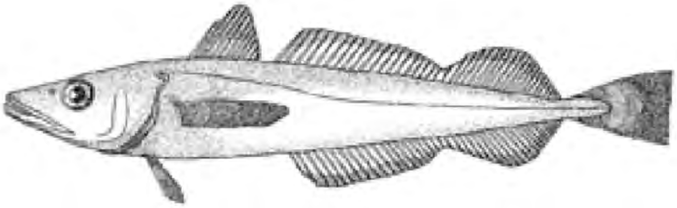
Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2021



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

March 2nd, 2021

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

Authors of this document are (all authors contribute extensively so the order rotates annually):
Kelli F. Johnson[1]
Andrew M. Edwards[2]
Aaron M. Berger[3]
Chris J. Grandin[2]

[1]*Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 2725 Montlake Blvd. East, Seattle, WA 98112-2097, USA*

[2]*Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Road, Nanaimo, B.C. V9T 6N7, Canada*

[3]*Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 2032 SE OSU Dr. Bldg. 955, Newport, OR 97365-5275, USA*

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APPENDICES

ONE-PAGE SUMMARY

- The stock assessment model for 2021 has the same structure as the 2020 model. It is fit to an acoustic survey index of abundance, annual commercial catch data, and age-composition data from the survey and commercial fisheries.

- The main technical change from 2020 is the use of a new efficient algorithm (the No-U-Turn Sampler) for obtaining posterior samples. Consequently, all model results, including sensitivity and retrospective analyses, are now based on posterior distributions rather than maximum likelihood estimates.

- Updates to the data include: fishery catch and age-composition data from 2020, weight-at-age data for 2020, and minor changes to pre-2020 data. Due to coronavirus disease 2019 (COVID-19), age data were unavailable from the Canadian freezer-trawler fleet in 2020.

- Coast-wide catch in 2020 was the fourth largest on record at 379,270 t [t represents metric tons], out of a total allowable catch (TAC), adjusted for carryovers, of 529,290 t. Quotas were specified unilaterally in 2020 due to the lack of a bilateral TAC agreement. The U.S. caught 287,908 t (67.8% of their quota) and Canada caught 91,362 t (87.4% of their quota).

- The median estimate of the 2021 relative spawning biomass (female spawning biomass at the start of 2021 divided by that at unfished equilibrium, B_0) is 59% but is highly uncertain (with 95% credible interval from 25% to 137%). The median relative spawning biomass has progressively declined since 2017 due to the aging large cohorts (2010, 2014, and 2016) and the recent four years of record catches.

- The median estimate of female spawning biomass at the start of 2021 is 980,850 t (with 95% credible interval from 404,145 to 2,388,462 t). This is less than the current assessment's median estimate for the 2020 female spawning biomass of 1,299,523 t (with 95% credible interval 636,627–2,913,582 t).

- The estimated probability that spawning biomass at the start of 2021 is below the $B_{40\%}$ (40% of B_0) reference point is 17.8%, and the probability that the relative fishing intensity exceeds its target at the end of 2020 is 2.1%. The joint probability of both these occurring is 1.7%.

- Based on the default harvest rule, the estimated median catch limit for 2021 is 565,191 t (with 95% credible interval from 181,094 to 1,649,905 t).

- Projections are highly uncertain due to uncertainty in estimates of recruitment for recent years and so were conducted for various catch levels. Projections setting the 2021 and 2022 catches equal to the 2020 coast-wide (unilaterally summed) TAC of 529,290 t show the estimated median relative spawning biomass decreasing from 59% in 2021 to 44% in 2022 and to 34% in 2023, with a 58% chance of the spawning biomass falling below $B_{40\%}$ in 2023. There is an estimated 89% chance of the spawning biomass declining from 2021 to 2022 and an 82% chance of it declining from 2022 to 2023 for these constant catches.

EXECUTIVE SUMMARY

STOCK

This assessment reports the status of the coastal Pacific Hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the United States and Canada at the start of 2021. 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 239,919 t from 1966 to 2020, 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. Across the time series, catch in U.S. waters averaged 181,620 t, (76.1% of the total catch) while catch from Canadian waters averaged 58,299 t. Over the last 10 years, 2011–2020 (Table a), the average coast-wide catch was 325,105 t with U.S. and Canadian catches averaging 258,306 t and 66,799 t, respectively. The coast-wide catch in 2020 was 379,270 t, out of a total allowable catch (TAC, adjusted for carryovers) of 529,290 t. Attainment in the U.S. was 67.8% of its quota and in Canada it was 87.4%.

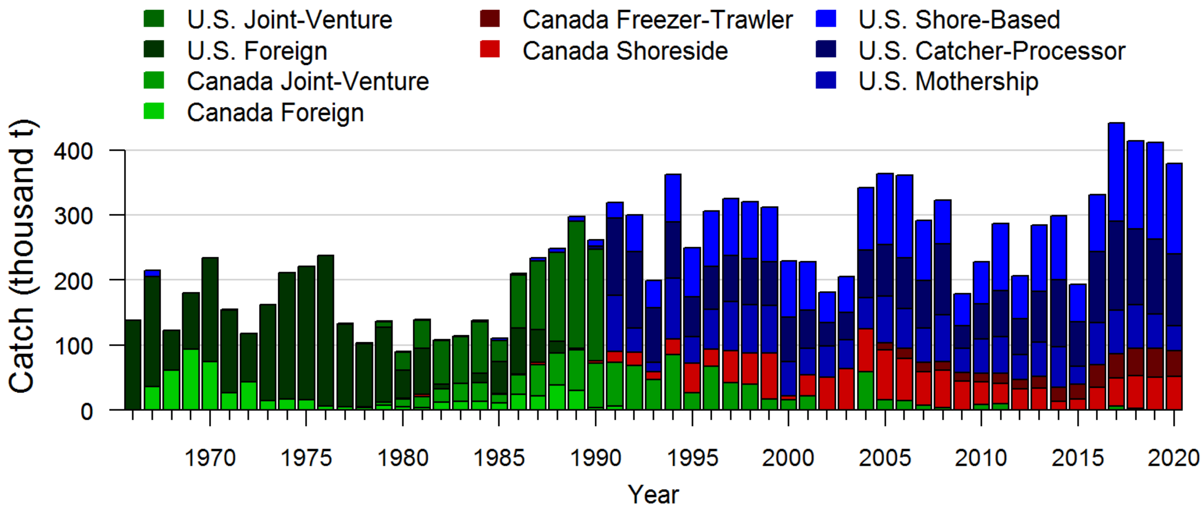

Figure a. Total Pacific Hake catch used in the assessment by sector, 1966–2020. U.S. tribal catches are included in the sectors where they are represented. CP is catcher-processor and MS is mothership.

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 is relatively small and not included in the table or model.

Year	US Mother-ship	US Catcher-Processor	US Shore-Based	US Research	US Total	CAN Joint-Venture	CAN Shoreside	CAN Freezer-Trawler	CAN Total	Total
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	148,210	0	317,002	0	50,621	43,950	94,571	411,574
2020	37,978	111,147	138,784	0	287,908	0	51,551	39,812	91,362	379,270

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 considerably above the long-term average catch (239,919 t), with the most recent four years having the highest catches on record. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal (through 2020) from that cohort estimated at approximately 1.29 million t. Through 2020, the total catch of the 2010, 2014, and 2016 year classes is estimated to be about 1.17 million t, 0.64 million t, and 0.31 million t, respectively. Landings in 2020 were most represented by the 2016 (35.23%) and 2014 (30.90%) year classes. Due to the coronavirus disease 2019 (COVID-19) pandemic, no biological samples were available from the Canadian freezer-trawler sector in 2020 because observers were not allowed on board.

DATA AND ASSESSMENT

This Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2020), acoustic survey biomass indices (Figure b) and age compositions (1995–2019), as well as fishery age compositions (1975–2020). The 2011 survey index value was the lowest in the time series and was followed by the index increasing in 2012, 2013, and again in 2015 before decreasing to near the time series average in 2017. 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 indices, acoustic survey age-composition data, and fishery age-composition data. Integrating the joint posterior distribution over model parameters provides probabilistic inferences about uncertain model parameters and forecasts derived from those parameters; this is done via Markov chain

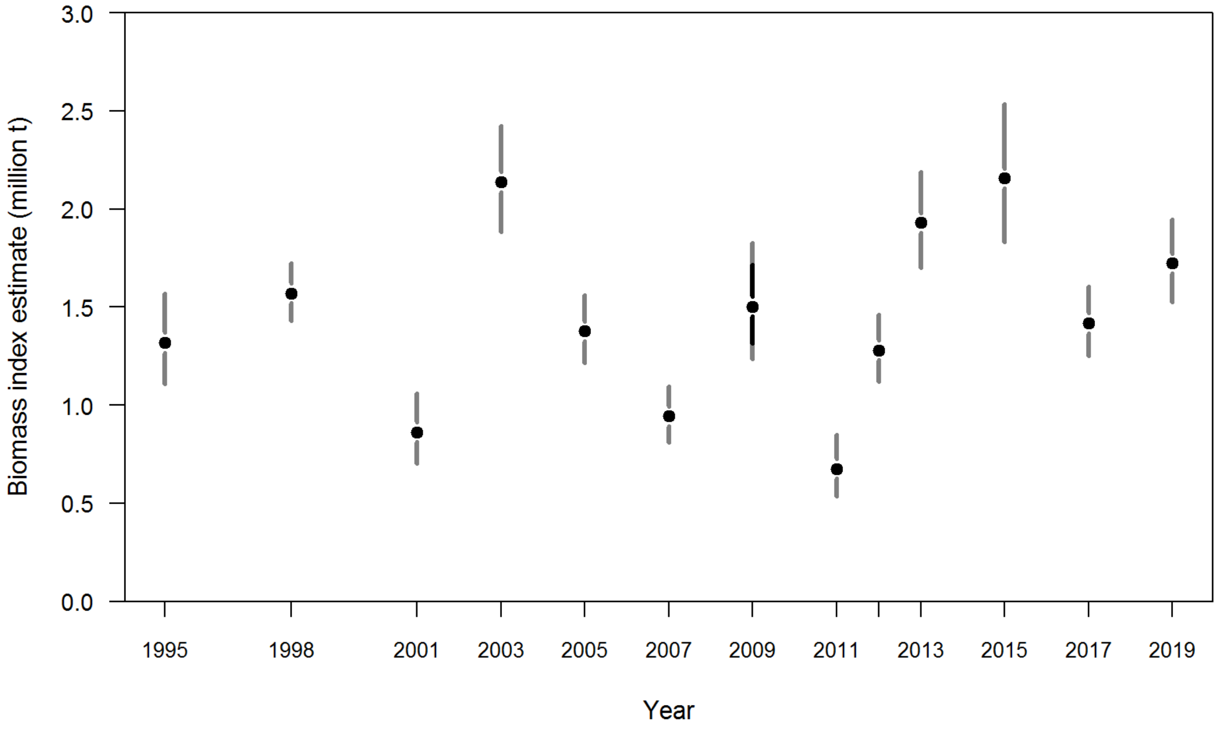

Figure b. Acoustic survey biomass indices (millions of tons). Approximate 95% confidence intervals are based on sampling variability (intervals without squid/hake apportionment uncertainty in 2009 are displayed in black). See Table 12 for values used in the base model.

Monte Carlo sampling using the efficient No-U-Turn Sampler (NUTS) that was successfully tested in the 2020 assessment. Sensitivity analyses are used to identify alternative model assumptions that may also be consistent with the data. This is the first assessment for which the sensitivity and retrospective analyses also use Bayesian estimation (rather than maximum likelihood estimation). 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 2021 assessment retains the structural form of the base assessment model from 2020 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-

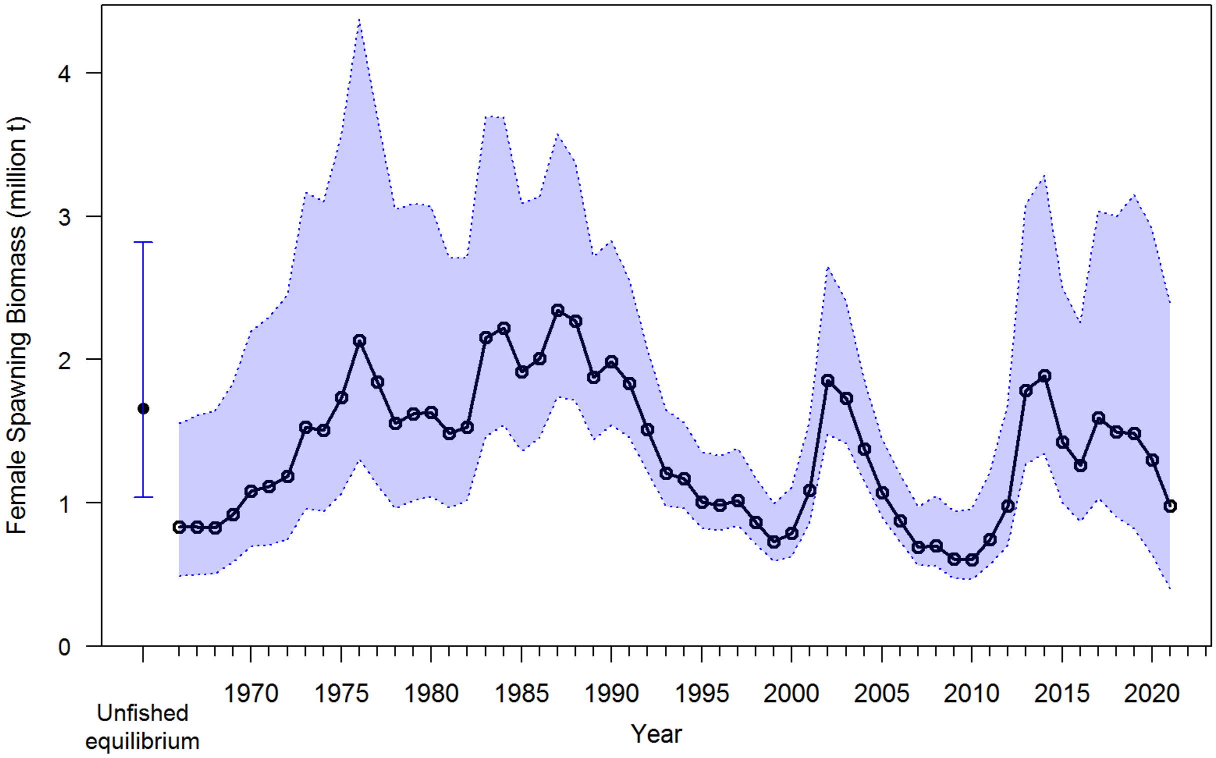

Figure c. Median of the posterior distribution for beginning of the year female spawning biomass (B_t in year t) through 2021 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

fore, we retain time-varying selectivity in this assessment. We retain the Dirichlet-multinomial estimation approach to weighting composition data. We again provide sensitivities to alternative data-weighting approaches. Time-varying fecundity, which was introduced in 2019, is retained. The weight-at-age information for the forecast period is a representation of the last five years, as for the 2020 assessment.

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 0.605 million t in 2010. Median spawning biomass is estimated to have 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

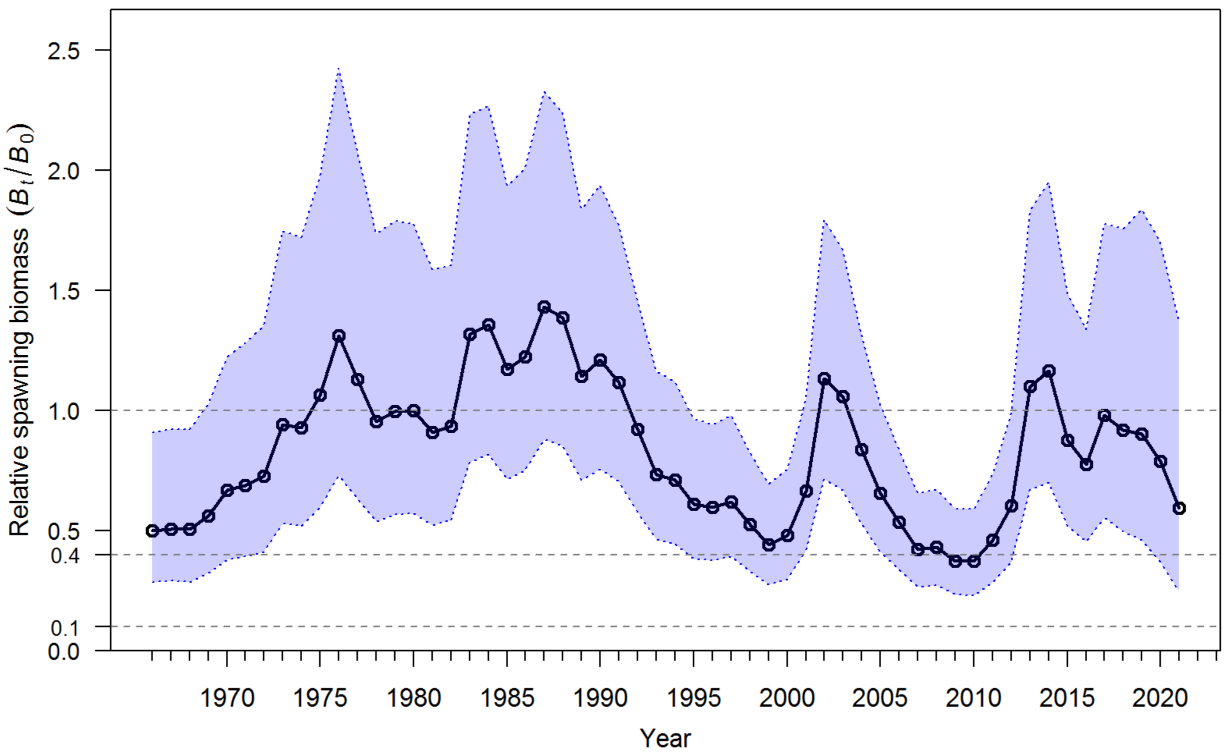

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2021 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

surpassing the age at which gains in weight from growth are greater than the loss in weight from mortality (growth-mortality transition). 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 as the 2014 year class moves through through the growth-mortality transition (and the 2010 year class continues to do so) during a time of record catches.

The median estimate of the 2021 relative spawning biomass (spawning biomass at the start of 2021 divided by that at unfished equilibrium, B_0) is 59%. However, the uncertainty is large, with a 95% posterior credibility interval from 25% to 137% (Table b). The median estimate of the 2021 female spawning biomass is 0.981 million t (with a 95% posterior credibility interval from 0.404 to 2.388 million t). The current estimate of the 2020 female spawning biomass is 1.300 (0.637–2.914) million t. This is a slightly higher median and broader credibility interval than the 1.196 (0.550–2.508) million t estimated in the 2020 assessment.

RECRUITMENT

The new data available and implementation of NUTS for this assessment do not significantly change the pattern of recruitment estimated in recent assessments. However, estimates of absolute recruitment for some recent years have slightly changed. For example, this assessment's median estimate of the 2014 recruitment is 0.5 billion fish lower than in last year's assessment (a 5% re-

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
2012	706.8	976.4	1,686.1	36.8%	60.3%	99.0%
2013	1,275.7	1,785.3	3,084.8	67.1%	110.0%	183.4%
2014	1,342.4	1,889.4	3,286.2	70.2%	116.3%	195.0%
2015	1,000.5	1,424.0	2,501.4	52.0%	87.6%	148.5%
2016	868.0	1,260.2	2,259.0	45.3%	77.4%	133.6%
2017	1,034.4	1,593.2	3,038.2	55.3%	97.9%	177.6%
2018	900.2	1,497.9	3,000.2	49.6%	91.7%	175.6%
2019	818.8	1,486.1	3,153.2	46.2%	90.3%	183.6%
2020	636.6	1,299.5	2,913.6	36.9%	78.8%	170.2%
2021	404.1	980.9	2,388.5	24.6%	59.2%	137.0%

Table c. Estimates of recent recruitment (millions of age-0 fish) 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
2011	171.0	442.2	1,078.8	-1.531	-0.570	0.192
2012	910.9	1,542.7	3,160.5	0.091	0.655	1.204
2013	106.5	336.1	921.7	-2.103	-0.926	-0.049
2014	5,355.2	8,908.3	18,744.6	1.773	2.354	2.944
2015	8.7	42.4	188.1	-4.526	-3.008	-1.560
2016	2,407.4	4,827.9	11,806.5	1.042	1.768	2.512
2017	771.6	2,133.2	6,142.2	-0.078	0.924	1.879
2018	17.1	179.1	1,719.4	-3.859	-1.557	0.576
2019	35.0	664.7	11,503.4	-3.117	-0.227	2.522
2020	42.3	820.1	17,452.2	-2.978	-0.018	2.970

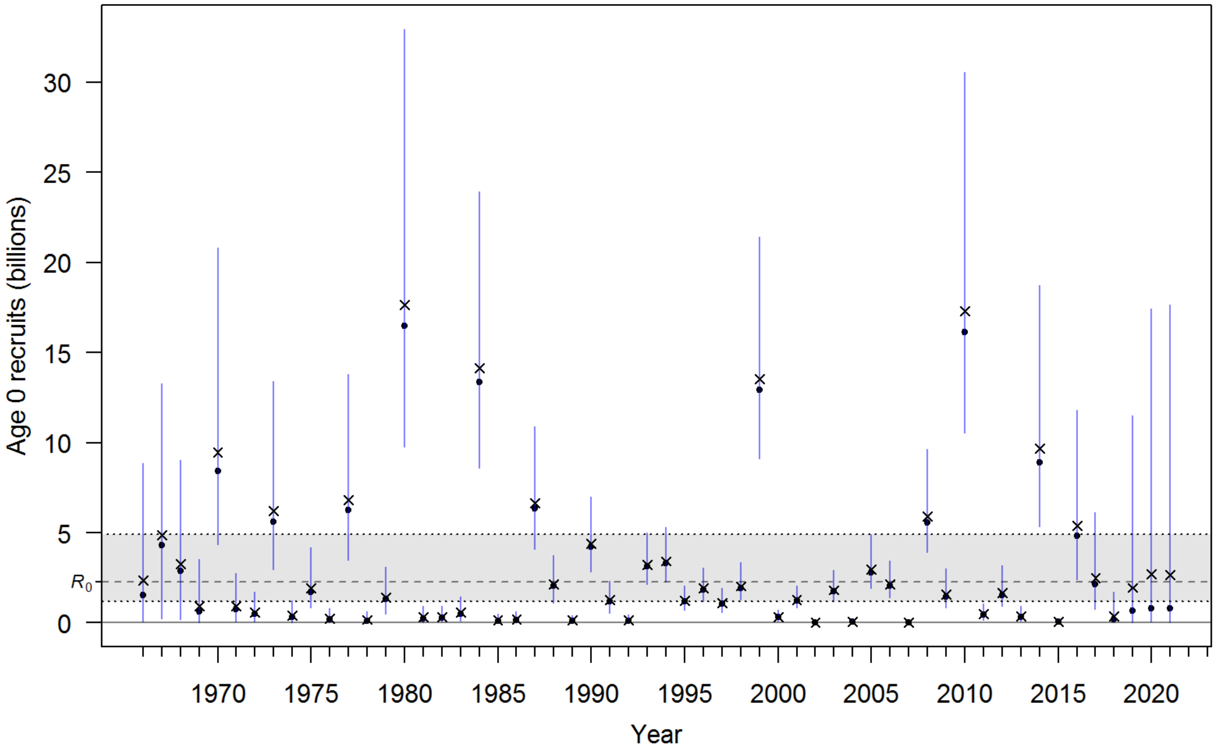

Figure e. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with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

duction). Similarly, estimates for 2016 and 2018 have changed by +6% and -50%, respectively, but the general notion remains that the 2016 cohort is above average and the 2018 cohort is well below average.

Pacific Hake appear to have low to moderate 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. Current estimates continue to indicate 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 (all unchanged from last year's assessment), and 15% of the 2020 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 46% probability that the 2010 year class is larger than the 1980 year class (this probability was 36% 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**
2011	0.573	0.871	1.160	0.099	0.162	0.213
2012	0.399	0.665	0.936	0.030	0.053	0.074
2013	0.390	0.638	0.850	0.041	0.071	0.099
2014	0.362	0.608	0.835	0.042	0.073	0.102
2015	0.245	0.455	0.679	0.031	0.055	0.078
2016	0.429	0.726	1.005	0.044	0.081	0.120
2017	0.455	0.779	1.137	0.069	0.132	0.205
2018	0.422	0.747	1.091	0.055	0.111	0.186
2019	0.416	0.749	1.102	0.053	0.114	0.209
2020	0.342	0.659	0.986	0.056	0.126	0.260

The 2014 and 2016 year classes are likely both larger than average, however there is a very high chance (99%) that 2014 is larger than 2016. There is very little information in the data to estimate the size of the 2019 year class because the 2019 acoustic survey did not sample age-0 fish and the 2020 fishery largely did not encounter this year class. There is no information in the data to estimate the sizes of the 2020 and 2021 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 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 similar levels 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 92.7% in 2010 to 45.5% in 2015, and then it leveled off around 75% from 2016 to 2019 before dropping to 65.9% in 2020. The exploitation fraction has increased from a

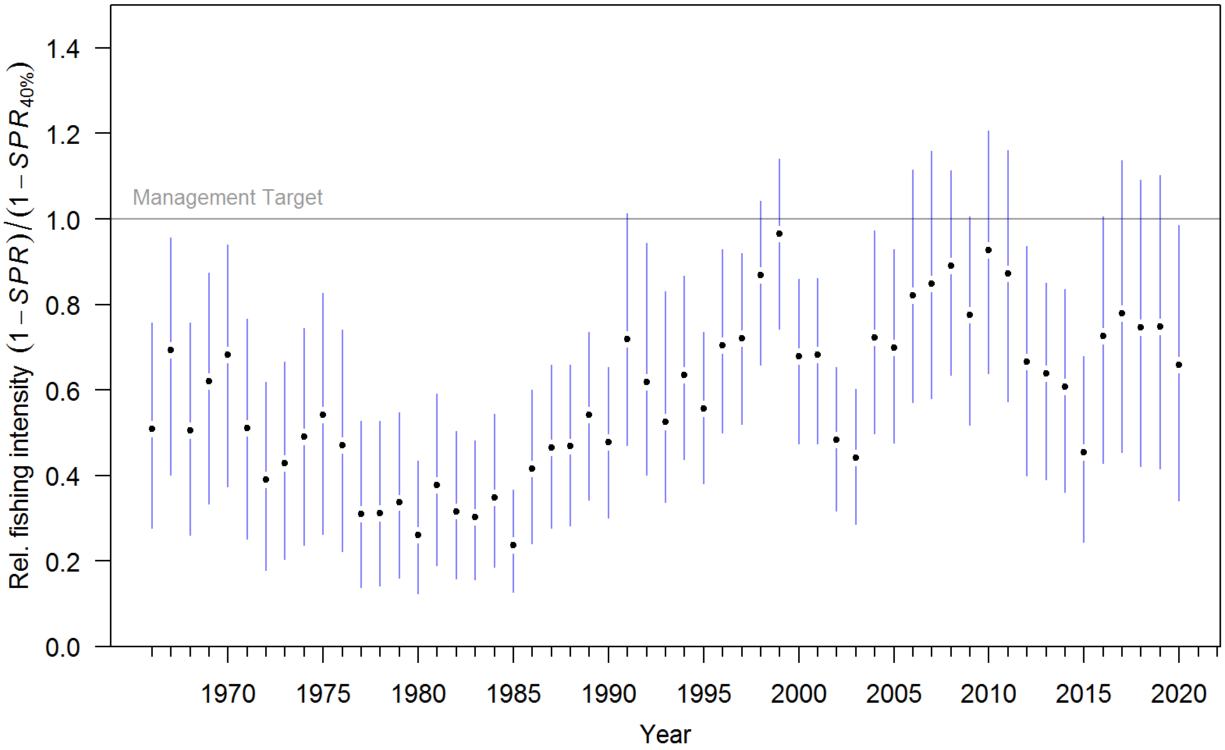

Figure f. Trend in median relative fishing intensity (relative to the SPR management target) through 2020 with 95% posterior credibility intervals. The management target defined in the Joint U.S.-Canada Agreement for Pacific Hake is shown as a horizontal line at 1.0.

recent low of 0.05 in 2012 to 0.13 in 2017 and has remained relatively stable since then (dropping no further than 0.11). 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 (2011–2020), the mean coast-wide utilization rate (proportion of catch target removed) has been 69.8% (Table e). Over the last five years (2016 to 2020), the mean utilization rates were 72.7% for the United States and 63.7% for Canada. However, country-specific quotas (or catch targets) in 2020 were specified unilaterally, due to the lack of an agreement on a coast-wide 2020 TAC. The U.S. catch target was 80.26% of the total coast-wide catch target, and the Canada catch target was 19.74%. These percentages are different to the usual 73.88% and 26.12% as specified in the Joint U.S.-Canada Agreement for Pacific Hake.

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.

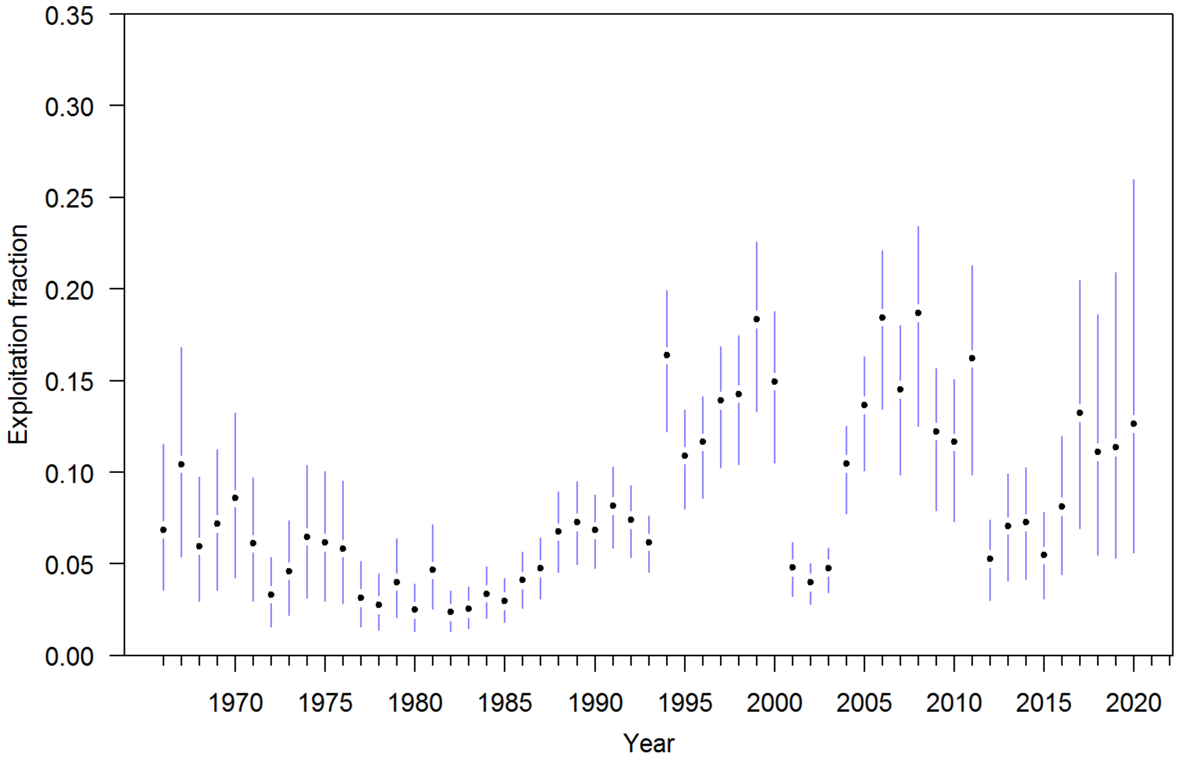

Figure g. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2020 with 95% posterior credibility intervals.

Table e. Recent trends in Pacific Hake landings and management decisions. Catch targets in 2020 were specified unilaterally.

Year	U.S. landings (t)	Canada landings (t)	Total landings (t)	U.S. proportion of total catch	Canada proportion of total catch	U.S. catch target (t)	Canada catch target (t)	Coast-wide catch target (t)	U.S. proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2011	231,261	56,073	287,334	80.5%	19.5%	290,903	102,848	393,751	79.5%	54.5%	73.0%
2012	160,144	47,059	207,203	77.3%	22.7%	186,036	65,773	251,809	86.1%	71.5%	82.3%
2013	233,578	52,249	285,828	81.7%	18.3%	269,745	95,367	365,112	86.6%	54.8%	78.3%
2014	264,141	35,118	299,259	88.3%	11.7%	316,206	111,794	428,000	83.5%	31.4%	69.9%
2015	154,160	39,684	193,844	79.5%	20.5%	325,072	114,928	440,000	47.4%	34.5%	44.1%
2016	262,327	69,743	332,070	79.0%	21.0%	367,553	129,947	497,500	71.4%	53.7%	66.7%
2017	354,229	86,721	440,950	80.3%	19.7%	441,433	156,067	597,500	80.2%	55.6%	73.8%
2018	318,306	95,413	413,719	76.9%	23.1%	441,433	156,067	597,500	72.1%	61.1%	69.2%
2019	317,002	94,571	411,574	77.0%	23.0%	441,433	156,067	597,500	71.8%	60.6%	68.9%
2020	287,908	91,362	379,270	75.9%	24.1%	424,810	104,480	529,290	67.8%	87.4%	71.7%

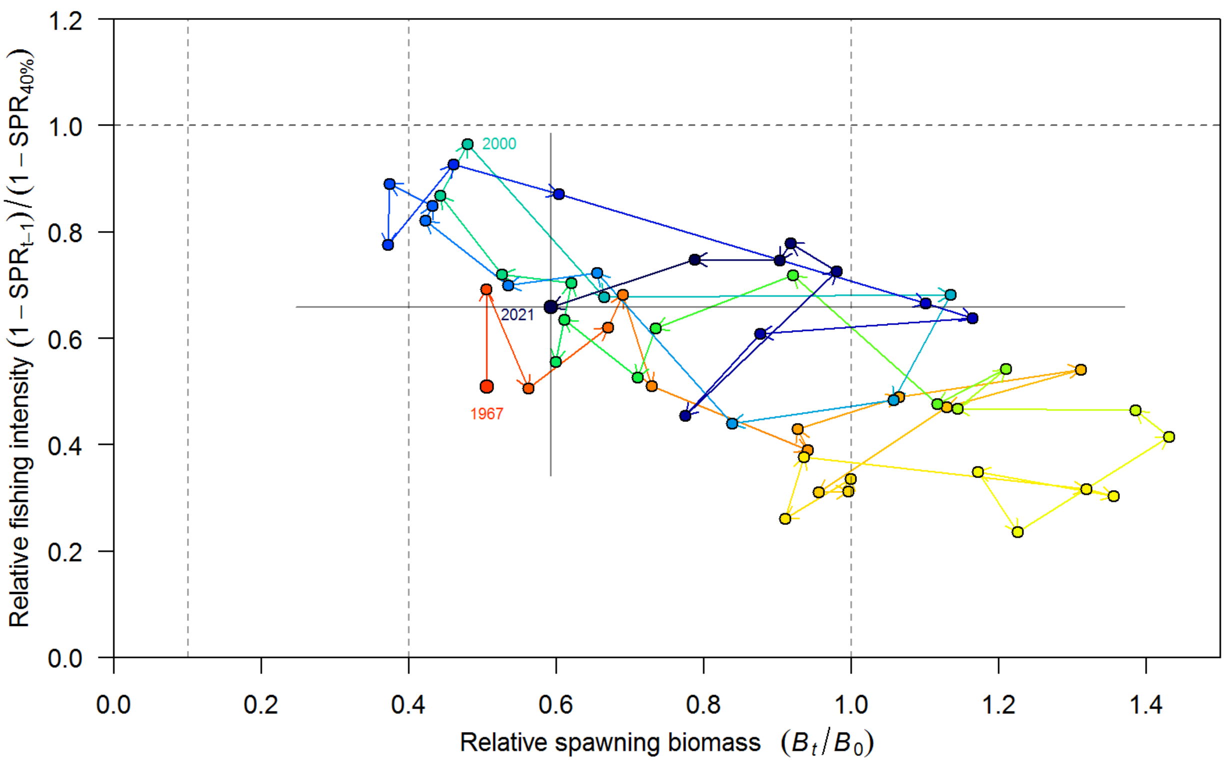

Figure h. Estimated historical path of median relative spawning biomass in year *t* and corresponding median relative fishing intensity in year $t-1$. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year *t* (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2021 relative spawning biomass (horizontal) and 2020 relative fishing intensity (vertical).

The median relative fishing intensity was below target in all years (Figures f and h). The median relative female spawning biomass was above the $B_{40\%}$ reference point in all years except 2009 and 2010 (Figures d and h). As such, the median relative fishing intensity has never been above the target of 1.0 when the female spawning biomass is below the reference point of $B_{40\%}$ (Figure h). This highlights the highly dynamic nature of the stock due to high variation in recruitment strength. The target fishing mortality ($F_{\mathrm{SPR}=40\%}$) and $B_{40\%}$ result in different population sizes (see Table f), highlighting that there are subtle differences in these conceptual reference points. Between 2007 and 2010, median relative fishing intensity ranged from 78% to 93% and median relative spawning biomass between 0.37 and 0.43. Biomass has risen from the 2010 low with the 2008, 2010, 2014, and 2016 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 1.7% joint probability of being both above the target relative fishing intensity in 2020 and below the $B_{40\%}$ relative spawning biomass level at the start of 2021.

Table f. Summary of median and 95% credibility intervals of equilibrium conceptual reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1975–2020 averages for mean weight-at-age and baseline selectivity-at-age (1966–1990; prior to time-varying deviations).

Quantity	**2.5^{th} percentile**	**Median**	**97.5^{th} percentile**
Unfished female spawning biomass (B_0, thousand t)	1,036	1,658	2,818
Unfished recruitment (R_0, millions)	1,201	2,264	4,935
Reference points (equilibrium) based on $F_{\text{SPR}=40\%}$			
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	332	584	999
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	16.0%	18.3%	21.0%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	148	275	530
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	415	663	1,127
SPR at $B_{40\%}$	40.6%	43.6%	51.6%
Exploitation fraction resulting in $B_{40\%}$	12.2%	16.1%	19.3%
Yield at $B_{40\%}$ (thousand t)	147	269	518
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	254	426	789
SPR at MSY	22.4%	30.0%	47.0%
Exploitation fraction corresponding to SPR at MSY	14.4%	25.5%	35.0%
MSY (thousand t)	153	290	568

REFERENCE POINTS

The term reference points is used throughout this document to describe common conceptual summary metrics. The Treaty specifically identifies $F_{\text{SPR}=40\%}$ as the default harvest rate and $B_{40\%}$ as a point where the 40:10 TAC adjustment is triggered (see the Glossary in Appendix C). Estimates of the 2021 base model reference points with posterior credibility intervals are in Table f. The medians of sustainable yields and biomass reference points are almost 9% lower than in the 2020 assessment. This is a result of increasing the effective sample size used to describe the posterior distributions of model parameters, leading to more accurate point estimates. The probability that spawning biomass at the beginning of 2021 is below $B_{40\%}$ is $\text{P}(B_{2021} < B_{40\%}) = 17.8\%$, and of being below $B_{25\%}$ is $\text{P}(B_{2021} < B_{25\%}) = 2.7\%$. The probability that the relative fishing intensity was above its target of 1.0 at the end of 2020 is 2.1%.

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 and present the key ones in the main document.

We also present detailed results for a model that includes the age-1 survey index and for the base model with Bayesian estimation performed using the random walk Metropolis Hastings algorithm (as used in previous assessments).

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 observed by the fishery and survey, typically at minimum age-3). Further, the interaction among variance parameters that govern variability in fishery selectivity and recruitment parameters through time, as well as those used in relative data weighting, is not well understood and could propagate uncertainty beyond what is presented in this assessment.

FORECAST DECISION TABLES

The catch limit for 2021 based on the default $F_{\text{SPR}=40\%}$–40:10 harvest policy has a median of 565,191 t with a wide range of uncertainty, the 95% credibility interval being 181,094–1,649,905 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 (2016–2020); and all other parameters as constant.

A relative fishing intensity above 1 (or 100% when shown as a percentage) indicates fishing greater than the $F_{\text{SPR}=40\%}$ default harvest rate catch target. This can happen for the median relative fishing intensity in projected years because the $F_{\text{SPR}=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of fishing in excess of the default harvest policy. Alternative catch levels where median relative fishing intensity is 100% for three years of projections are provided for comparison (scenario 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, g), including catch similar to 2020 (row d), to the (unilaterally summed) TAC from 2020 (row f), and to the TAC from 2019 (row g); and non-constant catch levels that result in a median relative fishing intensity of 100% (row h), median catch estimated via the default harvest policy ($F_{\text{SPR}=40\%}$–40:10, row i), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2021 and 2022 (row j). Catch in 2023 does not impact the beginning of the year biomass in 2023.

Within model quantile			5%	25%	50%	75%	95%
Management Action			Beginning of year relative spawning biomass				
	Year	Catch (t)					
a:	2021	0	28%	45%	59%	80%	120%
	2022	0	28%	44%	58%	80%	124%
	2023	0	29%	45%	61%	85%	145%
b:	2021	180,000	28%	45%	59%	80%	120%
	2022	180,000	24%	39%	54%	75%	118%
	2023	180,000	21%	36%	52%	75%	135%
c:	2021	350,000	28%	45%	59%	80%	120%
	2022	350,000	19%	35%	49%	70%	114%
	2023	350,000	12%	28%	43%	66%	126%
d:	2021	380,000	28%	45%	59%	80%	120%
2020	2022	380,000	19%	34%	48%	69%	113%
catch	2023	380,000	11%	26%	42%	64%	124%
e:	2021	430,000	28%	45%	59%	80%	120%
	2022	430,000	17%	33%	47%	68%	111%
	2023	430,000	9%	24%	39%	62%	121%
f:	2021	529,290	28%	45%	59%	80%	120%
2020	2022	529,290	15%	30%	44%	65%	109%
TAC	2023	529,290	7%	19%	34%	57%	117%
g:	2021	597,500	28%	45%	59%	80%	120%
2019	2022	597,500	13%	29%	42%	63%	107%
TAC	2023	597,500	7%	16%	31%	53%	113%
h:	2021	498,958	28%	45%	59%	80%	120%
FI=	2022	401,394	16%	31%	45%	66%	110%
100%	2023	345,712	8%	23%	39%	61%	121%
i:	2021	565,191	28%	45%	59%	80%	120%
default	2022	427,836	14%	29%	43%	64%	108%
HR	2023	353,096	7%	21%	36%	58%	118%
j:	2021	457,534	28%	45%	59%	80%	120%
C2021=	2022	457,506	17%	32%	46%	67%	111%
C2022	2023	371,194	8%	23%	38%	60%	120%

Table h. Forecast quantiles of Pacific Hake relative fishing intensity (1-SPR)/(1-SPR$_{40\%}$), expressed as a percentage, for the 2021–2023 catch alternatives presented in Table g. Values greater than 100% indicate relative fishing intensities greater than the $F_{\mathrm{SPR}=40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile Management Action			5%	25%	50%	75%	95%
	Year	Catch (t)			**Relative fishing intensity**		
a:	2021	0	0%	0%	0%	0%	0%
	2022	0	0%	0%	0%	0%	0%
	2023	0	0%	0%	0%	0%	0%
b:	2021	180,000	30%	44%	57%	70%	92%
	2022	180,000	29%	46%	59%	74%	99%
	2023	180,000	27%	45%	59%	76%	104%
c:	2021	350,000	49%	69%	84%	99%	121%
	2022	350,000	50%	74%	91%	108%	135%
	2023	350,000	47%	75%	95%	116%	143%
d:	2021	380,000	52%	73%	88%	103%	124%
2020	2022	380,000	53%	78%	95%	113%	139%
catch	2023	380,000	50%	80%	100%	122%	144%
e:	2021	430,000	57%	78%	93%	108%	129%
	2022	430,000	58%	84%	101%	120%	143%
	2023	430,000	56%	87%	108%	130%	146%
f:	2021	529,290	65%	87%	103%	117%	137%
2020	2022	529,290	67%	95%	113%	131%	145%
TAC	2023	529,290	65%	99%	122%	139%	147%
g:	2021	597,500	70%	92%	108%	122%	141%
2019	2022	597,500	73%	101%	120%	137%	146%
TAC	2023	597,500	70%	106%	129%	141%	147%
h:	2021	498,958	63%	85%	100%	115%	135%
FI=	2022	401,394	56%	82%	100%	119%	143%
100%	2023	345,712	48%	78%	100%	123%	145%
i:	2021	565,191	68%	90%	105%	120%	139%
default	2022	427,836	59%	86%	104%	124%	144%
HR	2023	353,096	49%	80%	103%	128%	145%
j:	2021	457,534	59%	81%	96%	111%	132%
C2021=	2022	457,506	61%	87%	105%	123%	144%
C2022	2023	371,194	51%	81%	103%	127%	145%

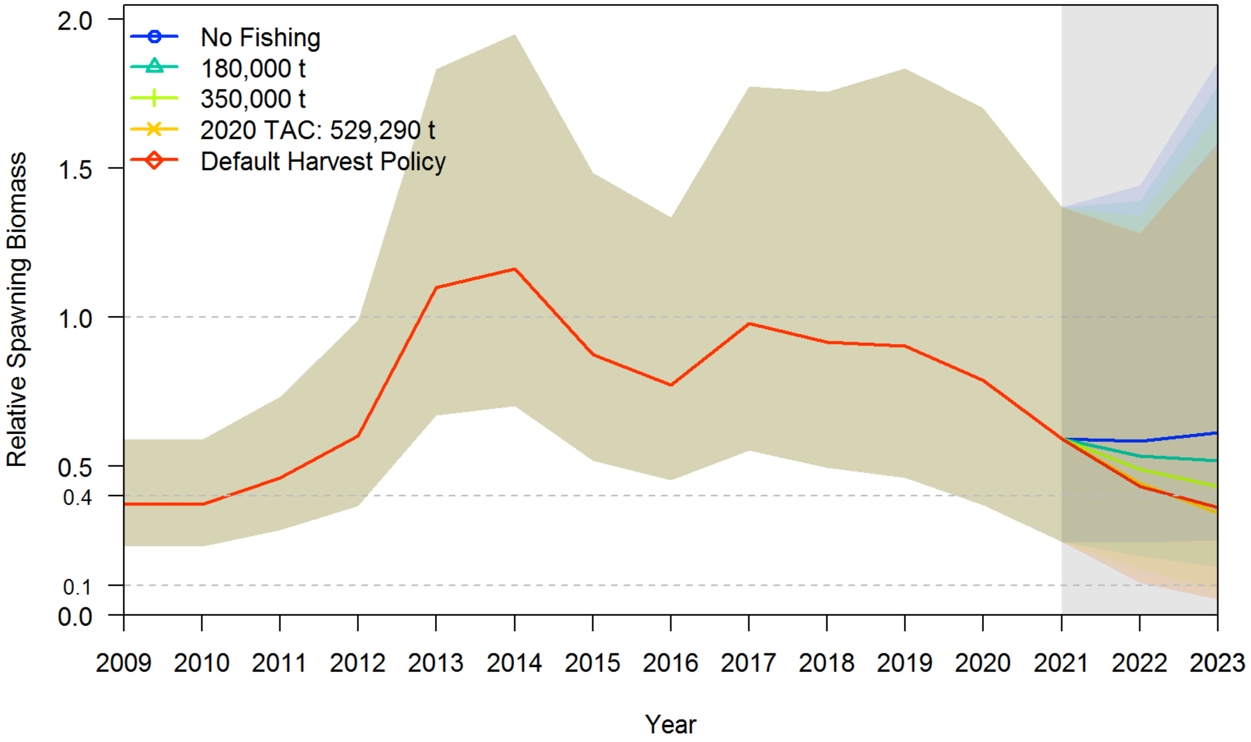

Figure i. Time series of estimated relative spawning biomass to 2021 from the base model, and forecast trajectories to 2023 (grey region) for several management actions defined in Table g, with 95% posterior credibility intervals.

Management metrics that were identified as important to the Joint Management Committee and the Advisory Panel in 2012 are presented for 2022 and 2023 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 2021 (Table i and Figure j). However, interpolation is not appropriate for all catches in 2022 because catch alternatives h and i have catches that are >430,000 t (the constant catch for alternative e) in 2021 but <430,000 t in 2022. This explains why a few probabilities decline (rather than rise) with increased 2022 catch levels in Table j and Figure k.

The predicted relative spawning biomass trajectory through 2023 is shown in Figure i for several of the management actions. With zero catch for the next two years, the biomass has a 65% probability of decreasing from 2021 to 2022 (Table i) and a 52% probability of decreasing from 2022 to 2023 (Table j).

The probability of the spawning biomass decreasing from 2021 to 2022 is over 65% for all catch levels (Table i and Figure j). It is 86% for the 2021 catch level similar to that for 2020 (catch alternative d). For all explored catches, the maximum probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2022 is 2%, and of dropping below $B_{40\%}$ is 46% (Table i and Figure j). As the large 2010 and 2014 cohorts continue to age, their biomass is expected to decrease as losses

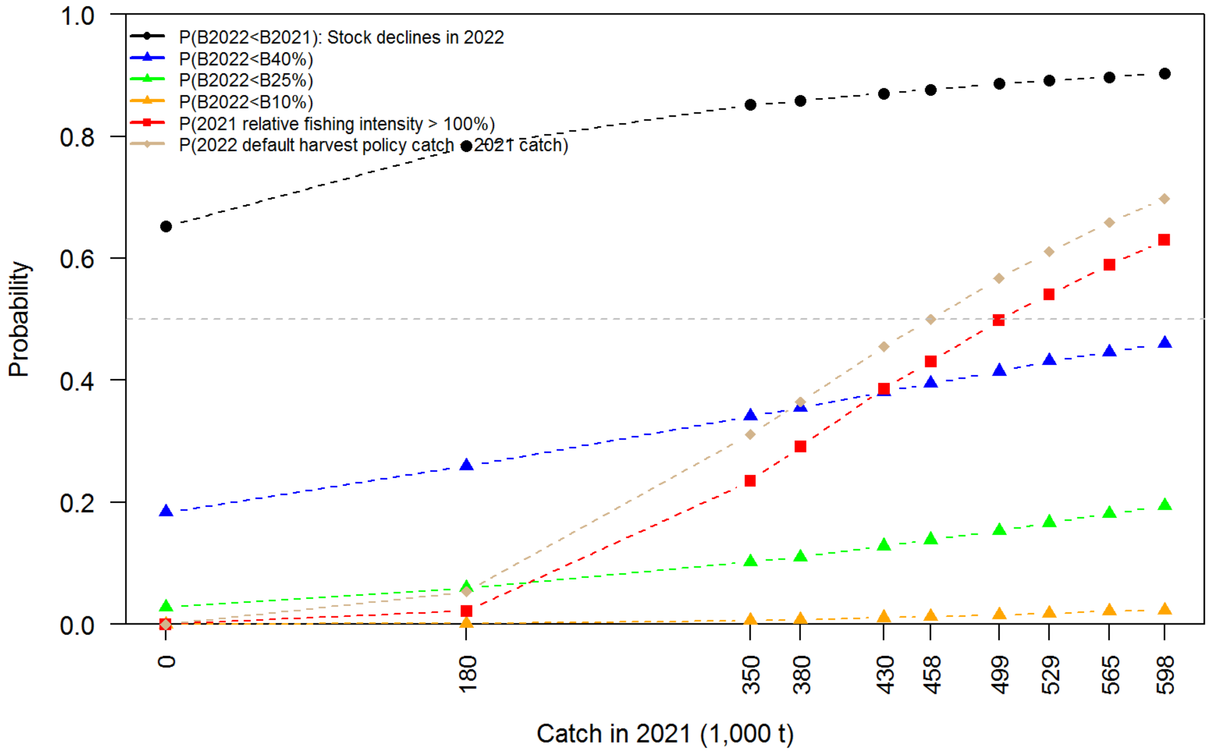

Figure j. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (explained in Table g) as listed in Table i. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table i. Probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 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	65%	18%	3%	0%	0%	0%
b: 180,000	78%	26%	6%	0%	2%	5%
c: 350,000	85%	34%	10%	1%	23%	31%
d: 380,000	86%	36%	11%	1%	29%	36%
e: 430,000	87%	38%	13%	1%	39%	46%
f: 529,290	89%	43%	17%	2%	54%	61%
g: 597,500	90%	46%	19%	2%	63%	70%
h: 498,958	89%	41%	15%	2%	50%	57%
i: 565,191	90%	45%	18%	2%	59%	66%
j: 457,534	88%	40%	14%	1%	43%	50%

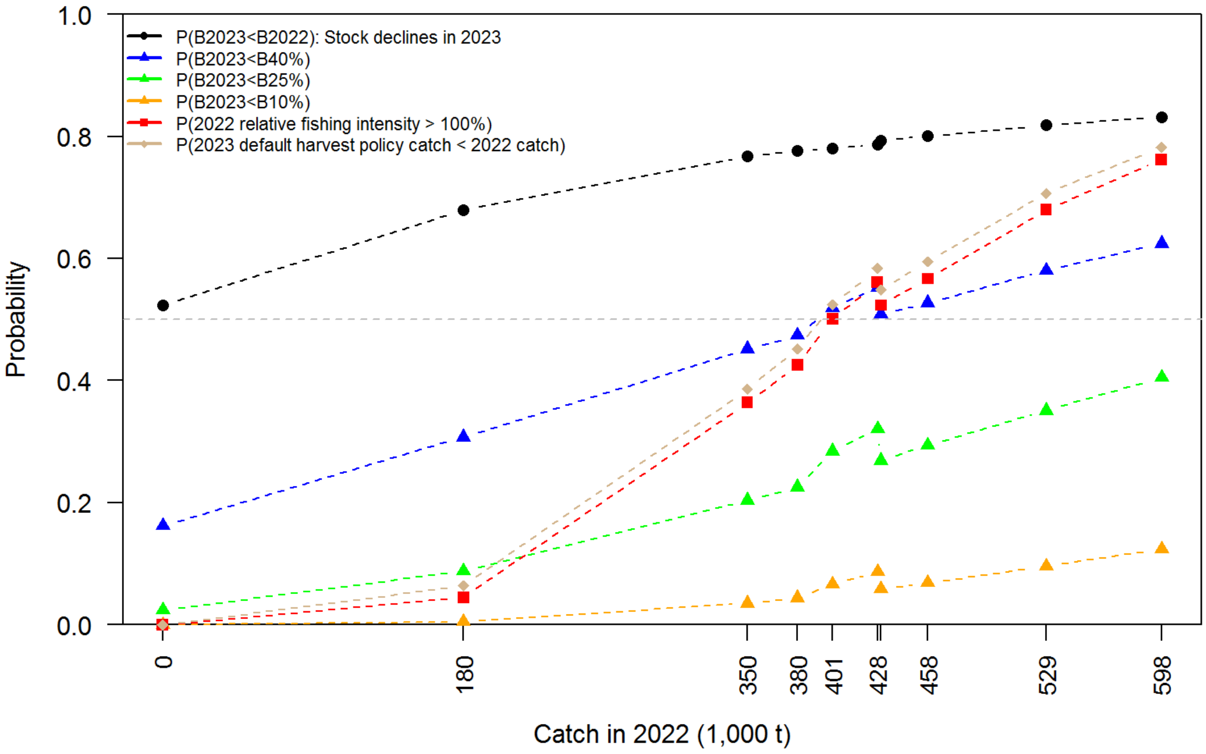

Figure k. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2023 default harvest policy catch for alternative 2022 catch options (including associated 2021 catch; catch options explained in Table g) as listed in Table j. The symbols indicate 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 2023 default harvest policy catch for alternative 2022 catch options, given the 2021 catch level shown in Table i (catch options explained in Table g).

Catch in 2022	Probability $B_{2023} < B_{2022}$	Probability $B_{2023} < B_{40\%}$	Probability $B_{2023} < B_{25\%}$	Probability $B_{2023} < B_{10\%}$	Probability 2022 relative fishing intensity > 100%	Probability 2023 default harvest policy catch < 2022 catch
a: 0	52%	16%	2%	0%	0%	0%
b: 180,000	68%	31%	9%	0%	4%	6%
c: 350,000	77%	45%	20%	4%	36%	39%
d: 380,000	78%	47%	23%	4%	43%	45%
e: 430,000	79%	51%	27%	6%	52%	55%
f: 529,290	82%	58%	35%	10%	68%	71%
g: 597,500	83%	62%	40%	12%	76%	78%
h: 401,394	78%	52%	28%	7%	50%	52%
i: 427,836	79%	55%	32%	9%	56%	58%
j: 457,506	80%	53%	29%	7%	57%	59%

from mortality outweigh increases from growth. The smaller but above-average 2016 cohort is entering this growth-mortality transition period, suggesting that its overall biomass will also decrease as it continues to age.

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 the investigation of links between hake biomass, spatial distribution, and recruitment 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 and the basic understanding of drivers of hake population dynamics and availability to fisheries and surveys. Related, there is a need to streamline and broaden the availability of products from oceanographic models (e.g., Regional Ocean Modeling System; ROMS) so that they are available stock-wide and can be used on a recurring 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. Utilize and adapt this simulation framework to address new and ongoing stock assessment research and data needs through the Pacific Hake MSE Working Group.

3. Document the existing survey methodologies, protocols, and adaptive survey-design decisions that lead to the development of Pacific Hake biomass and age-composition estimates used in the stock assessment. Such documentation will ensure transparency, enable repeatability, and provide a record of changes in procedures over time. Also, continue to conduct research to improve the estimation of age composition and abundance from data collected during the acoustic survey. This includes, but is not limited to, research on species identification, target verification, target strength, implications of the south-to-north directionality of the survey, alternative technologies to assist in the survey, and efficient analysis methods. The latter should include bootstrapping of the acoustic survey time series or related methods that can incorporate relevant uncertainties into the calculations of survey variance. Relevant uncertainties include topics such as the target strength relationship, subjective scoring of echograms, thresholding methods, and methods to estimate the species-mix that are used to interpret the acoustic backscatter. Continue to work with acousticians and survey personnel from the Northwest Fisheries Science Center and Fisheries and Oceans Canada to determine optimal survey designs given constraints, including designs that incorporate ecosystem-based factors and other potential target species (e.g., rockfish, euphausiids, and mesopelagics) for the Joint U.S. and Canadian Integrated Acoustic and Trawl Survey.

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 tenth 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 2021 base model, implemented using version 3.30.16.03 of the Stock Synthesis software (Methot and Wetzel, 2013), are the same as the 2020 base model (Grandin et al., 2020). The Bayesian estimation is computed using a new efficient approach that was successfully tested in last year's assessment (Grandin et al., 2020). Consequently, for the first time, all sensitivity analyses and retrospective runs are performed in a Bayesian context rather than just using maximum likelihood estimation. Responses to 2020 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. 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 in 1998), a larger proportion of the stock migrates into Canadian waters (Figure 2), due to temperature effects (Malick et al., 2020*a*) and possibly 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). In general, warmer than average thermal habitat conditions for mature Pacific Hake leads to higher biomass further north and lower biomass around the U.S-Canadian border, while cooler than average conditions leads to higher biomass of immature Pacific Hake coast-wide (Malick et al., 2020*a*). The distribution of age-1 fish also changes between years (Figure 3).

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; Malick et al., 2020*a*,*b*). The 2015 Pacific Hake stock assessment document presented a sensitivity analysis where hake mortality was linked to the Humboldt Squid index (Taylor et al., 2015). This sensitivity was not repeated in this assessment, although further research on this topic is needed. Ongoing research investigating abiotic (environmental conditions) and biotic (e.g., euphausiid distribution and abundance) drivers of hake distribution, recruitment, and survival could provide insight into how the hake population is linked with broader ecosystem considerations. For example, Turley and Rykaczewski (2019) found decreased survival of larval Pacific Hake as storm events increased, contrary to many other species in the southern California Current Ecosystem. 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 2005. However, a bilateral agreement on the coast-wide TAC could not be reached in 2020, and thus, catch targets were set unilaterally for the first time since the inception of the Agreement.

Throughout the last decade, the total coast-wide catch has tracked harvest targets reasonably well. Since 1999, catch targets have been calculated 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 coast-wide quota, and harvest rates have not exceeded 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 suggested based upon 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*), depleted rockfish stocks (though, all but yelloweye rockfish, *Sebastes ruberrimus*, have rebuilt in recent years), and other species as related to their specific harvest specifications. 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 amount 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 (including the 2020 fishing season, despite the COVID-19 pandemic).

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 (usually 26.12%) of the TAC as quota to individual license holders. In 2020, Canadian hake fishermen were allocated a TAC of 104,480 t, including 18,193 t of uncaught carryover fish from 2019. 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 2020, 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. However, due to the COVID-19 pandemic, observers were not allowed to board freezer trawler vessels for the entirety of the hake fishing season. All shoreside hake landings are usually subject to 100% verification by the groundfish Dockside Monitoring Program (DMP), but these were also impacted by the COVID-19 pandemic and fewer samples than usual were taken.

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 and has met the Marine Stewardship Council (MSC) Fisheries Standard to be certified as meeting sustainable fishing benchmarks since 2009. 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. In Canada, 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 in product mainly to Ukraine, China, South Africa and Lithuania (DFO, 2020).

In the US, over US$72 million in wages is estimated to have been paid to employees in 2018 (https://dataexplorer.northwestscience.fisheries.noaa.gov/fisheye/PerformanceMetrics/). This includes wages paid to crew and captains fishing on catcher vessels that deliver shoreside and at-sea to motherships, workers in shore-based processing facilities, crew, captains, and workers on catcher-processor vessels, and workers on mothership vessels. The exported value was US$129.5 million. The largest export volumes are to Ukraine, South Africa, and Nigeria, making up about 46% of the total (https://foss.nmfs.noaa.gov/apexfoss/f?p=215:200:2797069701321). The economic impact in terms of income resulting from whiting production on the U.S. West Coast economy is greater than the direct payments to captain, crew, and vessel owners (Leonard and Watson, 2011). Likewise, the economic impact in terms of the number of jobs created is also greater than the direct number of vessel employees. The direct effects of whiting production have ripple effects through the economy that stimulate additional income and employment among businesses that are indirectly related to the fishing industry itself. These effects include the impact on marinas, shipyards, refineries, grocery stores, etc. Including these multiplier effects, the total economic impacts of the whiting fishery on the U.S. West Coast in 2018 was estimated at US$279 million in income and 3,600 jobs.

1.4.1 Overview of the fisheries in 2020

The coast-wide TAC of 529,290 t for 2020 was specified as the sum of unilateral TAC decisions due to the lack of a bilateral agreement in 2020. The U.S. catch target was set at 424,810 t and the Canadian catch target at 104,480 t. The historical catch of Pacific Hake for 1966–2020 by nation and fishery sector is shown in Figure 4 and Tables 1–3. Table 3 also shows recent catches in relation to targets (see Section 3.4.2). A review of the 2020 fishery now follows by nation.

United States

The U.S. specified catch target (i.e., adjusted for carryovers) of 424,810 t was further divided among the research, tribal, catcher-processor, mothership, and shore-based sectors. After the tribal allocation of 17.5% (74,342 t), and a 1,500 t allocation for research catch and bycatch in non-groundfish fisheries, the 2020 non-tribal U.S. catch limit of 348,968 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 16 resulted in final quotas for the CP, MS, and shore-based sectors of 132,249 t, 93,352 t, and 163,367 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 start of the tribal fishery (September) was considerably delayed due to the COVID-19 pandemic.

The overall catch of Pacific Hake in U.S. waters was less than the past three years, but was the fourth highest value ever recorded (Table 1). Monthly catch rates in the at-sea sector were higher than in recent years for most months (Figure 5). Tribal landings available at the time of the assessment were 133 t. As in recent years, careful consideration was needed to accurately account for tribal landings. Ongoing efforts continue to work towards streamlining tribal catch reporting. The catcher-processor, mothership, and shore-based fleets caught 84.0%, 40.7%, and 85.0% of their final reallocated quotas, respectively. There was 32.2% of the total U.S. adjusted TAC that was not caught. For further details and specific impacts related to the COVID-19 pandemic see the report from the U.S. Advisory Panel (Appendix E). Thanks to serological testing of almost all crew members prior to departure, one fishing vessel that experienced an outbreak of COVID-19 provided the first direct evidence that neutralizing antibodies are protective against infection in humans, contributing to the science behind vaccine development (Addetia et al., 2020).

In both U.S. at-sea sectors (CP and MS) the most common fish in the fishery were age-4, age-6, and age-10 associated with the 2016, 2014, and 2010 year-classes. Age-2 fish were far less prevalent in the catch this year than in 2018 or 2019. Age sampling was conducted on 389 CP hauls and 186 MS hauls (Table 4). For the CP sector, the four most abundant age classes (by numbers) seen in 2020 were age-4 (40.8%), age-6 (31.7%), age-10 (11.1%), and age-3 (7.9%; Table 5). For the MS sector, the four most abundant age classes for 2020 were age-4 (40.4%), age-6 (28.4%), age-10 (11.3%), and age-3 (8.8%; Table 6). Age-samples from 96 shoreside trips showed similar age compositions in the catch with the highest occurrences being for age-4 (34.7%), age-6 (31.2%), age-10 (15.5%), and age-3 (8.5%) in 2020 (Table 7).

The at-sea fishery maintained moderately high catch rates throughout the year (Figure 5), averaging higher than in 2018 and 2019 for all months. The median fishing depth for the at-sea fleets was slightly deeper than last year, which was near average over recent years (Figure 6). From mid-June to September/October, operators in the at-sea fishery moved to their usual summer fishing grounds off the coast of Alaska in search of Bering sea Walleye Pollock. The shore-based fishery had the largest monthly catches during June, July, and August. The U.S. utilization rate (67.8%) 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 2020 Canadian Pacific Hake domestic fishery removed 91,362 t from Canadian waters, which was 87.4% of the Canadian TAC of 104,480 t. The attainment for Canada appears much higher than usual, due to Canadian managers setting a lower Canadian TAC than what would have been allotted using the usual method which is calculated as 26.12% of a bilaterally agreed-upon TAC.

The shoreside component, made up of vessels landing fresh round product onshore, landed 51,551 t. The freezer-trawler component, which freezes headed and gutted product while at sea, landed 39,812 t. There was no Joint-Venture fishery this year.

Fishing started in March and ended in early December. The general view from the Canadian fleet is that general abundance was down in 2020, especially in the shallower depths (Figure 7). When found, these aggregations appeared patchier and dissipated more quickly when put under fishing pressure than in 2019. The fish caught in Canada appeared to be mostly from one age class (600-800 gram body weight), with very few smaller fish caught.

Usually the most abundant age classes found in the freezer trawler catch are listed here, but due to COVID-19 there were no observers on board in 2020, so there were no age samples taken and therefore no representation of year-class composition from the freezer trawlers.

Every otolith sampled dockside from the shoreside fleet was aged this year, in order to make up for the loss of samples from the freezer trawlers. This kept the total number of otoliths sampled similar to other years, despite a smaller overall sample size.

The most abundant year classes in the Canadian Shoreside catch were age 6 at 30.2%, age 10 at 24.1%, age 4 at 19.8%, and age 3 at 9.6%.

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 used in this assessment (Figure 8) include the following sources:

- Total catch from all U.S. and Canadian fisheries that target hake from 1966 to 2020 (Tables 1–3).
- Age compositions aggregated by year and country for the last ten years are available (Tables 5–9) to investigate region-specific trends; age compositions aggregated by year, composed of data from the U.S. fishery (1975–2020) and the Canadian fishery (1985–2020) are used to fit the model (Table 10 and Figure 9).

- 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 11 and 12 and Figures 9 and 10). The age-1 index derived from the survey (Figure 11) is not used as data in the base model.

- Mean observed weight-at-age from fishery and survey catches (1975-2020; Figure 13) and, thus, derived fecundity-at-age as well (Figure 12).

The following biological relationships, derived from external analysis of auxiliary data, were input as fixed values in the assessment model:

- 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 13 and Figure 12).

Some data sources were not included in the base model but have been explored, used for sensitivity analyses, or were included in previous stock assessments. Data sources not discussed at all 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 following years of 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 1977–2020).

- NWFSC/Southwest Fisheries Science Center/PWCC coast-wide juvenile hake and rockfish surveys (2001–2020).

- 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.
- 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 1966–2020 is summarized by nation and fishery sector (Tables 1–3) and modeled as yearly catches. 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. 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 1991–2020 are calculated from the Alaska Fisheries Science Center (AFSC) North Pacific Groundfish and Halibut Observer (NORPAC) database, which also stores the NWFSC At-Sea Hake Observer Program data. Canadian Joint-Venture catches from 1989 are from the Groundfish Biological (GFBio) database. The 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).

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 in each codend and this is used for catch reporting. Canadian shoreside landings are recorded by dockside monitors using total catch weights provided by processing plants. Discards are negligible relative to the total fishery catch for all sectors.

For recent catches with haul or trip-level information, removals by month during the fishing season allowed for the estimation of monthly bycatch rates from observer information. This information has also allowed a detailed investigation of shifts in fishery timing (see Figure 5 in Taylor et al. 2014).

Minor updates to catches used in previous assessments were made based on the best available information extracted from the aforementioned databases. U.S. shore-based landings from 1986 were decreased by 33 t relative to previous assessments to reflect a change made in the PacFIN database years prior that is yet to be addressed in the data file. This was the most substantial change to U.S. shore-based historical catches; other years were changed less than 4 t. Tribal catches were not available in PacFIN for the U.S. tribal fishery at the time the data were extracted and 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 tribal catches will need to be provided after the fact. The Makah tribe is also working on providing historical catches such that shore-based catches can be summarized separately from tribal catches since the onset of the fishery.

2.1.2 Fishery biological data

Biological information from the U.S. at-sea fishery was extracted from the NORPAC database. This included sex, length, weight, and age information from the foreign and Joint-Venture fisheries from 1975–1990 and from the domestic at-sea fishery since 1990. Observers collect data by selecting fish randomly from each haul.

Biological samples from the U.S. shore-based fishery since 1991 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 typically 20 fish are randomly subsampled for otolith extraction. Updates to historical shore-based age compositions may be noticeable for some years compared to the last assessment because PacFIN increased the number of significant digits stored in their database, and thus more precision was available for creating these compositions.

Observers aboard Canadian freezer-trawler vessels (*Viking Enterprise, Northern Alliance, Osprey #1, Raw Spirit, Pacific Legacy #1, Sunderoey, and Viking Alliance*) sample otoliths and lengths from each haul. 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.

When there is a Canadian Joint-Venture fishery, 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. The sampled weight from which biological information is collected must be inferred from length-weight relationships.

The sampling unit for the shore-based fisheries is the trip, while the haul is the primary unit for the at-sea fisheries (Table 4). 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.

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 (1975–2020) confirm the well-known pattern of very large cohorts born in 1980, 1984, 1999, 2010, and 2014 and above average cohorts born in 1973, 1977, 1987, 2008, and 2016 (Table 10 and Figure 9). Recent age-composition data still easily track the 2010 cohort, as well as the large cohorts born since then (Table 10 and Figure 9). Currently, the 2016 cohort is the largest observed cohort in all three U.S. fleets (Tables 5–7), whereas the 2014 cohort is still the largest observed cohort in the Canadian shoreside fleet (Table 8). Canadian freezer trawlers did not carry observers in 2020 due to the COVID-19 pandemic, and thus did not collect ages in 2020. The 2010 cohort was the largest cohort observed in the Canadian freezer-trawler fleet in 2019 (Table 9). No fleet observed age-1 fish this year (Table 10). For the combined data in 2019, the 2014 cohort was the largest (32%), followed by the 2016 cohort (21%), then the 2010 cohort (19%). In 2020, the 2016 cohort was the largest (35%), followed by the 2014 cohort (31%), then the 2010 cohort (15%).

We caution that proportion-at-age data contain 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 model 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 2016.

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

2.2.1 Acoustic survey

The Joint U.S. and Canadian Integrated Acoustic and Trawl Survey (Stewart et al., 2011) has been the primary fishery-independent tool used to assess the distribution, abundance, and biology of coastal age-2+ Pacific Hake along the west coasts of the U.S. and Canada. 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 12). 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 age-2+ Pacific Hake stock. 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 their 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 used to fit the model in a sensitivity analysis.

The 2019 survey covered U.S. and Canadian waters from 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 approximately 3-5 days of the Shimada on any given transect. The utility of saildrones as a tool for Pacific Hake management is currently being evaluated.

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 because 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, distribution of Pacific Hake during the 2001 acoustic survey was compressed into the lower latitudes off the coast of Oregon and Northern California. There was a strong La Niña event in 2000. In 2003, 2005, and 2007 the distribution of Pacific Hake did not show an unusual coast-wide pattern despite 2003 and 2007 being characterized as El Niño years. 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 distribution. The distribution of Pacific Hake in 2017 was more latitudinally uniform than observed in 2015. 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). Weak 2019 El Niño conditions decreased in their prevalence starting in March 2020, leading to neutral conditions by July. Consequently, 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 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 (Malick et al., 2020*b*).

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 12 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 are analyzed using kriging, 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:

- fixed minimum (k_{min}=3) and maximum (k_{max}=10) number of points used to calculate the value in a cell;
- search radius is 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 western end of a transect, which was refined and supported by the SRG starting with the 2016 assessment (Grandin et al., 2016).

Thus, a full time series of consistently analyzed survey biomass (Table 12 and Figure 10) and age compositions (Table 11 and Figure 9) since 1995 are used to fit the stock assessment model. These data contain many sources of variability (see Stewart et al. 2011), but results from research done in 2010 and 2014 on their representativeness show that trawl sampling and post-stratification is only a small source of variability. Specifically, repeated trawls at different depths and spatial locations on the same aggregation of hake were similar and analyses regarding the method used to stratify the data led to similar overall conclusions.

Estimated age-2+ biomass in the survey increased steadily over the four surveys conducted in 2011-2013 and 2015 (Table 12 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 31.32%, 27.24%, 16.12%, 10.72%, and 3.18% from the 2014, 2016, 2010, 2017, and 2012 year classes, respectively.

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; Grandin et al., 2020) and was explored as a sensitivity (Appendix G). The age-1 index is not included in the base model because the survey is not specifically designed to representatively survey age-1 fish, and a detailed sensitivity analysis in the 2020 assessment (Grandin et al., 2020) found that its inclusion did not consistently improve estimates of recruitment and can give misleadingly optimistic forecasts. However, in this assessment 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 13 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 14). 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 Edwards et al. 2018*b* for more information). We retained the maturity ogive calculated for Edwards et al. (2018*b*), noting that additional samples are available (including samples collected from Canadian waters since 2018) but have yet to be analyzed.

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 age-15+ fish 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. Older, functionally immature fish are 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. It is the hope that these genetic samples 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 laboratory. 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, namely 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 2020 (Figure 13). Past investigations into calculating weight-at-age for the fishery and survey independently showed little impact on model results. New and historical samples were pulled from all relevant databases such that the derived matrices included the best available data. Samples from winter and research surveys are not included. Samples from the Canadian fishery are subset by area to exclude near-shore samples. Pre-1975 weight-at-age data available in the PacFIN database that were discovered during the 2018 assessment-review process were 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 (1975-2020), consistent with the 2020 base model. Both forecast weight-at-age data and forecast selectivity are based on the respective means from the most recent five years (2016–2020), 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 show that, in general, using empirical weight-at-age when many observations are available results in more accurate estimates of spawning biomass than modeling growth (Kuriyama et al., 2016).

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

Several prior distributions (Table 15) are used to fit the model. All informative priors are discussed below.

2.4.1 Natural Mortality

Since the 2011 assessment, 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 lognormal distribution with a median of -1.61 and a logarithmic standard deviation of 0.10. Sensitivity to this prior has been evaluated extensively in many previous hake assessments (see Hicks et al. 2013 for a discussion of the historical treatment of M and its prior) 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. (2018*b*) in detail.

For each age $a \geq A_{\text{min}}$, where A_{min} is the minimum age for which selectivity is allowed to be non-zero, there is an incremental selectivity parameter, p_a, for the fishery (for which $A_{\text{min}} = 1$). There is also an equivalent p_a for the survey (for which $A_{\text{min}} = 2$), 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

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

where

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

and

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

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

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 (age 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, $p_{A_{\text{min}}} = 0$ 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 fishery 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

$$-\log(\mathrm{L}) \propto \frac{1}{2} \sum_{a=A_{\min}}^{6} \sum_{y=1991}^{2020} \frac{\varepsilon_{ay}^2}{\Phi^2}, \tag{5}$$

where Φ is the standard deviation of the normal penalty function.

A parameterization for selectivity deviations was explored (Edwards et al., 2018*b*; Berger et al., 2019) based on 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 is believed to be 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 and the survey-composition data, respectively. 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 $\log \theta_{\text{surv}}$ was fixed at the estimate from a maximum likelihood estimate (MLE) run (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 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}.

The likelihood function for the D-M likelihood (see Equation 10 of Thorson et al. (2017)) is

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

where $\tilde{\pi}_a$ is the observed proportion at age a, π_a is the corresponding expected proportion at age a estimated by the model, $\tilde{\boldsymbol{\pi}}$ and $\boldsymbol{\pi}$ designate the vectors of these proportions, $A_{\max}$ is the maximum age in the model, and n is the input sample size. The parameter θ is defined as a linear scaling parameter such that θn is the variance-inflation parameter of the D-M distribution.

The effective sample size associated with this likelihood is given by

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

The input sample sizes used in this assessment, which are based on the number of trips or hauls, are large enough that the first term is insignificant compared to the second term. Consequently, $\theta/(1+\theta)$ can be compared to the sample size multipliers used in the McAllister-Ianelli data-weighting method (McAllister and Ianelli, 1997) that was used for assessments prior to 2018 (Table 16). 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.

A uniform prior between -5 and 20 for θ_{fish} and θ_{surv} tends to lead to inefficient sampling of $\log\theta_{\text{surv}}$ because many samples occur in a part of the parameter space where the effective sample size multiplier, $\theta_{\text{surv}}/(1+\theta_{\text{surv}})$, is between 0.99 and 1.0 (Berger et al., 2019). In that area, the input sample sizes given the uniform prior have full weight and the likelihood surface is almost completely flat with respect to $\log\theta_{\text{surv}}$. The current prior on $\log\theta_{\text{surv}}$ can be associated with an approximately uniform prior of the weight $\theta_{\text{surv}}/(1+\theta_{\text{surv}})$, where the parameters of the normal distribution were back-calculated from a uniform distribution with the bounds of 0 and 1 (Grandin et al., 2020). The normal prior for both θ_{fish} and $\log\theta_{\text{surv}}$ has a mean of 0 and a standard deviation of 1.813.

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 analyses using the McAllister-Ianelli and the Francis methods instead of the D-M method 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 (Grandin et al., 2020).

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, alternative MCMC sampling algorithms, and alternative control rules (Table 16).

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. In this assessment, a more efficient Bayesian MCMC sampler (No-U-Turn Sampler; NUTS; Hoffman and Gelman 2014) was used to create parameter posterior distributions (Monnahan and Kristensen, 2018; Monnahan et al., 2019), a change from previous assessments that used the random walk Metropolis Hastings (rwMH) sampler. NUTS has several advantages over the rwMH as described in Appendix H). 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: $F_{\text{SPR}=35\%}$, $F_{\text{SPR}=40\%}$, $F_{\text{SPR}=40\%}$–40:10, $F_{\text{SPR}=45\%}$, $F_{\text{SPR}=45\%}$–40:10, and $F_{\text{SPR}=50\%}$ (e.g., Dorn 1996; Hicks et al. 2013). The above is only a small fraction of the number of management procedures that have actually been investigated. There have been many other combinations of data, assessment models, and harvest control rules. In addition to the cases examined in the assessment documents, there have been many more requested at review panel meetings.

While there have been many changes to Pacific Hake management procedures, each one has been considered carefully. Available data have changed over the years, and there have been many advances in the discipline of fisheries science. In some ways, the latter has evolved considerably over the course of the historical hake fishery, new statistical techniques (e.g., Bayesian vs. maximum likelihood methods) and software (e.g., NUTS vs. random walk Metropolis Hastings samplers) have evolved and the scientific literature has suggested potentially important biological dynamics to consider (e.g., movement and connectivity). Policies requiring the application of specific control rules have also changed such as the United States' National Standards Guidelines in 2002 and the $F_{\text{SPR}=40\%}$–40:10 harvest control rule in the Agreement (see Glossary in Appendix 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 2021 base model is similar in structure to the base model in the 2020 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 3.30.16.03 was used. The largest changes between the 2020 and 2021 stock assessments are the addition of another year of fishery data and the incorporation of a more efficient MCMC sampling algorithm (NUTS; Hoffman and Gelman 2014) for constructing posterior densities. The latter led to the explicit use of Bayesian inference throughout the stock assessment, because full posterior distributions were calculated for all sensitivity and retrospective analyses for the first time in a Pacific Hake assessment.

The 2021 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 (1975–2020; 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 2021 base model with the magnitude of the allowable deviations unchanged from the 2020 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 -1.61 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 ($\log R_0$) freely estimated. This assessment uses the same Beta-distributed prior for stock-recruit steepness (h), based on Myers et al. (1999), that has been applied since 2011 (Stewart et al., 2011, 2012; Hicks et al., 2013; Taylor et al., 2014, 2015; Grandin et al., 2016; Berger et al., 2017; Edwards et al., 2018*b*; Berger et al., 2019; Grandin et al., 2020). Year-specific recruitment deviations were estimated from 1966–2019 as well as the years 2020, 2021, 2022, and 2023 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 2020 (Table 16). Survey catchability was calculated analytically as per Ludwig and Walters (1981) for each sample of posterior parameters, resulting in a distribution of survey catchability.

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 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 via MCMC simulations using NUTS, initiated to achieve a minimum of 8,000 posterior samples. Medians (50% quantiles) are reported together with the bounds of 95% credibility intervals calculated as the 2.5% quantile and the 97.5% quantile of posterior distributions from the MCMC samples, 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 4.0.3 (2020-10-10) (R Core Team, 2020) and many R packages (in particular r4ss, adnuts, 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 DFO workshop (Edwards et al., 2018*a*) shared such a ‘transparent, traceable, and transferable’ workflow with a wider audience, partly motivated by the ongoing Pacific Hake assessments.

3.3 RESPONSE TO 2020 SCIENTIFIC REVIEW GROUP (SRG) REVIEW

The Scientific Review Group (SRG) meeting was held from February 25-28, 2020 at the Graduate Seattle Hotel, Seattle, WA, USA.

The following are the 'SRG Recommendations and Conclusions for the Pacific Hake Stock Assessment' from the 2020 SRG report, and associated responses from the JTC:

1. The SRG notes that σ_R is an influential parameter and that determining the choice of σ_R remains a challenge and encourages the JTC to continue to work on the issue.

Response – Developing best practices for modeling equilibrium recruitment (R_0*) and recruitment variability (*σ_R*) remain broad topics of contemporary research. Recent recommendations have been that the next generation of stock assessments should concomitantly treat recruitment deviations as a random effect and estimate* σ_R *(Punt et al., 2020). 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. 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. We now briefly discuss several of these research endeavors.*

The JTC plans to participate in collaborative research to investigate the concurrent estimation of multiple variance parameters within stock assessments. For Pacific Hake, this includes the estimation of the variability associated with time-varying selectivity (Φ*),* σ_R*, the extra standard deviation parameters on survey-index data, and the Dirichlet-multinomial parameters* θ_{fish} *and* θ_{surv}*. In this assessment,* Φ *and* σ_R *are input as fixed values rather than estimated, though we have explored their estimation within Stock Synthesis in the past and did so again this year. Estimation of these variance parameters using wide, uniform priors (given the lack of information available on hyper priors within stock assessments) was unsuccessful. Estimates were clearly interrelated with 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. The Laplace approximation (Thorson et al., 2015) was also investigated this year as an alternative means to estimate these parameters. Estimates from this method were also large and need further investigation with respect to their correlation. This work is related to time-varying selectivity research, as discussed in response 2 below.*

The completion of the Management Strategy Evaluation framework for Pacific Hake continues to create considerable advantages for examining recruitment. The Template Model Builder (TMB) estimation code developed by Dr. Nis Jacobsen for the MSE mimics the stock assessment model and insights gained through the treatment of recruitment variability as random-effects (Thorson, 2019) is being explored. Other state-space stock assessment platforms (such as the Woods Hole Assessment Model, WHAM) may also be useful for investigating alternative approaches to estimate recruitment variability. The MSE framework can also be used to evaluate the robustness of recruitment modeling assumptions and the advantages of including environmentally-driven recruitment indices on management performance and uncertainty. Research being conducted by Dr. Cathleen Vestfals and colleagues at the Northwest Fisheries Science Center is focused on identifying climate drivers of Pacific Hake early life-history stages and recruitment, which could inform an explicit recruitment index, an environmental index linked to recruitment, indicators of recruitment variation (σ_R*), and indicators of current or forecast levels of recruitment. Further, the MSE could provide* *an additional framework for exploring the estimation of σ_R while further testing semi-parametric selectivity given its functionality with respect to estimating random effects.*

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. This work is expected to be published in the next year or so.

2. The JTC described efforts and collaborations with the ICES Methods Working Group to address the issue of estimating the variance parameter (Φ) for time-varying selectivity. Results from this collaboration are expected to inform the 2021 assessment. The SRG encourages ongoing work to develop approaches to estimating variance parameters.

Response – The JTC is involved with collaborative research to investigate the concurrent estimation of multiple variance parameters (for example through the use of the Laplace approximation to implement mixed-effect parameter estimation) and interactions among them. This is consistent with recent recommendations by (Xu et al., 2020) that simultaneous treatment of data weighting and time-varying selectivity (as well as other variance terms such as σ_R) is needed for use in operational stock assessments. Input sample sizes for age composition data can influence data weighting, further suggesting a comprehensive approach is needed.

Most methods that are available to estimate time-varying selectivity specifically require subjective choices (e.g., number of years or time blocks to model, the level of variability to use for a penalized vector, or the degree of smoothing for a spline). 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).

An ICES Methods Working Group project is in the process of comparing 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 is being fit to data from 10 stocks using multiple configurations. Results from this study will be comparisons 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. The JTC expects that the results, once completed, will inform best practices for this assessment. Currently, two of the four frameworks have been fit to the data and input files need to be converted to allow for fitting of the remaining frameworks.

3. The SRG notes that the removal of the zero-sum constraint on recruitment deviations has implications on the estimate of R_0 and the perception of stock status based on relative spawning biomass. As the stock is currently well above $B_{40\%}$, management decision-making is not expected to be affected in 2020. **The SRG recommends that the JTC explore alternative methods of estimating reference points, including dynamic reference points or reference points based on a defined time period. There is some urgency to this work as biomass is declining and the relative spawning biomass may fall below the target level $B_{40\%}$ within 2 years.**

Response – Members of the JTC are also part of the Pacific Hake MSE technical work group. Considerable developments have been made over the past year refining the MSE simulation code, as well as working with stakeholders through iterative JMC meetings to better define management objectives and performance metrics. Members of the JTC have contributed to an ICES reference point report (ICES, 2021) dedicated to density dependence and ecosystem change and a Canadian Ocean Frontier Institute workshop on management reference points in highly dynamic environments. In both cases, the benefits and costs of using dynamic reference points were discussed. Guidance stemming from these workshops confirms that careful consideration is warranted when using dynamic reference points and should preferably be examined in an MSE. The JTC anticipates using the MSE to broadly test alternative management procedures, including those related to alternative harvest rules and related reference points.

Preliminary investigations based on estimated no-fishing ("unfished") time series seems to suggest that the Pacific Hake stock may be more productive than what virgin equilibrium conditions otherwise indicate. If this is the case, estimates of relative fishing intensity would be higher than currently estimated, and estimates of relative stock size would be lower than currently estimated. However, many simplifying assumptions are made when estimating unfished time series and these need to be thoroughly examined.

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 will be monitoring guidance that stems from this initiative.

The JTC is collaborating with regional oceanographers and ecosystem scientists to develop a set of ecosystem indicators relative to Pacific Hake ecology and population dynamics for use as an annual reporting tool. These metrics could be evaluated as a set of "stoplight" indicators as a means to collectively support ecosystem-based fisheries management, and be presented to Treaty advisory bodies as supplementary information to the stock assessment.

4. The SRG notes that age-composition data sample sizes are high in recent years, increasing the weight of fishery age-composition data relative to the survey data. Artificially downweighting the sample sizes for recent years had a significant impact on assessment results. **The SRG recommends (1) that the JTC undertake simulations to investigate the effect of downweighting age-composition data on management performance, and (2) that the JTC explore temporal trends in sample sizes and appropriate ways of estimating the annual variability in age-composition data.**

Response – To inform these simulations, the JTC first engaged in an exploration of the data with the goal of determining how many fish and how many tows from each fleet currently inform the aggregated age compositions. This proved to be more difficult than it should have been. Historical age-composition data prior to 2008 are not investigated annually, and thus, there is no way to know if current extractions of historical data from the databases match what was used to generate the historical age-composition data. Though, we do provide the number of fish and the number of trips or tows now for some of the most recent data (Tables 5-7). Next steps include computing historical age compositions from recent data extractions to confirm that they match those currently *used to fit the assessment and updating tables to include all years for both countries. After which, simulations will be conducted to determine how to best assign sample sizes to disparate sampling methods when the data are combined into a single aggregated fleet for modeling purposes.*

Additionally, the JTC investigated how many tows are typically included in a trip for the shore-based fleet using records from observer data. Knowing how many tows are completed per trip will help to inform non-independence or the amount of overdispersion present in the data and, thus, the level of overdispersion that should be investigated in the simulation. Preliminary investigations suggest that on average there are about two hauls conducted per shore-based trip in the U.S.; and, combined, those hauls, on average, contain about half as much in catch weight as a single at-sea haul.

5. Two possible approaches to downweighting the fishery age-composition data were discussed during the SRG meeting: (1) add time-blocking to allow changes in the estimated Dirichlet-multinomial parameter that controls the effective sample size for the fishery age-composition data, and (2) investigate annual age-composition data among different fleets outside of the model. The first approach, although relatively easy to implement, does not resolve the potential problem that the input sample size in the current base model is measured using a mixture of metrics (the number of sampled tows for at-sea samples versus the number of sampled trips for shore-side samples). **The SRG recommends that the JTC undertake an analysis of the annual age-composition data in a more disaggregated form (e.g., by fleet) outside of the model to evaluate the sources of between-sample variability in the fishery age-compositions (month, year, fleet, sample size, etc.) and whether the variability relates to simple metrics of sample size such as the number of sampled tows, the number of sampled trips, and the number of sampled fish.**

Response to (1) – The investigation of how many fish are sampled per trip and tow for each fleet noted in response 4 will help inform whether or not a time block on the fishery-specific Dirichlet-multinomial parameter is supported by the data. Until that work is complete, there is no information available to inform when the time block should begin or end.

Response to (2) – In 2020, the JTC noted that they were working on a document to summarize the changes in the sampling protocol over time. This work is still in progress and is meant to be a living document that will be updated annually. As the JTC works towards documenting which fish are included in historical age-composition samples (not just sampled; response 4), investigating disaggregated forms of the compositional data will become a doable task because currently the raw data are unavailable. Thus, below we note our progress on investigating historical methods used to collect data beyond those noted before.

For the U.S. sectors, the average number of fish sampled per haul in the at-sea sector in recent years is three, whereas the average number of fish sampled per trip in the shore-based sector is twenty. We assign the input sample size of an at-sea haul or a shore-based trip equally but account for differences in sample weights by weighting composition by landings. The JTC explored several approaches for adjusting the input sample sizes for age composition data without changing the method of weighting by landings using data since 2008. These included adjusting the U.S. (or U.S. and Canadian) at-sea sectors to be more consistent with the shore-based sector ratio of fish *per sample, and applying generic regression equations built through meta-analysis of West coast groundfish stocks (I. Stewart and S. Miller, unpublished) that define candidate input sample sizes based on the number of samples (hauls or trips) and the number of fish sampled. In both cases, results from exploratory model runs showed similar estimates of equilibrium and current spawning stock biomass compared to what was estimated for this assessment (results not shown). In addition, systematically removing all age-composition data from the beginning of the assessment model time series through 1990 led to similar stock trajectories from 1990 forward (results not shown). Therefore, the JTC will prioritize investigations into input sample sizes for years that include fish still in the population before revisiting historical samples that can be removed from the model without affecting current estimated biomass.*

6.The SRG encourages work to develop a picture of the Pacific Hake reproductive cycle both seasonally and at the life-time scale based on histological and physiological measurements. In addition, the SRG notes that Canadian samples and those from the winter research cruises should be included in the maturity analysis. **The SRG encourages continued sampling to improve understanding of the Pacific Hake reproductive cycle.**

Response – No new ovary samples were collected in 2020 due to the cancellation of summer research cruises as a result of COVID-19. Additionally, no new maturity analyses have been conducted this year because, among other things, access to laboratory equipment was restricted.

Canadian ovaries from surveys have been collected in 2018 and 2019. These samples could be included in future updated maturity analyses. However, logistical considerations will need to be worked out regarding sample exchange and histological analysis workload between DFO and NWFSC.

A new project was initiated looking at improved methods to differentiate females that 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 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. Initial molecular analyses of gonad samples indicate differences in ribosomal RNA ratio between sexes and immature and mature fish that are consistent with results for liver lipids. Work is currently underway to expand the liver lipid analyses and develop additional 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. This project was significantly impacted by the COVID-19 pandemic, the inability to access labs, and the cancellation of the 2020 Summer Hake research survey, during which biological samples would have been collected. Despite these impacts, progress was made developing liver lipid analyses, developing a number of new molecular (gene expressions) assays for ribosomal RNAs in

Pacific Hake, completing histological analyses of ovarian tissue samples, and analyzing histology results in relation to potential physiological indicators of reproductive success.

7. **The SRG strongly supports the ongoing genetic analyses to determine whether there are genetic differences between Pacific Hake from the area south of Point Conception and other regions.**

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.

The second round of RADseq libraries, which include approximately 1200 individuals, have been constructed and are in the queue for sequencing at the University of Oregon. Approximately 75% of these individuals will pass quality filter parameters and will finalize data collection for the project. These include recently acquired samples that will fill in gaps in spatial-temporal boxes (especially from Canada) and 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. Research was expected to commence in 2020 but the lack of access to laboratories due to COVID-19 restrictions delayed the completion of the sequencing and analyses for these samples. Research and the submission of a peer-reviewed publication should be completed in 2021.

8. The SRG notes that the no-U-turn sampler (NUTS) algorithm is more efficient and explores parameter space more fully than the MCMC algorithm used to estimate parameter uncertainty in

the current and previous base assessment models. **The SRG supports the use of NUTS for the base model and sensitivity runs in the 2021 assessment.**

Response – NUTS has been used for the base model and all sensitivity and retrospective runs in the 2021 assessment.

9. **The SRG recommends sensitivity analyses structured as follows, if NUTS is used in the 2021 base model: (1) using the random walk Metropolis MCMC algorithm as in the 2020 assessment, and (2) using NUTS when including the age-1 index in the base model.**

Response – Detailed results from using the random walk Metropolis MCMC algorithm are presented in Appendix H, and full results from including the age-1 index are presented in Appendix G.

10. **The SRG also recommends the following additional sensitivities (conducted if possible using NUTS, but otherwise using MLE): steepness, natural mortality, σ_R, alternative standard deviations for time-varying selectivity, increasing maximum age for constant selectivity and downweighting fishery age-composition data.**

Response – These sensitivity analyses were all completed using NUTS (typically taking 3-4 hours to run). Results are presented in Section 3.8.

11. The SRG notes that there are currently multiple strong cohorts in the stock where previously there was only one strong cohort during the period of sample collection for the ageing error matrix that supports the assessment model. **Based on this observation, the SRG recommends that an ageing error study using samples collected during the past decade be conducted in conjunction with the Committee of Age Reading Experts (CARE).**

Response – An updated ageing error analysis is currently planned for after another CARE exchange between ageing labs is completed. This will allow for comprehensive inclusion of both within and between lab double reads spanning multiple years. The JTC also plans to utilize an upgraded ageing error software package currently in development by the University of Washington and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

12. **The SRG recommends that historical sources of data be investigated to determine whether they can be used to supplement the weight-at-age matrix,** including unaged otolith samples (and associated data) from the 1970s that may be available in the Burke Museum in Seattle.

Response – Due to impacts and closures related to COVID-19, no progress has been made visiting the Burke Museum to better understand archived samples or available data. First steps will be to investigate whether otoliths at the museum are in usable shape, and to create summaries of what is potentially available.

3.4 MODELING RESULTS

3.4.1 Changes from 2020

A set of ‘bridging’ models was constructed to evaluate the component-specific effects of all changes from the 2020 base model to the 2021 base model.

In short, these included the following:

- Update to the latest version of Stock Synthesis, version 3.30.16.03;
- Change the phase of data weighting parameters;
- Update catch data from years prior to 2020;
- Update age-composition data from years prior to 2020;
- Update weight-at-age data from years prior to 2020;
- Add 2020 total catch;
- Add 2020 fishery age-composition and weight-at-age data; and
- Implement the NUTS algorithm for Bayesian posterior sampling.

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 and adjusted the estimation phase for the data weighting parameters. The second step updated the information available from the fishery. The third step implemented other changes to the model structure or statistical framework.

Stock Synthesis version 3.30.16.03 includes a number of changes since the version used by Grandin et al. (2020), mostly related to options not explicitly used in this assessment. Adaptations within the stock synthesis modeling framework itself had no effect on parameter estimates compared to the 2020 base model and thus no effect on resulting time series (Figure 15). Similarly, changing the estimation of the Dirichlet Multinomial parameters to the final estimation phase (which more accurately reflects the timing of when other, manually-tuned, data weighting methods occur) had no effect on results.

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 as databases are continually updated. Samples that were recently aged but not available for the 2020 assessment were included. These changes to pre-2020 data were small enough that they had little impact on the model results (Figure 16).

The addition of 2020 catch allowed the model to be extended to the start of 2021, but the estimates for 2021 remained highly uncertain (Figure 16) in the absence of additional information about recent recruitment. Adding 2020 fishery age-composition and weight-at-age data had relatively little impact on the historical biomass estimates, indicating that the observed 2020 ages were consistent with the model estimates without those data (Figure 16). However, the addition of these data did slightly decrease the uncertainty with recent recruitment estimates, though overall uncertainty was still high. Recruitment estimates largely did not change with the addition of 2020 data, the exceptions being reductions in the 2015 and 2018 year classes with the addition of 2020 fishery age compositions (Figure 16). This bridging step also shifted the ending year of the deviations in the selectivity parameters from 2019 to 2020 because of the addition of fishery data in 2020.

Lastly, the JTC along with support from the SRG (see Section 3.3) updated the Bayesian statistical framework used in the 2021 assessment to utilize a more efficient MCMC sampler (NUTS; Hoffman and Gelman 2014) as implemented using the `adnuts` R package (Monnahan and Kristensen, 2018; Monnahan et al., 2019). NUTS is considered by many to be a straightforward improvement in efficiency with high dimensional models over classic random walk approaches as it implements Hamiltonian approaches (via adaptive sampling steps) as well as improved (more effective and consistent) parameter space coverage (Hoffman and Gelman 2014; Nishio and Arakawa 2019). A comparison with the previously used random walk Metropolis Hastings MCMC sampling algorithm is shown in Appendix H. The computational time for the base model run using NUTS was $\sim$3.5 hours, about 10 times quicker than using the Metropolis Hastings algorithm. Each sensitivity analysis using NUTS also took $\sim$3.5 hours; for previous assessments the maximum likelihood estimate (MLE) calculations for sensitivity analyses took a few minutes. The longest of the 20 retrospective analyses using NUTS took 74 hours.

3.4.2 Assessment model results

Model Fit

The `adnuts` R package was used to apply the NUTS algorithm to produce 8,250 MCMC samples to describe posterior distributions for model parameters and derived quantities. This is nearly a four-fold increase in samples from 2020 assessment (Berger et al., 2019).

Stationarity of the posterior distribution for model parameters was re-assessed via a suite of standard single-chain and multi-chain diagnostic tests via graphical summaries and interactive web applications (`ShinySTAN`; https://mc-stan.org/users/interfaces/shinystan). Key diagnostic figures are given in Appendix A and now discussed. All estimated parameters 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–A.3). 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 (examined via `ShinySTAN`). Correlations among key parameters were generally low, with the exception of M and $\log R_0$ (Figure A.5). Estimates of recruitment in 2010 and 2014 were correlated with the derived quantity of catch from the default harvest rule in 2021, as to be expected given the dependencies among these quantities (Figure A.5). An examination of deviations in recruitment (log-scale differences between estimated and expected recruitment values) from recent years (Figure A.6) indicates the highest correlation (0.82) between the 2012 and 2014 recruitment deviations. This continues to be likely caused by the relative proportion of these two cohorts being better informed by recent age-composition data rather than the absolute magnitude of these recruitments.

The estimate (median and 95% credible interval) for $\log\theta_{\text{fish}}$ is -0.569 (-0.773, -0.354), giving an effective sample size multiplier $\theta_{\text{fish}}/(1+\theta_{\text{fish}})$ of 0.361 (0.316, 0.412). The survey age-composition parameter is also well-sampled with $\log\theta_{\text{surv}}$ estimated as 2.324 (1.206, 4.474), and the resulting effective sample size multiplier $\theta_{\text{surv}}/(1+\theta_{\text{surv}})$ of 0.911 (0.770, 0.989).

The base model fit to the acoustic survey biomass index (Figure 17) remains similar to the 2020 base model. The addition of 2020 fishery data had negligible effect on the fit to survey biomass (Figure 16). The 2001 survey biomass index 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 12), 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 than 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 target strength to hake which could introduce bias in the biomass estimate for that year, and which also likely influenced hake population dynamics through predation in that year.

The median posterior density estimates underfit the 2015 survey index, overfit the 2017 index, and closely fit the 2019 index (Figure 17). 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 18). 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 2020 fishery, the 2016 cohort was the largest (35%), followed by the 2014 cohort (31%), then the 2010 cohort (15%). 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%), then the 2010 cohort (16%). Combined, the 2015–2020 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 18). The 2016 cohort, which has been observed once 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 19).

The median estimates for numbers, biomass, exploitation rate, and catch (in numbers and in biomass) for each age class in each year are given in Tables 17-21. For the major cohorts, the resulting estimated age-specific catch, natural mortality, and surviving biomasses are given in Table 22. For example, the catch weight of the 2014 cohort at age-5 was slightly less than that of the 2010 cohort at age-5 and the resulting surviving biomass of the 2014 cohort was approximately half of the surviving biomass of the 2010 cohort.

Posterior distributions for both steepness and natural mortality are strongly influenced by priors (Figure 20). 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 posterior distributions, including θ_{fish} and θ_{surv} (as outlined in Section 2.4.4).

The 2021 base model specified the same level of variation (standard deviation of $\Phi = 1.4$) associated with time-varying fishery selectivity as the 2020 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, given 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 recent years until 2020 when age-4 was large again (Figures 21 and 22). The median selectivity peaks at age 4 in 2010, 2012 and 2020 and at age 3 in 2011 suggesting targeting (or generally higher availability) 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 (Figure 18). Fishery selectivity on age-2 fish was at its highest in 2016, followed by 2018. Fishery selectivity for the most recent year was the lowest for age-2 since 2013, and then quickly peaked at age-4 before leveling off at older ages (Figure 22). Even though the survey selectivity is time invariant, the posterior shows a broad band of uncertainty between ages 2 and 5 (Figure 23). 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, 2014, and 2016 cohorts occurring in the survey at ages 3 and 5 but not age 4. Fishery selectivity is likewise very uncertain (Figures 22 and 23), 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 24 and 25 and Tables 23 and 24). 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 0.605 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 (growth-mortality transition). The 2014 year class is estimated to be large, though not as large as the 1999 and 2010 year classes, resulting in an increased biomass in 2017. The estimated biomass has declined since 2017 as the 2014 year class moves through the growth-mortality transition (and the 2010 year class continues to do so) during a time of record catches.

The median estimate of the 2021 relative spawning biomass (spawning biomass at the start of 2021 divided by that at unfished equilibrium, B_0) is 59%. However, the uncertainty is large, with a 95% posterior credibility interval from 25% to 137% (Tables 23 and 24).

The median estimate of the 2021 spawning biomass is 0.981 million t (with a 95% posterior credibility interval from 0.404 to 2.388 million t). The estimate of the 2020 female spawning biomass is 1.300 (0.637–2.914) million t. This is a slightly higher median and broader credibility interval than the 1.196 (0.550–2.508) million t estimated in the 2020 assessment, but there is considerable overlap of the credibility intervals.

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 recent years have slightly changed with the addition of new data. For example, this assessment's median estimate of the 2014 recruitment is 0.5 billion fish lower than in last year's assessment (a 5% reduction). Similarly, estimates for 2016 and 2018 have changed by +6% and -50%, respectively, but the general notion remains that the 2016 cohort is above average and the 2018 cohort is well below average.

Pacific Hake appear to have low average recruitment with occasional large year-classes (Figures 26 and 27, Tables 23 and 24). 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 28) 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, 19% of the 2019 catch, and 15% of the 2020 catch. The median estimate of the 2010 year class is just below the highest ever (for 1980), with a 46% probability that the 2010 year class is larger than the 1980 year class (this probability was 36% for last year's assessment).

The current assessment also estimates a strong 2014 year class (Figure 28) comprising 50% of the 2016 catch, 38% of the 2017 catch, 27% of the 2018 catch, 32% of the 2019 catch, and 31% of the 2020 catch. The 2016 cohort also appears to be above average at 26% of the 2018 catch, 21% of the 2019 catch, and 35% of the 2020 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, six 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 four 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. Only two years of fishery data are available to estimate the 2018 year class and one year for the 2019 year class. The 2020 fishery did not encounter very many fish from 2018 (age-2) or 2019 (age-1) cohorts.

The additional data in the 2020 assessment has decreased the median estimate of the 2014 year class to 8.908 billion fish (Table 23), from the 9.401 billion estimated in the 2020 assessment (Table 25 of Grandin et al. 2020). The 2014 year class remains the fifth largest estimated recruitment, albeit with large uncertainty (Table 24 and Figure 26). The median estimate for the 2016 year class is 4.828 billion fish (2.407–11.806 billion fish; Tables 23 and 24).

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) and 2020 (2019 year class) was well below that observed in 2018 (2017 year class) and 2017 (2016 year class; Table 10). There is little or no information in the data to estimate the sizes of the 2019, 2020, and 2021 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 29. 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 29). 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 1.75. 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 $\text{SPR}_{40\%}$ target for all years (Figure 30 and Tables 23 and 24). 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 31 and Tables 23 and 24). 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 92.7% in 2010 to 45.5% in 2015, then it leveled off at around 75% from 2016 to 2019 before dropping to 65.9% in 2020. The median exploitation fraction decreased from 0.16 in 2011 to recent lows of 0.05 in 2012 and 2015, and then increased to 0.13 in 2017 before decreasing slightly and then increasing to 0.13 in 2020. 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 and again in 2020 (Figure 30). 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 (2011–2020), the mean coast-wide utilization rate (i.e., proportion of catch target removed) has been 69.8% and catches have been below coast-wide targets (Table 3). From 2016 to 2020, the mean utilization rates differed between the United States (72.7%) and Canada (63.7%). However, country-specific quotas (or catch targets) in 2020 were specified unilaterally, due to the lack of an agreement on a coast-wide 2020 TAC. 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 underutilization in the United States was mostly a result of unrealized catch in the tribal apportionment, while reports from stakeholders in Canada suggested that hake were less aggregated in Canada and availability had declined. In 2016, the utilization rate increased but remained below pre-2015 levels, despite the total 2016 catch being one of the highest 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, but increased slightly in 2020 (71.7%). 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 23 and Figures 30 and 32). The median relative spawning biomass was above the $B_{40\%}$ reference point in all years except 2009-2010 (Table 23 and Figures 25 and 32). These are also shown on a phase plot of the joint history of relative spawning biomass and relative fishing intensity (Figure 32). 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 2020 estimates of relative fishing intensity and relative spawning biomass, the model estimates a 1.7% joint probability of being both above the target relative fishing intensity in 2020 and below the $B_{40\%}$ relative spawning biomass level at the start of 2021.

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 asymptotic approximations about MLEs because it allows for asymmetry (Figure 20; also see Stewart et al. 2012 for further discussion and examples); this is the first Pacific Hake assessment to almost exclusively use posterior distributions instead of MLEs.

The medians of the key parameters from the posterior distribution are similar to those in last year's base model (Table 25). However, medians of some of the derived quantities do change somewhat; in particular, the 2010 and 2016 recruitments increase while the 2014 recruitment decreases, and B_0 has declined from that estimated in the 2020 assessment.

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 full MCMC results (Section 3.8).

We also present appendices of MCMC results for inclusion of the age-1 survey index (Appendix G), and the use of the Metropolis Hastings MCMC algorithm for the base model as used in past assessments (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 use of the Metropolis Hastings algorithm is for comparison with the new NUTS algorithm, to complement the similar comparison conducted last year with the introduction of NUTS (Grandin et al., 2020).

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

The term reference points is used throughout this document to describe common conceptual summary metrics. The Treaty specifically identifies $F_{\text{SPR}=40\%}$ as the default harvest rate and $B_{40\%}$ as a point where the 40:10 TAC adjustment is triggered (see the Glossary in Appendix C).

We report estimates of the base reference points (e.g., $F_{\text{SPR}=40\%}$, $B_{40\%}$, B_{MSY}, and MSY) with posterior credibility intervals in Table 26. The median of the female spawning biomass at $F_{\text{SPR}=40\%}$ (namely the median of $B_{\text{SPR}=40\%}$) and the median yield at $F_{\text{SPR}=40\%}$ are slightly lower than the estimates in the 2020 assessment (Table 25).

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 2021 being above each of these points are $\text{P}(B_{2021} > B_{10\%}) = 100\%$ and $\text{P}(B_{2021} > B_{40\%}) = 82.2\%$ [in last year's assessment the equivalent calculation was $\text{P}(B_{2020} > B_{40\%}) = 90.1\%$], 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 $0.4B_{\text{MSY}}$ and provisional upper stock reference point of $0.8B_{\text{MSY}}$, the probabilities are $\text{P}(B_{2021} > 0.4B_{\text{MSY}}) = 100\%$ and $\text{P}(B_{2021} > 0.8B_{\text{MSY}}) = 98.5\%$ such that the stock is estimated to be in the provisional 'healthy zone'. For completeness, we note that $\text{P}(B_{2021} > B_{\text{MSY}}) = 96.0\%$

Reference levels of stock status that are used by the U.S. Pacific Fisheries Management Council (PFMC) include $B_{40\%}$ and a Minimum Stock Size Threshold (MSST) of $B_{25\%}$. For 2021, the estimated posterior median relative spawning biomass is 59%, such that the spawning biomass is above $B_{40\%}$ and well above $B_{25\%}$. The probability that spawning biomass at the beginning of 2021 is above $B_{40\%}$ is $\text{P}(B_{2021} > B_{40\%}) = 82.2\%$ (as noted above), and of being above $B_{25\%}$ is $\text{P}(B_{2021} > B_{25\%}) = 97.3\%$.

3.7 MODEL PROJECTIONS

The median catch limit for 2021 based on the default $F_{\text{SPR}=40\%}$–40:10 harvest policy is 565,191 t, but has a wide range of uncertainty (Figure 33), with the 95% credibility interval being 181,094–1,649,905 t.

Decision tables give projected population status (relative spawning biomass) and relative fishing intensity under different catch alternatives for the base model (Tables 27 and 28). 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 27 shows projected relative spawning biomass outcomes, and Table 28 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 (2016–2020); 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 $F_{\text{SPR}=40\%}$ default harvest rate limit. This can happen for the median relative fishing intensity in 2021, 2022 and 2023 because the $F_{\text{SPR}=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the projection of overfishing. An alternative catch level where median relative fishing intensity is 100% is provided for comparison (catch alternative h: 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 2022 and 2023 (Tables 29 and 30 and Figures 34–36). 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 2021 (Table 29 and Figure 35). However, interpolation is not appropriate for all catches in 2022 because catch alternatives h and i have catches that are larger than 430,000 t (the constant catch for alternative e) in 2021 but smaller than 430,000 t in 2022 (Table 28); this explains why a few probabilities decline (rather than rise) with increased 2022 catch levels in Table 30 and Figure 36.

Figure 34 shows the predicted relative spawning biomass trajectory through 2023 for several of these management actions. With zero catch for the next two years, the biomass has a probability of 65% of decreasing from 2021 to 2022 (Table 29 and Figure 35), and a probability of 52% of decreasing from 2022 to 2023 (Table 30 and Figure 36). Note that for zero catch in Figure 34, the median in 2021 essentially equals the median in 2022 (i.e., zero difference in the medians), which might be expected to imply a 50% probability of a decline (not the 65% just mentioned). However, this does not occur because the difference between the 2021 and 2022 medians is not the same as the median of the 2021 and 2022 differences. The median difference between 2021 and 2022 is a decline of 0.028 (from calculating the difference for each MCMC sample and then taking the median). About 15% of the MCMC samples have a decline in the range -0.028 to 0 (a decline greater than the median difference but less than the difference in the medians). This accounts for the apparent discrepancy in the 50% and 65% probabilities.

The probability of the spawning biomass decreasing from 2021 to 2022 is over 65% for all catch levels, including zero (Table 29 and Figure 35). It is 86% for the 2021 catch level similar to that for 2020 (catch alternative d). For all explored catches, the maximum probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2022 is 2%, and of dropping below $B_{40\%}$ is 46% (Table 29 and Figure 35). It should be noted that forecasted biomass 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. The smaller above-average 2016 cohort is entering this growth-mortality transition period, and the average 2017 cohort will do so soon. The below-average 2015 and 2018 cohorts will contribute much less to forecasted spawning biomass than the larger cohorts. The probability that the 2022 spawning biomass will be less than the 2021 spawning biomass ranges from 65% to 90% depending on the catch level (Table 29 and Figure 35).

The age composition (in numbers) of the catch in 2021 is projected to be (using MCMC medians) 16% age-4 fish from the 2017 year-class, 20% age-5 fish from the 2016 year-class, 27% age-7 fish from the 2014 year-class and 12% age-11 fish from the 2010 year-class (Figure 37). However, those estimates are highly uncertain with the 95% credibility interval for the age-7 fraction spanning 12%–39%. Due to the lower average weight at age-4 versus age-11, the median expected proportion of the 2021 catch by weight is 15% for the 2017 cohort (compared to 16% by numbers) and 16% for the 2010 cohort (compared to 12% by numbers; Figure 37).

With respect to the DFO reference points, with the largest 2021 catch of 597,500 t given in Table 29, at the start of 2022 the stock is expected to be above the critical zone with a probability of $\mathrm{P}(B_{2022} > B_{10\%}) = 98\%$ and in the healthy zone with a probability of $\mathrm{P}(B_{2022} > B_{40\%}) = 54\%$. 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 $\mathrm{P}(B_{2022} > 0.4B_{\mathrm{MSY}}) = 97\%$, in the healthy zone with a probability of $\mathrm{P}(B_{2022} > 0.8B_{\mathrm{MSY}}) = 86\%$, and above B_{MSY} with a probability of $\mathrm{P}(B_{2022} > B_{\mathrm{MSY}}) = 78\%$ for this catch.

With respect to PFMC stock size reference points, a level of 2021 catch consistent with the Treaty default harvest control rule (565,191 t) has a 45% estimated probability of resulting in the biomass going below $B_{40\%}$ at the start of 2022 (and 18% probability of going below $B_{25\%}$; Table 29). If catches in 2021 and 2022 are the same as in 2020 (380,000 t, catch scenario d) then the probability of the biomass going below $B_{40\%}$ is 36% for the start of 2022 and 47% for the start of 2023.

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. All sensitivity analyses compared MCMC posteriors that were created using the `adnuts` R package (Monnahan and Kristensen, 2018; Monnahan et al., 2019) to implement the NUTS algorithm with a similar number of posterior samples as the base model. For a comparison of the parameter estimates for the sensitivity analyses with those from the base model see Tables 31–33. Many additional sensitivity runs were conducted when developing and testing the 2021 base model. Here we focus on the main sensitivities which include the following:

1. Consideration of higher standard deviations on the prior distribution for natural mortality;
2. Consideration of alternative values for steepness;
3. Assumption of higher/lower variation about the stock-recruitment curve (σ_r);
4. Inclusion of 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 maximum age for fishery and survey selectivity;
9. Removal of cohort-based ageing error from the model; and
10. Use of the random walk Metropolis Hastings (rwMH) sampling algorithm for calculating posterior distributions.

The MCMC diagnostics were examined by creating a document containing the equivalent of Appendix A for all sensitivity analyses (.pdf file available from the JTC upon request). In general, diagnostics were similar to those for the base model. Minor differences include: sensitivity analyses related to M showed more autocorrelation in M and some failed Heidelberger and Welch statistics; the Francis reweighting had a lower effective sample size for most parameters; lower standard deviations for time-varying selectivity led to a few failed Heidelberger and Welch statistics; the analyses with alternative standard deviations for time-varying selectivity and the higher maximum age for selectivity both yielded lower effective sample sizes; and all three maximum-age-selectivity analyses led to a few failed Heidelberger and Welch statistics.

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, 2014, and 2016 cohorts. The overall scale of the population was impacted by various alternative assumptions, and the highly uncertain size of the recent 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 annually 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. The median of the MCMC posteriors for natural mortality increased from 0.230 with a 95% credible interval of 0.191–0.276 for the base model (prior standard deviation of 0.1) to 0.297 with a 95% credible interval of 0.224–0.352 for the sensitivity run with the prior standard deviation set to 0.3 (Table 31). 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 31 and Figures 38 and 39).

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 decrease in the MCMC estimate of steepness from a median of 0.807 with a 95% credible interval of 0.563–0.959 to a median of 0.541 with a 95% credible interval of 0.339–0.763 (Table 31). However, neither steepness sensitivity analysis had an impact on the overall model results (Figures 38 and 39).

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 MLEs of recruitment deviations in the period with the most informative data was 1.53, 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 1.87. 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 31 and Figures 38 and 39). 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

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

where $\mathrm{Var}(\hat{r})$ is the variance among deviations and $\mathrm{SE}(\hat{r}_y)$ is the standard error of each estimate. It produced a suggested σ_r of 1.71, which was not as similar to the base-model value of 1.4 as the 1.55 estimated in the 2020 assessment. Future work will assess similar metrics strictly in a Bayesian framework.

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 31, Figures 40 and 41). The 2021 estimates of relative spawning biomass are 59.2% for the base model (95% credible interval of 24.6–137.0%) and 70.9% for the age-1 index model (95% credible interval of 30.3–160.3%)). This change is likely due to the age-1 index suggesting higher recruitment in 2014 (age-1 in 2015) and 2018 (age-1 in 2019) than the base model (Figures 11 and 42). These changes are not large 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 both the 2017 and 2019 acoustic survey estimates compared to the base model (Figure 42). For further details and results from the age-1 survey index sensitivity see Appendix G.

The base model includes a Dirichlet-multinomial likelihood component, which uses two estimated parameters to automatically weight each of the fishery and survey age compositions. The base model was compared to the models that used the alternative 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 McAllister-Ianelli method estimated lower weights on the age compositions but generally gave very similar results to the Dirichlet-multinomial method. The McAllister-Ianelli method led to increased uncertainty in estimates of early recruitments compared to other weighting methods (Figure 43). The Francis method increased the weighting of the fishery composition data resulting in a similar time series of biomass, though slightly reduced in scale. As noted in Section 2.4.4, the Francis method is known to be sensitive to outliers and prone to convergence issues when selectivity is time-varying, as it is in this assessment.

The degree of flexibility of annual variation in the fishery selectivity was tested using three sensitivities which set alternative values of the Φ parameter (Figures 44-48). 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 46). However, recruitment estimates for 2016 and 2017 are linked to the choice of Φ, where the model with the smallest Φ at 0.21 estimates the 2016 and 2017 recruitment deviation as the highest of the Φ sensitivity models (Figure 47) and provides the worst fit to the most recent survey biomass estimate (Figure 48).

The estimated population trends throughout the time series are similar, irrespective of maximum selectivity age (Figures 49-50). The largest differences are prior to the mid-1980s when age-composition data was sparse. The maximum selectivity at age-5 model resulted in lower estimates of recent stock status compared to the other model runs, while runs with higher maximum age produced similar overall stock dynamics but at the cost of a considerable increase in the number of model parameters. The choice of age-6 as the maximum was retained in the base model as it offered more flexibility than the choice of age-5.

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 33 and Figure 51) and thus relative spawning biomass (Figure 52). 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. There is very little difference in the current relative biomass between the two, with the base model having a median relative biomass of 59.2% and the time-invariant ageing error vector model having a median relative biomass of 60.8%. The credible interval is larger for the time-invariant ageing error vector model.

The impact of using the random walk Metropolis Hastings (rwMH) MCMC algorithm with data inputs and model structure equivalent to the base model is shown in Table 33 and discussed in further details in Appendix H.

3.9 RETROSPECTIVE ANALYSES

Retrospective analyses were performed by iteratively removing the terminal years' data (going back 10 years) and estimating the posterior distribution of parameters under the assumptions of the base model. Models with 3 or 4 years of data removed had some information available regarding the above-average 2014 year class, but did not yet have information on the 2016 year class (Figure 53). Models with 2 and 3 years of data removed were just beginning to receive data on age-3 and age-2, respectively, individuals to predict the size of the 2016 year class. The base model now has four years of data to estimate the size of the 2016 cohort, and the uncertainty around this estimate has been considerably reduced compared to three years ago (Figure 53). Medians of various quantities of interest are given in Table 34.

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 with the most years removed (Figure 53). In the previous assessment, the retrospective bias was a mix of both positive and negative biases in these terminal years. In this assessment, there is very little retrospective bias other than a positive bias in spawning stock biomass four years previously when the 2014 year class was initially estimated too high. There is no indication from retrospective evaluations that the base model is displaying a systematic bias.

Cohort strength is usually not well estimated until the cohort reaches age 3 or more because at age 3 at least one year of survey age-composition data are available (Figure 54). Deviations for the 2010 and 2014 cohorts, which are the largest cohorts since 2010, exhibit the largest positive deviations. Estimated recruitment deviations for the 2014 cohort are above those for 2016 and 2017 cohorts, but the estimated size of the 2014 cohort didn't fully stabilize until age 4. The variability among cohort estimates relative to their estimated size in the base model (Figure 55) further indicates that the estimates can start to improve as early as age 2, 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 56. 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, values of 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 2021 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 the investigation of links between hake biomass, spatial distribution, and recruitment 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 MSE work and the basic understanding of drivers of hake population dynamics and availability to fisheries and surveys. Related, there is a need to streamline and broaden the availability of products from oceanographic models (e.g., ROMS) so that they are available stock-wide and can be used on a recurring 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. Utilize and adapt this simulation framework to address new and ongoing stock assessment research and data needs through the Pacific Hake MSE Working Group.

3. Document the existing survey methodologies, protocols, and adaptive survey-design decisions that lead to the development of Pacific Hake biomass and age-composition estimates used in the stock assessment. Such documentation will ensure transparency, enable repeatability, and provide a record of changes in procedures over time. Also, continue to conduct research to improve the estimation of age composition and abundance from data collected during the acoustic survey. This includes, but is not limited to, research on species identification, target verification, target strength, implications of the south-to-north directionality of the survey, alternative technologies to assist in the survey, and efficient analysis methods. The latter should include bootstrapping of the acoustic survey time series or related methods that can incorporate relevant uncertainties into the calculations of survey variance. Relevant uncertainties include topics such as the target strength relationship, subjective scoring of echograms, thresholding methods, and methods to estimate the species-mix that are used to interpret the acoustic backscatter. Continue to work with acousticians and survey personnel from the Northwest Fisheries Science Center and Fisheries and Oceans Canada to determine optimal survey designs given constraints, including designs that incorporate ecosystem-based factors and other potential target species (e.g., rockfish, euphausiids, and mesopelagics) for the Joint U.S. and Canadian Integrated Acoustic and Trawl Survey.

4. Explore potential recruitment indices for juvenile or young (age-0 and/or age-1) Pacific Hake, including further investigations into survey options, refinements, and analyses, as well as those that include environment linkages. Investigate alternative ways to model and forecast recruitment, given the uncertainty present.

5. Develop a set of candidate ecosystem indicators that are potentially associated with Pacific Hake biology and ecology (e.g., recruitment, distribution, predator, and prey). Such information can broaden the context within which a single species stock assessment is interpreted, be used to support model development, and provide non-assessment indicators to management.

6. Explore alternative approaches and related assumptions for parameterizing time-varying fishery selectivity in the assessment. Simulations that evaluate methods for including mul-

tiple variance structures, including interactions, tradeoffs, and related assumptions, across multiple processes (e.g., selectivity, recruitment, data weighting) in integrated stock assessment models would be particularly beneficial.

7. Conduct an inter-laboratory otolith exchange and use the results to update estimates of ageing error used in the stock assessment. This would include updated information about ageing imprecision and the effects of large cohorts as understood given simulation analyses and blind-source age reads of samples with differing underlying age distributions – with and without dominant year classes. The last inter-laboratory comparison was done in 2010 ("CARE" exchanges). In addition, investigate whether otolith collections at the Burke Museum in Seattle include Pacific Hake and if so what is the quality, quantity, and time period coverage of available samples. Such attributes will help determine if these samples could eventually contribute to the stock assessment.

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 and correlations with time, empirical growth, and population density. Improve understanding of 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. Continue to explore the possibility of using additional data types such as length data within the stock assessment. Additionally, a more spatially comprehensive maturity analysis that incorporates information from Canadian samples would be advantageous.

9. Continue to analyze Pacific Hake genetics. In particular, completing the ongoing genetics testing and analysis required to evaluate spatial-temporal population structure will provide an improved understanding across the extent of the coastal population.

10. 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.

11. Consider alternative methods for refining existing prior distributions for natural mortality (M), including the use of meta-analytic methods. Evaluate feasibility of estimating age-specific natural mortality for Pacific Hake.

12. Develop and evaluate new diagnostics for Bayesian MCMC model evaluations.

13. 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).

14. Develop mechanisms that improve computing capabilities and storage capacity through the use of cloud computing, local high performance computing clusters, or other similar productivity enhancements to improve assessment modeling and workflow that goes into building the assessment document.

5 ACKNOWLEDGMENTS

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7 TABLES

Table 1. Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2020. 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	1,023	0	75,577
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	3,432	0	154,932
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	203,049
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

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Year	Foreign	JV	Mothership	Catcher-Processor	Shore-based	Research	Total
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	148,210	0	317,002
2020	0	0	37,978	111,147	138,784	0	287,908

Table 2. Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2020.

Year	Foreign	JV	Shoreside	Freezer-Trawler	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

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Year	Foreign	JV	Shoreside	Freezer-Trawler	Total
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	50,621	43,950	94,571
2020	0	0	51,551	39,812	91,362

Table 3. Pacific Hake landings and management decisions. A dash (–) indicates the management decision was either not specified or was unknown to the authors at the time of this assessment. Catch targets in 2020 were specified unilaterally.

Year	U.S. landings (t)	Canada landings (t)	Total landings (t)	U.S. proportion of total catch	Canada proportion of total catch	U.S. catch target (t)	Canada catch target (t)	Coast-wide catch target (t)	U.S. proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
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%	130,000	–	–	75.7%	–	–
1979	124,680	12,430	137,110	90.9%	9.1%	198,900	35,000	–	62.7%	35.5%	–
1980	72,350	17,580	89,930	80.5%	19.5%	175,000	35,000	–	41.3%	50.2%	–
1981	114,760	24,360	139,120	82.5%	17.5%	175,000	35,000	–	65.6%	69.6%	–
1982	75,577	32,160	107,737	70.1%	29.9%	175,000	35,000	–	43.2%	91.9%	–
1983	73,151	40,780	113,931	64.2%	35.8%	175,000	45,000	–	41.8%	90.6%	–
1984	96,382	42,110	138,492	69.6%	30.4%	175,000	45,000	270,000	55.1%	93.6%	51.3%
1985	85,439	24,960	110,399	77.4%	22.6%	175,000	50,000	212,000	48.8%	49.9%	52.1%
1986	154,932	55,650	210,582	73.6%	26.4%	295,800	75,000	405,000	52.4%	74.2%	52.0%
1987	160,448	73,700	234,148	68.5%	31.5%	195,000	75,000	264,000	82.3%	98.3%	88.7%
1988	160,690	88,150	248,840	64.6%	35.4%	232,000	98,000	327,000	69.3%	89.9%	76.1%
1989	203,049	95,029	298,079	68.1%	31.9%	225,000	98,000	323,000	90.2%	97.0%	92.3%
1990	185,142	76,144	261,286	70.9%	29.1%	196,000	73,500	245,000	94.5%	103.6%	106.6%
1991	229,789	89,917	319,705	71.9%	28.1%	228,000	98,000	253,000	100.8%	91.8%	126.4%
1992	210,829	88,822	299,650	70.4%	29.6%	208,800	90,000	232,000	101.0%	98.7%	129.2%
1993	140,132	58,773	198,905	70.5%	29.5%	142,000	61,000	178,000	98.7%	96.3%	111.7%
1994	253,477	108,930	362,407	69.9%	30.1%	260,000	110,000	325,000	97.5%	99.0%	111.5%
1995	177,124	72,372	249,495	71.0%	29.0%	178,400	76,500	223,000	99.3%	94.6%	111.9%
1996	213,159	93,139	306,299	69.6%	30.4%	212,000	91,000	265,000	100.5%	102.4%	115.6%
1997	233,376	91,771	325,147	71.8%	28.2%	232,000	99,400	290,000	100.6%	92.3%	112.1%
1998	232,920	87,802	320,722	72.6%	27.4%	232,000	80,000	290,000	100.4%	109.8%	110.6%
1999	224,565	87,322	311,887	72.0%	28.0%	232,000	90,300	290,000	96.8%	96.7%	107.5%
2000	206,770	22,007	228,777	90.4%	9.6%	232,000	90,300	290,000	89.1%	24.4%	78.9%
2001	173,940	53,585	227,525	76.4%	23.6%	190,400	81,600	238,000	91.4%	65.7%	95.6%
2002	130,453	50,244	180,697	72.2%	27.8%	129,600	–	162,000	100.7%	–	111.5%

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Year	U.S. landings (t)	Canada landings (t)	Total landings (t)	U.S. proportion of total catch	Canada proportion of total catch	U.S. catch target (t)	Canada catch target (t)	Coast-wide catch target (t)	U.S. proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2003	141,945	63,217	205,162	69.2%	30.8%	148,200	–	228,000	95.8%	–	90.0%
2004	217,240	125,067	342,307	63.5%	36.5%	225,000	–	514,441	96.6%	–	66.5%
2005	260,120	103,014	363,135	71.6%	28.4%	269,069	95,128	364,197	96.7%	108.3%	99.7%
2006	266,955	94,744	361,699	73.8%	26.2%	269,545	95,297	364,842	99.0%	99.4%	99.1%
2007	217,682	73,566	291,247	74.7%	25.3%	242,591	85,767	328,358	89.7%	85.8%	88.7%
2008	248,496	74,605	323,101	76.9%	23.1%	269,545	95,297	364,842	92.2%	78.3%	88.6%
2009	121,324	57,359	178,683	67.9%	32.1%	135,939	48,061	184,000	89.2%	119.3%	97.1%
2010	171,043	57,016	228,059	75.0%	25.0%	193,935	68,565	262,500	88.2%	83.2%	86.9%
2011	231,261	56,073	287,334	80.5%	19.5%	290,903	102,848	393,751	79.5%	54.5%	73.0%
2012	160,144	47,059	207,203	77.3%	22.7%	186,036	65,773	251,809	86.1%	71.5%	82.3%
2013	233,578	52,249	285,828	81.7%	18.3%	269,745	95,367	365,112	86.6%	54.8%	78.3%
2014	264,141	35,118	299,259	88.3%	11.7%	316,206	111,794	428,000	83.5%	31.4%	69.9%
2015	154,160	39,684	193,844	79.5%	20.5%	325,072	114,928	440,000	47.4%	34.5%	44.1%
2016	262,327	69,743	332,070	79.0%	21.0%	367,553	129,947	497,500	71.4%	53.7%	66.7%
2017	354,229	86,721	440,950	80.3%	19.7%	441,433	156,067	597,500	80.2%	55.6%	73.8%
2018	318,306	95,413	413,719	76.9%	23.1%	441,433	156,067	597,500	72.1%	61.1%	69.2%
2019	317,002	94,571	411,574	77.0%	23.0%	441,433	156,067	597,500	71.8%	60.6%	68.9%
2020	287,908	91,362	379,270	75.9%	24.1%	424,810	104,480	529,290	67.8%	87.4%	71.7%

Table 4. 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).

	U.S.						Canada			
Year	**Foreign (hauls)**	**Joint-Venture (hauls)**	**Mother-ship (hauls)**	**Combined Mother-ship Catcher-processor (hauls)**	**Catcher-processor (hauls)**	**Shore-based (trips)**	**Foreign (hauls)**	**Joint-Venture (hauls)**	**Shoreside (trips)**	**Freezer Trawlers (hauls)**
1975	13	–	–	–	–	0	0	–	–	–
1976	142	–	–	–	–	0	0	–	–	–
1977	320	–	–	–	–	0	0	–	–	–
1978	336	5	–	–	–	0	0	0	–	–
1979	99	17	–	–	–	0	0	0	0	–
1980	191	30	–	–	–	0	0	0	0	–
1981	113	41	–	–	–	0	0	0	0	–
1982	52	118	–	–	–	0	0	0	–	–
1983	–	117	–	–	–	0	0	0	–	–
1984	49	74	–	–	–	0	0	0	–	–
1985	37	19	–	–	–	0	0	0	0	–
1986	88	32	–	–	–	0	0	0	0	–
1987	22	34	–	–	–	0	0	0	0	–
1988	39	42	–	–	–	0	0	3	0	–
1989	–	77	–	–	–	0	0	3	0	–
1990	–	143	–	0	–	15	0	5	0	–
1991	–	–	–	116	–	26	0	18	0	–
1992	–	–	–	164	–	46	–	33	0	–
1993	–	–	–	108	–	36	–	25	3	–
1994	–	–	–	143	–	50	–	41	1	–
1995	–	–	–	61	–	51	–	35	3	–
1996	–	–	–	123	–	35	–	28	1	–
1997	–	–	–	127	–	65	–	27	1	–
1998	–	–	–	149	–	64	–	21	9	–
1999	–	–	–	389	–	80	–	14	26	–
2000	–	–	–	413	–	91	–	25	1	–
2001	–	–	–	429	–	82	–	28	1	–
2002	–	–	–	342	–	71	–	–	36	–
2003	–	–	–	358	–	78	–	–	20	–
2004	–	–	–	381	–	72	–	20	28	–
2005	–	–	–	499	–	58	–	11	31	14
2006	–	–	–	549	–	83	–	21	21	46
2007	–	–	–	524	–	68	–	1	7	29
2008	–	–	324	–	356	63	–	0	20	31
2009	–	–	316	–	278	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
2020	–	–	186	–	389	96	–	–	32	–

Table 5. 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+
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
2020	909	389	0.00	0.19	7.90	40.75	1.16	31.65	1.85	1.61	1.80	11.14	0.68	1.08	0.00	0.05	0.13

Table 6. 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+
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
2020	509	186	0.00	0.00	8.81	40.36	2.56	28.39	1.59	2.20	2.18	11.30	1.34	0.85	0.42	0.00	0.00

Table 7. 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+
2011	1,599	81	0.05	2.99	86.71	3.37	3.04	1.66	0.41	0.57	0.35	0.16	0.00	0.55	0.09	0.00	0.05
2012	1,522	76	0.00	23.04	18.86	51.02	1.53	2.39	1.18	0.66	0.29	0.07	0.00	0.34	0.23	0.20	0.22
2013	1,915	96	0.00	0.36	79.28	5.93	9.79	0.67	1.38	1.01	0.36	0.37	0.13	0.04	0.09	0.31	0.27
2014	1,355	68	0.00	2.14	3.38	63.99	8.26	15.10	1.30	2.40	1.67	0.63	0.23	0.00	0.20	0.20	0.50
2015	1,680	84	6.12	1.34	7.42	4.91	67.24	4.05	5.06	0.78	1.05	1.28	0.24	0.17	0.00	0.00	0.32
2016	1,518	76	0.11	65.44	1.41	3.25	1.55	22.03	1.60	2.70	0.72	0.29	0.31	0.26	0.14	0.10	0.08
2017	2,235	112	3.68	0.71	35.37	2.63	3.66	2.50	43.03	2.89	2.12	1.66	0.64	0.53	0.27	0.11	0.20
2018	1,834	92	7.72	27.85	1.75	31.45	1.24	2.40	2.61	19.08	2.65	1.32	0.86	0.49	0.40	0.15	0.05
2019	1,826	92	0.00	17.23	21.94	0.90	30.77	1.85	3.36	1.87	16.75	1.54	1.77	0.80	0.57	0.32	0.33
2020	1,916	96	0.00	0.03	8.55	34.70	1.43	31.25	1.21	2.74	1.76	15.46	1.09	0.82	0.48	0.08	0.40

Table 8. 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+
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
2020	32	0.00	0.04	9.59	19.80	1.37	30.16	2.71	3.49	2.56	24.07	2.86	2.12	0.22	0.48	0.54

Table 9. 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+**
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 10. 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	0.09	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	1.85	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	1.89	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

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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+**
2008	794	0.76	9.82	30.53	2.40	14.42	1.03	3.63	3.17	28.07	3.05	1.15	0.73	0.49	0.31	0.43
2009	685	0.64	0.56	31.02	27.19	3.36	10.68	1.30	2.27	2.27	16.14	2.49	0.87	0.60	0.28	0.34
2010	874	0.03	25.23	3.37	35.38	21.43	2.29	2.94	0.43	0.58	0.98	5.86	0.93	0.29	0.10	0.15
2011	1,081	2.67	8.73	70.83	2.63	6.34	4.38	1.12	0.80	0.29	0.37	0.12	1.33	0.17	0.11	0.11
2012	851	0.18	40.93	11.54	32.99	2.49	5.10	2.52	1.13	0.66	0.23	0.33	0.35	0.87	0.28	0.38
2013	1,094	0.03	0.54	70.31	5.90	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	3.28	3.81	64.42	6.93	12.06	1.58	3.11	1.83	0.81	0.46	0.12	0.19	0.28	1.12
2015	798	3.64	1.14	6.88	3.94	69.99	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	50.22	1.69	4.47	2.48	32.86	2.78	3.23	0.76	0.44	0.37	0.23	0.06	0.05	0.07
2017	1,300	3.76	0.73	38.31	2.37	4.12	3.12	36.88	4.43	3.11	1.33	0.62	0.72	0.21	0.09	0.20
2018	1,174	7.35	25.53	1.49	26.98	1.52	2.80	3.04	22.75	4.31	1.91	0.94	0.55	0.41	0.31	0.10
2019	1,001	0.01	13.72	20.69	1.57	32.32	1.77	3.82	2.24	18.68	1.98	1.66	0.69	0.38	0.23	0.23
2020	703	0.00	0.08	8.51	35.23	1.46	30.90	1.69	2.41	1.94	14.77	1.24	1.10	0.28	0.12	0.29

Table 11. 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 12. 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 13. 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 14 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 1975–2020 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 14. Number of Pacific Hake ovaries collected for histological analysis. The maturity ogive was determined from a subset of these samples (up to and including 2017; see Edwards et al. 2018*b*).

Year	NWFSC Trawl Survey	CAN 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)	OR Dept. Fish & Wildlife	Total
2009	263	0	0	0	0	0	0	**263**
2012	71	0	199	0	0	0	0	**270**
2013	70	0	254	0	104	103	0	**531**
2014	276	0	0	0	105	142	0	**523**
2015	293	0	193	0	98	112	0	**696**
2016	277	0	26	309	96	162	0	**870**
2017	109	0	65	134	93	113	0	**514**
2018	147	0	64	0	0	0	7	**218**
2019	60	15	92	0	0	0	0	**167**
2020	0	0	0	0	0	0	0	**0**
Total	**1,566**	**15**	**893**	**443**	**496**	**632**	**7**	**4,052**

Table 15. Summary of estimated model parameters and priors in the base model. The Beta prior is parameterized with a mean and standard deviation. The Lognormal prior is parameterized with the median and standard deviation in log space.

Parameter	**Number of parameters**	**Bounds (low, high)**	**Prior (Mean, SD) single value = fixed**
Stock Dynamics			
Log (R_0)	1	(13, 17)	Uniform
Steepness (h)	1	(0.2, 1)	Beta (0.78, 0.11)
Recruitment variability (σ_r)	–	–	1.4
Log recruitment deviations: 1946–2020	75	(-6, 6)	Lognormal (0, σ_r)
Natural mortality (M)	1	(0.05, 0.4)	Lognormal (-1.61, 0.10)
Selectivity			
Acoustic Survey			
Additional variance for survey log (SE)	1	(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 (1991–2020, ages 2–6)	150	(-10, 10)	Normal (0, 1.4)
Data weighting			
Dirichlet-Multinomial likelihood ($\log \theta$)	2	(-5, 20)	Normal (0, 1.813)

Table 16. 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 (D-M) approaches, are explained in the main text.

Year	Framework	Survey	Comp Method	MCMC	Change
2011	SS 3-20, TINSS	yes	MI (0.10, 0.89)	999	Increased compatibility of SS and TINSS, except for age-composition likelihood
2012	SS 3-23b	yes	MI (0.12, 0.94)	999	One framework for base model; TINSS changed to CCAM
2013	SS 3-24j	no	MI (0.12, 0.94)	999	Developed MSE
2014	SS 3-24s	yes	MI (0.12, 0.94)	999	Time-varying fishery selectivity
2015	SS 3-24u	no	MI (0.12, 0.94)	999	No major changes
2016	SS 3-24u	yes	MI (0.11, 0.51)	999	Re-analyzed 1998-2015 acoustic-survey data; Removed 1995 survey data
2017	SS 3-24u	no	MI (0.14, 0.41)	999	Added 1995 survey data; Increased allowable selectivity variation to 0.20
2018	SS 3-30-10-00	yes	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	DM (0.46, 0.92)	2,000	Change to time-varying fecundity
2020	SS 3-30-14-08	yes	DM (0.46, 0.92)	2,000	Add Normal prior for Dirichlet parameters; remove rec devs sum to zero restriction
2021	SS 3-30-16-03	no	DM (0.46, 0.92)	8,250	No U-turn MCMC Sampling (adnuts)

Table 17. Estimated numbers-at-age at the beginning of the year from the base model (posterior medians; million).

Year	Age																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1966	1,513	1,330	810	445	272	172	126	99	82	67	59	48	41	32	28	23	18	15	12	10	33
1967	4,333	1,203	1,056	634	339	204	128	89	69	58	48	42	34	29	23	20	16	12	11	9	40
1968	2,863	3,462	956	823	472	242	143	83	57	45	38	31	27	22	19	15	13	11	8	7	39
1969	630	2,283	2,761	747	629	353	179	101	59	41	32	26	22	19	15	13	10	9	8	6	39
1970	8,425	501	1,819	2,158	560	460	254	121	68	39	27	21	18	15	13	10	9	7	6	5	35
1971	760	6,699	397	1,411	1,604	404	324	166	79	44	26	18	14	12	10	8	7	6	5	4	31
1972	487	606	5,313	311	1,076	1,202	299	229	117	56	31	18	13	10	8	7	6	5	4	3	28
1973	5,587	389	483	4,180	240	824	911	219	168	86	41	23	13	9	7	6	5	4	4	3	25
1974	324	4,438	310	382	3,225	183	620	661	159	122	62	30	17	10	7	5	4	4	3	3	23
1975	1,705	258	3,524	243	293	2,425	136	441	469	113	87	44	21	12	7	5	4	3	3	2	20
1976	186	1,357	206	2,765	187	222	1,823	98	319	338	82	62	32	15	9	5	3	3	2	2	17
1977	6,247	148	1,078	162	2,143	143	169	1,346	72	234	248	60	46	24	11	6	4	3	2	2	15
1978	121	4,962	118	852	127	1,661	111	128	1,020	55	177	188	46	35	18	8	5	3	2	1	14
1979	1,302	96	3,947	93	666	98	1,286	84	97	774	42	135	143	35	26	14	6	4	2	1	13
1980	16,475	1,037	77	3,113	73	516	76	971	64	73	584	31	102	108	26	20	10	5	3	2	12
1981	243	13,102	823	61	2,442	57	400	58	742	49	56	445	24	77	83	20	15	8	4	2	11
1982	284	194	10,420	650	47	1,876	44	298	43	552	36	42	331	18	58	61	15	11	6	3	11
1983	502	226	154	8,234	508	36	1,446	33	225	32	417	27	31	250	13	43	46	11	8	4	11
1984	13,358	401	180	121	6,447	394	28	1,098	25	171	25	317	21	24	190	10	33	35	9	6	13
1985	120	10,616	319	143	95	4,997	304	21	830	19	130	19	240	16	18	144	8	25	27	6	16
1986	163	95	8,436	252	112	73	3,873	232	16	633	14	99	14	183	12	14	110	6	19	20	19
1987	6,359	129	76	6,655	196	86	56	2,889	173	12	473	11	74	11	137	9	10	82	4	14	30
1988	2,045	5,049	103	60	5,154	150	66	41	2,129	128	9	349	8	54	8	101	7	8	60	3	33
1989	107	1,628	4,018	81	46	3,930	113	48	30	1,561	94	7	255	6	40	6	74	5	6	44	27
1990	4,217	85	1,296	3,147	62	34	2,915	80	34	21	1,106	66	5	181	4	28	4	52	3	4	51
1991	1,209	3,355	67	1,019	2,429	47	26	2,130	58	25	16	807	48	3	132	3	21	3	38	2	40
1992	119	963	2,662	51	703	1,814	33	19	1,531	42	18	11	580	35	2	95	2	15	2	27	31
1993	3,134	94	764	2,091	36	495	1,338	23	13	1,061	29	12	8	402	24	2	66	1	10	1	40
1994	3,298	2,492	75	604	1,570	25	354	964	17	9	765	21	9	6	289	17	1	47	1	7	30
1995	1,205	2,622	1,981	58	467	1,109	16	223	609	10	6	482	13	6	4	182	11	1	30	1	24
1996	1,835	957	2,082	1,565	45	356	774	11	148	403	7	4	320	9	4	2	121	7	1	20	16
1997	1,051	1,458	759	1,565	1,146	32	258	486	7	92	253	4	2	201	5	2	1	76	5	0	23
1998	1,939	836	1,160	598	1,093	776	22	161	303	4	58	158	3	2	125	3	1	1	47	3	14
1999	12,943	1,543	664	898	374	753	461	14	101	190	3	36	99	2	1	79	2	1	1	30	11
2000	312	10,288	1,225	483	592	214	478	282	8	62	116	2	22	60	1	1	48	1	1	0	25
2001	1,243	248	8,179	964	352	425	144	301	178	5	39	73	1	14	38	1	0	30	1	0	16
2002	31	988	197	6,449	711	238	286	95	199	117	3	26	48	1	9	25	0	0	20	1	11
2003	1,740	24	785	156	4,999	521	168	203	68	141	83	2	18	34	0	7	18	0	0	14	8
2004	56	1,382	19	622	122	3,763	377	120	145	48	101	60	2	13	25	0	5	13	0	0	16
2005	2,814	44	1,099	15	463	74	2,626	252	80	97	32	67	40	1	9	16	0	3	9	0	11
2006	2,037	2,235	35	868	11	325	45	1,691	162	52	62	21	43	26	1	6	11	0	2	5	7

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Year	Age																			
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
2007	24	1,622	1,772	26	617	7	199	27	1,023	98	31	38	13	26	16	0	3	6	0	1	8
2008	5,578	19	1,286	1,350	16	407	4	118	16	608	58	19	22	7	16	9	0	2	4	0	5
2009	1,463	4,433	15	977	902	11	246	2	65	9	338	32	10	12	4	9	5	0	1	2	3
2010	16,150	1,164	3,521	11	688	627	7	157	2	42	6	216	21	7	8	3	6	3	0	1	3
2011	442	12,826	924	2,688	8	380	400	5	106	1	28	4	146	14	4	5	2	4	2	0	3
2012	1,542	352	10,182	714	1,592	5	259	280	3	74	1	20	3	102	10	3	4	1	3	2	2
2013	335	1,226	280	7,871	523	1,075	3	185	200	2	53	1	14	2	73	7	2	3	1	2	2
2014	8,906	267	972	220	5,844	385	782	2	125	135	2	36	0	9	1	49	5	1	2	1	3
2015	42	7,074	212	756	159	4,312	280	541	2	86	93	1	24	0	7	1	34	3	1	1	2
2016	4,829	34	5,593	165	572	117	3,169	209	404	1	64	69	1	18	0	5	1	25	2	1	3
2017	2,135	3,835	26	4,038	121	411	84	2,241	147	286	1	45	49	1	13	0	3	0	18	2	2
2018	180	1,695	3,023	19	2,895	82	286	55	1,467	96	187	1	29	32	0	8	0	2	0	12	3
2019	663	143	1,309	2,186	13	2,091	59	189	36	972	64	124	0	19	21	0	6	0	1	0	10
2020	818	527	113	961	1,579	9	1,436	38	123	23	635	41	81	0	13	14	0	4	0	1	6
2021	810	649	419	88	734	1,020	6	947	24	81	15	417	27	53	0	8	9	0	2	0	5

Table 18. Estimated biomass-at-age at the beginning of the year from the base model (posterior medians; 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	20	122	208	171	132	92	73	65	58	52	50	45	40	34	28	24	18	16	13	10	34
1967	58	111	272	243	164	109	74	58	49	45	40	39	33	31	23	20	17	13	11	9	41
1968	39	319	246	315	229	129	83	54	41	35	32	28	26	23	19	15	13	11	8	7	41
1969	9	210	711	286	305	188	104	66	42	32	27	24	21	20	16	14	11	9	8	6	40
1970	114	46	468	827	272	245	148	79	48	31	23	20	17	15	13	11	9	7	6	5	36
1971	10	617	102	541	779	215	188	109	56	35	22	16	13	12	10	9	7	6	5	4	32
1972	7	56	1,368	119	522	640	174	150	83	43	26	17	12	10	8	7	6	5	4	3	29
1973	75	36	124	1,602	117	439	530	143	119	67	35	21	13	10	7	6	5	4	4	3	26
1974	4	409	80	146	1,566	97	361	432	113	95	52	27	16	10	7	5	5	4	3	3	24
1975	94	41	1,053	89	180	1,529	107	385	453	103	84	75	32	23	13	13	10	9	7	6	55
1976	10	134	49	1,380	97	154	1,465	90	384	451	118	103	58	28	17	14	9	7	6	5	48
1977	344	13	432	80	1,278	96	128	1,125	70	255	298	76	62	39	22	14	8	5	4	4	33
1978	6	360	15	400	67	1,001	71	94	859	54	195	234	61	51	31	20	11	6	5	3	33
1979	63	7	951	24	388	68	987	75	89	802	50	168	219	54	47	27	13	7	4	3	25
1980	745	83	16	1,410	29	253	39	636	45	64	621	37	131	140	33	28	14	7	4	2	16
1981	10	1,407	176	21	1,286	22	210	32	554	35	46	464	26	104	123	24	18	9	5	3	13
1982	11	23	2,569	217	15	1,046	18	159	25	425	25	36	351	17	59	72	17	13	7	3	12
1983	18	29	21	2,808	188	12	752	17	139	23	367	25	32	258	18	64	69	17	13	6	17
1984	429	53	30	30	2,826	162	12	645	14	116	17	302	24	24	243	19	62	66	16	12	25
1985	3	1,847	71	36	39	2,725	164	12	582	12	87	16	181	15	12	123	7	21	23	6	14
1986	4	15	2,345	73	34	27	2,101	133	10	520	13	117	17	252	20	22	177	9	31	33	31
1987	141	19	11	2,522	55	25	20	1,668	104	8	362	11	68	13	165	13	14	116	6	20	42
1988	39	707	19	19	2,428	55	24	21	1,378	88	6	321	9	56	11	147	10	11	88	5	48
1989	2	226	1,100	25	13	2,027	50	19	16	1,016	63	4	233	4	33	7	87	6	6	52	32
1990	66	12	316	1,108	25	18	1,629	52	23	11	860	54	10	215	4	41	6	76	5	6	74
1991	19	459	19	377	1,117	24	14	1,258	42	21	17	580	31	3	159	7	49	7	91	6	96
1992	2	131	616	18	333	968	19	12	981	27	11	8	427	29	2	97	2	15	2	28	32
1993	49	12	190	707	14	224	660	12	6	583	15	16	8	247	14	1	45	1	7	1	28
1994	51	297	22	219	702	11	186	549	10	5	485	10	6	4	203	13	1	35	1	6	23
1995	19	291	531	20	228	595	11	139	402	8	4	359	11	5	2	146	9	1	24	1	19
1996	28	97	599	623	21	189	437	7	88	256	4	3	216	7	6	2	91	5	0	15	12
1997	16	135	270	676	565	18	141	283	4	56	160	4	1	143	4	2	1	66	4	0	20
1998	29	70	243	215	552	402	12	102	184	3	45	112	2	1	93	3	1	1	38	2	11
1999	197	211	166	310	159	396	257	8	62	133	2	29	75	1	1	64	2	1	0	24	9
2000	5	1,954	472	229	341	141	343	205	6	52	95	1	19	57	1	1	45	1	1	0	23
2001	19	13	2,345	467	230	282	108	260	152	5	37	72	1	15	38	1	0	30	1	0	15
2002	0	75	71	2,943	414	177	206	74	181	101	3	23	41	1	10	26	0	0	21	1	11
2003	26	2	200	68	2,612	307	127	140	50	117	64	2	17	27	0	7	18	0	0	14	8
2004	1	149	4	271	59	2,002	244	85	95	34	81	51	1	13	21	0	4	11	0	0	14
2005	42	5	286	6	235	40	1,492	159	52	68	26	55	32	1	10	16	0	3	8	0	10
2006	30	296	13	397	6	186	27	1,011	106	36	45	15	34	17	0	5	10	0	2	5	7

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Year	**Age**																				
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
2007	0	72	405	11	332	4	121	17	663	69	24	29	10	23	12	0	3	6	0	1	7
2008	79	3	314	551	9	259	3	80	11	439	44	15	19	6	14	8	0	2	3	0	4
2009	20	290	4	333	417	7	162	2	49	7	257	26	11	10	4	9	5	0	1	2	3
2010	208	127	819	3	298	333	5	131	2	43	6	190	18	7	6	2	5	3	0	1	3
2011	5	1,083	227	865	3	196	238	3	90	1	27	4	154	14	5	5	2	3	2	0	2
2012	18	45	2,184	252	652	2	170	194	3	67	1	19	3	101	10	3	4	1	2	1	2
2013	4	159	80	2,830	246	549	2	132	146	2	53	1	17	2	78	7	2	3	1	2	3
2014	93	27	397	103	2,803	206	449	1	82	97	1	41	0	9	1	52	5	2	2	1	3
2015	0	537	52	295	71	2,030	155	322	1	59	66	1	23	0	7	1	42	4	1	2	3
2016	44	6	1,364	63	238	52	1,476	107	209	1	42	50	0	17	0	7	1	37	4	1	4
2017	18	538	8	1,622	59	216	47	1,241	86	187	0	33	39	0	11	0	3	0	17	2	2
2018	3	317	1,071	9	1,456	44	158	34	865	62	120	0	20	23	0	9	0	2	0	12	3
2019	13	10	376	975	7	1,130	36	118	24	663	46	95	0	16	19	0	5	0	1	0	9
2020	16	36	39	457	801	5	818	22	74	15	410	29	51	0	11	13	0	3	0	1	6
2021	12	82	129	38	362	531	3	550	14	51	10	299	19	44	0	9	10	0	3	0	5

Table 19. 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 (posterior medians; percentage of age class removed by fishing). Annual exploitation rates for ages 6+ are equivalent because those fish are fully selected.

Year	**Age**																				
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
1966	0.00	0.08	1.34	3.41	5.08	5.97	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64	9.64
1967	0.00	0.13	2.25	5.65	8.42	9.83	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71	15.71
1968	0.00	0.08	1.33	3.37	5.04	5.92	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61	9.61
1969	0.00	0.11	1.85	4.66	6.96	8.14	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11
1970	0.00	0.13	2.20	5.54	8.26	9.66	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45	15.45
1971	0.00	0.08	1.35	3.41	5.11	6.01	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75
1972	0.00	0.05	0.91	2.33	3.50	4.12	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69	6.69
1973	0.00	0.06	1.04	2.66	3.98	4.68	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60
1974	0.00	0.07	1.27	3.22	4.84	5.66	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18
1975	0.00	0.06	1.07	2.72	4.08	4.80	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79
1976	0.00	0.05	0.88	2.25	3.36	3.96	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46
1977	0.00	0.03	0.57	1.46	2.21	2.59	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24	4.24
1978	0.00	0.03	0.53	1.35	2.02	2.38	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91
1979	0.00	0.04	0.60	1.54	2.31	2.72	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46
1980	0.00	0.03	0.47	1.21	1.82	2.14	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
1981	0.00	0.04	0.77	1.96	2.95	3.46	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65	5.65
1982	0.00	0.04	0.62	1.57	2.37	2.79	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56	4.56
1983	0.00	0.03	0.52	1.33	2.00	2.36	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86	3.86
1984	0.00	0.03	0.58	1.48	2.22	2.62	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29
1985	0.00	0.03	0.49	1.25	1.88	2.22	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
1986	0.00	0.04	0.73	1.87	2.80	3.29	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
1987	0.00	0.05	0.89	2.27	3.38	4.00	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52	6.52
1988	0.00	0.06	0.95	2.42	3.63	4.27	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96	6.96
1989	0.00	0.08	1.34	3.40	5.08	5.98	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68
1990	0.00	0.06	1.01	2.56	3.83	4.52	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35	7.35
1991	0.00	0.08	2.79	11.59	5.54	6.19	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62	8.62
1992	0.00	0.06	1.09	6.19	9.96	6.27	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38	11.38
1993	0.00	0.04	0.64	4.95	7.35	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42
1994	0.00	0.03	0.59	1.98	9.69	9.88	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47	18.47
1995	0.00	0.03	0.47	1.51	3.33	10.87	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88
1996	0.00	0.15	4.57	6.80	6.50	6.83	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77	18.77
1997	0.00	0.04	0.76	10.68	13.18	10.17	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00	19.00
1998	0.00	0.09	2.01	18.43	11.80	22.43	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85
1999	0.00	0.11	7.20	15.25	25.30	18.04	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55	20.55
2000	0.00	0.03	1.01	7.16	8.64	12.96	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43	18.43
2001	0.00	0.04	0.68	6.28	13.13	13.66	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10	15.10
2002	0.00	0.02	0.31	2.23	7.02	9.76	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34	9.34
2003	0.00	0.01	0.18	1.13	4.71	8.01	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08

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Year	**Age**																				
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20+**
2004	0.00	0.05	1.14	5.54	19.60	10.98	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07	14.07
2005	0.00	0.02	0.46	2.67	10.33	17.94	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96	16.96
2006	0.00	0.12	4.25	9.23	13.42	20.35	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40	21.40
2007	0.00	0.09	3.59	11.47	14.96	13.43	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61	22.61
2008	0.00	0.23	3.71	14.28	12.33	21.35	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82	26.82
2009	0.00	0.05	1.47	10.17	11.19	9.28	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47	17.47
2010	0.00	0.05	3.47	9.97	27.36	17.74	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48	13.48
2011	0.00	0.15	2.21	22.75	13.49	12.37	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27	10.27
2012	0.00	0.10	2.22	6.87	13.37	8.53	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.01
2013	0.00	0.03	0.67	5.88	6.19	7.40	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37
2014	0.00	0.07	1.84	7.83	6.38	7.35	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71	11.71
2015	0.00	0.19	1.27	4.08	5.69	6.76	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44
2016	0.00	0.52	8.22	6.49	8.46	8.13	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68	9.68
2017	0.00	0.89	6.95	8.61	12.08	10.79	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75	15.75
2018	0.00	2.50	8.12	7.74	8.09	6.92	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80
2019	0.00	0.20	6.78	8.14	8.79	12.06	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07	16.07
2020	0.00	0.03	0.53	3.06	16.88	10.41	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50	15.50

Table 20. Estimated catch-at-age in numbers for each year from the base model (posterior medians; thousands).

Year	Age																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
1966	0	972	10,751	15,235	13,544	10,337	12,426	9,618	7,917	6,579	5,668	4,666	4,057	3,170	2,689	2,238	1,741	1,466	1,202	944	3,249
1967	0	1,520	23,151	36,618	28,588	19,707	20,437	14,017	11,030	8,965	7,417	6,451	5,331	4,612	3,581	3,089	2,565	1,968	1,668	1,385	6,204
1968	0	2,577	12,558	27,702	23,694	14,172	13,502	8,009	5,537	4,304	3,523	2,921	2,531	2,086	1,808	1,407	1,205	1,011	767	658	3,741
1969	0	2,369	51,423	34,611	43,859	28,512	23,317	12,911	7,689	5,320	4,124	3,363	2,820	2,413	1,994	1,718	1,343	1,158	970	738	5,062
1970	0	617	39,691	121,416	45,430	43,786	39,069	18,319	10,226	6,074	4,156	3,249	2,673	2,233	1,906	1,575	1,344	1,067	903	764	5,295
1971	0	5,332	5,247	48,872	82,801	23,777	31,795	15,959	7,564	4,251	2,507	1,705	1,336	1,103	925	784	649	559	439	370	2,908
1972	0	316	48,857	7,155	37,784	50,686	19,823	15,324	7,801	3,691	2,046	1,220	839	652	537	449	385	316	272	212	1,813
1973	0	230	5,045	111,640	9,551	38,882	70,469	16,289	12,764	6,463	3,080	1,727	1,014	697	542	447	372	317	264	229	1,894
1974	0	3,344	3,914	12,361	156,207	10,142	57,536	62,000	14,328	11,125	5,663	2,699	1,506	884	612	478	391	327	280	234	2,053
1975	0	155	37,927	6,628	12,029	117,036	10,425	35,005	37,410	8,709	6,729	3,435	1,638	915	535	369	288	236	198	170	1,526
1976	0	707	1,813	62,357	6,354	8,844	118,465	6,250	20,906	22,435	5,256	4,037	2,041	980	546	323	221	172	142	119	1,102
1977	0	49	6,250	2,384	47,502	3,708	7,246	57,551	3,033	10,153	10,891	2,529	1,948	992	478	265	156	108	83	69	645
1978	0	1,550	621	11,548	2,577	39,704	4,318	5,034	39,947	2,110	7,066	7,574	1,757	1,357	688	332	184	108	74	58	538
1979	0	33	23,875	1,438	15,482	2,667	57,543	3,765	4,377	34,683	1,838	6,128	6,548	1,524	1,176	600	288	159	94	65	556
1980	0	281	364	37,734	1,330	11,148	2,660	34,219	2,230	2,588	20,582	1,098	3,624	3,912	909	696	357	171	95	56	400
1981	0	5,980	6,303	1,185	72,316	1,979	22,915	3,276	42,012	2,737	3,189	25,285	1,344	4,458	4,803	1,118	857	436	210	116	606
1982	0	66	64,368	10,178	1,106	52,413	1,980	13,692	1,965	25,149	1,647	1,907	15,121	807	2,676	2,878	671	514	263	126	471
1983	0	66	788	109,888	10,160	853	56,141	1,271	8,781	1,259	16,150	1,053	1,223	9,666	517	1,702	1,829	427	329	169	430
1984	0	132	1,035	1,769	143,204	10,299	1,214	47,291	1,065	7,383	1,057	13,619	882	1,027	8,145	435	1,439	1,554	362	277	566
1985	0	3,089	1,553	1,781	1,763	111,230	11,021	772	30,327	683	4,758	681	8,748	568	660	5,239	280	925	986	233	590
1986	0	40	62,424	4,691	3,134	2,391	208,688	12,463	867	34,266	772	5,349	766	9,865	640	743	5,912	317	1,039	1,111	1,020
1987	0	65	667	152,116	6,610	3,422	3,652	188,520	11,237	786	30,930	698	4,826	693	8,904	580	672	5,326	286	937	1,942
1988	0	2,846	973	1,420	188,302	6,371	4,545	2,850	148,054	8,837	615	24,302	548	3,792	542	6,997	453	523	4,193	224	2,278
1989	0	1,274	54,057	2,723	2,280	236,276	10,968	4,634	2,924	150,678	8,995	627	24,714	558	3,870	554	7,124	461	535	4,263	2,627
1990	0	49	12,969	81,029	2,341	1,527	215,061	5,909	2,492	1,569	81,218	4,847	338	13,305	300	2,085	297	3,833	249	287	3,730
1991	0	2,647	1,741	118,096	136,678	2,743	2,203	184,192	5,035	2,106	1,340	69,378	4,119	286	11,367	255	1,772	252	3,268	212	3,444
1992	0	571	29,360	3,012	70,685	114,536	3,745	2,087	174,337	4,757	2,018	1,265	65,878	3,903	273	10,778	241	1,688	240	3,107	3,497
1993	0	30	4,901	104,689	2,488	41,959	112,583	1,926	1,069	89,839	2,430	1,032	647	33,856	2,012	140	5,530	125	866	123	3,394
1994	0	810	421	11,655	154,050	2,316	65,006	178,084	3,056	1,691	141,337	3,865	1,649	1,026	53,351	3,185	222	8,729	197	1,369	5,567
1995	0	869	9,286	856	15,538	121,508	2,433	32,821	90,172	1,533	857	71,733	1,962	825	521	27,114	1,614	111	4,443	100	3,539
1996	0	1,396	95,781	107,506	2,927	23,929	145,350	2,027	27,469	75,404	1,283	715	60,001	1,636	692	433	22,589	1,350	94	3,705	3,051
1997	0	556	5,667	169,180	152,144	3,176	48,974	92,441	1,284	17,396	47,844	817	456	38,137	1,037	435	276	14,353	854	60	4,299
1998	0	744	23,594	110,242	130,026	175,324	4,030	30,047	57,135	788	10,761	29,602	509	283	23,587	645	271	171	8,896	527	2,712
1999	0	1,679	48,308	137,564	95,290	137,066	94,202	2,732	20,550	38,904	541	7,326	20,208	346	191	16,070	436	183	116	6,073	2,210
2000	0	2,990	12,581	35,145	51,659	27,963	87,841	51,852	1,515	11,328	21,373	297	4,031	11,084	189	105	8,809	241	101	64	4,544
2001	0	90	56,461	61,255	46,671	58,464	21,422	45,362	26,635	777	5,822	10,995	152	2,081	5,716	98	54	4,544	124	53	2,380
2002	0	160	604	145,465	50,493	23,451	26,510	8,768	18,575	10,932	321	2,380	4,499	62	855	2,338	40	22	1,866	51	1,006
2003	0	2	1,430	1,753	237,036	42,446	15,136	18,375	6,079	12,833	7,543	219	1,633	3,116	43	589	1,621	27	15	1,287	728
2004	0	674	214	34,838	24,316	415,399	52,892	16,593	20,169	6,699	14,104	8,317	241	1,807	3,428	47	649	1,781	31	17	2,228
2005	0	10	5,138	394	48,515	13,213	445,518	42,536	13,460	16,256	5,407	11,339	6,686	193	1,455	2,759	38	522	1,431	25	1,805
2006	0	2,713	1,367	80,290	1,488	66,081	9,551	362,258	34,571	10,961	13,250	4,390	9,235	5,432	157	1,185	2,245	31	423	1,163	1,494
2007	0	1,545	64,731	2,845	93,122	944	44,741	6,107	231,712	22,167	7,004	8,475	2,817	5,904	3,477	101	757	1,435	20	271	1,704
2008	0	41	48,405	193,810	1,952	87,220	1,177	31,516	4,295	163,529	15,572	4,918	5,967	1,975	4,159	2,449	71	532	1,008	14	1,398
2009	0	2,215	218	99,584	101,561	969	42,798	428	11,409	1,551	59,280	5,653	1,789	2,159	718	1,509	890	26	193	366	513
2010	0	607	123,472	1,153	188,543	111,514	946	21,236	212	5,654	771	29,429	2,792	884	1,065	353	749	441	13	96	438
2011	0	19,788	21,003	612,977	1,006	47,380	41,048	478	10,870	108	2,883	391	15,078	1,431	449	544	180	382	226	6	273
2012	0	381	226,410	49,740	213,681	405	23,255	25,230	298	6,667	67	1,768	240	9,214	874	276	334	110	234	138	173
2013	0	369	1,932	464,351	32,866	80,558	432	24,655	26,672	313	7,094	70	1,887	255	9,826	925	294	355	117	249	332
2014	0	186	18,324	17,612	373,520	28,884	92,192	256	14,583	15,711	186	4,159	41	1,106	150	5,769	547	173	209	69	343
2015	0	14,158	2,735	31,508	9,275	291,406	15,159	29,575	82	4,642	5,033	59	1,337	13	354	48	1,849	175	55	67	132
2016	0	173	461,588	10,945	49,032	9,767	306,286	20,095	39,010	108	6,153	6,689	79	1,757	18	467	64	2,443	232	73	265
2017	0	34,752	1,902	348,699	14,930	45,077	13,135	352,908	23,186	44,991	124	7,076	7,670	91	2,029	20	539	73	2,817	267	392
2018	0	43,628	246,151	1,487	235,034	5,723	42,496	8,049	217,902	14,277	27,745	77	4,363	4,739	56	1,251	13	333	45	1,739	410
2019	0	314	89,401	178,748	1,157	253,184	9,440	30,537	5,817	156,592	10,261	19,927	55	3,149	3,403	40	899	9	239	33	1,541
2020	0	164	625	30,564	267,790	892	224,258	5,924	19,154	3,640	98,352	6,427	12,491	35	1,963	2,138	25	562	6	150	988

Table 21. Estimated catch-at-age in biomass for each year from the base model (posterior medians; 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	0	90	2,768	5,840	6,576	5,506	7,229	6,288	5,632	5,115	4,782	4,314	3,913	3,364	2,694	2,316	1,802	1,517	1,244	977	3,362
1967	0	140	5,961	14,036	13,879	10,496	11,890	9,165	7,847	6,970	6,258	5,964	5,142	4,894	3,588	3,197	2,654	2,037	1,726	1,434	6,419
1968	0	237	3,234	10,618	11,503	7,548	7,855	5,236	3,939	3,346	2,972	2,700	2,441	2,214	1,811	1,456	1,247	1,046	794	681	3,871
1969	0	218	13,242	13,266	21,293	15,186	13,566	8,441	5,470	4,137	3,480	3,109	2,720	2,561	1,998	1,778	1,390	1,199	1,004	764	5,239
1970	0	57	10,220	46,539	22,056	23,320	22,730	11,977	7,275	4,722	3,507	3,004	2,578	2,370	1,910	1,629	1,391	1,104	934	791	5,480
1971	0	491	1,351	18,733	40,200	12,664	18,498	10,434	5,381	3,305	2,115	1,576	1,289	1,171	927	812	672	578	454	383	3,009
1972	0	29	12,581	2,743	18,344	26,996	11,533	10,019	5,549	2,869	1,726	1,128	809	692	538	465	399	327	281	220	1,876
1973	0	21	1,299	42,792	4,637	20,708	40,999	10,650	9,081	5,025	2,598	1,597	978	740	543	462	385	328	273	237	1,960
1974	0	308	1,008	4,738	75,838	5,402	33,474	40,536	10,193	8,650	4,778	2,495	1,453	939	614	495	405	339	290	242	2,125
1975	0	24	11,329	2,425	7,390	73,803	8,208	30,587	36,205	7,904	6,527	5,816	2,457	1,738	1,047	1,012	790	647	543	466	4,187
1976	0	70	428	31,116	3,297	6,134	95,222	5,728	25,219	29,917	7,618	6,664	3,688	1,822	1,068	886	607	473	390	326	3,025
1977	0	4	2,506	1,173	28,335	2,492	5,495	48,118	2,950	11,045	13,065	3,212	2,626	1,627	955	565	333	230	177	147	1,376
1978	0	112	79	5,426	1,367	23,926	2,760	3,724	33,644	2,070	7,771	9,436	2,336	2,010	1,198	776	429	253	174	135	1,255
1979	0	3	5,754	372	9,012	1,832	44,175	3,354	3,995	35,963	2,204	7,649	10,036	2,366	2,112	1,190	570	315	185	129	1,102
1980	0	23	77	17,090	522	5,467	1,374	22,427	1,591	2,262	21,870	1,277	4,675	5,086	1,154	972	498	239	132	78	558
1981	0	642	1,347	406	38,067	778	12,040	1,789	31,358	1,972	2,625	26,330	1,477	5,995	7,170	1,356	1,039	529	255	141	735
1982	0	8	15,867	3,395	345	29,220	796	7,309	1,122	19,360	1,153	1,643	16,024	756	2,751	3,365	784	601	307	148	551
1983	0	8	107	37,472	3,753	280	29,193	639	5,426	889	14,212	979	1,266	9,966	683	2,523	2,710	633	487	251	638
1984	0	17	170	441	62,781	4,236	528	27,769	618	4,989	741	12,956	1,002	1,053	10,432	818	2,705	2,921	681	521	1,065
1985	0	537	344	447	718	60,665	5,931	431	21,241	431	3,193	584	6,590	538	446	4,491	240	793	845	200	506
1986	0	6	17,354	1,363	948	893	113,234	7,129	557	28,129	726	6,344	912	13,551	1,075	1,200	9,542	512	1,678	1,794	1,647
1987	0	10	93	57,652	1,841	982	1,322	108,870	6,714	501	23,625	685	4,464	860	10,712	821	951	7,541	405	1,326	2,749
1988	0	398	182	453	88,709	2,351	1,695	1,472	95,835	6,083	442	22,387	599	3,870	787	10,173	659	760	6,096	325	3,312
1989	0	177	14,795	849	668	121,871	4,811	1,883	1,511	98,077	6,059	395	22,502	373	3,205	649	8,341	540	626	4,992	3,076
1990	0	7	3,158	28,522	946	791	120,176	3,807	1,659	831	63,155	3,949	744	15,797	304	3,022	430	5,555	361	416	5,407
1991	0	362	480	43,660	62,845	1,409	1,198	108,802	3,630	1,790	1,473	49,848	2,638	292	13,698	608	4,223	601	7,788	504	8,205
1992	0	77	6,800	1,046	33,526	61,093	2,179	1,296	111,680	3,106	1,277	913	48,447	3,318	267	11,071	247	1,734	246	3,191	3,593
1993	0	4	1,218	35,427	985	19,045	55,560	966	522	49,331	1,240	1,304	663	20,771	1,206	96	3,788	85	593	85	2,325
1994	0	96	126	4,226	68,845	1,036	34,206	101,508	1,900	947	89,622	1,874	1,071	749	37,415	2,374	165	6,507	147	1,020	4,150
1995	0	96	2,491	293	7,576	65,214	1,583	20,510	59,487	1,159	571	53,405	1,569	751	354	21,713	1,292	89	3,558	80	2,834
1996	0	142	27,547	42,809	1,368	12,723	82,137	1,319	16,363	47,972	776	536	40,537	1,327	1,028	325	16,962	1,014	71	2,782	2,291
1997	0	52	2,015	73,119	75,022	1,739	26,705	53,921	752	10,561	30,214	705	271	27,146	687	379	240	12,477	742	52	3,737
1998	0	62	4,950	39,599	65,663	90,747	2,181	19,062	34,732	529	8,425	21,100	403	219	17,542	512	215	136	7,066	418	2,153
1999	0	230	12,087	47,528	40,508	72,165	52,461	1,565	12,571	27,350	360	5,853	15,265	304	141	13,156	357	150	95	4,972	1,810
2000	0	568	4,846	16,659	29,787	18,450	63,035	37,743	1,142	9,491	17,438	262	3,449	10,409	166	98	8,224	225	95	60	4,242
2001	0	5	16,187	29,666	30,462	38,850	16,000	39,143	22,786	684	5,607	10,764	152	2,184	5,675	96	53	4,438	121	51	2,325
2002	0	12	216	66,376	29,407	17,466	19,167	6,840	16,972	9,370	282	2,149	3,769	52	924	2,448	42	23	1,954	53	1,053
2003	0	0	365	763	123,852	24,979	11,428	12,714	4,540	10,582	5,797	195	1,513	2,460	36	587	1,615	27	15	1,282	726
2004	0	73	44	15,189	11,686	220,951	34,268	11,736	13,269	4,751	11,353	7,136	186	1,754	2,961	42	582	1,596	27	15	1,997
2005	0	1	1,337	170	24,675	7,127	253,143	26,951	8,817	11,425	4,306	9,190	5,421	147	1,666	2,670	37	505	1,384	24	1,747
2006	0	359	524	36,732	794	37,930	5,645	216,594	22,678	7,670	9,618	3,169	7,160	3,574	101	1,132	2,144	30	404	1,110	1,426
2007	0	69	14,785	1,188	50,007	532	27,171	3,864	150,056	15,639	5,409	6,464	2,292	5,138	2,784	88	658	1,249	17	236	1,482
2008	0	6	11,811	79,055	1,099	55,515	808	21,488	3,049	117,921	11,660	3,970	5,062	1,531	3,674	2,041	59	443	840	12	1,165
2009	0	145	54	33,918	46,952	609	28,106	288	8,538	1,262	45,070	4,572	1,842	1,814	703	1,560	920	27	200	379	530
2010	0	66	28,720	336	81,677	59,124	623	17,730	230	5,810	739	25,789	2,380	995	767	319	675	398	12	86	395
2011	0	1,670	5,160	197,317	389	24,363	24,423	322	9,276	100	2,820	420	15,965	1,471	474	501	166	352	208	6	252
2012	0	49	48,565	17,588	87,481	198	15,260	17,424	232	6,049	64	1,705	231	9,115	868	260	315	104	221	130	163
2013	0	48	555	166,934	15,437	41,117	271	17,665	19,498	260	7,087	76	2,321	286	10,496	975	310	374	124	262	350
2014	0	19	7,476	8,253	179,178	15,488	52,928	159	9,610	11,271	129	4,843	42	1,050	145	6,103	579	183	221	73	363
2015	0	1,075	676	12,304	4,123	137,194	8,384	17,591	55	3,194	3,613	49	1,273	13	386	60	2,310	219	69	84	165
2016	0	29	112,581	4,193	20,417	4,307	142,637	10,319	20,215	55	4,071	4,815	47	1,680	26	679	93	3,553	337	106	386
2017	0	4,876	592	140,038	7,251	23,728	7,373	195,405	13,460	29,492	76	5,096	6,128	70	1,653	19	503	68	2,627	249	366
2018	0	8,159	87,236	689	118,198	3,066	23,449	4,969	128,475	9,127	17,843	52	3,005	3,430	50	1,338	13	356	48	1,860	438
2019	0	21	25,676	79,704	639	136,770	5,764	19,140	3,906	106,921	7,480	15,318	39	2,609	3,025	38	846	8	225	31	1,449
2020	0	11	215	14,551	135,930	500	127,760	3,500	11,502	2,329	63,585	4,503	7,916	29	1,716	1,999	23	525	5	140	923

Table 22. Calculations showing changes in biomass at each age due to natural mortality and fishing for recent strong cohorts. 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 posterior medians.

	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	196.7	0.0	40.3	156.4	208.3	0.0	42.9	165.5	92.6	0.0	19.0	73.6	44.4	0.0	9.1	35.3
1	1,953.7	0.6	400.0	1,553.2	1,082.5	1.7	221.5	859.4	536.9	1.1	111.3	424.5	538.0	4.9	109.0	424.1
2	2,345.0	16.2	479.7	1,849.0	2,184.0	48.6	447.2	1,688.3	1,364.2	112.6	266.8	984.8	1,071.4	87.2	209.5	774.6
3	2,942.8	66.4	595.6	2,280.9	2,829.6	166.9	561.7	2,100.9	1,621.5	140.0	318.7	1,162.8	974.6	79.7	191.0	703.9
4	2,611.8	123.9	521.7	1,966.2	2,803.4	179.2	555.8	2,068.3	1,456.1	118.2	286.2	1,051.7	801.3	135.9	147.5	517.9
5	2,001.6	221.0	384.0	1,396.7	2,030.0	137.2	401.0	1,491.8	1,129.7	136.8	217.3	775.7	531.4			
6	1,492.0	253.1	277.8	961.0	1,475.6	142.6	289.1	1,043.9	818.0	127.8	150.8	539.4				
7	1,011.2	216.6	182.9	611.8	1,241.1	195.4	233.6	812.2	549.6							
8	662.6	150.1	118.7	393.9	864.8	128.5	163.4	572.9								
9	438.6	117.9	76.6	244.0	663.5	106.9	123.1	433.4								
10	257.3	45.1	47.8	164.4	410.4	63.6	77.0	269.8								
11	189.5	25.8	36.0	127.8	299.3											
12	154.4	16.0	30.2	108.2												
13	101.1	9.1	19.9	72.1												
14	77.9	10.5	14.9	52.5												
15	51.9	6.1	10.1	35.8												
16	42.2	2.3	8.5	31.5												
17	36.6	3.6	7.1	26.0												
18	16.7	2.6	3.1	10.9												
19	12.5	1.9	0.4	10.2												
20	9.0															

Table 23. 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$_{40\%}$). A dash (–) indicates a quantity requiring 2021 catch which has not taken place yet.

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	832	50.1%	1,795	1,651	1,517	50.9%	6.9%
1967	831	50.5%	1,820	1,672	4,320	69.3%	10.4%
1968	824	50.5%	1,875	1,613	2,868	50.6%	6.0%
1969	919	56.1%	2,114	1,947	629	62.0%	7.2%
1970	1,083	66.9%	2,229	2,103	8,423	68.3%	8.6%
1971	1,117	68.9%	2,370	1,933	760	51.1%	6.1%
1972	1,184	72.8%	2,677	2,623	487	39.0%	3.3%
1973	1,529	94.0%	2,727	2,646	5,589	42.9%	4.6%
1974	1,507	92.6%	2,737	2,449	323	49.1%	6.5%
1975	1,733	106.4%	3,420	3,318	1,707	54.2%	6.2%
1976	2,136	131.1%	3,608	3,504	186	47.0%	5.9%
1977	1,843	112.9%	3,374	3,115	6,248	31.0%	3.1%
1978	1,557	95.5%	2,775	2,505	121	31.2%	2.8%
1979	1,623	99.6%	3,163	3,110	1,302	33.7%	4.0%
1980	1,632	99.8%	3,389	2,750	16,474	26.1%	2.5%
1981	1,487	91.0%	3,617	2,494	243	37.8%	4.7%
1982	1,531	93.6%	4,093	4,066	284	31.6%	2.4%
1983	2,153	131.8%	3,977	3,942	502	30.4%	2.5%
1984	2,218	135.5%	4,217	3,841	13,360	34.9%	3.4%
1985	1,915	117.1%	4,955	3,478	120	23.7%	3.0%
1986	2,007	122.5%	5,001	4,984	163	41.5%	4.1%
1987	2,343	143.0%	4,562	4,434	6,358	46.5%	4.8%
1988	2,271	138.5%	4,659	4,061	2,045	46.8%	6.8%
1989	1,877	114.3%	4,291	4,094	107	54.2%	7.3%
1990	1,989	121.0%	3,974	3,908	4,218	47.7%	6.8%
1991	1,836	111.6%	3,801	3,412	1,208	71.9%	8.2%
1992	1,515	92.1%	3,271	3,153	119	61.9%	7.4%
1993	1,209	73.5%	2,484	2,431	3,135	52.6%	6.2%
1994	1,169	71.0%	2,493	2,202	3,298	63.6%	16.4%
1995	1,004	61.1%	2,468	2,207	1,205	55.6%	10.9%
1996	983	59.8%	2,378	2,267	1,835	70.4%	11.6%
1997	1,019	62.0%	2,268	2,140	1,050	72.1%	13.9%
1998	864	52.6%	1,867	1,785	1,940	86.8%	14.3%
1999	727	44.2%	1,823	1,486	12,946	96.6%	18.3%
2000	787	47.9%	3,382	1,751	312	67.8%	15.0%
2001	1,090	66.5%	3,496	3,468	1,243	68.2%	4.8%
2002	1,857	113.4%	3,798	3,737	31	48.4%	4.0%
2003	1,731	105.6%	3,344	3,321	1,740	44.1%	4.8%
2004	1,374	83.8%	2,784	2,661	56	72.3%	10.5%
2005	1,074	65.5%	2,258	2,218	2,813	69.9%	13.7%
2006	875	53.4%	1,969	1,708	2,037	82.2%	18.5%
2007	689	42.2%	1,562	1,501	23	84.9%	14.5%
2008	703	43.1%	1,584	1,520	5,578	89.1%	18.7%
2009	607	37.3%	1,347	1,099	1,464	77.6%	12.2%
2010	605	37.2%	1,804	1,548	16,149	92.7%	11.6%
2011	747	46.0%	2,338	1,509	442	87.1%	16.2%
2012	976	60.3%	2,943	2,891	1,543	66.5%	5.3%
2013	1,785	110.0%	3,418	3,299	336	63.8%	7.1%
2014	1,889	116.3%	3,457	3,366	8,908	60.8%	7.3%
2015	1,424	87.6%	2,881	2,486	42	45.5%	5.5%
2016	1,260	77.4%	2,903	2,865	4,828	72.6%	8.1%
2017	1,593	97.9%	3,163	2,754	2,133	77.9%	13.2%

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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**
2018	1,498	91.7%	3,160	2,921	179	74.7%	11.1%
2019	1,486	90.3%	2,635	2,599	665	74.9%	11.4%
2020	1,300	78.8%	2,094	1,990	820	65.9%	12.6%
2021	981	59.2%	1,789	1,610	810	–	–

Table 24. Time-series of 95% posterior credibility intervals for the quantities shown in Table 23. A dash (–) indicates a quantity requiring 2021 catch which has not taken place yet.

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	487 - 1,555	28.7 - 90.9%	1,386 - 4,184	1,193 - 3,871	49 - 8,869	27.8 - 75.7%	3.6 - 11.5%
1967	502 - 1,608	29.3 - 92.1%	1,485 - 4,389	1,275 - 3,973	226 - 13,295	40.1 - 95.6%	5.4 - 16.8%
1968	508 - 1,644	28.6 - 92.1%	1,576 - 4,792	1,252 - 4,123	209 - 9,026	26.0 - 75.8%	3.0 - 9.7%
1969	585 - 1,832	32.4 - 102.8%	1,788 - 5,535	1,603 - 5,061	41 - 3,523	33.4 - 87.4%	3.6 - 11.2%
1970	694 - 2,201	38.0 - 122.3%	1,875 - 5,954	1,775 - 5,510	4,339 - 20,803	37.4 - 93.9%	4.3 - 13.2%
1971	709 - 2,296	39.2 - 128.1%	1,977 - 6,637	1,597 - 5,197	77 - 2,757	25.1 - 76.6%	3.0 - 9.7%
1972	745 - 2,454	41.3 - 135.4%	2,236 - 7,641	2,193 - 7,447	55 - 1,720	17.9 - 61.9%	1.6 - 5.4%
1973	956 - 3,169	53.0 - 174.7%	2,269 - 7,604	2,205 - 7,363	2,959 - 13,385	20.4 - 66.7%	2.2 - 7.4%
1974	943 - 3,100	52.0 - 172.0%	2,281 - 7,659	2,031 - 6,672	36 - 1,229	23.8 - 74.5%	3.2 - 10.4%
1975	1,068 - 3,562	59.8 - 197.3%	2,833 - 9,625	2,748 - 9,343	839 - 4,185	26.2 - 82.6%	3.0 - 10.1%
1976	1,306 - 4,373	73.0 - 242.5%	2,987 - 9,990	2,889 - 9,685	20 - 811	22.2 - 74.1%	2.9 - 9.6%
1977	1,128 - 3,703	63.3 - 207.7%	2,795 - 9,258	2,580 - 8,492	3,478 - 13,788	13.8 - 52.7%	1.6 - 5.1%
1978	964 - 3,050	53.8 - 173.6%	2,305 - 7,349	2,079 - 6,590	16 - 607	14.2 - 52.8%	1.4 - 4.5%
1979	1,019 - 3,092	56.7 - 178.7%	2,655 - 8,111	2,607 - 7,961	515 - 3,114	16.1 - 54.8%	2.1 - 6.4%
1980	1,043 - 3,071	57.0 - 177.4%	2,852 - 8,379	2,318 - 6,821	9,772 - 32,960	12.3 - 43.5%	1.3 - 3.9%
1981	968 - 2,711	52.1 - 158.6%	3,054 - 8,511	2,114 - 5,912	26 - 951	18.9 - 59.1%	2.6 - 7.2%
1982	1,017 - 2,708	54.6 - 160.4%	3,439 - 9,200	3,410 - 9,134	43 - 918	15.9 - 50.4%	1.3 - 3.5%
1983	1,464 - 3,697	78.5 - 223.2%	3,361 - 8,514	3,321 - 8,420	92 - 1,448	15.6 - 48.2%	1.5 - 3.7%
1984	1,543 - 3,692	81.6 - 226.8%	3,605 - 8,656	3,264 - 7,816	8,598 - 23,919	18.5 - 54.4%	2.0 - 4.9%
1985	1,358 - 3,093	71.3 - 193.5%	4,275 - 9,893	2,962 - 6,733	16 - 501	12.7 - 36.7%	1.8 - 4.2%
1986	1,460 - 3,142	75.3 - 201.0%	4,385 - 9,551	4,367 - 9,521	21 - 624	24.1 - 60.0%	2.6 - 5.6%
1987	1,739 - 3,577	87.8 - 232.7%	4,038 - 8,341	3,913 - 8,072	4,113 - 10,882	27.7 - 65.9%	3.1 - 6.4%
1988	1,714 - 3,375	85.5 - 223.8%	4,167 - 8,289	3,612 - 7,115	1,112 - 3,729	28.3 - 65.8%	4.5 - 8.9%
1989	1,442 - 2,723	71.0 - 183.6%	3,878 - 7,388	3,697 - 7,038	16 - 390	34.3 - 73.5%	5.0 - 9.5%
1990	1,548 - 2,828	75.5 - 193.8%	3,620 - 6,644	3,558 - 6,517	2,841 - 6,981	30.1 - 65.3%	4.8 - 8.8%
1991	1,457 - 2,557	70.3 - 176.9%	3,499 - 6,230	3,134 - 5,503	546 - 2,333	47.1 - 101.3%	5.9 - 10.3%
1992	1,217 - 2,077	57.8 - 145.6%	3,024 - 5,242	2,921 - 5,043	17 - 461	40.1 - 94.4%	5.4 - 9.3%
1993	979 - 1,648	46.2 - 116.2%	2,309 - 3,919	2,263 - 3,822	2,150 - 4,996	33.8 - 83.1%	4.5 - 7.6%
1994	961 - 1,563	44.5 - 112.0%	2,328 - 3,874	2,054 - 3,355	2,288 - 5,310	43.7 - 86.6%	12.2 - 19.9%
1995	822 - 1,352	38.2 - 96.4%	2,304 - 3,886	2,056 - 3,426	717 - 2,062	38.1 - 73.5%	8.0 - 13.4%
1996	809 - 1,326	37.6 - 94.0%	2,229 - 3,715	2,129 - 3,528	1,196 - 3,059	50.1 - 92.8%	8.6 - 14.1%
1997	842 - 1,382	39.1 - 97.8%	2,119 - 3,525	2,002 - 3,294	587 - 1,919	52.0 - 92.0%	10.3 - 16.9%
1998	712 - 1,172	32.9 - 82.4%	1,746 - 2,916	1,668 - 2,760	1,266 - 3,354	66.0 - 104.1%	10.4 - 17.5%
1999	592 - 998	27.7 - 69.5%	1,694 - 3,010	1,387 - 2,352	9,135 - 21,408	74.2 - 114.0%	13.3 - 22.5%
2000	628 - 1,111	29.9 - 75.5%	3,072 - 6,008	1,620 - 2,906	99 - 697	47.4 - 86.0%	10.5 - 18.8%
2001	861 - 1,570	41.7 - 105.2%	3,197 - 6,024	3,174 - 5,973	844 - 2,059	47.5 - 86.2%	3.2 - 6.2%
2002	1,478 - 2,654	71.5 - 179.3%	3,490 - 6,297	3,428 - 6,183	7 - 107	31.7 - 65.3%	2.8 - 5.0%
2003	1,414 - 2,405	66.7 - 166.7%	3,108 - 5,310	3,086 - 5,261	1,198 - 2,944	28.5 - 60.2%	3.4 - 5.9%
2004	1,149 - 1,859	53.0 - 131.3%	2,617 - 4,289	2,505 - 4,054	9 - 199	49.9 - 97.2%	7.7 - 12.5%
2005	904 - 1,446	41.3 - 102.4%	2,132 - 3,481	2,097 - 3,402	1,938 - 4,922	47.7 - 92.8%	10.1 - 16.3%
2006	731 - 1,201	33.7 - 83.6%	1,858 - 3,190	1,610 - 2,653	1,401 - 3,450	57.1 - 111.5%	13.4 - 22.1%
2007	565 - 976	26.6 - 65.6%	1,471 - 2,631	1,416 - 2,521	6 - 94	58.0 - 115.9%	9.9 - 18.0%
2008	562 - 1,048	27.2 - 67.3%	1,484 - 2,810	1,424 - 2,666	3,938 - 9,635	63.5 - 111.3%	12.5 - 23.4%
2009	473 - 941	23.3 - 59.1%	1,258 - 2,555	1,023 - 2,029	826 - 3,000	51.7 - 100.5%	7.9 - 15.7%
2010	467 - 959	23.2 - 59.1%	1,675 - 3,617	1,447 - 2,975	10,525 - 30,557	63.9 - 120.7%	7.3 - 15.1%
2011	569 - 1,216	28.5 - 73.5%	2,142 - 4,999	1,400 - 3,013	171 - 1,079	57.3 - 116.0%	9.9 - 21.3%
2012	707 - 1,686	36.8 - 99.0%	2,662 - 6,484	2,620 - 6,382	911 - 3,161	39.9 - 93.6%	3.0 - 7.4%
2013	1,276 - 3,085	67.1 - 183.4%	3,086 - 7,547	2,975 - 7,218	107 - 922	39.0 - 85.0%	4.1 - 9.9%
2014	1,342 - 3,286	70.2 - 195.0%	3,091 - 7,704	3,018 - 7,471	5,355 - 18,745	36.2 - 83.5%	4.2 - 10.2%
2015	1,000 - 2,501	52.0 - 148.5%	2,550 - 6,638	2,207 - 5,556	9 - 188	24.5 - 67.9%	3.1 - 7.8%
2016	868 - 2,259	45.3 - 133.6%	2,524 - 6,916	2,491 - 6,810	2,407 - 11,806	42.9 - 100.5%	4.4 - 12.0%
2017	1,034 - 3,038	55.3 - 177.6%	2,661 - 8,039	2,323 - 6,861	772 - 6,142	45.5 - 113.7%	6.9 - 20.5%
2018	900 - 3,000	49.6 - 175.6%	2,508 - 8,739	2,335 - 7,953	17 - 1,719	42.2 - 109.1%	5.5 - 18.6%
2019	819 - 3,153	46.2 - 183.6%	1,980 - 7,711	1,950 - 7,616	35 - 11,503	41.6 - 110.2%	5.3 - 20.9%
2020	637 - 2,914	36.9 - 170.2%	1,457 - 6,696	1,384 - 6,399	42 - 17,452	34.2 - 98.6%	5.6 - 26.0%
2021	404 - 2,388	24.6 - 137.0%	1,050 - 6,988	930 - 6,265	34 - 17,629	–	–

Table 25. Select parameters, derived quantities, and reference point posterior median estimates for the (2021) base model compared to the previous assessment's (2020) base model.

	2021 Base model	2020 Base model
Parameters		
Natural mortality (M)	0.230	0.229
Unfished recruitment (R_0, millions)	2,264	2,505
Steepness (h)	0.807	0.816
Additional acoustic survey SD	0.302	0.297
Dirichlet-Multinomial fishery (log θ_{fish})	-0.569	-0.559
Dirichlet-Multinomial survey (log θ_{surv})	2.324	2.332
Catchability (q)	0.864	0.903
Derived Quantities		
2010 recruitment (millions)	16,149	15,344
2014 recruitment (millions)	8,908	9,401
2016 recruitment (millions)	4,828	4,550
Unfished female spawning biomass (B_0, thousand t)	1,658	1,832
2009 relative spawning biomass	37.3%	33.4%
2021 relative spawning biomass	59.2%	–
Reference Points based on $F_{\text{SPR}=40\%}$		
2020 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	65.9%	–
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	584	656
SPR at $F_{\text{SPR}=40\%}$	40.0%	40.0%
Exploitation fraction corresponding to SPR	18.3%	18.3%
Yield at $B_{\text{SPR}=40\%}$ (thousand t)	275	308

Table 26. Summary of median and 95% credibility intervals of equilibrium conceptual reference points for the base assessment model. Equilibrium reference points were computed using 2016–2020 averages for mean weight-at-age and baseline selectivity (1966–1990; prior to time-varying deviations.)

Quantity	**2.5^{th} percentile**	**Median**	**97.5^{th} percentile**
Unfished female spawning biomass (B_0, thousand t)	1,036	1,658	2,818
Unfished recruitment (R_0, millions)	1,201	2,264	4,935
Reference points (equilibrium) based on $F_{\text{SPR}=40\%}$			
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	332	584	999
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	16.0%	18.3%	21.0%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	148	275	530
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	415	663	1,127
SPR at $B_{40\%}$	40.6%	43.6%	51.6%
Exploitation fraction resulting in $B_{40\%}$	12.2%	16.1%	19.3%
Yield at $B_{40\%}$ (thousand t)	147	269	518
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	254	426	789
SPR at MSY	22.4%	30.0%	47.0%
Exploitation fraction corresponding to SPR at MSY	14.4%	25.5%	35.0%
MSY (thousand t)	153	290	568

Table 27. Forecast quantiles of 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, g), including catch similar to 2020 (row d), to the (unilaterally summed) TAC from 2020 (row f), and to the TAC from 2019 (row g); and non-constant catch levels that result in a median relative fishing intensity of 100% (row h), the median values estimated via the default harvest policy ($F_{\text{SPR}=40\%}$–40:10, row i), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2021 and 2022 (row j). Catch in 2023 does not impact the beginning of the year biomass in 2023.

Within model quantile			5%	25%	50%	75%	95%
Management Action	Year	Catch (t)	**Beginning of year relative spawning biomass**				
a:	2021	0	28%	45%	59%	80%	120%
	2022	0	28%	44%	58%	80%	124%
	2023	0	29%	45%	61%	85%	145%
b:	2021	180,000	28%	45%	59%	80%	120%
	2022	180,000	24%	39%	54%	75%	118%
	2023	180,000	21%	36%	52%	75%	135%
c:	2021	350,000	28%	45%	59%	80%	120%
	2022	350,000	19%	35%	49%	70%	114%
	2023	350,000	12%	28%	43%	66%	126%
d:	2021	380,000	28%	45%	59%	80%	120%
2020	2022	380,000	19%	34%	48%	69%	113%
catch	2023	380,000	11%	26%	42%	64%	124%
e:	2021	430,000	28%	45%	59%	80%	120%
	2022	430,000	17%	33%	47%	68%	111%
	2023	430,000	9%	24%	39%	62%	121%
f:	2021	529,290	28%	45%	59%	80%	120%
2020	2022	529,290	15%	30%	44%	65%	109%
TAC	2023	529,290	7%	19%	34%	57%	117%
g:	2021	597,500	28%	45%	59%	80%	120%
2019	2022	597,500	13%	29%	42%	63%	107%
TAC	2023	597,500	7%	16%	31%	53%	113%
h:	2021	498,958	28%	45%	59%	80%	120%
FI=	2022	401,394	16%	31%	45%	66%	110%
100%	2023	345,712	8%	23%	39%	61%	121%
i:	2021	565,191	28%	45%	59%	80%	120%
default	2022	427,836	14%	29%	43%	64%	108%
HR	2023	353,096	7%	21%	36%	58%	118%
j:	2021	457,534	28%	45%	59%	80%	120%
C2021=	2022	457,506	17%	32%	46%	67%	111%
C2022	2023	371,194	8%	23%	38%	60%	120%

Table 28. Decision table of forecast quantiles of relative fishing intensity (1-SPR)/(1-SPR$_{40\%}$), expressed as a percentage, for the 2021–2023 catch alternatives presented in Table 27. Values greater than 100% indicate fishing intensities greater than the $F_{\mathrm{SPR}=40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Relative fishing intensity**				
	Year	Catch (t)					
a:	2021	0	0%	0%	0%	0%	0%
	2022	0	0%	0%	0%	0%	0%
	2023	0	0%	0%	0%	0%	0%
b:	2021	180,000	30%	44%	57%	70%	92%
	2022	180,000	29%	46%	59%	74%	99%
	2023	180,000	27%	45%	59%	76%	104%
c:	2021	350,000	49%	69%	84%	99%	121%
	2022	350,000	50%	74%	91%	108%	135%
	2023	350,000	47%	75%	95%	116%	143%
d:	2021	380,000	52%	73%	88%	103%	124%
2020	2022	380,000	53%	78%	95%	113%	139%
catch	2023	380,000	50%	80%	100%	122%	144%
e:	2021	430,000	57%	78%	93%	108%	129%
	2022	430,000	58%	84%	101%	120%	143%
	2023	430,000	56%	87%	108%	130%	146%
f:	2021	529,290	65%	87%	103%	117%	137%
2020	2022	529,290	67%	95%	113%	131%	145%
TAC	2023	529,290	65%	99%	122%	139%	147%
g:	2021	597,500	70%	92%	108%	122%	141%
2019	2022	597,500	73%	101%	120%	137%	146%
TAC	2023	597,500	70%	106%	129%	141%	147%
h:	2021	498,958	63%	85%	100%	115%	135%
FI=	2022	401,394	56%	82%	100%	119%	143%
100%	2023	345,712	48%	78%	100%	123%	145%
i:	2021	565,191	68%	90%	105%	120%	139%
default	2022	427,836	59%	86%	104%	124%	144%
HR	2023	353,096	49%	80%	103%	128%	145%
j:	2021	457,534	59%	81%	96%	111%	132%
C2021=	2022	457,506	61%	87%	105%	123%	144%
C2022	2023	371,194	51%	81%	103%	127%	145%

Table 29. Probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (catch options explained in Table 27).

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%	18%	3%	0%	0%	0%
b: 180,000	78%	26%	6%	0%	2%	5%
c: 350,000	85%	34%	10%	1%	23%	31%
d: 380,000	86%	36%	11%	1%	29%	36%
e: 430,000	87%	38%	13%	1%	39%	46%
f: 529,290	89%	43%	17%	2%	54%	61%
g: 597,500	90%	46%	19%	2%	63%	70%
h: 498,958	89%	41%	15%	2%	50%	57%
i: 565,191	90%	45%	18%	2%	59%	66%
j: 457,534	88%	40%	14%	1%	43%	50%

Table 30. Probabilities related to spawning biomass, relative fishing intensity, and the 2023 default harvest policy catch for alternative 2022 catch options, given the 2021 catch level shown in Table 29 (catch options explained in Table 27).

Catch in 2022	**Probability $B_{2023} < B_{2022}$**	**Probability $B_{2023} < B_{40\%}$**	**Probability $B_{2023} < B_{25\%}$**	**Probability $B_{2023} < B_{10\%}$**	**Probability 2022 relative fishing intensity > 100%**	**Probability 2023 default harvest policy catch < 2022 catch**
a: 0	52%	16%	2%	0%	0%	0%
b: 180,000	68%	31%	9%	0%	4%	6%
c: 350,000	77%	45%	20%	4%	36%	39%
d: 380,000	78%	47%	23%	4%	43%	45%
e: 430,000	79%	51%	27%	6%	52%	55%
f: 529,290	82%	58%	35%	10%	68%	71%
g: 597,500	83%	62%	40%	12%	76%	78%
h: 401,394	78%	52%	28%	7%	50%	52%
i: 427,836	79%	55%	32%	9%	56%	58%
j: 457,506	80%	53%	29%	7%	57%	59%

Table 31. Posterior medians for select parameters, derived quantities, reference points, and negative log likelihoods for the base model and some sensitivity runs (described in Section 3.8). A dash (–) indicates that the parameter or derived quantity was not estimated in the model.

	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)	0.230	0.233	0.228	0.228	0.230	0.280	0.297	0.231	0.231	0.229
Unfished recruitment (R_0, millions)	2,264	2,349	2,233	1,749	2,670	4,399	5,748	2,468	2,484	1,953
Steepness (h)	0.807	0.541	–	0.812	0.808	0.800	0.797	0.810	0.809	0.816
Additional acoustic survey SD	0.302	0.306	0.306	0.296	0.302	0.311	0.314	0.315	0.302	0.294
Dirichlet-Multinomial fishery (log θ_{fish})	-0.569	-0.572	-0.569	-0.629	-0.554	-0.570	-0.573	-0.574	–	–
Dirichlet-Multinomial survey (log θ_{surv})	2.324	2.314	2.328	2.246	2.330	2.327	2.329	2.309	–	–
Additional age-1 index SD	–	–	–	–	–	–	–	0.316	–	–
Catchability (q)	0.864	–	–	–	–	–	–	0.821	0.900	0.934
Derived Quantities										
2010 recruitment (millions)	16,149	16,433	15,990	15,627	16,182	27,927	35,144	17,317	15,664	15,504
2014 recruitment (millions)	8,908	8,912	8,853	8,562	8,910	14,539	17,788	9,938	8,503	7,897
2016 recruitment (millions)	4,828	4,822	4,798	4,611	4,849	7,773	9,518	5,394	4,811	4,749
Unfished female spawning biomass (B_0, thousand t)	1,658	1,685	1,656	1,305	1,946	2,235	2,572	1,781	1,797	1,440
2009 relative spawning biomass	37.3%	37.3%	37.1%	46.6%	31.8%	40.0%	41.2%	36.2%	32.5%	40.1%
2021 relative spawning biomass	59.2%	57.7%	59.2%	74.1%	49.6%	63.0%	64.0%	70.9%	53.2%	62.4%
Reference Points based on $F_{\text{SPR}=40\%}$										
2020 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	65.9%	66.0%	66.2%	66.1%	66.5%	44.8%	37.9%	59.6%	68.9%	69.7%
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	584	382	662	465	693	779	892	631	639	515
SPR at $F_{\text{SPR}=40\%}$	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	18.3%	18.5%	18.2%	18.2%	18.3%	21.2%	22.2%	18.4%	18.4%	18.2%
Yield at $B_{\text{SPR}=40\%}$ (thousand t)	275	182	310	217	326	446	547	300	302	241
Negative log likelihoods										
Total	701.62	706.46	711.40	714.43	700.08	701.45	701.32	705.46	184.60	482.81
Survey	-8.02	-6.45	-8.02	-8.05	-8.01	-7.99	-7.97	-6.25	-8.15	-8.44
Survey age compositions	555.99	555.84	556.00	563.36	554.11	556.15	556.28	557.83	104.28	387.83
Fishery age compositions	87.02	87.97	87.02	87.81	86.80	87.06	87.07	87.12	39.27	31.96
Recruitment	50.41	51.76	50.17	54.38	51.18	49.87	49.52	50.28	41.21	52.68
Parameter priors	0.78	0.90	10.80	0.77	0.80	0.85	0.84	0.80	0.08	0.03
Parameter deviations	15.42	16.43	15.42	16.16	15.18	15.50	15.57	15.67	7.92	18.74

Table 32. Posterior medians for 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)
Parameters				
Natural mortality (M)	0.230	0.217	0.226	0.230
Unfished recruitment (R_0, millions)	2,264	2,179	2,185	2,263
Steepness (h)	0.807	0.810	0.811	0.807
Additional acoustic survey SD	0.302	0.331	0.296	0.302
Dirichlet-Multinomial fishery (log θ_{fish})	-0.569	-0.853	-0.619	-0.569
Dirichlet-Multinomial survey (log θ_{surv})	2.324	2.361	2.312	2.325
Catchability (q)	0.864	0.896	0.890	0.864
Derived Quantities				
2010 recruitment (millions)	16,149	15,252	15,395	16,127
2014 recruitment (millions)	8,908	9,591	8,561	8,895
2016 recruitment (millions)	4,828	8,965	5,171	4,820
Unfished female spawning biomass (B_0, thousand t)	1,658	1,768	1,652	1,657
2009 relative spawning biomass	37.3%	32.0%	36.0%	37.3%
2021 relative spawning biomass	59.2%	90.2%	62.3%	59.2%
Reference Points based on $F_{\text{SPR}=40\%}$				
2020 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	65.9%	56.6%	66.1%	66.0%
Female spawning biomass at $F_{\text{SPR=40\%}}$ ($B_{\text{SPR=40\%}}$, thousand t)	584	628	588	584
SPR at $F_{\text{SPR=40\%}}$	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	18.3%	17.5%	18.1%	18.3%
Yield at $B_{\text{SPR=40\%}}$ (thousand t)	275	281	273	275
Negative log likelihoods				
Total	701.62	819.08	728.91	701.62
Survey	-8.02	-7.24	-8.06	-8.02
Survey age compositions	555.99	639.22	572.60	555.99
Fishery age compositions	87.02	87.74	87.17	87.02
Recruitment	50.41	50.15	51.30	50.41
Parameter priors	0.78	0.78	0.74	0.78
Parameter deviations	15.42	48.40	25.14	15.42

Table 33. Posterior medians for select parameters, derived quantities, reference points, and negative log likelihoods for the base model and further sensitivity runs (described in Section 3.8). A dash (–) indicates that the parameter was not estimated in the model.

	Base model	Time-invariant ageing error vector	Max. age selectivity 5	Max. age selectivity 7	Max. age selectivity 8	RW Metrop. Hast. (rwMH)
Parameters						
Natural mortality (M)	0.230	0.221	0.227	0.228	0.230	0.229
Unfished recruitment (R_0, millions)	2,264	2,427	2,240	2,108	2,109	2,474
Steepness (h)	0.807	0.789	0.809	0.809	0.807	0.816
Additional acoustic survey SD	0.302	0.277	0.284	0.313	0.295	0.298
Dirichlet-Multinomial fishery (log θ_{fish})	-0.569	-1.918	-0.617	-0.498	-0.480	-0.585
Dirichlet-Multinomial survey (log θ_{surv})	2.324	0.629	2.229	2.491	2.450	2.314
Catchability (q)	0.864	–	–	–	–	0.871
Derived Quantities						
2010 recruitment (millions)	16,149	17,530	15,411	14,286	14,443	15,900
2014 recruitment (millions)	8,908	9,571	7,327	9,278	9,176	8,750
2016 recruitment (millions)	4,828	4,707	4,208	4,791	5,060	4,800
Unfished female spawning biomass (B_0, thousand t)	1,658	1,912	1,679	1,556	1,539	1,815
2009 relative spawning biomass	37.3%	40.6%	37.2%	36.3%	36.1%	33.7%
2021 relative spawning biomass	59.2%	60.8%	48.4%	59.3%	62.0%	53.8%
Reference Points based on $F_{\text{SPR}=40\%}$						
2020 rel. fishing intensity: (1-SPR)/(1-SPR$_{40\%}$)	65.9%	65.9%	74.1%	70.3%	68.2%	66.4%
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	584	662	594	553	549	650
SPR at $F_{\text{SPR}=40\%}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	18.3%	17.6%	18.1%	18.3%	18.4%	18.3%
Yield at $B_{\text{SPR}=40\%}$ (thousand t)	275	296	276	260	259	305
Negative log likelihoods						
Total	701.62	1,033.31	727.59	674.20	656.93	701.62
Survey	-8.02	-9.09	-8.43	-7.81	-8.35	-8.02
Survey age compositions	555.99	868.47	580.52	531.42	514.19	555.99
Fishery age compositions	87.02	117.05	90.75	81.60	80.45	87.02
Recruitment	50.41	46.87	50.11	50.65	50.91	50.41
Parameter priors	0.78	0.51	0.77	0.84	0.83	0.78
Parameter deviations	15.42	9.51	13.86	17.50	18.89	15.42

Table 34. Posterior medians from the base model for select parameters, derived quantities, reference point estimates, and negative log likelihoods for retrospective analyses. Some values are implied since they occur after the ending year of the respective retrospective analysis. A dash (–) indicates that the parameter or derived quantity was not estimated in the model.

	2021 Base model	-1 year	-2 years	-3 years	-4 years	-5 years
Parameters						
Natural mortality (*M*)	0.230	0.231	0.230	0.229	0.229	0.229
Unfished recruitment (R_0, millions)	2,264	2,291	2,334	2,294	2,400	2,397
Steepness (*h*)	0.807	0.810	0.812	0.811	0.809	0.807
Additional acoustic survey SD	0.302	0.303	0.315	0.319	0.311	0.313
Dirichlet-Multinomial fishery (log θ_{fish})	-0.569	-0.546	-0.537	-0.551	-0.572	-0.608
Dirichlet-Multinomial survey (log θ_{surv})	2.324	2.319	2.098	2.080	1.594	1.572
Catchability (*q*)	0.864	–	–	–	–	–
Derived Quantities						
2010 recruitment (millions)	16,149	15,296	13,805	13,518	15,657	15,520
2014 recruitment (millions)	8,908	9,290	8,601	8,949	16,524	6,943
2016 recruitment (millions)	4,828	4,439	4,109	4,236	914	954
Unfished female spawning biomass (B_0, thousand t)	1,658	1,675	1,706	1,687	1,770	1,779
2009 relative spawning biomass	37.3%	36.0%	34.1%	33.8%	34.3%	35.7%
2021 relative spawning biomass	59.2%	58.6%	74.8%	68.6%	91.7%	66.3%
Reference Points based on $F_{\text{SPR}=40\%}$						
2020 rel. fishing intensity: (1-SPR)/(1-$\text{SPR}_{40\%}$)	65.9%	67.9%	65.9%	66.7%	51.0%	64.7%
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	584	595	605	599	626	631
SPR at $F_{\text{SPR}=40\%}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	18.3%	18.3%	18.3%	18.2%	18.3%	18.2%
Yield at $B_{\text{SPR}=40\%}$ (thousand t)	275	280	285	282	294	296

8 FIGURES

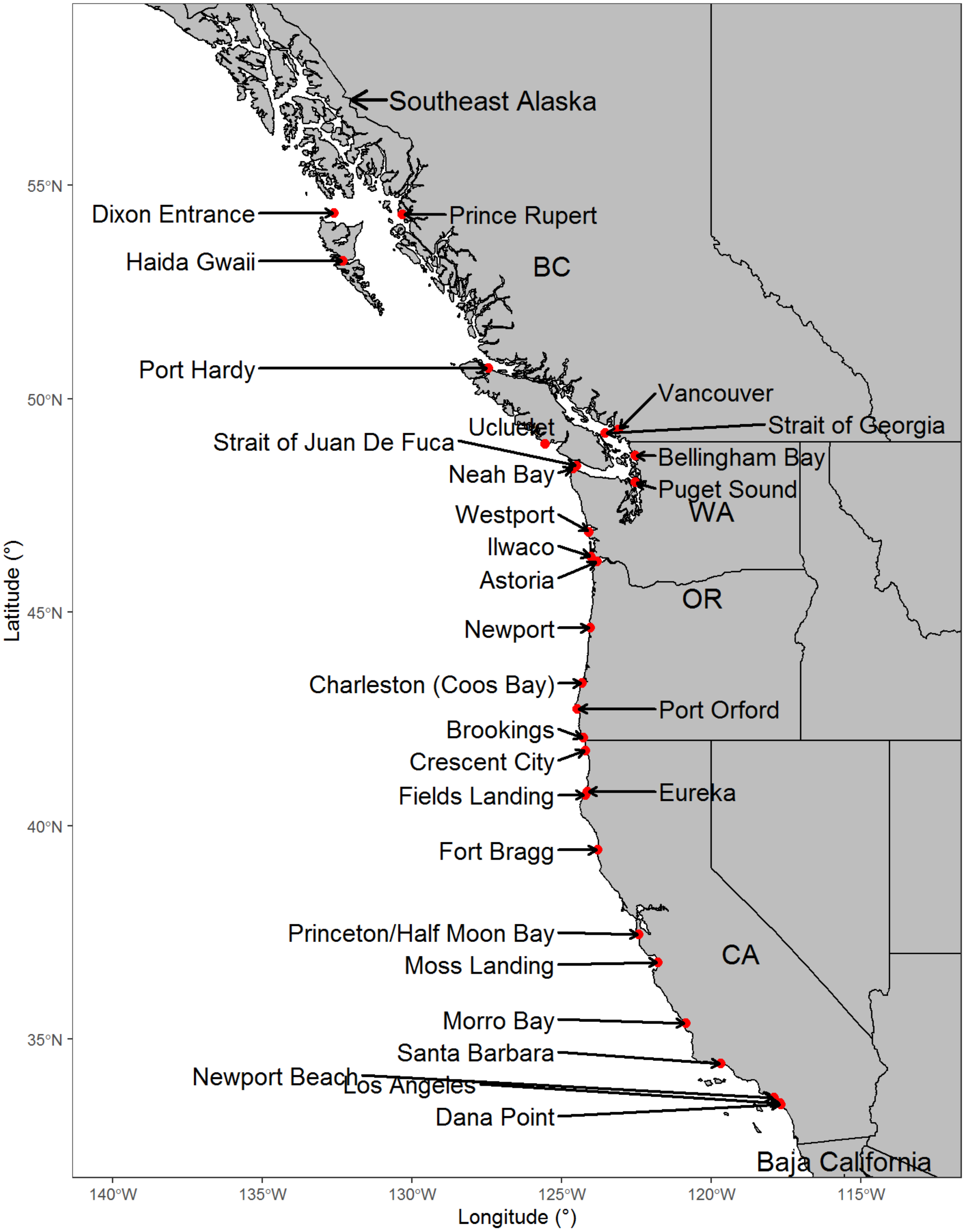


Figure 1. Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.

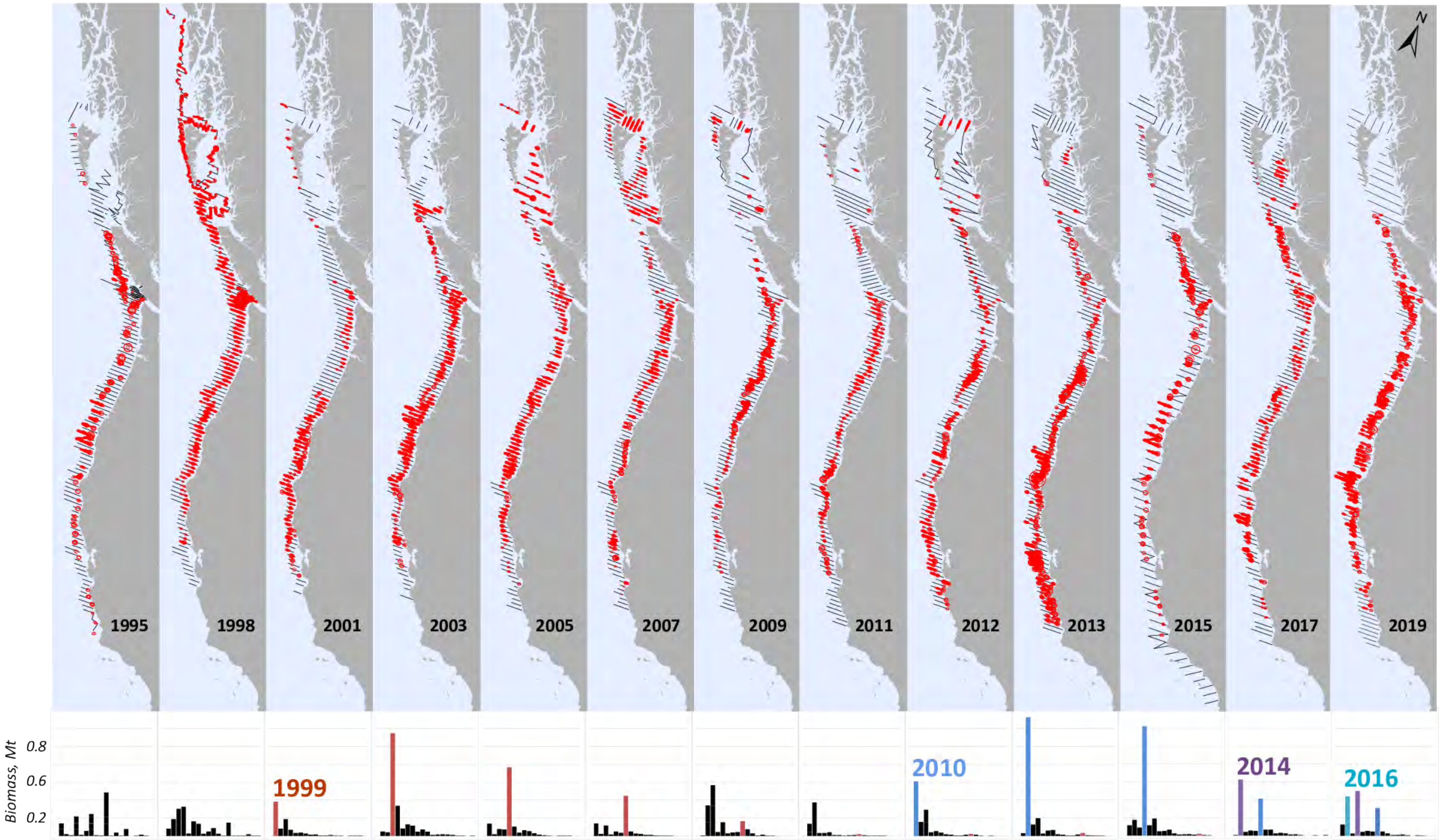


Figure 2. Spatial distribution of acoustic backscatter attributable to age-2 and older Pacific Hake from the Joint U.S. and Canada acoustic surveys 1995–2019. Area of the circle is roughly proportional to observed backscatter. Barplots show survey-estimated biomass for ages 2 to 20, with major cohorts highlighted in color. Figure produced by Julia Clemons (NOAA).

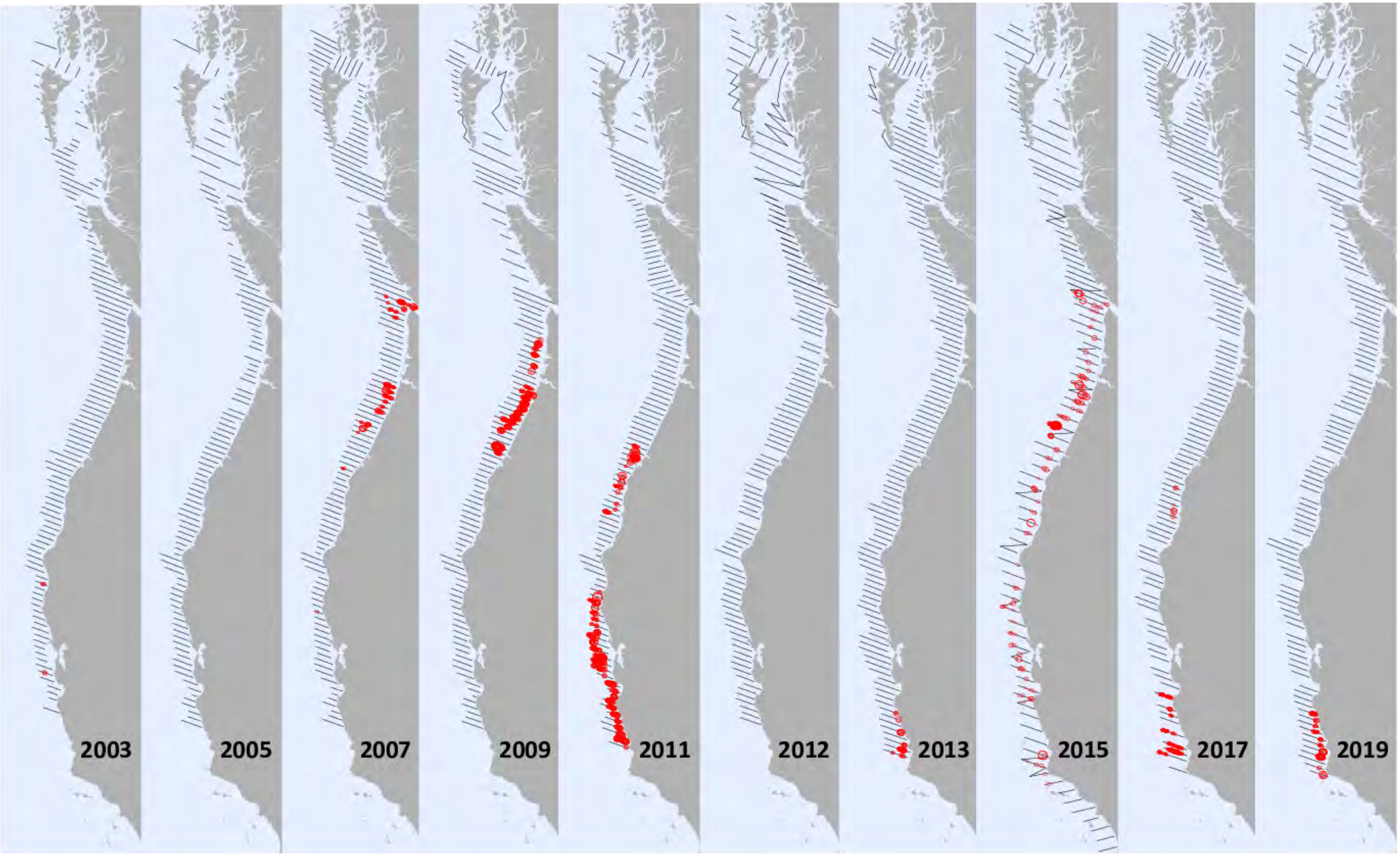


Figure 3. Spatial distribution of acoustic backscatter attributable to age-1 Pacific Hake from the Joint U.S. and Canada acoustic surveys 2003–2019. Age-1 Pacific Hake are not fully sampled during the acoustic survey and were not explicitly considered during establishment of the survey sampling design. Area of the circle is roughly proportional to observed backscatter. Figure produced by Julia Clemons (NOAA).

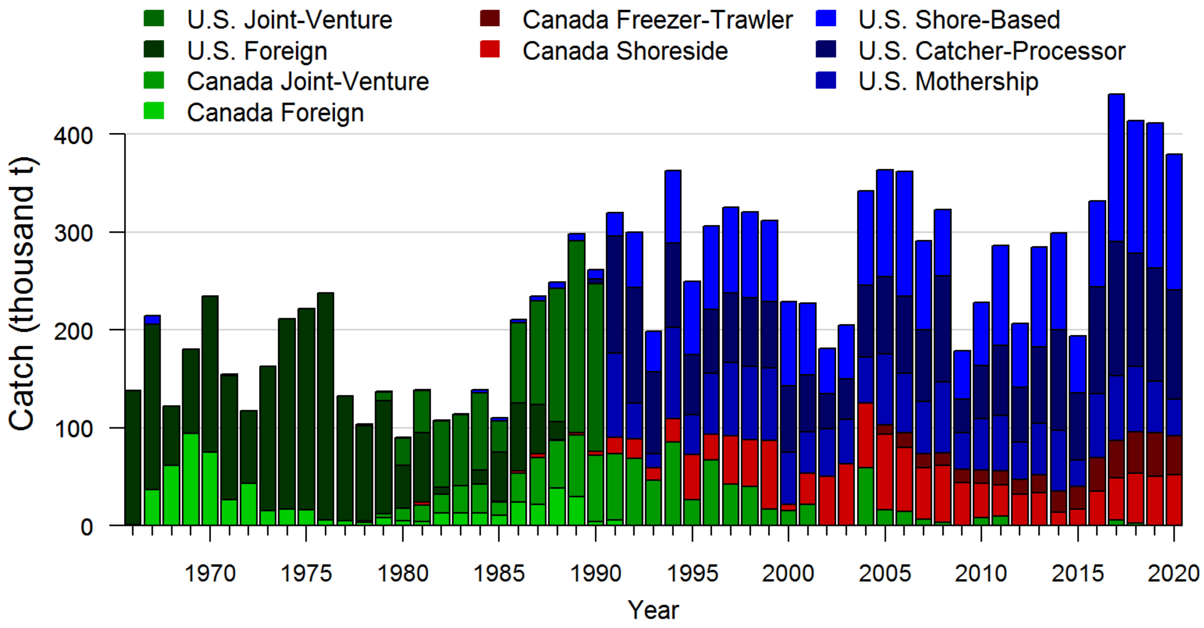


Figure 4. Total Pacific Hake catch used in the assessment by sector, 1966–2020. U.S. tribal catches are included in the appropriate sector.

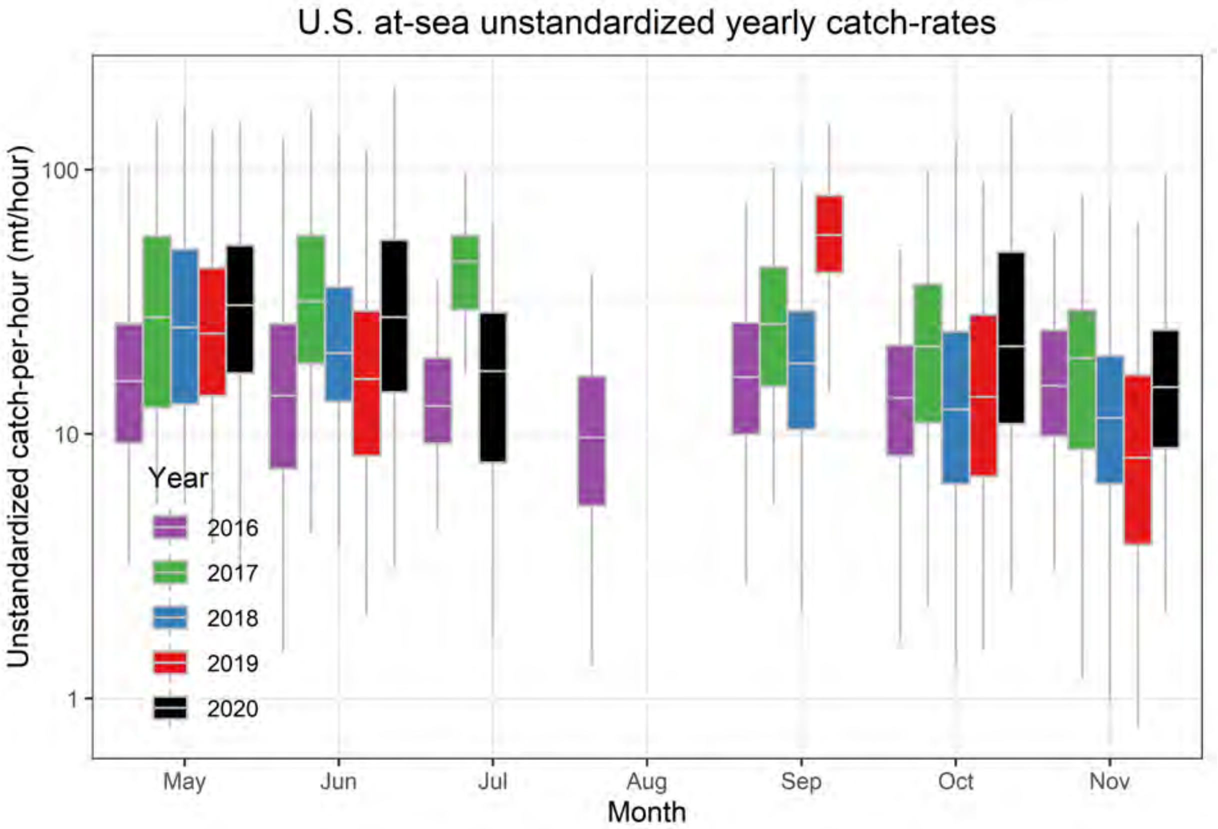


Figure 5. Unstandardized (raw) catch-rates (t/hr) of Pacific Hake catches by tow in the U.S. at-sea fleet from 2016–2020.

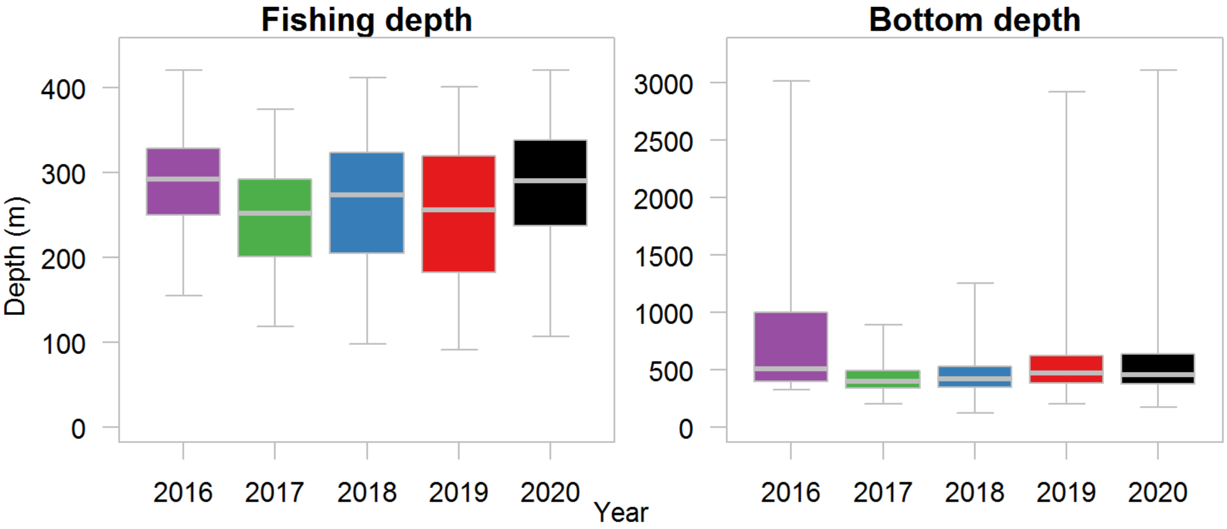


Figure 6. Distribution of fishing depths (left) and bottom depths (right), in meters, of hauls targeting Pacific Hake in the U.S. Catcher-Processor and Mothership sectors from 2016–2020. Horizontal lines in each box represents the median depth and boxes encompass the middle 50% of the data. Whiskers encompass the 95% quantiles.

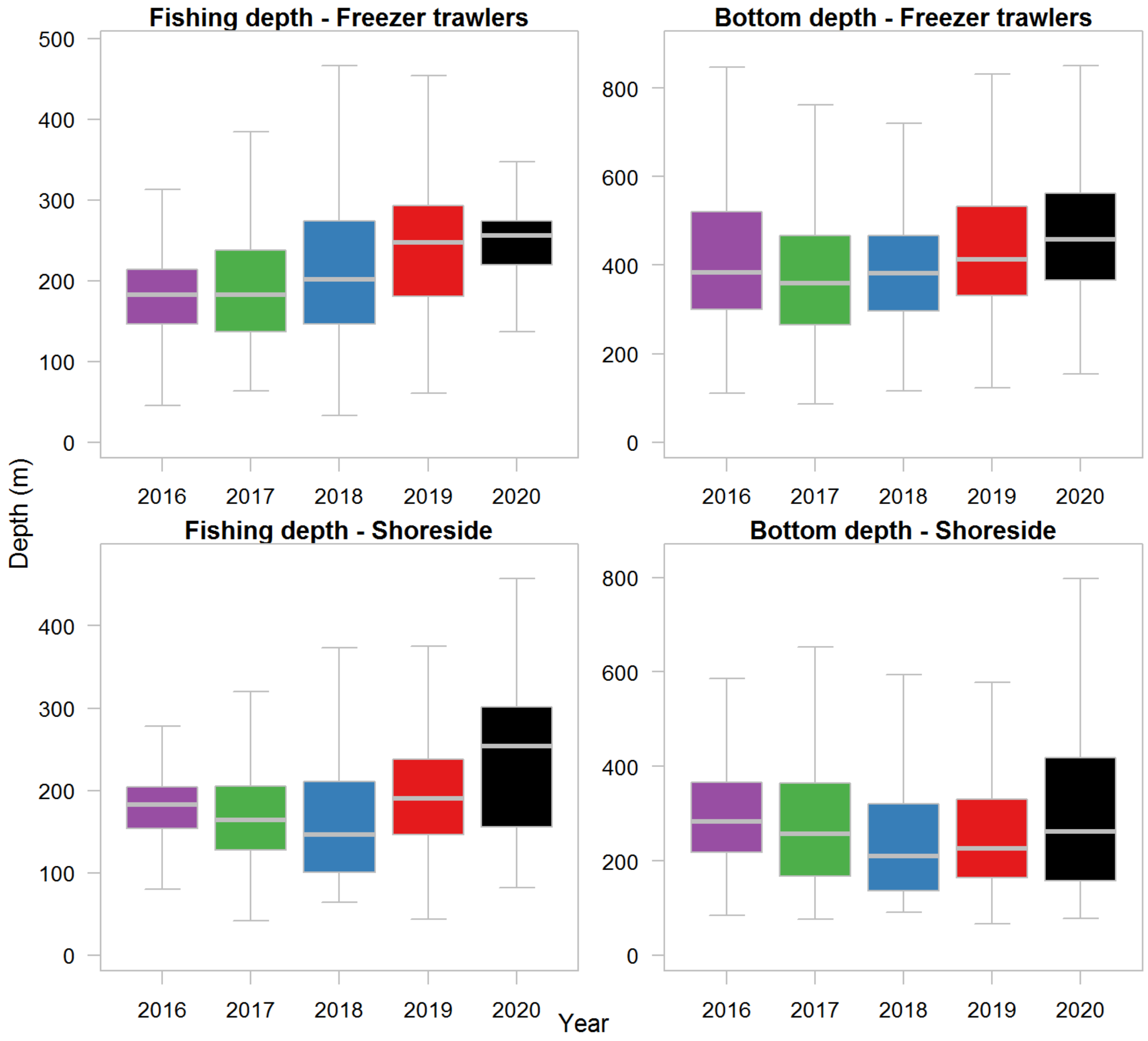


Figure 7. Distribution of fishing depths (left) and bottom depths (right), in meters, of hauls targeting Pacific Hake in the Canadian fleets from 2016–2020. Horizontal lines in each box represents the median depth and boxes encompass the middle 50% of the data. Whiskers encompass the 95% quantiles.

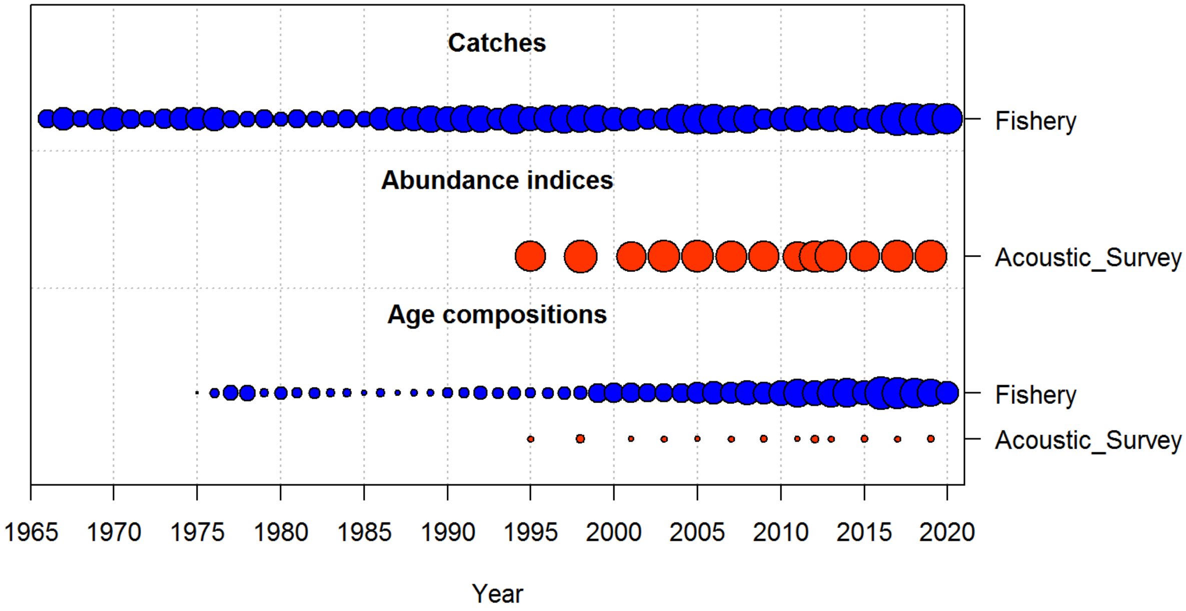


Figure 8. Overview of data used in this assessment, 1966–2020. Circle areas are proportional to the precision within the data type.

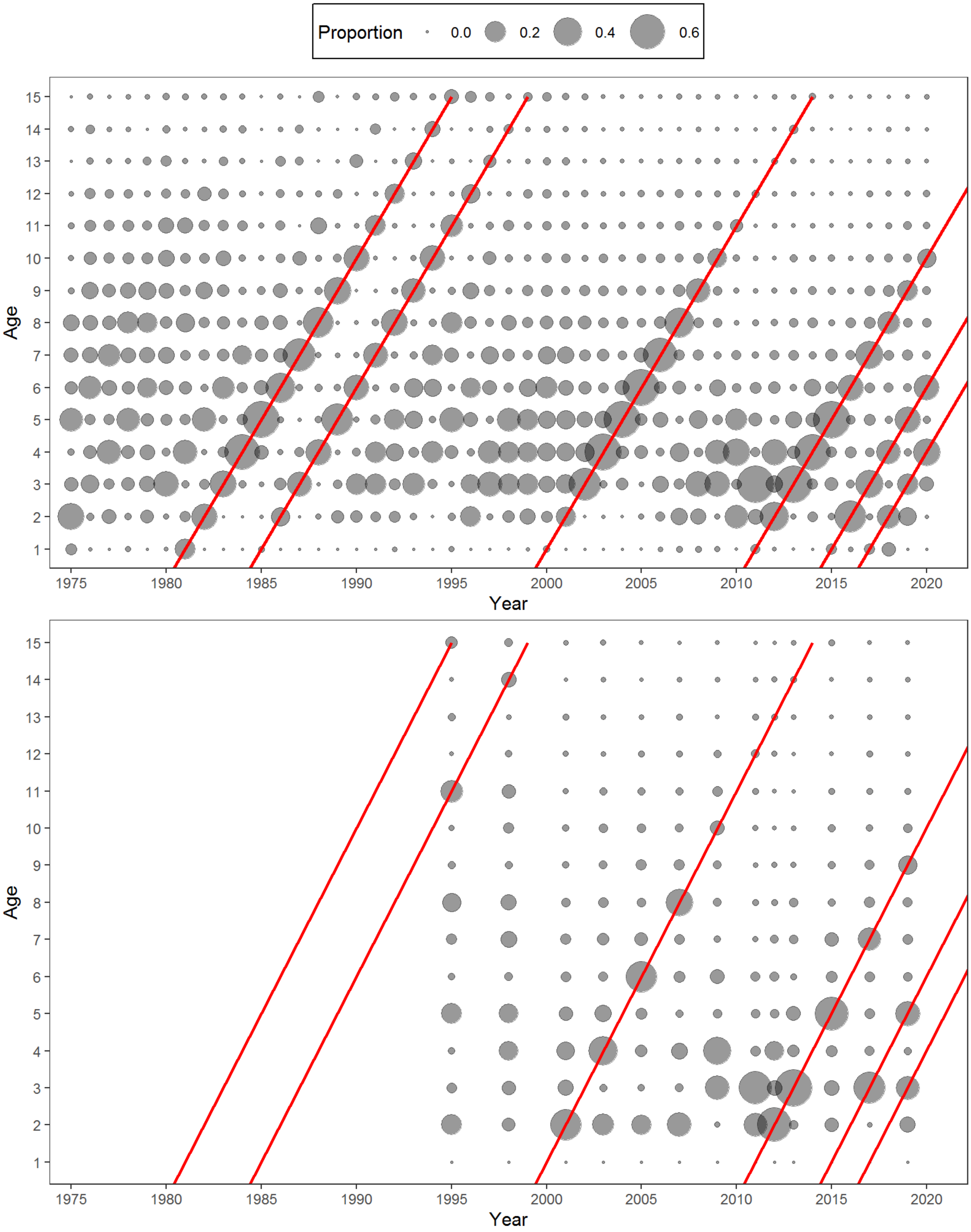


Figure 9. Age compositions for the aggregate fishery (top, all sectors combined) and acoustic survey (bottom) for the years 1975–2020. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble in the fishery data is 0.71 for age 3 in 2011 and in the survey data is 0.75 for age 3 in 2013. Red lines track cohorts from years of large recruitment events.

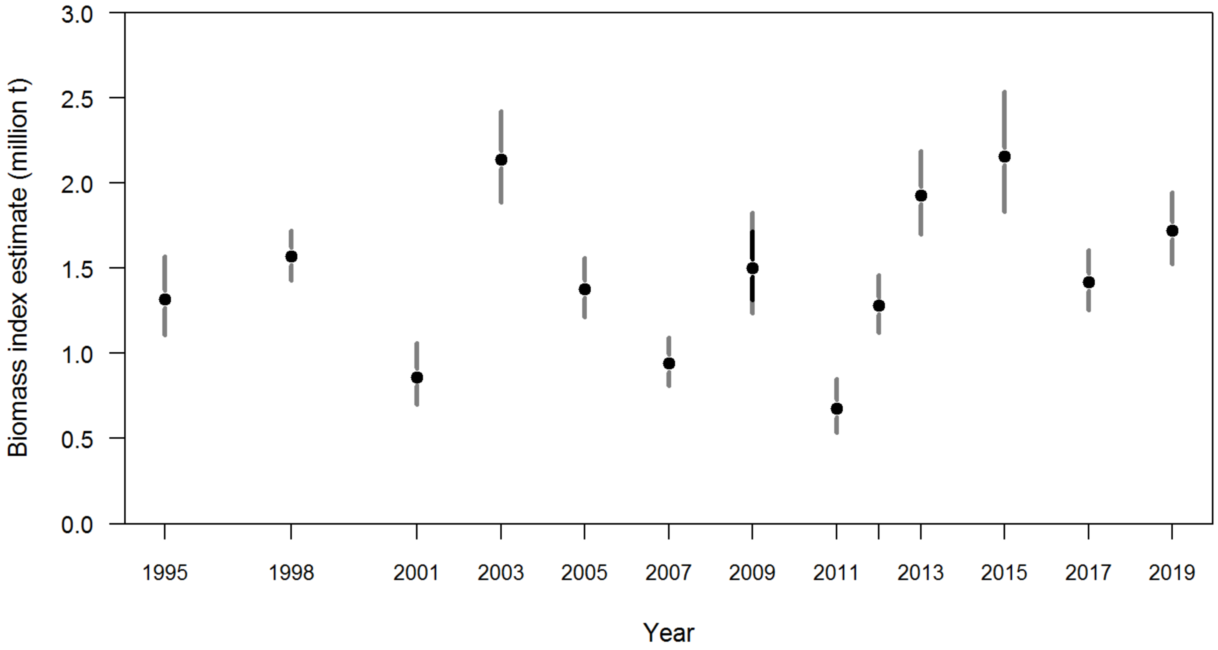


Figure 10. Acoustic survey biomass indices (millions of tons). Approximate 95% confidence intervals are based on sampling variability (intervals without squid/hake apportionment uncertainty in 2009 are displayed in black). See Table 12 for values used in the base model.

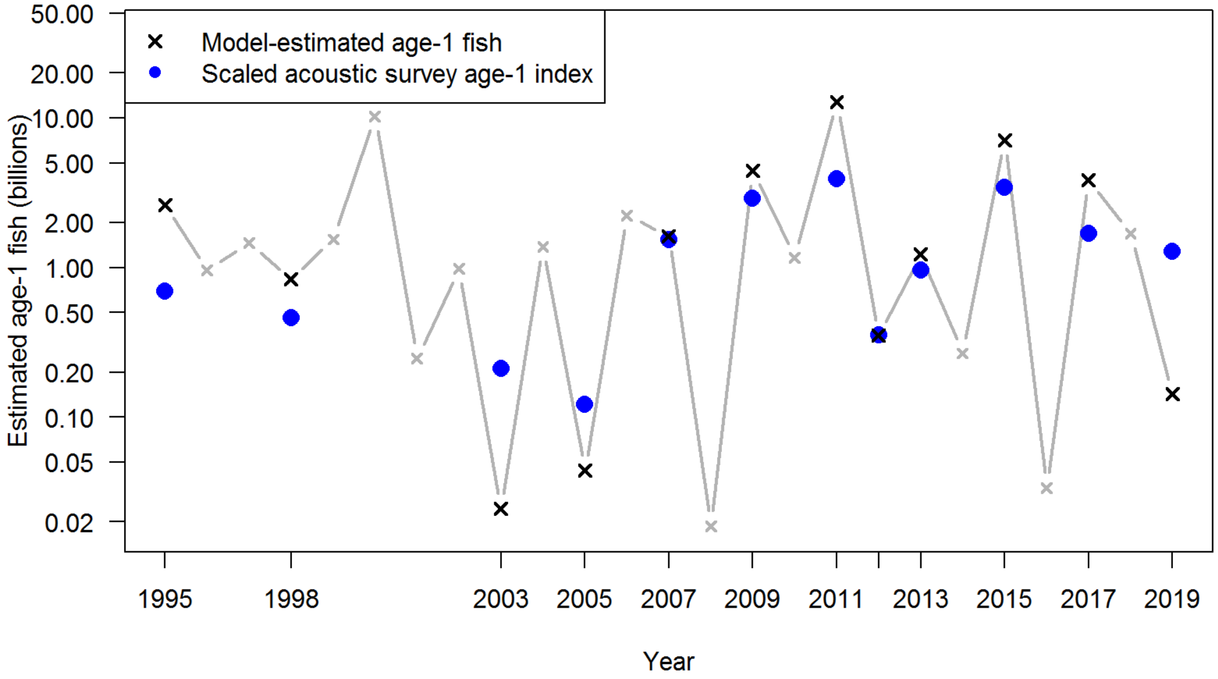


Figure 11. Preliminary acoustic survey age-1 index overlaid on estimated numbers of age-1 fish (medians of the posterior distribution from the base model).

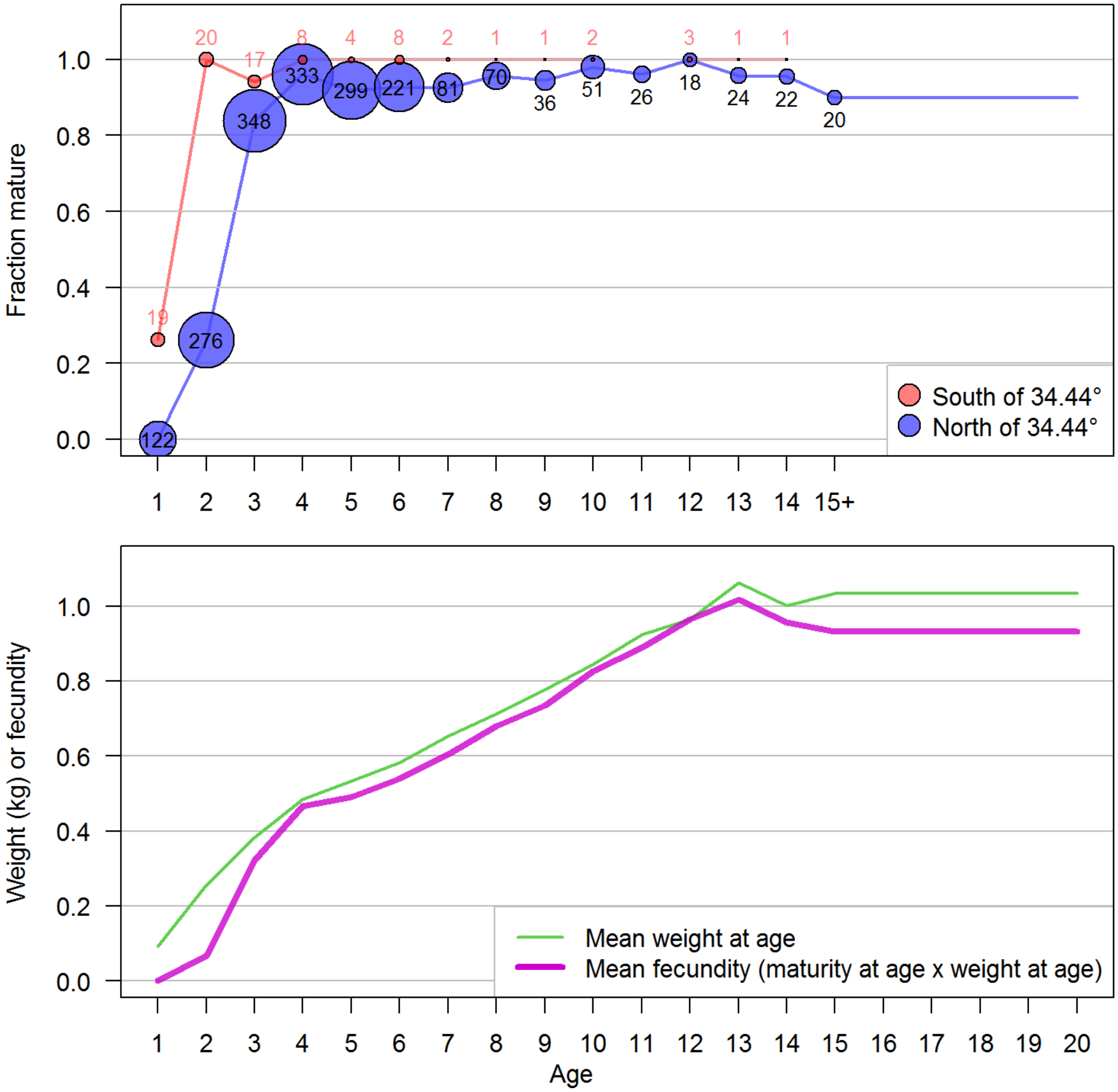
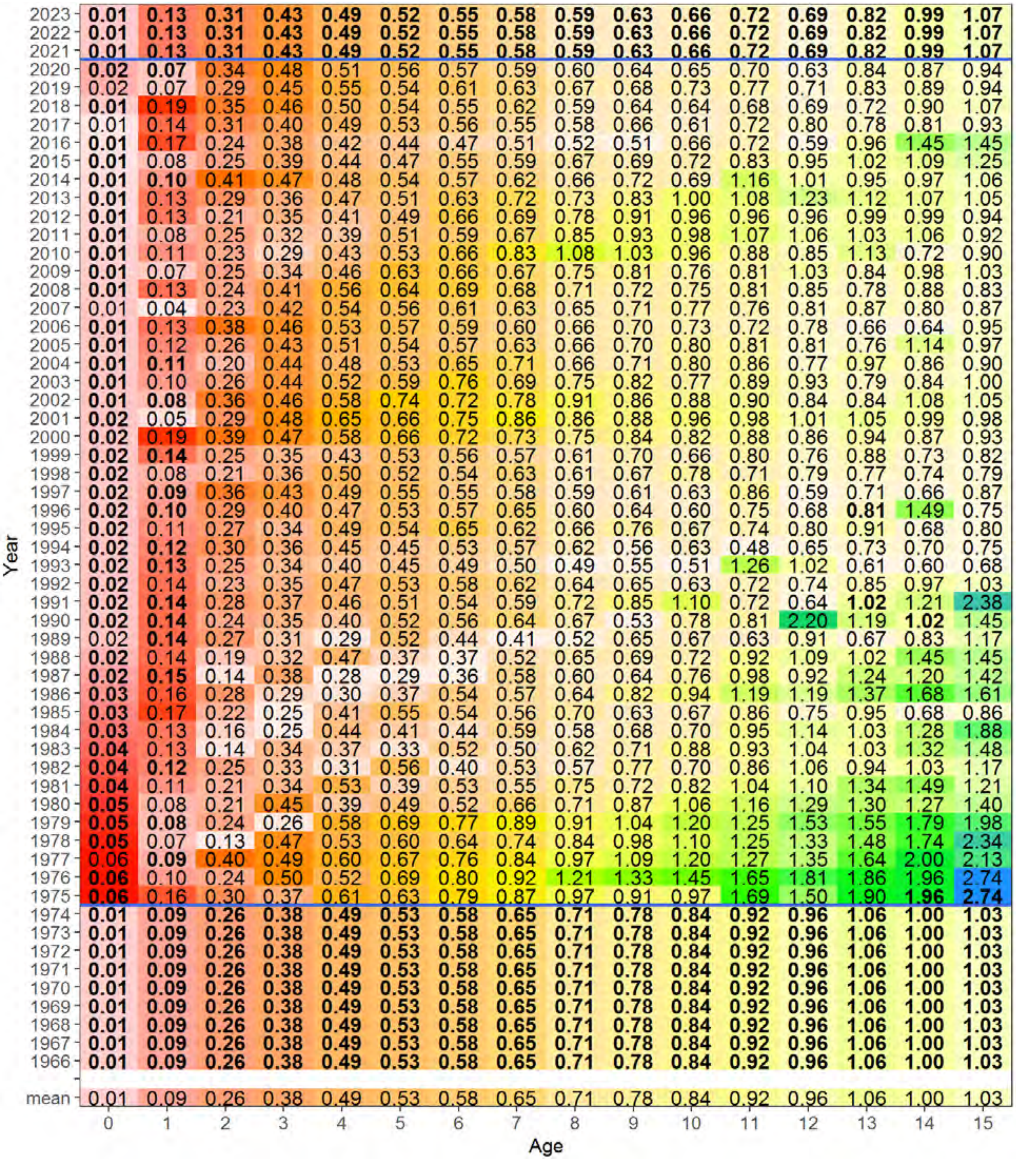
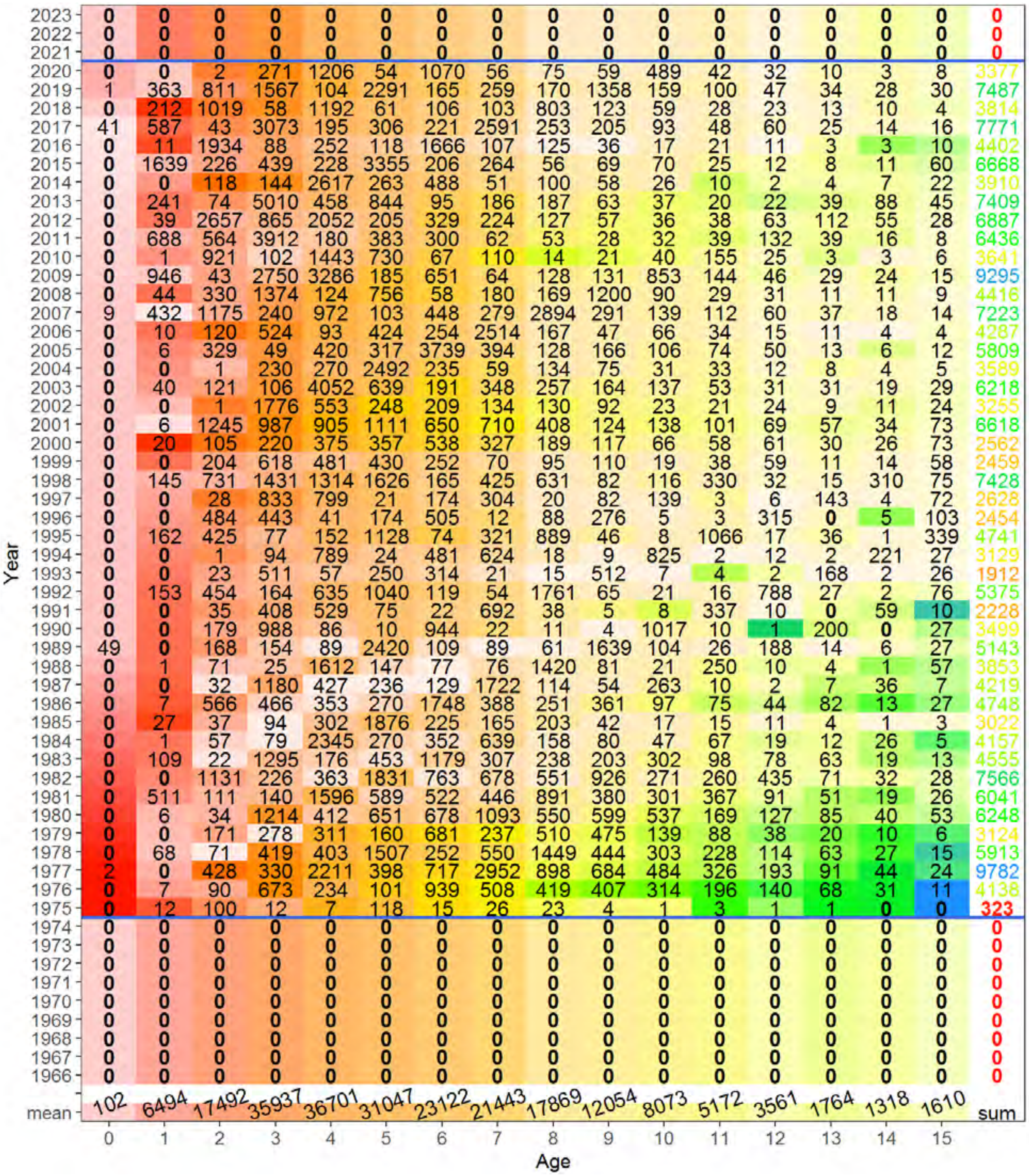


Figure 12. Fraction of fish that are mature at each age north and south of 34.44°N (upper panel) and the fecundity relationship (lower panel). The fecundity relationship (purple line) is the product of the weight-at-age and the maturity-at-age for the samples collected from North of 34.44°N (blue line in upper plot) averaged across 1975 to 2020.



Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2023	**0.01**	**0.13**	**0.31**	**0.43**	**0.49**	**0.52**	**0.55**	**0.58**	**0.59**	**0.63**	**0.66**	**0.72**	**0.69**	**0.82**	**0.99**	**1.07**
2022	**0.01**	**0.13**	**0.31**	**0.43**	**0.49**	**0.52**	**0.55**	**0.58**	**0.59**	**0.63**	**0.66**	**0.72**	**0.69**	**0.82**	**0.99**	**1.07**
2021	**0.01**	**0.13**	**0.31**	**0.43**	**0.49**	**0.52**	**0.55**	**0.58**	**0.59**	**0.63**	**0.66**	**0.72**	**0.69**	**0.82**	**0.99**	**1.07**
2020	**0.02**	**0.07**	0.34	0.48	0.51	0.56	0.57	0.59	0.60	0.64	0.65	0.70	0.63	0.84	0.87	0.94
2019	0.02	0.07	0.29	0.45	0.55	0.54	0.61	0.63	0.67	0.68	0.73	0.77	0.71	0.83	0.89	0.94
2018	**0.01**	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	0.01	0.14	0.31	0.40	0.49	0.53	0.56	0.55	0.58	0.66	0.61	0.72	0.80	0.78	0.81	0.93
2016	**0.01**	0.17	0.24	0.38	0.42	0.44	0.47	0.51	0.52	0.51	0.66	0.72	0.59	0.96	1.45	1.45
2015	**0.01**	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	**0.01**	**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	**0.01**	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	**0.01**	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	**0.01**	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	**0.01**	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	**0.01**	0.07	0.25	0.34	0.46	0.63	0.66	0.67	0.75	0.81	0.76	0.81	1.03	0.84	0.98	1.03
2008	**0.01**	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	0.42	0.54	0.56	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	0.58	0.74	0.72	0.78	0.91	0.86	0.88	0.90	0.84	0.84	1.08	1.05
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	0.39	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	0.36	0.50	0.52	0.54	0.63	0.61	0.67	0.78	0.71	0.79	0.77	0.74	0.79
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	0.40	0.52	0.56	0.64	0.67	0.53	0.78	0.81	2.20	1.19	**1.02**	1.45
1989	0.02	**0.14**	0.27	0.31	0.29	0.52	0.44	0.41	0.52	0.65	0.67	0.63	0.91	0.67	0.83	1.17
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	0.22	0.25	0.41	0.55	0.54	0.56	0.70	0.63	0.67	0.86	0.75	0.95	0.68	0.86
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	0.56	0.40	0.53	0.57	0.77	0.70	0.86	1.06	0.94	1.03	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	0.60	0.67	0.76	0.84	0.97	1.09	1.20	1.27	1.35	1.64	2.00	2.13
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	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1973	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1972	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1971	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1970	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1969	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1968	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1967	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
1966	**0.01**	**0.09**	**0.26**	**0.38**	**0.49**	**0.53**	**0.58**	**0.65**	**0.71**	**0.78**	**0.84**	**0.92**	**0.96**	**1.06**	**1.00**	**1.03**
mean	0.01	0.09	0.26	0.38	0.49	0.53	0.58	0.65	0.71	0.78	0.84	0.92	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 1975–2020. Values based on assumptions for the pre-1975 and forecast years are shown outside the blue lines. Bold values between 1975–2020 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	sum
2023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	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	0
2020	0	0	2	271	1206	54	1070	56	75	59	489	42	32	10	3	8	3377
2019	1	363	811	1567	104	2291	165	259	170	1358	159	100	47	34	28	30	7487
2018	0	212	1019	58	1192	61	106	103	803	123	59	28	23	13	10	4	3814
2017	41	587	43	3073	195	306	221	2591	253	205	93	48	60	25	14	16	7771
2016	0	11	1934	88	252	118	1666	107	125	36	17	21	11	3	3	10	4402
2015	0	1639	226	439	228	3355	206	264	56	69	70	25	12	8	11	60	6668
2014	0	0	118	144	2617	263	488	51	100	58	26	10	2	4	7	22	3910
2013	0	241	74	5010	458	844	95	186	187	63	37	20	22	39	88	45	7409
2012	0	39	2657	865	2052	205	329	224	127	57	36	38	63	112	55	28	6887
2011	0	688	564	3912	180	383	300	62	53	28	32	39	132	39	16	8	6436
2010	0	1	921	102	1443	730	67	110	14	21	40	155	25	3	3	6	3641
2009	0	946	43	2750	3286	185	651	64	128	131	853	144	46	29	24	15	9295
2008	0	44	330	1374	124	756	58	180	169	1200	90	29	31	11	11	9	4416
2007	9	432	1175	240	972	103	448	279	2894	291	139	112	60	37	18	14	7223
2006	0	10	120	524	93	424	254	2514	167	47	66	34	15	11	4	4	4287
2005	0	6	329	49	420	317	3739	394	128	166	106	74	50	13	6	12	5809
2004	0	0	1	230	270	2492	235	59	134	75	31	33	12	8	4	5	3589
2003	0	40	121	106	4052	639	191	348	257	164	137	53	31	31	19	29	6218
2002	0	0	1	1776	553	248	209	134	130	92	23	21	24	9	11	24	3255
2001	0	6	1245	987	905	1111	650	710	408	124	138	101	69	57	34	73	6618
2000	0	20	105	220	375	357	538	327	189	117	66	58	61	30	26	73	2562
1999	0	0	204	618	481	430	252	70	95	110	19	38	59	11	14	58	2459
1998	0	145	731	1431	1314	1626	165	425	631	82	116	330	32	15	310	75	7428
1997	0	0	28	833	799	21	174	304	20	82	139	3	6	143	4	72	2628
1996	0	0	484	443	41	174	505	12	88	276	5	3	315	0	5	103	2454
1995	0	162	425	77	152	1128	74	321	889	46	8	1066	17	36	1	339	4741
1994	0	0	1	94	789	24	481	624	18	9	825	2	12	2	221	27	3129
1993	0	0	23	511	57	250	314	21	15	512	7	4	2	168	2	26	1912
1992	0	153	454	164	635	1040	119	54	1761	65	21	16	788	27	2	76	5375
1991	0	0	35	408	529	75	22	692	38	5	8	337	10	0	59	10	2228
1990	0	0	179	988	86	10	944	22	11	4	1017	10	1	200	0	27	3499
1989	49	0	168	154	89	2420	109	89	61	1639	104	26	188	14	6	27	5143
1988	0	1	71	25	1612	147	77	76	1420	81	21	250	10	4	1	57	3853
1987	0	0	32	1180	427	236	129	1722	114	54	263	10	2	7	36	7	4219
1986	0	7	566	466	353	270	1748	388	251	361	97	75	44	82	13	27	4748
1985	0	27	37	94	302	1876	225	165	203	42	17	15	11	4	1	3	3022
1984	0	1	57	79	2345	270	352	639	158	80	47	67	19	12	26	5	4157
1983	0	109	22	1295	176	453	1179	307	238	203	302	98	78	63	19	13	4555
1982	0	0	1131	226	363	1831	763	678	551	926	271	260	435	71	32	28	7566
1981	0	511	111	140	1596	589	522	446	891	380	301	367	91	51	19	26	6041
1980	0	6	34	1214	412	651	678	1093	550	599	537	169	127	85	40	53	6248
1979	0	0	171	278	311	160	681	237	510	475	139	88	38	20	10	6	3124
1978	0	68	71	419	403	1507	252	550	1449	444	303	228	114	63	27	15	5913
1977	2	0	428	330	2211	398	717	2952	898	684	484	326	193	91	44	24	9782
1976	0	7	90	673	234	101	939	508	419	407	314	196	140	68	31	11	4138
1975	0	12	100	12	7	118	15	26	23	4	1	3	1	1	0	0	323
1974	0	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	0
1972	0	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	0
1970	0	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	0
1968	0	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	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mean	102	6494	17492	35937	36701	31047	23122	21443	17869	12054	8073	5172	3561	1764	1318	1610	

Figure 14. Sample sizes of empirical weight-at-age measurements used to calculate mean weight-at-age fit in the base model. Colors and transparency are identical to Figure 13 and based on mean values. Sample sizes of zero highlight years for which data are not available, i.e., pre 1975 and post 2020. The total sample sizes for each age used in the mean over all years are shown at the bottom and year-specific sample sizes are shown to the right using the same color scale with red indicating small sample sizes and blue indicating the large sample sizes.

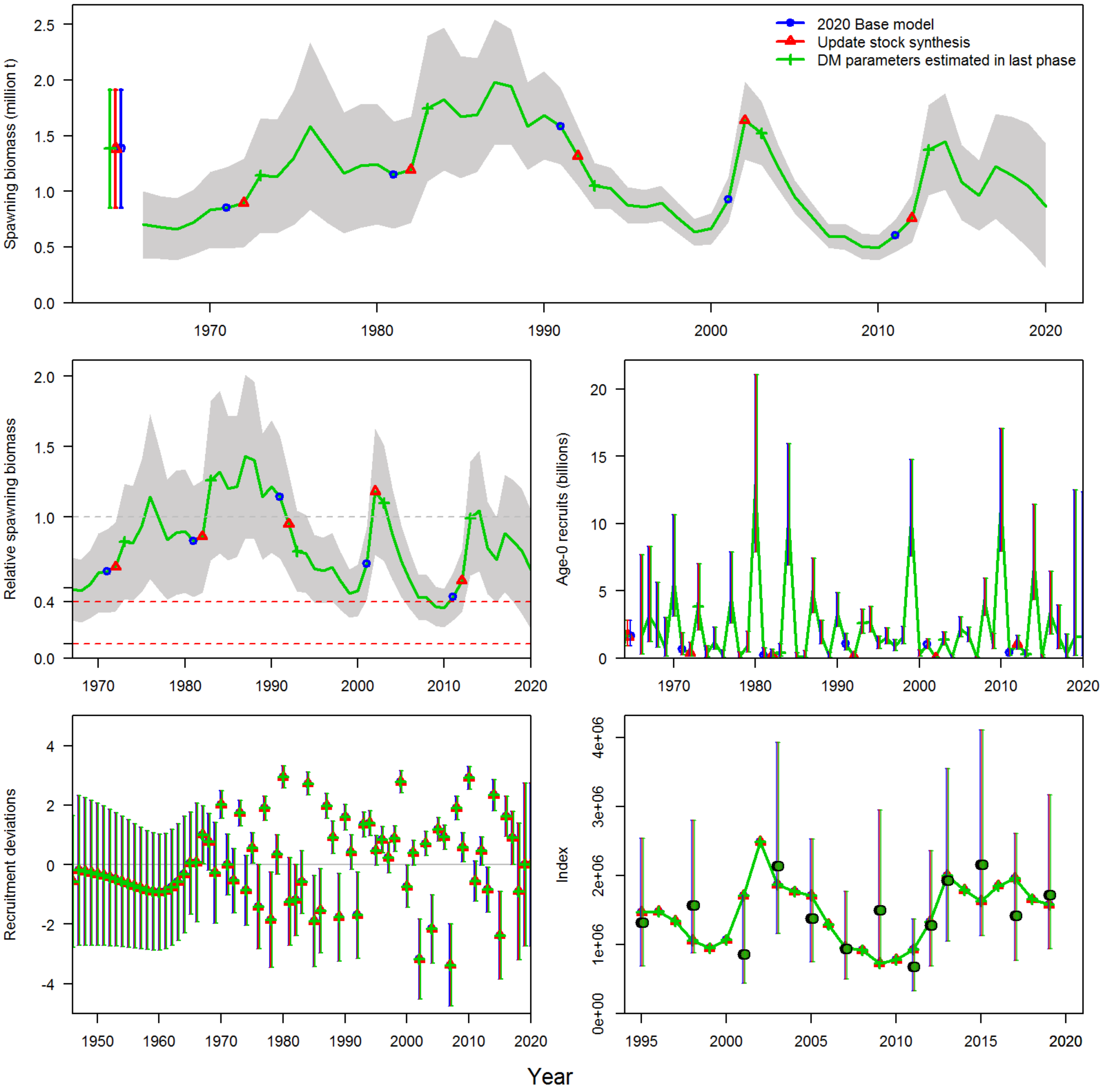


Figure 15. Bridging models showing the 2020 base model and the sequential influence of updating to the latest version of Stock Synthesis and changing the estimation of the Dirichlet Multinomial parameters to the final estimation phase. Moving the data weighting parameters to the final phase more accurately reflects the timing used in other methods that manually tune data weights. 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).

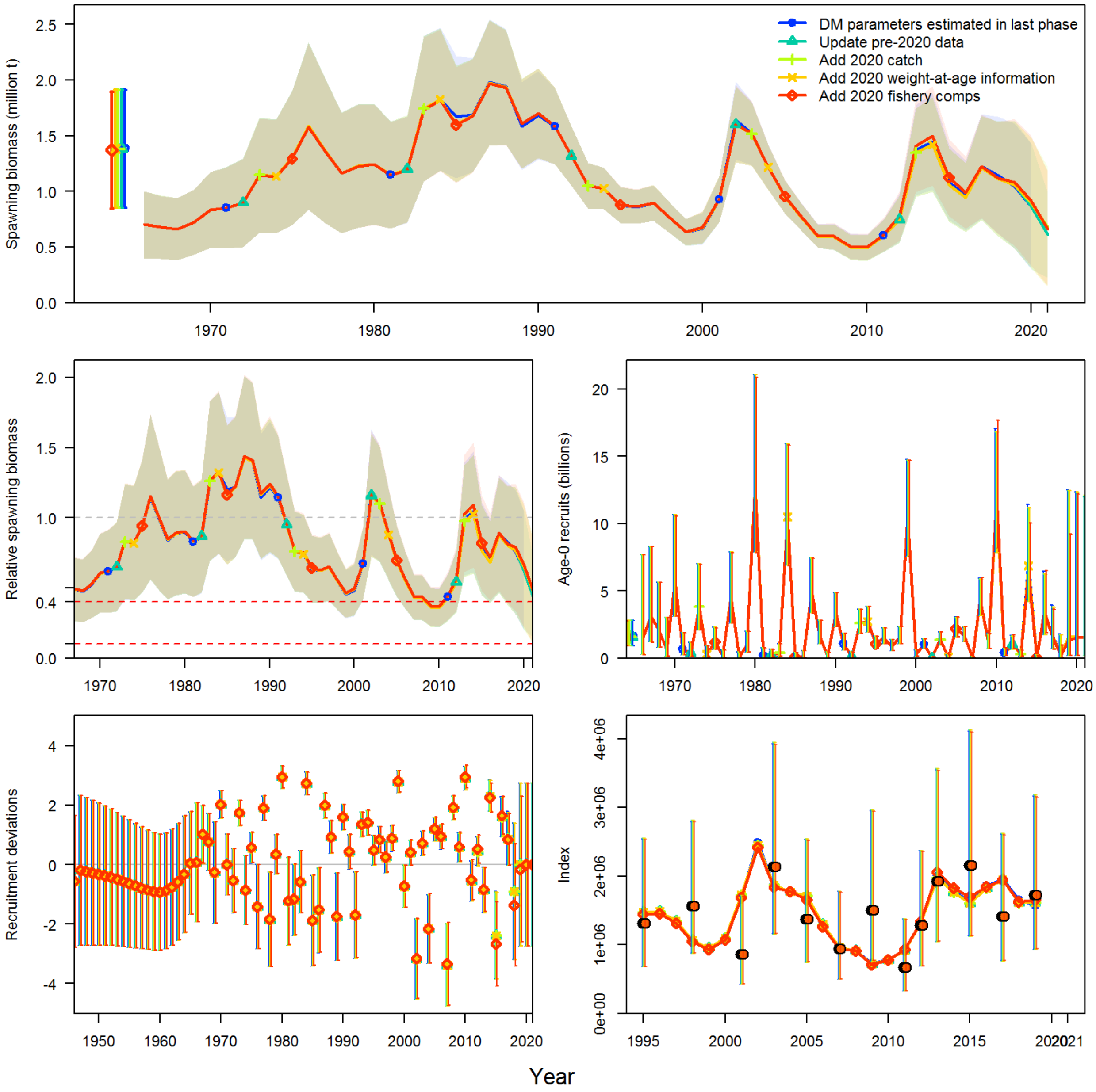


Figure 16. Bridging models showing the sequential addition of updating pre-2020 fishery data, adding 2020 catch data, and adding 2020 weight-at-age information, and adding 2020 fishery composition data starting from the final bridge model in Figure 15. Panels are spawning biomass (upper panel), relative 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).

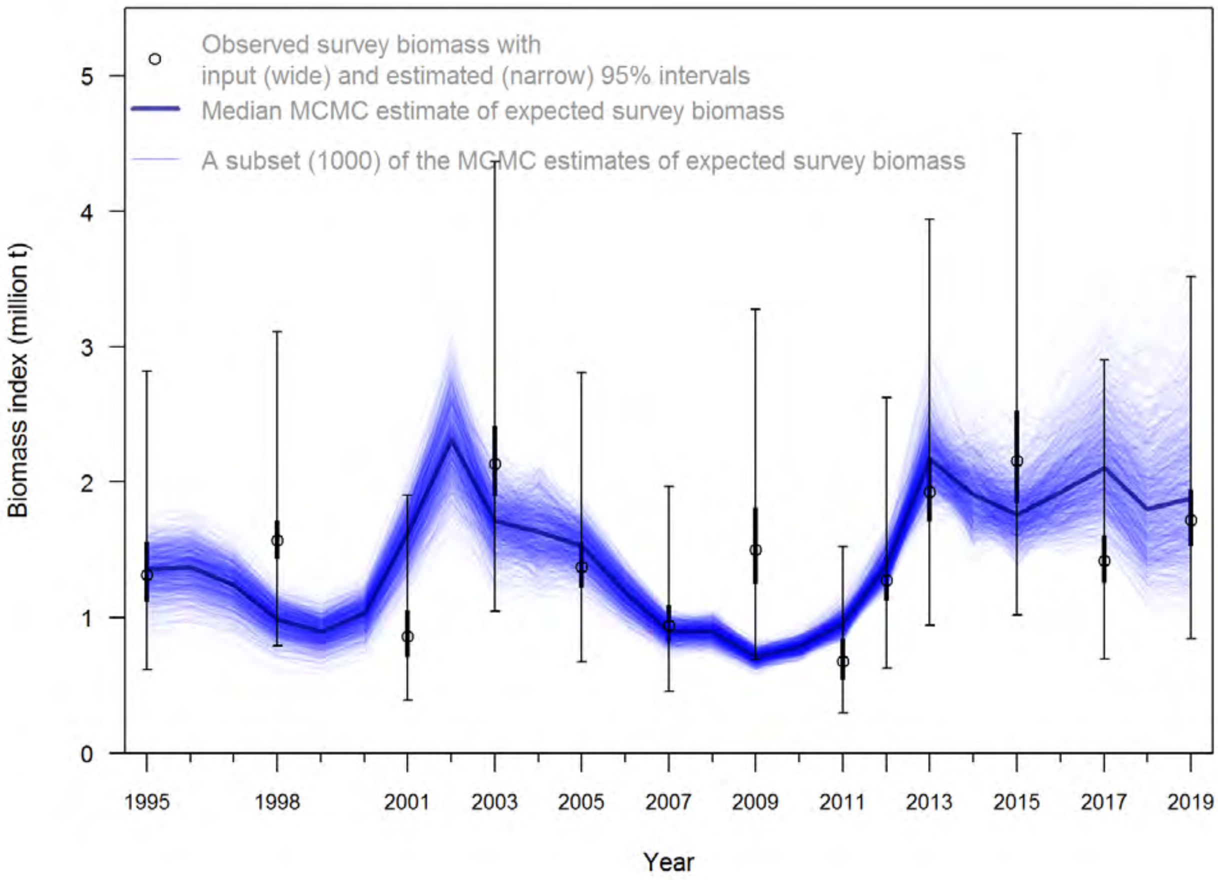
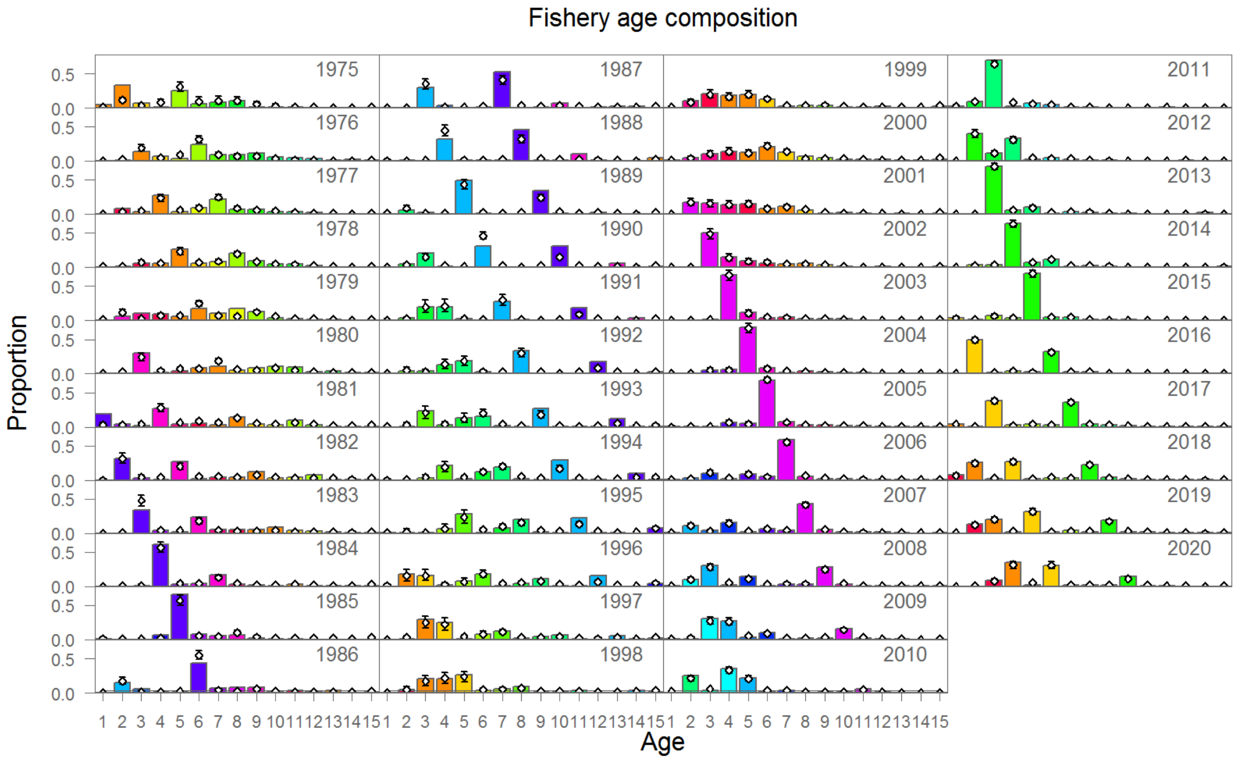


Figure 17. Fits (colored lines) to the acoustic survey (points) with input 95% intervals around the observations. The thin blue lines are the results of a random subset of individual MCMC samples. Thicker uncertainty intervals around observed survey points indicate 95% log-normal uncertainty intervals estimated by the kriging method and are used as input to the assessment model. Thinner uncertainty intervals indicate estimated 95% uncertainty intervals that account for the model estimate of additional uncertainty.



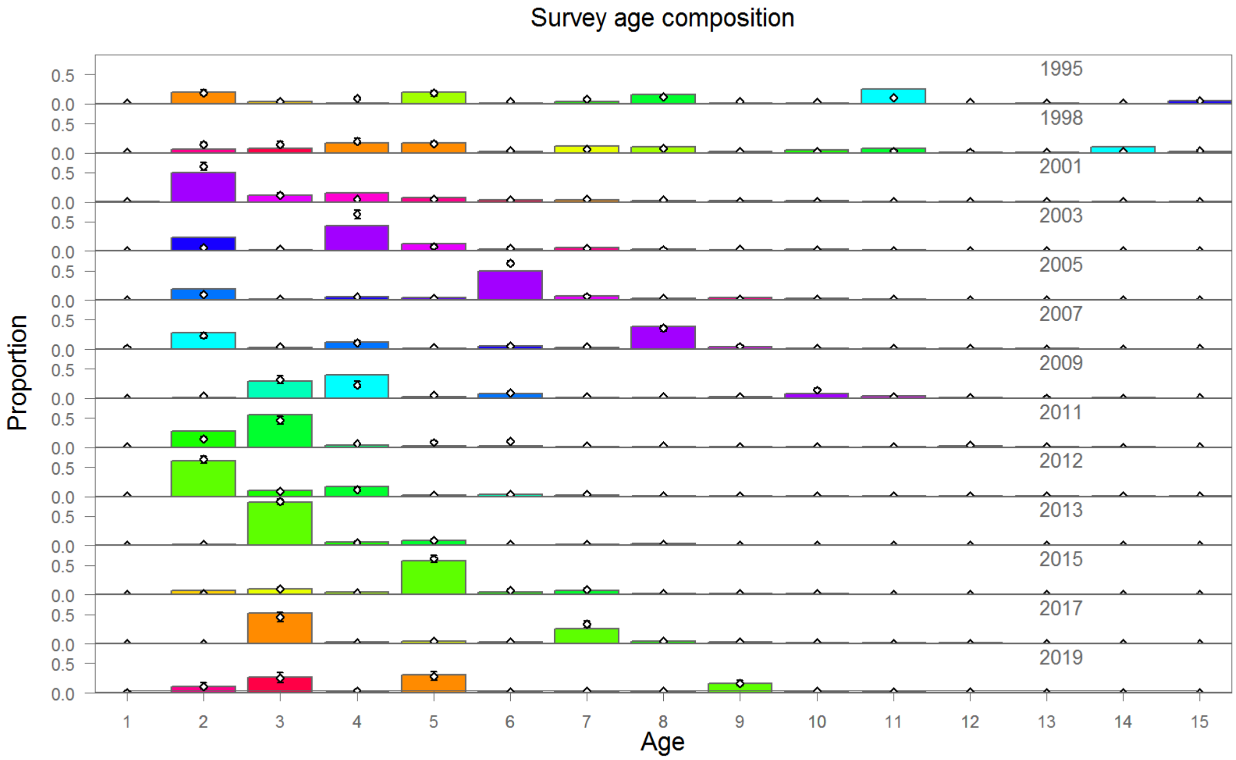


Figure 18. Base model fits to the observed fishery (top) and acoustic survey (bottom) age-composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% credibility intervals from the MCMC calculations.

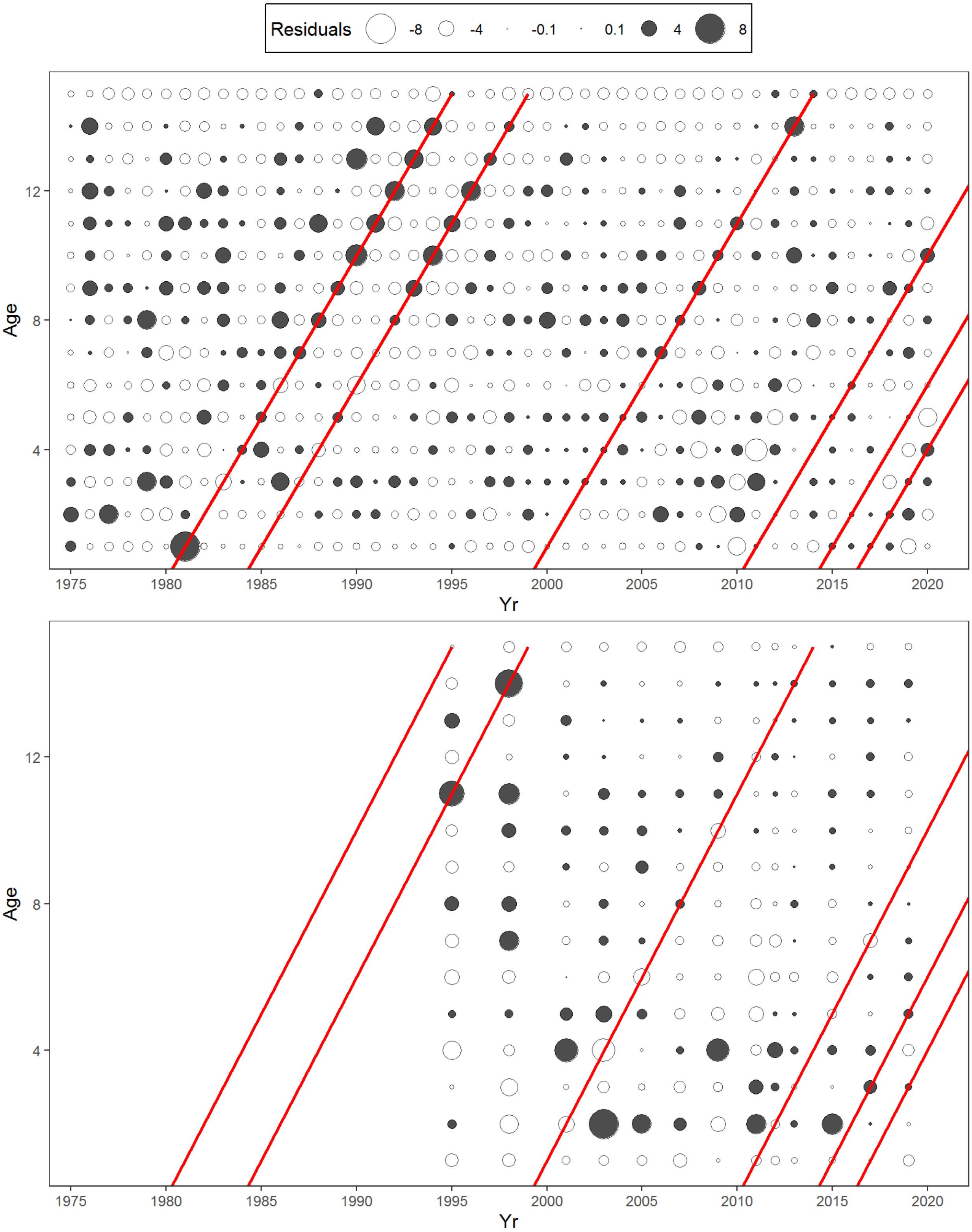


Figure 19. Pearson residuals for base model fits to the age-composition data for the medians of the MCMC posteriors. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected). Red lines track cohorts from years of large recruitment events.

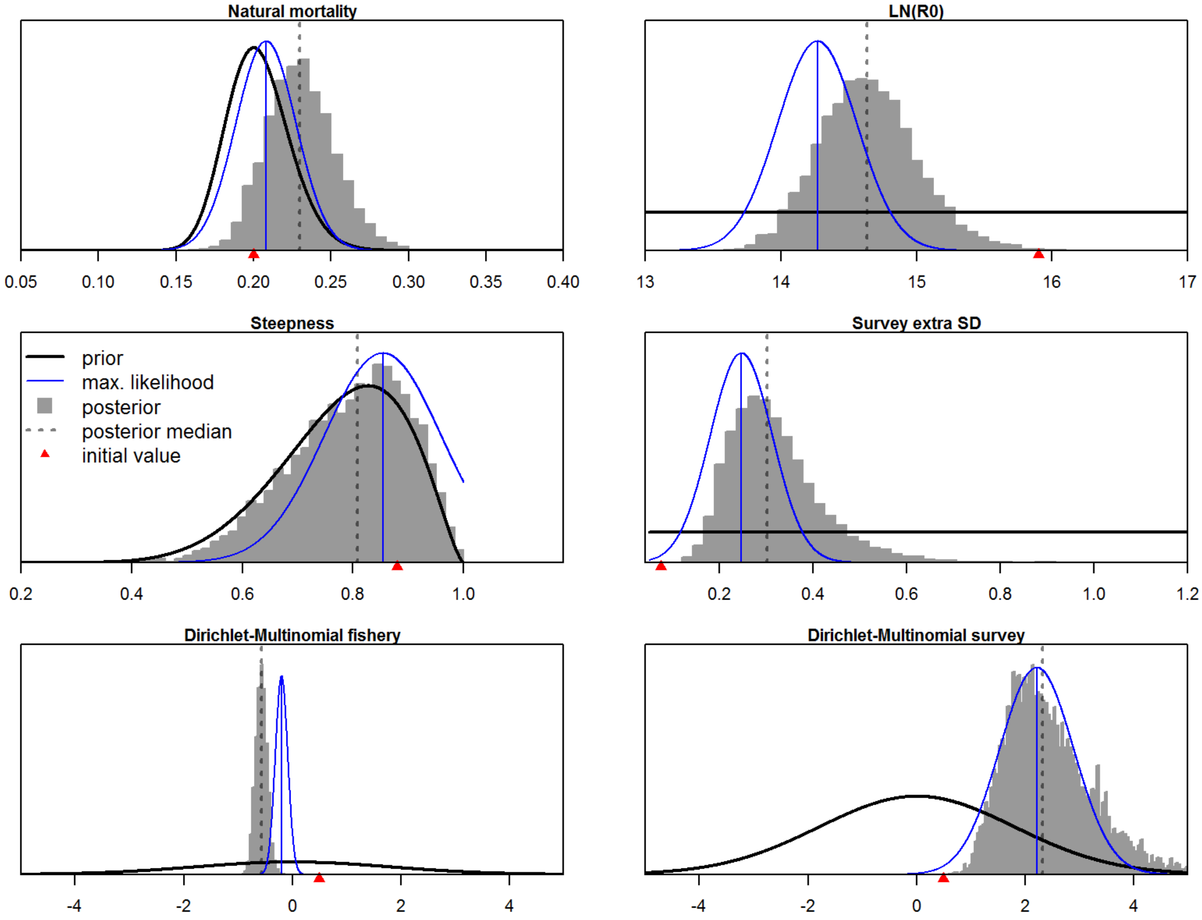


Figure 20. Prior (black lines) and posterior (gray histograms) distributions for key parameters in the base model. The parameters are: natural mortality (M), equilibrium log recruitment ($\log R_0$), steepness (h), the additional process-error standard deviation for the acoustic survey, and the Dirichlet-multinomial parameters for the fishery (θ_{fish}) and the survey (θ_{surv}). 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.

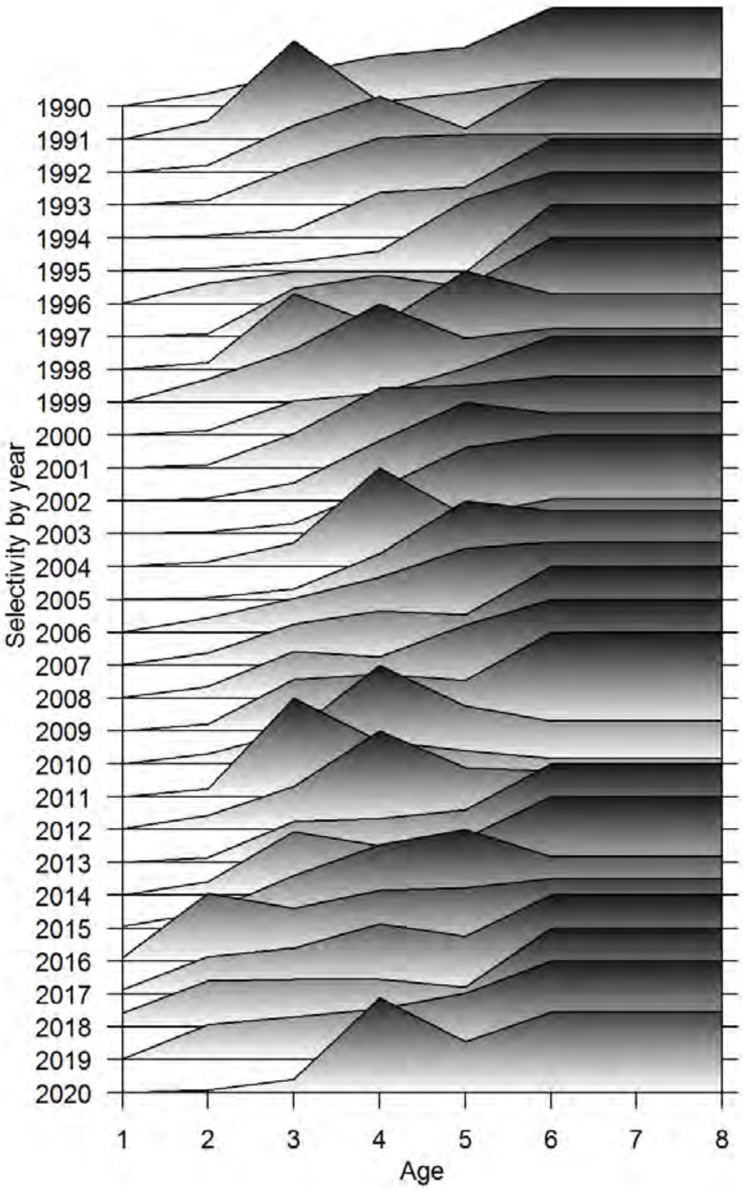


Figure 21. Mountains plot of median fishery selectivity in each year for the base model. Range of selectivity is 0 to 1 in each year.

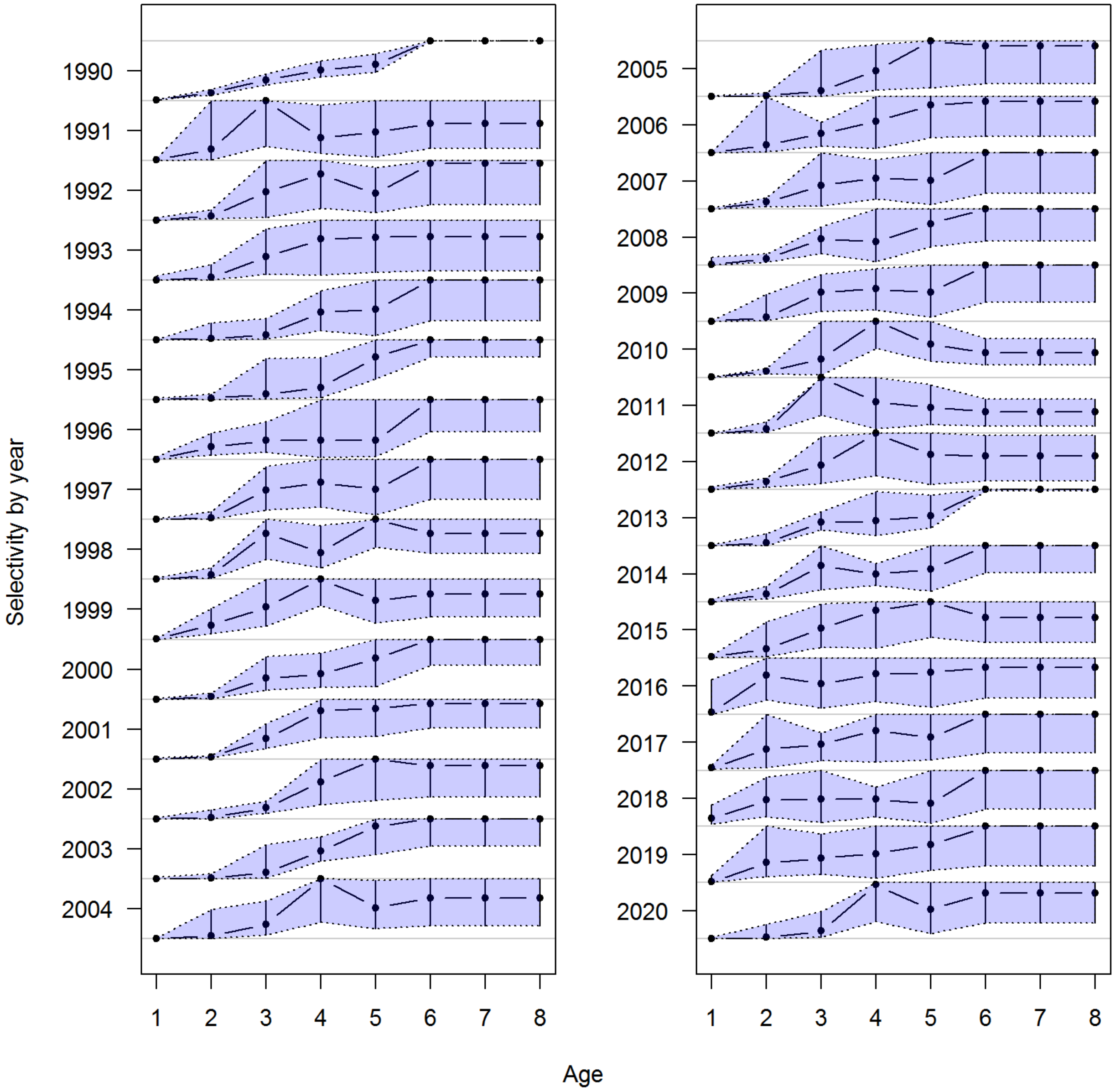


Figure 22. Fishery selectivity sampled from posterior probability distribution by year for the base model. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared for all years from 1966 to 1990.

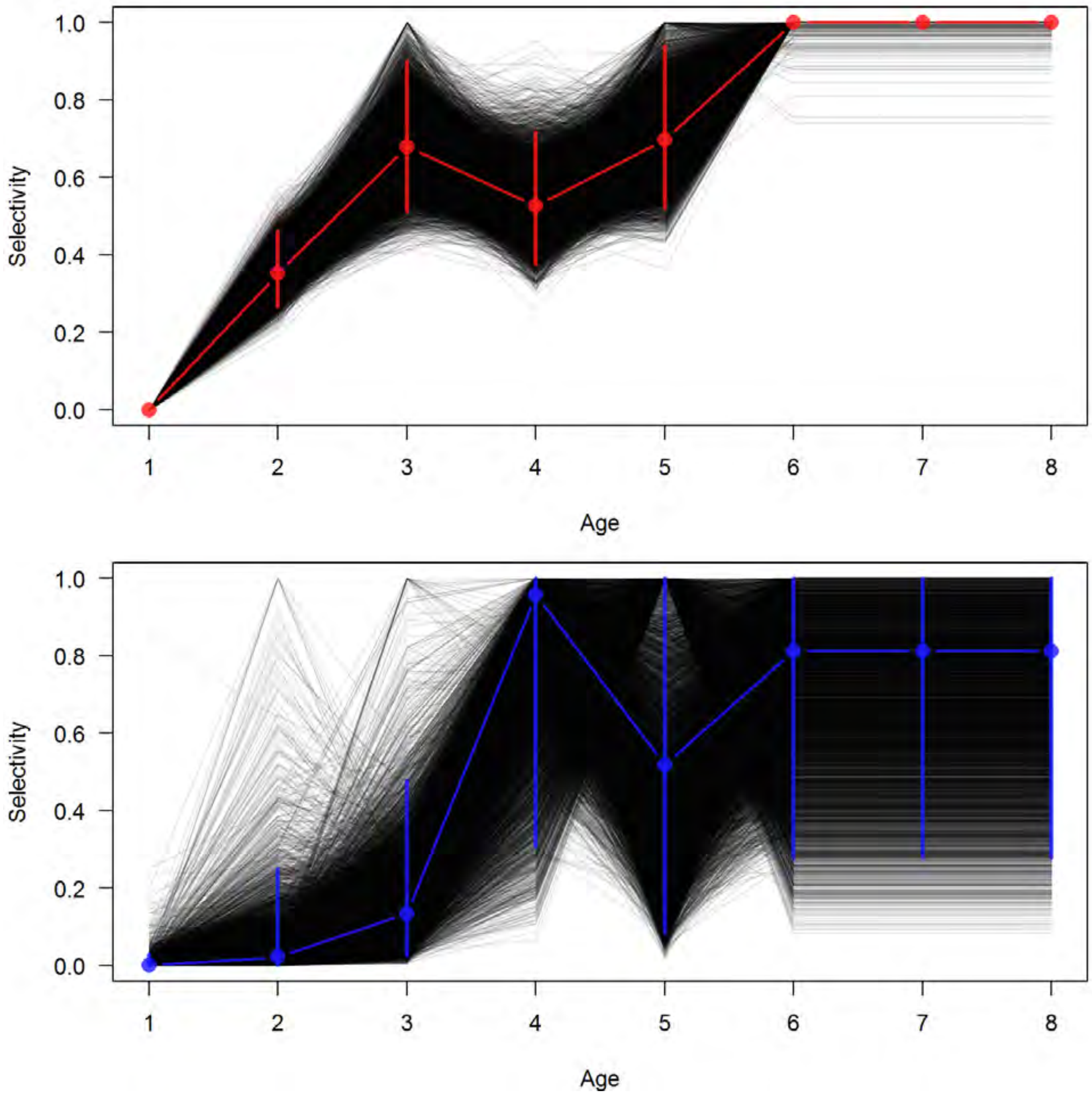


Figure 23. Estimated acoustic (top – for all years) and fishery selectivities (bottom – for 2020 only) from the posterior distribution for the base model.

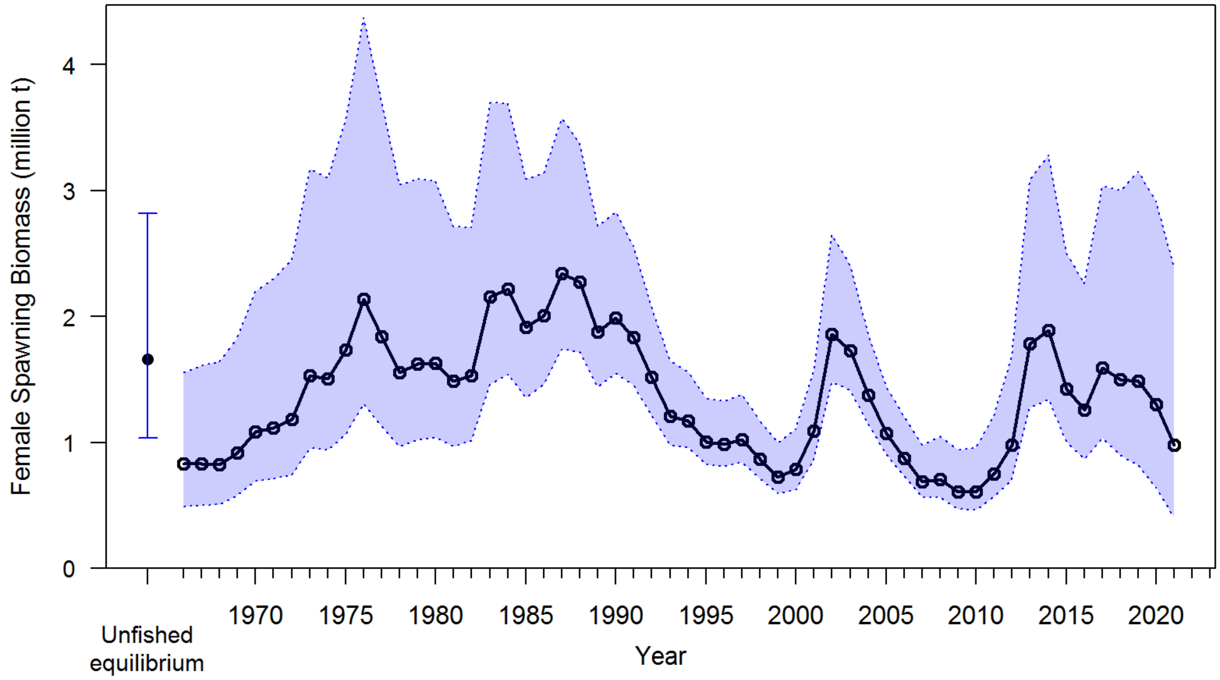


Figure 24. Median of the posterior distribution for female spawning biomass at the start of each year (B_t) for the base model up to 2021 (solid line) with 95% posterior credibility intervals (shaded area).

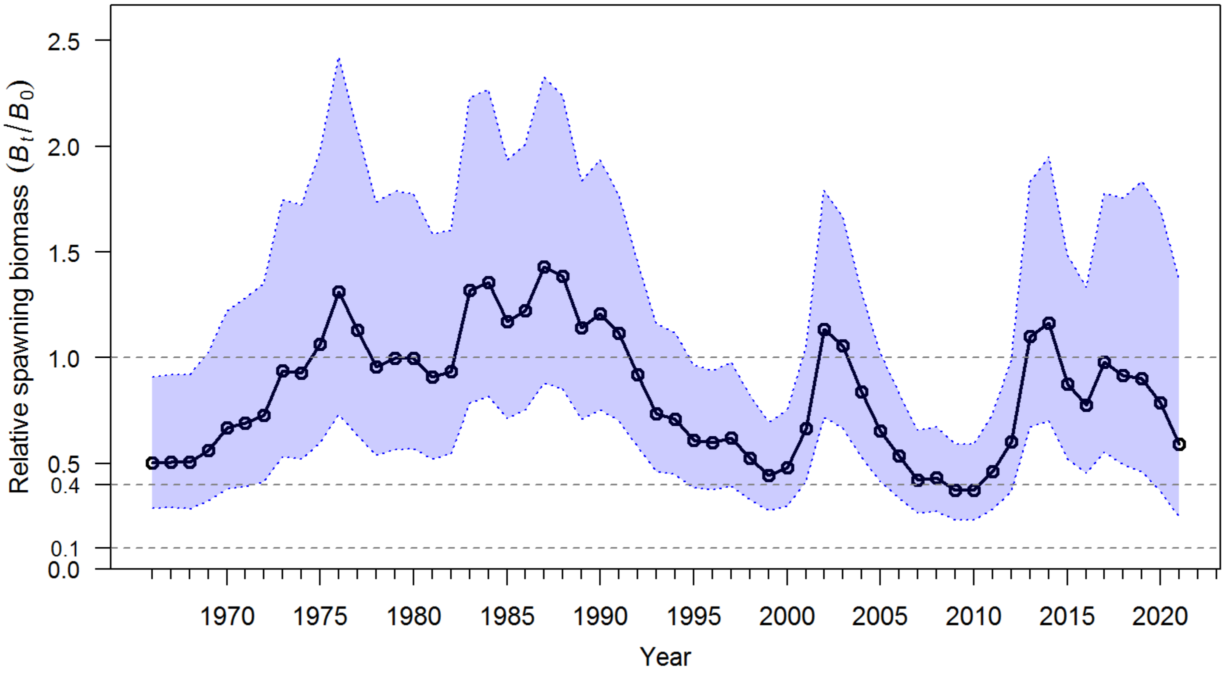


Figure 25. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) for the base model through 2021 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

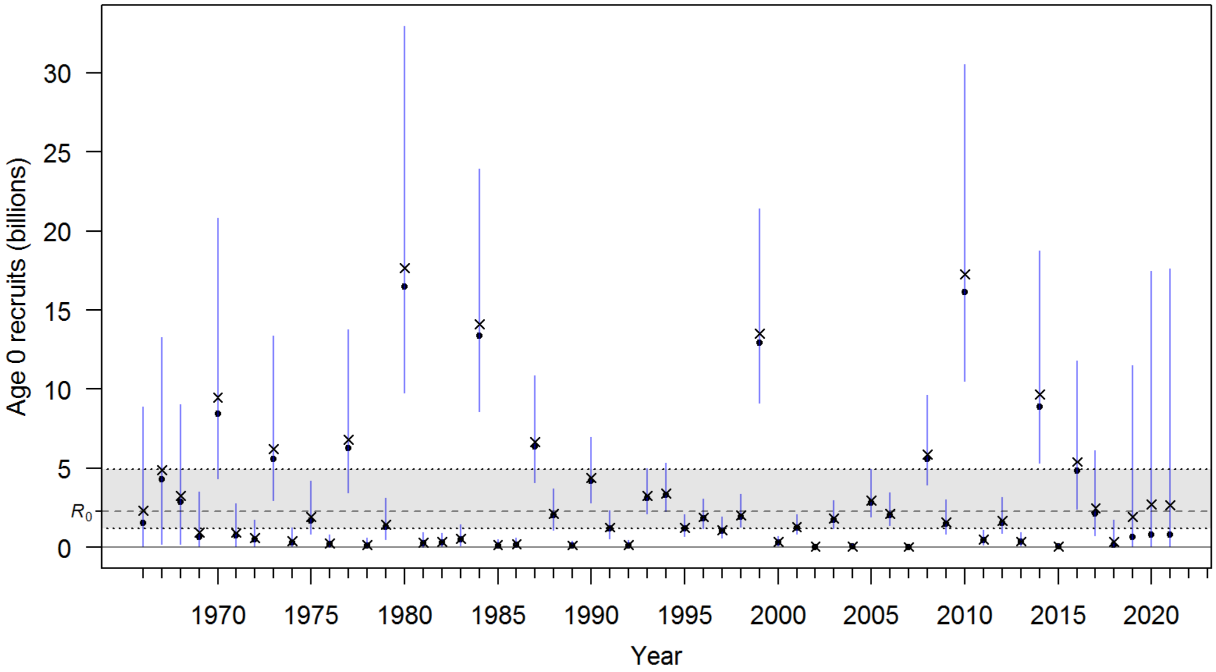


Figure 26. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0 fish) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

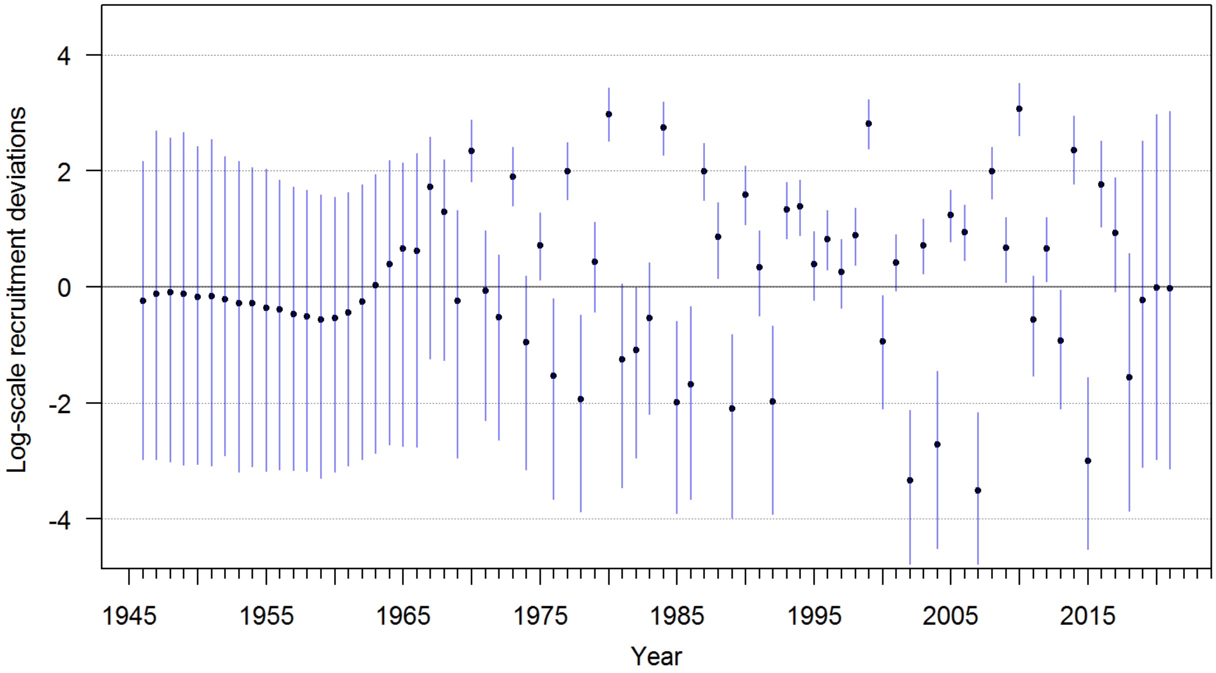


Figure 27. Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model.

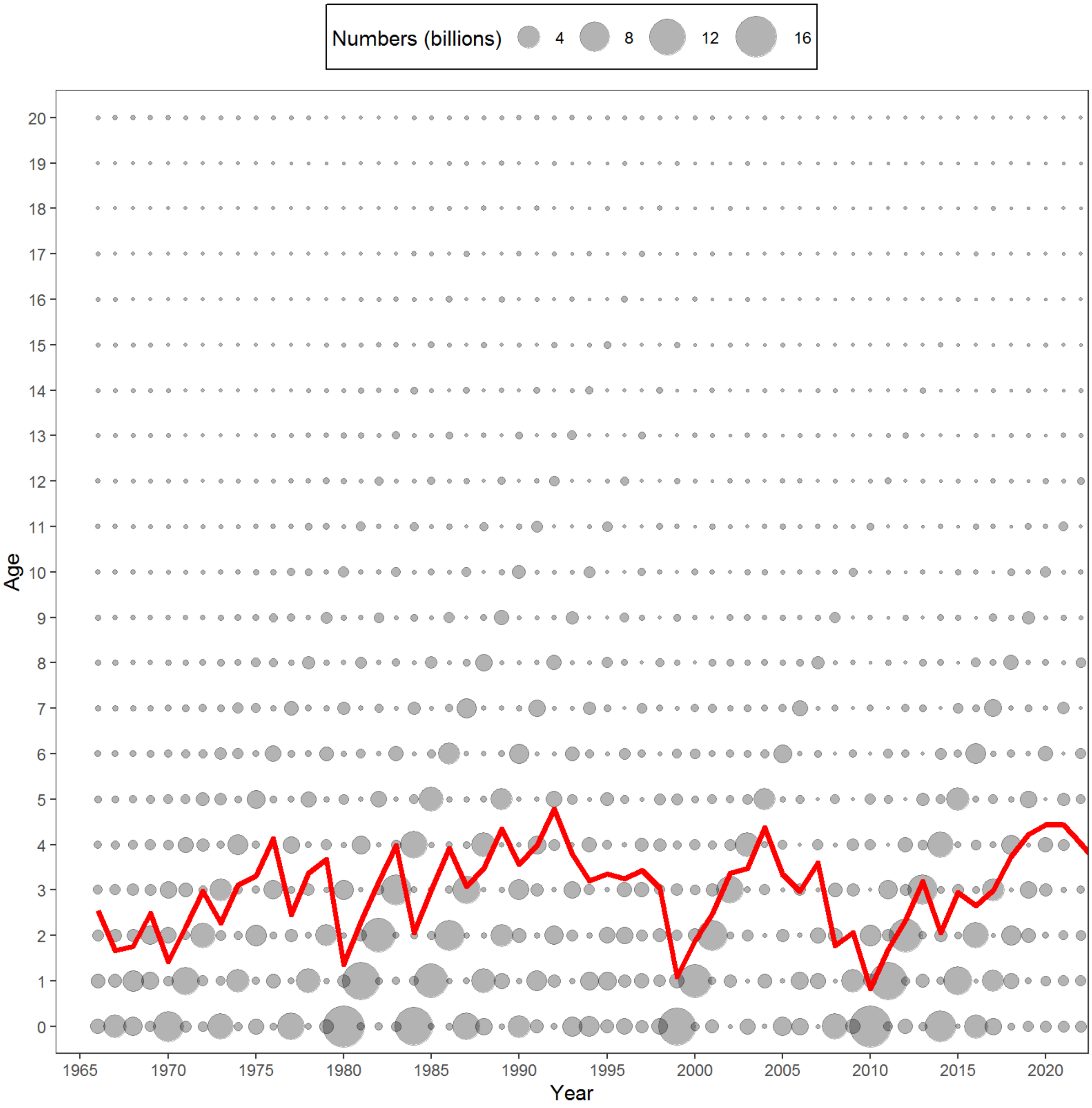


Figure 28. Bubble plot of the medians of the posterior distributions of population numbers at age at the beginning of each year, where diagonals follow each year-class through time. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish; the largest overall bubble represents the 16.5 billion age-0 recruits in 1980. See Table 17 for values.

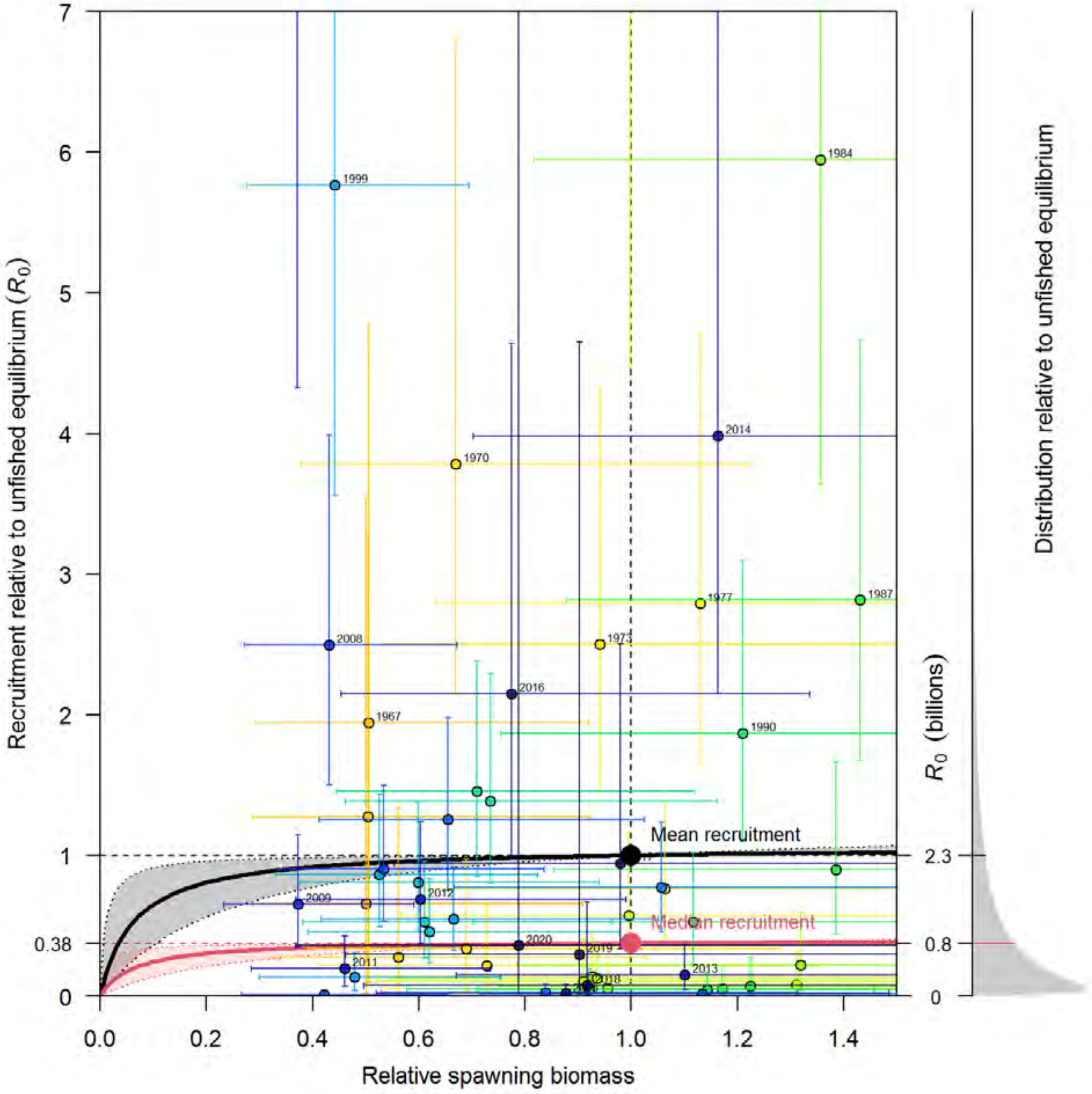


Figure 29. Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (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.

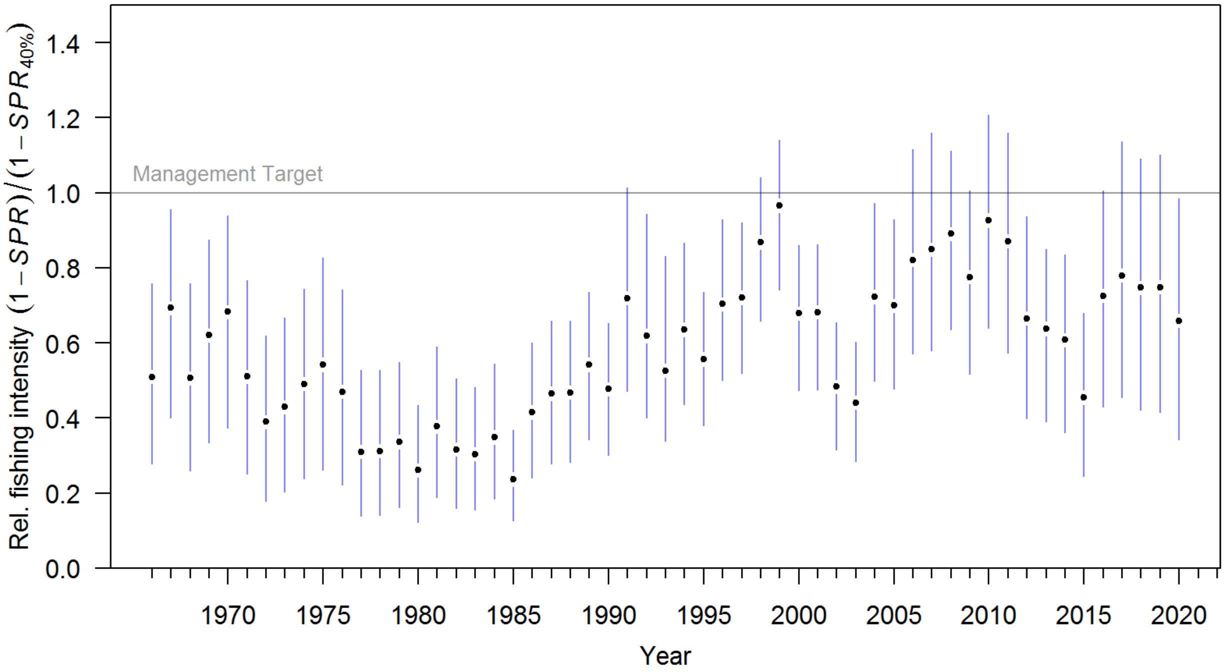


Figure 30. Trend in median fishing intensity (relative to the SPR management target) through 2020 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

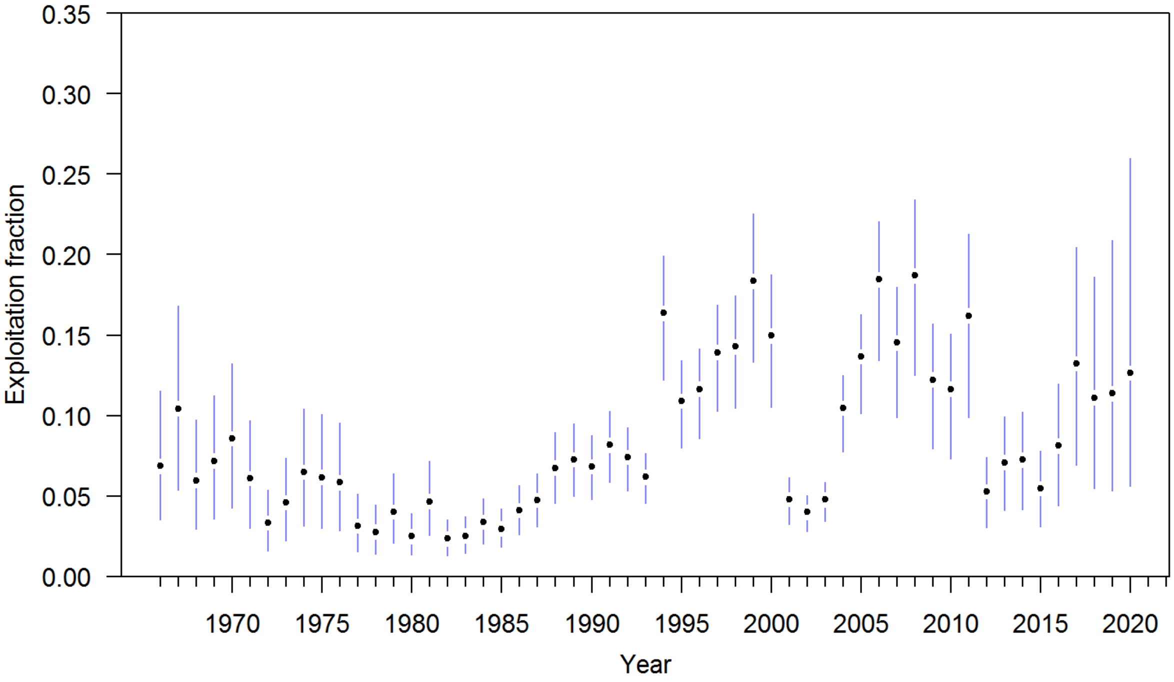


Figure 31. Trend in median exploitation fraction (catch divided by biomass of fish of age-2 and above) through 2020 with 95% posterior credibility intervals.

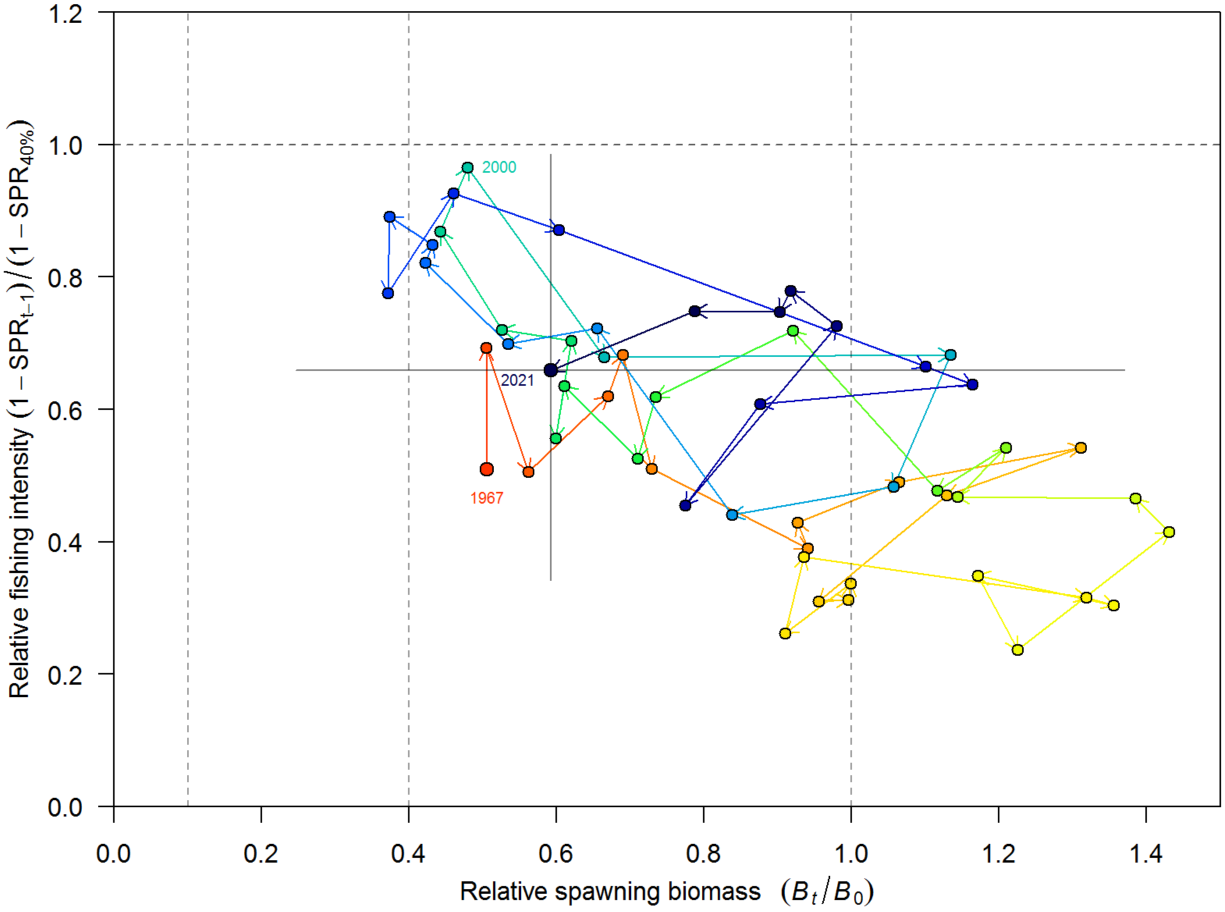


Figure 32. Estimated historical path of median relative spawning biomass in year t and corresponding median relative fishing intensity in year $t-1$. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year t (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2021 relative spawning biomass (horizontal) and 2020 relative fishing intensity (vertical).

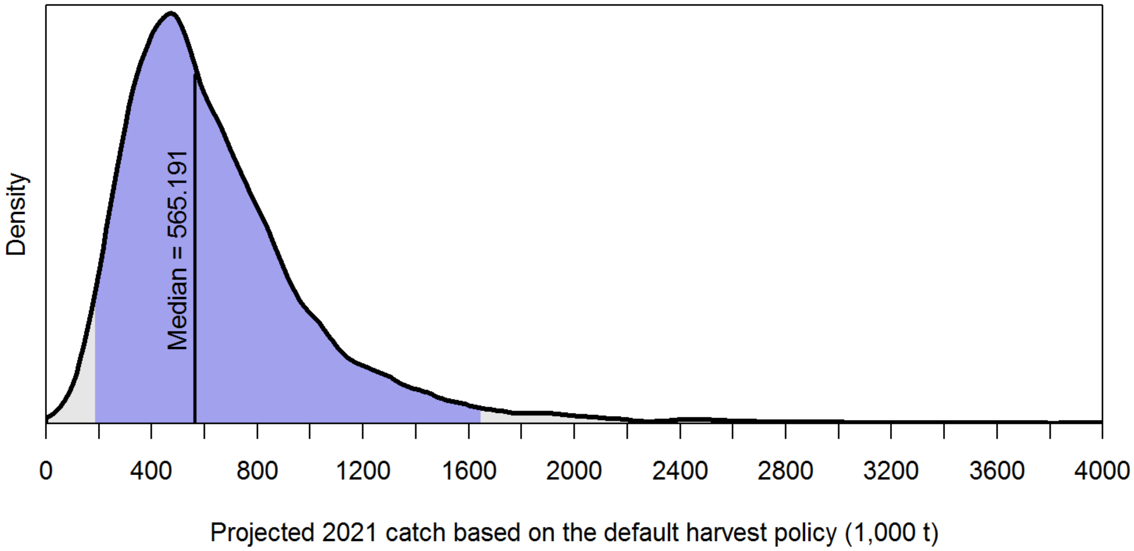


Figure 33. The posterior distribution of the default 2021 catch limit calculated using the default harvest policy ($F_{\text{SPR}=40\%}$–40:10). The median is 565,191 t (vertical line), with the dark shaded area ranging from the 2.5% quantile to the 97.5% quantile, covering the range 181,094–1,649,905 t.

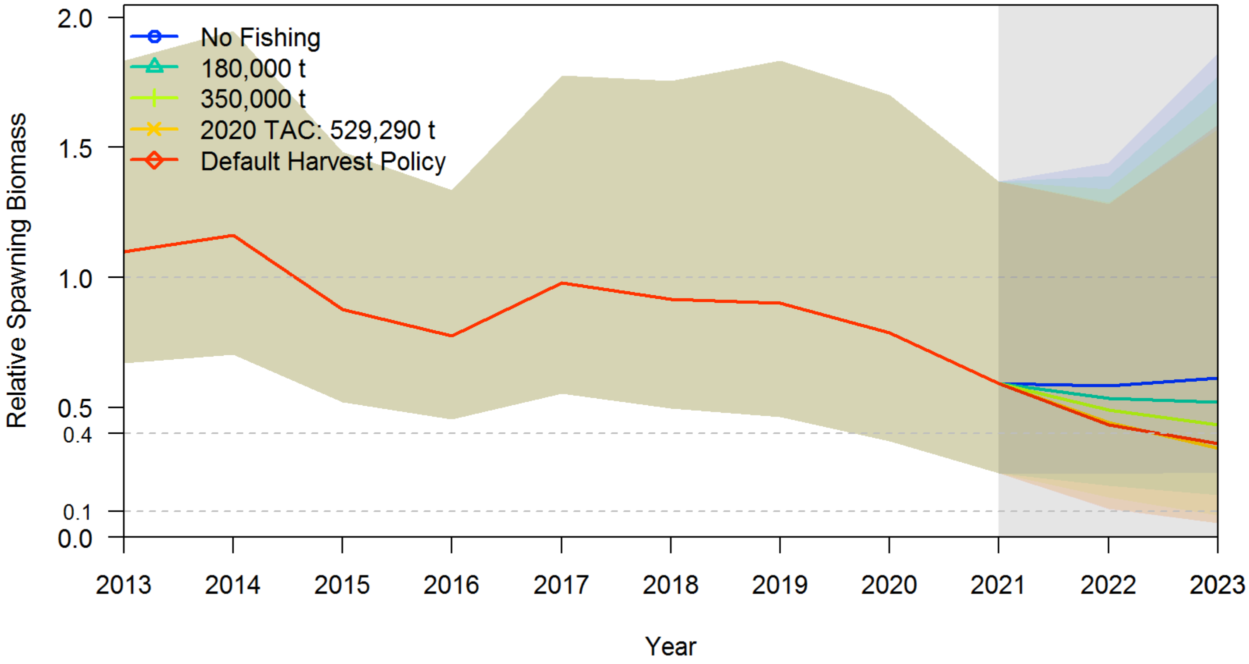


Figure 34. Time series of relative spawning biomass at the start of each year until 2021 as estimated from the base model, and forecast trajectories to the start of 2023 for several management options from the decision table (grey region), with 95% posterior credibility intervals. The 2021 catch of 565,191 t was calculated using the default harvest policy, as defined in the Agreement.

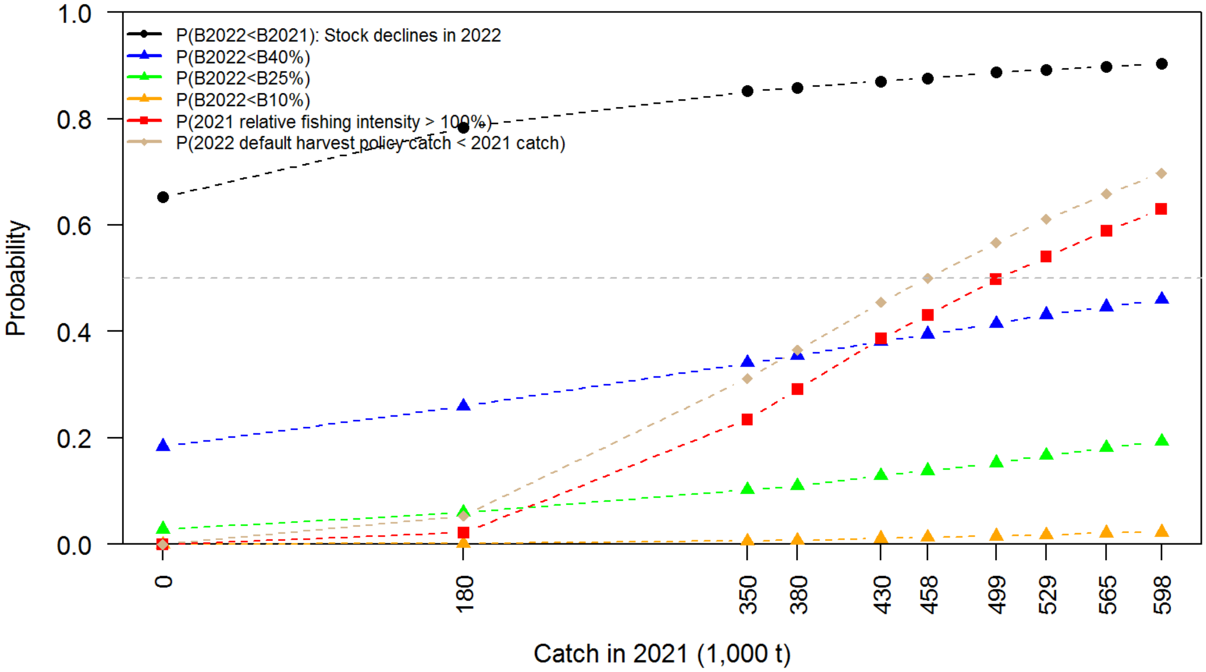


Figure 35. Graphical representation of the base model results presented in Table 29 for various catches in 2021. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

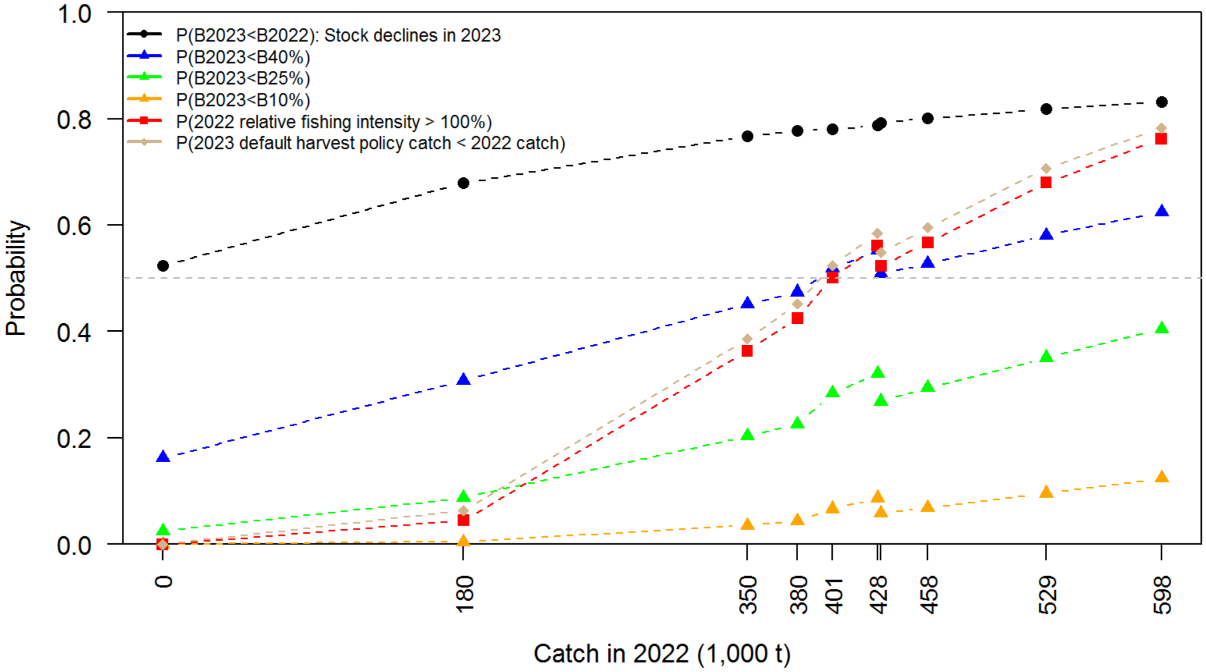


Figure 36. Graphical representation of the base model results presented in Table 30 for catch in 2022, given the 2021 catch level shown in Table 29. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

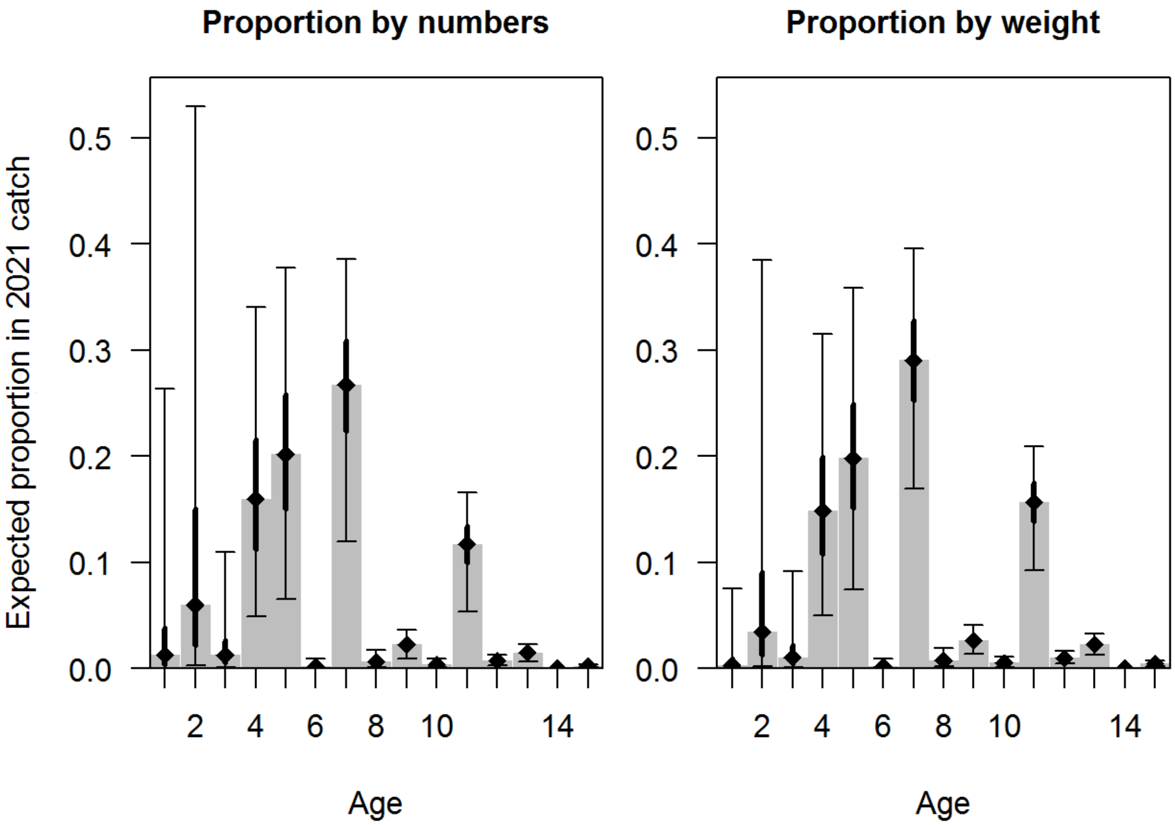


Figure 37. Forecast age compositions in numbers and in weight for the 2021 fishery catch (combined across all sectors in both countries). Gray bars show median estimates. Thick black lines show 50% credibility intervals and thin black lines show 95% credibility intervals. These estimates are based on 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 2021 (see Table 17 for the MCMC medians of 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.

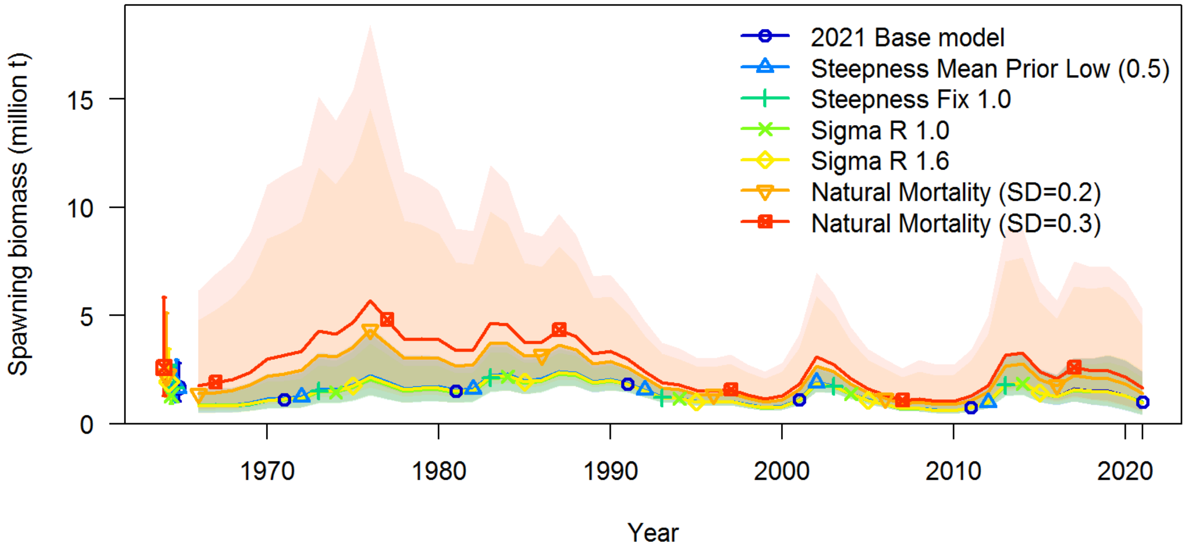


Figure 38. MCMC estimates of spawning biomass for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, lower (1.0) and higher (1.6) levels of variation assumed about the stock-recruitment relationship (σ_r), and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3.

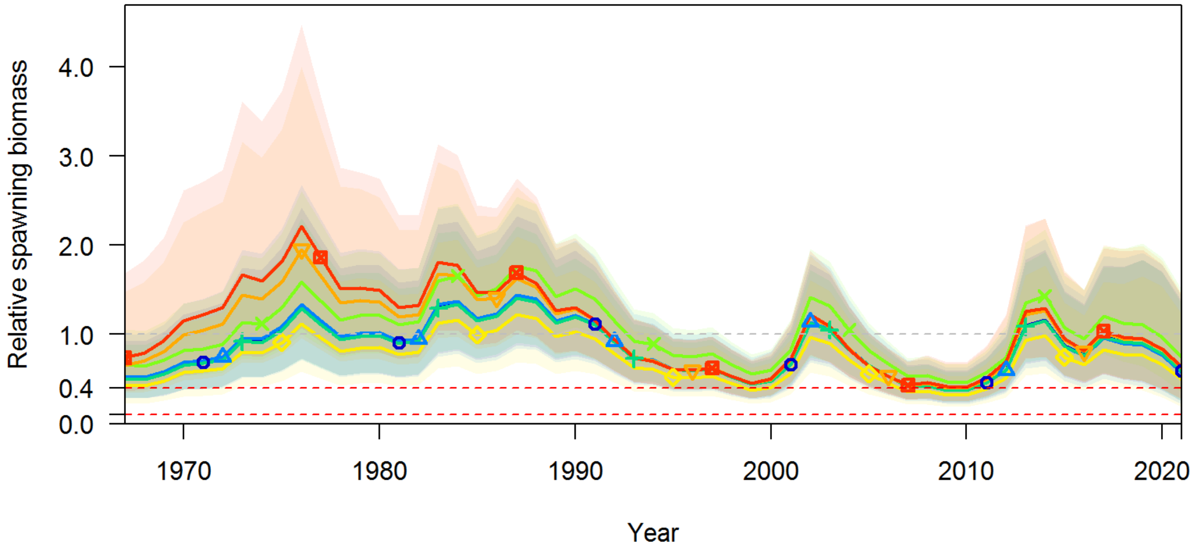


Figure 39. MCMC estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changing key parameters. See Figure 38 for sensitivity descriptions.

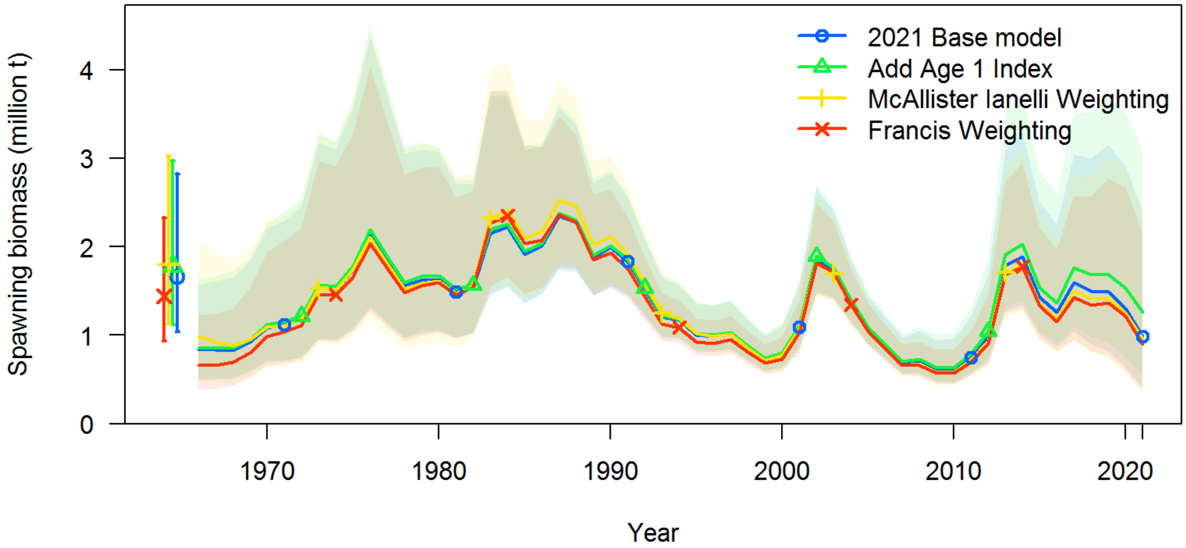


Figure 40. MCMC estimates of spawning biomass for the base model and alternative sensitivity runs that represent the following changes in data: adding an age-1 index of abundance, using the McAllister-Ianelli approach to weight composition data, and using the Francis approach to weight composition data.

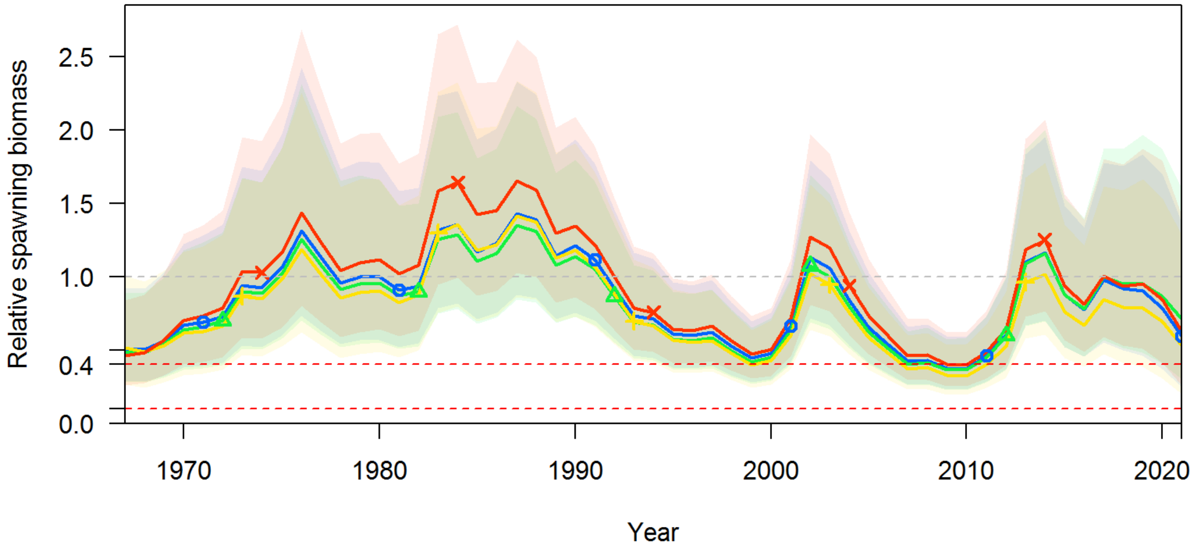


Figure 41. MCMC estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs that represent changes in data. See Figure 40 for sensitivity descriptions.

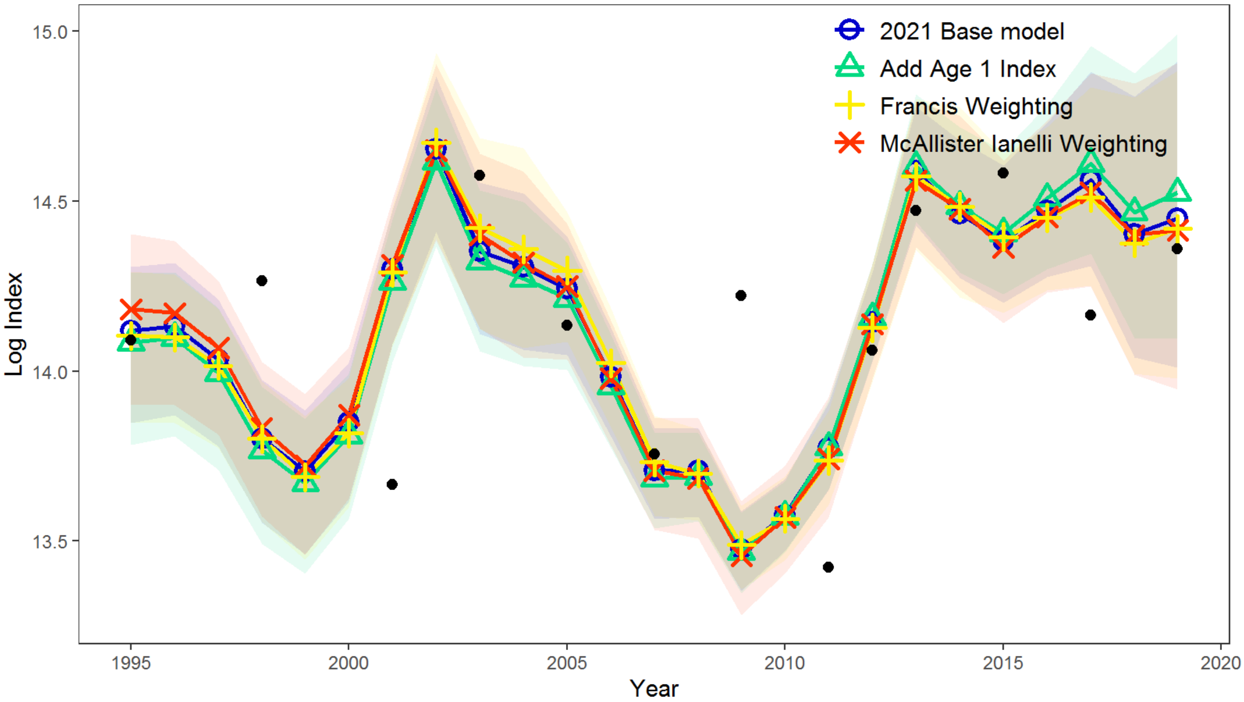


Figure 42. MCMC estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs that represent changes in data. See Figure 40 for sensitivity descriptions.

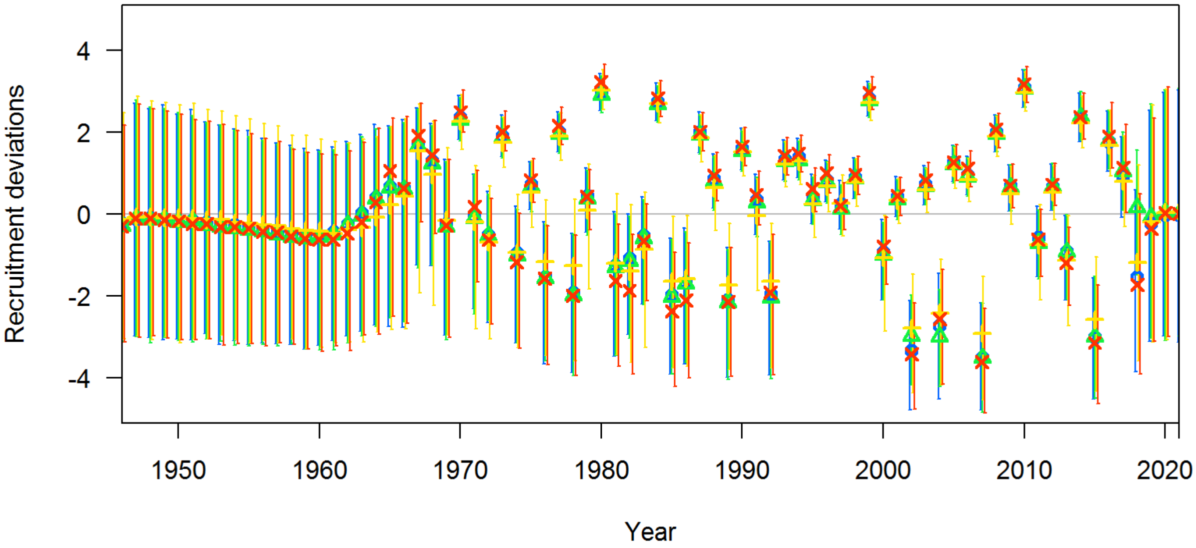


Figure 43. MCMC estimates of recruitment deviations for the base model and alternative sensitivity runs that represent changes in data. See Figure 40 for sensitivity descriptions.

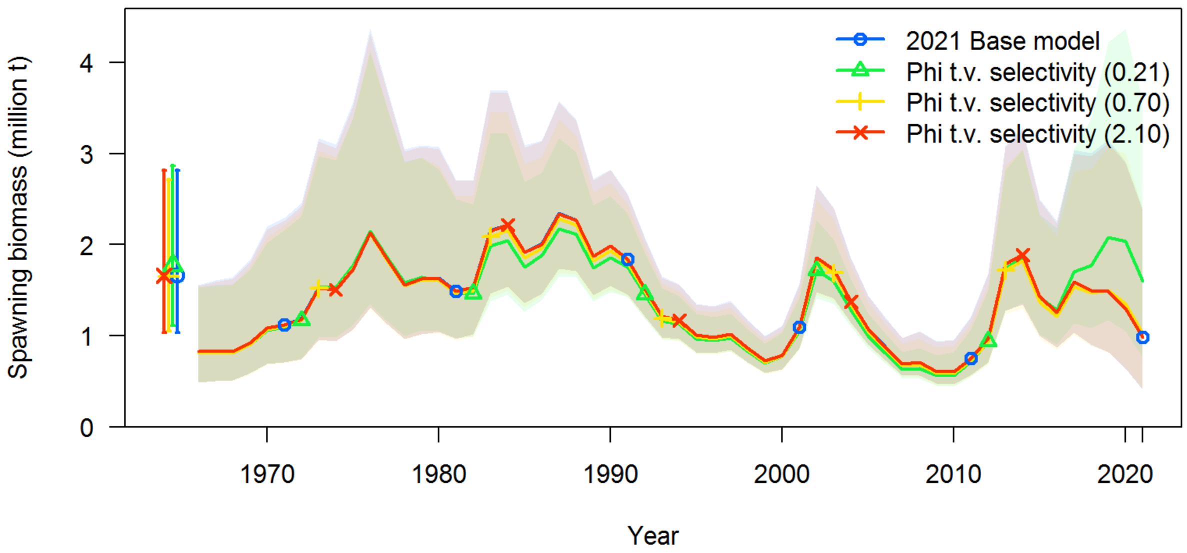


Figure 44. MCMC estimates of spawning biomass for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity.

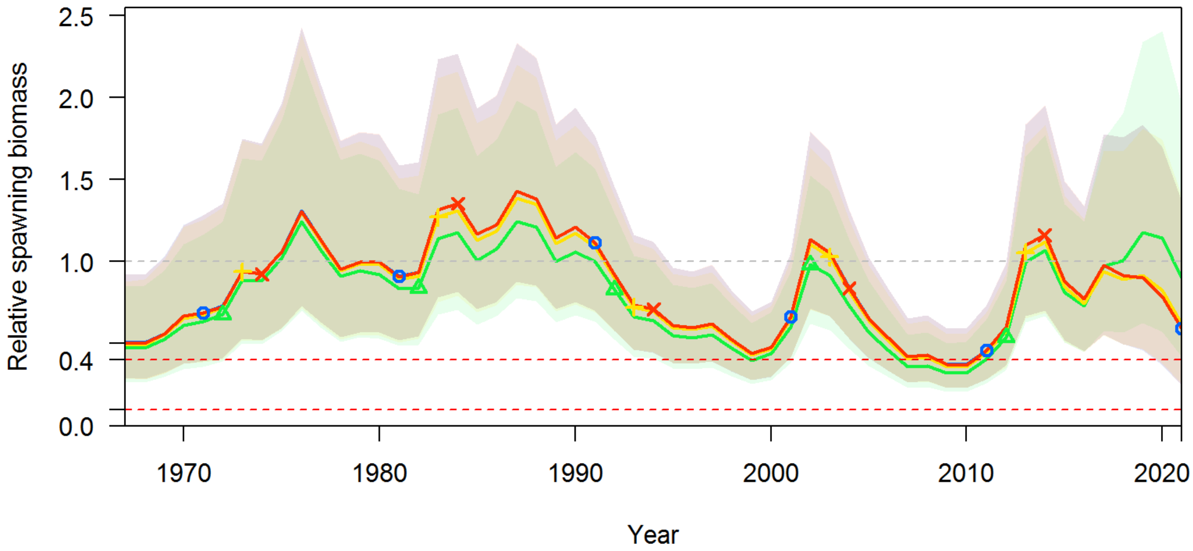


Figure 45. MCMC estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity. See Figure 44 for sensitivity descriptions.

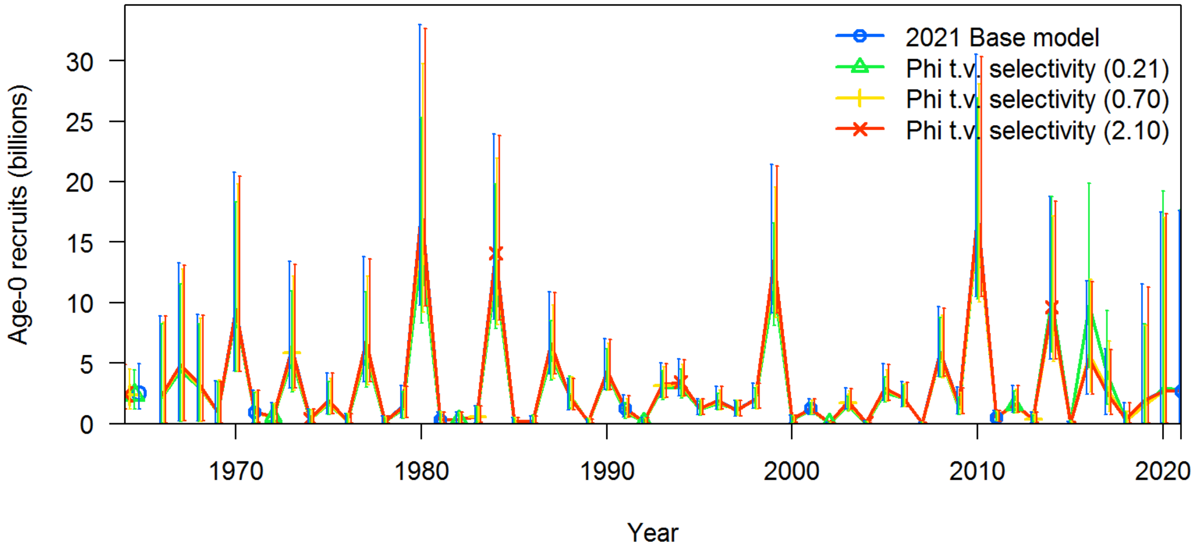


Figure 46. MCMC estimates of recruitment for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity. See Figure 44 for sensitivity descriptions.

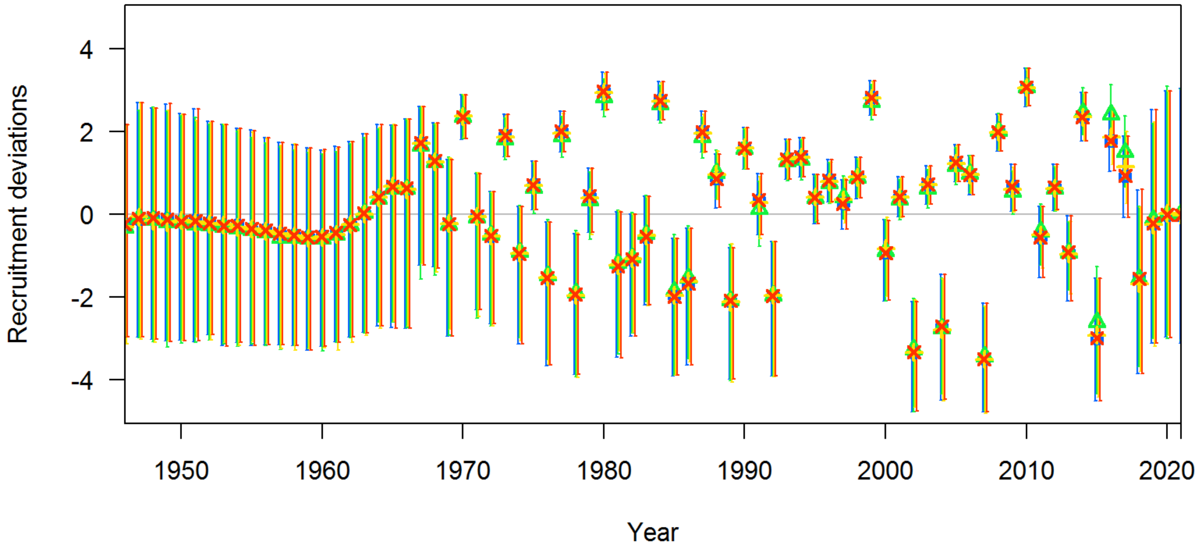


Figure 47. MCMC estimates of recruitment deviations for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity. See Figure 44 for sensitivity descriptions.

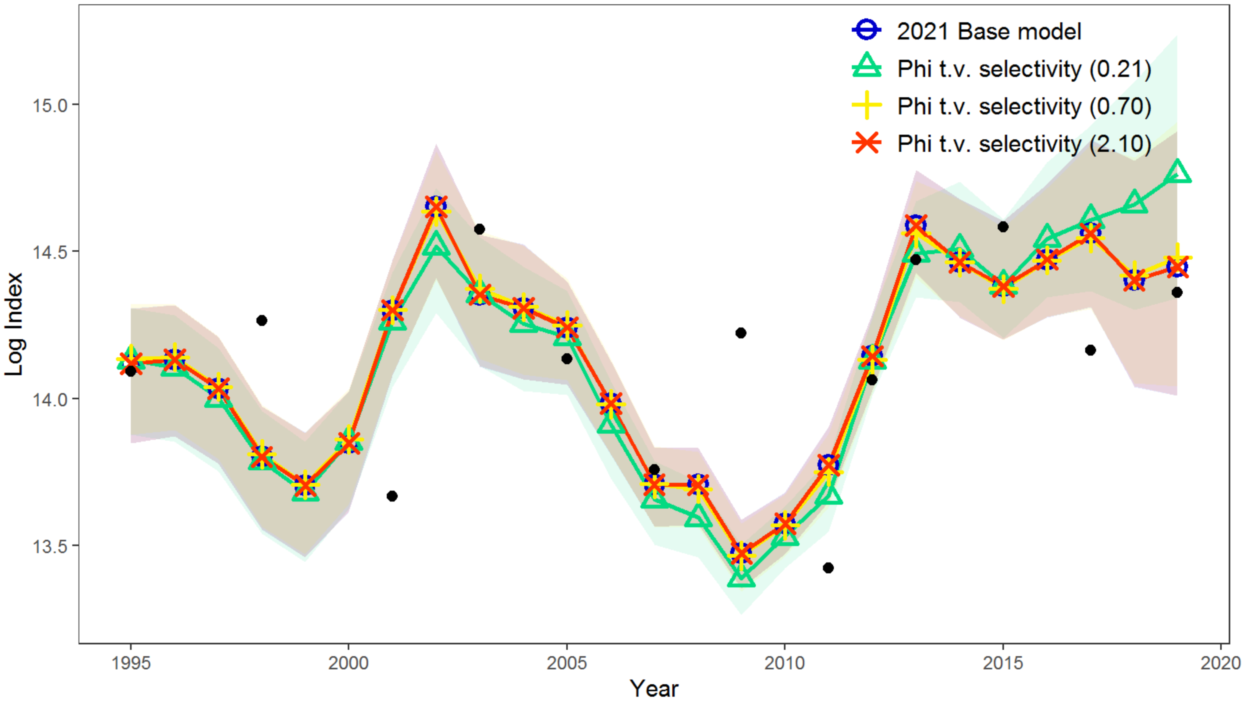


Figure 48. MCMC estimates of the fit to the survey index of abundance for the base model and alternative sensitivity runs representing different standard deviations (Φ) associated with time-varying selectivity. See Figure 44 for sensitivity descriptions.

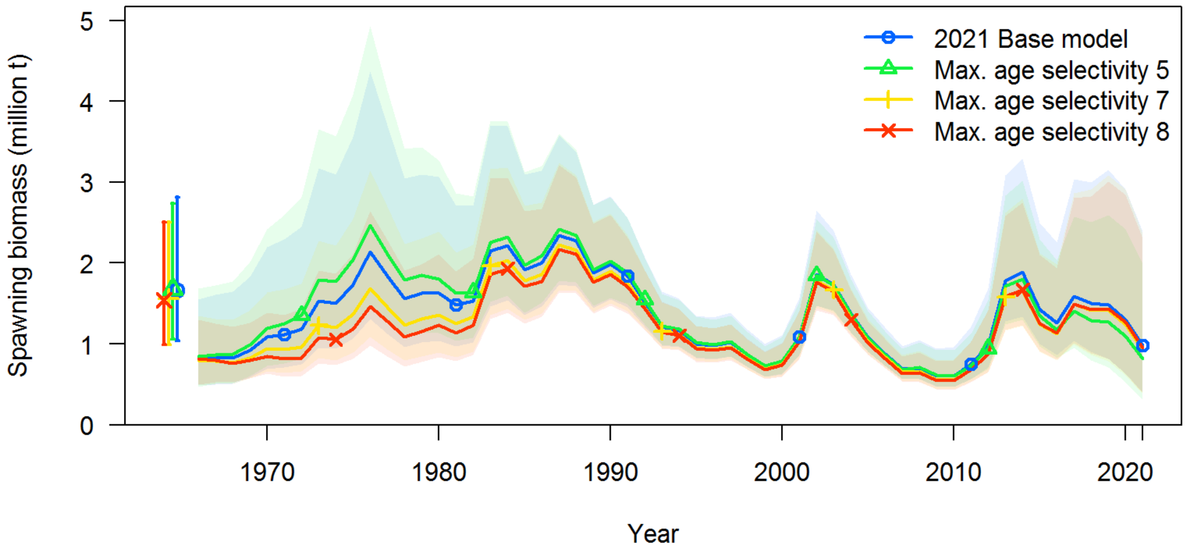


Figure 49. MCMC estimates of spawning biomass for the base model and alternative sensitivity runs with maximum age-based selectivity decreased (age-5) or increased (age-7 and age-8) relative to the base model (age-6).

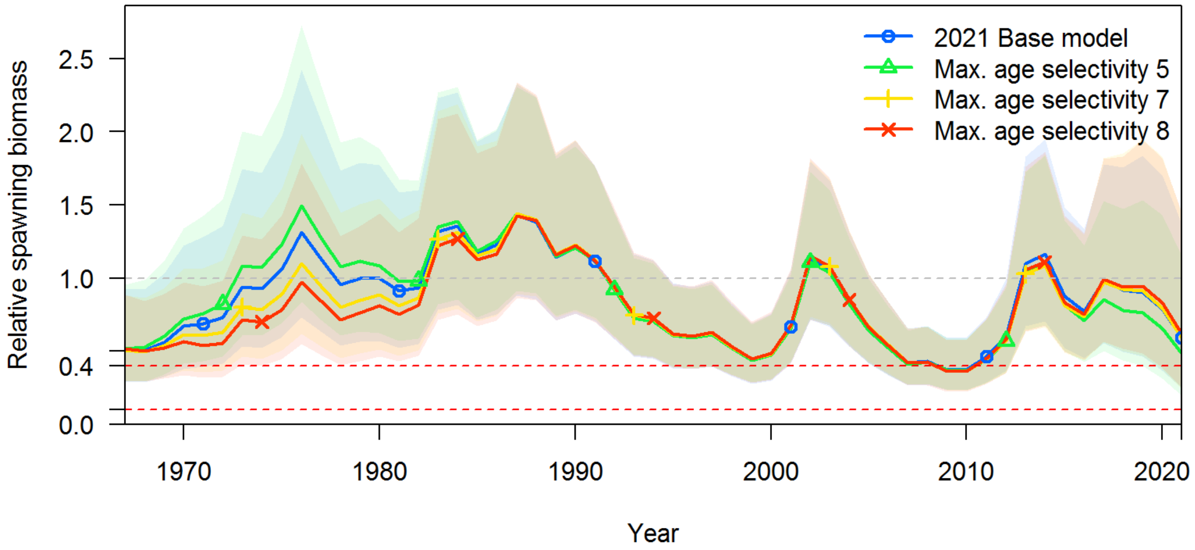


Figure 50. MCMC estimates of stock status for the base model and alternative sensitivity runs with maximum age-based selectivity decreased (age-5) or increased (age-7 and age-8) relative to the base model (age-6).

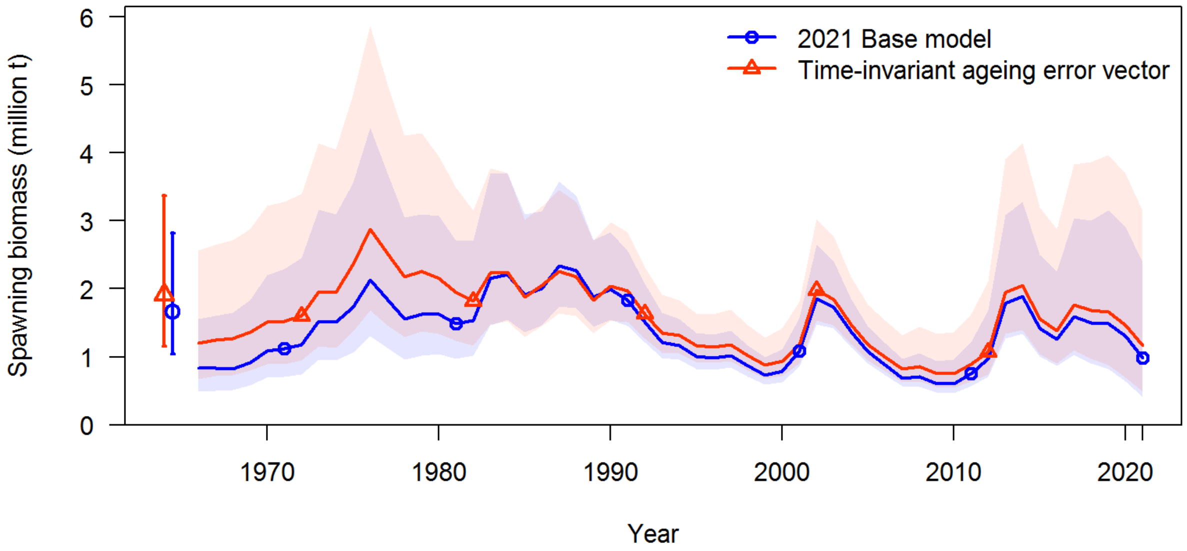


Figure 51. MCMC estimates of spawning biomass for the base model and alternative sensitivity run with cohort-based ageing error replaced with a time-invariant ageing error vector.

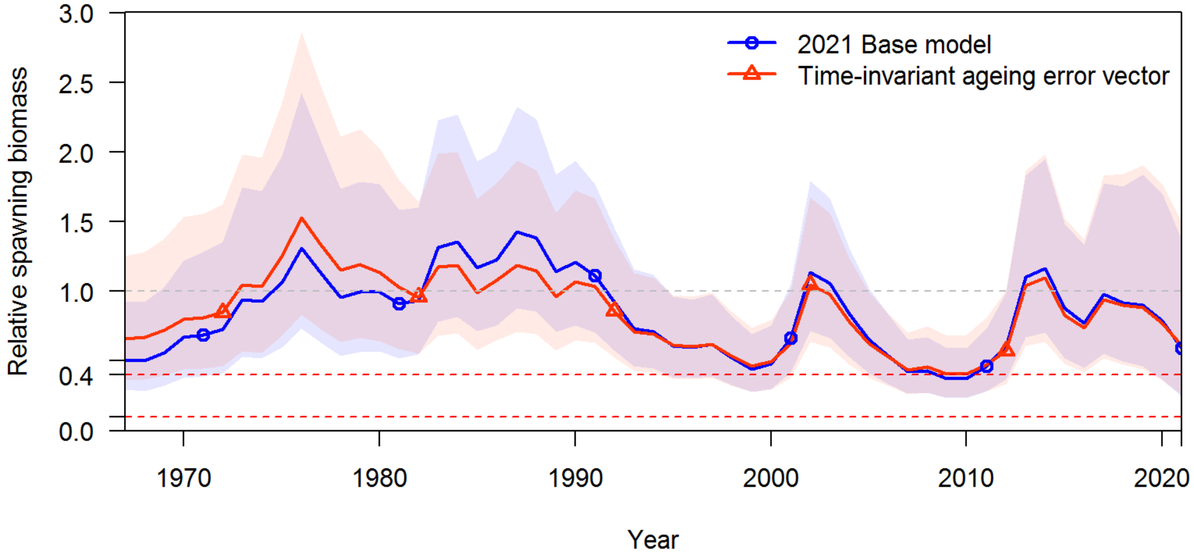


Figure 52. MCMC estimates of stock status for the base model and alternative sensitivity run with cohort-based ageing error replaced with a time-invariant ageing error vector.

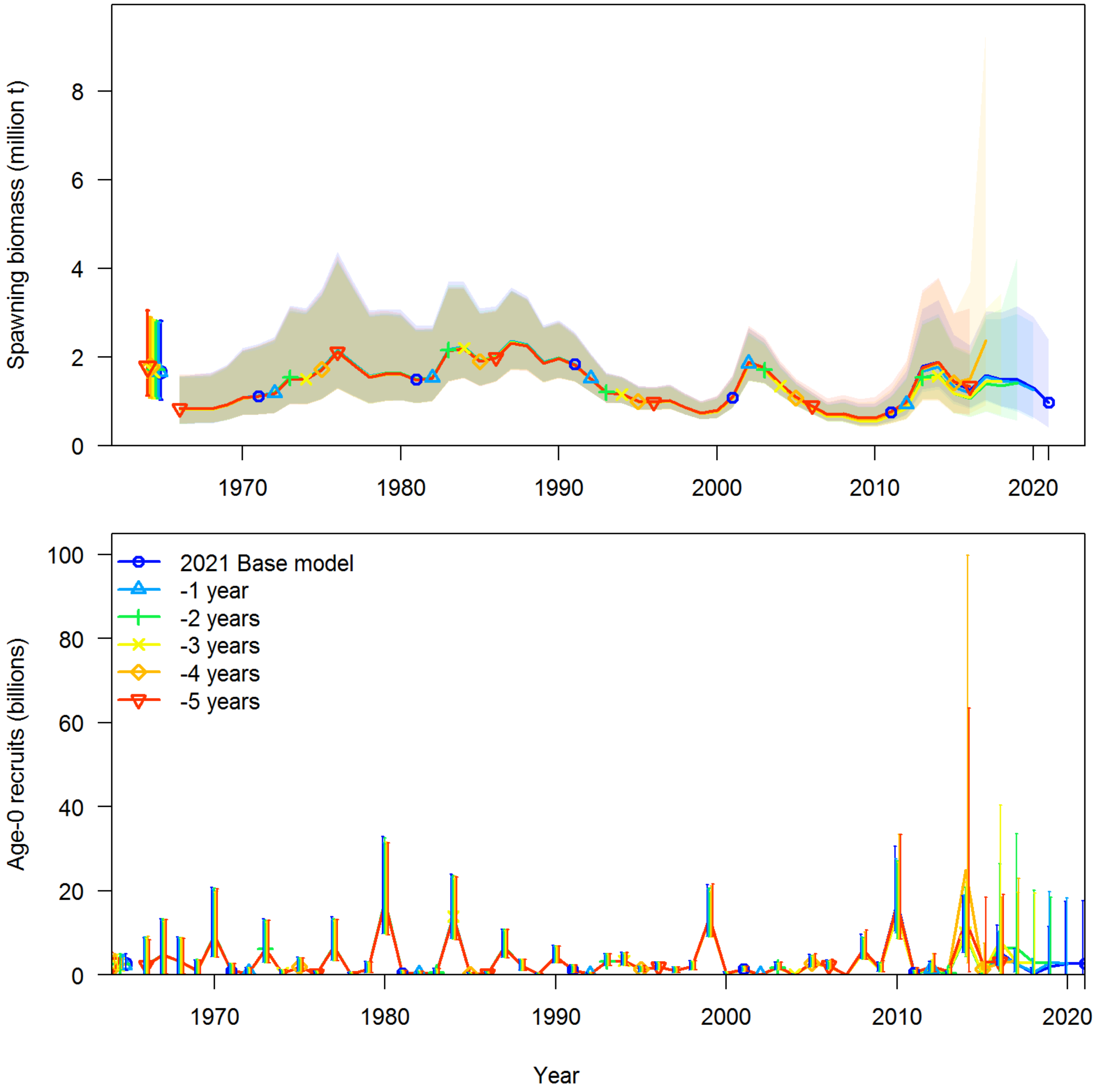


Figure 53. Estimates of spawning biomass at the start of each year (top) and recruitment (bottom) for the base model and retrospective runs (based on MCMC model runs).

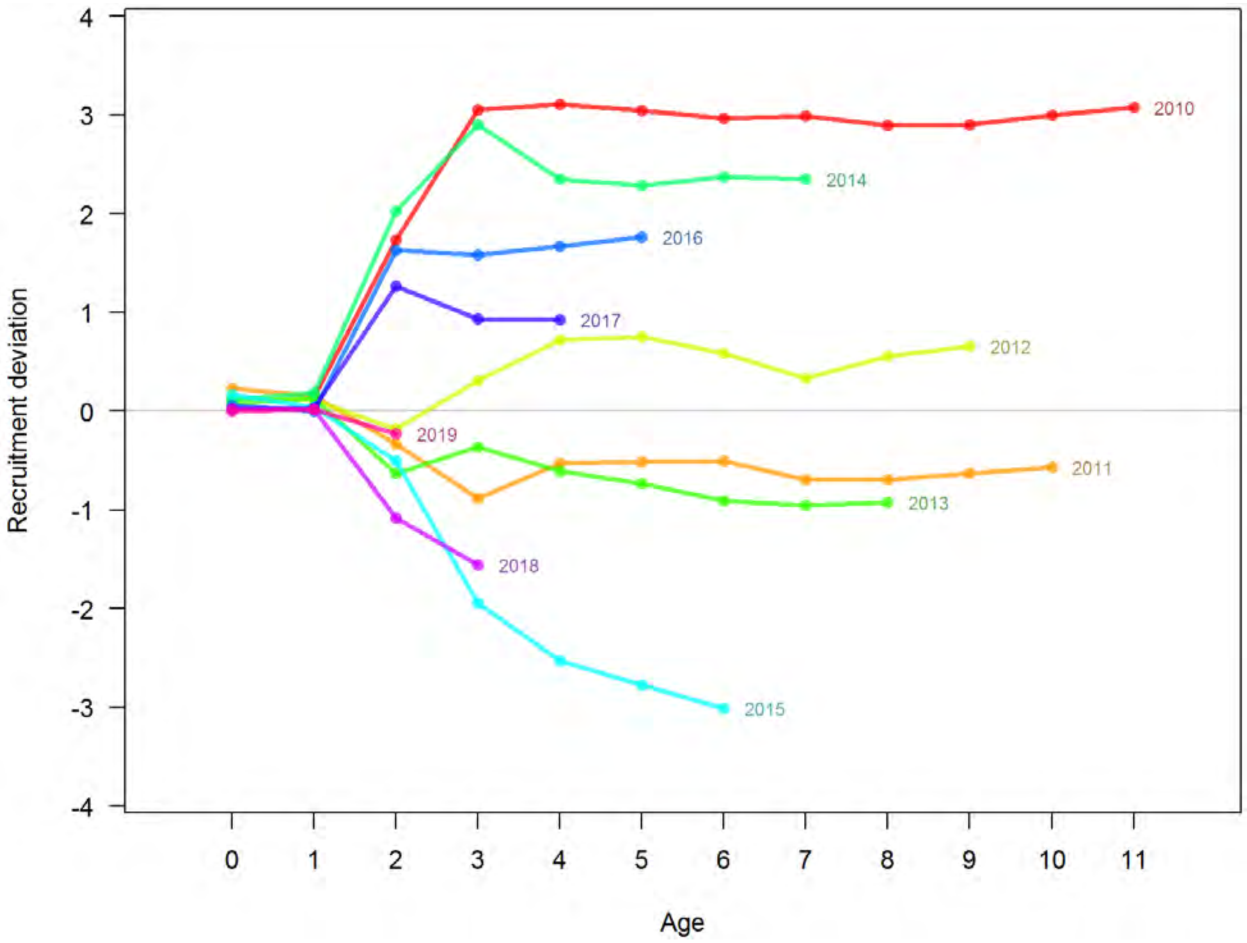


Figure 54. Retrospective analysis of recruitment deviations from MCMC models over the last 11 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Age-0 recruitment deviations are non-zero because MCMC allows for sampling from the full log-normal distribution. Lines represent estimated recruitment deviations for cohorts from 2010 to 2019, 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.

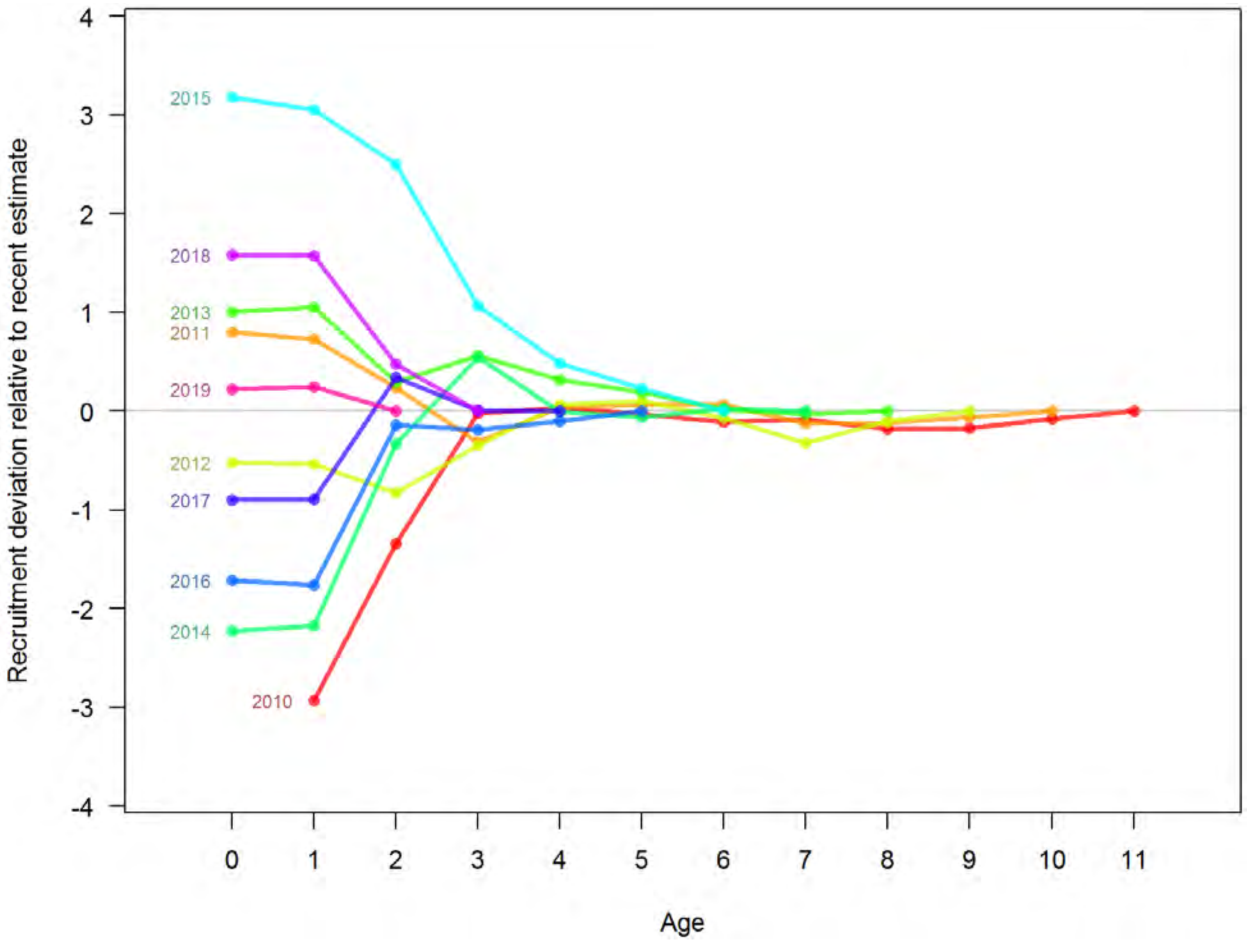


Figure 55. Retrospective recruitment estimates shown in Figure 54 scaled relative to the most recent estimate of the strength of each cohort.

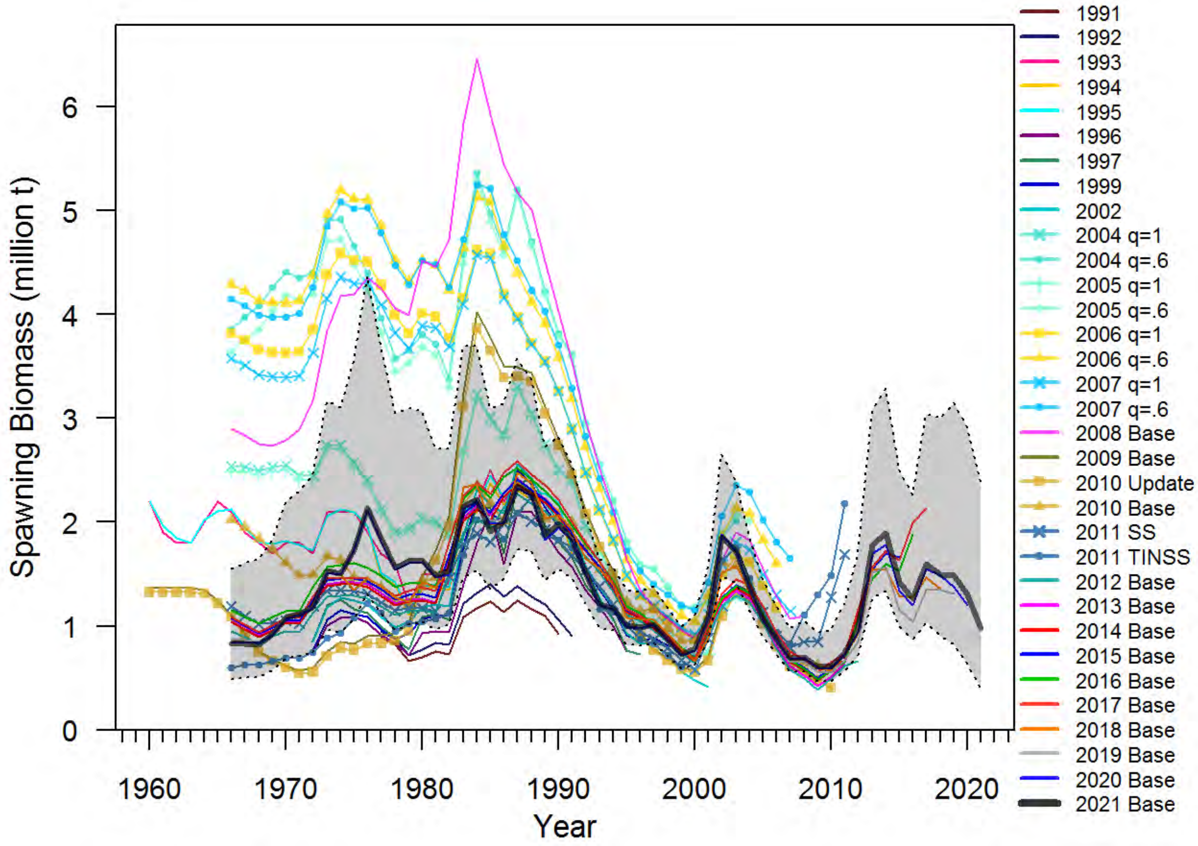


Figure 56. Summary of historical Pacific Hake assessment estimates of spawning biomass. Estimates are MLEs or MCMC medians depending on the model structure. Shading represents the approximate 95% confidence range from the 2021 base model.

A BASE MODEL MCMC DIAGNOSTICS

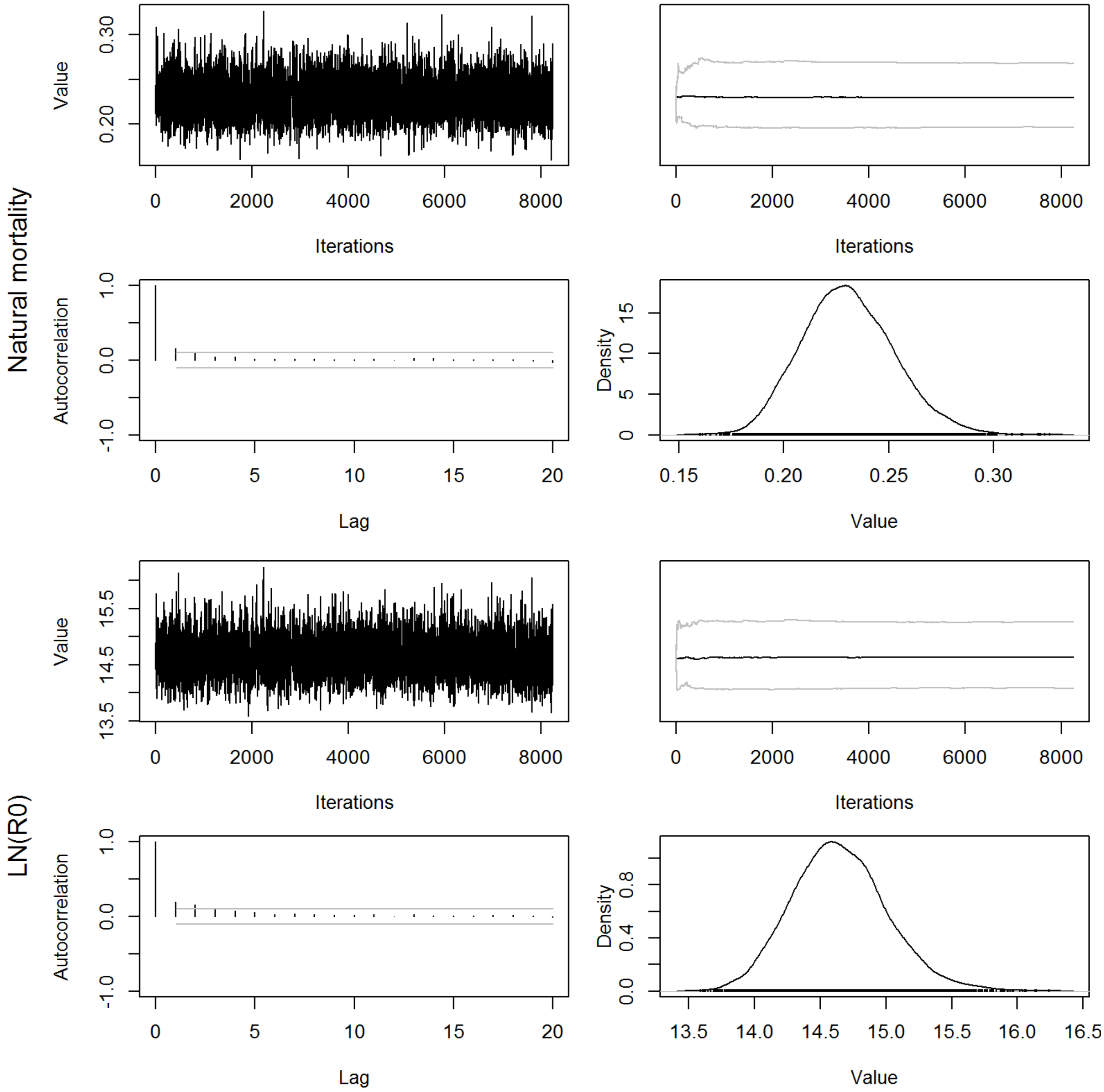


Figure A.1. Summary of MCMC diagnostics for natural mortality (upper panels) and the log of mean unfished equilibrium recruitment (log(R_0); lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 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).

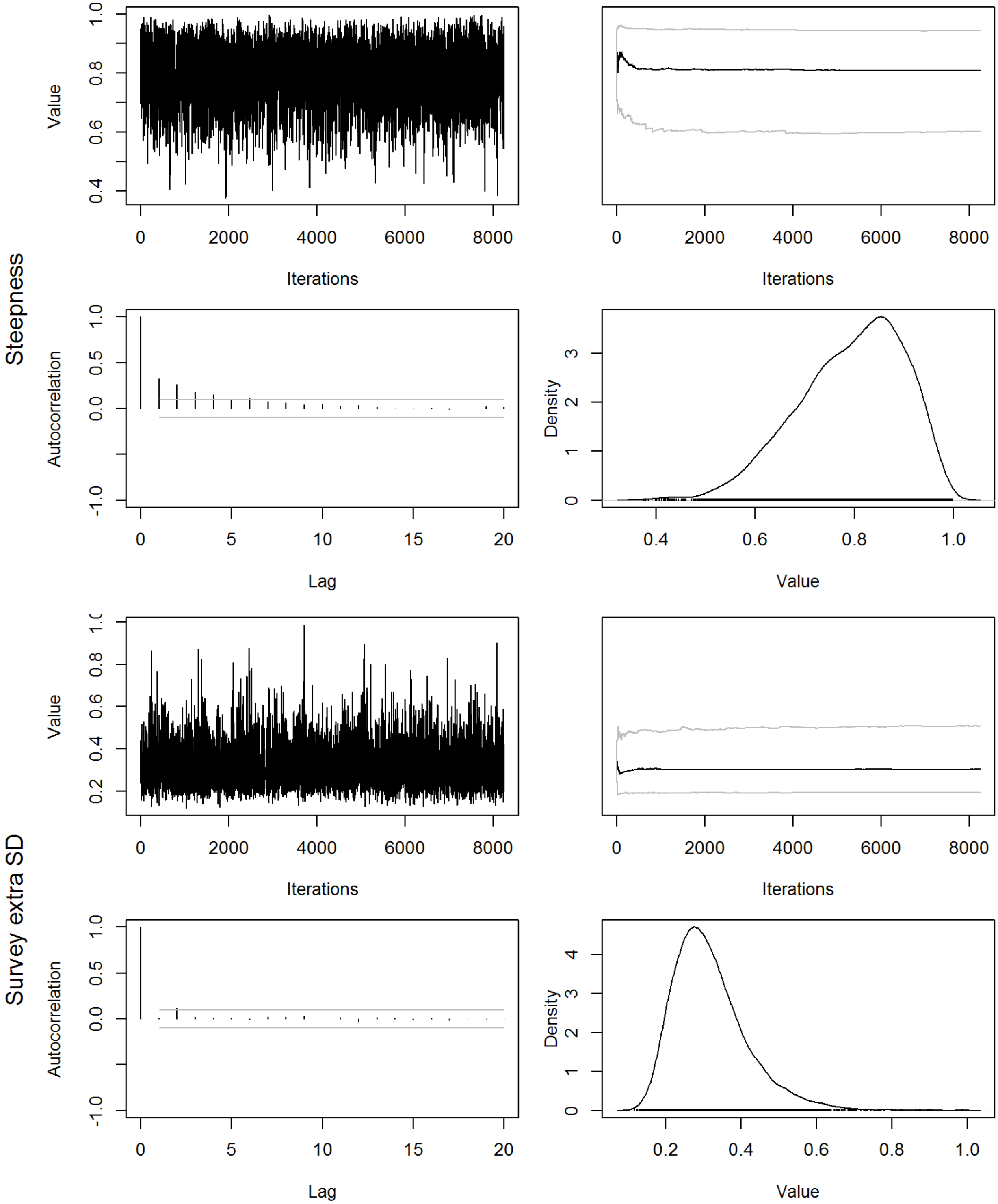


Figure A.2. Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 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).

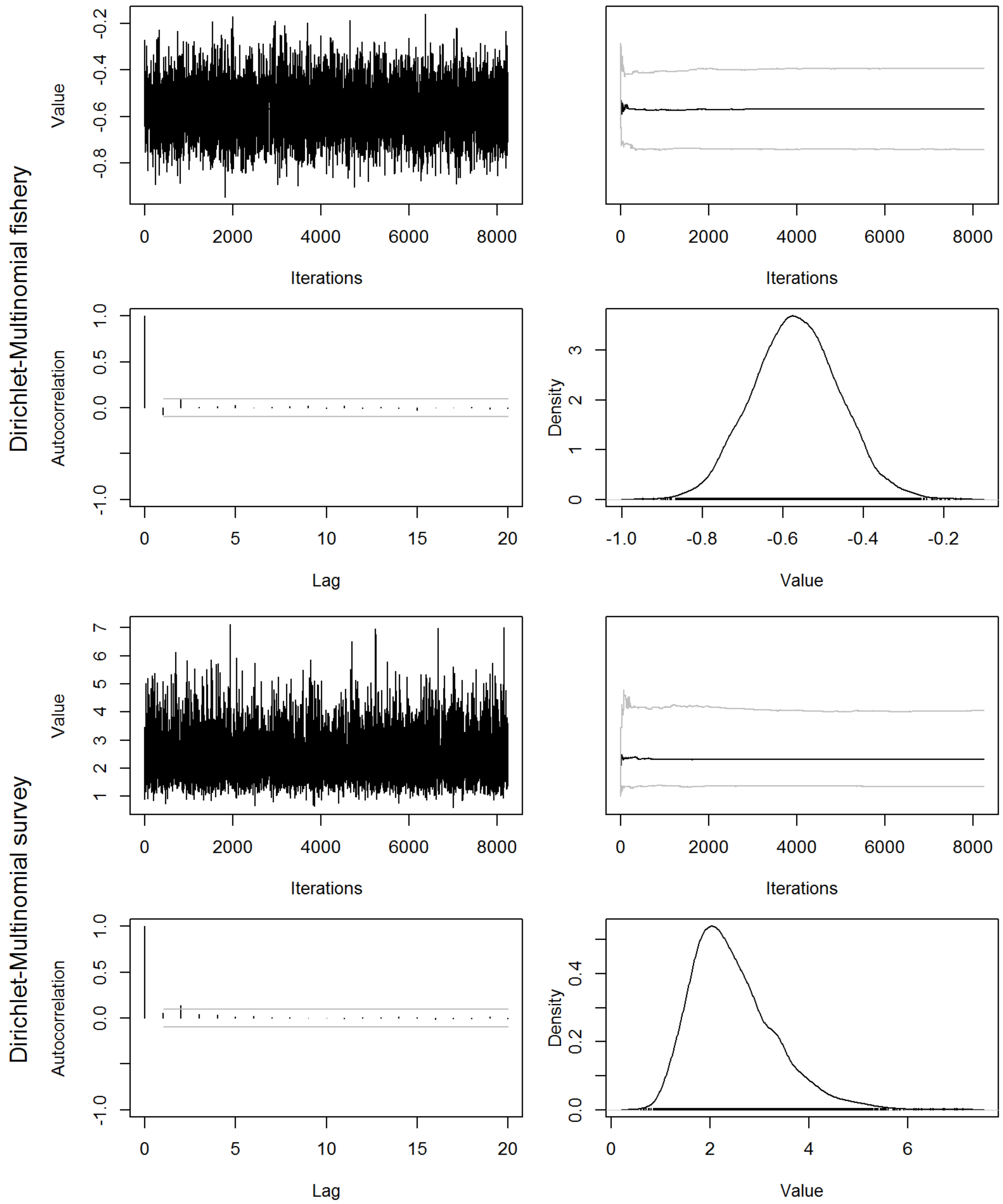


Figure A.3. Summary of MCMC diagnostics for the Dirichlet-multinomial age-composition parameters for the fishery (θ_{fish}, upper panels) and the survey (θ_{surv}, lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative 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).

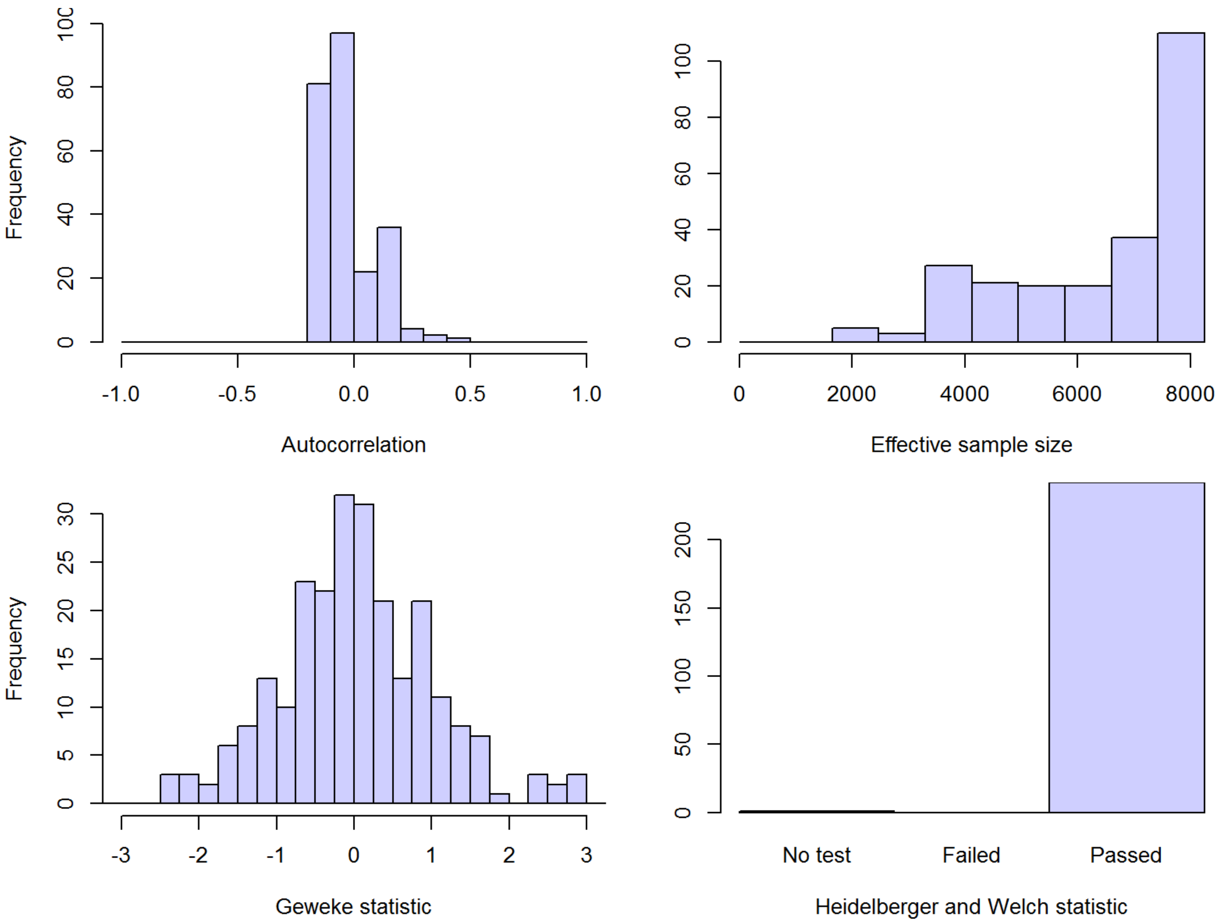


Figure A.4. Summary histograms of MCMC diagnostics for all base model parameters. The level of autocorrelation in the chain (distribution across lag times, i.e., distance between samples in the chain, shown in the top left panel) influences the effective sample size (top right panel) used to estimate 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.

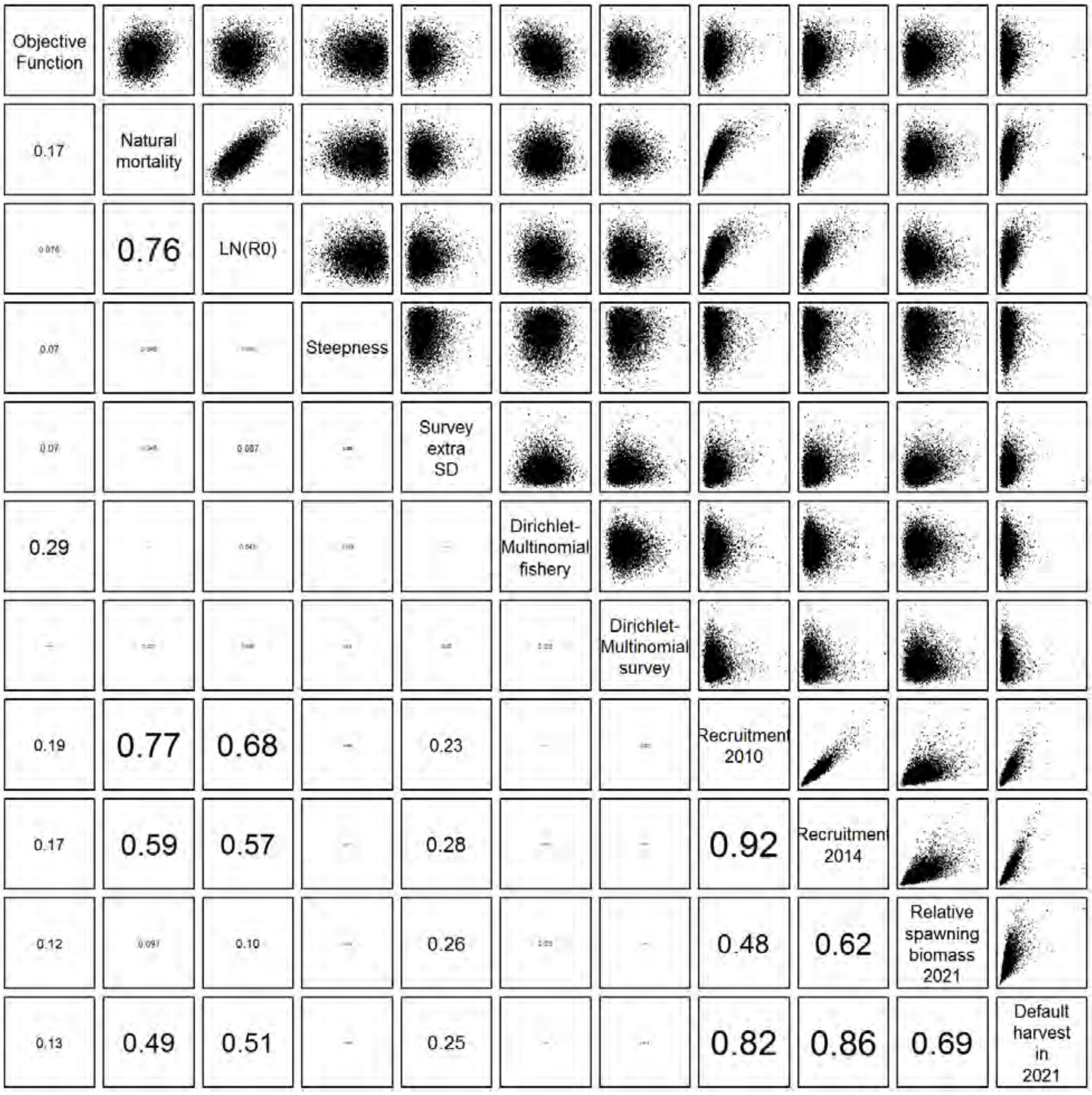


Figure A.5. Posterior correlations among key base-model parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

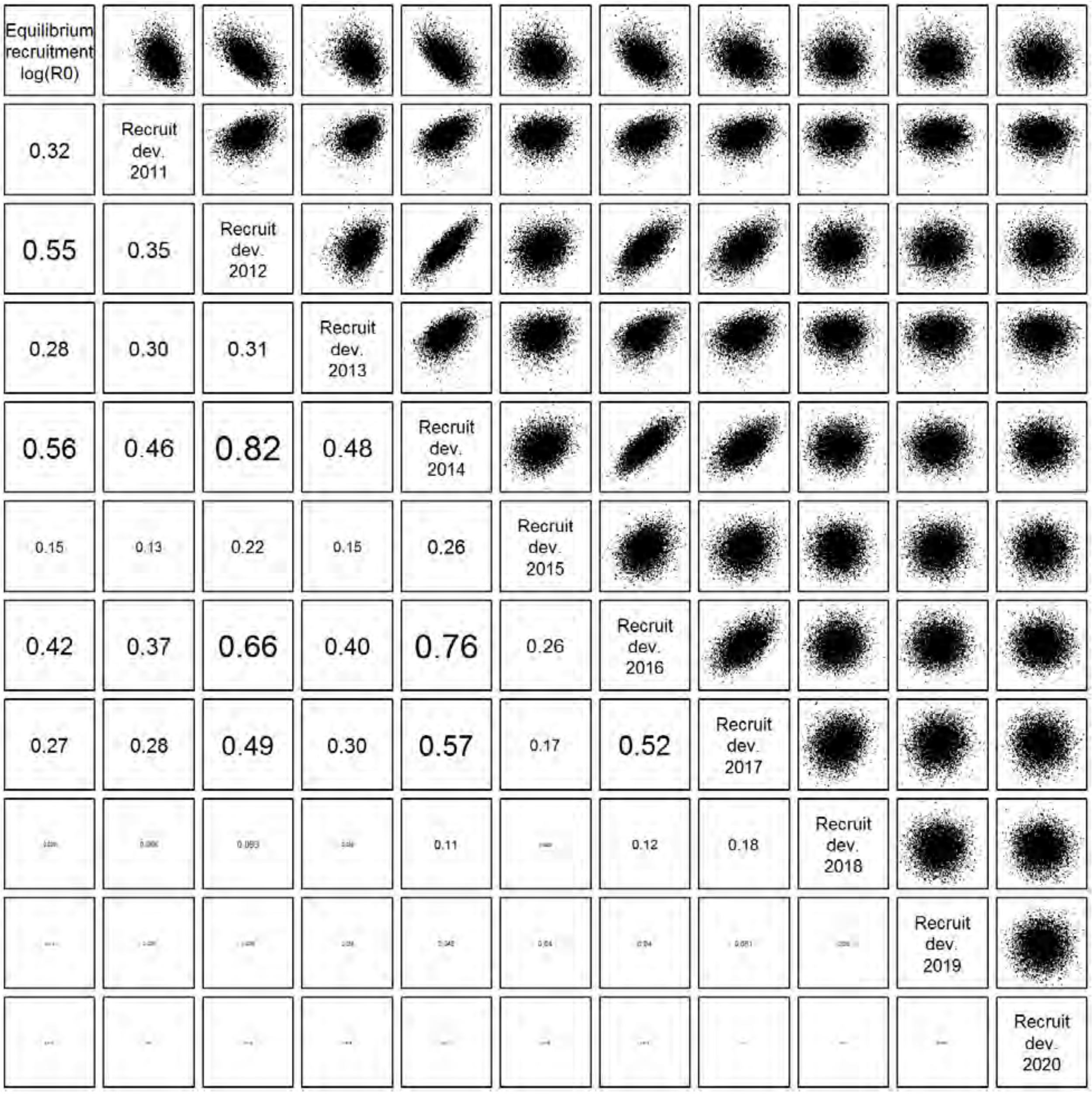


Figure A.6. Posterior correlations among recruitment deviations from recent years and equilibrium recruitment. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

B SCIENTIFIC REVIEW GROUP (SRG) REQUESTS FROM 2021 MEETING

This appendix will summarize results produced in response to any Scientific Review Group requests made during the virtual meeting held from 22nd to 25th February 2021.

B.1 DAY 1

Request 1:

Please plot the NUTS and random walk Metropolis-Hastings estimator outputs for relative biomass with the same scale (one plot) so that the SRG can evaluate any differences that may have occurred.

JTC Response:

The JTC made the density plot and included additional plots to show densities of other key parameters and estimates of recruitment for large cohorts. For most parameters the medians are comparable (Figures B.1.1–B.1.9), but for $\ln R_0$, h, and Dirichlet-multinomial θ for the fishery the median value for the NUTS model is slightly less. In all cases, the parameter space appears to be better explored with the NUTS model due to the presence of more samples in the tails of the distributions (blue hash marks).

The following two summaries of Betancourt (2018) were presented to the SRG regarding differences between rwMH and NUTS and their appropriateness to high-dimensional models such as the Pacific Hake assessment model:

> Random Walk Metropolis is popular in many applications because of its conceptual simplicity. But, that seductive simplicity hides a performance that scales poorly with increasing dimension and complexity of the target distribution. For high-dimensional probability distributions of practical interest we need a better way of exploring the typical set. In particular, we need to better exploit the geometry of the typical set itself.
>
> Hamiltonian Monte Carlo approaches [e.g., NUTS] can better follow the contours of high probability mass, coherently gliding through the typical set. Results show that implementations of the Hamiltonian Monte Carlo method are geometrically ergodic over a large class of target distributions. In particular, this class is significantly larger than the class for non-gradient based algorithms like Random Walk Metropolis Hastings, consistent with the intuition that gradients are critical to robust Markov chain Monte Carlo in high-dimensional problems.

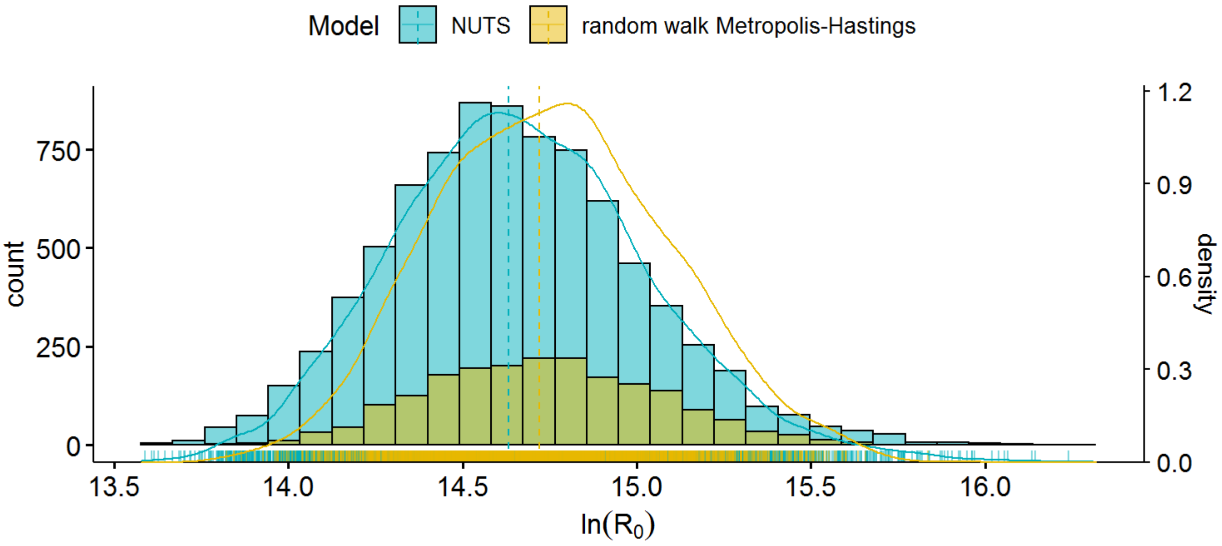


Figure B.1.1. Density of the $\ln R_0$ parameter for the NUTS and rwMH models. Medians are shown using dashed vertical lines. Raw count is shown on the left y-axis and density is shown on the right y-axis. Hash marks above x axis are locations of samples.

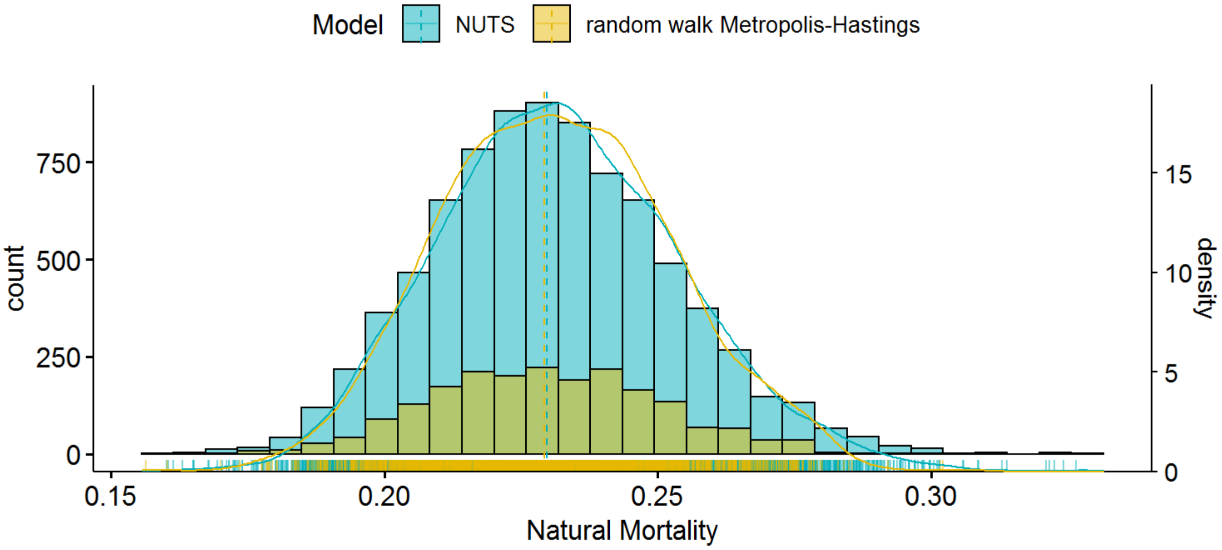


Figure B.1.2. Density of the M (natural mortality) parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

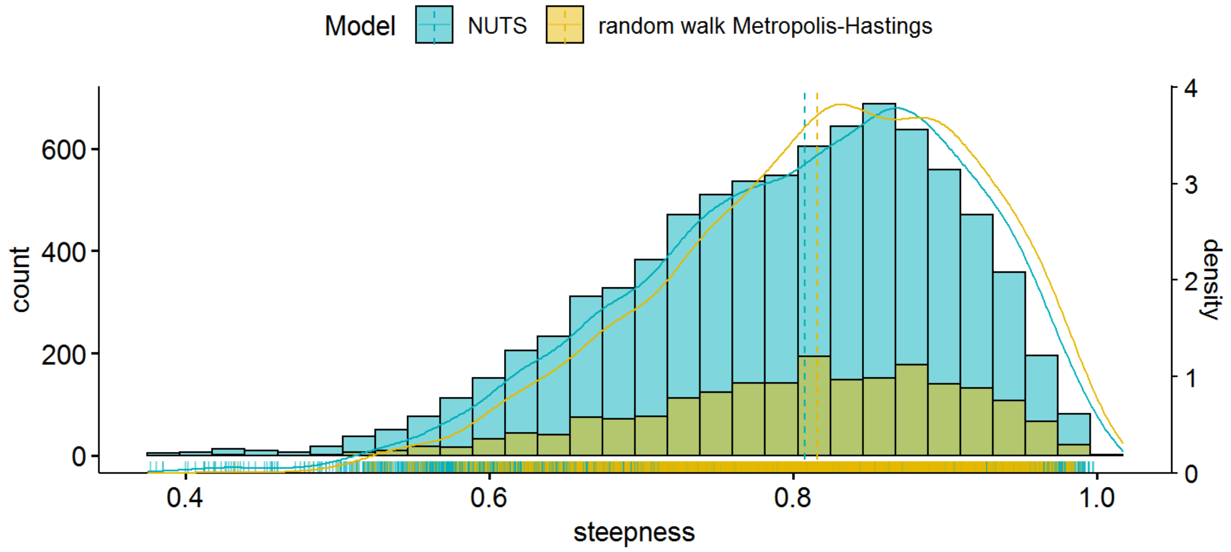


Figure B.1.3. Density of the *h* (steepness) parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

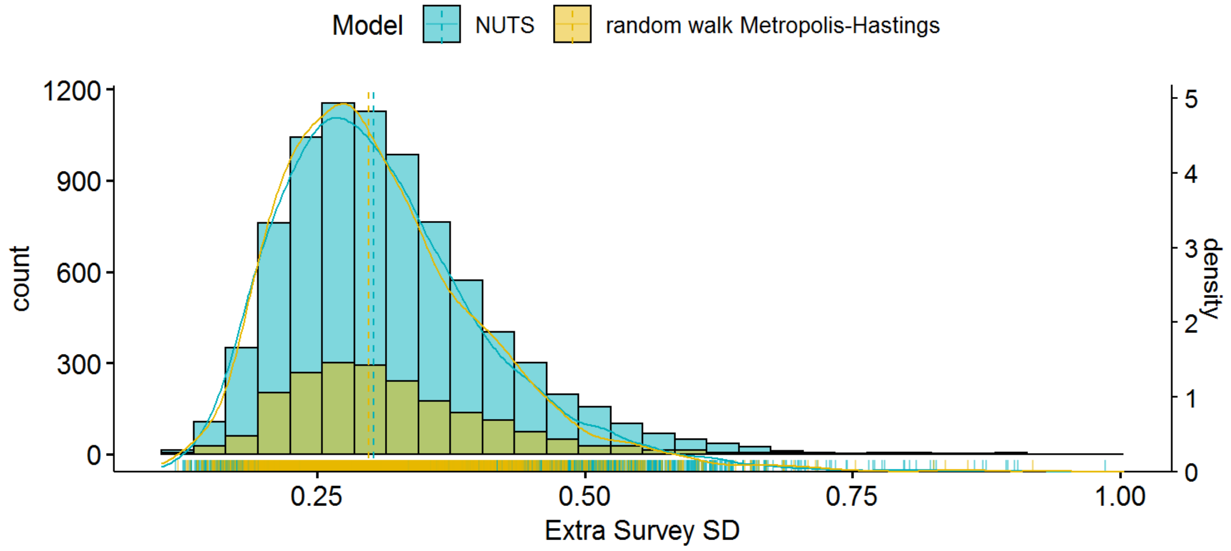


Figure B.1.4. Density of the Extra survey SD parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

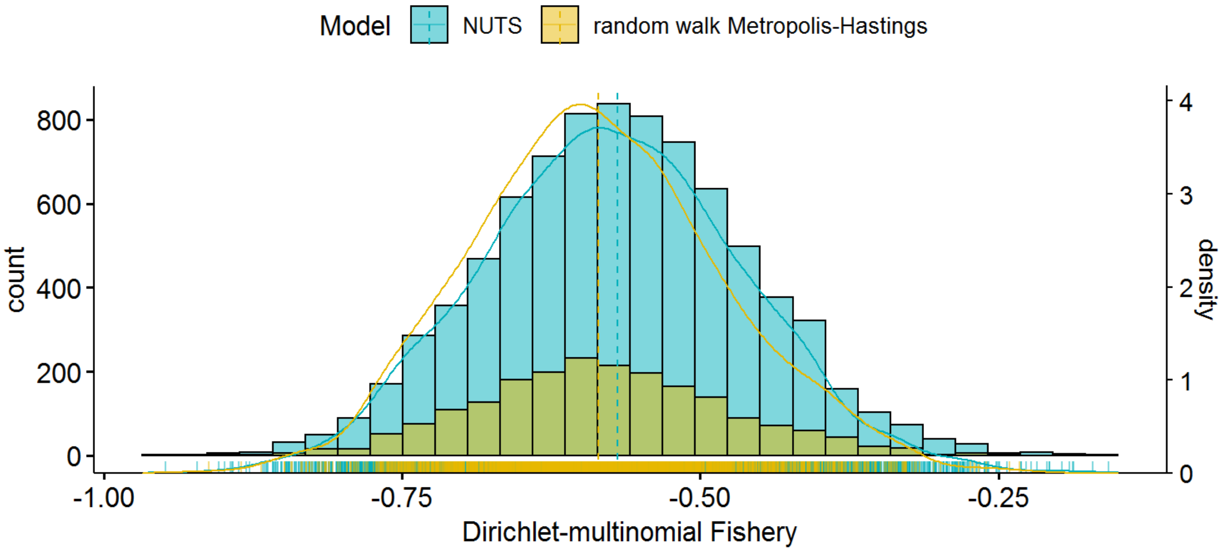


Figure B.1.5. Density of the Dirichlet-multinomial (fishery) parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

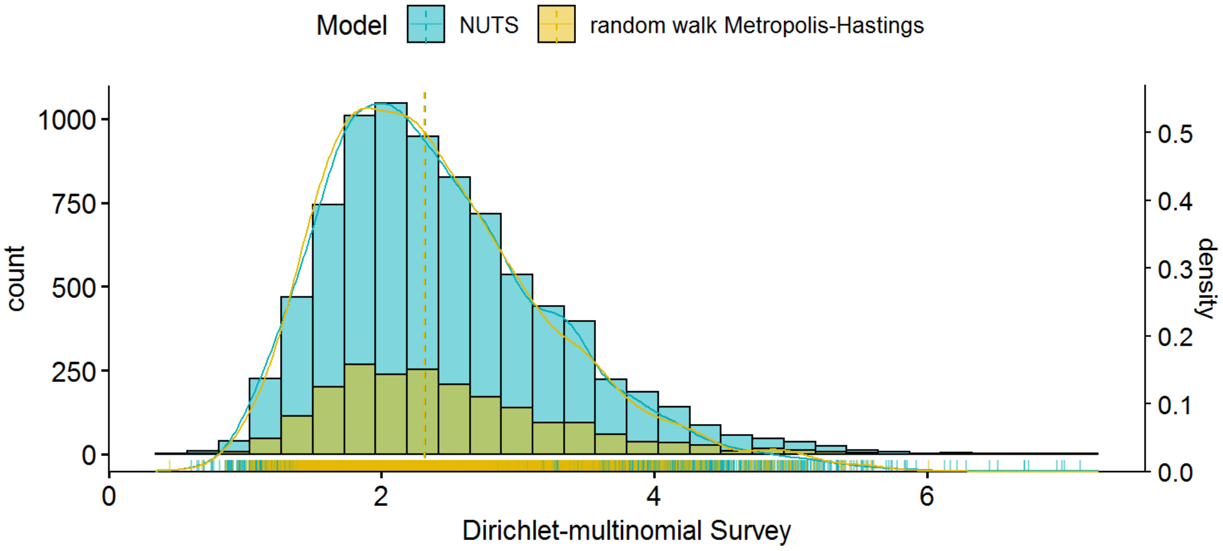


Figure B.1.6. Density of the Dirichlet-multinomial (survey) parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

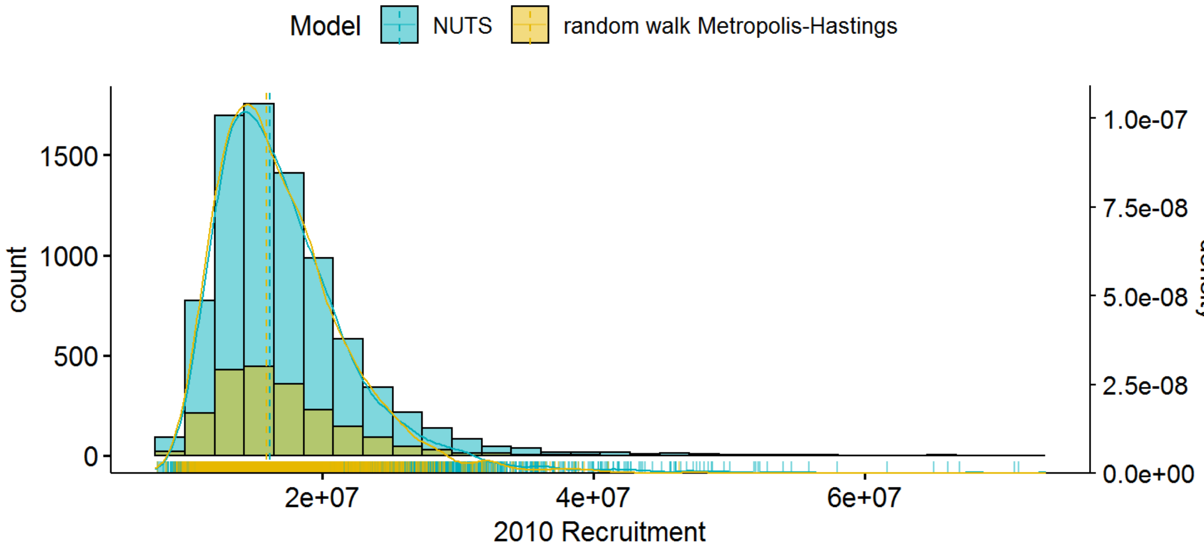


Figure B.1.7. Density of the 2010 recruitment parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

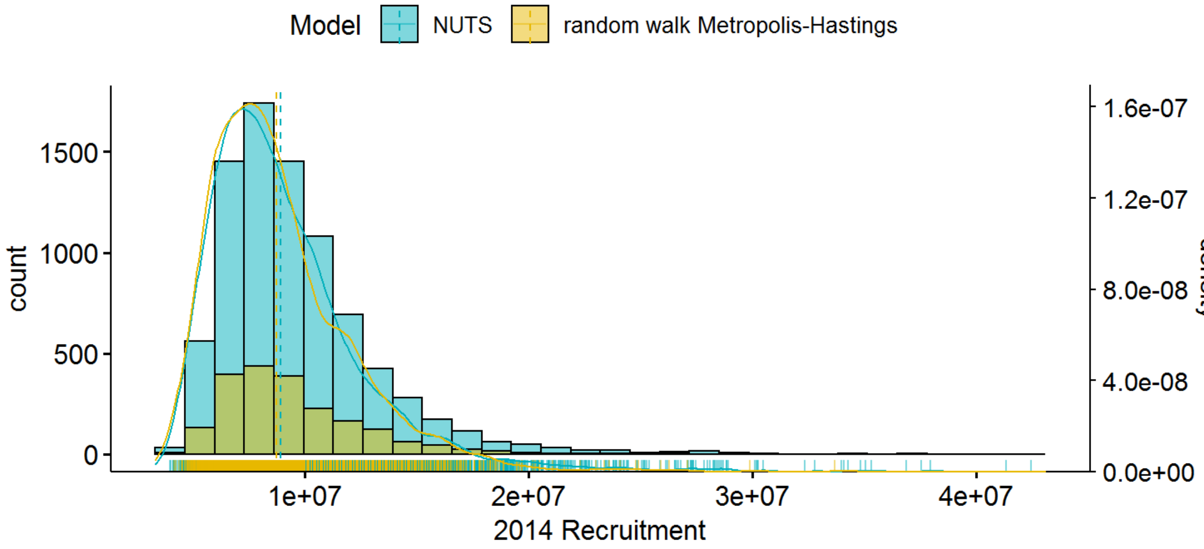


Figure B.1.8. Density of the 2014 recruitment parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

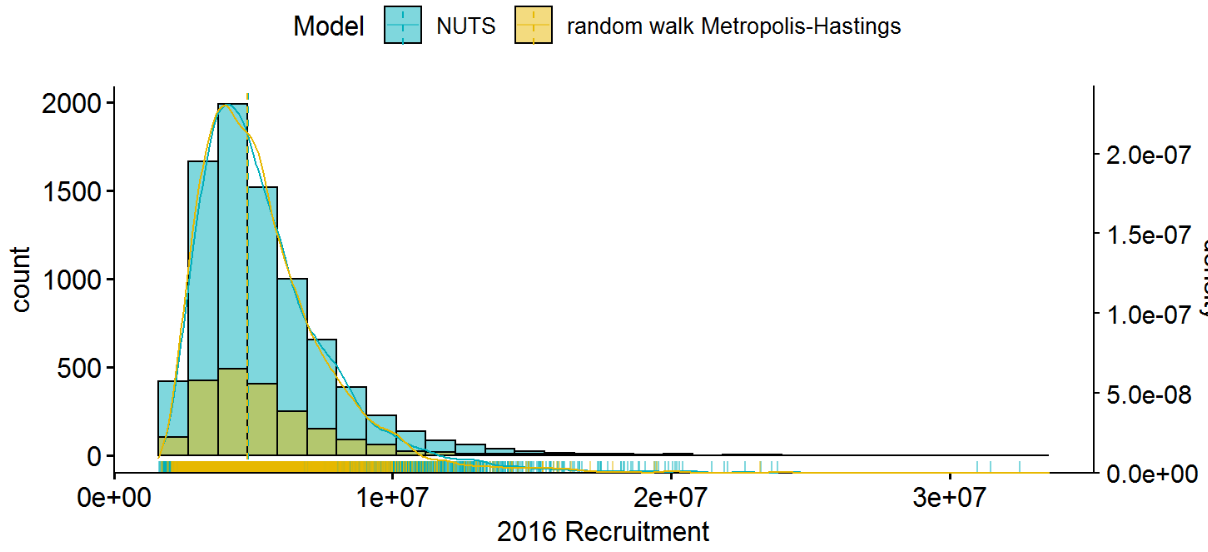


Figure B.1.9. Density of the 2016 recruitment parameter for the NUTS and rwMH models. See Figure B.1.1 for details.

The SRG informally requested that a figure shown in the Data presentation be included. This figure shows the weight-at-age through time for ages 2–10 and is included here as Figure B.1.10.

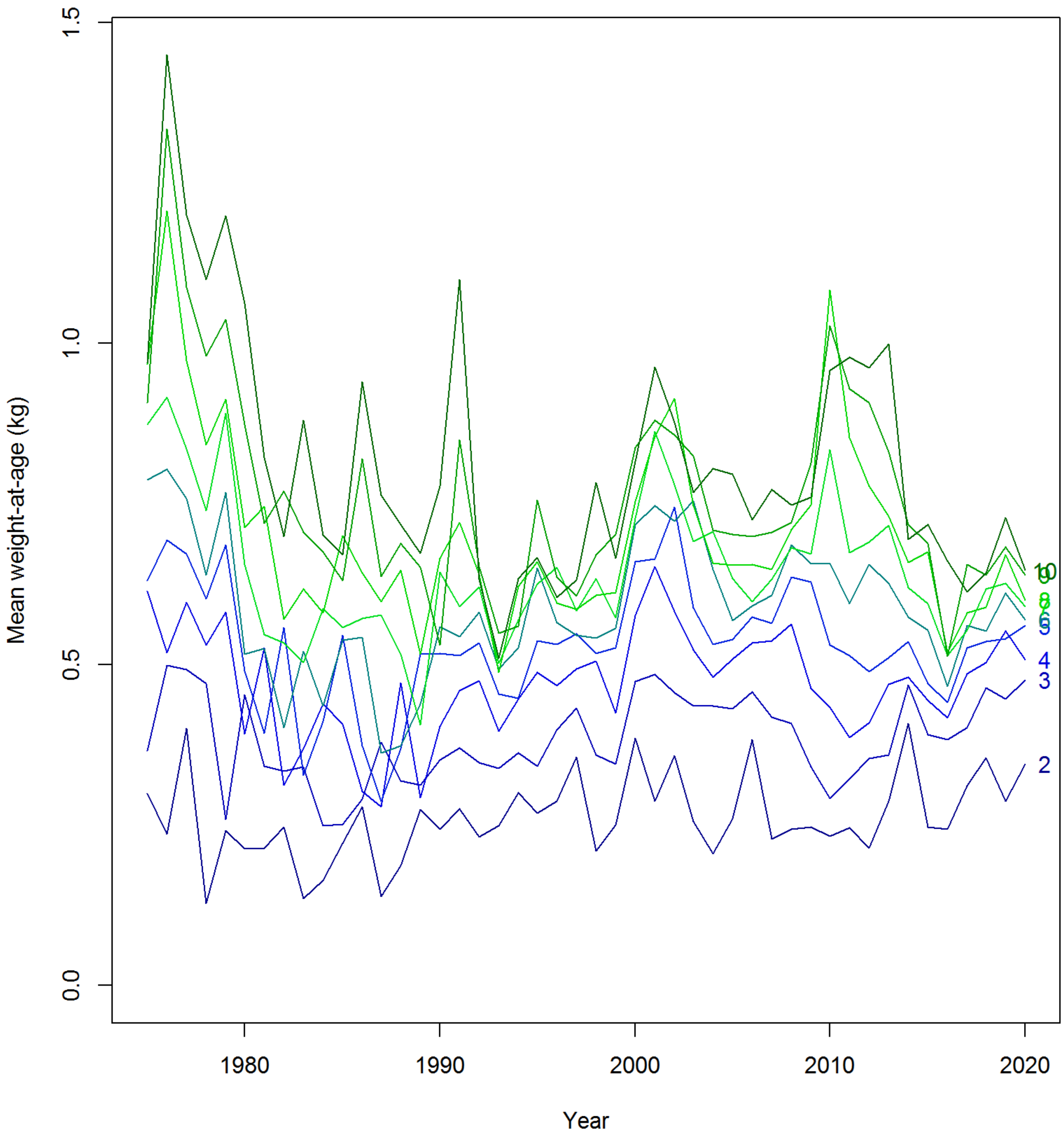


Figure B.1.10. Annual mean weight-at-age by age (colors for ages one through ten) through time. Blue lines are for the youngest ages and green lines are for the oldest ages shown.

B.2 DAY 2

Request 1:

The SRG requests that the JTC use a three year average of weight-at-age to produce projections of spawning biomass for constant catch levels of 0 and 380,000 t, and associated one-year probabilities with these catches as in Table i of the Executive Summary. The catch associated with the default harvest rate for 2021 would also be useful. These results will show the influence of the 5-year averaging of weight-at-age in the projections, especially given that 2016 is a year with low weight-at-age. It may support investigating alternative methods for predicting weight-at-age in the future. If the JTC has done this kind of analysis in the past, then the JTC can use it's discretion regarding completion of this request.

JTC Response:

The JTC followed the request of the SRG and calculated a three-year average weight-at-age to produce projections using the forecast parameters in Stock Synthesis. Forecast parameters are estimated simultaneously with other parameters, and thus, the base-model results needed to be re-estimated to produce these forecasts with the new weights-at-age. This run took approximately 4.5 hours for the NUTS portion and another 3 hours for the forecasting and model loading steps. Table B.1 shows the relative biomass decision table for this model, which is identical in format to the decision table (Table g) found in the Executive Summary and can be compared directly.

Compared to the base model, three-year average weights-at-age for the forecast period led to an increase in median relative spawning biomass for all constant catch streams (rows a–g in Table B.1). Credible intervals are also shifted upwards by several percent relative to the base model.

Table B.2 shows probabilities of several important biomass events compared across catch levels. When compared to the base model (Table i), the probability that

- B_{2022} is less than B_{2021} is within 1% of the base model;

- B_{2022} is less than $B_{40\%}$ is lower for all constant catch levels and within 4% of the base model; and

- B_{2022} is less than $B_{10\%}$ is 0% or 1% for all constant catch levels and within 1% of the base model.

Table B.1. Request 1 Model: 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, g), including catch similar to 2020 (row d), to the (unilaterally summed) TAC from 2020 (row f), and to the TAC from 2019 (row g); and non-constant catch levels that result in a median relative fishing intensity of 100% (row h), median catch estimated via the default harvest policy ($F_{\text{SPR}=40\%}$–40:10, row i), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2021 and 2022 (row j). Catch in 2023 does not impact the beginning of the year biomass in 2023.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2021	0	30%	46%	61%	82%	124%
	2022	0	30%	46%	61%	81%	129%
	2023	0	31%	47%	63%	89%	156%
b:	2021	180,000	30%	46%	61%	82%	124%
	2022	180,000	26%	41%	56%	76%	124%
	2023	180,000	22%	38%	54%	79%	146%
c:	2021	350,000	30%	46%	61%	82%	124%
	2022	350,000	22%	36%	51%	72%	119%
	2023	350,000	14%	30%	46%	70%	136%
d:	2021	380,000	30%	46%	61%	82%	124%
2020	2022	380,000	21%	35%	50%	71%	118%
catch	2023	380,000	12%	28%	44%	68%	134%
e:	2021	430,000	30%	46%	61%	82%	124%
	2022	430,000	20%	34%	49%	70%	117%
	2023	430,000	10%	26%	41%	66%	132%
f:	2021	529,290	30%	46%	61%	82%	124%
2020	2022	529,290	17%	32%	46%	67%	114%
TAC	2023	529,290	8%	21%	36%	61%	127%
g:	2021	597,500	30%	46%	61%	82%	124%
2019	2022	597,500	15%	30%	45%	65%	113%
TAC	2023	597,500	7%	18%	33%	57%	123%
h:	2021	538,838	30%	46%	61%	82%	124%
FI=	2022	426,456	17%	31%	46%	67%	114%
100%	2023	362,249	9%	23%	39%	63%	130%
i:	2021	586,990	30%	46%	61%	82%	124%
default	2022	441,844	16%	30%	45%	65%	113%
HR	2023	370,910	8%	22%	38%	62%	128%
j:	2021	472,633	30%	46%	61%	82%	124%
C2021=	2022	472,595	19%	33%	48%	68%	116%
C2022	2023	388,692	9%	24%	39%	64%	130%

Table B.2. Request 1 Model: Probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (explained in Table B.1).

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%	17%	2%	0%	0%	0%
b: 180,000	77%	24%	4%	0%	1%	4%
c: 350,000	84%	31%	8%	0%	19%	28%
d: 380,000	85%	32%	9%	0%	24%	33%
e: 430,000	86%	35%	11%	1%	32%	43%
f: 529,290	89%	39%	14%	1%	49%	58%
g: 597,500	90%	43%	17%	1%	58%	67%
h: 538,838	89%	39%	15%	1%	50%	60%
i: 586,990	90%	42%	17%	1%	56%	65%
j: 472,633	87%	36%	12%	1%	40%	50%

Request 2:

Run the 3 yr projection for relative spawning biomass to the start of 2024. These results will enable the SRG to evaluate the width of the CI really for a three year projection, we have the data if we decide to include a 3-yr projection in the table, and the Canadian delegation has the numbers (even if this does not make it into the assessment or SRG report). (With default weight etc.)

JTC Response:

The JTC ran the 3-year projections required to make the table and re-coded the decision table to display the results in a way similar to that shown in a mock-up table provided by the SRG. Due to there being one more forecast parameter compared to the base model, the entire NUTS run had to be re-run for this new model prior to running the 3-year forecasting. This run took approximately 4.5 hours for the NUTS portion and another 4 hours for the forecasting and model loading steps.

The 3-year projections (Table B.3) can be compared with the base model decision table (Table g) found in the Executive Summary.

Differences between Table B.3 and Table g are summarized below.

- 2021 biomass is shown in a single row at the top (*Start 2021*) in the new table. Whereas, 2021 biomass is the first row in every row chunk (a–j) in Table g.

- Values are shown as proportions instead of percentages allowing the removal of percentage signs after relative biomass values which can be distracting.

- Removal of the 25% and 75% columns.

- Addition of a new column, *Biomass year*, which explains the timing of the biomass estimates.

- Re-naming of the header for the relative biomass values from *Beginning of year relative spawning biomass* to *Resulting relative spawning biomass*.

- The values shown in the *Resulting relative spawning biomass* columns now represent the biomass at the beginning of the year which result due to the catch taken in the previous year. These catches are in the (*Catch year*) column.

- Extension of the projections of relative spawning biomass to the start of the *third* projection year (2024), rather than just the second year.

Table B.3. Request 2 Model: Forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e, f, g), including catch similar to 2020 (row d), to the (unilaterally summed) TAC from 2020 (row f), and to the TAC from 2019 (row g); and non-constant catch levels that result in a median relative fishing intensity of 100% (row h), median catch estimated via the default harvest policy ($F_{\text{SPR}=40\%}$–40:10, row i), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2021 and 2022 (row j).

			Model quantile	5%	50%	95%
Management Action			Biomass year	**Resulting relative spawning biomass**		
	Catch year	Catch (t)	Start 2021	0.27	0.58	1.20
a:	2021	0	Start 2022	0.28	0.58	1.23
	2022	0	Start 2023	0.29	0.61	1.46
	2023	0	Start 2024	0.33	0.69	1.67
b:	2021	180,000	Start 2022	0.24	0.53	1.17
	2022	180,000	Start 2023	0.20	0.51	1.36
	2023	180,000	Start 2024	0.18	0.54	1.52
c:	2021	350,000	Start 2022	0.19	0.48	1.12
	2022	350,000	Start 2023	0.11	0.43	1.26
	2023	350,000	Start 2024	0.06	0.40	1.38
d:	2021	380,000	Start 2022	0.19	0.47	1.12
2020	2022	380,000	Start 2023	0.09	0.41	1.25
catch	2023	380,000	Start 2024	0.05	0.37	1.36
e:	2021	430,000	Start 2022	0.17	0.46	1.10
	2022	430,000	Start 2023	0.08	0.39	1.22
	2023	430,000	Start 2024	0.05	0.33	1.32
f:	2021	529,290	Start 2022	0.15	0.43	1.07
2020	2022	529,290	Start 2023	0.06	0.33	1.16
TAC	2023	529,290	Start 2024	0.04	0.26	1.26
g:	2021	597,500	Start 2022	0.13	0.41	1.05
2019	2022	597,500	Start 2023	0.06	0.30	1.13
TAC	2023	597,500	Start 2024	0.04	0.22	1.20
h:	2021	489,677	Start 2022	0.16	0.44	1.08
FI=	2022	392,061	Start 2023	0.07	0.38	1.22
100%	2023	339,252	Start 2024	0.04	0.36	1.34
i:	2021	554,678	Start 2022	0.14	0.43	1.06
default	2022	414,557	Start 2023	0.07	0.36	1.19
HR	2023	352,540	Start 2024	0.04	0.33	1.32
j:	2021	446,126	Start 2022	0.17	0.45	1.10
C2021=	2022	446,088	Start 2023	0.08	0.38	1.21
C2022	2023	366,916	Start 2024	0.04	0.34	1.33

B.3 FURTHER ANALYSES

During the JTC's briefing presentation to the Joint Management Committee on February 11, 2021, a comment was raised about the probabilities in the decision tables (such as Tables 29 and 30) changing from assessment to assessment. The probabilities do indeed change between assessments because, for example, between the 2020 and 2021 assessment the 2021 assessment model depends on the catch in 2020, and has updated data (such as more proportions-at-age for earlier cohorts). This comment led us to investigate the general question of how much confidence can we have in the probabilities in the decision tables.

As an example, the 2019 assessment provides the estimated probability of the spawning stock biomass declining in the subsequent year, i.e., P($B_{2020} < B_{2019}$), for several possible catches in 2019 (such as 0 t, 180,000 t, 350,000 t, 410,000 t etc.). Now, in 2021, we *know* that the catch in 2019 was 411,574 t. Therefore, we can select the 410,000 t row (which is close enough to 411,574 t) in the table from the 2019 assessment to give that assessment's $\mathrm{P}(B_{2020} < B_{2019}) = 61\%$, given the catch that we now know occurred in 2019.

We can also calculate P($B_{2020} < B_{2019}$) using the current assessment model, i.e., calculate our most up-to-date estimate of the probability that the stock declined from 2019 to 2020 using all available data. This implicitly includes the 411,574 t catch from 2019. From the current assessment model we get $\mathrm{P}(B_{2020} < B_{2019}) = 98\%$. The 65% and 98% probabilities are shown for 2019 in Figure B.3.1.

We extracted similar probabilities from past assessment documents going back to 2012 (Figure B.3.1). For each assessment year t, we take the value of $\mathrm{P}(B_{t+1} < B_t)$ from year t's stock assessment document, specifically the row in the decision table corresponding to the catch that we now know to have occurred in year t. This can require interpolation between catch levels if the exact catch in year t was not given in the decision tables in year t's assessment. We also calculate analogous probabilities, $\mathrm{P}(B_{t+1} < B_t)$, from the current base model (Figure B.3.1).

The probability of 43% from the 2012 assessment is somewhat above the 0% calculated using the current assessment model (Figure B.3.1). But, this makes sense because the 2012 assessment model had no information that the 2010 recruitment was going to be very large, whereas the current base model does have such information from many years of age data. Hence, the current model confidently 'expects' a large increase in spawning biomass from 2012 to 2013 as the individuals in the 2010 cohort grew in size. The 2013 assessment model had some information on the 2010 cohort, so the lower estimated probability that the stock would decline from 2013 to 2014 better concurs with the current base model than results from the 2012 assessment (Figure B.3.1).

For later years, the probabilities vary, but for each year the probabilities either both lie above the 50% line or both lie below it (Figure B.3.1). So, each assessment correctly predicts whether the stock will increase or decrease the following year. Also, for all years (except 2018) the assessment year's probabilities are closer to 50% than those from the current base model. Such behavior is desirable and sensible. These probabilities are for binary events that either happen or do not happen (the stock either declines or it does not decline, similar to a tossed coin only being a head or a tail). The current assessment model has more information and thus provides a more definitive

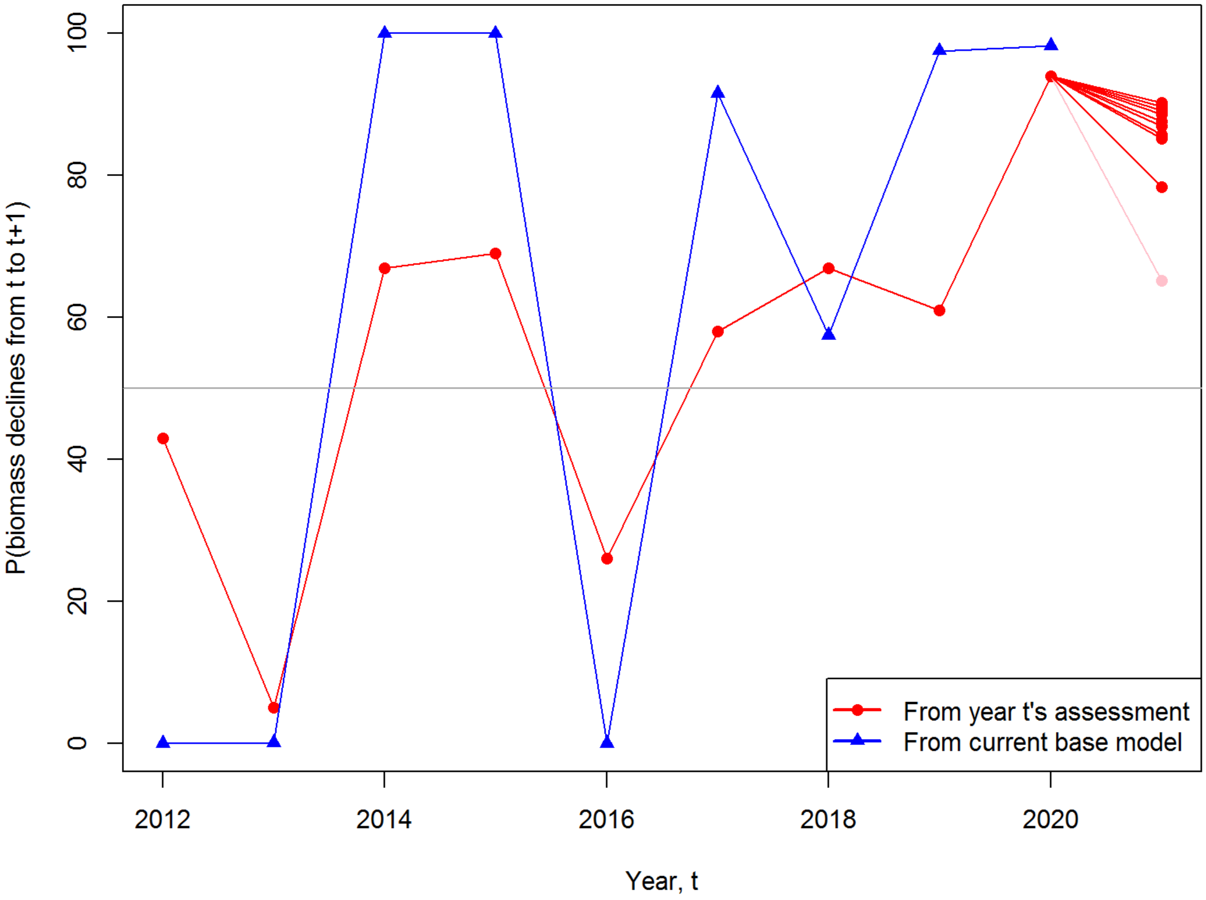


Figure B.3.1. For each year t, the probability that the spawning biomass at the start of $t+1$ is below that at the start of t is calculated in two ways. Red: the probability is taken from year t's stock assessment document, from the row in the decision table corresponding to the consequent catch in year t (with interpolation if necessary). Blue: the probability is calculated using the current 2021 base model. The grey horizontal line is the 50% value. For each year, both probabilities lie on the same side of the grey line, indicating that each year's assessment model 'correctly' estimates an increase or decrease the subsequent year's biomass. For the 2021 assessment the probabilities are shown for all catch alternatives for 2021, as described in Table 27, with 0 t shown in pink.

probability (closer to 0% or to 100%) than year t's assessment document. It is desirable that the probabilities from the assessment documents are not too definitive (too close to 0% or to 100%) because they are admitting a wide range of uncertainty given unknown recruitments.

Only for 2018 is the probability from the current assessment model closer to 50% than that from that year's assessment. This may be because there is no definitive trend in biomass around that time (Figure 24) and it may or may not get resolved in the future with additional data.

From this current 2021 assessment's projections, we show the probabilities for all catch alternatives in Figure B.3.1 because we do not yet know which will correspond to the 2021 catch. Catching zero fish in 2021 (colored in pink) obviously gives the lowest probability that the stock will decline from 2021 to 2022.

We also provide similar calculations for the probability of the biomass falling below $B_{40\%}$ in the subsequent year (Figure B.3.2), i.e., $\mathrm{P}(B_{t+1} < B_{40\%})$. The 2012 assessment gave a $>$ 50% chance of the biomass falling below $B_{40\%}$ in the subsequent year. This was the highest such probability from all assessments and also the poorest performing because the biomass did not fall below $B_{40\%}$, thanks again to the very large 2010 year class. The 2013-2017 assessments had information on the 2010 year class and estimated low probabilities of falling below $B_{40\%}$. Again, these estimates are closer to 50% than those from the current base model (blue dots), which is desirable behavior as mentioned above – the assessments gave low probabilities of an unlikely event occurring that we now believe to have been even more unlikely to have occurred. Since the 2018 assessment, the estimated probability of the biomass falling below $B_{40\%}$ are $>$ 10% and continue to rise (Figure B.3.2).

Probabilities from past assessments lie below those estimated from the current model (the blue line is below the red line). But, this won't necessarily always be the case. In particular, the probabilities calculated from projections in this year's assessment, $\mathrm{P}(B_{2022} < B_{40\%})$, are mostly in the 30%-50% range, which has not previously occurred. Also, the biomass has been relatively high in the time period shown, so 'correctly expecting' the biomass to remain $> B_{40\%}$ may not be a particular high bar to attain. Thus, we cannot simply conclude that the current assessment's probabilities will also turn out to be over-estimates of the probability of being $< B_{40\%}$ once we have more data (i.e., the blue line may cross the red line in the future).

Overall, these results suggest good confidence in the projected probabilities from the assessment model. Past projections of increases or decreases in the stock the following year have been 'correct' (the most probable direction has been correct). And, except for the 2012 assessment incorrectly expecting the biomass to fall below $B_{40\%}$ (which did not happen thanks the large 2010 year class), projections 'correctly' estimated the biomass to not go below $B_{40\%}$.

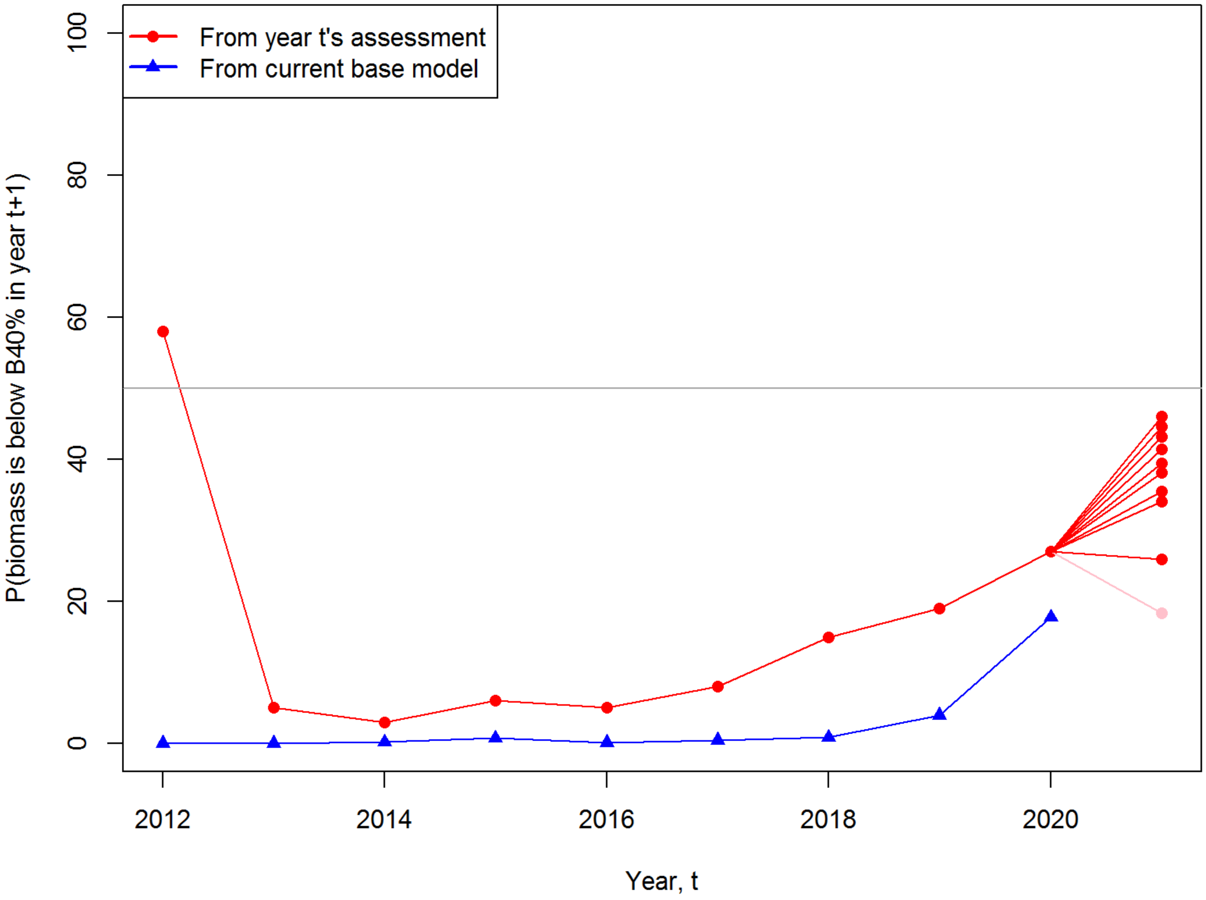


Figure B.3.2. For each year t, the probability that the spawning biomass at the start of $t+1$ is below $B_{40\%}$ is calculated in two ways (as for Figure B.3.1). Red: the probability is taken from year t's stock assessment document, from the row in the decision table corresponding to the consequent catch in year t (with interpolation if necessary). Blue: the probability is calculated using the current 2021 base model. The grey horizontal line is the 50% value. For each year except 2012, both probabilities lie on the same side of the grey line, indicating that each year's assessment model 'correctly' estimates that the subsequent year's biomass will not fall below $B_{40\%}$. For the 2021 assessment the probabilities are shown for all catch alternatives for 2021, as described in Table 27, with 0 t shown in pink.

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., $B_{10\%} = 0.1 B_0$. 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., $B_{40\%} = 0.4 B_0$. This is the level below which the calculated TAC is decreased from the value associated with $F_{\text{SPR}=40\%}$, 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.

NUTS: No-U-Turn Sampler is an advanced Hamiltonian Bayesian MCMC sampling algorithm used to efficiently create posterior distributions and used in Pacific Hake Bayesian stock assessments beginning in 2021.

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.

rwMH: Random walk Metropolis Hastings Bayesian MCMC sampling algorithm used to create posterior distributions used in Pacific Hake Bayesian stock assessment models prior to 2021.

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 8,250 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

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

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 ($\text{SPR}_{40\%}$): The spawning potential ratio of 40%, where the 40% relates to the default harvest rate of $F_{\text{SPR}=40\%}$ specified in the Agreement. Even under equilibrium conditions, $F_{\text{SPR}=40\%}$ would not necessarily result in a spawning biomass of $B_{40\%}$ because $F_{\text{SPR}=40\%}$ 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'.

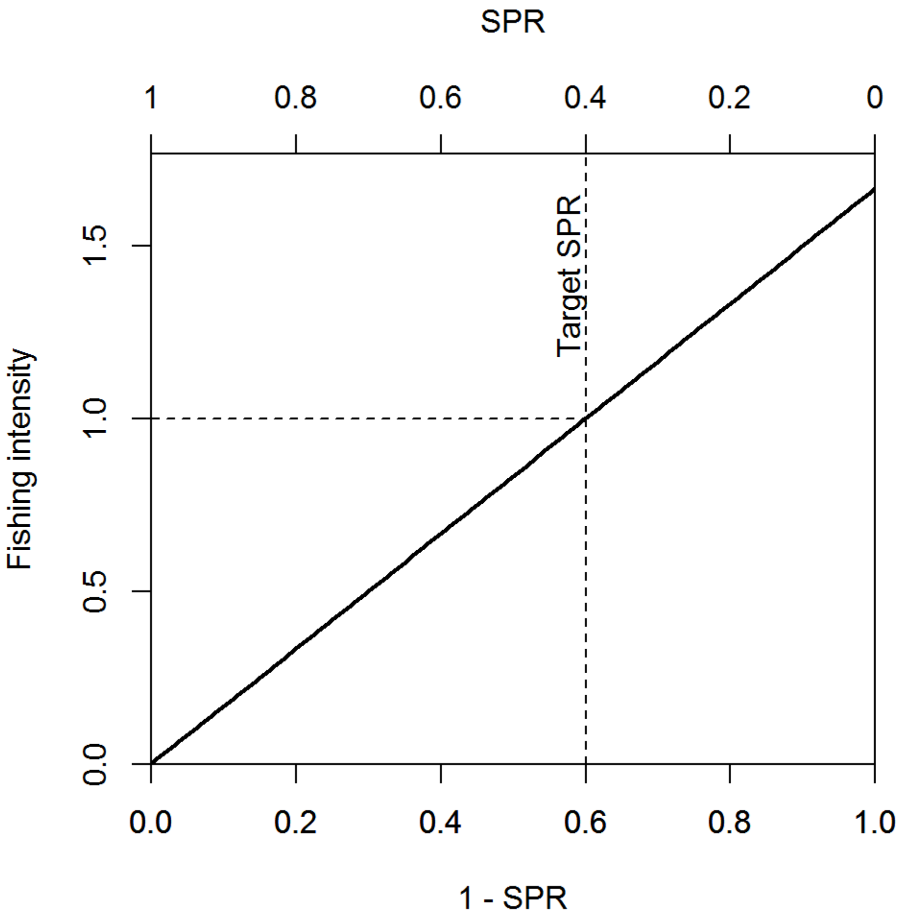


Figure C.1. Fishing intensity as a function of SPR (top axis) and 1-SPR (bottom axis); given the target SPR of 40%, the bold line is simply $1/0.6$, as shown in equation (C.5).

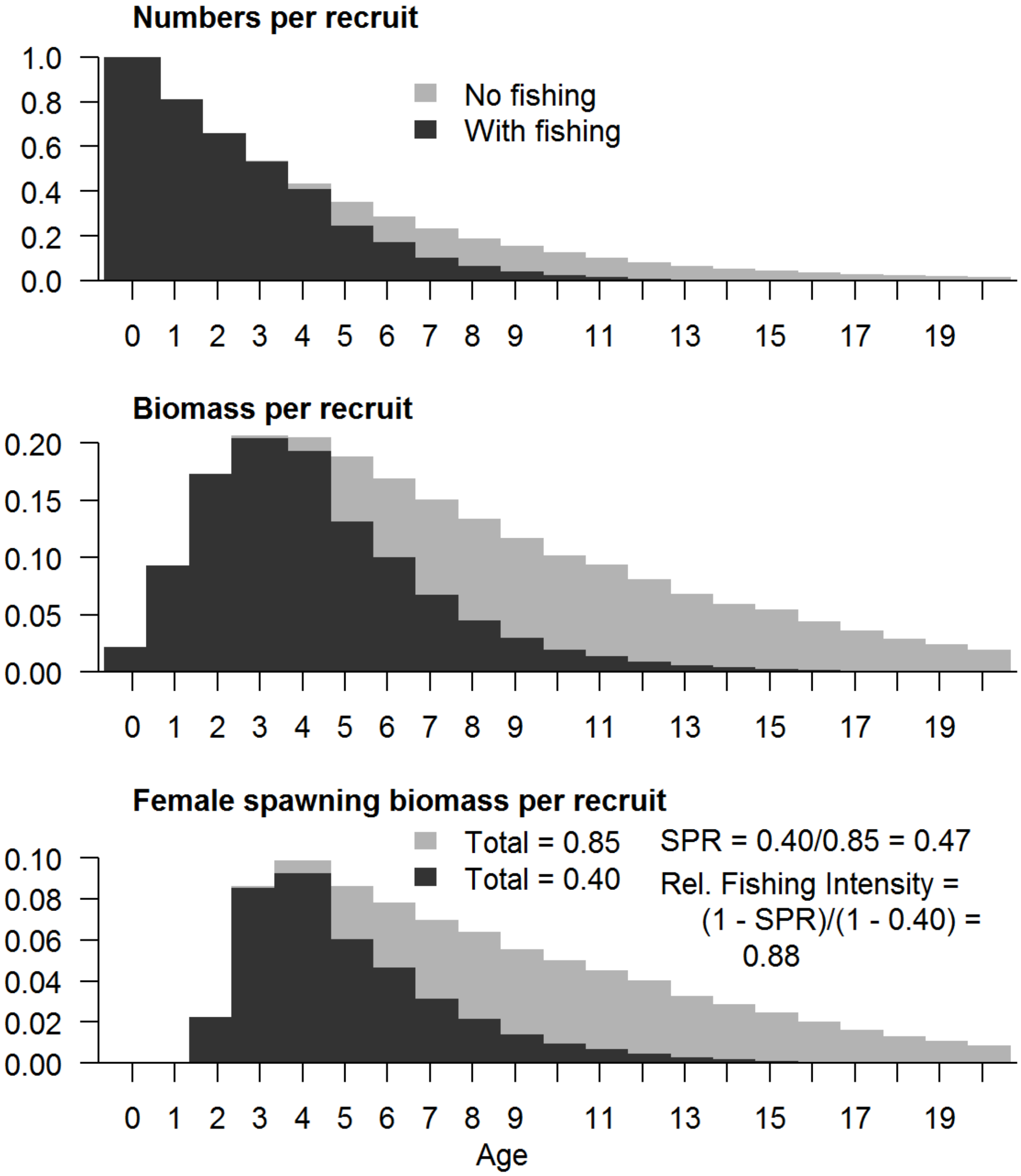


Figure C.2. Illustration of the spawning potential ratio (SPR) calculation based on the combination of maturity and fecundity used in the model, using the maximum likelihood estimates of natural mortality, selectivity, and fishing mortality in the final year of the base model.

D REPORT OF THE 2020 PACIFIC HAKE FISHERY IN CANADA

Prepared by the Canadian Advisory Panel and submitted for inclusion in this assessment document on February 3, 2021.

While there was some exploratory hake fishing in early March, significant effort and catch didn't start until early April and continued through to early December. A total of 94,262.62 tonnes of hake was caught in 2020 which equates to 90.22% of the Adjusted TAC of 104,480 tonnes.

Hake fishing occurred from the southern Canada/US border all the way up to lower Queen Charlotte Sound both on the shelf and off the edge at depths between 50-130 fathoms, in addition to fishing in the scuzz in deeper water at approximately 150 fathoms.

The general view from the Canadian fleet is that, especially in the shallower depths on the shelf or just off the edge that the hake abundance was lower in 2020, with much more time spent searching for fish, and when found it was patchy and didn't sustain effort as long as in 2019. This had a greater impact on the majority of the vessels delivering fresh fish for shoreside processing.

The Canadian commercial fishery saw predominantly medium to large fish (600 - 800 grams round weight), with almost no small fish in the catch.

Juvenile sablefish bycatch was down from 2019, as was bocaccio bycatch, but bocaccio was still being intercepted in all areas. Pollock bycatch was higher in the south on the shelf while rougheye bycatch was high in the deeper water scuzz fishing.

Provided below in bullet form are comments from various fishing vessel owners and skippers in response to questions they were asked.

How was the 2020 Canadian hake fishery relative to the 2019 fishery?

1. Good fishing in the shallows (50-80 fathoms) off Tofino, but generally not as good as 2019.
2. Abundance seemed to be down, tow times up, and less schooled fish.
3. More time spent looking for fish than 2019.
4. Hake abundance in an area at a given time did not last as long as in 2019 and there was more searching this year.
5. Hake abundance seemed to be down about 10% from 2019.
6. There seemed to be more fish out in the scuzz this year than last year but fishing was more difficult because of mandatory rockfish retention.
7. Biomass looks smaller this year than in 2019.
8. It was harder to find fish this year and when you found them the schools didn't hold up for long before you had to search again.

9. For fresh boats fishing shallower and on the shelf the abundance was patchier than 2019 and the patches wouldn't generally hold up for a second day of fishing.
10. For fresh boats the lack of hake resulted in more searching this year which resulted in higher bycatches of bocaccio, sablefish and pollock.

Where has most of the fishing occurred (location and depth)?

1. Lots of the fishing was on Tofino Flats and in the Solander area at depths on and off the edge between 80-130 fathoms.
2. Fish started out the year on the edge, mostly up off Winter Harbour.
3. In the summer there was good fishing on the shrimp grounds off Tofino and Nootka at depths from 60-80 fathoms.
4. In the fall the fish were just inside Barkley Canyon in the 70-80 fathom range or along the finger bank (where there was higher pollock bycatch).
5. Caught lots of fish on the edge at 110 fathoms.
6. Freezer trawlers were catch hake in the scuzz at a depth normally around 150 fathoms.
7. Fresh boats fished all the way from Nit Nat Canyon (at the Washington border) to the Goose Bank in Queen Charlotte Sound.
8. From end of July until mid August some larger fresh boats fished the Goose Bank (too far for smaller boats out of Ucluelet to travel).
9. From end of July to mid August fresh boats out of Ucluelet were fishing hake on the shrimp grounds in 50-75 fathoms west of the Big Bank.
10. August was a fairly scratchy month for fresh boats with a lot of running looking for spots to set on and September was even spottier, with patches from Esperanza to Pisces Canyon, but rarely enough for most fresh boats to set on.
11. Freezer trawlers were finding hake in September from Nootka to Pisces.

What sizes of fish were you seeing (round weight or product weight in grams)?

1. Mostly seeing fish 500 gms (product weight) or larger.
2. Didn't see or catch many small fish.
3. The fish out on the edge seemed to be mostly mediums, very few small fish, and few large.
4. The fish caught on the shrimp grounds had quite a few large fish but mostly mediums (mostly one year class).

5. Freezer trawlers saw very little small fish.
6. Freezer trawler average weight was 400 gms (product weight) plus.
7. Seemed to be generally all the same year class.

What has the bycatch been like (juvenile sablefish, bocaccio, pollock, rougheye, greenies, etc)?

1. Bocaccio seem to be everywhere (even in a bottom depth of 600 fathoms off the edge).
2. Primary bycatch species would be greenies and pollock when fishing the inside grounds.
3. We caught a few Bocaccio everywhere we went.
4. There were small pockets of juvenile sablefish, but we moved when encountered.
5. Pollock bycatch was mostly south near the border.
6. Rougheye bycatch was low if you stayed out of the deep scuzz.
7. High bycatch of pollock at the finger bank and sawyer bank.

How has the market affected your fishing effort and operations?

1. Had to work much harder for half the money.
2. Nobody wanted rockfish which was a good part of the money from 2019.
3. Price was down 30%.

E REPORT OF THE 2020 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, 2021.

The Mothership (MS), Catcher Processor (CP), and Shoreside (SS) sectors of the U.S. fishery started on May 15. The Tribal sector did not begin until early September and had only minimal effort thereafter. Consistent with normal fishing patterns, the SS sector continued to harvest and process its allocation throughout the summer while the MS and CP sectors completed their spring fishery during the first week of July and then paused hake fishing and processing until after the completion of the Bering Sea pollock fishery. Effort in the three non-tribal sectors (as well as the Tribal sector) was significantly reduced by direct and indirect impacts of COVID-19. The initial start-up of the spring fishery was slow due to vessels and processing facilities COVID-19 related testing and quarantine protocols in addition to shipyard schedules. Effort in the spring fishery was also reduced due to plant closures (COVID-19 and a water shortage), a two week breakdown of one of the MS vessels and vessel tie ups resulting from COVID-19 outbreaks in the SS and CP sectors. There was one less MS than normal operating in the 2020 spring fishery.

Fall fishery effort in the CP and MS sectors began later than normal due to a longer than normal Bering Sea Pollock fishery that resulted from a high pollock TAC, slow fishing, and COVID-19 related factors. In addition to the later and slower start than normal, the fall at-sea fishery also had less effort than normal due to vessel shipyard schedules and COVID-19 fatigue. Participation was reduced in the fall, only two MS vessels participated (three fewer than normal), and overall there were many fewer days at sea than in recent years past. CP participation was also affected, but the number of vessels was generally consistent with recent years. Participating vessels reported excellent fishing and the best fall fishing seen in recent years.

In spite of the foregoing setbacks impacting fishing and processing effort throughout the year, fishery performance overall was very good in terms of CPUE, fish size, wide spread availability on the grounds and in proximity to the plants, and lower than normal bycatch rates. During the spring fishery, participants reported stronger schools of fish than in recent years with fishing effort spread out along the coast from north to south and in both deep and shallow bottom depths. The at-sea sectors caught fish, on average, of about 500 grams with weights generally ranging from 450-600 grams. Some bigger fish were mixed in the catch and schools of smaller fish were encountered, but were easier to stay away from and not as prevalent as in recent years past. Fish size remained consistent throughout the year with the SS plants noting little change in quality, size and consistency though the spring, summer and fall. Throughout the entire year, fish quality was excellent with "healthy and fat" fish being reported by at-sea and shoreside processors alike.

Despite the better than normal whiting fishing, bycatch avoidance continued to dominate U.S. fishery patterns with avoidance of Chinook salmon and rockfish being the primary driver of fishing location. At-sea rockfish and sablefish bycatch was lower overall than recent years, however, their encounters continued to range coast-wide. There was one lightning strike tow of darkblotched rockfish in the CP sector during the spring fishery; otherwise, rockfish and salmon bycatch rates were maintained within a tolerable range. Aside from initial bycatch of yellowtail rockfish and widow rockfish off Washington, the at-sea sectors generally had very low bycatch and consistent fishing throughout daylight fishing hours. This is notably different from prior years in which good CPUE was found in the mornings only. Shortbelly rockfish (an emergent, healthy, and abundant species typically found in California waters well south of the whiting fishing grounds) continued to be a problem that necessitated avoidance by the fleet.

Overall, the U.S. harvest in 2020 was down from that of 2019 in spite of the excellent fishing conditions throughout the spring and summer and the better than normal fall fishing conditions. While the SS fishery achieved a higher catch than in 2019, both at-sea sector's catch was lower than 2019 and recent years past, especially the MS sector. This reduced harvest was purely due to the above noted COVID-19 and other constraints. It was not related in any way to fishing conditions or abundance.

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	0.2296
SR_LN(R0)	14.6328
SR_BH_steep	0.8074
Q_extraSD_Acoustic_Survey(2)	0.3024
ln(DM_theta)_1	-0.5694
ln(DM_theta)_2	2.3242
Early_InitAge_20	-0.2424
Early_InitAge_19	-0.1146
Early_InitAge_18	-0.0936
Early_InitAge_17	-0.1274
Early_InitAge_16	-0.1797
Early_InitAge_15	-0.1651
Early_InitAge_14	-0.2207
Early_InitAge_13	-0.2894
Early_InitAge_12	-0.2782
Early_InitAge_11	-0.3569
Early_InitAge_10	-0.3913
Early_InitAge_9	-0.4696
Early_InitAge_8	-0.5137
Early_InitAge_7	-0.5625
Early_InitAge_6	-0.5391
Early_InitAge_5	-0.4507
Early_InitAge_4	-0.2518
Early_InitAge_3	0.0203
Early_InitAge_2	0.3927
Early_InitAge_1	0.6661
Early_RecrDev_1966	0.6259
Early_RecrDev_1967	1.7187
Early_RecrDev_1968	1.2951
Early_RecrDev_1969	-0.2480
Main_RecrDev_1970	2.3467
Main_RecrDev_1971	-0.0626
Main_RecrDev_1972	-0.5255
Main_RecrDev_1973	1.9023
Main_RecrDev_1974	-0.9535
Main_RecrDev_1975	0.7112
Main_RecrDev_1976	-1.5404
Main_RecrDev_1977	1.9996
Main_RecrDev_1978	-1.9377
Main_RecrDev_1979	0.4323
Main_RecrDev_1980	2.9729
Main_RecrDev_1981	-1.2578
Main_RecrDev_1982	-1.0970
Main_RecrDev_1983	-0.5440
Main_RecrDev_1984	2.7444
Main_RecrDev_1985	-1.9933
Main_RecrDev_1986	-1.6796
Main_RecrDev_1987	1.9939
Main_RecrDev_1988	0.8576
Main_RecrDev_1989	-2.0996

Continued on next page

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

Parameter	Posterior median
Main_RecrDev_1990	1.5934
Main_RecrDev_1991	0.3393
Main_RecrDev_1992	-1.9744
Main_RecrDev_1993	1.3328
Main_RecrDev_1994	1.3843
Main_RecrDev_1995	0.3932
Main_RecrDev_1996	0.8163
Main_RecrDev_1997	0.2494
Main_RecrDev_1998	0.8952
Main_RecrDev_1999	2.8195
Main_RecrDev_2000	-0.9394
Main_RecrDev_2001	0.4158
Main_RecrDev_2002	-3.3453
Main_RecrDev_2003	0.7182
Main_RecrDev_2004	-2.7253
Main_RecrDev_2005	1.2446
Main_RecrDev_2006	0.9424
Main_RecrDev_2007	-3.5081
Main_RecrDev_2008	1.9889
Main_RecrDev_2009	0.6710
Main_RecrDev_2010	3.0739
Main_RecrDev_2011	-0.5698
Main_RecrDev_2012	0.6549
Main_RecrDev_2013	-0.9263
Main_RecrDev_2014	2.3538
Main_RecrDev_2015	-3.0077
Main_RecrDev_2016	1.7680
Main_RecrDev_2017	0.9244
Main_RecrDev_2018	-1.5568
Late_RecrDev_2019	-0.2270
Late_RecrDev_2020	-0.0178
ForeRecr_2021	-0.0227
ForeRecr_2022	-0.0206
ForeRecr_2023	-0.0400
AgeSel_P3_Fishery(1)	2.8303
AgeSel_P4_Fishery(1)	0.9430
AgeSel_P5_Fishery(1)	0.4110
AgeSel_P6_Fishery(1)	0.1636
AgeSel_P7_Fishery(1)	0.5014
AgeSel_P4_Acoustic_Survey(2)	0.6582
AgeSel_P5_Acoustic_Survey(2)	-0.2594
AgeSel_P6_Acoustic_Survey(2)	0.2825
AgeSel_P7_Acoustic_Survey(2)	0.3601
AgeSel_P3_Fishery(1)_DEVadd_1991	0.5822
AgeSel_P3_Fishery(1)_DEVadd_1992	0.0389
AgeSel_P3_Fishery(1)_DEVadd_1993	0.0105
AgeSel_P3_Fishery(1)_DEVadd_1994	0.1180
AgeSel_P3_Fishery(1)_DEVadd_1995	-0.1541
AgeSel_P3_Fishery(1)_DEVadd_1996	0.4346
AgeSel_P3_Fishery(1)_DEVadd_1997	0.1153
AgeSel_P3_Fishery(1)_DEVadd_1998	0.1881

Continued on next page

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

Parameter	Posterior median
AgeSel_P3_Fishery(1)_DEVadd_1999	1.0155
AgeSel_P3_Fishery(1)_DEVadd_2000	0.5196
AgeSel_P3_Fishery(1)_DEVadd_2001	0.0474
AgeSel_P3_Fishery(1)_DEVadd_2002	0.1035
AgeSel_P3_Fishery(1)_DEVadd_2003	-0.0218
AgeSel_P3_Fishery(1)_DEVadd_2004	0.3318
AgeSel_P3_Fishery(1)_DEVadd_2005	0.0000
AgeSel_P3_Fishery(1)_DEVadd_2006	0.5979
AgeSel_P3_Fishery(1)_DEVadd_2007	0.5955
AgeSel_P3_Fishery(1)_DEVadd_2008	-0.0214
AgeSel_P3_Fishery(1)_DEVadd_2009	0.4708
AgeSel_P3_Fishery(1)_DEVadd_2010	0.9836
AgeSel_P3_Fishery(1)_DEVadd_2011	-0.1193
AgeSel_P3_Fishery(1)_DEVadd_2012	0.1372
AgeSel_P3_Fishery(1)_DEVadd_2013	0.2259
AgeSel_P3_Fishery(1)_DEVadd_2014	0.2927
AgeSel_P3_Fishery(1)_DEVadd_2015	-0.6854
AgeSel_P3_Fishery(1)_DEVadd_2016	-0.0280
AgeSel_P3_Fishery(1)_DEVadd_2017	-0.5366
AgeSel_P3_Fishery(1)_DEVadd_2018	-1.1752
AgeSel_P3_Fishery(1)_DEVadd_2019	0.5203
AgeSel_P3_Fishery(1)_DEVadd_2020	0.1239
AgeSel_P4_Fishery(1)_DEVadd_1991	0.3833
AgeSel_P4_Fishery(1)_DEVadd_1992	0.5979
AgeSel_P4_Fishery(1)_DEVadd_1993	0.7987
AgeSel_P4_Fishery(1)_DEVadd_1994	0.1566
AgeSel_P4_Fishery(1)_DEVadd_1995	0.2246
AgeSel_P4_Fishery(1)_DEVadd_1996	-0.3735
AgeSel_P4_Fishery(1)_DEVadd_1997	1.2678
AgeSel_P4_Fishery(1)_DEVadd_1998	0.9852
AgeSel_P4_Fishery(1)_DEVadd_1999	-0.1036
AgeSel_P4_Fishery(1)_DEVadd_2000	0.7673
AgeSel_P4_Fishery(1)_DEVadd_2001	0.9346
AgeSel_P4_Fishery(1)_DEVadd_2002	0.7340
AgeSel_P4_Fishery(1)_DEVadd_2003	0.6627
AgeSel_P4_Fishery(1)_DEVadd_2004	0.4439
AgeSel_P4_Fishery(1)_DEVadd_2005	0.6432
AgeSel_P4_Fishery(1)_DEVadd_2006	-0.0887
AgeSel_P4_Fishery(1)_DEVadd_2007	0.1965
AgeSel_P4_Fishery(1)_DEVadd_2008	0.3271
AgeSel_P4_Fishery(1)_DEVadd_2009	0.7418
AgeSel_P4_Fishery(1)_DEVadd_2010	0.1125
AgeSel_P4_Fishery(1)_DEVadd_2011	1.0715
AgeSel_P4_Fishery(1)_DEVadd_2012	0.1558
AgeSel_P4_Fishery(1)_DEVadd_2013	0.8736
AgeSel_P4_Fishery(1)_DEVadd_2014	0.3924
AgeSel_P4_Fishery(1)_DEVadd_2015	0.1651
AgeSel_P4_Fishery(1)_DEVadd_2016	-0.8371
AgeSel_P4_Fishery(1)_DEVadd_2017	-0.5311
AgeSel_P4_Fishery(1)_DEVadd_2018	-0.6983
AgeSel_P4_Fishery(1)_DEVadd_2019	-0.5402

Continued on next page

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

Parameter	Posterior median
AgeSel_P4_Fishery(1)_DEVadd_2020	0.5967
AgeSel_P5_Fishery(1)_DEVadd_1991	-0.8473
AgeSel_P5_Fishery(1)_DEVadd_1992	0.0616
AgeSel_P5_Fishery(1)_DEVadd_1993	0.0152
AgeSel_P5_Fishery(1)_DEVadd_1994	0.8766
AgeSel_P5_Fishery(1)_DEVadd_1995	0.2595
AgeSel_P5_Fishery(1)_DEVadd_1996	-0.3150
AgeSel_P5_Fishery(1)_DEVadd_1997	-0.1352
AgeSel_P5_Fishery(1)_DEVadd_1998	-0.6449
AgeSel_P5_Fishery(1)_DEVadd_1999	0.1202
AgeSel_P5_Fishery(1)_DEVadd_2000	-0.1576
AgeSel_P5_Fishery(1)_DEVadd_2001	0.2660
AgeSel_P5_Fishery(1)_DEVadd_2002	0.5443
AgeSel_P5_Fishery(1)_DEVadd_2003	0.7317
AgeSel_P5_Fishery(1)_DEVadd_2004	0.6835
AgeSel_P5_Fishery(1)_DEVadd_2005	0.6963
AgeSel_P5_Fishery(1)_DEVadd_2006	0.0140
AgeSel_P5_Fishery(1)_DEVadd_2007	-0.0936
AgeSel_P5_Fishery(1)_DEVadd_2008	-0.3896
AgeSel_P5_Fishery(1)_DEVadd_2009	-0.2173
AgeSel_P5_Fishery(1)_DEVadd_2010	0.4974
AgeSel_P5_Fishery(1)_DEVadd_2011	-0.7019
AgeSel_P5_Fishery(1)_DEVadd_2012	0.2052
AgeSel_P5_Fishery(1)_DEVadd_2013	-0.2483
AgeSel_P5_Fishery(1)_DEVadd_2014	-0.4630
AgeSel_P5_Fishery(1)_DEVadd_2015	-0.0475
AgeSel_P5_Fishery(1)_DEVadd_2016	-0.1126
AgeSel_P5_Fishery(1)_DEVadd_2017	-0.0259
AgeSel_P5_Fishery(1)_DEVadd_2018	-0.2726
AgeSel_P5_Fishery(1)_DEVadd_2019	-0.2338
AgeSel_P5_Fishery(1)_DEVadd_2020	0.9984
AgeSel_P6_Fishery(1)_DEVadd_1991	-0.0381
AgeSel_P6_Fishery(1)_DEVadd_1992	-0.4749
AgeSel_P6_Fishery(1)_DEVadd_1993	-0.0470
AgeSel_P6_Fishery(1)_DEVadd_1994	-0.1012
AgeSel_P6_Fishery(1)_DEVadd_1995	0.7607
AgeSel_P6_Fishery(1)_DEVadd_1996	-0.1363
AgeSel_P6_Fishery(1)_DEVadd_1997	-0.3043
AgeSel_P6_Fishery(1)_DEVadd_1998	0.3957
AgeSel_P6_Fishery(1)_DEVadd_1999	-0.3991
AgeSel_P6_Fishery(1)_DEVadd_2000	0.1871
AgeSel_P6_Fishery(1)_DEVadd_2001	-0.0933
AgeSel_P6_Fishery(1)_DEVadd_2002	0.1268
AgeSel_P6_Fishery(1)_DEVadd_2003	0.2805
AgeSel_P6_Fishery(1)_DEVadd_2004	-0.5775
AgeSel_P6_Fishery(1)_DEVadd_2005	0.3068
AgeSel_P6_Fishery(1)_DEVadd_2006	0.2000
AgeSel_P6_Fishery(1)_DEVadd_2007	-0.1968
AgeSel_P6_Fishery(1)_DEVadd_2008	0.3024
AgeSel_P6_Fishery(1)_DEVadd_2009	-0.2410
AgeSel_P6_Fishery(1)_DEVadd_2010	-0.4788

Continued on next page

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

Parameter	Posterior median
AgeSel_P6_Fishery(1)_DEVadd_2011	-0.1918
AgeSel_P6_Fishery(1)_DEVadd_2012	-0.4416
AgeSel_P6_Fishery(1)_DEVadd_2013	0.0069
AgeSel_P6_Fishery(1)_DEVadd_2014	-0.0024
AgeSel_P6_Fishery(1)_DEVadd_2015	-0.0058
AgeSel_P6_Fishery(1)_DEVadd_2016	-0.1397
AgeSel_P6_Fishery(1)_DEVadd_2017	-0.2074
AgeSel_P6_Fishery(1)_DEVadd_2018	-0.2229
AgeSel_P6_Fishery(1)_DEVadd_2019	0.1155
AgeSel_P6_Fishery(1)_DEVadd_2020	-0.5211
AgeSel_P7_Fishery(1)_DEVadd_1991	-0.1203
AgeSel_P7_Fishery(1)_DEVadd_1992	0.0801
AgeSel_P7_Fishery(1)_DEVadd_1993	-0.3564
AgeSel_P7_Fishery(1)_DEVadd_1994	0.1213
AgeSel_P7_Fishery(1)_DEVadd_1995	-0.1196
AgeSel_P7_Fishery(1)_DEVadd_1996	0.4172
AgeSel_P7_Fishery(1)_DEVadd_1997	0.1203
AgeSel_P7_Fishery(1)_DEVadd_1998	-0.5014
AgeSel_P7_Fishery(1)_DEVadd_1999	-0.2606
AgeSel_P7_Fishery(1)_DEVadd_2000	-0.0850
AgeSel_P7_Fishery(1)_DEVadd_2001	-0.2911
AgeSel_P7_Fishery(1)_DEVadd_2002	-0.3916
AgeSel_P7_Fishery(1)_DEVadd_2003	-0.2659
AgeSel_P7_Fishery(1)_DEVadd_2004	-0.1669
AgeSel_P7_Fishery(1)_DEVadd_2005	-0.4099
AgeSel_P7_Fishery(1)_DEVadd_2006	-0.3265
AgeSel_P7_Fishery(1)_DEVadd_2007	0.0438
AgeSel_P7_Fishery(1)_DEVadd_2008	-0.1721
AgeSel_P7_Fishery(1)_DEVadd_2009	0.1170
AgeSel_P7_Fishery(1)_DEVadd_2010	-0.5711
AgeSel_P7_Fishery(1)_DEVadd_2011	-0.5045
AgeSel_P7_Fishery(1)_DEVadd_2012	-0.3356
AgeSel_P7_Fishery(1)_DEVadd_2013	0.0913
AgeSel_P7_Fishery(1)_DEVadd_2014	-0.0142
AgeSel_P7_Fishery(1)_DEVadd_2015	-0.5146
AgeSel_P7_Fishery(1)_DEVadd_2016	-0.2407
AgeSel_P7_Fishery(1)_DEVadd_2017	-0.0758
AgeSel_P7_Fishery(1)_DEVadd_2018	0.2048
AgeSel_P7_Fishery(1)_DEVadd_2019	-0.1344
AgeSel_P7_Fishery(1)_DEVadd_2020	-0.0320

G SENSITIVITY RUN THAT INCLUDES THE AGE-1 SURVEY

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 (also see Table 31). 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 meant to provide supplemental information, and should not be viewed as an alternative base model. The figures and tables show results from this sensitivity run.

The estimated size of the 2010 and 2014 year classes when 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 54). In terms of general year class strength, the main difference between models is with the 2018 year class where the age-1 index estimates it to be near average in size whereas the base model estimates to be well below average (Figures G.1 and 54). Despite possible advantages in some instances, previous comparisons with the age-1 survey sensitivity have indicated that its use could lead to misleading results. For example, the perception of the 2008 year class was higher in 2011 (near 20%) and 2012 (near 100%) retrospectively when using the age-1 survey sensitivity instead of the base model. 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.

Figures G.3–G.11 and Tables G.1–G.7 show further quantities of interest and decision tables from the MCMC results when including the age-1 index.

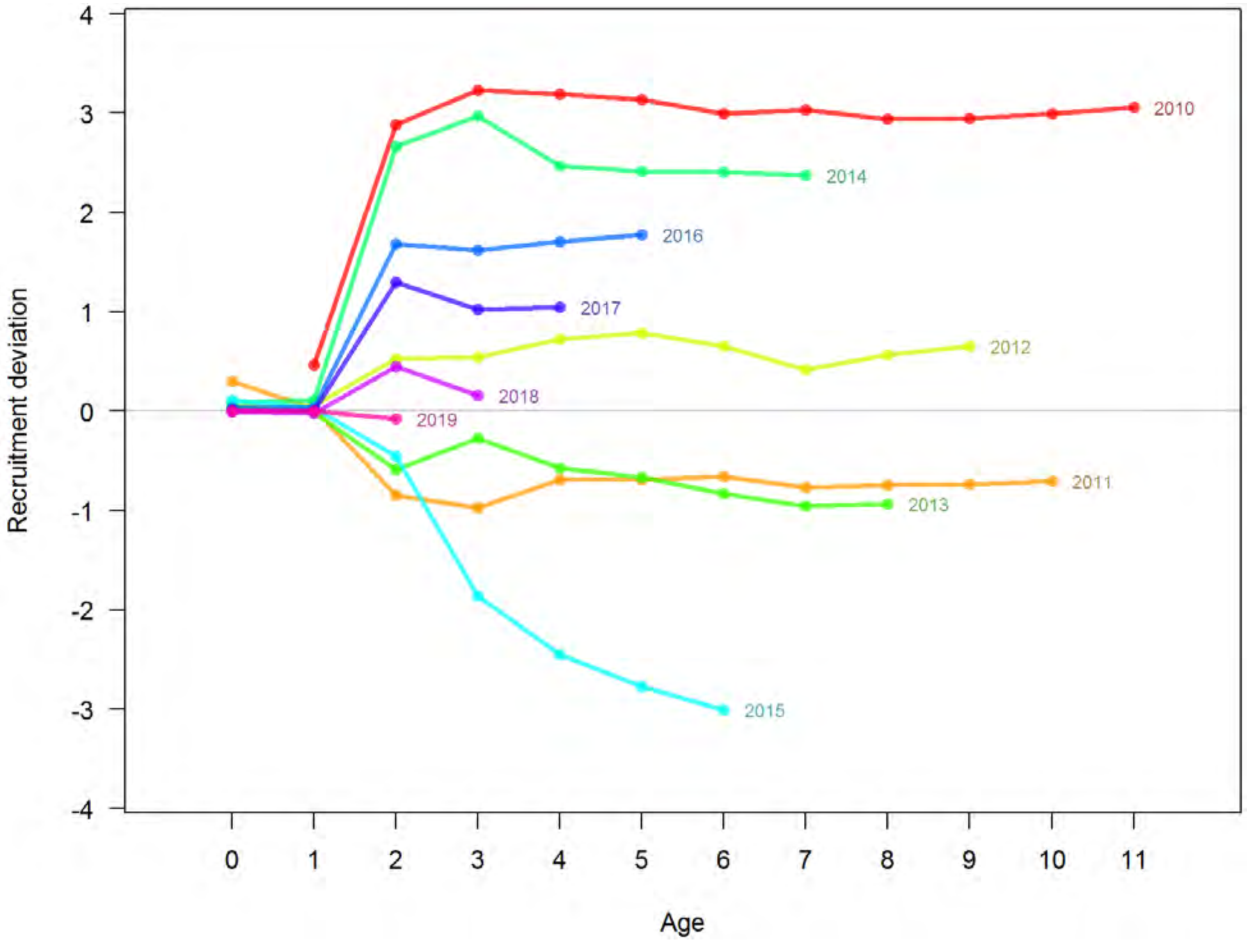


Figure G.1. Retrospective analysis of recruitment deviations from MCMC models over the last 6 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for cohorts from 2010 to 2019, 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.

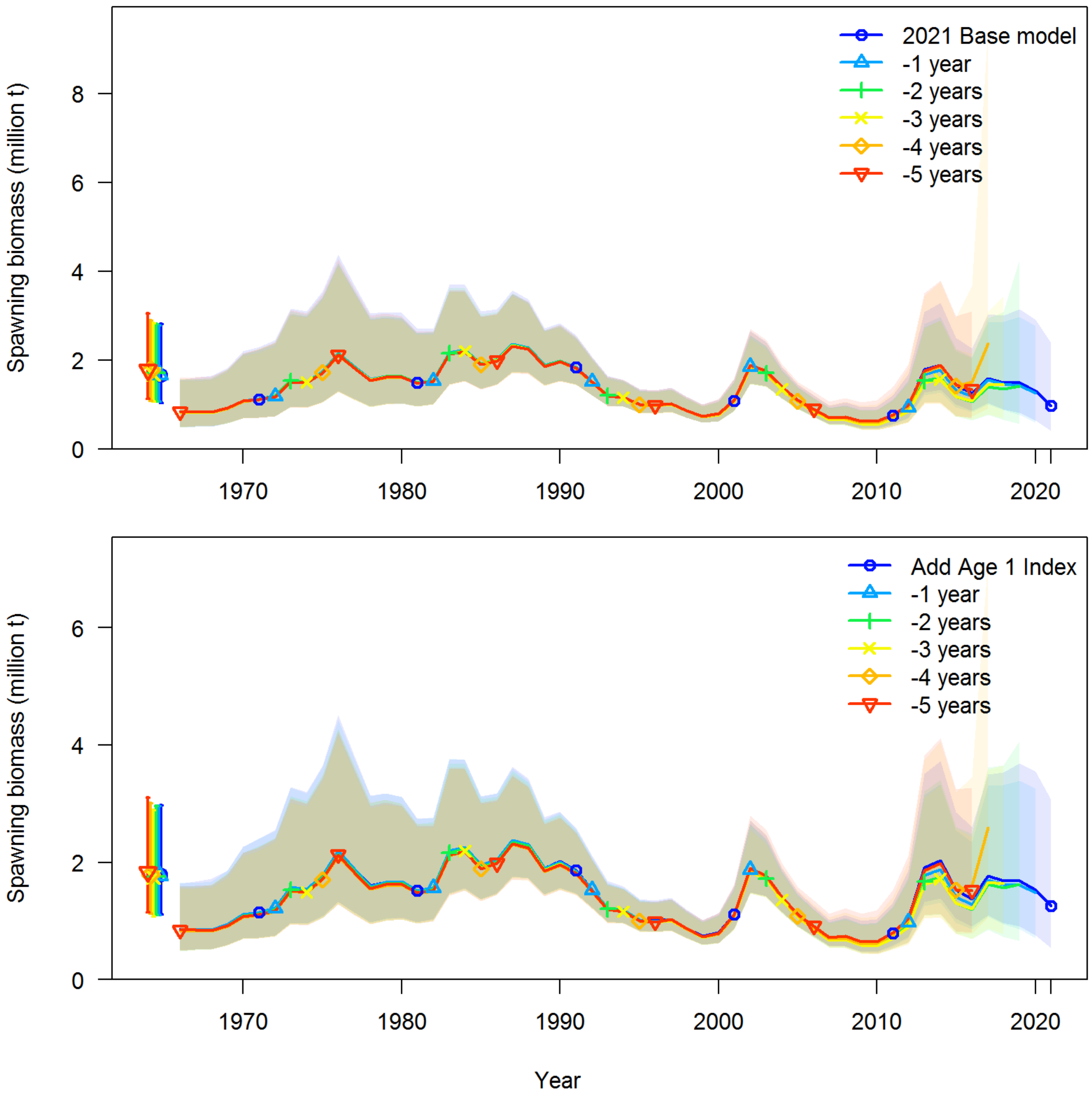


Figure G.2. Spawning biomass from retrospective MCMC model runs and associated uncertainties for the base model (top) and age-1 index sensitivity run (bottom).

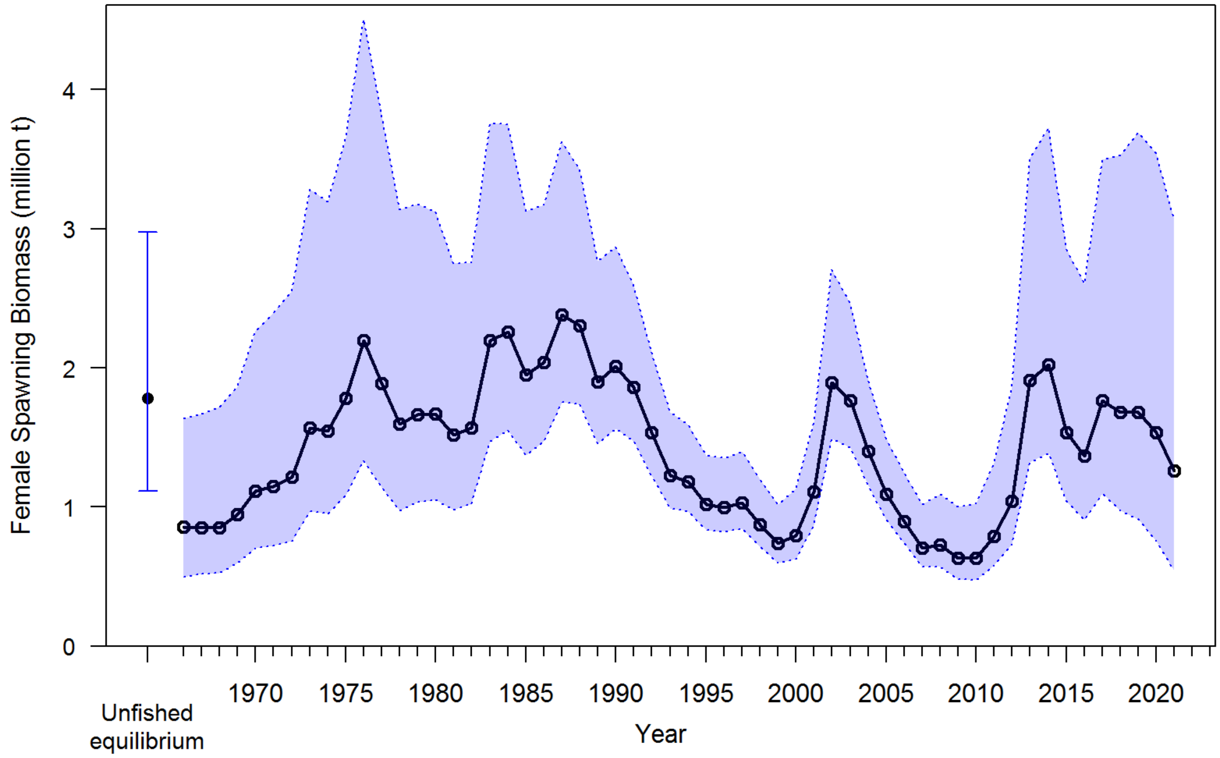


Figure G.3. Median of the posterior distribution for beginning of the year female spawning biomass through 2021 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

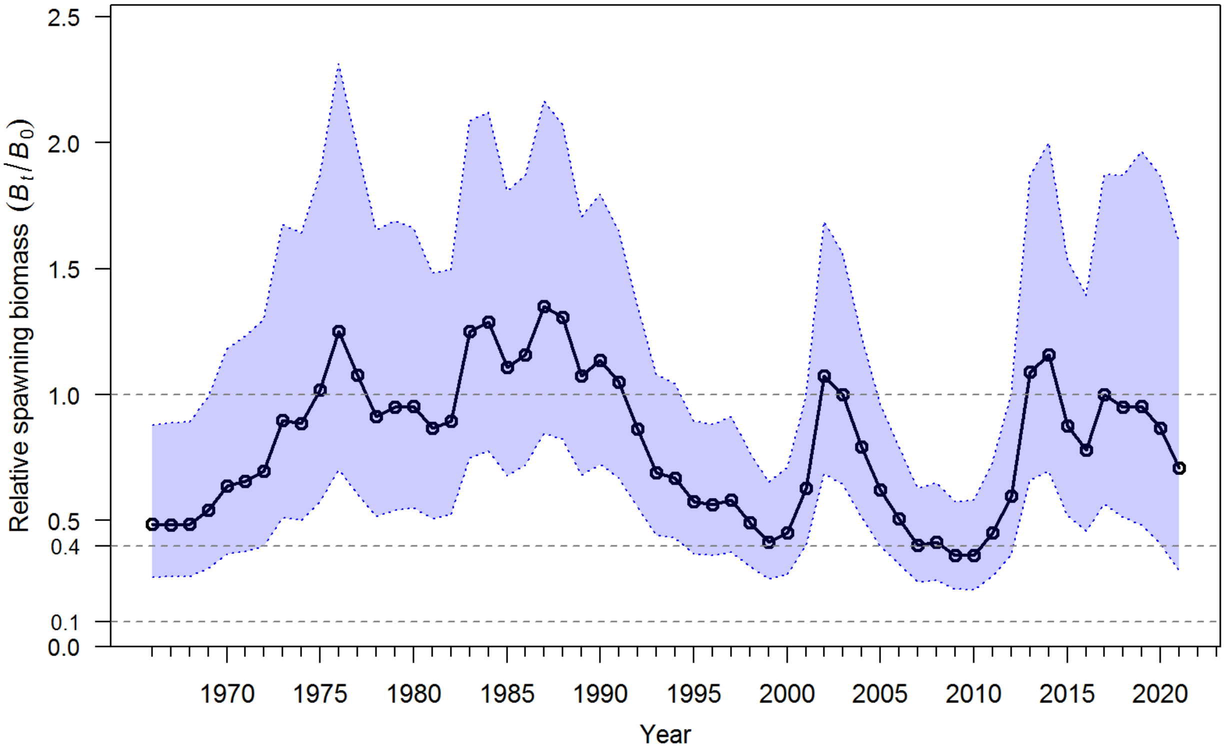


Figure G.4. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2021 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

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**
2012	733.4	1,042.2	1,862.2	36.6%	59.6%	100.3%
2013	1,323.5	1,910.6	3,507.7	66.3%	109.1%	187.0%
2014	1,390.6	2,024.3	3,723.3	69.7%	115.7%	200.1%
2015	1,040.6	1,533.9	2,851.4	52.1%	87.5%	153.6%
2016	907.7	1,368.9	2,607.0	45.8%	78.1%	139.5%
2017	1,099.6	1,762.9	3,498.0	56.8%	100.0%	187.4%
2018	973.6	1,680.2	3,530.2	51.3%	95.2%	187.0%
2019	910.2	1,681.6	3,691.7	48.3%	95.2%	196.8%
2020	754.7	1,532.2	3,540.8	40.9%	86.6%	186.9%
2021	542.4	1,257.9	3,066.5	30.3%	70.9%	160.3%

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**
2011	169.1	423.2	1,049.2	-1.584	-0.707	0.089
2012	966.2	1,688.9	3,671.1	0.106	0.656	1.235
2013	112.8	367.8	1,007.6	-2.084	-0.930	-0.030
2014	5,689.9	9,938.4	21,776.8	1.800	2.373	2.992
2015	9.7	46.0	217.2	-4.497	-3.008	-1.520
2016	2,677.6	5,393.8	13,095.1	1.089	1.781	2.521
2017	937.7	2,637.4	7,674.1	0.080	1.044	1.988
2018	192.7	1,092.6	4,665.4	-1.492	0.161	1.562
2019	41.9	868.4	15,410.0	-3.036	-0.078	2.682
2020	41.5	951.4	20,817.4	-3.082	0.045	3.019

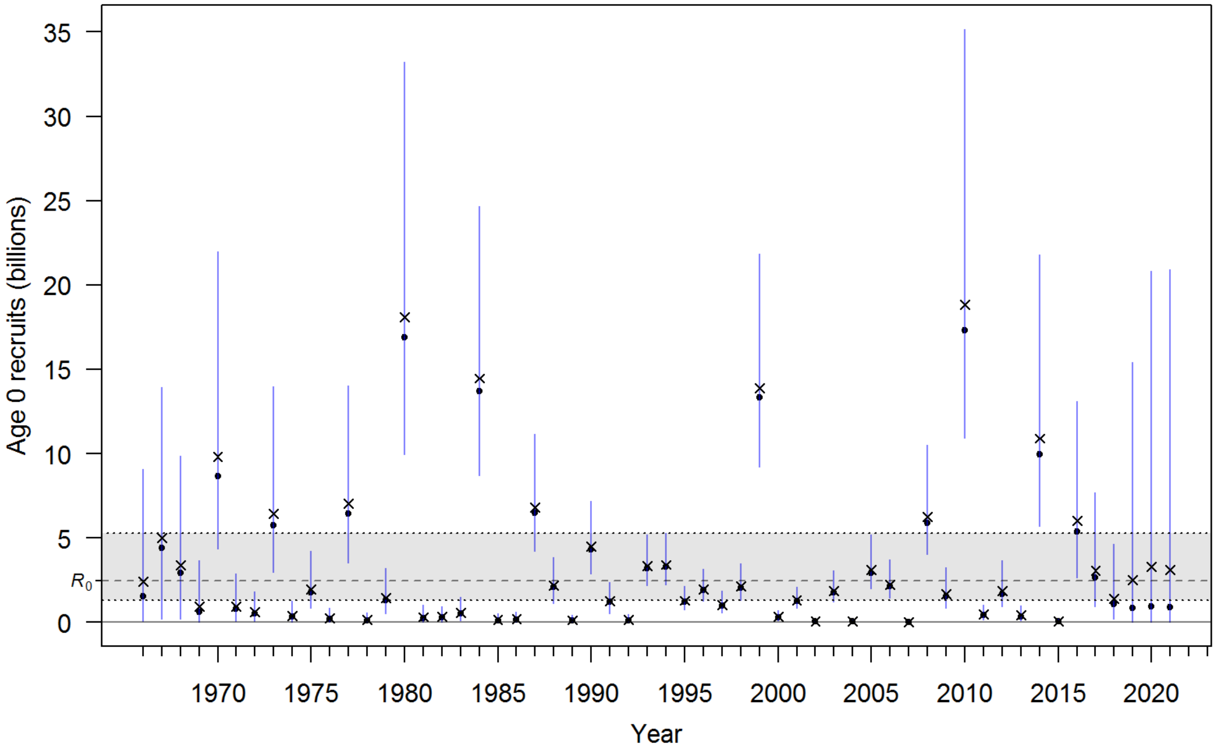


Figure G.5. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

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
2011	0.533	0.842	1.143	0.092	0.154	0.209
2012	0.375	0.635	0.913	0.027	0.050	0.072
2013	0.361	0.611	0.827	0.036	0.066	0.096
2014	0.331	0.582	0.821	0.037	0.068	0.099
2015	0.221	0.428	0.664	0.027	0.051	0.075
2016	0.384	0.685	0.967	0.038	0.074	0.114
2017	0.417	0.738	1.116	0.060	0.120	0.193
2018	0.371	0.692	1.051	0.047	0.099	0.172
2019	0.364	0.683	1.030	0.045	0.099	0.185
2020	0.300	0.596	0.923	0.045	0.104	0.210

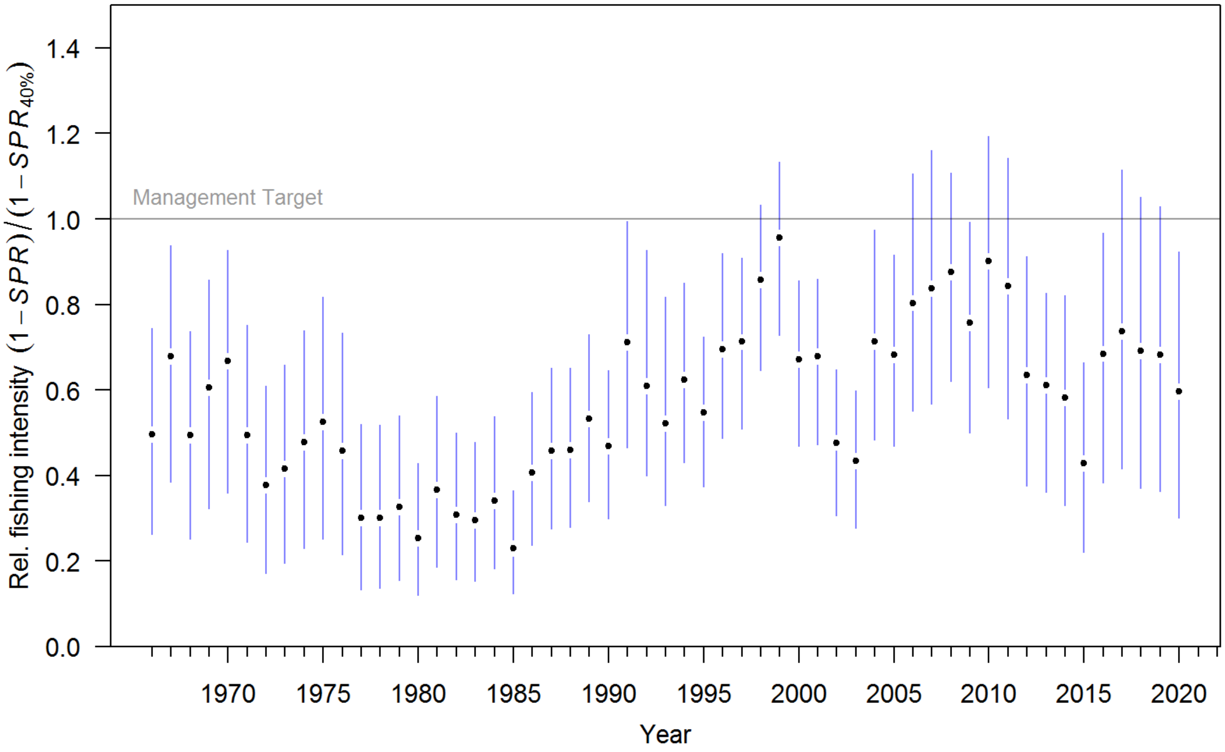


Figure G.6. Trend in median relative fishing intensity (relative to the SPR management target) through 2020 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

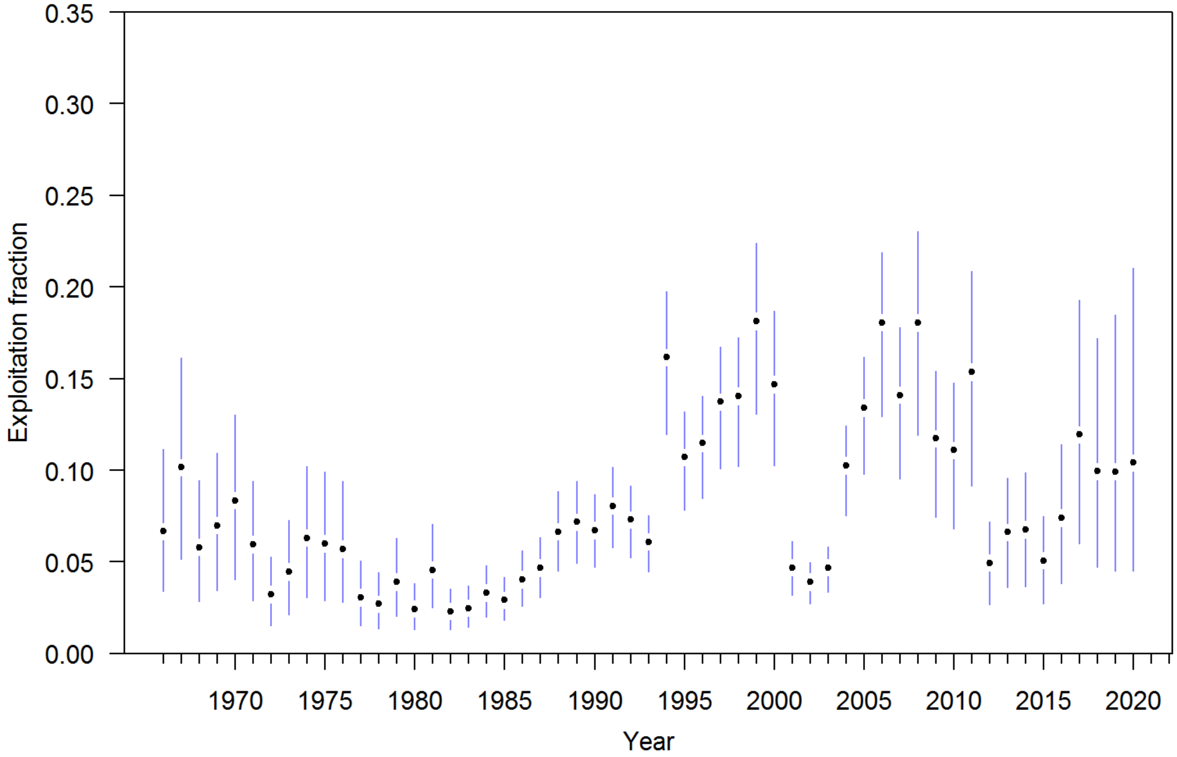


Figure G.7. Trend in median exploitation fraction (catch divided by age-2+ biomass) through 2020 with 95% posterior credibility intervals.

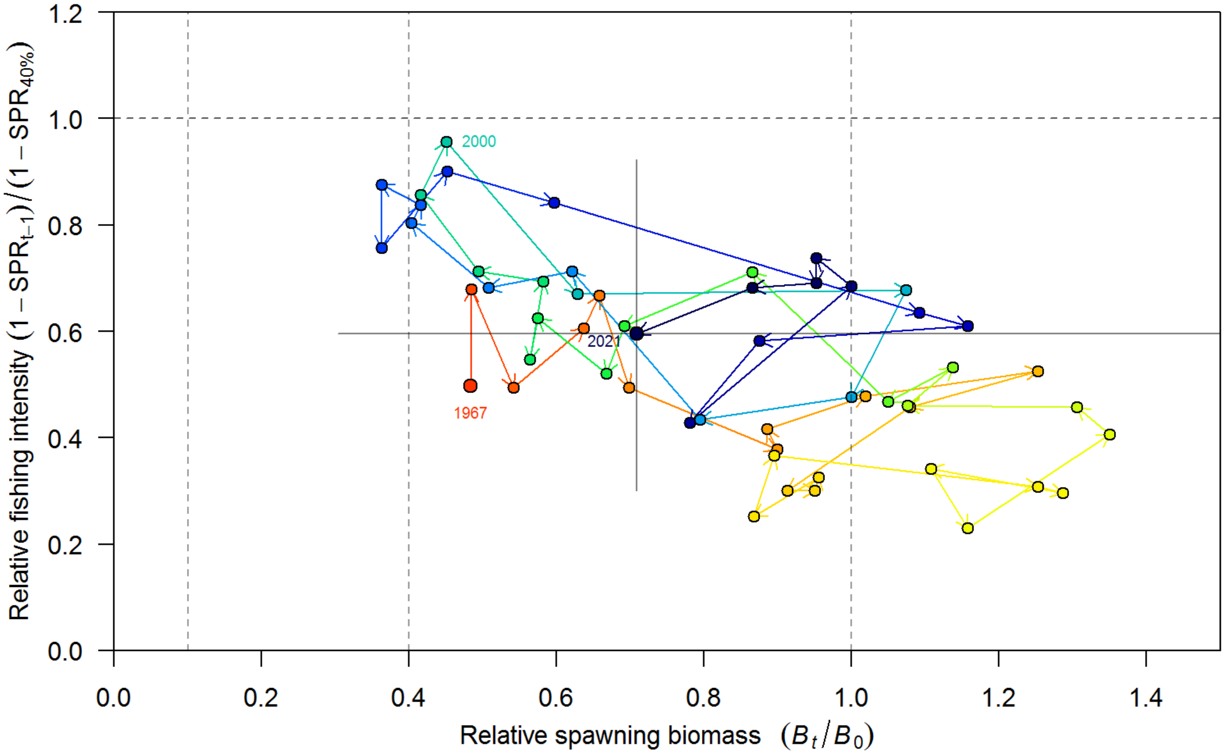


Figure G.8. Estimated historical path of median relative spawning biomass in year *t* and corresponding median relative fishing intensity in year $t-1$, as for Figure 32. Labels show the start year, end year and year of highest relative fishing intensity; labels correspond to year *t* (i.e., year of the relative spawning biomass). Gray bars span the 95% credibility intervals for 2021 relative spawning biomass (horizontal) and 2020 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 1966–2020 averages for mean size-at-age and selectivity-at-age.

Quantity	**2.5$^{\text{th}}$ percentile**	**Median**	**97.5$^{\text{th}}$ percentile**
Unfished female spawning biomass (B_0, thousand t)	1,115	1,781	2,974
Unfished recruitment (R_0, millions)	1,308	2,468	5,304
Reference points (equilibrium) based on $F_{\text{SPR}=40\%}$			
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	371	631	1,059
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)	164	300	570
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	446	713	1,190
SPR at $B_{40\%}$	40.6%	43.5%	51.3%
Exploitation fraction resulting in $B_{40\%}$	12.3%	16.2%	19.4%
Yield at $B_{40\%}$ (thousand t)	163	292	555
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	270	456	831
SPR at MSY	22.5%	29.8%	46.5%
Exploitation fraction corresponding to SPR at MSY	14.6%	25.8%	35.0%
MSY (thousand t)	171	315	611

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, g), including catch similar to 2020 (row d) and the TAC from 2020 (row f), the catch values that result in a median relative fishing intensity of 100% (row h), the median values estimated via the default harvest policy ($F_{\text{SPR}=40\%}$–40:10) for the base model (row i), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2021 and 2022 (row j). Catch in 2023 does not impact the beginning of the year biomass in 2023.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2021	0	35%	54%	71%	93%	141%
	2022	0	35%	53%	71%	94%	147%
	2023	0	36%	54%	73%	99%	166%
b:	2021	180,000	35%	54%	71%	93%	141%
	2022	180,000	31%	49%	66%	89%	141%
	2023	180,000	28%	46%	64%	90%	157%
c:	2021	350,000	35%	54%	71%	93%	141%
	2022	350,000	27%	45%	62%	85%	137%
	2023	350,000	20%	38%	55%	82%	148%
d:	2021	380,000	35%	54%	71%	93%	141%
2020	2022	380,000	26%	44%	61%	84%	136%
catch	2023	380,000	19%	36%	54%	80%	147%
e:	2021	430,000	35%	54%	71%	93%	141%
	2022	430,000	25%	43%	60%	83%	134%
	2023	430,000	17%	34%	52%	78%	144%
f:	2021	529,290	35%	54%	71%	93%	141%
2020	2022	529,290	23%	40%	57%	80%	132%
TAC	2023	529,290	12%	29%	47%	73%	139%
g:	2021	597,500	35%	54%	71%	93%	141%
2019	2022	597,500	21%	38%	56%	79%	130%
TAC	2023	597,500	10%	26%	44%	70%	136%
h:	2021	644,002	35%	54%	71%	93%	141%
FI=	2022	514,270	20%	37%	55%	77%	129%
100%	2023	434,472	10%	27%	45%	71%	137%
i:	2021	723,090	35%	54%	71%	93%	141%
default	2022	551,753	19%	36%	53%	76%	127%
HR	2023	444,096	9%	24%	42%	68%	135%
j:	2021	587,217	35%	54%	71%	93%	141%
C2021=	2022	587,183	22%	39%	56%	79%	130%
C2022	2023	466,528	10%	26%	44%	70%	136%

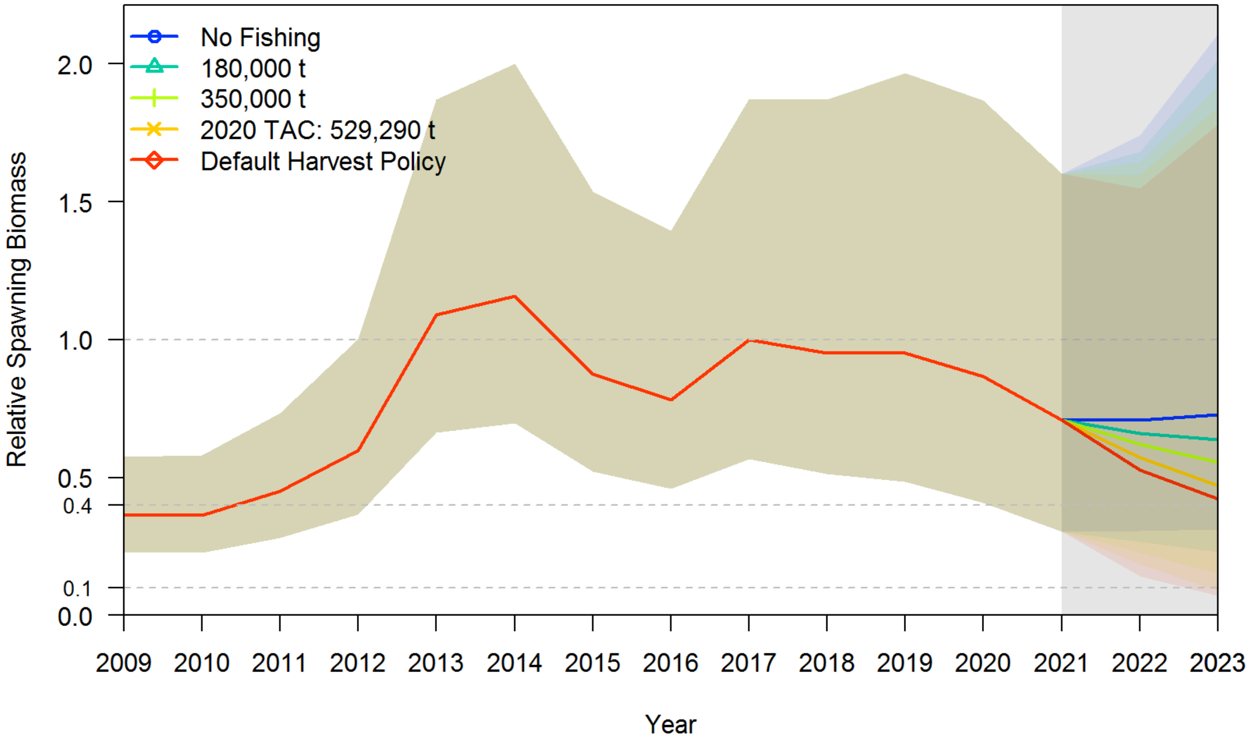


Figure G.9. Time series of estimated relative spawning biomass to 2021 from the base model, and forecast trajectories to 2023 (grey region) for several management actions defined in Table G.5, with 95% posterior credibility intervals.

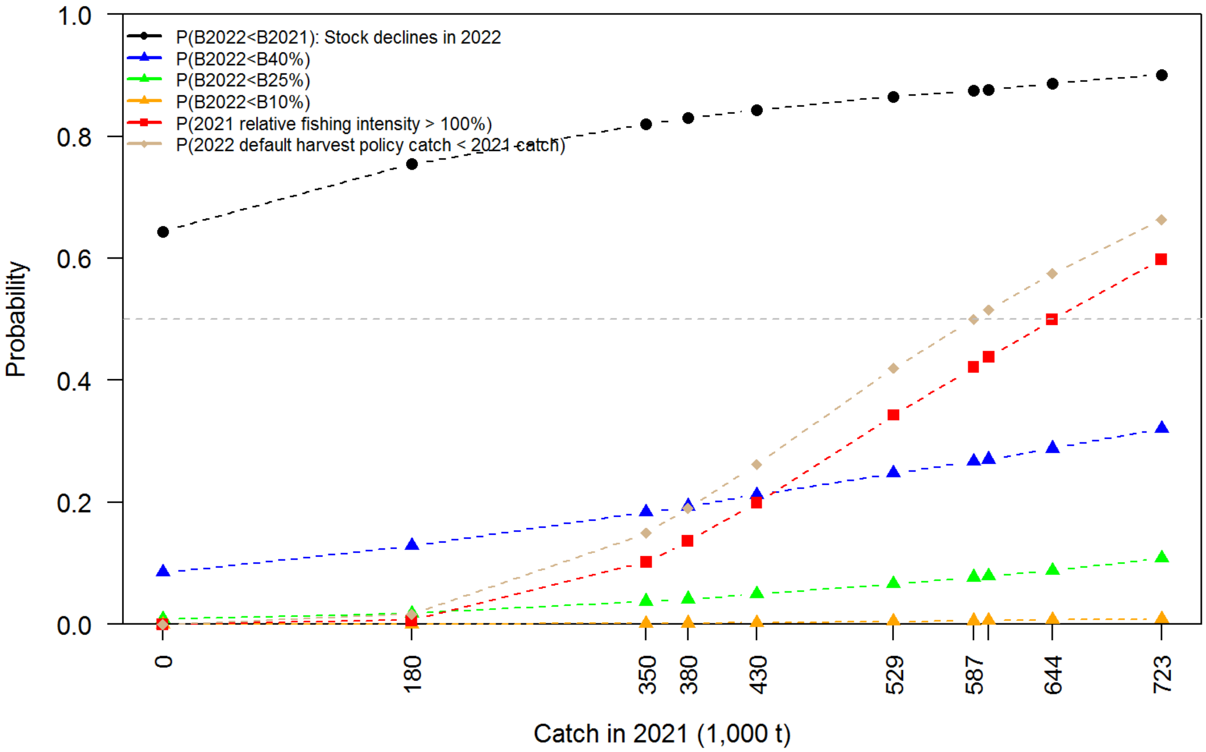


Figure G.10. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (catch options explained in Table G.5) as listed in Table G.6. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table G.6. Probabilities related to spawning biomass, relative fishing intensity, and the 2022 default harvest policy catch for alternative 2021 catch options (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	64%	9%	1%	0%	0%	0%
b: 180,000	75%	13%	2%	0%	1%	2%
c: 350,000	82%	18%	4%	0%	10%	15%
d: 380,000	83%	19%	4%	0%	14%	19%
e: 430,000	84%	21%	5%	0%	20%	26%
f: 529,290	87%	25%	7%	0%	34%	42%
g: 597,500	88%	27%	8%	1%	44%	52%
h: 644,002	89%	29%	9%	1%	50%	58%
i: 723,090	90%	32%	11%	1%	60%	66%
j: 587,217	87%	27%	8%	1%	42%	50%

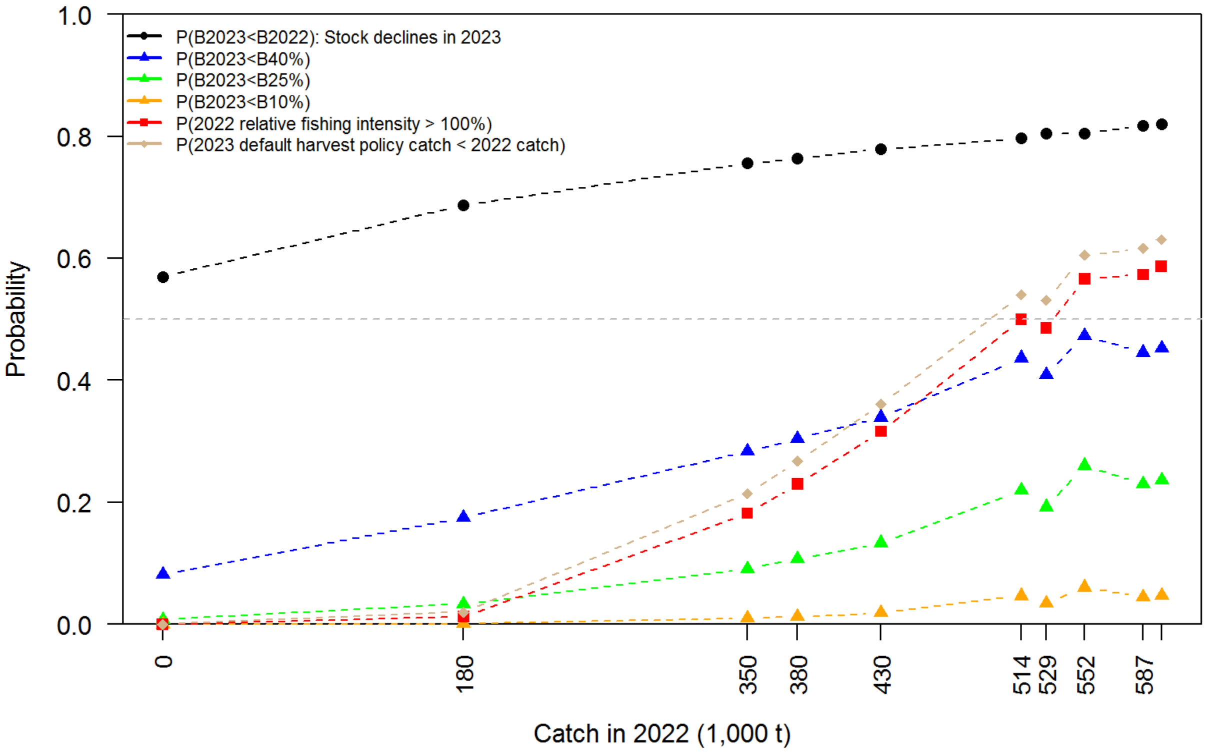


Figure G.11. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2023 default harvest policy catch for alternative 2022 catch options (including associated 2021 catch; catch options explained in Table G.5) as listed in Table G.7. The symbols 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 2023 default harvest policy catch for alternative 2022 catch options, given the 2021 catch level shown in Table G.6 (catch options explained in Table G.5).

Catch in 2022	Probability $B_{2023} < B_{2022}$	Probability $B_{2023} < B_{40\%}$	Probability $B_{2023} < B_{25\%}$	Probability $B_{2023} < B_{10\%}$	Probability 2022 relative fishing intensity > 100%	Probability 2023 default harvest policy catch < 2022 catch
a: 0	57%	8%	1%	0%	0%	0%
b: 180,000	69%	17%	3%	0%	1%	2%
c: 350,000	76%	28%	9%	1%	18%	21%
d: 380,000	76%	30%	11%	1%	23%	27%
e: 430,000	78%	34%	13%	2%	32%	36%
f: 529,290	80%	41%	19%	3%	49%	53%
g: 597,500	82%	45%	24%	5%	59%	63%
h: 514,270	80%	44%	22%	5%	50%	54%
i: 551,753	81%	47%	26%	6%	57%	61%
j: 587,183	82%	45%	23%	4%	57%	62%

H SENSITIVITY RUN USING THE RANDOM WALK MH ALGORITHM

This appendix contains base model Bayesian MCMC results using the random walk Metropolis Hastings (rwMH) algorithm for obtaining MCMC samples. This was the approach used for Bayesian MCMC sampling in prior assessments. This year the stock assessment applies 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 appendix is provided solely as supplemental information, as NUTS is considered by many to be a straightforward improvement in efficiency with high dimensional models relative to classic Hamiltonian approaches (via adaptive sampling steps), as well as improved parameter space coverage over classic random walk approaches.

A comparison between the base model and the rwMH 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 2.264 billion and the rwMH run being 2.474 billion. This small difference causes the downward scaling effect to the relative biomass (Figure H.2) for the rwMH run. The base model NUTS run had a three-fold increase in the effective sample size used to estimate the R_0 posterior over the rwMH, while reducing computing time by 15-fold. Longer rwMH runs (8 days) resulted in more comparable R_0 effective sample sizes between algorithms, but only reduced this discrepancy between the posterior median R_0 estimates slightly. This confirms that recent advances improving the parameter space coverage in MCMC sampling algorithms since the use of the rwMH, particularly for high dimensional models such as integrated stock assessments, can have highest posterior density implications. Despite this minor difference, the uncertainty associated with both the NUTS and rwMH approaches largely overlap (Figures H.1 and H.2).

Diagnostics for the rwMH run are generally adequate for all key posteriors given the effective sample sizes produced and run-time constraints (Figures H.6–H.9). Parameter autocorrelation remains low for the rwMH run (bottom-left panels). The rwMH run resulted in 2,041 posterior samples, with parameter-specific effective sample sizes at or below that maximum. For reference, the base model NUTS run resulted in 8,250 posterior samples and, in particular, improved the smoothness of the estimated posterior distribution (Figure A.1) compared to the rwMH sensitivity (Figure H.6). 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.9 for the rwMH run. Correlations among parameters (Figures A.5–A.6 and H.10–H.11) are very similar, with the main difference being the density of the scatterplots due to the number of posterior samples.

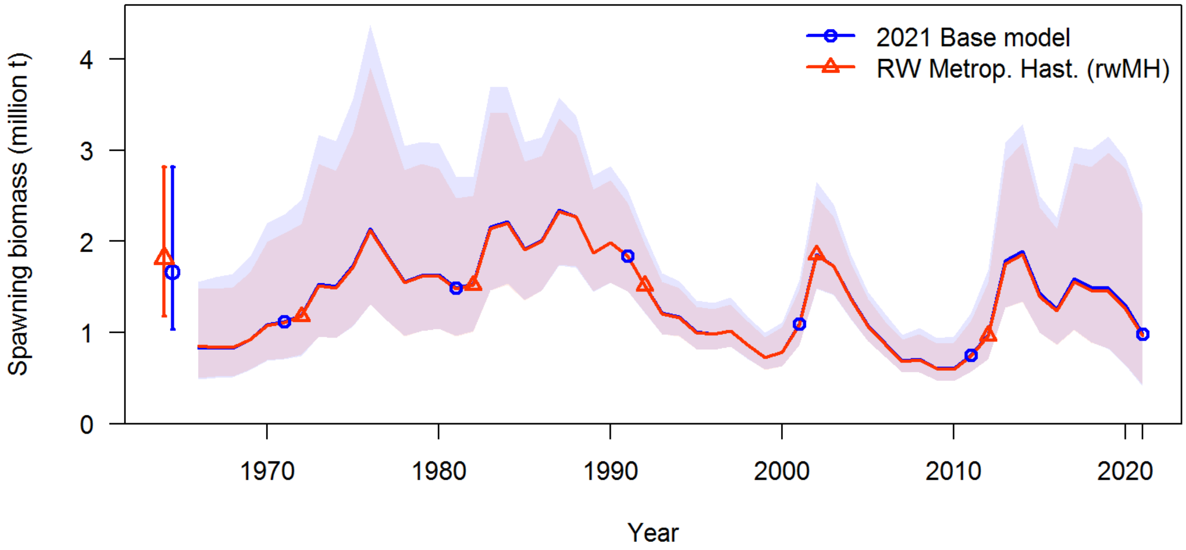


Figure H.1. MCMC median posterior estimates with 95% credible intervals of spawning biomass for the base model and alternative sensitivity run using rwMH.

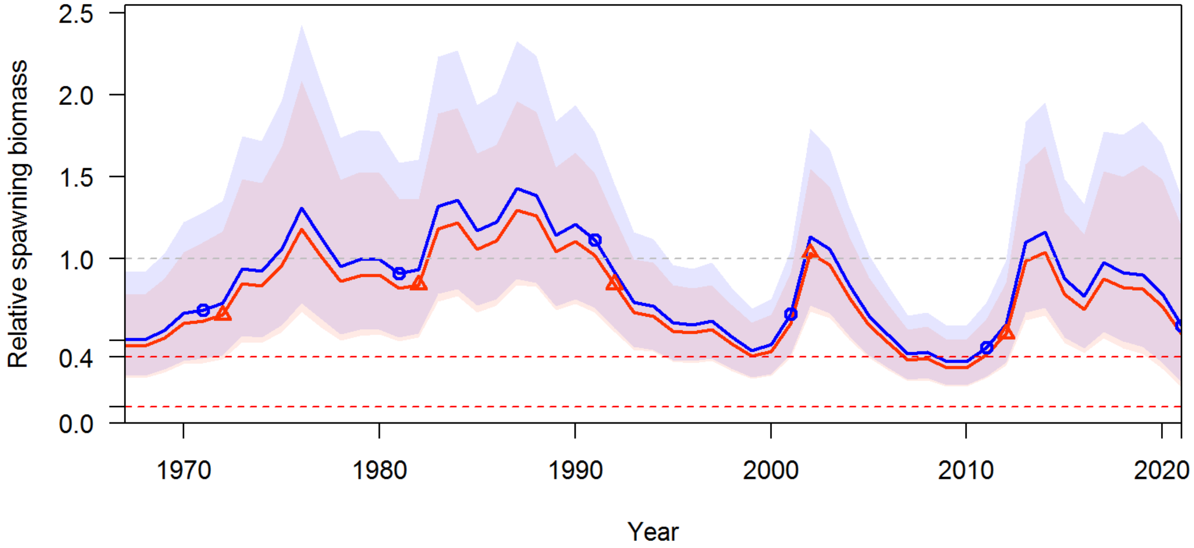


Figure H.2. MCMC median posterior estimates with 95% credible intervals of relative spawning biomass for the base model and alternative sensitivity run using rwMH.

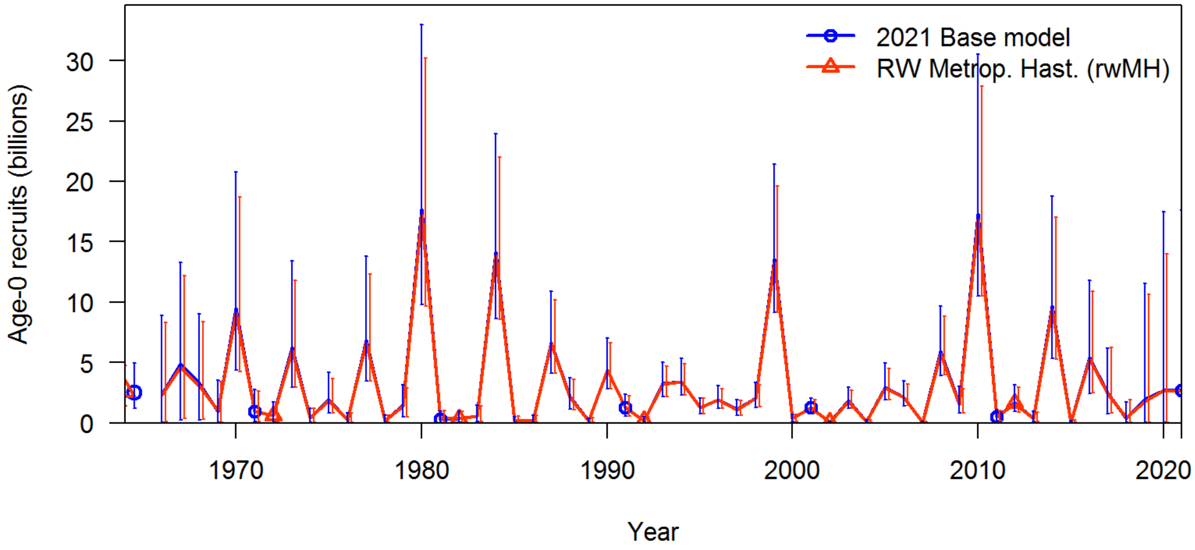


Figure H.3. MCMC median posterior estimates with 95% credible intervals of recruitment for the base model and the alternative sensitivity run using rwMH.

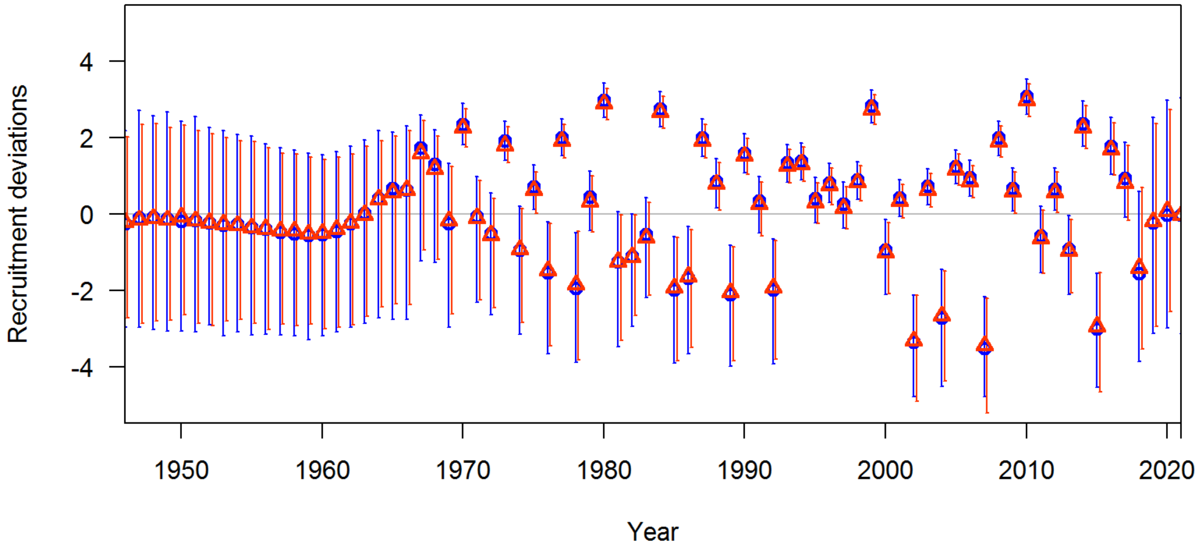


Figure H.4. MCMC median posterior estimates with 95% credible intervals for recruitment deviations for the base model and alternative sensitivity run using rwMH.

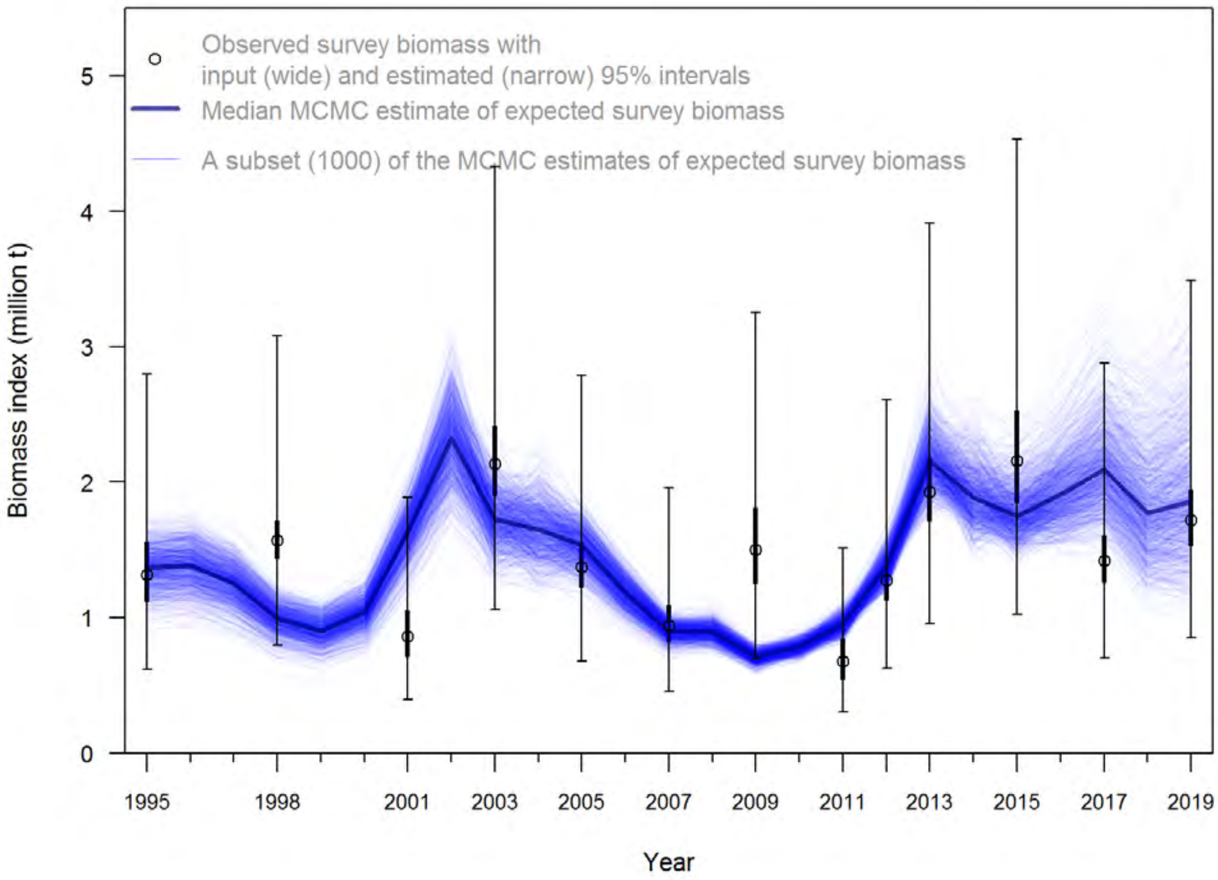


Figure H.5. Fits (colored lines) to the acoustic survey (points) with input 95% intervals around the observations. The thin blue lines are the results of a random subset of individual rwMH MCMC samples. Thicker uncertainty intervals around observed survey points indicate 95% log-normal uncertainty intervals estimated by the kriging method and are used as input to the assessment model. Thinner uncertainty intervals indicate estimated 95% uncertainty intervals that account for the model estimate of additional uncertainty.

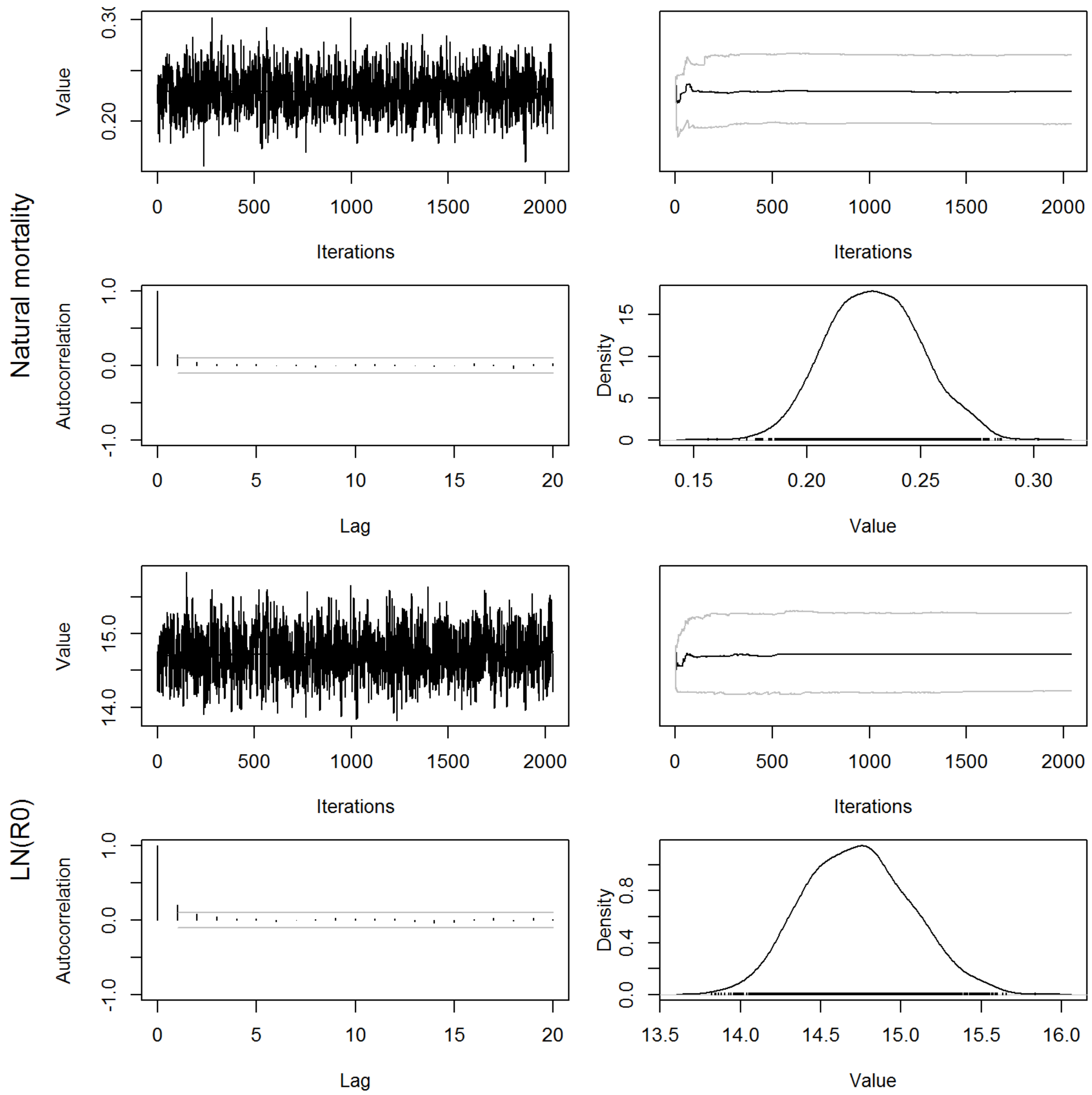


Figure H.6. Summary of rwMH MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels). Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower left sub-panel 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).

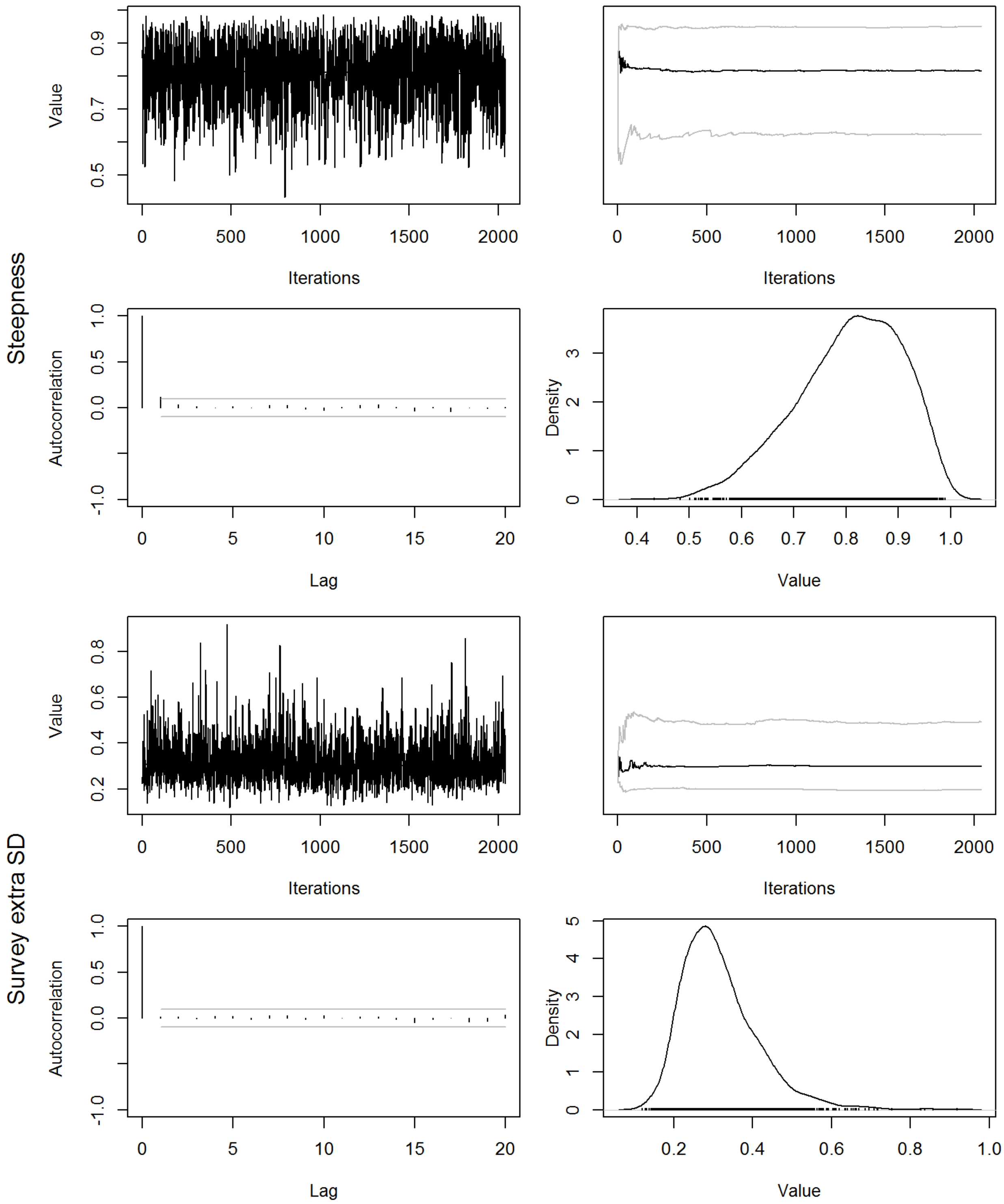


Figure H.7. Summary of rwMH MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels). Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, 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).

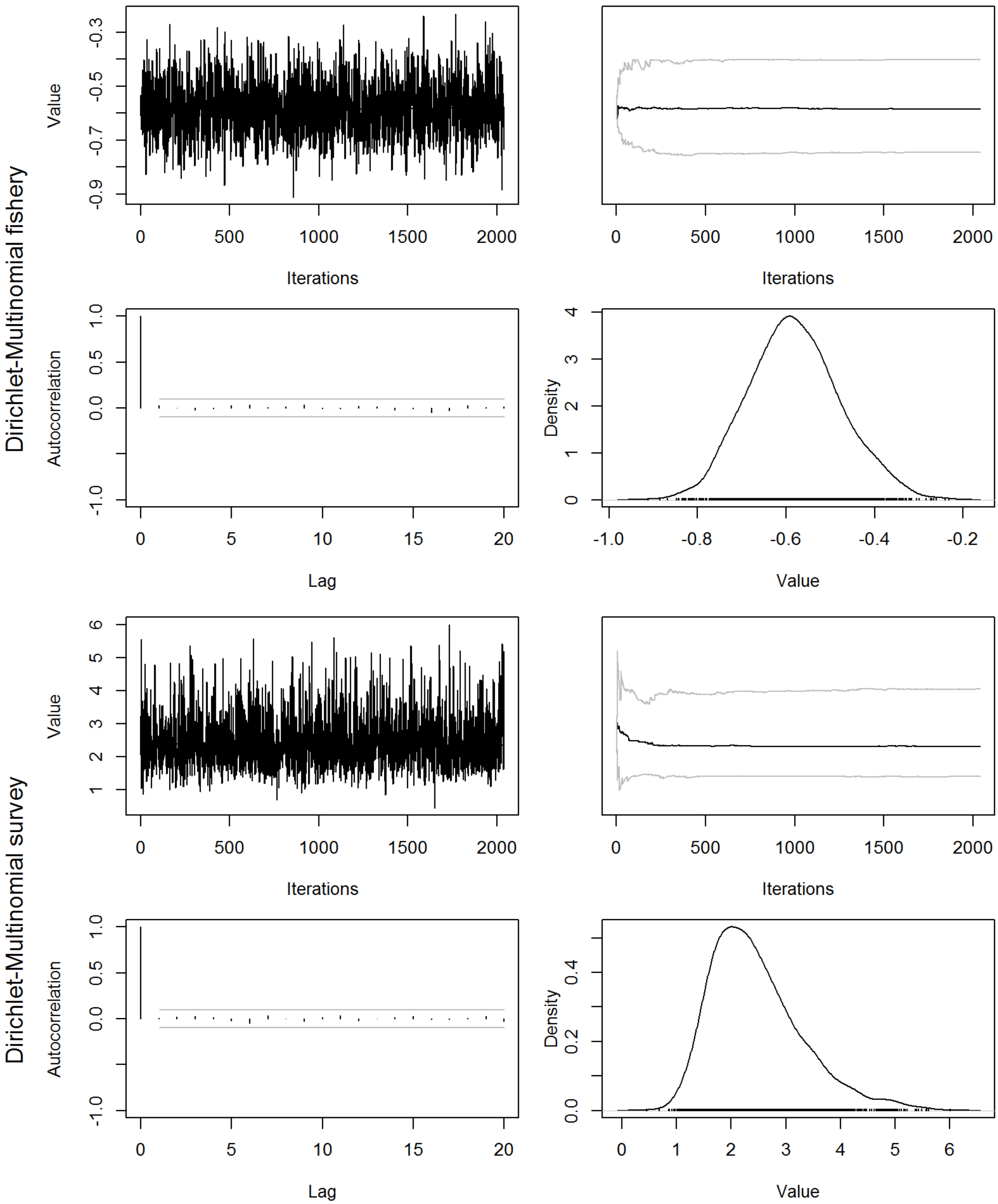


Figure H.8. Summary of rwMH MCMC diagnostics for the Dirichlet-multinomial age-composition parameters for the fishery (θ_{fish}, upper panels) and the survey (θ_{surv}, lower panels). Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running 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).

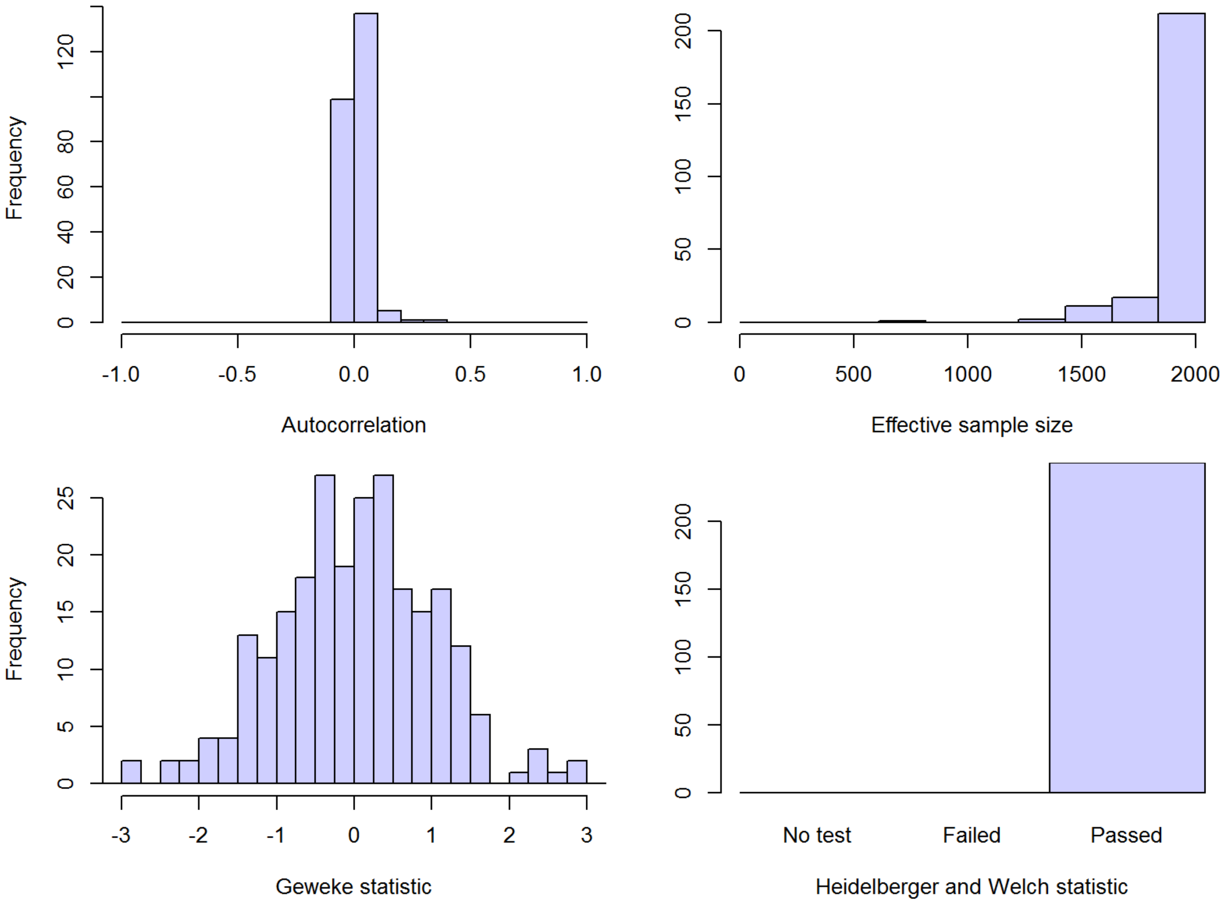


Figure H.9. Summary histograms of MCMC diagnostics for all rwMH model parameters. The level of autocorrelation in the chain (distribution across lag times, i.e., distance between samples in the chain, shown in the top left panel) influences the effective sample size (top right panel) used to estimate 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.

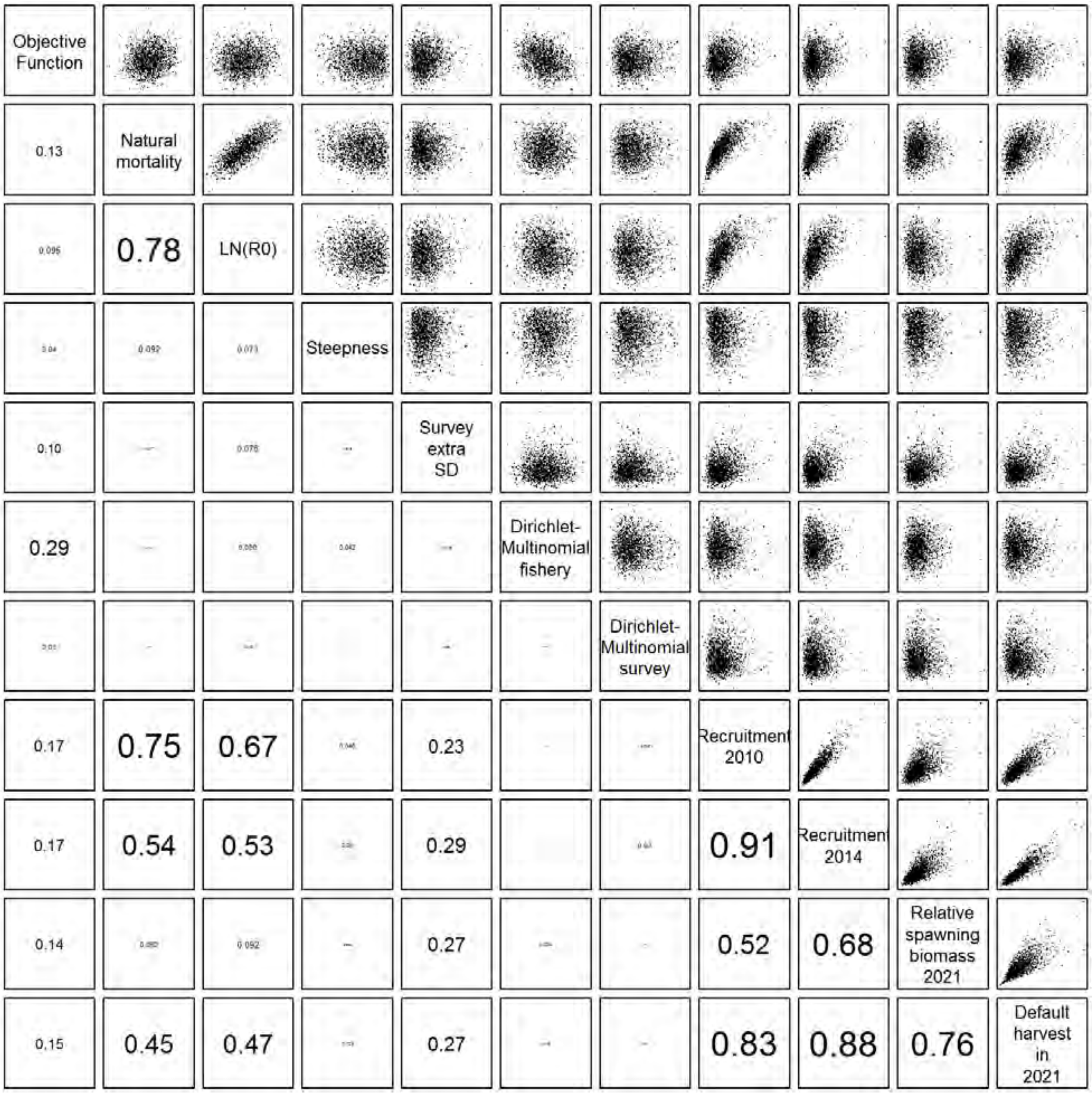


Figure H.10. Posterior correlations among key parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

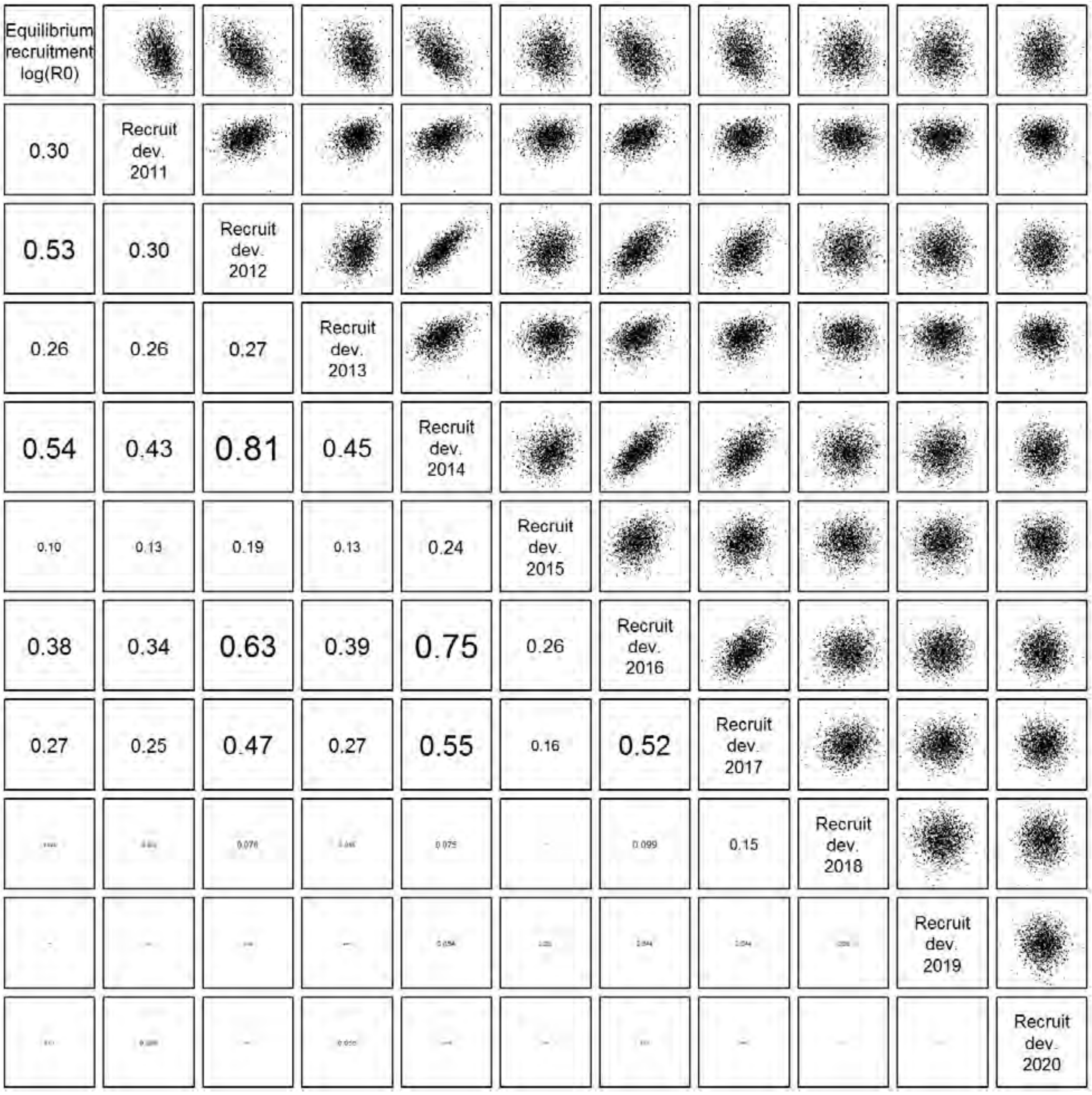


Figure H.11. Posterior correlations among recruitment deviations from recent years and equilibrium recruitment. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

I STOCK SYNTHESIS DATA FILE

../models/2021.00.04_base_v1/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
2020 #_endyr
1 #_nseas
12 #_months_per_seas
2 #_Nsubseasons
1 #_spawn_month
1 #_Ngenders
20 #_Nages
1 #_N_areas
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
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 1977 1 1 132690.0  0.01  #_13
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 1979 1 1 137110.0  0.01  #_15
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 1983 1 1 113931.0  0.01  #_19
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 1987 1 1 234147.6  0.01  #_23
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 1990 1 1 261286.1  0.01  #_26
 1991 1 1 319705.4  0.01  #_27
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 1993 1 1 198905.0  0.01  #_29
 1994 1 1 362406.8  0.01  #_30
```

```
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 2007 1 1 291247.2  0.01  #_43
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 2011 1 1 287333.9  0.01  #_47
 2012 1 1 207203.4  0.01  #_48
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 2014 1 1 299259.5  0.01  #_50
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 2016 1 1 332070.0  0.01  #_52
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 2018 1 1 413718.7  0.01  #_54
 2019 1 1 411573.7  0.01  #_55
 2020 1 1 379270.2  0.01  #_56
-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
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 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
```

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#
#_ageing_error
48 #_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
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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  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
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   0.996322        0.641575        1.375570        1.632440        1.8580
    2.1720  2.5300  2.9340  3.3880 #_42
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
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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 #_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
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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  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
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   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
   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
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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 #_85
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         1.0219
    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
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 #_95
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809 0.2575991
   0.517841  0.57863 0.653316  0.4097918 0.857813  0.996322  1.1665
   1.37557 1.63244 1.858 2.172 2.53  2.934 3.388 #_96
#
#_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 20.4800000   3.26000
   1.06000  19.33000   1.03000   4.03000  16.370000  1.440000  0.720000
   24.860000  0.240000  1.6700000  0.2100000 5.3200000 #_1
1998  7 2 0 0 26  -1  -1   105   0.00000000  6.8300000   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 50.6200000  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 23.0600000   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 19.0700000   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 28.2900000   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  0.5500000  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 27.6200000  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 62.1200000   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  2.1700000  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  7.4500000   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  0.4900000  52.73000
   2.80000   3.70000   3.31000  26.02000   4.130000  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 10.7200000  27.23000
   1.51000  31.31000   2.50000   3.18000   2.680000 16.120000  2.280000
   0.960000  0.360000  0.3800000  0.4700000 0.2800000 #_13
1975  7 1 0 0  3  -1  -1    13   4.60800000 33.8460000   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 #_14
1976  7 1 0 0  4  -1  -1   142   0.08500000  1.3370000  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 #_15
1977  7 1 0 0  5  -1  -1   320   0.00000000  8.4480000   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 #_16
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1978  7 1 0 0  6  -1  -1   341   0.47200000  1.1100000   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 #_17
1979  7 1 0 0  7  -1  -1   116   0.00000000  6.4920000  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 #_18
1980  7 1 0 0  8  -1  -1   221   0.14800000  0.5440000  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 #_19
1981  7 1 0 0  9  -1  -1   154  19.49300000  4.0300000   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 #_20
1982  7 1 0 0 10  -1  -1   170   0.00000000 32.0500000   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 #_21
1983  7 1 0 0 11  -1  -1   117   0.00000000  0.0000000  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 #_22
1984  7 1 0 0 12  -1  -1   123   0.00000000  0.0000000   1.39300
   61.90400   3.62500   3.84900  16.77800   2.853000  1.509000  1.239000
   3.342000  0.923000  0.5860000  1.4390000 0.5610000 #_23
1985  7 1 0 0 13  -1  -1    57   0.92500000  0.1110000   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 #_24
1986  7 1 0 0 14  -1  -1   120   0.00000000 15.3440000   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 #_25
1987  7 1 0 0 15  -1  -1    56   0.00000000  0.0000000  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 #_26
1988  7 1 0 0 16  -1  -1    84   0.00000000  0.6530000   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 #_27
1989  7 1 0 0 17  -1  -1    80   0.00000000  5.6160000   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 #_28
1990  7 1 0 0 18  -1  -1   163   0.00000000  5.1940000  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 #_29
1991  7 1 0 0 19  -1  -1   160   0.00000000  3.4640000  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 #_30
1992  7 1 0 0 20  -1  -1   243   0.46100000  4.2380000   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 #_31
1993  7 1 0 0 21  -1  -1   172   0.00000000  1.0510000  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 #_32
1994  7 1 0 0 22  -1  -1   235   0.00000000  0.0370000   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 #_33
1995  7 1 0 0 23  -1  -1   147   0.61900000  1.2810000   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 #_34
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1996  7 1 0 0 24  -1  -1   186   0.00000000 18.2820000  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 #_35
1997  7 1 0 0 25  -1  -1   220   0.00000000  0.7370000  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 #_36
1998  7 1 0 0 26  -1  -1   243   0.01500000  4.7790000  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 #_37
1999  7 1 0 0 27  -1  -1   509   0.06200000 10.2440000  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 #_38
2000  7 1 0 0 28  -1  -1   530   0.99600000  4.2180000  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 #_39
2001  7 1 0 0 29  -1  -1   540   0.00000000 17.3380000  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 #_40
2002  7 1 0 0 30  -1  -1   449   0.00000000  0.0330000  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 #_41
2003  7 1 0 0 31  -1  -1   456   0.00000000  0.1050000   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 #_42
2004  7 1 0 0 32  -1  -1   501   0.00000000  0.0220000   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 #_43
2005  7 1 0 0 33  -1  -1   613   0.01800000  0.5690000   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 #_44
2006  7 1 0 0 34  -1  -1   720   0.32600000  2.8080000  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 #_45
2007  7 1 0 0 35  -1  -1   629   0.77500000 11.5220000   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 #_46
2008  7 1 0 0 36  -1  -1   794   0.76217629  9.8184022  30.53299
   2.40166  14.41640   1.02693   3.63033   3.166856 28.074557  3.048841
   1.147078  0.734035  0.4946042  0.3137319 0.4314137 #_2008
2009  7 1 0 0 37  -1  -1   685   0.63640827  0.5633553  31.02086
   27.18762   3.36137  10.67570   1.30456   2.266831  2.266227 16.141759
   2.487675  0.868125  0.5973745  0.2815890 0.3405384 #_2009
2010  7 1 0 0 38  -1  -1   874   0.02702724 25.2288948   3.37439
   35.38316  21.43336   2.28555   2.94176   0.431663  0.578570  0.982213
   5.862915  0.926190  0.2874233  0.1039092 0.1529776 #_2010
2011  7 1 0 0 39  -1  -1  1081   2.67217840  8.7250559  70.83479
   2.62940   6.34331   4.37837   1.12131   0.800128  0.293278  0.369626
   0.116706  1.330711  0.1698430  0.1053935 0.1098972 #_2011
2012  7 1 0 0 40  -1  -1   851   0.18083911 40.9265469  11.53787
   32.99357   2.49337   5.09647   2.52332   1.133874  0.661252  0.232469
   0.329852  0.348490  0.8743714  0.2834955 0.3842115 #_2012
2013  7 1 0 0 41  -1  -1  1094   0.03025880  0.5438753  70.31059
   5.90463  10.47325   1.12211   3.41281   2.057710  0.906199  1.367310
   0.263968  0.332820  0.5293924  2.2822510 0.4628263 #_2013
```

```
2014  7 1 0 0 42  -1  -1  1153   0.00000000  3.2833105   3.80619
   64.41904   6.92999  12.06028   1.58416   3.109329  1.826251  0.811216
   0.462856  0.117057  0.1906106  0.2765460 1.1231602 #_2014
2015  7 1 0 0 43  -1  -1   798   3.63501714  1.1390924   6.88150
   3.94362  69.98580   4.93683   5.08613   0.958252  1.549779  1.087923
   0.201822  0.205398  0.0606899  0.0540738 0.2740771 #_2015
2016  7 1 0 0 44  -1  -1  1440   0.29164589 50.2153989   1.69038
   4.47021   2.47532  32.85661   2.77599   3.233376  0.760669  0.441814
   0.367093  0.234895  0.0631441  0.0545013 0.0689544 #_2016
2017  7 1 0 0 45  -1  -1  1300   3.75795865  0.7257353  38.31341
   2.37449   4.12280   3.12032  36.87909   4.426461  3.108637  1.330523
   0.616509  0.718660  0.2082172  0.0929605 0.2042389 #_2017
2018  7 1 0 0 46  -1  -1  1174   7.35100682 25.5346326   1.49248
   26.97985   1.51574   2.80453   3.03623  22.754902  4.311260  1.911831
   0.943318  0.545069  0.4097240  0.3143701 0.0950628 #_2018
2019  7 1 0 0 47  -1  -1  1001   0.00523155 13.7154966  20.68780
   1.57321  32.32376   1.76941   3.82443   2.243624 18.683264  1.983118
   1.660599  0.688168  0.3842234  0.2278193 0.2298378 #_2019
2020  7 1 0 0 48  -1  -1   703   0.00000000  0.0799458   8.51160
   35.22999   1.46006  30.90212   1.68540   2.406840  1.936679 14.773664
   1.237056  1.097952  0.2766521  0.1169040 0.2851304 #_2020
-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/2021.00.04_base_v1/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)
#
4 # recr_dist_method for parameters:  2=main effects for GP, Settle
   timing, Area; 3=each Settle entity; 4=none when N_GP*Nsettle*pop==1
1 # not yet implemented; Future usage: Spawner-Recruitment: 1=global;
   2=by area
1 #  number of recruitment settlement assignments
0 # unused option
#GPattern month  area  age (for each settlement assignment)
 1        1      1     0
#
#_Cond 0 # N_movement_definitions goes here if Nareas > 1
#_Cond 1.0 # first age that moves (real age at begin of season, not
   integer) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1,
   source=1 dest=2, age1=4, age2=10
#
0 #_Nblock_Patterns
#
# controls for all timevary parameters
1 #_env/block/dev_adjust_method for all time-vary parms (1=warn relative
   to base parm bounds; 3=no bound check)
#  autogen
1 1 1 1 1 # autogen: 1st element for biology, 2nd for SR, 3rd for Q, 4th
   reserved, 5th for selex
# where: 0 = autogen all time-varying parms; 1 = read each time-varying
   parm line; 2 = read then autogen if parm min==-12345
#
#
# setup for M, growth, maturity, fecundity, recruitment distibution,
   movement
#
0 #_natM_type:_0=1Parm;
   1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
  #_no additional input for selected M option; read 1P per morph
1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2;
   3=age_specific_K; 4=not implemented
1 #_Age(post-settlement)_for_L1;linear growth below this
20 #_Growth_Age_for_L2 (999 to use as Linf)
-999 #_exponential decay for growth above maxage (fixed at 0.2 in 3.24;
   value should approx initial Z; -999 replicates 3.24)
0  #_placeholder for future growth feature
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4
   logSD=F(A)
```

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

```
 0 0 0 0 0 0 0 0 0 0
   #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
#_Spawner-Recruitment
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop;
   7=survival_3Parm; 8=Shepard_3Parm
0  # 0/1 to use steepness in initial equ recruitment calculation
0  #  future feature:  0/1 to make realized sigmaR a function of SR
   curvature
#_          LO            HI          INIT         PRIOR          PR_SD
         PR_type      PHASE    env-var    use_dev   dev_mnyr   dev_mxyr
       dev_PH      Block    Blk_Fxn #  parm_name
            13            17          15.9            15            99
               0          1          0          0          0          0
            0          0          0 # SR_LN(R0)
           0.2             1          0.88         0.777         0.113
               2          4          0          0          0          0
            0          0          0 # SR_BH_steep
             1           1.6           1.4           1.1            99
               0         -6          0          0          0          0
            0          0          0 # SR_sigmaR
            -5             5             0             0            99
               0        -50          0          0          0          0
            0          0          0 # SR_regime
             0             2             0             1            99
               0        -50          0          0          0          0
            0          0          0 # SR_autocorr
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 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           5          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       2020
            5          0          0  #  AgeSel_P3_Fishery(1)
            -5             9           0.1            -1           0.01
               0          2          0          2       1991       2020
            5          0          0  #  AgeSel_P4_Fishery(1)
            -5             9           0.1            -1           0.01
               0          2          0          2       1991       2020
            5          0          0  #  AgeSel_P5_Fishery(1)
            -5             9           0.1            -1           0.01
               0          2          0          2       1991       2020
            5          0          0  #  AgeSel_P6_Fishery(1)
            -5             9             0            -1           0.01
               0          2          0          2       1991       2020
            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           5          0          0          0          0
            0          0           0  #  ln(EffN_mult)_1
            -5            20             .5             0            1.813
               6           5          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 0 0 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/2021.00.04_base_v1/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
0 # 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/2021.00.04_base_v1/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)
2021  #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/2021.00.04_base_v1/wtatage.ss

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2021-01-10 21:57:58
###################################################
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 0.0672075 0.3215887 0.4665655
   0.489992 0.5399104 0.6054188 0.6808098 0.7339600 0.826826 0.8894652
   0.9645 1.0167254 0.9568145 0.931320 0.931320 0.931320 0.931320
   0.931320 0.931320
  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 2.470050 2.470050 2.470050 2.470050
   2.470050 2.470050
  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 2.470050 2.470050 2.470050 2.470050
   2.470050 2.470050
  1977    1       1  1      1    -2  0  0 0.1046349 0.4127041 0.5732365
   0.618424 0.7037952 0.7742286 0.9309696 1.0269776 1.175608 1.2217400
   1.3482 1.5709284 1.9080900 1.920420 1.920420 1.920420 1.920420
   1.920420 1.920420
  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 2.101770 2.101770 2.101770 2.101770
   2.101770 2.101770
  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 1.783530 1.783530 1.783530 1.783530
   1.783530 1.783530
  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 1.256490 1.256490 1.256490 1.256490
   1.256490 1.256490
  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 1.091520 1.091520 1.091520 1.091520
   1.091520 1.091520
  1982    1       1  1      1    -2  0  0 0.0643365 0.2798904 0.3001203
   0.512900 0.3731488 0.4942988 0.5464470 0.7266912 0.685706 0.8290516
   1.0597 0.8973586 0.9814535 1.052370 1.052370 1.052370 1.052370
   1.052370 1.052370
```

```
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 1.334070 1.334070 1.334070 1.334070
 1.334070 1.334070
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 1.692000 1.692000 1.692000 1.692000
 1.692000 1.692000
1985    1       1  1     1    -2  0   0 0.0578115 0.2106729 0.3912231
 0.501768 0.4994496 0.5167080 0.6702828 0.5952864 0.657678 0.8257808
 0.7533 0.9060764 0.6454845 0.771570 0.771570 0.771570 0.771570
 0.771570 0.771570
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 1.452780 1.452780 1.452780 1.452780
 1.452780 1.452780
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 1.274130 1.274130 1.274130 1.274130
 1.274130 1.274130
1988    1       1  1     1    -2  0   0 0.0488070 0.2675571 0.4527271
 0.339480 0.3461440 0.4781864 0.6194661 0.6497552 0.704032 0.8861944
 1.0929 0.9779264 1.3847500 1.308510 1.308510 1.308510 1.308510
 1.308510 1.308510
1989    1       1  1     1    -2  0   0 0.0714357 0.2617680 0.2816691
 0.474536 0.4070208 0.3763264 0.4944819 0.6144496 0.660128 0.6058676
 0.9105 0.6405188 0.7909310 1.053810 1.053810 1.053810 1.053810
 1.053810 1.053810
1990    1       1  1     1    -2  0   0 0.0635535 0.2953280 0.3881479
 0.476192 0.5185664 0.5965292 0.6371706 0.5003200 0.762048 0.7838376
 2.2000 1.1374334 0.9708530 1.304550 1.304550 1.304550 1.304550
 1.304550 1.304550
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 0.9759146 1.1508705 2.144520 2.144520 2.144520 2.144520
 2.144520 2.144520
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 0.924480 0.924480 0.924480 0.924480
 0.924480 0.924480
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 0.616500 0.616500 0.616500 0.616500
 0.616500 0.616500
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 0.670950 0.670950 0.670950 0.670950
 0.670950 0.670950
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 0.720720 0.720720 0.720720 0.720720
 0.720720 0.720720
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 0.675810 0.675810 0.675810 0.675810
 0.675810 0.675810
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 0.782370 0.782370 0.782370 0.782370
 0.782370 0.782370
1998    1       1  1      1     -2  0   0 0.0547578 0.3013688 0.4853050
 0.476192 0.5023264 0.5874544 0.5817603 0.6336128 0.767242 0.6857136
 0.7907 0.7408214 0.7102335 0.714780 0.714780 0.714780 0.714780
 0.714780 0.714780
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 0.736830 0.736830 0.736830 0.736830
 0.736830 0.736830
2000    1       1  1      1     -2  0   0 0.1005372 0.3976860 0.5541126
 0.607016 0.6659328 0.6740354 0.7214823 0.7908832 0.799582 0.8479068
 0.8554 0.8996578 0.8350520 0.840240 0.840240 0.840240 0.840240
 0.840240 0.840240
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 0.879120 0.879120 0.879120 0.879120
 0.879120 0.879120
2002    1       1  1      1     -2  0   0 0.0935163 0.3828357 0.5596864
 0.685216 0.6709440 0.7223726 0.8744109 0.8091024 0.859264 0.8686860
 0.8378 0.8026124 1.0318775 0.942210 0.942210 0.942210 0.942210
 0.942210 0.942210
2003    1       1  1      1     -2  0   0 0.0665811 0.3653845 0.5021225
 0.541420 0.7006400 0.6406994 0.7147833 0.7784224 0.753130 0.8587774
 0.9266 0.7562452 0.8035370 0.896850 0.896850 0.896850 0.896850
 0.896850 0.896850
2004    1       1  1      1     -2  0   0 0.0535050 0.3658040 0.4618566
 0.489348 0.6012512 0.6549598 0.6296103 0.6694848 0.788802 0.8253960
 0.7716 0.9298348 0.8247380 0.806490 0.806490 0.806490 0.806490
 0.806490 0.806490
2005    1       1  1      1     -2  0   0 0.0679383 0.3617768 0.4887646
 0.496248 0.5272896 0.5867136 0.6268350 0.6634432 0.780374 0.7797010
 0.8109 0.7281758 1.0933795 0.870840 0.870840 0.870840 0.870840
 0.870840 0.870840
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 0.859500 0.859500 0.859500 0.859500
 0.859500 0.859500
2007    1       1  1      1     -2  0   0 0.0596124 0.3502825 0.5160570
 0.519064 0.5635744 0.5859728 0.6197532 0.6659920 0.756854 0.7337174
 0.8137 0.8336516 0.7647640 0.782820 0.782820 0.782820 0.782820
 0.782820 0.782820
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 0.749880 0.749880 0.749880 0.749880
 0.749880 0.749880
2009    1       1  1      1     -2  0   0 0.0642843 0.2857634 0.4442703
 0.578128 0.6094176 0.6225498 0.7161231 0.7684160 0.745094 0.7779694
 1.0293 0.8050074 0.9353270 0.930060 0.930060 0.930060 0.930060
 0.930060 0.930060
```

```
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 0.811890 0.811890 0.811890 0.811890
 0.811890 0.811890
2011    1      1  1     1    -2  0  0 0.0641277 0.2700741 0.3716187
 0.473064 0.5521600 0.6247722 0.8167038 0.8773536 0.958538 1.0340538
 1.0588 0.9847282 1.0081935 0.829080 0.829080 0.829080 0.829080
 0.829080 0.829080
2012    1      1  1     1    -2  0  0 0.0559845 0.2966704 0.3934334
 0.449788 0.6089536 0.6394956 0.7441632 0.8565856 0.943348 0.9275604
 0.9638 0.9477494 0.9478375 0.848430 0.848430 0.848430 0.848430
 0.848430 0.848430
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 0.949050 0.949050 0.949050 0.949050
 0.949050 0.949050
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 0.952110 0.952110 0.952110 0.952110
 0.952110 0.952110
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 1.124370 1.124370 1.124370 1.124370
 1.124370 1.124370
2016    1      1  1     1    -2  0  0 0.0636579 0.3214209 0.4001604
 0.405720 0.4321696 0.4755010 0.4959174 0.4846496 0.648466 0.6924476
 0.5921 0.9162312 1.3857050 1.308690 1.308690 1.308690 1.308690
 1.308690 1.308690
2017    1      1  1     1    -2  0  0 0.0813015 0.3369424 0.4667577
 0.484288 0.5208864 0.5127262 0.5555385 0.6187920 0.600446 0.6928324
 0.7990 0.7424500 0.7778475 0.839430 0.839430 0.839430 0.839430
 0.839430 0.839430
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 0.963000 0.963000 0.963000 0.963000
 0.963000 0.963000
2019    1      1  1     1    -2  0  0 0.0749592 0.3741101 0.5308564
 0.496984 0.5666368 0.5804168 0.6425298 0.6445632 0.714420 0.7394894
 0.7150 0.7935114 0.8488040 0.846540 0.846540 0.846540 0.846540
 0.846540 0.846540
2020    1      1  1     1    -2  0  0 0.0900450 0.3994479 0.4878036
 0.515844 0.5286816 0.5470808 0.5746785 0.6040656 0.633570 0.6740734
 0.6337 0.8037620 0.8346700 0.841500 0.841500 0.841500 0.841500
 0.841500 0.841500
2021    1      1  1     1    -2  0  0 0.0804924 0.3641260 0.4737730
 0.479136 0.5120890 0.5374874 0.5665823 0.5911139 0.645428 0.6898502
 0.6857 0.7898710 0.9407323 0.959832 0.959832 0.959832 0.959832
 0.959832 0.959832
2022    1      1  1     1    -2  0  0 0.0804924 0.3641260 0.4737730
 0.479136 0.5120890 0.5374874 0.5665823 0.5911139 0.645428 0.6898502
 0.6857 0.7898710 0.9407323 0.959832 0.959832 0.959832 0.959832
 0.959832 0.959832
2023    1      1  1     1    -2  0  0 0.0804924 0.3641260 0.4737730
 0.479136 0.5120890 0.5374874 0.5665823 0.5911139 0.645428 0.6898502
```

```
   0.6857 0.7898710 0.9407323 0.959832 0.959832 0.959832 0.959832
   0.959832 0.959832
#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 0.0135 0.0921 0.2575 0.3833 0.4855
   0.5326 0.58180 0.65380 0.71140 0.77750 0.8437 0.9246 0.9645 1.0613
   1.00190 1.03480 1.03480 1.03480 1.03480 1.03480 1.03480
  1975    1      1  1     1    -1 0.0550 0.1575 0.2987 0.3658 0.6143
   0.6306 0.78730 0.87380 0.96780 0.90750 0.9700 1.6933 1.5000 1.9000
   1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
  1976    1      1  1     1    -1 0.0550 0.0986 0.2359 0.4990 0.5188
   0.6936 0.80380 0.91650 1.20630 1.33350 1.4495 1.6507 1.8066 1.8588
   1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
  1977    1      1  1     1    -1 0.0550 0.0855 0.4009 0.4919 0.5965
   0.6722 0.75840 0.83610 0.97280 1.08790 1.1996 1.2700 1.3482 1.6398
   1.99800 2.13380 2.13380 2.13380 2.13380 2.13380 2.13380
  1978    1      1  1     1    -1 0.0517 0.0725 0.1275 0.4699 0.5302
   0.6026 0.63920 0.73970 0.84220 0.98110 1.0997 1.2459 1.3295 1.4814
   1.74190 2.33530 2.33530 2.33530 2.33530 2.33530 2.33530
  1979    1      1  1     1    -1 0.0484 0.0763 0.2410 0.2587 0.5821
   0.6868 0.76770 0.89090 0.91280 1.03690 1.1987 1.2482 1.5326 1.5520
   1.79500 1.98170 1.98170 1.98170 1.98170 1.98170 1.98170
  1980    1      1  1     1    -1 0.0452 0.0800 0.2125 0.4529 0.3922
   0.4904 0.51660 0.65540 0.71360 0.87400 1.0626 1.1623 1.2898 1.3001
   1.26990 1.39610 1.39610 1.39610 1.39610 1.39610 1.39610
  1981    1      1  1     1    -1 0.0419 0.1074 0.2137 0.3422 0.5264
   0.3933 0.52540 0.54620 0.74640 0.72040 0.8231 1.0413 1.0989 1.3449
   1.49260 1.21280 1.21280 1.21280 1.21280 1.21280 1.21280
  1982    1      1  1     1    -1 0.0386 0.1181 0.2465 0.3336 0.3123
   0.5575 0.40210 0.53380 0.57100 0.76980 0.6997 0.8618 1.0597 0.9367
   1.02770 1.16930 1.16930 1.16930 1.16930 1.16930 1.16930
  1983    1      1  1     1    -1 0.0353 0.1287 0.1357 0.3410 0.3694
   0.3277 0.52000 0.50280 0.61790 0.70600 0.8800 0.9299 1.0356 1.0310
   1.32170 1.48230 1.48230 1.48230 1.48230 1.48230 1.48230
  1984    1      1  1     1    -1 0.0321 0.1315 0.1642 0.2493 0.4384
   0.4113 0.43520 0.58720 0.58020 0.67580 0.7010 0.9513 1.1364 1.0258
   1.28070 1.88000 1.88000 1.88000 1.88000 1.88000 1.88000
  1985    1      1  1     1    -1 0.0288 0.1740 0.2215 0.2511 0.4071
   0.5454 0.53820 0.55800 0.70040 0.63060 0.6711 0.8584 0.7533 0.9458
   0.67590 0.85730 0.85730 0.85730 0.85730 0.85730 0.85730
  1986    1      1  1     1    -1 0.0255 0.1555 0.2780 0.2906 0.3024
   0.3735 0.54260 0.57200 0.64210 0.82090 0.9403 1.1860 1.1900 1.3737
   1.68000 1.61420 1.61420 1.61420 1.61420 1.61420 1.61420
  1987    1      1  1     1    -1 0.0222 0.1478 0.1388 0.3790 0.2786
   0.2870 0.36210 0.57750 0.59750 0.63690 0.7638 0.9820 0.9250 1.2407
   1.20310 1.41570 1.41570 1.41570 1.41570 1.41570 1.41570
  1988    1      1  1     1    -1 0.0190 0.1400 0.1870 0.3189 0.4711
   0.3690 0.37300 0.51640 0.64730 0.68830 0.7184 0.9212 1.0929 1.0208
   1.45000 1.45390 1.45390 1.45390 1.45390 1.45390 1.45390
```

```
1989    1       1  1      1    -1 0.0157 0.1389 0.2737 0.3120 0.2931
 0.5158 0.43860 0.40640 0.51670 0.65090 0.6736 0.6298 0.9105 0.6686
 0.82820 1.17090 1.17090 1.17090 1.17090 1.17090 1.17090
1990    1       1  1      1    -1 0.0156 0.1378 0.2435 0.3520 0.4039
 0.5176 0.55880 0.64420 0.66580 0.53000 0.7776 0.8148 2.2000 1.1873
 1.01660 1.44950 1.44950 1.44950 1.44950 1.44950 1.44950
1991    1       1  1      1    -1 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.54370 0.59070 0.72100 0.84970 1.0997 0.7185 0.6403 1.0187
 1.20510 2.38280 2.38280 2.38280 2.38280 2.38280 2.38280
1992    1       1  1      1    -1 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.58170 0.62100 0.64060 0.65300 0.6330 0.7217 0.7354 0.8501
 0.97500 1.02720 1.02720 1.02720 1.02720 1.02720 1.02720
1993    1       1  1      1    -1 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.49350 0.50170 0.48800 0.54910 0.5100 1.2630 1.0250 0.6135
 0.59950 0.68500 0.68500 0.68500 0.68500 0.68500 0.68500
1994    1       1  1      1    -1 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.52620 0.57000 0.62180 0.55980 0.6341 0.4850 0.6491 0.7300
 0.70130 0.74550 0.74550 0.74550 0.74550 0.74550 0.74550
1995    1       1  1      1    -1 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.65060 0.62490 0.65970 0.75600 0.6670 0.7445 0.7998 0.9101
 0.68040 0.80080 0.80080 0.80080 0.80080 0.80080 0.80080
1996    1       1  1      1    -1 0.0153 0.1018 0.2876 0.3982 0.4674
 0.5317 0.56510 0.65090 0.59570 0.63620 0.6049 0.7500 0.6756 0.8109
 1.48530 0.75090 0.75090 0.75090 0.75090 0.75090 0.75090
1997    1       1  1      1    -1 0.0153 0.0928 0.3555 0.4322 0.4931
 0.5476 0.54530 0.58330 0.58550 0.60710 0.6315 0.8633 0.5946 0.7118
 0.66180 0.86930 0.86930 0.86930 0.86930 0.86930 0.86930
1998    1       1  1      1    -1 0.0152 0.0838 0.2098 0.3592 0.5050
 0.5176 0.54130 0.63440 0.60790 0.67120 0.7829 0.7128 0.7907 0.7733
 0.74370 0.79420 0.79420 0.79420 0.79420 0.79420 0.79420
1999    1       1  1      1    -1 0.0152 0.1368 0.2502 0.3455 0.4251
 0.5265 0.55690 0.57270 0.61170 0.70300 0.6650 0.7989 0.7554 0.8787
 0.73480 0.81870 0.81870 0.81870 0.81870 0.81870 0.81870
2000    1       1  1      1    -1 0.0151 0.1899 0.3852 0.4740 0.5766
 0.6598 0.71760 0.72790 0.75390 0.83780 0.8159 0.8814 0.8554 0.9391
 0.87440 0.93360 0.93360 0.93360 0.93360 0.93360 0.93360
2001    1       1  1      1    -1 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.74690 0.86290 0.85550 0.88020 0.9630 0.9790 1.0054 1.0494
 0.99270 0.97680 0.97680 0.97680 0.97680 0.97680 0.97680
2002    1       1  1      1    -1 0.0150 0.0756 0.3583 0.4563 0.5824
 0.7448 0.72300 0.78010 0.91370 0.85710 0.8768 0.9030 0.8378 0.8378
 1.08050 1.04690 1.04690 1.04690 1.04690 1.04690 1.04690
2003    1       1  1      1    -1 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.75500 0.69190 0.74690 0.82460 0.7685 0.8927 0.9266 0.7894
 0.84140 0.99650 0.99650 0.99650 0.99650 0.99650 0.99650
2004    1       1  1      1    -1 0.0149 0.1081 0.2050 0.4360 0.4806
 0.5319 0.64790 0.70730 0.65790 0.70920 0.8049 0.8580 0.7716 0.9706
 0.86360 0.89610 0.89610 0.89610 0.89610 0.89610 0.89610
2005    1       1  1      1    -1 0.0149 0.1162 0.2603 0.4312 0.5086
 0.5394 0.56820 0.63360 0.65500 0.70280 0.7963 0.8105 0.8109 0.7601
 1.14490 0.96760 0.96760 0.96760 0.96760 0.96760 0.96760
2006    1       1  1      1    -1 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.59100 0.59790 0.65600 0.69970 0.7259 0.7220 0.7753 0.6580
 0.63990 0.95500 0.95500 0.95500 0.95500 0.95500 0.95500
```

```
  2007    1      1  1     1    -1 0.0148 0.0445 0.2284 0.4175 0.5370
   0.5642 0.60730 0.63280 0.64760 0.70550 0.7723 0.7627 0.8137 0.8702
   0.80080 0.86980 0.86980 0.86980 0.86980 0.86980 0.86980
  2008    1      1  1     1    -1 0.0142 0.1346 0.2440 0.4079 0.5630
   0.6365 0.68650 0.68180 0.70980 0.72110 0.7488 0.8073 0.8483 0.7755
   0.88340 0.83320 0.83320 0.83320 0.83320 0.83320 0.83320
  2009    1      1  1     1    -1 0.0135 0.0654 0.2463 0.3406 0.4623
   0.6284 0.65670 0.67230 0.74830 0.81400 0.7603 0.8087 1.0293 0.8403
   0.97940 1.03340 1.03340 1.03340 1.03340 1.03340 1.03340
  2010    1      1  1     1    -1 0.0129 0.1089 0.2326 0.2918 0.4332
   0.5302 0.65820 0.83490 1.08280 1.02760 0.9582 0.8763 0.8524 1.1253
   0.72000 0.90210 0.90210 0.90210 0.90210 0.90210 0.90210
  2011    1      1  1     1    -1 0.0123 0.0844 0.2457 0.3219 0.3867
   0.5142 0.59500 0.67470 0.85340 0.92940 0.9781 1.0749 1.0588 1.0279
   1.05570 0.92120 0.92120 0.92120 0.92120 0.92120 0.92120
  2012    1      1  1     1    -1 0.0117 0.1290 0.2145 0.3536 0.4094
   0.4889 0.65620 0.69060 0.77760 0.90740 0.9626 0.9642 0.9638 0.9893
   0.99250 0.94270 0.94270 0.94270 0.94270 0.94270 0.94270
  2013    1      1  1     1    -1 0.0110 0.1297 0.2874 0.3595 0.4697
   0.5104 0.62600 0.71650 0.73100 0.83130 0.9989 1.0752 1.2303 1.1187
   1.06820 1.05450 1.05450 1.05450 1.05450 1.05450 1.05450
  2014    1      1  1     1    -1 0.0104 0.1028 0.4080 0.4686 0.4797
   0.5362 0.57410 0.61980 0.65900 0.71740 0.6950 1.1645 1.0150 0.9491
   0.96740 1.05790 1.05790 1.05790 1.05790 1.05790 1.05790
  2015    1      1  1     1    -1 0.0098 0.0759 0.2471 0.3905 0.4445
   0.4708 0.55310 0.59480 0.67490 0.68790 0.7179 0.8337 0.9523 1.0185
   1.08930 1.24930 1.24930 1.24930 1.24930 1.24930 1.24930
  2016    1      1  1     1    -1 0.0092 0.1653 0.2439 0.3831 0.4164
   0.4410 0.46570 0.51350 0.51820 0.51340 0.6617 0.7198 0.5921 0.9564
   1.45100 1.45410 1.45410 1.45410 1.45410 1.45410 1.45410
  2017    1      1  1     1    -1 0.0085 0.1403 0.3115 0.4016 0.4857
   0.5264 0.56130 0.55370 0.58050 0.65550 0.6127 0.7202 0.7990 0.7750
   0.81450 0.93270 0.93270 0.93270 0.93270 0.93270 0.93270
  2018    1      1  1     1    -1 0.0143 0.1870 0.3544 0.4633 0.5029
   0.5357 0.55180 0.61740 0.58960 0.63930 0.6431 0.6761 0.6887 0.7238
   0.89700 1.07000 1.07000 1.07000 1.07000 1.07000 1.07000
  2019    1      1  1     1    -1 0.0200 0.0677 0.2872 0.4459 0.5524
   0.5402 0.61060 0.62680 0.67140 0.68280 0.7290 0.7687 0.7150 0.8283
   0.88880 0.94060 0.94060 0.94060 0.94060 0.94060 0.94060
  2020    1      1  1     1    -1 0.0200 0.0677 0.3450 0.4761 0.5076
   0.5607 0.56970 0.59080 0.60050 0.63990 0.6465 0.7007 0.6337 0.8390
   0.87400 0.93500 0.93500 0.93500 0.93500 0.93500 0.93500
  2021    1      1  1     1    -1 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2022    1      1  1     1    -1 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2023    1      1  1     1    -1 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648

#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 0.0135 0.0921 0.2575 0.3833 0.4855
  0.5326 0.58180 0.65380 0.71140 0.77750 0.8437 0.9246 0.9645 1.0613
  1.00190 1.03480 1.03480 1.03480 1.03480 1.03480 1.03480
 1975    1      1  1     1     0 0.0550 0.1575 0.2987 0.3658 0.6143
  0.6306 0.78730 0.87380 0.96780 0.90750 0.9700 1.6933 1.5000 1.9000
  1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
 1976    1      1  1     1     0 0.0550 0.0986 0.2359 0.4990 0.5188
  0.6936 0.80380 0.91650 1.20630 1.33350 1.4495 1.6507 1.8066 1.8588
  1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
 1977    1      1  1     1     0 0.0550 0.0855 0.4009 0.4919 0.5965
  0.6722 0.75840 0.83610 0.97280 1.08790 1.1996 1.2700 1.3482 1.6398
  1.99800 2.13380 2.13380 2.13380 2.13380 2.13380 2.13380
 1978    1      1  1     1     0 0.0517 0.0725 0.1275 0.4699 0.5302
  0.6026 0.63920 0.73970 0.84220 0.98110 1.0997 1.2459 1.3295 1.4814
  1.74190 2.33530 2.33530 2.33530 2.33530 2.33530 2.33530
 1979    1      1  1     1     0 0.0484 0.0763 0.2410 0.2587 0.5821
  0.6868 0.76770 0.89090 0.91280 1.03690 1.1987 1.2482 1.5326 1.5520
  1.79500 1.98170 1.98170 1.98170 1.98170 1.98170 1.98170
 1980    1      1  1     1     0 0.0452 0.0800 0.2125 0.4529 0.3922
  0.4904 0.51660 0.65540 0.71360 0.87400 1.0626 1.1623 1.2898 1.3001
  1.26990 1.39610 1.39610 1.39610 1.39610 1.39610 1.39610
 1981    1      1  1     1     0 0.0419 0.1074 0.2137 0.3422 0.5264
  0.3933 0.52540 0.54620 0.74640 0.72040 0.8231 1.0413 1.0989 1.3449
  1.49260 1.21280 1.21280 1.21280 1.21280 1.21280 1.21280
 1982    1      1  1     1     0 0.0386 0.1181 0.2465 0.3336 0.3123
  0.5575 0.40210 0.53380 0.57100 0.76980 0.6997 0.8618 1.0597 0.9367
  1.02770 1.16930 1.16930 1.16930 1.16930 1.16930 1.16930
 1983    1      1  1     1     0 0.0353 0.1287 0.1357 0.3410 0.3694
  0.3277 0.52000 0.50280 0.61790 0.70600 0.8800 0.9299 1.0356 1.0310
  1.32170 1.48230 1.48230 1.48230 1.48230 1.48230 1.48230
 1984    1      1  1     1     0 0.0321 0.1315 0.1642 0.2493 0.4384
  0.4113 0.43520 0.58720 0.58020 0.67580 0.7010 0.9513 1.1364 1.0258
  1.28070 1.88000 1.88000 1.88000 1.88000 1.88000 1.88000
 1985    1      1  1     1     0 0.0288 0.1740 0.2215 0.2511 0.4071
  0.5454 0.53820 0.55800 0.70040 0.63060 0.6711 0.8584 0.7533 0.9458
  0.67590 0.85730 0.85730 0.85730 0.85730 0.85730 0.85730
 1986    1      1  1     1     0 0.0255 0.1555 0.2780 0.2906 0.3024
  0.3735 0.54260 0.57200 0.64210 0.82090 0.9403 1.1860 1.1900 1.3737
  1.68000 1.61420 1.61420 1.61420 1.61420 1.61420 1.61420
 1987    1      1  1     1     0 0.0222 0.1478 0.1388 0.3790 0.2786
  0.2870 0.36210 0.57750 0.59750 0.63690 0.7638 0.9820 0.9250 1.2407
  1.20310 1.41570 1.41570 1.41570 1.41570 1.41570 1.41570
 1988    1      1  1     1     0 0.0190 0.1400 0.1870 0.3189 0.4711
  0.3690 0.37300 0.51640 0.64730 0.68830 0.7184 0.9212 1.0929 1.0208
  1.45000 1.45390 1.45390 1.45390 1.45390 1.45390 1.45390
 1989    1      1  1     1     0 0.0157 0.1389 0.2737 0.3120 0.2931
  0.5158 0.43860 0.40640 0.51670 0.65090 0.6736 0.6298 0.9105 0.6686
  0.82820 1.17090 1.17090 1.17090 1.17090 1.17090 1.17090
 1990    1      1  1     1     0 0.0156 0.1378 0.2435 0.3520 0.4039
  0.5176 0.55880 0.64420 0.66580 0.53000 0.7776 0.8148 2.2000 1.1873
  1.01660 1.44950 1.44950 1.44950 1.44950 1.44950 1.44950
```

```
1991    1       1  1     1     0 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.54370 0.59070 0.72100 0.84970 1.0997 0.7185 0.6403 1.0187
 1.20510 2.38280 2.38280 2.38280 2.38280 2.38280 2.38280
1992    1       1  1     1     0 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.58170 0.62100 0.64060 0.65300 0.6330 0.7217 0.7354 0.8501
 0.97500 1.02720 1.02720 1.02720 1.02720 1.02720 1.02720
1993    1       1  1     1     0 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.49350 0.50170 0.48800 0.54910 0.5100 1.2630 1.0250 0.6135
 0.59950 0.68500 0.68500 0.68500 0.68500 0.68500 0.68500
1994    1       1  1     1     0 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.52620 0.57000 0.62180 0.55980 0.6341 0.4850 0.6491 0.7300
 0.70130 0.74550 0.74550 0.74550 0.74550 0.74550 0.74550
1995    1       1  1     1     0 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.65060 0.62490 0.65970 0.75600 0.6670 0.7445 0.7998 0.9101
 0.68040 0.80080 0.80080 0.80080 0.80080 0.80080 0.80080
1996    1       1  1     1     0 0.0153 0.1018 0.2876 0.3982 0.4674
 0.5317 0.56510 0.65090 0.59570 0.63620 0.6049 0.7500 0.6756 0.8109
 1.48530 0.75090 0.75090 0.75090 0.75090 0.75090 0.75090
1997    1       1  1     1     0 0.0153 0.0928 0.3555 0.4322 0.4931
 0.5476 0.54530 0.58330 0.58550 0.60710 0.6315 0.8633 0.5946 0.7118
 0.66180 0.86930 0.86930 0.86930 0.86930 0.86930 0.86930
1998    1       1  1     1     0 0.0152 0.0838 0.2098 0.3592 0.5050
 0.5176 0.54130 0.63440 0.60790 0.67120 0.7829 0.7128 0.7907 0.7733
 0.74370 0.79420 0.79420 0.79420 0.79420 0.79420 0.79420
1999    1       1  1     1     0 0.0152 0.1368 0.2502 0.3455 0.4251
 0.5265 0.55690 0.57270 0.61170 0.70300 0.6650 0.7989 0.7554 0.8787
 0.73480 0.81870 0.81870 0.81870 0.81870 0.81870 0.81870
2000    1       1  1     1     0 0.0151 0.1899 0.3852 0.4740 0.5766
 0.6598 0.71760 0.72790 0.75390 0.83780 0.8159 0.8814 0.8554 0.9391
 0.87440 0.93360 0.93360 0.93360 0.93360 0.93360 0.93360
2001    1       1  1     1     0 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.74690 0.86290 0.85550 0.88020 0.9630 0.9790 1.0054 1.0494
 0.99270 0.97680 0.97680 0.97680 0.97680 0.97680 0.97680
2002    1       1  1     1     0 0.0150 0.0756 0.3583 0.4563 0.5824
 0.7448 0.72300 0.78010 0.91370 0.85710 0.8768 0.9030 0.8378 0.8378
 1.08050 1.04690 1.04690 1.04690 1.04690 1.04690 1.04690
2003    1       1  1     1     0 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.75500 0.69190 0.74690 0.82460 0.7685 0.8927 0.9266 0.7894
 0.84140 0.99650 0.99650 0.99650 0.99650 0.99650 0.99650
2004    1       1  1     1     0 0.0149 0.1081 0.2050 0.4360 0.4806
 0.5319 0.64790 0.70730 0.65790 0.70920 0.8049 0.8580 0.7716 0.9706
 0.86360 0.89610 0.89610 0.89610 0.89610 0.89610 0.89610
2005    1       1  1     1     0 0.0149 0.1162 0.2603 0.4312 0.5086
 0.5394 0.56820 0.63360 0.65500 0.70280 0.7963 0.8105 0.8109 0.7601
 1.14490 0.96760 0.96760 0.96760 0.96760 0.96760 0.96760
2006    1       1  1     1     0 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.59100 0.59790 0.65600 0.69970 0.7259 0.7220 0.7753 0.6580
 0.63990 0.95500 0.95500 0.95500 0.95500 0.95500 0.95500
2007    1       1  1     1     0 0.0148 0.0445 0.2284 0.4175 0.5370
 0.5642 0.60730 0.63280 0.64760 0.70550 0.7723 0.7627 0.8137 0.8702
 0.80080 0.86980 0.86980 0.86980 0.86980 0.86980 0.86980
2008    1       1  1     1     0 0.0142 0.1346 0.2440 0.4079 0.5630
 0.6365 0.68650 0.68180 0.70980 0.72110 0.7488 0.8073 0.8483 0.7755
 0.88340 0.83320 0.83320 0.83320 0.83320 0.83320 0.83320
```

```
  2009    1      1  1     1     0 0.0135 0.0654 0.2463 0.3406 0.4623
   0.6284 0.65670 0.67230 0.74830 0.81400 0.7603 0.8087 1.0293 0.8403
   0.97940 1.03340 1.03340 1.03340 1.03340 1.03340 1.03340
  2010    1      1  1     1     0 0.0129 0.1089 0.2326 0.2918 0.4332
   0.5302 0.65820 0.83490 1.08280 1.02760 0.9582 0.8763 0.8524 1.1253
   0.72000 0.90210 0.90210 0.90210 0.90210 0.90210 0.90210
  2011    1      1  1     1     0 0.0123 0.0844 0.2457 0.3219 0.3867
   0.5142 0.59500 0.67470 0.85340 0.92940 0.9781 1.0749 1.0588 1.0279
   1.05570 0.92120 0.92120 0.92120 0.92120 0.92120 0.92120
  2012    1      1  1     1     0 0.0117 0.1290 0.2145 0.3536 0.4094
   0.4889 0.65620 0.69060 0.77760 0.90740 0.9626 0.9642 0.9638 0.9893
   0.99250 0.94270 0.94270 0.94270 0.94270 0.94270 0.94270
  2013    1      1  1     1     0 0.0110 0.1297 0.2874 0.3595 0.4697
   0.5104 0.62600 0.71650 0.73100 0.83130 0.9989 1.0752 1.2303 1.1187
   1.06820 1.05450 1.05450 1.05450 1.05450 1.05450 1.05450
  2014    1      1  1     1     0 0.0104 0.1028 0.4080 0.4686 0.4797
   0.5362 0.57410 0.61980 0.65900 0.71740 0.6950 1.1645 1.0150 0.9491
   0.96740 1.05790 1.05790 1.05790 1.05790 1.05790 1.05790
  2015    1      1  1     1     0 0.0098 0.0759 0.2471 0.3905 0.4445
   0.4708 0.55310 0.59480 0.67490 0.68790 0.7179 0.8337 0.9523 1.0185
   1.08930 1.24930 1.24930 1.24930 1.24930 1.24930 1.24930
  2016    1      1  1     1     0 0.0092 0.1653 0.2439 0.3831 0.4164
   0.4410 0.46570 0.51350 0.51820 0.51340 0.6617 0.7198 0.5921 0.9564
   1.45100 1.45410 1.45410 1.45410 1.45410 1.45410 1.45410
  2017    1      1  1     1     0 0.0085 0.1403 0.3115 0.4016 0.4857
   0.5264 0.56130 0.55370 0.58050 0.65550 0.6127 0.7202 0.7990 0.7750
   0.81450 0.93270 0.93270 0.93270 0.93270 0.93270 0.93270
  2018    1      1  1     1     0 0.0143 0.1870 0.3544 0.4633 0.5029
   0.5357 0.55180 0.61740 0.58960 0.63930 0.6431 0.6761 0.6887 0.7238
   0.89700 1.07000 1.07000 1.07000 1.07000 1.07000 1.07000
  2019    1      1  1     1     0 0.0200 0.0677 0.2872 0.4459 0.5524
   0.5402 0.61060 0.62680 0.67140 0.68280 0.7290 0.7687 0.7150 0.8283
   0.88880 0.94060 0.94060 0.94060 0.94060 0.94060 0.94060
  2020    1      1  1     1     0 0.0200 0.0677 0.3450 0.4761 0.5076
   0.5607 0.56970 0.59080 0.60050 0.63990 0.6465 0.7007 0.6337 0.8390
   0.87400 0.93500 0.93500 0.93500 0.93500 0.93500 0.93500
  2021    1      1  1     1     0 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2022    1      1  1     1     0 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2023    1      1  1     1     0 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648

#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 0.0135 0.0921 0.2575 0.3833 0.4855
   0.5326 0.58180 0.65380 0.71140 0.77750 0.8437 0.9246 0.9645 1.0613
   1.00190 1.03480 1.03480 1.03480 1.03480 1.03480 1.03480
```

```
1975     1       1  1      1      1 0.0550 0.1575 0.2987 0.3658 0.6143
 0.6306 0.78730 0.87380 0.96780 0.90750 0.9700 1.6933 1.5000 1.9000
 1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
1976     1       1  1      1      1 0.0550 0.0986 0.2359 0.4990 0.5188
 0.6936 0.80380 0.91650 1.20630 1.33350 1.4495 1.6507 1.8066 1.8588
 1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
1977     1       1  1      1      1 0.0550 0.0855 0.4009 0.4919 0.5965
 0.6722 0.75840 0.83610 0.97280 1.08790 1.1996 1.2700 1.3482 1.6398
 1.99800 2.13380 2.13380 2.13380 2.13380 2.13380 2.13380
1978     1       1  1      1      1 0.0517 0.0725 0.1275 0.4699 0.5302
 0.6026 0.63920 0.73970 0.84220 0.98110 1.0997 1.2459 1.3295 1.4814
 1.74190 2.33530 2.33530 2.33530 2.33530 2.33530 2.33530
1979     1       1  1      1      1 0.0484 0.0763 0.2410 0.2587 0.5821
 0.6868 0.76770 0.89090 0.91280 1.03690 1.1987 1.2482 1.5326 1.5520
 1.79500 1.98170 1.98170 1.98170 1.98170 1.98170 1.98170
1980     1       1  1      1      1 0.0452 0.0800 0.2125 0.4529 0.3922
 0.4904 0.51660 0.65540 0.71360 0.87400 1.0626 1.1623 1.2898 1.3001
 1.26990 1.39610 1.39610 1.39610 1.39610 1.39610 1.39610
1981     1       1  1      1      1 0.0419 0.1074 0.2137 0.3422 0.5264
 0.3933 0.52540 0.54620 0.74640 0.72040 0.8231 1.0413 1.0989 1.3449
 1.49260 1.21280 1.21280 1.21280 1.21280 1.21280 1.21280
1982     1       1  1      1      1 0.0386 0.1181 0.2465 0.3336 0.3123
 0.5575 0.40210 0.53380 0.57100 0.76980 0.6997 0.8618 1.0597 0.9367
 1.02770 1.16930 1.16930 1.16930 1.16930 1.16930 1.16930
1983     1       1  1      1      1 0.0353 0.1287 0.1357 0.3410 0.3694
 0.3277 0.52000 0.50280 0.61790 0.70600 0.8800 0.9299 1.0356 1.0310
 1.32170 1.48230 1.48230 1.48230 1.48230 1.48230 1.48230
1984     1       1  1      1      1 0.0321 0.1315 0.1642 0.2493 0.4384
 0.4113 0.43520 0.58720 0.58020 0.67580 0.7010 0.9513 1.1364 1.0258
 1.28070 1.88000 1.88000 1.88000 1.88000 1.88000 1.88000
1985     1       1  1      1      1 0.0288 0.1740 0.2215 0.2511 0.4071
 0.5454 0.53820 0.55800 0.70040 0.63060 0.6711 0.8584 0.7533 0.9458
 0.67590 0.85730 0.85730 0.85730 0.85730 0.85730 0.85730
1986     1       1  1      1      1 0.0255 0.1555 0.2780 0.2906 0.3024
 0.3735 0.54260 0.57200 0.64210 0.82090 0.9403 1.1860 1.1900 1.3737
 1.68000 1.61420 1.61420 1.61420 1.61420 1.61420 1.61420
1987     1       1  1      1      1 0.0222 0.1478 0.1388 0.3790 0.2786
 0.2870 0.36210 0.57750 0.59750 0.63690 0.7638 0.9820 0.9250 1.2407
 1.20310 1.41570 1.41570 1.41570 1.41570 1.41570 1.41570
1988     1       1  1      1      1 0.0190 0.1400 0.1870 0.3189 0.4711
 0.3690 0.37300 0.51640 0.64730 0.68830 0.7184 0.9212 1.0929 1.0208
 1.45000 1.45390 1.45390 1.45390 1.45390 1.45390 1.45390
1989     1       1  1      1      1 0.0157 0.1389 0.2737 0.3120 0.2931
 0.5158 0.43860 0.40640 0.51670 0.65090 0.6736 0.6298 0.9105 0.6686
 0.82820 1.17090 1.17090 1.17090 1.17090 1.17090 1.17090
1990     1       1  1      1      1 0.0156 0.1378 0.2435 0.3520 0.4039
 0.5176 0.55880 0.64420 0.66580 0.53000 0.7776 0.8148 2.2000 1.1873
 1.01660 1.44950 1.44950 1.44950 1.44950 1.44950 1.44950
1991     1       1  1      1      1 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.54370 0.59070 0.72100 0.84970 1.0997 0.7185 0.6403 1.0187
 1.20510 2.38280 2.38280 2.38280 2.38280 2.38280 2.38280
1992     1       1  1      1      1 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.58170 0.62100 0.64060 0.65300 0.6330 0.7217 0.7354 0.8501
 0.97500 1.02720 1.02720 1.02720 1.02720 1.02720 1.02720
```

```
1993    1      1  1     1     1 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.49350 0.50170 0.48800 0.54910 0.5100 1.2630 1.0250 0.6135
 0.59950 0.68500 0.68500 0.68500 0.68500 0.68500 0.68500
1994    1      1  1     1     1 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.52620 0.57000 0.62180 0.55980 0.6341 0.4850 0.6491 0.7300
 0.70130 0.74550 0.74550 0.74550 0.74550 0.74550 0.74550
1995    1      1  1     1     1 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.65060 0.62490 0.65970 0.75600 0.6670 0.7445 0.7998 0.9101
 0.68040 0.80080 0.80080 0.80080 0.80080 0.80080 0.80080
1996    1      1  1     1     1 0.0153 0.1018 0.2876 0.3982 0.4674
 0.5317 0.56510 0.65090 0.59570 0.63620 0.6049 0.7500 0.6756 0.8109
 1.48530 0.75090 0.75090 0.75090 0.75090 0.75090 0.75090
1997    1      1  1     1     1 0.0153 0.0928 0.3555 0.4322 0.4931
 0.5476 0.54530 0.58330 0.58550 0.60710 0.6315 0.8633 0.5946 0.7118
 0.66180 0.86930 0.86930 0.86930 0.86930 0.86930 0.86930
1998    1      1  1     1     1 0.0152 0.0838 0.2098 0.3592 0.5050
 0.5176 0.54130 0.63440 0.60790 0.67120 0.7829 0.7128 0.7907 0.7733
 0.74370 0.79420 0.79420 0.79420 0.79420 0.79420 0.79420
1999    1      1  1     1     1 0.0152 0.1368 0.2502 0.3455 0.4251
 0.5265 0.55690 0.57270 0.61170 0.70300 0.6650 0.7989 0.7554 0.8787
 0.73480 0.81870 0.81870 0.81870 0.81870 0.81870 0.81870
2000    1      1  1     1     1 0.0151 0.1899 0.3852 0.4740 0.5766
 0.6598 0.71760 0.72790 0.75390 0.83780 0.8159 0.8814 0.8554 0.9391
 0.87440 0.93360 0.93360 0.93360 0.93360 0.93360 0.93360
2001    1      1  1     1     1 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.74690 0.86290 0.85550 0.88020 0.9630 0.9790 1.0054 1.0494
 0.99270 0.97680 0.97680 0.97680 0.97680 0.97680 0.97680
2002    1      1  1     1     1 0.0150 0.0756 0.3583 0.4563 0.5824
 0.7448 0.72300 0.78010 0.91370 0.85710 0.8768 0.9030 0.8378 0.8378
 1.08050 1.04690 1.04690 1.04690 1.04690 1.04690 1.04690
2003    1      1  1     1     1 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.75500 0.69190 0.74690 0.82460 0.7685 0.8927 0.9266 0.7894
 0.84140 0.99650 0.99650 0.99650 0.99650 0.99650 0.99650
2004    1      1  1     1     1 0.0149 0.1081 0.2050 0.4360 0.4806
 0.5319 0.64790 0.70730 0.65790 0.70920 0.8049 0.8580 0.7716 0.9706
 0.86360 0.89610 0.89610 0.89610 0.89610 0.89610 0.89610
2005    1      1  1     1     1 0.0149 0.1162 0.2603 0.4312 0.5086
 0.5394 0.56820 0.63360 0.65500 0.70280 0.7963 0.8105 0.8109 0.7601
 1.14490 0.96760 0.96760 0.96760 0.96760 0.96760 0.96760
2006    1      1  1     1     1 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.59100 0.59790 0.65600 0.69970 0.7259 0.7220 0.7753 0.6580
 0.63990 0.95500 0.95500 0.95500 0.95500 0.95500 0.95500
2007    1      1  1     1     1 0.0148 0.0445 0.2284 0.4175 0.5370
 0.5642 0.60730 0.63280 0.64760 0.70550 0.7723 0.7627 0.8137 0.8702
 0.80080 0.86980 0.86980 0.86980 0.86980 0.86980 0.86980
2008    1      1  1     1     1 0.0142 0.1346 0.2440 0.4079 0.5630
 0.6365 0.68650 0.68180 0.70980 0.72110 0.7488 0.8073 0.8483 0.7755
 0.88340 0.83320 0.83320 0.83320 0.83320 0.83320 0.83320
2009    1      1  1     1     1 0.0135 0.0654 0.2463 0.3406 0.4623
 0.6284 0.65670 0.67230 0.74830 0.81400 0.7603 0.8087 1.0293 0.8403
 0.97940 1.03340 1.03340 1.03340 1.03340 1.03340 1.03340
2010    1      1  1     1     1 0.0129 0.1089 0.2326 0.2918 0.4332
 0.5302 0.65820 0.83490 1.08280 1.02760 0.9582 0.8763 0.8524 1.1253
 0.72000 0.90210 0.90210 0.90210 0.90210 0.90210 0.90210
```

```
  2011    1      1  1     1     1 0.0123 0.0844 0.2457 0.3219 0.3867
   0.5142 0.59500 0.67470 0.85340 0.92940 0.9781 1.0749 1.0588 1.0279
   1.05570 0.92120 0.92120 0.92120 0.92120 0.92120 0.92120
  2012    1      1  1     1     1 0.0117 0.1290 0.2145 0.3536 0.4094
   0.4889 0.65620 0.69060 0.77760 0.90740 0.9626 0.9642 0.9638 0.9893
   0.99250 0.94270 0.94270 0.94270 0.94270 0.94270 0.94270
  2013    1      1  1     1     1 0.0110 0.1297 0.2874 0.3595 0.4697
   0.5104 0.62600 0.71650 0.73100 0.83130 0.9989 1.0752 1.2303 1.1187
   1.06820 1.05450 1.05450 1.05450 1.05450 1.05450 1.05450
  2014    1      1  1     1     1 0.0104 0.1028 0.4080 0.4686 0.4797
   0.5362 0.57410 0.61980 0.65900 0.71740 0.6950 1.1645 1.0150 0.9491
   0.96740 1.05790 1.05790 1.05790 1.05790 1.05790 1.05790
  2015    1      1  1     1     1 0.0098 0.0759 0.2471 0.3905 0.4445
   0.4708 0.55310 0.59480 0.67490 0.68790 0.7179 0.8337 0.9523 1.0185
   1.08930 1.24930 1.24930 1.24930 1.24930 1.24930 1.24930
  2016    1      1  1     1     1 0.0092 0.1653 0.2439 0.3831 0.4164
   0.4410 0.46570 0.51350 0.51820 0.51340 0.6617 0.7198 0.5921 0.9564
   1.45100 1.45410 1.45410 1.45410 1.45410 1.45410 1.45410
  2017    1      1  1     1     1 0.0085 0.1403 0.3115 0.4016 0.4857
   0.5264 0.56130 0.55370 0.58050 0.65550 0.6127 0.7202 0.7990 0.7750
   0.81450 0.93270 0.93270 0.93270 0.93270 0.93270 0.93270
  2018    1      1  1     1     1 0.0143 0.1870 0.3544 0.4633 0.5029
   0.5357 0.55180 0.61740 0.58960 0.63930 0.6431 0.6761 0.6887 0.7238
   0.89700 1.07000 1.07000 1.07000 1.07000 1.07000 1.07000
  2019    1      1  1     1     1 0.0200 0.0677 0.2872 0.4459 0.5524
   0.5402 0.61060 0.62680 0.67140 0.68280 0.7290 0.7687 0.7150 0.8283
   0.88880 0.94060 0.94060 0.94060 0.94060 0.94060 0.94060
  2020    1      1  1     1     1 0.0200 0.0677 0.3450 0.4761 0.5076
   0.5607 0.56970 0.59080 0.60050 0.63990 0.6465 0.7007 0.6337 0.8390
   0.87400 0.93500 0.93500 0.93500 0.93500 0.93500 0.93500
  2021    1      1  1     1     1 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2022    1      1  1     1     1 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2023    1      1  1     1     1 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648

#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 0.0135 0.0921 0.2575 0.3833 0.4855
   0.5326 0.58180 0.65380 0.71140 0.77750 0.8437 0.9246 0.9645 1.0613
   1.00190 1.03480 1.03480 1.03480 1.03480 1.03480 1.03480
  1975    1      1  1     1     2 0.0550 0.1575 0.2987 0.3658 0.6143
   0.6306 0.78730 0.87380 0.96780 0.90750 0.9700 1.6933 1.5000 1.9000
   1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
  1976    1      1  1     1     2 0.0550 0.0986 0.2359 0.4990 0.5188
   0.6936 0.80380 0.91650 1.20630 1.33350 1.4495 1.6507 1.8066 1.8588
   1.95550 2.74450 2.74450 2.74450 2.74450 2.74450 2.74450
```

```
1977    1       1  1      1      2 0.0550 0.0855 0.4009 0.4919 0.5965
 0.6722 0.75840 0.83610 0.97280 1.08790 1.1996 1.2700 1.3482 1.6398
 1.99800 2.13380 2.13380 2.13380 2.13380 2.13380 2.13380
1978    1       1  1      1      2 0.0517 0.0725 0.1275 0.4699 0.5302
 0.6026 0.63920 0.73970 0.84220 0.98110 1.0997 1.2459 1.3295 1.4814
 1.74190 2.33530 2.33530 2.33530 2.33530 2.33530 2.33530
1979    1       1  1      1      2 0.0484 0.0763 0.2410 0.2587 0.5821
 0.6868 0.76770 0.89090 0.91280 1.03690 1.1987 1.2482 1.5326 1.5520
 1.79500 1.98170 1.98170 1.98170 1.98170 1.98170 1.98170
1980    1       1  1      1      2 0.0452 0.0800 0.2125 0.4529 0.3922
 0.4904 0.51660 0.65540 0.71360 0.87400 1.0626 1.1623 1.2898 1.3001
 1.26990 1.39610 1.39610 1.39610 1.39610 1.39610 1.39610
1981    1       1  1      1      2 0.0419 0.1074 0.2137 0.3422 0.5264
 0.3933 0.52540 0.54620 0.74640 0.72040 0.8231 1.0413 1.0989 1.3449
 1.49260 1.21280 1.21280 1.21280 1.21280 1.21280 1.21280
1982    1       1  1      1      2 0.0386 0.1181 0.2465 0.3336 0.3123
 0.5575 0.40210 0.53380 0.57100 0.76980 0.6997 0.8618 1.0597 0.9367
 1.02770 1.16930 1.16930 1.16930 1.16930 1.16930 1.16930
1983    1       1  1      1      2 0.0353 0.1287 0.1357 0.3410 0.3694
 0.3277 0.52000 0.50280 0.61790 0.70600 0.8800 0.9299 1.0356 1.0310
 1.32170 1.48230 1.48230 1.48230 1.48230 1.48230 1.48230
1984    1       1  1      1      2 0.0321 0.1315 0.1642 0.2493 0.4384
 0.4113 0.43520 0.58720 0.58020 0.67580 0.7010 0.9513 1.1364 1.0258
 1.28070 1.88000 1.88000 1.88000 1.88000 1.88000 1.88000
1985    1       1  1      1      2 0.0288 0.1740 0.2215 0.2511 0.4071
 0.5454 0.53820 0.55800 0.70040 0.63060 0.6711 0.8584 0.7533 0.9458
 0.67590 0.85730 0.85730 0.85730 0.85730 0.85730 0.85730
1986    1       1  1      1      2 0.0255 0.1555 0.2780 0.2906 0.3024
 0.3735 0.54260 0.57200 0.64210 0.82090 0.9403 1.1860 1.1900 1.3737
 1.68000 1.61420 1.61420 1.61420 1.61420 1.61420 1.61420
1987    1       1  1      1      2 0.0222 0.1478 0.1388 0.3790 0.2786
 0.2870 0.36210 0.57750 0.59750 0.63690 0.7638 0.9820 0.9250 1.2407
 1.20310 1.41570 1.41570 1.41570 1.41570 1.41570 1.41570
1988    1       1  1      1      2 0.0190 0.1400 0.1870 0.3189 0.4711
 0.3690 0.37300 0.51640 0.64730 0.68830 0.7184 0.9212 1.0929 1.0208
 1.45000 1.45390 1.45390 1.45390 1.45390 1.45390 1.45390
1989    1       1  1      1      2 0.0157 0.1389 0.2737 0.3120 0.2931
 0.5158 0.43860 0.40640 0.51670 0.65090 0.6736 0.6298 0.9105 0.6686
 0.82820 1.17090 1.17090 1.17090 1.17090 1.17090 1.17090
1990    1       1  1      1      2 0.0156 0.1378 0.2435 0.3520 0.4039
 0.5176 0.55880 0.64420 0.66580 0.53000 0.7776 0.8148 2.2000 1.1873
 1.01660 1.44950 1.44950 1.44950 1.44950 1.44950 1.44950
1991    1       1  1      1      2 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.54370 0.59070 0.72100 0.84970 1.0997 0.7185 0.6403 1.0187
 1.20510 2.38280 2.38280 2.38280 2.38280 2.38280 2.38280
1992    1       1  1      1      2 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.58170 0.62100 0.64060 0.65300 0.6330 0.7217 0.7354 0.8501
 0.97500 1.02720 1.02720 1.02720 1.02720 1.02720 1.02720
1993    1       1  1      1      2 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.49350 0.50170 0.48800 0.54910 0.5100 1.2630 1.0250 0.6135
 0.59950 0.68500 0.68500 0.68500 0.68500 0.68500 0.68500
1994    1       1  1      1      2 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.52620 0.57000 0.62180 0.55980 0.6341 0.4850 0.6491 0.7300
 0.70130 0.74550 0.74550 0.74550 0.74550 0.74550 0.74550
```

```
1995    1       1  1     1      2 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.65060 0.62490 0.65970 0.75600 0.6670 0.7445 0.7998 0.9101
 0.68040 0.80080 0.80080 0.80080 0.80080 0.80080 0.80080
1996    1       1  1     1      2 0.0153 0.1018 0.2876 0.3982 0.4674
 0.5317 0.56510 0.65090 0.59570 0.63620 0.6049 0.7500 0.6756 0.8109
 1.48530 0.75090 0.75090 0.75090 0.75090 0.75090 0.75090
1997    1       1  1     1      2 0.0153 0.0928 0.3555 0.4322 0.4931
 0.5476 0.54530 0.58330 0.58550 0.60710 0.6315 0.8633 0.5946 0.7118
 0.66180 0.86930 0.86930 0.86930 0.86930 0.86930 0.86930
1998    1       1  1     1      2 0.0152 0.0838 0.2098 0.3592 0.5050
 0.5176 0.54130 0.63440 0.60790 0.67120 0.7829 0.7128 0.7907 0.7733
 0.74370 0.79420 0.79420 0.79420 0.79420 0.79420 0.79420
1999    1       1  1     1      2 0.0152 0.1368 0.2502 0.3455 0.4251
 0.5265 0.55690 0.57270 0.61170 0.70300 0.6650 0.7989 0.7554 0.8787
 0.73480 0.81870 0.81870 0.81870 0.81870 0.81870 0.81870
2000    1       1  1     1      2 0.0151 0.1899 0.3852 0.4740 0.5766
 0.6598 0.71760 0.72790 0.75390 0.83780 0.8159 0.8814 0.8554 0.9391
 0.87440 0.93360 0.93360 0.93360 0.93360 0.93360 0.93360
2001    1       1  1     1      2 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.74690 0.86290 0.85550 0.88020 0.9630 0.9790 1.0054 1.0494
 0.99270 0.97680 0.97680 0.97680 0.97680 0.97680 0.97680
2002    1       1  1     1      2 0.0150 0.0756 0.3583 0.4563 0.5824
 0.7448 0.72300 0.78010 0.91370 0.85710 0.8768 0.9030 0.8378 0.8378
 1.08050 1.04690 1.04690 1.04690 1.04690 1.04690 1.04690
2003    1       1  1     1      2 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.75500 0.69190 0.74690 0.82460 0.7685 0.8927 0.9266 0.7894
 0.84140 0.99650 0.99650 0.99650 0.99650 0.99650 0.99650
2004    1       1  1     1      2 0.0149 0.1081 0.2050 0.4360 0.4806
 0.5319 0.64790 0.70730 0.65790 0.70920 0.8049 0.8580 0.7716 0.9706
 0.86360 0.89610 0.89610 0.89610 0.89610 0.89610 0.89610
2005    1       1  1     1      2 0.0149 0.1162 0.2603 0.4312 0.5086
 0.5394 0.56820 0.63360 0.65500 0.70280 0.7963 0.8105 0.8109 0.7601
 1.14490 0.96760 0.96760 0.96760 0.96760 0.96760 0.96760
2006    1       1  1     1      2 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.59100 0.59790 0.65600 0.69970 0.7259 0.7220 0.7753 0.6580
 0.63990 0.95500 0.95500 0.95500 0.95500 0.95500 0.95500
2007    1       1  1     1      2 0.0148 0.0445 0.2284 0.4175 0.5370
 0.5642 0.60730 0.63280 0.64760 0.70550 0.7723 0.7627 0.8137 0.8702
 0.80080 0.86980 0.86980 0.86980 0.86980 0.86980 0.86980
2008    1       1  1     1      2 0.0142 0.1346 0.2440 0.4079 0.5630
 0.6365 0.68650 0.68180 0.70980 0.72110 0.7488 0.8073 0.8483 0.7755
 0.88340 0.83320 0.83320 0.83320 0.83320 0.83320 0.83320
2009    1       1  1     1      2 0.0135 0.0654 0.2463 0.3406 0.4623
 0.6284 0.65670 0.67230 0.74830 0.81400 0.7603 0.8087 1.0293 0.8403
 0.97940 1.03340 1.03340 1.03340 1.03340 1.03340 1.03340
2010    1       1  1     1      2 0.0129 0.1089 0.2326 0.2918 0.4332
 0.5302 0.65820 0.83490 1.08280 1.02760 0.9582 0.8763 0.8524 1.1253
 0.72000 0.90210 0.90210 0.90210 0.90210 0.90210 0.90210
2011    1       1  1     1      2 0.0123 0.0844 0.2457 0.3219 0.3867
 0.5142 0.59500 0.67470 0.85340 0.92940 0.9781 1.0749 1.0588 1.0279
 1.05570 0.92120 0.92120 0.92120 0.92120 0.92120 0.92120
2012    1       1  1     1      2 0.0117 0.1290 0.2145 0.3536 0.4094
 0.4889 0.65620 0.69060 0.77760 0.90740 0.9626 0.9642 0.9638 0.9893
 0.99250 0.94270 0.94270 0.94270 0.94270 0.94270 0.94270
```

```
  2013    1      1  1     1     2 0.0110 0.1297 0.2874 0.3595 0.4697
   0.5104 0.62600 0.71650 0.73100 0.83130 0.9989 1.0752 1.2303 1.1187
   1.06820 1.05450 1.05450 1.05450 1.05450 1.05450 1.05450
  2014    1      1  1     1     2 0.0104 0.1028 0.4080 0.4686 0.4797
   0.5362 0.57410 0.61980 0.65900 0.71740 0.6950 1.1645 1.0150 0.9491
   0.96740 1.05790 1.05790 1.05790 1.05790 1.05790 1.05790
  2015    1      1  1     1     2 0.0098 0.0759 0.2471 0.3905 0.4445
   0.4708 0.55310 0.59480 0.67490 0.68790 0.7179 0.8337 0.9523 1.0185
   1.08930 1.24930 1.24930 1.24930 1.24930 1.24930 1.24930
  2016    1      1  1     1     2 0.0092 0.1653 0.2439 0.3831 0.4164
   0.4410 0.46570 0.51350 0.51820 0.51340 0.6617 0.7198 0.5921 0.9564
   1.45100 1.45410 1.45410 1.45410 1.45410 1.45410 1.45410
  2017    1      1  1     1     2 0.0085 0.1403 0.3115 0.4016 0.4857
   0.5264 0.56130 0.55370 0.58050 0.65550 0.6127 0.7202 0.7990 0.7750
   0.81450 0.93270 0.93270 0.93270 0.93270 0.93270 0.93270
  2018    1      1  1     1     2 0.0143 0.1870 0.3544 0.4633 0.5029
   0.5357 0.55180 0.61740 0.58960 0.63930 0.6431 0.6761 0.6887 0.7238
   0.89700 1.07000 1.07000 1.07000 1.07000 1.07000 1.07000
  2019    1      1  1     1     2 0.0200 0.0677 0.2872 0.4459 0.5524
   0.5402 0.61060 0.62680 0.67140 0.68280 0.7290 0.7687 0.7150 0.8283
   0.88880 0.94060 0.94060 0.94060 0.94060 0.94060 0.94060
  2020    1      1  1     1     2 0.0200 0.0677 0.3450 0.4761 0.5076
   0.5607 0.56970 0.59080 0.60050 0.63990 0.6465 0.7007 0.6337 0.8390
   0.87400 0.93500 0.93500 0.93500 0.93500 0.93500 0.93500
  2021    1      1  1     1     2 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2022    1      1  1     1     2 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648
  2023    1      1  1     1     2 0.0144 0.1256 0.3084 0.4340 0.4930
   0.5208 0.55182 0.58044 0.59204 0.62618 0.6586 0.7171 0.6857 0.8245
   0.98506 1.06648 1.06648 1.06648 1.06648 1.06648 1.06648

# 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
```