1  1     1     2 0.0190 0.1400 0.1870 0.3018 0.4689
 0.3665 0.3564 0.4878 0.6265 0.6679 0.6709 0.9183 0.9388 1.0250 1.0156
 1.5650 1.5650 1.5650 1.5650 1.5650 1.5650
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
 1.1264 1.1264 1.1264 1.1264 1.1264 1.1264
1990    1       1  1     1     2 0.0156 0.1378 0.2435 0.3496 0.3901
 0.5111 0.5467 0.6176 0.6674 0.5300 0.7651 0.8311 2.2000 1.1881 1.0166
 1.4669 1.4669 1.4669 1.4669 1.4669 1.4669
1991    1       1  1     1     2 0.0155 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0191 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1       1  1     1     2 0.0154 0.1356 0.2316 0.3473 0.4769
 0.5380 0.5880 0.6210 0.6440 0.6530 0.6383 0.7217 0.7371 0.8501 0.9750
 1.0240 1.0240 1.0240 1.0240 1.0240 1.0240
1993    1       1  1     1     2 0.0152 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     2 0.0151 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     2 0.0150 0.1108 0.2682 0.3340 0.4835
 0.5362 0.6454 0.6216 0.6572 0.7567 0.6332 0.7414 0.8039 0.9101 0.6804
 0.7959 0.7959 0.7959 0.7959 0.7959 0.7959
1996    1       1  1     1     2 0.0149 0.1019 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     2 0.0148 0.0929 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     2 0.0147 0.0840 0.2098 0.3592 0.5050
 0.5176 0.5413 0.6344 0.6079 0.6712 0.7829 0.7128 0.7907 0.7733 0.7437
 0.7942 0.7942 0.7942 0.7942 0.7942 0.7942
1999    1       1  1     1     2 0.0146 0.1369 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     2 0.0145 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     2 0.0144 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     2 0.0142 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     2 0.0141 0.1000 0.2551 0.4355 0.5225
  0.5885 0.7506 0.6847 0.7339 0.7909 0.7685 0.7543 0.8132 0.7894 0.8414
  0.9040 0.9040 0.9040 0.9040 0.9040 0.9040
 2004    1       1  1     1     2 0.0140 0.1081 0.2025 0.4364 0.4837
  0.5393 0.6715 0.7198 0.6737 0.7191 0.7945 0.8492 0.8105 0.9375 0.8292
  0.8715 0.8715 0.8715 0.8715 0.8715 0.8715
 2005    1       1  1     1     2 0.0139 0.1162 0.2603 0.4356 0.5110
  0.5501 0.5776 0.6435 0.6737 0.7136 0.7905 0.8011 0.8117 0.7700 1.0727
  0.9747 0.9747 0.9747 0.9747 0.9747 0.9747
 2006    1       1  1     1     2 0.0138 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     2 0.0137 0.0429 0.2182 0.3824 0.5331
  0.5586 0.6135 0.6428 0.6556 0.7116 0.7762 0.7491 0.8217 0.8555 0.7844
  0.8563 0.8563 0.8563 0.8563 0.8563 0.8563
 2008    1       1  1     1     2 0.0144 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 0.0152 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 0.0159 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 0.0167 0.0844 0.2457 0.3238 0.3875
  0.5142 0.5950 0.6727 0.8530 0.9294 0.9767 1.0749 1.0591 1.0279 1.0557
  0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
 2012    1       1  1     1     2 0.0174 0.1290 0.2145 0.3536 0.4095
  0.4889 0.6562 0.6906 0.7776 0.9074 0.9626 0.9642 0.9638 0.9893 0.9925
  0.9427 0.9427 0.9427 0.9427 0.9427 0.9427
 2013    1       1  1     1     2 0.0182 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 0.0189 0.2120 0.3721 0.4608 0.4812
  0.5417 0.5757 0.6191 0.6660 0.7356 0.6998 1.1324 0.9145 0.9491 1.0760
  1.0434 1.0434 1.0434 1.0434 1.0434 1.0434
 2015    1       1  1     1     2 0.0155 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 0.0120 0.1653 0.2439 0.3831 0.4164
  0.4410 0.4657 0.5135 0.5182 0.5134 0.6617 0.7198 0.5921 0.9564 1.4510
  1.4541 1.4541 1.4541 1.4541 1.4541 1.4541
 2017    1       1  1     1     2 0.0085 0.1362 0.2835 0.3947 0.4842
  0.5220 0.5590 0.5521 0.5793 0.6540 0.6080 0.7186 0.7967 0.7748 0.8142
  0.9497 0.9497 0.9497 0.9497 0.9497 0.9497
 2018    1       1  1     1     2 0.0085 0.1785 0.3564 0.4695 0.5098
  0.5522 0.5721 0.6371 0.6067 0.6184 0.6736 0.6667 0.7068 0.8511 0.8971
  1.1071 1.1071 1.1071 1.1071 1.1071 1.1071
# End of wtatage.ss file
```

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-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
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