# Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2020

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

March 3$^{\text{rd}}$, 2020

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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This document should be cited as follows:
Grandin, C.J., K.F. Johnson, A.M. Edwards, and A.M. Berger. 2020. Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2020. Prepared by the Joint Technical Committee of the U.S. and Canada Pacific Hake/Whiting Agreement, National Marine Fisheries Service and Fisheries and Oceans Canada. 273 p.

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APPENDICES

ONE-PAGE SUMMARY

- The stock assessment model for 2020 is similar in structure to the 2019 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.

- Structural changes from 2019 involve a new prior distribution for the parameters that weight the age-composition data, removal of the constraint that estimated recruitment deviations must sum to zero, and using the average of the most recent five years (rather than all years) of weight-at-age data for calculating forecasts.

- Updates to the data include: the biomass estimate and age-composition data from the acoustic survey conducted in 2019, fishery catch and age-composition data from 2019, weight-at-age data for 2019, and minor changes to pre-2019 data.

- Coast-wide catch in 2019 was the third largest on record at 411,283 t [t represents metric tons], out of a Total Allowable Catch (adjusted for carryovers) of 597,500 t. Attainment in the U.S. was 71.8% of its quota (down 0.3% from last year); attainment in Canada was 60.4% (down 0.7% from last year).

- The median estimate of the 2020 relative spawning biomass (female spawning biomass at the start of 2020 divided by that at unfished equilibrium, B_0) is 65% but is highly uncertain (with 95% credible interval from 31% to 129%). The median relative spawning biomass reached a historical low of 33% in 2010, increased due to large estimated 2010 and 2014 cohorts, and has gradually declined since 2017 during a period of record catches.

- The median estimate of female spawning biomass at the start of 2020 is 1.196 million t (with 95% credible interval from 0.550 to 2.508 million t). This is a decrease from the 2019 median of 1.379 million t (with 95% credible interval 0.736–2.706 million t).

- The estimated probability that spawning biomass at the start of 2020 is below the $B_{40\%}$ (40% of B_0) reference point is 9.9%, and the probability that the relative fishing intensity is above its target at the end of 2019 is 8.4%. The joint probability of both these occurring is 4.3%.

- Based on the default harvest rule, the estimated median catch limit for 2020 is 666,458 t (with 95% credible interval from 258,675 to 1,588,947 t).

- Projections are highly uncertain due to uncertainty in estimates of recruitment for recent years and, thus, were conducted across a range of catch levels. Projections setting the 2020 and 2021 catch equal to the 2019 Total Allowable Catch of 597,500 t show the estimated median spawning biomass decreasing from 65% of B_0 in 2020 to 47% of B_0 in 2021 and to 34% of B_0 in 2022, with a 60% chance of the spawning biomass falling below $B_{40\%}$ in 2022. There is an estimated 97% chance of the spawning biomass declining from 2020 to 2021 and an 87% chance of it declining from 2021 to 2022 under this constant level of catch.

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 2020. 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 237,334 t from 1966 to 2019, with a low of 89,930 t in 1980 and a peak of 440,950 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, and catch in U.S. waters averaged 179,652 t, (76.1% of the total catch) while catch from Canadian waters averaged 57,682 t. Over the last 10 years, 2010–2019 (Table a), the average coast-wide catch was 309,955 t with U.S. and Canadian catches
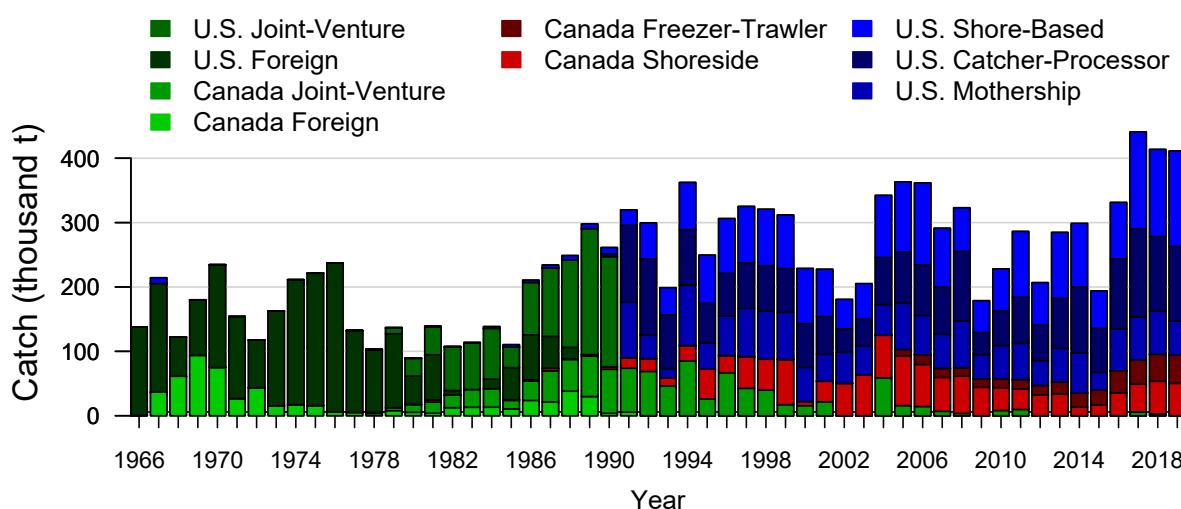
Figure a. Total Pacific Hake catch used in the assessment by sector, 1966–2019. U.S. tribal catches are included in the sectors where they are represented. CP is catcher-processor and MS is mothership.

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 table or 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
2010	52,022	54,284	64,736	0	171,043	8,081	35,362	13,573	57,016	228,059
2011	56,394	71,678	102,146	1,042	231,261	9,717	31,760	14,596	56,073	287,334
2012	38,512	55,264	65,919	448	160,144	0	32,147	14,912	47,059	207,203
2013	52,470	77,950	102,141	1,018	233,578	0	33,665	18,584	52,249	285,828
2014	62,102	103,203	98,640	197	264,141	0	13,326	21,792	35,118	299,259
2015	27,665	68,484	58,011	0	154,160	0	16,775	22,909	39,684	193,844
2016	65,036	108,786	87,760	745	262,327	0	35,012	34,731	69,743	332,070
2017	66,428	136,960	150,841	0	354,229	5,608	43,427	37,686	86,721	440,950
2018	67,121	116,073	135,112	0	318,306	2,724	50,747	41,942	95,413	413,719
2019	52,646	116,146	148,211	0	317,003	0	50,330	43,950	94,280	411,283

averaging 246,619 t and 63,336 t, respectively. The coast-wide catch in 2019 was 411,283 t, out of a total allowable catch (TAC, adjusted for carryovers) of 597,500 t. Attainment in the U.S. was 71.8% of its quota and in Canada it was 60.4%.

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 were above the long-term average catch (237,334 t) in 2016, 2017, 2018, and 2019 (these last three years being the highest catches on record) 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 2019) from that cohort estimated at approximately 1.29 million t. Through 2019, the total catch of the 2010, 2014, and 2016 year classes is estimated to be about 1.10 million t, 0.51 million t, and 0.17 million t, respectively.

DATA AND ASSESSMENT

This Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2019), acoustic survey biomass indices (Figure b) and age compositions (1995–2019), as well as fishery age compositions (1975–2019). The 2011 survey index value was the lowest in the time series and was followed by the index increasing in 2012, 2013, and 2015; the 2019 estimate is the fourth highest of the series. Age-composition data from the aggregated fisheries and the acoustic survey provide data that facilitates estimating relative cohort strength, i.e., 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
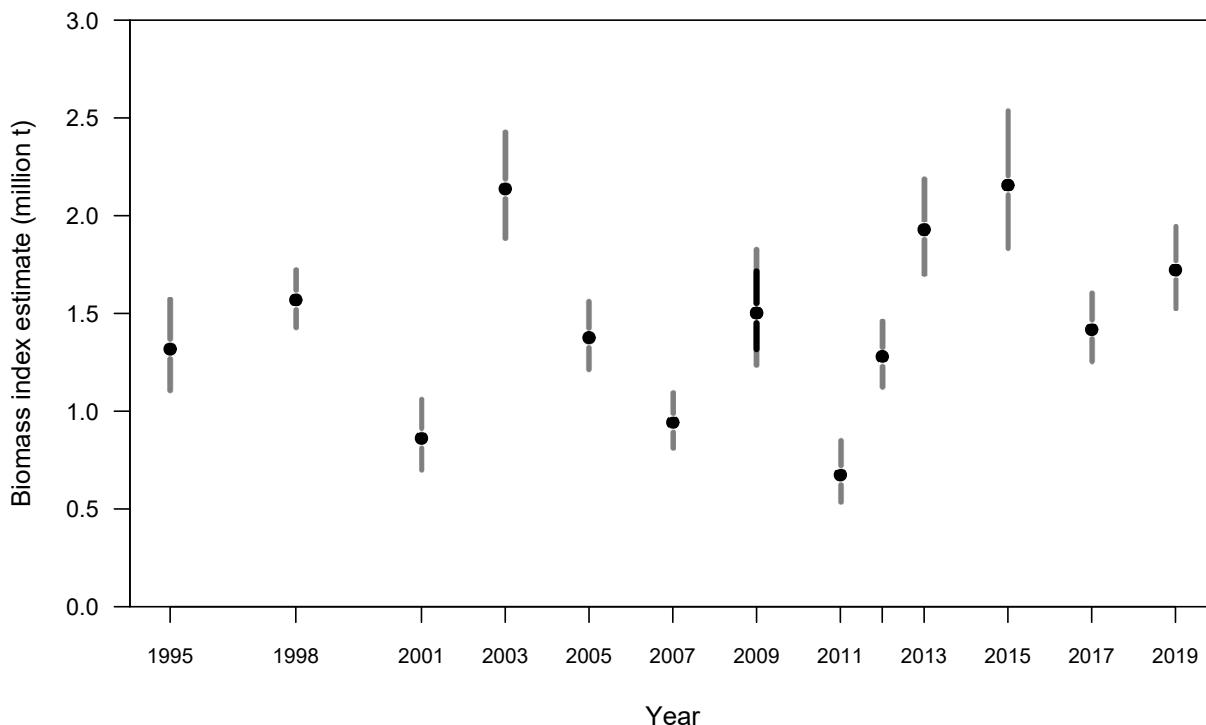
Figure b. Acoustic survey biomass indices (millions of tons). Approximate 95% confidence intervals are based on sampling variability (intervals without squid/hake apportionment uncertainty in 2009 are displayed in black). See Table 13 for values used in the base model.

indices, acoustic survey age-composition data, and fishery age-composition data. Integrating the joint posterior distribution over model parameters (via the Markov chain Monte Carlo algorithm) provides probabilistic inferences about uncertain model parameters and forecasts derived from those parameters. Sensitivity analyses are used to identify alternative 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.

This 2020 assessment retains most of the structural form of the base assessment model from 2019 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 parameterized with time-varying fishery selectivity led to higher median average catch, lower risk of falling below 10% of unfished biomass, smaller probability of fishery closures, and lower inter-annual variability in catch compared to assessment models parameterized with time-invariant fishery selectivity. Even a small degree of flexibility in the fishery selectivity could reduce the effects of errors caused by assuming selectivity is constant over time. There-
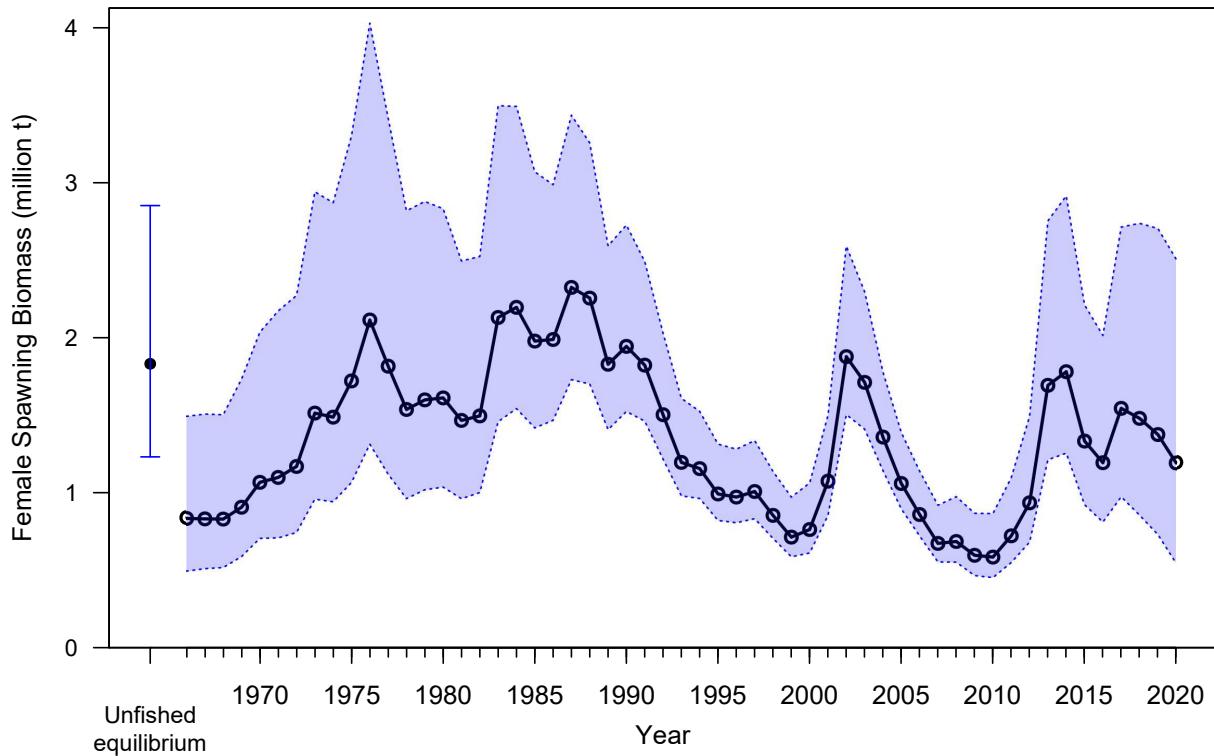
Figure c. Median of the posterior distribution for beginning of the year female spawning biomass (B_t in year t) through 2020 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

fore, we retain time-varying selectivity in this assessment. We retain the Dirichlet-Multinomial approach to weighting composition data and use a new prior for the corresponding parameters. We again provide sensitivities to alternative data-weighting approaches. Time-varying fecundity, which was introduced in 2019, was retained. The weight-at-age information for the forecast period was changed to be a representation of the last five years rather than all years to match the years used for other time-varying processes.

STOCK BIOMASS

Results from the base model indicate that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to above unfished equilibrium (Figures c and d). Model estimates suggest that it was below the unfished equilibrium in the 1960s, at the start of the assessment period, due to lower than average recruitment. The stock is estimated to have increased rapidly and was above unfished equilibrium in the mid-1970s and mid-1980s (after two large recruitments in the early 1980s). It then declined steadily to a low in 1999. This 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 0.591 million t in 2010. The assessment model estimates that median

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2020 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

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, increasing the biomass in 2017. The estimated biomass has declined since 2017, during a time of record catches.

The median estimate of the 2020 relative spawning biomass (spawning biomass at the start of 2020 divided by that at unfished equilibrium, B_0) is 65%. However, the uncertainty is large, with a 95% posterior credibility interval from 31% to 129% (Table b). The median estimate of the 2020 female spawning biomass is 1.196 million t (with a 95% posterior credibility interval from 0.550 to 2.508 million t). The estimate of the 2019 female spawning biomass is 1.379 (0.736–2.706) million t. This is a slightly higher median and narrower credibility interval than the 1.312 (0.471-3.601) million t estimated in the 2019 assessment.

RECRUITMENT

The new data available for this assessment do not significantly change the pattern of recruitment estimated in recent assessments. However, estimated recruitments for some years have changed.

Table b. Recent trends in estimated beginning of the year female spawning biomass (thousand t) and spawning biomass 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
2011	555.6	727.4	1,101.7	26.3%	40.1%	61.6%
2012	686.7	939.7	1,496.6	33.6%	51.6%	82.6%
2013	1,217.1	1,696.3	2,754.8	60.7%	93.6%	152.0%
2014	1,259.6	1,784.0	2,915.8	63.4%	98.5%	160.4%
2015	927.4	1,337.3	2,213.5	46.8%	73.9%	122.3%
2016	816.1	1,198.1	2,017.4	41.5%	66.0%	110.1%
2017	978.9	1,548.0	2,715.1	51.1%	85.2%	146.9%
2018	860.2	1,483.6	2,738.9	46.1%	81.2%	143.7%
2019	735.5	1,379.4	2,706.2	39.8%	75.6%	140.1%
2020	550.1	1,196.3	2,507.7	30.7%	65.0%	129.5%

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
2010	9,997.5	15,344.3	27,750.0	2.511	2.921	3.349
2011	162.5	432.2	955.0	-1.652	-0.687	0.049
2012	835.7	1,424.8	2,751.5	-0.057	0.485	1.002
2013	110.1	338.7	860.2	-2.101	-1.025	-0.196
2014	5,386.6	9,401.4	18,478.6	1.757	2.305	2.871
2015	10.8	62.9	281.1	-4.382	-2.671	-1.326
2016	2,178.4	4,550.5	10,016.1	0.908	1.590	2.287
2017	807.1	2,206.4	5,970.8	-0.106	0.864	1.752
2018	30.3	357.7	3,836.4	-3.318	-0.953	1.340
2019	57.7	924.4	16,936.9	-2.747	0.005	2.757
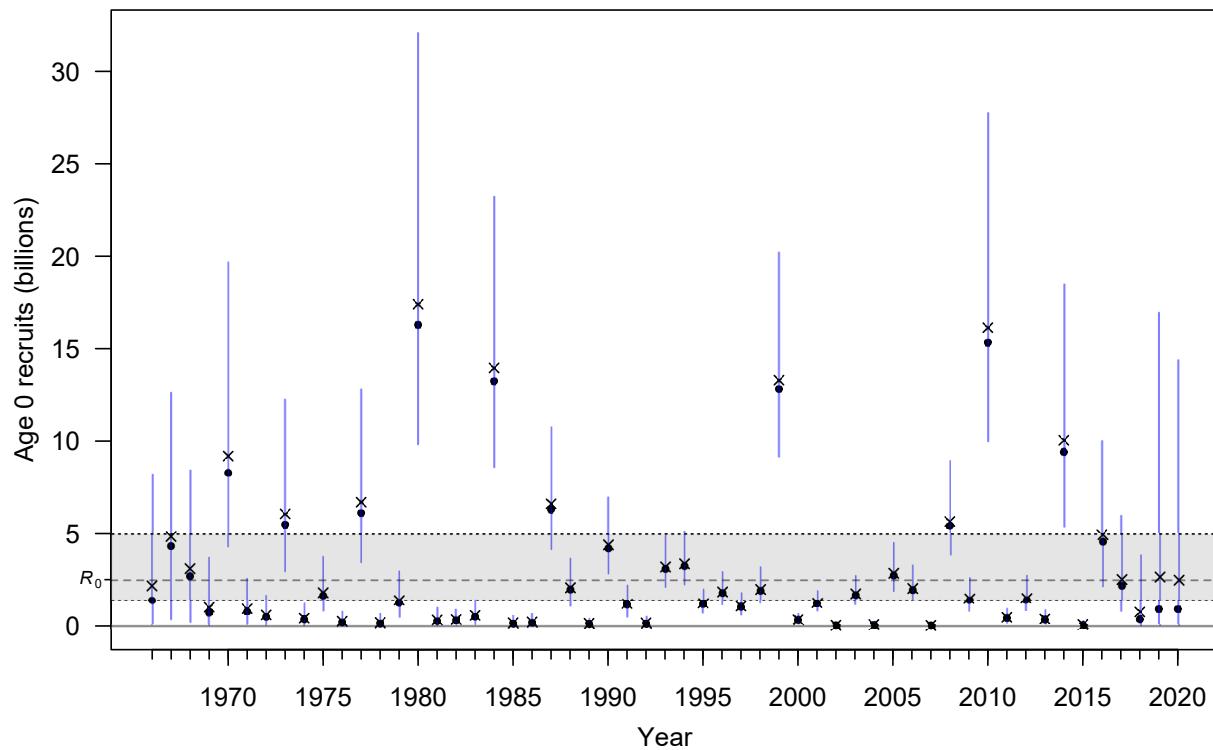
Figure e. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

For example, this assessment's median estimate of the 2010 recruitment is 1.8 billion more fish (a 13% increase) than last year's assessment. This difference is largely driven by the addition of the 2019 acoustic survey age compositions where the proportion of age-9 fish was higher than what the 2019 assessment model results would have otherwise suggested given mortality.

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 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, 23% of the 2018 catch, and 19% of the 2019 catch. The decline from 2014 to 2016 was due to the large influx of the 2014 year class (50% of the 2016 catch was age-2 fish from the 2014 year class; this was larger than the proportion of age-2 fish, 41%, from the 2010 year class in 2012). The median estimate of the 2010 year class is just below the highest ever (for 1980), with a 36% probability that the 2010 year class is larger than the 1980 year class (this probability was 18% for last year's assessment). The model currently estimates small 2011, 2013, 2015, and 2018 year classes (median recruitment well below the mean of all median recruitments).

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
2010	0.682	0.940	1.201	0.080	0.118	0.153
2011	0.625	0.890	1.165	0.109	0.167	0.218
2012	0.442	0.679	0.937	0.034	0.055	0.077
2013	0.428	0.652	0.862	0.046	0.075	0.104
2014	0.393	0.618	0.854	0.047	0.077	0.109
2015	0.276	0.472	0.706	0.035	0.058	0.084
2016	0.471	0.746	1.024	0.049	0.083	0.125
2017	0.494	0.782	1.136	0.076	0.133	0.212
2018	0.450	0.754	1.082	0.062	0.116	0.201
2019	0.454	0.764	1.093	0.057	0.115	0.218

The 2014 year class is likely larger than average but has only a 0.2% chance of being larger than the 2010 year class. There is no information in the data to estimate the sizes of the 2019 and 2020 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 model age-3 (observed at age-2).

DEFAULT HARVEST POLICY

The default $F_{\text{SPR}=40\%}$–40:10 harvest policy prescribes the maximum rate of fishing mortality to equal $F_{\text{SPR}=40\%}$. This rate gives a spawning potential ratio (SPR) of 40%, meaning that the spawning biomass per recruit with $F_{\text{SPR}=40\%}$ is 40% of that without fishing. If spawning biomass is below $B_{40\%}$ (40% of B_0), the policy reduces the TAC linearly until it equals zero at $B_{10\%}$ (10% of B_0). Relative fishing intensity for fishing rate F is $(1 - \text{SPR}(F))/(1 - \text{SPR}_{40\%})$, where $\text{SPR}_{40\%}$ is the target SPR of 40%; 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 slightly 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 since 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 94.0% in 2010 to 47.2% in 2015 before leveling off to 75-78% since 2016.
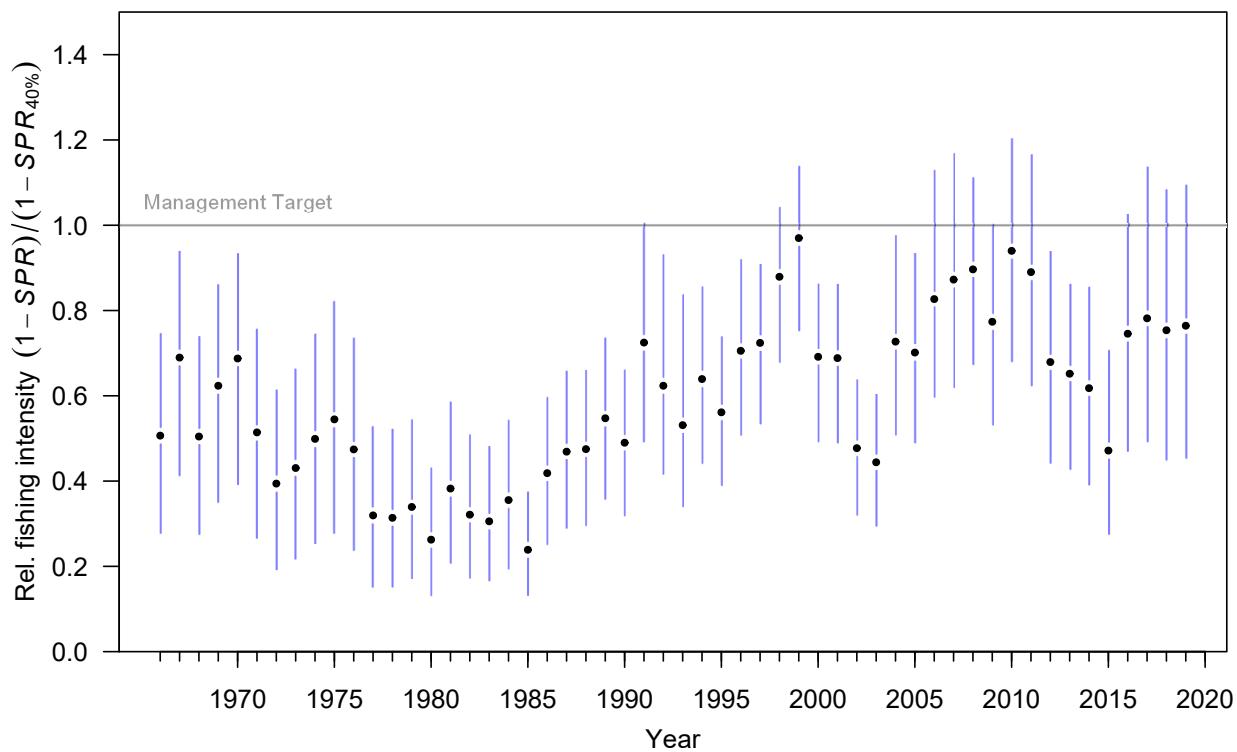
Figure f. Trend in median relative fishing intensity (relative to the SPR management target) through 2019 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

The exploitation fraction has increased from a recent low of 0.06 in 2012 to 0.13 in 2017 before slightly decreasing to 0.12 in 2018 and 2019. 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 2016–2019 (Figure f).

MANAGEMENT PERFORMANCE

Over the last decade (2010–2019), the mean coast-wide utilization rate (proportion of catch target removed) has been 71.3% (Table e). Over the last five years (2015 to 2019), the mean utilization rates were 68.6% for the United States and 53.1% 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 spawning biomass was above the $B_{40\%}$ reference point in all years except 1999 and 2007-2010 (Figure d).

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
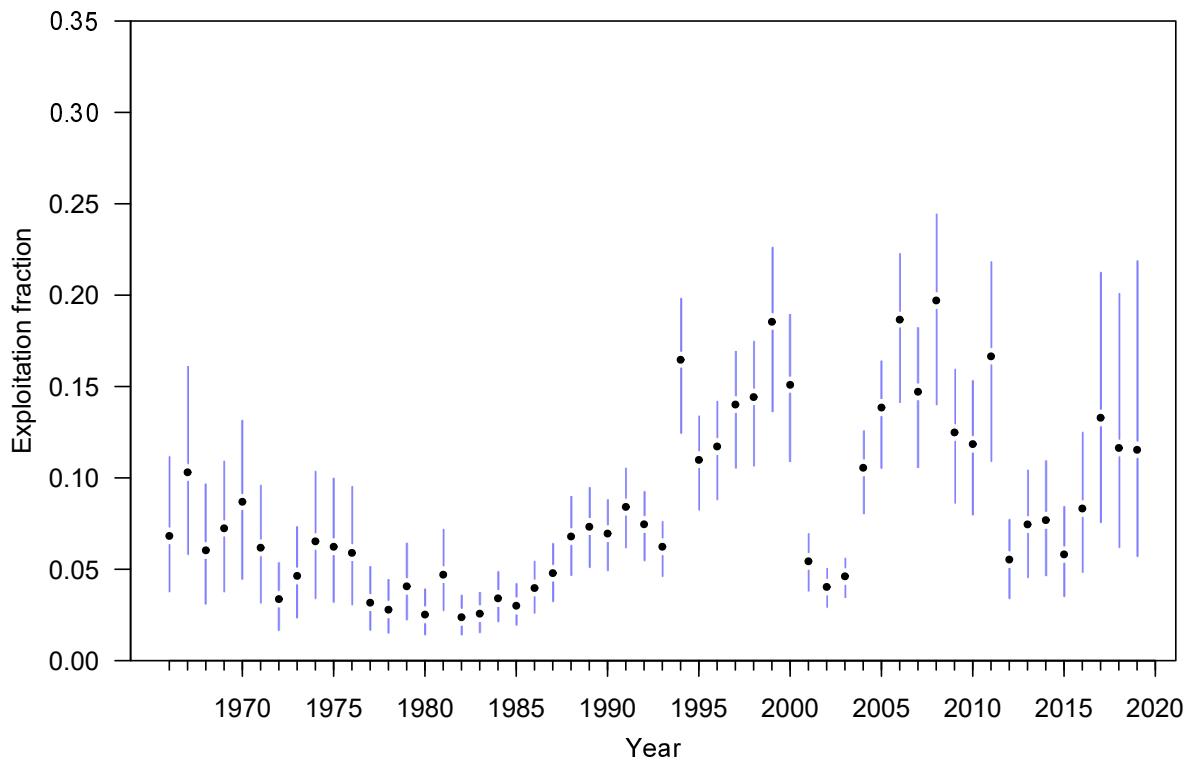
Figure g. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2019 with 95% posterior credibility intervals.

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

Year	U.S. landings (t)	Canada landings (t)	Total landings (t)	Coast-wide catch target (t)	U.S. catch target (t)	Canada catch target (t)	U.S. proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2010	171,043	57,016	228,059	262,500	193,935	68,565	88.2%	83.2%	86.9%
2011	231,261	56,073	287,334	393,751	290,903	102,848	79.5%	54.5%	73.0%
2012	160,144	47,059	207,203	251,809	186,036	65,773	86.1%	71.5%	82.3%
2013	233,578	52,249	285,828	365,112	269,745	95,367	86.6%	54.8%	78.3%
2014	264,141	35,118	299,259	428,000	316,206	111,794	83.5%	31.4%	69.9%
2015	154,160	39,684	193,844	440,000	325,072	114,928	47.4%	34.5%	44.1%
2016	262,327	69,743	332,070	497,500	367,553	129,947	71.4%	53.7%	66.7%
2017	354,229	86,721	440,950	597,500	441,433	156,067	80.2%	55.6%	73.8%
2018	318,306	95,413	413,719	597,500	441,433	156,067	72.1%	61.1%	69.2%
2019	317,003	94,280	411,283	597,500	441,433	156,067	71.8%	60.4%	68.8%

Figure h. Estimated historical path of median relative spawning biomass in year t and corresponding median relative fishing intensity in year $t-1$. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year t (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2020 relative spawning biomass (horizontal) and 2019 relative fishing intensity (vertical).

nature of the stock due to high variation in recruitment strength. While the target fishing mortality ($F_{\mathrm{SPR=40\%}}$) and $B_{40\%}$ result in different population sizes (see Table f), this difference is not, by far, the major driver of the observed dynamics. Between 2007 and 2010, median relative fishing intensity ranged from 77% to 94% and median relative spawning biomass between 0.33 and 0.38. 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 2011.

While there is large uncertainty in the estimates of relative fishing intensity and relative spawning biomass, the model estimates a 4.3% joint probability of being both above the target relative fishing intensity in 2019 and below the $B_{40\%}$ relative spawning biomass level at the start of 2020.

REFERENCE POINTS

Estimates of the 2020 base model reference points with posterior credibility intervals are in Table f. The medians of sustainable yields and biomass reference points are almost 10% lower than in the 2019 assessment. The probability that spawning biomass at the beginning of 2020 is below $B_{40\%}$ is $P(B_{2020} < B_{40\%}) = 9.9\%$, and of being below $B_{25\%}$ is $P(B_{2020} < B_{25\%}) = 0.6\%$. The probability that the relative fishing intensity was above its target of 1.0 at the end of 2019 was 8.4%.

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 1975–2019 averages for mean weight-at-age and 1966–2019 averages for selectivity-at-age.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (B_0, thousand t)	1,231	1,832	2,853
Unfished recruitment (R_0, millions)	1,403	2,505	4,961
Reference points (equilibrium) based on $F_{SPR=40\%}$			
Female spawning biomass at $F_{SPR=40\%}$ (thousand t)	397	656	1,025
SPR at $F_{SPR=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{SPR=40\%}$	16.0%	18.3%	20.9%
Yield associated with $F_{SPR=40\%}$ (thousand t)	176	308	544
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	492	733	1,141
SPR at $B_{40\%}$	40.6%	43.4%	50.6%
Exploitation fraction resulting in $B_{40\%}$	12.6%	16.2%	19.2%
Yield at $B_{40\%}$ (thousand t)	174	301	531
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	295	466	799
SPR at MSY	22.3%	29.4%	45.4%
Exploitation fraction corresponding to SPR at MSY	15.2%	25.8%	35.0%
MSY (thousand t)	182	325	585

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) and the scientific basis for prior probability distributions. To address such structural uncertainties, we performed sensitivity analyses to investigate a range of alternative assumptions using maximum likelihood estimation, and present the key ones in the main document. We also present full Bayesian analyses for a model that includes the age-1 survey index and a model that uses the new efficient No-U-Turn-Sampler (NUTS) within the R package `adnuts`.

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 $B_{10\%}$, 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 intensive sampling, which may not be the case for the existing age-1 index.

This is why the estimates are included in a sensitivity run rather than the base model.

The Pacific Hake stock displays high recruitment variability relative to other west coast groundfish stocks, resulting in large and rapid biomass changes. This leads to a dynamic fishery that potentially targets strong cohorts and results 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 they are (i.e., cohort strength is not well known until it is has been observed by the fishery and survey, typically at minimum age-3).

FORECAST DECISION TABLES

The catch limit for 2020 based on the default $F_{\mathrm{SPR}=40\%}$–40:10 harvest policy has a median of 666,458 t with a wide range of uncertainty, the 95% credibility interval being 258,675–1,588,947 t.

Decision tables give the projected population status (relative spawning biomass) and fishing intensity relative to the target under different catch alternatives for the base model (Tables g and h). The tables are organized such that the projected outcome for each potential catch level and year (each row) can be evaluated across the quantiles (columns) of the posterior distribution. Figure i shows the projected biomass for several catch alternatives. Population dynamics and governing parameters assumed during the forecast period include average recruitment (no recruitment deviation); selectivity, weight-at-age and fecundity averaged over the five most recent years (2015–2019); and all other parameters as constant.

A relative fishing intensity above 1 (or 100% when shown as a percentage) indicates fishing greater than the $F_{\mathrm{SPR}=40\%}$ default harvest rate catch target. This can happen for the median relative fishing intensity in projected years because the $F_{\mathrm{SPR}=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of fishing in excess of the default harvest policy. Alternative catch levels where median relative fishing intensity is 100% for three years of projections are provided for comparison (scenario g: FI=100%).

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 2019 (row d) and the TAC from 2019 (row f), catch values that result in a median relative fishing intensity of 100% (row g), median catch 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 2020 and 2021 (row i). Catch in 2022 does not impact the beginning of the year biomass in 2022.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2020	0	35%	51%	65%	83%	116%
	2021	0	34%	48%	62%	79%	111%
	2022	0	33%	48%	62%	80%	125%
b:	2020	180,000	35%	51%	65%	83%	116%
	2021	180,000	30%	44%	58%	74%	106%
	2022	180,000	26%	40%	53%	71%	116%
c:	2020	350,000	35%	51%	65%	83%	116%
	2021	350,000	26%	40%	53%	70%	101%
	2022	350,000	18%	32%	45%	63%	107%
d:	2020	410,000	35%	51%	65%	83%	116%
2019	2021	410,000	24%	38%	52%	69%	99%
catch	2022	410,000	15%	29%	42%	60%	104%
e:	2020	500,000	35%	51%	65%	83%	116%
	2021	500,000	22%	36%	50%	66%	97%
	2022	500,000	11%	25%	38%	56%	100%
f:	2020	597,500	35%	51%	65%	83%	116%
2019	2021	597,500	20%	34%	47%	64%	94%
TAC	2022	597,500	9%	21%	34%	52%	95%
g:	2020	558,094	35%	51%	65%	83%	116%
FI=	2021	438,261	21%	35%	48%	65%	95%
100%	2022	361,901	11%	26%	39%	56%	100%
h:	2020	666,458	35%	51%	65%	83%	116%
default	2021	484,844	18%	32%	46%	62%	92%
HR	2022	387,238	9%	22%	35%	53%	96%
i:	2020	523,713	35%	51%	65%	83%	116%
C2020=	2021	523,714	22%	36%	49%	66%	96%
C2021	2022	411,472	10%	24%	37%	55%	99%

Table h. Forecast quantiles of Pacific Hake relative fishing intensity $(1\text{-SPR})/(1\text{-SPR}_{40\%})$, expressed as a percentage, for the 2020–2022 catch alternatives presented in Table g. Values greater than 100% indicate relative fishing intensities greater than the $F_{\text{SPR}=40\%}$ harvest policy calculated using baseline selectivity.

| Within model quantile			5%	25%	50%	75%	95%
Management Action			Relative fishing intensity				
	Year	Catch (t)					
a:	2020	0	0%	0%	0%	0%	0%
	2021	0	0%	0%	0%	0%	0%
	2022	0	0%	0%	0%	0%	0%
b:	2020	180,000	30%	42%	52%	63%	82%
	2021	180,000	31%	44%	55%	67%	88%
	2022	180,000	30%	45%	57%	70%	93%
c:	2020	350,000	50%	67%	79%	91%	112%
	2021	350,000	53%	71%	86%	100%	123%
	2022	350,000	53%	75%	92%	108%	135%
d:	2020	410,000	56%	73%	86%	98%	118%
2019	2021	410,000	59%	79%	94%	109%	132%
catch	2022	410,000	60%	83%	101%	118%	143%
e:	2020	500,000	64%	82%	95%	107%	127%
	2021	500,000	68%	89%	105%	120%	141%
	2022	500,000	69%	95%	114%	132%	147%
f:	2020	597,500	71%	90%	103%	115%	134%
2019	2021	597,500	76%	98%	114%	129%	145%
TAC	2022	597,500	79%	106%	125%	140%	148%
g:	2020	558,094	68%	87%	100%	112%	131%
FI=	2021	438,261	63%	84%	100%	116%	139%
100%	2022	361,901	56%	81%	100%	119%	144%
h:	2020	666,458	76%	95%	108%	120%	138%
default	2021	484,844	68%	90%	107%	123%	144%
HR	2022	387,238	60%	86%	107%	127%	146%
i:	2020	523,713	66%	84%	97%	109%	129%
C2020=	2021	523,714	70%	91%	107%	122%	143%
C2021	2022	411,472	62%	87%	107%	126%	146%

Figure i. Time series of estimated relative spawning biomass to 2020 from the base model, and forecast trajectories to 2022 (grey region) for several management actions defined in Table g, with 95% posterior credibility intervals.

Management metrics that were identified as important to the JMC and the Advisory Panel (AP) in 2012 are presented for 2021 and 2022 projections (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 in 2020 (Table i and Figure j). However, interpolation is not appropriate for all catches in 2021 because catch alternatives g and h have catches that are larger than 500,000 t (the constant catch for alternative e) in 2020 but smaller than 500,000 t in 2021 (Table h); this explains why a few probabilities decline (rather than rise) with increased 2021 catch levels in Table j and Figure k.

Figure i shows the predicted relative spawning biomass trajectory through 2022 for several of the management actions. With zero catch for the next two years, the biomass has a 81% probability of decreasing from 2020 to 2021 (Table i) and a 63% probability of decreasing from 2021 to 2022 (Table j).

The probability of the spawning biomass decreasing from 2020 to 2021 is over 80% for all catch levels, including zero (Table i and Figure j). It is 95% for the 2020 catch level similar to that for 2019 (catch alternative d). For all explored catches, the maximum probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2021 is 1%, and of dropping below $B_{40\%}$ is 40% (Table i and Figure j). As the large 2010 and 2014 cohorts continue to age, their biomass is
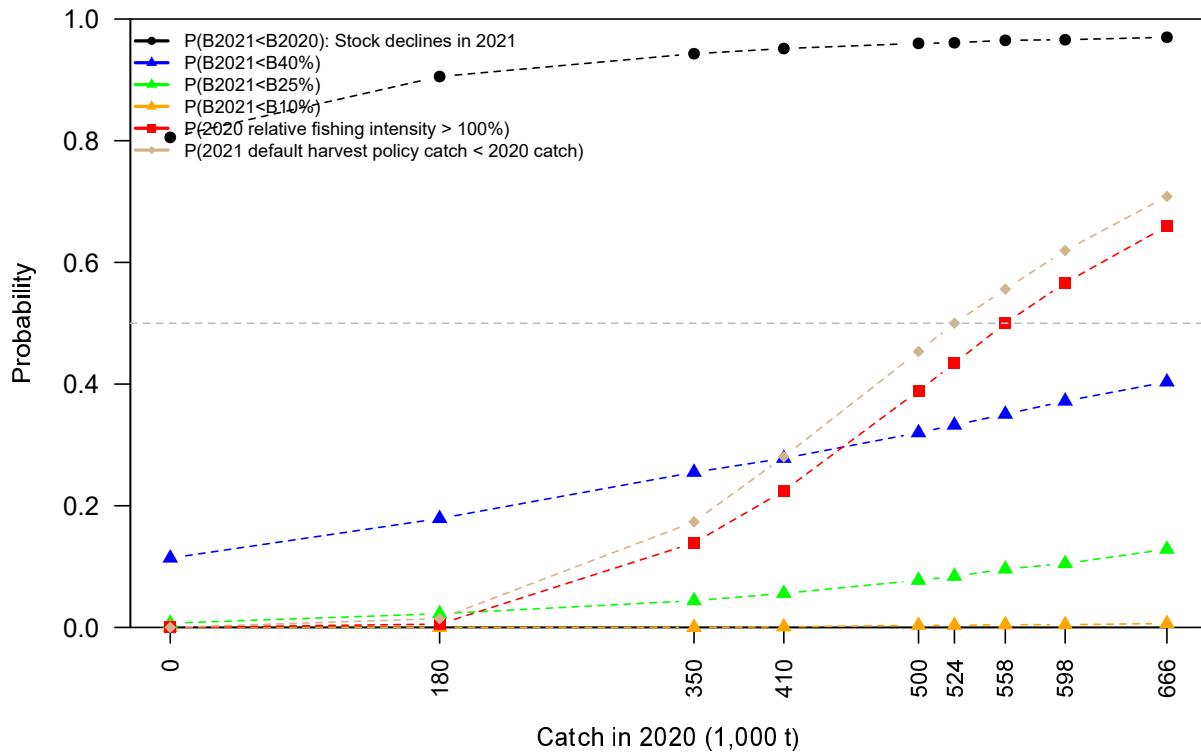
Figure j. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (explained in Table g) as listed in Table i. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table i. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 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	81%	11%	1%	0%	0%	0%
b: 180,000	91%	18%	2%	0%	1%	1%
c: 350,000	94%	26%	4%	0%	14%	17%
d: 410,000	95%	28%	6%	0%	22%	28%
e: 500,000	96%	32%	8%	0%	39%	45%
f: 597,500	97%	37%	10%	0%	57%	62%
g: 558,094	96%	35%	10%	0%	50%	56%
h: 666,458	97%	40%	13%	1%	66%	71%
i: 523,713	96%	33%	8%	0%	43%	50%

Figure k. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (including associated 2020 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 2022 default harvest policy catch for alternative 2021 catch options, given the 2020 catch level shown in Table i (catch options explained in Table g).

Catch in 2021	Probability $B_{2022}<B_{2021}$	Probability $B_{2022}<B_{40\%}$	Probability $B_{2022}<B_{25\%}$	Probability $B_{2022}<B_{10\%}$	Probability 2021 relative fishing intensity >100%	Probability 2022 default harvest policy catch <2021 catch
a: 0	63%	12%	1%	0%	0%	0%
b: 180,000	75%	25%	5%	0%	1%	2%
c: 350,000	82%	40%	12%	1%	25%	27%
d: 410,000	83%	46%	17%	2%	39%	40%
e: 500,000	86%	53%	24%	4%	58%	59%
f: 597,500	87%	60%	33%	7%	72%	74%
g: 438,261	84%	52%	24%	4%	50%	51%
h: 484,844	84%	58%	31%	7%	61%	62%
i: 523,714	86%	54%	27%	5%	62%	63%

expected to decrease as losses from mortality outweigh increases from growth, while the smaller but above-average 2016 cohort will add to overall spawning biomass as it matures.

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 links 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. Related, there is a need to streamline the availability of products from oceanographic models (e.g., Regional Ocean Modeling System; ROMS) so that they can be used on a reoccurring basis as informative links in operational stock assessments.

2. Use and build upon the existing MSE framework 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 interested parties into further development of operating and/or estimation models, through the Pacific Hake MSE Working Group.

3. Continue to 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 (or related) 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 Northwest Fisheries Science Center and from Fisheries and Oceans Canada 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 transparent and repeatable 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 ninth 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) that consists 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 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 2020 base model, implemented using version 3.30.14.08 of the Stock Synthesis software (Methot and Wetzel, 2013), are largely the same as the 2019 base model (Berger et al., 2019), though we incorporate the following three changes. First, instead of using prescribed constant values, a nearly uniform prior (in transformed space) was applied to the Dirichlet-Multinomial parameters used to weight the age-composition data. Second, we removed the constraint that estimated recruitment deviations should sum to zero. Lastly, weight-at-age data for the forecast period was calculated using the average of the five most recent years rather than all years. Responses to 2019 SRG requests are in Section 3.3 and a Glossary of terms appears in Appendix C.

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 Ocean due to their relatively large total biomass and potentially large role as both prey and predator. 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 abi-

otic (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. In terms of an 'Ecosystem Approach to Fisheries Management' (a new priority for DFO), the use of empirical weight-at-age somewhat accounts for ecosystem effects (see Section 2.3.3).

1.3 MANAGEMENT OF PACIFIC HAKE

Since the 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 countries' 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 112% of the limit. The Agreement between the U.S. and Canada establishes U.S. and Canadian shares of the coast-wide total allowable catch (TAC) 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%, to zero catch at relative spawning biomass values of 10% or less (called the default harvest policy in the Agreement); relative spawning biomass is the female spawning biomass divided by that at unfished equilibrium. 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 risk averse in years when very large quotas were determined using the default 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 (*Oncorhynchus tshawytscha*) and several depleted rockfish stocks (though all but one of the 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) components. 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 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, 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 (MS) fleet has also formed a cooperative 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 TAC as quota to individual license holders. In 2019, Canadian hake fishermen were allocated a TAC of 156,067 t, including 20,824 t of uncaught carryover fish from 2018. 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. The last year a Joint-Venture fishery was conducted was in 2018.

In 2019, 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).

The Pacific Hake stock is of huge commercial value. For example, in Canada alone over CA\$26 million in wages was estimated to have been paid to employees of the processing industry in 2018, with an exported value of CA\$100 million mainly to Ukraine, China, South Africa and Lithuania (DFO Groundfish Pacific Region 2020 Integrated Fisheries Management Plan summary, in prep., to be available at http://www.pac.dfo-mpo.gc.ca/fm-gp/ifmp-eng.html).

1.4.1 Overview of the fisheries in 2019

The Joint Management Committee (JMC) determined an adjusted (for carryovers) coast-wide TAC of 597,500 t for 2019, 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 1966–2019 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 2019 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 2019 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 13 resulted in final quotas for the CP, MS, and shore-based sectors of 136,912 t, 96,644 t, and 169,126 t, respectively.

The midwater fishery for Pacific Hake began on May 15 for the shore-based 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 shore-based 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 2018, but was the third highest value ever recorded (Table 1). Monthly catch rates were similar to those calculated for 2018, except for September which was considerably higher in 2019 compared to 2018 (Figure 5). Tribal landings available at the time of the assessment were 4,192 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%, 54.5%, and 87.6% of their final reallocated quotas, respectively. Overall, 124,430 t (28.2%) of the total U.S. adjusted TAC was not caught. For further details see the report from the U.S. Advisory Panel (Appendix E).

In both U.S. at-sea sectors (CP and MS) the most common cohorts in the fishery were age-9, age-5, and age-3 fish associated with the 2010, 2014, and 2016 year-classes. Age-2 fish were more present in the catch this year than in 2018. Sampling by sector varied with 494 and 286 sampled hauls from each sector, respectively (Table 5). For the CP sector, the four most abundant age classes (by numbers) seen in 2019 were age-5 (39.0%), age-3 (25.0%), age-9 (17.4%), and age-2 (6.8%; Table 6). For the MS sector, the four most abundant age classes for 2019 were age-5 (36.5%), age-3 (20.4%), age-9 (16.5%), and age-2 (15.2%; Table 7). Age-samples from 92 shoreside trips showed a similar proportional abundances for age-5 (30.8%), age-3 (22.0%), age-2 (17.2%), and age-9 (16.7%) in 2019 (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, the spring fisheries saw a decline in catch rates, whereas catch rates were higher in September and October. The median fishing depth for the at-sea fleets was slightly shallower than last year, which was shallower than previous years (Figure 6). From mid-June to September/October, operators in the at-sea fishery moved to their usual summer fishing grounds where they experienced slower than normal fishing of Bering Sea Walleye Pollock. The shore-based fishery had the largest monthly catches during July, August, and September. The U.S. utilization rate (71.8%) continued to be maintained close to what it has been in recent years because of high catch rates, despite vessels needing to implement bycatch-avoidance measures (see Appendix E for more details).

Canada

The 2019 Canadian Pacific Hake domestic fishery removed 94,280 t from Canadian waters, which was 60.4% of the Canadian TAC of 156,067 t.

The shoreside component, made up of vessels landing fresh round product onshore, landed 50,330 t. The freezer trawler component, which freezes headed and gutted product while at sea, landed 43,950 t. There was no Joint-Venture fishery this year.

Fishing started in February and ended in early December. This year most of the fish were caught in the deep water 'scuzz' layer as opposed to the usual large aggregations. Fish migration appeared normal with early fishing in the South and moving northward throughout the season. The deeper 'scuzz' fishing resulted in higher than normal bycatch of Rougheye and Bocaccio rockfish. Small fish (aged 2-3 years) were found over the whole fishing season in the North, around Queen Charlotte Sounds and Milbank Sound.

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.

The most abundant year classes (by numbers) in the Canadian Freezer trawler catch were age 9 at 23.4%, age 5 at 19.0%, age 2 at 17.1%, and age 3 at 15.6%.

The most abundant year classes in the Canadian Shoreside catch were age 5 at 28.7%, age 9 at 25.8%, age 2 at 14.3%, and age 3 at 11.6%.

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.

For further details see the report from the Canadian Advisory Panel (Appendix D).

2 DATA

Fishery-dependent and fishery-independent data sources used in this assessment (Figure 8) include:

- Total catch from all U.S. and Canadian target fisheries (1966–2019; Tables 1–3).

- Age compositions composed of data from the U.S. fishery (1975–2019) and the Canadian fishery (1990–2019). 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, 2017, and 2019; Tables 12 and 13).

- Mean observed weight-at-age from fishery and survey catches (1975-2019; Figure 13) 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 12).

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

- Fishery and acoustic survey length compositions.

- Fishery and acoustic survey age-at-length compositions.

- 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 1977–2019).

- NWFSC/Southwest Fisheries Science Center/PWCC coast-wide juvenile hake and rockfish surveys (2001–2019).

- 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.

- California Cooperative Oceanic Fisheries Investigations (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 this index has not been revisited since the 2008 stock assessment.

- 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 1966–2019 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 information 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 U.S. domestic at-sea catches for 1991–2019 are calculated from the Alaska Fisheries Science Center (AFSC) North Pacific Groundfish and Halibut Observer (NOR-PAC) 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 Canadian shore-based landings are from the Groundfish Catch (GFCatch) database (from 1989 to 1995), the Pacific Harvest Trawl (PacHarvTrawl) database (from 1996 to March 31 2007), and the Fisheries Operations System (FOS) database (from April 1 2007 to present). 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. Canadian 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.

Minor updates to catches for years pre-2019 were made based on the best available information extracted from the aforementioned databases. Catches not yet entered in PacFIN for the U.S. tribal fishery were added to the extracted number based on information provided by the Makah tribe. With the movement towards digital fish tickets for reporting tribal catches, this should be the last year that catches used in the assessment do not match those extracted from PacFIN. Additional, historical Canadian Joint-Venture catches, which were inadvertently removed from the data used to fit the model in the 2019 assessment, were replaced to match what was used previously.

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 1991–2019. 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 1991–2019 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 (46.6% in 2019). The Joint-Venture fishery also has 100% observer coverage on their processing vessels. 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. Sample weight must be inferred from a length-weight relationship applied to all lengths taken and summed over each haul because the weight of the sample from which biological information is taken is not recorded.

The sampling unit for the shore-based fisheries is the trip, while the haul is the primary unit for the at-sea fisheries. There is no least common denominator for aggregating at-sea and shore-based fishery samples because detailed haul-level information is not recorded for trips in the shore-based fishery and hauls sampled in the at-sea fishery cannot be aggregated to a comparable trip level. 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 earlier stock assessment documents (Hicks et al., 2013; Taylor et al., 2014).

The aggregate fishery age-composition data (1975–2019) confirm the well-known pattern of very large cohorts born in 1980, 1984, and 1999 (Table 11 and Figure 9). 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 (Table 11 and Figure 9). Since 2016, substantial proportions of the catch have come from the 2010 and 2014 (Tables 6–11 and Figure 9). Currently, the 2014 cohort is the largest cohort in all three U.S. fleets (Tables 6–8) and the Canadian shoreside fleet (Table 9), while the 2010 cohort is largest in Canadian freezer-trawler fleet (Table 10). The Canadian fleets also landed a higher than normal proportion of age-2 fish this year. Table 11 shows the combined age proportions of all fleets, U.S. and Canadian. For the combined data in 2018, the 2014 cohort was the largest (27%), followed by the 2016 cohort (26%), followed by the 2010 cohort (23%). In 2019, the 2014 cohort was the largest (32%), followed by the 2016 cohort (21%), followed by the 2010 cohort (19%).

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 persisted in small proportions for years in the fishery catch, although were much reduced starting in 2011 due to mortality and the overwhelming size of the more recent large 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 has been apparent since 2017.

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 the 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 U.S. 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, 2017 and 2019 were used in this assessment (Table 13). The acoustic survey samples transects that represent 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 it is only included in a sensitivity analysis.

A survey was completed in 2019 that covered U.S. and Canadian waters from the Point Conception to north of Haida Gwaii using 113 transects (Figure 2). On average, U.S. transects were separated by 10 nmi, while Canadian transects were separated by 20 nmi. The NOAA ship Bell M. Shimada completed the U.S. portion of the survey and met with the F/V Nordic Pearl off the southern end of Vancouver Island before the Nordic Pearl completed the Canadian portion. Four saildrones (Saildrone, Inc) accompanied the Shimada in U.S. waters during the survey, attempting to remain within $\pm$ 3-5 days of the Shimada on any given transect.

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. El Niño conditions decreased in their prevalence starting in March 2019, leading to neutral conditions by July. The 2019 survey saw Pacific Hake on all survey transects from just north of Morro Bay, California to the northern end of Vancouver Island, with the greatest offshore extent of hake found off of Cape Mendocino. 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 are post-stratified, based on similarity in size composition, and the composite length frequency is 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 TS is not explicitly accounted for in the assessment.

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

For the 2016 assessment (Grandin et al., 2016), the data from all surveys since 1998 were scrutinized and reanalyzed using consistent assumptions, an updated version of the EchoPro software, and a common input-file structure because some previously generated files had spurious off-transect zeros because of how the data were exported. The same analytical procedure was carried out during the reanalysis of 1995 survey data (Berger et al., 2017) and during the preparation of survey data collected since 2017. The assumptions are as follows:

- 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; and

- biomass decays with distance from the end of the transect when extrapolating biomass beyond the end of a transect.

Thus, a full time-series of consistently analyzed survey biomass (Table 13 and Figure 10) and age compositions (Table 12 and Figure 9) since 1995 are being input into the assessment model. Current and historical values were verified with the survey analysts in 2019 to ensure that the final results from the re-analyses matched input values, which led to a few minor changes in historical values.

Results from research done in 2010 and 2014 on the 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 (Table 13 and Figure 10). It decreased in 2017 to 1.42 million t and then increased to 1.72 million t in 2019. The 2019 survey age composition was made up of 16.1% age-9 fish from the 2010 year-class, 31.3% age-5 fish from the 2014 year-class, 27.2% age-3 fish from the 2016 year class, and 10.7% age-2 fish from the 2017 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 (Hicks et al., 2013) and was explored as a sensitivity (see Appendix G). It is currently not included in the base model because more investigations are needed regarding how to best model the data, the implications of its inclusion are not fully understood, the uncertainty of each estimate is unknown, and the survey is not specifically designed to representatively survey age-1 hake. However, the estimates track the estimated recruitment reasonably well (Figure 11).

2.2.2 Other fishery-independent data

Fishery-independent data from the AFSC bottom trawl survey, the 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 fecundity relationship data 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 12) was developed using histological estimates of functional maturity from 1,947 ovaries that were associated with age estimates. These samples were collected from the acoustic survey, winter and summer acoustic research trips, from the U.S. At-Sea Hake Observer Program observers aboard commercial Catcher-Processor vessels, and from the U.S. West Coast bottom trawl survey (Table 15). Samples from south of Point Conception, California (34.44°N) were excluded from this analysis because they were thought to mature at earlier ages and smaller sizes (see Berger et al. 2019 for more information). We retained the maturity ogive calculated by Edwards et al. (2018*b*), though note that the ogive used for earlier assessments was not updated annually from that developed by Dorn and Saunders (1997).

Time-varying fecundity-at-age was modeled using year-specific weight-at-age values in the calculation of fecundity (Berger et al., 2019). Samples from ages 15 and above were pooled for both the maturity and weight-at-age estimation due to limited sample sizes. Consequently, the age 15+ estimates were applied to ages 15-20 for purposes of modeling the population dynamics (Figure 12).

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

Tissue samples for genetic analyses have been collected from many of the same fish from which ovaries were sampled – this may help determine whether the fish south of 34.44°N are from the same stock as the rest of the coastal 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 west coast stock assessments have utilized the cross- and double-reads approach to generate an ageing-error matrix 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 results were analyzed via an optimization routine to estimate both ageing error and cohort effect. The resultant ageing error was similar to the ageing error derived from the 2008 analysis. Since 2011, cohort-specific ageing error has been used to reduce the ageing-error standard deviation 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 year classes that a reduction has not been included for the 2008 year class in any assessment since then. 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 13) 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 2019 (Figure 13). Past investigations into calculating weight-at-age for the fishery and survey independently showed little impact on model results. Pre-1975 weight-at-age data available in the PacFIN database that were discovered during the 2018 assessment-review process were quickly confirmed to be samples collected within Puget Sound and have not been included in any assessment. 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. The number of samples (Figure 14) 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.

Prior to 1975, weight-at-age is assumed to be equal to the mean across all years with data (1975-2019), consistent with the 2019 base model. For the forecast years, in 2019 we noted that Stock Synthesis did not have the desired settings to properly use the mean across recent years (Berger et al., 2019). For the 2019 base model we therefore used the long-term mean weight-at-age (the

mean from 1975–2018). In the 2019 sensitivity run 54 we used the mean across the most recent three years (2016–2018), but Stock Synthesis required also setting the 2018 weight-at-age to be the mean of 2016–2018; this run 54 yielded similar results to the base model. Stock Synthesis no longer has this anomalous requirement, so for the current assessment we use the recent mean for the forecasts and the correct data for the most recent year (2019). For the current assessment, both forecast weight-at-age data and forecast selectivity are based on the respective means from the most recent five years (2015–2019), for consistency.

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.

The temporal changes in weight-at-age may be due to ecosystem effects such as prey availability, predator abundance and ocean temperature. Thus, while not explicitly parameterized in the assessment, such ecosystem effects are somewhat implicitly accounted for, especially compared to assuming time-invariant weight-at-age.

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 2006-2010 assessments that attempted to estimate the parameters describing a parametric growth curve, strong patterns were 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 Pacific Hake. The lack of success 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 modeling weight-at-age used since 2011 and described above, which models this variability implicitly.

2.4 ESTIMATED PARAMETERS AND PRIOR PROBABILITY DISTRIBUTIONS

The prior probability distributions and estimated parameters used in this stock assessment are reported in Tables 16 and 27. 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 and described by Edwards et al. (2018b) in detail.

For each age $a \geq A_{\min}$, where $A_{\min}$ is the minimum age for which selectivity is allowed to be non-zero, there is an incremental selectivity parameter, p_a, for the fishery (for which $A_{\min} = 1$). There is also an equivalent p_a for the survey (for which $A_{\min} = 2$), but to keep the notation simple we do not distinguish between 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, Φ, associated with these deviations has been fixed at 1.4 since the 2018 assessment (see Edwards et al. 2018*b* for justification). It is calculated using

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

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

$$-\log(\mathrm{L}) \propto \frac{1}{2} \sum_{a=A_{\min}}^{6} \sum_{y=1991}^{2019} \frac{\varepsilon_{ay}^2}{\Phi^2}, \tag{5}$$

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 and 2019, 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

Since 2018 the assessment has used a Dirichlet-Multinomial (D-M) likelihood (Thorson et al., 2017) to fit the age-composition data. Estimated parameters θ_{fish} and θ_{surv} serve to automatically adjust the weight given to the fishery-composition data (using θ_{fish}) and the survey-composition data (using θ_{surv}). Both priors for θ_{fish} and θ_{surv} are a normal distribution with a mean of 0 and standard deviation of 1.813. In the 2019 assessment, uniform priors were used, but $\log \theta_{\mathrm{surv}}$ had to be set to its MLE value (see below).

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 are 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

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

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

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

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.

In the 2019 assessment we used a uniform prior between -5 and 20 for θ_{fish} and θ_{surv}. The parameter θ_{fish} was well sampled by the MCMC algorithm. However, $\log\theta_{\mathrm{surv}}$ was not being sampled efficiently due to many samples occurring in a part of the parameter space where the effective sample size multiplier, $\theta_{\mathrm{surv}}/(1+\theta_{\mathrm{surv}})$, was between 0.99 and 1.0 (Berger et al., 2019). In that area, the input sample sizes were given full weight and the likelihood surface was almost completely flat with respect to $\log\theta_{\mathrm{surv}}$, and so to improve MCMC convergence $\log\theta_{\mathrm{surv}}$ was fixed at the MLE estimate of 2.44, corresponding to a weight of $\theta_{\mathrm{surv}}/(1+\theta_{\mathrm{surv}}) = 0.92$.

To enable estimation of θ_{surv}, James Thorson (NOAA, pers. comm.) suggested that a prior on $\log\theta_{\mathrm{surv}}$ could be associated with an approximately uniform prior of the weight $\theta_{\mathrm{surv}}/(1+\theta_{\mathrm{surv}})$. Ian Taylor (NOAA, pers. comm.) used a uniform prior between 0 and 1 to determine that a normal prior on $\log\theta_{\mathrm{surv}}$ with mean 0 and standard deviation 1.813 is suitable. We use this prior for both $\log\theta_{\mathrm{fish}}$ and $\log\theta_{\mathrm{surv}}$.

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 iterative (unlike the D-M method which estimates the weights), 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 National Marine Fisheries Service (NMFS) triennial acoustic survey estimates of absolute abundance at age (Hollowed et al., 1988). Since 1989, Stock Synthesis models using fishery catch-at-age data and acoustic survey estimates of population biomass and age composition have been the primary assessment method (Berger et al., 2019).

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).

Data processing, choices, and weighting have been modified several times in historical hake assessments. For example, the processing of acoustic data 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). The process for generating fecundity-at-age from weight-at-age data changed in 2019 from using time-invariant to year-specific values. 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 the assessment models has perhaps had the largest number of changes. In terms of spatial models, analysts have considered spatially explicit forms (Dorn, 1994, 1997), spatially

implicit forms (Helser et al., 2006), and single-area models (Stewart et al., 2012). Predicted recruitment has been modeled by sampling historical recruitment (e.g., Dorn 1994; Helser et al. 2005), using a stock-recruitment relationship parameterized using maximum sustainable yield (MSY) and the fishing mortality rate 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 C). 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 2020 base model is predominantly an update of the base model in the 2019 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 3.30.14.08 was used. The largest changes between the 2019 and 2020 stock assessments are the addition of another year of acoustic survey and fishery data, the use of just five recent years (rather than all years) of weight-at-age data to calculate fecundity-at-age in the forecast period, and the following two structural changes: (1) a nearly

uniform prior (in transformed space) was placed on the Dirichlet-Multinomial parameters used to weight the age-composition data; and (2) estimated recruitment deviations were no longer constrained to sum to zero.

The 2020 base model includes an acoustic data time series from 1995 to 2019. Maturity is assumed to be time-invariant and the maturity ogive updated in 2018 was retained (see Section 2.3.1). 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– 2019; see Section 2.3.3). 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 2020 base model with the magnitude of the allowable deviations unchanged from the 2019 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 selectivity of the acoustic survey 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 are used for a select few parameters 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., 2018b). Year-specific recruitment deviations were estimated from 1966–2018 as well as the years 2020, 2021, and 2022 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 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 2019 (Table 18). Survey catchability was set at the median unbiased estimate calculated analytically as per Ludwig and Walters (1981).

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).

Uncertainty of estimated quantities was calculated around the median results (50% quantile) 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 base model are given in Appendices I-M.

Calculations and figures from Stock Synthesis output were performed using R version 3.6.2 (2019-12-12) (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) allows for the completion of a full assessment in the limited time available. A recent DFO workshop (Edwards et al., 2018a) shared such a 'transparent, traceable, and transferable' workflow with a wider audience, partly motivated by our ongoing Pacific Hake assessments.

3.3   RESPONSE TO 2019 SCIENTIFIC REVIEW GROUP (SRG) REVIEW

The Scientific Review Group (SRG) meeting was held from February 19-22, 2019 at the Simon Fraser University Harbour Centre, Vancouver, BC, Canada.

The following are the 'SRG Recommendations and Conclusions for the Hake Stock Assessment' from the 2019 SRG report, and associated responses from the JTC:

1. 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 equilibrium recruitment (R_0) and recruitment variability (σ_R) remain broad topics of contemporary research. The JTC continues to conduct, collaborate on, and monitor ongoing research projects concerning approaches for advancing recruitment estimation, as applied to Pacific Hake and in general. We now briefly discuss several of these research endeavors.

The JTC is conducting and collaborating on simulation projects looking into the concurrent estimation of multiple variance parameters. This includes the estimation of variability associated with time-varying selectivity, σ_R, of the extra standard deviation parameters on survey index data, and of the Dirichlet-Multinomial parameters θ_{fish} and θ_{surv}. Variance parameters in stock assessment models have a tendency to be interrelated when they capture other sources of variance attributed to model mis-specification rather than variability directly related to the given process. This is particularly important for σ_R because without an index of recruitment to directly inform the estimation of σ_R it tends to soak up unspecified variability. This work is related with other time-varying selectivity research, as discussed in response 2 below.

The near completion of the Management Strategy Evaluation framework for Pacific Hake cre-

ates considerable advantages for examining recruitment. For example, using the Template Model Builder (TMB) estimation code developed by Dr. Nis Jacobsen for the MSE, there is opportunity to explore random-effects treatment of recruitment variability (Thorson, 2019). The MSE framework can also be used to evaluated the robustness of recruitment modeling assumptions on management performance and uncertainty. Further, the MSE could be an additional option for estimating σ_R in MCMC runs while further testing semi-parametric selectivity.

The JTC conducted an analysis looking into autocorrelation of recruitment deviations over time. Results showed no indication of autocorrelation, suggesting there is no need to add additional variance terms to account for temporally-related recruitment deviations. The assessment model is adequately accounting for general life-history traits and includes an adequate representation of ageing error. Along with no apparent retrospective pattern (see Section 3.9), this result suggests that the assessment model is not overly mis-specified. Given the lack of autocorrelation, the assessment model was not sensitive to the addition of an autocorrelation parameter.

The JTC is following work being conducted by Dr. Cathleen Vestfals and colleagues at the Northwest Fisheries Science Center looking at identifying climate drivers of Pacific Hake early life-history stages and recruitment. Possible outcomes from this work of direct use to the assessment include the development of an explicit recruitment index, an environmental index linked to recruitment, indicators of recruitment variation (σ_R), and indicators of current or forecasted levels of recruitment. Related work on making fisheries advice robust to time-varying productivity is being conducted at the Pacific Biological Station, as part of a national DFO initiative on an Ecosystem Approach to Fisheries Management.

The JTC is also following work being conducted by the International Council for the Exploration of the Sea (ICES) Methods Working Group which, among other things, is looking at meta-analytical approaches for estimating recruitment parameters. Results from this work could be used to develop informative prior distributions on key recruitment parameters.

The JTC plans to continue to work towards evaluating and testing best practices for modeling recruitment variability, including the use of multi-stage recruitment functions. In general, many of these issues are widespread in stock assessment, and scientific-based solutions are likely to be the result of medium to long-term research projects.

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. This year the JTC presented a semi-parametric method of characterizing the flexibility in selectivity, but this method did not resolve the sensitivity of results to the choice of Φ. **The SRG recommends that the JTC provide a review of how time-varying selectivity is parameterized and estimated in other assessments.**

Response – Most methods that are available to estimate time-varying selectivity require subjective choices. Common choices include which years to model using a time block, the level of variability

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to use for a penalized vector, or the degree of smoothing for a spline. Alternatively, state-space models can be used estimate time-varying selectivity in two dimensions, age and time, where the degree of smoothing is estimated (Nielsen and Berg, 2014).

A comparison project was recently launched by the ICES Methods Working Group to compare the results of four stock assessment frameworks that estimate time-varying selectivity using different assumptions: State-Space Assessment Model (SAM), Woods Hole Assessment Method (WHAM), Stock Synthesis, and Age Structured Assessment Program (ASAP). Each framework will be fit to data from 10 stocks using multiple configurations. This study will allow for the comparison of estimated trajectories between two state-space frameworks and two well-used statistical catch-at-age models when time-varying selectivity is ignored or estimated using the current best practices for each framework. Results will inform best practices for this assessment in 2021.

3. The histological analysis of ovaries for maturity presented in 2018 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 (34.5°N). These data show 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. Hake found in Canada are generally older, and including samples of these fish in the maturity analysis should improve the accuracy of the maturity ogive. The JTC noted that work began late in 2018 to address this recommendation. **The SRG strongly supports the ongoing genetic analyses to determine whether there are genetic differences among the two southern regions and other regions. In addition, the SRG notes that Canadian samples should be included in the maturity analysis.**

Response – The JTC is in communication with the research team conducting Pacific Hake genetic analyses. They provided the following update.

Genetic samples have been collected from along the Pacific coast during summer, fall (BC to CA) and winter (OR and CA) and within the Strait of Georgia (BC) during the spring. We have begun a genetics study to characterize the spatial-temporal population structure of Pacific Hake coast wide. Prior genetic analyses in 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).

For this study, samples were grouped in boxes based on spatial-temporal collection information (i.e., year, season, and location) and selected samples distributed across these boxes. RADseq (Baird et al., 2008; Ali et al., 2016) has been utilized to generate 8,763 genome wide polymorphic markers, which will allow for powerful population genomic analyses as well as association tests of genetic variability with life-history characteristics such as growth rates and age at maturation.

In the initial round of sequencing, DNA were extracted from 1,092 individuals from across spatial-temporal boxes from 2015–2017. Of these, 876 samples were sequenced based on sufficient DNA concentrations, 667 of which passed quality filters. Preliminary findings generally corroborate the single stock hypothesis with low differentiation amongst locations. A Principal Component Analysis (PCA) groups all coastal individuals across space and time together with Salish Sea individuals clearly distinct. However, using a Bayesian clustering analysis there was evidence

for seasonal migration across several winter boxes (across years and location) showing signs of differentiation from the same location in different season and years. This was corroborated with weak but significant pairwise FST comparisons.

For the next round of sequencing, and to finalize data collection for the project, the team will sequence approximately another 1,000 individuals. These include recently acquired samples, with the goal of filling in gaps in spatial-temporal boxes (especially from Canada) and to add additional samples to existing boxes to boost sample sizes. This approach will provide the best picture to date of Pacific Hake genetic population structure. The team expects to complete the sequencing and analyses for these samples in 2020, culminating in the submission of a peer-reviewed publication.

Canadian ovaries from surveys have been collected since 2018 and could be included in updated maturity analyses planned for the upcoming year. However, logistical considerations will need to be worked out regarding sample exchange and histological analysis workload between DFO and NWFSC.

A new project has been initiated looking at improved methods to differentiate which females will likely spawn from those that will not and, thus, should or should not be included as spawning biomass. The study is using liver and ovary samples collected during NWFSC acoustic surveys (2017–2019) to develop metabolic markers linked to key female reproductive stages. Liver physiology and levels of certain lipid classes may reveal overall metabolic and reproductive status. Preliminary results from initial liver lipid analyses indicate that levels of important structural (phospholipids) and storage (triglycerides) lipids are indicative of female maturation status (immature vs. mature) and may be predictive of reproductive failure (atresia) and/or skipped spawning in Pacific Hake. Work is currently underway to expand the liver lipid analyses and develop molecular markers for lipid synthesis (liver RNA) and ovarian growth and atresia (ovarian RNA). Molecular information from liver and ovary samples together with liver lipid analyses and gonadal histology should provide a broader picture of reproductive status of female Pacific Hake and better inform stock assessments.

4. The issue of data weighting remains a significant technical challenge for stock assessments that integrate information of different forms (e.g., biomass indices and age compositions) from different sources (e.g., different fishing sectors). 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. The annual number of at-sea hauls and shore-based trips from which fish ages were incorporated into the age-composition series are summed to provide initial sample sizes. If there are changes in the number of fish associated with each sample unit (haul or trip) over time, then a corresponding change in the information content of an age- composition sample would be expected. 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 notes that the JTC included information in the 2019 assessment on the annual numbers of fish underlying each annual age-composition observation, but were unable to**

complete an analysis, as requested in the 2018 SRG report, on the effect of potential changes in sampling protocols that could influence the input sample sizes. The SRG reiterates its request for this analysis.

Response – Progress was made on documenting the historical methods utilized to sample Pacific Hake for otoliths, which began in the 1970s with observers on foreign vessels. Many protocols have remain unchanged over time, but some methods of collecting fish for ageing and the numbers of fish aged per tow or trip have changed. Below, we summarize known major changes.

A clear change in protocol was initiated in 1999 for the U.S. at-sea fishery with the move towards random sampling of fish for ages rather than random-stratified sampling, which attempts to collect ages in each 1 cm length bin. Additionally, in 2009 at-sea observers started collecting three instead of five sets of otoliths from a haul.

In Canada, target sample size (n=50) has not changed over time for at-sea observers aboard foreign joint-venture vessels. On domestic vessels observers are currently instructed to collect age samples from 60 fish, whereas prior to 2001 the target may have only been 50. This lower target potentially only pertained to shoreside hake vessels before at-sea observer coverage was discontinued with the installment of electronic monitoring.

In 2016, dockside observers were asked to change their protocols based on JTC input. Samples changed from being collected during dedicated weeks to the landing level.

A more complete summary of the changes in the sampling protocol over time will be completed in the upcoming months and included in the 2021 assessment as an appendix. Currently, this information has been used to inform a simulation study that investigated repercussions of biased input sample sizes. Preliminary results suggest that the D-M parameters combined with time-varying selectivity can estimate the time series of spawning stock biomass with little bias when there is no temporal trend in the bias applied to the input sample size. Future investigations will look into temporal trends in this bias, where the trend will be informed by changes in the protocols used to specify the collection of otoliths in the Pacific Hake fishery.

5. A recent advance in Bayesian analysis (the No U-Turn Sampler, NUTS) raises the possibility that the assessment model could reach convergence much more quickly than is now possible. Many 2019 sensitivity runs were limited to maximum likelihood estimates (MLE) values, rather than Markov chain Monte Carlo (MCMC) values, to save computing time, minutes versus 2.5 days per run, respectively. **The SRG recommends that the JTC continue to explore NUTS and similar options, as using MCMC for all runs would provide better comparability between the base assessment model and sensitivity runs.**

Response – The JTC evaluated the No U-turn Sampler (NUTS) for conducting efficient Bayesian MCMC sampling using the `adnuts` *R package (Monnahan and Kristensen, 2018; Monnahan et al., 2019). Results from this evaluation, including comparisons to the current approach for Bayesian MCMC sampling, are shown in Appendix* **H.** *In addition, the JTC explored the added utility of using the ShinyStan application* `shinystan` *features in* `adnuts` *to better visualize MCMC diagnostics, including mixing, sampling and divergence metrics, among other things. A demonstration of this*

application will be shown at the 2020 SRG meeting. The code used for running NUTS is given at the end of Appendix H.

6. Delays in entry and validation of catches reported on paper tickets in Washington and entry into the PACFIN database was identified as a potential issue. This concern has most often applied to tribal catches. The preferred process is that all data are available from managed regional databases in time for JTC data extraction, which usually occurs early in January. **The SRG recommends that the JTC continue to set a deadline for the extraction of catch data and be transparent about the sources of data used in the assessment in the event that data have to be obtained directly from the sources.**

Response – The JTC set the deadline 3 January 2020 for the extraction of data. In addition, the JTC communicated with U.S. State partners to ensure the most up-to-date data would be available. The streamlining of getting tribal fish tickets into regional databases is advancing with the recent electronic ticket pilot study jointly conducted by the Makah Tribe in Washington State and the Pacific States Marine Fisheries Commission (see the tribal fishery report in Appendix E). However, nearly 50% of the tribal catch had yet to be incorporated into the PacFIN regional database by the data deadline. Nonetheless, the JTC worked with the Makah Tribe and Washington Department of Fish and Wildlife to ensure the best estimates of tribal catch were included in the stock assessment, despite not yet appearing in PacFIN. The JTC anticipates that data will consistently be available in PacFIN in timely manner moving forward with continued use of electronic ticket reporting for all tribal catch.

The JTC also notes that the SRG concurred with our approach in 2019 of using the long-term averages of time-varying fecundity for years without weight-at-age data (i.e. before 1975 and for forecasts). For this assessment we used the long-term (all data 1975–2019) average for the years prior to 1975 and the average of the last five years for the forecast period (2020–2022).

Based on an informal request at the 2018 SRG meeting, we have changed the y-axis in the historical phase plots (Figures h and 33) to show the relative fishing intensity in year $t-1$ (rather than year t), such that the 2020 relative biomass appears on the figure.

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 2019

A set of 'bridging' models was constructed to evaluate the component-specific effects of all changes from the 2019 base model to the 2020 base model.

In short, these included the following:

- Update to the latest version of Stock Synthesis, version 3.30.14.08;

- Change to estimating a simple vector of recruitment deviations rather than a vector of deviations that are constrained to sum to zero;

- Update catch data from years prior to 2019;

- Update age-composition data from years prior to 2019;

- Update weight-at-age data from years prior to 2019;

- Add 2019 total catch;

- Add 2019 fishery age-composition and weight-at-age data;

- Add 2019 survey biomass estimate;

- Add 2019 survey age-composition data; and

- Implement new prior distributions on the D-M parameters.

The bridging steps can be grouped into three main sets of changes, with the majority of the steps being those that are performed routinely. The first step updated the Stock Synthesis framework to follow current best practices. The second step updated the information available from the fishery. The third step updated the information available from the survey and implemented changes to the model structure.

Stock Synthesis version 3.30.14.08 includes a number of changes since the version used by Berger et al. (2019), mostly related to forecasting options. Changes relevant to the assessment of Pacific Hake include changes to increase the convergence of estimates of catchability and parameter deviations, performance of jitter runs when parameters are near boundary conditions, and stability of the transition to MCMC when the parameters specifying bias adjustment of the recruitment deviations are turned off. Collectively, these changes led to small differences in estimates of parameter deviations compared to the 2019 base model but essentially no change in the time series (Figure 15).

We relaxed the constraint that recruitment deviations during the main period sum to zero. The

constraint leads to a mismatch between the MCMC samples that are drawn versus those that are reported by the MCMC algorithms run through the AD Model Builder software because AD Model Builder applies the constraint during its evaluation phase where results are calculated rather than during sampling. This is a known error and AD Model Builder developers are working on ways to fix this problem. Until then, best practices suggest removing the constraint such that the sampling and evaluation algorithms match.

One advantage of using a zero-centered recruitment deviation vector is to maintain tractability when estimating recruitments, especially for assessments that have less information about recruitment (little data). The theory behind the use of a zero-centered recruitment deviation vector is that the R_0 and B_0 reference points should be reflective of the central tendency for the time period with the best information about recruitment. A mismatch between R_0 and estimates of recruitment during the data-rich period could, in theory, lead to a better fit to the indices of abundance or some other data source which wouldn't otherwise be expected to be informative about recruitment. However, for Pacific Hake the stock assessment is relatively data-rich and the index is pretty consistent with the recruitments, so such tension doesn't seem to be present.

Estimating recruitment deviations that are not constrained to sum to zero will increase the compatibility between MCMC and MLE results, and also increase the stability of model results, because penalties have implications for calculating derivatives. The non-zero centered approach resulted in a median recruitment deviation distribution of 0.086 in the 2020 base model. Compared to the 2019 assessment, the time series of spawning biomass and fishing mortality, as well as the fit to the survey index were largely unchanged. However, relative spawning biomass increased for all years because the estimate of $\log R_0$ increased and estimates of recruitment deviations were slightly more positive (Figure 15). Nonetheless, the moderate increase in relative spawning biomass is well within the uncertainty bounds of models that apply and do not apply this relaxed constraint.

The second set of bridging steps was conducted to update the fishery-dependent data. This primarily included minor adjustments in catch, fishery age-composition, and weight-at-age values. Historical catches from the Canadian Joint-Venture fishery that were inadvertently left out of last year's assessment were included. Also included were additional age data from the U.S. shoreside fleet that were previously filtered from the analysis because of a lack of delineation regarding the method used to age the samples. Weight-at-age data that lack information about the month in which they were collected are now included. Samples that were recently aged but not available for the 2019 assessment were included. These changes to pre-2019 data were small enough that they had little impact on the model results (Figure 16).

The addition of 2019 catch allowed the model to be extended to the start of 2020, but the estimates for 2020 remained highly uncertain (Figure 16) in the absence of additional information about recent recruitment. Adding 2019 fishery age-composition and weight-at-age data had relatively little impact on the historical biomass estimates, indicating that the observed 2019 ages were consistent with the model estimates without those data (Figure 16). However, the addition of these data did alter recent recruitment estimates, increasing the estimated size of the 2016 and 2017 year classes and decreasing the 2018 year class. This bridging step also shifted the ending year of the deviations in the selectivity parameters from 2018 to 2019 because of the addition of fishery data in

2019.

Including the fishery-independent biomass estimate led to a slightly more optimistic trajectory of the stock over the last couple of years (Figure 17), which was to be expected given the increase in the index relative to 2017. The addition of survey age-composition data led to reduced uncertainty, particularly for the 2010, 2014, 2016, and 2017 year classes. The 2010 and 2014 year classes are estimated to be higher in this assessment than they were in the 2019 assessment. This increase is largely driven by the addition of the 2019 acoustic survey age compositions where the proportion of age-9 fish and age-5 fish were higher than what the 2019 assessment model would have otherwise predicted given mortality. The 2019 acoustic survey was the first time the 2016 and 2017 cohorts were adequately sampled (age-2 or older) by the survey, which is why the uncertainty associated with these cohorts was reduced (though still quite uncertain; Figure 17).

The final bridging step involved using the new priors on the D-M parameters θ_{fish} and θ_{surv}, and explicitly estimating θ_{surv} (see Section 2.4.4). This resulted in the 2020 base model (Table 18). The new priors led to a slight increase in correlation between estimates of M and $\log R_0$ (Appendix A), though a decrease compared to the 2019 assessment, and effectively no difference in the trajectory of the stock or estimates of its status (Figure 17). 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 to account for the addition of information about recruitment for the 2018 cohort.

3.4.2 Assessment model results

Model Fit

For the base model, the MCMC chain length was 24 million as it was in the 2019 assessment (Berger et al., 2019). The first 4,000,000 values were discarded to eliminate 'burn-in' effects and each 10,000th value thereafter was retained, resulting in 2,000 samples from the posterior distributions for model parameters and derived quantities.

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 sampling, no evidence for lack of convergence, and low autocorrelation (results for some key parameters are shown in Figures A.1 and A.2). 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 A.4). The Gelman-Rubin multi-chain diagnostic test, which compares within-chain variance to among-chain variance, further indicated that convergence was adequately achieved (Figure A.5). Correlations among key parameters were generally low, with the exception of M and $\log R_0$ (Figure A.6). Estimates of recruitment in 2010 and 2014 were correlated with the derived quantity of catch from the default harvest rule in 2020, as to be expected given the dependencies among these quantities (Figure A.6). An examination of deviations in recruitment (log-scale differences between estimated and expected recruitment values) from recent years (Figure A.7) indicates the highest correlation

(0.81) 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 new prior for θ_{fish} and θ_{surv} results in the estimate (median and 95% credible interval) for $\log \theta_{\text{fish}}$ of -0.559 (-0.762, -0.344), giving an effective sample size multiplier $\theta_{\text{fish}}/(1 + \theta_{\text{fish}})$ of 0.364 (0.318, 0.415). The new prior results in the survey age-composition parameter being well-sampled (unlike in the 2019 assessment where it encountered bounds and so was fixed) with $\log \theta_{\text{surv}}$ estimated as 2.332 (1.192, 4.519), and the resulting effective sample size multiplier $\theta_{\text{surv}}/(1 + \theta_{\text{surv}})$ of 0.912 (0.767, 0.989).

The base model fit to the acoustic survey biomass index (Figure 18) remains similar to the 2019 base model. The 2019 survey biomass estimate resulted in an upward shift in the fit to the 2015 and 2017 survey data points and a lengthening of the stable biomass trend over recent years (Figure 18). The addition of 2019 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 underestimation of the 2009 biomass estimate is much larger the underestimation of any other year. The uncertainty of this point (both modeled and actual) is high because of the presence of large numbers of Humboldt Squid during the survey. Humboldt Squid have similar TS 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 estimates underfit the 2015 survey index, overfit the 2017 index, and closely fit the 2019 index (Figure 18). This is likely due to slight differences in what the fishery composition data and survey composition data, when considered independently, would otherwise suggest as population trends. Additionally, the population has undergone recent high catch levels and produced a couple of above-average cohorts that are now mature.

Fits to the age-composition data continue to show close correspondence to the dominant and small cohorts observed in the data when the data give a consistent signal (Figure 19). 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. In the 2019 fishery, the 2014 cohort was the largest (32%), followed by the 2016 cohort (21%), followed by the 2010 cohort (19%). Age compositions from the 2019 acoustic survey suggest a similar age structure, i.e., the 2014 cohort was the largest (31%), followed by the 2016 cohort (27%), followed by the 2010 cohort (16%). Combined, the 2015–2019 fishery age-composition data and the 2017–2019 acoustic survey age-composition data suggest that 2014 was a strong recruitment year, and the model was able to adequately fit to these observations (Figure 19). The 2016 cohort, which has now been observed twice by the survey, appears to be smaller than the 2014 cohort. The 2019 survey was the first to sample the 2017 cohort, confirming that it was not extremely large (10.7% of the 2019 survey catch). Residual patterns to the fishery and survey age data do not show patterns that would indicate systematic bias in model predictions (Figure 20).

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 estimated age-specific catch, natural mortality, and surviving biomasses are given in Table 24. For example, the catch weight of the 2014 cohort at age-5 was slightly larger than that of the 2010 cohort at age-5, but the resulting surviving biomass of the 2014 cohort was only just over half of the surviving biomass of the 2010 cohort.

Posterior distributions for both steepness and natural mortality are strongly influenced by priors (Figure 21). The posterior for steepness is only slightly updated 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 diffuse priors to stationary posterior distributions, including θ_{surv} (unlike in the 2019 assessment, as outlined in Section 2.4.4).

The 2020 base model specified the same level of variation (standard deviation of $\Phi = 1.4$) associated with time-varying fishery selectivity as the 2019 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 2019 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 for age-3 and age-4 fish are larger from 2010 to 2012 than in more recent years (Figures 22 and 23). 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 19 and 55). Fishery selectivity on age-2 fish was at its highest in 2016, followed by 2018. Fishery selectivity for the most recent year leveled off between ages less than six even more so than it did for the previous year, suggesting equal selectivity-at-age for younger ages Figure 23). Even though the survey selectivity is time invariant, the posterior shows a broad band of uncertainty between ages 2 and 5 (Figure 24). 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 2010 and 2014 cohorts occurring at ages 3 and 5 but not age 4. Fishery selectivity is likewise very uncertain (Figures 23 and 24), 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 above unfished equilibrium (Figures 25 and 26 and Tables 25 and 26). The model estimates that it was below the unfished equilibrium in the 1960s, at

the start of the assessment period, due to lower than average recruitment. The stock is estimated to have increased rapidly and was above unfished equilibrium in the mid-1970s and mid-1980s (after two large recruitments in the early 1980s). It then declined steadily to a low in 1999. This 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 0.591 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, increasing the biomass in 2017. The estimated biomass has declined in each of 2018, 2019 and 2020, during a time of record catches.

The median estimate of the 2020 relative spawning biomass (spawning biomass at the start of 2020 divided by that at unfished equilibrium, B_0) is 65%. However, the uncertainty is large, with a 95% posterior credibility interval from 31% to 129% (Tables 25 and 26).

The median estimate of the 2020 spawning biomass is 1.196 million t (with a 95% posterior credibility interval from 0.550 to 2.508 million t). The estimate of the 2019 female spawning biomass is 1.379 (0.736–2.706) million t. This is a slightly higher median than the 1.312 (0.471-3.601) million t estimated in the 2019 assessment, and the credibility interval lies well within that from the 2019 assessment.

Recruitment

The new data available for this assessment do not significantly change the estimated patterns of recruitment estimated in recent assessments. However, estimated recruitments for some years have changed. For example, this year's median assessment of the 2010 recruitment is 1.8 billion more fish (a 13% increase) than last year's assessment. This difference is largely driven by the addition of the 2019 acoustic survey age compositions (Figure 17) in which the proportion of age-9 fish in 2020 was higher than predicted by the 2019 assessment model given mortality.

Pacific Hake appear to have low average recruitment with occasional large year-classes (Figures 27 and 28, 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 29) 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, 23% of the 2018 catch, and 19% of the 2019 catch. The median estimate of the 2010 year class is just below the highest ever (for 1980), with a 36% probability that the 2010 year class is larger than the 1980 year class (this probability was 18% for last year's assessment).

The current assessment also estimates a strong 2014 year class (Figure 29) comprising 50% of the 2016 catch, 38% of the 2017 catch, 27% of the 2018 catch, and 32% of the 2019 catch. The 2016 cohort also appears to be above average at 26% of the 2018 catch, and 21% of the 2019 catch. Although the absolute size of the 2014 year class remains uncertain, at least more so than cohorts that have been observed for more years, five years of fishery data and two years of survey data suggest that it is a strong year class. The 2016 year class is estimated to be above average (similar in size to the 2008 year class) from three years of fishery data and one year of survey data. The 2017 year class was first observed by the survey in 2019 and is estimated to be about average in size. Currently, only one year of fishery data is used to estimate the below-average size of the 2018 year class.

The additional data in the 2019 assessment has increased the median estimate of the 2014 year class to 9.401 billion fish (Table 25), from the 8.467 billion estimated in the 2019 assessment (Table 25 of Berger et al. 2019). The 2014 year class remains the fifth largest estimated recruitment, albeit with large uncertainty (Table 26 and Figure 27). The median estimate for the 2016 year class is 4.550 billion fish (2.178–10.016 billion fish; Tables 25 and 26).

The model currently estimates small 2011, 2013, 2015, and 2018 year classes (median recruitment well below the mean of all median recruitments) and near average 2012 and 2017 year class. The proportion of the catch that was age-1 fish in 2019 (2018 year class) was well below that observed in 2018 (2017 year class) and 2017 (2016 year class; Table 11). There is little or no information in the data to estimate the sizes of the 2019 and 2020 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 year and the overall stock recruit relationship are provided in Figure 30. Extremely large variability about the expectation and about the joint uncertainty of individual recruitment and spawning biomass pairs are evident. High and low recruitments have been produced throughout the range of observed spawning biomass (Figure 30). The standard deviation of the time series of median recruitment deviation estimates for the years 1970-2018, which are informed by the age compositions, is 1.68. This value is higher than, but consistent with, the base model value of 1.4.

Exploitation status

Median relative fishing intensity is estimated to have been below the SPR$_{40\%}$ target for all years (Figure 31 and Tables 25 and 26). It 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 32 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 94.0% in 2010 to 47.2% in 2015, after which it increased to 78.2% in 2017 and has since stayed relatively constant. The median exploitation fraction decreased from 0.17 in 2011 to recent lows of

0.06 in 2012 and 2015, and then increased to 0.13 in 2017 before ending at 0.12 in 2019. 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 31). The median estimates for 2016 through 2019 are below the management target, however the 95% posterior credibility intervals do include the target level.

Management performance

Over the last decade (2010–2019), the mean coast-wide utilization rate (i.e., landings/quota) has been 71.3% and catches have been below coast-wide targets (Table 4). From 2015 to 2019, the mean utilization rates differed between the United States (68.6%) and Canada (53.1%). In 2015, the utilization rate for the fishery was the lowest of the previous decade (44.1%) due, in part, to difficulties locating aggregations of fish and possibly economic reasons. Before 2015, the under-utilization 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 of the preceding years. This is in large part due to increasing catch targets as biomass continues to increase. The total utilization rate in recent years (2017–2019) has been close to the average over the last decade. During the last two years, utilization rates have been stable in both the United States (72%) and Canada (about 61%). 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 (Table 25 and Figures 31 and 33). The median relative spawning biomass was above the $B_{40\%}$ reference point in all years except 1999 and 2007-2010 (Table 25 and Figures 26 and 33). These are also shown by phase plot of the joint history of relative spawning biomass and relative fishing intensity (Figure 33). Relative spawning biomass increased from the lows in 2007–2010 with the 2008, 2010, 2014, and 2016 recruitments and, correspondingly, relative fishing intensity has remained well below target despite recent increases in total catch. While there is large uncertainty in the 2019 estimates of relative fishing intensity and relative spawning biomass, the model estimates a 4.3% joint probability of being both above the target relative fishing intensity in 2019 and below the $B_{40\%}$ relative spawning biomass level at the start of 2020.

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 $\log R_0$ 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, recruitment deviations, and survey and fishery data weights (via the Dirichlet-Multinomial parameters θ_{fish} and θ_{surv}). The uncertainty portrayed by the posterior distribution is a better representation of uncertainty than the asymptotic approximations about the maximum

likelihood estimates (MLEs) because it allows for asymmetry (Figure 21; 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.

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 (Table 27). Figure 34 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. The 95% credibility (from MCMC) and confidence (from MLE) intervals overlap considerably, but are by no means identical.

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.

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 using maximum likelihood estimation (Section 3.8).

We also present two appendices, each highlighting Bayesian MCMC results from models with different structural assumptions or analytical choices compared to the base model. These include the incorporation of the age-1 survey index (Appendix G), and the use of a new analytical tool for conducting efficient Bayesian MCMC sampling, the No-U-Turn Sampler (NUTS; Hoffman and Gelman 2014), implemented using the `adnuts` R package (Monnahan and Kristensen, 2018; Monnahan et al., 2019) in Appendix H. The inclusion of the age-1 survey model was chosen because it may improve estimates of recruitment near the end of the time series and of age compositions during the forecast period, even though the acoustic survey design is not structured specifically for indexing age-1 fish. The model that uses the more efficient `adnuts` package for conducting MCMC allows comparison with our existing methods, a necessary documented first step should `adnuts` be used in future Pacific Hake assessments.

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 engaged in similar research. Incorporating feedback from the Working Group and stakeholders will ensure that operating models will be able to provide insight into the important questions defined by interested parties.

Specifically, the development of MSE tools will evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery, and will compare potential methods to address them.

3.6 REFERENCE POINTS

We report estimates of the base reference points (e.g., $F_{SPR=40\%}$, $B_{40\%}$, B_{MSY}, and MSY) with posterior credibility intervals in Table 28. Only those based on $F_{SPR=40\%}$ explicitly relate to target reference points per the treaty Agreement (see Section 1.3 and Appendix C). The estimates are only slightly different than the estimates in the 2019 assessment (see also Table 27).

As part of the DFO Sustainable Fisheries Framework, DFO (2009) defined a limit reference point as being a biomass below which serious harm is believed to be occurring to the stock, and an upper stock reference point above which the stock is considered to be healthy. These would equate to the Agreement reference points of $B_{10\%}$ and $B_{40\%}$ (the female spawning biomass being 10% and 40%, respectively, of the unfished equilibrium female spawning biomass). The probabilities of the female spawning biomass at the start of 2020 being above each of these points are $P(B_{2020} > B_{10\%}) = 100\%$ and $P(B_{2020} > B_{40\%}) = 90.1\%$ such that the stock is estimated to be in the 'healthy zone' (above the upper stock reference point of $B_{40\%}$).

With respect to DFO's provisional limit reference point of $0.4B_{MSY}$ and provisional upper stock reference point of $0.8B_{MSY}$, the probabilities are $P(B_{2020} > 0.4B_{MSY}) = 100\%$ and $P(B_{2020} > 0.8B_{MSY}) = 99.8\%$ such that the stock is estimated to be in the provisional 'healthy zone'. For completeness, we note that $P(B_{2020} > B_{MSY}) = 98.8\%$

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 2020, the estimated posterior median relative spawning biomass is 65%, such that the spawning biomass is above $B_{40\%}$ and well above $B_{25\%}$. The probability that spawning biomass at the beginning of 2020 is above $B_{40\%}$ is $P(B_{2020} > B_{40\%}) = 90.1\%$ (as noted above), and of being above $B_{25\%}$ is $P(B_{2020} > B_{25\%}) = 99.4\%$.

3.7 MODEL PROJECTIONS

The median catch limit for 2020 based on the default $F_{SPR=40\%}$–40:10 harvest policy is 666,458 t, but has a wide range of uncertainty (Figure 35), with the 95% credibility interval being 258,675–1,588,947 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). Population dynamics and governing parameters assumed during the forecast period include average recruitment (no recruitment deviation); selectivity, weight-at-age and fecundity averaged over the five most recent years (2015–2019); and all estimated parameters constant (at their estimates for each particular MCMC sample).

Relative fishing intensity exceeding 1 (or 100% when shown as a percentage) indicates fishing in excess of the $F_{SPR=40\%}$ default harvest rate limit. This can happen for the median relative fishing intensity in 2020, 2021 and 2022 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 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 g: 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 2021 and 2022 (Tables 31 and 32 and Figures 36, 37, and 38). 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 in 2020 (Table 31 and Figure 37). However, interpolation is not appropriate for all catches in 2021 because catch alternatives g and h have catches that are larger than 500,000 t (the constant catch for alternative e) in 2020 but smaller than 500,000 t in 2021 (Table 30); this explains why a few probabilities decline (rather than rise) with increased 2021 catch levels in Table 32 and Figure 38.

Figure 36 shows the predicted relative spawning biomass trajectory through 2022 for several of these management actions. With zero catch for the next two years, the biomass has a probability of 81% of decreasing from 2020 to 2021 (Table 31 and Figure 37), and a probability of 63% of decreasing from 2021 to 2022 (Table 32 and Figure 38).

The probability of the spawning biomass decreasing from 2020 to 2021 is over 80% for all catch levels, including zero (Table 31 and Figure 37). It is 95% for the 2020 catch level similar to that for 2019 (catch alternative d). For all explored catches, the maximum probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2021 is 1%, and of dropping below $B_{40\%}$ is 40% (Table 31 and Figure 37). It should be noted that forecasted abundance is not only influenced by catch levels. As the large 2010 and 2014 cohorts continue to age, their biomass is expected to decrease as losses from mortality outweigh increases from growth, while the smaller but above-average and average 2016 and 2017 cohorts will add to overall spawning biomass as they mature. The below-average 2015 and 2018 cohorts will contribute much less to forecasted spawning biomass. The probability that the 2021 spawning biomass will be less than the 2020 spawning biomass ranges from 81% to 97% depending on the catch level (Table 31 and Figure 37).

The age composition (in numbers) of the catch in 2020 is projected to be (using MCMC medians) 13% age-3 fish from the 2017 year-class, 23% age-4 fish from the 2016 year-class, 35% age-6 fish from the 2014 year-class and 12% age-10 fish from the 2010 year-class (Figure 39). However, those estimates are highly uncertain with the 95% credibility interval for the age-6 fraction span-

ning 22%–50%. Due to the lower average weight at age-3 versus age-10, the median expected proportion of the 2020 catch by weight is 11% for the 2017 cohort (compared to 13% by numbers) and 16% for the 2010 cohort (compared to 12% by numbers).

With respect to the DFO reference points, even with the largest 2020 catch of 666,458 t given in Table 31, at the start of 2021 the stock is expected to be above the critical zone with a probability of $P(B_{2021} > B_{10\%}) = 99\%$ and in the healthy zone with a probability of $P(B_{2021} > B_{40\%}) = 60\%$. With respect to the DFO provisional reference points (based on B_{MSY}), the the stock is expected to be above the provisional critical zone with a probability of $P(B_{2021} > 0.4B_{MSY}) = 99\%$, in the healthy zone with a probability of $P(B_{2021} > 0.8B_{MSY}) = 92\%$, and above B_{MSY} with a probability of $P(B_{2021} > B_{MSY}) = 86\%$.

With respect to PFMC stock size reference points, a level of 2020 catch consistent with the Treaty default harvest control rule (666,458 t) has a 40% estimated probability of the biomass going below $B_{40\%}$ in 2021 (13% probability of going below $B_{25\%}$; Table 31). That probability decreases to 28% and 6%, respectively, if the catch level stays about the same in 2021 as in 2020.

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 MLE estimates, see Tables 33–35. 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;

9. Removal of cohort-based ageing error from the model; and

10. Running the base model using the No-U-Turn-Sampler (NUTS; Hoffman and Gelman (2014) within the R package `adnuts` (Monnahan and Kristensen, 2018; Monnahan et al., 2019).

In general, none of the sensitivities resulted in any substantial 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 2010 and the 2014 cohorts. 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 for 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 0.209 for the base model (prior standard deviation of 0.1) to 0.238 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 40 and 41).

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 0.854 to 0.562 (Table 33). However, neither steepness sensitivity analysis had a strong impact on the overall model results (Figures 40 and 41). 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 30).

The value of σ_r was changed from a value of 1.4 (base) to alternative high (1.6) 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, $\sigma_r = 1.6$, resulted in a model with a more consistent standard deviation for the estimated recruitment deviations, at 1.69. 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 40 and 41). 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 1.55, which was similar to the base-model value of 1.4.

The sensitivity of the base model to the inclusion of the age-1 survey index provides an additional source of information about the recruitment of different year classes (see discussion in Section 2.2.1), which can be particularly useful for the most recent years when little information on

cohort strength is otherwise available. Compared to the base model, estimates of spawning biomass throughout most of the time series are similar, but do diverge near the end of the time series (Table 33; Figures 42 and 43; 2020 estimates are 62.6% of unfished biomass for the base model and 71.8% for the age-1 index model). This change is likely due to the base model overfitting the age-1 index estimates of the size of the 2005 and 2012 cohorts (Figure 11). 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 a worse fit to the 2017 acoustic survey estimate and a better fit to the 2019 estimate compared to the base model (Figure 44).

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, has now been implemented in the base model. The base model was compared to the models that used the McAllister-Ianelli and Francis methods. Both sensitivity 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 45). 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.

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 46-50).

The consideration of alternative standard deviations (Φ) for time-varying selectivity is discussed earlier in Section 2.4.3. Changing the values of the parameter Φ controlling the flexibility in time-varying selectivity from the base model value of $\Phi = 1.40$ to alternative values of 0.21, 0.70, and 2.10, did not appreciably influence the estimates, or precision, associated with recruitment in 2014 (Figure 48). However, recruitment estimates for 2017 are linked to the choice of Φ, where the model with the smallest Φ at 0.21 estimates the 2017 recruitment deviation as the highest of the Φ sensitivity models (Figure 49) and provides the worst fit of the most recent survey biomass estimate (Figure 50).

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 51). 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 no pairs of time-varying selectivity deviation parameters with correlations above 0.7 or below -0.7 in the semi-parametric model that most closely matched the base model. This is in contrast to the base model, which had 38 pairs with correlations above 0.7 or below -0.7.

Both models with alternative σ_s parameters ($\sigma_s = 0.695$ and $\sigma_s = 1.0$) had higher estimates of 2016 and 2017 recruitment compared to the base model, and the $\sigma_s = 0.695$ model had a visibly worse fit to the recent survey biomass estimates (Figures 46-50). 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 past assessments, the parameter selectivity was kept as before for this assessment.

The impact of assuming a time-invariant ageing error vector instead of a cohort-based ageing error matrix (as in the base model) was evaluated. The largest changes to model results are associated with estimates of equilibrium unfished biomass (Table 35 and Figure 52) and thus relative spawning biomass (Figure 53). These differences stem from the population model being restricted in the time-invariant case to fitting age-composition data with a stationary level of measurement error associated with each age.

The impact of using the NUTS MCMC algorithm (Table 36) is discussed in detail in Appendix H.

An additional sensitivity run arising from the Scientific Review Group meeting held from 25th February to 28nd February 2020 related to input sample size is documented in Appendix B. Briefly, arbitrarily decreasing the weight of recent fishery age-composition data by taking the square root of the input sample size led to similar estimates of the recent trend in spawning biomass but differences in stock status because of more optimistic estimates of the stock at unfished equilibrium. Further responses to other SRG requests are also given in Appendix B.

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 4, 5, or 6 years of data removed had information available regarding the large 2010 year class, but did not yet have

information on the 2014 year class (Figure 54). Models with 1 and 2 years of data removed were just beginning to receive data on age-3 and age-2, respectively, individuals to predict the size of the 2014 year class. The base model now has five years of data to estimate the size of the 2014 cohort, and the uncertainty around this estimate has been considerably reduced compared to three years ago (Figure 54).

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 (Figure 54). In the previous assessment, the retrospective bias was predominately positive in these terminal years. In this assessment the bias is a mix of both positive and negative biases with no systematic pattern indicating that the model is more correctly specified than one that shows a pattern.

Cohort strength is not well estimated until several ($\sim$4-9) years of fishery catch-at-age data and survey age-composition data have been collected (Figure 55). Deviations for the 1999 and 2010 cohorts, which are the largest cohorts, exhibit the largest positive biases, and the sizes of several cohorts (particularly the large 2010 and 2014 cohorts) increase with the final year of data. Estimated recruitment deviations for the 2014 cohort are above the 2008 and 1999 cohorts at a similar point in time. The variability among cohort estimates relative to their estimated size in the base model (Figure 56) further indicates that the estimates can start to improve as early as age-3, but some estimates of cohort strength may not stabilize until the cohort approaches an age upward of 7 years old. The lack of systematic bias in the assessment results could be because both of the largest cohorts are now older than 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 57. There have been substantial differences in the structural assumptions of the models and, thus, results submitted each year. The variability between model results, especially early on in the time series, is larger than the uncertainty (95% credibility interval) reported from any single model in recent years. Prior to 2004, survey catchability was fixed at 1.0 and this assumption was heavily investigated between 2004 and 2007, leading to variability in model results because of the use of several different, but fixed, survey catchability. Since 2008, catchability has been freely estimated by the model. 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 remained similar to the previous assessment but declined relative to the 2015-2017 assessments. The difference is most likely related to the recent under-fitting of the 2017 survey estimate of biomass despite the consistency in the structure of the assessment model in recent years. The uncertainty interval associated with the 2020 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 links 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. Related, there is a need to streamline the availability of products from oceanographic models (e.g., Regional Ocean Modeling System; ROMS) so that they can be used on a reoccurring basis as informative links in operational stock assessments.

2. Use and build upon the existing MSE framework 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 interested parties into further development of operating and/or estimation models, through the Pacific Hake MSE Working Group.

3. Continue to 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 (or related) 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 Northwest Fisheries Science Center and from Fisheries and Oceans Canada 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 transparent and repeatable 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. Explore alternative approaches and related assumptions for parameterizing time-varying fishery selectivity in the assessment.

5. Continue investigations into Pacific Hake fecundity and maturity, including trying to understand links between fecundity and size, age, weight, and batch spawning, as well as spatio-temporal variability in the timing of spawning, skip spawning, batch fecundity, and size and age at maturity. Additionally, a more spatially comprehensive maturity analyses that incorporates information from Canadian samples would be advantageous.

6. Explore potential recruitment indices for juvenile or young (0 and/or 1 year old) Pacific Hake, including further investigations into survey options, refinements and analyses, as well as environmental linkages to recruitment. Also investigate alternative ways to model and forecast recruitment, given the uncertainty present.

7. Update ageing error calculations using information from recent double reads and inter-laboratory ageing comparisons. This would include updated information about 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. The last inter-laboratory comparison was done in 2010 ('CARE' exchanges), so another exchange program is needed to obtain the best current available information on ageing error.

8. 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. Continue to explore the possibility of using additional data types (such as length data) within the stock assessment.

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

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

11. 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 (Stienessen et al., 2019).

5   ACKNOWLEDGMENTS

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7 TABLES

Table 1. Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2019. 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 table or 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	102,141	1,018	233,578

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	67,121	116,073	135,112	0	318,306
2019	0	0	52,646	116,146	148,211	0	317,003

Table 2. Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2019.

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	6,820	52,624	14,122	73,566
2008	0	3,592	57,799	13,214	74,605

2009	0	0	44,136	13,223	57,359
2010	0	8,081	35,362	13,573	57,016
2011	0	9,717	31,760	14,596	56,073
2012	0	0	32,147	14,912	47,059
2013	0	0	33,665	18,584	52,249
2014	0	0	13,326	21,792	35,118
2015	0	0	16,775	22,909	39,684
2016	0	0	35,012	34,731	69,743
2017	0	5,608	43,427	37,686	86,721
2018	0	2,724	50,747	41,942	95,413
2019	0	0	50,330	43,950	94,280

Table 3. Total U.S., Canadian and coast-wide catches of Pacific Hake (t) from 1966-2019. 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	73,566	291,247	74.7	25.3
2008	248,496	74,605	323,101	76.9	23.1
2009	121,324	57,359	178,683	67.9	32.1
2010	171,043	57,016	228,059	75.0	25.0
2011	231,261	56,073	287,334	80.5	19.5
2012	160,144	47,059	207,203	77.3	22.7
2013	233,578	52,249	285,828	81.7	18.3
2014	264,141	35,118	299,259	88.3	11.7
2015	154,160	39,684	193,844	79.5	20.5
2016	262,327	69,743	332,070	79.0	21.0
2017	354,229	86,721	440,950	80.3	19.7
2018	318,306	95,413	413,719	76.9	23.1
2019	317,003	94,280	411,283	77.1	22.9

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

Year	U.S. landings (t)	Canada landings (t)	Total landings (t)	Coast-wide catch target (t)	U.S. catch target (t)	Canada catch target (t)	U.S. proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2010	171,043	57,016	228,059	262,500	193,935	68,565	88.2%	83.2%	86.9%
2011	231,261	56,073	287,334	393,751	290,903	102,848	79.5%	54.5%	73.0%
2012	160,144	47,059	207,203	251,809	186,036	65,773	86.1%	71.5%	82.3%
2013	233,578	52,249	285,828	365,112	269,745	95,367	86.6%	54.8%	78.3%
2014	264,141	35,118	299,259	428,000	316,206	111,794	83.5%	31.4%	69.9%
2015	154,160	39,684	193,844	440,000	325,072	114,928	47.4%	34.5%	44.1%
2016	262,327	69,743	332,070	497,500	367,553	129,947	71.4%	53.7%	66.7%
2017	354,229	86,721	440,950	597,500	441,433	156,067	80.2%	55.6%	73.8%
2018	318,306	95,413	413,719	597,500	441,433	156,067	72.1%	61.1%	69.2%
2019	317,003	94,280	411,283	597,500	441,433	156,067	71.8%	60.4%	68.8%

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 three fish every third haul).

Year	U.S.						Canada			
	Foreign (hauls)	Joint-Venture (hauls)	Mother-ship (hauls)	Combined Mother-ship Catcher-processor (hauls)	Catcher-processor (hauls)	Shore-based (trips)	Foreign (hauls)	Joint-Venture (hauls)	Shoreside (trips)	Freezer Trawlers (hauls)
1975	13	–	–	–	–	0	0	–	–	–
1976	142	–	–	–	–	0	0	–	–	–
1977	320	–	–	–	–	0	0	–	–	–
1978	336	5	–	–	–	0	0	0	–	–
1979	99	17	–	–	–	0	0	0	0	–
1980	191	30	–	–	–	0	0	0	0	–
1981	113	41	–	–	–	0	0	0	0	–
1982	52	118	–	–	–	0	0	0	–	–
1983	–	117	–	–	–	0	0	0	–	–
1984	49	74	–	–	–	0	0	0	–	–
1985	37	19	–	–	–	0	0	0	0	–
1986	88	32	–	–	–	0	0	0	0	–
1987	22	34	–	–	–	0	0	0	0	–
1988	39	42	–	–	–	0	0	3	0	–
1989	–	77	–	–	–	0	0	3	0	–
1990	–	143	–	0	–	15	0	5	0	–
1991	–	–	–	116	–	26	0	18	0	–
1992	–	–	–	164	–	46	–	33	0	–
1993	–	–	–	108	–	36	–	25	3	–
1994	–	–	–	143	–	50	–	41	1	–
1995	–	–	–	61	–	51	–	35	3	–
1996	–	–	–	123	–	35	–	28	1	–
1997	–	–	–	127	–	65	–	27	1	–
1998	–	–	–	149	–	64	–	21	9	–
1999	–	–	–	389	–	80	–	14	26	–
2000	–	–	–	413	–	91	–	25	1	–
2001	–	–	–	429	–	82	–	28	1	–
2002	–	–	–	342	–	71	–	–	36	–
2003	–	–	–	358	–	78	–	–	20	–
2004	–	–	–	381	–	72	–	20	28	–
2005	–	–	–	499	–	58	–	11	31	14
2006	–	–	–	549	–	83	–	21	21	46
2007	–	–	–	524	–	68	–	1	7	29
2008	–	–	324	–	356	63	–	0	20	31
2009	–	–	316	–	278	65	–	–	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	–	–	423	–	557	68	–	–	26	79
2015	–	–	203	–	431	84	–	–	6	74
2016	–	–	502	–	671	76	–	–	75	116
2017	–	–	353	–	684	112	–	–	75	76
2018	–	–	403	–	549	92	–	–	47	83
2019	–	–	286	–	494	92	–	–	48	81

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
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	1,162	549	5.42	35.76	1.05	26.03	2.14	2.65	2.69	19.36	2.50	1.25	0.28	0.40	0.29	0.10	0.07
2019	1,190	494	0.00	6.84	25.00	1.35	39.00	1.48	4.09	1.81	17.40	1.15	0.84	0.45	0.05	0.16	0.38

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
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	818	403	17.23	26.16	1.93	27.24	0.69	2.31	1.75	16.91	3.32	1.00	0.52	0.33	0.20	0.34	0.06
2019	824	286	0.00	15.17	20.36	0.94	36.52	1.24	4.01	1.61	16.51	1.46	1.08	0.44	0.50	0.15	0.01

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

Year	Number of fish	Number of trips	Age (% of total for each year)														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2010	1,584	75	0.09	32.90	1.93	37.37	16.29	1.64	2.96	0.14	0.66	1.01	3.87	0.70	0.14	0.00	0.31
2011	1,599	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	1,522	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	1,915	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	1,355	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	1,680	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	1,518	76	0.11	65.36	1.41	3.27	1.56	22.09	1.60	2.70	0.72	0.29	0.31	0.27	0.14	0.10	0.08
2017	2,236	112	3.68	0.70	35.37	2.63	3.66	2.51	43.02	2.90	2.12	1.67	0.64	0.53	0.27	0.11	0.20
2018	1,835	92	7.71	27.81	1.74	31.41	1.24	2.40	2.61	19.17	2.65	1.32	0.85	0.49	0.40	0.15	0.05
2019	1,826	92	0.00	17.23	21.96	0.90	30.78	1.84	3.36	1.87	16.75	1.54	1.77	0.80	0.56	0.32	0.33

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
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
2019	48	0.00	14.30	11.60	2.62	28.74	2.26	4.33	2.51	25.84	2.91	3.15	1.23	0.51	0.00	0.00

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
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
2019	81	0.05	17.09	15.62	4.11	19.02	2.36	3.96	5.20	23.39	5.31	2.47	0.61	0.36	0.46	0.00

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	9.80	30.53	2.40	14.42	1.03	3.63	3.17	28.09	3.05	1.15	0.73	0.50	0.31	0.43
2009	685	0.64	0.53	29.65	27.19	3.46	11.01	1.35	2.40	2.35	16.69	2.58	0.92	0.63	0.29	0.33
2010	874	0.03	25.61	3.38	35.09	21.35	2.30	2.94	0.43	0.58	0.97	5.86	0.91	0.29	0.10	0.16
2011	1,079	2.77	8.93	70.27	2.73	6.20	4.53	1.16	0.82	0.31	0.38	0.12	1.38	0.18	0.11	0.11
2012	851	0.18	40.89	11.56	33.01	2.49	5.09	2.52	1.13	0.66	0.23	0.33	0.35	0.87	0.28	0.39
2013	1,094	0.03	0.54	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	64.41	6.98	12.09	1.59	3.12	1.84	0.82	0.47	0.12	0.19	0.28	1.13
2015	798	3.59	1.14	6.88	3.95	70.01	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	50.18	1.69	4.47	2.48	32.88	2.78	3.23	0.76	0.44	0.37	0.24	0.06	0.05	0.07
2017	1,300	3.76	0.72	38.37	2.37	4.12	3.12	36.85	4.41	3.10	1.33	0.62	0.72	0.21	0.09	0.20
2018	1,174	7.35	25.52	1.49	26.97	1.52	2.80	3.04	22.78	4.31	1.91	0.94	0.55	0.41	0.31	0.10
2019	1,001	0.01	13.71	20.72	1.57	32.35	1.76	3.82	2.24	18.66	1.98	1.66	0.69	0.38	0.23	0.23

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	58	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
2019	75	0.00	10.72	27.24	1.51	31.32	2.50	3.18	2.68	16.12	2.28	0.96	0.36	0.38	0.47	0.28

Table 13. Summary of the acoustic surveys from 1995 to 2019.

Year	Start date	End date	Vessels	Biomass index (million t)	Sampling CV	Number of hauls with age samples
1995	1-Jul	1-Sep	Miller Freeman Ricker	1.318	0.086	69
1998	6-Jul	27-Aug	Miller Freeman Ricker	1.569	0.046	105
2001	15-Jun	18-Aug	Miller Freeman Ricker	0.862	0.102	57
2003	29-Jun	1-Sep	Ricker	2.138	0.062	71
2005	20-Jun	19-Aug	Miller Freeman	1.376	0.062	47
2007	20-Jun	21-Aug	Miller Freeman	0.943	0.074	69
2009	30-Jun	7-Sep	Miller Freeman Ricker	1.502	0.096	72
2011	26-Jun	10-Sep	Bell Shimada Ricker	0.675	0.113	46
2012	23-Jun	7-Sep	Bell Shimada Ricker F/V Forum Star	1.279	0.065	94
2013	13-Jun	11-Sep	Bell Shimada Ricker	1.929	0.062	67
2015	15-Jun	14-Sep	Bell Shimada Ricker	2.156	0.081	78
2017	22-Jun	13-Sep	Bell Shimada Nordic Pearl	1.418	0.063	58
2019	13-Jun	15-Sep	Bell Shimada Nordic Pearl	1.723	0.062	75

Table 14. Information on maturity and fecundity used in this assessment as shown in Figure 12. The sample sizes refer to the subset of samples in Table 15 for which age readings and histological estimates of maturity have been completed. The mean weight (kg) is based on a much larger set of samples. Mean fecundity is the product of maturity and mean weight, but note that year-specific fecundities from 1975–2019 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	0.094	0.000
2	276	0.261	0.257	0.067
3	348	0.839	0.383	0.321
4	333	0.961	0.485	0.466
5	299	0.920	0.532	0.490
6	221	0.928	0.581	0.539
7	81	0.926	0.646	0.598
8	70	0.957	0.712	0.681
9	36	0.944	0.769	0.726
10	51	0.980	0.854	0.837
11	26	0.962	0.925	0.890
12	18	1.000	0.964	0.964
13	24	0.958	1.060	1.015
14	22	0.955	1.003	0.958
15	8	0.900	1.031	0.928
16	9	0.900	1.031	0.928
17	2	0.900	1.031	0.928
18	1	0.900	1.031	0.928
19	0	0.900	1.031	0.928
20	0	0.900	1.031	0.928

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. (2018b).

Year	Canada Acoustic survey/Research (Summer)	U.S. Acoustic survey/Research (Summer)	U.S. Acoustic survey/Research (Winter)	U.S. At-sea Hake Observer Program (Spring)	U.S. At-sea Hake Observer Program (Fall)	Total
2009	0	0	0	0	0	**263**
2012	0	199	0	0	0	**270**
2013	0	254	0	104	103	**531**
2014	0	0	0	105	142	**523**
2015	0	193	0	98	112	**696**
2016	0	26	309	100	162	**874**
2017	0	65	134	93	113	**514**
2018	0	64	0	0	0	**213**
2019	15	106	0	0	0	**181**
Total	**15**	**907**	**443**	**500**	**632**	**4,065**

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

Parameter	Number of parameters	Bounds (low, high)	Prior (Mean, SD) single value = fixed
Stock Dynamics			
$\text{Log}(R_0)$	1	(13,17)	Uniform
Steepness (h)	1	(0.2,1)	Beta(0.78,0.11)
Recruitment variability (σ_r)	–	–	1.4
Log recruitment deviations: 1946–2019	74	(-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 variance 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 (1991–2019, ages 2–6)	145	–	Normal(0,1.4)
Data weighting			
Dirichlet-Multinomial likelihood ($\log \theta$)	2	(-5,20)	Normal(0,1.813)

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.

	2020 Base model	-1 year	-2 years	-3 years	-4 years	-5 years
Parameters						
Natural mortality (M)	0.209	0.209	0.208	0.209	0.208	0.208
R_0 (millions)	1,600	1,602	1,596	1,656	1,648	1,620
Steepness (h)	0.854	0.854	0.855	0.855	0.855	0.855
Additional acoustic survey SD	0.249	0.264	0.265	0.260	0.259	0.268
Dirichlet-Multinomial fishery (log θ_{fish})	-0.164	-0.155	-0.178	-0.221	-0.263	-0.302
Dirichlet-Multinomial survey (log θ_{surv})	2.246	2.008	2.011	1.600	1.585	1.298
Derived Quantities						
2010 recruitment (millions)	11,648	10,180	9,965	11,201	10,984	11,361
2014 recruitment (millions)	7,034	6,232	6,455	9,160	3,665	817
2016 recruitment (millions)	3,385	2,739	2,454	694	686	763
B_0 (thousand t)	1,385	1,387	1,385	1,431	1,431	1,405
2009 relative spawning biomass	36.7%	35.1%	34.8%	35.0%	36.1%	37.2%
2020 relative spawning biomass	62.6%	49.6%	42.8%	51.3%	26.5%	14.1%
Reference Points based on $F_{\mathbf{SPR}=40\%}$						
2019 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	89.2%	96.6%	97.5%	86.0%	106.3%	123.9%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	517	518	517	534	535	525
SPR$_{MSY\text{-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.0%	17.0%	17.0%	17.0%	17.0%	17.0%
Yield at $B_{F_{40\%}}$ (thousand t)	223	223	223	231	230	226
Negative log likelihoods						
Total	682.82	666.46	654.81	645.50	637.36	625.81
Survey	-7.95	-6.74	-6.68	-6.26	-6.31	-5.50
Survey age compositions	86.45	84.31	83.63	82.35	82.02	78.86
Fishery age compositions	538.86	524.53	515.35	509.08	502.52	495.39
Recruitment	49.82	48.81	47.88	46.94	45.68	44.90
Parameter priors	0.81	0.66	0.66	0.45	0.43	0.31
Parameter deviations	14.83	14.90	13.97	12.94	13.02	11.82

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
2020	SS 3.30.14.08	yes	0.87	DM (0.46, 0.92)	2,000	Add Normal prior for Dirichlet parameters

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	1,436	1,360	758	475	322	230	180	149	128	111	97	85	74	65	56	254
1967	3,155	1,166	1,103	604	369	245	172	128	106	91	79	69	61	53	46	221
1968	2,138	2,561	944	867	454	267	173	111	83	69	59	51	45	39	34	172
1969	664	1,735	2,076	752	672	344	199	122	79	58	49	42	36	32	28	146
1970	5,763	539	1,405	1,639	570	493	246	132	81	52	39	32	28	24	21	115
1971	661	4,678	436	1,102	1,224	409	343	156	84	51	33	25	20	18	15	86
1972	387	537	3,791	347	850	921	302	239	109	58	36	23	17	14	12	71
1973	3,835	314	435	3,033	272	655	701	221	175	80	43	26	17	13	10	61
1974	284	3,113	255	348	2,366	208	494	506	160	126	57	31	19	12	9	51
1975	1,195	231	2,523	203	269	1,785	154	347	355	112	89	40	22	13	9	42
1976	166	970	187	2,014	158	205	1,344	111	249	255	80	64	29	16	10	37
1977	4,531	134	786	150	1,580	122	156	986	81	183	187	59	47	21	11	34
1978	106	3,678	109	633	119	1,241	95	119	750	62	139	142	45	36	16	34
1979	955	86	2,983	88	503	94	971	73	91	574	47	106	109	34	27	39
1980	12,900	775	70	2,399	70	395	73	737	55	69	435	36	81	83	26	50
1981	195	10,470	629	56	1,913	55	310	56	568	42	53	335	28	62	64	59
1982	206	158	8,491	504	44	1,488	42	231	42	423	32	40	250	21	46	91
1983	381	167	128	6,829	400	35	1,159	32	176	32	321	24	30	190	16	104
1984	10,504	310	136	103	5,441	316	27	890	25	135	24	247	18	23	146	92
1985	103	8,526	251	109	82	4,284	247	21	680	19	103	19	189	14	18	182
1986	147	83	6,917	203	87	65	3,378	191	16	527	15	80	14	146	11	155
1987	4,987	119	68	5,558	160	68	51	2,549	144	12	397	11	60	11	110	125
1988	1,724	4,048	97	54	4,378	125	52	38	1,893	107	9	295	8	45	8	175
1989	118	1,400	3,283	77	43	3,389	95	39	28	1,397	79	7	218	6	33	135
1990	3,378	95	1,134	2,616	60	32	2,532	68	27	20	992	56	5	155	4	119
1991	1,047	2,742	77	908	2,052	46	25	1,858	50	20	14	728	41	3	114	91
1992	124	850	2,222	60	624	1,543	34	18	1,343	36	15	10	526	30	3	148
1993	2,589	101	689	1,776	43	441	1,150	24	12	933	25	10	7	366	21	104
1994	2,726	2,101	82	554	1,346	32	314	834	17	9	677	18	7	5	265	91
1995	1,071	2,213	1,704	66	438	954	22	196	520	11	6	422	11	5	3	222
1996	1,527	869	1,795	1,374	52	339	663	15	129	342	7	4	278	7	3	148
1997	845	1,240	703	1,365	1,018	38	248	410	9	80	212	4	2	172	5	93
1998	1,590	686	1,006	565	952	686	27	153	253	6	49	131	3	1	106	60
1999	10,555	1,291	556	793	353	656	399	17	95	156	3	30	81	2	1	103
2000	313	8,568	1,046	404	520	198	409	239	10	57	94	2	18	48	1	62
2001	992	254	6,951	837	296	376	133	253	147	6	35	58	1	11	30	39
2002	29	805	206	5,591	624	197	253	87	164	96	4	23	38	1	7	45
2003	1,390	23	653	166	4,412	462	138	181	62	118	69	3	16	27	1	37
2004	78	1,128	19	529	133	3,368	335	99	130	45	85	49	2	12	19	27
2005	2,191	63	915	15	397	80	2,364	223	66	86	30	56	33	1	8	31
2006	1,658	1,779	51	737	12	279	47	1,518	143	42	56	19	36	21	1	25
2007	22	1,346	1,440	37	527	8	166	28	907	86	25	33	11	22	13	15
2008	4,332	18	1,091	1,111	24	344	5	96	16	526	50	15	19	7	13	16
2009	1,136	3,516	15	841	728	17	200	3	51	9	280	26	8	10	4	15
2010	11,648	922	2,852	12	598	501	12	124	2	32	5	173	16	5	6	12
2011	372	9,454	748	2,200	8	317	307	8	82	1	21	4	114	11	3	12
2012	1,038	302	7,655	586	1,241	5	214	212	5	56	1	14	2	79	7	10
2013	293	842	244	6,009	429	816	4	152	150	4	40	1	10	2	56	13
2014	7,034	238	683	196	4,461	317	590	3	100	99	3	26	0	7	1	45
2015	63	5,709	193	538	142	3,286	229	397	2	67	67	2	18	0	5	31
2016	3,385	51	4,621	154	408	105	2,406	171	297	1	50	50	1	13	0	27
2017	1,659	2,748	41	3,336	113	288	74	1,678	119	207	1	35	35	1	9	19
2018	276	1,347	2,198	30	2,388	76	193	46	1,042	74	129	1	22	22	1	17
2019	1,579	224	1,051	1,564	22	1,728	54	120	29	650	46	80	0	14	13	11
2020	1,561	1,282	182	766	1,101	16	1,163	32	70	17	380	27	47	0	8	14

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	24	128	194	182	156	122	104	96	91	86	83	79	72	69	56	50	43	36	31	26	76
1967	53	110	283	231	179	130	100	83	76	70	68	64	58	56	46	41	35	30	26	22	73
1968	36	241	242	332	220	142	100	72	59	53	50	47	43	41	34	31	27	23	20	17	61
1969	11	163	533	288	326	183	115	79	56	45	41	39	35	33	28	25	22	19	16	14	55
1970	97	51	361	627	276	262	143	85	58	40	33	30	27	25	21	19	17	14	12	11	46
1971	11	441	112	422	593	218	199	101	60	39	28	23	20	19	15	14	12	10	9	8	36
1972	7	51	973	133	412	490	175	155	77	45	31	21	17	15	12	11	10	8	7	6	30
1973	65	30	112	1,161	132	349	407	143	125	61	37	24	16	13	10	9	8	7	6	5	27
1974	5	293	65	133	1,147	111	287	326	114	97	49	29	18	13	9	8	7	6	5	4	23
1975	66	36	754	74	165	1,126	121	303	343	102	86	68	32	25	17	17	14	12	11	9	52
1976	9	96	44	1,005	82	142	1,081	102	301	340	117	105	52	29	19	17	13	10	9	8	44
1977	249	11	316	73	933	81	117	816	80	202	231	78	66	37	24	15	10	7	6	5	31
1978	5	267	14	297	63	748	61	88	632	61	153	177	60	53	28	20	12	8	6	5	29
1979	46	7	719	23	293	64	746	65	83	595	57	133	167	53	49	25	13	8	5	4	22
1980	583	62	15	1,087	27	194	38	483	39	60	463	42	104	107	33	29	13	7	4	3	14
1981	8	1,125	134	19	1,007	22	163	31	424	31	44	349	30	84	95	24	19	9	5	3	11
1982	8	19	2,093	168	14	818	17	122	24	322	22	34	267	18	47	55	17	14	6	3	10
1983	13	22	17	2,329	148	11	603	16	109	22	283	22	31	196	21	52	53	17	13	6	13
1984	337	41	22	26	2,385	130	12	523	14	91	17	235	21	24	187	23	51	52	16	13	18
1985	3	1,484	58	29	36	2,355	135	13	507	13	75	16	164	13	12	125	10	23	24	7	14
1986	4	13	1,923	59	26	24	1,833	109	10	432	14	95	17	201	18	22	139	11	26	26	24
1987	111	18	9	2,107	45	20	18	1,472	86	8	304	11	56	14	133	12	15	92	8	17	34
1988	33	567	18	17	2,063	46	20	19	1,225	74	7	272	9	46	12	119	9	11	70	6	39
1989	2	194	898	24	13	1,740	42	16	14	875	52	4	191	4	27	7	68	5	6	40	25
1990	53	13	276	917	23	17	1,383	41	18	10	763	47	10	183	4	34	6	63	5	6	61
1991	16	375	21	336	944	24	13	1,098	36	17	16	523	26	4	137	8	41	7	75	6	79
1992	2	115	515	21	296	823	20	11	860	23	9	8	387	25	2	84	2	13	2	23	26
1993	40	13	171	601	17	200	568	12	6	513	13	13	7	224	12	1	39	1	6	1	23
1994	42	250	24	201	602	14	165	476	11	5	429	9	5	4	186	11	1	31	1	5	19
1995	16	245	457	22	213	512	14	122	343	8	4	314	9	4	2	132	8	1	21	1	16
1996	23	88	516	547	24	180	375	10	77	218	4	3	188	6	4	2	82	5	0	13	10
1997	13	112	250	590	502	21	135	239	5	48	134	4	1	122	3	2	1	58	3	0	16
1998	24	55	210	200	480	355	15	98	154	4	40	94	2	1	80	2	1	1	33	2	9
1999	160	174	139	274	150	345	222	10	58	110	2	24	61	1	1	54	1	1	0	21	7
2000	5	1,627	336	191	300	131	294	174	8	47	76	2	16	45	1	0	37	1	0	0	19
2001	15	13	1,993	405	193	250	100	218	126	5	34	57	1	12	30	1	0	24	1	0	13
2002	0	61	74	2,558	378	161	192	74	161	89	4	23	37	1	8	21	0	0	17	0	9
2003	21	2	167	72	2,305	272	105	125	47	97	53	3	15	21	1	5	14	0	0	11	6
2004	1	122	4	231	64	1,792	217	70	85	32	68	42	2	11	17	0	3	9	0	0	11
2005	33	7	238	6	202	43	1,343	141	43	61	24	46	27	1	9	12	0	2	6	0	8
2006	25	236	20	337	6	160	28	908	94	30	40	14	28	14	1	5	8	0	2	4	5
2007	0	60	327	14	282	4	101	18	587	60	20	25	9	19	10	0	3	4	0	1	5
2008	66	2	266	453	14	219	3	66	12	379	37	12	16	5	11	6	0	1	2	0	3
2009	18	235	4	288	343	11	134	2	38	7	215	22	8	9	3	7	4	0	1	2	2
2010	188	100	663	3	259	266	8	103	2	33	5	152	14	5	5	2	4	2	0	1	2
2011	6	798	184	708	3	163	183	5	70	1	21	4	121	11	3	4	1	3	1	0	2
2012	18	39	1,642	207	508	3	140	146	4	51	1	14	2	78	7	2	3	1	2	1	1
2013	5	109	70	2,160	201	416	2	109	110	3	40	1	13	2	60	6	2	2	1	1	2
2014	125	24	279	92	2,140	170	339	2	66	71	2	31	0	6	1	39	4	1	1	0	2
2015	1	433	48	210	63	1,547	127	236	1	46	48	1	17	0	5	1	31	3	1	1	2
2016	63	8	1,127	59	170	46	1,116	88	153	1	33	36	1	10	0	5	1	29	3	1	3
2017	32	386	13	1,338	53	147	39	910	68	128	1	24	26	1	7	0	2	0	12	1	2
2018	5	252	779	14	1,201	41	107	28	614	47	83	0	15	16	1	6	0	2	0	9	2
2019	32	15	296	690	11	903	29	70	18	401	29	55	0	11	9	0	3	0	1	0	5
2020	30	163	52	318	510	8	615	18	42	10	247	19	34	0	8	9	0	2	0	1	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	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0.00	0.13	1.60	3.87	5.68	7.00	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02
1967	0.00	0.23	2.81	6.72	9.79	11.99	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55	18.55
1968	0.00	0.14	1.72	4.15	6.09	7.50	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78	11.78
1969	0.00	0.20	2.46	5.91	8.63	10.59	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46	16.46
1970	0.00	0.25	3.02	7.23	10.52	12.87	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85	19.85
1971	0.00	0.15	1.87	4.52	6.62	8.15	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78	12.78
1972	0.00	0.10	1.27	3.08	4.53	5.59	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85
1973	0.00	0.12	1.46	3.53	5.19	6.40	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09	10.09
1974	0.00	0.15	1.80	4.34	6.36	7.83	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29
1975	0.00	0.12	1.49	3.61	5.30	6.54	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30	10.30
1976	0.00	0.10	1.25	3.02	4.45	5.49	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69	8.69
1977	0.00	0.07	0.81	1.97	2.91	3.59	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72	5.72
1978	0.00	0.06	0.73	1.78	2.63	3.25	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18	5.18
1979	0.00	0.07	0.84	2.03	3.00	3.71	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90	5.90
1980	0.00	0.05	0.65	1.58	2.34	2.89	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61	4.61
1981	0.00	0.08	1.05	2.55	3.76	4.65	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
1982	0.00	0.07	0.82	2.00	2.95	3.65	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81	5.81
1983	0.00	0.06	0.69	1.67	2.47	3.05	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87	4.87
1984	0.00	0.06	0.75	1.83	2.70	3.34	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32
1985	0.00	0.05	0.58	1.41	2.08	2.58	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12
1986	0.00	0.07	0.91	2.20	3.25	4.01	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38	6.38
1987	0.00	0.09	1.10	2.67	3.93	4.85	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.69
1988	0.00	0.09	1.17	2.85	4.19	5.18	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20
1989	0.00	0.13	1.65	3.99	5.85	7.20	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33
1990	0.00	0.10	1.24	3.01	4.44	5.47	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66
1991	0.00	0.13	3.79	13.86	6.66	7.80	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93	9.93
1992	0.00	0.12	1.39	10.03	11.79	7.40	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98	12.98
1993	0.00	0.07	0.82	5.98	9.47	10.95	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59	9.59
1994	0.00	0.07	0.89	2.49	11.47	11.94	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09	21.09
1995	0.00	0.07	0.60	1.98	4.10	12.98	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11	17.11
1996	0.00	0.24	5.70	7.92	8.07	8.85	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64	21.64
1997	0.00	0.07	0.93	12.75	15.32	11.45	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75	21.75
1998	0.00	0.15	2.55	20.83	13.66	25.83	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74	21.74
1999	0.00	0.17	9.42	17.37	28.03	21.00	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79	23.79
2000	0.00	0.04	1.26	8.95	9.95	15.60	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73
2001	0.00	0.06	0.82	7.37	16.31	15.59	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89	17.89
2002	0.00	0.03	0.40	2.52	7.89	12.20	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48	10.48
2003	0.00	0.02	0.26	1.58	5.36	9.65	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66	10.66
2004	0.00	0.09	1.67	6.71	23.06	12.26	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23
2005	0.00	0.05	0.63	3.51	12.29	24.71	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90	18.90
2006	0.00	0.22	10.65	10.83	16.64	24.07	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98	23.98
2007	0.00	0.16	4.53	17.16	17.71	17.22	25.87	25.88	25.88	25.88	25.88	25.88	25.87	25.87	25.88	25.87	25.87	25.88	25.88	25.88	25.88
2008	0.00	0.38	4.53	17.45	12.70	25.81	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27	31.27
2009	0.00	0.08	1.81	11.19	13.71	10.93	21.59	21.59	21.59	21.73	21.59	21.59	21.59	21.59	21.59	21.59	21.59	21.59	21.59	21.59	21.59
2010	0.00	0.08	4.48	12.28	31.51	22.29	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90	16.90
2011	0.00	0.23	3.19	27.71	16.39	15.26	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50
2012	0.00	0.22	2.96	8.91	17.22	11.43	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49	11.49
2013	0.00	0.07	1.05	7.73	8.06	9.88	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23	17.23
2014	0.00	0.14	2.77	9.58	8.36	9.97	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39	15.39
2015	0.00	0.26	1.65	5.86	7.87	8.86	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23
2016	0.00	0.97	10.01	8.27	11.86	12.45	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73
2017	0.00	1.32	8.27	10.67	16.04	15.75	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
2018	0.00	3.48	11.13	8.28	9.83	10.45	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97	20.97
2019	0.00	0.32	9.28	12.04	10.07	15.45	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32	25.32

Table 22. Estimated catch-at-age in numbers for each year from the base model (MLE; thousands).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0	1,761	12,144	18,390	18,321	16,116	19,807	16,456	14,124	12,272	10,710	9,375	8,178	7,125	6,183	5,322	4,557	3,878	3,282	2,762	8,165
1967	0	2,659	30,936	40,600	36,104	29,395	31,962	23,759	19,738	16,942	14,721	12,847	11,246	9,810	8,546	7,416	6,383	5,466	4,652	3,937	13,107
1968	0	3,558	16,221	35,992	27,640	20,016	20,330	13,101	9,738	8,090	6,944	6,034	5,266	4,609	4,021	3,503	3,040	2,616	2,240	1,907	6,986
1969	0	3,465	51,085	44,414	57,937	36,390	32,714	20,058	12,925	9,608	7,982	6,851	5,953	5,195	4,548	3,967	3,456	2,999	2,581	2,210	8,773
1970	0	1,327	42,507	118,506	59,975	63,485	48,913	26,214	16,072	10,357	7,699	6,396	5,490	4,770	4,163	3,644	3,179	2,769	2,403	2,068	8,801
1971	0	7,092	8,175	49,832	81,062	33,332	43,864	19,953	10,694	6,556	4,225	3,141	2,609	2,239	1,946	1,698	1,487	1,297	1,130	980	4,434
1972	0	551	48,205	10,687	38,536	51,495	26,718	21,170	9,630	5,161	3,164	2,039	1,516	1,259	1,081	939	820	717	626	545	2,613
1973	0	370	6,354	107,183	14,112	41,943	70,752	22,324	17,689	8,046	4,312	2,644	1,704	1,266	1,052	903	785	685	599	523	2,639
1974	0	4,526	4,578	15,077	150,479	16,283	60,736	62,113	19,598	15,529	7,064	3,786	2,321	1,496	1,112	924	793	689	601	526	2,776
1975	0	278	37,642	7,313	14,238	116,675	15,886	35,723	36,533	11,527	9,133	4,155	2,227	1,365	880	654	543	466	405	354	1,942
1976	0	976	2,332	60,906	7,023	11,265	116,755	9,633	21,661	22,152	6,989	5,538	2,519	1,350	828	533	397	329	283	246	1,392
1977	0	88	6,369	2,947	45,907	4,377	8,948	56,420	4,655	10,467	10,704	3,378	2,676	1,217	652	400	258	192	159	137	791
1978	0	2,164	797	11,262	3,121	40,343	4,919	6,161	38,850	3,205	7,208	7,371	2,326	1,843	838	449	275	177	132	110	639
1979	0	58	24,951	1,785	15,100	3,472	57,328	4,289	5,372	33,870	2,794	6,284	6,426	2,028	1,607	731	392	240	155	115	653
1980	0	405	453	37,946	1,626	11,418	3,361	33,988	2,543	3,185	20,080	1,657	3,725	3,810	1,202	952	433	232	142	92	455
1981	0	8,875	6,615	1,436	71,965	2,558	22,878	4,137	41,836	3,130	3,920	24,718	2,039	4,586	4,690	1,480	1,172	533	286	175	673
1982	0	105	69,893	10,098	1,309	54,338	2,464	13,448	2,432	24,592	1,840	2,304	14,529	1,199	2,695	2,757	870	689	313	168	499
1983	0	92	880	114,045	9,871	1,062	56,397	1,566	8,550	1,546	15,636	1,170	1,465	9,238	762	1,714	1,753	553	438	199	424
1984	0	187	1,021	1,892	146,974	10,563	1,454	47,397	1,316	7,186	1,299	13,140	983	1,231	7,764	641	1,440	1,473	465	368	524
1985	0	3,968	1,454	1,541	1,713	110,534	10,184	860	28,027	778	4,249	768	7,770	581	728	4,591	379	852	871	275	527
1986	0	61	62,668	4,460	2,833	2,615	215,488	12,211	1,031	33,604	933	5,095	921	9,317	697	873	5,504	454	1,021	1,044	962
1987	0	106	744	148,284	6,301	3,313	3,887	195,999	11,106	937	30,565	849	4,634	838	8,474	634	794	5,007	413	929	1,825
1988	0	3,835	1,135	1,547	183,610	6,447	4,300	3,077	155,162	8,792	742	24,197	672	3,668	663	6,708	502	629	3,963	327	2,180
1989	0	1,865	54,137	3,084	2,495	244,101	10,795	4,386	3,139	158,254	8,968	757	24,679	685	3,742	677	6,842	512	641	4,042	2,557
1990	0	96	14,109	78,864	2,663	1,773	219,226	5,859	2,380	1,704	85,896	4,867	411	13,395	372	2,031	367	3,714	278	348	3,582
1991	0	3,684	2,934	125,828	136,688	3,617	2,454	184,567	4,933	2,004	1,434	72,316	4,098	346	11,277	313	1,710	309	3,127	234	3,309
1992	0	988	30,965	6,040	73,612	114,209	4,462	2,317	174,303	4,659	1,893	1,354	68,294	3,870	327	10,650	296	1,615	292	2,953	3,345
1993	0	68	5,640	106,145	4,113	48,241	110,299	2,292	1,190	89,528	2,393	972	696	35,078	1,988	168	5,470	152	829	150	3,235
1994	0	1,371	725	13,826	154,445	3,768	66,308	175,988	3,657	1,899	142,847	3,818	1,551	1,110	55,969	3,172	268	8,728	242	1,323	5,401
1995	0	1,625	10,272	1,302	17,931	123,825	3,806	33,512	88,944	1,848	960	72,195	1,930	784	561	28,287	1,603	135	4,411	123	3,398
1996	0	2,074	102,316	108,826	4,205	30,006	143,564	3,169	27,900	74,049	1,539	799	60,105	1,606	653	467	23,550	1,334	113	3,672	2,931
1997	0	855	6,510	174,054	155,950	4,410	54,000	89,181	1,968	17,331	45,999	956	496	37,337	998	405	290	14,629	829	70	4,102
1998	0	1,056	25,592	117,715	129,956	177,299	5,932	33,302	54,998	1,214	10,688	28,368	589	306	23,026	615	250	179	9,022	511	2,573
1999	0	2,162	52,334	137,785	99,050	137,713	94,834	4,007	22,496	37,152	820	7,220	19,163	398	207	15,554	416	169	121	6,094	2,083
2000	0	3,730	13,184	36,193	51,761	30,945	88,884	51,858	2,191	12,302	20,316	448	3,948	10,479	218	113	8,505	227	92	66	4,472
2001	0	160	56,952	61,680	48,222	58,610	23,841	45,189	26,365	1,114	6,254	10,329	228	2,007	5,327	111	57	4,324	116	47	2,307
2002	0	250	815	140,758	49,206	23,996	26,485	9,098	17,245	10,061	425	2,387	3,942	87	766	2,033	42	22	1,650	44	898
2003	0	5	1,698	2,634	236,652	44,601	14,730	19,329	6,640	12,586	7,343	310	1,742	2,877	63	559	1,484	31	16	1,204	688
2004	0	1,050	315	35,464	30,583	413,124	54,384	16,051	21,062	7,235	13,714	8,001	338	1,898	3,135	69	609	1,617	34	17	2,062
2005	0	32	5,768	527	48,820	19,838	446,681	42,206	12,457	16,346	5,615	10,643	6,210	262	1,473	2,433	54	473	1,255	26	1,614
2006	0	3,851	5,472	79,842	1,947	67,103	11,373	364,160	34,409	10,155	13,326	4,578	8,677	5,062	214	1,201	1,983	44	385	1,023	1,337
2007	0	2,104	65,238	6,316	93,339	1,335	43,014	7,327	234,612	22,168	6,543	8,585	2,949	5,590	3,261	138	774	1,278	28	248	1,520
2008	0	69	49,404	193,794	3,076	88,806	1,593	30,170	5,139	164,557	15,549	4,589	6,022	2,069	3,921	2,288	97	543	896	20	1,240
2009	0	2,728	263	94,106	99,762	1,847	43,146	586	11,090	1,889	60,487	5,715	1,687	2,213	760	1,441	841	36	199	329	463
2010	0	778	127,766	1,417	188,439	111,740	2,038	20,887	284	5,369	915	29,282	2,767	817	1,072	368	698	407	17	97	384
2011	0	21,819	23,886	609,516	1,327	48,419	41,439	1,075	11,022	150	2,833	483	15,452	1,460	431	565	194	368	215	9	253
2012	0	655	226,793	52,171	213,647	615	24,599	24,356	632	6,478	88	1,665	284	9,082	858	253	332	114	216	126	154
2013	0	593	2,576	464,338	34,555	80,583	658	26,140	25,882	672	6,884	93	1,769	301	9,651	912	269	353	121	230	298
2014	0	328	18,900	18,777	372,799	31,600	90,818	386	15,348	15,197	394	4,042	55	1,039	177	5,667	535	158	207	71	310
2015	0	15,014	3,179	31,502	11,185	291,020	16,543	28,737	122	4,857	4,809	125	1,279	17	329	56	1,793	169	50	66	121
2016	0	492	462,528	12,702	48,398	13,125	306,421	21,758	37,796	161	6,388	6,325	164	1,682	23	432	74	2,358	223	66	245
2017	0	36,287	3,373	355,915	18,168	45,336	15,736	357,975	25,419	44,155	188	7,462	7,389	192	1,965	27	505	86	2,755	260	363
2018	0	46,843	244,586	2,492	234,748	7,910	40,484	9,605	218,508	15,516	26,952	115	4,555	4,510	117	1,200	16	308	53	1,682	380
2019	0	718	97,499	188,319	2,234	266,968	13,756	30,496	7,235	164,600	11,688	20,303	86	3,431	3,397	88	904	12	232	40	1,553

Table 23. Estimated catch-at-age in biomass for each year from the base model (MLE; metric tons).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0	166	3,116	7,038	8,882	8,577	11,506	10,627	10,052	9,444	9,150	8,675	7,886	7,551	6,201	5,486	4,698	3,998	3,383	2,848	8,417
1967	0	250	7,938	15,538	17,503	15,644	18,567	15,343	14,048	13,037	12,576	11,887	10,844	10,396	8,572	7,645	6,581	5,635	4,796	4,058	13,512
1968	0	335	4,162	13,774	13,400	10,653	11,810	8,460	6,931	6,226	5,932	5,583	5,078	4,885	4,033	3,611	3,134	2,697	2,310	1,966	7,202
1969	0	326	13,109	16,997	28,088	19,367	19,004	12,953	9,199	7,393	6,819	6,339	5,740	5,506	4,561	4,090	3,563	3,092	2,661	2,279	9,045
1970	0	125	10,907	45,352	29,076	33,787	28,414	16,929	11,439	7,970	6,577	5,918	5,294	5,055	4,175	3,757	3,277	2,855	2,477	2,132	9,073
1971	0	668	2,098	19,071	39,299	17,739	25,481	12,886	7,611	5,045	3,609	2,906	2,516	2,373	1,952	1,751	1,532	1,337	1,165	1,011	4,571
1972	0	52	12,369	4,090	18,682	27,406	15,520	13,672	6,854	3,971	2,703	1,887	1,462	1,335	1,084	968	845	740	645	562	2,694
1973	0	35	1,631	41,019	6,841	22,322	41,100	14,417	12,589	6,192	3,684	2,446	1,643	1,342	1,055	931	809	706	618	539	2,721
1974	0	426	1,175	5,770	72,952	8,666	35,282	40,112	13,948	11,949	6,035	3,503	2,238	1,585	1,115	952	817	710	620	543	2,862
1975	0	44	11,244	2,675	8,746	73,575	12,507	31,215	35,356	10,461	8,859	7,035	3,340	2,594	1,720	1,795	1,491	1,280	1,112	970	5,330
1976	0	96	550	30,392	3,644	7,813	93,848	8,828	26,129	29,539	10,131	9,142	4,551	2,510	1,619	1,464	1,088	904	776	674	3,820
1977	0	7	2,560	1,439	27,094	2,911	6,701	46,671	4,552	11,568	13,210	4,441	3,754	2,132	1,370	884	570	423	352	302	1,749
1978	0	157	102	5,292	1,655	24,311	3,144	4,557	32,720	3,145	7,926	9,183	3,092	2,730	1,460	1,049	643	415	308	256	1,492
1979	0	4	6,013	462	8,790	2,385	44,011	3,821	4,903	35,120	3,350	7,843	9,849	3,147	2,884	1,448	776	476	307	228	1,293
1980	0	32	96	17,186	638	5,599	1,736	22,276	1,814	2,783	21,338	1,926	4,805	4,953	1,527	1,330	605	324	199	128	635
1981	0	953	1,414	491	37,882	1,006	12,020	2,260	31,227	2,255	3,227	25,738	2,241	6,167	7,000	1,795	1,422	647	347	213	816
1982	0	12	17,229	3,369	405	29,864	975	7,094	1,369	18,704	1,258	1,968	15,503	1,054	2,746	3,223	1,017	806	367	196	583
1983	0	12	119	38,889	3,646	348	29,326	788	5,283	1,092	13,759	1,088	1,517	9,524	1,007	2,540	2,598	820	650	295	628
1984	0	25	168	472	64,433	4,344	633	27,832	764	4,856	911	12,500	1,117	1,263	9,943	1,204	2,708	2,769	874	692	985
1985	0	691	334	413	756	60,749	5,575	517	20,886	540	3,073	660	6,759	550	492	5,149	425	955	977	308	592
1986	0	9	17,422	1,296	857	977	116,924	6,985	662	27,586	878	6,042	1,096	12,798	1,171	1,409	8,885	733	1,648	1,686	1,553
1987	0	16	103	56,200	1,755	951	1,408	113,189	6,636	597	23,346	834	4,286	1,040	10,195	897	1,124	7,088	585	1,315	2,583
1988	0	537	212	493	86,499	2,378	1,604	1,589	100,405	6,053	533	22,288	734	3,751	962	9,752	730	914	5,762	475	3,169
1989	0	259	14,817	940	731	125,321	4,735	1,782	1,622	99,114	5,928	456	21,614	458	3,099	762	7,707	577	722	4,553	2,880
1990	0	13	3,436	27,650	1,040	906	119,741	3,560	1,590	903	66,114	4,046	904	15,869	378	2,979	539	5,447	407	510	5,254
1991	0	504	808	46,519	62,849	1,858	1,334	109,024	3,557	1,703	1,577	51,959	2,624	352	13,590	746	4,074	737	7,450	557	7,884
1992	0	134	7,171	2,098	34,964	60,919	2,596	1,439	111,659	3,042	1,198	978	50,223	3,290	318	10,940	304	1,659	300	3,033	3,436
1993	0	9	1,402	35,919	1,629	21,897	54,433	1,150	581	49,160	1,220	1,228	713	21,521	1,192	115	3,747	104	568	103	2,216
1994	0	163	218	5,013	69,021	1,685	34,891	100,313	2,274	1,063	90,579	1,852	1,007	810	39,251	2,364	200	6,507	181	987	4,026
1995	0	180	2,755	445	8,743	66,457	2,476	20,942	58,677	1,397	640	53,749	1,543	713	382	22,652	1,284	108	3,532	98	2,721
1996	0	209	29,426	43,335	1,965	15,954	81,128	2,063	16,620	47,110	931	599	40,607	1,303	969	351	17,684	1,002	85	2,758	2,201
1997	0	77	2,314	75,226	76,899	2,415	29,446	52,020	1,153	10,522	29,048	825	295	26,576	660	352	252	12,717	721	61	3,566
1998	0	85	5,351	41,659	65,511	91,699	3,215	21,353	33,543	822	8,634	20,351	477	237	17,292	491	199	143	7,198	408	2,053
1999	0	292	13,094	47,605	42,106	72,506	52,813	2,295	13,761	26,118	545	5,768	14,476	350	152	12,734	340	138	99	4,989	1,706
2000	0	708	4,240	17,116	29,845	20,418	63,783	37,748	1,652	10,306	16,576	395	3,377	9,841	190	106	7,941	212	86	62	4,175
2001	0	8	16,328	29,872	31,475	38,947	17,807	38,993	22,555	981	6,023	10,112	229	2,106	5,289	108	56	4,224	113	46	2,254
2002	0	19	292	64,397	29,809	19,581	20,078	7,723	16,850	9,379	390	2,380	3,898	80	862	2,150	45	23	1,745	47	950
2003	0	0	433	1,147	123,651	26,248	11,149	13,366	4,959	10,378	5,648	276	1,614	2,271	53	557	1,479	31	16	1,200	685
2004	0	113	63	15,462	14,701	219,741	35,230	11,345	13,856	5,133	11,040	6,866	261	1,842	2,705	62	546	1,448	30	16	1,847
2005	0	4	1,501	227	24,830	10,699	253,804	26,742	8,159	11,486	4,471	8,625	5,035	199	1,686	2,354	52	458	1,214	25	1,562
2006	0	510	2,096	36,528	1,040	38,517	6,721	217,731	22,572	7,106	9,673	3,305	6,727	3,331	137	1,147	1,894	42	368	977	1,277
2007	0	94	14,822	2,385	49,955	738	26,122	4,637	151,911	15,640	5,053	6,548	2,400	4,864	2,612	120	673	1,111	25	216	1,322
2008	0	9	12,055	79,049	1,732	56,525	1,094	20,570	3,648	118,662	11,643	3,705	5,108	1,604	3,464	1,906	81	452	747	16	1,034
2009	0	182	64	32,288	47,000	1,176	28,916	407	8,276	1,554	46,418	4,652	1,712	1,882	729	1,489	869	37	206	340	479
2010	0	85	29,718	414	81,632	59,245	1,341	17,439	307	5,517	876	25,660	2,358	919	772	332	629	367	16	87	346
2011	0	1,841	5,869	196,203	513	24,897	24,656	725	9,406	139	2,771	519	16,360	1,501	455	521	179	339	198	8	233
2012	0	84	48,647	18,448	87,467	301	16,142	16,823	491	5,877	85	1,605	273	8,981	852	239	313	108	204	119	145
2013	0	77	740	166,930	16,231	41,130	412	18,729	18,920	558	6,876	100	2,177	337	10,309	962	284	372	128	242	314
2014	0	34	7,711	8,799	178,832	16,944	52,138	239	10,115	10,902	274	4,707	56	986	171	5,995	566	167	219	75	328
2015	0	1,140	786	12,302	4,972	137,012	9,150	17,093	82	3,341	3,452	104	1,218	18	358	70	2,240	212	62	82	151
2016	0	81	112,811	4,866	20,129	5,783	142,118	11,186	19,518	82	4,139	4,552	98	1,305	33	683	116	3,727	352	104	387
2017	0	5,098	1,051	142,758	8,539	23,126	8,390	194,058	14,519	27,292	115	5,147	5,581	144	1,566	24	451	77	2,457	232	324
2018	0	8,760	86,681	1,154	118,055	4,238	22,339	5,930	128,832	9,919	17,333	77	3,137	3,264	105	1,284	17	330	56	1,799	407
2019	0	49	27,456	83,049	1,082	139,571	7,426	17,730	4,504	101,641	7,371	13,910	56	2,888	2,307	70	717	10	184	31	1,232

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. Estimated quantities are MLEs.

	1999 cohort				2010 cohort				2014 cohort				2016 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	Start Biomass 000s t	Catch Weight 000s t	M 000s t	Surviving Biomass 000s t
0	160.4	0.0	30.2	130.2	187.5	0.0	35.3	152.2	125.2	0.0	23.6	101.6	63.3	0.0	11.9	51.4
1	1,627.0	0.7	306.3	1,320.0	798.0	1.8	150.1	646.0	433.3	1.1	81.5	350.7	386.1	5.1	72.2	308.8
2	1,992.8	16.3	373.6	1,602.9	1,641.9	48.6	304.2	1,289.0	1,127.0	112.8	200.6	813.5	778.9	86.7	137.8	554.4
3	2,557.8	64.4	475.1	2,018.3	2,160.4	166.9	389.8	1,603.7	1,337.9	142.8	237.3	957.9	689.9	83.0	121.4	485.5
4	2,305.1	123.7	421.5	1,760.0	2,139.9	178.8	384.7	1,576.4	1,201.0	118.1	214.0	868.9	510.3			
5	1,791.6	219.7	314.7	1,257.1	1,547.2	137.0	277.3	1,132.8	903.3	139.6	155.6	608.1				
6	1,342.9	253.8	226.4	862.7	1,116.0	142.1	195.5	778.4	614.5							
7	907.8	217.7	148.0	542.1	909.8	194.1	151.0	564.8								
8	587.1	151.9	94.5	340.7	614.3	128.8	102.2	383.3								
9	379.5	118.7	58.7	202.1	401.4	101.6	64.8	234.9								
10	215.0	46.4	35.6	133.0	247.5											
11	151.9	25.7	25.9	100.3												
12	121.2	16.4	21.1	83.7												
13	78.2	9.0	13.8	55.4												
14	59.8	10.3	10.2	39.3												
15	38.9	6.0	6.7	26.2												
16	31.0	2.2	5.6	23.1												
17	29.3	3.7	5.1	20.4												
18	11.5	2.5	1.9	7.2												
19	8.6	1.8	0.2	6.6												
20	4.9															

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	839	45.6%	2,214	2,018	1,407	50.7%	6.8%
1967	836	45.9%	2,296	2,080	4,317	69.0%	10.3%
1968	835	45.8%	2,411	2,024	2,718	50.4%	6.0%
1969	912	50.5%	2,725	2,488	715	62.4%	7.2%
1970	1,072	59.7%	2,907	2,699	8,269	68.7%	8.7%
1971	1,103	61.5%	3,155	2,502	776	51.4%	6.2%
1972	1,174	65.6%	3,559	3,489	496	39.4%	3.4%
1973	1,517	84.3%	3,643	3,506	5,481	43.1%	4.6%
1974	1,491	83.3%	3,658	3,236	353	49.9%	6.5%
1975	1,725	96.2%	4,588	4,450	1,679	54.5%	6.2%
1976	2,117	118.2%	4,831	4,685	202	47.4%	5.9%
1977	1,819	101.5%	4,513	4,160	6,114	31.9%	3.2%
1978	1,541	85.7%	3,683	3,324	143	31.4%	2.8%
1979	1,603	89.2%	4,159	4,078	1,281	33.9%	4.1%
1980	1,615	89.5%	4,389	3,583	16,291	26.3%	2.5%
1981	1,470	81.3%	4,603	3,206	263	38.3%	4.7%
1982	1,499	83.4%	5,116	5,078	303	32.1%	2.4%
1983	2,133	118.3%	4,898	4,844	506	30.6%	2.6%
1984	2,198	121.6%	5,136	4,649	13,248	35.5%	3.4%
1985	1,981	109.2%	6,150	4,314	140	23.9%	3.0%
1986	1,991	109.9%	5,978	5,956	184	41.9%	4.0%
1987	2,326	128.3%	5,396	5,238	6,310	46.9%	4.8%
1988	2,258	124.4%	5,480	4,751	2,006	47.5%	6.8%
1989	1,832	101.0%	4,944	4,715	122	54.7%	7.3%
1990	1,947	107.2%	4,560	4,479	4,199	49.0%	7.0%
1991	1,826	100.3%	4,398	3,931	1,173	72.5%	8.4%
1992	1,507	82.7%	3,750	3,624	132	62.4%	7.5%
1993	1,200	65.9%	2,836	2,771	3,105	53.1%	6.2%
1994	1,160	63.6%	2,830	2,487	3,260	63.9%	16.5%
1995	997	54.6%	2,809	2,506	1,202	56.1%	11.0%
1996	977	53.5%	2,694	2,571	1,820	70.5%	11.7%
1997	1,013	55.4%	2,557	2,411	1,041	72.4%	14.0%
1998	859	47.0%	2,111	2,012	1,941	87.9%	14.4%
1999	719	39.4%	2,093	1,690	12,823	97.0%	18.5%
2000	768	42.2%	3,886	1,941	322	69.1%	15.1%
2001	1,079	59.4%	4,055	4,026	1,229	68.8%	5.4%
2002	1,881	103.2%	4,433	4,360	34	47.7%	4.0%
2003	1,715	94.3%	3,778	3,749	1,707	44.4%	4.6%
2004	1,363	74.9%	3,119	2,972	64	72.7%	10.6%
2005	1,064	58.5%	2,527	2,478	2,759	70.1%	13.8%
2006	865	47.5%	2,231	1,909	1,978	82.7%	18.7%
2007	679	37.3%	1,782	1,710	27	87.3%	14.7%
2008	691	38.1%	1,835	1,750	5,424	89.6%	19.7%
2009	602	33.4%	1,611	1,298	1,416	77.4%	12.5%
2010	591	32.7%	2,203	1,829	15,344	94.0%	11.8%
2011	727	40.1%	2,826	1,794	432	89.0%	16.7%
2012	940	51.6%	3,579	3,508	1,425	67.9%	5.5%
2013	1,696	93.6%	4,111	3,958	339	65.2%	7.5%
2014	1,784	98.5%	4,225	4,031	9,401	61.8%	7.7%
2015	1,337	73.9%	3,527	2,960	63	47.2%	5.8%
2016	1,198	66.0%	3,703	3,605	4,550	74.6%	8.3%
2017	1,548	85.2%	4,071	3,512	2,206	78.2%	13.3%
2018	1,484	81.2%	4,206	3,824	358	75.4%	11.6%
2019	1,379	75.6%	3,442	3,355	924	76.4%	11.5%
2020	1,196	65.0%	2,916	2,640	923	–	–

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	500-1,497	27.9- 78.0%	1,455-3,982	1,235-3,642	83- 8,153	27.8- 74.5%	3.8-11.1%
1967	516-1,511	28.2- 79.5%	1,538-4,142	1,334-3,672	377-12,616	41.3- 93.8%	5.8-16.1%
1968	523-1,507	27.7- 80.7%	1,600-4,550	1,269-3,905	202- 8,413	27.6- 73.8%	3.1- 9.6%
1969	594-1,736	31.0- 86.4%	1,828-5,155	1,651-4,766	53- 3,708	35.1- 86.0%	3.8-10.9%
1970	711-2,038	36.1-106.2%	1,918-5,644	1,789-5,243	4,289-19,656	39.4- 93.1%	4.5-13.1%
1971	714-2,175	36.5-111.3%	2,015-6,255	1,614-4,868	96- 2,590	26.8- 75.6%	3.2- 9.6%
1972	749-2,274	38.3-119.0%	2,252-7,072	2,203-6,953	61- 1,681	19.3- 61.3%	1.7- 5.3%
1973	963-2,942	48.3-151.5%	2,304-7,090	2,218-6,833	2,973-12,260	21.8- 66.1%	2.4- 7.3%
1974	946-2,872	48.0-149.5%	2,315-7,092	2,047-6,214	39- 1,209	25.4- 74.5%	3.4-10.3%
1975	1,071-3,303	54.8-171.8%	2,838-8,897	2,766-8,638	815- 3,751	27.8- 82.1%	3.2-10.0%
1976	1,317-4,027	67.4-209.4%	2,999-9,202	2,921-8,917	27- 783	24.0- 73.5%	3.1- 9.5%
1977	1,124-3,416	58.8-180.5%	2,810-8,480	2,570-7,832	3,457-12,796	15.2- 52.8%	1.7- 5.1%
1978	967-2,820	49.9-149.5%	2,315-6,761	2,088-6,103	19- 666	15.2- 52.1%	1.5- 4.4%
1979	1,024-2,880	52.8-154.3%	2,637-7,487	2,595-7,336	501- 2,980	17.3- 54.3%	2.3- 6.4%
1980	1,041-2,833	54.0-152.8%	2,851-7,784	2,310-6,270	9,839-32,036	13.3- 43.1%	1.4- 3.9%
1981	966-2,496	49.6-135.6%	3,050-7,953	2,102-5,434	34- 1,024	20.9- 58.5%	2.8- 7.2%
1982	1,006-2,526	51.6-138.9%	3,427-8,611	3,399-8,571	57- 903	17.2- 50.8%	1.4- 3.6%
1983	1,462-3,497	73.2-193.0%	3,353-8,037	3,322-7,961	89- 1,428	16.7- 48.1%	1.6- 3.7%
1984	1,546-3,492	76.0-196.8%	3,616-8,225	3,268-7,384	8,598-23,199	19.5- 54.2%	2.2- 4.9%
1985	1,422-3,071	68.9-174.1%	4,390-9,673	3,103-6,683	21- 535	13.4- 37.4%	2.0- 4.2%
1986	1,471-2,988	70.2-170.9%	4,384-9,089	4,368-9,077	22- 649	25.2- 59.6%	2.6- 5.4%
1987	1,732-3,435	83.2-199.7%	4,012-8,025	3,902-7,744	4,148-10,755	29.1- 65.6%	3.2- 6.4%
1988	1,705-3,256	81.7-190.7%	4,154-8,054	3,588-6,857	1,117- 3,656	29.7- 65.8%	4.7- 8.9%
1989	1,411-2,594	66.7-153.6%	3,836-7,122	3,635-6,791	21- 409	36.0- 73.5%	5.1- 9.5%
1990	1,527-2,728	71.1-160.4%	3,594-6,402	3,538-6,288	2,855- 6,937	32.0- 66.0%	4.9- 8.8%
1991	1,466-2,494	66.8-149.2%	3,514-6,058	3,152-5,357	509- 2,227	49.2-100.4%	6.2-10.5%
1992	1,221-2,032	55.3-122.8%	3,035-5,108	2,929-4,911	20- 489	41.8- 92.9%	5.5- 9.2%
1993	984-1,612	43.8- 97.9%	2,323-3,827	2,270-3,720	2,144- 4,866	34.2- 83.6%	4.7- 7.6%
1994	968-1,528	42.4- 94.0%	2,334-3,774	2,070-3,274	2,272- 5,101	44.2- 85.5%	12.5-19.8%
1995	826-1,318	36.8- 81.0%	2,305-3,773	2,063-3,329	740- 2,013	39.0- 73.8%	8.2-13.4%
1996	811-1,285	35.9- 80.1%	2,220-3,617	2,114-3,412	1,188- 2,950	50.9- 91.9%	8.8-14.2%
1997	838-1,341	37.1- 82.7%	2,108-3,430	1,996-3,206	586- 1,825	53.6- 90.7%	10.6-16.9%
1998	711-1,142	31.1- 70.1%	1,737-2,841	1,666-2,693	1,255- 3,205	67.9-104.1%	10.6-17.4%
1999	592- 976	26.1- 59.1%	1,683-2,891	1,382-2,305	9,154-20,186	75.4-113.8%	13.6-22.6%
2000	617-1,068	28.0- 63.1%	3,012-5,607	1,551-2,693	107- 671	49.3- 86.2%	10.9-18.9%
2001	858-1,504	39.2- 88.6%	3,194-5,727	3,172-5,682	841- 1,935	49.0- 86.1%	3.8- 6.9%
2002	1,508-2,593	67.7-153.3%	3,557-6,135	3,498-6,034	7- 115	32.1- 63.6%	2.9- 5.0%
2003	1,414-2,298	62.3-138.7%	3,113-5,092	3,092-5,039	1,200- 2,739	29.4- 60.2%	3.4- 5.6%
2004	1,147-1,781	49.5-109.3%	2,613-4,122	2,499-3,894	12- 213	50.9- 97.5%	8.1-12.6%
2005	901-1,392	38.7- 85.3%	2,121-3,345	2,082-3,267	1,926- 4,491	49.0- 93.2%	10.5-16.4%
2006	726-1,144	31.8- 70.3%	1,846-3,015	1,599-2,527	1,385- 3,301	59.8-112.8%	14.1-22.3%
2007	559- 924	25.0- 55.5%	1,455-2,462	1,400-2,360	5- 93	62.1-116.8%	10.6-18.2%
2008	558- 979	25.4- 57.7%	1,475-2,599	1,414-2,469	3,860- 8,900	67.4-111.0%	14.0-24.4%
2009	472- 872	21.9- 50.7%	1,256-2,355	1,019-1,880	806- 2,630	53.4-100.1%	8.6-15.9%
2010	458- 871	21.4- 50.0%	1,678-3,345	1,416-2,713	9,998-27,750	68.2-120.1%	8.0-15.3%
2011	556-1,102	26.3- 61.6%	2,090-4,485	1,364-2,715	162- 955	62.5-116.5%	10.9-21.8%
2012	687-1,497	33.6- 82.6%	2,570-5,815	2,529-5,703	836- 2,752	44.2- 93.7%	3.4- 7.7%
2013	1,217-2,755	60.7-152.0%	2,933-6,685	2,831-6,443	110- 860	42.8- 86.2%	4.6-10.4%
2014	1,260-2,916	63.4-160.4%	2,953-6,993	2,830-6,645	5,387-18,479	39.3- 85.4%	4.7-10.9%
2015	927-2,214	46.8-122.3%	2,425-5,918	2,049-4,892	11- 281	27.6- 70.6%	3.5- 8.4%
2016	816-2,017	41.5-110.1%	2,446-6,365	2,391-6,201	2,178-10,016	47.1-102.4%	4.9-12.5%
2017	979-2,715	51.1-146.9%	2,524-7,184	2,204-6,143	807- 5,971	49.4-113.6%	7.6-21.2%
2018	860-2,739	46.1-143.7%	2,426-8,022	2,214-7,168	30- 3,836	45.0-108.2%	6.2-20.1%
2019	736-2,706	39.8-140.1%	1,821-6,863	1,767-6,681	58-16,937	45.4-109.3%	5.7-21.8%
2020	550-2,508	30.7-129.5%	1,368-6,398	1,243-5,498	54-14,387	–	–

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 (2019) base model.

	MLE	Posterior median	Posterior median from 2019 base model
Parameters			
Natural mortality (M)	0.209	0.229	0.231
Unfished recruitment (R_0, millions)	1,600	2,505	2,770
Steepness (h)	0.854	0.816	0.816
Additional acoustic survey SD	0.249	0.297	0.308
Dirichlet-Multinomial fishery (log θ_{fish})	-0.164	-0.559	-0.551
Dirichlet-Multinomial survey (log θ_{surv})	2.246	2.332	–
Catchability (q)	1.088	0.903	0.964
Derived Quantities			
2010 recruitment (millions)	11,648	15,344	13,583
2014 recruitment (millions)	7,034	9,401	8,467
2016 recruitment (millions)	3,385	4,550	3,895
Unfished female spawning biomass (B_0, thousand t)	1,385	1,832	2,026
2009 relative spawning biomass	36.7%	33.4%	28.1%
2020 relative spawning biomass	62.6%	65.0%	–
2019 relative fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	89.2%	76.4%	–
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	517	656	722
Reference Points (equilibrium) based on $F_{\text{SPR}=40\%}$			
SPR at $F_{\text{SPR}=40\%}$	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.0%	18.3%	18.3%
Yield at $B_{\text{SPR}=40\%}$ (thousand t)	223	308	339

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 2015–2019 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)	1,231	1,832	2,853
Unfished recruitment (R_0, millions)	1,403	2,505	4,961
Reference points (equilibrium) based on $F_{SPR=40\%}$			
Female spawning biomass at $F_{SPR=40\%}$ (thousand t)	397	656	1,025
SPR at $F_{SPR=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{SPR=40\%}$	16.0%	18.3%	20.9%
Yield associated with $F_{SPR=40\%}$ (thousand t)	176	308	544
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	492	733	1,141
SPR at $B_{40\%}$	40.6%	43.4%	50.6%
Exploitation fraction resulting in $B_{40\%}$	12.6%	16.2%	19.2%
Yield at $B_{40\%}$ (thousand t)	174	301	531
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	295	466	799
SPR at MSY	22.3%	29.4%	45.4%
Exploitation fraction corresponding to SPR at MSY	15.2%	25.8%	35.0%
MSY (thousand t)	182	325	585

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 2019 (row d) and the TAC from 2019 (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 2020 and 2021 (row i). Catch in 2022 does not impact the beginning of the year biomass in 2022.

Within model quantile			5%	25%	50%	75%	95%
Management Action			Beginning of year relative spawning biomass				
	Year	Catch (t)					
a:	2020	0	35%	51%	65%	83%	116%
	2021	0	34%	48%	62%	79%	111%
	2022	0	33%	48%	62%	80%	125%
b:	2020	180,000	35%	51%	65%	83%	116%
	2021	180,000	30%	44%	58%	74%	106%
	2022	180,000	26%	40%	53%	71%	116%
c:	2020	350,000	35%	51%	65%	83%	116%
	2021	350,000	26%	40%	53%	70%	101%
	2022	350,000	18%	32%	45%	63%	107%
d:	2020	410,000	35%	51%	65%	83%	116%
2019	2021	410,000	24%	38%	52%	69%	99%
catch	2022	410,000	15%	29%	42%	60%	104%
e:	2020	500,000	35%	51%	65%	83%	116%
	2021	500,000	22%	36%	50%	66%	97%
	2022	500,000	11%	25%	38%	56%	100%
f:	2020	597,500	35%	51%	65%	83%	116%
2019	2021	597,500	20%	34%	47%	64%	94%
TAC	2022	597,500	9%	21%	34%	52%	95%
g:	2020	558,094	35%	51%	65%	83%	116%
FI=	2021	438,261	21%	35%	48%	65%	95%
100%	2022	361,901	11%	26%	39%	56%	100%
h:	2020	666,458	35%	51%	65%	83%	116%
default	2021	484,844	18%	32%	46%	62%	92%
HR	2022	387,238	9%	22%	35%	53%	96%
i:	2020	523,713	35%	51%	65%	83%	116%
C2020=	2021	523,714	22%	36%	49%	66%	96%
C2021	2022	411,472	10%	24%	37%	55%	99%

Table 30. Decision table of forecast quantiles of Pacific Hake relative fishing intensity $(1\text{-SPR})/(1\text{-SPR}_{40\%})$, expressed as a percentage, for the 2020–2022 catch alternatives presented in Table 29. Values greater than 100% indicate fishing intensities greater than the $F_{SPR=40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Relative fishing intensity**				
	Year	Catch (t)					
a:	2020	0	0%	0%	0%	0%	0%
	2021	0	0%	0%	0%	0%	0%
	2022	0	0%	0%	0%	0%	0%
b:	2020	180,000	30%	42%	52%	63%	82%
	2021	180,000	31%	44%	55%	67%	88%
	2022	180,000	30%	45%	57%	70%	93%
c:	2020	350,000	50%	67%	79%	91%	112%
	2021	350,000	53%	71%	86%	100%	123%
	2022	350,000	53%	75%	92%	108%	135%
d:	2020	410,000	56%	73%	86%	98%	118%
2019	2021	410,000	59%	79%	94%	109%	132%
catch	2022	410,000	60%	83%	101%	118%	143%
e:	2020	500,000	64%	82%	95%	107%	127%
	2021	500,000	68%	89%	105%	120%	141%
	2022	500,000	69%	95%	114%	132%	147%
f:	2020	597,500	71%	90%	103%	115%	134%
2019	2021	597,500	76%	98%	114%	129%	145%
TAC	2022	597,500	79%	106%	125%	140%	148%
g:	2020	558,094	68%	87%	100%	112%	131%
FI=	2021	438,261	63%	84%	100%	116%	139%
100%	2022	361,901	56%	81%	100%	119%	144%
h:	2020	666,458	76%	95%	108%	120%	138%
default	2021	484,844	68%	90%	107%	123%	144%
HR	2022	387,238	60%	86%	107%	127%	146%
i:	2020	523,713	66%	84%	97%	109%	129%
C2020=	2021	523,714	70%	91%	107%	122%	143%
C2021	2022	411,472	62%	87%	107%	126%	146%

Table 31. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (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	81%	11%	1%	0%	0%	0%
b: 180,000	91%	18%	2%	0%	1%	1%
c: 350,000	94%	26%	4%	0%	14%	17%
d: 410,000	95%	28%	6%	0%	22%	28%
e: 500,000	96%	32%	8%	0%	39%	45%
f: 597,500	97%	37%	10%	0%	57%	62%
g: 558,094	96%	35%	10%	0%	50%	56%
h: 666,458	97%	40%	13%	1%	66%	71%
i: 523,713	96%	33%	8%	0%	43%	50%

Table 32. Probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options, given the 2020 catch level shown in Table 31 (catch options explained in Table 29).

Catch in 2021	Probability $B_{2022}<B_{2021}$	Probability $B_{2022}<B_{40\%}$	Probability $B_{2022}<B_{25\%}$	Probability $B_{2022}<B_{10\%}$	Probability 2021 relative fishing intensity >100%	Probability 2022 default harvest policy catch <2021 catch
a: 0	63%	12%	1%	0%	0%	0%
b: 180,000	75%	25%	5%	0%	1%	2%
c: 350,000	82%	40%	12%	1%	25%	27%
d: 410,000	83%	46%	17%	2%	39%	40%
e: 500,000	86%	53%	24%	4%	58%	59%
f: 597,500	87%	60%	33%	7%	72%	74%
g: 438,261	84%	52%	24%	4%	50%	51%
h: 484,844	84%	58%	31%	7%	61%	62%
i: 523,714	86%	54%	27%	5%	62%	63%

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 1.6	Natural Mortality (SD=0.2)	Natural Mortality (SD=0.3)	Add Age 1 Index	McAllister Ianelli Weighting	Francis Weighting
Parameters										
Natural mortality (M)	0.209	0.212	0.208	0.210	0.209	0.226	0.238	0.210	0.211	0.209
R_0 (millions)	1,600	1,624	1,588	1,322	1,860	1,955	2,283	1,670	1,978	1,517
Steepness (h)	0.854	0.562	1.000	0.855	0.858	0.851	0.849	0.854	0.856	0.855
Additional acoustic survey SD	0.249	0.249	0.249	0.248	0.249	0.249	0.250	0.252	0.245	0.240
Dirichlet-Multinomial fishery (log θ_{fish})	-0.164	-0.164	-0.164	-0.224	-0.148	-0.166	-0.167	-0.171	–	–
Dirichlet-Multinomial survey (log θ_{surv})	2.246	2.246	2.246	2.180	2.265	2.242	2.239	2.236	–	–
Additional age-1 index SD	–	–	–	–	–	–	–	0.160	–	–
Derived Quantities										
2010 recruitment (millions)	11,648	11,927	11,572	11,753	11,652	13,539	15,210	12,223	11,678	11,435
2014 recruitment (millions)	7,034	7,160	6,999	7,021	7,048	8,042	8,928	7,749	6,846	6,517
2016 recruitment (millions)	3,385	3,429	3,373	3,362	3,394	3,860	4,278	3,745	3,374	3,312
B_0 (thousand t)	1,385	1,369	1,383	1,133	1,608	1,468	1,550	1,432	1,681	1,313
2009 relative spawning biomass	36.7%	37.7%	36.6%	45.4%	31.6%	37.8%	38.3%	36.2%	29.6%	37.8%
2020 relative spawning biomass	62.6%	63.5%	62.6%	76.8%	53.8%	64.5%	65.5%	71.8%	51.2%	62.5%
Reference Points based on $F_{\text{SPR}=40\%}$										
2019 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	89.2%	88.3%	89.5%	88.0%	89.5%	81.9%	76.4%	83.9%	89.5%	90.6%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	517	349	553	423	601	547	577	535	628	490
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	17.0%	17.2%	16.9%	17.1%	17.0%	18.0%	18.7%	17.1%	17.1%	17.0%
Yield at $B_{F_{40\%}}$ (thousand t)	223	153	238	183	259	254	283	232	274	211
Negative log likelihoods										
Total	682.82	683.96	692.61	695.16	681.43	682.63	682.49	685.68	181.45	458.62
Survey	-7.95	-7.95	-7.96	-8.00	-7.94	-7.94	-7.92	-6.85	-8.09	-8.31
Survey age compositions	86.45	86.44	86.46	87.29	86.23	86.51	86.54	86.61	39.52	32.65
Fishery age compositions	538.86	538.80	538.87	545.97	537.05	539.03	539.16	540.34	101.69	365.04
Recruitment	49.82	50.73	49.58	53.61	50.66	49.23	48.86	50.05	40.88	51.64
Parameter priors	0.81	1.12	10.83	0.80	0.83	0.90	0.88	0.83	0.09	0.04
Parameter deviations	14.83	14.83	14.83	15.49	14.60	14.90	14.97	14.71	7.36	17.55

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)	0.209	0.205	0.206	0.210	0.210	0.211
R_0 (millions)	1,600	1,696	1,566	1,626	1,749	1,687
Steepness (h)	0.854	0.856	0.855	0.854	0.855	0.855
Additional acoustic survey SD	0.249	0.254	0.247	0.249	0.272	0.252
Dirichlet-Multinomial fishery ($\log \theta_{\text{fish}}$)	-0.164	-0.590	-0.265	-0.120	-0.396	-0.208
Dirichlet-Multinomial survey ($\log \theta_{\text{surv}}$)	2.246	2.072	2.225	2.244	2.248	2.252
Derived Quantities						
2010 recruitment (millions)	11,648	11,775	11,400	11,782	12,320	11,886
2014 recruitment (millions)	7,034	7,244	6,877	7,054	9,511	7,921
2016 recruitment (millions)	3,385	5,858	3,430	3,414	6,245	4,283
B_0 (thousand t)	1,385	1,510	1,384	1,393	1,492	1,433
2009 relative spawning biomass	36.7%	32.8%	36.2%	36.8%	33.8%	35.6%
2020 relative spawning biomass	62.6%	98.4%	66.4%	61.4%	105.1%	74.7%
Reference Points based on $F_{\text{SPR}=40\%}$						
2019 rel. fishing intensity: $(1\text{-SPR})/(1\text{-SPR}_{40\%})$	89.2%	78.6%	89.2%	88.3%	76.4%	82.6%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	517	564	517	520	557	535
$\text{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.0%	16.8%	16.9%	17.0%	17.1%	17.1%
Yield at $B_{F_{40\%}}$ (thousand t)	223	239	221	225	242	233
Negative log likelihoods						
Total	682.82	792.63	708.48	672.19	829.27	832.20
Survey	-7.95	-7.78	-8.04	-7.94	-7.13	-7.86
Survey age compositions	86.45	91.42	86.93	86.47	87.58	86.52
Fishery age compositions	538.86	611.01	554.98	532.18	574.89	543.67
Recruitment	49.82	49.94	50.65	49.28	50.60	49.41
Parameter priors	0.81	0.70	0.76	0.84	0.87	0.87
Parameter deviations	14.83	47.34	23.19	11.37	122.45	159.59

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	No ageing error
Parameters		
Natural mortality (M)	0.209	0.205
R_0 (millions)	1,600	1,851
Steepness (h)	0.854	0.836
Additional acoustic survey SD	0.249	0.222
Dirichlet-Multinomial fishery (log θ_{fish})	-0.164	-1.711
Dirichlet-Multinomial survey (log θ_{surv})	2.246	0.746
Derived Quantities		
2010 recruitment (millions)	11,648	13,212
2014 recruitment (millions)	7,034	7,507
2016 recruitment (millions)	3,385	3,377
B_0 (thousand t)	1,385	1,649
2009 relative spawning biomass	36.7%	37.3%
2020 relative spawning biomass	62.6%	60.4%
Reference Points based on $F_{\mathbf{SPR=40\%}}$		
2019 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	89.2%	85.7%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	517	609
SPR$_{\mathrm{MSY\text{-}proxy}}$	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.0%	16.6%
Yield at $B_{F_{40\%}}$ (thousand t)	223	256
Negative log likelihoods		
Total	682.82	1,004.67
Survey	-7.95	-9.06
Survey age compositions	86.45	116.93
Fishery age compositions	538.86	840.50
Recruitment	49.82	46.64
Parameter priors	0.81	0.49
Parameter deviations	14.83	9.16

Table 36. 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 No-U-Turn Sampler (NUTS).

	MLE	Posterior median	AD NUTS
Parameters			
Natural mortality (M)	0.209	0.229	0.231
Unfished recruitment (R_0, millions)	1,600	2,505	2,314
Steepness (h)	0.854	0.816	0.810
Additional acoustic survey SD	0.249	0.297	0.301
Dirichlet-Multinomial fishery (log θ_{fish})	-0.164	-0.559	-0.542
Dirichlet-Multinomial survey (log θ_{surv})	2.246	2.332	2.355
Catchability (q)	1.088	0.903	0.893
Derived Quantities			
2010 recruitment (millions)	11,648	15,344	15,528
2014 recruitment (millions)	7,034	9,401	9,567
2016 recruitment (millions)	3,385	4,550	4,617
Unfished female spawning biomass (B_0, thousand t)	1,385	1,832	1,679
2009 relative spawning biomass	36.7%	33.4%	36.4%
2020 relative spawning biomass	62.6%	65.0%	–
2019 relative fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	89.2%	76.4%	–
Female spawning biomass at $F_{SPR=40\%}$ ($B_{SPR=40\%}$, thousand t)	517	656	597
Reference Points (equilibrium) based on $F_{SPR=40\%}$			
SPR at $F_{SPR=40\%}$	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	17.0%	18.3%	18.3%
Yield at $B_{SPR=40\%}$ (thousand t)	223	308	281

8 FIGURES
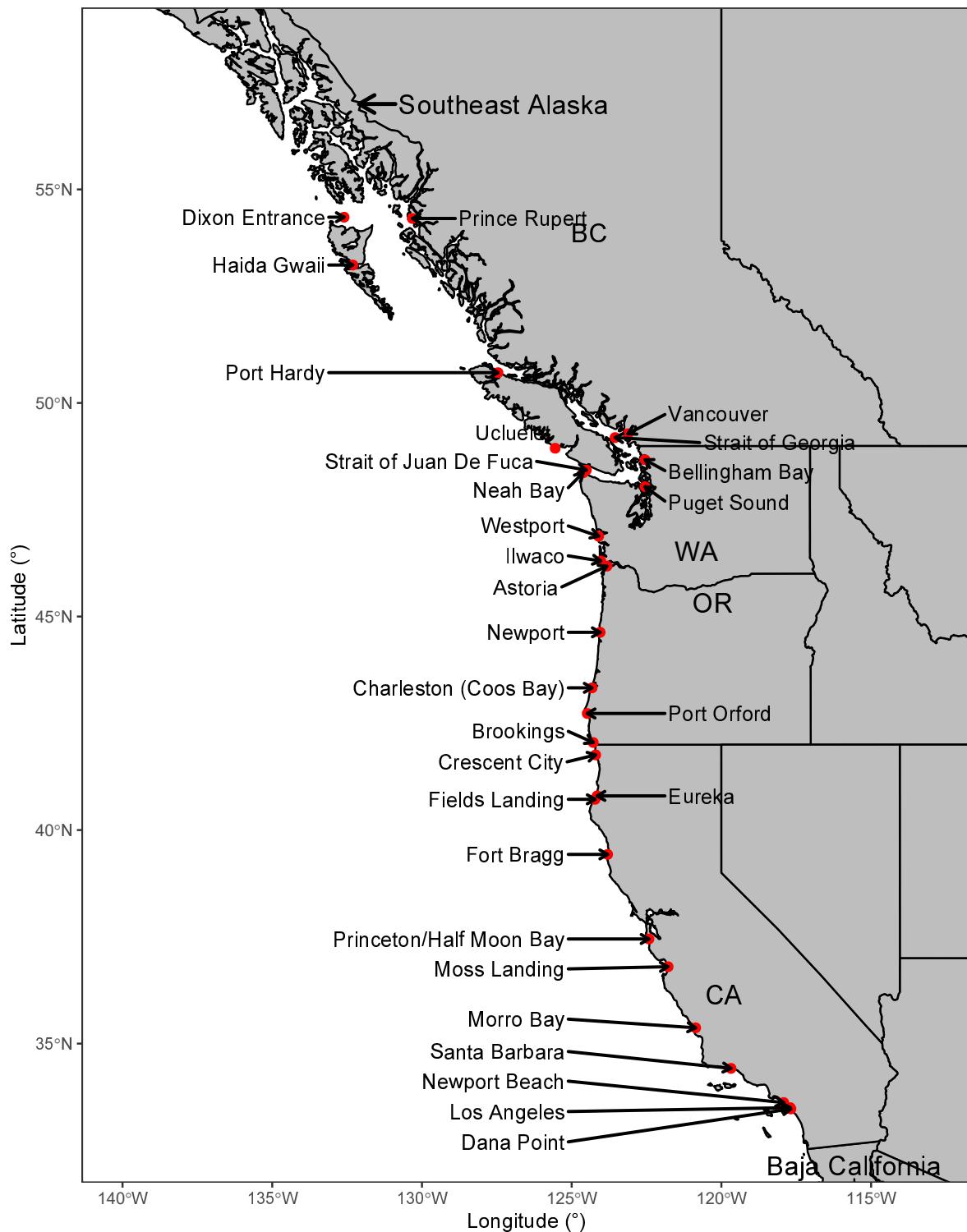
Figure 1. Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.
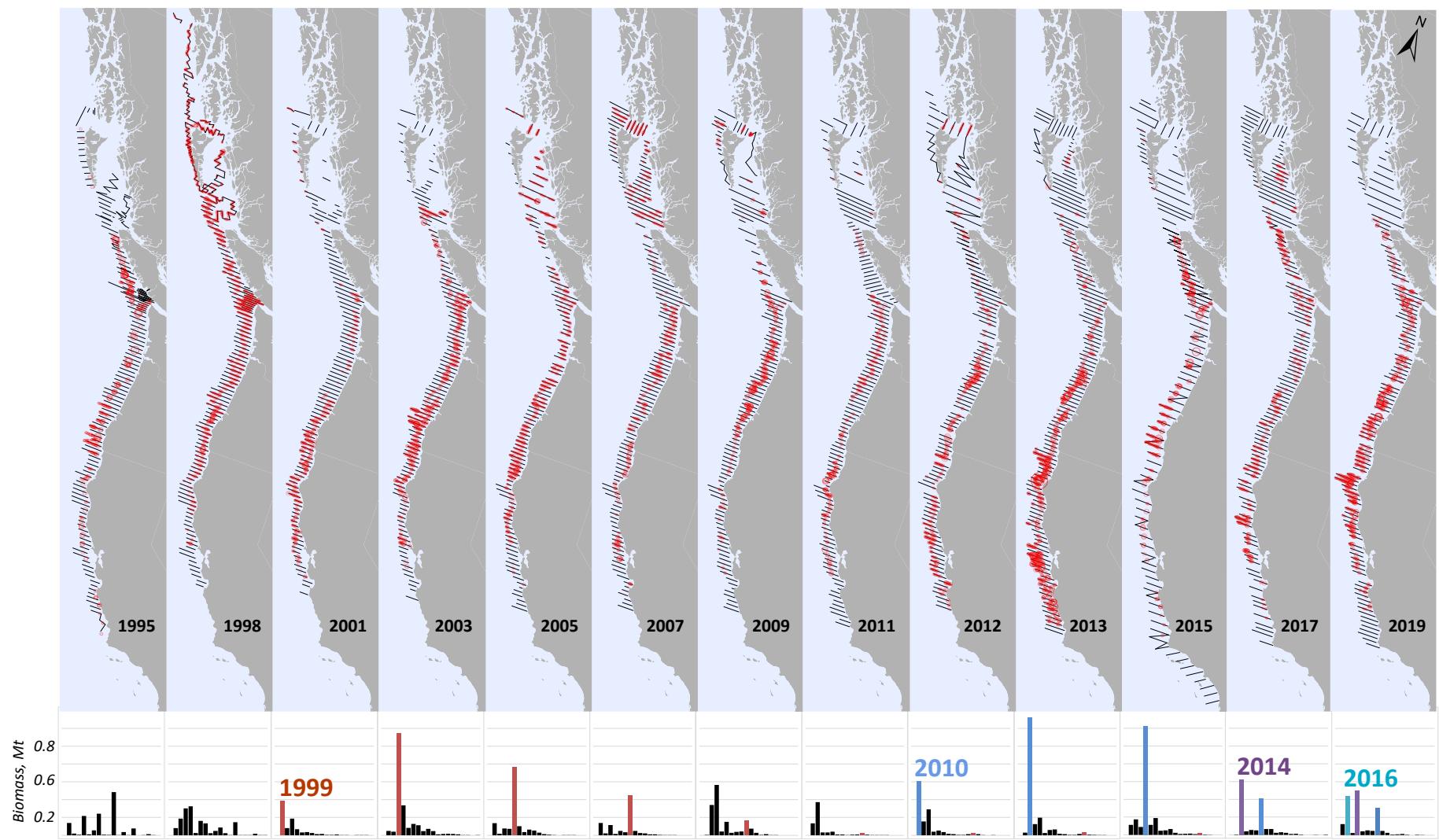
Figure 2. Spatial distribution of acoustic backscatter attributable to age-2 and older Pacific Hake from the Joint U.S. and Canada acoustic surveys 1995–2019. Area of the circle is roughly proportional to observed backscatter. Histograms show survey-estimated biomass for ages 2 to 20, with major cohorts highlighted in color. Figure produced by Julia Clemons (NOAA).
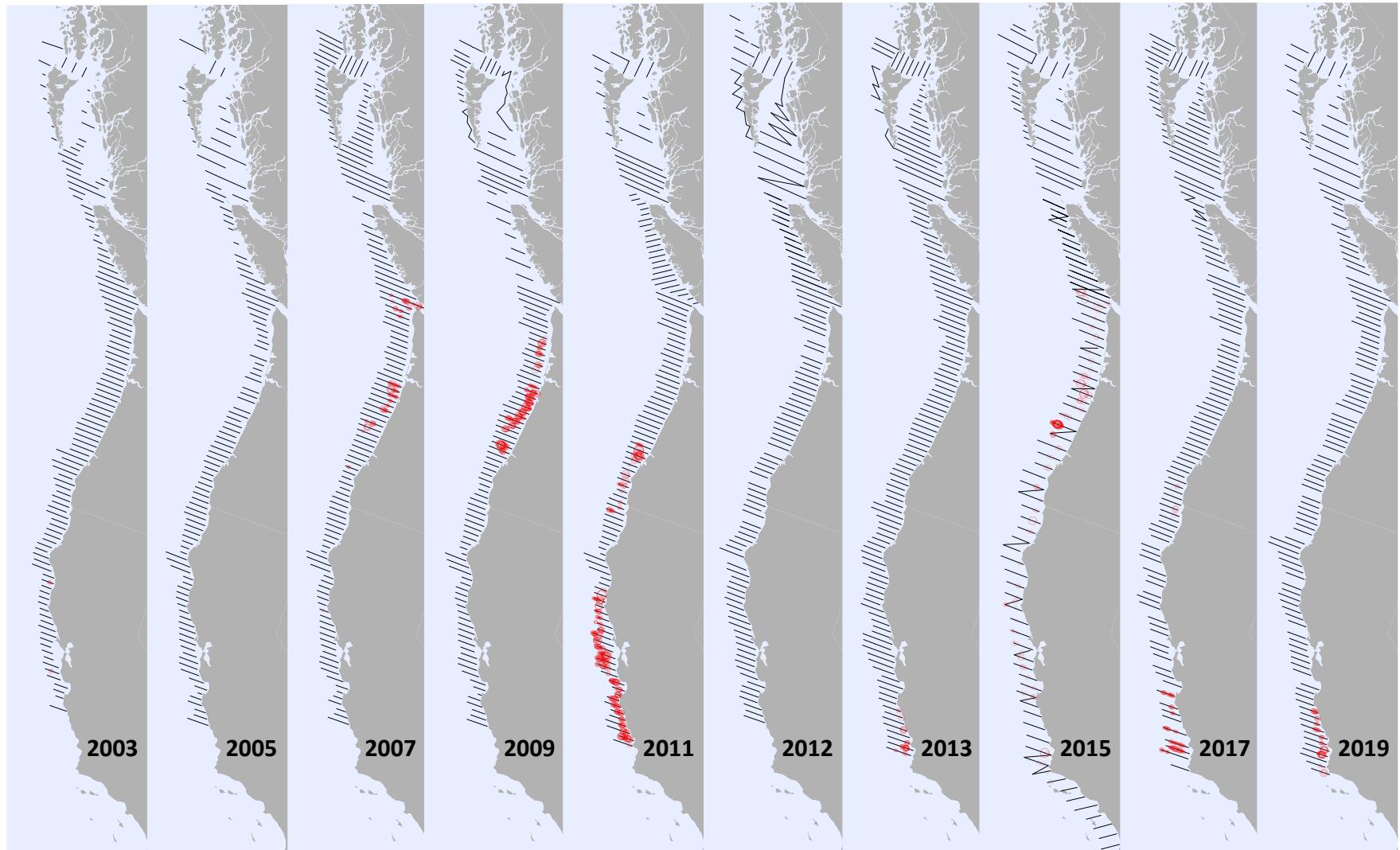
Figure 3. Spatial distribution of acoustic backscatter attributable to age-1 Pacific Hake from the Joint U.S. and Canada acoustic surveys 2003–2019. Age-1 Pacific Hake are not fully sampled during the acoustic survey and were not explicitly considered during establishment of the survey sampling design. Area of the circle is roughly proportional to observed backscatter. Figure produced by Julia Clemons (NOAA).
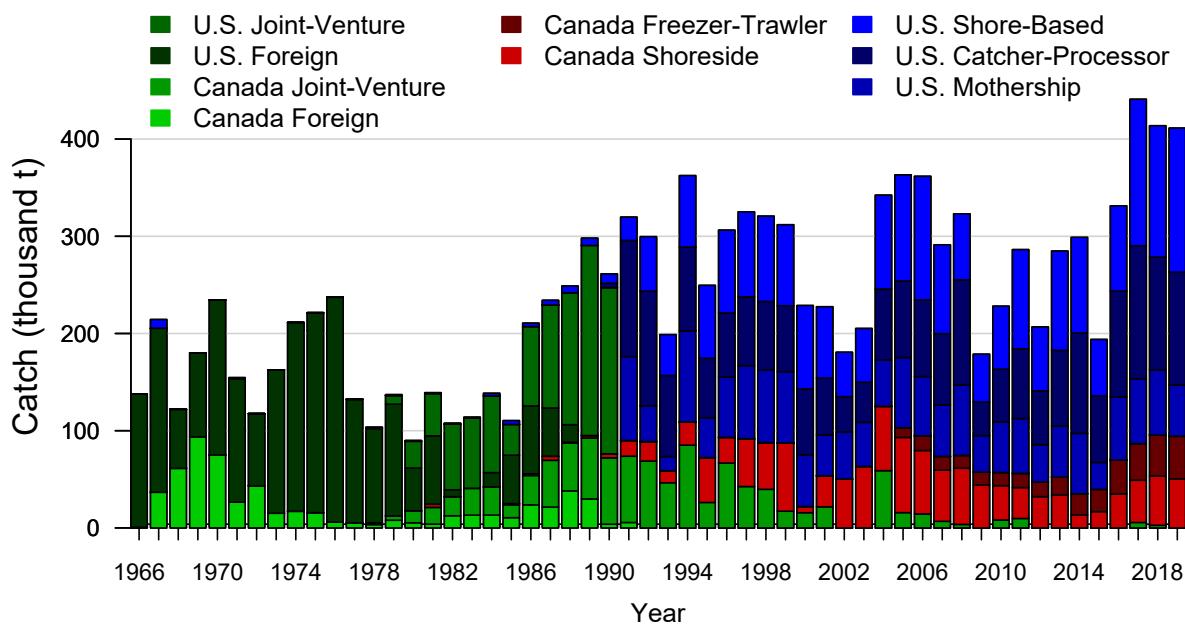
Figure 4. Total Pacific Hake catch used in the assessment by sector, 1966–2019. U.S. tribal catches are included in the appropriate sector.

U.S. at-sea unstandardized catch-rate
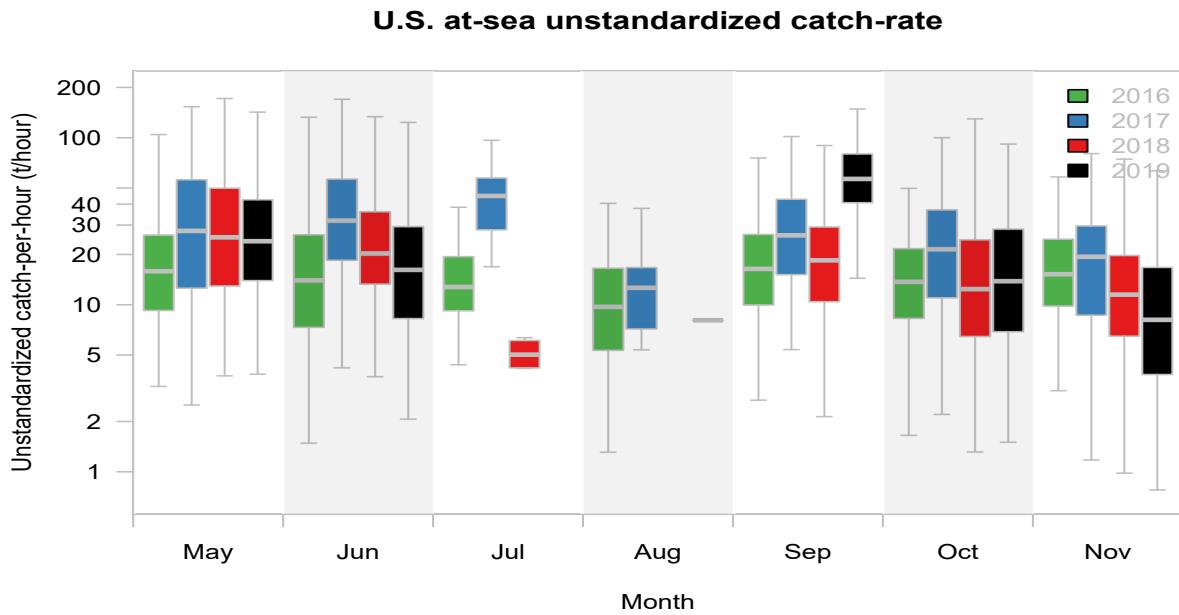
Figure 5. Unstandardized (raw) catch-rates (t/hr) of Pacific Hake catches by tow in the U.S. at-sea fleet from 2014–2019.
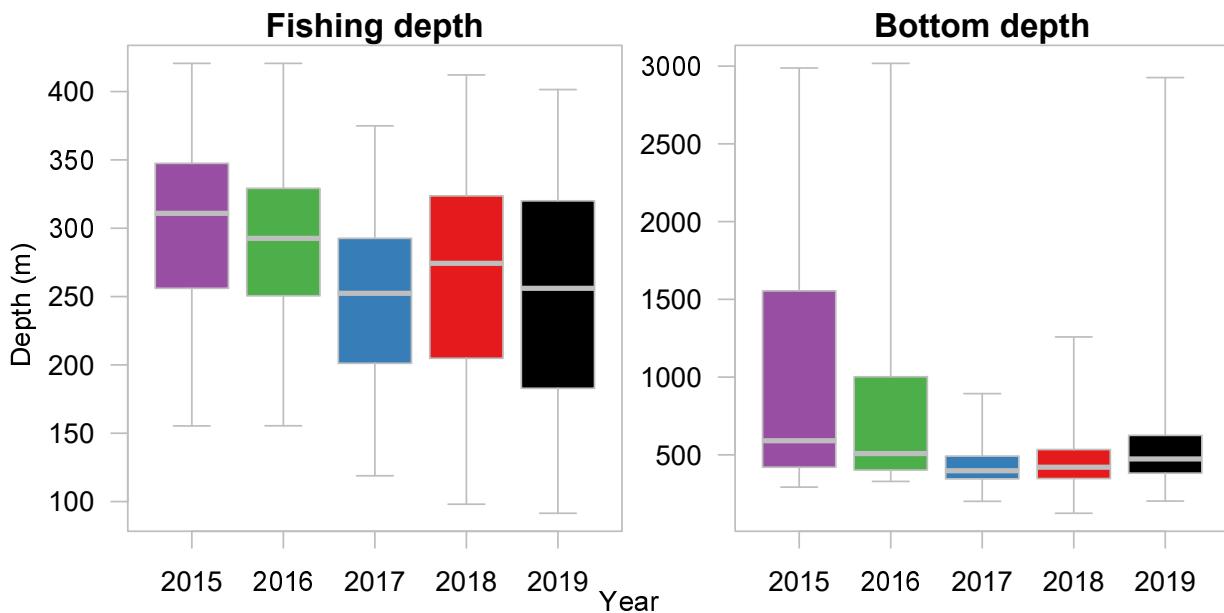
Figure 6. Distribution of fishing depths (left) and bottom depths (right), in meters, of Pacific Hake catches in the U.S. Catcher-Processor and Mothership sectors from 2015–2019. Horizontal lines in each box represents the median depth and boxes encompass the middle 50% of the data. Whiskers encompass the 95% quantiles.
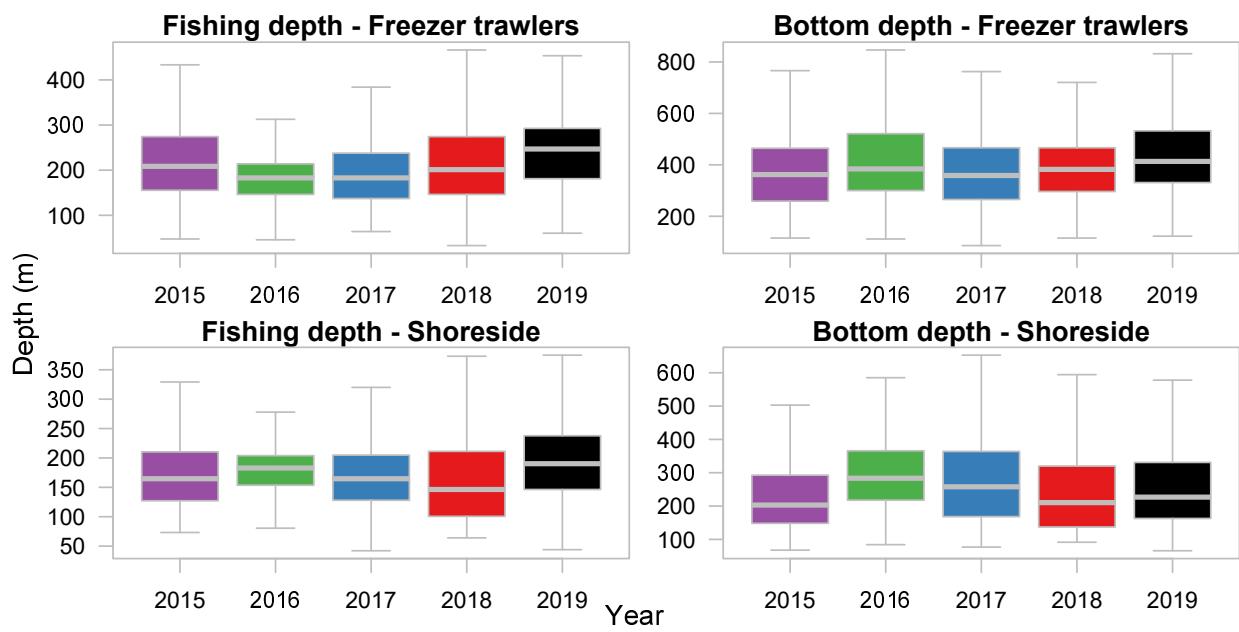
Figure 7. Distribution of fishing depths (left) and bottom depths (right), in meters, of Pacific Hake catches in the Canadian fleets from 2015–2019. Horizontal lines in each box represents the median depth and boxes encompass the middle 50% of the data. Whiskers encompass the 95% quantiles.
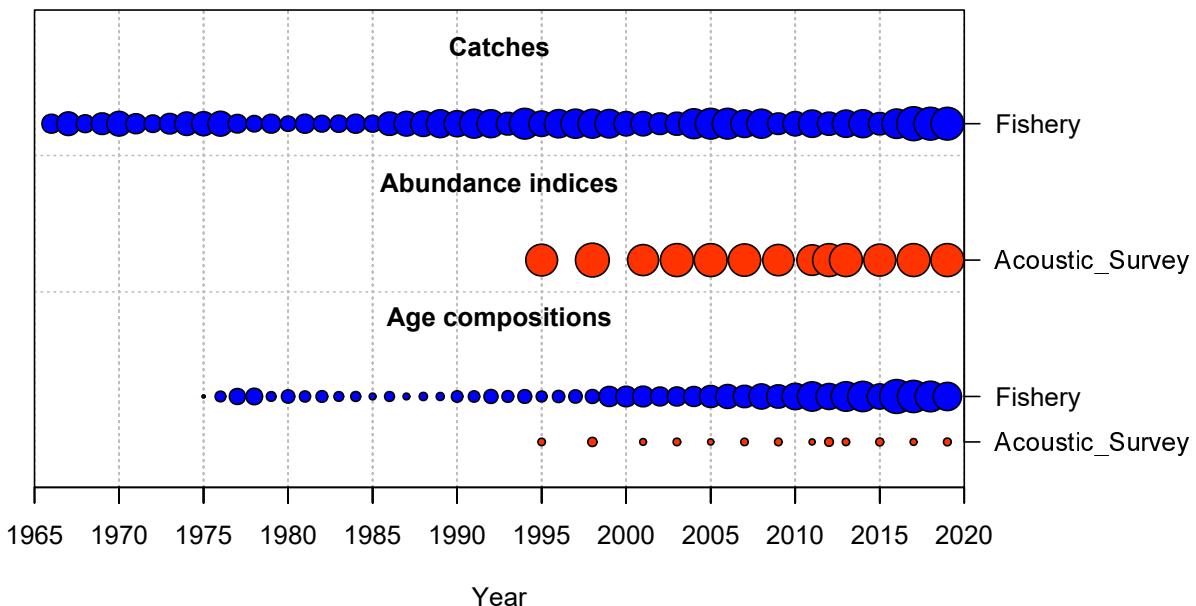
Figure 8. Overview of data used in this assessment, 1966–2019. Circle areas are proportional to the precision within the data type.
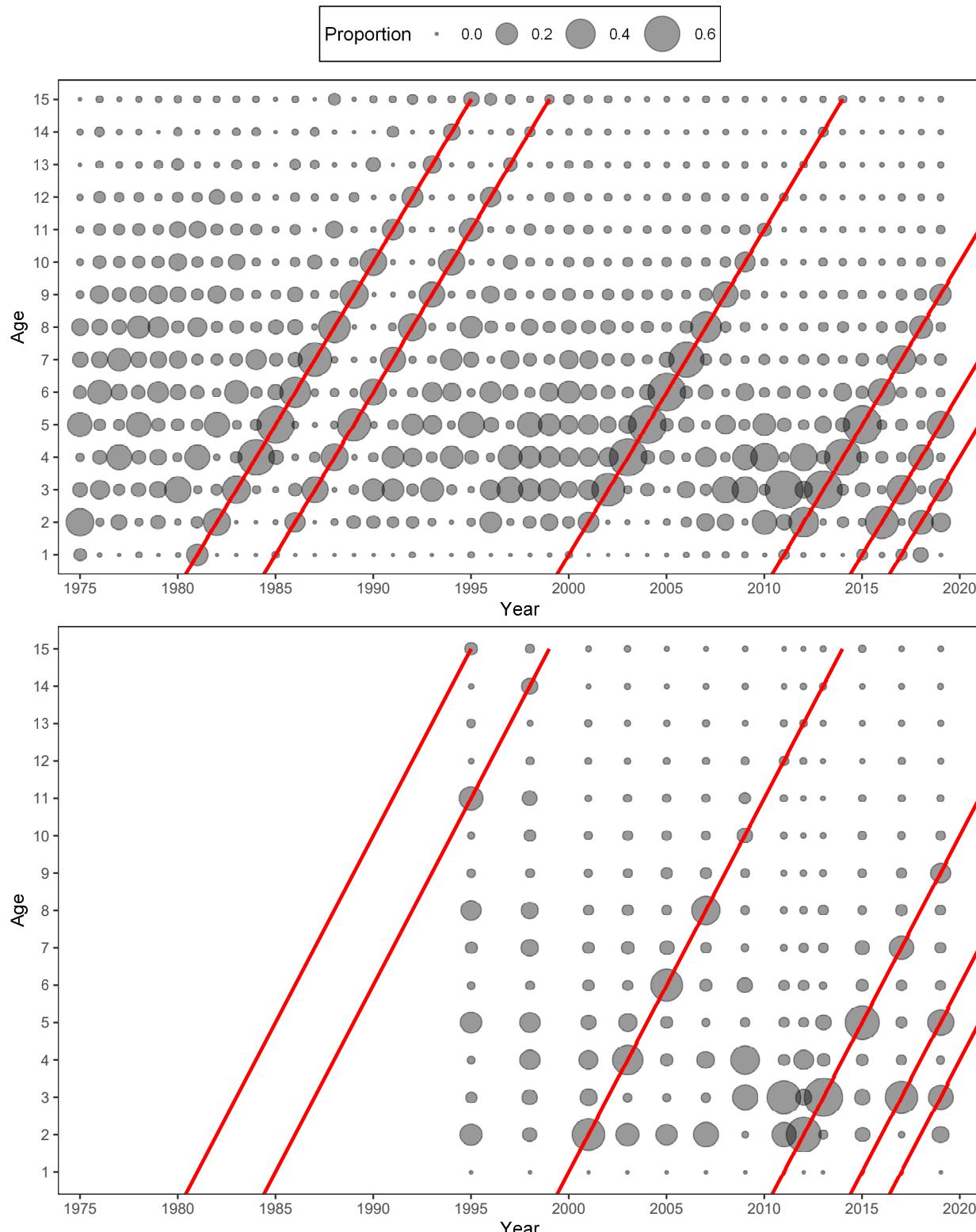
Figure 9. Age compositions for the aggregate fishery (top, all sectors combined) and acoustic survey (bottom) for the years 1975–2019. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble in the survey data is 0.75 for age 3 in 2013 and in the fishery is 0.70 for age 3 in 2013. Red lines track cohorts from years of large recruitment events.
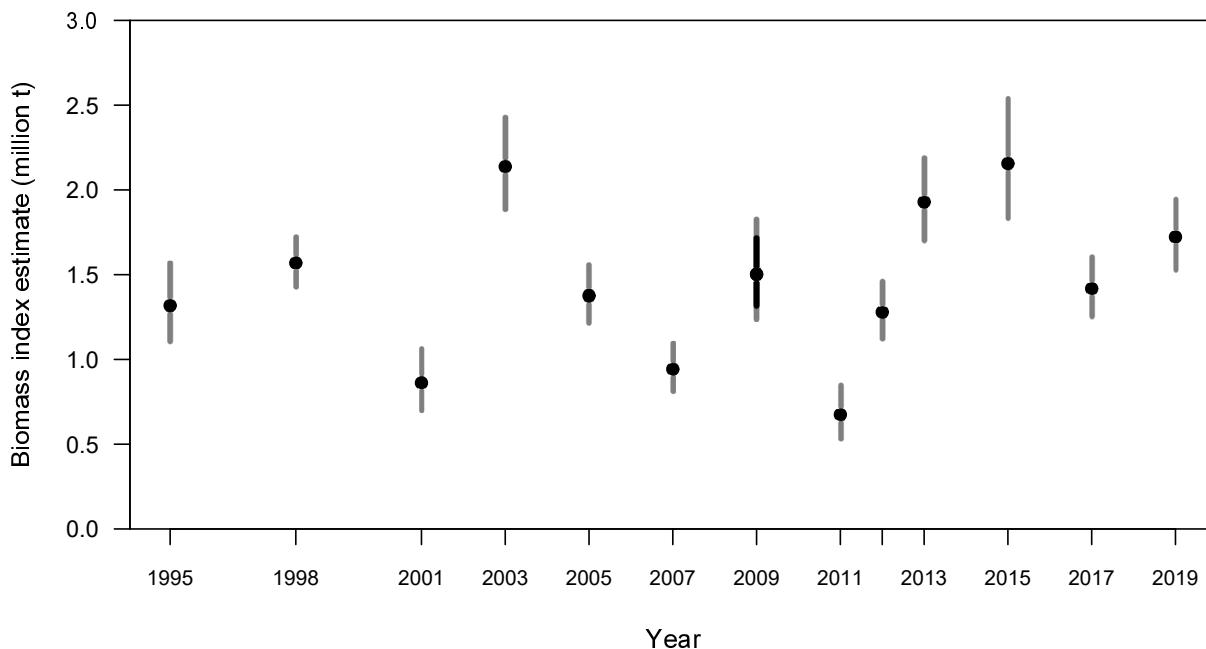
Figure 10. Acoustic survey biomass indices (millions of tons). Approximate 95% confidence intervals are based on sampling variability (intervals without squid/hake apportionment uncertainty in 2009 are displayed in black). See Table 13 for values used in the base model.
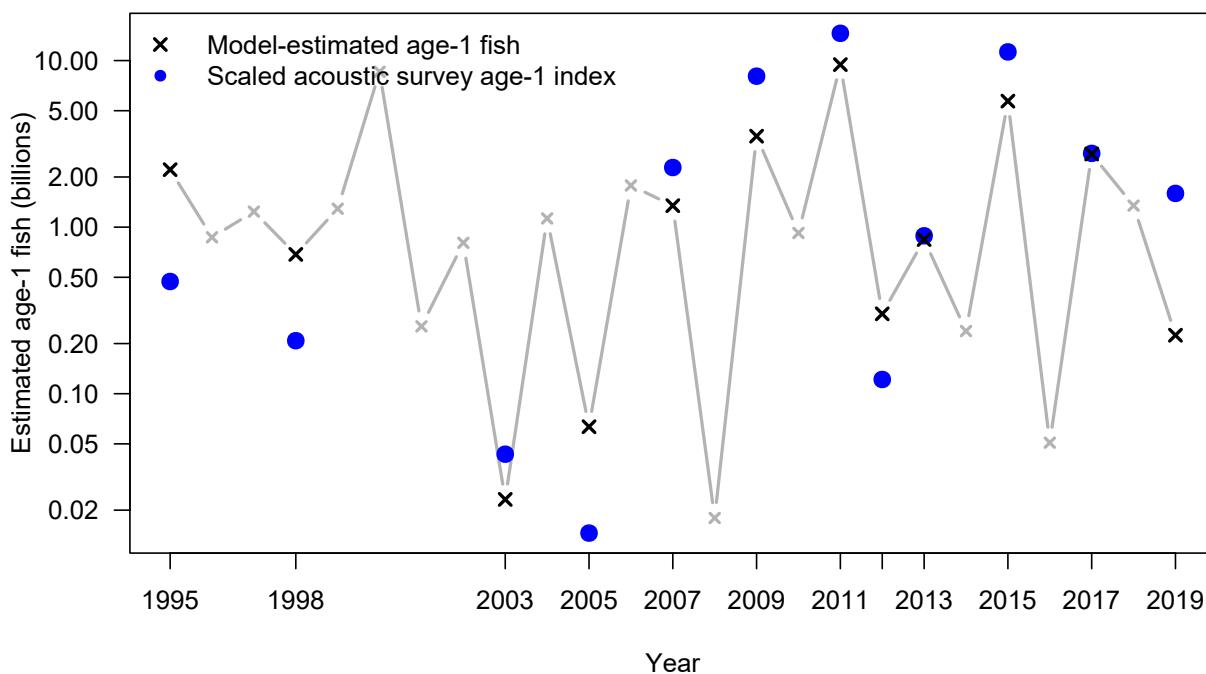
Figure 11. Preliminary acoustic survey age-1 index overlaid on estimated numbers of age-1 fish (MLE from the base model).

Figure 12. Fraction of fish that are mature at each age north and south of 34.44°N (upper panel) and 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 2019.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2022	0.02	0.13	0.29	0.42	0.46	0.50	0.53	0.57	0.59	0.62	0.65	0.72	0.73	0.82	0.98	1.12
2021	0.02	0.13	0.29	0.42	0.46	0.50	0.53	0.57	0.59	0.62	0.65	0.72	0.73	0.82	0.98	1.12
2020	0.02	0.13	0.29	0.42	0.46	0.50	0.53	0.57	0.59	0.62	0.65	0.72	0.73	0.82	0.98	1.12
2019	0.02	0.07	0.28	0.44	0.48	0.52	0.54	0.58	0.62	0.62	0.63	0.69	0.65	0.84	0.68	0.79
2018	0.02	0.19	0.35	0.46	0.50	0.54	0.55	0.62	0.59	0.64	0.64	0.68	0.69	0.72	0.90	1.07
2017	0.02	0.14	0.31	0.40	0.47	0.51	0.53	0.54	0.57	0.62	0.61	0.69	0.76	0.75	0.80	0.89
2016	0.02	0.17	0.24	0.38	0.42	0.44	0.46	0.51	0.52	0.51	0.65	0.72	0.59	0.78	1.45	1.58
2015	0.02	0.08	0.25	0.39	0.44	0.47	0.55	0.59	0.67	0.69	0.72	0.83	0.95	1.02	1.09	1.25
2014	0.02	0.10	0.41	0.47	0.48	0.54	0.57	0.62	0.66	0.72	0.69	1.16	1.01	0.95	0.97	1.06
2013	0.02	0.13	0.29	0.36	0.47	0.51	0.63	0.72	0.73	0.83	1.00	1.08	1.23	1.12	1.07	1.05
2012	0.02	0.13	0.21	0.35	0.41	0.49	0.66	0.69	0.78	0.91	0.96	0.96	0.96	0.99	0.99	0.94
2011	0.02	0.08	0.25	0.32	0.39	0.51	0.59	0.67	0.85	0.93	0.98	1.07	1.06	1.03	1.06	0.92
2010	0.02	0.11	0.23	0.29	0.43	0.53	0.66	0.83	1.08	1.03	0.96	0.88	0.85	1.13	0.72	0.90
2009	0.02	0.07	0.24	0.34	0.47	0.64	0.67	0.69	0.75	0.82	0.77	0.81	1.01	0.85	0.96	1.03
2008	0.02	0.13	0.24	0.41	0.56	0.64	0.69	0.68	0.71	0.72	0.75	0.81	0.85	0.78	0.88	0.83
2007	0.01	0.04	0.23	0.38	0.54	0.55	0.61	0.63	0.65	0.71	0.77	0.76	0.81	0.87	0.80	0.87
2006	0.01	0.13	0.38	0.46	0.53	0.57	0.59	0.60	0.66	0.70	0.73	0.72	0.78	0.66	0.64	0.95
2005	0.01	0.12	0.26	0.43	0.51	0.54	0.57	0.63	0.66	0.70	0.80	0.81	0.81	0.76	1.14	0.97
2004	0.01	0.11	0.20	0.44	0.48	0.53	0.65	0.71	0.66	0.71	0.80	0.86	0.77	0.97	0.86	0.90
2003	0.01	0.10	0.26	0.44	0.52	0.59	0.76	0.69	0.75	0.82	0.77	0.89	0.93	0.79	0.84	1.00
2002	0.01	0.08	0.36	0.46	0.61	0.82	0.76	0.85	0.98	0.93	0.92	1.00	0.99	0.92	1.12	1.06
2001	0.02	0.05	0.29	0.48	0.65	0.66	0.75	0.86	0.86	0.88	0.96	0.98	1.01	1.05	0.99	0.98
2000	0.02	0.19	0.32	0.47	0.58	0.66	0.72	0.73	0.75	0.84	0.82	0.88	0.86	0.94	0.87	0.93
1999	0.02	0.14	0.25	0.35	0.43	0.53	0.56	0.57	0.61	0.70	0.66	0.80	0.76	0.88	0.73	0.82
1998	0.02	0.08	0.21	0.35	0.50	0.52	0.54	0.64	0.61	0.68	0.81	0.72	0.81	0.77	0.75	0.80
1997	0.02	0.09	0.36	0.43	0.49	0.55	0.55	0.58	0.59	0.61	0.63	0.86	0.59	0.71	0.66	0.87
1996	0.02	0.10	0.29	0.40	0.47	0.53	0.57	0.65	0.60	0.64	0.60	0.75	0.68	0.81	1.49	0.75
1995	0.02	0.11	0.27	0.34	0.49	0.54	0.65	0.62	0.66	0.76	0.67	0.74	0.80	0.91	0.68	0.80
1994	0.02	0.12	0.30	0.36	0.45	0.45	0.53	0.57	0.62	0.56	0.63	0.48	0.65	0.73	0.70	0.75
1993	0.02	0.13	0.25	0.34	0.40	0.45	0.49	0.50	0.49	0.55	0.51	1.26	1.02	0.61	0.60	0.68
1992	0.02	0.14	0.23	0.35	0.47	0.53	0.58	0.62	0.64	0.65	0.63	0.72	0.74	0.85	0.97	1.03
1991	0.02	0.14	0.28	0.37	0.46	0.51	0.54	0.59	0.72	0.85	1.10	0.72	0.64	1.02	1.21	2.38
1990	0.02	0.14	0.24	0.35	0.39	0.51	0.55	0.61	0.67	0.53	0.77	0.83	2.20	1.18	1.02	1.47
1989	0.02	0.14	0.27	0.30	0.29	0.51	0.44	0.41	0.52	0.63	0.66	0.60	0.88	0.67	0.83	1.13
1988	0.02	0.14	0.19	0.32	0.47	0.37	0.37	0.52	0.65	0.69	0.72	0.92	1.09	1.02	1.45	1.45
1987	0.02	0.15	0.14	0.38	0.28	0.29	0.36	0.58	0.60	0.64	0.76	0.98	0.92	1.24	1.20	1.42
1986	0.03	0.16	0.28	0.29	0.30	0.37	0.54	0.57	0.64	0.82	0.94	1.19	1.19	1.37	1.68	1.61
1985	0.03	0.17	0.23	0.27	0.44	0.55	0.55	0.60	0.75	0.69	0.72	0.86	0.87	0.95	0.68	1.12
1984	0.03	0.13	0.16	0.25	0.44	0.41	0.44	0.59	0.58	0.68	0.70	0.95	1.14	1.03	1.28	1.88
1983	0.04	0.13	0.14	0.34	0.37	0.33	0.52	0.50	0.62	0.71	0.88	0.93	1.04	1.03	1.32	1.48
1982	0.04	0.12	0.25	0.33	0.31	0.55	0.40	0.53	0.56	0.76	0.68	0.85	1.07	0.88	1.02	1.17
1981	0.04	0.11	0.21	0.34	0.53	0.39	0.53	0.55	0.75	0.72	0.82	1.04	1.10	1.34	1.49	1.21
1980	0.05	0.08	0.21	0.45	0.39	0.49	0.52	0.66	0.71	0.87	1.06	1.16	1.29	1.30	1.27	1.40
1979	0.05	0.08	0.24	0.26	0.58	0.69	0.77	0.89	0.91	1.04	1.20	1.25	1.53	1.55	1.79	1.98
1978	0.05	0.07	0.13	0.47	0.53	0.60	0.64	0.74	0.84	0.98	1.10	1.25	1.33	1.48	1.74	2.34
1977	0.06	0.09	0.40	0.49	0.59	0.66	0.75	0.83	0.98	1.11	1.23	1.31	1.40	1.75	2.10	2.21
1976	0.06	0.10	0.24	0.50	0.52	0.69	0.80	0.92	1.21	1.33	1.45	1.65	1.81	1.86	1.96	2.74
1975	0.06	0.16	0.30	0.37	0.61	0.63	0.79	0.87	0.97	0.91	0.97	1.69	1.50	1.90	1.96	2.74
1974	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1973	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1972	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1971	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1970	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1969	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1968	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1967	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
1966	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03
mean	0.02	0.09	0.26	0.38	0.48	0.53	0.58	0.65	0.71	0.77	0.85	0.93	0.96	1.06	1.00	1.03

Figure 13. Empirical weight-at-age (kg) values used for the base model. Colors correspond to the values, with red being the lightest fish (across all years and ages) and blue being the heaviest fish. For each age, the most transparent cells indicate the lightest fish of that age. Data are only available from 1975–2019. Values based on assumptions for the pre-1975 and forecast years are shown outside the blue lines. Bold values between 1975–2019 represent unavailable data such that weights were interpolated or extrapolated from adjacent ages or years. The bottom row (mean) is the sample-weighted mean weight-at-age.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019	1	363	800	1540	91	2205	144	236	152	1228	130	89	40	30	24	23
2018	0	212	1019	58	1192	61	106	103	803	123	59	28	23	13	10	4
2017	0	585	43	3065	186	290	198	2447	240	171	93	40	55	23	13	12
2016	0	11	1934	88	246	116	1604	101	118	35	15	21	10	2	3	8
2015	0	1565	226	428	218	3185	184	221	52	59	63	23	12	8	10	57
2014	0	0	118	144	2617	263	488	51	100	58	26	10	2	4	7	22
2013	0	241	74	5009	458	844	93	177	182	57	29	12	10	22	60	29
2012	0	39	2657	849	1967	185	210	144	84	32	20	18	22	37	24	17
2011	0	688	564	3859	168	360	278	52	35	19	14	4	72	14	6	4
2010	0	1	921	102	1443	730	67	110	14	21	40	155	25	3	3	6
2009	0	488	31	1999	2233	132	455	40	89	76	554	76	19	18	10	9
2008	0	44	330	1374	124	756	58	180	169	1200	90	29	31	11	11	9
2007	9	432	1195	312	981	108	448	279	2895	291	139	112	60	37	18	14
2006	0	10	120	524	93	424	254	2514	167	47	66	34	15	11	4	4
2005	0	6	329	49	420	317	3739	394	128	166	106	74	50	13	6	12
2004	0	0	1	230	270	2492	235	59	134	75	31	33	12	8	4	5
2003	0	40	121	106	4049	639	191	347	257	164	136	54	31	31	19	29
2002	0	0	1	1786	604	386	253	175	248	144	39	38	40	11	17	35
2001	0	6	1245	987	905	1111	650	710	408	124	138	101	69	57	34	73
2000	0	20	154	221	375	357	538	327	189	117	66	58	61	30	26	73
1999	0	0	204	618	481	430	252	70	95	110	19	38	59	11	14	58
1998	0	125	728	1332	1161	1421	149	376	576	78	101	310	29	15	291	74
1997	0	0	28	833	799	21	174	304	20	82	139	3	6	143	4	72
1996	0	0	484	443	41	174	505	12	88	276	5	3	315	0	5	103
1995	0	162	425	77	152	1128	74	321	889	46	8	1066	17	36	1	339
1994	0	0	1	94	789	24	481	624	18	9	825	2	12	2	221	27
1993	0	0	23	511	57	250	314	21	15	512	7	4	2	168	2	26
1992	0	153	454	164	635	1040	119	54	1761	65	21	16	788	27	2	76
1991	0	0	35	408	529	75	22	692	38	5	8	337	10	0	59	10
1990	0	0	179	978	79	9	843	17	9	4	931	8	1	192	0	25
1989	49	0	168	152	89	2370	109	89	61	1518	100	25	169	14	6	25
1988	0	1	71	25	1612	147	77	76	1419	81	21	250	10	4	1	57
1987	0	0	32	1180	427	236	129	1722	114	54	263	10	2	7	36	7
1986	0	7	566	466	353	270	1748	388	251	361	97	75	44	82	13	27
1985	0	27	38	99	350	1906	232	186	240	52	19	15	16	4	1	7
1984	0	1	57	79	2345	270	352	639	158	80	47	67	19	12	26	5
1983	0	109	22	1295	176	453	1179	307	238	203	302	98	78	63	19	13
1982	0	0	1131	226	361	1791	756	668	541	896	260	251	371	60	26	28
1981	0	511	111	140	1596	589	522	446	891	380	301	367	91	51	19	26
1980	0	6	34	1214	412	651	678	1093	550	599	537	169	127	85	40	53
1979	0	0	171	278	311	160	681	237	510	475	139	88	38	20	10	6
1978	0	68	71	419	403	1507	252	550	1449	444	303	228	114	63	27	15
1977	2	0	428	330	2211	398	717	2952	898	684	484	326	193	91	44	24
1976	0	7	90	673	234	101	939	508	419	407	314	196	140	68	31	11
1975	0	12	100	12	7	118	15	26	23	4	1	3	1	1	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mean	61	5940	17534	34776	34250	30500	21512	21045	17735	11632	7106	4964	3311	1602	1207	1559

Figure 14. Sample sizes for developing empirical weight-at-age values (colors and transparency as for Figure 13) used in the base model. Data are available from 1975–2019. The total sample size for each age is shown at the bottom.

Figure 15. Bridging models showing the 2019 base model and the sequential influence of updating to the latest version of Stock Synthesis and changing the constrain on recruitment deviations. Simple deviations (i.e., residuals from the mean) are applied rather than forcing residuals to sum to zero across the main recruitment period (see Section 3.2). 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).
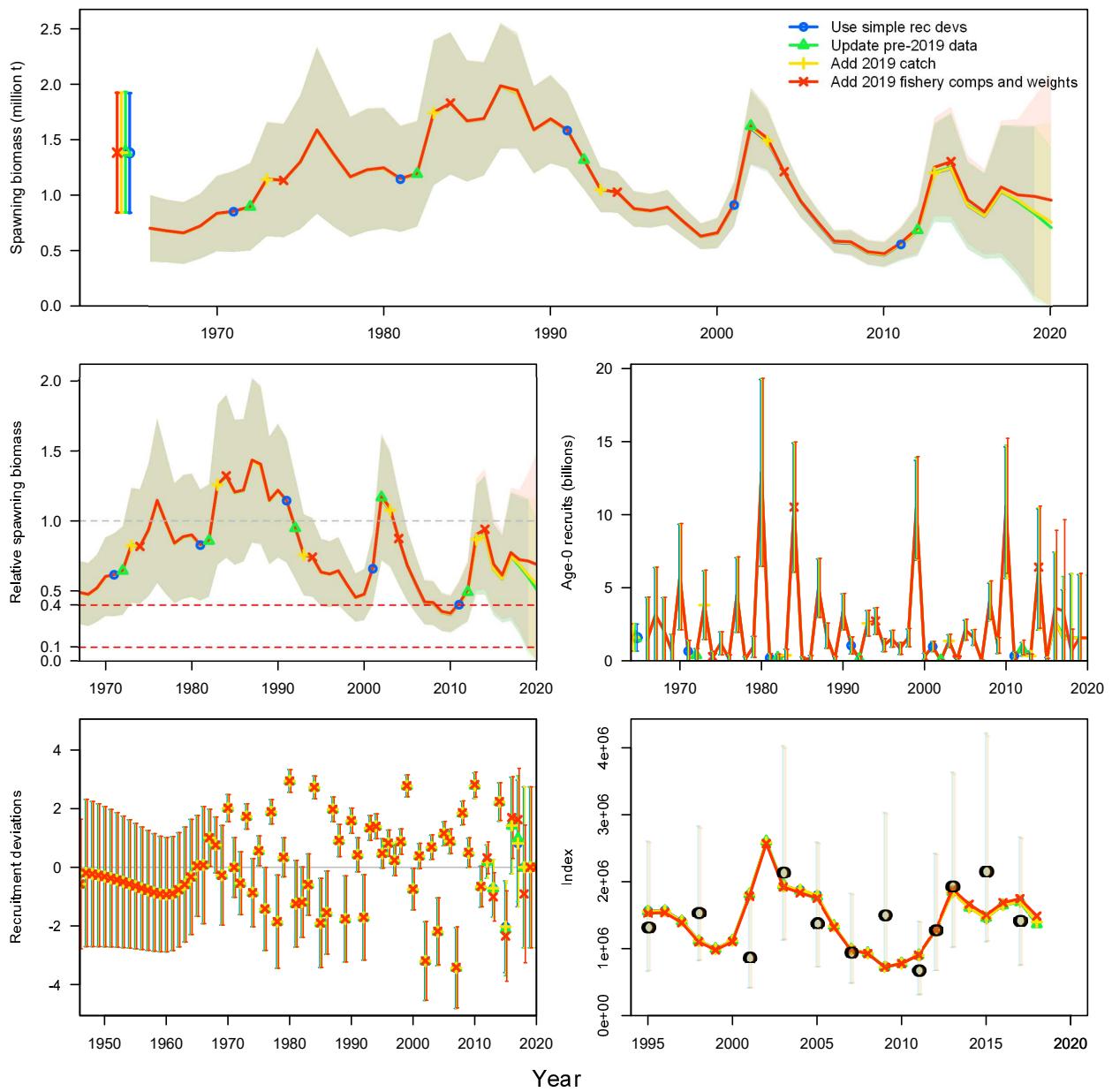
Figure 16. Bridging models starting with the addition of simple recruitment deviations (shown in Figure 15) and then with sequential changes including updating pre-2019 fishery data, adding 2019 catch data, and adding 2019 weight-at-age and fishery composition data. Panels are spawning biomass (upper 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).
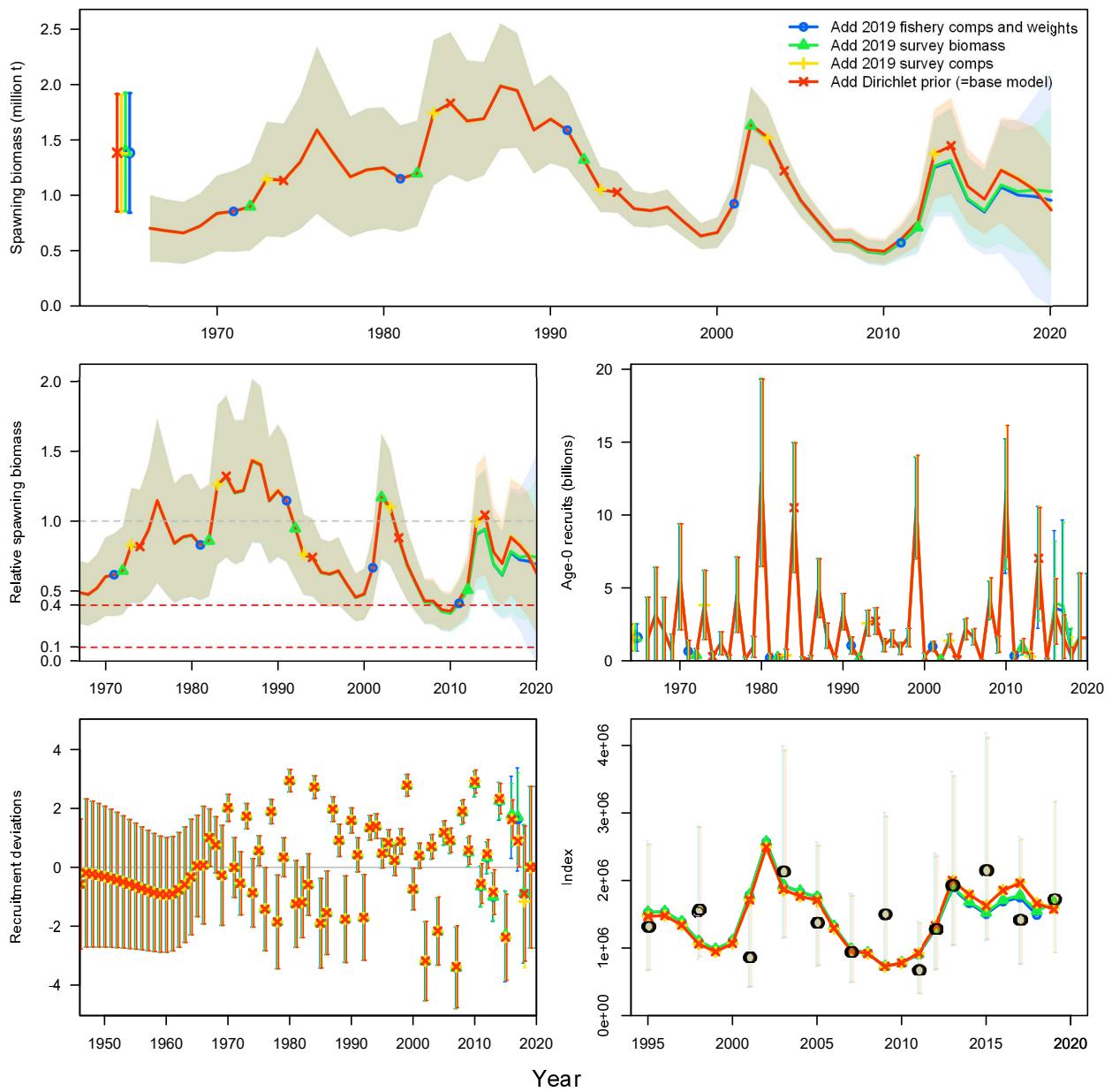
Figure 17. Bridging models starting with the addition of 2019 fishery compositions and weights (shown in Figure 16) and then with sequential changes including updating and adding 2019 survey biomass data, adding 2019 survey composition data, and then adding a prior on the survey Dirichlet-Multinomial parameter, giving the 2020 base model. 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). For models without 2019 data, estimates shown for 2020 are forecasts.
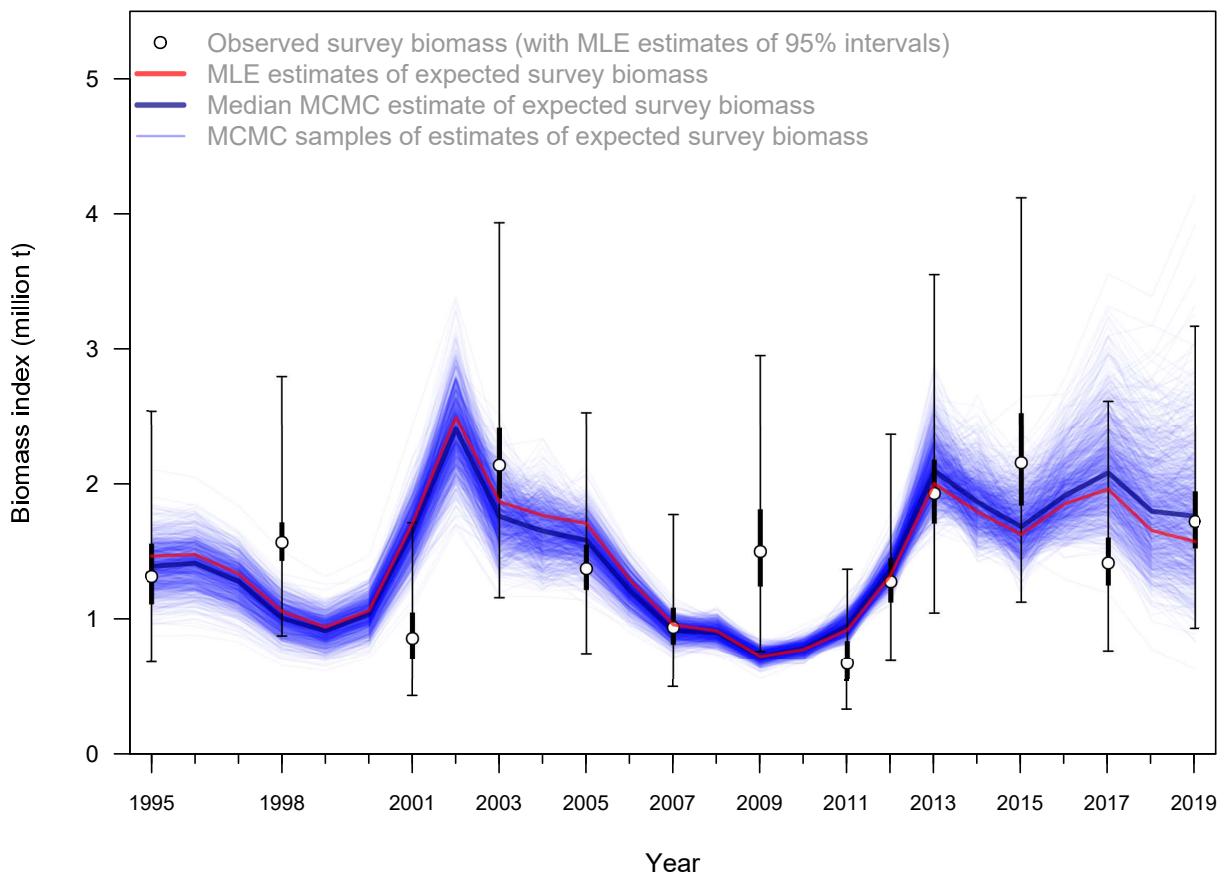
Figure 18. Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker 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.

Fishery age composition

Survey age composition
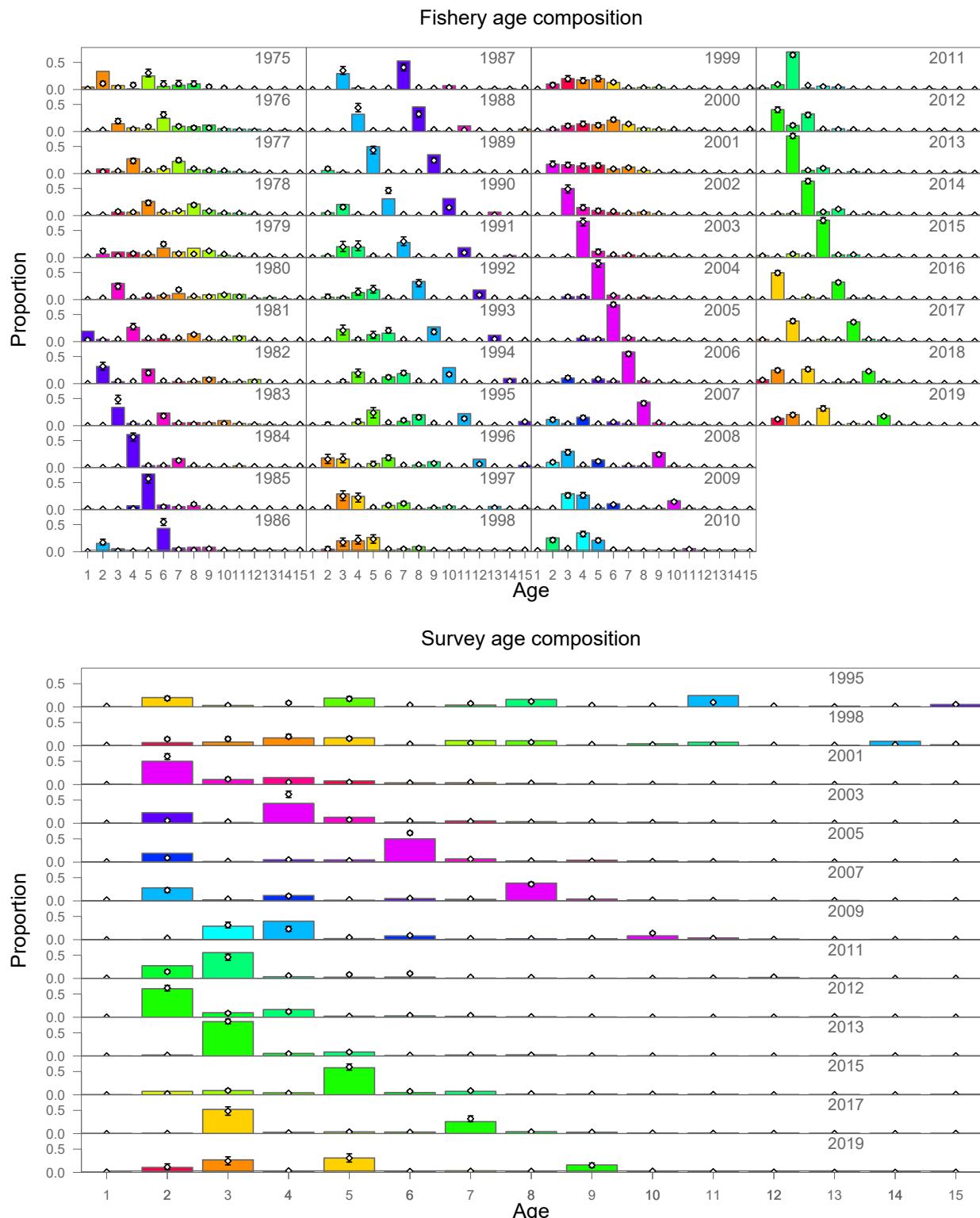
Figure 19. Base model fits to the observed fishery (top) and acoustic survey (bottom) age-composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% credibility intervals from the MCMC calculations.
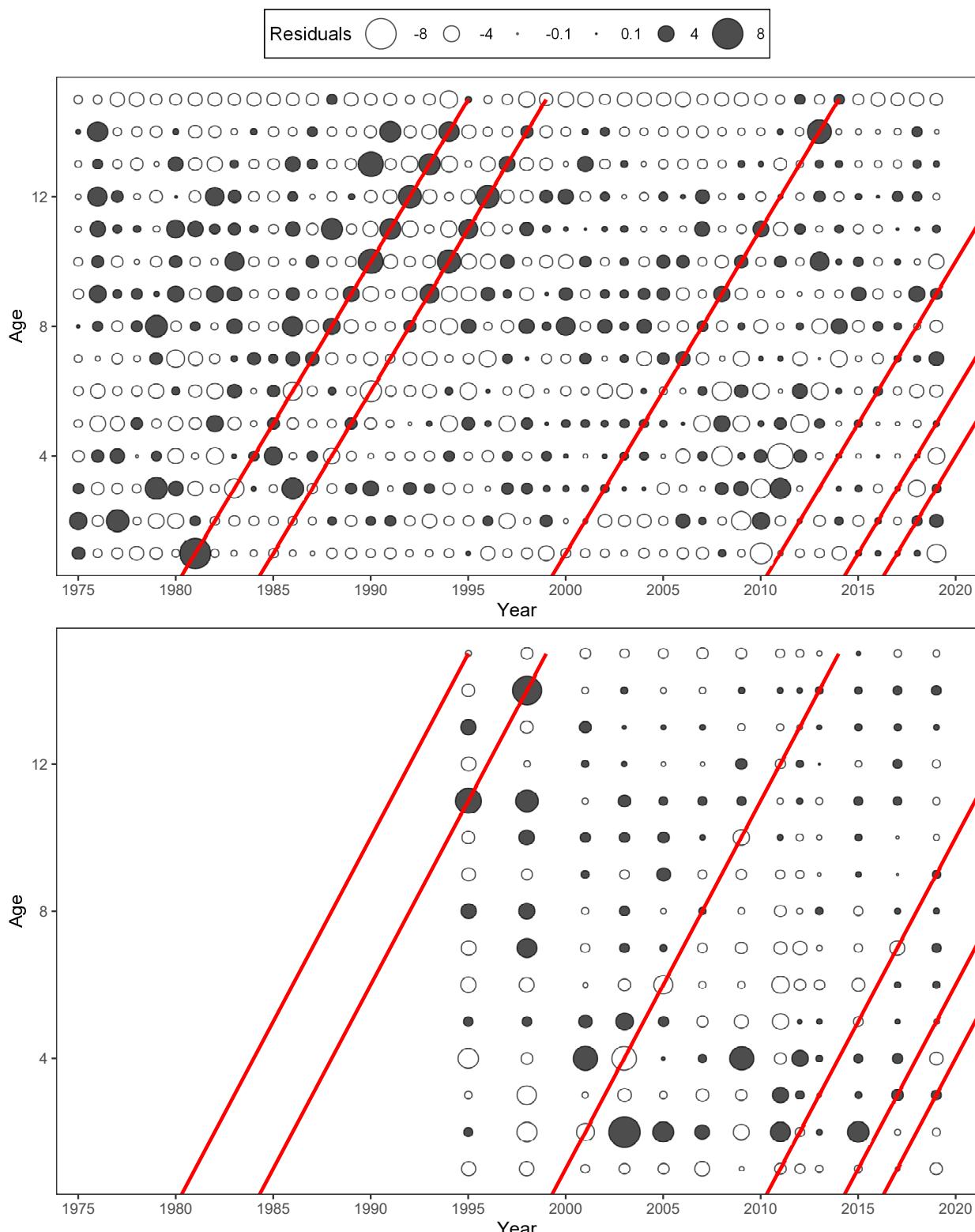
Figure 20. Pearson residuals for base model MLE fits to the age-composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).
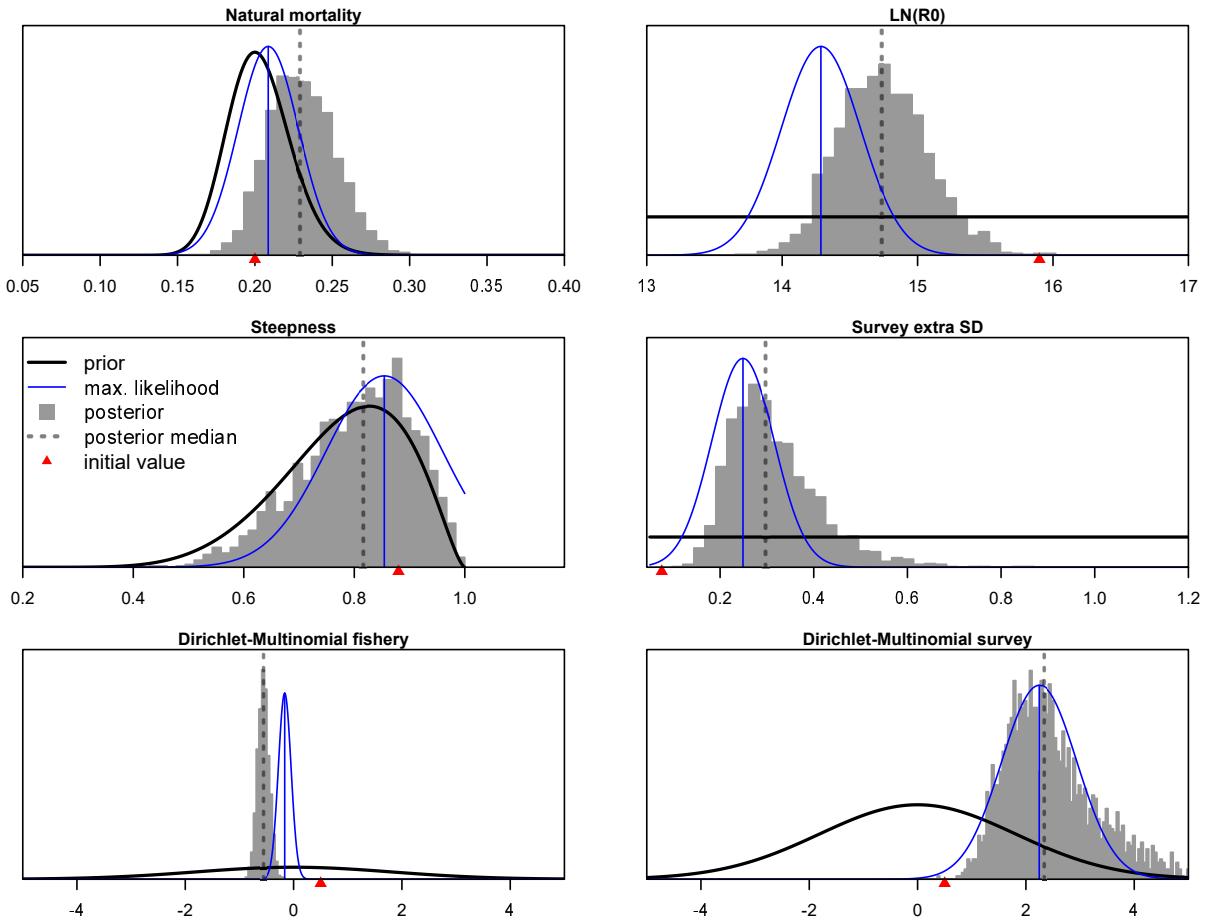
Figure 21. Prior (black lines) and posterior (gray histograms) distributions for key parameters in the base model. The parameters are: natural mortality (M), equilibrium log recruitment $\log(R_0)$, steepness (h), the additional process-error standard deviation for the acoustic survey, and the Dirichlet-Multinomial parameters for the fishery and the survey. The maximum likelihood estimates and associated symmetric uncertainty intervals are also shown (blue lines). There are 50 bins for each posterior except the two Dirichlet-Multinomial parameters which are grouped into 500 bins.
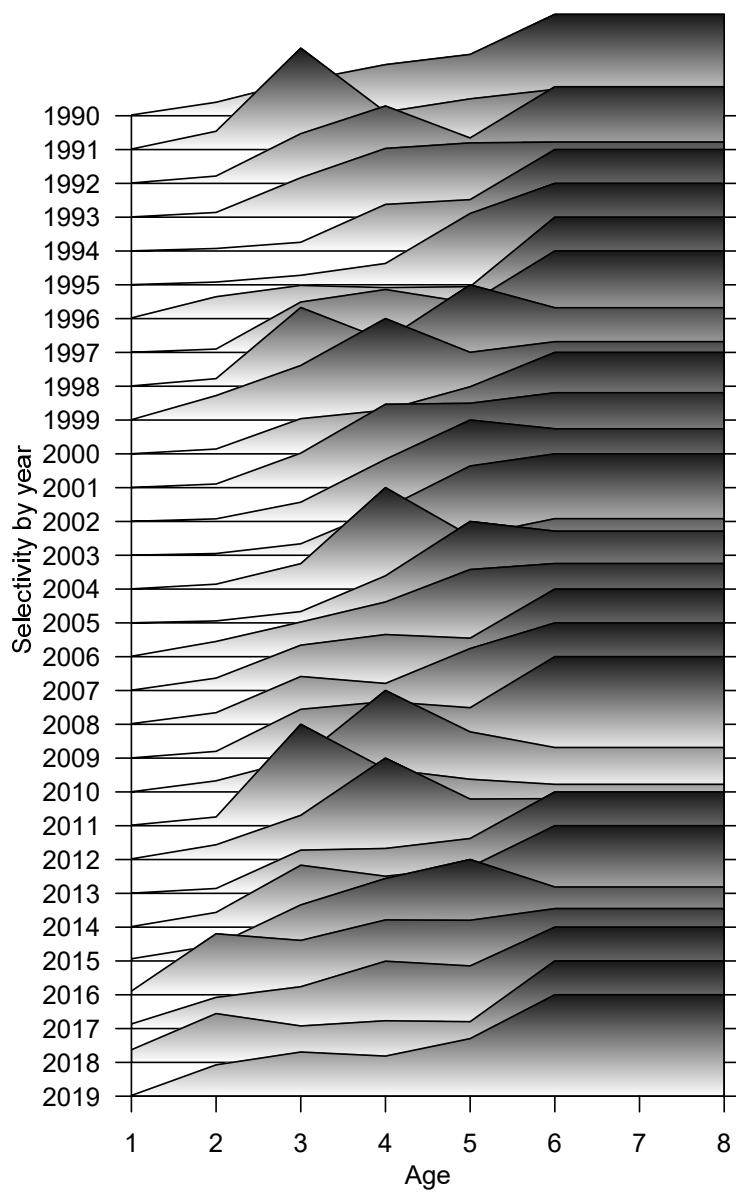
Figure 22. Mountains plot of median fishery selectivity in each year for the base model. Range of selectivity is 0 to 1 in each year.
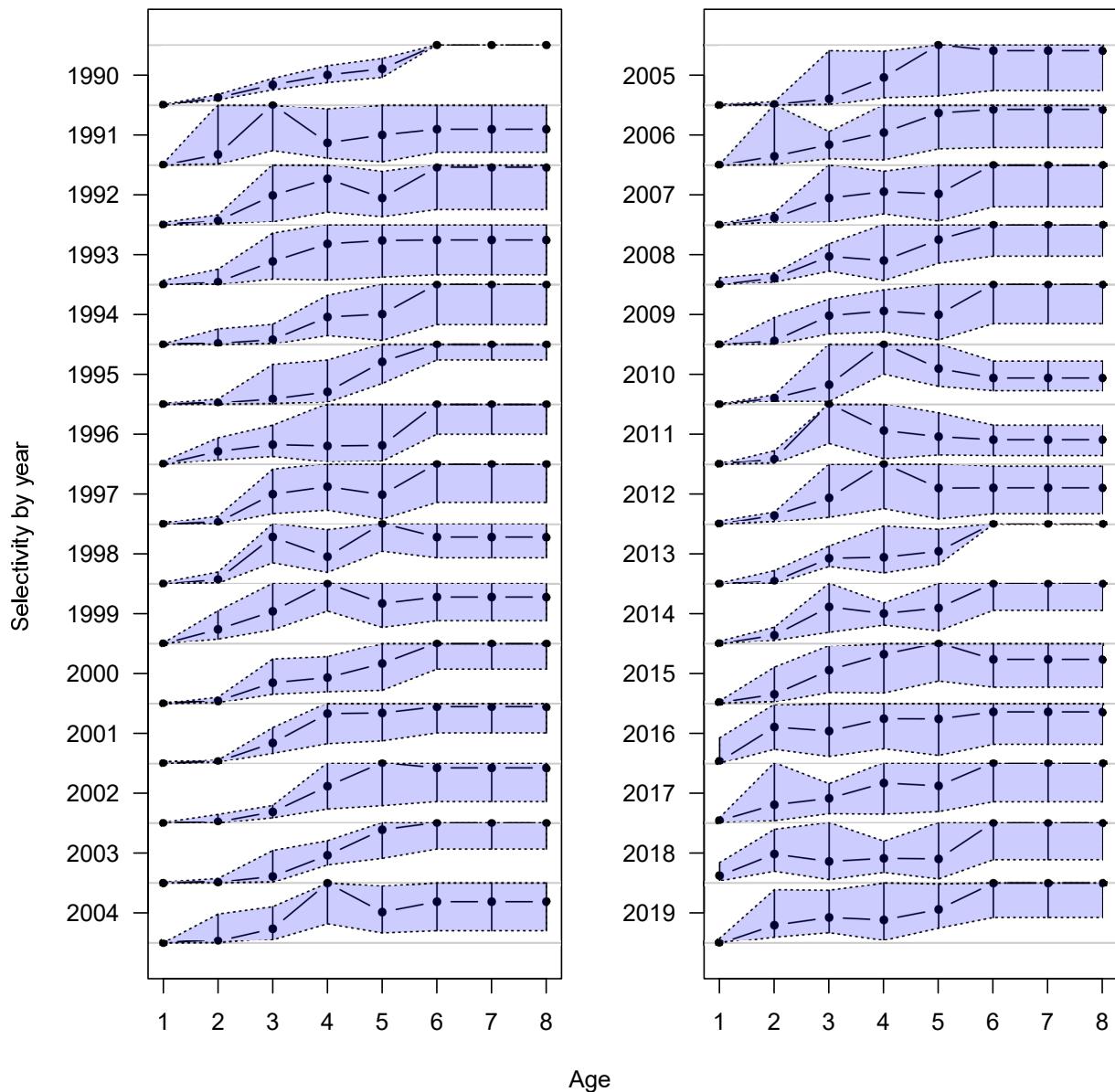
Figure 23. Fishery selectivity sampled from posterior probability distribution by year for the base model. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared for all years from 1966 to 1990.
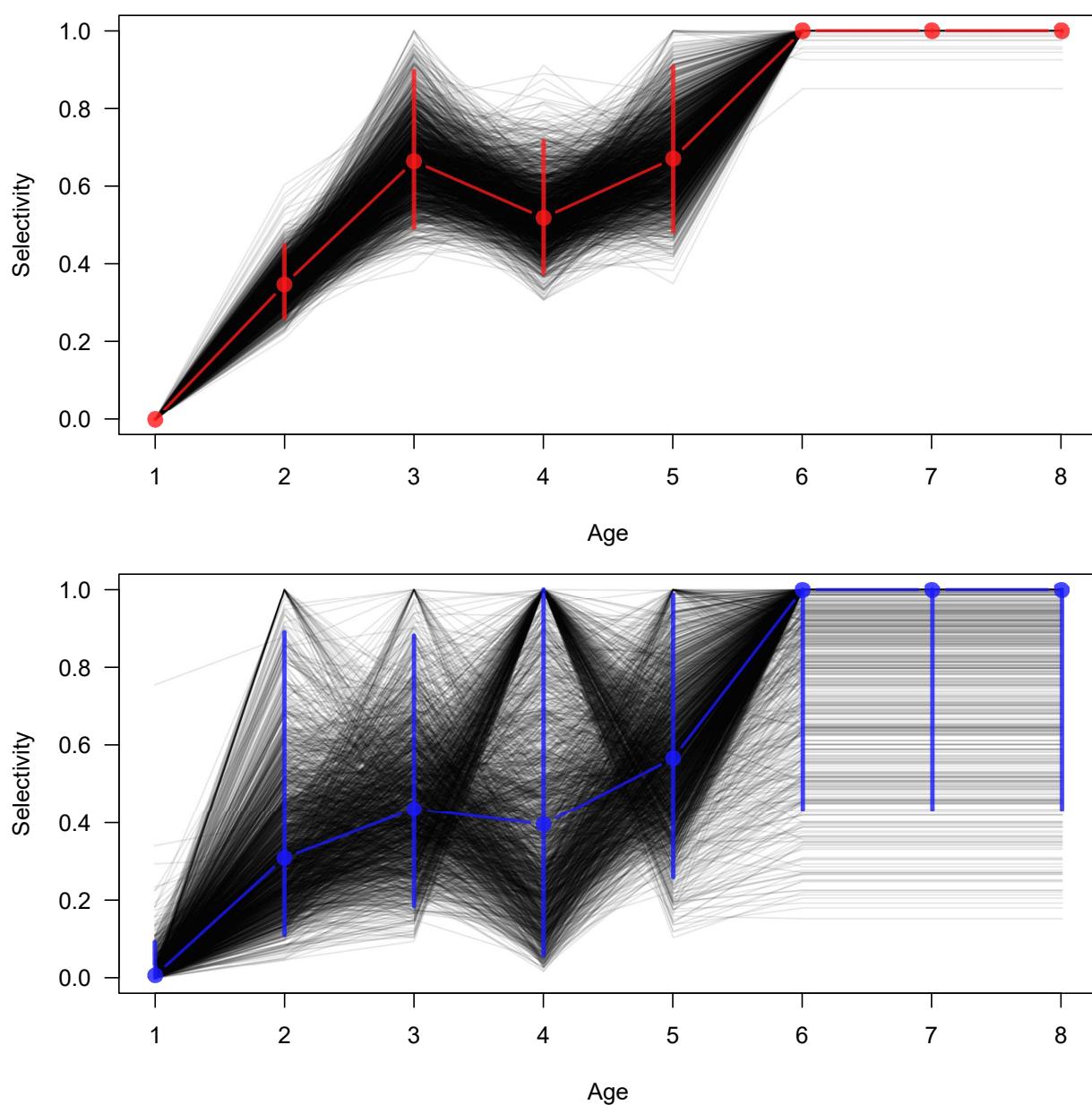
Figure 24. Estimated acoustic (top – for all years) and fishery selectivities (bottom – for 2019 only) from the posterior distribution for the base model.
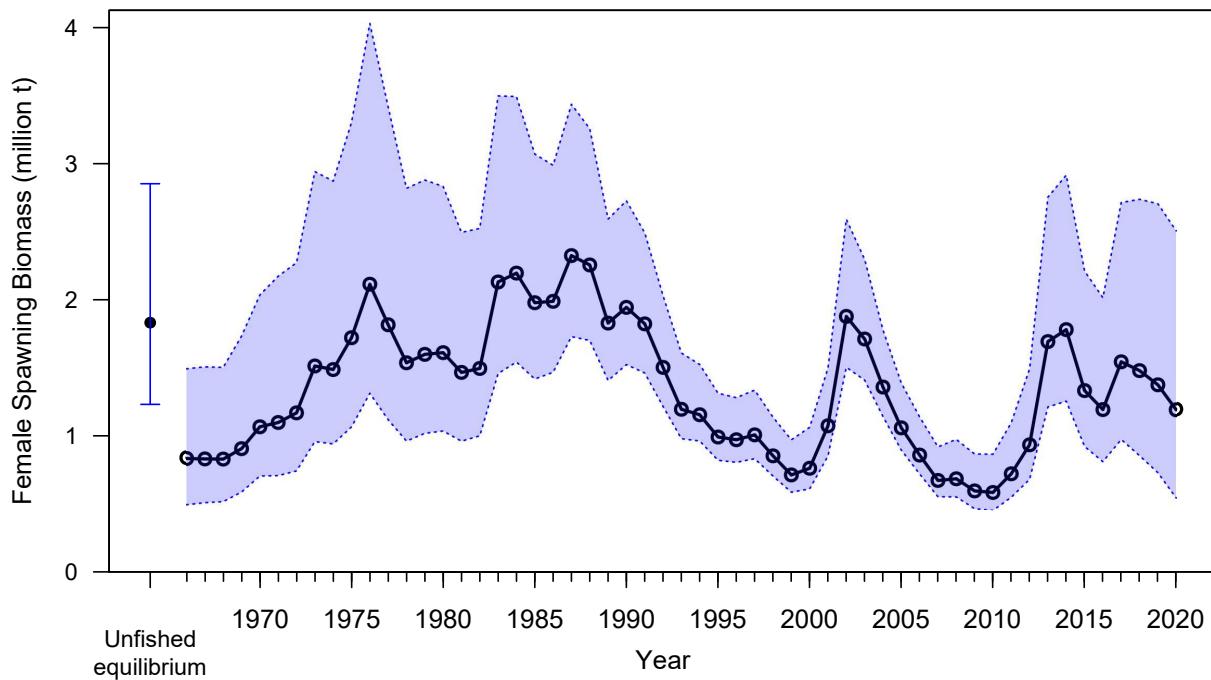
Figure 25. Median of the posterior distribution for female spawning biomass at the start of each year (B_t) for the base model up to 2020 (solid line) with 95% posterior credibility intervals (shaded area).
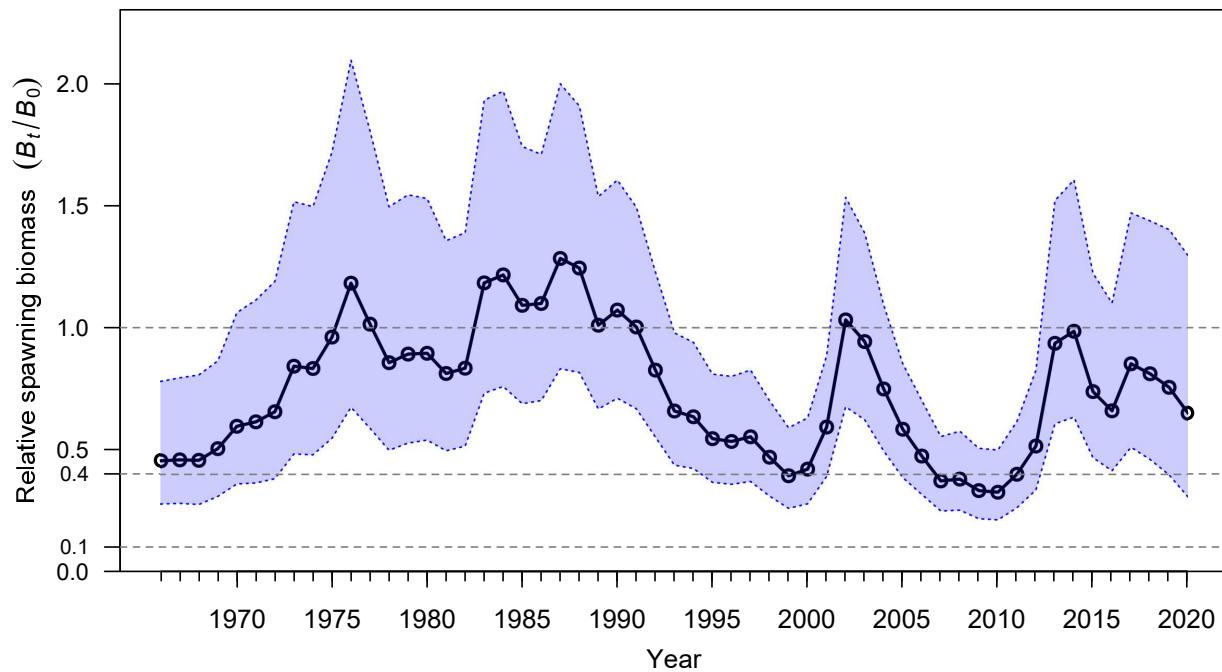
Figure 26. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) for the base model through 2020 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.
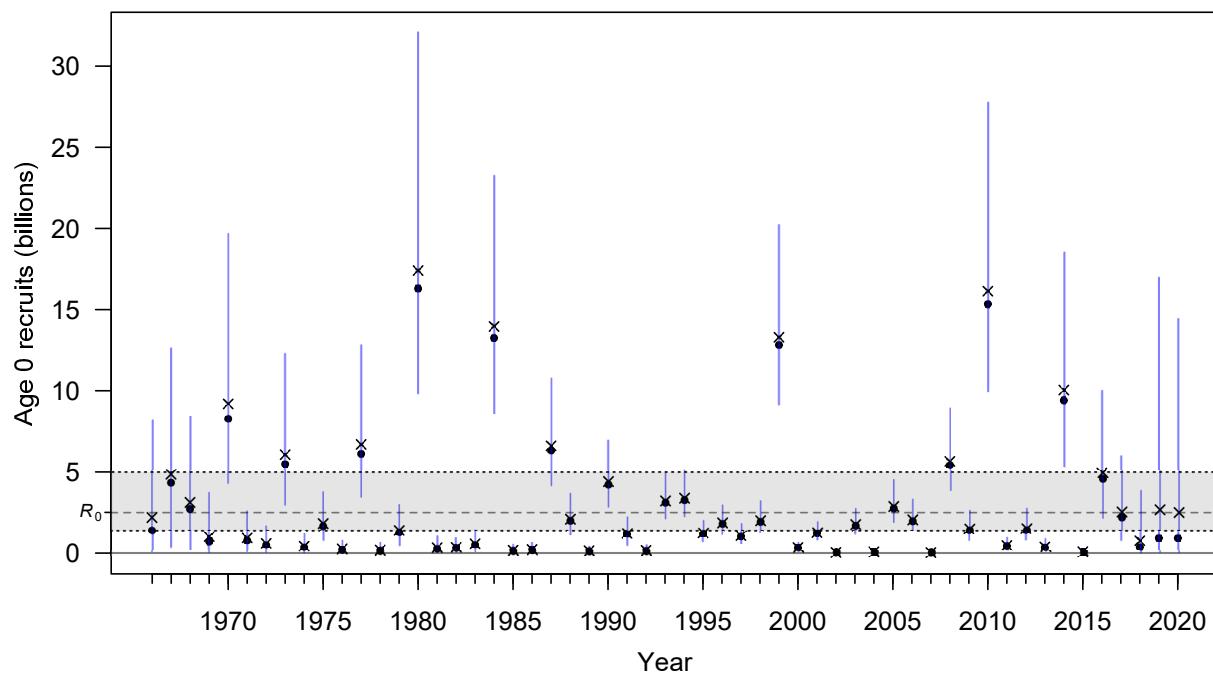
Figure 27. Medians (solid circles) and means ($\times$) of the posterior distribution for recruitment (billions of age-0 fish) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.
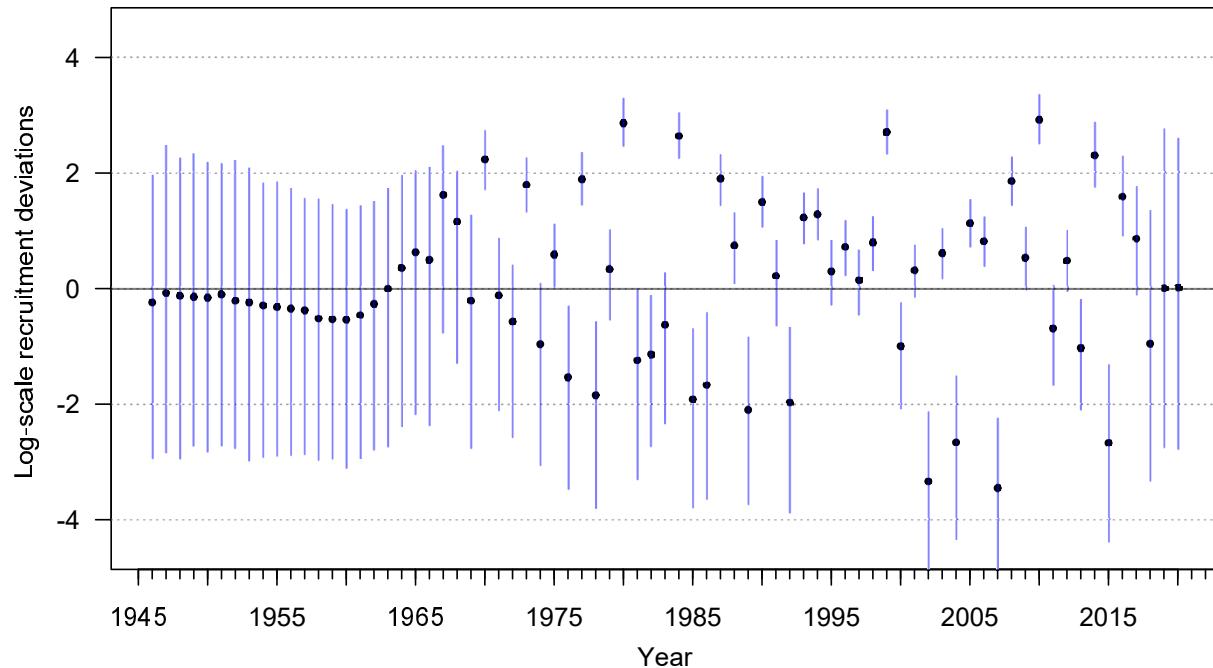
Figure 28. Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model.
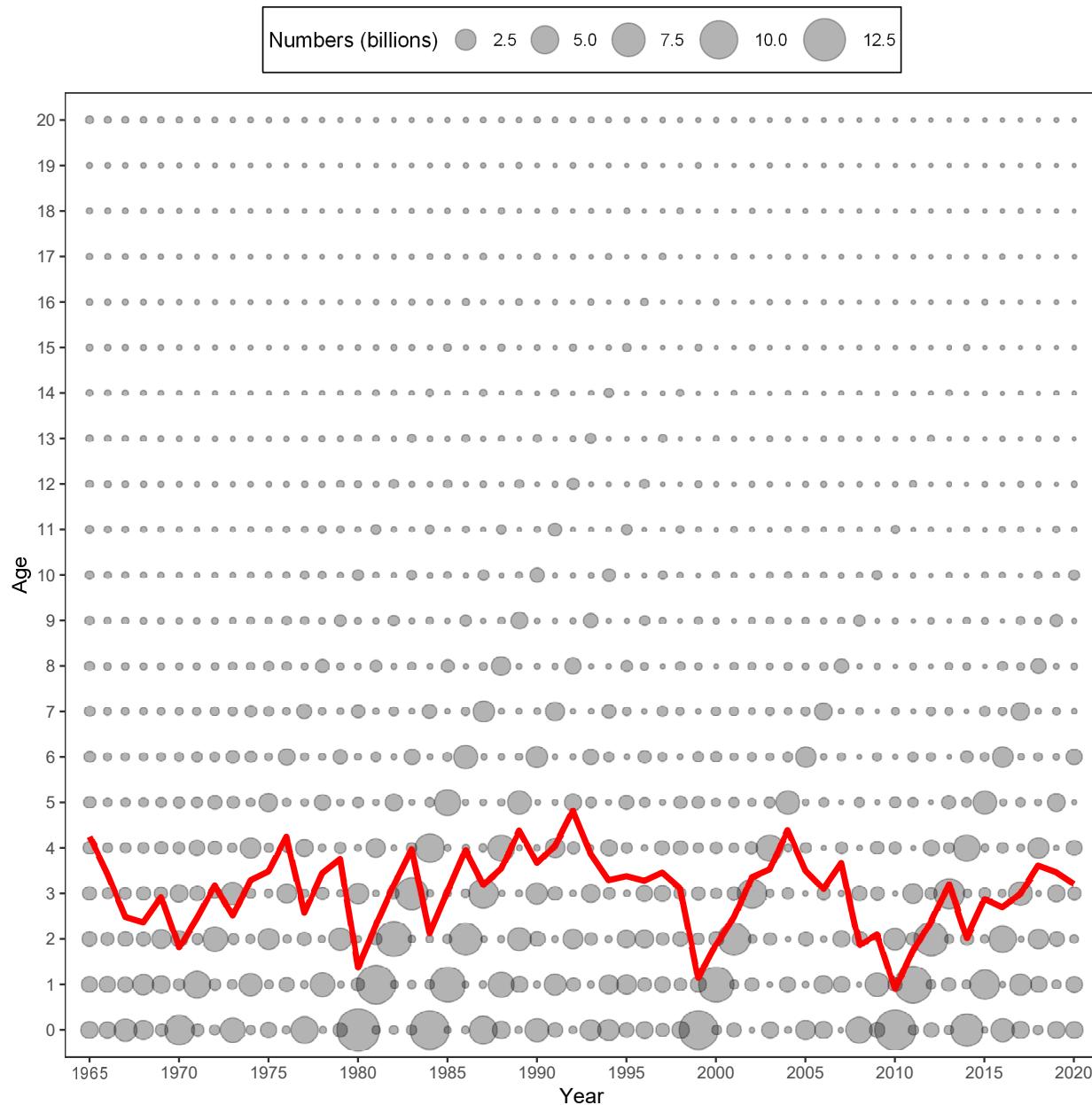
Figure 29. Bubble plot of MLE estimates of population numbers at age at the beginning of each year, where diagonals follow each year-class through time. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish (with the largest bubble representing 12.9 billion age-0 recruits in 1980). See Table 19 for values.
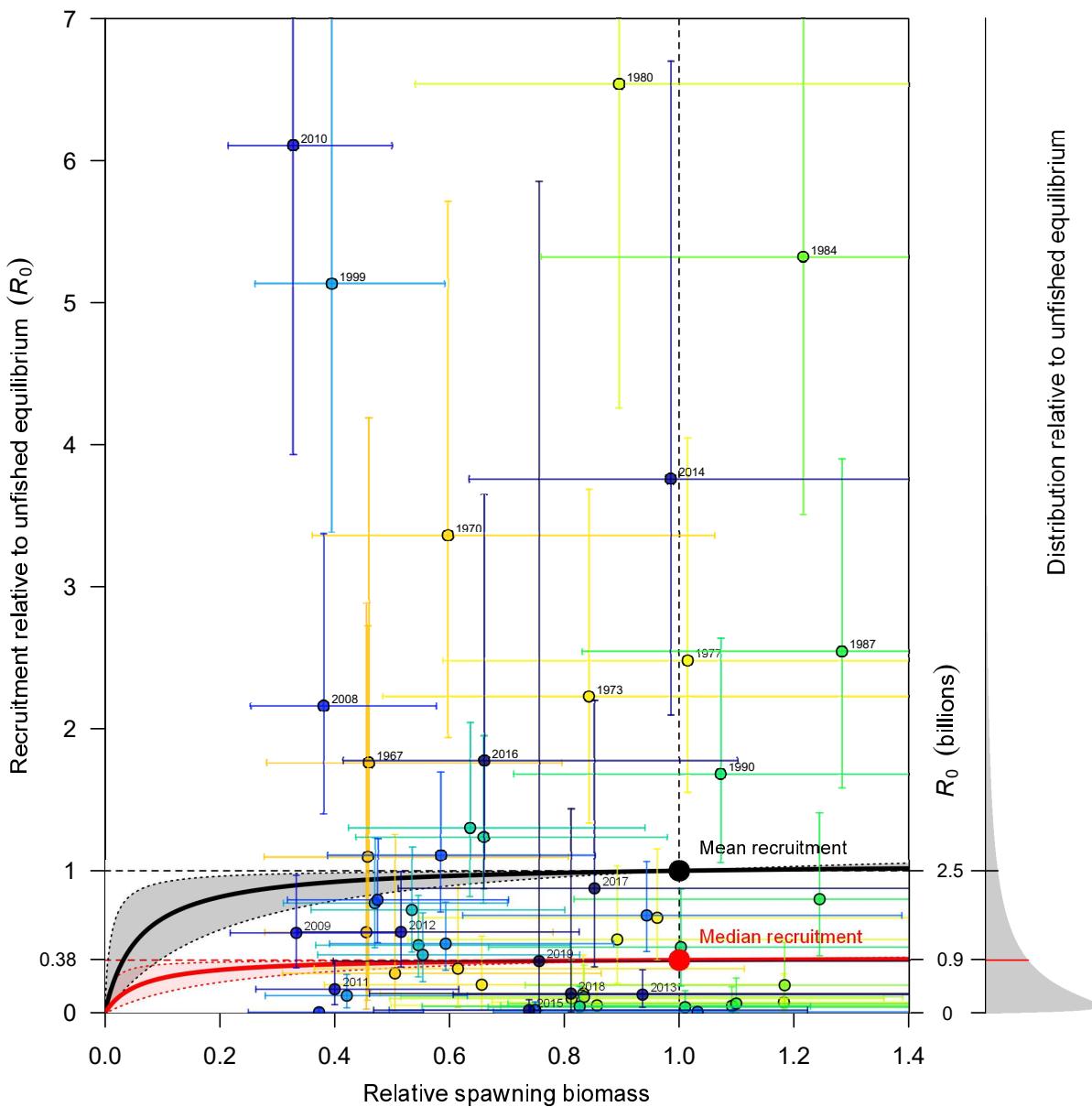
Figure 30. Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (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.
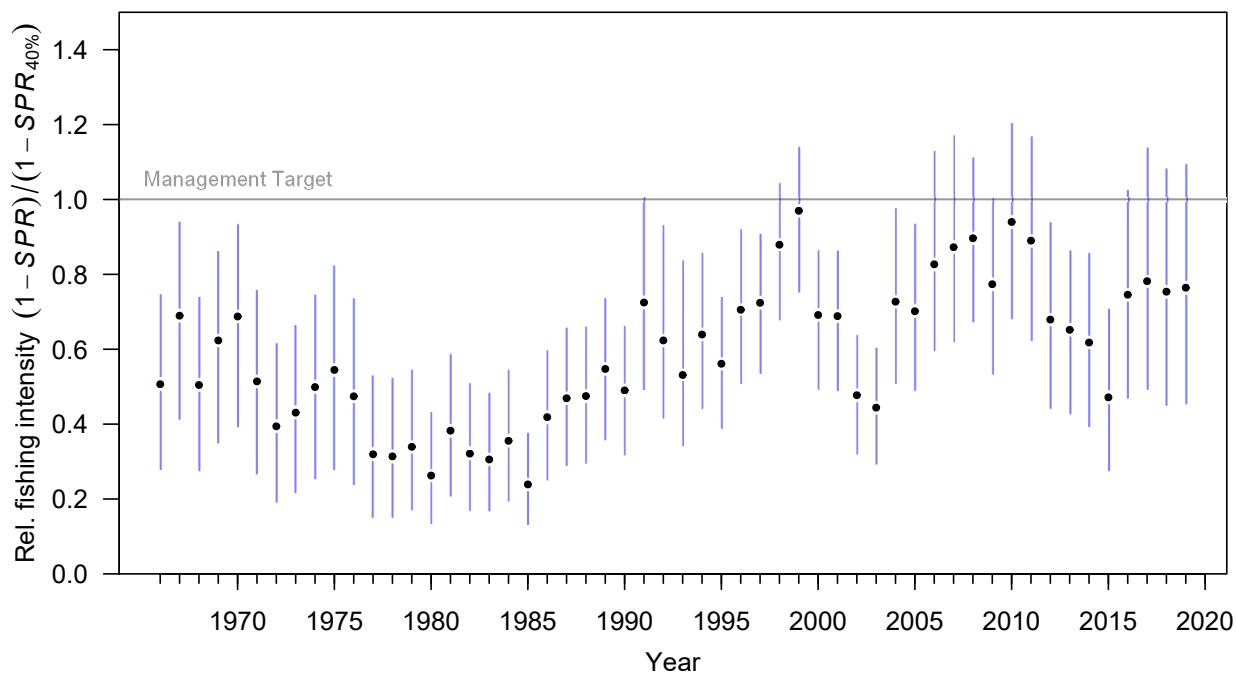
Figure 31. Trend in median fishing intensity (relative to the SPR management target) through 2019 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.
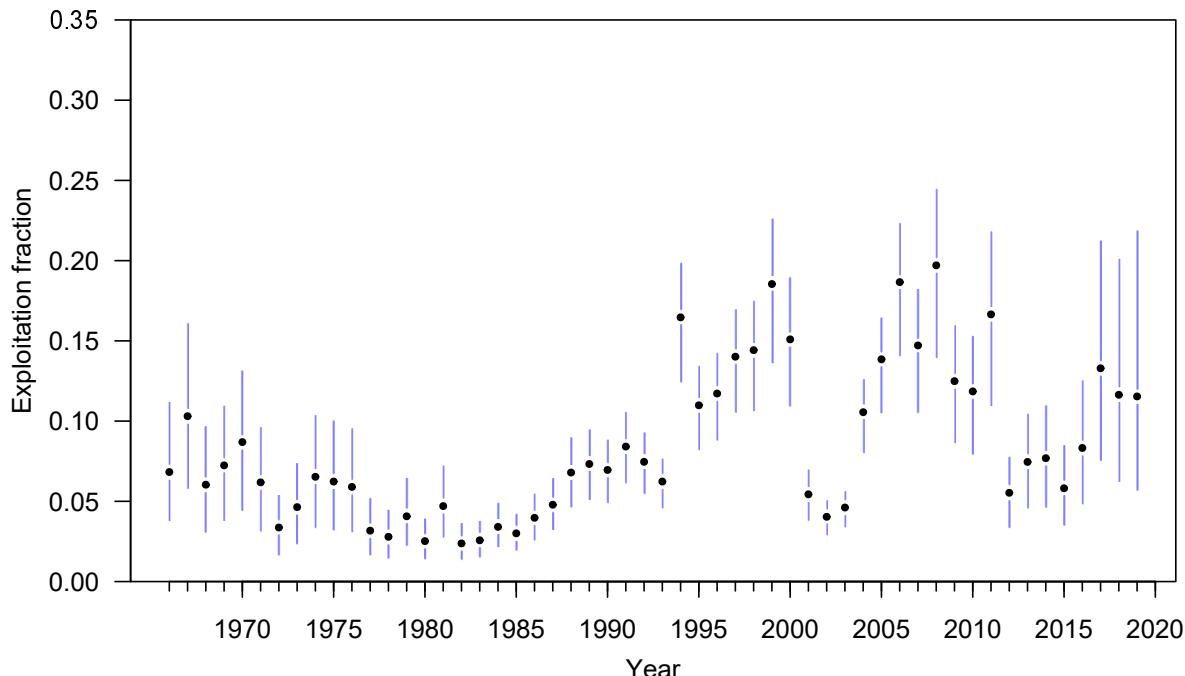
Figure 32. Trend in median exploitation fraction (catch divided by biomass of fish of age-2 and above) through 2019 with 95% posterior credibility intervals.
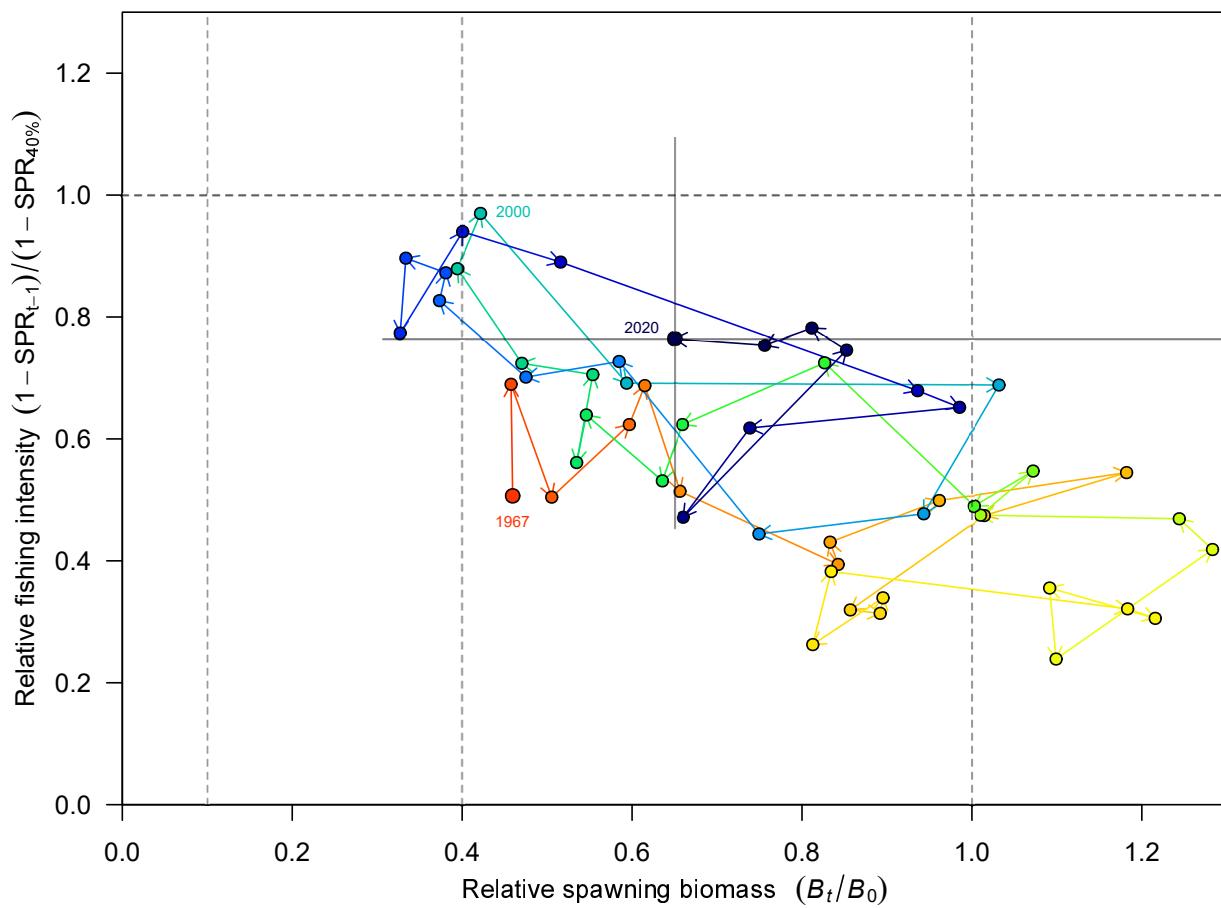
Figure 33. Estimated historical path of median relative spawning biomass in year t and corresponding median relative fishing intensity in year $t-1$. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year t (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2020 relative spawning biomass (horizontal) and 2019 relative fishing intensity (vertical).
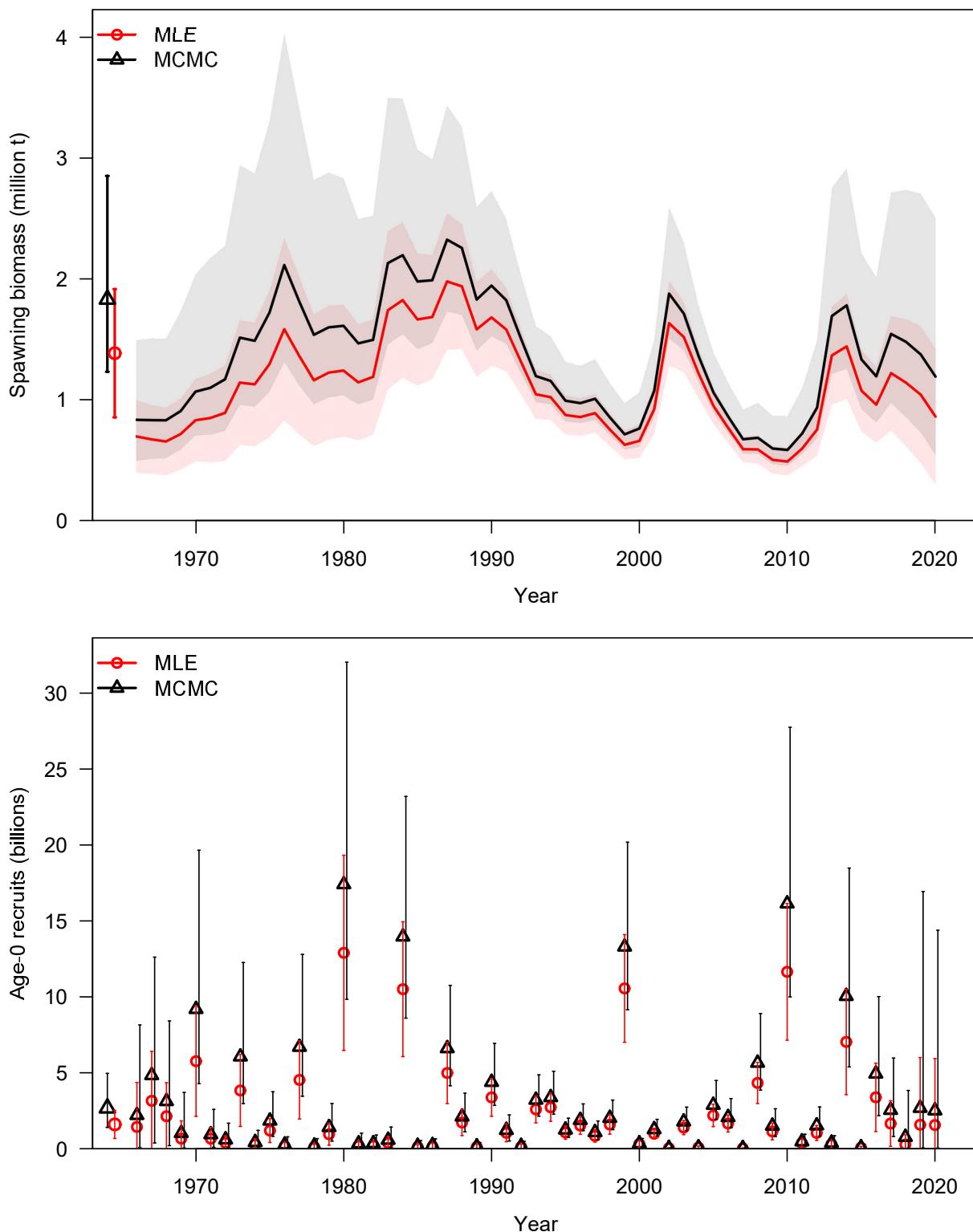
Figure 34. A comparison of maximum likelihood estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the posterior distribution with 95% credibility intervals (black). The posterior median is shown for spawning biomass (upper panel), while the posterior mean is shown for recruitment (lower panel) to be more comparable to the MLE value.
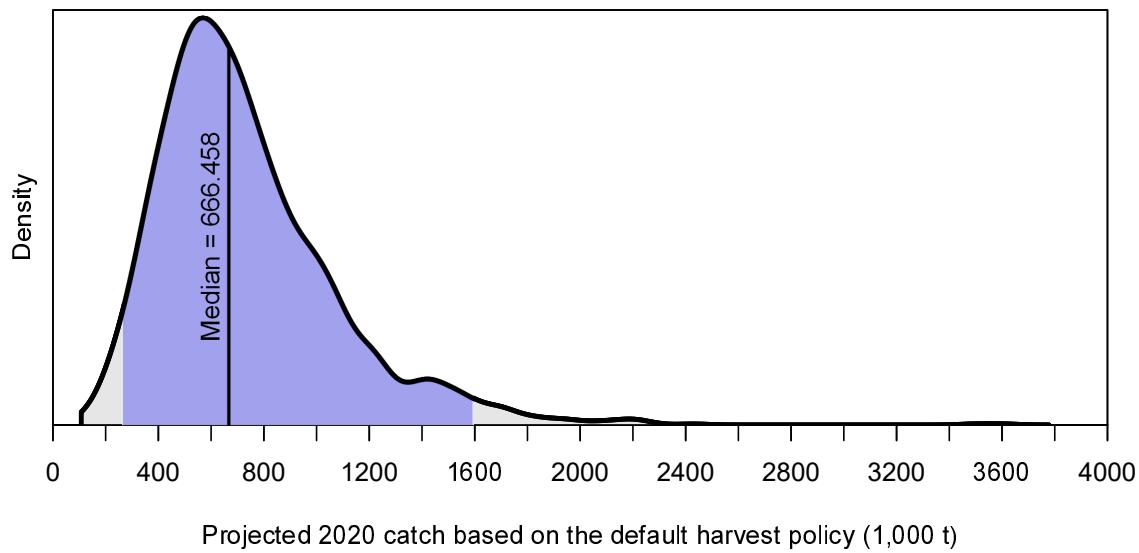
Figure 35. The posterior distribution of the default 2020 catch limit calculated using the default harvest policy ($F_{\text{SPR}=40\%}$–40:10). The median is 666,458 t (vertical line), with the dark shaded area ranging from the 2.5% quantile to the 97.5% quantile, covering the range 258,675–1,588,947 t.
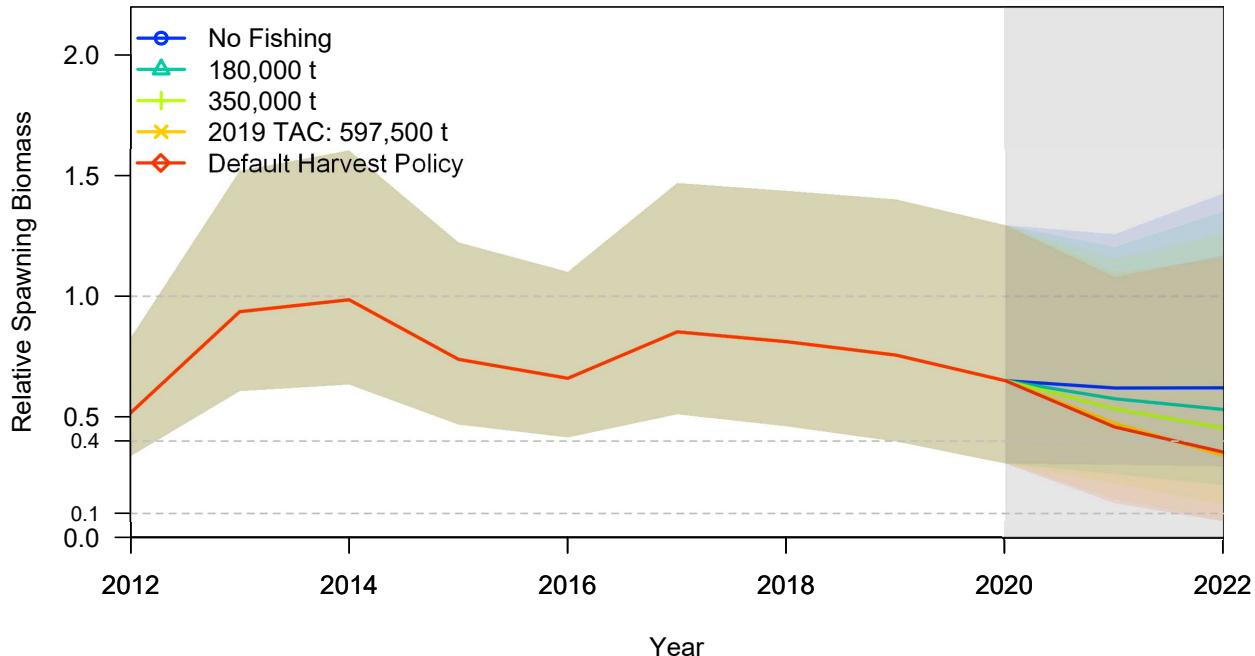
Figure 36. Time series of relative spawning biomass at the start of each year until 2020 as estimated from the base model, and forecast trajectories to the start of 2022 for several management options from the decision table (grey region), with 95% posterior credibility intervals. The 2020 catch of 666,458 t was calculated using the default harvest policy, as defined in the Agreement.
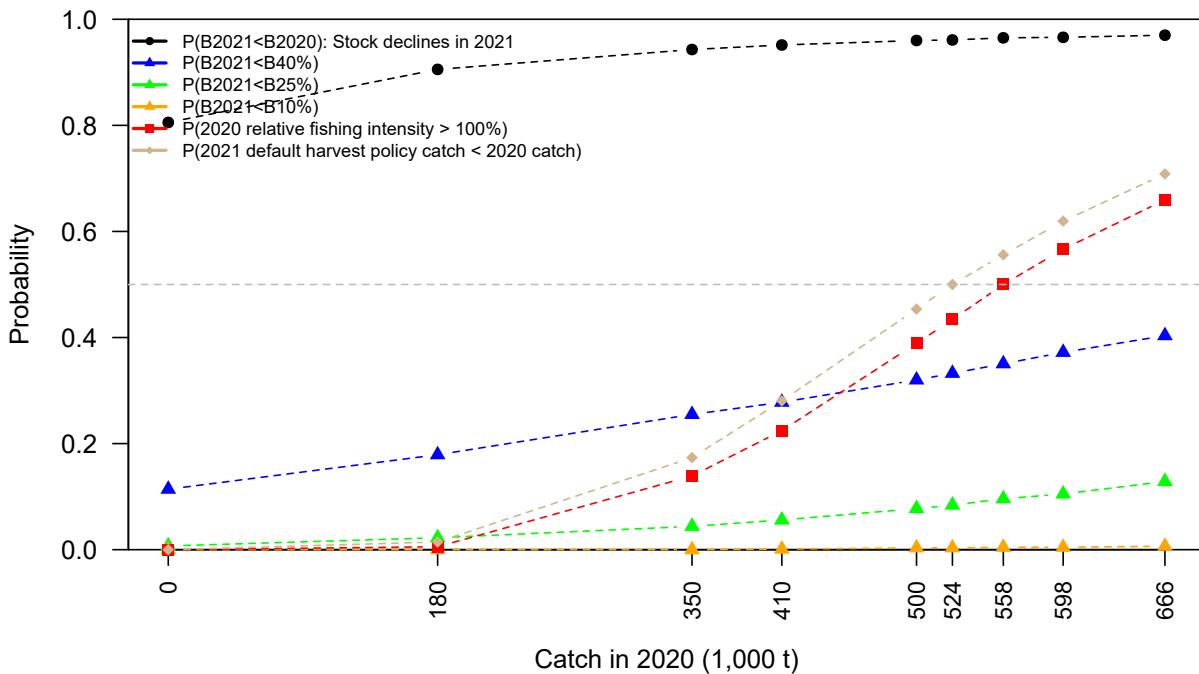
Figure 37. Graphical representation of the base model results presented in Table 31 for various catches in 2020. The symbols indicate points that were computed directly from model output and lines interpolate between the points.
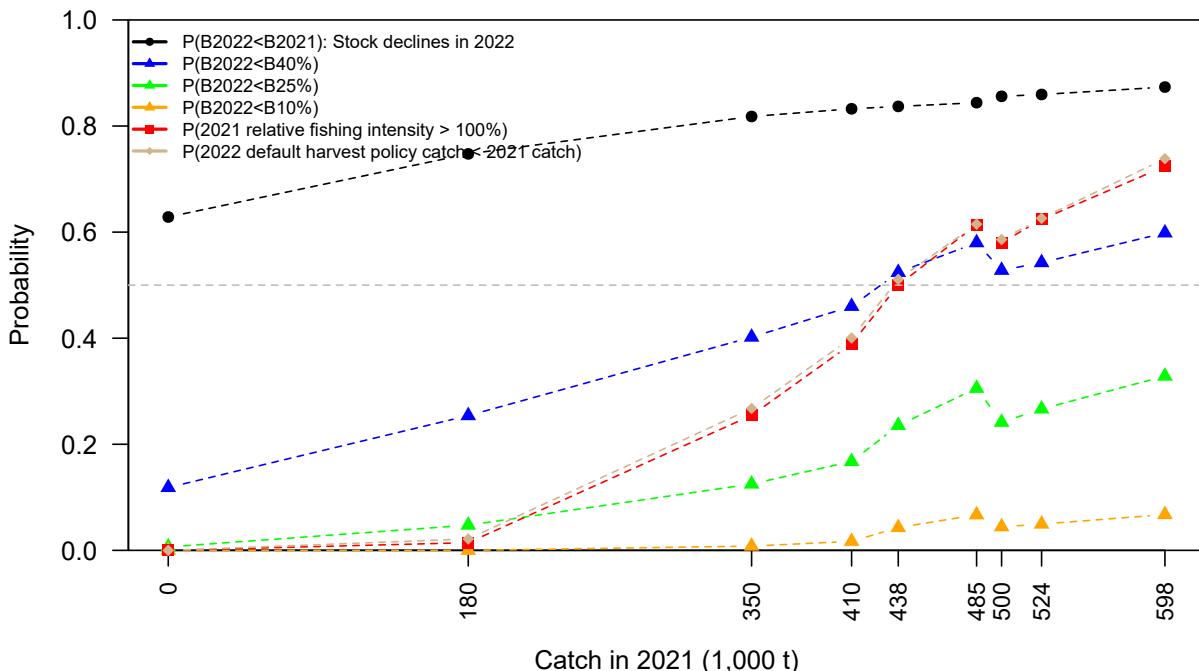
Figure 38. Graphical representation of the base model results presented in Table 32 for catch in 2021, given the 2020 catch level shown in Table 31. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Proportion by numbers　　　　　**Proportion by weight**
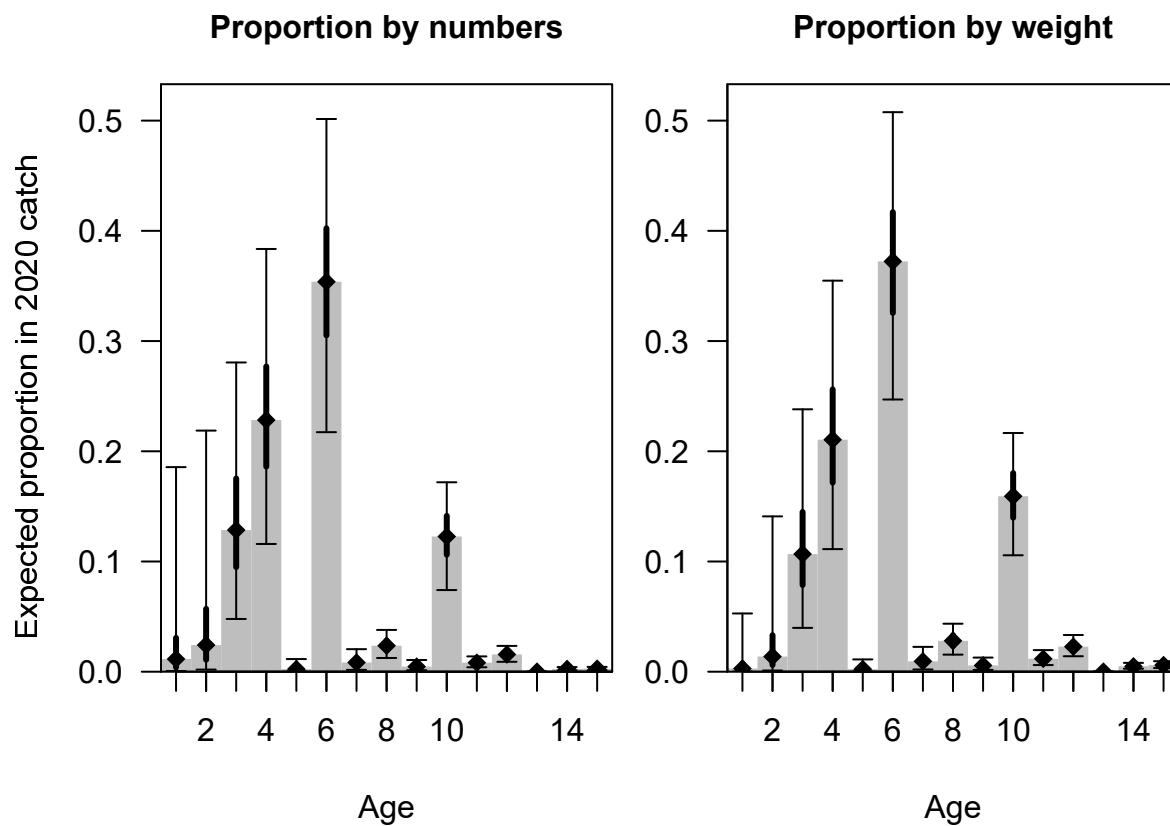
Figure 39. Forecast age compositions in numbers and in weight for the 2020 fishery catch (combined across all sectors in both countries). Gray bars show median estimates. Thick black lines show 50% credibility intervals and thin black lines show 95% credibility intervals. These estimates are based on the posterior distribution for selectivity averaged across the most recent five years, weight-at-age data averaged across the most recent five years, and the distribution for expected numbers at age at the start of 2020 (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 the last five years.
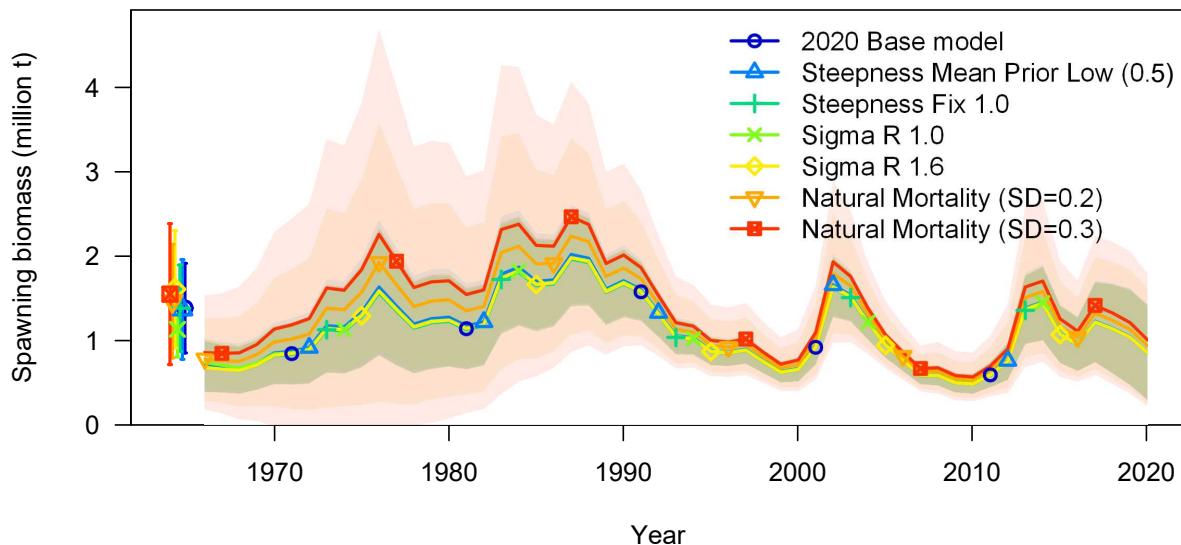
Figure 40. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, lower (1.0) and higher (1.6) levels of variation assumed about the stock-recruitment relationship (σ_r), and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3.
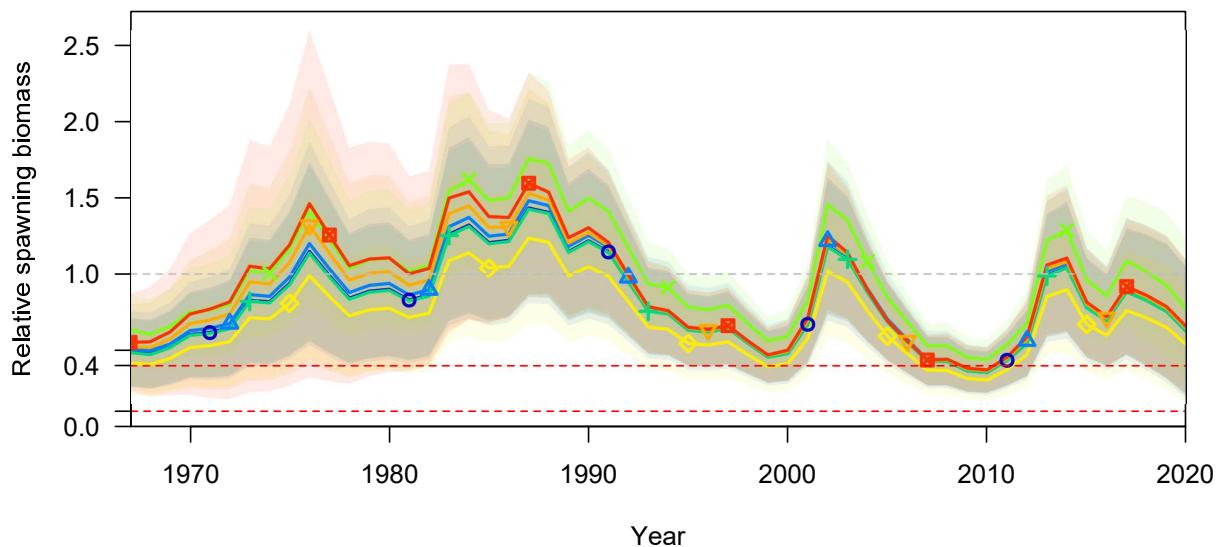
Figure 41. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changing key parameters. See Figure 40 for sensitivity descriptions.
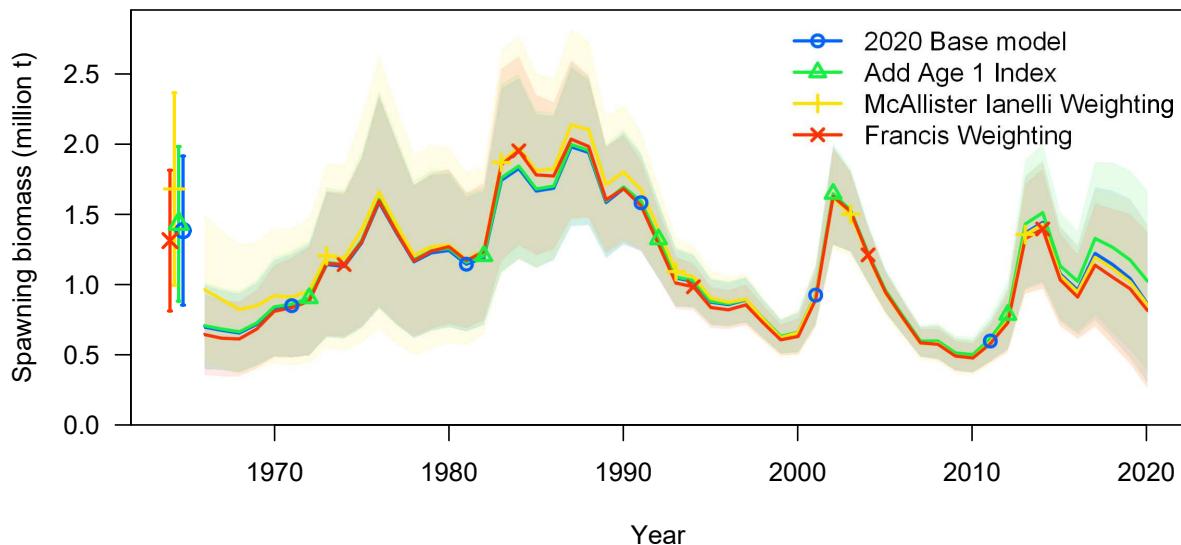
Figure 42. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs that represent the following changes in data: adding an age-1 index of abundance, using the McAllister-Ianelli approach to weight composition data, and using the Francis approach to weight composition data.
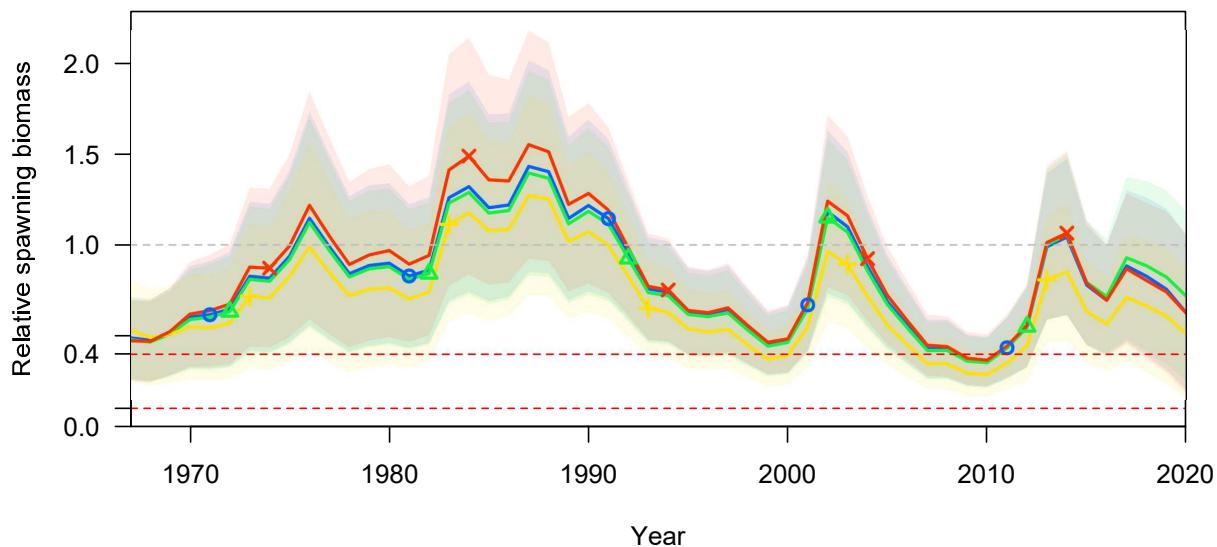
Figure 43. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs that represent changes in data. See Figure 42 for sensitivity descriptions.
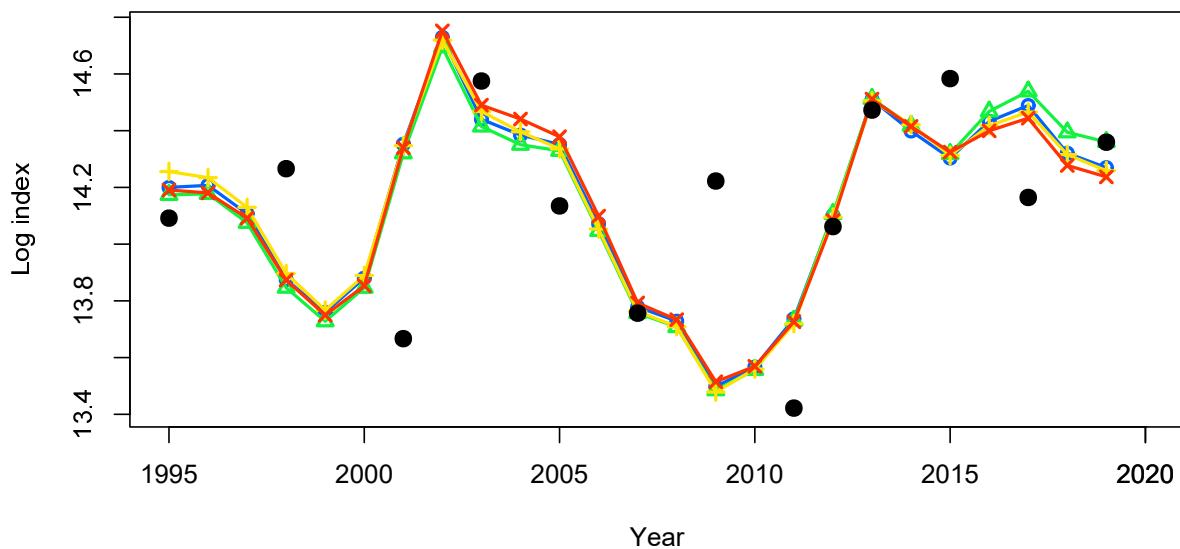
Figure 44. Maximum likelihood estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs that represent changes in data. See Figure 42 for sensitivity descriptions.
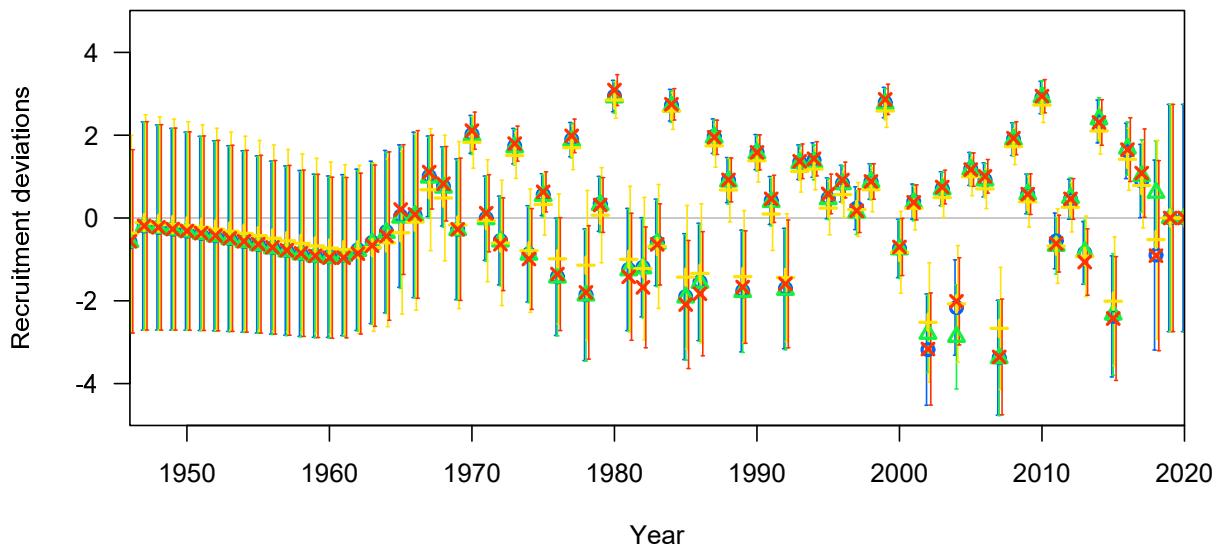
Figure 45. Maximum likelihood estimates of recruitment deviations for the base model and alternative sensitivity runs that represent changes in data. See Figure 42 for sensitivity descriptions.
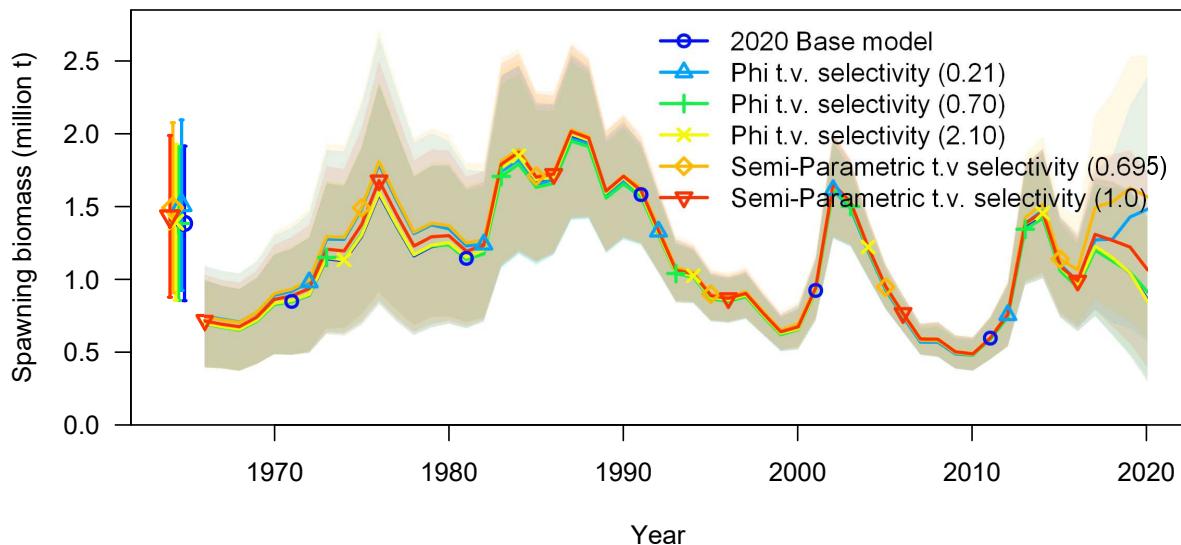
Figure 46. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s).
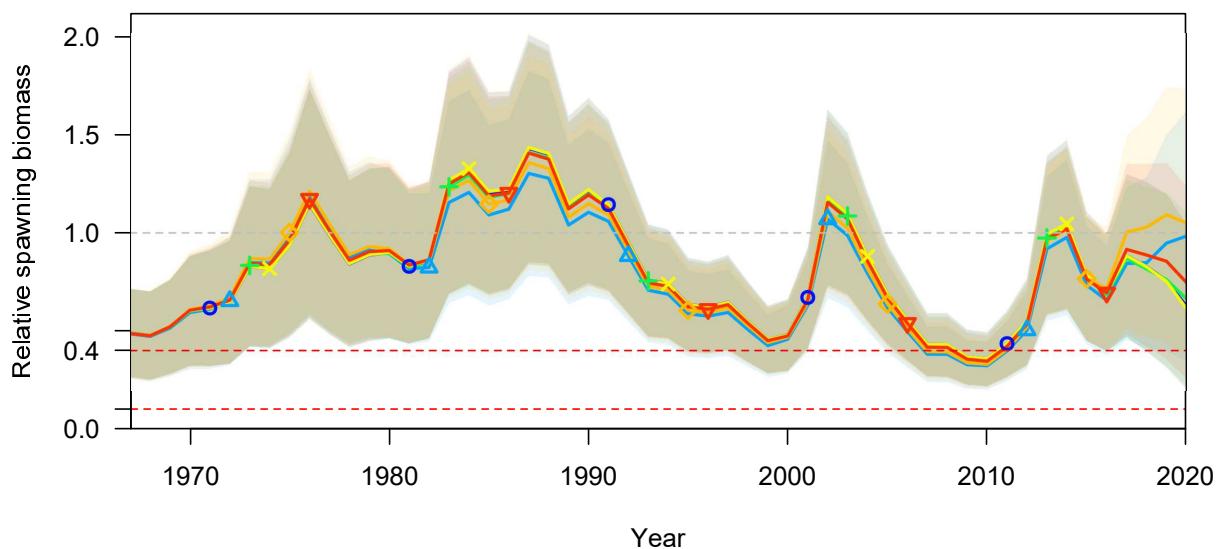
Figure 47. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 46 for legend.
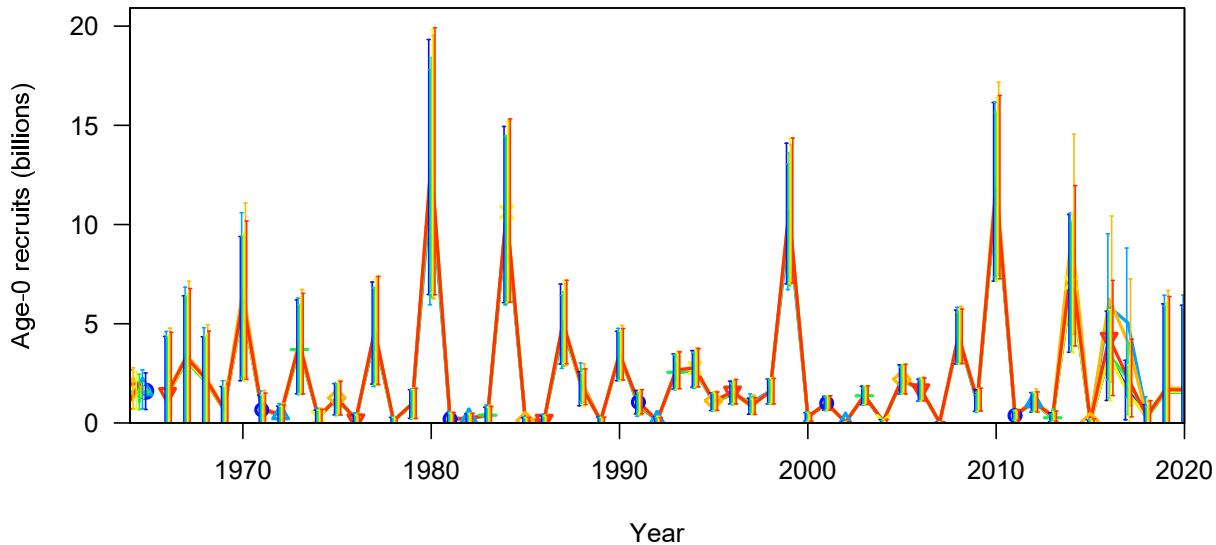
Figure 48. Maximum likelihood estimates of recruitment for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 46 for legend.
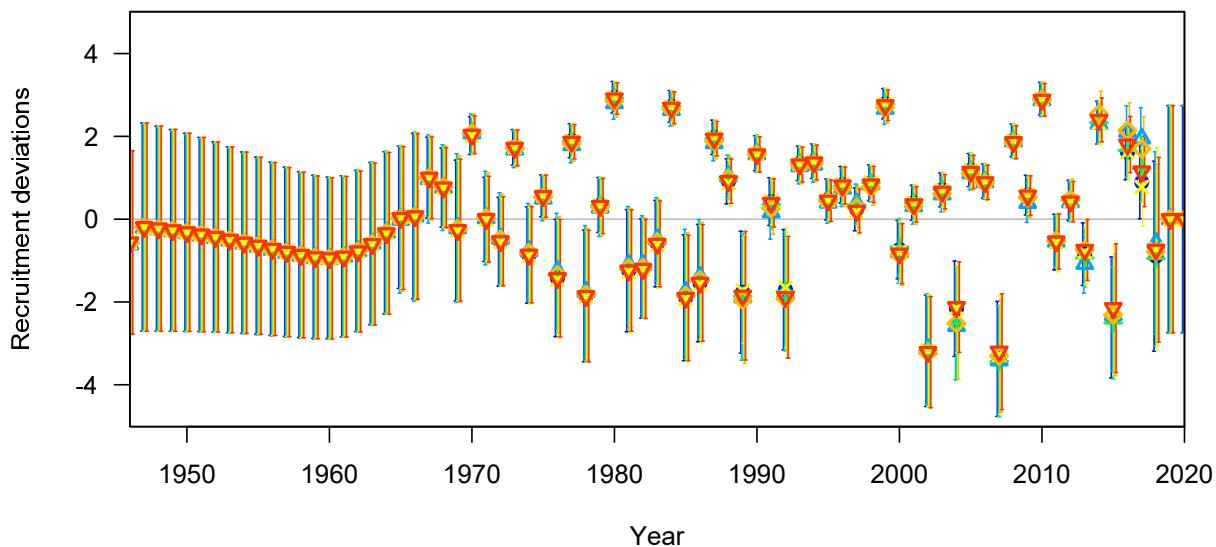
Figure 49. Maximum likelihood estimates of recruitment deviations for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 46 for legend.
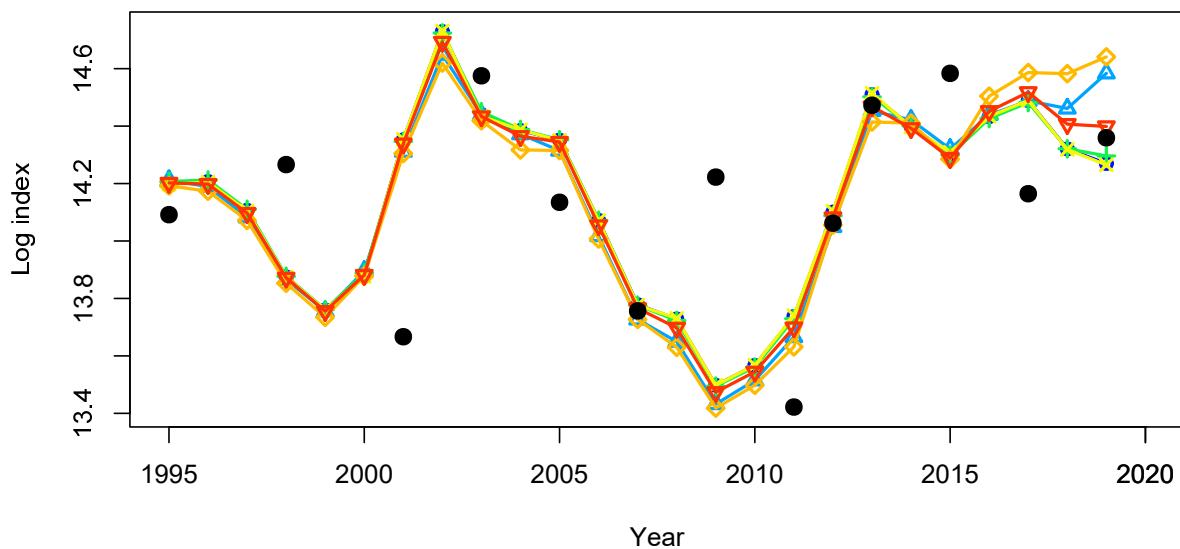
Figure 50. Maximum likelihood estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity and the use of a semi-parametric approach for implementing time-varying selectivity (σ_s). See Figure 46 for legend.
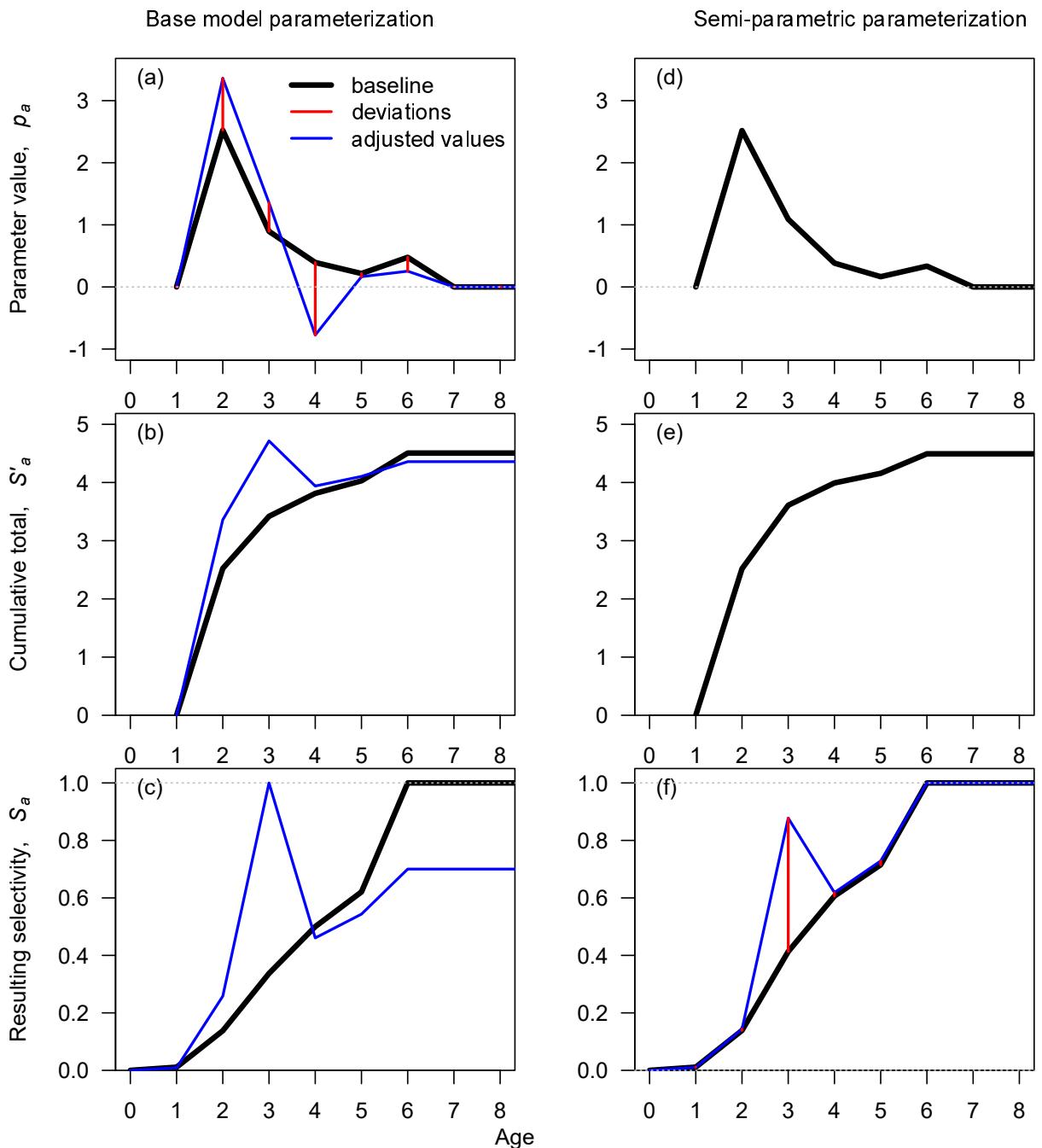
Figure 51. Illustration of parameterization of time-varying selectivity as represented in the base model (left) and the semi-parametric approach used in sensitivity analyses (right). Panels show transformation from estimated parameters (a) to cumulative sum up to each age (b) and the resulting selectivity 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).
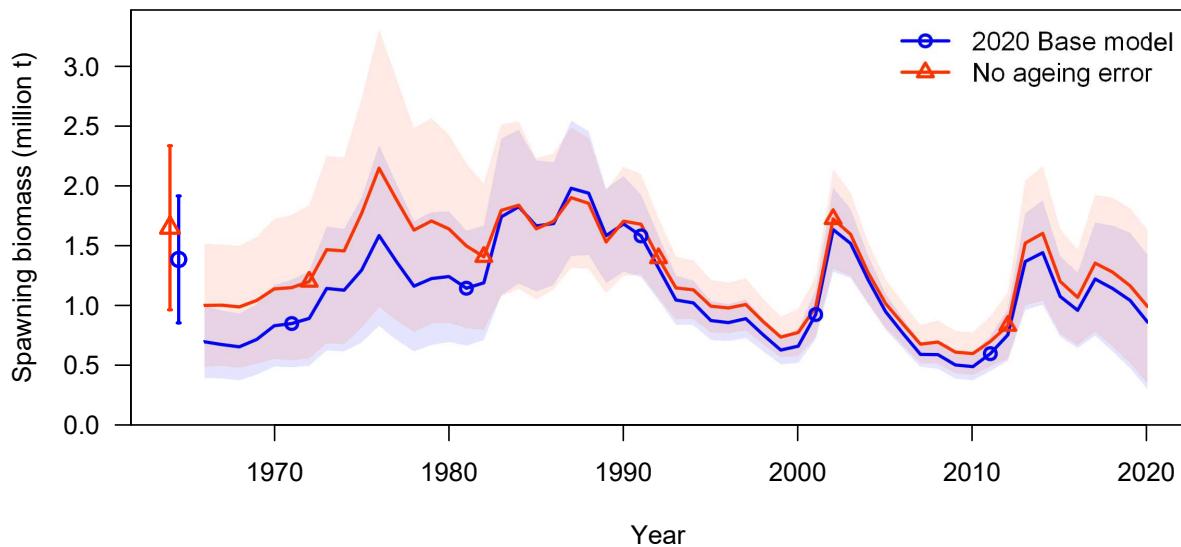
Figure 52. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity run with cohort-based ageing error removed.
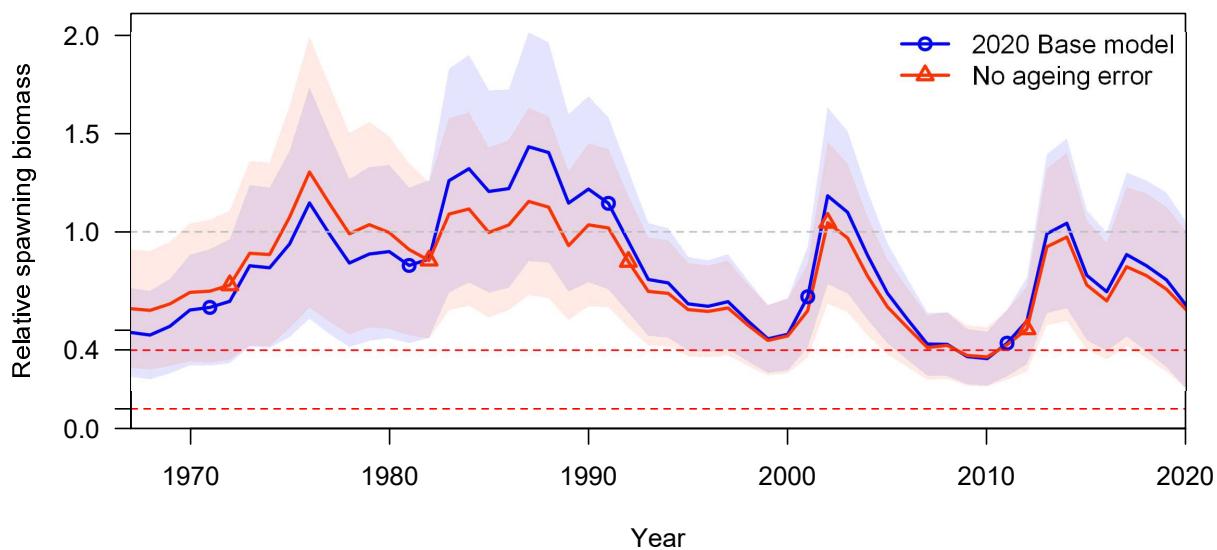
Figure 53. Maximum likelihood estimates of stock status for the base model and alternative sensitivity run with cohort-based ageing error removed.
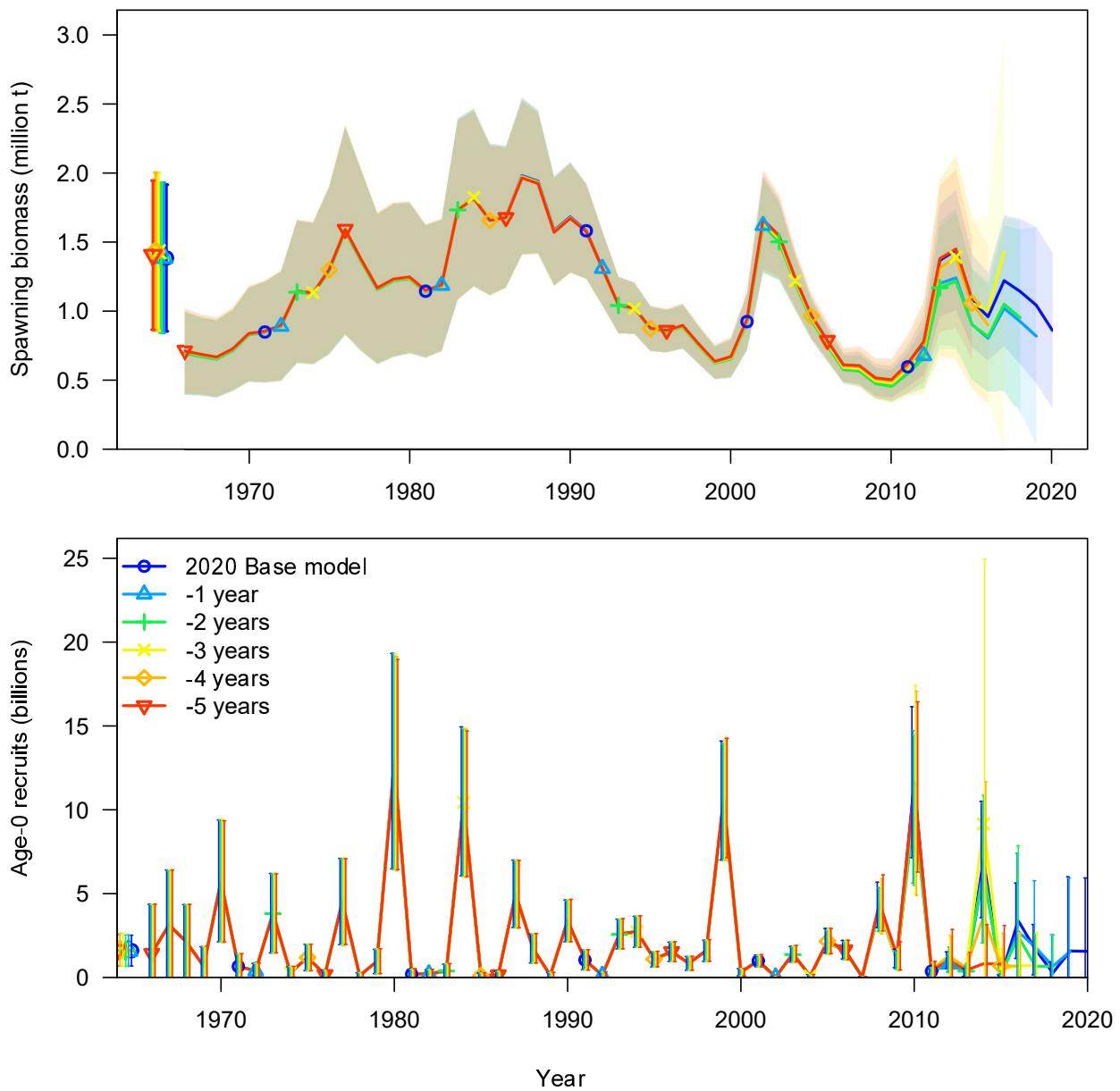
Figure 54. Estimates of spawning biomass at the start of each year (top) and recruitment (bottom) for the base model and retrospective runs (based on MLE model runs).
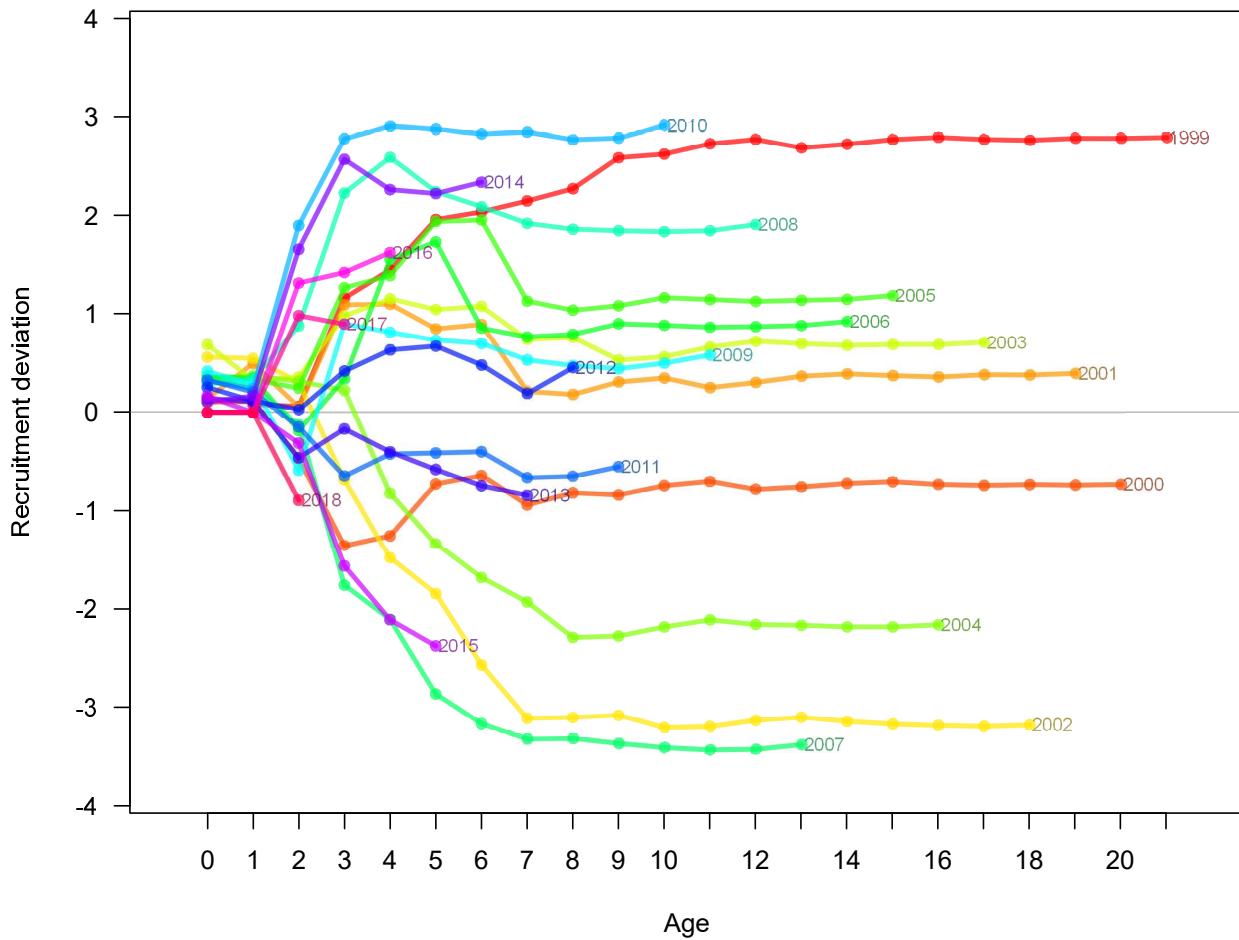
Figure 55. Retrospective analysis of recruitment deviations from MLE models over the last 21 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for cohorts from 1999 to 2018, 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.
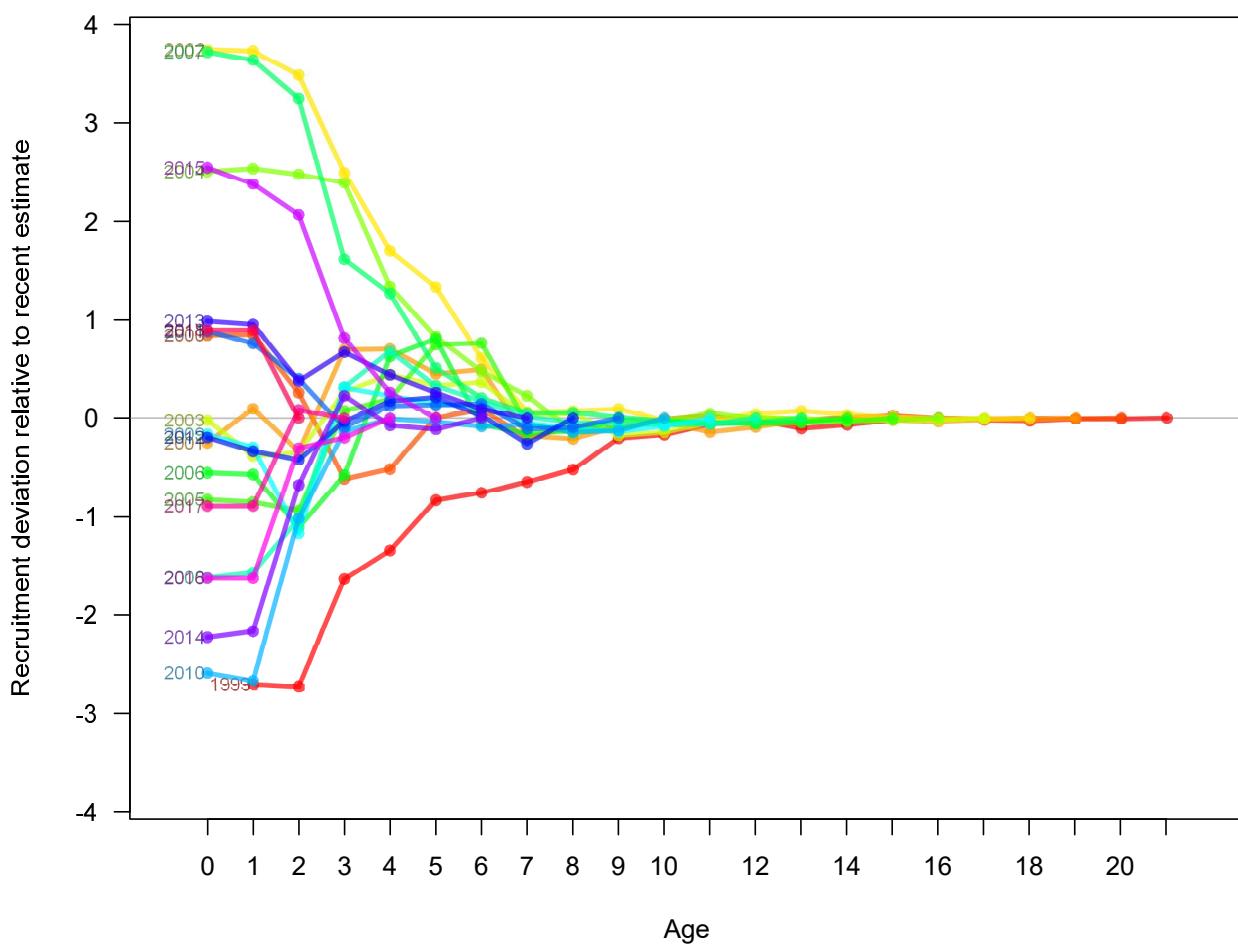
Figure 56. Retrospective recruitment estimates shown in Figure 55 scaled relative to the most recent estimate of the strength of each cohort.
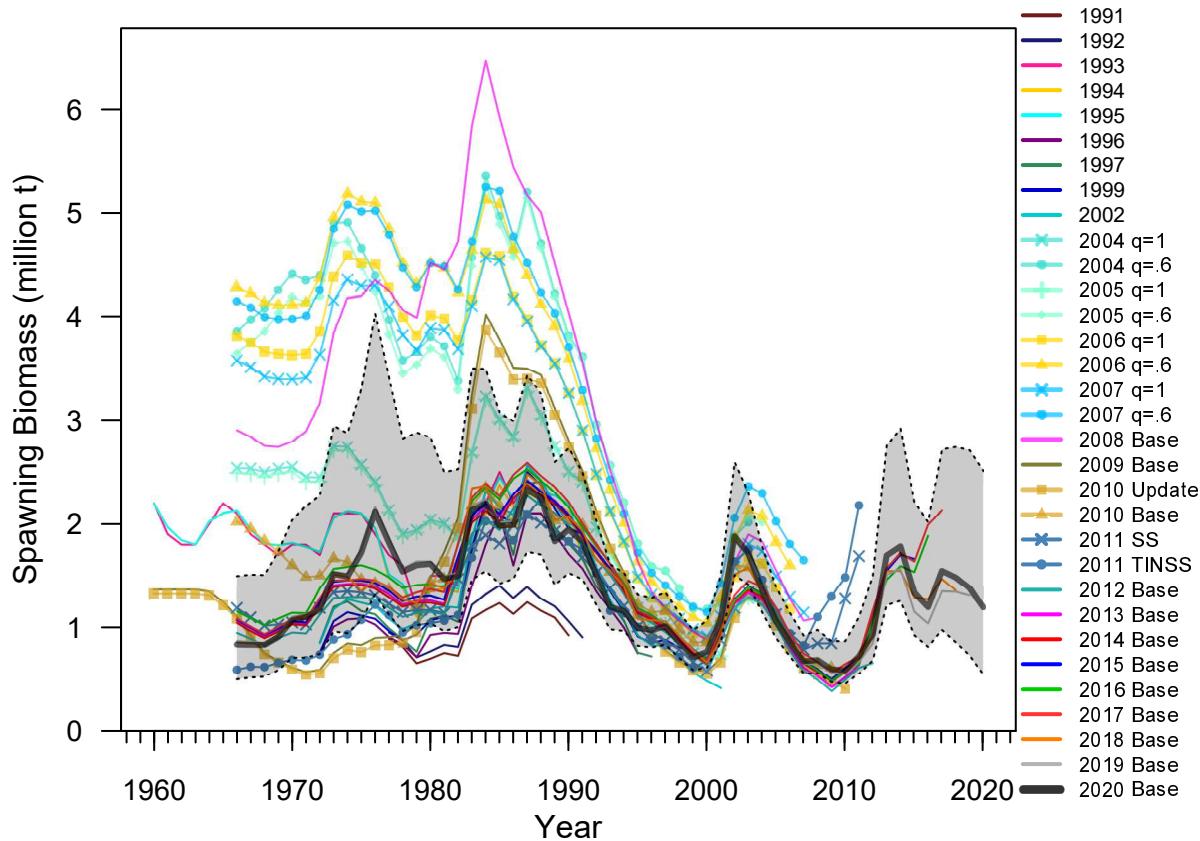
Figure 57. Summary of historical Pacific Hake assessment estimates of spawning biomass. Estimates are MLEs or MCMC medians depending on the model structure. Shading represents the approximate 95% confidence range from the 2020 base model.

A   BASE MODEL MCMC DIAGNOSTICS
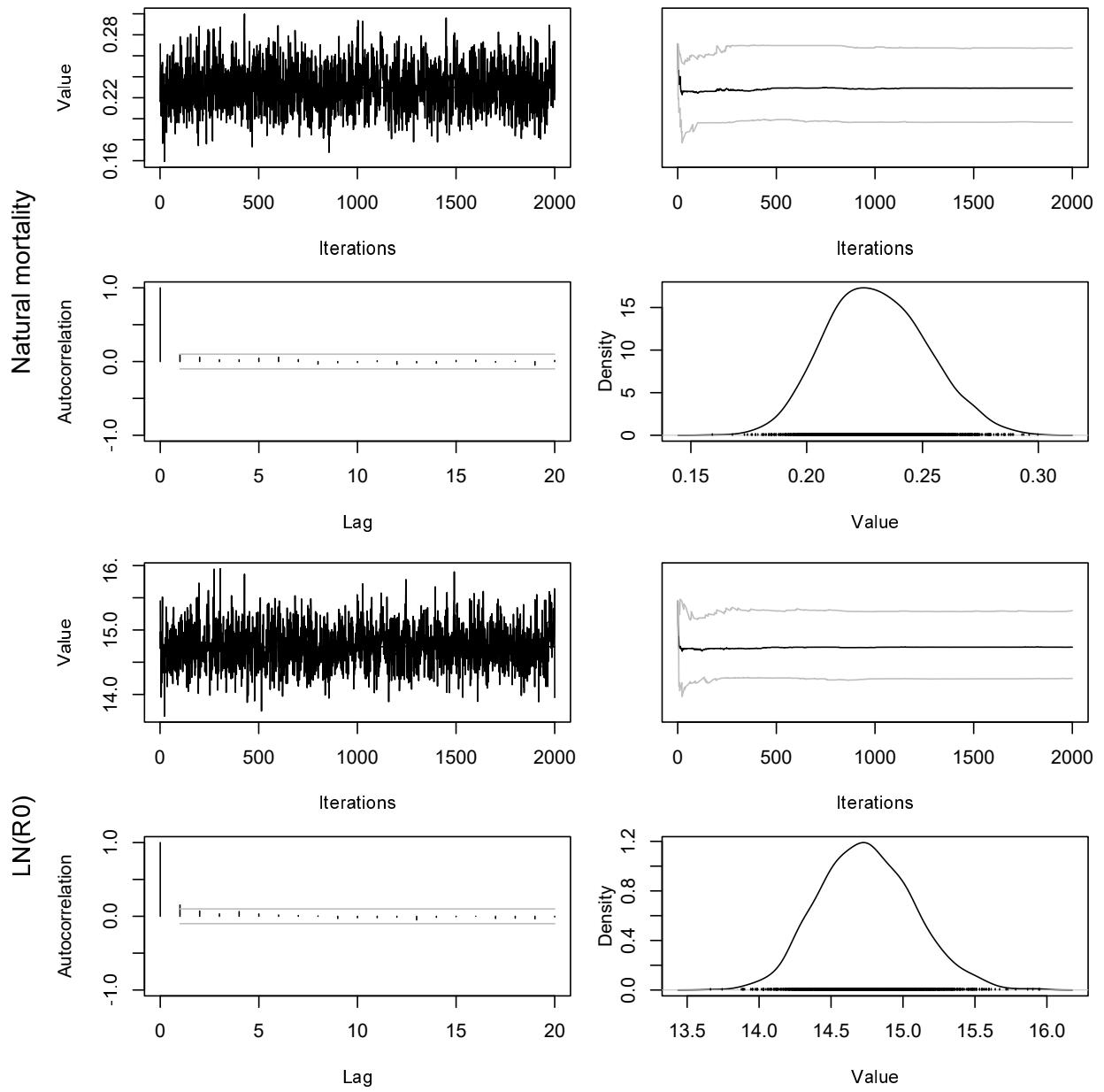
Figure A.1. Summary of MCMC diagnostics for natural mortality (upper panels) and $\log(R_0)$ (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower 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).
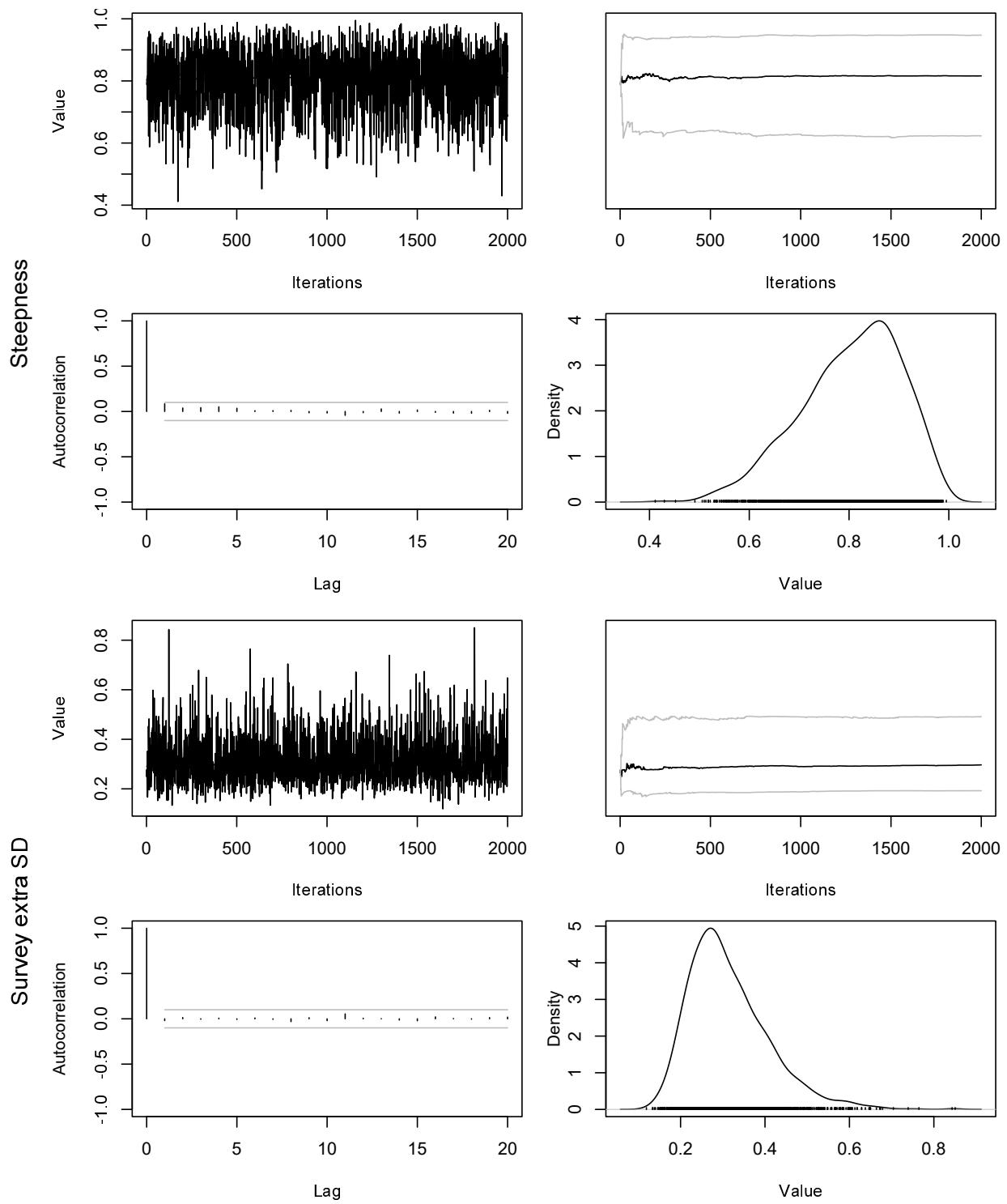
Figure A.2. Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 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).
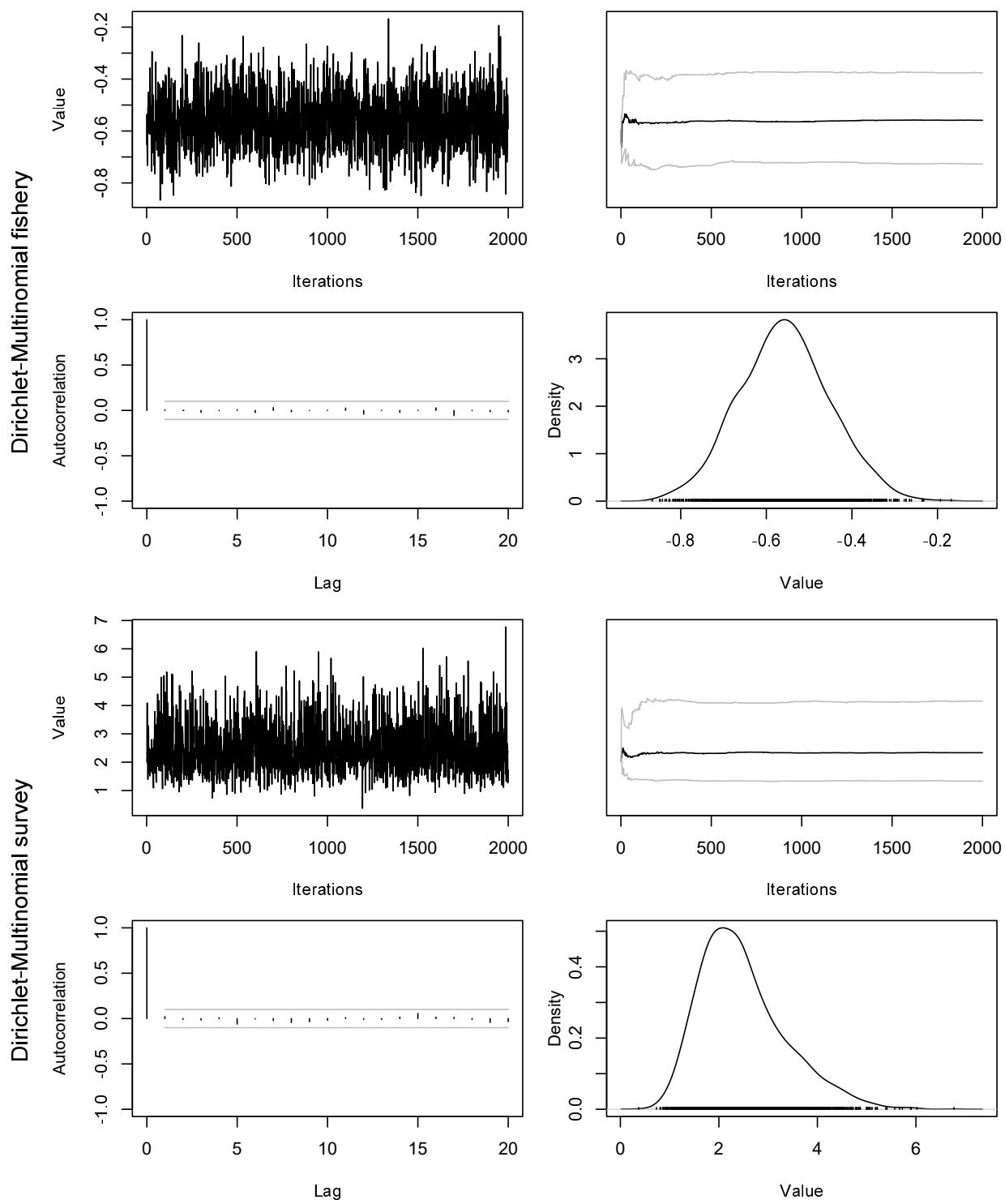
Figure A.3. Summary of MCMC diagnostics for the Dirichlet-Multinomial age-composition parameters for the fishery (upper panels) and the survey (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 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).
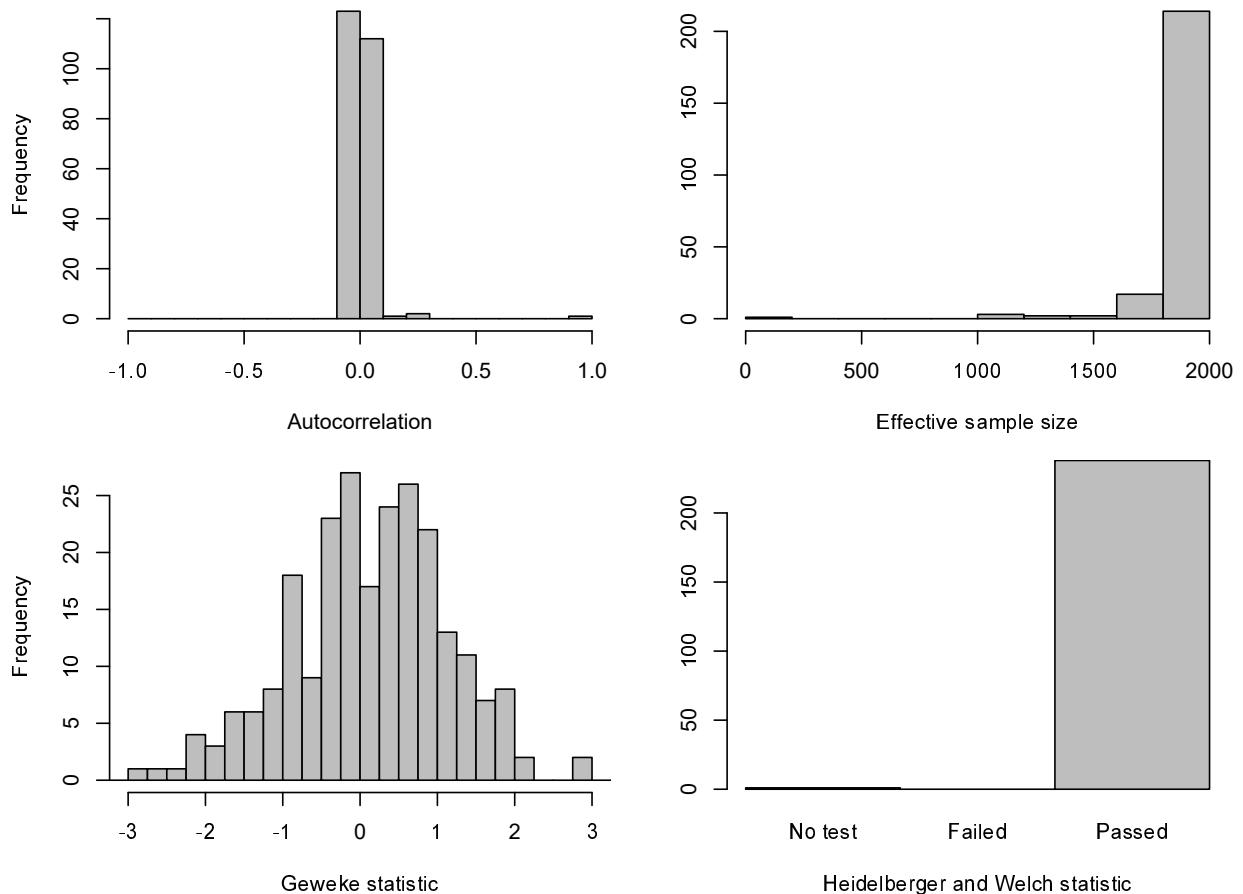
Figure A.4. Summary histograms of MCMC diagnostics for all base model parameters together with the derived time series of spawning biomass and relative spawning biomass. The level of autocorrelation in the chain (distribution across lag times, i.e., distance between samples in the chain, shown in the 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.
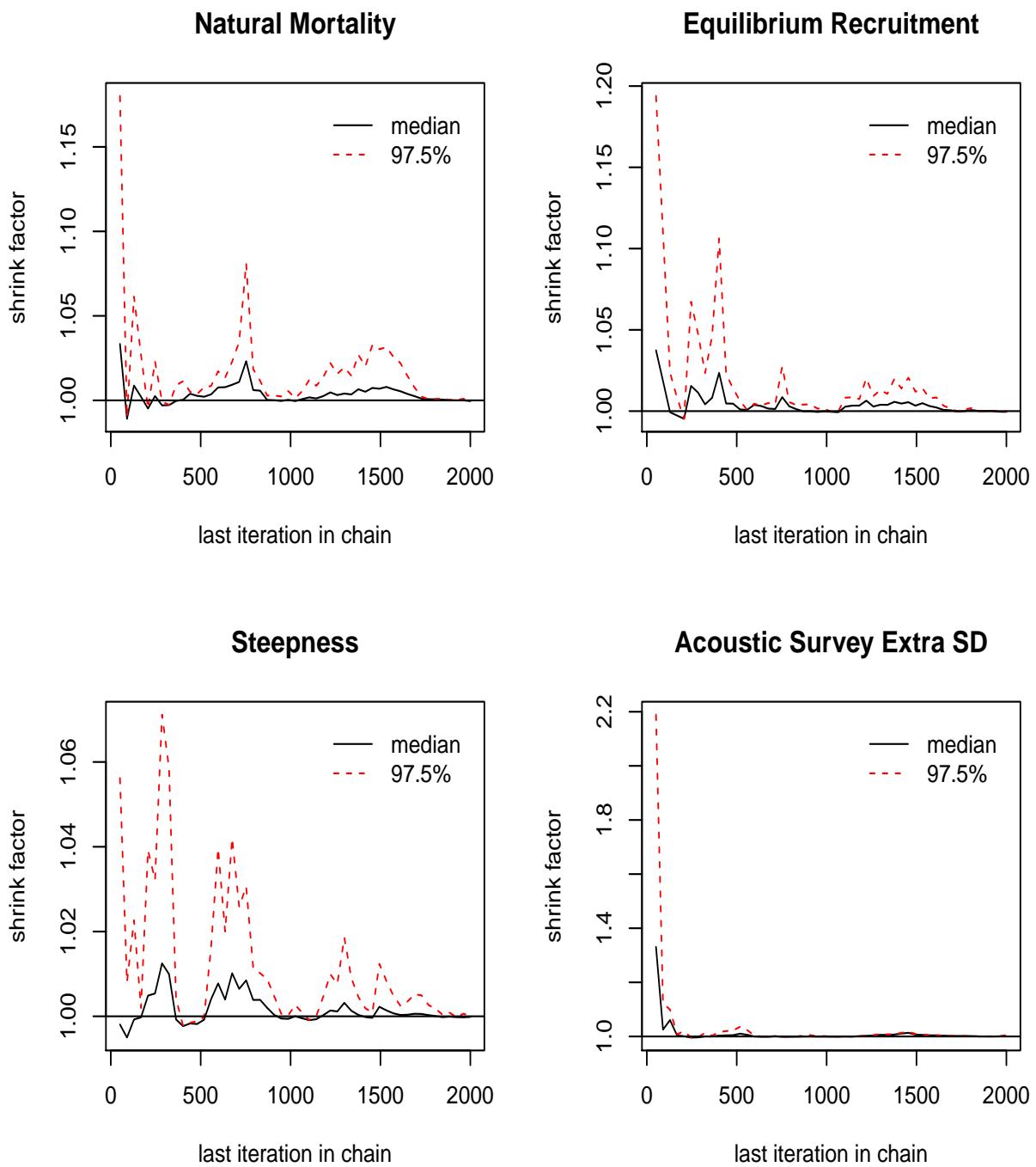
Figure A.5. Gelman-Rubin plot showing the development of the scale-reduction (shrink factor) across the chain length for key posterior parameter distributions. A factor close to 1 indicates that between chain variance and within chain variance are equal. Values much greater than 1.1 indicate a notable difference between chains and the possible lack of achieving a converged stationary posterior distribution.
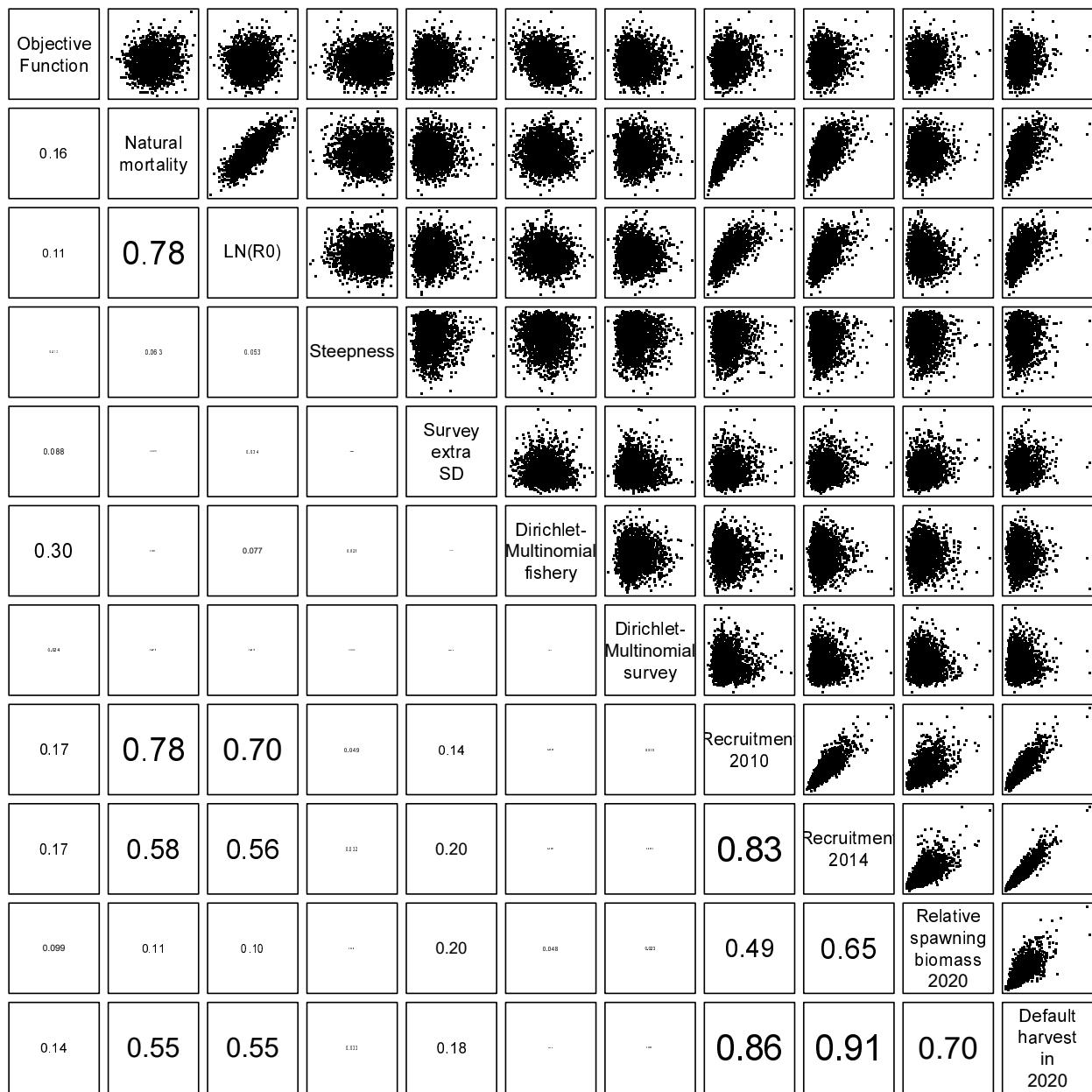
Figure A.6. Posterior correlations among key base-model parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.
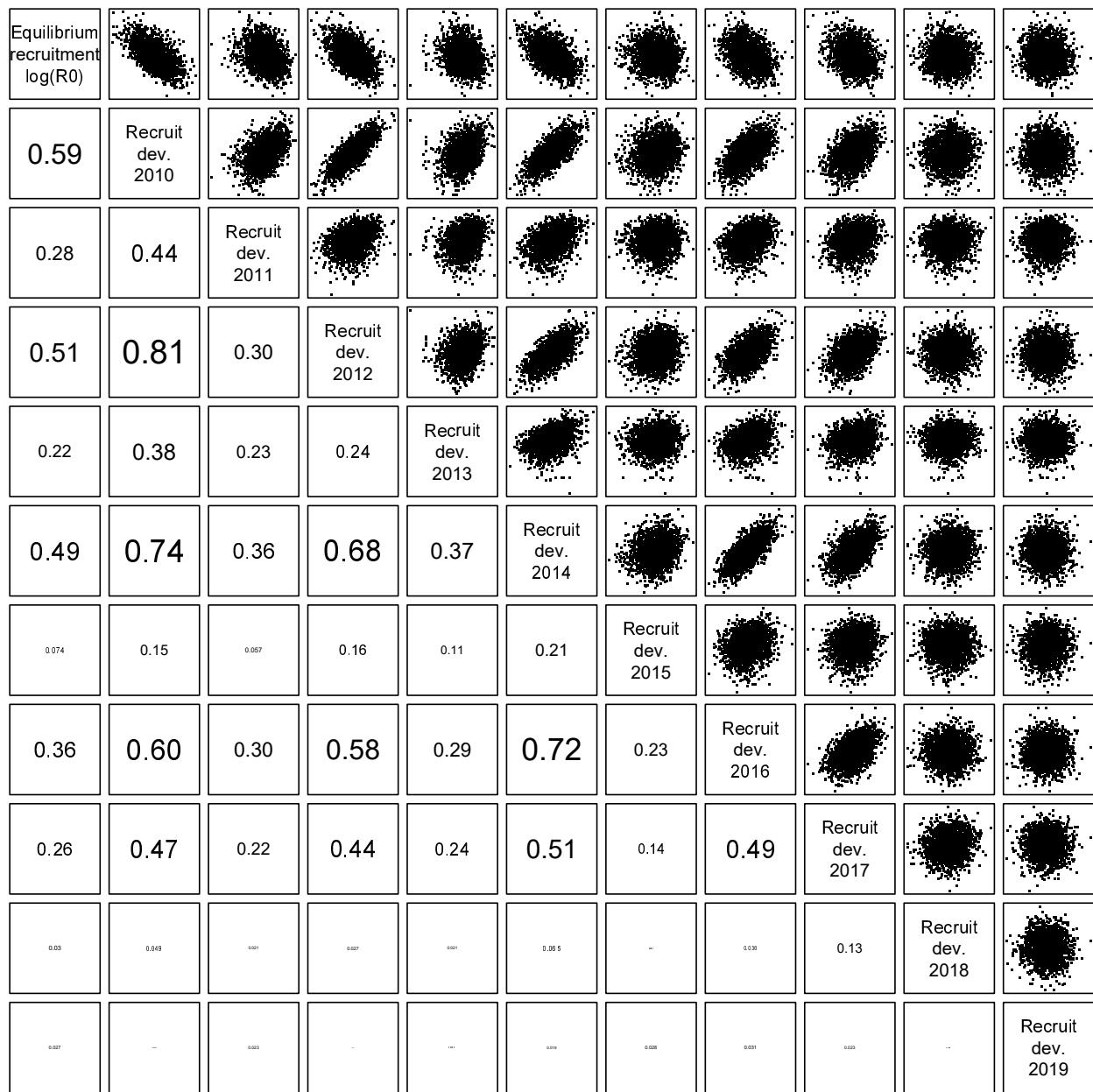
Figure A.7. Posterior correlations among recruitment deviations from recent years and equilibrium recruitment. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

B SCIENTIFIC REVIEW GROUP (SRG) REQUESTS FROM 2020 MEETING

This appendix summarizes results produced in response to Scientific Review Group requests made during the meeting held from 25th February to 28th February, 2020 in Seattle, WA, USA.

B.1 DAY 1

Request 1 – Show the 'squid plot' for the base-case model with and without Age-1 index.

These are Figures 55 and G.1.

Request 2 – Colour code weight-at-age matrix by column rather than global colouring.

Weight-at-age matrices were produced with global colouring (previous default), age-specific colouring (as requested), and age-specific transparency of global colouring. The option with transparency was chosen to use going forward and is provided in this document (Figures 13 and 14).

Request 3 – Investigate changes in weight-at-age for 1987, when 1977 was expected to change but did not occur (compare 2019 to 2020).

The changes that were noted by the SRG occurred in 1988, not 1987. These changes occurred because some Canadian Joint-Venture samples were extracted from an archived file rather than data provided in 2017. The older file included information for an age-14 fish, as well as other fish, that were not included in the more recent file. This led to minor differences in weight-at-age as well as age 14 in 1988 not being extrapolated, i.e., wrongly marked with bold text for this data set. The differences in weight-at-age as compared to what was included in 2019 led to essentially no differences in estimated spawning biomass. Work will be completed prior to the 2021 assessment to ensure all appropriate Canadian samples are included as well as samples from the 1977 Poland Acoustic Survey that were talked about during the SRG Meeting.

Request 4 – Calculate average of recruitment deviations over the main period (1970–2018); include both MLE and MCMC (current algorithm and NUTS). Attempting to understand equilibrium recruitment assumption relative R_0.

- Mean recruitment deviation 2020 base model MLE: 0.209

- Mean recruitment deviation 2020 MCMC models:

    - for base model 0.088

    - for adnuts model 0.129

Request 5 - Redo ADNUTs plots thinning down to about 2,000 samples from samples avail-

able, and redo convergence diagnostic plots.

MCMC diagnostics are shown as plots below. Figure B.1.1 shows the adnuts model with extra thinning applied resulting in 2,000 samples and Figure B.1.2 shows the adnuts model with extra thinning applied resulting in 1,000 samples.

The plots should be compared with Figures A.4 and H.17. Comparing these with the base model diagnostics, the effective sample size appears to be equivalent, with large effective sample size and little autocorrelation. The Geweke statistic shows a Normal distribution in all instances. It is notable that the diagnostics improve with fewer samples, which can be attributed to more space between samples giving a reduced chance of having poor samples included.

Trace plots for the M and R_0 parameters are shown in Figures B.1.3 and B.1.4 for the adnuts model thinned to 2,000 samples and 1,000 sample respectively. Trace plots show good parameter mixing in all cases, and autocorrelation is minimal.

Applying extra thinning has little effect to the adnuts model output. However, the fewer samples that are included, the less precise the resulting estimates will be.
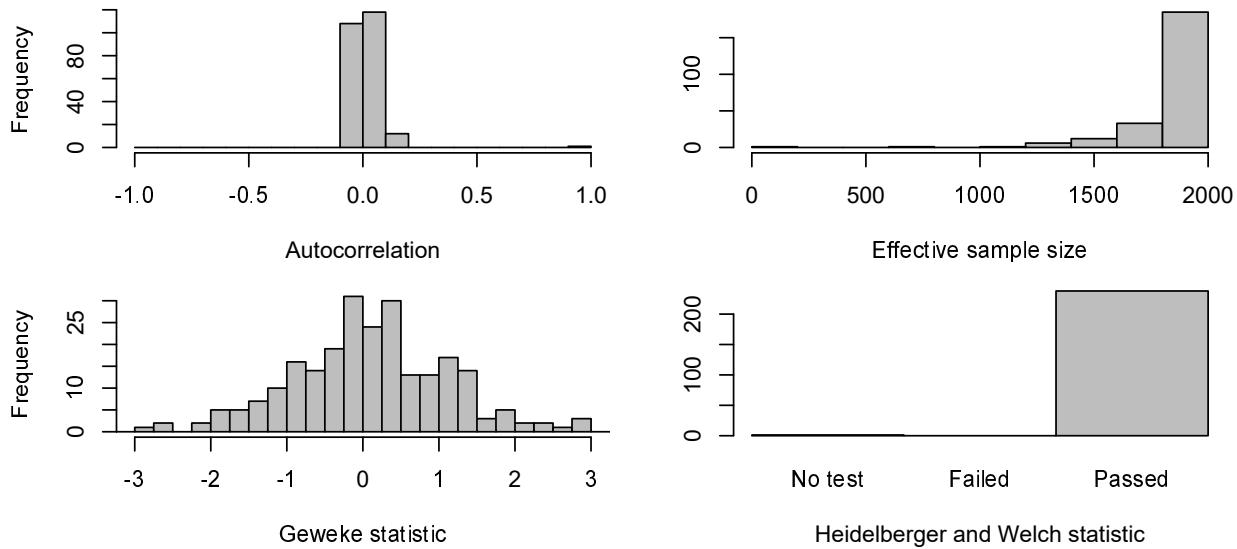
Figure B.1.1. The same as Figure H.17, but including extra thinning down to 2,000 samples. The thinning was done by taking every 3rd sample which resulted in 2,616 samples. The last 616 were stripped leaving the first 2,000.
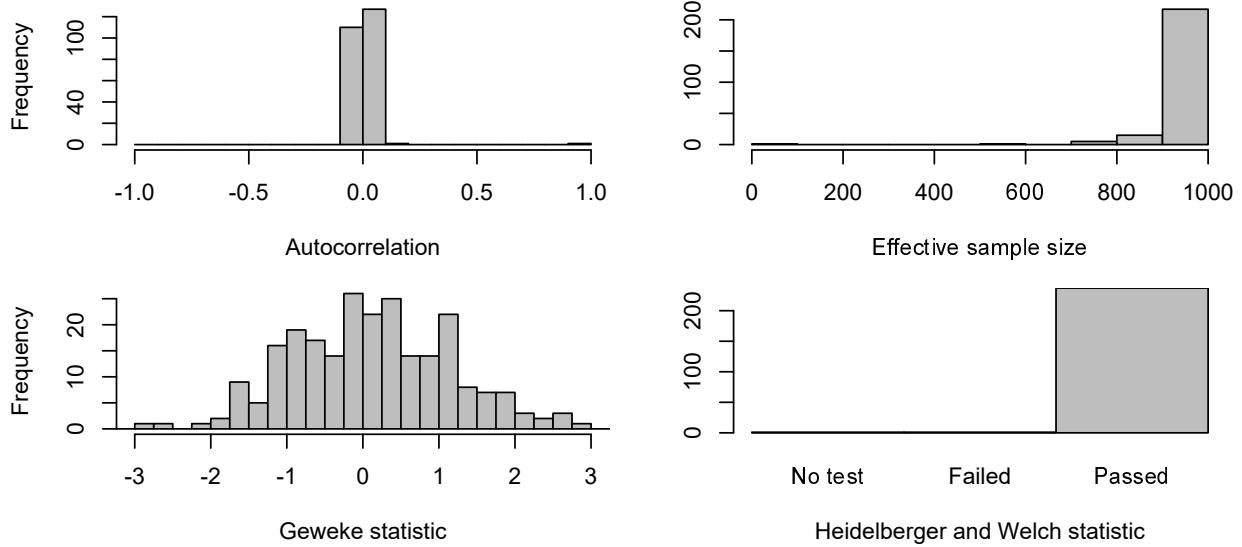
Figure B.1.2. The same as Figure H.17, but thinned to 1,000 samples. The thinning was done by taking every 7th sample which resulted in 1,121 samples. The last 121 were stripped leaving the first 1,000.
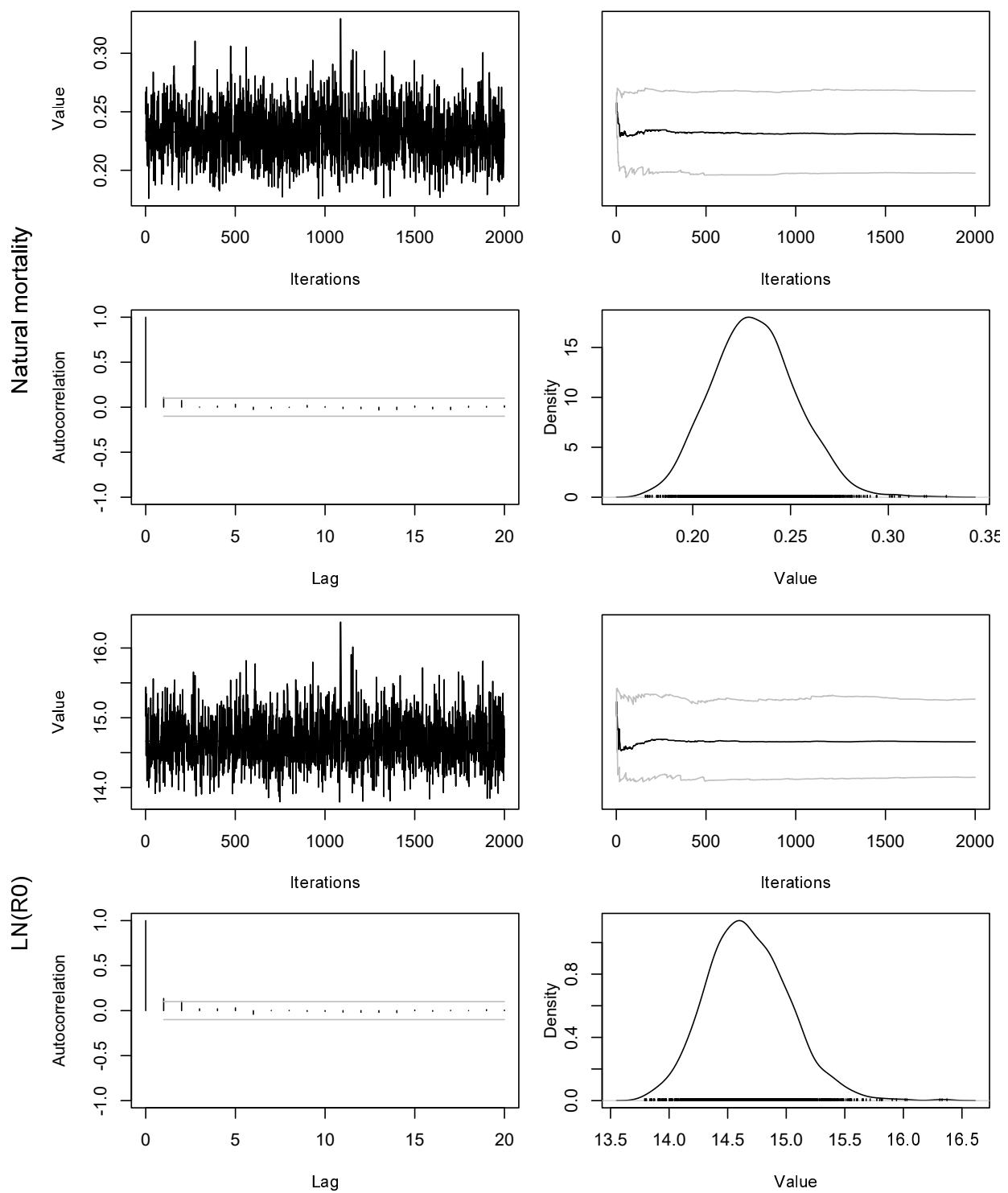
Figure B.1.3. The same as Figure H.14, but including extra thinning down to 2,000 samples. The thinning was done by taking every 3rd sample which resulted in 2,616 samples. The last 616 were stripped leaving the first 2,000.
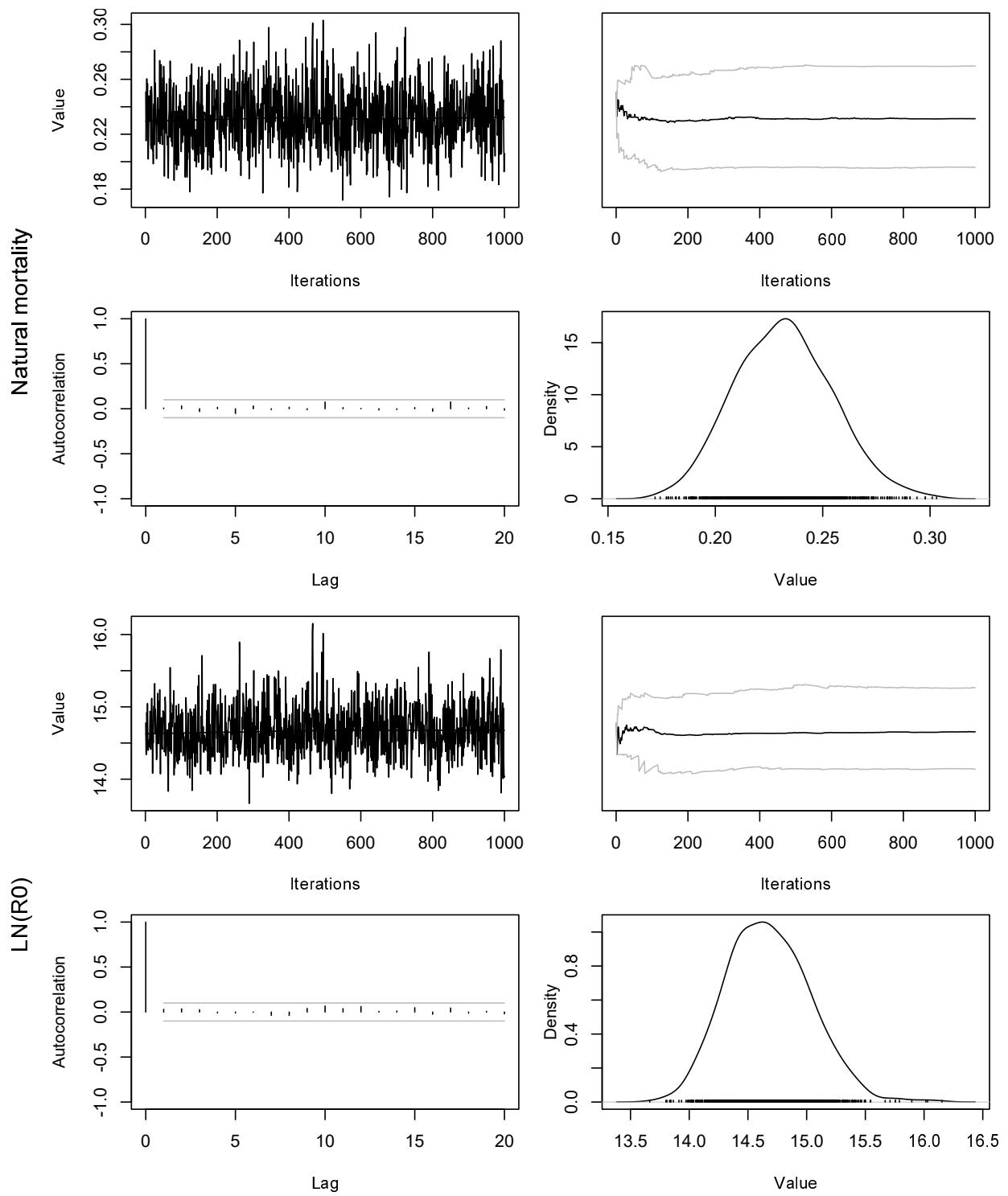
Figure B.1.4. The same as Figure H.14, but thinned to 1,000 samples. The thinning was done by taking every 7th sample which resulted in 1,121 samples. The last 121 were stripped leaving the first 1,000.

Request 6 - Redo recruitment retrospective analysis including Age-1 index, focusing on the 2014 and other strong year-classes.

Several figures were presented during the meeting, and two informative ones are shown in Figures G.2 and G.3, comparing the base model with inclusion of the age-1 index.

Request 7 – Produce a time plot of effective *N* and input *N* to look for temporal patterns. Are recent samples upweighted relative to historical samples?

Input sample sizes and effective sample sizes have increased over time, where the latter increase appears to be positively autocorrelated with periods of highs and lows (Figure B.1.5).
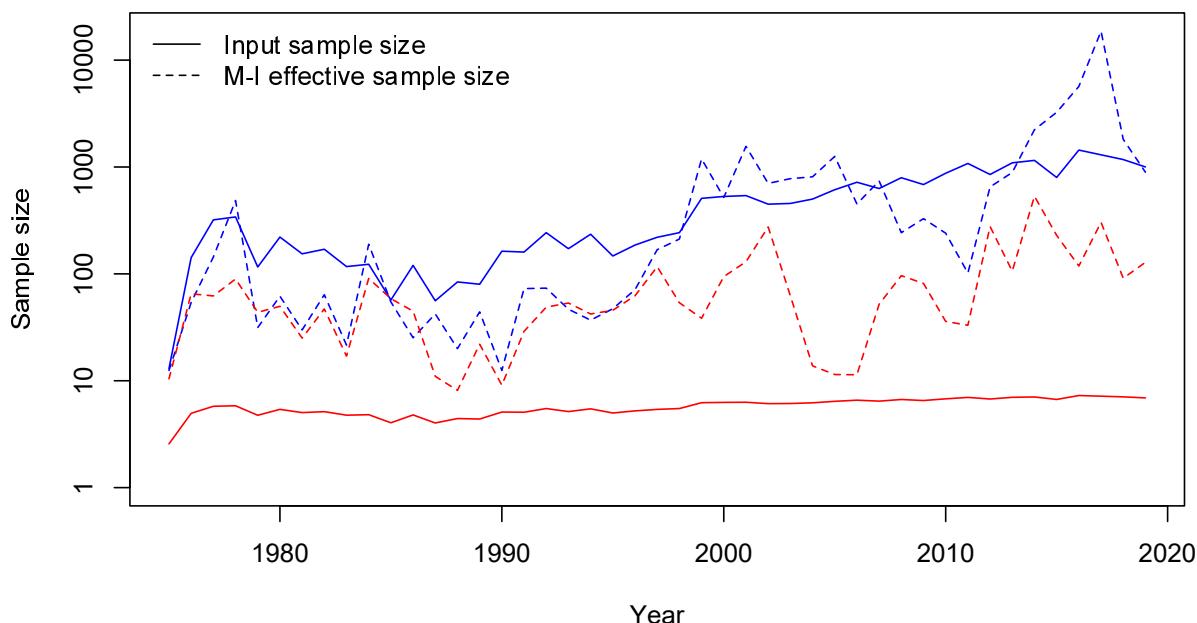
Figure B.1.5. Input (solid line) and effective sample size calculated using the McAllister-Ianelli approach (dashed line) versus time for fishery age-composition data for the base model (blue) and a sensitivity run where recent samples were arbitrarily down-weighted using log input sample sizes (red).

B.2 DAY 2

Request 1 – Find the estimated absolute recruitment when the MLE mode was done for age 2 (X_i) of each cohort and the estimated recruitment of that same cohort in the most recent assessment (Y_i). Then create a histogram of X_i/Y_i for the base model and X_i/Y_i for the model including the age-1 index. If the age-1 index helps, the ratios should be closer to one than for the base model.

The number of estimated ratios that were close to one did not drastically improve when the age-1 index was included in the base model (Figure B.2.1).
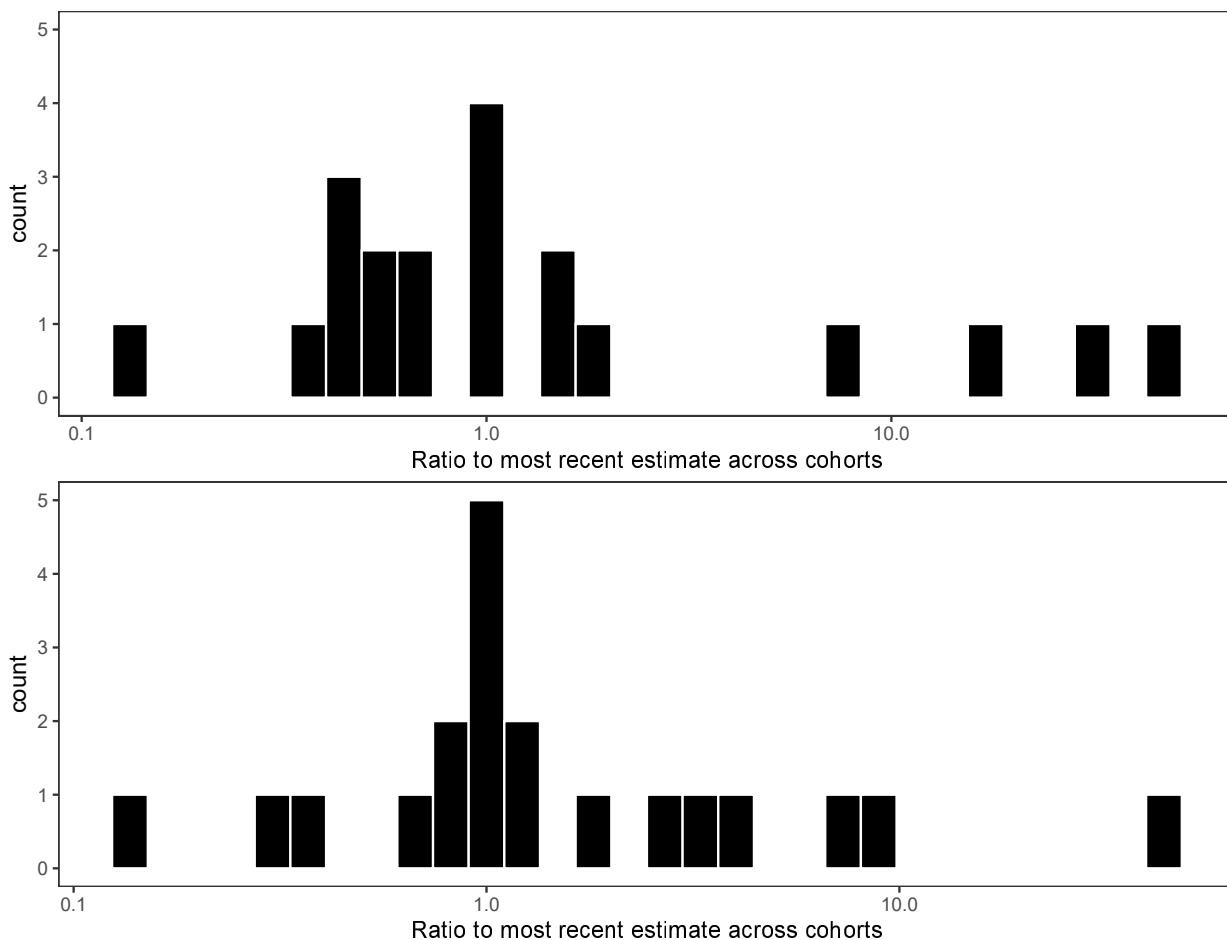
Figure B.2.1. Ratio of estimated recruitment (billions of fish) for two year olds relative to their current estimated numbers at recruitment for the base model (top) and the model that includes an age-1 index (bottom).

Request 2 – For each MCMC draw, get the R_0 estimate and the mean of the recruitment deviates for the main period and for all years, and plot one against the other to look for correlations. Repeat for adnuts.

Correlations were similar between the base model and the adnuts model. Correlations decreased when the full time period was analyzed as compared to just the main recruitment period (Figure B.2.2).
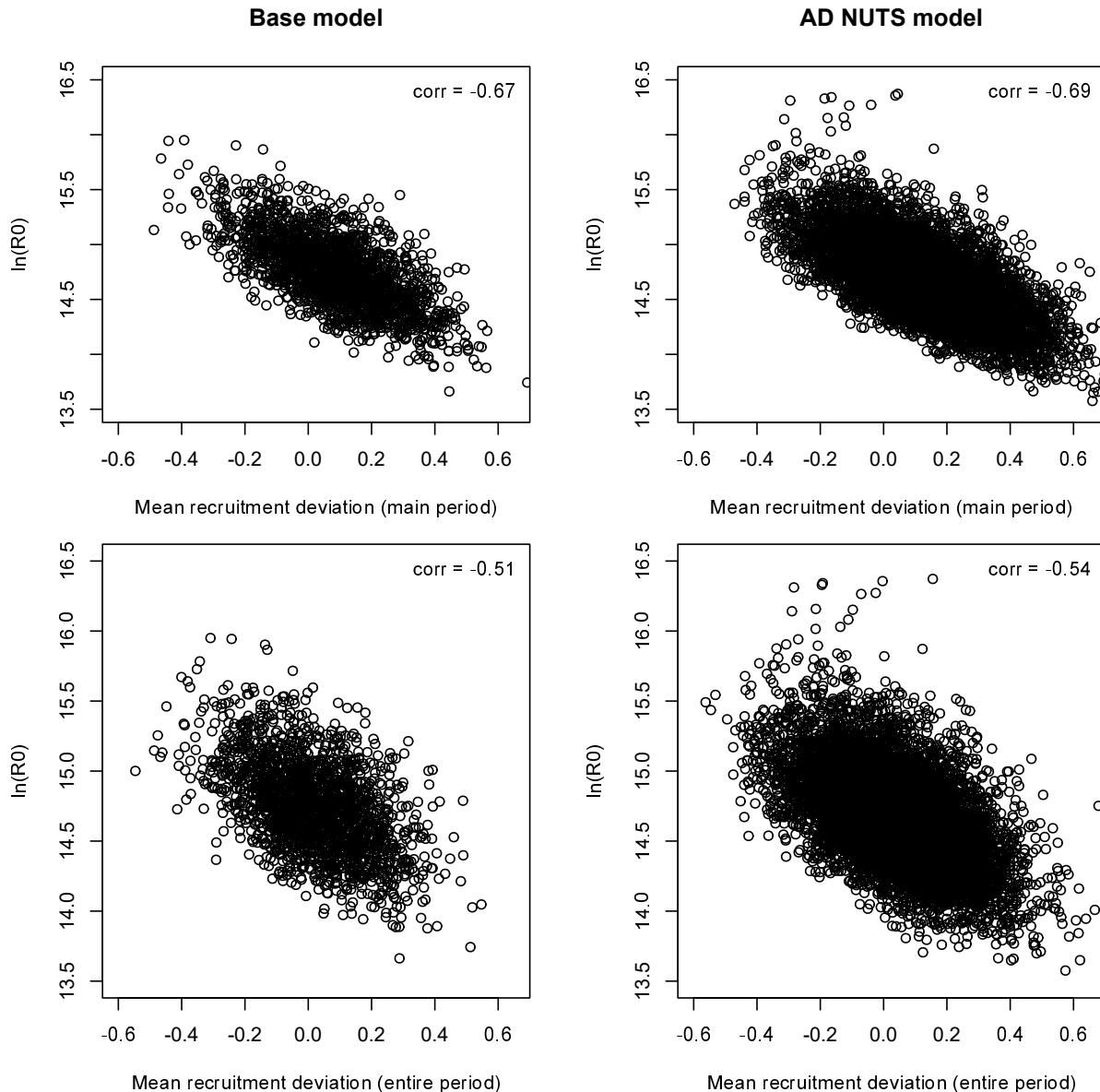
Figure B.2.2. Correlation between recruitment deviations and R_0 for the base model (left panels) and the model implemented using the No-U-Turn Sampler (NUTS, right panels) for the main time period (top panels) and the entire period (bottom panels). Correlations are reported in the upper right corner of each panel.

Request 3 – Run the MLE model with the ln(input sample size) to down-weight more recent age data compare to older age data.

Arbitrarily down-weighting recent fishery age compositions by fitting to logged input sample sizes led to similar recent trends but dissimilar estimates of equilibrium conditions (Figures B.2.3-B.2.5). The estimate of R_0 increased from 1.6 to 2.19 billion fish. The calculated effective sample size of the logged input sample size increased at a slower rate than for the base model and did not have such high values in the most recent period (Figure B.1.5).
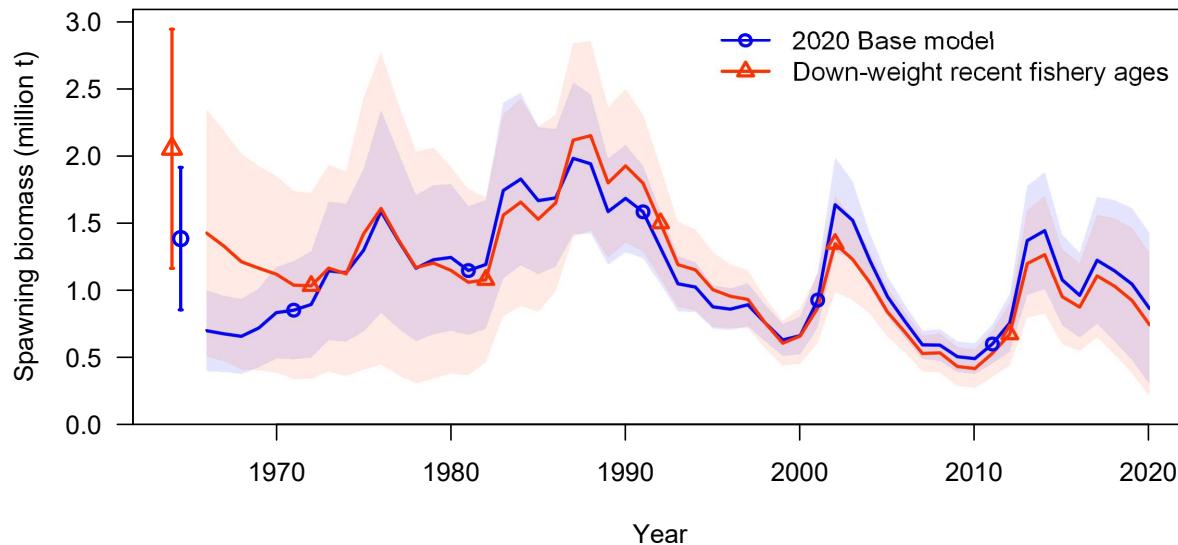
Figure B.2.3. Maximum likelihood estimates of spawning biomass for the base model and a sensitivity run that arbitrarily down-weights recent fishery age compositions using log-input sample size.
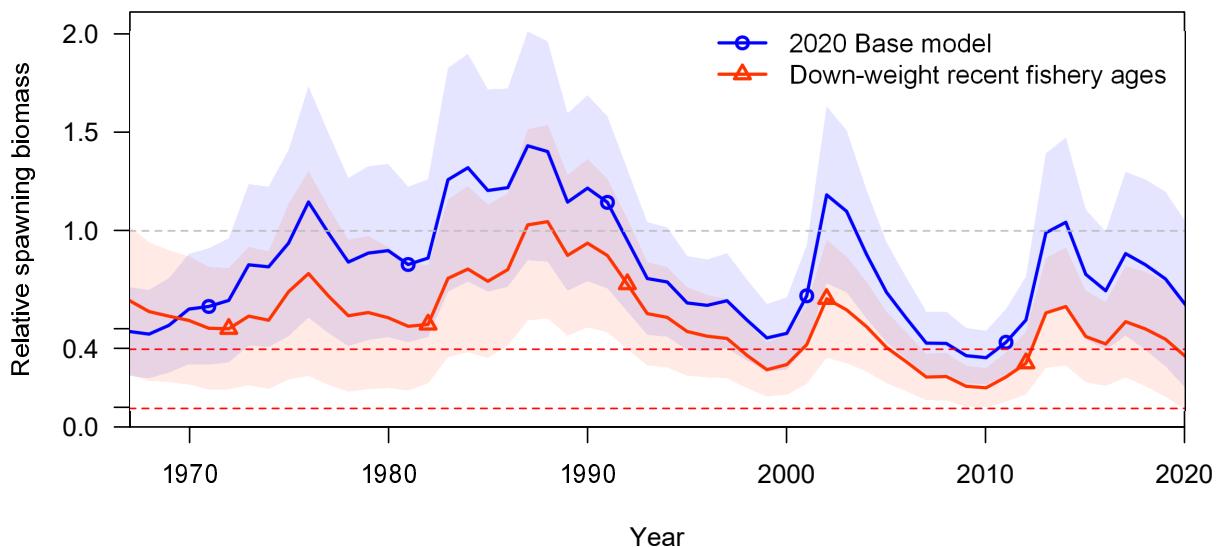
Figure B.2.4. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and a sensitivity run that arbitrarily down-weights recent fishery age compositions using log-input sample size.
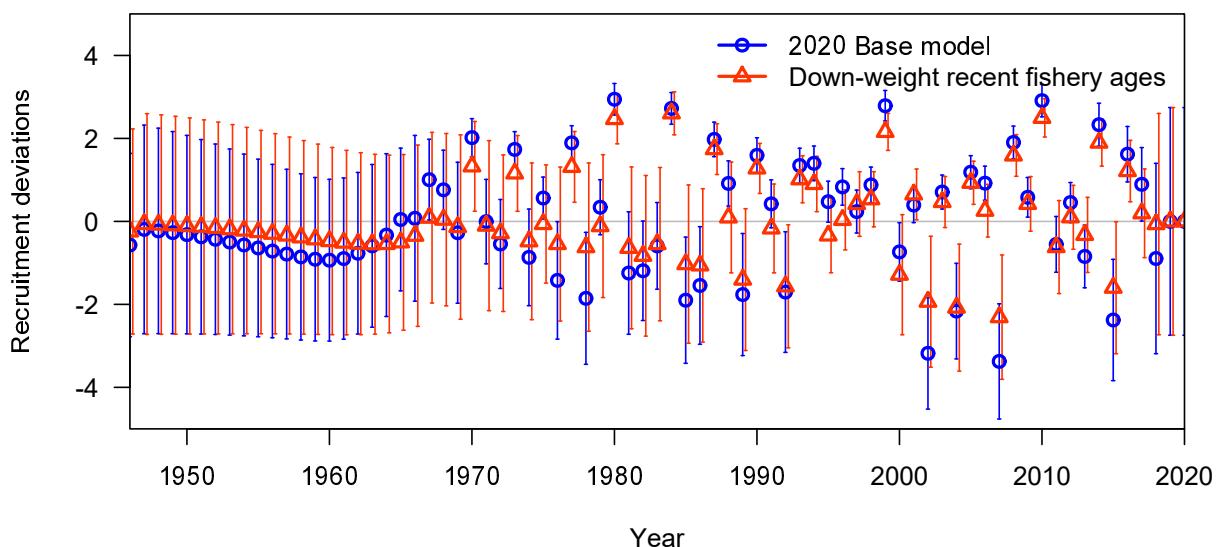
Figure B.2.5. Maximum likelihood estimates of recruitment deviations for the base model and a sensitivity run that arbitrarily down-weights recent fishery age compositions using log-input sample size.

Request 4 – Calculate mean recruitment deviations over the entire period from the MLE model run.

The mean of recruitment deviations for the base model estimated using MLE was 0.209 for the main period and 0.013 for the entire period.

B.3   OTHER EXPLORATIONS

Several other data and model explorations were conducted during the review panel week. In particular, the JTC responded to an 'informal' SRG request to compile and compare likelihood profiles (MLE context) over the parameter R_0 for the base model and a model similar to the base model but with inclusion of the zero-sum constraint on recruitment deviations. Individual likelihood components contributing to the overall likelihood were generally similar between the two MLE models. The fishery and survey Dirichlet-Multinomial parameters as well as the survey extra SD parameter were not sensitive to alternative values of R_0 used in likelihood profiles.

C   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, 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 established by the Agreement.

Agreement ("Treaty"): The Agreement between the government of the United States and the government of Canada on Pacific Hake, 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 average 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 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

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

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:

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

where $\text{SPR}(F)$ is the spawning potential ratio for the value of F accumulated over the entire year. It is 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

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

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

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

as shown in Figure C.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:

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

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

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

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 C.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'.
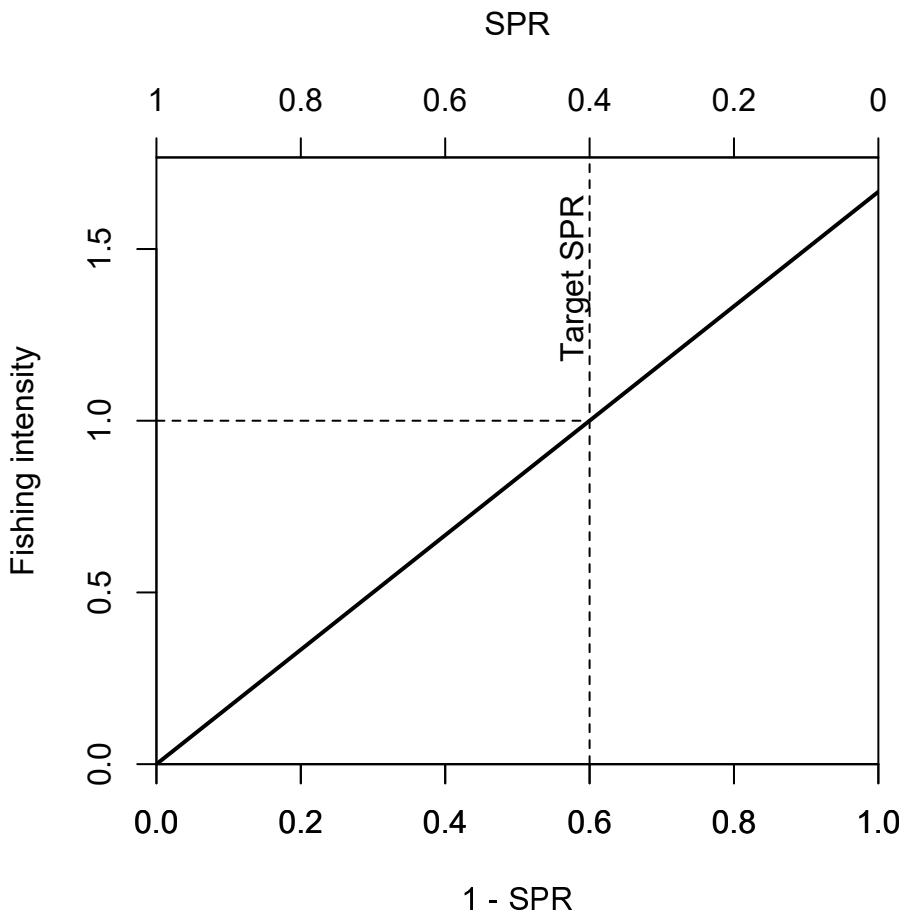
Figure C.1. Fishing intensity as a function of SPR (top axis) and 1-SPR (bottom axis); given the target SPR of 40%, the bold line is simply $1/0.6$, as shown in equation (C.5).
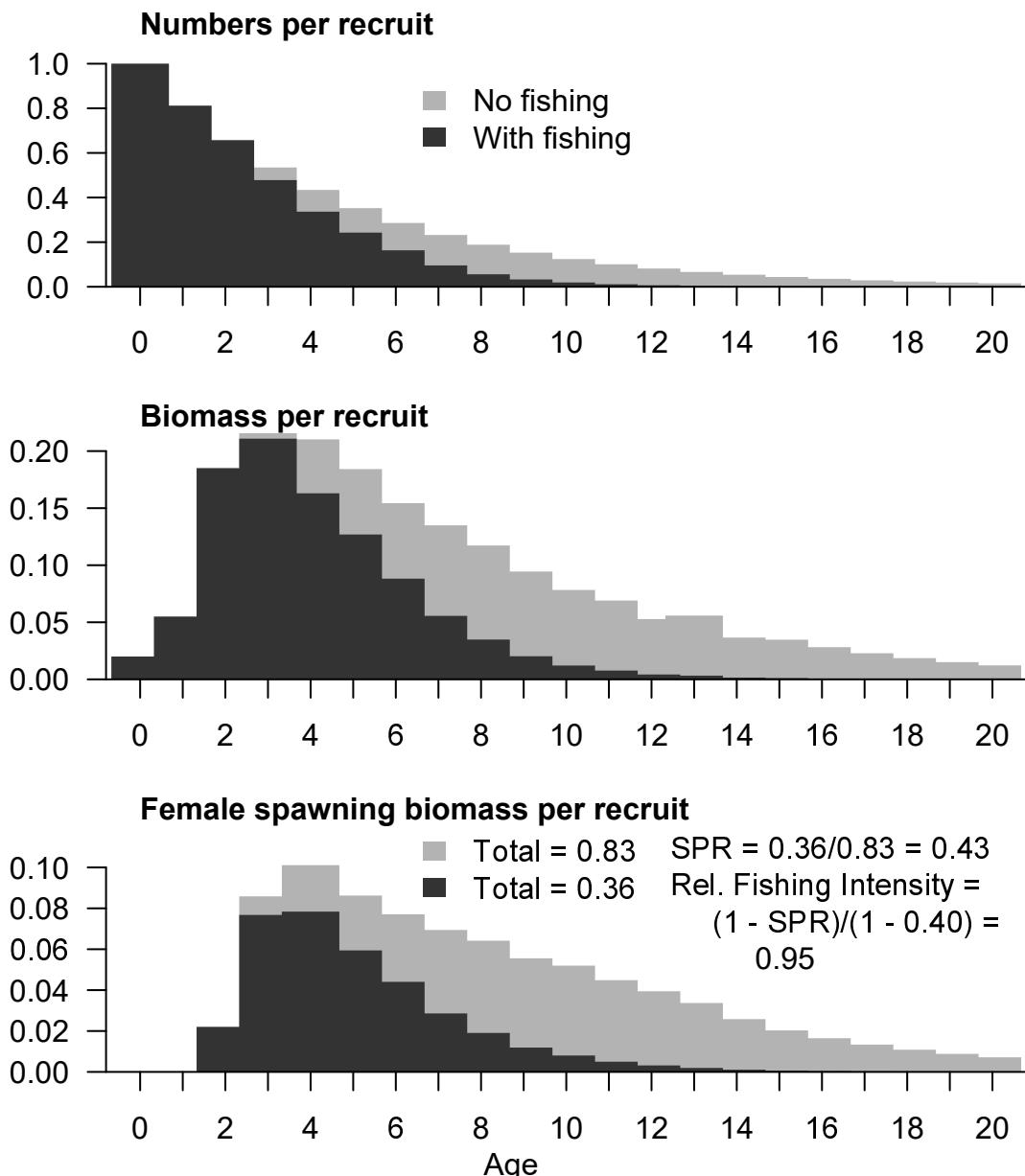
Figure C.2. Illustration of the spawning potential ratio (SPR) calculation based on the combination of maturity and fecundity used in the model, using the maximum likelihood estimates of natural mortality, selectivity, and fishing mortality in the final year of the base model.

D   REPORT OF THE 2019 PACIFIC HAKE FISHERY IN CANADA

Prepared by the Canadian Advisory Panel and submitted for inclusion in this assessment document on February 5th, 2020.

The 2019/20 Offshore Pacific TAC for Canada was 135,781 mt. Combined with carryover from the 2017/18 fishery of 20,286 mt, this year's total available harvest was 156,067 mt, which is the same as the TAC for 2018. As of December 9, this year's total catch of Offshore Pacific hake by Canadian vessels was 94,904 mt which equates to 70% of the Canadian TAC and 61% of the available harvest. Following two years (2017 and 2018) of a Joint Venture fishery in Pacific Canada, there was no JV fishery in 2019.

Fishing in the Canadian zone started in late February with very low landings and continued through until early December. Fishing occurred over the entire west coast of Vancouver Island as well as Queen Charlotte Sound at times. There wasn't any quantity of fish found in San Juan for a majority of the season, but a fairly good amount of fish found in Nitinat Canyon. There was a large area from just north of Barkley Canyon to Kyuquot Canyon where very little to no fish showed up for several months during the season. The water was warmer than usual in this area. This year the fish were found mainly in deep water, especially in August and September when sea surface temperatures were high (approximately 2 degrees Celsius warmer than usual). This year was mainly a deep water scuzz fishery with very large areas of scuzz compared to last year which had smaller areas of dense "worm" style aggregations. However, there was still fish available at different times on top of the shelf in the waters off Barkley Sound, Quatsino Sound and Queen Charlotte Sound. Fish migration seemed generally normal with the best early season fishing happening in the south and then moving north later in the summer followed by good fishing in the southern waters late in the season.

The deepwater scuzz fishing resulted in a high bycatch of rougheye rockfish. Bocaccio rockfish bycatch was also a concern this year when fishing in northern waters on top of the shelf. Unlike 2017 and 2018, juvenile sablefish interception was not a problem for the fleet this year as it seems they have moved to the bottom and are no longer mixing with the hake.

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) and 2018 (29 vessels) with only 25 vessels fishing, due in part to no JV fishery. The average fish round weight varied throughout the season ranging from approximately 600 grams to 800 grams, with larger fish caught predominantly in July, August and November. Small fish were found (estimated to be 2-3 year olds) for much of the season over a large area that included Solander Island, Quatsino Sound, Queen Charlotte Sound and Milbank Sound (which may be a local stock).

The 2019 Canadian hake fishery caught a record amount of catch, slightly more than in 2018. However, this may be due to increased fishing power in the fleet (horse power and larger nets). There has been a steady improvement in the market since 2014, with the industry finding new mar-

kets in Eastern Europe while maintaining markets in China and South Africa. The weak Canadian dollar is also likely helping.

E   REPORT OF THE 2019 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 4, 2020.

The Mothership (MS), Catcher Processor (CP), and Shoreside (SS), and tribal sectors of the U.S. Pacific whiting fishery started fishing on May 15, 2019. Consistent with normal operations, the MS and CP sector vessels suspended fishing in mid-June to participate in the Bering Sea pollock fishery, in the SS sector harvest continued through the summer. Due to slower than normal fishing conditions in the pollock fishery, fishing resumed later than normal in the at-sea sectors. Several CPs resumed in mid-September, but the majority of the CPs and the MSs resumed harvesting and processing activities in mid-October or later.

Harvesting and processing effort was generally consistent with previous years, although there was an additional MS processor that participated in both the spring and fall fisheries in 2019.

At Sea Sectors

The Spring Fishery was characterized by strong fishing conditions on good schools of fish along the coasts of Washington and Oregon. Bycatch avoidance continued to dominate fishery behavior with an abundance of yellowtail rockfish and sablefish encounters dominating the spring fishery, particularly to the north, although sablefish were found throughout the fishing range. Early season salmon bycatch was minimal. In late September and early October, 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. Occasional pockets of relatively clean hake would be located, but would then disperse over the course of a few days.

The vessels reported finding hake 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. In coordination with the PFMC and NMFS, the at-sea sectors voluntarily avoided Chinook salmon, a large year-class of sablefish that was abundant in large concentrations in several areas along the coast, and a surprising emergence of shortbelly rockfish in Oregon waters. These voluntary avoidance measures for Chinook, sablefish, and shortbelly, 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, there are sector-specific hard caps for both species; thus, efforts were also made to avoid these two species.

Fishing in the at-sea sectors continued into November. Both the MS and CP sectors experienced bycatch of rockfish and Chinook salmon in higher amounts than the spring fishery, which necessitated vigilant tracking of bycatch and frequent transiting to avoid and respond to bycatch events. As it became increasingly difficult to locate consistent hake schools void of bycatch, vessels in both sectors opted to cease fishing prior to attaining their respective allocations. As noted above,

both at-sea sectors left significant amounts of whiting unharvested (45% in the MS sector and 15% in the CP sector).

Shoreside Sectors

The SS sector increased its harvest compared to 2018 and utilized 85% of its 2019 whiting allocation. The high attainment was buoyed by the availability of good-sized fish, especially off Washington, but also off the north coast of Oregon. Most shore plants experienced an above average season with steady production well into October, very few down days, and most fish averaging 400–500 grams or more.

Boats were usually able to avoid smaller fish, although some boats did run south and north to avoid a smaller grade near the Columbia River. Pockets of smaller fish were also observed (and avoided) around Willapa Bay (Washington) and in shallower depths. The fish that were avoided were likely a 3-year old class in the 275–350 gram range.

Bycatch issues were significant at times for the SS sector, particularly for the northern areas. By volume, rockfish was the most significant bycatch concern for the fleet (including, yellowtail, widow, and darkblotched rockfish), which is a substantial concern for vessels that spend part of the year targeting groundfish and rockfish because they would prefer to use their quota shares for target species rather than to cover whiting fishery bycatch. Similar to 2018, some boats moved off sablefish bycatch that was encountered off the Willapa Bay towards the Columbia River during the summer (in addition to the whiting being smaller in this area). Sablefish bycatch was all small-sized fish, less than 450 grams.

Tribal Fishery

The 2019 tribal whiting fishery opened on May 15th and closed on December 31st. The tribal allocation for whiting was 17.5% of the U.S. portion of the TAC, equating to 77,251 mt for the 2019 fishing season. The tribal fishing fleet made the first landing on June 11, 2019 and the last landing on October 8, 2019. In the 2019 fishing season, the tribes landed a total of 4,191.5 mt. On September 13, 2019 the tribes agreed to a reapportionment of 40,000 mt of the tribal whiting TAC to be utilized within the non-tribal whiting sectors.

For the 2019, fishing season the Makah Tribe implemented a draft electronic fish ticket program with Pacific States Marine Fisheries Commission. Both paper fish tickets and a draft electronic fish tickets were filled out for every landing. By comparing the draft electronic fish ticket program and the paper tickets, we were able to identify multiple errors and correct the tribal landings in a much more streamlined process.

Table E.1. 2019 allocations and catch totals (metric tons, mt). Note that 441,433 mt U.S. TAC reduced by 1,500 mt for research and incidental catch set aside.

	U.S. TAC	Shoreside (SS)	Catcher Processor (CP)	Mothership (MS)	Tribal
Allocation (mt)	439,933	169,126	136,912	96,644	37,251
Catch (mt)	316,734	143,747	116,147	52,648	4,192
% Utilization	72.0%	85.0%	84.8%	54.5%	11.3%

F ESTIMATED PARAMETERS IN THE BASE ASSESSMENT MODEL

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

Parameter	Posterior median
NatM_p_1_Fem_GP_1	0.2292
SR_LN(R0)	14.7338
SR_BH_steep	0.8161
Q_extraSD_Acoustic_Survey(2)	0.2967
ln(EffN_mult)_1	-0.5587
ln(EffN_mult)_2	2.3325
Early_InitAge_20	-0.2393
Early_InitAge_19	-0.0734
Early_InitAge_18	-0.1262
Early_InitAge_17	-0.1456
Early_InitAge_16	-0.1569
Early_InitAge_15	-0.1019
Early_InitAge_14	-0.2127
Early_InitAge_13	-0.2395
Early_InitAge_12	-0.2895
Early_InitAge_11	-0.3195
Early_InitAge_10	-0.3467
Early_InitAge_9	-0.3735
Early_InitAge_8	-0.5140
Early_InitAge_7	-0.5282
Early_InitAge_6	-0.5360
Early_InitAge_5	-0.4620
Early_InitAge_4	-0.2653
Early_InitAge_3	-0.0050
Early_InitAge_2	0.3555
Early_InitAge_1	0.6295
Early_RecrDev_1966	0.4995
Early_RecrDev_1967	1.6212
Early_RecrDev_1968	1.1577
Early_RecrDev_1969	-0.2119
Main_RecrDev_1970	2.2357
Main_RecrDev_1971	-0.1192
Main_RecrDev_1972	-0.5724
Main_RecrDev_1973	1.7937
Main_RecrDev_1974	-0.9606
Main_RecrDev_1975	0.5884
Main_RecrDev_1976	-1.5322
Main_RecrDev_1977	1.8906
Main_RecrDev_1978	-1.8441
Main_RecrDev_1979	0.3340
Main_RecrDev_1980	2.8644
Main_RecrDev_1981	-1.2382
Main_RecrDev_1982	-1.1340
Main_RecrDev_1983	-0.6282
Main_RecrDev_1984	2.6407
Main_RecrDev_1985	-1.9156
Main_RecrDev_1986	-1.6658
Main_RecrDev_1987	1.9012
Main_RecrDev_1988	0.7444
Main_RecrDev_1989	-2.0990
Main_RecrDev_1990	1.4972
Main_RecrDev_1991	0.2173
Main_RecrDev_1992	-1.9713
Main_RecrDev_1993	1.2283
Main_RecrDev_1994	1.2839
Main_RecrDev_1995	0.2990
Main_RecrDev_1996	0.7196
Main_RecrDev_1997	0.1480
Main_RecrDev_1998	0.7945

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

Parameter	Posterior median
Main_RecrDev_1999	2.7087
Main_RecrDev_2000	-0.9952
Main_RecrDev_2001	0.3153
Main_RecrDev_2002	-3.3362
Main_RecrDev_2003	0.6119
Main_RecrDev_2004	-2.6617
Main_RecrDev_2005	1.1299
Main_RecrDev_2006	0.8188
Main_RecrDev_2007	-3.4526
Main_RecrDev_2008	1.8588
Main_RecrDev_2009	0.5357
Main_RecrDev_2010	2.9209
Main_RecrDev_2011	-0.6874
Main_RecrDev_2012	0.4846
Main_RecrDev_2013	-1.0255
Main_RecrDev_2014	2.3049
Main_RecrDev_2015	-2.6714
Main_RecrDev_2016	1.5901
Main_RecrDev_2017	0.8643
Main_RecrDev_2018	-0.9526
Late_RecrDev_2019	0.0052
ForeRecr_2020	0.0154
ForeRecr_2021	-0.0045
ForeRecr_2022	0.0377
AgeSel_P3_Fishery(1)	2.8306
AgeSel_P4_Fishery(1)	0.9405
AgeSel_P5_Fishery(1)	0.3858
AgeSel_P6_Fishery(1)	0.1803
AgeSel_P7_Fishery(1)	0.5028
AgeSel_P4_Acoustic_Survey(2)	0.6502
AgeSel_P5_Acoustic_Survey(2)	-0.2445
AgeSel_P6_Acoustic_Survey(2)	0.2515
AgeSel_P7_Acoustic_Survey(2)	0.3990
AgeSel_P3_Fishery(1)_DEVadd_1991	0.5849
AgeSel_P3_Fishery(1)_DEVadd_1992	0.0305
AgeSel_P3_Fishery(1)_DEVadd_1993	-0.0120
AgeSel_P3_Fishery(1)_DEVadd_1994	0.1164
AgeSel_P3_Fishery(1)_DEVadd_1995	-0.1508
AgeSel_P3_Fishery(1)_DEVadd_1996	0.4240
AgeSel_P3_Fishery(1)_DEVadd_1997	0.1469
AgeSel_P3_Fishery(1)_DEVadd_1998	0.2160
AgeSel_P3_Fishery(1)_DEVadd_1999	1.0001
AgeSel_P3_Fishery(1)_DEVadd_2000	0.5260
AgeSel_P3_Fishery(1)_DEVadd_2001	0.0079
AgeSel_P3_Fishery(1)_DEVadd_2002	0.1036
AgeSel_P3_Fishery(1)_DEVadd_2003	0.0271
AgeSel_P3_Fishery(1)_DEVadd_2004	0.2924
AgeSel_P3_Fishery(1)_DEVadd_2005	0.0508
AgeSel_P3_Fishery(1)_DEVadd_2006	0.5967
AgeSel_P3_Fishery(1)_DEVadd_2007	0.5991
AgeSel_P3_Fishery(1)_DEVadd_2008	0.0065
AgeSel_P3_Fishery(1)_DEVadd_2009	0.4091
AgeSel_P3_Fishery(1)_DEVadd_2010	0.9909
AgeSel_P3_Fishery(1)_DEVadd_2011	-0.0884
AgeSel_P3_Fishery(1)_DEVadd_2012	0.0902
AgeSel_P3_Fishery(1)_DEVadd_2013	0.2259
AgeSel_P3_Fishery(1)_DEVadd_2014	0.3003
AgeSel_P3_Fishery(1)_DEVadd_2015	-0.6111
AgeSel_P3_Fishery(1)_DEVadd_2016	-0.0839
AgeSel_P3_Fishery(1)_DEVadd_2017	-0.6844
AgeSel_P3_Fishery(1)_DEVadd_2018	-1.0709

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

Parameter	Posterior median
AgeSel_P3_Fishery(1)_DEVadd_2019	0.6642
AgeSel_P4_Fishery(1)_DEVadd_1991	0.3824
AgeSel_P4_Fishery(1)_DEVadd_1992	0.6202
AgeSel_P4_Fishery(1)_DEVadd_1993	0.7812
AgeSel_P4_Fishery(1)_DEVadd_1994	0.1847
AgeSel_P4_Fishery(1)_DEVadd_1995	0.2333
AgeSel_P4_Fishery(1)_DEVadd_1996	-0.3868
AgeSel_P4_Fishery(1)_DEVadd_1997	1.2454
AgeSel_P4_Fishery(1)_DEVadd_1998	0.9728
AgeSel_P4_Fishery(1)_DEVadd_1999	-0.1126
AgeSel_P4_Fishery(1)_DEVadd_2000	0.7658
AgeSel_P4_Fishery(1)_DEVadd_2001	0.9295
AgeSel_P4_Fishery(1)_DEVadd_2002	0.7451
AgeSel_P4_Fishery(1)_DEVadd_2003	0.7074
AgeSel_P4_Fishery(1)_DEVadd_2004	0.4699
AgeSel_P4_Fishery(1)_DEVadd_2005	0.6477
AgeSel_P4_Fishery(1)_DEVadd_2006	-0.1298
AgeSel_P4_Fishery(1)_DEVadd_2007	0.2365
AgeSel_P4_Fishery(1)_DEVadd_2008	0.3359
AgeSel_P4_Fishery(1)_DEVadd_2009	0.7168
AgeSel_P4_Fishery(1)_DEVadd_2010	0.1021
AgeSel_P4_Fishery(1)_DEVadd_2011	1.0034
AgeSel_P4_Fishery(1)_DEVadd_2012	0.1485
AgeSel_P4_Fishery(1)_DEVadd_2013	0.8856
AgeSel_P4_Fishery(1)_DEVadd_2014	0.3117
AgeSel_P4_Fishery(1)_DEVadd_2015	0.1996
AgeSel_P4_Fishery(1)_DEVadd_2016	-0.7703
AgeSel_P4_Fishery(1)_DEVadd_2017	-0.4558
AgeSel_P4_Fishery(1)_DEVadd_2018	-0.8958
AgeSel_P4_Fishery(1)_DEVadd_2019	-0.4408
AgeSel_P5_Fishery(1)_DEVadd_1991	-0.8304
AgeSel_P5_Fishery(1)_DEVadd_1992	0.0373
AgeSel_P5_Fishery(1)_DEVadd_1993	0.0308
AgeSel_P5_Fishery(1)_DEVadd_1994	0.9087
AgeSel_P5_Fishery(1)_DEVadd_1995	0.3085
AgeSel_P5_Fishery(1)_DEVadd_1996	-0.3370
AgeSel_P5_Fishery(1)_DEVadd_1997	-0.1176
AgeSel_P5_Fishery(1)_DEVadd_1998	-0.6234
AgeSel_P5_Fishery(1)_DEVadd_1999	0.1269
AgeSel_P5_Fishery(1)_DEVadd_2000	-0.1319
AgeSel_P5_Fishery(1)_DEVadd_2001	0.2976
AgeSel_P5_Fishery(1)_DEVadd_2002	0.5441
AgeSel_P5_Fishery(1)_DEVadd_2003	0.7264
AgeSel_P5_Fishery(1)_DEVadd_2004	0.6819
AgeSel_P5_Fishery(1)_DEVadd_2005	0.7085
AgeSel_P5_Fishery(1)_DEVadd_2006	0.0032
AgeSel_P5_Fishery(1)_DEVadd_2007	-0.1205
AgeSel_P5_Fishery(1)_DEVadd_2008	-0.4147
AgeSel_P5_Fishery(1)_DEVadd_2009	-0.1609
AgeSel_P5_Fishery(1)_DEVadd_2010	0.5136
AgeSel_P5_Fishery(1)_DEVadd_2011	-0.6932
AgeSel_P5_Fishery(1)_DEVadd_2012	0.2300
AgeSel_P5_Fishery(1)_DEVadd_2013	-0.2468
AgeSel_P5_Fishery(1)_DEVadd_2014	-0.3948
AgeSel_P5_Fishery(1)_DEVadd_2015	-0.0703
AgeSel_P5_Fishery(1)_DEVadd_2016	-0.0510
AgeSel_P5_Fishery(1)_DEVadd_2017	0.0280
AgeSel_P5_Fishery(1)_DEVadd_2018	-0.1775
AgeSel_P5_Fishery(1)_DEVadd_2019	-0.3922
AgeSel_P6_Fishery(1)_DEVadd_1991	-0.0116
AgeSel_P6_Fishery(1)_DEVadd_1992	-0.4781

Continued on next page

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

Parameter	Posterior median
AgeSel_P6_Fishery(1)_DEVadd_1993	-0.0429
AgeSel_P6_Fishery(1)_DEVadd_1994	-0.1063
AgeSel_P6_Fishery(1)_DEVadd_1995	0.7198
AgeSel_P6_Fishery(1)_DEVadd_1996	-0.1063
AgeSel_P6_Fishery(1)_DEVadd_1997	-0.3328
AgeSel_P6_Fishery(1)_DEVadd_1998	0.3798
AgeSel_P6_Fishery(1)_DEVadd_1999	-0.3949
AgeSel_P6_Fishery(1)_DEVadd_2000	0.1458
AgeSel_P6_Fishery(1)_DEVadd_2001	-0.1106
AgeSel_P6_Fishery(1)_DEVadd_2002	0.1160
AgeSel_P6_Fishery(1)_DEVadd_2003	0.2662
AgeSel_P6_Fishery(1)_DEVadd_2004	-0.5594
AgeSel_P6_Fishery(1)_DEVadd_2005	0.3010
AgeSel_P6_Fishery(1)_DEVadd_2006	0.1970
AgeSel_P6_Fishery(1)_DEVadd_2007	-0.2079
AgeSel_P6_Fishery(1)_DEVadd_2008	0.3164
AgeSel_P6_Fishery(1)_DEVadd_2009	-0.2624
AgeSel_P6_Fishery(1)_DEVadd_2010	-0.4892
AgeSel_P6_Fishery(1)_DEVadd_2011	-0.2190
AgeSel_P6_Fishery(1)_DEVadd_2012	-0.5000
AgeSel_P6_Fishery(1)_DEVadd_2013	0.0057
AgeSel_P6_Fishery(1)_DEVadd_2014	-0.0184
AgeSel_P6_Fishery(1)_DEVadd_2015	0.0104
AgeSel_P6_Fishery(1)_DEVadd_2016	-0.1730
AgeSel_P6_Fishery(1)_DEVadd_2017	-0.1554
AgeSel_P6_Fishery(1)_DEVadd_2018	-0.1665
AgeSel_P6_Fishery(1)_DEVadd_2019	0.1752
AgeSel_P7_Fishery(1)_DEVadd_1991	-0.1705
AgeSel_P7_Fishery(1)_DEVadd_1992	0.0807
AgeSel_P7_Fishery(1)_DEVadd_1993	-0.3671
AgeSel_P7_Fishery(1)_DEVadd_1994	0.1191
AgeSel_P7_Fishery(1)_DEVadd_1995	-0.1035
AgeSel_P7_Fishery(1)_DEVadd_1996	0.4279
AgeSel_P7_Fishery(1)_DEVadd_1997	0.1399
AgeSel_P7_Fishery(1)_DEVadd_1998	-0.5023
AgeSel_P7_Fishery(1)_DEVadd_1999	-0.2569
AgeSel_P7_Fishery(1)_DEVadd_2000	-0.0614
AgeSel_P7_Fishery(1)_DEVadd_2001	-0.2814
AgeSel_P7_Fishery(1)_DEVadd_2002	-0.3727
AgeSel_P7_Fishery(1)_DEVadd_2003	-0.2711
AgeSel_P7_Fishery(1)_DEVadd_2004	-0.1677
AgeSel_P7_Fishery(1)_DEVadd_2005	-0.4058
AgeSel_P7_Fishery(1)_DEVadd_2006	-0.3215
AgeSel_P7_Fishery(1)_DEVadd_2007	0.0548
AgeSel_P7_Fishery(1)_DEVadd_2008	-0.1760
AgeSel_P7_Fishery(1)_DEVadd_2009	0.1432
AgeSel_P7_Fishery(1)_DEVadd_2010	-0.5719
AgeSel_P7_Fishery(1)_DEVadd_2011	-0.4573
AgeSel_P7_Fishery(1)_DEVadd_2012	-0.2864
AgeSel_P7_Fishery(1)_DEVadd_2013	0.0812
AgeSel_P7_Fishery(1)_DEVadd_2014	-0.0149
AgeSel_P7_Fishery(1)_DEVadd_2015	-0.5139
AgeSel_P7_Fishery(1)_DEVadd_2016	-0.2224
AgeSel_P7_Fishery(1)_DEVadd_2017	-0.0854
AgeSel_P7_Fishery(1)_DEVadd_2018	0.2655
AgeSel_P7_Fishery(1)_DEVadd_2019	0.0088

G SENSITIVITY RUN THAT INCLUDES THE AGE-1 SURVEY – MCMC RESULTS

This appendix contains Bayesian MCMC results for the model run in which the age-1 survey index is included as an index of recruitment as described in Sections 2.2.1 and 3.8 (Table 33). It highlights model uncertainty arising from a different structural assumption or analytical choice compared to the base model, and the inclusion of the age-1 index was deemed important enough to warrant further consideration, especially in the context of characterizing forecast uncertainty. Nonetheless, this appendix is only meant to provide supplemental information, and should not be viewed as a viable alternative to the base model. The figures and tables show results from this sensitivity run (though note that some plots necessarily show MLE results).

The estimated size of the 2010 recruitment using only data when that cohort is age-2 is closer to the final estimated size when using the age-1 index (Figure G.1) than it is for the base model (Figure 55). However, the 2008 and 2014 recruitments are considerably overestimated at age-2 when using the age-1 index (Figure G.1). For the 2008 recruitment (Figure G.2) in the base model, the estimated recruitment when taking off nine years of data (as though assessing the stock in 2011) is just under 10 billion fish, reducing to about 6 billion when taking off eight years. However, when using the age-1 index the 2008 recruitment is estimated at over 12 billion fish when taking off nine and eight years of data (as though assessing the stock in 2011 and 2012), which is about 8 billion more fish than the current estimate of the 2008 recruitment. Given that the stock was in a low biomass state in 2011 and 2012, including the age-1 index at that time would have given misleadingly optimistic forecasts.

The inclusion of the age-1 index does not greatly change the uncertainty of historical or forecast spawning biomass (Figure G.3); this is also true for the retrospective runs. Overall, it appears that the inclusion of the age-1 index does not consistently improve estimates of recruitments, and, in fact, can be overly optimistic in some situations (Figure G.2). Recall that the survey design is not structured specifically for indexing age-1 fish.

Figures G.4–G.12 and Tables G.1–G.7 show further quantities of interest and decision tables from the MCMC results when including the age-1 index.
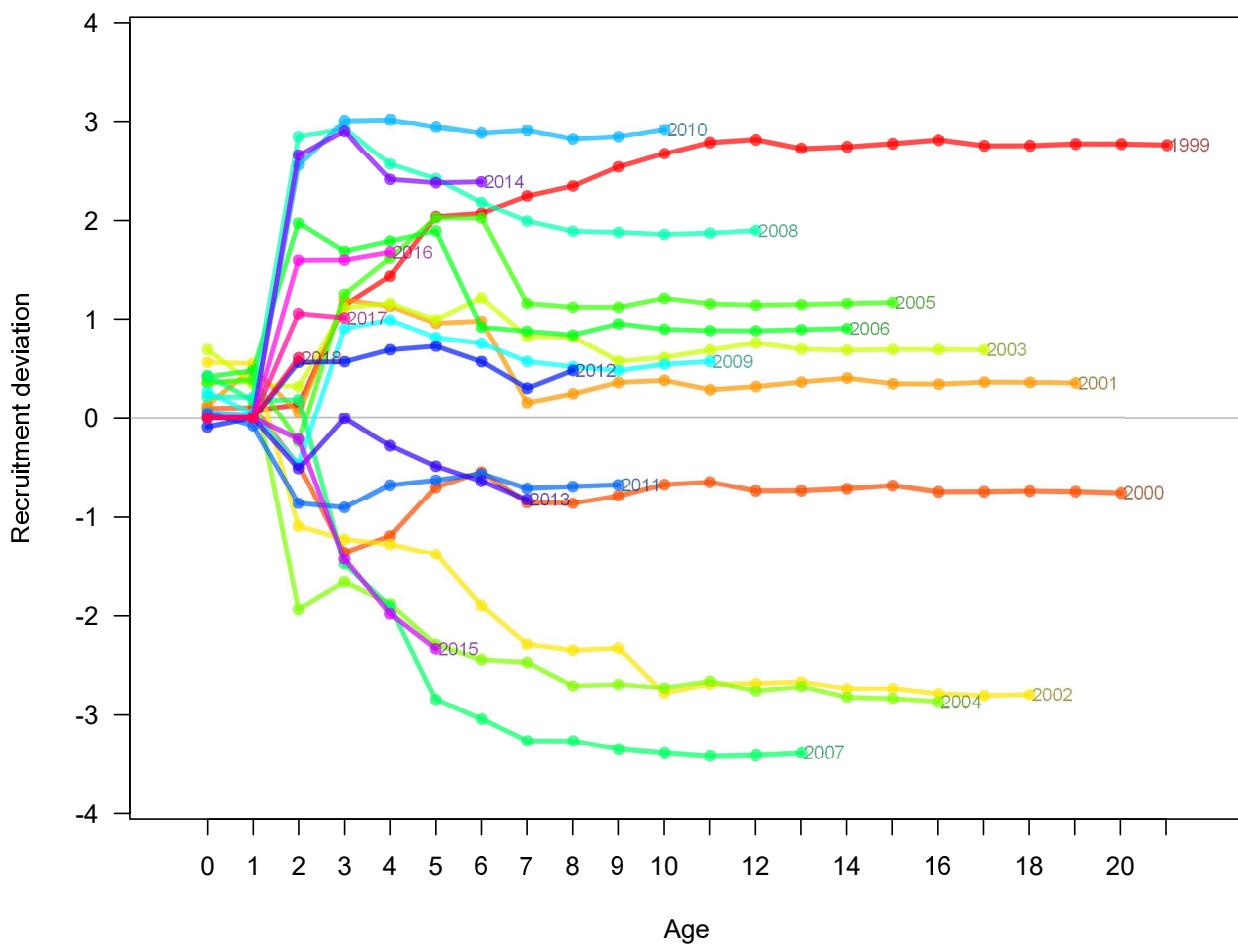
Figure G.1. Retrospective analysis of recruitment deviations from MLE models over the last 21 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for cohorts from 1999 to 2018, 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.
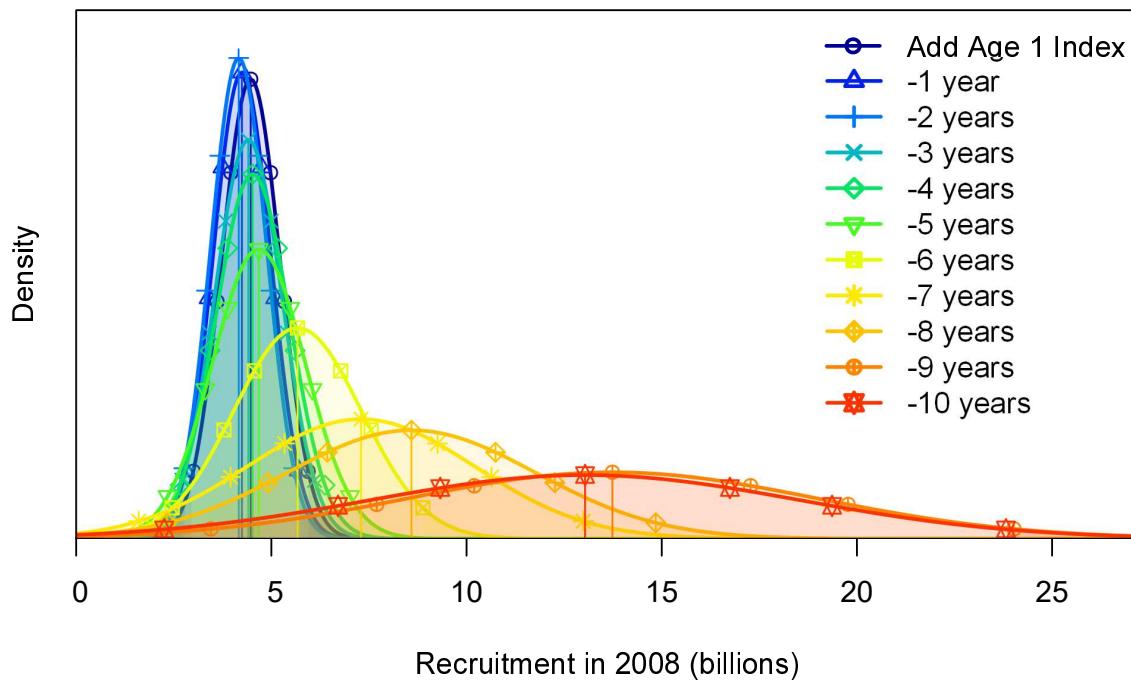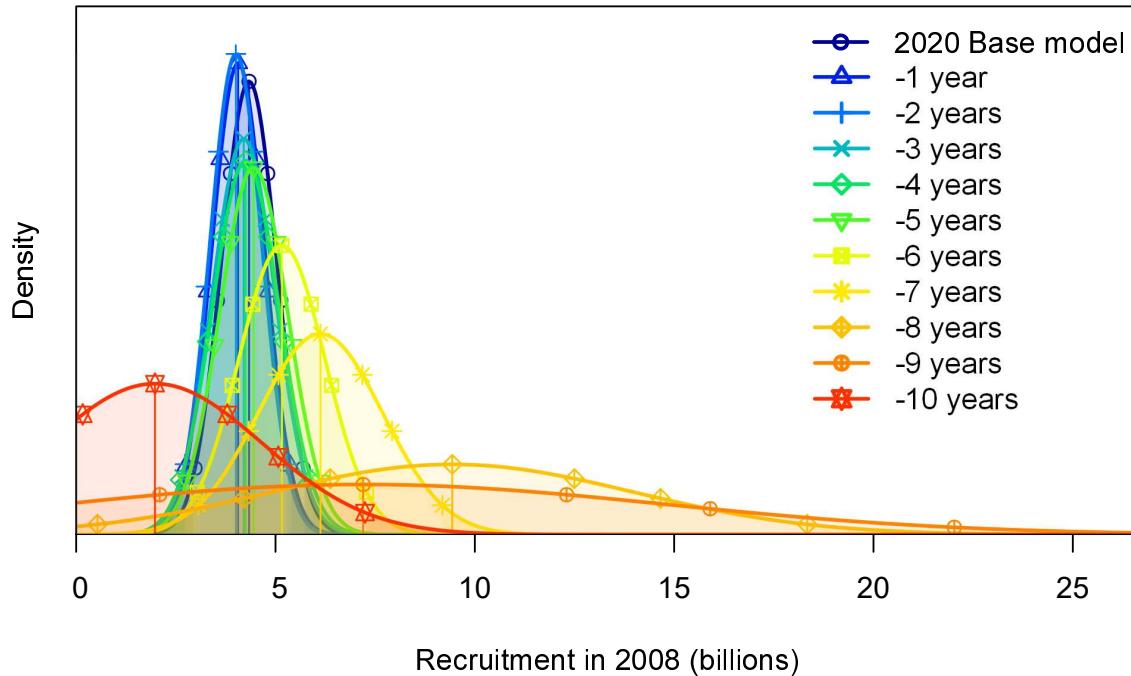
Figure G.2. The retrospective MLEs and associated uncertainties of the recruitment in 2008 for the base model (top) and age-1 index sensitivity run (bottom). When running the model with all data (the top run in each key) this cohort is observed in 2019 at age-11; so taking off 9 years of data, for example, means that cohort is only observed up to age-2.
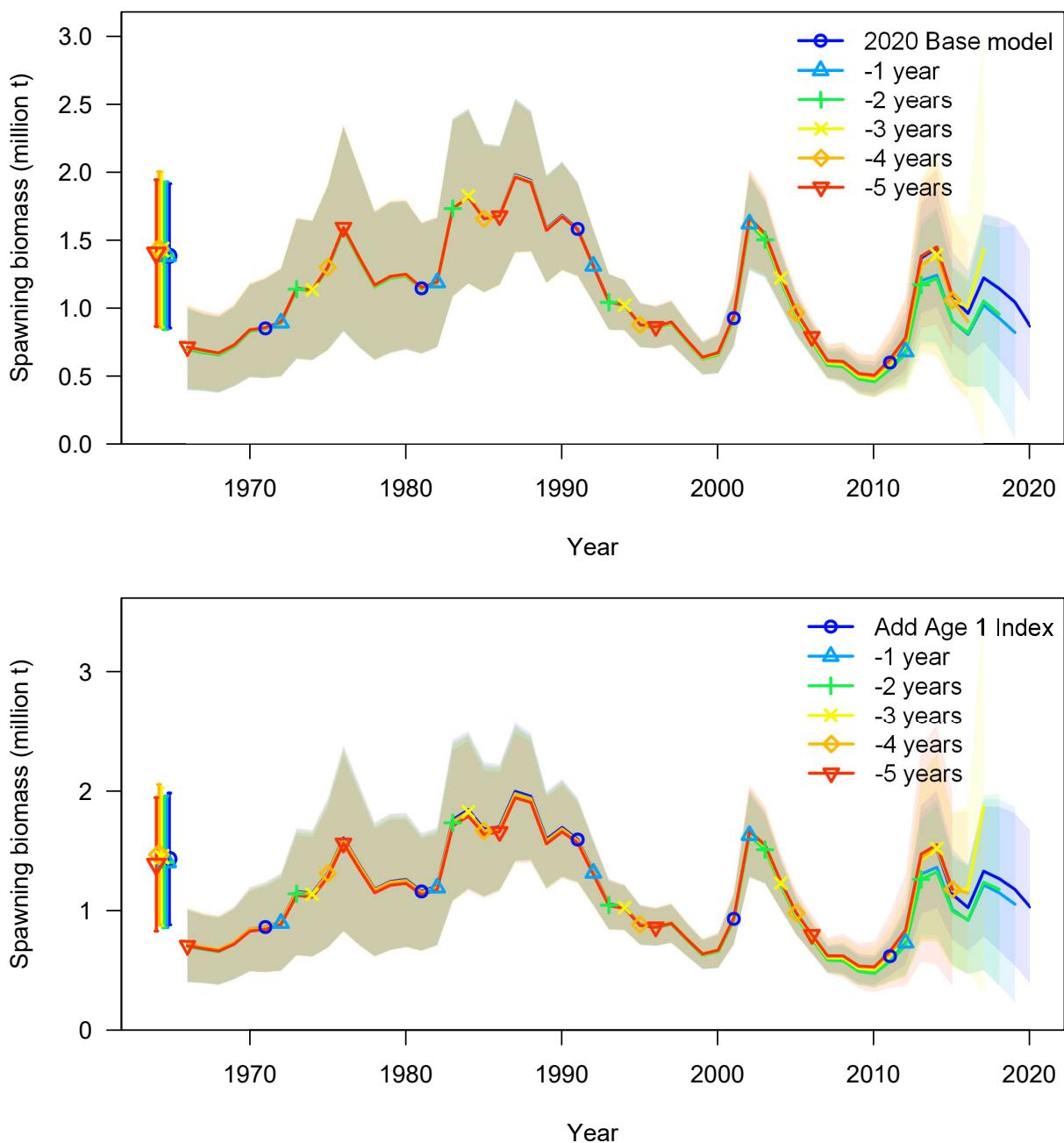
Figure G.3. The retrospective MLEs and associated uncertainties of the spawning biomass for the base model (top) and age-1 index sensitivity run (bottom).
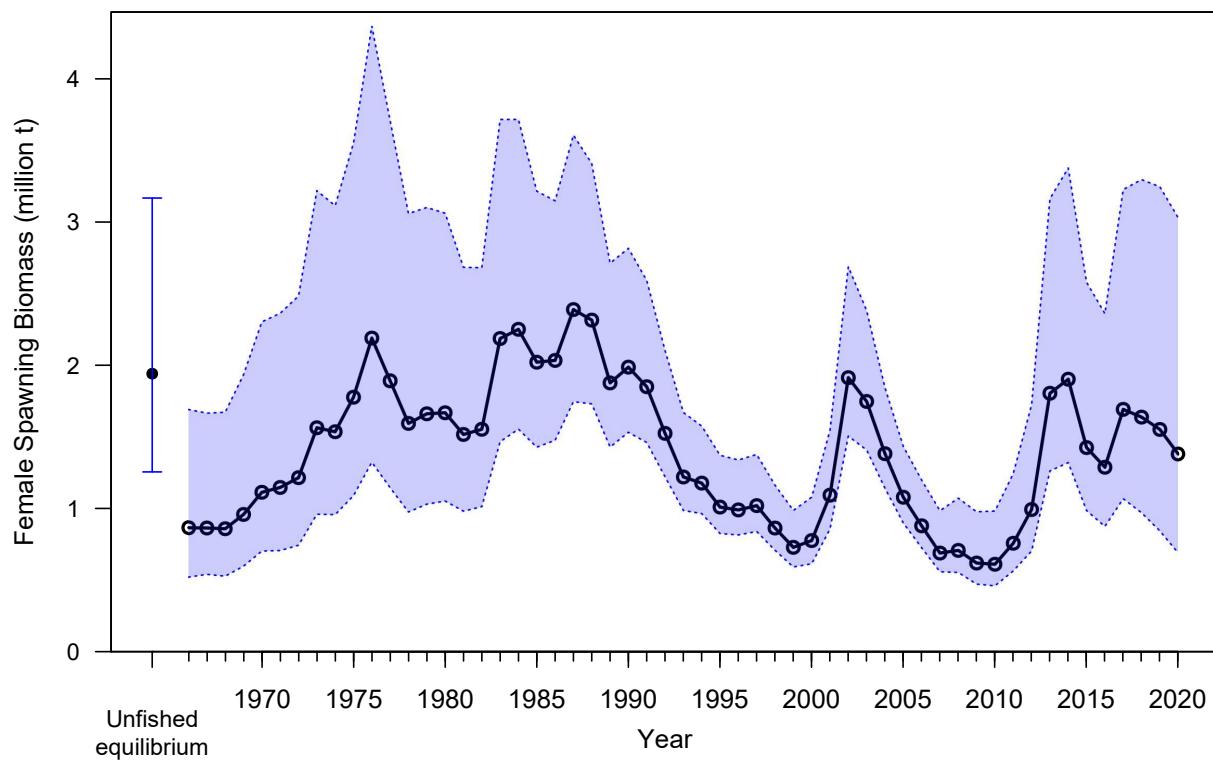
Figure G.4. Median of the posterior distribution for beginning of the year female spawning biomass through 2020 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.
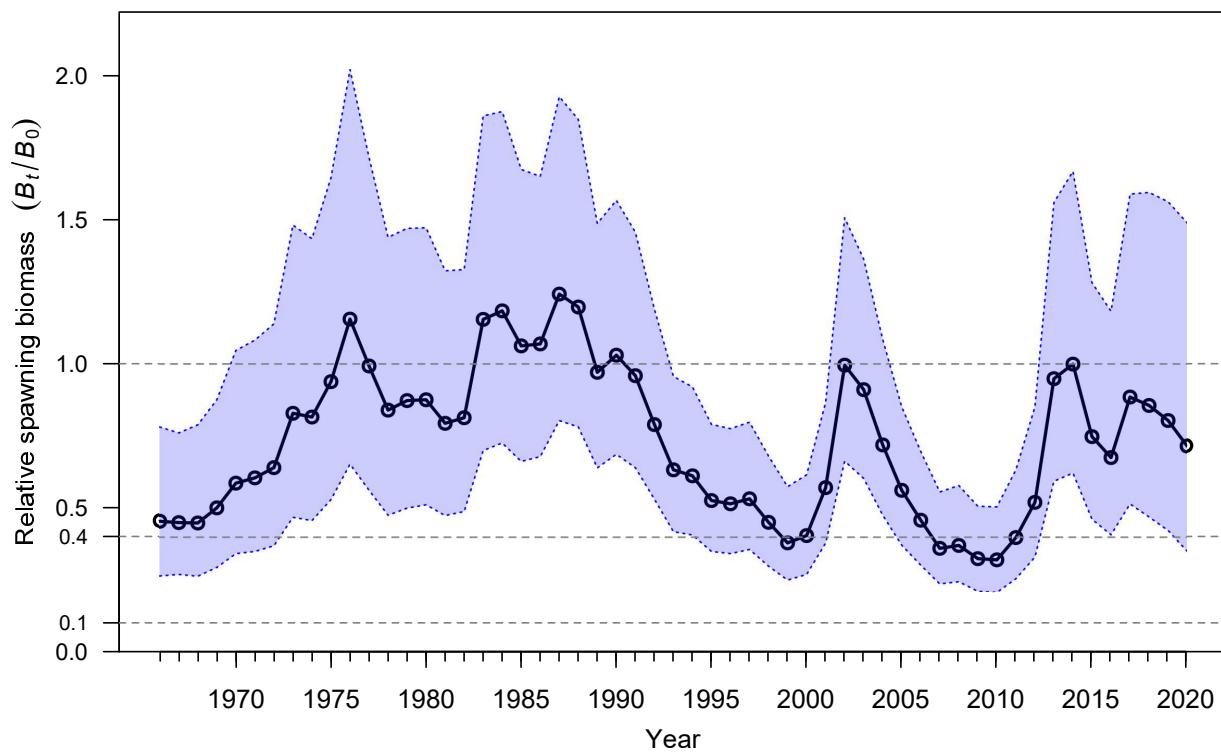
Figure G.5. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2020 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

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
2011	565.1	758.3	1,244.5	25.6%	39.9%	63.3%
2012	704.3	993.6	1,724.0	33.1%	52.1%	85.1%
2013	1,262.8	1,804.6	3,161.5	59.4%	94.9%	155.9%
2014	1,320.9	1,902.6	3,376.0	62.2%	99.9%	166.7%
2015	986.2	1,425.7	2,578.8	46.2%	74.8%	128.1%
2016	875.6	1,288.7	2,360.3	40.8%	67.6%	118.3%
2017	1,068.9	1,692.4	3,225.9	51.5%	88.5%	158.8%
2018	970.8	1,638.2	3,295.0	47.0%	85.6%	159.4%
2019	844.2	1,552.2	3,245.1	42.3%	80.4%	156.2%
2020	690.6	1,380.7	3,028.5	35.2%	71.6%	148.8%

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
2010	10,259.4	16,364.4	32,074.9	2.496	2.922	3.370
2011	165.9	410.4	948.8	-1.700	-0.793	-0.087
2012	884.8	1,541.6	3,322.7	-0.063	0.481	1.077
2013	117.6	373.0	988.8	-2.089	-1.005	-0.144
2014	5,854.9	10,474.8	22,415.9	1.761	2.338	2.933
2015	11.7	68.5	322.3	-4.375	-2.683	-1.259
2016	2,506.9	5,052.2	11,853.4	0.974	1.629	2.337
2017	952.4	2,603.8	7,705.3	-0.065	0.951	1.860
2018	278.5	1,493.5	5,692.2	-1.152	0.375	1.754
2019	56.7	1,011.9	13,737.5	-2.805	0.024	2.482
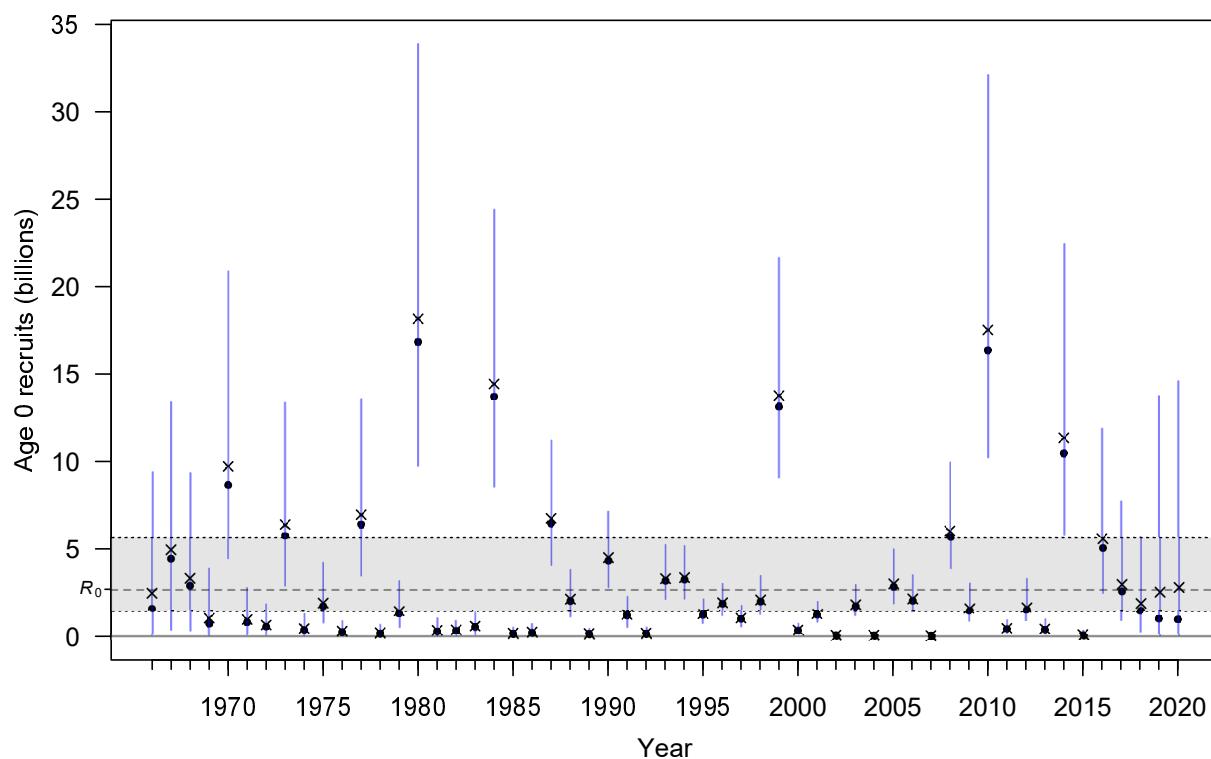
Figure G.6. Medians (solid circles) and means ($\times$) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed 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
2010	0.630	0.920	1.187	0.071	0.114	0.151
2011	0.554	0.862	1.155	0.096	0.160	0.216
2012	0.392	0.650	0.943	0.030	0.052	0.075
2013	0.379	0.629	0.854	0.040	0.070	0.100
2014	0.349	0.599	0.846	0.041	0.072	0.104
2015	0.239	0.447	0.690	0.030	0.054	0.079
2016	0.413	0.708	0.995	0.042	0.077	0.116
2017	0.437	0.747	1.073	0.064	0.122	0.193
2018	0.401	0.707	1.039	0.053	0.105	0.179
2019	0.403	0.705	1.024	0.049	0.103	0.189
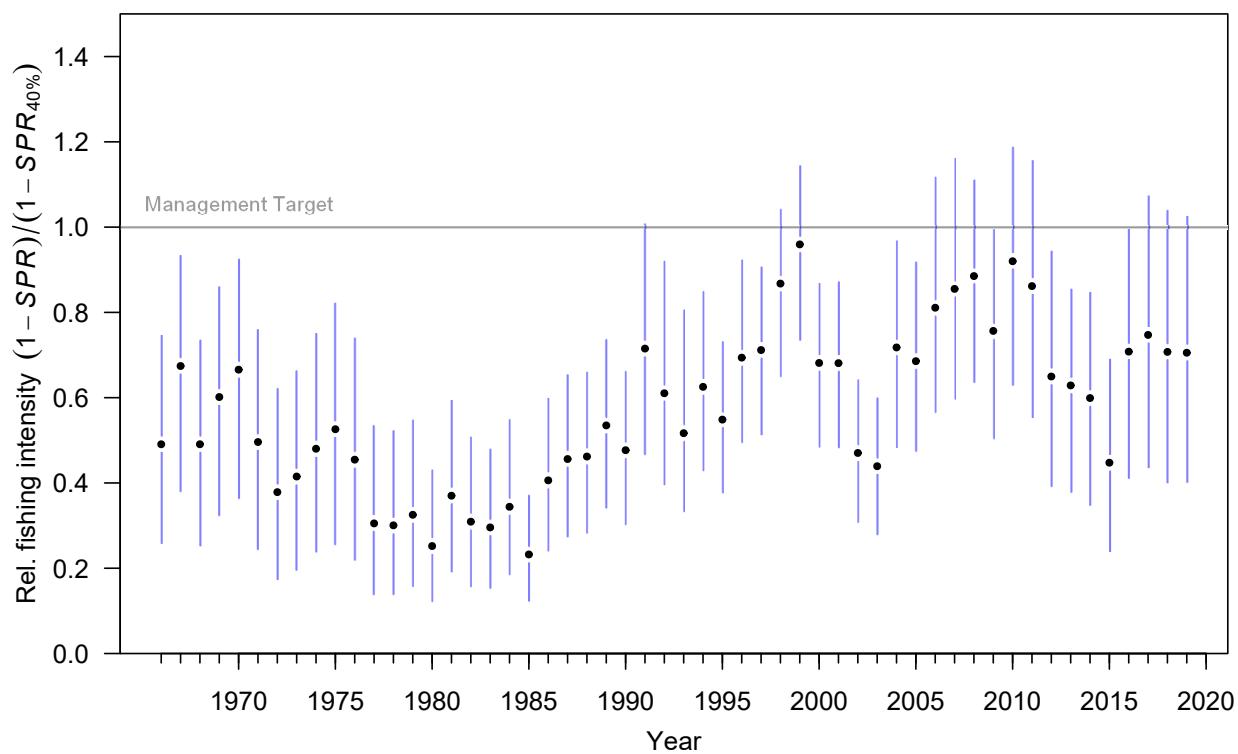
Figure G.7. Trend in median relative fishing intensity (relative to the SPR management target) through 2019 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.
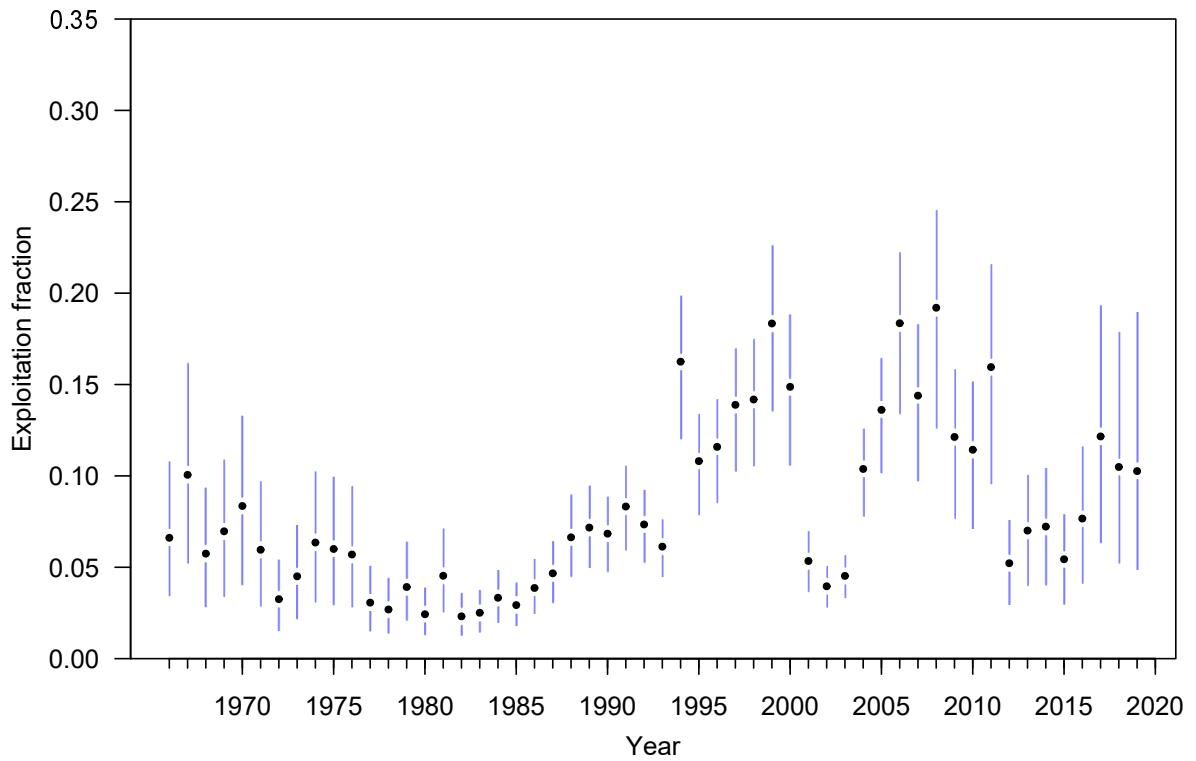
Figure G.8. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2019 with 95% posterior credibility intervals.
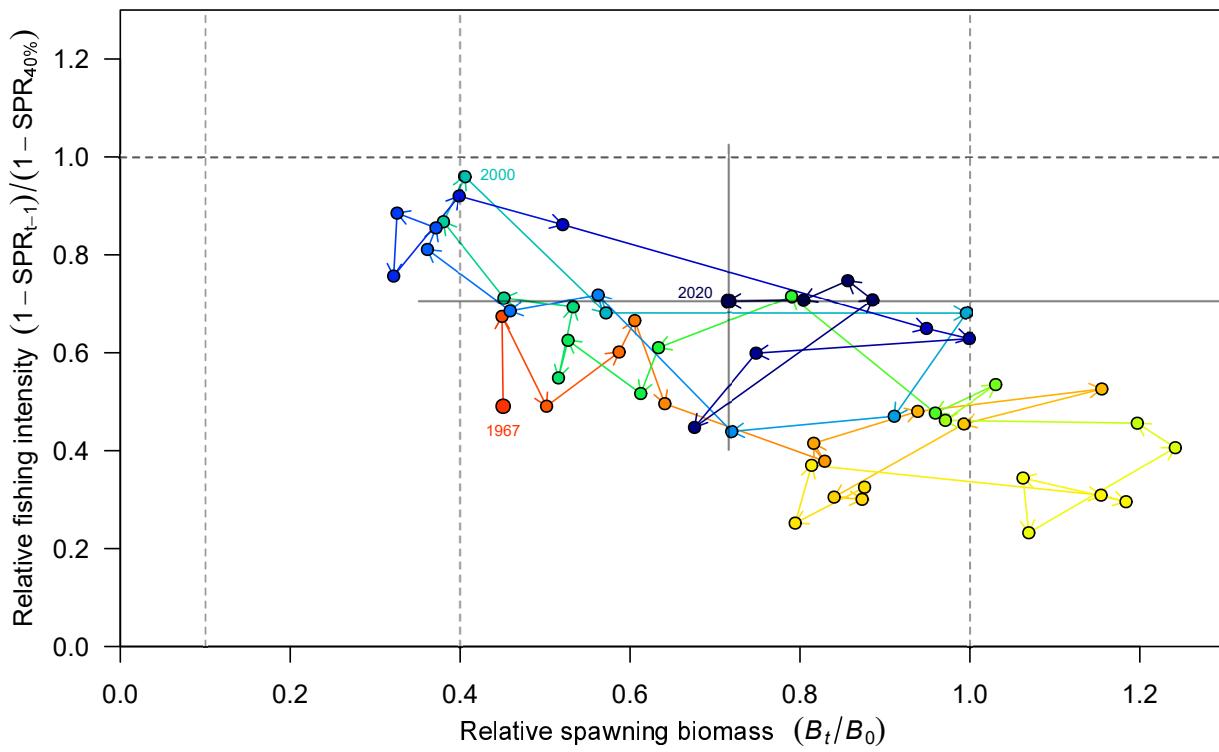
Figure G.9. Estimated historical path of median relative spawning biomass in year t and corresponding median relative fishing intensity in year $t - 1$, as for Figure 33. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year t (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2020 relative spawning biomass (horizontal) and 2019 relative fishing intensity (vertical).

Table G.4. For the alternative run, summary of median and 95% credibility intervals of equilibrium reference points. Equilibrium reference points were computed using 1966–2019 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)	1,255	1,941	3,168
Unfished recruitment (R_0, millions)	1,449	2,687	5,644
Reference points (equilibrium) based on $F_{\text{SPR}=40\%}$			
Female spawning biomass at $F_{\text{SPR}=40\%}$ (thousand t)	423	694	1,102
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	16.0%	18.4%	21.1%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	188	328	605
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	502	776	1,267
SPR at $B_{40\%}$	40.6%	43.3%	50.7%
Exploitation fraction resulting in $B_{40\%}$	12.4%	16.4%	19.5%
Yield at $B_{40\%}$ (thousand t)	186	321	585
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	294	489	908
SPR at MSY	22.5%	29.1%	45.4%
Exploitation fraction corresponding to SPR at MSY	14.8%	26.5%	35.1%
MSY (thousand t)	195	348	635

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 2019 (row d) and the TAC from 2019 (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 2020 and 2021 (row i). Catch in 2022 does not impact the beginning of the year biomass in 2022.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2020	0	39%	57%	72%	91%	133%
	2021	0	40%	56%	71%	89%	127%
	2022	0	40%	55%	71%	89%	135%
b:	2020	180,000	39%	57%	72%	91%	133%
	2021	180,000	36%	52%	67%	85%	123%
	2022	180,000	32%	48%	62%	81%	126%
c:	2020	350,000	39%	57%	72%	91%	133%
	2021	350,000	32%	49%	63%	80%	119%
	2022	350,000	25%	41%	55%	73%	119%
d:	2020	410,000	39%	57%	72%	91%	133%
2019	2021	410,000	31%	47%	61%	79%	118%
catch	2022	410,000	23%	38%	52%	70%	115%
e:	2020	500,000	39%	57%	72%	91%	133%
	2021	500,000	29%	45%	59%	76%	115%
	2022	500,000	19%	34%	48%	66%	111%
f:	2020	597,500	39%	57%	72%	91%	133%
2019	2021	597,500	27%	43%	57%	74%	113%
TAC	2022	597,500	15%	30%	44%	62%	106%
g:	2020	674,548	39%	57%	72%	91%	133%
FI=	2021	528,062	25%	41%	55%	72%	111%
100%	2022	440,714	15%	30%	44%	62%	106%
h:	2020	797,158	39%	57%	72%	91%	133%
default	2021	594,178	22%	39%	52%	69%	108%
HR	2022	472,046	12%	26%	40%	58%	101%
i:	2020	637,033	39%	57%	72%	91%	133%
C2020=	2021	637,032	26%	42%	56%	73%	112%
C2021	2022	501,998	13%	29%	42%	60%	104%
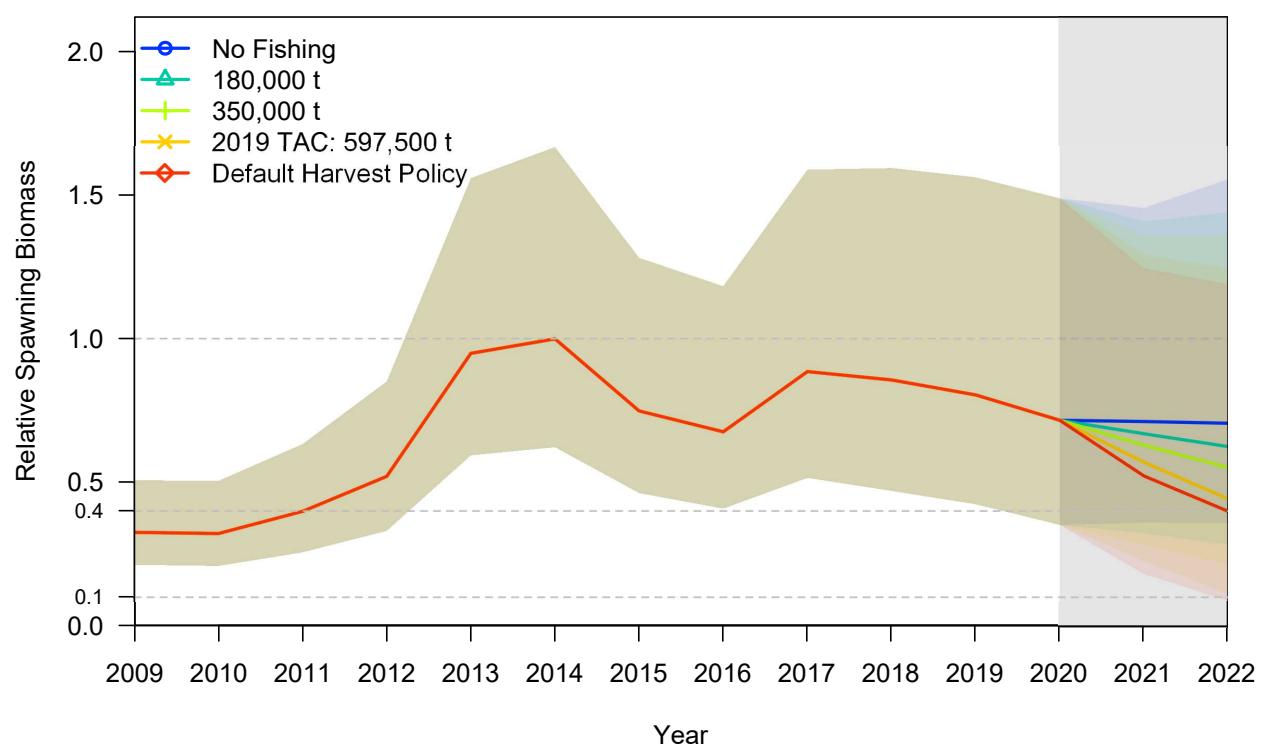
Figure G.10. Time series of estimated relative spawning biomass to 2020 from the base model, and forecast trajectories to 2022 (grey region) for several management actions defined in Table G.5, with 95% posterior credibility intervals.
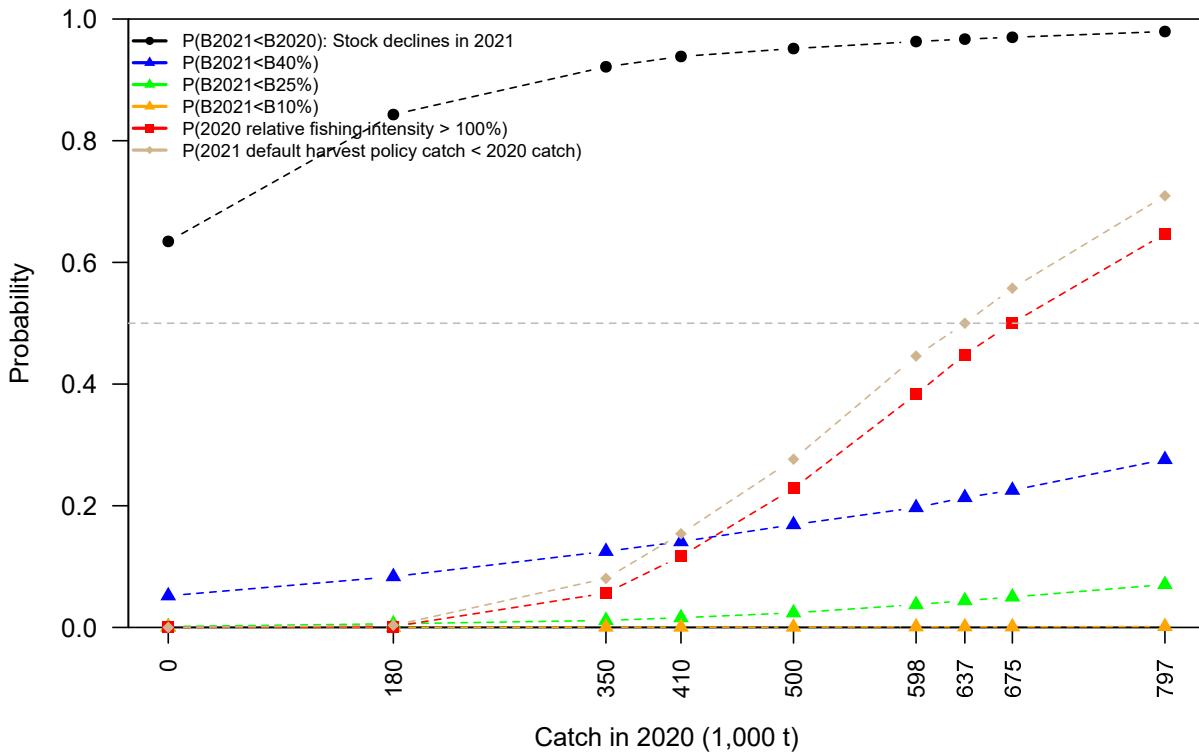
Figure G.11. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (catch options explained in Table G.5) as listed in Table G.6. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table G.6. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (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	63%	5%	0%	0%	0%	0%
b: 180,000	84%	8%	1%	0%	0%	0%
c: 350,000	92%	12%	1%	0%	6%	8%
d: 410,000	94%	14%	2%	0%	12%	15%
e: 500,000	95%	17%	2%	0%	23%	28%
f: 597,500	96%	20%	4%	0%	38%	45%
g: 674,548	97%	23%	5%	0%	50%	56%
h: 797,158	98%	28%	7%	0%	65%	71%
i: 637,033	97%	21%	4%	0%	45%	50%
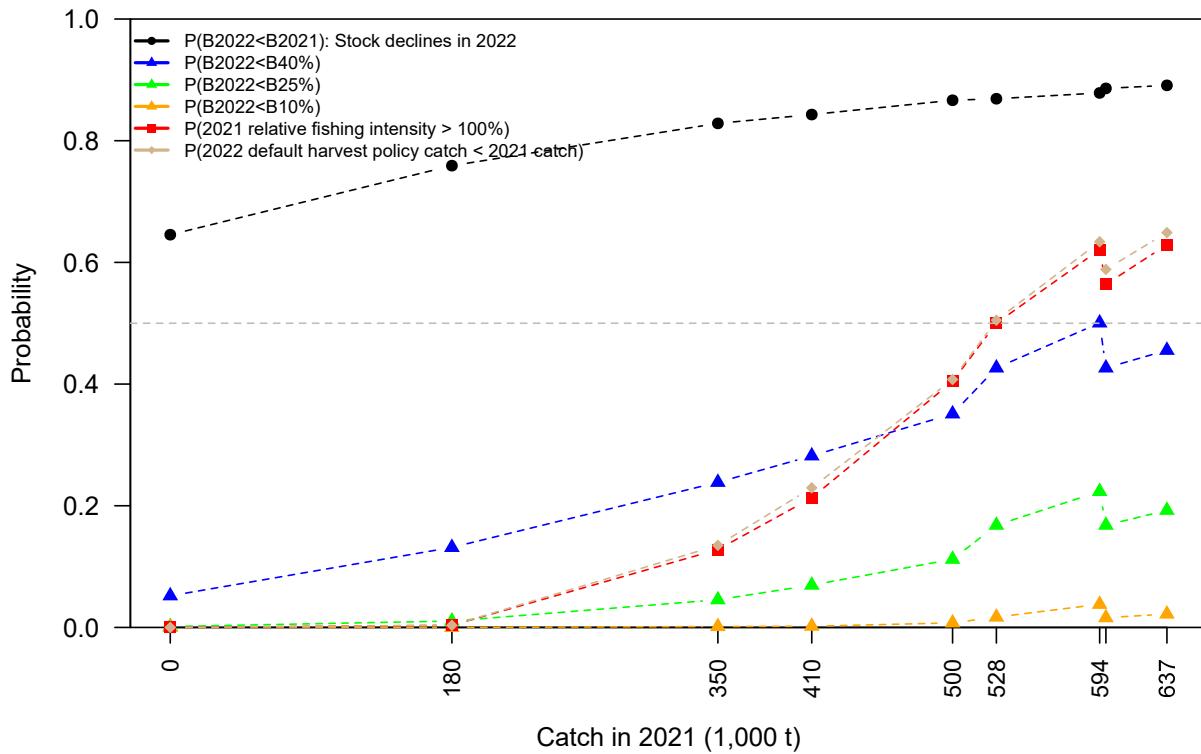
Figure G.12. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (including associated 2020 catch; catch options explained in Table G.5) as listed in Table G.7. The symbols 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 2022 default harvest policy catch for alternative 2021 catch options, given the 2020 catch level shown in Table G.6 (catch options explained in Table G.5).

Catch in 2021	Probability $B_{2022}<B_{2021}$	Probability $B_{2022}<B_{40\%}$	Probability $B_{2022}<B_{25\%}$	Probability $B_{2022}<B_{10\%}$	Probability 2021 relative fishing intensity >100%	Probability 2022 default harvest policy catch <2021 catch
a: 0	65%	5%	0%	0%	0%	0%
b: 180,000	76%	13%	1%	0%	0%	0%
c: 350,000	83%	24%	5%	0%	13%	14%
d: 410,000	84%	28%	7%	0%	21%	23%
e: 500,000	87%	35%	11%	1%	40%	41%
f: 597,500	89%	43%	17%	2%	56%	59%
g: 528,062	87%	43%	17%	2%	50%	50%
h: 594,178	88%	50%	22%	4%	62%	63%
i: 637,032	89%	46%	19%	2%	63%	65%

H   SENSITIVITY RUN USING NUTS – MCMC RESULTS

This appendix contains base model Bayesian MCMC results using a new analytical tool for conducting efficient Bayesian MCMC sampling, the No-U-Turn Sampler (NUTS; Hoffman and Gelman 2014), implemented using the `adnuts` R package (Monnahan and Kristensen, 2018; Monnahan et al., 2019). This tool has the potential to improve the applicability of Bayesian methods in stock assessment due to, among other things, decreased model run times. This appendix is provided solely as supplemental information to better understand the effect (if any) of potential future changes to a more efficient MCMC sampling algorithm.

The R code that was used to run `adnuts`, following general guidelines provided by C. Monnahan (pers. comm.), is provided at the end of this appendix. It took approximately 4.5 hours to run (including a 2.5-hour step that would likely not be required for sensitivity runs), compared to 40 hours for the usual MCMC algorithm. The NUTS run resulted in 7,850 samples – reducing this would improve run times further. Figures and tables follow the format of the Executive Summary, with additional figures showing MCMC diagnostics and comparing results with those of the base model.

A comparison between the base model and the NUTS run shows little difference in median spawning biomass (Figure H.1), although the NUTS run suggests slightly higher uncertainty. The main difference is with the estimate of initial recruitment, R_0, with the base model median being 2.505 billion and the NUTS run being 2.314 billion. This small difference causes an upward scaling effect to the relative biomass (Figure H.2) for the NUTS run. Figures H.5–H.13 and Tables H.1– H.7 show the Executive-Summary style results.

Diagnostics for the NUTS run are comparable to the base model for all key posteriors (Figures A.1–A.3 and Figures H.14–H.16). There is only a slight difference in the posterior density plots (bottom-right panels) for $\log R_0$. Parameter autocorrelation remains low for the NUTS run (bottom-left panels). The traceplots (top-left panels) appear denser for the NUTS run because the number of samples from the posterior is 7,850 compared to 2,000 for the base model.

The summary histograms showing autocorrelation, effective sample size, Geweke statistic, and Heidelberger and Walsh statistic are shown in Figure A.4 for the base model and Figure H.17 for the NUTS run. The NUTS run has higher effective sample sizes, due to the near four-fold increase in posterior samples, which will improve posterior density estimates. Other diagnostics are comparable between the two models.

Correlations among parameters (Figures A.6–A.7 and H.18–H.19) are very similar, with the main difference being the density of the scatterplots due to the number of posterior samples.

Considering sampling and convergence diagnostics, the similarity in estimated posteriors for key parameters, and the considerable increase in efficiency of the algorithm, the JTC recommends that the NUTS approach be further considered for use in next year's base model. The increased efficiency may allow all, or a portion of, sensitivity runs to be in an MCMC context as opposed to MLE.
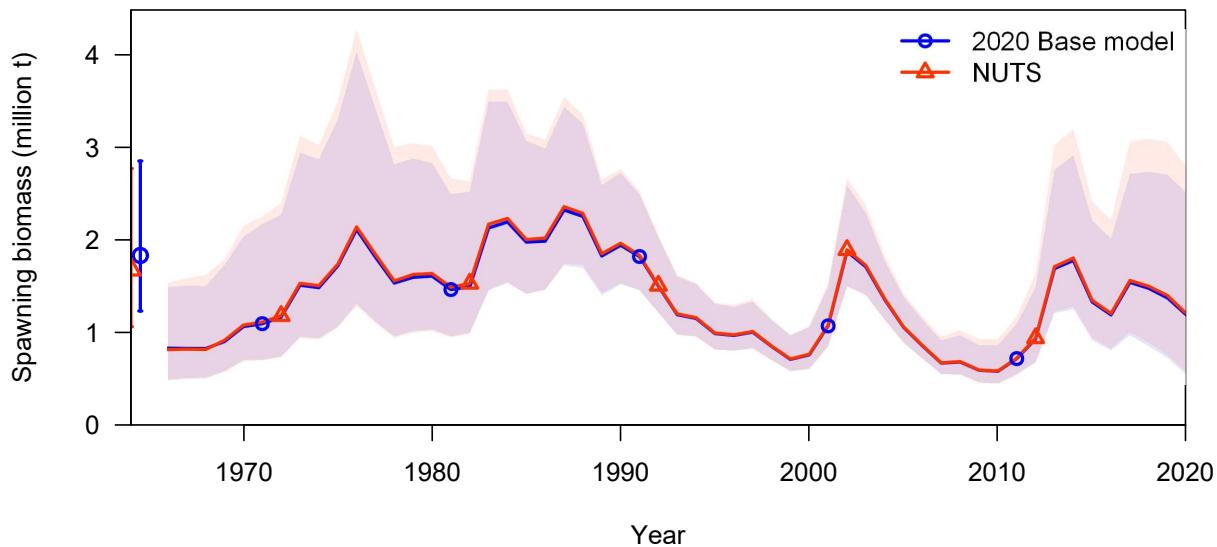
Figure H.1. MCMC median posterior estimates with 95% credible intervals of spawning biomass for the base model and alternative sensitivity run using NUTS.
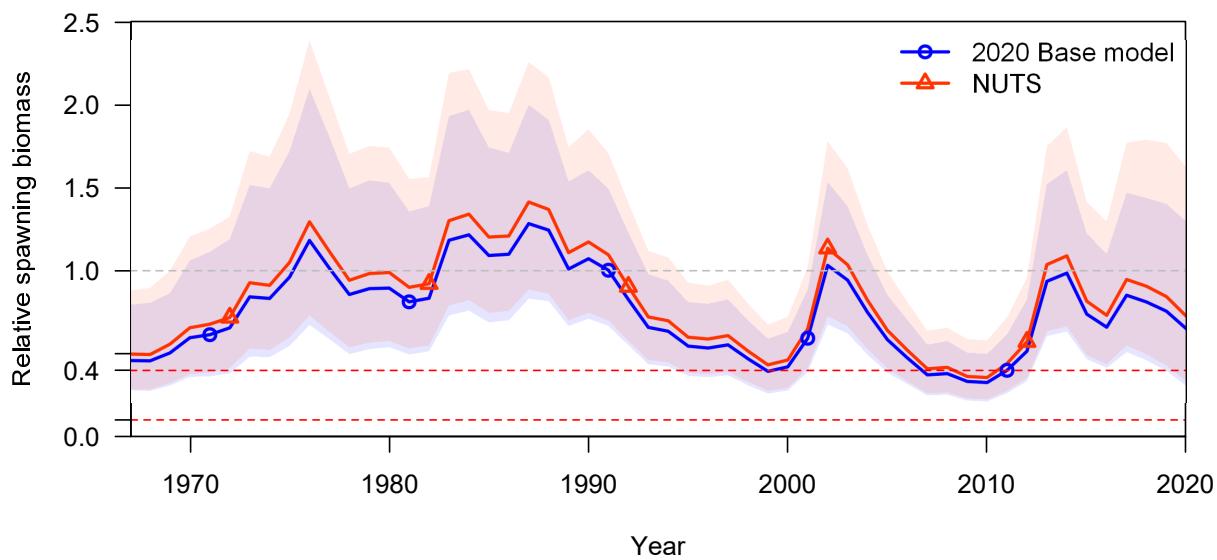
Figure H.2. MCMC median posterior estimates with 95% credible intervals of relative spawning biomass for the base model and alternative sensitivity run using NUTS.
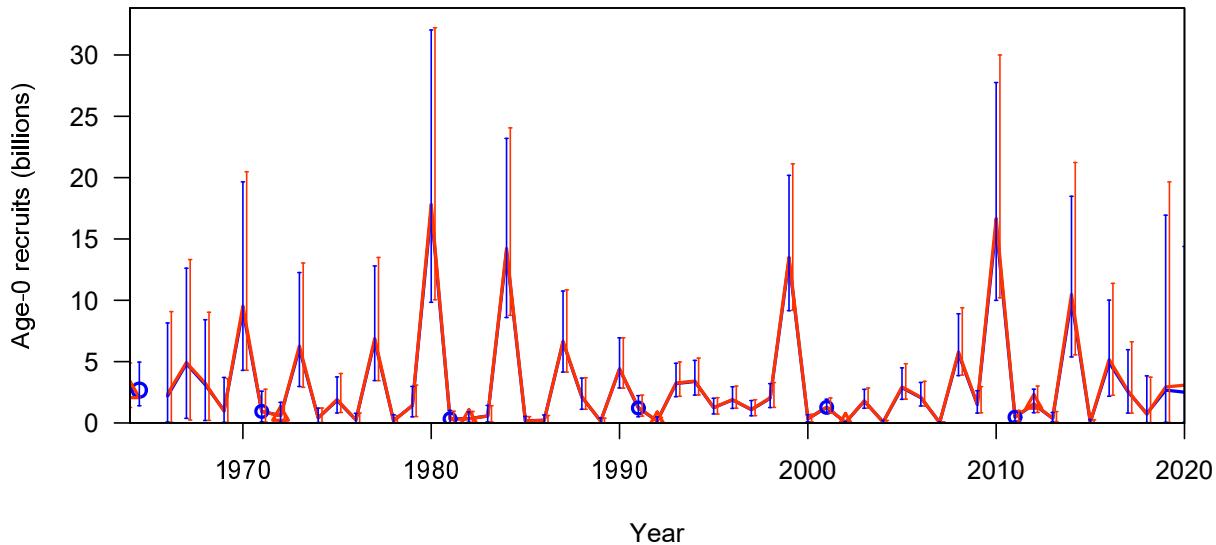
Figure H.3. MCMC median posterior estimates with 95% credible intervals of recruitment for the base model and the alternative sensitivity run using NUTS. See Figure H.1 for legend.
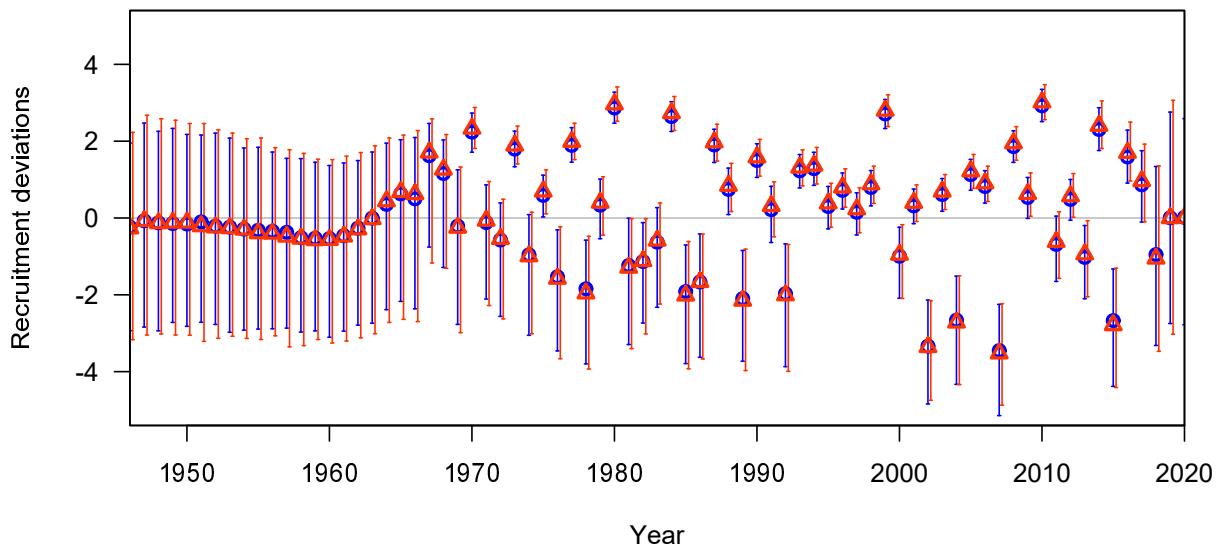
Figure H.4. MCMC median posterior estimates with 95% credible intervals for recruitment deviations for the base model and alternative sensitivity run using NUTS. See Figure H.1 for legend.
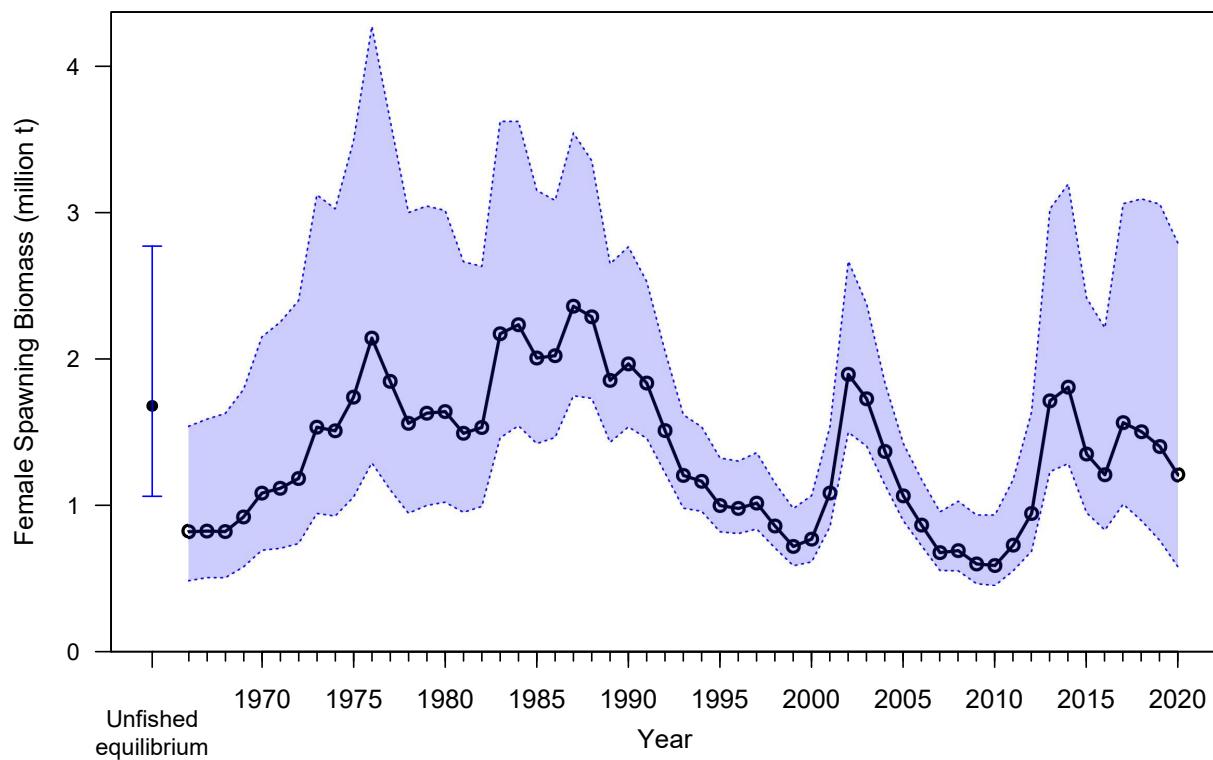
Figure H.5. Median of the posterior distribution for beginning of the year female spawning biomass through 2020 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.
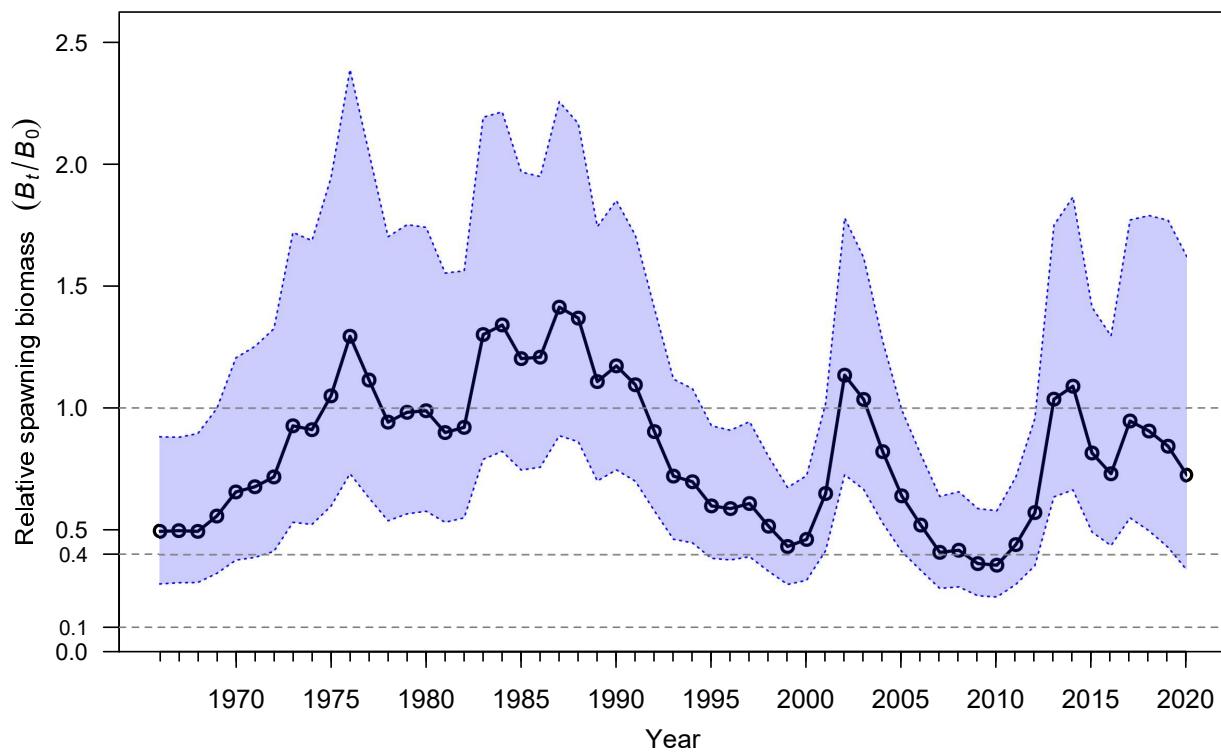
Figure H.6. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2020 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

Table H.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
2011	558.4	732.9	1,181.4	27.9%	44.1%	71.9%
2012	691.6	948.9	1,641.8	35.5%	57.3%	95.8%
2013	1,233.9	1,716.9	3,025.1	63.7%	103.7%	174.8%
2014	1,289.1	1,810.2	3,196.2	66.5%	109.0%	186.4%
2015	953.3	1,354.1	2,417.8	49.3%	81.6%	141.3%
2016	835.6	1,213.0	2,214.1	43.7%	73.1%	129.5%
2017	1,012.5	1,568.3	3,061.4	55.1%	94.7%	177.0%
2018	899.3	1,506.2	3,094.2	49.8%	90.6%	178.8%
2019	764.0	1,405.2	3,057.6	43.0%	84.4%	176.9%
2020	582.1	1,210.6	2,787.5	33.6%	72.5%	161.8%

Table H.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
2010	10,202.6	15,528.5	29,998.6	2.561	3.012	3.472
2011	168.0	434.2	1,024.7	-1.571	-0.622	0.160
2012	859.8	1,443.9	3,009.1	0.020	0.568	1.156
2013	117.9	337.9	925.0	-2.051	-0.944	-0.071
2014	5,553.3	9,567.3	21,231.2	1.808	2.401	3.047
2015	9.9	53.6	247.2	-4.413	-2.789	-1.306
2016	2,261.5	4,617.5	11,380.9	0.963	1.699	2.497
2017	800.4	2,262.3	6,613.3	-0.098	0.962	1.923
2018	24.5	306.5	3,731.8	-3.471	-1.055	1.357
2019	39.9	862.6	19,647.0	-3.025	-0.003	3.064
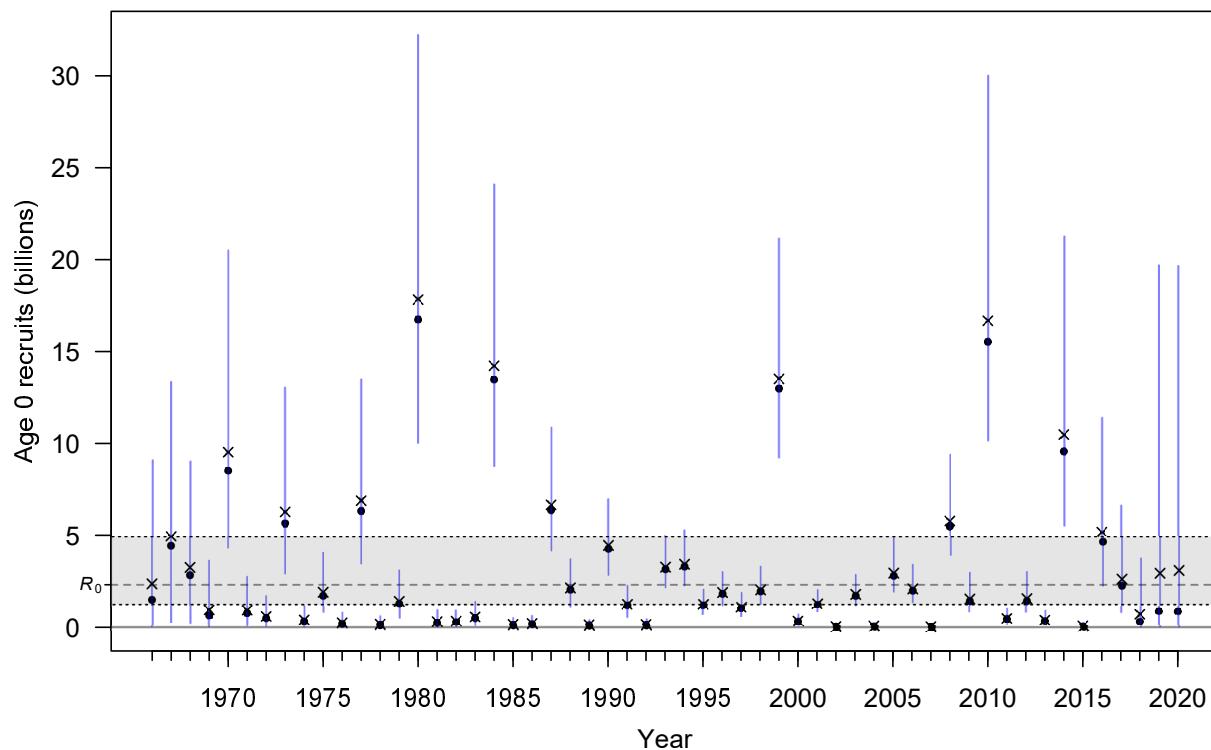
Figure H.7. Medians (solid circles) and means ($\times$) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

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

Year	Relative fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2010	0.644	0.934	1.215	0.075	0.118	0.153
2011	0.582	0.882	1.172	0.102	0.165	0.217
2012	0.407	0.675	0.933	0.031	0.055	0.077
2013	0.397	0.649	0.856	0.042	0.074	0.103
2014	0.366	0.616	0.851	0.043	0.076	0.107
2015	0.254	0.465	0.688	0.032	0.058	0.082
2016	0.433	0.739	1.006	0.044	0.082	0.122
2017	0.460	0.784	1.115	0.067	0.131	0.205
2018	0.426	0.747	1.073	0.055	0.114	0.193
2019	0.428	0.760	1.091	0.052	0.114	0.209
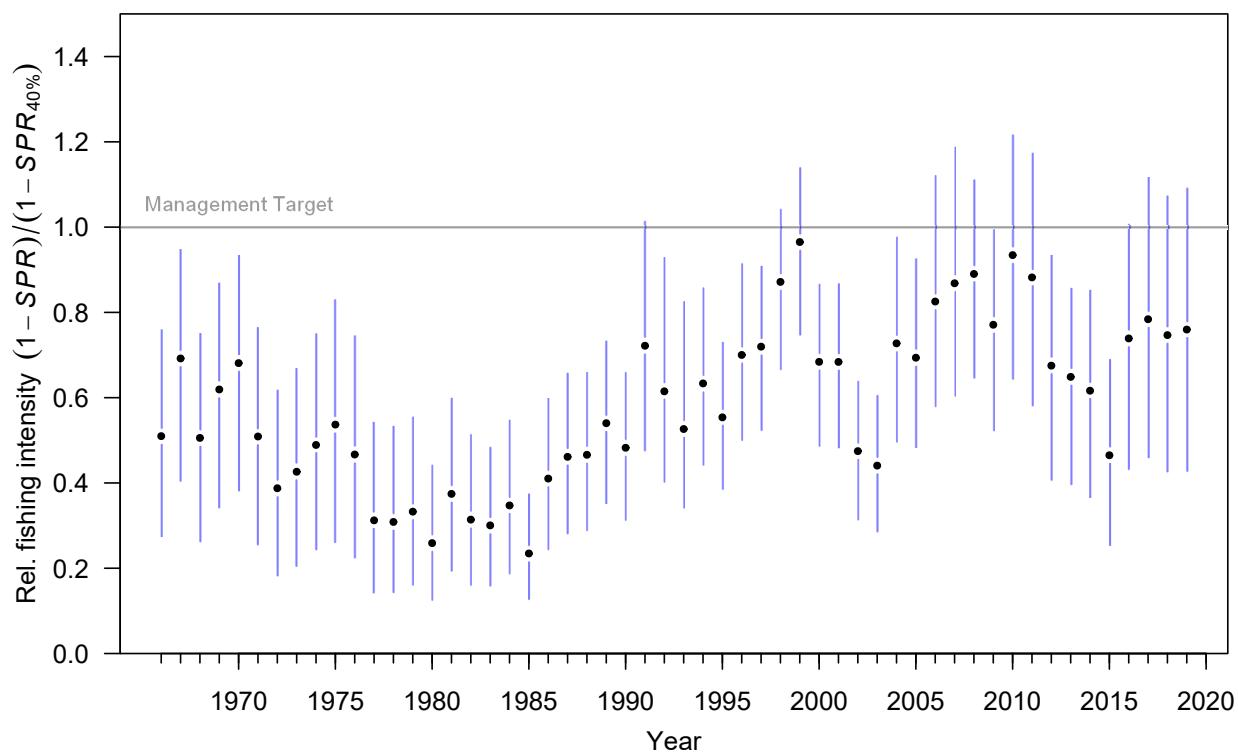
Figure H.8. Trend in median relative fishing intensity (relative to the SPR management target) through 2019 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.
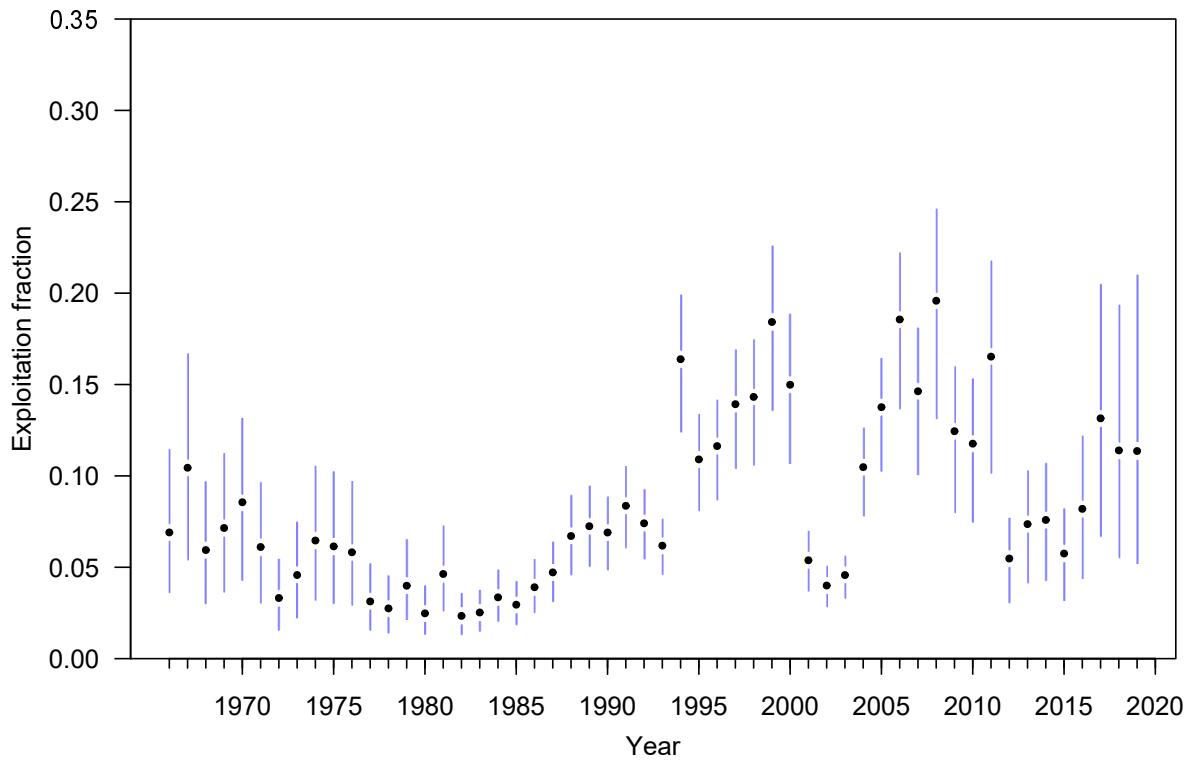
Figure H.9. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2019 with 95% posterior credibility intervals.
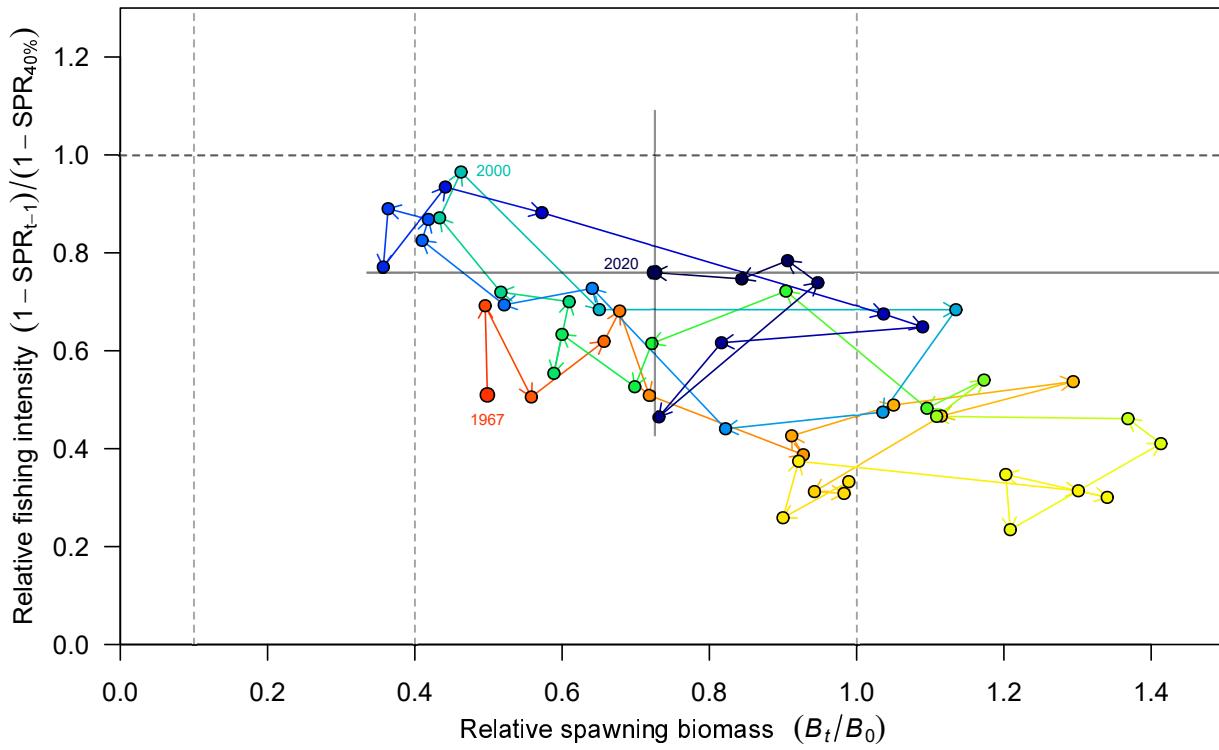
Figure H.10. Estimated historical path of median relative spawning biomass in year t and corresponding median relative fishing intensity in year $t − 1$, as for Figure 33. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year t (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2020 relative spawning biomass (horizontal) and 2019 relative fishing intensity (vertical).

Table H.4. For the alternative run, summary of median and 95% credibility intervals of equilibrium reference points. Equilibrium reference points were computed using 1966–2019 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)	1,062	1,679	2,771
Unfished recruitment (R_0, millions)	1,255	2,314	4,893
Reference points (equilibrium) based on $F_{\mathrm{SPR}=40\%}$			
Female spawning biomass at $F_{\mathrm{SPR}=40\%}$ (thousand t)	350	597	1,001
SPR at $F_{\mathrm{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\mathrm{SPR}=40\%}$	16.0%	18.3%	21.0%
Yield associated with $F_{\mathrm{SPR}=40\%}$ (thousand t)	157	281	529
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	425	672	1,108
SPR at $B_{40\%}$	40.7%	43.5%	51.2%
Exploitation fraction resulting in $B_{40\%}$	12.5%	16.2%	19.3%
Yield at $B_{40\%}$ (thousand t)	155	274	514
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	260	431	775
SPR at MSY	22.5%	29.8%	46.4%
Exploitation fraction corresponding to SPR at MSY	14.8%	25.7%	34.8%
MSY (thousand t)	162	295	564

Table H.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 2019 (row d) and the TAC from 2019 (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 2020 and 2021 (row i). Catch in 2022 does not impact the beginning of the year biomass in 2022.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2020	0	38%	56%	73%	94%	141%
	2021	0	37%	53%	69%	89%	132%
	2022	0	36%	53%	69%	92%	149%
b:	2020	180,000	38%	56%	73%	94%	141%
	2021	180,000	32%	49%	64%	84%	127%
	2022	180,000	28%	44%	60%	82%	139%
c:	2020	350,000	38%	56%	73%	94%	141%
	2021	350,000	28%	44%	59%	79%	122%
	2022	350,000	20%	36%	51%	73%	130%
d:	2020	410,000	38%	56%	73%	94%	141%
2019	2021	410,000	27%	43%	57%	77%	120%
catch	2022	410,000	17%	33%	48%	70%	127%
e:	2020	500,000	38%	56%	73%	94%	141%
	2021	500,000	24%	40%	55%	75%	118%
	2022	500,000	13%	29%	43%	65%	121%
f:	2020	597,500	38%	56%	73%	94%	141%
2019	2021	597,500	22%	38%	52%	72%	115%
TAC	2022	597,500	10%	24%	39%	60%	116%
g:	2020	575,531	38%	56%	73%	94%	141%
FI=	2021	446,530	22%	38%	53%	72%	115%
100%	2022	373,622	12%	28%	43%	65%	121%
h:	2020	682,111	38%	56%	73%	94%	141%
default	2021	497,828	20%	35%	50%	70%	112%
HR	2022	393,142	10%	25%	39%	61%	117%
i:	2020	537,629	38%	56%	73%	94%	141%
C2020=	2021	537,629	23%	39%	54%	74%	116%
C2021	2022	417,154	11%	27%	42%	63%	119%
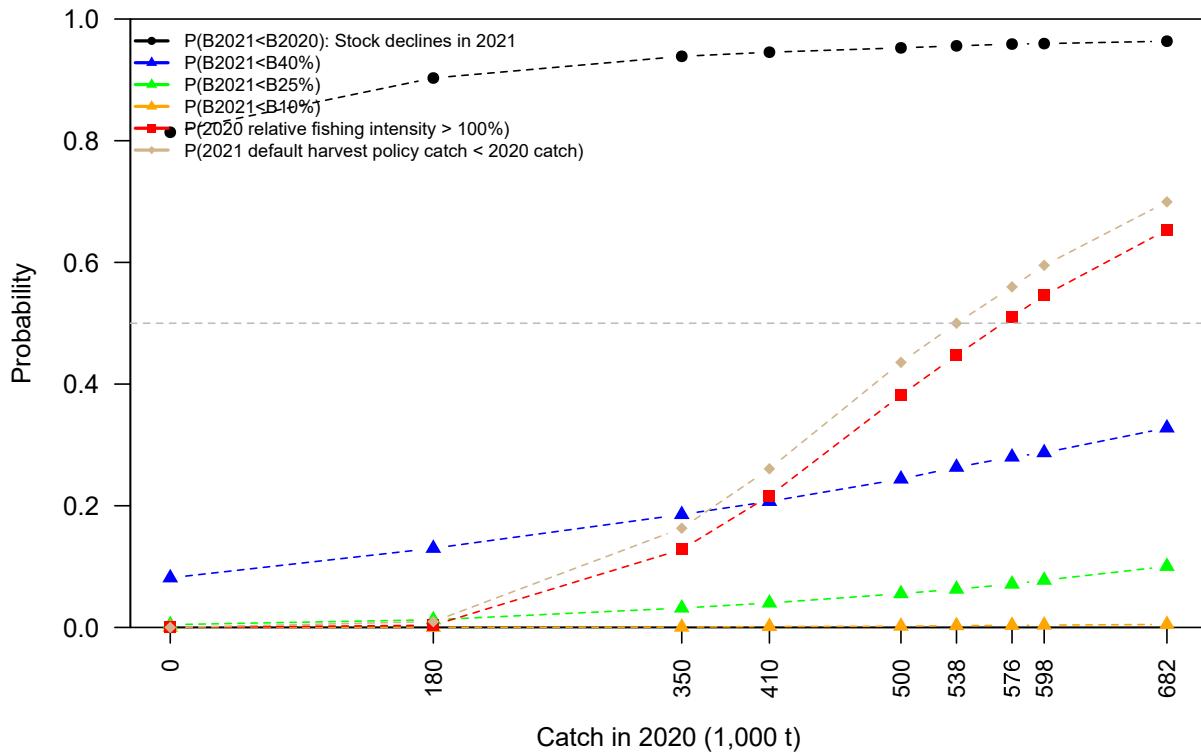
Figure H.11. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (catch options explained in Table H.5) as listed in Table H.6. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table H.6. Probabilities related to spawning biomass, relative fishing intensity, and the 2021 default harvest policy catch for alternative 2020 catch options (catch options explained in Table H.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	81%	8%	0%	0%	0%	0%
b: 180,000	90%	13%	1%	0%	0%	1%
c: 350,000	94%	19%	3%	0%	13%	16%
d: 410,000	95%	21%	4%	0%	22%	26%
e: 500,000	95%	24%	6%	0%	38%	44%
f: 597,500	96%	29%	8%	0%	55%	60%
g: 575,531	96%	28%	7%	0%	51%	56%
h: 682,111	96%	33%	10%	0%	65%	70%
i: 537,629	96%	26%	6%	0%	45%	50%
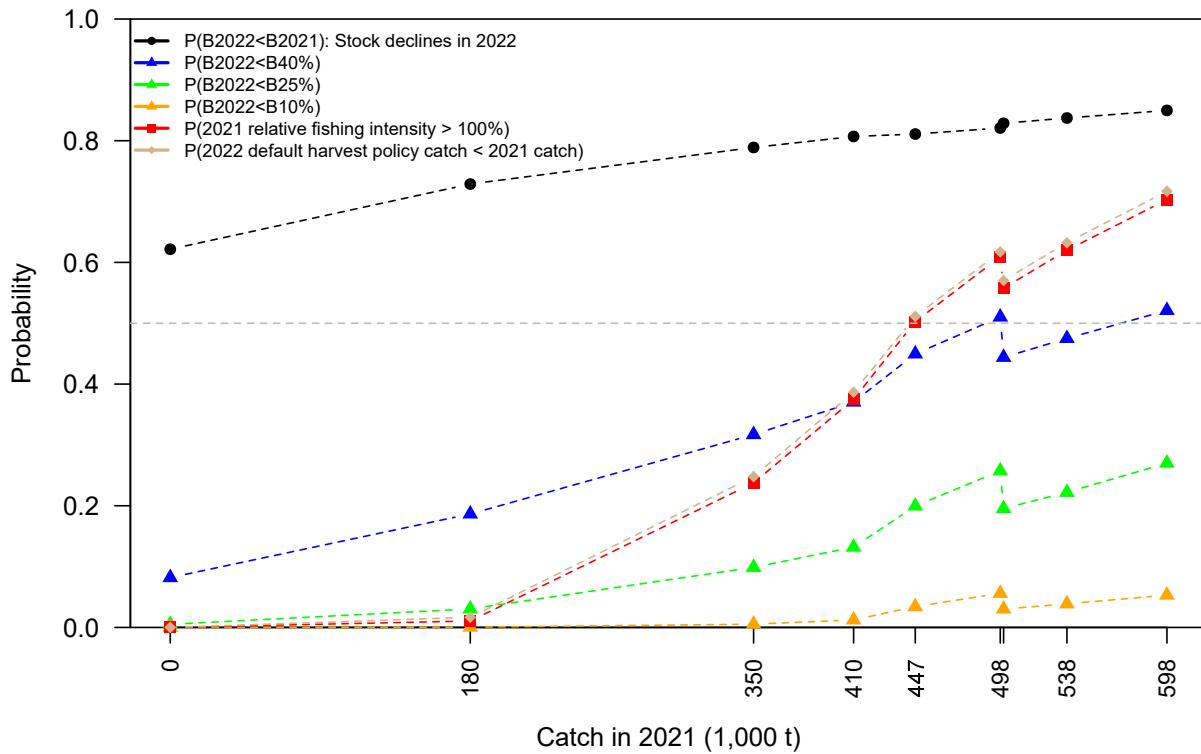
Figure H.12. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (including associated 2020 catch; catch options explained in Table H.5) as listed in Table H.7. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table H.7. Probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options, given the 2020 catch level shown in Table H.6 (catch options explained in Table H.5).

Catch in 2021	Probability $B_{2022}<B_{2021}$	Probability $B_{2022}<B_{40\%}$	Probability $B_{2022}<B_{25\%}$	Probability $B_{2022}<B_{10\%}$	Probability 2021 relative fishing intensity >100%	Probability 2022 default harvest policy catch <2021 catch
a: 0	62%	8%	1%	0%	0%	0%
b: 180,000	73%	19%	3%	0%	1%	2%
c: 350,000	79%	32%	10%	1%	24%	25%
d: 410,000	81%	37%	13%	1%	37%	39%
e: 500,000	83%	44%	20%	3%	56%	57%
f: 597,500	85%	52%	27%	5%	70%	72%
g: 446,530	81%	45%	20%	3%	50%	51%
h: 497,828	82%	51%	26%	6%	61%	62%
i: 537,629	84%	48%	22%	4%	62%	63%
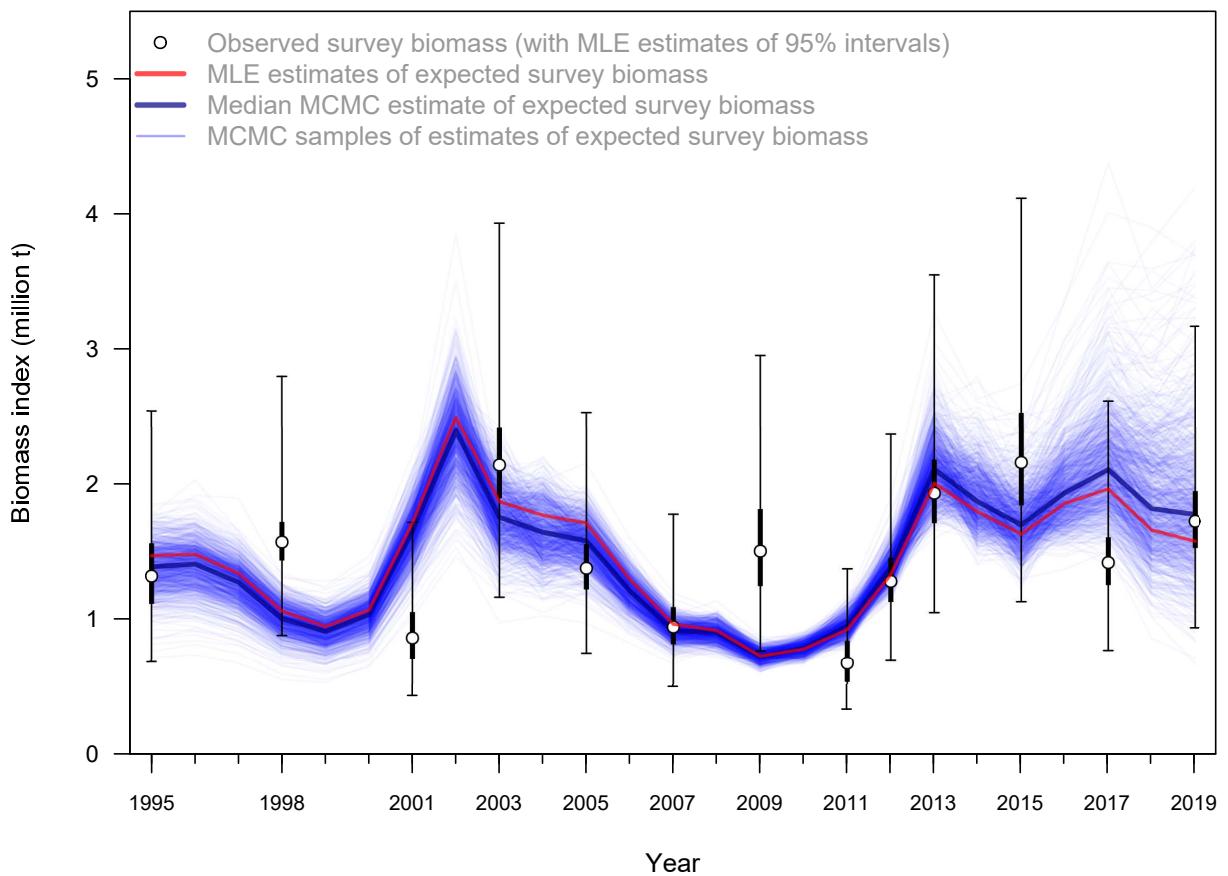
Figure H.13. Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker 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.
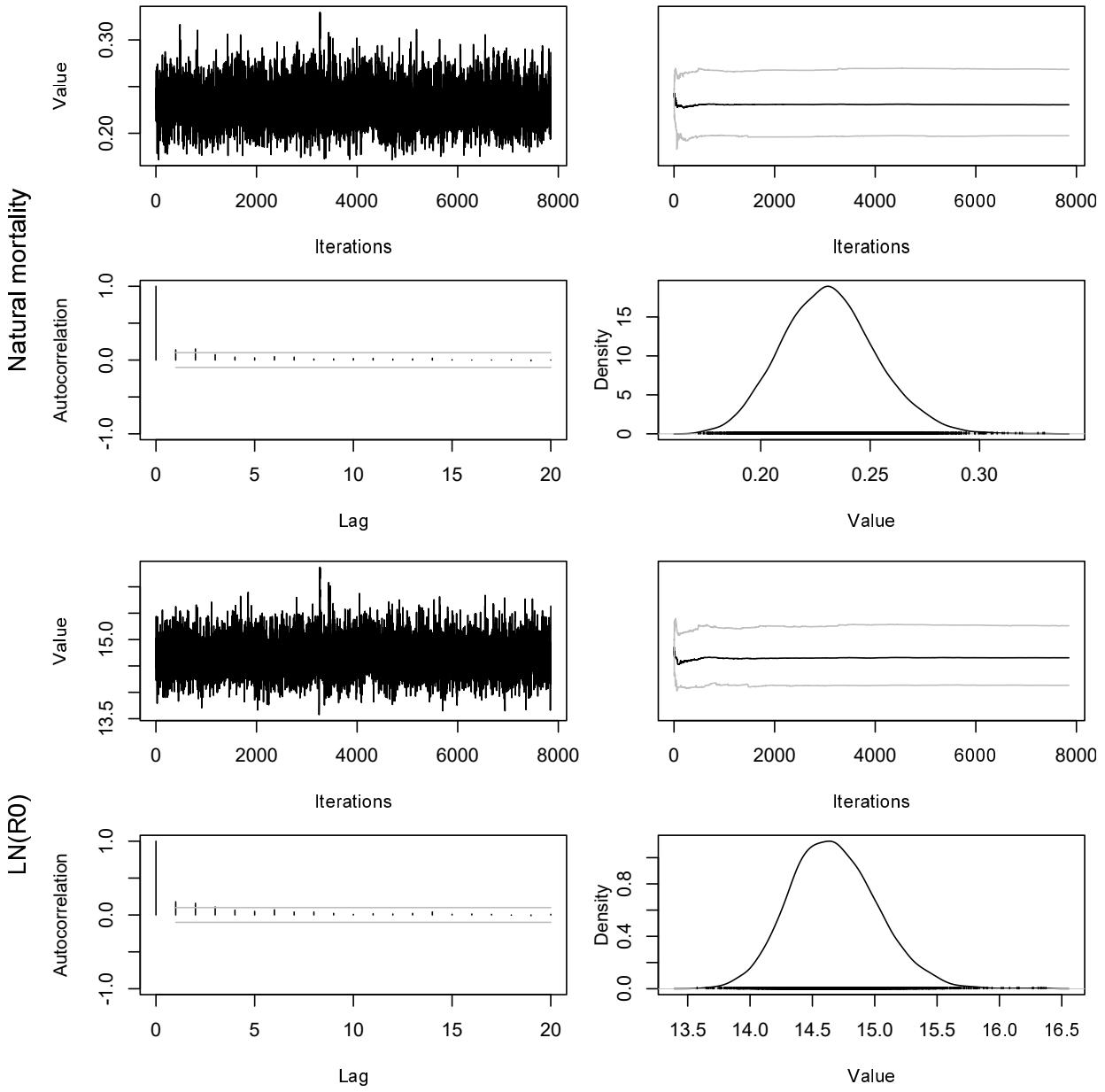
Figure H.14. Summary of MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels). Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower left sub-panel indicates 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).
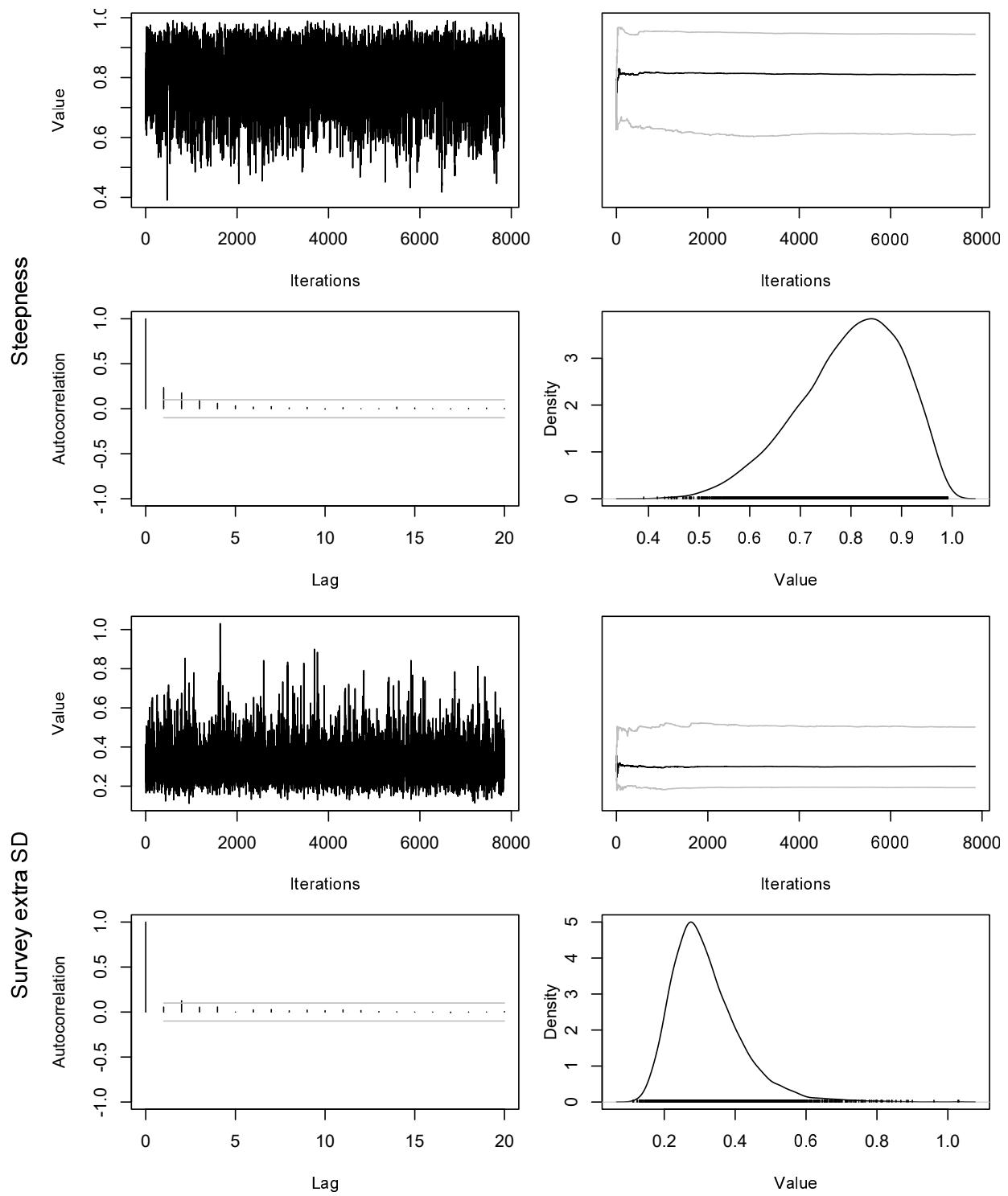
Figure H.15. Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels). Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, 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).
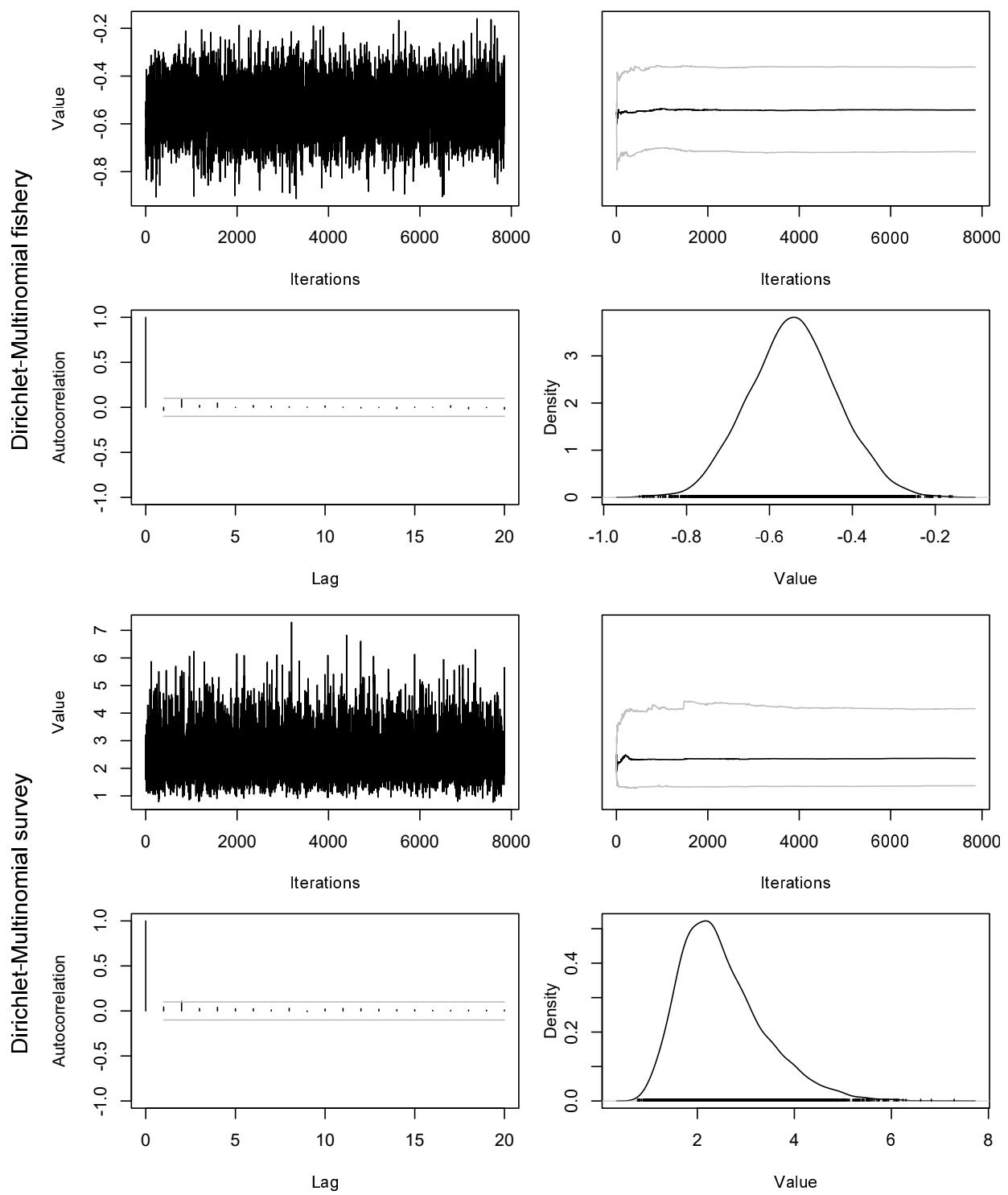
Figure H.16. Summary of MCMC diagnostics for the Dirichlet-Multinomial age-composition parameters for the fishery (upper panels) and the survey (lower panels). Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, 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).
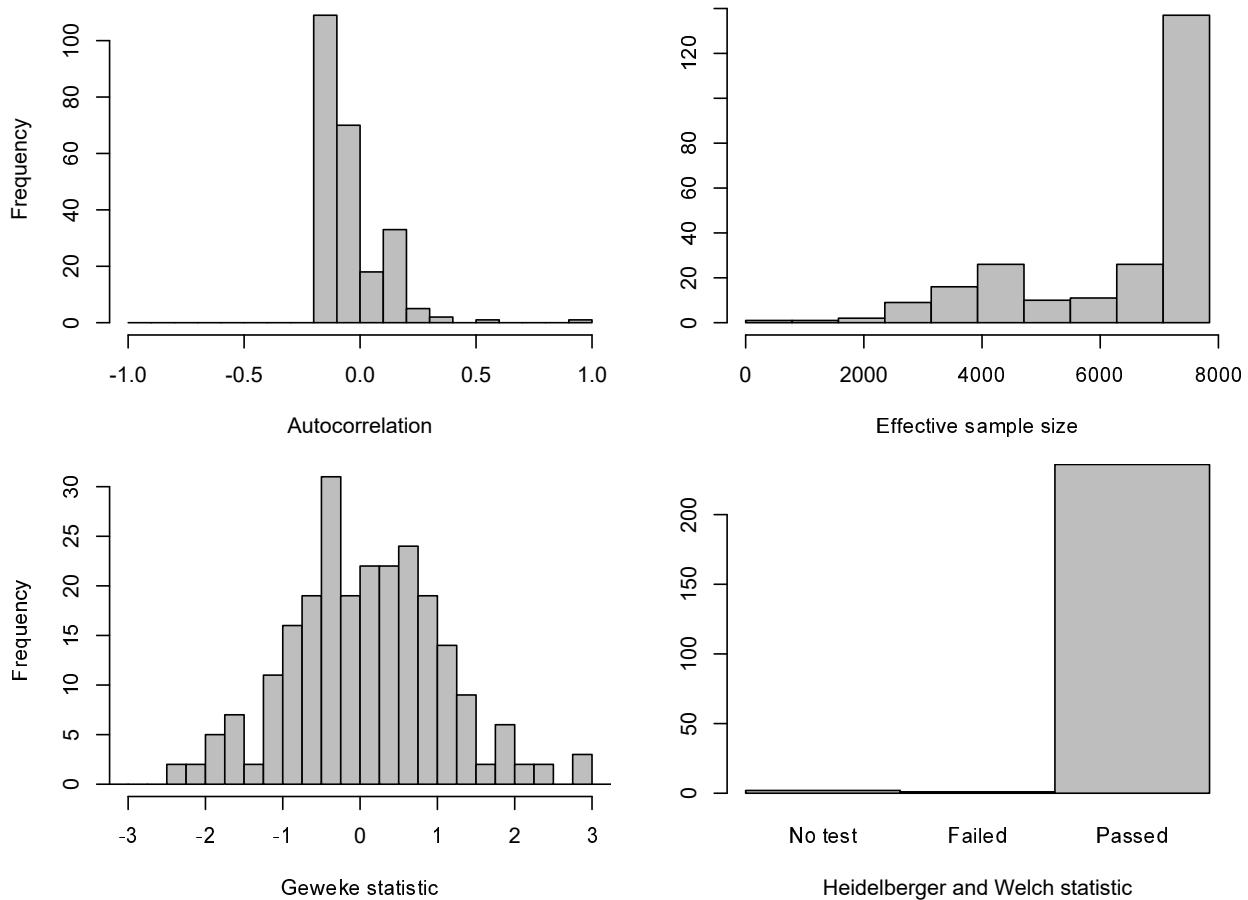
Figure H.17. Summary histograms of MCMC diagnostics for all parameters together with the derived time series of spawning biomass and relative spawning biomass. The level of autocorrelation in the chain (distribution across lag times, i.e., distance between samples in the chain, shown in the top left 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.
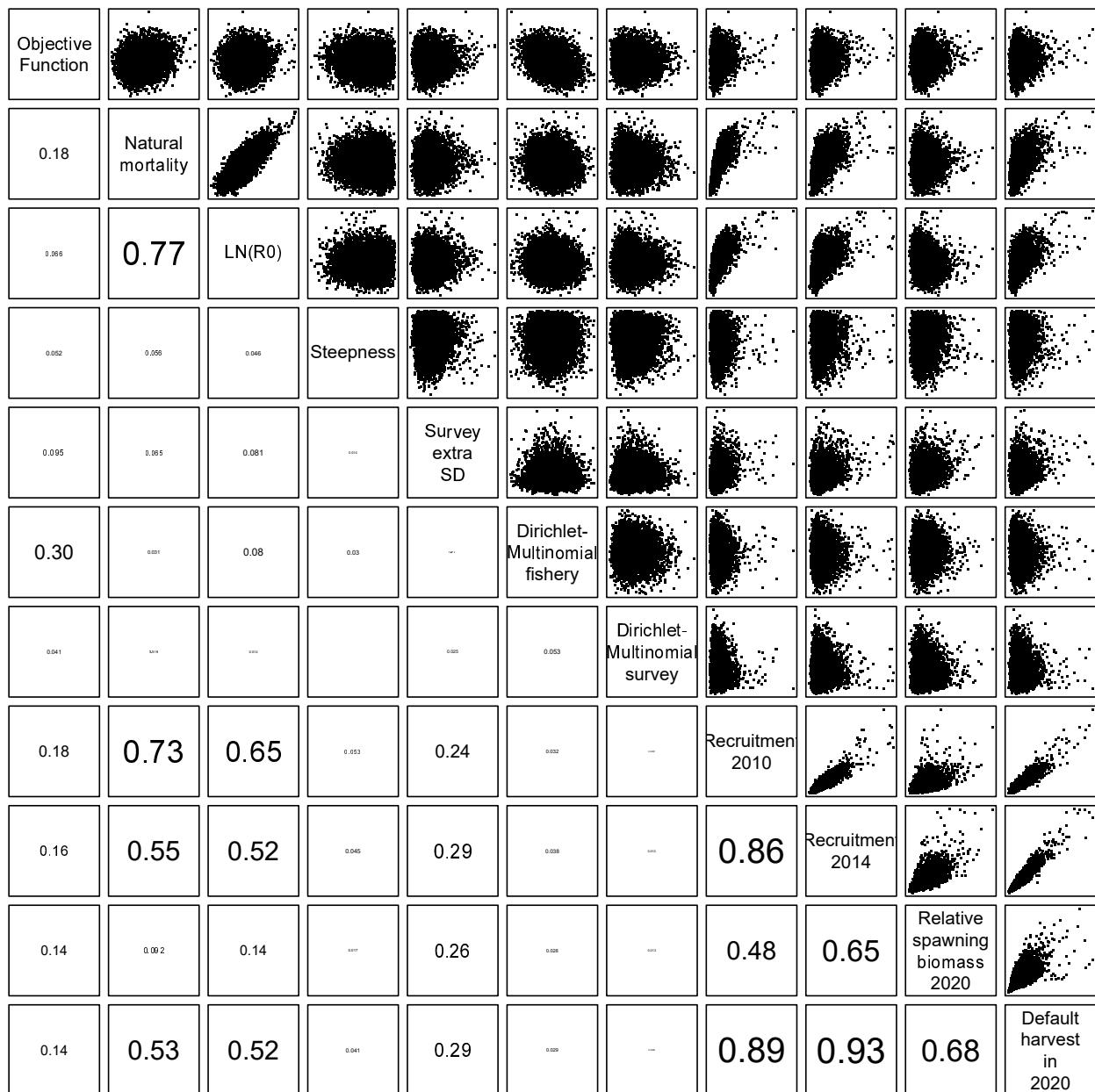
Figure H.18. Posterior correlations among key parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.
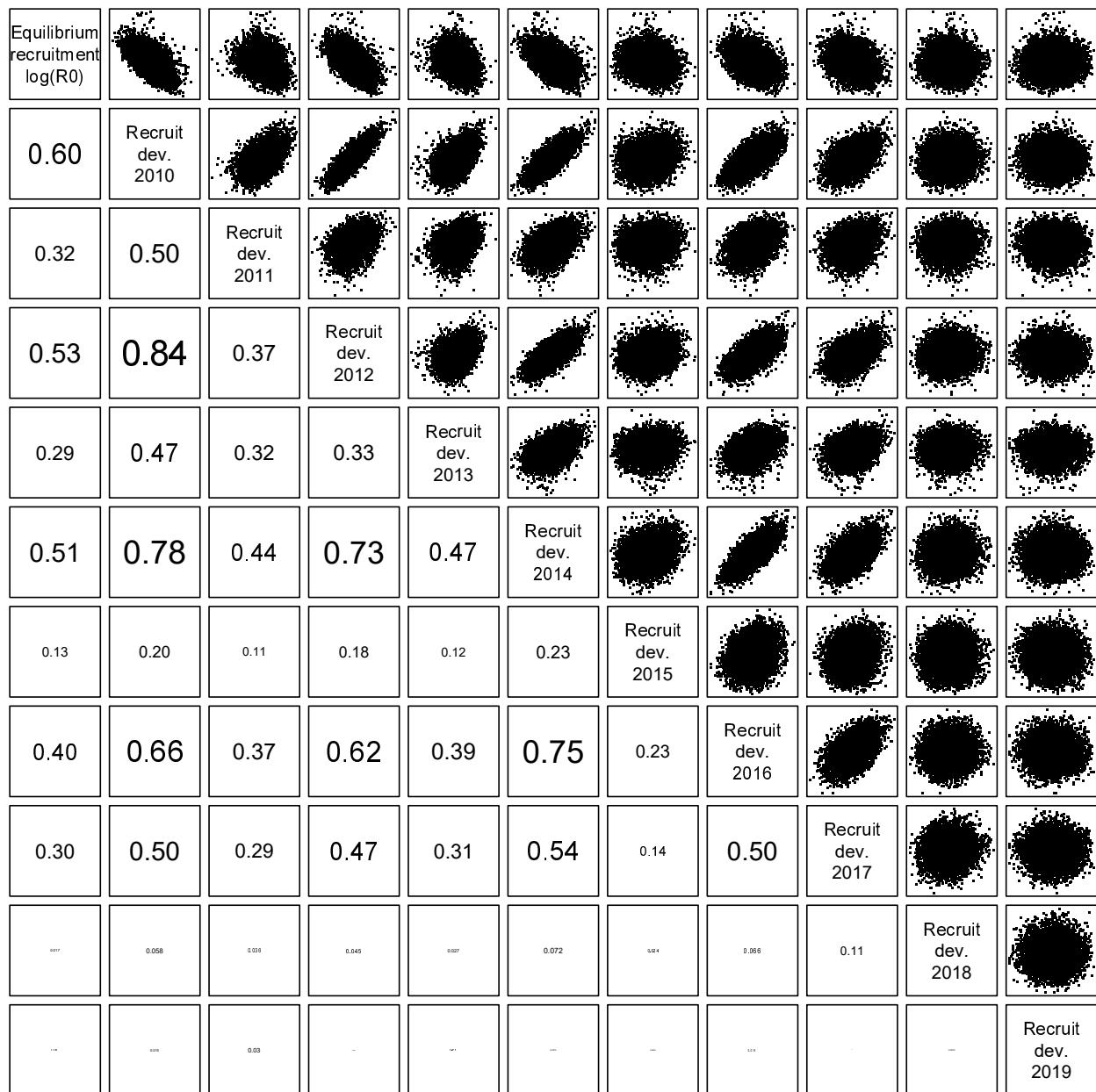
Figure H.19. Posterior correlations among recruitment deviations from recent years and equilibrium recruitment. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

The R code that was used to manually run `adnuts` is:

```
library(adnuts)
library(snowfall)
library(rstan)
library(shinystan)
library(matrixcalc)
```

```r
start_time <- Sys.time()

## Chains to run in parallel
reps <- parallel::detectCores() - 1
set.seed(352)
seeds <- sample(1:1e4, size = reps)
pth <- "."
exe <- "ss"
alg = "NUTS"
rdata_file <- "hake.Rdata"
system(paste0(exe, " -nox -iprint 200 -mcmc 15"))

## Then run parallel RWM chains as a first test to ensure
## mcmc itself is working properly, or that model is converging in mcmc space
thin <- 10
## iter is per core
iter <- 100 * thin
warmup <- iter / 4
## Start chains from MLE
inits <- NULL
pilot <- sample_admb(model = exe,
                     iter = iter,
                     thin = thin,
                     seeds = seeds,
                     init = inits,
                     parallel = TRUE,
                     chains = reps,
                     warmup = warmup,
                     path = pth,
                     cores = reps,
                     algorithm = "RWM")
save.image(file = rdata_file)

## Check convergence and slow mixing parameters
mon <- monitor(pilot$samples,
               warmup = pilot$warmup,
               print = FALSE)
## max(mon[,'Rhat'])
## min(mon[,'n_eff'])
## Examine the slowest mixing parameters
slow <- names(sort(mon[,"n_eff"]))[1:8]
pairs_admb(fit = pilot, pars = slow)
pairs_admb(fit = pilot, pars = c("MGparm[1]", "SR_parm[1]", "SR_parm[2]"))
```

```r
## After regularizing run NUTS chains. First reoptimize to get the
## correct mass matrix for NUTS. Note the -hbf 1 argument. This is a
## technical requirement b/c NUTS uses a different set of bounding
## functions and thus the mass matrix will be different.
system(paste0(exe, " -hbf 1 -nox -iprint 200 -mcmc 15"))
save.image(file = rdata_file)

## Use default MLE covariance (mass matrix) and short parallel NUTS chains
## started from the MLE.
nuts.mle <-
  sample_admb(model = exe,
              iter = 500,
              init = NULL,
              algorithm = alg,
              seeds = seeds,
              parallel = TRUE,
              chains = reps,
              warmup = 100,
              path = pth,
              cores = reps,
              control = list(metric = "mle",
                             adapt_delta = 0.8))
save.image(file = rdata_file)

## Check for issues like slow mixing, divergences, max treedepths with
## ShinyStan and pairs_admb as above. Fix and rerun this part as needed.
## launch_shinyadmb(nuts.mle)

## Once acceptable, run again for inference using updated mass matrix. Increase
## adapt_delta toward 1 if you have divergences (runs will take longer).
## Note this is in unbounded parameter space
mass <- nuts.mle$covar.est
inits <- sample_inits(nuts.mle, reps)
## The following, nuts.updated, was used for inferences in this appendix
nuts.updated <-
  sample_admb(model = exe,
              iter = 1000,
              init = inits,
              algorithm = alg,
              seeds = seeds,
              parallel = TRUE,
              chains = reps,
              warmup = 250,
              path = pth,
```

```
                 cores = reps,
                 mceval = TRUE,
                 control = list(metric = mass,
                                adapt_delta = 0.9))
save.image(file = rdata_file)
end_time <- Sys.time()
cat("Elapsed time: ", end_time - start_time, "\n")
launch_shinyadmb(nuts.updated)
```

I STOCK SYNTHESIS DATA FILE

../models/2020.01.09_DMprior_base/hake_data.ss

```
#V3.30
#C data file created using the SS_writedat function in the R package r4ss
#C should work with SS version:
#C file write time: 2020-01-13 10:57:32
#
1966 #_styr
2019 #_endyr
1 #_nseas
12 #_months_per_seas
2 #_Nsubseasons
1 #_spawn_month
1 #_Nsexes
20 #_Nages
1 #_Nareas
2 #_Nfleets
#_fleetinfo
#_type   surveytiming    area     units    need_catch_mult fleetname
1        -1        1       1         0       Fishery          #_1
3         1        1       2         0       Acoustic_Survey #_2
#_Catch data
#_year   season  fleet   catch    catch_se
 -999    1       1            0.0         0.01    #_1
 1966    1       1       137700.0         0.01    #_2
 1967    1       1       214370.0         0.01    #_3
 1968    1       1       122180.0         0.01    #_4
 1969    1       1       180130.0         0.01    #_5
 1970    1       1       234590.0         0.01    #_6
 1971    1       1       154620.0         0.01    #_7
 1972    1       1       117540.0         0.01    #_8
 1973    1       1       162640.0         0.01    #_9
 1974    1       1       211260.0         0.01    #_10
 1975    1       1       221350.0         0.01    #_11
 1976    1       1       237520.0         0.01    #_12
 1977    1       1       132690.0         0.01    #_13
 1978    1       1       103637.4         0.01    #_14
 1979    1       1       137110.0         0.01    #_15
 1980    1       1        89929.9         0.01    #_16
 1981    1       1       139119.7         0.01    #_17
 1982    1       1       107740.9         0.01    #_18
 1983    1       1       113931.0         0.01    #_19
 1984    1       1       138492.1         0.01    #_20
 1985    1       1       110399.2         0.01    #_21
 1986    1       1       210615.9         0.01    #_22
 1987    1       1       234147.6         0.01    #_23
 1988    1       1       248839.6         0.01    #_24
 1989    1       1       298079.0         0.01    #_25
 1990    1       1       261286.1         0.01    #_26
 1991    1       1       319705.4         0.01    #_27
 1992    1       1       299650.3         0.01    #_28
 1993    1       1       198905.1         0.01    #_29
```

```
1994    1        1        362406.8          0.01    #_30
1995    1        1        249495.4          0.01    #_31
1996    1        1        306298.5          0.01    #_32
1997    1        1        325146.8          0.01    #_33
1998    1        1        320722.3          0.01    #_34
1999    1        1        311886.7          0.01    #_35
2000    1        1        228776.8          0.01    #_36
2001    1        1        227525.2          0.01    #_37
2002    1        1        180697.4          0.01    #_38
2003    1        1        205162.4          0.01    #_39
2004    1        1        342307.2          0.01    #_40
2005    1        1        363134.6          0.01    #_41
2006    1        1        361699.0          0.01    #_42
2007    1        1        291247.2          0.01    #_43
2008    1        1        323101.2          0.01    #_44
2009    1        1        178683.3          0.01    #_45
2010    1        1        228059.3          0.01    #_46
2011    1        1        287333.9          0.01    #_47
2012    1        1        207203.4          0.01    #_48
2013    1        1        285827.6          0.01    #_49
2014    1        1        299259.5          0.01    #_50
2015    1        1        193843.9          0.01    #_51
2016    1        1        332070.0          0.01    #_52
2017    1        1        440949.8          0.01    #_53
2018    1        1        413718.7          0.01    #_54
2019    1        1        411282.7          0.01    #_55
-9999   0        0             0.0          0.00    #_terminator
#_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
#
#_CPUE_data
#_year  seas     index    obs       se_log
 1995   7         2       1318035 0.0859   #_1
 1996   7        -2             1 1.0000   #_2
 1997   7        -2             1 1.0000   #_3
 1998   7         2       1569148 0.0460   #_4
 1999   7        -2             1 1.0000   #_5
 2000   7        -2             1 1.0000   #_6
 2001   7         2        861744 0.1020   #_7
 2002   7        -2             1 1.0000   #_8
 2003   7         2       2137528 0.0619   #_9
 2004   7        -2             1 1.0000   #_10
 2005   7         2       1376099 0.0616   #_11
 2006   7        -2             1 1.0000   #_12
 2007   7         2        942721 0.0738   #_13
 2008   7        -2             1 1.0000   #_14
 2009   7         2       1502273 0.0957   #_15
 2010   7        -2             1 1.0000   #_16
 2011   7         2        674617 0.1133   #_17
```

```
 2012    7          2      1279421 0.0647   #_18
 2013    7          2      1929235 0.0620   #_19
 2014    7         -2            1 1.0000   #_20
 2015    7          2      2155853 0.0809   #_21
 2016    7         -2            1 1.0000   #_22
 2017    7          2      1417811 0.0632   #_23
 2018    7         -2            1 1.0000   #_24
 2019    7          2      1722611 0.0619   #_25
-9999    0          0            0 0.0000   #_terminator
0 #_N_discard_fleets
#_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
#
#_discard_fleet_info
#
#_discard_data
#
#_meanbodywt
0 #_use_meanbodywt
 #_DF_for_meanbodywt_T-distribution_like
#
#_population_length_bins
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_lencomp
#
#_len_info
#_mintailcomp    addtocomp        combine_M_F    CompressBins
   CompError       ParmSelect       minsamplesize
-1      0.001   0        0        0        0       0.001   #_Fishery
-1      0.001   0        0        0        0       0.001   #_Acoustic_Survey
26 #_N_lbins
#_lbin_vector
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 #_lbin_vector
#
#_lencomp
#_X.9999         X0      X0.1     X0.2     X0.3     X0.4     X0.5     X0.6
   X0.7    X0.8    X0.9     X0.10    X0.11    X0.12    X0.13    X0.14
   X0.15   X0.16   X0.17    X0.18    X0.19    X0.20    X0.21    X0.22
   X0.23   X0.24   X0.25    X0.26    X0.27    X0.28    X0.29    X0.30
-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        #_terminator
15 #_N_agebins
#
#_agebin_vector
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 #_agebin_vector
```

```
#
#_ageing_error
47 #_N_ageerror_definitions
#_age0  age1    age2    age3    age4    age5    age6    age7    age8
   age9    age10   age11   age12   age13   age14   age15   age16
   age17   age18   age19   age20
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000         11.500000
   12.500000         13.500000         14.500000         15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_1
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440        1.8580
    2.1720  2.5300  2.9340  3.3880 #_2
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000         11.500000
   12.500000         13.500000         14.500000         15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_3
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440        1.8580
    2.1720  2.5300  2.9340  3.3880 #_4
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000         11.500000
   12.500000         13.500000         14.500000         15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_5
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440        1.8580
    2.1720  2.5300  2.9340  3.3880 #_6
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000         11.500000
   12.500000         13.500000         14.500000         15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_7
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440        1.8580
    2.1720  2.5300  2.9340  3.3880 #_8
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000         11.500000
   12.500000         13.500000         14.500000         15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_9
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
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    0.996322           1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_10
0.500000           1.500000           2.500000           3.500000
     4.500000           5.50000 6.500000           7.500000
     8.500000           9.500000           10.500000           11.500000
     12.500000           13.500000           14.500000           15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_11
0.329242           0.329242           0.346917           0.368632
     0.395312           0.42809 0.468362           0.517841
     0.578630           0.653316           0.745076           0.857813
     0.996322           1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_12
0.500000           1.500000           2.500000           3.500000
     4.500000           5.50000 6.500000           7.500000
     8.500000           9.500000           10.500000           11.500000
     12.500000           13.500000           14.500000           15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_13
0.329242           0.329242           0.346917           0.368632
     0.395312           0.42809 0.468362           0.517841
     0.578630           0.653316           0.745076           0.857813
     0.996322           1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_14
0.500000           1.500000           2.500000           3.500000
     4.500000           5.50000 6.500000           7.500000
     8.500000           9.500000           10.500000           11.500000
     12.500000           13.500000           14.500000           15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_15
0.329242           0.329242           0.346917           0.368632
     0.395312           0.42809 0.468362           0.517841
     0.578630           0.653316           0.745076           0.857813
     0.996322           1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_16
0.500000           1.500000           2.500000           3.500000
     4.500000           5.50000 6.500000           7.500000
     8.500000           9.500000           10.500000           11.500000
     12.500000           13.500000           14.500000           15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_17
0.329242           0.329242           0.346917           0.368632
     0.395312           0.42809 0.468362           0.517841
     0.578630           0.653316           0.745076           0.857813
     0.996322           1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_18
0.500000           1.500000           2.500000           3.500000
     4.500000           5.50000 6.500000           7.500000
     8.500000           9.500000           10.500000           11.500000
     12.500000           13.500000           14.500000           15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_19
0.329242           0.329242           0.190804           0.368632
     0.395312           0.42809 0.468362           0.517841
     0.578630           0.653316           0.745076           0.857813
     0.996322           1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_20
0.500000           1.500000           2.500000           3.500000
     4.500000           5.50000 6.500000           7.500000
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    8.500000        9.500000        10.500000        11.500000
   12.500000       13.500000        14.500000        15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_21
0.329242        0.329242        0.346917        0.202748
   0.395312        0.42809 0.468362        0.517841
   0.578630        0.653316        0.745076        0.857813
   0.996322        1.166500        1.375570        1.632440        1.8580
    2.1720   2.5300   2.9340   3.3880 #_22
0.500000        1.500000        2.500000        3.500000
   4.500000        5.50000 6.500000        7.500000
   8.500000        9.500000        10.500000        11.500000
   12.500000       13.500000        14.500000        15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_23
0.329242        0.329242        0.346917        0.368632
   0.217422        0.42809 0.468362        0.517841
   0.578630        0.653316        0.745076        0.857813
   0.996322        1.166500        1.375570        1.632440        1.8580
    2.1720   2.5300   2.9340   3.3880 #_24
0.500000        1.500000        2.500000        3.500000
   4.500000        5.50000 6.500000        7.500000
   8.500000        9.500000        10.500000        11.500000
   12.500000       13.500000        14.500000        15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_25
0.329242        0.329242        0.346917        0.368632
   0.395312        0.23545 0.468362        0.517841
   0.578630        0.653316        0.745076        0.857813
   0.996322        1.166500        1.375570        1.632440        1.8580
    2.1720   2.5300   2.9340   3.3880 #_26
0.500000        1.500000        2.500000        3.500000
   4.500000        5.50000 6.500000        7.500000
   8.500000        9.500000        10.500000        11.500000
   12.500000       13.500000        14.500000        15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_27
0.329242        0.329242        0.190804        0.368632
   0.395312        0.42809 0.257599        0.517841
   0.578630        0.653316        0.745076        0.857813
   0.996322        1.166500        1.375570        1.632440        1.8580
    2.1720   2.5300   2.9340   3.3880 #_28
0.500000        1.500000        2.500000        3.500000
   4.500000        5.50000 6.500000        7.500000
   8.500000        9.500000        10.500000        11.500000
   12.500000       13.500000        14.500000        15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_29
0.329242        0.329242        0.346917        0.202748
   0.395312        0.42809 0.468362        0.284813
   0.578630        0.653316        0.745076        0.857813
   0.996322        1.166500        1.375570        1.632440        1.8580
    2.1720   2.5300   2.9340   3.3880 #_30
0.500000        1.500000        2.500000        3.500000
   4.500000        5.50000 6.500000        7.500000
   8.500000        9.500000        10.500000        11.500000
   12.500000       13.500000        14.500000        15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_31
0.329242        0.329242        0.346917        0.368632
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    0.217422          0.42809 0.468362          0.517841
    0.318246          0.653316          0.745076          0.857813
    0.996322          1.166500          1.375570          1.632440          1.8580
    2.1720  2.5300  2.9340  3.3880 #_32
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_33
0.329242          0.329242          0.346917          0.368632
    0.395312          0.23545 0.468362          0.517841
    0.578630          0.359324          0.745076          0.857813
    0.996322          1.166500          1.375570          1.632440          1.8580
    2.1720  2.5300  2.9340  3.3880 #_34
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_35
0.329242          0.329242          0.346917          0.368632
    0.395312          0.42809 0.257599          0.517841
    0.578630          0.653316          0.409792          0.857813
    0.996322          1.166500          1.375570          1.632440          1.8580
    2.1720  2.5300  2.9340  3.3880 #_36
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_37
0.329242          0.329242          0.346917          0.368632
    0.395312          0.42809 0.468362          0.284813
    0.578630          0.653316          0.745076          0.471797
    0.996322          1.166500          1.375570          1.632440          1.8580
    2.1720  2.5300  2.9340  3.3880 #_38
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_39
0.329242          0.329242          0.346917          0.368632
    0.395312          0.42809 0.468362          0.517841
    0.318246          0.653316          0.745076          0.857813
    0.547977          1.166500          1.375570          1.632440          1.8580
    2.1720  2.5300  2.9340  3.3880 #_40
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_41
0.329242          0.329242          0.346917          0.368632
    0.395312          0.42809 0.468362          0.517841
    0.578630          0.359324          0.745076          0.857813
    0.996322          0.641575          1.375570          1.632440          1.8580
    2.1720  2.5300  2.9340  3.3880 #_42
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0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_43
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.409792          0.857813
   0.996322          1.166500          0.756564          1.632440          1.8580
    2.1720   2.5300   2.9340   3.3880 #_44
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_45
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.471797
   0.996322          1.166500          1.375570          0.897842          1.8580
    2.1720   2.5300   2.9340   3.3880 #_46
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_47
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.547977          1.166500          1.375570          1.632440          1.0219
    2.1720   2.5300   2.9340   3.3880 #_48
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_49
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          0.641575          1.375570          1.632440          1.8580
    1.1946   2.5300   2.9340   3.3880 #_50
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_51
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          0.756564          1.632440          1.8580
    2.1720   1.3915   2.9340   3.3880 #_52
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
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   16.5000 17.5000 18.5000 19.5000 20.5000 #_53
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          0.897842          1.8580
    2.1720  2.5300  1.6137  3.3880 #_54
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_55
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440          1.0219
    2.1720  2.5300  2.9340  1.8634 #_56
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_57
0.329242          0.329242          0.190804          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440          1.8580
    1.1946  2.5300  2.9340  3.3880 #_58
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_59
0.329242          0.329242          0.346917          0.202748
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440          1.8580
    2.1720  1.3915  2.9340  3.3880 #_60
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_61
0.329242          0.329242          0.346917          0.368632
   0.217422          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          1.632440          1.8580
    2.1720  2.5300  1.6137  3.3880 #_62
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
   12.500000          13.500000          14.500000          15.500000
   16.5000 17.5000 18.5000 19.5000 20.5000 #_63
0.329242          0.329242          0.346917          0.368632
   0.395312          0.23545 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
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   0.996322          1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   1.8634 #_64
0.500000          1.500000          2.500000          3.500000
     4.500000          5.50000 6.500000          7.500000
     8.500000          9.500000          10.500000          11.500000
     12.500000          13.500000          14.500000          15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_65
0.329242          0.329242          0.346917          0.368632
     0.395312          0.42809 0.257599          0.517841
     0.578630          0.653316          0.745076          0.857813
     0.996322          1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_66
0.500000          1.500000          2.500000          3.500000
     4.500000          5.50000 6.500000          7.500000
     8.500000          9.500000          10.500000          11.500000
     12.500000          13.500000          14.500000          15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_67
0.329242          0.329242          0.346917          0.368632
     0.395312          0.42809 0.468362          0.284813
     0.578630          0.653316          0.745076          0.857813
     0.996322          1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_68
0.500000          1.500000          2.500000          3.500000
     4.500000          5.50000 6.500000          7.500000
     8.500000          9.500000          10.500000          11.500000
     12.500000          13.500000          14.500000          15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_69
0.329242          0.329242          0.346917          0.368632
     0.395312          0.42809 0.468362          0.517841
     0.318246          0.653316          0.745076          0.857813
     0.996322          1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_70
0.500000          1.500000          2.500000          3.500000
     4.500000          5.50000 6.500000          7.500000
     8.500000          9.500000          10.500000          11.500000
     12.500000          13.500000          14.500000          15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_71
0.329242          0.329242          0.346917          0.368632
     0.395312          0.42809 0.468362          0.517841
     0.578630          0.359324          0.745076          0.857813
     0.996322          1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_72
0.500000          1.500000          2.500000          3.500000
     4.500000          5.50000 6.500000          7.500000
     8.500000          9.500000          10.500000          11.500000
     12.500000          13.500000          14.500000          15.500000
     16.5000 17.5000 18.5000 19.5000 20.5000 #_73
0.329242          0.329242          0.346917          0.368632
     0.395312          0.42809 0.468362          0.517841
     0.578630          0.653316          0.409792          0.857813
     0.996322          1.166500           1.375570           1.632440           1.8580
     2.1720   2.5300   2.9340   3.3880 #_74
0.500000          1.500000          2.500000          3.500000
     4.500000          5.50000 6.500000          7.500000
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   8.500000         9.500000          10.500000          11.500000
  12.500000        13.500000          14.500000          15.500000
  16.5000 17.5000 18.5000 19.5000 20.5000 #_75
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.471797
   0.996322          1.166500          1.375570          1.632440          1.8580
   2.1720   2.5300   2.9340   3.3880 #_76
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
  12.500000        13.500000          14.500000          15.500000
  16.5000 17.5000 18.5000 19.5000 20.5000 #_77
0.329242          0.329242          0.346917          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.547977          1.166500          1.375570          1.632440          1.8580
   2.1720   2.5300   2.9340   3.3880 #_78
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
  12.500000        13.500000          14.500000          15.500000
  16.5000 17.5000 18.5000 19.5000 20.5000 #_79
0.329242          0.329242          0.190804          0.368632
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          0.641575          1.375570          1.632440          1.8580
   2.1720   2.5300   2.9340   3.3880 #_80
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
  12.500000        13.500000          14.500000          15.500000
  16.5000 17.5000 18.5000 19.5000 20.5000 #_81
0.329242          0.329242          0.346917          0.202748
   0.395312          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          0.756564          1.632440          1.8580
   2.1720   2.5300   2.9340   3.3880 #_82
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
  12.500000        13.500000          14.500000          15.500000
  16.5000 17.5000 18.5000 19.5000 20.5000 #_83
0.329242          0.329242          0.346917          0.368632
   0.217422          0.42809 0.468362          0.517841
   0.578630          0.653316          0.745076          0.857813
   0.996322          1.166500          1.375570          0.897842          1.8580
   2.1720   2.5300   2.9340   3.3880 #_84
0.500000          1.500000          2.500000          3.500000
   4.500000          5.50000 6.500000          7.500000
   8.500000          9.500000          10.500000          11.500000
  12.500000        13.500000          14.500000          15.500000
  16.5000 17.5000 18.5000 19.5000 20.5000 #_85
0.329242          0.329242          0.346917          0.368632
```

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    0.395312          0.23545 0.468362          0.517841
    0.578630          0.653316          0.745076          0.857813
    0.996322          1.166500          1.375570          1.632440          1.0219
     2.1720  2.5300  2.9340  3.3880 #_86
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_87
0.329242          0.329242          0.190804          0.368632
    0.395312          0.42809 0.257599          0.517841
    0.578630          0.653316          0.745076          0.857813
    0.996322          1.166500          1.375570          1.632440          1.8580
     1.1946  2.5300  2.9340  3.3880 #_88
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_89
0.329242          0.329242          0.346917          0.202748
    0.395312          0.42809 0.468362          0.284813
    0.578630          0.653316          0.745076          0.857813
    0.996322          1.166500          1.375570          1.632440          1.8580
     2.1720  1.3915  2.9340  3.3880 #_90
0.500000          1.500000          2.500000          3.500000
    4.500000          5.50000 6.500000          7.500000
    8.500000          9.500000          10.500000          11.500000
    12.500000          13.500000          14.500000          15.500000
    16.5000 17.5000 18.5000 19.5000 20.5000 #_91
0.329242          0.329242          0.346917          0.368632
    0.217422          0.42809 0.468362          0.517841
    0.318246          0.653316          0.745076          0.857813
    0.996322          1.166500          1.375570          1.632440          1.8580
     2.1720  2.5300  1.6137  3.3880 #_92
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   # 2019
0.329242  0.329242  0.346917  0.368632  0.395312  0.2354495 0.468362
    0.517841  0.57863 0.3593238 0.745076  0.857813  0.996322  1.1665
    1.37557 1.63244 1.858 2.172 2.53  2.934 1.8634  # 2019
#
#_age_info
#_mintailcomp   addtocomp         combine_M_F      CompressBins
   CompError        ParmSelect        minsamplesize
-1      0.001   0        0         1        1        0.001   #_Fishery
-1      0.001   0        0         1        2        0.001   #_Acoustic_Survey
1 #_Lbin_method: 1=poplenbins; 2=datalenbins; 3=lengths
 #_combine males into females at or below this bin number
#_Yr     Seas    FltSvy  Gender   Part     Ageerr   Lbin_lo  Lbin_hi Nsamp
    a1       a2       a3       a4       a5       a6       a7       a8
    a9       a10      a11      a12      a13      a14      a15
1995     7        2        0        0        23       -1       -1         69
    0.00000000      20.480000        3.26000         1.06000
    19.33000        1.03000          4.03000         16.370000
    1.440000        0.720000        24.860000        0.240000
```

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     1.6700000        0.2100000        5.3200000        #_1
1998     7     2       0        0        26       -1       -1        105
     0.00000000       6.830000         8.03000        17.03000
    17.25000          1.77000         11.37000        10.790000
     1.730000         4.190000         7.600000        1.270000
     0.3400000        9.7400000        2.0600000       #_2
2001     7     2       0        0        29       -1       -1        57
     0.00000000      50.620000        10.95000        15.12000
     7.86000          3.64000          3.84000         2.600000
     1.300000         1.340000         0.650000        0.680000
     0.8700000        0.1500000        0.3900000       #_3
2003     7     2       0        0        31       -1       -1        71
     0.00000000      23.060000         1.63000        43.40000
    13.07000          2.71000          5.14000         3.430000
     1.820000         2.440000         1.440000        0.490000
     0.4300000        0.4200000        0.5200000       #_4
2005     7     2       0        0        33       -1       -1        47
     0.00000000      19.070000         1.23000         5.10000
     4.78000         50.67000          6.99000         2.500000
     3.990000         2.450000         1.710000        0.740000
     0.4800000        0.1400000        0.1600000       #_5
2007     7     2       0        0        35       -1       -1        69
     0.00000000      28.290000         2.16000        11.64000
     1.38000          5.01000          3.25000        38.640000
     3.920000         1.940000         1.700000        0.830000
     0.7700000        0.3400000        0.1200000       #_6
2009     7     2       0        0        37       -1       -1        72
     0.00000000       0.550000        29.33000        40.21000
     2.29000          8.22000          1.25000         1.790000
     1.930000         8.320000         3.630000        1.440000
     0.2800000        0.4800000        0.2600000       #_7
2011     7     2       0        0        39       -1       -1        46
     0.00000000      27.620000        56.32000         3.71000
     2.64000          2.94000          0.70000         0.780000
     0.380000         0.660000         0.970000        2.100000
     0.7600000        0.3100000        0.1100000       #_8
2012     7     2       0        0        40       -1       -1        94
     0.00000000      62.120000         9.78000        16.70000
     2.26000          2.92000          1.94000         1.010000
     0.500000         0.230000         0.270000        0.660000
     0.9800000        0.5100000        0.1200000       #_9
2013     7     2       0        0        41       -1       -1        67
     0.00000000       2.170000        74.97000         5.63000
     8.68000          0.95000          2.20000         2.590000
     0.710000         0.350000         0.100000        0.130000
     0.3600000        0.7700000        0.3800000       #_10
2015     7     2       0        0        43       -1       -1        78
     0.00000000       7.450000         9.19000         4.38000
    58.98000          4.88000          7.53000         1.690000
     1.680000         1.640000         0.950000        0.160000
     0.2900000        0.2400000        0.9200000       #_11
2017     7     2       0        0        45       -1       -1        58
     0.00000000       0.490000        52.73000         2.80000
     3.70000          3.31000         26.02000         4.130000
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   2.910000          1.140000          0.910000          0.870000
   0.4200000         0.3300000         0.2500000         #_12
2019    7        2        0        0        47       -1       -1        75
   0.00000000        10.72             27.23             1.51             31.31
           2.50              3.18             2.68             16.12
           2.28              0.96             0.36             0.38
           0.47              0.28                  #_13
1975    7        1        0        0        3        -1       -1        13
   4.60800000        33.846000         7.43200           1.24800
   25.39700          5.54600           8.03100           10.537000
   0.953000          0.603000          0.871000          0.451000
   0.0000000         0.4760000         0.0000000         #_13
1976    7        1        0        0        4        -1       -1        142
   0.08500000        1.337000          14.47400          6.74200
   4.09700           24.58200          9.76600           8.899000
   12.099000         5.431000          4.303000          4.075000
   1.0680000         2.3550000         0.6870000         #_14
1977    7        1        0        0        5        -1       -1        320
   0.00000000        8.448000          3.68300           27.47300
   3.59400           9.10600           22.68200          7.599000
   6.544000          4.016000          3.550000          2.308000
   0.5720000         0.3080000         0.1190000         #_15
1978    7        1        0        0        6        -1       -1        341
   0.47200000        1.110000          6.51100           6.31000
   26.41600          6.09100           8.86800           21.505000
   9.776000          4.711000          4.680000          2.339000
   0.5220000         0.3530000         0.3370000         #_16
1979    7        1        0        0        7        -1       -1        116
   0.00000000        6.492000          10.24100          9.38200
   5.72100           17.66600          10.25600          17.370000
   12.762000         4.180000          2.876000          0.963000
   1.6450000         0.0000000         0.4450000         #_17
1980    7        1        0        0        8        -1       -1        221
   0.14800000        0.544000          30.08700          1.85500
   4.48800           8.16500           11.22700          5.012000
   8.941000          11.076000         9.460000          2.628000
   3.7850000         1.5160000         1.0680000         #_18
1981    7        1        0        0        9        -1       -1        154
   19.49300000       4.030000          1.40300           26.72600
   3.90100           5.54800           3.37600           14.675000
   3.769000          3.195000          10.185000         2.313000
   0.5040000         0.1630000         0.7200000         #_19
1982    7        1        0        0        10       -1       -1        170
   0.00000000        32.050000         3.52100           0.48600
   27.34700          1.52600           3.68000           3.894000
   11.764000         3.268000          3.611000          7.645000
   0.2410000         0.3020000         0.6640000         #_20
1983    7        1        0        0        11       -1       -1        117
   0.00000000        0.000000          34.14400          3.99700
   1.82500           23.45800          5.12600           5.647000
   5.300000          9.383000          3.910000          3.128000
   2.2590000         1.1300000         0.6950000         #_21
1984    7        1        0        0        12       -1       -1        123
   0.00000000        0.000000          1.39300           61.90400
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   3.62500              3.84900            16.77800             2.853000
   1.509000             1.239000            3.342000            0.923000
   0.5860000            1.4390000           0.5610000            #_22
1985     7        1        0        0        13        -1        -1        57
   0.92500000           0.111000            0.34800             7.24100
  66.75500              8.40700             5.60500             7.106000
   2.042000             0.530000            0.654000            0.246000
   0.0000000            0.0000000           0.0320000            #_23
1986     7        1        0        0        14        -1        -1        120
   0.00000000          15.344000            5.38500             0.52700
   0.76100             43.63400             6.89700             8.153000
   8.260000             2.189000            2.817000            1.834000
   3.1340000            0.4570000           0.6090000            #_24
1987     7        1        0        0        15        -1        -1        56
   0.00000000           0.000000           29.58300             2.90400
   0.13500              1.01300            53.26000             0.404000
   1.250000             7.091000            0.000000            0.744000
   1.8590000            1.7570000           0.0000000            #_25
1988     7        1        0        0        16        -1        -1        84
   0.00000000           0.653000            0.06600            32.27600
   0.98000              1.45000             0.66400            46.046000
   1.351000             0.839000           10.483000            0.789000
   0.0540000            0.0650000           4.2830000            #_26
1989     7        1        0        0        17        -1        -1        80
   0.00000000           5.616000            2.43100             0.28800
  50.20600              1.25700             0.29200             0.084000
  35.192000             1.802000            0.395000            2.316000
   0.0840000            0.0000000           0.0370000            #_27
1990     7        1        0        0        18        -1        -1        163
   0.00000000           5.194000           20.56000             1.88500
   0.59200             31.34800             0.51200             0.200000
   0.042000            31.901000            0.296000            0.067000
   6.4110000            0.0000000           0.9920000            #_28
1991     7        1        0        0        19        -1        -1        160
   0.00000000           3.464000           20.37200            19.63200
   2.52200              0.79000            28.26000             1.177000
   0.145000             0.181000           18.688000            0.423000
   0.0000000            3.6060000           0.7410000            #_29
1992     7        1        0        0        20        -1        -1        243
   0.46100000           4.238000            4.30400            13.05300
  18.59400              2.27100             1.04300            33.926000
   0.767000             0.078000            0.340000           18.050000
   0.4130000            0.0370000           2.4260000            #_30
1993     7        1        0        0        21        -1        -1        172
   0.00000000           1.051000           23.24000             3.26000
  12.98000             15.66700             1.50000             0.810000
  27.422000             0.674000            0.089000            0.120000
  12.0040000            0.0540000           1.1290000            #_31
1994     7        1        0        0        22        -1        -1        235
   0.00000000           0.037000            2.83200            21.39000
   1.26500             12.62800            18.68700             1.571000
   0.573000            29.906000            0.262000            0.282000
   0.0220000            9.6340000           0.9090000            #_32
1995     7        1        0        0        23        -1        -1        147
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     0.61900000        1.281000        0.46800           6.30800
    28.96700           1.15200         8.05300          20.269000
     1.577000          0.222000       22.424000          0.435000
     0.4510000         0.0370000       7.7350000         #_33
1996    7      1        0        0       24      -1       -1        186
     0.00000000       18.282000       16.24200           1.50600
     7.74200          18.13900         1.00200           4.909000
    10.981000          0.576000        0.347000         15.717000
     0.0090000         0.1080000       4.4390000         #_34
1997    7      1        0        0       25      -1       -1        220
     0.00000000        0.737000       29.47400          24.95200
     1.46900           7.83900        12.48800           1.798000
     3.978000          6.671000        1.284000          0.216000
     6.0800000         0.7330000       2.2820000         #_35
1998    7      1        0        0       26      -1       -1        243
     0.01500000        4.779000       20.33500          20.29400
    26.59600           2.86800         5.40600           9.312000
     0.917000          1.561000        3.901000          0.353000
     0.0920000         2.9420000       0.6280000         #_36
1999    7      1        0        0       27      -1       -1        509
     0.06200000       10.244000       20.36400          17.98200
    20.06200          13.19800         2.68800           3.930000
     4.008000          0.989000        1.542000          2.140000
     0.3920000         0.3340000       2.0660000         #_37
2000    7      1        0        0       28      -1       -1        530
     0.99600000        4.218000       10.93500          14.28500
    12.88000          21.06300        13.11500           6.548000
     4.648000          2.509000        2.070000          2.306000
     1.2920000         0.7200000       2.4140000         #_38
2001    7      1        0        0       29      -1       -1        540
     0.00000000       17.338000       16.24700          14.25000
    15.68500           8.55900        12.10100           5.989000
     1.778000          2.232000        1.810000          0.698000
     1.4210000         0.6850000       1.2090000         #_39
2002    7      1        0        0       30      -1       -1        449
     0.00000000        0.033000       50.64200          14.93400
     9.68700           5.71900         4.43800           6.580000
     3.546000          0.871000        0.845000          1.036000
     0.2420000         0.4750000       0.9530000         #_40
2003    7      1        0        0       31      -1       -1        456
     0.00000000        0.105000        1.39400          67.79100
    11.66400           3.35200         5.00900           3.203000
     3.153000          2.119000        0.879000          0.438000
     0.5360000         0.1260000       0.2320000         #_41
2004    7      1        0        0       32      -1       -1        501
     0.00000000        0.022000        5.34300           6.12600
    68.29300           8.11500         2.17800           4.133000
     2.506000          1.270000        1.073000          0.346000
     0.2680000         0.1580000       0.1700000         #_42
2005    7      1        0        0       33      -1       -1        613
     0.01800000        0.569000        0.46400           6.56100
     5.38100          68.72300         7.95400           2.359000
     2.908000          2.208000        1.177000          1.091000
     0.2500000         0.0900000       0.2480000         #_43
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2006     7         1         0         0        34        -1        -1        720
   0.32600000        2.808000      10.44400          1.67300
   8.56700           4.87900       59.03700          5.276000
   1.716000          2.376000       1.134000         1.015000
   0.4260000         0.1360000      0.1880000        #_44
2007     7         1         0         0        35        -1        -1        629
   0.77500000       11.522000       3.80700         15.69700
   1.58900           6.88700        3.81100         43.947000
   5.080000          1.713000       2.203000         1.661000
   0.4820000         0.1870000      0.6390000        #_45
2008     7         1         0         0        36        -1        -1        794
   0.75679821        9.795093      30.52686          2.40239
   14.41985          1.02719        3.63153          3.168500
   28.092042         3.054095       1.148803         0.734782
   0.4957480         0.3143184      0.4320080        #_2008
2009     7         1         0         0        37        -1        -1        685
   0.64311484        0.526597      29.65303         27.18754
   3.45672          11.00914        1.34707          2.398268
   2.347152         16.688388       2.575804         0.923796
   0.6251194         0.2906352      0.3276235        #_2009
2010     7         1         0         0        38        -1        -1        874
   0.02865265       25.609874       3.37629         35.09493
   21.34933          2.30165        2.94340          0.431384
   0.576582          0.968846       5.860373         0.905850
   0.2897352         0.1044690      0.1586334        #_2010
2011     7         1         0         0        39        -1        -1       1079
   2.77232533        8.934132      70.26926          2.72756
   6.19559           4.52697        1.15897          0.818457
   0.306175          0.384307       0.121100         1.384398
   0.1769355         0.1094331      0.1143941        #_2011
2012     7         1         0         0        40        -1        -1        851
   0.18087182       40.891273      11.55582         33.01189
   2.49230           5.09419        2.52226          1.134747
   0.661800          0.232792       0.329985         0.347764
   0.8748382         0.2843057      0.3851643        #_2012
2013     7         1         0         0        41        -1        -1       1094
   0.03026022        0.544574      70.31354          5.90264
   10.46529          1.12317        3.41238          2.059308
   0.906810          1.366783       0.264304         0.333171
   0.5297531         2.2846907      0.4633246        #_2013
2014     7         1         0         0        42        -1        -1       1153
   0.00000000        3.297004       3.67925         64.40508
   6.97866          12.08576        1.59203          3.122998
   1.836234          0.817526       0.466011         0.117885
   0.1915912         0.2780210      1.1319493        #_2014
2015     7         1         0         0        43        -1        -1        798
   3.59100635        1.135642       6.88240          3.94579
   70.00903          4.93897        5.09405          0.961148
   1.553502          1.090202       0.202279         0.206483
   0.0607570         0.0541822      0.2745556        #_2015
2016     7         1         0         0        44        -1        -1       1440
   0.29168954       50.181780       1.69143          4.47390
   2.47691          32.87515        2.77723          3.234990
   0.761144          0.443687       0.369046         0.235391
```

```
      0.0635183          0.0546519          0.0694803          #_2016
2017      7       1         0          0           45      -1          -1          1300
      3.75856888         0.724561          38.37394           2.37377
      4.12355            3.11634           36.84699           4.414092
      3.100525           1.329598           0.615852           0.717990
      0.2077289          0.0926810          0.2038050          #_2017
2018      7       1         0          0           46      -1          -1          1174
      7.34806614        25.520558           1.49211          26.96714
      1.51678            2.80500            3.03601          22.783263
      4.311422           1.911611           0.942228           0.545360
      0.4108031          0.3144076          0.0952474          #_2018
2019      7       1         0          0           47      -1          -1          1001
      0.00518811        13.706896          20.71518           1.56961
     32.34901            1.76491            3.82249            2.239704
     18.663888           1.977719           1.656258           0.687149
      0.3833954          0.2277514          0.2308542          #_2019
-9999     0       0         0          0            0       0           0           0
      0.00000000         0.000000           0.00000            0.00000
      0.00000            0.00000            0.00000            0.000000
      0.000000           0.000000           0.000000           0.000000
      0.0000000          0.0000000          0.0000000          #_terminator
#
#_MeanSize_at_Age_obs
0 #_use_MeanSize_at_Age_obs
0 #_N_environ_variables
0 #_N_sizefreq_methods
0 #_do_tags
0 #_morphcomp_data
0 #_use_selectivity_priors
#
999
```

J STOCK SYNTHESIS CONTROL FILE

../models/2020.01.09_DMprior_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 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
2 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1970 # first year of main recr_devs; early devs can preceed this era
2018 # 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
 2018 #_last_yr_fullbias_adj_in_MPD
 2019 #_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
# 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
# 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         2019
         5            0            0  #  AgeSel_P3_Fishery(1)
         -5            9            0.1          -1            0.01
            0            2            0           2         1991         2019
         5            0            0  #  AgeSel_P4_Fishery(1)
         -5            9            0.1          -1            0.01
            0            2            0           2         1991         2019
         5            0            0  #  AgeSel_P5_Fishery(1)
         -5            9            0.1          -1            0.01
            0            2            0           2         1991         2019
         5            0            0  #  AgeSel_P6_Fishery(1)
         -5            9            0          -1            0.01
            0            2            0           2         1991         2019
         5            0            0  #  AgeSel_P7_Fishery(1)
         -5            9            0          -1            0.01
            0           -2            0           0            0            0
         0            0            0  #  AgeSel_P8_Fishery(1)
         -5            9            0          -1            0.01
            0           -2            0           0            0            0
         0            0            0  #  AgeSel_P9_Fishery(1)
         -5            9            0          -1            0.01
            0           -2            0           0            0            0
         0            0            0  #  AgeSel_P10_Fishery(1)
         -5            9            0          -1            0.01
            0           -2            0           0            0            0
```

```
     0              0             0  #  AgeSel_P11_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P12_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P13_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P14_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P15_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P16_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P17_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P18_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P19_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P20_Fishery(1)
    -5              9                 0            -1           0.01
         0          -2             0          0           0          0
     0              0             0  #  AgeSel_P21_Fishery(1)
 -1002              3             -1000          -1           0.01
         0          -2             0          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             0  #  AgeSel_P2_Acoustic_Survey(2)
    -1              1                 0            -1           0.01
         0          -2             0          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             0  #  AgeSel_P4_Acoustic_Survey(2)
    -5              9               0.1          -1           0.01
         0          2              0          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             0  #  AgeSel_P6_Acoustic_Survey(2)
    -5              9                 0            -1           0.01
         0          2              0          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              1.813
              6              2              0              0              0              0
        0              0              0    #   ln(EffN_mult)_1
       -5                     20                     .5              0              1.813
              6              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
```

K STOCK SYNTHESIS STARTER FILE

../models/2020.01.09_DMprior_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
```

L   STOCK SYNTHESIS FORECAST FILE

../models/2020.01.09_DMprior_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
```

M   STOCK SYNTHESIS WEIGHT-AT-AGE FILE

../models/2020.01.09_DMprior_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: 2020-01-10 09:17:44
######################################################
20 # Maximum age

#Maturity x Fecundity: Fleet = -2 (Values maturity unchanged from 2012
    Stock Assessment)
#Maturity x Fecundity: Fleet = -2 (are maturity * wtatage)

 #_#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 0.0669726 0.3210853 0.4658928
   0.489624 0.5390752 0.5980108 0.6810969 0.7264080 0.837214 0.8901386
   0.9643 1.0152884 0.9578650 0.92781 0.92781 0.92781 0.92781 0.92781
   0.92781
  1975    1     1   1     1    -2   0   0 0.0779607 0.3069062 0.5903423
   0.580152 0.7306144 0.8091388 0.9261846 0.8566800 0.950600 1.6289546
   1.5000 1.8202000 1.8675025 2.47005 2.47005 2.47005 2.47005 2.47005
   2.47005
  1976    1     1   1     1    -2   0   0 0.0615699 0.4186610 0.4985668
   0.638112 0.7459264 0.8486790 1.1544291 1.2588240 1.420510 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 0.1049220 0.4095998 0.5671822
   0.611800 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 0.0629010 0.2170493 0.5593981
   0.631856 0.7124256 0.8249734 0.8735496 0.9788336 1.174726 1.2007684
   1.5326 1.4868160 1.7142250 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 0.8250560 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 1.4254330 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 0.4884650 0.5386953 0.7180064 0.670026 0.8214518
   1.0670 0.8423694 0.9727630 1.05237 1.05237 1.05237 1.05237 1.05237
   1.05237
  1983    1     1   1     1    -2   0   0 0.0354177 0.2860990 0.3549934
```

```
       0.301484 0.4825600 0.4655928 0.5913303 0.6664640 0.862400 0.8945638
       1.0356 0.9876980 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 0.686980 0.9151506
       1.1364 0.9827164 1.2230685 1.69200 1.69200 1.69200 1.69200 1.69200
       1.69200
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 0.0725580 0.2438134 0.2906064
       0.343620 0.5035328 0.5296720 0.6144897 0.7749296 0.921494 1.1409320
       1.1900 1.3160046 1.6044000 1.45278 1.45278 1.45278 1.45278 1.45278
       1.45278
1987     1      1  1      1     -2   0   0 0.0362268 0.3179810 0.2677346
       0.264040 0.3360288 0.5347650 0.5718075 0.6012336 0.748524 0.9446840
       0.9250 1.1885906 1.1489605 1.27413 1.27413 1.27413 1.27413 1.27413
       1.27413
1988     1      1  1      1     -2   0   0 0.0488070 0.2675571 0.4527271
       0.339388 0.3462368 0.4780938 0.6192747 0.6498496 0.703934 0.8860982
       1.0924 0.9795550 1.3847500 1.30833 1.30833 1.30833 1.30833 1.30833
       1.30833
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 0.7909310 1.01376 1.01376 1.01376 1.01376 1.01376
       1.01376
1990     1      1  1      1     -2   0   0 0.0635535 0.2941534 0.3753666
       0.470212 0.5068736 0.5626376 0.6390846 0.5003200 0.754306 0.7996144
       2.2000 1.1349426 0.9708530 1.32012 1.32012 1.32012 1.32012 1.32012
       1.32012
1991     1      1  1      1     -2   0   0 0.0718794 0.3101783 0.4418678
       0.472696 0.5045536 0.5469882 0.6899970 0.8021168 1.077706 0.6911970
       0.6403 0.9746692 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 0.4558023
       0.490728 0.5398176 0.5750460 0.6130542 0.6164320 0.620340 0.6942754
       0.7354 0.8143958 0.9311250 0.92448 0.92448 0.92448 0.92448 0.92448
       0.92448
1993     1      1  1      1     -2   0   0 0.0648846 0.2839176 0.3805560
       0.417588 0.4579680 0.4645742 0.4670160 0.5183504 0.499800 1.2150060
       1.0250 0.5877330 0.5725225 0.61650 0.61650 0.61650 0.61650 0.61650
       0.61650
1994     1      1  1      1     -2   0   0 0.0783000 0.3042214 0.4294709
       0.411516 0.4883136 0.5278200 0.5950626 0.5284512 0.621418 0.4665700
       0.6491 0.6993400 0.6697415 0.67095 0.67095 0.67095 0.67095 0.67095
       0.67095
1995     1      1  1      1     -2   0   0 0.0700002 0.2867702 0.4685836
       0.493764 0.6037568 0.5786574 0.6313329 0.7136640 0.653660 0.7162090
       0.7998 0.8718758 0.6497820 0.72072 0.72072 0.72072 0.72072 0.72072
       0.72072
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 0.7215000
       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 0.618870 0.8304946
   0.5946 0.6819044 0.6320190 0.78237 0.78237 0.78237 0.78237 0.78237
   0.78237
1998    1       1  1      1     -2   0   0 0.0545751 0.2969221 0.4844401
   0.475824 0.5029760 0.5937512 0.5836743 0.6389936 0.791644 0.6901388
   0.8100 0.7408214 0.7172050 0.71811 0.71811 0.71811 0.71811 0.71811
   0.71811
1999    1       1  1      1     -2   0   0 0.0653022 0.2898745 0.4085211
   0.484380 0.5168032 0.5303202 0.5853969 0.6636320 0.651700 0.7685418
   0.7554 0.8417946 0.7017340 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 0.8350520 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
   0.611340 0.6931232 0.7990454 0.8187135 0.8309088 0.943740 0.9417980
   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
   0.750720 0.7035168 0.7859888 0.9350847 0.8799968 0.899248 0.9594988
   0.9890 0.8848088 1.0743750 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
   0.541420 0.7024032 0.6403290 0.7147833 0.7784224 0.753816 0.8549294
   0.9266 0.7562452 0.8035370 0.89685 0.89685 0.89685 0.89685 0.89685
   0.89685
2004    1       1  1      1     -2   0   0 0.0522000 0.3658040 0.4619527
   0.489348 0.6011584 0.6544968 0.6296103 0.6696736 0.788900 0.8254922
   0.7715 0.9296432 0.8242605 0.80631 0.80631 0.80631 0.80631 0.80631
   0.80631
2005    1       1  1      1     -2   0   0 0.0679383 0.3616929 0.4887646
   0.496156 0.5272896 0.5867136 0.6268350 0.6633488 0.780276 0.7796048
   0.8109 0.7282716 1.0933795 0.87102 0.87102 0.87102 0.87102 0.87102
   0.87102
2006    1       1  1      1     -2   0   0 0.0999891 0.3838425 0.5132701
   0.528080 0.5484480 0.5536554 0.6277920 0.6605168 0.711382 0.6945640
   0.7753 0.6303640 0.6111045 0.85950 0.85950 0.85950 0.85950 0.85950
   0.85950
2007    1       1  1      1     -2   0   0 0.0592992 0.3168064 0.5143272
   0.508760 0.5635744 0.5859728 0.6196575 0.6659920 0.756854 0.7337174
   0.8137 0.8336516 0.7647640 0.78282 0.78282 0.78282 0.78282 0.78282
   0.78282
2008    1       1  1      1     -2   0   0 0.0636840 0.3422281 0.5410430
   0.585580 0.6370720 0.6313468 0.6792786 0.6807184 0.733824 0.7766226
   0.8483 0.7429290 0.8436470 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 0.9150810 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 0.6876000 0.81189 0.81189 0.81189 0.81189 0.81189
   0.81189
2011    1      1 1      1     -2   0    0 0.0641277 0.2700741 0.3716187
   0.473064 0.5521600 0.6246796 0.8167038 0.8773536 0.958440 1.0340538
   1.0588 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 0.3934334
   0.449788 0.6089536 0.6395882 0.7440675 0.8563968 0.944034 0.9272718
   0.9639 0.9473662 0.9477420 0.84825 0.84825 0.84825 0.84825 0.84825
   0.84825
2013    1      1 1      1     -2   0    0 0.0750114 0.3016205 0.4513817
   0.469568 0.5809280 0.6634790 0.6995670 0.7847472 0.978922 1.0343424
   1.2303 1.0717146 1.0201310 0.94905 0.94905 0.94905 0.94905 0.94905
   0.94905
2014    1      1 1      1     -2   0    0 0.1064880 0.3931554 0.4609917
   0.493304 0.5327648 0.5739348 0.6306630 0.6772256 0.681100 1.1202490
   1.0150 0.9092378 0.9238670 0.95211 0.95211 0.95211 0.95211 0.95211
   0.95211
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 0.9757230 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 0.3996799
   0.405352 0.4304064 0.4760566 0.4941948 0.4839888 0.635040 0.6924476
   0.5948 0.7430248 1.3857050 1.42218 1.42218 1.42218 1.42218 1.42218
   1.42218
2017    1      1 1      1     -2   0    0 0.0813015 0.3365229 0.4516700
   0.469292 0.4948096 0.5019846 0.5466384 0.5834864 0.600446 0.6634914
   0.7554 0.7195538 0.7611350 0.80271 0.80271 0.80271 0.80271 0.80271
   0.80271
2018    1      1 1      1     -2   0    0 0.0924984 0.3887087 0.4832869
   0.492844 0.5120704 0.5717124 0.5642472 0.6034992 0.630238 0.6504082
   0.6887 0.6934004 0.8566350 0.96300 0.96300 0.96300 0.96300 0.96300
   0.96300
2019    1      1 1      1     -2   0    0 0.0734976 0.3699990 0.4655084
   0.480976 0.5009344 0.5383764 0.5957325 0.5829200 0.618086 0.6590662
   0.6455 0.8062528 0.6484450 0.71406 0.71406 0.71406 0.71406 0.71406
   0.71406
2020    1      1 1      1     -2   0    0 0.0750897 0.3488562 0.44546194
   0.45632 0.49029952  0.52778296  0.56933844  0.5806544 0.6374704
   0.69348656  0.72734 0.78759096  0.9384403 1.005264  1.005264  1.005264
    1.005264  1.005264  1.005264
2021    1      1 1      1     -2   0    0 0.0750897 0.3488562 0.44546194
   0.45632 0.49029952  0.52778296  0.56933844  0.5806544 0.6374704
   0.69348656  0.72734 0.78759096  0.9384403 1.005264  1.005264  1.005264
   1.005264  1.005264  1.005264
2022    1      1 1      1     -2   0    0 0.0750897 0.3488562 0.44546194
   0.45632 0.49029952  0.52778296  0.56933844  0.5806544 0.6374704
   0.69348656  0.72734 0.78759096  0.9384403 1.005264  1.005264  1.005264
    1.005264  1.005264  1.005264

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

```
#Weight at age for population in middle of the year: Fleet = -1
 #_#Yr seas gender GP bseas fleet       a0       a1       a2       a3       a4
    a5       a6       a7       a8       a9      a10      a11      a12      a13      a14
    a15      a16      a17      a18      a19      a20
 -1940     1        1   1       1       -1 0.0169 0.0942 0.2566 0.3827 0.4848
   0.5322 0.5809 0.6458 0.7117 0.7695 0.8543 0.9253 0.9643 1.0598 1.0030
   1.0309 1.0309 1.0309 1.0309 1.0309 1.0309
  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 0.3189 0.4711
   0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
   1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
  1989     1        1   1       1       -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 0.3506 0.3906
   0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
```

```
 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991    1       1  1       1      -1 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1       1  1       1      -1 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993    1       1  1       1      -1 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994    1       1  1       1      -1 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995    1       1  1       1      -1 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996    1       1  1       1      -1 0.0153 0.1007 0.2876 0.3982 0.4674
 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997    1       1  1       1      -1 0.0153 0.0906 0.3555 0.4322 0.4931
 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998    1       1  1       1      -1 0.0152 0.0805 0.2091 0.3539 0.5041
 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999    1       1  1       1      -1 0.0152 0.1352 0.2502 0.3455 0.4251
 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000    1       1  1       1      -1 0.0151 0.1899 0.3216 0.4729 0.5766
 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001    1       1  1       1      -1 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
 0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
2002    1       1  1       1      -1 0.0150 0.0756 0.3583 0.4575 0.6058
 0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974 0.9890 0.9236 1.1250
 1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
2003    1       1  1       1      -1 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887 0.9266 0.7894 0.8414
 0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
2004    1       1  1       1      -1 0.0149 0.1081 0.2000 0.4360 0.4807
 0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581 0.7715 0.9704 0.8631
 0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
2005    1       1  1       1      -1 0.0149 0.1162 0.2603 0.4311 0.5086
 0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104 0.8109 0.7602 1.1449
 0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
2006    1       1  1       1      -1 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220 0.7753 0.6580 0.6399
 0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
2007    1       1  1       1      -1 0.0148 0.0445 0.2272 0.3776 0.5352
 0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627 0.8137 0.8702 0.8008
 0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008    1       1  1       1      -1 0.0152 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
```

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     0.8332 0.8332 0.8332 0.8332 0.8332 0.8332
  2009    1      1  1      1    -1 0.0156 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 0.0161 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 0.0165 0.0844 0.2457 0.3219 0.3867
    0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
    0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1      1  1      1    -1 0.0170 0.1290 0.2145 0.3536 0.4094
    0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
    0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
  2013    1      1  1      1    -1 0.0174 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 0.0178 0.1028 0.4080 0.4686 0.4797
    0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
    1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
  2015    1      1  1      1    -1 0.0183 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 0.0187 0.1653 0.2439 0.3831 0.4159
    0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
    1.5802 1.5802 1.5802 1.5802 1.5802 1.5802
  2017    1      1  1      1    -1 0.0191 0.1405 0.3115 0.4011 0.4700
    0.5101 0.5332 0.5421 0.5712 0.6181 0.6127 0.6897 0.7554 0.7511 0.7970
    0.8919 0.8919 0.8919 0.8919 0.8919 0.8919
  2018    1      1  1      1    -1 0.0196 0.1870 0.3544 0.4633 0.5029
    0.5357 0.5518 0.6174 0.5896 0.6393 0.6431 0.6761 0.6887 0.7238 0.8970
    1.0700 1.0700 1.0700 1.0700 1.0700 1.0700
  2019    1      1  1      1    -1 0.0200 0.0677 0.2816 0.4410 0.4844
    0.5228 0.5398 0.5814 0.6225 0.6175 0.6307 0.6851 0.6455 0.8416 0.6790
    0.7934 0.7934 0.7934 0.7934 0.7934 0.7934
  2020    1      1  1      1    -1 0.01914 0.12728 0.2877   0.4158   0.46354
    0.496 0.52834 0.56996 0.59492 0.6151   0.65048 0.72088 0.72734 0.82212
    0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
  2021    1      1  1      1    -1 0.01914 0.12728 0.2877   0.4158   0.46354
    0.496 0.52834 0.56996 0.59492 0.6151   0.65048 0.72088 0.72734 0.82212
    0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
  2022    1      1  1      1    -1 0.01914 0.12728 0.2877   0.4158   0.46354
    0.496 0.52834 0.56996 0.59492 0.6151   0.65048 0.72088 0.72734 0.82212
    0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696

#Weight at age for population at beginning of the year: Fleet = 0
 #_#Yr seas gender GP bseas fleet     a0      a1      a2      a3      a4
    a5      a6      a7      a8      a9     a10     a11     a12     a13     a14
    a15     a16     a17     a18     a19     a20
 -1940    1      1  1      1     0 0.0169 0.0942 0.2566 0.3827 0.4848
    0.5322 0.5809 0.6458 0.7117 0.7695 0.8543 0.9253 0.9643 1.0598 1.0030
    1.0309 1.0309 1.0309 1.0309 1.0309 1.0309
  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 0.3189 0.4711
 0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989     1       1  1     1      0 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 0.3506 0.3906
 0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991     1       1  1     1      0 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992     1       1  1     1      0 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993     1       1  1     1      0 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
```

```
1994      1       1   1       1       0 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995      1       1   1       1       0 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996      1       1   1       1       0 0.0153 0.1007 0.2876 0.3982 0.4674
 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997      1       1   1       1       0 0.0153 0.0906 0.3555 0.4322 0.4931
 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998      1       1   1       1       0 0.0152 0.0805 0.2091 0.3539 0.5041
 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999      1       1   1       1       0 0.0152 0.1352 0.2502 0.3455 0.4251
 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000      1       1   1       1       0 0.0151 0.1899 0.3216 0.4729 0.5766
 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001      1       1   1       1       0 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
 0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
2002      1       1   1       1       0 0.0150 0.0756 0.3583 0.4575 0.6058
 0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974 0.9890 0.9236 1.1250
 1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
2003      1       1   1       1       0 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887 0.9266 0.7894 0.8414
 0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
2004      1       1   1       1       0 0.0149 0.1081 0.2000 0.4360 0.4807
 0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581 0.7715 0.9704 0.8631
 0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
2005      1       1   1       1       0 0.0149 0.1162 0.2603 0.4311 0.5086
 0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104 0.8109 0.7602 1.1449
 0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
2006      1       1   1       1       0 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220 0.7753 0.6580 0.6399
 0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
2007      1       1   1       1       0 0.0148 0.0445 0.2272 0.3776 0.5352
 0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627 0.8137 0.8702 0.8008
 0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008      1       1   1       1       0 0.0152 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 0.0156 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 0.0161 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 0.0165 0.0844 0.2457 0.3219 0.3867
 0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
```

```
 2012     1       1  1       1       0 0.0170 0.1290 0.2145 0.3536 0.4094
   0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
   0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
 2013     1       1  1       1       0 0.0174 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 0.0178 0.1028 0.4080 0.4686 0.4797
   0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
   1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
 2015     1       1  1       1       0 0.0183 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 0.0187 0.1653 0.2439 0.3831 0.4159
   0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
   1.5802 1.5802 1.5802 1.5802 1.5802 1.5802
 2017     1       1  1       1       0 0.0191 0.1405 0.3115 0.4011 0.4700
   0.5101 0.5332 0.5421 0.5712 0.6181 0.6127 0.6897 0.7554 0.7511 0.7970
   0.8919 0.8919 0.8919 0.8919 0.8919 0.8919
 2018     1       1  1       1       0 0.0196 0.1870 0.3544 0.4633 0.5029
   0.5357 0.5518 0.6174 0.5896 0.6393 0.6431 0.6761 0.6887 0.7238 0.8970
   1.0700 1.0700 1.0700 1.0700 1.0700 1.0700
 2019     1       1  1       1       0 0.0200 0.0677 0.2816 0.4410 0.4844
   0.5228 0.5398 0.5814 0.6225 0.6175 0.6307 0.6851 0.6455 0.8416 0.6790
   0.7934 0.7934 0.7934 0.7934 0.7934 0.7934
 2020     1       1  1       1       0 0.01914 0.12728 0.2877  0.4158  0.46354
   0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
   0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
 2021     1       1  1       1       0 0.01914 0.12728 0.2877  0.4158  0.46354
   0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
   0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
 2022     1       1  1       1       0 0.01914 0.12728 0.2877  0.4158  0.46354
   0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
   0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696


#Weight at age for Fishery: Fleet = 1
 #_#Yr seas gender GP bseas fleet    a0     a1     a2     a3     a4
   a5     a6     a7     a8     a9     a10    a11    a12    a13    a14
   a15    a16    a17    a18    a19    a20
 -1940    1       1  1       1       1 0.0169 0.0942 0.2566 0.3827 0.4848
   0.5322 0.5809 0.6458 0.7117 0.7695 0.8543 0.9253 0.9643 1.0598 1.0030
   1.0309 1.0309 1.0309 1.0309 1.0309 1.0309
 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 0.3189 0.4711
     0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
     1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989      1      1   1      1      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 0.3506 0.3906
     0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
     1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991      1      1   1      1      1 0.0156 0.1367 0.2754 0.3697 0.4598
     0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
     2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992      1      1   1      1      1 0.0155 0.1356 0.2316 0.3473 0.4743
     0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
     1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993      1      1   1      1      1 0.0155 0.1274 0.2486 0.3384 0.3960
     0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
     0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994      1      1   1      1      1 0.0154 0.1191 0.3000 0.3626 0.4469
     0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
     0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995      1      1   1      1      1 0.0154 0.1108 0.2682 0.3418 0.4876
     0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
     0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996      1      1   1      1      1 0.0153 0.1007 0.2876 0.3982 0.4674
     0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
     0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997      1      1   1      1      1 0.0153 0.0906 0.3555 0.4322 0.4931
```

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   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 0.0152 0.0805 0.2091 0.3539 0.5041
   0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
   0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999     1       1  1       1       1 0.0152 0.1352 0.2502 0.3455 0.4251
   0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
   0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000     1       1  1       1       1 0.0151 0.1899 0.3216 0.4729 0.5766
   0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
   0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001     1       1  1       1       1 0.0151 0.0512 0.2867 0.4843 0.6527
   0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
   0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
2002     1       1  1       1       1 0.0150 0.0756 0.3583 0.4575 0.6058
   0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974 0.9890 0.9236 1.1250
   1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
2003     1       1  1       1       1 0.0150 0.1000 0.2551 0.4355 0.5225
   0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887 0.9266 0.7894 0.8414
   0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
2004     1       1  1       1       1 0.0149 0.1081 0.2000 0.4360 0.4807
   0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581 0.7715 0.9704 0.8631
   0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
2005     1       1  1       1       1 0.0149 0.1162 0.2603 0.4311 0.5086
   0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104 0.8109 0.7602 1.1449
   0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
2006     1       1  1       1       1 0.0148 0.1324 0.3831 0.4575 0.5341
   0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220 0.7753 0.6580 0.6399
   0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
2007     1       1  1       1       1 0.0148 0.0445 0.2272 0.3776 0.5352
   0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627 0.8137 0.8702 0.8008
   0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008     1       1  1       1       1 0.0152 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 0.0156 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 0.0161 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 0.0165 0.0844 0.2457 0.3219 0.3867
   0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
   0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
2012     1       1  1       1       1 0.0170 0.1290 0.2145 0.3536 0.4094
   0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
   0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
2013     1       1  1       1       1 0.0174 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 0.0178 0.1028 0.4080 0.4686 0.4797
   0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
   1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
2015     1       1  1       1       1 0.0183 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 0.0187 0.1653 0.2439 0.3831 0.4159
      0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
      1.5802 1.5802 1.5802 1.5802 1.5802 1.5802
    2017    1      1  1      1      1 0.0191 0.1405 0.3115 0.4011 0.4700
      0.5101 0.5332 0.5421 0.5712 0.6181 0.6127 0.6897 0.7554 0.7511 0.7970
      0.8919 0.8919 0.8919 0.8919 0.8919 0.8919
    2018    1      1  1      1      1 0.0196 0.1870 0.3544 0.4633 0.5029
      0.5357 0.5518 0.6174 0.5896 0.6393 0.6431 0.6761 0.6887 0.7238 0.8970
      1.0700 1.0700 1.0700 1.0700 1.0700 1.0700
    2019    1      1  1      1      1 0.0200 0.0677 0.2816 0.4410 0.4844
      0.5228 0.5398 0.5814 0.6225 0.6175 0.6307 0.6851 0.6455 0.8416 0.6790
      0.7934 0.7934 0.7934 0.7934 0.7934 0.7934
    2020    1      1  1      1      1 0.01914 0.12728 0.2877  0.4158  0.46354
      0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
      0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
    2021    1      1  1      1      1 0.01914 0.12728 0.2877  0.4158  0.46354
      0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
      0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
    2022    1      1  1      1      1 0.01914 0.12728 0.2877  0.4158  0.46354
      0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
      0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696


#Weight at age for Survey: Fleet = 2
 #_#Yr seas gender GP bseas fleet     a0      a1      a2      a3      a4
    a5      a6      a7      a8      a9     a10     a11     a12     a13     a14
    a15     a16     a17     a18     a19     a20
 -1940    1      1  1      1      2 0.0169 0.0942 0.2566 0.3827 0.4848
      0.5322 0.5809 0.6458 0.7117 0.7695 0.8543 0.9253 0.9643 1.0598 1.0030
      1.0309 1.0309 1.0309 1.0309 1.0309 1.0309
    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 0.3189 0.4711
  0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
  1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989     1       1  1       1       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 0.3506 0.3906
  0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
  1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991     1       1  1       1       2 0.0156 0.1367 0.2754 0.3697 0.4598
  0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
  2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992     1       1  1       1       2 0.0155 0.1356 0.2316 0.3473 0.4743
  0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
  1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993     1       1  1       1       2 0.0155 0.1274 0.2486 0.3384 0.3960
  0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
  0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994     1       1  1       1       2 0.0154 0.1191 0.3000 0.3626 0.4469
  0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
  0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995     1       1  1       1       2 0.0154 0.1108 0.2682 0.3418 0.4876
  0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
  0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996     1       1  1       1       2 0.0153 0.1007 0.2876 0.3982 0.4674
  0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
  0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997     1       1  1       1       2 0.0153 0.0906 0.3555 0.4322 0.4931
  0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
  0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998     1       1  1       1       2 0.0152 0.0805 0.2091 0.3539 0.5041
  0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
  0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999     1       1  1       1       2 0.0152 0.1352 0.2502 0.3455 0.4251
  0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
  0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000     1       1  1       1       2 0.0151 0.1899 0.3216 0.4729 0.5766
  0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
```

```
  0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001    1       1  1       1       2 0.0151 0.0512 0.2867 0.4843 0.6527
  0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
  0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
2002    1       1  1       1       2 0.0150 0.0756 0.3583 0.4575 0.6058
  0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974 0.9890 0.9236 1.1250
  1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
2003    1       1  1       1       2 0.0150 0.1000 0.2551 0.4355 0.5225
  0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887 0.9266 0.7894 0.8414
  0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
2004    1       1  1       1       2 0.0149 0.1081 0.2000 0.4360 0.4807
  0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581 0.7715 0.9704 0.8631
  0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
2005    1       1  1       1       2 0.0149 0.1162 0.2603 0.4311 0.5086
  0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104 0.8109 0.7602 1.1449
  0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
2006    1       1  1       1       2 0.0148 0.1324 0.3831 0.4575 0.5341
  0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220 0.7753 0.6580 0.6399
  0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
2007    1       1  1       1       2 0.0148 0.0445 0.2272 0.3776 0.5352
  0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627 0.8137 0.8702 0.8008
  0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008    1       1  1       1       2 0.0152 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 0.0156 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 0.0161 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 0.0165 0.0844 0.2457 0.3219 0.3867
  0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
  0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
2012    1       1  1       1       2 0.0170 0.1290 0.2145 0.3536 0.4094
  0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
  0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
2013    1       1  1       1       2 0.0174 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 0.0178 0.1028 0.4080 0.4686 0.4797
  0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
  1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
2015    1       1  1       1       2 0.0183 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 0.0187 0.1653 0.2439 0.3831 0.4159
  0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
  1.5802 1.5802 1.5802 1.5802 1.5802 1.5802
2017    1       1  1       1       2 0.0191 0.1405 0.3115 0.4011 0.4700
  0.5101 0.5332 0.5421 0.5712 0.6181 0.6127 0.6897 0.7554 0.7511 0.7970
  0.8919 0.8919 0.8919 0.8919 0.8919 0.8919
2018    1       1  1       1       2 0.0196 0.1870 0.3544 0.4633 0.5029
  0.5357 0.5518 0.6174 0.5896 0.6393 0.6431 0.6761 0.6887 0.7238 0.8970
```

```
   1.0700 1.0700 1.0700 1.0700 1.0700 1.0700
  2019    1      1  1      1      2 0.0200 0.0677 0.2816 0.4410 0.4844
   0.5228 0.5398 0.5814 0.6225 0.6175 0.6307 0.6851 0.6455 0.8416 0.6790
   0.7934 0.7934 0.7934 0.7934 0.7934 0.7934
  2020    1      1  1      1      2 0.01914 0.12728 0.2877  0.4158  0.46354
   0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
   0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
  2021    1      1  1      1      2 0.01914 0.12728 0.2877  0.4158  0.46354
   0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
   0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696
  2022    1      1  1      1      2 0.01914 0.12728 0.2877  0.4158  0.46354
   0.496 0.52834 0.56996 0.59492 0.6151  0.65048 0.72088 0.72734 0.82212
   0.98266 1.11696 1.11696 1.11696 1.11696 1.11696 1.11696

# terminator line
 #_#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
 -9999    0      0  0      0      2 0  0  0  0  0  0  0  0  0  0   0   0
   0   0   0   0   0   0   0   0   0
# End of wtatage.ss file
```