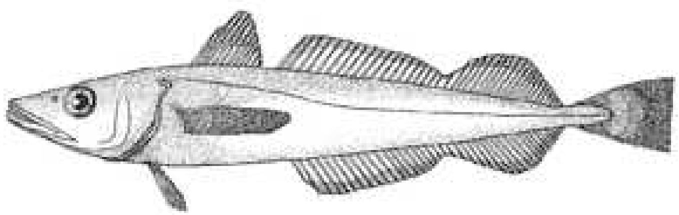
Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2017



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

February 22, 2017

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

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APPENDICES

ONE-PAGE SUMMARY

- The stock assessment model for 2017 is similar in structure to the 2016 model. Updates to the data include the addition of fishery catch and age compositions from 2016, reanalyzed acoustic survey biomass and age compositions for 1995 (completing the reanalyzed acoustic survey time series initiated in the 2016 model), and other minor refinements such as catch estimates from earlier years.

- The stock assessment model is fit to an acoustic survey index of abundance and annual commercial catch, as well as age compositions from the survey and commercial fisheries.

- Coastwide catch in 2016 was 329,427 t, out of a TAC (adjusted for carryovers) of 497,500 t. Attainment in the U.S. was 70.7% of its quota; in Canada it was 53.7%. A variety of factors influenced the attainment of the quota.

- The stock is estimated to be at its highest biomass level since the 1980s as a result of estimated large 2010 and 2014 cohorts. The 2014 cohort has not yet been observed by the survey and only twice by the commercial fishery, thus its absolute size is highly uncertain.

- The median estimate of 2017 relative spawning biomass (spawning biomass at the start of 2017 divided by that at unfished equilibrium, B_0) is 89.2% but is highly uncertain (with 95% credible interval from 37.1% to 270.8%).

- The median estimate of 2017 female spawning biomass is 2.129 million t (with 95% credible interval from 0.763 to 7.445 million t).

- The spawning biomass in 2017 is estimated to have increased from 2016 due to the 2014 year-class likely being above average size.

- Based on the default harvest rule, the estimated median catch limit for 2017 is 969,840 t (with 95% credible interval from 293,697 to 3,710,305 t).

- As in the past, forecasts are highly uncertain due to uncertainty in estimates of recruitment for recent years. Forecasts were conducted across a range of catch levels.

- Projections setting the 2017 and 2018 catch equal to the 2016 TAC of 497,500 t show the estimated median relative spawning biomass decreasing from 89% in 2017 to 85% in 2018 and 79% in 2019. However, due to uncertainty there is an estimated 16% chance of the spawning biomass falling below 40% of B_0 in 2019. There is an estimated 63% chance of the spawning biomass declining from 2017 to 2018, and a 80% chance of it declining from 2018 to 2019 under this constant catch level.

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 2017. 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 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 226,439 t from 1966 to 2016, with a low of 89,930 t in 1980 and a peak of 363,135 t in 2005 (Figure a). Prior to 1966, total removals were negligible compared to the modern fishery. Over the early period, 1966–1990, most removals were from foreign or joint-venture fisheries. Over all years, the fishery in U.S. waters averaged 170,765 t, or 75.4% of the average total landings, while catch from Canadian waters averaged 55,824 t. Over the last 10 years, 2007–2016 (Table a), the average coastwide catch was 262,496 t

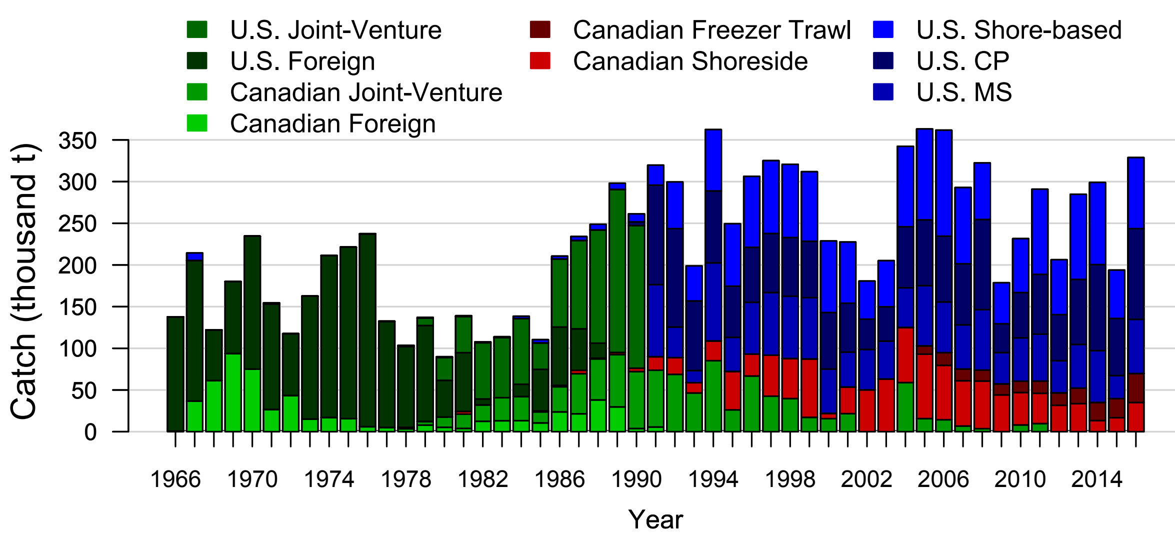

Figure a. Total Pacific Hake catch used in the assessment by sector, 1966–2016. U.S. tribal catches are included in the sectors where they are represented.

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

Year	US Mother-ship	US Catcher-Processor	US Shore-based	US Research	US Total	CAN Joint Venture	CAN Shore-side	CAN Freezer-Trawler	CAN Total	Total
2006	60,926	78,864	127,165	0	266,955	14,319	65,289	15,136	94,744	361,699
2007	52,977	73,263	91,441	0	217,682	6,780	54,295	14,121	75,196	293,389
2008	72,440	108,195	67,861	0	248,496	3,592	57,117	13,214	73,924	321,802
2009	37,550	34,552	49,222	0	121,324	0	44,136	13,223	57,359	177,171
2010	52,022	54,284	64,736	0	171,043	8,081	38,907	13,573	60,562	230,755
2011	56,394	71,678	102,146	1,042	231,261	9,717	36,363	14,593	60,672	291,670
2012	38,512	55,264	65,919	448	160,144	0	31,699	14,909	46,608	205,787
2013	52,447	77,950	102,143	1,018	233,558	0	33,665	18,584	52,249	285,591
2014	62,102	103,203	98,640	197	264,141	0	13,326	21,787	35,113	298,705
2015	27,661	68,484	58,011	0	154,156	0	16,775	22,903	39,678	190,663
2016	65,035	108,786	85,293	572	259,687	0	35,012	34,729	69,741	329,427

with U.S. and Canadian catches averaging 206,149 t and 57,110 t, respectively. The coastwide catch in 2016 was 329,427 t, out of a total allowable catch (TAC, adjusted for carryovers) of 497,500 t. Attainment in the U.S. was 70.7% of its quota; in Canada it was 53.7%.

In this stock assessment, the terms catch and landings are used interchangeably. Estimates of discard within the target fishery are included, but discarding of Pacific Hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings in recent years. During the last five years, catches have been above the long-term average catch (226,439 t) in 2013, 2014 and 2016, and below it in 2012 and 2015. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal (through 2016) from that cohort estimated at approximately 1.28 million t. Through 2016, the total catch of the 2010 year class is estimated to be about 0.67 million t.

DATA AND ASSESSMENT

There was no survey in 2016. New data for this 2017 assessment, that were not in the 2016 assessment, are the 1995 survey biomass estimate (with associated age compositions) and the 2016 fishery catch and fishery age compositions. The mean weight at age for 2016 was added and minor refinements to historical catch estimates were also made. Finally, there was a minor revision to the 1998 survey biomass estimate (an increase of 2%). The 2016 assessment did not include the 1995 survey biomass estimate due to issues with the older survey data, but those issues have now been resolved. The revision to the 1998 point was due to discovery of a better set of variables used in the processing of the acoustic data for that year. Various other data types, including data on maturity, have been explored since the 2014 stock assessment, but are not included in the base model this year.

This Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2016), acoustic survey biomass estimates (Figure b) and age-compositions (1995–2015), as well as fishery age-compositions (1975–2016). While the 2011 survey index value was the lowest in the time series, the index increased steadily over the four surveys conducted in 2011, 2012, 2013,

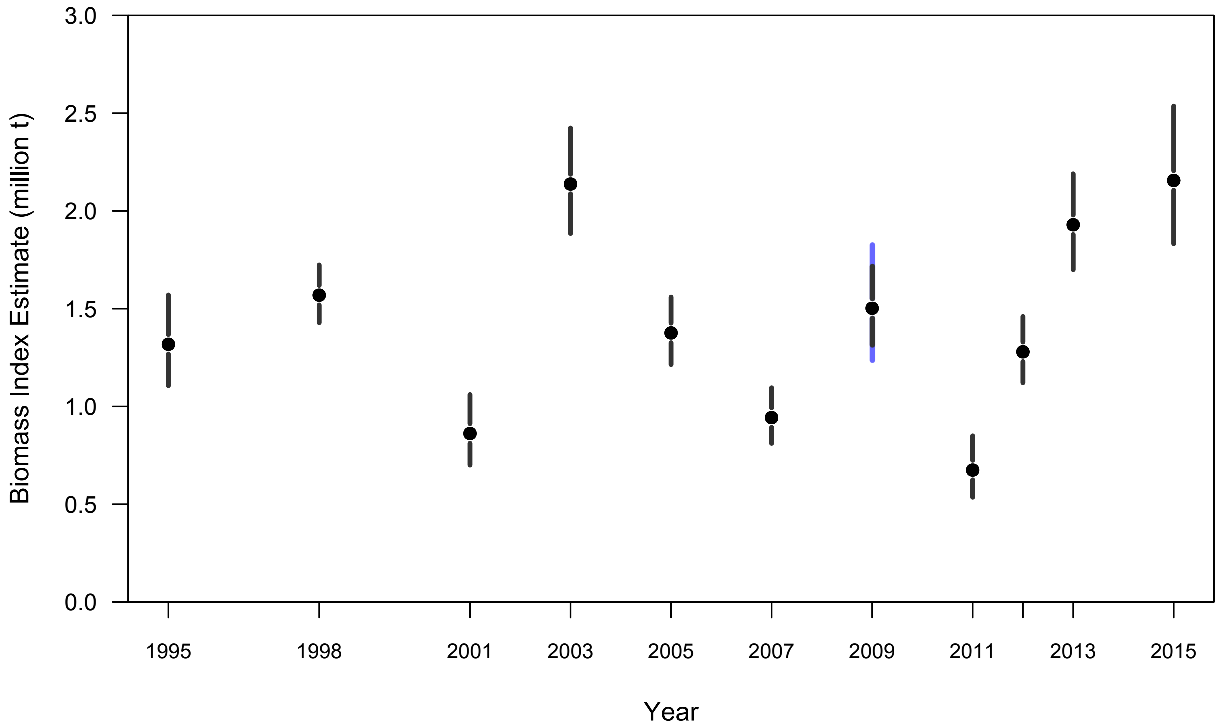

Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2015) in addition to squid/hake apportionment uncertainty (2009, in blue).

and 2015. Age-composition data from the aggregated fisheries and the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts.

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

This 2017 assessment retains the structural form of the base assessment model from 2016 as well as

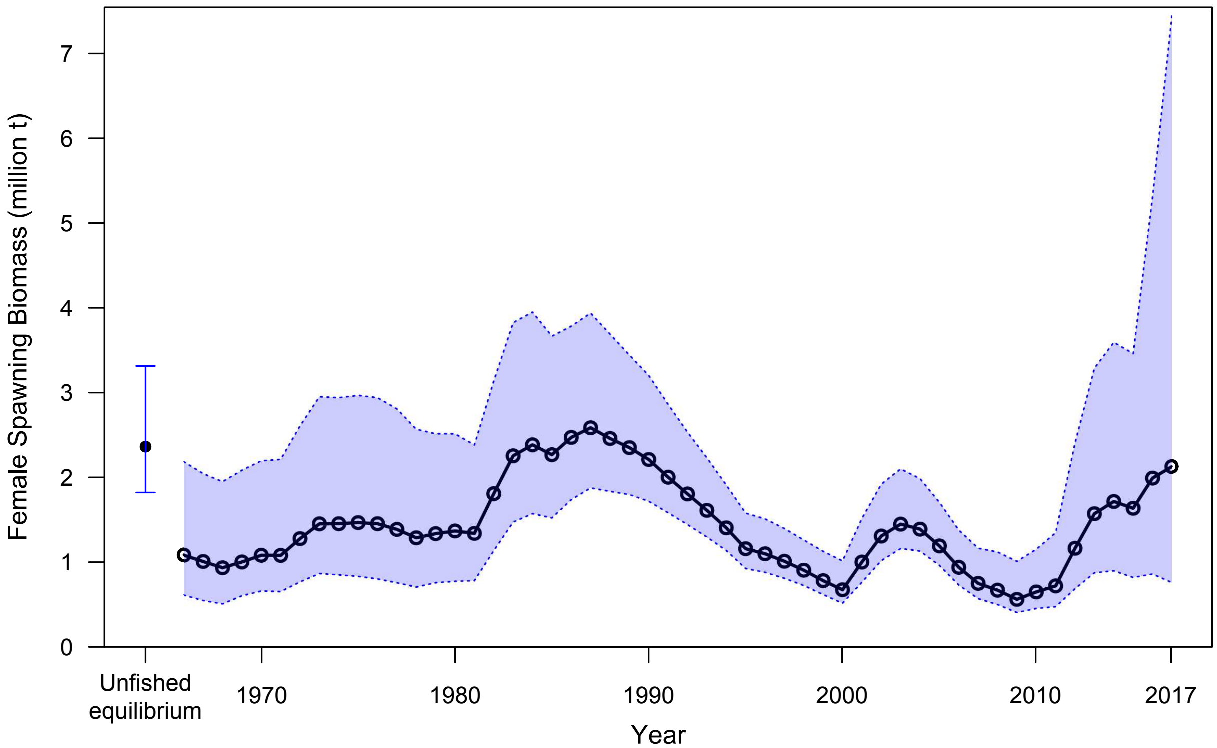

Figure c. Median of the posterior distribution for beginning of the year female spawning biomass through 2017 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

many of the previous elements as configured in Stock Synthesis (SS). Analyses conducted in 2014 showed that allowing for time-varying (rather than fixed) selectivity reduced the magnitude of extreme cohort strength estimates. In closed-loop simulations, management based upon assessment models allowing for time-varying fishery selectivity led to higher median average catch, lower risk of falling below 10% of unfished biomass (B_0), smaller probability of fishery closures, and lower inter-annual variability in catch compared to assessment models which force time-invariant fishery selectivity. Even a small degree of flexibility in the assessment model fishery selectivity could reduce the effects of errors caused by assuming selectivity is constant over time. Therefore, we retain time-varying selectivity in this assessment. The constraint on annual deviation in selectivity was loosened for this assessment, as the settings used in previous assessments resulted in an extremely large estimate of the 2014 year class without adequate basis (i.e., based upon quite limited data).

STOCK BIOMASS

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

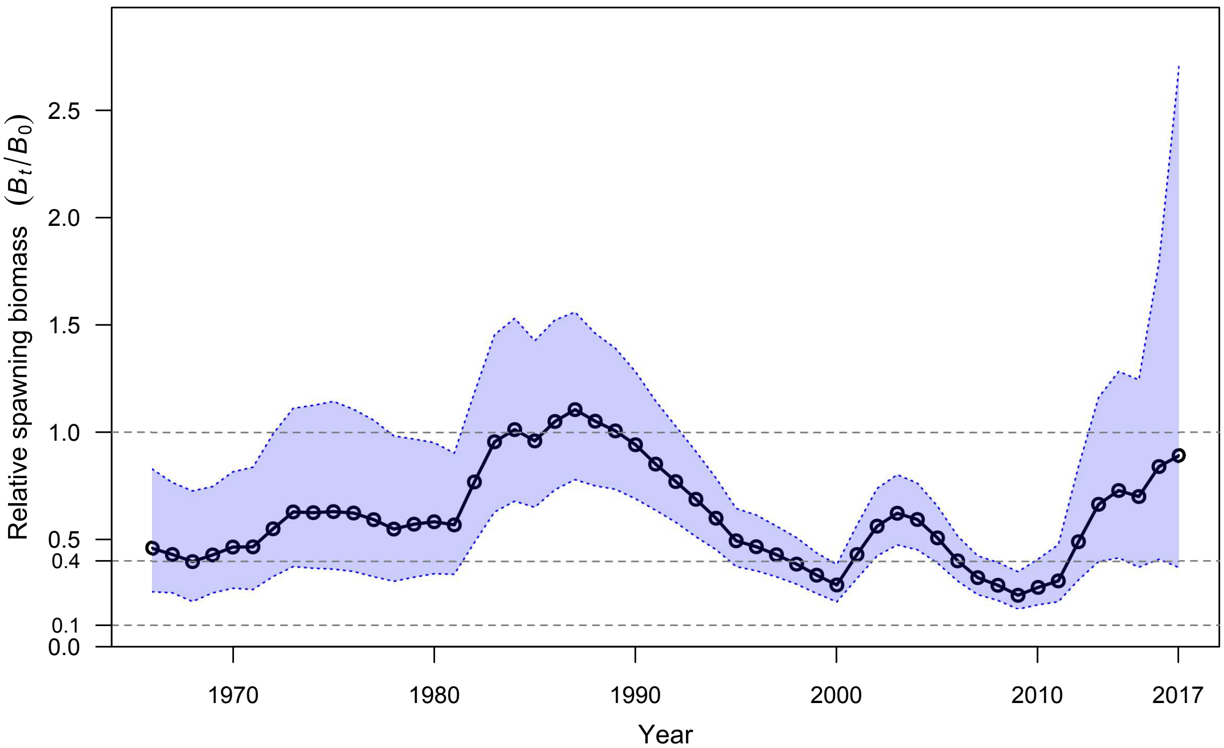

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2017 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

to near unfished equilibrium after two or more large recruitments in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.565 million t in 2009. The assessment model estimates that median spawning biomass declined from 2014 to 2015 after five years of increases from 2009 to 2014. These estimated increases were the result of a large 2010 cohort and an above-average 2008 cohort, and the recent decline is from the 2010 cohort surpassing the age at which gains in weight from growth are greater than the loss in weight from natural mortality. The model then estimates an increases from 2015 to 2017 due to the estimated large 2014 year class, which, on average, is similar to the average estimated size of the 2010 year class.

The median estimate of the 2017 relative spawning biomass (spawning biomass at the start of 2017 divided by that at unfished equilibrium, B_0) is 89.2% but is highly uncertain (with a 95% posterior credibility interval from 37.1% to 270.8%; Table b). The median estimate of the 2017 spawning biomass is 2.129 million t (with a 95% posterior credibility interval from 0.763 to 7.445 million t). The estimate of the 2016 female spawning biomass is 1.993 (0.864–5.307) million t. This is slightly higher than the 1.885 (0.791-4.781) million t estimated in the 2016 assessment.

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

Year	Spawning Biomass (thousand t)			Relative spawning biomass (B_t/B_0)		
	2.5^{th} percentile	Median	97.5^{th} percentile	2.5^{th} percentile	Median	97.5^{th} percentile
2008	503.5	673.0	1,123.4	21.8%	28.9%	39.5%
2009	409.4	564.9	1,012.6	17.8%	24.2%	35.2%
2010	457.9	652.3	1,155.8	19.8%	27.9%	41.1%
2011	478.4	723.7	1,350.4	21.2%	30.9%	47.8%
2012	690.6	1,166.9	2,408.3	31.4%	49.2%	84.1%
2013	877.8	1,574.4	3,289.5	39.9%	66.6%	116.3%
2014	901.6	1,717.9	3,593.7	41.6%	73.0%	128.5%
2015	823.1	1,638.2	3,460.7	37.3%	70.2%	124.5%
2016	863.6	1,993.3	5,307.3	41.0%	84.2%	179.1%
2017	762.7	2,129.1	7,444.8	37.1%	89.2%	270.8%

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

Year	Absolute recruitment (millions)			Recruitment deviations		
	2.5^{th} percentile	Median	97.5^{th} percentile	2.5^{th} percentile	Median	97.5^{th} percentile
2007	9.7	54.1	232.9	-4.547	-2.993	-1.684
2008	3,548.9	5,556.3	11,520.1	1.383	1.707	2.085
2009	517.0	1,212.8	3,272.3	-0.515	0.207	0.896
2010	8,397.7	15,807.7	36,920.2	2.273	2.755	3.230
2011	101.9	439.4	1,733.4	-2.223	-0.859	0.298
2012	594.7	1,722.0	5,692.2	-0.518	0.422	1.404
2013	53.4	402.3	2,114.8	-2.920	-1.098	0.451
2014	2,184.1	12,104.6	90,734.9	0.744	2.331	4.171
2015	51.4	733.4	11,789.4	-2.917	-0.442	2.196
2016	89.9	1,269.0	18,995.9	-2.563	0.047	2.812

RECRUITMENT

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

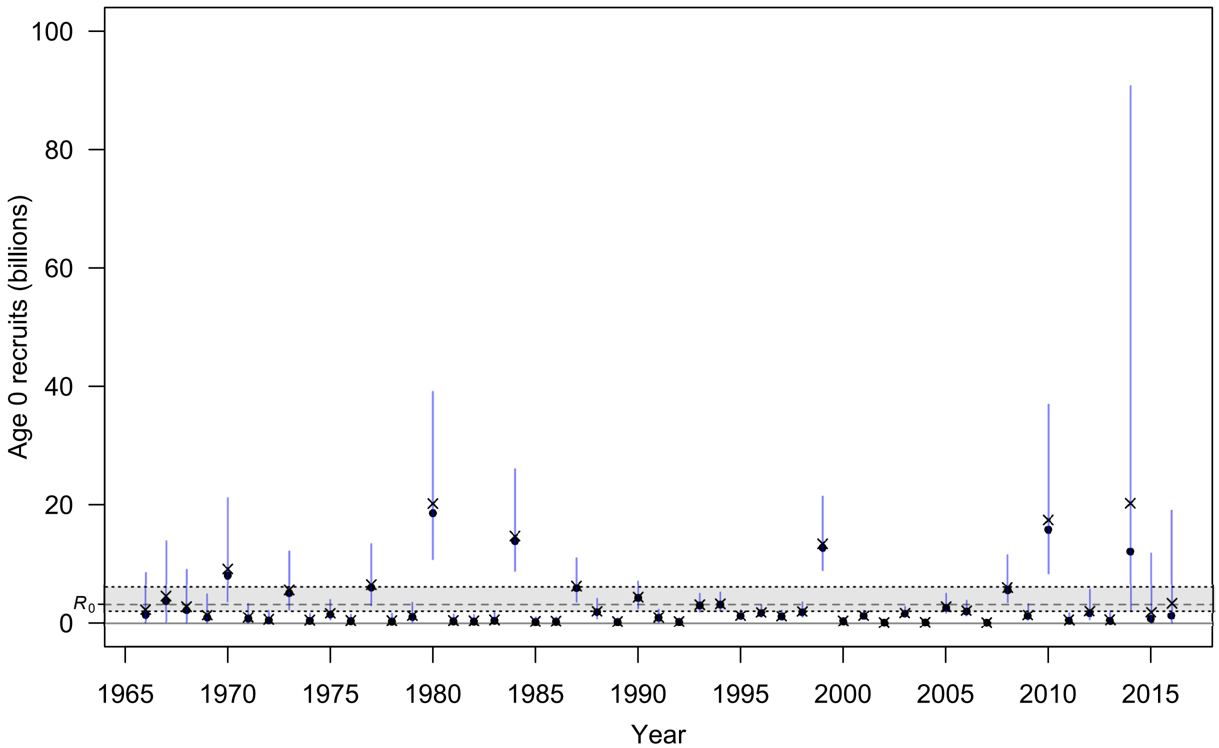

Figure e. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with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

class comprising 70% of the coast-wide commercial catch in 2013, 64% of the 2014 catch, 71% of the 2015 catch and 37% of the 2016 catch. The smaller proportion of the 2010 year class in the 2016 catch is due to the large influx of the 2014 year class (47% of the 2016 catch was age-2 fish from the 2014 year class, which was similar to the proportion of age-2 fish, 41%, from the 2010 year class in 2012). The size of the 2010 year class is more uncertain than older cohorts but the median estimate is the second highest in the time series (after that for 1980). The model currently estimates smaller-than-average 2011, 2012 and 2013 year classes (median recruitment below the mean of all median recruitments). The 2014 year class is likely larger than average and potentially a similar magnitude as the 2010 year class, but is still highly uncertain. There is no information in the data to estimate the sizes of the 2016 and 2017 year classes. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable prior to model age-3 (observed at age-2).

DEFAULT HARVEST POLICY

The default $F_{\text{SPR}=40\%}$–40:10 harvest policy prescribes the maximum rate of fishing mortality to equal $F_{\text{SPR}=40\%}$. This rate gives a spawning potential ratio (SPR) of 40%, meaning that the spawning biomass per recruit with $F_{\text{SPR}=40\%}$ is 40% of that without fishing. If spawning biomass is below

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

Year	Relative fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2007	0.649	0.952	1.338	0.138	0.222	0.284
2008	0.693	0.995	1.300	0.133	0.226	0.299
2009	0.518	0.811	1.113	0.078	0.140	0.191
2010	0.621	0.959	1.397	0.123	0.226	0.328
2011	0.526	0.883	1.298	0.092	0.183	0.270
2012	0.367	0.690	1.042	0.072	0.144	0.236
2013	0.350	0.666	0.941	0.034	0.072	0.129
2014	0.327	0.661	1.001	0.037	0.079	0.150
2015	0.197	0.450	0.810	0.029	0.061	0.123
2016	0.344	0.688	1.267	0.065	0.139	0.295

$B_{40\%}$ (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 $(1-\mathrm{SPR}(F))/(1-\mathrm{SPR}_{40\%})$, where SPR$_{40\%}$ is the target SPR of 40%.

EXPLOITATION STATUS

Median relative fishing intensity on the stock is estimated to have been below the target of 1.0 except for the year 1999 when spawning biomass was low (Table d (for recent years) and Figure f). Median exploitation fraction (catch divided by biomass of fish of age 3 and above) also peaked in 1999, and then reached even higher values in 2007, 2008 and 2010 (Table d and Figure g). Median relative fishing intensity is estimated to have declined from 95.9% in 2010 to 68.8% in 2016, while the exploitation fraction has decreased from 0.23 in 2010 to 0.14 in 2016. There is a considerable amount of uncertainty around estimates of relative fishing intensity, with the 95% posterior credibility interval reaching above the SPR management target for 2016 (Figure f).

MANAGEMENT PERFORMANCE

Over the last decade (2007–2016), the mean coast-wide utilization rate (i.e., landings/quota) has been 77.5% (Table e). Over the last five years (2012 to 2016), the mean utilization rates differed between the United States (74.9%) and Canada (49.1%). 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 except 1999 (Figure f). The median female spawning biomass was above the $B_{40\%}$ reference point in all years except 1968, 1998-2000 and 2007-2011 (Figure d).

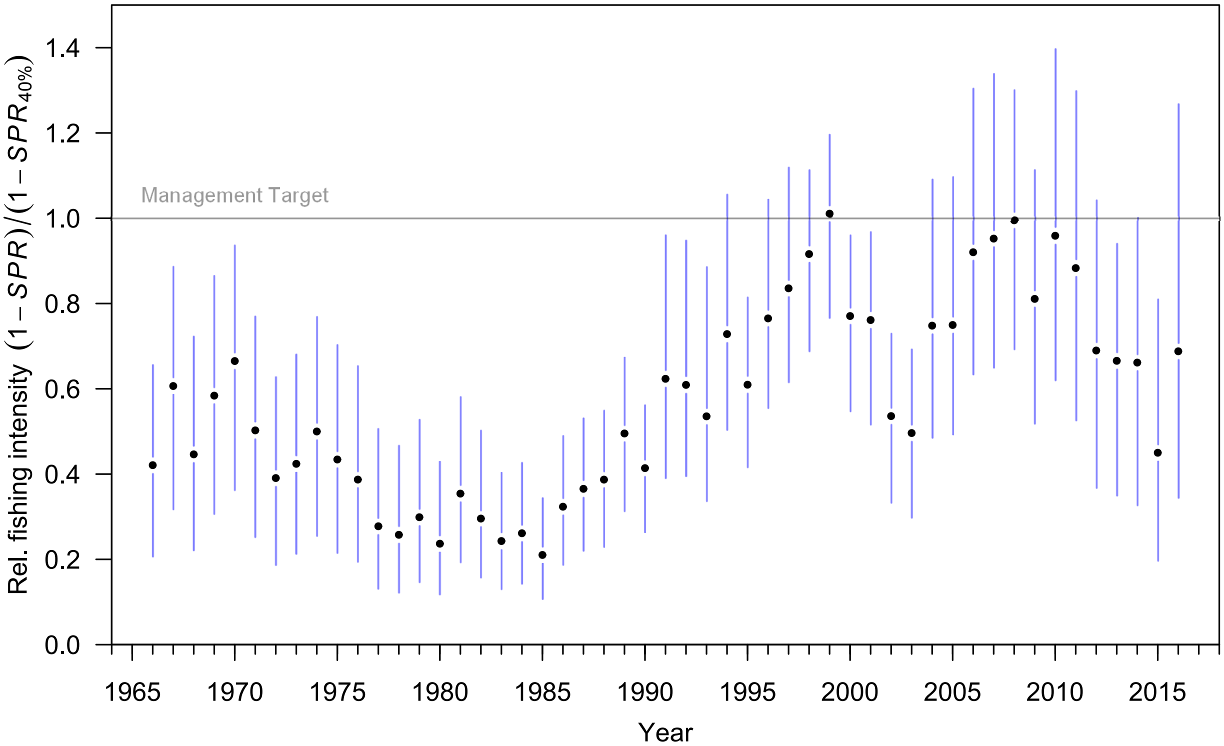

Figure f. Trend in median relative fishing intensity (relative to the SPR management target) through 2016 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

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

Year	US landings (t)	Canadian landings (t)	Total landings (t)	Coast-wide (US+Canada) catch target (t)	US catch target (t)	Canada catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2007	217,682	75,196	293,389	328,358	242,591	85,767	89.7%	87.7%	89.4%
2008	248,496	73,924	321,802	364,842	269,545	95,297	92.2%	77.6%	88.2%
2009	121,324	57,359	177,171	184,000	135,939	48,061	89.2%	119.3%	96.3%
2010	171,043	60,562	230,755	262,500	193,935	68,565	88.2%	88.3%	87.9%
2011	231,261	60,672	291,670	393,751	290,903	102,848	79.5%	59.0%	74.1%
2012	160,144	46,608	205,787	251,809	186,036	65,773	86.1%	70.9%	81.7%
2013	233,558	52,249	285,591	365,112	269,745	95,367	86.6%	54.8%	78.2%
2014	264,141	35,113	298,705	428,000	316,206	111,794	83.5%	31.4%	69.8%
2015	154,156	39,678	190,663	440,000	325,072	114,928	47.4%	34.5%	43.3%
2016	259,687	69,741	329,427	497,500	367,553	129,947	70.7%	53.7%	66.2%

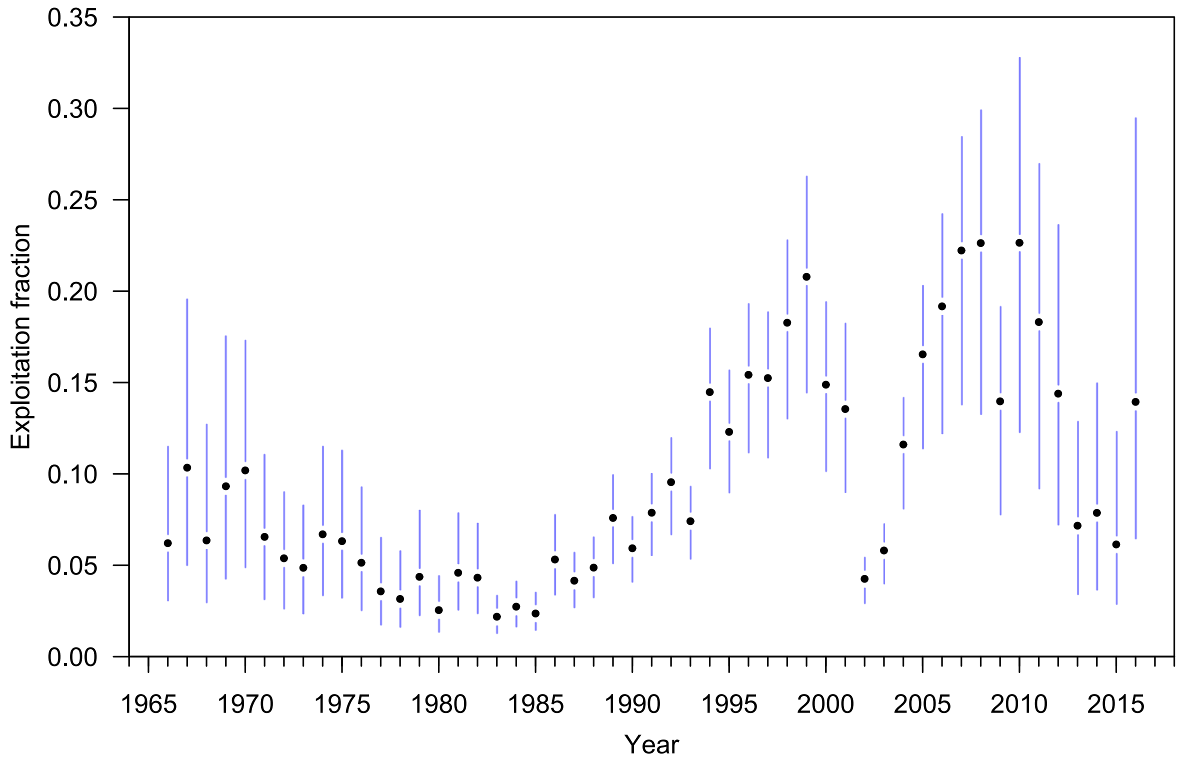

Figure g. Trend in median exploitation fraction (catch divided by age-3+ biomass) through 2016 with 95% posterior credibility intervals.

The joint history of the medians of relative spawning biomass and relative fishing intensity shows that only in 1999 was the median relative fishing intensity above the target of 1.0 and the female spawning biomass below the reference point of $B_{40\%}$ (Figure h). Between 2007 and 2011, however, median relative fishing intensity ranged from 81% to 100% and median relative spawning biomass between 0.24 and 0.32. Biomass has risen recently with the 2008, 2010 and 2014 recruitments, and median relative spawning biomass has been above the reference point of 40% since 2012.

While there is large uncertainty in the 2016 estimates of relative fishing intensity and relative spawning biomass, the model predicts a less than 4% joint probability of being both above the target relative fishing intensity in 2016 and below the $B_{40\%}$ relative spawning biomass level at the start of 2017.

REFERENCE POINTS

Estimates of the 2017 base model reference points with posterior credibility intervals are in Table f. The estimates are slightly different than those in the 2016 assessment, with slightly lower sustainable yields and reference biomasses estimated in this assessment.

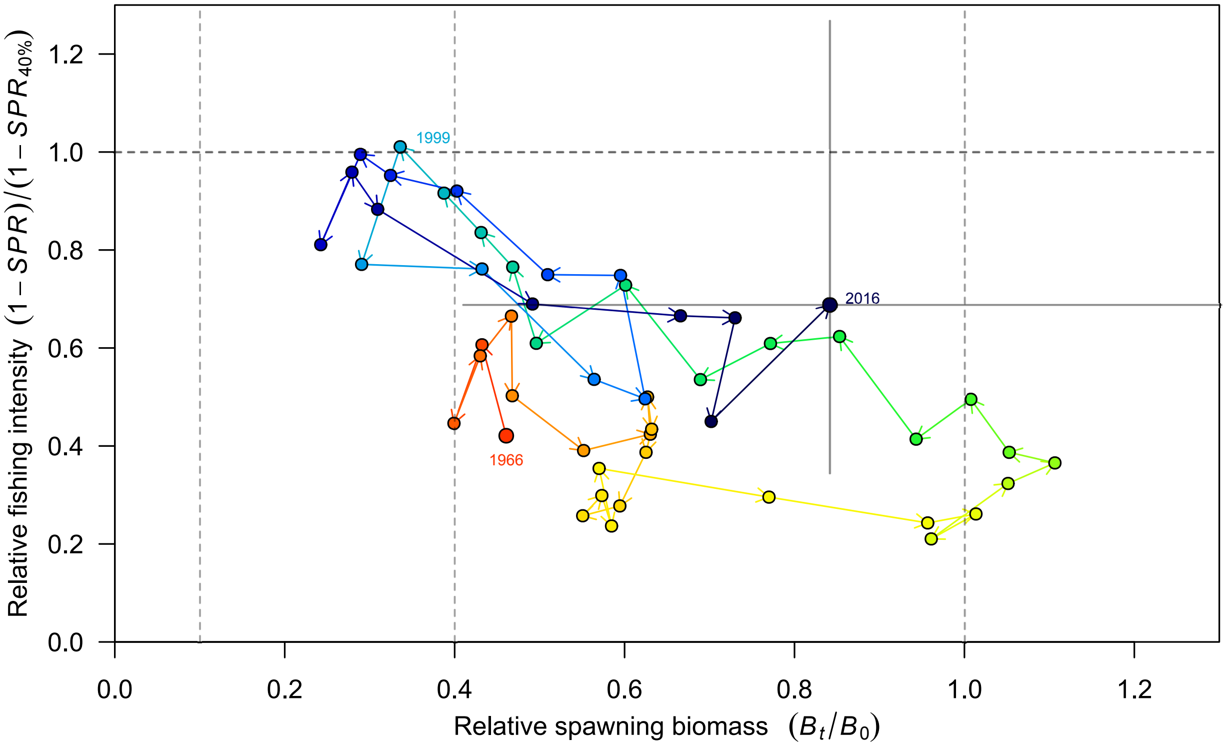

Figure h. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2016 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

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

The Pacific Hake stock displays a very high recruitment variability relative to other west coast groundfish stocks, resulting in large and rapid biomass changes. This leads to a dynamic fishery that potentially targets strong cohorts resulting in time-varying fishery selectivity. This volatility results in a high level of uncertainty in estimates of current stock status and stock projections because, with limited data to estimate incoming recruitment, the cohorts are fished before the assessment can accurately determine how big the cohort is (i.e., cohort strength is not well known until it is at least age-3). This is particularly apparent for this assessment, because the 2014 cohort is potentially very large but is still highly uncertain (Figure e).

The JTC presented results from closed-loop simulations evaluating the effect of including potential age-1 indices on management outcomes at a 2015 Joint Management Committee (JMC) meeting

Table f. Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2016 averages for mean size-at-age and selectivity-at-age.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (B_0, thousand t)	1,822	2,362	3,314
Unfished recruitment (R_0, millions)	2,054	3,170	6,121
Reference points (equilibrium) based on $F_{\mathrm{SPR}=40\%}$			
Female spawning biomass at $F_{\mathrm{SPR}=40\%}$ (thousand t)	624	836	1,152
SPR at $F_{\mathrm{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\mathrm{SPR}=40\%}$	18.9%	22.2%	27.0%
Yield associated with $F_{\mathrm{SPR}=40\%}$ (thousand t)	260	380	590
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	729	945	1,326
SPR at $B_{40\%}$	40.9%	43.4%	50.9%
Exploitation fraction resulting in $B_{40\%}$	14.7%	19.4%	24.0%
Yield at $B_{40\%}$ (thousand t)	263	371	577
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	393	594	997
SPR at MSY	20.1%	29.5%	46.2%
Exploitation fraction corresponding to SPR at MSY	17.9%	33.1%	56.4%
MSY (thousand t)	275	400	645

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

FORECAST DECISION TABLES

The catch limit for 2017 based on the default $F_{\mathrm{SPR}=40\%}$–40:10 harvest policy has a median of 969,840 t with a wide range of uncertainty, the 2.5% to 97.5% range being 293,697–3,710,305 t.

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

Relative fishing intensity exceeding 100% indicates fishing in excess of the $F_{\mathrm{SPR}=40\%}$ default har-

Table g. Forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e), including the TAC from 2016 (row d), the catch values that result in a median relative fishing intensity of 100% (row f), the median values estimated via the default harvest policy ($F_{\mathrm{SPR}=40\%}$–40:10) for the base model (row g), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2017 and 2018 (row h). Row e uses 600,000 t rather than the 500,000 t from last year's assessment, because 500,000 t is essentially row d. Catch in 2019 does not impact the beginning of the year biomass in 2019.

Within model quantile			5%	25%	50%	75%	95%
Management Action			Beginning of year relative spawning biomass				
	Year	Catch (t)					
a:	2017	0	41%	65%	89%	120%	224%
	2018	0	43%	70%	95%	135%	264%
	2019	0	46%	72%	99%	141%	276%
b:	2017	180,000	41%	65%	89%	120%	224%
	2018	180,000	39%	66%	91%	131%	261%
	2019	180,000	38%	65%	92%	134%	269%
c:	2017	350,000	41%	65%	89%	120%	224%
	2018	350,000	35%	62%	87%	127%	257%
	2019	350,000	30%	58%	85%	127%	261%
d:	2017	497,500	41%	65%	89%	120%	224%
2016	2018	497,500	32%	59%	85%	124%	254%
TAC	2019	497,500	24%	51%	79%	121%	256%
e:	2017	600,000	41%	65%	89%	120%	224%
	2018	600,000	30%	57%	82%	122%	252%
	2019	600,000	20%	47%	74%	117%	253%
f:	2017	934,000	41%	65%	89%	120%	224%
FI=	2018	848,000	23%	49%	76%	115%	246%
100%	2019	698,000	12%	35%	63%	105%	244%
g:	2017	969,840	41%	65%	89%	120%	224%
default	2018	843,566	22%	48%	75%	115%	245%
HR	2019	679,881	12%	34%	63%	104%	244%
h:	2017	866,263	41%	65%	89%	120%	224%
C2017=	2018	866,263	24%	51%	77%	117%	247%
C2018	2019	683,014	13%	36%	64%	106%	245%

Table h. Forecast quantiles of Pacific Hake relative fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2017–2019 catch alternatives presented in Table g. Values greater than 100% indicate relative fishing intensities greater than the $F_{SPR=40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Relative fishing intensity**				
	Year	Catch (t)					
a:	2017	0	0%	0%	0%	0%	0%
	2018	0	0%	0%	0%	0%	0%
	2019	0	0%	0%	0%	0%	0%
b:	2017	180,000	14%	25%	35%	47%	68%
	2018	180,000	11%	23%	33%	46%	68%
	2019	180,000	11%	23%	33%	47%	70%
c:	2017	350,000	26%	43%	58%	74%	97%
	2018	350,000	21%	40%	56%	75%	103%
	2019	350,000	21%	42%	58%	79%	110%
d:	2017	497,500	35%	55%	72%	89%	112%
2016	2018	497,500	29%	53%	72%	94%	122%
TAC	2019	497,500	29%	57%	76%	100%	131%
e:	2017	600,000	40%	63%	80%	98%	120%
	2018	600,000	34%	61%	81%	104%	131%
	2019	600,000	34%	65%	86%	112%	138%
f:	2017	934,000	56%	82%	100%	116%	135%
FI=	2018	848,000	45%	78%	100%	123%	141%
100%	2019	698,000	40%	76%	100%	127%	141%
g:	2017	969,840	57%	84%	102%	118%	136%
default	2018	843,566	45%	78%	100%	124%	141%
HR	2019	679,881	40%	75%	99%	127%	141%
h:	2017	866,263	53%	78%	97%	113%	133%
C2017=	2018	866,263	46%	79%	100%	123%	141%
C2018	2019	683,014	39%	75%	98%	126%	141%

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

Management metrics that were identified as important to the JMC and the Advisory Panel (AP) in 2012 are presented for projections to 2018 and 2019 (Tables i and j and Figures j and k). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from these results for intermediate catch values. Figure i shows the predicted relative spawning biomass trajectory through 2019 for several of these management actions. With zero catch for the next two years, the biomass has a 17% probability of decreasing from 2017 to 2018, and a 39% probability

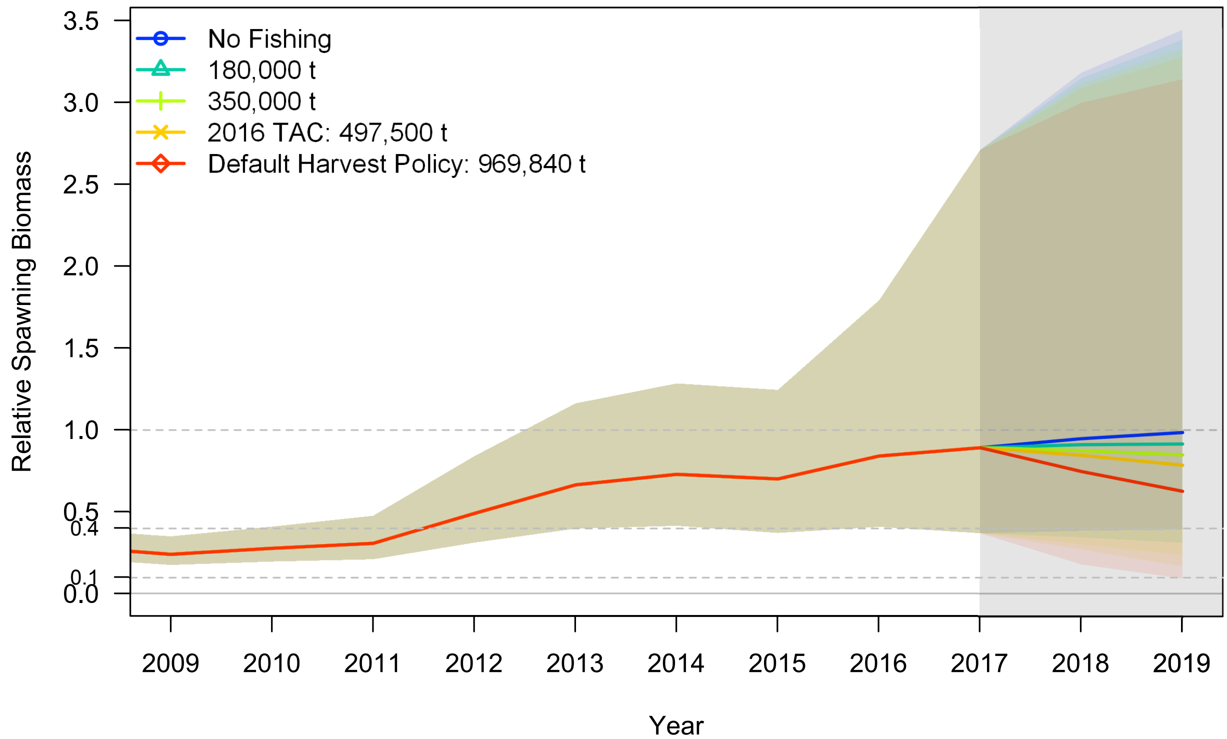

Figure i. Time series of estimated relative spawning biomass to 2017 from the base model, and forecast trajectories to 2019 for several management actions defined in Table g (grey region), with 95% posterior credibility intervals.

Table i. Probabilities related to spawning biomass, relative fishing intensity, and the 2018 default harvest policy catch for alternative 2017 catch options (catch options explained in Table g).

Catch in 2017	Probability $B_{2018}<B_{2017}$	Probability $B_{2018}<B_{40\%}$	Probability $B_{2018}<B_{25\%}$	Probability $B_{2018}<B_{10\%}$	Probability 2017 relative fishing intensity >100%	Probability 2018 default harvest policy catch <2017 catch
a: 0	17%	3%	0%	0%	0%	0%
b: 180,000	37%	6%	1%	0%	0%	1%
c: 350,000	51%	7%	1%	0%	4%	6%
d: 497,500	63%	9%	2%	0%	15%	18%
e: 600,000	67%	11%	3%	0%	23%	27%
f: 934,000	80%	18%	7%	0%	50%	55%
g: 969,840	82%	18%	7%	0%	52%	57%
h: 866,263	78%	17%	6%	0%	44%	50%

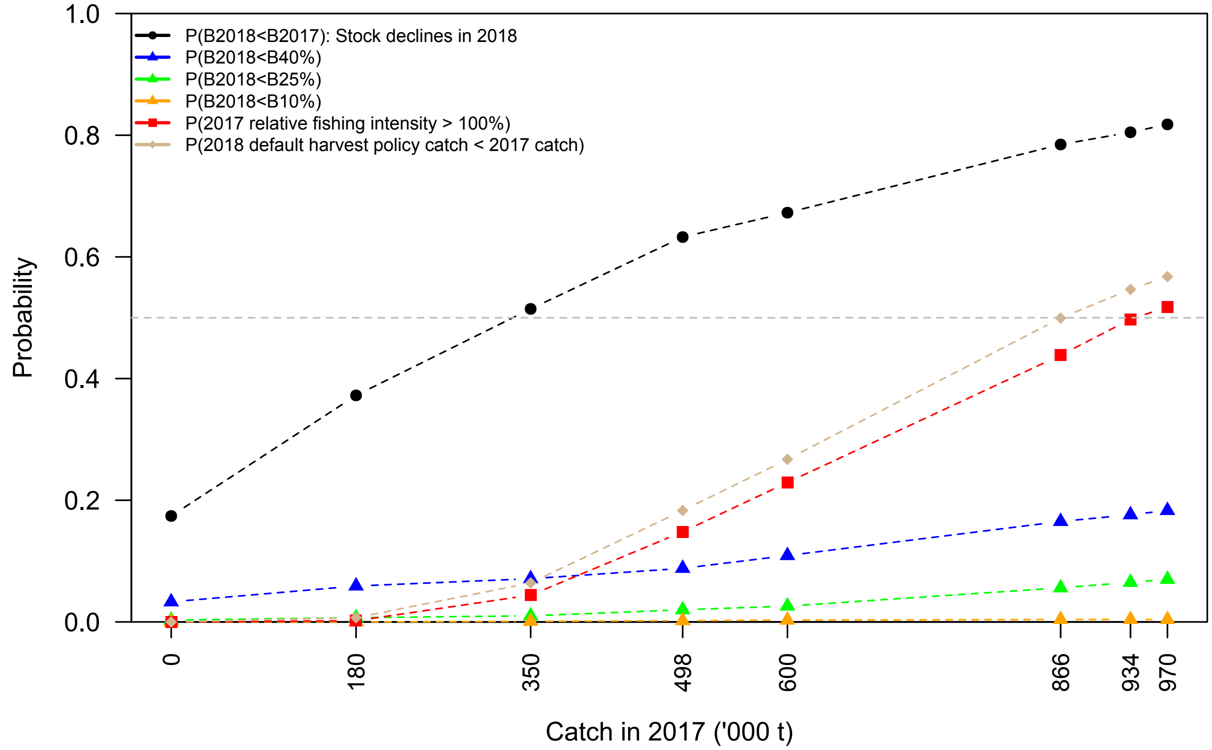

Figure j. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2018 default harvest policy catch for alternative 2017 catch options (catch options explained in Table g) as listed in Table i. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

of decreasing from 2018 to 2019

The probability of the spawning biomass decreasing from 2017 to 2018 is less than 50% for only the 0 t and 180,000 t catch levels (Table i and Figure j). The highest probability of decrease is 82%, which is for the default harvest policy. The predicted probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2018 is less than 1% and the maximum probability of dropping below $B_{40\%}$ is 18% for all catches explored (Table i and Figure j). It should be noted that the natural mortality rate is larger than the current and future growth rate for the large 2010 year class. The model estimated below-average recruitment for the 2011, 2012 and 2013 cohorts, but a potentially large 2014 cohort that will result in increases to the spawning biomass as it continues to mature.

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. Investigate links between hake biomass, its spatial distribution and how these dynamics vary with ocean conditions and ecosystem variables such as temperature and prey availability.

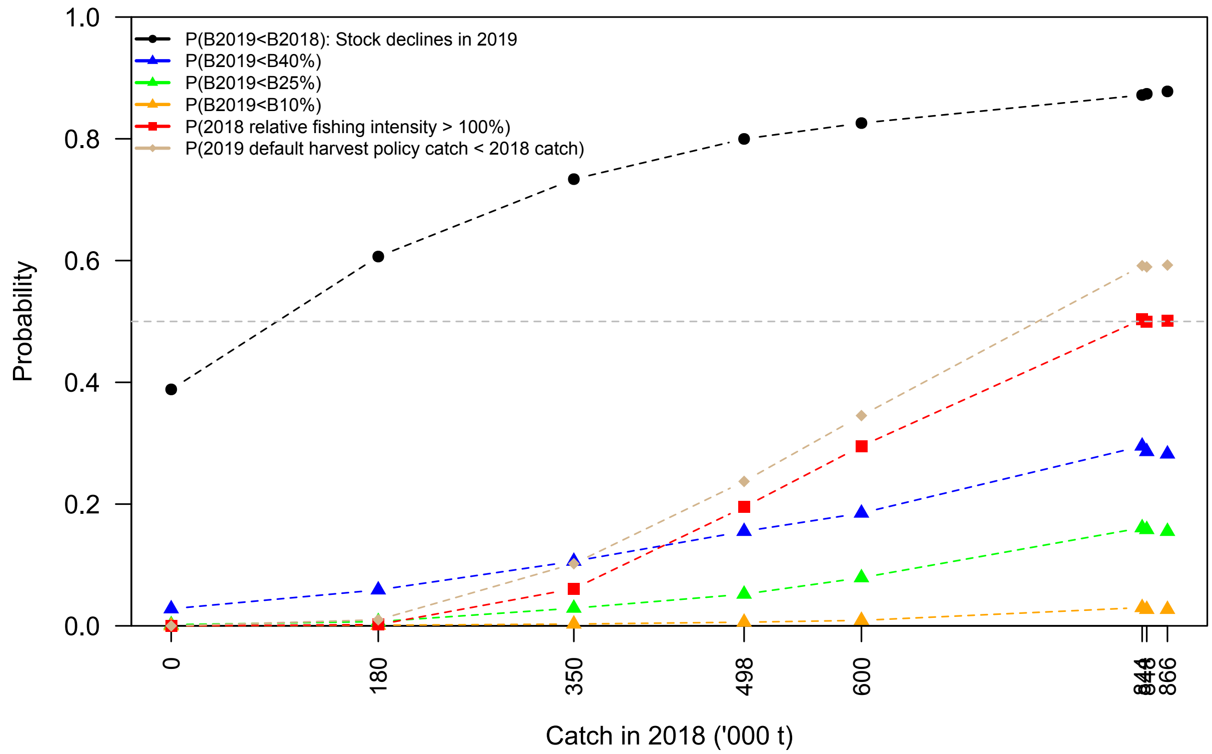

Figure k. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (including associated 2017 catch; catch options explained in Table g) as listed in Table j. The symbols indicate 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 2019 default harvest policy catch for alternative 2018 catch options, given the 2017 catch level shown in Table i (catch options explained in Table g).

Catch in 2018	Probability $B_{2019}<B_{2018}$	Probability $B_{2019}<B_{40\%}$	Probability $B_{2019}<B_{25\%}$	Probability $B_{2019}<B_{10\%}$	Probability 2018 relative fishing intensity >100%	Probability 2019 default harvest policy catch <2018 catch
a: 0	39%	3%	0%	0%	0%	0%
b: 180,000	61%	6%	1%	0%	0%	1%
c: 350,000	73%	11%	3%	0%	6%	10%
d: 497,500	80%	16%	5%	1%	20%	24%
e: 600,000	83%	19%	8%	1%	30%	35%
f: 848,000	87%	29%	16%	3%	50%	59%
g: 843,566	87%	30%	16%	3%	50%	59%
h: 866,263	88%	28%	16%	3%	50%	59%

These investigations have the potential to improve the scenarios considered in future management strategy evaluation (MSE) work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.

2. Continue development of the MSE tools to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them. Incorporate the feedback from JMC/AP/SRG/MSE Advisory Panels into operating model development. Specifically, make sure that the operating model is able to provide insight into the important questions defined by these groups. If a spatially, seasonally explicit operating model is needed, then research should focus on how best to model these dynamics in order to capture seasonal effects and potential climate forcing influences in the simulations (see item 1). Investigate the impact of making incorrect assumptions about the underlying recruitment process. Continue to coordinate our MSE research with other scientists in the region engaging in similar research.

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

1 INTRODUCTION

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

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

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

This assessment is fully Bayesian, with the base model incorporating prior information on several key parameters (including natural mortality, M, and steepness of the stock-recruit relationship, h) and integrating over parameter uncertainty to provide results that can be probabilistically interpreted. From a range of alternate models investigated by the JTC, a subset of sensitivity analyses are also reported in order to provide a broad qualitative comparison of structural uncertainty with respect to the base case. These sensitivity analyses are thoroughly described in this assessment document. The structural assumptions of this 2017 base model are effectively the same as the 2016 base model, including time-varying fishery selectivity.

1.1 STOCK STRUCTURE AND LIFE HISTORY

Pacific Hake is a semi-pelagic schooling species distributed along the west coast of North America, generally ranging in latitude from 25°N to 55°N (see Figure 1 for an overview map). It is among 18 species of hake from four genera (being the majority of the family 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, Puget Sound, and the Gulf of California. Genetic studies indicate that the Strait of Georgia and the Puget Sound populations are genetically distinct from the coastal population (Iwamoto et al., 2004; King et al., 2012). Genetic differences have also been found between the coastal population and hake off the west coast of Baja California (Vrooman and Paloma, 1977). The coastal stock is also distinguished from the inshore populations by larger size-at-age and seasonal migratory behavior.

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

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

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

1.2 ECOSYSTEM CONSIDERATIONS

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

1.3 MANAGEMENT OF PACIFIC HAKE

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

Throughout the last decade, the total coast-wide catch has tracked harvest targets reasonably well (Table 4). Since 1999, catch targets have been determined using an $F_{\mathrm{SPR}=40\%}$ default harvest rate with a 40:10 adjustment. This decreases the catch linearly from the catch target at a relative spawning biomass of 40% and above, to zero catch at relative spawning biomass values of 10% or less (called the default harvest policy in the Agreement). Further considerations have often resulted in catch targets to be set lower than the recommended catch limit. In the last decade, total catch has never exceeded the quota, although retrospectively, as estimated in this assessment, harvest rates in some of those years approached the $F_{\mathrm{SPR}=40\%}$ target. Overall, management appears to be effective at maintaining a sustainable stock size, in spite of uncertain stock assessments and a highly dynamic population. However, management has been precautionary in years when very large quotas were determined from the stock assessment.

1.3.1 Management of Pacific Hake in the United States

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

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

1.3.2 Management of Pacific Hake in Canada

Canadian groundfish managers distribute their portion (26.12%) of the Total Allowable Catch (TAC) as quota to individual license holders. In 2016, Canadian hake fishermen were allocated a TAC of 129,947 t, including 15,020 t of uncaught carryover fish from 2015. 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 joint-venture program was conducted in 2011.

In 2016, all Canadian Pacific Hake trips remained subject to 100% observer coverage, by either electronic monitoring for the shoreside component of the domestic fishery or on-board observer for the freezer trawler component. All shoreside hake landings were also subject to 100% verification by the groundfish Dockside Monitoring Program (DMP). Retention of all catch, with the exception of prohibited species, was mandatory. The retention of groundfish other than Sablefish, Mackerel, Walleye Pollock, and Pacific Halibut on non-observed but electronically monitored, dedicated Pacific Hake trips, was not allowed to exceed 10% of the landed catch weight. The bycatch allowance for Walleye Pollock was 30% of the total landed weight.

1.4 FISHERIES

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

A more detailed description of the history of the fishery is provided in the 2013 Pacific Hake stock assessment (Hicks et al., 2013).

1.4.1 Overview of the fisheries in 2016

The Joint Management Committee (JMC) determined an adjusted (for carryovers) coast-wide catch target of 497,500 t for 2016, with a U.S. allocation of 367,553 t (73.88%) and a Canadian allocation of 129,947 t (26.12%). The historical catch of Pacific Hake for 1966–2016 by nation and fishery sector is shown in Figure 4 and Tables 1, 2 and 3. A review of the 2016 fishery follows.

United States

The U.S. adjusted allocation (i.e. adjusted for carryovers) of 367,553 t was further divided among the research, tribal, catcher-processor, mothership, and shore-based sectors. After the tribal allocation of 17.5% (64,322 t), and a 1,500 t allocation for research catch and bycatch in non-groundfish fisheries, the 2016 non-tribal U.S. catch limit of 301,731 t was allocated to the catcher-processor (34%), mothership (24%), and shore-based (42%) commercial sectors. Reallocation of 34,000 t of tribal quota to non-tribal sectors on September 15 resulted in final quotas for the catcher-processor (CP), mothership (MS), and shore-based (Shore) sectors of 114,149 t, 80,575 t, and 141,007 t, respectively.

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

The overall catch of Pacific Hake in U.S. waters was substantially greater than in the previous year and catch rates were more stable throughout the year (Figure 6). Initial database extractions reported no landings of hake by tribal fisheries in 2016. However, the U.S. advisory panel report on the 2016 fishery (Appendix D) indicated a tribal catch of 2,470 mt. The Joint Technical Committee was not made aware of this catch until late in the assessment preparation process, thereby precluding an update to the overall catch this year. However, this amount of catch is negligible relative to the total catch and thus would have negligible influence on model results and subsequent management forecasts. The catcher-processor, mothership, and shore-based fleets caught 95.3%, 80.7%, and 60.5% of their final reallocated quotas, respectively. Overall, 107,866 t (29.3%) of the total U.S. adjusted TAC was not caught. For further details see the report from the U.S. Advisory Panel (Appendix D).

In both U.S. at-sea sectors (CP and MS) the most common cohort in the spring fishery was age-6 fish associated with the 2010 year-class, but by the fall, both sectors were catching a majority of age-2 fish from the 2014 cohort. In total, 47% of the CP catch was age-2 and 36% was age-6 (Table 6). For the MS sector, the total for the year was 59% age-2 and 29% age-6 (Table 7). These totals were based on samples from over 500 hauls in each sector (Table 5). Age-samples from 59 shoreside trips showed an even higher proportion of age-2 fish than the at-sea sectors, at 62%, with 24% of the shoreside samples coming from the 2010 year class (Table 8). Age-4 fish from the 2012 year-class were the third largest proportion in all three U.S. fishery sectors, but made up only 3–7% of the age samples in each case.

The at-sea fishery maintained relatively consistent catch rates throughout the year (Figure 6), averaging around 15 t/hr. Relative to last year, the spring (May–June) fishery saw lower catch rates, whereas the fall (September–November) fishery fared substantially better. The at-sea fleets sometimes fished in deeper water than observed in past years (Figure 5). During July and August, some operators in the at-sea fishery continued to fish hake, forgoing the usual summer opportunities in

Alaskan waters. The shorebased fishery had the largest monthly catches during July and August. Due to these moderate but consistent catch-rates throughout the year (for all U.S. fleets), the U.S. utilization rate went up to 71% from 47% last year.

Canada

The 2016 Canadian Pacific Hake domestic fishery removed 69,741 t from Canadian waters, which was 53.7% of the Canadian TAC of 129,947 t.

The shoreside component, made up of vessels landing fresh round product onshore, landed 35,012 t. The freezer trawler component, made up of four vessels which freeze headed and gutted product while at sea, landed 34,729 t.

The Canadian fishery began in early March, two months earlier than in 2015, and the last delivery for the freezer trawler vessels was in mid-November. Fish were present continuously along the shelf break and on the shelf off the West Coast of Vancouver Island throughout the season. Similar to 2015, there appeared to be a larger hake biomass in Canada than in 2013 and 2014. Bycatch was seldom a problem throughout the year. For further details see the report from the Canadian Advisory Panel (Appendix C).

The most abundant year classes in the Canadian Freezer trawler catch were age 6 at 56.8%, age 7 at 9.2%, age 8 at 8.1%, and age 5 at 7.0%. The most abundant year classes in the Canadian Shoreside catch were age 6 at 70.5%, age 7 at 9.3%, age 8 at 8.6%, and age 2 at 4.7%.

For an overview of Canadian catch by year and fleet, see Table 2. For 2002, 2003, 2009, 2012, 2013, 2014, 2015 and 2016 there was no Joint-Venture fishery operating in Canada and this is reflected as zero catch in that sector for those years in Table 2.

2 DATA

Fishery-dependent and fishery-independent data sources used here (Figure 3) include:

- Total catch from all U.S. and Canadian target fisheries (1966–2016; Tables 1–3).
- Age compositions composed of data from the U.S. fishery (1975–2016) and the Canadian fishery (1990–2016). The last 9 years of these data are shown in Tables 6–10, and the aggregated data for all years shown in Table 11.
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012, 2013 and 2015; Tables 12 and 13).
- Mean observed weight-at-age from fishery and survey catches (1975-2016; Figure 12).

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

- Ageing-error matrices based on cross-read and double-blind-read otoliths.
- Proportion of female hake maturity by age (Dorn and Saunders, 1997); Table 15.

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

- Fishery and acoustic survey length composition information.
- Fishery and acoustic survey age-at-length composition information.
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1977, 1980, 1983, 1986, 1989 and 1992).
- Bottom trawl surveys in the U.S. and Canada (various years and spatial coverage from 1977–2016).
- NWFSC/SWFSC/PWCC coast-wide juvenile hake and rockfish surveys (2001–2016).
- Bycatch of Pacific Hake in the trawl fishery for pink shrimp off the coast of Oregon, 2004, 2005, 2007 and 2008.
- Historical biological samples collected in Canada prior to 1990, but currently not available in electronic form.
- Historical biological samples collected in the U.S. prior to 1975, but currently not available in electronic form or too incomplete to allow analysis with methods consistent with more current sampling programs.
- CalCOFI larval hake production index, 1951-2006. The data source was previously explored and rejected as a potential index of hake spawning stock biomass, and has not been revisited since the 2008 stock assessment.
- Joint-U.S. and Canada acoustic survey index of age-1 Pacific Hake.
- NWFSC winter 2016 acoustic research survey of spawning Pacific Hake.
- Histological analysis of ovary samples collected in recent years (described in Table 16).

2.1 FISHERY-DEPENDENT DATA

2.1.1 Total catch

The catch of Pacific Hake for 1966–2016 by nation and fishery sector is shown in Figure 4 and Tables 1, 2 and 3. Catches in U.S. waters prior to 1978 are available only by year from Bailey et al. (1982) and historical assessment documents. Canadian catches prior to 1989 are also unavailable in disaggregated form. For more recent catches, haul or trip-level information was available to partition the removals by month during the hake fishing season, and estimate bycatch rates from observer information at this temporal resolution. This has allowed a more detailed investigation of shifts in fishery timing (see Figure 5 in Taylor et al. 2014). The U.S. shore-based landings are from the Pacific Fishery Information Network (PacFIN). Foreign and joint-venture catches for 1981–1990 and domestic at-sea catches for 1991–2016 are estimated from the AFSC's and, subsequently, the NWFSC's at-sea hake observer programs stored in the NORPAC database. Canadian Joint-Venture catches from 1989 are from the Groundfish Biological (GFBio) database, the shore-based landings from 1989 to 1995 are from the Groundfish Catch (GFCatch) database, from 1996 to March 31, 2007 from the Pacific Harvest Trawl (PacHarvTrawl) database, and from April 1, 2007 to present from the Fisheries Operations System (FOS) database. Discards are negligible relative to the total fishery catch. The vessels in the U.S. shore-based fishery carry observers and are required to retain all catch and bycatch for sampling by plant observers. All U.S. at-sea vessels, Canadian Joint-Venture, and Canadian freezer trawler catches are monitored by at-sea observers. Observers use volume/density methods to estimate total catch. Canadian shoreside landings are recorded by dockside monitors using total catch weights provided by processing plants.

2.1.2 Fishery biological data

Biological information from the U.S. at-sea commercial Pacific Hake fishery was extracted from the NORPAC database. This included length, weight, and age information from the foreign and joint-venture fisheries from 1975–1990, and from the domestic at-sea fishery from 1991–2016. Specifically, these data include sex-specific length and age data which observers collect by selecting fish randomly from each haul for biological data collection and otolith extraction. Biological samples from the U.S. shore-based fishery from 1991–2016 were collected by port samplers located where there are substantial landings of Pacific Hake: primarily Eureka, Newport, Astoria, and Westport. Port samplers routinely take one sample per offload (or trip) consisting of 100 randomly selected fish for individual length and weight, and from these 20 are randomly subsampled for otolith extraction.

The Canadian domestic fishery is subject to 100% observer coverage on the four freezer trawler vessels *Viking Enterprise*, *Osprey #1*, *Northern Alliance*, and *Raw Spirit*, which together make up a large portion of the Canadian catch (49.8% in 2016). Their catch exceeded that of the Shoreside vessels for the first time in 2014 (prior to 2013 the shoreside sector caught more than double that of the freezer-trawl sector), again in 2015, and nearly equal in 2016. The Joint-Venture fishery has 100% observer coverage on their processing vessels, which in 2011 made up 16% of the

Canadian catch, but has been non-existent since that time. On observed freezer trawler trips, otoliths (for ageing) and lengths are sampled from Pacific Hake caught for each haul of the trip. The sampled weight from which biological information is collected must be inferred from length-weight relationships. For electronically observed shoreside trips, port samplers obtain biological data from the landed catch. Observed domestic haul-level information is then aggregated to the trip level to be consistent with the unobserved trips that are sampled in ports.

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

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

The aggregate fishery age-composition data (1975–2016) confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999 (Figure 7 and Table 11). The more recent age-composition data consisted of high proportions of 2008 and 2010 year classes in the 2012 fishery, and the 2010 year class from 2013 to 2015 fisheries (Figure 7 and Table 11). In 2016, the 2010 and 2014 cohorts showed up as significant proportions (Figure 7 and Tables 6–11). The 2014 cohort was the largest in all three U.S. fleets (Tables 6–8) while the 2010 cohort was largest in both Canadian fleets (Tables 9 and 10); the 2014 cohort was the largest for the aggregated data (Table 11).

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

Both the weight- and length-at-age information suggest that hake growth has changed markedly over time (see Figure 7 in Stewart et al. 2011). This is particularly evident in the frequency of larger fish (> 55 cm) before 1990 and a shift to much smaller fish in more recent years. The treatment of weight- and length-at-age are described in more detail in sections 2.3.3 and 2.3.4 below. Although length composition data are not fit explicitly in the base assessment models presented here, the presence of the 2008 and 2010 year classes have been clearly observed in length data from both of the U.S. fishery sectors, and the 2014 year class was apparent in 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 assessment of this stock. There are many reasons that fishery CPUE would not index the abundance of Pacific Hake, which are discussed in the 2013 stock assessment (Hicks et al., 2013).

2.2 FISHERY-INDEPENDENT DATA

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

2.2.1 Acoustic survey

The joint biennial U.S. and Canadian integrated acoustic and trawl survey has been the primary fishery-independent tool used to assess the distribution, abundance and biology of coastal Pacific Hake along the west coasts of the United States and Canada. A detailed history of the acoustic survey is given by Stewart et al. (2011). The acoustic surveys performed in 1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012, 2013 and 2015 were used in this assessment (Table 13). The acoustic survey samples all waters off the coasts of the U.S. and Canada thought to contain all portions of the Pacific Hake stock age-2 and older. Age-0 and age-1 hake have been historically excluded from the survey efforts, due to largely different schooling behavior relative to older hake, concerns about different catchability by the trawl gear, and differences in expected location during the summer months when the survey takes place. However, observations of age-1 are still collected during the survey, and an age-1 index has been developed but is not included in the base assessment.

Distributions of hake backscatter plotted for each acoustic survey since 1995 illustrate the variable spatial patterns of age-2+ hake among years (Figure 2). This variability is partly due to the age of the population (older Pacific Hake tend to migrate farther north), but also environmental factors. The 1998 acoustic survey is notable because it shows an extremely northward occurrence that is thought to be related to the strong 1997-1998 El Niño. In contrast, the distribution of hake during the 2001 survey was compressed into the lower latitudes off the coast of Oregon and Northern California. In 2003, 2005 and 2007 the distribution of Pacific Hake did not show an unusual coast-wide pattern, but in 2009, 2011, 2012, and 2013 the majority of the hake distribution was again found in U.S. waters, which is more likely due to age-composition than the environment, although 2013 showed some warmer than average sea-surface temperatures. In 2015, sea-surface temperatures were warmer again, resulting in a northern shift in the overall hake distribution.

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

Acoustic survey data from 1995 onward have been analyzed using geostatistical techniques (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 was scrutinized and reanalyzed using consistent assumptions. These include:

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

However, the data from the 1995 survey was not in a format that could be processed, so the biomass estimate and associated age composition for that year were excluded from the model. Those 1995 data have now been processed in the same manner as the subsequent years and included in the time series (Table 14).

As part of that data-processing step, it was discovered that the variogram used in the kriging for the 1998 data required a revision, which resulted in a increase in the biomass index for that year of approximately 2%, from 1.534 to 1.569 million t, and a decrease in the associated CV from 0.0526 to 0.0479. The coefficient of variation estimated for the 2015 survey was revised in early 2016 from 0.092 to 0.0829. That change came too late for inclusion in the previous assessment document but is included in this present analysis.

This model thus includes a full time-series of consistently analyzed survey biomass (Table 13 and

Figures 8 and 9) and age compositions (Figure 7 and Table 12).

Results from research done in 2010 and 2014 on representativeness of the biological data (i.e. repeated trawls at different depths and spatial locations on the same aggregation of hake) and sensitivity analyses of stratified data showed that trawl sampling and post-stratification is only a small source of variability among all of the sources of variability inherent to the acoustic analysis (see Stewart et al. 2011).

Estimated age-2+ biomass in the survey has increased steadily over the four most recent surveys conducted in 2011-2013 and 2015. The 2015 survey biomass index is 2.16 million metric tons, which is 1.69 times the 2012 survey biomass index and 3.19 times the 2011 acoustic survey biomass index (Table 13 and Figure 8). The 2015 survey age composition was made up of 58.98% age-5 fish from the 2010 year-class.

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

The acoustic survey data in this assessment do not include age-1 fish, although a separate age-1 index has been explored in the past. The age-1 index is used in this stock assessment as a sensitivity because more time is needed to develop and investigate the index, the uncertainty of each estimate is unknown, and the survey is not specifically designed to representatively survey age-1 hake. Given the design changes that have occurred over time, the index was not included in the base model. However, the estimates that have been provided seem to track the estimated recruitment reasonably well (Figure 10). The 2013 stock assessment provides a more detailed description of the age-1 index (Hicks et al., 2013).

2.2.2 Other fishery-independent data

Fishery-independent data from the Alaska Fisheries Science Center (AFSC) bottom trawl survey, the Northwest Fishery Science Center (NWFSC) bottom trawl survey, the NWFSC and Pacific Whiting Conservation Cooperative (PWCC) pre-recruit survey 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

The fraction of fish mature, by size and age, is based on data reported in Dorn and Saunders (1997) (Table 15), and has remained unchanged in the base models since the 2006 stock assessment. These data consisted of 782 maturity estimates based on visual examination of ovaries by observers. The proportion mature by length was converted to estimates of fecundity-at-age using an estimated growth curve and weight-length relationships estimated in a 2011 model which included length data. The resulting product of maturity and weight results in a relative contribution for each age to the female spawning biomass of 0.10 at age-2, 0.25 at age-3, 0.40 at age-4, and 0.52 at age-5. Dividing these values by the average weight-at-age relationship indicates that the current model setup is equivalent to assuming that the fraction mature is 41% at age-2, 69% at age-3, 84% at age-4 and 98% at age-5.

Histological samples have been collected in recent years from bottom trawl surveys, acoustic surveys, winter and summer acoustic research trips, and from the U.S. At-Sea Hake Observer Program (A-SHOP) observers aboard commercial Catcher-Processor vessels (Table 16). In the course of the surveys, length bins were targeted for ovary collection to ensure an even coverage. Details on the sampling procedure and histological methods are provided in the 2016 assessment document (Grandin et al., 2016).

Estimates of maturity-at-length conducted for the 2015 assessment (Taylor et al., 2015) found similar patterns of maturity-at-length to those reported in Dorn and Saunders (1997), with the exception of samples from south of 34.5°N (Table 15, Figure 11). There are also some large fish classified as immature based on the histological criteria, which may in fact be mature individuals which are "skip spawners" and will not be spawning in the upcoming year.

No new maturity analyses were completed in time for this assessment, but the large set of ovaries associated with the large 2014 cohort, including samples in all four seasons in 2016, is expected to contribute to a thorough analysis of maturity in time for the 2018 stock assessment.

Tissue samples for genetic analyses have been collected from many of the same fish from which ovaries were sampled which may help determine whether the fish south of 34.5°N are from the same stock as the rest of the population.

2.3.2 Ageing error

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

To account for these observation errors in the model, year-specific ageing-error matrices (defined via vectors of standard deviations of observed age at true age) are applied, where the standard deviations of strong year classes were reduced by a constant proportion. For the 2009 and 2010 assessments this proportion was determined empirically by comparing double-read error rates for strong year classes with rates for other year classes. In 2010, a blind double-read study was conducted using otoliths collected across the years 2003-2009. One read was conducted by a reader who was aware of the year of collection, and therefore of the age of the strong year classes in each sample, while the other read was performed by a reader without knowledge of the year of collection, and therefore with little or no information to indicate which ages would be more prevalent. The resulting data were analyzed via an optimization routine to estimate both ageing error and the cohort effect. The resultant ageing error was similar to the ageing error derived from the 2008 analysis. The application of the cohort-specific ageing error was similar between assessments since 2011, with the ageing-error standard deviation reduced by a factor of 0.55 for the largest cohorts: 1980, 1984, 1999, 2010, and 2014. In the 2014 base model (Taylor et al., 2014), the 2008 cohort was also included in this set, but current estimates show this year-class to be enough less than the four largest that a reduction in ageing was not included for the 2008 year class in the 2015 assessment (Taylor et al., 2015) as well as this assessment. Also, the model presented here does not include the reduction in ageing error for age-1 fish under the assumption that they never represent a large enough proportion of the samples to cause the cohort-effect. A sensitivity analysis without any cohort ageing error is provided in Section 3.8.

2.3.3 Weight-at-age

A matrix of empirically derived population weight-at-age by year is used in the current assessment model to translate numbers-at-age directly to biomass-at-age (Figure 12). Mean weight-at-age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2016 (Figure 12). Past investigations into calculating weight-at-age for the fishery and survey independently showed little impact on model results. Ages-15 and over for each year were pooled and assumed to have a constant weight-at-age. The combinations of age and year with no observations were assumed to change linearly over time between observations at any given age. For those years before and after all the observations at a given age, mean weights were assumed to remain constant prior to the first observation and after the last observation. The number of samples is generally proportional to the amount of catch, so the combinations of year and age with no samples should have relatively little importance in the overall estimates of the population dynamics. The use of empirical weight-at-age is a convenient method to capture the variability in both the weight-at-length relationship within and among years, as well as the variability in length-at-age, without requiring parametric models to represent these relationships. However, this method requires the assumption that observed values are not biased by strong selectivity at length or weight and that the spatial and temporal patterns of the data sources provide a representative view of the underlying population. Simulations performed by Kuriyama et al. (2016) showed that, in general, using empirical weight-at-age when many observations are available resulted in more accurate estimates of spawning biomass.

For purposes of forecasting, Stock Synthesis does not yet include options for averaging weight-at-age values from recent years as it does with selectivity and other quantities. Therefore, the mean weights at each age in the forecast were set equal to the mean across all years which therefore match the equilibrium and reference point calculations. Mean weight has been declining for most ages over the past few years and in 2016 was less than the mean weight-at-age over all years for ages 2–13. The 2010 cohort declined in average weight from 2015 to 2016, as did several older cohorts.

2.3.4 Length-at-age

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

2.4 ESTIMATED PARAMETERS AND PRIOR PROBABILITY DISTRIBUTIONS

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

2.4.1 Natural Mortality

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

2.4.2 Steepness

The prior for steepness is based on the median (0.79), 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 is distributed Beta(9.76, 2.80) which translates 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 (explained further below).

Recent assessments (Taylor et al., 2014, 2015; Grandin et al., 2016) used $\phi = 0.03$, which was estimated externally by treating the deviations as random effects and integrating over them using the Laplace method, as described by Thorson et al. (2014). This value allowed for the estimation of time-varying selectivity without allowing large year-to-year changes. This year, the JTC explored flexibility of the fishery selectivity parameter, because $\phi = 0.03$ led to a record-high estimate for the 2014 year class – see Section 3.8.

The choice of a more flexible fishery selectivity parameter value of $\phi = 0.20$ for this assessment instead of the less flexible $\phi = 0.03$ used in recent assessments was based on multiple criteria. First, ocean conditions in recent years have been reported as unusual, resulting in potentially greater changes in fishing behavior than in the past, suggesting that the extra flexibility may be necessary to model the observed age compositions. Second, the model with $\phi = 0.20$ estimated similar magnitude for the 2010 and 2014 recruitments, which is more consistent with the age-1 index (Figure 10) than models with less flexible fishery selectivity. Third, a model with $\phi = 0.20$ performed well when explored in the Management Strategy Evaluation (Taylor et al., 2014). In the MSE, two levels of flexibility in the estimation model, $\phi = 0.05$ and $\phi = 0.20$ were considered, as well as a case without time-varying selectivity ($\phi = 0$), all relative to a value of $\phi = 0.20$ in the operating model. Under these assumptions, models with time-varying selectivity had similar performance and both performed better than the model without that feature (Table A.5 in Taylor et al. (2014)). However, the estimation model with more flexible selectivity ($\phi = 0.20$) had equal or slightly better performance in most areas, including a lower probability of estimating the stock below $B_{10\%}$ and a lower average annual variability in the catch.

Finally, the JTC notes that modeling time-varying selectivity is an active area of research in fisheries science that we hope to benefit from and contribute to. For instance, exploring ways of representing potential targeting of large cohorts may allow better estimation of past patterns as well as improve forecast accuracy.

Further details on the time-varying selectivity function are now given.

For each age $a \geq A_{\mathrm{min}}$ there is a selectivity parameter, p_a, for the fishery (for which $A_{\mathrm{min}} = 1$) and a parameter p_a for the survey (for which $A_{\min} = 2$). The selectivity at age a is computed as

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

where

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

and

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

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

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

Time-varying fishery selectivity is implemented through annual deviations in the p_a, formulated as

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

where the ε_{ay} are additional parameters estimated in the model.

The values of ε_{ay} are included in an additional likelihood component with negative log-likelihood proportional to

$$-\log(\mathrm{L}) \propto \frac{1}{2} \sum_{a=A_{\min}}^{6} \sum_{y=1991}^{2016} \frac{\varepsilon_{ay}^2}{\phi^2}, \tag{5}$$

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

The current selectivity parameterization is limiting because each individual selectivity-at-age is correlated with the selectivity of other ages. In other words, it is difficult to disentangle the correlations. Therefore, we recommend that future research be expended on investigating alternative selectivity patterns that allow for easily interpretable annual variations. Such research is ongoing but no clear alternative was available in Stock Synthesis for this assessment.

3 ASSESSMENT

3.1 MODELING HISTORY

In spite of the relatively short history of fishing, Pacific Hake have surely been subject to a larger number of stock assessments than any marine species off the west coast of the U.S. and Canada. These assessments have included a large variety of age-structured models. Initially, a cohort analysis tuned to fishery CPUE was used (Francis et al., 1982). Later, the cohort analysis was tuned to NMFS triennial acoustic survey estimates of absolute abundance at age (Hollowed et al., 1988). Since 1989, stock-synthesis models using fishery catch-at-age data and acoustic survey estimates of population biomass and age composition have been the primary assessment method (Dorn and Methot, 1991).

While the age-structured assessment form 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, a huge number of structural assumptions for the stock assessment model, and alternative control rules.

Data processing, choices, and weighting have been modified several times in historical hake assessments. For example, acoustic data processing has been modified over the years through modifications to target strength calculations (Dorn and Saunders, 1997) or the introduction of kriging (Stewart and Hamel, 2010). While survey data have been the key index for abundance since 1988, which surveys 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 their sampling had been insufficient to be comparable with more recent data; various recruitment indices have been considered, but subsequently rejected (Helser et al., 2002, 2005; Stewart and Hamel, 2010). Even where data have been consistently used, their weighting in the statistical likelihood has varied through various emphasis factors (e.g. Dorn 1994; Dorn et al. 1999), use of a multinomial sample size on age-composition (Dorn et al., 1999; Helser et al., 2002, 2005; Stewart et al., 2011) and assumptions regarding survey variance. The list of changes discussed above is for illustrative purposes only; it is only a small fraction of the different data choices analysts have made and that reviewers/panels have required.

The structure of assessment models has perhaps had the largest number of changes. In terms of spatial models since 1994, 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 F_{MSY} and MSY (Martell, 2010), and using several alternative steepness priors (Stewart et al., 2012; Hicks et al., 2013). Selectivity has also been modeled in several ways: it has been invariant (Stewart et al., 2012; Hicks et al., 2013), time-varying with (Helser et al., 2002) and without (Dorn, 1994; Dorn and Saunders, 1997; Stewart et al., 2012; Hicks et al., 2013) a random walk, age-based (Dorn, 1994; Dorn and Saunders, 1997; Stewart et al., 2012; Hicks et al., 2013) and length-based (Helser and Martell, 2007).

Several harvest control rules have been explored for providing catch limits from these stock assessments. Pacific Hake stock assessments have presented decision makers with constant F, variable F and hybrid control rules: $F_{\mathrm{SPR}=35\%}$, $F_{\mathrm{SPR}=40\%}$, $F_{\mathrm{SPR}=40\%}$–40:10, $F_{\mathrm{SPR}=45\%}$, $F_{\mathrm{SPR}=45\%}$–40:10 and $F_{\mathrm{SPR}=50\%}$ (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 assorted review panel meetings.

While there have been many changes to Pacific Hake management procedures, they have not been capricious. Available data have changed over the years, and there have been many advances in the discipline of fisheries science. In some ways, the latter has evolved considerably over the course of the historical hake fishery: new statistical techniques and software have evolved (Bayesian vs. maximum likelihood methods for example); and the scientific literature has suggested potentially important biological dynamics to consider (explicit modeling of length-at-age for example). Policies requiring the application of specific control rules have also changed such as the United States' National Standards Guidelines in 2002 and the $F_{\mathrm{SPR}=40\%}$–40:10 harvest control rule in The Agreement. 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 reviewers. Until the Management Strategy Evaluation (MSE) that was begun in 2013 (Hicks et al., 2013), none of these management procedure changes were evaluated by simulation and quantitatively compared with performance measures.

3.2 RESPONSE TO 2016 SCIENTIFIC REVIEW GROUP (SRG) REVIEW

The Scientific Review Group (SRG) meeting was held from February 23–25, 2016, at the Watertown Hotel, Seattle, WA, USA.

The following are the Assessment Recommendations from the 2016 SRG report, as listed from highest to lowest priority, and associated responses from the JTC:

- Given the information and analyses presented to the SRG this meeting, the SRG agrees with the decision to fit the 2016 base assessment model to the survey biomass time series with limited extrapolation. This decision should be continued for the 2017 base assessment model.

  Response – The acoustic survey biomass index included in the 2017 base model continues to use the survey biomass time series with limited extrapolation, which includes the incorporation of a tapering function to ensure extrapolated biomass goes to zero the further the prediction was from observed data. The 2016 assessment did not include the 1995 survey biomass estimate due to issues with the older survey data, but those issues have now been resolved so the 2017 base model now includes the reanalyzed (following procedures described *in Grandin et al. (2016), Section 2.2.1) 1995 estimate. The 1998 survey estimate was also revised due to a discovery of a better set of variables used in the processing of the acoustic data for that year.*

- The list of sensitivity tests presented in the 2016 assessment covers the major axes of uncertainty, and should be continued in the 2017 assessment.

  Response – The list of sensitivity tests (i.e., prior on natural mortality, prior on steepness, and σ_r) was retained this year, as requested. Several other sensitivity runs were conducted to gauge the impact of alternative sources of data, model structural assumptions, and parameterizations (see Section 3.8).

- Age-1 index: the SRG supports the continued development of an age-1 index from the acoustic survey, and recommends continuing to run sensitivity tests in future assessments fitted to the age-1 index.

  Response – The addition of a separate age-1 acoustic index is included as a sensitivity run to the 2017 base assessment model (see Section 3.8). This age-1 index is used in this stock assessment as a sensitivity because more time is needed to develop and investigate the index, the uncertainty of each estimate is unknown, and in particular because the survey is not specifically designed to survey age-1 hake.

- Sensitivity tests that changed σ_r (which sets variability around the theoretical recruitment model) from the default value of 1.4 to values of 1.0 and 2.0 resulted in large changes to estimates of R_0 and B_0. Since this is the only parameter that showed a large impact on population status, we recommend that the value of σ_r be explored more fully.

  Response – In addition to sensitivity runs that applied σ_r values of 1.0 and 2.0 as bounds, a value of 1.51 was identified as a possible alternative using the diagnostic outputs provided in the R package 'r4ss' based on the main recruitment deviation time period (1970-2014). A likelihood profile was also used to evaluate the change in the likelihood surface across a range of plausible σ_r values. Results indicate that the σ_r used in the 2017 base model (1.4) is near the minimum and is predominantly informed by age data and recruitment.

- Current biological evidence does not support including Pacific Hake south of Point Conception in the assessment. The SRG encourages continued collection and processing of genetic material to resolve stock structure in the California Current region, especially given increasing catches of Pacific Hake in Mexican waters.

  Response – The JTC supports this recommendation.

- The SRG continues to support collection of ovaries across the range of Pacific Hake and further estimation of maturity schedules based on histological techniques. We recommend updating the current maturity ogive for the stock north of Point Conception (34° N), given that the current stock assessment is based on older information (Dorn and Saunders 1997). We encourage the ongoing collection and processing of biological samples on survey and other platforms.

Response – Samples from Pacific Hake ovaries were collected in 2016 from the NWFSC bottom trawl survey, the acoustic survey (summer and winter research cruises), and the At-Sea Hake Observer Program (U.S. catcher-processors and motherships). No new maturity analyses were completed in time for this assessment, but the large set of ovaries associated with the large 2014 cohort, including samples in all four seasons in 2016, is expected to contribute to a thorough analysis of maturity in time for the 2018 stock assessment. Other biological sampling continued throughout 2016 at similar rates to recent years. The one exception was that the Canadian shoreside fishery contributed nearly twice as many age samples this year than in any year prior (see Table 5).

3.3 DESCRIPTION OF BASE MODEL

The 2017 base model is structurally an update of the base model in the 2016 stock assessment. Stock Synthesis (Methot and Wetzel, 2013) version 3.24 was used, the same as for the previous assessment (Grandin et al., 2016). The largest change between the 2017 and 2016 stock assessments is the addition of the 1995 acoustic survey index estimate and an increase in the allowable variation associated with time-varying selectivity estimates in the base model. In 2016, acoustic data from 1998 to 2015 were reanalyzed, taking advantage of improvements in methodology (including assumptions applied to the extrapolation of survey observations to areas beyond the spatial sampling frame of the survey). The reanalysis of 1995 acoustic data was completed this year, following the same updated procedures as were followed for the years 1998 to 2015, and is now included in the acoustic survey index time series. Time-varying fishery selectivity is retained in the 2017 base model as it has been applied since 2014, with the exception that the magnitude of the allowable deviations was increased from a standard deviation of 0.03 to 0.20. Otherwise, the general parameterization of selectivity was retained, although additional parameters were required to estimate an additional year of deviations. The acoustic survey selectivity is assumed to not change over time. Selectivity curves were modeled as non-parametric functions estimating age-specific values for each age beginning at age 2 for the acoustic survey (because age-1 fish are mainly excluded from the sampling design) and age-1 for the fishery until a maximum age of 6 (all fish 6 and older have the same selectivity).

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

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 multinomial likelihood was applied to age-composition data, weighted by the sum of the number of trips or hauls actually sampled across all fishing fleets, and the number of trawl sets in the research surveys. Input sample sizes were then iteratively down-weighted to allow for additional sources of process and observation error. This process resulted in tuned input sample sizes roughly equal to the harmonic mean of the effective sample sizes after model fitting. Tuning quantities did not change in assessments from 2012 to 2015, however additional tuning was required in 2016 and this year given the updated acoustic survey index composition data and refinements to fishery composition data.

Uncertainty of estimated quantities was calculated via Markov Chain Monte Carlo (MCMC) simulations. The bounds of 95% credibility intervals were calculated as the 2.5% quantile and the 97.5% quantile of posterior distributions from the MCMC simulations, to give equal-tailed intervals.

Calculations and figures from Stock Synthesis output were performed using R version 3.3.1 (2016-06-21) (R Core Team, 2015) and many R packages (in particular r4ss and xtable). The use of R, knitr, LaTeX and GitHub immensely facilitated the collaborative writing of this document.

For this assessment document we have updated and refined the Glossary (Appendix B), in particular clarifying the definitions of the various terms involved in the default harvest policy.

3.4 MODELING RESULTS

3.4.1 Changes from 2016

A set of 'bridging' models was constructed to evaluate the component-specific effects of all changes to the base model from 2016 to 2017. These changes included updating historic (pre-2016) catch, fishery age-composition, and weight-at-age data; reanalyzing 1995 acoustic survey data; updating the survey index time series and age-composition data; adding 2016 catch and fishery age-composition data; and 'tuning' the 2017 base model given the extended survey time series and additional year of fishery data. Updating pre-2016 catch and fishery age-compositions had no observable effects on spawning biomass (Figure 13).

The next bridging step was to update the acoustic survey index time series. Updates included a revised estimate and standard error for 1998, a revised standard error for 2015 estimate, and the extension of the survey time series to include 1995 (Figure 14). The new survey time series spanned the years 1995 through 2015. These updates had almost no observable effects on the fit to the survey index (Figure 14, lower right panel) or to spawning biomass (Figure 14, top panel).

The addition of 2016 fishery data had a large effect on estimates of recruitment in 2014 (Figure 13). In particular, a relatively large proportion of age-2 fish were caught in the 2016 fishery, providing the second straight year of evidence to the population model that 2014 could be an above average year-class. The acoustic survey will not have a chance to fully sample the 2014 year-class until summer of 2017 (for use in the 2018 assessment).

The final bridging steps were to adjust the time period that applies to estimating recruitment deviations and for conducting bias corrections; allowing for more flexible time-varying selectivity; and to adjust the compositional weights in the 2017 base model (Figure 15). Adjusting the main (full bias adjustment) and late (ramping down bias adjustment) recruitment deviation periods to corroborate with current data led to minor differences compared to the addition of 2016 fishery data (Figures 43 and 44). Providing the model with increased flexibility to fit time-varying selectivity patterns (by increasing the standard deviation of the deviates) had a considerable affect on 2014 recruitment estimates (Figure 15, lower panels) and thus recent estimates of spawning biomass (Figure 15, top panels). Relaxing the penalty associated with the deviates for time-varying selectivity resulted in a more plausible 2014 recruitment estimate, corroborating with recruitment estimates from the 2016 assessment and the acoustic survey age-1 index). Tuning the survey and fishery age-composition weights (harmonic mean approach; McAllister and Ianelli 1997) had a minor effect on model results. More information about the 2017 base model is provided below.

3.4.2 Assessment model results

Model Fit

For the base model, the MCMC chain was the same length as in the 2016 assessment (Grandin et al., 2016). This included 12,000,000 iterations with the first 2,010,000 discarded to eliminate 'burn-in' effects and retaining each 10,000th value thereafter, resulting in 999 samples from the posterior distributions for model parameters and derived quantities. Stationarity of the posterior distribution for model parameters was re-assessed via a suite of standard diagnostic tests. The objective function, as well as all estimated parameters and derived quantities, showed good mixing during the chain, no evidence for lack of convergence, and low autocorrelation (Figures 16 and 17). 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 18). Traceplots show that the MCMC chain was well behaved and had little autocorrelation (Figures 16 and 17). Correlations among key parameters were generally low, with the exception of natural mortality, M, and the unexploited equilibrium recruitment level, $\log(R_0)$; Figure 19. Derived quantities for recruitment in 2008 and 2010 as well as the relationship between relative spawning biomass in 2017 with both the default harvest catch in 2017 and recruitment in 2014 were highly correlated as expected given the dependencies among these quantities (Figure 19). An examination of deviations in recruitment (log-scale differences between estimated and expected recruitment values) from recent years (Figure 20) indicates the highest correlation (0.64) between the 2008 and 2010 recruitment deviations. This continues to be likely caused by the relative proportion of these two cohorts being better informed by recent age composition data than the absolute magnitude of these recruitments.

The base model fit to the acoustic survey biomass index in Figure 21 remains similar to the 2016 base model, despite the addition of 1995 and updated 1998 estimates to the time series this year (Figure 9). The 2001 data point continues to be well below any model predictions that were evaluated, and no direct cause for this is known. The survey did began earlier that year than all other surveys between 1995 and 2009 (Table 13), which may explain some portion of the anomaly, along with El Niño conditions and age structure. The 2009 index is much higher than any predicted value observed during model evaluation. The uncertainty of this point is also higher than in other years, due to the presence of large numbers of Humboldt Squid during the survey. The MLE and median posterior density estimate underfit the 2015 survey index. This is likely due to fishery data suggesting slightly different population dynamics than the survey in recent years. This phenomenon can arise when the fishery gets a prominent signal about age-1 fish, as it did in 2015, whereas the survey contains information on age-2 and older fish.

Fits to the age-composition data continue to show close correspondence to the dominant cohorts observed in the data and also the identification of small cohorts, where the data give a consistent signal (Figure 22). Because of the time-varying fishery selectivity, the fit to commercial age-composition data is particularly good, although models with time-invariant selectivity used in previous years also fit the age compositions well. The 2016 age composition was dominated by age-2 fish from the 2014 year-class (47% of the catch in the fishery) and age-6 fish from the 2010 year-class (35% of the catch in the fishery). Age composition from the 2015 acoustic survey also indicated that the 2010 year-class was large (59% of the catch for that year). The 2015 survey was unable to fully sample the 2014 year-class, because it is designed to sample age-2 and older fish. It is expected that the survey will have the opportunity to sample the 2014 year-class during the upcoming summer 2017 survey. The pattern for the 2010 year-class was expected given the strength of that cohort from the 2012 fishery composition data onwards, and thus are fit well by the model. Combined, the 2015 and 2016 fishery age composition data suggest that 2014 could be a strong recruitment year, and the model was able to adequately fit to these observations (Figure 22). Residual patterns to the fishery and survey age data do not show patterns that would indicate systematic bias in model predictions (Figure 23). The MLEs for numbers, biomass, exploitation rate and catch (in numbers and in biomass) for each age class in each year are given in Tables 20-24. For the major cohorts, the resulting age-specific catch, natural mortality and survival biomasses are given in Table 25.

Posterior distributions for both steepness and natural mortality are strongly influenced by priors (Figure 24). The posterior for steepness was not updated much by the data, as expected given the low sensitivity to steepness values found in previous hake assessments. The natural mortality parameter, on the other hand, is shifted to the right of the prior distribution and the prior may be constraining the posterior distribution. Other parameters showed updating from non-informative priors to stationary posterior distributions.

The 2017 base model increased the level of variation (standard deviation) associated with time-varying fishery selectivity, effectively allowing the model more flexibility (i.e., a lower penalty on the overall likelihood) to fit to data that suggests high variability among years for each age. This increase in the allowed magnitude of the annual deviations lead to more plausible results (otherwise the model estimates an unrealistically large 2014 year class) given limited data on the 2014 recruitment class, uncertainty with spatial changes in fish availability (due to movement), and recent variability in oceanographic conditions. Estimated selectivity deviations from 2010 to 2012 are the largest in recent years (Figures 25 and 26). Fishery selectivity from 2010 through 2012 show a more rapid increase in selectivity-at-age than most other years since 2005 (almost fully selected by age-4 in 2010 and 2012, and by age-3 in 2011). Fishery selectivity on age-2 fish was the highest throughout the time series in 2016. Even though the survey selectivity is time invariant, the posterior shows a broad band of uncertainty between ages 2 and 5 (Figure 27). Fishery selectivity is likewise very uncertain (Figures 26 and 27), but in spite of this uncertainty, changes in year-to-year patterns in the estimates are still evident, particularly for age-3 and age-4 fish, though these patterns might also reflect time-varying mortality processes.

Stock biomass

The base stock assessment model indicates that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium (Figures 28 and 29 and Tables 18 and 19). The model estimates that it was below the unfished equilibrium in the 1960s and 1970s due to lower than average recruitment. The stock is estimated to have increased rapidly to near unfished equilibrium after two or more large recruitments in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.565 million t in 2009. The assessment model estimates that spawning biomass declined slightly from 2014 to 2015 after five years of increases from 2009 to 2014. These estimated increases were the result of a large 2010 cohort and an above-average 2008 cohort, and the recent decline is from the 2010 cohort surpassing the age at which gains in weight from growth are greater than the loss in weight from natural mortality. The model estimates increases from 2015 to 2017 due to the large 2014 year class, which, on average, is estimated to be similar to the size of the 2010 year class.

The median estimate of the 2017 relative spawning biomass (spawning biomass at the start of 2017 divided by that at unfished equilibrium, B_0) is 89.2% but is highly uncertain (with a 95% posterior credibility interval from 37.1% to 270.8%; see Tables 18 and 19). The median estimate of the 2017 beginning of the year female spawning biomass is 2.129 million t (with a 95% posterior credibility interval from 0.763 to 7.445 million t). The estimated 2016 female spawning biomass is 1.993

(0.864–5.307) million t.

Recruitment

The new data available for this assessment do not significantly change the estimated patterns of recruitment. Pacific Hake appear to have low average recruitment with occasional large year-classes (Figures 30 and 31, Tables 18 and 19). Very large year classes in 1980, 1984, and 1999 supported much of the commercial catch from the 1980s to the mid-2000s. From 2000 to 2007, estimated recruitment was at some of the lowest values in the time-series followed by a moderately large 2008 year class. The current assessment estimates a very strong 2010 year class (Figure 33) comprising 70% of the coast-wide commercial catch in 2013, 64% of the 2014 catch, 71% of the 2015 catch, and 35% of the 2016 catch. The current assessment also estimates a strong 2014 year class (Figure 33) comprising 47% of the 2016 catch. The size of the 2014 year class remains highly uncertain, more so than cohorts that have been observed for more years, but the median estimate suggests that it is one of the higher estimates in the time series. The model currently estimates small 2011 and 2013 year classes (median recruitment below the mean of all median recruitments) and a slightly above average 2012 year class. There is little or no information in the data to estimate the sizes of the 2016 and 2017 year classes. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable prior to at least age-3 (Hicks et al., 2013).

The estimated recruitments with uncertainty for each predicted point and the overall stock recruit relationship are provided in Figure 32. Extremely large variability about the expectation and about the joint uncertainty of individual recruitment and spawning biomass pairs are evident in this plot. High and low recruitments have been produced throughout the range of observed spawning biomass (Figure 32). The standard deviation of the time series of median recruitment deviation estimates for the years 1970-2014, which are informed by the age compositions, is 1.52. This value is consistent with the base model value of $\sigma_r = 1.4$.

Exploitation status

Median relative fishing intensity on the stock is estimated to have been below the $SPR_{40\%}$ target except for the year 1999 when spawning biomass was low (Figure 34 and Tables 18 and 19). It should be noted, however, that the median relative fishing intensity was close to the target in 2007, 2008 and 2010, but harvest in those years did not exceed the catch limits that were specified, based on the best available science and harvest control rules in place at the time. Exploitation fraction (catch divided by biomass of fish of age-3 and above) has shown relatively similar patterns (Figure 35 and and Tables 18 and 19). Although similar patterns, the exploitation fraction does not necessarily correspond to fishing intensity because fishing intensity more directly accounts for age-structure of both the population and the catch. For example, relative fishing intensity remained nearly constant from 2012 to 2013 but the exploitation fraction declined in these years because of the large estimated proportion of 2-year-old fish in 2012. Median relative fishing intensity is estimated to have declined from 95.9% in 2010 to 68.8% in 2016, while the exploitation fraction has decreased from 0.23 in 2010 to 0.14 in 2016. 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 2013 through 2015. The median estimate for 2016 is well below the management target, however the 95% posterior credibility interval does include the target level due to the aforementioned uncertainties.

Management performance

Over the last decade (2007–2016), the mean coast-wide utilization rate (i.e., landings/quota) has been 77.5% and catches have generally been below coast-wide targets (Table 4). From 2012 to 2016, the mean utilization rates differed between the United States (74.9%) and Canada (49.1%). In 2015, the utilization rate for the fishery was the lowest in the previous decade (66.2%) due, in part, to difficulties locating aggregations of fish and possibly economic reasons. In years previous to 2015, the underutilization in the United States was mostly a result of unrealized catch in the tribal apportionment, while reports from stakeholders in Canada suggested that hake were less aggregated in Canada and availability had declined. In 2016, the utilization rate increased but remained below pre-2015 levels, despite the total 2016 catch being one of the highest in recent years. This is in large part due to increasing catch targets as biomass continues to increase. 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 except 1999 (Figure 34). The female spawning biomass was above target all years except in 1968, from 1998-2000, and from 2006-2011.

The joint history of biomass and F-based target reference points shows that before 2007, median relative fishing intensity was below target and female spawning biomass was mostly above $B_{40\%}$ (Figure 36). Between 2007 and 2011, however, median relative fishing intensity ranged from 81% to 100% and median relative spawning biomass between 0.24 and 0.32. Biomass has risen recently with the 2008, 2010, and 2014 recruitments and, correspondingly, relative fishing intensity has fallen well below targets. Relative spawning biomass has been above the target since 2012. While there is large uncertainty in the 2016 estimates of relative fishing intensity and relative spawning biomass, the model predicts a less than 4% joint probability of being both above the target relative fishing intensity in 2016 and below the $B_{40\%}$ relative spawning biomass level at the start of 2017.

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, and recruitment deviations. The uncertainty portrayed by the posterior distribution is a better representation of the uncertainty when compared to asymptotic approximations about the maximum likelihood estimates (MLE) because it allows for asymmetry (Figure 24; also see Stewart et al. (2012) for further discussion and examples). Table 26 shows that most key derived quantities from the posterior distribution are larger than their respective MLEs (e.g., median biomass, recruitment, and relative spawning biomass), however some parameter estimates (e.g., steepness and catchability) are smaller. Figure 37 shows the MLE and Bayesian (from MCMC) estimates as well as the skewed uncertainty in the posterior distributions for spawning biomass and recruitment for each year.

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), 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 a subset of key sensitivity analyses in the main document.

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

The JTC continues to be committed to advancing MSE analyses, through further internal technical developments and by coordinating research with other scientists in the region engaging in similar research. In particular, the JTC aspires to advance MSE research in 2017 by collaborating with a new post-doctoral scientist that will be dedicated to MSE-related analyses. Incorporating feedback from JMC/AP/SRG/MSE Advisory Panels will ensure that the operating model is able to provide insight into the important questions defined by these groups. Specifically, the development of MSE tools to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them remains an important goal. If a spatially, seasonally explicit operating model is needed, then research should focus on how best to model these dynamics in order to capture seasonal effects and potential climate forcing influences in the simulations. Further, investigations into the impact of making incorrect assumptions about the underlying recruitment process is central to the adequate characterization of uncertainty when applied to proposed management procedures.

3.6 REFERENCE POINTS

We report estimates of the base reference points (relative to $F_{\mathrm{SPR}=40\%}$, $B_{40\%}$, and MSY) with posterior credibility intervals in Table 27. Only those based on $F_{\mathrm{SPR}=40\%}$ explicitly relate to target reference points per the treaty Agreement (see Section 1.3 and Appendix B). The estimates are slightly different than the estimates in the previous 2016 assessment with slightly smaller equilibrium yields and biomasses estimated in this assessment.

3.7 MODEL PROJECTIONS

The median catch limit for 2017 based on the default $F_{SPR=40\%}$–40:10 harvest policy is 969,840 t, but has a wide range of uncertainty (Figure 38), with the 2.5% to 97.5% range being 293,697–3,710,305 t.

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

Relative fishing intensity exceeding 100% indicates fishing in excess of the $F_{SPR=40\%}$ default harvest rate catch limit. This can happen for the median relative fishing intensity in 2017, 2018 and 2019 because the $F_{SPR=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of overfishing. An alternative catch level where median relative fishing intensity is 100% is provided for comparison (catch alternative e: FI=100%).

Management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP) in 2012 are presented for projections to 2018 and 2019 (Tables 30 and 31). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values. Figure 39 shows the predicted relative spawning biomass trajectory through 2019 for several of these management actions. With zero catch for the next two years, the biomass has a probability of 17% of decreasing from 2017 to 2018 (Table 30 and Figure 40), and a probability of 39% of decreasing from 2018 to 2019 (Table 31 and Figure 41).

The spawning biomass is predicted to decrease from 2017 to 2018 with a greater than 50% probability for catch levels investigated that were at or above 350,000 t (Table 28 and Figure 39). The model predicts high biomass levels and the predicted probability of dropping below 10% in 2018 is less than 1% and the probability of dropping below $B_{40\%}$ is less than 18% for all catches explored (Table 30). It should be noted that the natural mortality rate has overtaken the growth rate for the 2010 year class, the model estimated below average recruitment for the 2011 and 2013 cohorts, but a large predicted 2014 year class will result in increases to the spawning biomass as it enters maturity. The probability that the 2018 spawning biomass will be less than the 2017 spawning biomass ranges from 17% to 82% depending on the catch level (Table 30 and Figure 40).

The age composition of the catch in 2017 is forecast to be 52% age-3 fish from the 2014 year-class and 27% age-7 fish from the 2010 year-class (Figure 42). However, those estimates are highly uncertain with the 95% credibility interval for the age-3 fraction spanning 14%–87%. Due to the lower average weight at age 3 vs. 7, the expected proportion of the 2017 catch by weight is expected to be roughly equal among these two cohorts, with 39% and 36%, respectively.

3.8 SENSITIVITY ANALYSES

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

1. Include the age-1 survey index as an additional source of information;
2. Assume no cohort-based ageing error (i.e., time invariant ageing error);
3. No reduction in ageing error associated with the estimated large 2014 recruitment class;
4. Consideration of alternative standard deviations for time-varying selectivity;
5. Consideration of alternative maximum age assumptions for estimating selectivity;
6. Consideration of a higher standard deviation on the prior distribution for natural mortality;
7. Assume higher/lower variation about the stock-recruitment curve (σ_r); and
8. Consideration of alternative values for steepness.

In general, none of the sensitivities resulted in any significant departure from the main population dynamics of the base model; all models showed large estimated increases in spawning biomass in recent years that continues to be driven by the large 2010 cohort and the 2014 cohort.

The 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 (Figures 55 and 56; 2017 estimates are 74.2% of unfished biomass for the base model and 97.6% for the age-1 index model). In terms of recruitment, the age-1 index tends to reduce uncertainty associated with the estimated deviations from the Beverton-Holt stock-recruitment relationship; the most prominent of these reductions is for the 2014 year-class, where the estimated standard error of the deviate is reduced by 38%.

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 (B_0 under the time-invariant assumption decreases by 13%), relative spawning biomass (increase of 20% in 2016), and recruitment (equilibrium unfished levels and annual deviations; Table 33). 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. If the 2014 year class was not considered to be a major recruitment year (and thus ageing error for this cohort was not reduced by 55% as in the base model), it would result in a small positive impact on estimates of spawning biomass in the most recent years (Figure 55).

The consideration of alternative standard deviations (ϕ) for time-varying selectivity is discussed earlier in section 2.4.3. In short, low values of the parameter ϕ controlling the flexibility in time-varying selectivity resulted in potentially implausibly high estimates of the 2014 recruitment as this was the only available explanation of the large proportion of age-2 fish in the 2016 fishery. For example, with $\phi = 0.03$, as used in recent assessments, there is a record-high estimate for the 2014 year class (the median being 2.5 times larger than any other in the time series) resulting in a huge estimated current biomass (Figures 46 and 47). Models with more flexible selectivity ($\phi = 0.20$, chosen for the base model, and $\phi = 0.30$) had estimates of the 2014 recruitment at a similar magnitude to the 2010 cohort (Table 33, Figures 46 and 47). The biomass estimates for 2014 and earlier appear relatively insensitive to all tested values of ϕ.

Figures 48 and 49 show estimated selectivities with uncertainty for each year for the $\phi = 0.03$ case, which can be compared to Figures 25 and 26 for the base model. Figure 50 shows the uncertainty between the MCMC samples for 2016 fishery selectivity and can be compared with the same figure for the base model (Figure 27). Most notably, the variability between samples for the base model is larger than for the $\phi = 0.03$. The median 2016 fishery selectivity estimates also show strong differences, with the largest being a selectivity value for age-2 in the base model of almost 0.4 compared to 0.1 in the model with less flexible selectivity. This difference indicates that the base model is attributing the large proportion of age-2 fish in the 2016 fishery to a combination of high recruitment and increasing targeting of this cohort, and not just very high recruitment. Figures 50 and 27 also indicate that the base model has more cases of dome-shaped selectivity in 2016 among the 999 sets of selectivity parameters from the MCMC sampling, all associated with a peak at an age younger than age-6. The data support an increase in age-2 selectivity in 2016, but the selectivity curves that peak at ages 3, 4, or 5 are less clearly connected to any pattern in the data. However, the parameterization of selectivity used in this assessment represents the selectivity at each year as an offset from the previous year. Therefore, allowing the flexibility for selectivity at age-2 to increase requires a decrease in the offset associated with each additional age. Thus, the additional variability between ages 2 and 6 in Figure 27 appears to be a necessary condition of allowing the age-2 selectivity to increase above the value associated with the less flexible model shown in Figure 50.

Selectivity in the base model is asymptotic, such that all ages equal to or greater than the specified maximum age (age-6) are fully selected. Three alternative maximum age values (5, 7, and 10) were considered to investigate the asymptotic properties of fishery and survey selectivity patterns and the impact maximum age has on model behavior. Estimated population trends throughout the time series are similar, irrespective of maximum age (Figure 45). However, absolute levels of spawning biomass are different, particularly for the age-10 case, mainly as a result of scaling the population through estimated B_0 and R_0 parameters. The most similar levels of spawning biomass compared to the base model are reached when using a maximum age of 5 throughout all but the most recent years in the time series, when setting the maximum age to 7 is most similar. A logical feature of many selectivity patterns is the incremental increase (decrease) in relative selectivity with age as the fully selected age is approached (moved away from). For each of the three alternative maximum age values, the estimated MLE selectivity-at-age estimates are not continually increasing for survey (age-5, 7, and 12) and fishery (age-7, 10) selectivity patterns (Figure 45). This feature is mostly preserved in the base model (maximum age of 6).

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

The standard deviation of the prior distribution on natural mortality was increased from the base model value of 0.1 to 0.2 and 0.3. Maximum likelihood estimates of natural mortality increased from 0.216 for the base model (prior standard deviation of 0.1) to 0.258 for the sensitivity run with the prior standard deviation set to 0.3. In addition to allowing a higher estimated value for natural mortality, the broader prior in M also increased the overall scale of the population, the estimated stock status relative to B_0, and the uncertainty in spawning biomass on both absolute and relative scales (Figures 53 and 54).

The mean of the prior distribution on steepness was decreased from 0.777 (base) to 0.5, and steepness was also fixed at 1.0. The decrease in the mean of the prior resulted in a change in the maximum likelihood estimate of steepness 0.865 to 0.611. However, neither steepness sensitivity had a strong impact on the overall model results (Figures 53 and 54). The small influence of steepness on model results is related to the relatively large σ_r value which allows the recruitments to deviate far from the underlying stock-recruit relationship (Figure 32).

The value of σ_r was changed from a value of 1.4 (base) to alternative high (2.0) and low (1.0) states. An additional value of 1.51 was added this year. The value of 1.51 is based on the suggestion of Methot and Taylor (2011) that σ_r could be tuned using a combination of the variability among the estimated deviations and the uncertainty around the estimates using the formula

$$\sigma_r^2 = \mathrm{Var}(\hat{r}) + \overline{\mathrm{SE}(\hat{r}_y)}^2, \tag{6}$$

where $\mathrm{Var}(\hat{r})$ is the variance among deviations and $\mathrm{SE}(\hat{r}_y)$ is the standard error of each estimate. Applying the formula to the set of all years with recruitment deviations produced a suggested σ_r of 1.41, which was very similar to the status-quo base-model value, but applying the formula to just the "main" recruitment deviations, spanning the years with the most information (1970–2014), produced a suggested alternative σ_r of 1.51. The three alternative σ_r values had relatively little influence on the estimated dynamics over most of the time series, but the estimated initial age structure in the start and the size of the 2014 recruitment were both strongly influenced by the choice of σ_r. This resulted in little change in the overall scale of the population (Figure 51) prior to the final year, but the higher σ_r values resulted in initial conditions that diverged more from B_0, resulting in very different estimates of stock status (Table 32, Figure 52). The impact on the likelihood of different σ_r values is primarily in improved fit to the age compositions with higher σ_r, but little change in the fit to the survey index. In general, the strong cohorts lead to high variability in estimated recruitment deviations over a broad range of σ_r values, and the theory proposed by Methot and Taylor (2011) suggests that the status-quo value of 1.4 is reasonable.

Several additional sensitivity runs were completed in response to SRG requests during the Feb 13-16, 2017 meeting in Vancouver, B.C., Canada (see Appendix A). These include model sensitivity to the standard deviation associated with time-varying selectivity, further inclusion of the age-1 index, and model convergence diagnostics when using a longer MCMC chain.

3.9 RETROSPECTIVE ANALYSES

Retrospective analyses were performed by iteratively removing the terminal years' data and estimating the parameters under the assumptions of the base model. Models with 4 or 5 years of data removed had little to no information available regarding the high 2010 year class, and therefore estimated quite different trends in biomass relative to more recent models that contained information about the size of the 2010 cohort (Figure 57). The base model contains some information about the size of the 2014 cohort, but with even 1 year of data removed that estimate declines significantly.

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

Figure 58 shows the retrospective patterns of estimated recruitment deviations for various cohorts. The magnitude of the deviation is not well estimated until several (∼4-7) years of fishery catch-at-age data and survey age-composition data have been collected on the cohort. Very strong and weak cohorts tend to be identified in the model at a younger age than intermediate cohorts. For example, the strong 2010 cohort has been fairly well determined in the model by age 3 and the weak 2007 cohort by age 5. Estimated recruitment deviations for the 2014 cohort appear to be similar to the 2010 cohort. One major difference between the 2010 and 2014 cohorts is that by age-3 the 2010 cohort had been fully sampled by the acoustic survey (when they were age-3 in the assessment model), whereas the 2014 cohort will not be sampled by the survey until they are age-4 in the assessment model. The variability among cohort estimates relative to their estimated size in the base model (Figure 59) further indicates that the estimates can start to improve as early as age-3, but some may not stabilize until the cohort approaches an age upwards of 7 years old. This illustrates that multiple observations of each cohort are needed in order to more accurately determine their recruitment strength.

A comparison of the actual assessment models used in each year since 1991 is shown in Figure 60. There have been substantial differences in model structural assumptions and thus results submitted each year, which can clearly be seen by looking at the spawning biomass trajectories. The variability between models, especially early on in the time series, is larger than the uncertainty (95% credibility interval) reported in any single model in recent years. One important avenue which was investigated between 2004 and 2007 was the inclusion of several different, but fixed, survey catchability (q) values followed by a span of years (2008 to present) where it was freely estimated by the model. In all years prior to 2004, survey catchability was fixed at 1.0. The fixing of survey catchability had the effect of driving the estimate of initial biomass upward, which in turn scaled the entire biomass trajectory up, leading to higher estimates of relative spawning biomass than in more recent years. The 2017 base model estimates of spawning biomass are fairly consistent with recent assessments, although the model structure has remained relatively consistent, and the uncertainty intervals associated with recent assessments bracket the majority of the historical estimates.

4 RESEARCH AND DATA NEEDS

4.1 RESEARCH AND DATA NEEDS FOR THE FUTURE

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

1. Investigate links between hake biomass, its spatial distribution and how these dynamics vary with ocean conditions and ecosystem variables such as temperature and prey availability. These investigations have the potential to improve the scenarios considered in future management strategy evaluation (MSE) work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.

2. Continue development of the MSE tools to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them. Incorporate the feedback from JMC/AP/SRG/MSE Advisory Panels into operating model development. Specifically, make sure that the operating model is able to provide insight into the important questions defined by these groups. If a spatially, seasonally explicit operating model is needed, then research should focus on how best to model these dynamics in order to capture seasonal effects and potential climate forcing influences in the simulations (see item 1). Investigate the impact of making incorrect assumptions about the underlying recruitment process. Continue to coordinate our MSE research with other scientists in the region engaging in similar research.

3. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength, directionality of survey and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring

of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others. Continue to work with acousticians and survey personnel from the NWFSC, the SWFSC, and DFO to determine an optimal design for the Joint U.S./Canada acoustic survey. Develop automation and methods to allow for the availability of biomass and age composition estimates to the JTC in a timely manner after a survey is completed.

4. Continue to explore and develop statistical methods to parameterize time-varying fishery selectivity in the assessment and with regard to forecasting.

5. Continue to investigate maturity observations of Pacific Hake and explore additional sampling sources to determine fecundity and when spawning occurs. Continue to explore ways to include new maturity estimates in the assessment. This would involve:

   (a) Read ages for samples that do not currently have an age.

   (b) Further investigation of the smaller maturity-at-length south of Point Conception.

   (c) Determining the significance of batch spawning and viability of spawning events throughout the year.

   (d) Studying fecundity as a function of size, age, weight, and batch spawning.

6. Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific Hake, including investigations into the winter acoustic surveys.

7. Continue to investigate alternative ways to model and forecast recruitment, given the uncertainty present.

8. Improve the characterization and accounting of research catch that is reported to standard databases to improve data tracking and avoid double counting.

9. Update ageing error calculations given new information from recent double reads. Conduct further exploration of ageing imprecision and the effects of large cohorts via simulation and blind source age-reading of samples with differing underlying age distributions – with and without dominant year classes.

10. Continue to collect and analyze life-history data, including weight, maturity and fecundity for Pacific Hake. Explore possible relationships among these life history traits including time-varying changes as well as with body growth and population density. Currently available information is limited and outdated. Continue to explore the possibility of using additional data types (such as length data) within the stock assessment.

11. Maintain the flexibility to undertake annual acoustic surveys for Pacific Hake under pressing circumstances in which uncertainty in the hake stock assessment presents a potential risk to or underutilization of the stock.

12. Evaluate the quantity and quality of historical biological data (prior to 1989 from the Cana-

dian fishery, and prior to 1975 from the U.S. fishery) for use as age-composition and weight-at-age data, and/or any historical indications of abundance fluctuations.

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

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

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7 TABLES

Table 1. Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2016. Tribal catches are included in the sector totals. Research Catch includes landed catch associated with research-related activities. Catch associated with surveys and discarded bycatch in fisheries not targeting hake is not currently included in the model.

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

2014	0	0	62,102	103,203	98,640	197	264,141
2015	0	0	27,661	68,484	58,011	0	154,156
2016	0	0	65,035	108,786	85,293	572	259,687

Table 2. Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2016.

Year	Foreign	JV	Shoreside	Freezer-trawl	Total
1966	700	0	0	0	700
1967	36,710	0	0	0	36,710
1968	61,360	0	0	0	61,360
1969	93,850	0	0	0	93,850
1970	75,010	0	0	0	75,010
1971	26,700	0	0	0	26,700
1972	43,410	0	0	0	43,410
1973	15,130	0	0	0	15,130
1974	17,150	0	0	0	17,150
1975	15,700	0	0	0	15,700
1976	5,970	0	0	0	5,970
1977	5,190	0	0	0	5,190
1978	3,450	1,810	0	0	5,260
1979	7,900	4,230	300	0	12,430
1980	5,270	12,210	100	0	17,580
1981	3,920	17,160	3,280	0	24,360
1982	12,480	19,680	0	0	32,160
1983	13,120	27,660	0	0	40,780
1984	13,200	28,910	0	0	42,110
1985	10,530	13,240	1,190	0	24,960
1986	23,740	30,140	1,770	0	55,650
1987	21,450	48,080	4,170	0	73,700
1988	38,080	49,240	830	0	88,150
1989	29,750	62,718	2,562	0	95,029
1990	3,810	68,314	4,021	0	76,144
1991	5,610	68,133	16,174	0	89,917
1992	0	68,779	20,043	0	88,822
1993	0	46,422	12,352	0	58,773
1994	0	85,154	23,776	0	108,930
1995	0	26,191	46,181	0	72,372
1996	0	66,779	26,360	0	93,139
1997	0	42,544	49,227	0	91,771
1998	0	39,728	48,074	0	87,802
1999	0	17,201	70,121	0	87,322
2000	0	15,625	6,382	0	22,007
2001	0	21,650	31,935	0	53,585
2002	0	0	50,244	0	50,244
2003	0	0	63,217	0	63,217
2004	0	58,892	66,175	0	125,067
2005	0	15,695	77,335	9,985	103,014
2006	0	14,319	65,289	15,136	94,744
2007	0	6,780	54,295	14,121	75,196
2008	0	3,592	57,117	13,214	73,924
2009	0	0	44,136	13,223	57,359
2010	0	8,081	38,907	13,573	60,562
2011	0	9,717	36,363	14,593	60,672

2012	0	0	31,699	14,909	46,608
2013	0	0	33,665	18,584	52,249
2014	0	0	13,326	21,787	35,113
2015	0	0	16,775	22,903	39,678
2016	0	0	35,012	34,729	69,741

Table 3. Total U.S., Canadian and coastwide catches of Pacific Hake (t) from 1966-2016. The percentage of the total catch from each country's waters is also given.

Year	Total U.S.	Total Canada	Total coastwide	Percent U.S.	Percent Canada
1966	137,000	700	137,700	99.5	0.5
1967	177,660	36,710	214,370	82.9	17.1
1968	60,820	61,360	122,180	49.8	50.2
1969	86,280	93,850	180,130	47.9	52.1
1970	159,580	75,010	234,590	68.0	32.0
1971	127,920	26,700	154,620	82.7	17.3
1972	74,130	43,410	117,540	63.1	36.9
1973	147,510	15,130	162,640	90.7	9.3
1974	194,110	17,150	211,260	91.9	8.1
1975	205,650	15,700	221,350	92.9	7.1
1976	231,550	5,970	237,520	97.5	2.5
1977	127,500	5,190	132,690	96.1	3.9
1978	98,377	5,260	103,637	94.9	5.1
1979	124,680	12,430	137,110	90.9	9.1
1980	72,350	17,580	89,930	80.5	19.5
1981	114,760	24,360	139,120	82.5	17.5
1982	75,581	32,160	107,741	70.2	29.8
1983	73,151	40,780	113,931	64.2	35.8
1984	96,382	42,110	138,492	69.6	30.4
1985	85,439	24,960	110,399	77.4	22.6
1986	154,966	55,650	210,616	73.6	26.4
1987	160,448	73,700	234,148	68.5	31.5
1988	160,690	88,150	248,840	64.6	35.4
1989	203,050	95,029	298,079	68.1	31.9
1990	185,142	76,144	261,286	70.9	29.1
1991	229,789	89,917	319,705	71.9	28.1
1992	210,829	88,822	299,650	70.4	29.6
1993	140,132	58,773	198,905	70.5	29.5
1994	253,477	108,930	362,407	69.9	30.1
1995	177,124	72,372	249,495	71.0	29.0
1996	213,159	93,139	306,299	69.6	30.4
1997	233,376	91,771	325,147	71.8	28.2
1998	232,920	87,802	320,722	72.6	27.4
1999	224,565	87,322	311,887	72.0	28.0
2000	206,770	22,007	228,777	90.4	9.6
2001	173,940	53,585	227,525	76.4	23.6
2002	130,453	50,244	180,697	72.2	27.8
2003	141,945	63,217	205,162	69.2	30.8
2004	217,240	125,067	342,307	63.5	36.5
2005	260,120	103,014	363,135	71.6	28.4
2006	266,955	94,744	361,699	73.8	26.2
2007	217,682	75,196	293,389	74.2	25.6

2008	248,496	73,924	321,802	77.2	23.0
2009	121,324	57,359	177,171	68.5	32.4
2010	171,043	60,562	230,755	74.1	26.2
2011	231,261	60,672	291,670	79.3	20.8
2012	160,144	46,608	205,787	77.8	22.6
2013	233,558	52,249	285,591	81.8	18.3
2014	264,141	35,113	298,705	88.4	11.8
2015	154,156	39,678	190,663	80.9	20.8
2016	259,687	69,741	329,427	78.8	21.2

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

Year	US landings (t)	Canadian landings (t)	Total landings (t)	Coast-wide (US+Canada) catch target (t)	US catch target (t)	Canada catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2007	217,682	75,196	293,389	328,358	242,591	85,767	89.7%	87.7%	89.4%
2008	248,496	73,924	321,802	364,842	269,545	95,297	92.2%	77.6%	88.2%
2009	121,324	57,359	177,171	184,000	135,939	48,061	89.2%	119.3%	96.3%
2010	171,043	60,562	230,755	262,500	193,935	68,565	88.2%	88.3%	87.9%
2011	231,261	60,672	291,670	393,751	290,903	102,848	79.5%	59.0%	74.1%
2012	160,144	46,608	205,787	251,809	186,036	65,773	86.1%	70.9%	81.7%
2013	233,558	52,249	285,591	365,112	269,745	95,367	86.6%	54.8%	78.2%
2014	264,141	35,113	298,705	428,000	316,206	111,794	83.5%	31.4%	69.8%
2015	154,156	39,678	190,663	440,000	325,072	114,928	47.4%	34.5%	43.3%
2016	259,687	69,741	329,427	497,500	367,553	129,947	70.7%	53.7%	66.2%

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

	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	Joint-Venture (hauls)	Shoreside (trips)	Freezer-trawl (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	0	–
1996	–	–	–	123	–	35	–	28	0	–
1997	–	–	–	127	–	65	–	27	1	–
1998	–	–	–	149	–	64	–	21	9	–
1999	–	–	–	389	–	80	–	14	26	–
2000	–	–	–	413	–	91	–	25	1	–
2001	–	–	–	429	–	82	–	28	1	–
2002	–	–	–	342	–	71	–	–	36	–
2003	–	–	–	358	–	78	–	–	20	–
2004	–	–	–	381	–	72	–	20	28	–
2005	–	–	–	499	–	58	–	11	31	14
2006	–	–	–	549	–	83	–	21	21	46
2007	–	–	–	524	–	68	–	1	7	29
2008	–	–	324	–	356	63	–	0	20	31
2009	–	–	316	–	278	66	–	–	7	19
2010	–	–	443	–	331	75	–	0	8	17
2011	–	–	481	–	506	81	–	2	4	7
2012	–	–	299	–	332	76	–	–	43	101
2013	–	–	409	–	474	96	–	–	10	105
2014	–	–	400	–	557	68	–	–	26	79
2015	–	–	203	–	431	84	–	–	6	74
2016	–	–	502	–	558	59	–	–	70	111

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

Year	Number of fish	Number of hauls	Age (% of total for each year)														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
2008	1,757	356	0.16	9.78	40.43	1.99	12.57	1.13	4.25	3.37	23.59	1.35	0.52	0.50	0.03	0.29	0.04
2009	1,323	278	0.96	0.86	33.18	42.88	1.96	8.04	0.91	1.28	0.58	7.83	1.09	0.07	0.13	0.22	0.00
2010	976	331	0.00	13.91	8.30	41.94	29.31	1.27	1.42	0.06	0.34	0.18	2.81	0.32	0.00	0.09	0.05
2011	1,185	506	6.92	16.79	53.03	1.83	9.12	7.22	1.47	0.69	0.36	0.33	0.04	1.79	0.23	0.09	0.09
2012	981	332	0.00	50.41	9.94	23.82	2.95	5.30	2.72	1.64	0.79	0.28	0.47	0.49	0.56	0.33	0.31
2013	1,402	474	0.10	0.51	72.04	7.12	13.80	1.50	1.19	1.44	0.84	0.36	0.24	0.10	0.07	0.44	0.24
2014	1,652	557	0.00	4.13	5.17	71.41	5.98	8.89	0.89	2.03	0.89	0.44	0.09	0.00	0.00	0.09	0.00
2015	1,263	431	3.49	1.66	7.55	3.45	76.45	3.20	2.16	0.33	0.77	0.52	0.00	0.12	0.12	0.00	0.15
2016	1,660	558	0.46	46.86	2.31	6.29	2.36	35.70	1.79	2.34	0.88	0.21	0.53	0.22	0.00	0.05	0.00

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

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

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

Year	Number of trips	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2008	63	1.88	13.86	26.09	2.32	21.71	1.34	3.85	2.87	21.99	1.99	0.99	0.42	0.22	0.23	0.24
2009	66	0.00	0.28	44.84	28.34	2.22	8.98	0.51	1.81	1.68	8.50	1.21	0.59	0.58	0.08	0.38
2010	75	0.09	32.90	1.93	37.37	16.30	1.64	2.96	0.14	0.66	1.01	3.87	0.70	0.14	0.00	0.31
2011	81	0.05	2.70	86.98	3.42	3.00	1.68	0.41	0.54	0.36	0.16	0.00	0.56	0.09	0.00	0.05
2012	76	0.00	22.91	18.92	51.10	1.52	2.39	1.18	0.66	0.29	0.07	0.00	0.33	0.23	0.20	0.22
2013	96	0.00	0.37	79.28	5.93	9.78	0.67	1.38	1.02	0.36	0.37	0.13	0.04	0.09	0.31	0.27
2014	68	0.00	2.18	3.00	63.95	8.41	15.20	1.32	2.44	1.70	0.64	0.23	0.00	0.20	0.20	0.51
2015	84	5.98	1.33	7.43	4.92	67.34	4.06	5.08	0.78	1.06	1.28	0.24	0.17	0.00	0.00	0.32
2016	59	0.14	61.98	1.47	3.79	1.76	23.96	1.94	2.83	0.92	0.37	0.32	0.20	0.18	0.05	0.10

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

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

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

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

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

Year	Number of samples	Age (% of total for each year)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1975	13	4.61	33.85	7.43	1.25	25.40	5.55	8.03	10.54	0.95	0.60	0.87	0.45	0.00	0.48	0.00
1976	142	0.08	1.34	14.47	6.74	4.10	24.58	9.77	8.90	12.10	5.43	4.30	4.08	1.07	2.36	0.69
1977	320	0.00	8.45	3.68	27.47	3.59	9.11	22.68	7.60	6.54	4.02	3.55	2.31	0.57	0.31	0.12
1978	341	0.47	1.11	6.51	6.31	26.42	6.09	8.87	21.50	9.78	4.71	4.68	2.34	0.52	0.35	0.34
1979	116	0.00	6.49	10.24	9.38	5.72	17.67	10.26	17.37	12.76	4.18	2.88	0.96	1.65	0.00	0.45
1980	221	0.15	0.54	30.09	1.86	4.49	8.17	11.23	5.01	8.94	11.07	9.46	2.63	3.79	1.52	1.07
1981	154	19.49	4.03	1.40	26.73	3.90	5.55	3.38	14.67	3.77	3.19	10.19	2.31	0.50	0.16	0.72
1982	170	0.00	32.05	3.52	0.49	27.35	1.53	3.68	3.89	11.76	3.27	3.61	7.65	0.24	0.30	0.66
1983	117	0.00	0.00	34.14	4.00	1.82	23.46	5.13	5.65	5.30	9.38	3.91	3.13	2.26	1.13	0.69
1984	123	0.00	0.00	1.39	61.90	3.62	3.85	16.78	2.85	1.51	1.24	3.34	0.92	0.59	1.44	0.56
1985	57	0.92	0.11	0.35	7.24	66.75	8.41	5.60	7.11	2.04	0.53	0.65	0.25	0.00	0.00	0.03
1986	120	0.00	15.34	5.38	0.53	0.76	43.64	6.90	8.15	8.26	2.19	2.82	1.83	3.13	0.46	0.61
1987	56	0.00	0.00	29.58	2.90	0.14	1.01	53.26	0.40	1.25	7.09	0.00	0.74	1.86	1.76	0.00
1988	84	0.00	0.66	0.06	32.35	0.98	1.45	0.66	45.96	1.34	0.83	10.50	0.79	0.05	0.06	4.30
1989	80	0.00	5.62	2.43	0.29	50.21	1.26	0.29	0.08	35.19	1.80	0.40	2.32	0.08	0.00	0.04
1990	163	0.00	5.19	20.56	1.88	0.59	31.35	0.51	0.20	0.04	31.90	0.30	0.07	6.41	0.00	0.99
1991	160	0.00	3.46	20.37	19.63	2.52	0.79	28.26	1.18	0.14	0.18	18.69	0.42	0.00	3.61	0.74
1992	243	0.46	4.24	4.30	13.05	18.59	2.27	1.04	33.93	0.77	0.08	0.34	18.05	0.41	0.04	2.43
1993	172	0.00	1.05	23.24	3.26	12.98	15.67	1.50	0.81	27.42	0.67	0.09	0.12	12.00	0.05	1.13
1994	235	0.00	0.04	2.83	21.39	1.27	12.63	18.69	1.57	0.57	29.91	0.26	0.28	0.02	9.63	0.91
1995	147	0.62	1.28	0.47	6.31	28.97	1.15	8.05	20.27	1.58	0.22	22.42	0.44	0.45	0.04	7.73
1996	186	0.00	18.28	16.24	1.51	7.74	18.14	1.00	4.91	10.98	0.58	0.35	15.72	0.01	0.11	4.44
1997	220	0.00	0.74	29.48	24.95	1.47	7.84	12.49	1.80	3.98	6.67	1.28	0.22	6.08	0.73	2.28
1998	243	0.02	4.79	20.35	20.29	26.60	2.87	5.40	9.31	0.92	1.56	3.90	0.35	0.09	2.94	0.63
1999	509	0.06	10.24	20.36	17.98	20.06	13.20	2.69	3.93	4.01	0.99	1.54	2.14	0.39	0.33	2.07
2000	530	1.00	4.22	10.94	14.29	12.88	21.06	13.12	6.55	4.65	2.51	2.07	2.31	1.29	0.72	2.41
2001	540	0.00	17.34	16.25	14.25	15.68	8.56	12.10	5.99	1.78	2.23	1.81	0.70	1.42	0.68	1.21
2002	449	0.00	0.03	50.64	14.93	9.69	5.72	4.44	6.58	3.55	0.87	0.84	1.04	0.24	0.47	0.95
2003	456	0.00	0.11	1.40	67.90	11.64	3.34	4.99	3.19	3.14	2.11	0.87	0.44	0.53	0.13	0.23
2004	501	0.00	0.02	5.31	6.07	68.29	8.15	2.19	4.15	2.51	1.28	1.08	0.35	0.27	0.16	0.17
2005	613	0.02	0.57	0.46	6.56	5.38	68.72	7.95	2.36	2.91	2.21	1.18	1.09	0.25	0.09	0.25
2006	720	0.33	2.81	10.44	1.67	8.57	4.88	59.04	5.28	1.72	2.38	1.13	1.01	0.43	0.14	0.19
2007	629	0.76	11.31	3.74	15.47	1.59	6.86	3.83	44.11	5.18	1.72	2.28	1.77	0.50	0.19	0.69
2008	794	0.76	9.85	30.59	2.40	14.42	1.03	3.63	3.17	28.01	3.04	1.14	0.73	0.49	0.31	0.43
2009	686	0.64	0.52	30.63	27.55	3.36	10.70	1.30	2.26	2.29	16.19	2.48	0.87	0.59	0.28	0.34
2010	874	0.03	25.34	3.36	34.85	21.53	2.36	3.00	0.44	0.58	0.97	6.06	0.93	0.31	0.10	0.16
2011	1,081	2.64	8.50	70.85	2.65	6.41	4.45	1.14	0.82	0.29	0.39	0.12	1.35	0.17	0.11	0.11
2012	851	0.18	40.95	11.56	32.99	2.49	5.08	2.52	1.13	0.66	0.23	0.33	0.35	0.87	0.28	0.38
2013	1,094	0.03	0.54	70.31	5.91	10.47	1.12	3.41	2.06	0.91	1.37	0.26	0.33	0.53	2.28	0.46
2014	1,130	0.00	3.31	3.73	64.30	6.93	12.17	1.59	3.14	1.83	0.82	0.47	0.12	0.19	0.28	1.13
2015	798	3.59	1.14	6.88	3.95	70.02	4.94	5.09	0.96	1.55	1.09	0.20	0.20	0.06	0.05	0.27
2016	1,300	0.32	46.96	1.69	4.87	2.59	35.05	3.00	3.38	0.87	0.47	0.40	0.22	0.07	0.04	0.08

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

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

Table 13. Summary of the acoustic surveys from 1995 to 2015.

Year	Start date	End date	Vessels	Biomass index (million t)	Sampling CV	Number of hauls with bio. samples
1995	1-Jul	1-Sep	Miller Freeman Ricker	1.318	0.089	69
1998	6-Jul	27-Aug	Miller Freeman Ricker	1.534	0.053	105
2001	15-Jun	18-Aug	Miller Freeman Ricker	0.862	0.106	57
2003	29-Jun	1-Sep	Ricker	2.138	0.064	71
2005	20-Jun	19-Aug	Miller Freeman	1.376	0.064	47
2007	20-Jun	21-Aug	Miller Freeman	0.943	0.077	69
2009	30-Jun	7-Sep	Miller Freeman Ricker	1.502	0.010	72
2011	26-Jun	10-Sep	Bell Shimada Ricker	0.675	0.118	46
2012	23-Jun	7-Sep	Bell Shimada Ricker F/V Forum Star	1.279	0.067	94
2013	13-Jun	11-Sep	Bell Shimada Ricker	1.929	0.065	67
2015	15-Jun	14-Sep	Bell Shimada Ricker	2.156	0.083	78

Table 14. Biomass indices from the acoustic survey (million t) used in the 2016 and 2017 assessments.

Year	Biomass estimate 2016 (million t)	Sampling CV 2016	Biomass estimate 2017 (million t)	Sampling CV 2017
1995	–	–	1.318	8.9%
1998	1.535	5.3%	1.569	4.8%
2001	0.862	10.6%	0.862	10.6%
2003	2.138	6.4%	2.138	6.4%
2005	1.376	6.4%	1.376	6.4%
2007	0.943	7.7%	0.943	7.7%
2009	1.502	10.0%	1.502	10.0%
2011	0.675	11.8%	0.675	11.8%
2012	1.279	6.7%	1.279	6.7%
2013	1.929	6.5%	1.929	6.5%
2015	2.156	9.2%	2.156	8.3%

Table 15. Estimated fraction mature at length as shown in Figure 11.

Length (cm)	Dorn and Saunders (1997)	2015 assessment
20	0.00	0.00
22	0.00	0.00
24	0.00	0.00
26	0.01	0.00
28	0.01	0.00
30	0.04	0.00
32	0.09	0.03
34	0.20	0.14
36	0.39	0.49
38	0.63	0.81
40	0.82	0.91
42	0.92	0.93
44	0.97	0.93
46	0.99	0.93
48	1.00	0.93
50	1.00	0.93

Table 16. Number of Pacific Hake ovaries collected for histological analysis with maturity determined from different years and different sources. Numbers for 2016 are preliminary and may be adjusted when preparation of the samples is completed.

Year	NWFSC Trawl Survey	Acoustic Survey/Research (Summer)	Acoustic Survey/Research (Winter)	U.S. At-Sea Hake Observer Program (Spring)	U.S. At-Sea Hake Observer Program (Fall)	Total
2009	263	0	0	0	0	**263**
2012	71	199	0	0	0	**270**
2013	70	254	0	104	103	**531**
2014	276	0	0	105	142	**523**
2015	293	193	0	98	112	**696**
2016	277	26	311	102	100	**816**
Total	**1,250**	**672**	**311**	**409**	**457**	**3,099**

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

Parameter	Number estimated	Bounds (low,high)	Prior (Mean, SD) single value = fixed
Stock dynamics			
Log(R_0)	1	(13,17)	Uniform
Steepness (h)	1	(0.2,1)	Beta(0.78,0.11)
Recruitment variability (σ_r)	–	NA	1.4
Log recruitment deviations: 1946–2016	71	(-6,6)	Lognormal(0,σ_r)
Natural mortality (M)	1	(0.05,0.4)	Lognormal(0.20,1.11)
Catchability and selectivity (double normal)			
Acoustic survey			
Catchability (q)	1	NA	Analytic solution
Additional value for survey log(SE)	–	(0.05,1.2)	Uniform
Non-parametric age-based selectivity: ages 3–6	4	(-5,9)	Uniform
Fishery			
Non-parametric age-based selectivity: ages 2–6	5	(-5,9)	Uniform
Selectivity deviations (1991–2016, ages 2–6)	130	NA	Normal(0,0.20)

Table 18. Time-series of median posterior population estimates from the base model. Relative spawning biomass is spawning biomass relative to the unfished equilibrium (B_0). Total biomass includes females and males of all ages. Exploitation fraction is total catch divided by total age-3+ biomass. Relative fishing intensity is (1-SPR)/(1-$SPR_{40\%}$).

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Total biomass (thousand t)	Age-0 recruits (millions)	Relative fishing intensity	Exploitation fraction
1966	1,086	46.1%	2,599	1,393	42.1%	6.2%
1967	1,011	43.2%	2,539	3,736	60.7%	10.3%
1968	937	39.9%	2,552	2,195	44.6%	6.4%
1969	1,005	43.0%	2,793	938	58.4%	9.3%
1970	1,084	46.7%	2,948	8,030	66.5%	10.2%
1971	1,083	46.8%	3,116	787	50.3%	6.6%
1972	1,281	55.2%	3,540	498	39.1%	5.4%
1973	1,455	63.0%	3,632	5,085	42.4%	4.9%
1974	1,456	62.7%	3,601	417	50.0%	6.7%
1975	1,469	63.2%	4,626	1,464	43.4%	6.3%
1976	1,456	62.5%	4,822	349	38.7%	5.1%
1977	1,389	59.4%	4,491	6,007	27.8%	3.6%
1978	1,290	55.1%	3,669	287	25.8%	3.2%
1979	1,339	57.3%	4,125	1,029	29.9%	4.4%
1980	1,371	58.5%	4,536	18,559	23.7%	2.5%
1981	1,342	57.0%	4,833	319	35.4%	4.6%
1982	1,810	77.0%	5,494	286	29.6%	4.3%
1983	2,256	95.7%	5,299	428	24.3%	2.2%
1984	2,386	101.4%	5,577	13,854	26.1%	2.7%
1985	2,269	96.1%	6,685	206	21.0%	2.4%
1986	2,473	105.1%	6,461	249	32.3%	5.3%
1987	2,587	110.7%	5,815	5,927	36.5%	4.2%
1988	2,460	105.3%	5,827	1,886	38.7%	4.9%
1989	2,353	100.8%	5,186	198	49.5%	7.6%
1990	2,213	94.3%	4,788	4,284	41.4%	5.9%
1991	2,004	85.3%	4,569	907	62.3%	7.9%
1992	1,807	77.2%	3,856	207	60.9%	9.5%
1993	1,614	68.9%	2,895	3,018	53.5%	7.4%
1994	1,408	60.1%	2,872	3,164	72.8%	14.5%
1995	1,162	49.6%	2,829	1,211	61.0%	12.3%
1996	1,102	46.8%	2,691	1,743	76.5%	15.4%
1997	1,014	43.1%	2,539	1,115	83.6%	15.2%
1998	908	38.8%	2,090	1,873	91.6%	18.3%
1999	785	33.6%	2,074	12,746	101.1%	20.8%
2000	678	29.0%	3,854	322	77.1%	14.9%
2001	1,004	43.2%	4,025	1,220	76.1%	13.5%
2002	1,311	56.4%	4,394	67	53.6%	4.3%
2003	1,451	62.4%	3,759	1,609	49.6%	5.8%
2004	1,392	59.5%	3,092	96	74.8%	11.6%
2005	1,195	50.9%	2,508	2,624	75.0%	16.5%
2006	942	40.3%	2,195	1,995	92.0%	19.2%
2007	753	32.5%	1,747	54	95.2%	22.2%
2008	673	28.9%	1,807	5,556	99.5%	22.6%
2009	565	24.2%	1,593	1,213	81.1%	14.0%
2010	652	27.9%	2,185	15,808	95.9%	22.6%
2011	724	30.9%	2,857	439	88.3%	18.3%
2012	1,167	49.2%	3,655	1,722	69.0%	14.4%
2013	1,574	66.6%	4,279	402	66.6%	7.2%
2014	1,718	73.0%	4,606	12,105	66.1%	7.9%
2015	1,638	70.2%	4,224	733	45.0%	6.1%
2016	1,993	84.2%	4,800	1,269	68.8%	13.9%
2017	2,129	89.2%	5,280	1,367	–	–

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

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Total biomass (thousand t)	Age-0 recruits (millions)	(1-SPR) / (1-$SPR_{40\%}$)	Exploitation fraction
1966	615-2,187	25.9- 83.0%	1,505- 5,383	100- 8,506	20.7- 65.6%	3.1-11.5%
1967	551-2,046	25.4- 76.7%	1,528- 5,065	223-13,881	31.8- 88.6%	5.0-19.5%
1968	512-1,951	21.3- 72.8%	1,578- 5,203	112- 9,045	22.1- 72.3%	3.0-12.7%
1969	607-2,086	25.3- 74.9%	1,757- 5,554	95- 4,910	30.6- 86.5%	4.3-17.5%
1970	664-2,197	27.5- 81.7%	1,840- 5,873	3,677-21,117	36.3- 93.6%	4.9-17.3%
1971	657-2,213	26.9- 83.9%	1,899- 6,298	78- 3,314	25.2- 77.0%	3.2-11.0%
1972	771-2,609	33.0- 99.3%	2,112- 7,301	53- 2,139	18.7- 62.7%	2.6- 9.0%
1973	869-2,952	37.6-111.3%	2,138- 7,317	2,334-12,163	21.3- 68.1%	2.4- 8.3%
1974	853-2,941	36.8-112.7%	2,096- 7,287	46- 1,598	25.6- 76.9%	3.4-11.5%
1975	836-2,968	36.4-114.5%	2,612- 9,372	563- 3,964	21.5- 70.2%	3.2-11.3%
1976	805-2,941	35.3-110.8%	2,674- 9,736	41- 1,435	19.5- 65.4%	2.5- 9.3%
1977	760-2,809	32.9-105.7%	2,498- 8,904	3,024-13,368	13.2- 50.6%	1.8- 6.5%
1978	710-2,570	30.8- 98.4%	2,056- 7,121	36- 1,593	12.2- 46.7%	1.6- 5.8%
1979	761-2,516	32.7- 97.0%	2,350- 7,720	187- 3,508	14.7- 52.8%	2.3- 8.0%
1980	777-2,515	34.3- 95.3%	2,741- 8,250	10,827-39,079	11.8- 42.9%	1.4- 4.4%
1981	785-2,384	34.0- 90.4%	3,020- 8,511	35- 1,484	19.4- 58.1%	2.6- 7.8%
1982	1,138-3,138	48.8-118.5%	3,495- 9,432	30- 1,390	15.8- 50.2%	2.4- 7.3%
1983	1,476-3,826	63.0-145.5%	3,457- 8,976	54- 1,814	13.1- 40.3%	1.3- 3.3%
1984	1,575-3,950	68.0-153.1%	3,721- 9,058	8,866-26,027	14.4- 42.6%	1.7- 4.1%
1985	1,525-3,666	65.2-142.7%	4,647-10,890	26- 1,030	10.7- 34.5%	1.5- 3.5%
1986	1,740-3,784	73.4-152.4%	4,581-10,209	25- 1,032	18.7- 48.9%	3.4- 7.8%
1987	1,878-3,938	78.1-156.0%	4,261- 8,982	3,626-11,009	22.0- 53.1%	2.7- 5.7%
1988	1,838-3,690	75.2-146.2%	4,405- 8,753	726- 4,163	23.0- 54.9%	3.2- 6.5%
1989	1,799-3,443	73.6-139.2%	3,998- 7,748	28- 811	31.3- 67.4%	5.1- 9.9%
1990	1,720-3,202	69.2-128.3%	3,731- 6,964	2,513- 7,037	26.4- 56.2%	4.1- 7.7%
1991	1,585-2,862	63.8-114.7%	3,593- 6,505	140- 2,347	39.0- 96.0%	5.6-10.0%
1992	1,446-2,535	58.2-102.9%	3,089- 5,462	32- 793	39.6- 94.8%	6.7-12.0%
1993	1,299-2,232	51.5- 91.2%	2,319- 4,020	1,938- 4,995	33.6- 88.6%	5.4- 9.3%
1994	1,141-1,912	45.5- 78.8%	2,317- 3,954	2,088- 5,209	50.3-105.6%	10.3-18.0%
1995	929-1,581	37.6- 64.7%	2,259- 3,957	610- 2,259	41.6- 81.4%	9.0-15.7%
1996	883-1,513	35.6- 61.6%	2,155- 3,760	1,033- 3,042	55.5-104.4%	11.2-19.3%
1997	813-1,400	32.8- 56.5%	2,052- 3,567	536- 2,153	61.6-111.9%	10.9-18.8%
1998	728-1,265	29.4- 51.1%	1,675- 2,978	1,059- 3,580	68.8-111.3%	13.0-22.8%
1999	621-1,131	25.1- 43.9%	1,617- 3,094	8,971-21,373	76.6-119.6%	14.5-26.3%
2000	519-1,018	21.2- 38.6%	2,931- 5,927	57- 900	54.8- 96.0%	10.2-19.4%
2001	767-1,519	32.0- 56.9%	3,099- 6,043	741- 2,171	51.6- 96.8%	9.0-18.2%
2002	1,021-1,922	42.6- 74.0%	3,436- 6,512	11- 269	33.3- 73.0%	2.9- 5.4%
2003	1,164-2,102	47.7- 80.4%	3,024- 5,448	1,075- 2,821	29.8- 69.3%	4.0- 7.3%
2004	1,134-1,987	45.4- 76.4%	2,511- 4,410	16- 353	48.6-109.1%	8.1-14.2%
2005	965-1,708	39.2- 65.7%	2,014- 3,591	1,694- 5,005	49.2-109.6%	11.4-20.3%
2006	733-1,382	30.9- 51.8%	1,724- 3,340	1,309- 3,840	63.4-130.5%	12.2-24.2%
2007	573-1,167	24.6- 42.6%	1,333- 2,806	10- 233	64.9-133.8%	13.8-28.4%
2008	504-1,123	21.8- 39.5%	1,361- 3,028	3,549-11,520	69.3-130.0%	13.3-29.9%
2009	409-1,013	17.8- 35.2%	1,141- 2,806	517- 3,272	51.8-111.3%	7.8-19.1%
2010	458-1,156	19.8- 41.1%	1,488- 4,154	8,398-36,920	62.1-139.7%	12.3-32.8%
2011	478-1,350	21.2- 47.8%	1,791- 5,785	102- 1,733	52.6-129.8%	9.2-27.0%
2012	691-2,408	31.4- 84.1%	2,126- 7,640	595- 5,692	36.7-104.2%	7.2-23.6%
2013	878-3,289	39.9-116.3%	2,387- 8,917	53- 2,115	35.0- 94.1%	3.4-12.9%
2014	902-3,594	41.6-128.5%	2,417- 9,808	2,184-90,735	32.7-100.1%	3.7-15.0%
2015	823-3,461	37.3-124.5%	1,952-10,907	51-11,789	19.7- 81.0%	2.9-12.3%
2016	864-5,307	41.0-179.1%	1,846-18,236	90-18,996	34.4-126.7%	6.5-29.5%
2017	763-7,445	37.1-270.8%	1,835-21,383	88-24,562	–	–

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

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1966	1,662	1,208	780	571	445	362	305	262	227	197	171	148	127	109	93	405
1967	2,992	1,339	973	623	447	344	277	228	196	169	147	127	110	95	81	372
1968	2,186	2,412	1,078	772	478	336	253	195	160	137	119	103	90	77	67	318
1969	1,059	1,762	1,942	860	603	368	255	187	144	118	102	88	76	66	57	285
1970	6,382	854	1,419	1,542	661	453	271	180	132	102	83	72	62	54	47	241
1971	835	5,145	687	1,121	1,166	486	324	183	121	89	68	56	48	42	36	194
1972	482	673	4,143	546	866	884	362	233	131	87	64	49	40	35	30	165
1973	4,097	388	542	3,307	427	668	674	269	173	97	65	47	36	30	26	145
1974	405	3,303	313	432	2,571	327	504	493	197	126	71	47	35	27	22	125
1975	1,266	326	2,659	249	333	1,944	243	359	351	140	90	51	34	25	19	105
1976	336	1,020	263	2,119	193	255	1,467	178	263	257	102	66	37	25	18	90
1977	4,954	271	822	210	1,655	149	194	1,086	131	194	190	76	49	27	18	80
1978	278	3,993	218	658	165	1,295	116	148	828	100	148	145	58	37	21	75
1979	964	224	3,217	175	521	130	1,009	89	113	635	77	114	111	44	28	74
1980	15,512	777	181	2,575	138	407	101	766	67	86	482	58	86	84	34	78
1981	319	12,504	626	145	2,040	109	318	77	590	52	66	371	45	66	65	86
1982	257	257	10,073	500	113	1,580	83	237	58	441	39	50	277	34	50	113
1983	448	207	207	8,062	394	89	1,224	63	180	44	335	29	38	211	26	123
1984	11,827	361	167	166	6,385	310	69	941	49	139	34	258	23	29	162	114
1985	212	9,534	291	134	131	5,007	241	53	720	37	106	26	197	17	22	212
1986	234	171	7,682	234	106	104	3,931	187	41	558	29	82	20	153	13	181
1987	5,054	189	138	6,144	184	83	80	2,969	141	31	422	22	62	15	115	147
1988	1,797	4,074	152	110	4,814	142	63	60	2,217	106	23	315	16	46	11	196
1989	217	1,448	3,281	121	86	3,716	109	47	44	1,646	78	17	234	12	34	154
1990	3,526	175	1,166	2,609	94	65	2,772	78	34	32	1,182	56	12	168	9	135
1991	969	2,843	141	930	2,035	72	49	2,044	57	25	24	872	42	9	124	106
1992	214	781	2,287	109	657	1,518	53	36	1,483	42	18	17	633	30	7	167
1993	2,651	172	629	1,818	82	474	1,124	37	25	1,039	29	13	12	443	21	122
1994	2,773	2,137	139	501	1,380	61	344	814	27	18	753	21	9	9	321	103
1995	1,122	2,235	1,721	111	390	995	42	216	510	17	11	472	13	6	5	266
1996	1,495	904	1,801	1,380	87	299	700	28	143	337	11	8	312	9	4	180
1997	1,024	1,205	726	1,376	1,021	64	216	435	17	89	210	7	5	194	5	114
1998	1,677	825	970	576	960	686	43	134	270	11	55	130	4	3	120	74
1999	11,090	1,351	664	758	376	652	404	26	82	164	7	33	79	3	2	118
2000	371	8,940	1,086	494	493	217	403	240	16	48	98	4	20	47	2	71
2001	1,056	299	7,202	865	368	354	147	245	146	10	29	59	2	12	29	44
2002	71	851	241	5,757	646	253	235	94	157	94	6	19	38	2	8	47
2003	1,411	57	686	193	4,515	478	181	166	67	111	66	4	13	27	1	39
2004	109	1,138	46	551	153	3,428	347	129	119	48	79	47	3	10	19	28
2005	2,227	88	916	36	410	101	2,393	229	85	78	32	52	31	2	6	31
2006	1,724	1,795	71	733	28	288	65	1,527	146	54	50	20	33	20	1	24
2007	56	1,390	1,444	54	522	19	171	38	906	87	32	30	12	20	12	15
2008	4,611	45	1,118	1,114	37	341	12	98	22	518	50	18	17	7	11	15
2009	1,126	3,717	36	863	734	24	194	6	51	11	271	26	10	9	4	14
2010	12,374	908	2,994	29	610	503	17	119	4	31	7	166	16	6	5	11
2011	490	9,975	730	2,309	20	316	301	11	78	3	21	5	109	10	4	11
2012	1,419	395	8,024	569	1,289	13	211	209	8	54	2	14	3	75	7	10
2013	504	1,144	318	6,275	412	842	9	149	147	5	38	1	10	2	53	12
2014	10,501	406	921	253	4,652	302	605	6	95	94	3	24	1	6	1	42
2015	1,282	8,465	327	726	188	3,419	216	402	4	63	63	2	16	1	4	29
2016	2,598	1,034	6,812	260	559	142	2,497	160	298	3	47	46	2	12	0	24
2017	2,607	2,094	830	5,126	195	407	102	1,719	110	205	2	32	32	1	8	17

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

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	28	102	191	211	212	191	179	174	164	154	146	137	124	116	94	82	69	58	48	40	124
1967	51	114	238	230	213	182	162	151	141	133	125	118	108	101	82	72	61	51	43	36	123
1968	37	205	264	285	228	177	148	129	115	108	102	96	87	82	67	59	51	43	36	30	111
1969	18	149	475	318	288	195	149	124	104	93	87	82	75	70	58	51	44	38	32	27	105
1970	108	72	347	570	315	240	159	119	95	80	71	67	61	57	47	42	36	31	26	22	93
1971	14	436	168	414	556	257	190	121	88	70	58	52	47	44	37	33	28	24	21	18	78
1972	8	57	1,013	202	413	467	212	154	95	68	54	46	39	37	30	27	23	20	17	15	69
1973	69	33	133	1,223	204	353	394	178	125	76	55	44	36	32	26	23	20	17	15	13	62
1974	7	280	76	160	1,227	173	295	326	142	99	61	44	34	28	22	20	17	15	13	11	55
1975	70	51	794	91	205	1,226	191	314	340	127	87	86	51	47	37	43	37	32	28	24	124
1976	18	101	62	1,057	100	177	1,179	163	317	342	148	109	67	46	35	38	31	27	23	20	108
1977	272	23	330	102	977	99	145	898	129	215	235	100	68	48	38	30	23	19	16	14	77
1978	14	289	28	309	88	781	74	109	697	98	163	181	77	55	37	32	24	18	15	13	73
1979	47	17	775	45	303	89	775	79	104	658	92	142	170	69	51	32	21	15	12	10	56
1980	701	62	38	1,166	54	199	52	502	48	75	512	68	111	110	43	30	17	11	8	6	35
1981	13	1,343	134	50	1,074	43	167	42	440	37	55	387	49	89	97	31	20	11	8	6	28
1982	10	30	2,483	167	35	868	33	125	33	335	26	42	296	30	51	57	23	15	8	5	24
1983	16	27	28	2,749	146	29	636	32	111	31	295	27	39	217	34	56	55	22	14	8	28
1984	380	48	27	41	2,799	128	30	552	28	94	24	245	26	30	207	37	55	53	21	14	35
1985	6	1,659	67	36	58	2,752	132	32	537	26	77	22	171	16	15	139	17	25	24	10	22
1986	6	27	2,136	68	32	39	2,133	107	26	458	27	98	24	210	23	28	155	19	28	27	36
1987	112	28	19	2,329	51	24	29	1,715	84	20	322	21	58	19	139	14	18	103	12	18	42
1988	34	570	28	35	2,268	53	24	31	1,435	73	17	290	18	47	16	125	11	14	79	10	46
1989	3	201	898	37	25	1,908	48	19	23	1,031	52	10	205	8	29	9	72	6	8	45	32
1990	55	24	284	915	37	33	1,514	47	23	17	910	47	27	199	9	36	9	67	6	8	72
1991	15	389	39	344	936	37	27	1,207	41	21	26	626	27	9	149	15	43	11	81	7	96
1992	3	106	530	38	312	809	31	22	950	27	11	12	465	26	6	92	5	14	3	25	32
1993	41	22	156	615	32	215	555	19	12	571	15	16	12	272	13	3	43	2	6	2	27
1994	43	254	42	182	617	27	181	464	17	10	477	10	6	6	225	11	3	34	2	5	22
1995	17	248	462	38	190	534	28	135	336	13	8	351	11	5	4	161	8	2	23	1	18
1996	23	91	518	549	41	159	396	18	85	215	7	6	211	7	6	3	100	5	1	14	12
1997	16	109	258	595	503	35	118	254	10	54	132	6	3	138	4	2	2	72	3	1	19
1998	25	66	203	204	484	355	24	86	165	7	44	93	4	2	90	3	1	1	41	2	11
1999	169	183	166	262	160	343	225	15	50	116	4	27	60	2	1	60	2	1	1	26	8
2000	6	1,698	349	233	284	143	289	175	12	41	80	3	17	44	1	1	41	1	0	0	23
2001	16	15	2,065	419	241	235	110	211	125	8	28	58	2	13	28	1	1	26	1	0	15
2002	1	64	86	2,634	391	207	178	80	153	87	6	19	38	1	9	19	1	0	18	1	11
2003	21	6	175	84	2,359	281	137	115	50	92	51	4	12	21	1	5	13	0	0	12	7
2004	2	123	9	240	73	1,823	225	91	78	34	64	41	2	9	17	1	4	8	0	0	12
2005	33	10	238	16	208	55	1,360	145	56	55	25	43	25	2	7	12	0	3	6	0	9
2006	26	238	27	335	15	165	38	913	96	38	36	15	26	13	1	4	8	0	2	4	6
2007	1	62	328	20	280	10	104	24	587	61	25	23	10	17	9	1	2	4	0	1	5
2008	68	6	273	454	21	217	8	67	16	374	37	15	14	5	10	6	0	1	2	0	3
2009	17	248	9	296	346	16	130	4	38	9	208	21	10	8	3	6	4	0	1	1	2
2010	183	99	696	8	264	267	11	100	4	32	7	145	14	7	4	2	3	2	0	0	2
2011	7	842	179	743	8	163	179	7	67	2	20	5	115	11	4	3	1	2	1	0	2
2012	21	51	1,721	201	528	6	138	144	6	49	2	14	3	75	7	3	2	1	2	1	1
2013	7	148	91	2,256	194	430	5	106	107	4	38	1	12	3	57	5	2	2	1	1	2
2014	155	42	376	119	2,231	162	347	3	63	68	2	28	1	6	1	36	3	1	1	0	2
2015	19	642	81	284	84	1,610	119	239	2	43	45	2	15	1	5	1	28	3	1	1	2
2016	38	171	1,661	100	232	62	1,158	82	154	1	30	33	1	9	1	5	1	26	3	1	3

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

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0.00	0.07	0.93	2.87	4.09	5.23	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74	7.74
1967	0.00	0.12	1.60	4.99	7.13	9.17	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68	13.68
1968	0.00	0.08	1.02	3.18	4.53	5.80	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59
1969	0.00	0.11	1.56	4.86	6.95	8.93	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32	13.32
1970	0.00	0.15	2.04	6.40	9.18	11.83	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78
1971	0.00	0.10	1.37	4.27	6.09	7.82	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63	11.63
1972	0.00	0.07	0.98	3.06	4.35	5.57	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
1973	0.00	0.09	1.16	3.59	5.12	6.57	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74	9.74
1974	0.00	0.11	1.44	4.50	6.43	8.25	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29	12.29
1975	0.00	0.09	1.16	3.60	5.13	6.58	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76
1976	0.00	0.08	1.01	3.15	4.49	5.75	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51	8.51
1977	0.00	0.05	0.67	2.08	2.96	3.78	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57	5.57
1978	0.00	0.04	0.60	1.87	2.65	3.39	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99	4.99
1979	0.00	0.05	0.72	2.24	3.18	4.06	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
1980	0.00	0.04	0.55	1.71	2.43	3.10	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57	4.57
1981	0.00	0.07	0.91	2.81	4.01	5.12	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58	7.58
1982	0.00	0.05	0.71	2.21	3.14	4.02	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92
1983	0.00	0.04	0.57	1.77	2.51	3.21	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72	4.72
1984	0.00	0.05	0.62	1.93	2.75	3.51	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17	5.17
1985	0.00	0.04	0.47	1.46	2.08	2.65	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
1986	0.00	0.06	0.78	2.42	3.44	4.40	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49	6.49
1987	0.00	0.07	0.91	2.83	4.03	5.16	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63	7.63
1988	0.00	0.07	0.98	3.04	4.33	5.55	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21	8.21
1989	0.00	0.10	1.36	4.23	6.04	7.75	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54	11.54
1990	0.00	0.08	1.06	3.29	4.69	6.00	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90	8.90
1991	0.00	0.19	3.52	13.21	7.79	8.44	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
1992	0.00	0.10	1.37	7.32	11.09	8.48	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98	13.98
1993	0.00	0.09	1.18	6.06	8.54	10.51	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71	10.71
1994	0.00	0.07	0.97	3.58	11.13	14.33	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.04
1995	0.00	0.04	0.57	2.37	4.91	13.50	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68	19.68
1996	0.00	0.32	5.37	8.54	9.40	10.99	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88	25.88
1997	0.00	0.11	1.69	14.37	18.17	16.95	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09	26.09
1998	0.00	0.19	3.04	20.91	17.15	31.16	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85	27.85
1999	0.00	0.29	8.08	21.52	33.37	26.51	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28	30.28
2000	0.00	0.05	1.19	7.69	11.47	17.13	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06	28.06
2001	0.00	0.06	0.85	7.68	15.97	19.56	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64	22.64
2002	0.00	0.04	0.56	2.74	8.53	11.90	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73	12.73
2003	0.00	0.03	0.38	2.04	5.98	10.57	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37	12.37
2004	0.00	0.12	1.89	7.94	19.48	14.36	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77	19.77
2005	0.00	0.06	0.75	4.52	13.66	22.88	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25	23.25
2006	0.00	0.22	4.66	12.30	19.05	30.14	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38	30.38
2007	0.00	0.21	4.41	16.52	20.92	22.96	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06	34.06
2008	0.00	0.32	4.36	20.01	20.00	34.42	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69	42.69
2009	0.00	0.09	1.92	13.03	16.16	16.09	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16	27.16
2010	0.00	0.17	4.41	16.28	43.43	29.63	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65	20.65
2011	0.00	0.20	3.41	36.35	22.76	18.95	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05
2012	0.00	0.20	3.02	10.70	20.98	14.92	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45	13.45
2013	0.00	0.08	1.21	8.38	9.58	11.41	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89	22.89
2014	0.00	0.13	2.22	8.21	9.23	12.10	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35
2015	0.00	0.17	1.39	4.68	6.82	9.85	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32
2016	0.00	0.33	6.88	7.09	10.07	11.35	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74	15.74

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

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0	743	6,454	14,516	15,997	16,565	20,406	17,541	15,200	13,183	11,424	9,882	8,505	7,298	6,226	5,274	4,443	3,720	3,099	2,569	8,010
1967	0	1,416	13,829	27,238	27,646	27,069	31,826	26,163	22,489	19,487	16,902	14,646	12,669	10,904	9,356	7,983	6,762	5,696	4,770	3,973	13,564
1968	0	1,639	9,857	21,688	19,001	16,978	18,708	14,383	11,824	10,164	8,807	7,638	6,619	5,726	4,928	4,228	3,608	3,056	2,574	2,156	7,925
1969	0	1,816	26,932	36,677	36,344	28,254	28,628	20,990	16,138	13,267	11,404	9,882	8,570	7,427	6,424	5,529	4,744	4,048	3,429	2,888	11,311
1970	0	1,151	25,711	85,895	52,076	45,453	39,786	26,395	19,353	14,880	12,232	10,514	9,111	7,902	6,847	5,923	5,098	4,374	3,732	3,161	13,092
1971	0	4,667	8,386	42,032	61,857	32,804	32,021	18,066	11,985	8,788	6,756	5,554	4,774	4,137	3,588	3,109	2,690	2,315	1,986	1,695	7,380
1972	0	440	36,431	14,775	33,106	43,027	25,758	16,559	9,342	6,198	4,544	3,494	2,872	2,469	2,139	1,855	1,608	1,391	1,197	1,027	4,693
1973	0	298	5,593	104,840	19,165	38,124	56,217	22,419	14,412	8,131	5,395	3,955	3,041	2,500	2,149	1,862	1,615	1,399	1,211	1,042	4,979
1974	0	3,156	4,021	17,076	143,749	23,275	52,415	51,229	20,430	13,134	7,410	4,916	3,604	2,771	2,278	1,958	1,697	1,472	1,275	1,103	5,486
1975	0	250	27,466	7,894	14,961	111,113	20,288	30,022	29,343	11,702	7,523	4,244	2,816	2,064	1,587	1,305	1,122	972	843	730	3,774
1976	0	687	2,380	59,041	7,620	12,792	107,540	13,015	19,258	18,823	7,506	4,826	2,723	1,806	1,324	1,018	837	719	623	541	2,890
1977	0	121	4,944	3,876	43,312	4,961	9,445	52,848	6,396	9,464	9,250	3,689	2,371	1,338	888	651	500	411	354	306	1,686
1978	0	1,604	1,180	10,931	3,888	38,736	5,054	6,467	36,185	4,379	6,480	6,334	2,526	1,624	916	608	446	343	282	242	1,364
1979	0	108	20,789	3,476	14,632	4,644	52,754	4,635	5,931	33,185	4,016	5,943	5,808	2,316	1,489	840	557	409	314	258	1,473
1980	0	286	895	39,228	2,973	11,150	4,029	30,714	2,698	3,453	19,321	2,338	3,460	3,382	1,349	867	489	325	238	183	1,008
1981	0	7,534	5,076	3,607	71,924	4,868	20,826	5,074	38,683	3,398	4,349	24,334	2,945	4,358	4,259	1,699	1,092	616	409	300	1,500
1982	0	122	64,310	9,820	3,151	55,836	4,291	12,259	2,987	22,771	2,000	2,560	14,324	1,733	2,565	2,507	1,000	643	363	241	1,059
1983	0	79	1,061	126,854	8,781	2,510	50,652	2,614	7,466	1,819	13,868	1,218	1,559	8,723	1,056	1,562	1,527	609	391	221	792
1984	0	150	933	2,856	155,233	9,593	3,128	42,537	2,195	6,270	1,528	11,646	1,023	1,309	7,326	887	1,312	1,282	511	329	850
1985	0	3,007	1,236	1,744	2,425	117,583	8,282	1,817	24,715	1,275	3,643	888	6,766	594	761	4,256	515	762	745	297	685
1986	0	89	53,600	5,012	3,223	4,006	221,831	10,559	2,317	31,509	1,626	4,644	1,132	8,627	758	970	5,427	657	972	950	1,252
1987	0	114	1,123	154,199	6,527	3,737	5,284	196,046	9,332	2,048	27,847	1,437	4,104	1,000	7,624	670	857	4,796	580	859	1,946
1988	0	2,652	1,330	2,959	183,384	6,899	4,485	4,233	157,067	7,476	1,641	22,310	1,151	3,288	801	6,108	537	687	3,842	465	2,247
1989	0	1,304	39,727	4,513	4,525	249,027	10,629	4,604	4,346	161,233	7,674	1,684	22,902	1,182	3,376	822	6,270	551	705	3,944	2,784
1990	0	123	11,028	75,847	3,853	3,412	211,985	5,961	2,582	2,437	90,420	4,304	944	12,844	663	1,893	461	3,516	309	395	3,773
1991	0	4,796	4,366	103,498	137,062	5,237	4,434	183,123	5,149	2,230	2,105	78,109	3,718	816	11,095	572	1,635	398	3,038	267	3,601
1992	0	698	27,935	6,943	61,993	110,876	6,262	4,213	173,978	4,892	2,119	2,000	74,209	3,532	775	10,541	544	1,554	379	2,886	3,675
1993	0	134	6,642	95,983	6,029	42,485	102,577	3,415	2,298	94,885	2,668	1,156	1,091	40,472	1,926	423	5,749	297	847	206	3,578
1994	0	1,249	1,198	15,816	130,639	7,286	68,721	162,608	5,414	3,642	150,415	4,230	1,832	1,729	64,158	3,054	670	9,113	470	1,343	5,999
1995	0	877	8,784	2,327	16,790	112,961	6,818	34,674	82,047	2,732	1,838	75,894	2,134	924	873	32,372	1,541	338	4,598	237	3,705
1996	0	2,564	84,509	101,490	7,024	27,978	144,131	5,769	29,339	69,422	2,311	1,555	64,216	1,806	782	738	27,391	1,304	286	3,891	3,335
1997	0	1,215	10,908	165,586	152,694	8,972	44,763	90,176	3,609	18,356	43,434	1,446	973	40,177	1,130	489	462	17,137	816	179	4,521
1998	0	1,442	26,105	97,863	136,198	166,006	9,544	29,400	59,227	2,371	12,056	28,527	950	639	26,388	742	321	303	11,256	536	3,087
1999	0	3,563	46,271	132,319	96,606	136,992	95,331	6,253	19,262	38,805	1,553	7,899	18,691	622	419	17,289	486	211	199	7,374	2,374
2000	0	4,042	11,549	32,802	47,968	30,682	88,927	53,000	3,476	10,709	21,574	864	4,391	10,391	346	233	9,612	270	117	111	5,419
2001	0	162	54,418	57,483	48,915	56,642	26,844	44,659	26,616	1,746	5,378	10,834	434	2,205	5,218	174	117	4,827	136	59	2,777
2002	0	294	1,206	139,940	47,439	25,523	25,191	10,143	16,874	10,057	660	2,032	4,094	164	833	1,972	66	44	1,824	51	1,072
2003	0	15	2,357	3,509	235,475	43,090	18,941	17,406	7,008	11,659	6,949	456	1,404	2,829	113	576	1,362	45	31	1,260	776
2004	0	1,177	774	37,733	24,333	412,237	55,985	20,833	19,144	7,708	12,824	7,643	501	1,544	3,111	125	633	1,498	50	34	2,239
2005	0	43	6,127	1,448	47,045	18,662	447,541	42,850	15,945	14,652	5,900	9,815	5,850	384	1,182	2,381	95	485	1,147	38	1,740
2006	0	3,514	2,882	76,250	4,385	67,778	15,359	361,664	34,628	12,886	11,841	4,768	7,932	4,727	310	955	1,924	77	392	927	1,437
2007	0	2,643	55,902	7,434	88,809	3,459	44,803	10,058	236,833	22,676	8,438	7,754	3,122	5,194	3,096	203	625	1,260	50	256	1,548
2008	0	130	42,779	181,895	6,049	89,985	3,781	30,949	6,948	163,598	15,664	5,829	5,356	2,157	3,588	2,138	140	432	870	35	1,246
2009	0	2,835	616	94,733	98,591	3,268	41,716	1,343	10,991	2,467	58,101	5,563	2,070	1,902	766	1,274	759	50	153	309	455
2010	0	1,394	116,007	3,857	195,501	116,629	2,819	20,030	645	5,278	1,185	27,898	2,671	994	913	368	612	365	24	74	367
2011	0	18,168	21,966	637,651	3,584	49,168	37,827	1,381	9,811	316	2,585	580	13,665	1,308	487	447	180	300	179	12	216
2012	0	719	214,610	51,898	219,661	1,562	23,866	23,619	862	6,126	197	1,614	362	8,532	817	304	279	112	187	112	142
2013	0	772	3,441	453,024	33,823	81,575	1,604	27,397	27,114	990	7,032	226	1,853	416	9,795	938	349	321	129	215	291
2014	0	492	18,172	17,932	368,625	30,909	95,867	883	15,078	14,922	545	3,870	125	1,020	229	5,390	516	192	176	71	278
2015	0	13,136	4,042	29,838	11,133	288,182	15,458	28,811	265	4,531	4,484	164	1,163	37	306	69	1,620	155	58	53	105
2016	0	3,078	406,501	15,981	48,096	13,649	327,059	20,938	39,026	359	6,138	6,074	222	1,576	51	415	93	2,194	210	78	214

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

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1966	0	63	1,578	5,368	7,634	8,760	11,944	11,619	10,962	10,335	9,737	9,181	8,301	7,738	6,305	5,480	4,616	3,866	3,220	2,670	8,323
1967	0	120	3,381	10,073	13,193	14,314	18,628	17,330	16,219	15,278	14,407	13,608	12,365	11,562	9,474	8,295	7,026	5,919	4,956	4,129	14,094
1968	0	139	2,410	8,020	9,067	8,978	10,949	9,528	8,527	7,968	7,507	7,097	6,460	6,071	4,990	4,394	3,749	3,175	2,675	2,240	8,235
1969	0	154	6,585	13,563	17,343	14,941	16,756	13,904	11,639	10,401	9,720	9,181	8,365	7,874	6,505	5,745	4,930	4,206	3,563	3,001	11,753
1970	0	98	6,286	31,764	24,851	24,036	23,287	17,484	13,957	11,666	10,426	9,769	8,892	8,378	6,934	6,155	5,297	4,545	3,878	3,285	13,604
1971	0	396	2,050	15,544	29,518	17,347	18,742	11,967	8,644	6,890	5,759	5,160	4,660	4,386	3,633	3,231	2,795	2,405	2,064	1,761	7,669
1972	0	37	8,907	5,464	15,798	22,753	15,076	10,969	6,738	4,859	3,874	3,246	2,803	2,618	2,166	1,928	1,671	1,445	1,244	1,067	4,876
1973	0	25	1,367	38,770	9,145	20,160	32,904	14,850	10,394	6,375	4,598	3,675	2,968	2,651	2,176	1,935	1,678	1,454	1,258	1,083	5,173
1974	0	268	983	6,315	68,597	12,308	30,678	33,934	14,734	10,297	6,316	4,567	3,518	2,938	2,307	2,035	1,763	1,529	1,325	1,146	5,701
1975	0	39	8,204	2,888	9,191	70,068	15,973	26,233	28,398	10,619	7,297	7,187	4,224	3,922	3,104	3,581	3,078	2,667	2,313	2,005	10,358
1976	0	68	561	29,461	3,953	8,872	86,441	11,928	23,231	25,100	10,881	7,966	4,919	3,357	2,590	2,794	2,297	1,975	1,711	1,484	7,931
1977	0	10	1,988	1,892	25,563	3,299	7,073	43,716	6,254	10,460	11,416	4,850	3,326	2,343	1,864	1,438	1,106	909	781	677	3,725
1978	0	116	150	5,136	2,061	23,342	3,230	4,783	30,475	4,296	7,126	7,891	3,358	2,405	1,596	1,419	1,041	800	658	565	3,185
1979	0	8	5,010	899	8,517	3,190	40,499	4,129	5,413	34,409	4,814	7,418	8,902	3,595	2,673	1,665	1,105	810	623	512	2,919
1980	0	23	190	17,767	1,166	5,468	2,081	20,130	1,926	3,018	20,530	2,718	4,463	4,397	1,713	1,210	683	453	332	255	1,407
1981	0	809	1,085	1,234	37,861	1,914	10,942	2,772	28,873	2,448	3,579	25,339	3,236	5,861	6,357	2,060	1,324	747	496	363	1,819
1982	0	14	15,852	3,276	976	30,687	1,698	6,467	1,681	17,319	1,368	2,186	15,283	1,524	2,613	2,932	1,169	752	424	281	1,239
1983	0	10	144	43,257	3,244	823	26,339	1,314	4,613	1,284	12,203	1,133	1,614	8,994	1,395	2,316	2,263	903	580	327	1,173
1984	0	20	153	712	68,054	3,946	1,361	24,977	1,273	4,237	1,071	11,078	1,163	1,343	9,382	1,667	2,466	2,411	961	618	1,598
1985	0	523	284	467	1,070	64,624	4,534	1,094	18,417	884	2,634	762	5,885	562	514	4,774	578	855	836	333	768
1986	0	14	14,901	1,456	975	1,496	120,366	6,040	1,488	25,866	1,529	5,508	1,347	11,850	1,273	1,565	8,760	1,060	1,569	1,533	2,021
1987	0	17	156	58,441	1,818	1,073	1,913	113,217	5,576	1,304	21,269	1,411	3,797	1,241	9,172	948	1,213	6,789	822	1,216	2,755
1988	0	371	249	944	86,392	2,545	1,673	2,186	101,638	5,147	1,178	20,550	1,258	3,362	1,162	8,879	780	998	5,585	676	3,267
1989	0	181	10,873	1,375	1,326	127,850	4,662	1,871	2,245	100,980	5,074	1,015	20,057	790	2,796	926	7,063	620	794	4,443	3,136
1990	0	17	2,685	26,592	1,505	1,744	115,786	3,622	1,724	1,292	69,596	3,577	2,078	15,216	674	2,777	677	5,158	453	580	5,535
1991	0	656	1,203	38,263	63,021	2,691	2,411	108,171	3,713	1,895	2,315	56,122	2,381	830	13,370	1,364	3,897	949	7,238	636	8,580
1992	0	95	6,470	2,411	29,403	59,141	3,642	2,616	111,450	3,195	1,341	1,443	54,573	3,003	756	10,828	559	1,596	389	2,964	3,775
1993	0	17	1,651	32,481	2,388	19,284	50,622	1,713	1,121	52,101	1,361	1,460	1,118	24,830	1,155	290	3,938	203	580	141	2,451
1994	0	149	359	5,735	58,383	3,259	36,161	92,687	3,366	2,039	95,378	2,051	1,189	1,262	44,994	2,277	500	6,794	351	1,001	4,472
1995	0	97	2,356	796	8,187	60,626	4,436	21,668	54,126	2,065	1,226	56,503	1,707	841	594	25,923	1,234	271	3,682	190	2,967
1996	0	258	24,305	40,413	3,283	14,876	81,448	3,755	17,477	44,166	1,398	1,166	43,384	1,464	1,162	554	20,568	979	215	2,921	2,505
1997	0	110	3,878	71,566	75,293	4,913	24,409	52,600	2,113	11,144	27,429	1,248	578	28,598	748	425	402	14,897	709	156	3,930
1998	0	116	5,459	34,634	68,657	85,858	5,173	18,851	36,123	1,605	9,739	20,465	769	494	19,817	592	256	242	8,981	427	2,463
1999	0	482	11,577	45,716	41,067	72,126	53,090	3,581	11,783	27,280	1,033	6,311	14,119	547	308	14,155	398	172	163	6,037	1,943
2000	0	768	3,714	15,512	27,658	20,244	63,814	38,578	2,621	8,972	17,602	761	3,756	9,758	302	217	8,974	252	109	103	5,060
2001	0	8	15,602	27,839	31,927	37,639	20,049	38,536	22,770	1,537	5,179	10,607	436	2,314	5,180	170	114	4,715	133	57	2,713
2002	0	22	432	64,023	28,739	20,827	19,097	8,609	16,488	9,375	605	2,027	4,049	151	937	2,085	69	47	1,928	54	1,133
2003	0	1	601	1,528	123,036	25,358	14,337	12,036	5,234	9,614	5,345	405	1,301	2,233	95	574	1,358	45	30	1,256	773
2004	0	127	155	16,451	11,697	219,269	36,267	14,725	12,595	5,468	10,323	6,558	387	1,499	2,685	112	567	1,342	45	30	2,006
2005	0	5	1,595	624	23,927	10,064	254,293	27,150	10,444	10,296	4,697	7,954	4,743	292	1,353	2,304	92	469	1,110	37	1,684
2006	0	465	1,104	34,884	2,342	38,905	9,077	216,239	22,716	9,016	8,595	3,442	6,149	3,110	198	912	1,838	74	374	885	1,372
2007	0	118	12,701	2,807	47,531	1,913	27,209	6,365	153,349	15,998	6,517	5,914	2,540	4,520	2,479	177	544	1,096	44	223	1,346
2008	0	17	10,438	74,195	3,406	57,275	2,596	21,101	4,932	117,971	11,729	4,706	4,544	1,672	3,170	1,782	117	360	725	29	1,038
2009	0	189	151	32,503	46,456	2,082	27,958	932	8,203	2,030	44,587	4,528	2,100	1,617	734	1,317	785	51	159	319	470
2010	0	152	26,983	1,125	84,691	61,837	1,855	16,723	698	5,423	1,135	24,447	2,277	1,119	658	332	552	329	22	66	331
2011	0	1,533	5,397	205,260	1,386	25,282	22,507	931	8,373	294	2,528	624	14,468	1,345	514	412	166	276	165	11	199
2012	0	93	46,034	18,351	89,929	764	15,661	16,314	670	5,557	190	1,556	349	8,437	811	287	263	106	176	105	134
2013	0	100	989	162,862	15,887	41,636	1,004	19,630	19,820	823	7,025	243	2,280	465	10,463	989	368	338	136	227	307
2014	0	51	7,414	8,403	176,829	16,574	55,037	547	9,936	10,705	379	4,507	126	968	221	5,702	546	203	187	75	295
2015	0	997	999	11,652	4,949	135,676	8,550	17,137	179	3,117	3,219	136	1,108	38	334	86	2,024	194	72	66	131
2016	0	509	99,146	6,122	20,003	6,014	151,690	10,764	20,153	184	3,977	4,372	132	1,222	74	656	147	3,467	332	124	338

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

	1999 cohort				2010 cohort				2014 cohort			
Age	Start Biomass (000s t)	Catch Weight (000s t)	M (000s t)	Surviving Biomass (000s t)	Start Biomass (000s t)	Catch Weight (000s t)	M (000s t)	Surviving Biomass (000s t)	Start Biomass (000s t)	Catch Weight (000s t)	M (000s t)	Surviving Biomass (000s t)
0	168.6	0.0	32.7	135.9	183.1	0.0	35.5	147.6	155.4	0.0	30.1	125.3
1	1,697.6	0.8	329.1	1,367.8	841.9	1.5	163.1	677.2	642.5	1.0	124.5	517.0
2	2,065.0	15.6	398.8	1,650.5	1,721.2	46.0	329.1	1,346.1	1,661.3	99.1	312.0	1,250.2
3	2,633.8	64.0	504.2	2,065.6	2,256.0	162.9	420.8	1,672.3				
4	2,359.0	123.0	444.9	1,791.1	2,231.4	176.8	414.7	1,640.0				
5	1,823.3	219.3	331.2	1,272.9	1,609.5	135.7	298.3	1,175.6				
6	1,359.8	254.3	237.7	867.8	1,158.1	151.7	209.1	797.4				
7	913.1	216.2	155.0	541.9								
8	586.9	153.3	98.1	335.4								
9	373.5	118.0	60.4	195.2								
10	207.7	44.6	35.7	127.4								
11	145.5	24.4	25.7	95.3								
12	115.2	14.5	20.9	79.8								
13	74.6	8.4	13.6	52.5								
14	56.7	10.5	9.9	36.3								
15	36.0	5.7	6.4	23.9								
16	28.2	2.0	5.3	20.9								
17	26.5	3.5	4.8	18.2								
18												
19												
20												

Table 26. Select parameters, derived quantities, and reference point estimates for the base model MLE and posterior median (MCMC) estimates with an additional comparison to posterior median estimates from the previous (2016) base model.

	MLE	Posterior median	Posterior median from 2016 base model
Parameters			
Natural mortality (M)	0.216	0.229	0.226
Unfished recruitment (R_0, millions)	2,643	3,170	3,125
Steepness (h)	0.865	0.815	0.814
Additional acoustic survey SD	0.255	0.310	0.338
Catchability (q)	1.082	0.940	1.029
Derived Quantities			
2008 recruitment (millions)	4,611	5,556	5,426
2010 recruitment (millions)	12,374	15,808	14,785
2014 recruitment (millions)	10,501	12,105	13,071
Unfished female spawning biomass (B_0, thousand t)	2,190	2,362	2,397
2009 relative spawning biomass	22.4%	24.2%	20.3%
2017 relative spawning biomass	74.2%	84.2%	–
2016 relative fishing intensity: (1-SPR)/(1-SPR)$_{40\%}$)	73.8%	68.8%	102.2%
Female spawning biomass at $F_{\text{SPR}=40\%}$ ($B_{\text{SPR}=40\%}$, thousand t)	822	836	856
Reference Points (equilibrium) based on $F_{\text{SPR}=40\%}$			
SPR at $F_{\text{SPR}=40\%}$	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	21.0%	22.2%	21.9%
Yield at $B_{\text{SPR}=40\%}$ (thousand t)	353	380	382

Table 27. Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2016 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)	1,822	2,362	3,314
Unfished recruitment (R_0, millions)	2,054	3,170	6,121
Reference points (equilibrium) based on $F_{\text{SPR}=40\%}$			
Female spawning biomass at $F_{\text{SPR}=40\%}$ (thousand t)	624	836	1,152
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	18.9%	22.2%	27.0%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	260	380	590
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	729	945	1,326
SPR at $B_{40\%}$	40.9%	43.4%	50.9%
Exploitation fraction resulting in $B_{40\%}$	14.7%	19.4%	24.0%
Yield at $B_{40\%}$ (thousand t)	263	371	577
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	393	594	997
SPR at MSY	20.1%	29.5%	46.2%
Exploitation fraction corresponding to SPR at MSY	17.9%	33.1%	56.4%
MSY (thousand t)	275	400	645

Table 28. Decision table of forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Quantiles from the base model are shown for various harvest alternatives (rows) based on: constant catch levels (rows a, b, c, d, e), including the TAC from 2016 (row d), the catch values that result in a median relative fishing intensity of 100% (row f), the median values estimated via the default harvest policy ($F_{\mathrm{SPR}=40\%}$–40:10) using the base model (row g), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2017 and 2018 (row h). Row e uses 600,000 t rather than the 500,000 t from last year's assessment, because 500,000 t is essentially row d. Catch in 2019 does not impact the beginning of the year biomass in 2019.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2017	0	41%	65%	89%	120%	224%
	2018	0	43%	70%	95%	135%	264%
	2019	0	46%	72%	99%	141%	276%
b:	2017	180,000	41%	65%	89%	120%	224%
	2018	180,000	39%	66%	91%	131%	261%
	2019	180,000	38%	65%	92%	134%	269%
c:	2017	350,000	41%	65%	89%	120%	224%
	2018	350,000	35%	62%	87%	127%	257%
	2019	350,000	30%	58%	85%	127%	261%
d:	2017	497,500	41%	65%	89%	120%	224%
2016	2018	497,500	32%	59%	85%	124%	254%
TAC	2019	497,500	24%	51%	79%	121%	256%
e:	2017	600,000	41%	65%	89%	120%	224%
	2018	600,000	30%	57%	82%	122%	252%
	2019	600,000	20%	47%	74%	117%	253%
f:	2017	934,000	41%	65%	89%	120%	224%
FI=	2018	848,000	23%	49%	76%	115%	246%
100%	2019	698,000	12%	35%	63%	105%	244%
g:	2017	969,840	41%	65%	89%	120%	224%
default	2018	843,566	22%	48%	75%	115%	245%
HR	2019	679,881	12%	34%	63%	104%	244%
h:	2017	866,263	41%	65%	89%	120%	224%
C2017=	2018	866,263	24%	51%	77%	117%	247%
C2018	2019	683,014	13%	36%	64%	106%	245%

Table 29. Decision table of forecast quantiles of Pacific Hake relative fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2017–2019 catch alternatives presented in Table 28. Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile			5%	25%	50%	75%	95%
Management Action			Relative fishing intensity				
	Year	Catch (t)					
a:	2017	0	0%	0%	0%	0%	0%
	2018	0	0%	0%	0%	0%	0%
	2019	0	0%	0%	0%	0%	0%
b:	2017	180,000	14%	25%	35%	47%	68%
	2018	180,000	11%	23%	33%	46%	68%
	2019	180,000	11%	23%	33%	47%	70%
c:	2017	350,000	26%	43%	58%	74%	97%
	2018	350,000	21%	40%	56%	75%	103%
	2019	350,000	21%	42%	58%	79%	110%
d:	2017	497,500	35%	55%	72%	89%	112%
2016	2018	497,500	29%	53%	72%	94%	122%
TAC	2019	497,500	29%	57%	76%	100%	131%
e:	2017	600,000	40%	63%	80%	98%	120%
	2018	600,000	34%	61%	81%	104%	131%
	2019	600,000	34%	65%	86%	112%	138%
f:	2017	934,000	56%	82%	100%	116%	135%
FI=	2018	848,000	45%	78%	100%	123%	141%
100%	2019	698,000	40%	76%	100%	127%	141%
g:	2017	969,840	57%	84%	102%	118%	136%
default	2018	843,566	45%	78%	100%	124%	141%
HR	2019	679,881	40%	75%	99%	127%	141%
h:	2017	866,263	53%	78%	97%	113%	133%
C2017=	2018	866,263	46%	79%	100%	123%	141%
C2018	2019	683,014	39%	75%	98%	126%	141%

Table 30. Probabilities related to spawning biomass, relative fishing intensity, and the 2018 default harvest policy catch for alternative 2017 catch options (catch options explained in Table 28).

Catch in 2017	Probability $B_{2018}<B_{2017}$	Probability $B_{2018}<B_{40\%}$	Probability $B_{2018}<B_{25\%}$	Probability $B_{2018}<B_{10\%}$	Probability 2017 relative fishing intensity >100%	Probability 2018 default harvest policy catch <2017 catch
a: 0	17%	3%	0%	0%	0%	0%
b: 180,000	37%	6%	1%	0%	0%	1%
c: 350,000	51%	7%	1%	0%	4%	6%
d: 497,500	63%	9%	2%	0%	15%	18%
e: 600,000	67%	11%	3%	0%	23%	27%
f: 934,000	80%	18%	7%	0%	50%	55%
g: 969,840	82%	18%	7%	0%	52%	57%
h: 866,263	78%	17%	6%	0%	44%	50%

Table 31. Probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options, given the 2017 catch level shown in Table 30 (catch options explained in Table 28).

Catch in 2018	Probability $B_{2019}<B_{2018}$	Probability $B_{2019}<B_{40\%}$	Probability $B_{2019}<B_{25\%}$	Probability $B_{2019}<B_{10\%}$	Probability 2018 relative fishing intensity >100%	Probability 2019 default harvest policy catch <2018 catch
a: 0	39%	3%	0%	0%	0%	0%
b: 180,000	61%	6%	1%	0%	0%	1%
c: 350,000	73%	11%	3%	0%	6%	10%
d: 497,500	80%	16%	5%	1%	20%	24%
e: 600,000	83%	19%	8%	1%	30%	35%
f: 848,000	87%	29%	16%	3%	50%	59%
g: 843,566	87%	30%	16%	3%	50%	59%
h: 866,263	88%	28%	16%	3%	50%	59%

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

	Base model	Sigma R 1.0	Sigma R 2.0	Sigma R 1.51	Steepness prior mean 0.5	Fix steepness 1.0	Natural mortality SD 0.2	Natural mortality SD 0.3
Parameters								
Natural mortality (M)	0.216	0.212	0.223	0.217	0.223	0.214	0.243	0.258
R_0 (millions)	2,643	1,847	6,370	3,016	3,194	2,500	3,538	4,214
Steepness (h)	0.865	0.857	0.899	0.869	0.611	1.000	0.854	0.848
Additional acoustic survey SD	0.255	0.253	0.256	0.255	0.256	0.254	0.254	0.254
Derived Quantities								
2008 recruitment (millions)	4,611	4,458	4,908	4,659	4,852	4,552	5,708	6,513
2010 recruitment (millions)	12,374	11,825	13,372	12,538	13,028	12,219	15,961	18,621
2014 recruitment (millions)	10,501	6,635	17,685	11,718	10,708	10,415	14,331	17,233
B_0 (thousand t)	2,190	1,573	4,952	2,474	2,486	2,107	2,351	2,489
2009 relative spawning biomass	22.4%	31.0%	10.3%	20.0%	20.5%	23.1%	24.2%	25.0%
2017 relative spawning biomass	74.2%	85.7%	43.0%	69.2%	65.6%	77.0%	83.3%	88.2%
Reference Points based on $F_{\mathrm{SPR}=40\%}$								
2016 rel. fishing intensity: (1-SPR)/(1-$\mathrm{SPR}_{40\%}$)	73.8%	78.7%	67.8%	72.6%	72.1%	74.3%	61.5%	54.8%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	822	588	1,895	931	712	843	877	926
$\mathrm{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	21.0%	20.7%	21.6%	21.1%	21.6%	20.8%	23.4%	24.9%
Yield at $B_{F_{40\%}}$ (thousand t)	353	249	840	402	315	359	421	472

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

	Base model	Ageing error: cohort invariant	Ageing error: standard for 2014	Include age-1 index	Selectivity SD 0.03	Selectivity SD 0.10	Selectivity SD 0.30
Parameters							
Natural mortality (M)	0.216	0.209	0.216	0.215	0.217	0.215	0.216
R_0 (millions)	2,643	2,132	2,648	2,658	2,744	2,643	2,658
Steepness (h)	0.865	0.845	0.865	0.864	0.864	0.864	0.865
Additional acoustic survey SD	0.255	0.242	0.254	0.249	0.270	0.261	0.252
Derived Quantities							
2008 recruitment (millions)	4,611	4,586	4,617	5,022	4,750	4,545	4,646
2010 recruitment (millions)	12,374	13,960	12,412	14,105	12,586	12,004	12,566
2014 recruitment (millions)	10,501	11,876	13,236	15,504	37,637	19,383	7,103
B_0 (thousand t)	2,190	1,862	2,194	2,211	2,254	2,197	2,193
2009 relative spawning biomass	22.4%	26.3%	22.4%	23.3%	20.0%	21.7%	22.7%
2017 relative spawning biomass	74.2%	97.1%	82.2%	97.6%	152.4%	98.8%	65.2%
Reference Points based on $F_{\mathrm{SPR}=40\%}$							
2016 rel. fishing intensity: (1-SPR)/(1-$\mathrm{SPR}_{40\%}$)	73.8%	68.8%	70.1%	66.5%	70.9%	74.4%	74.6%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	822	691	824	830	846	825	824
$\mathrm{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	21.0%	20.4%	21.0%	20.9%	21.0%	20.9%	21.0%
Yield at $B_{F_{40\%}}$ (thousand t)	353	289	354	356	365	354	354

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

	2017 Base model	-1 year	-2 years	-3 years	-4 years	-5 years
Parameters						
Natural mortality (M)	0.216	0.215	0.213	0.213	0.214	0.213
R_0 (millions)	2,643	2,584	2,407	2,390	2,416	2,373
Steepness (h)	0.865	0.864	0.862	0.863	0.866	0.860
Additional acoustic survey SD	0.255	0.253	0.267	0.283	0.344	0.363
Derived Quantities						
2008 recruitment (millions)	4,611	4,638	4,582	5,015	5,552	6,597
2010 recruitment (millions)	12,374	12,222	10,923	11,117	8,654	1,869
2014 recruitment (millions)	10,501	3,689	1,038	1,323	1,324	1,237
B_0 (thousand t)	2,190	2,155	2,038	2,024	2,036	2,001
2009 relative spawning biomass	22.4%	23.3%	23.9%	22.0%	19.2%	20.9%
2017 relative spawning biomass	74.2%	55.2%	42.5%	44.5%	37.6%	17.9%
Reference Points based on $F_{\text{SPR}=40\%}$						
2016 rel. fishing intensity: (1-SPR)/(1-$\text{SPR}_{40\%}$)	73.8%	80.1%	86.7%	86.0%	93.1%	119.5%
Female spawning biomass ($B_{F_{40\%}}$; thousand t)	822	809	765	760	765	750
$\text{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation fraction corresponding to SPR	21.0%	20.9%	20.7%	20.7%	20.8%	20.8%
Yield at $B_{F_{40\%}}$ (thousand t)	353	346	325	323	326	319

8 FIGURES

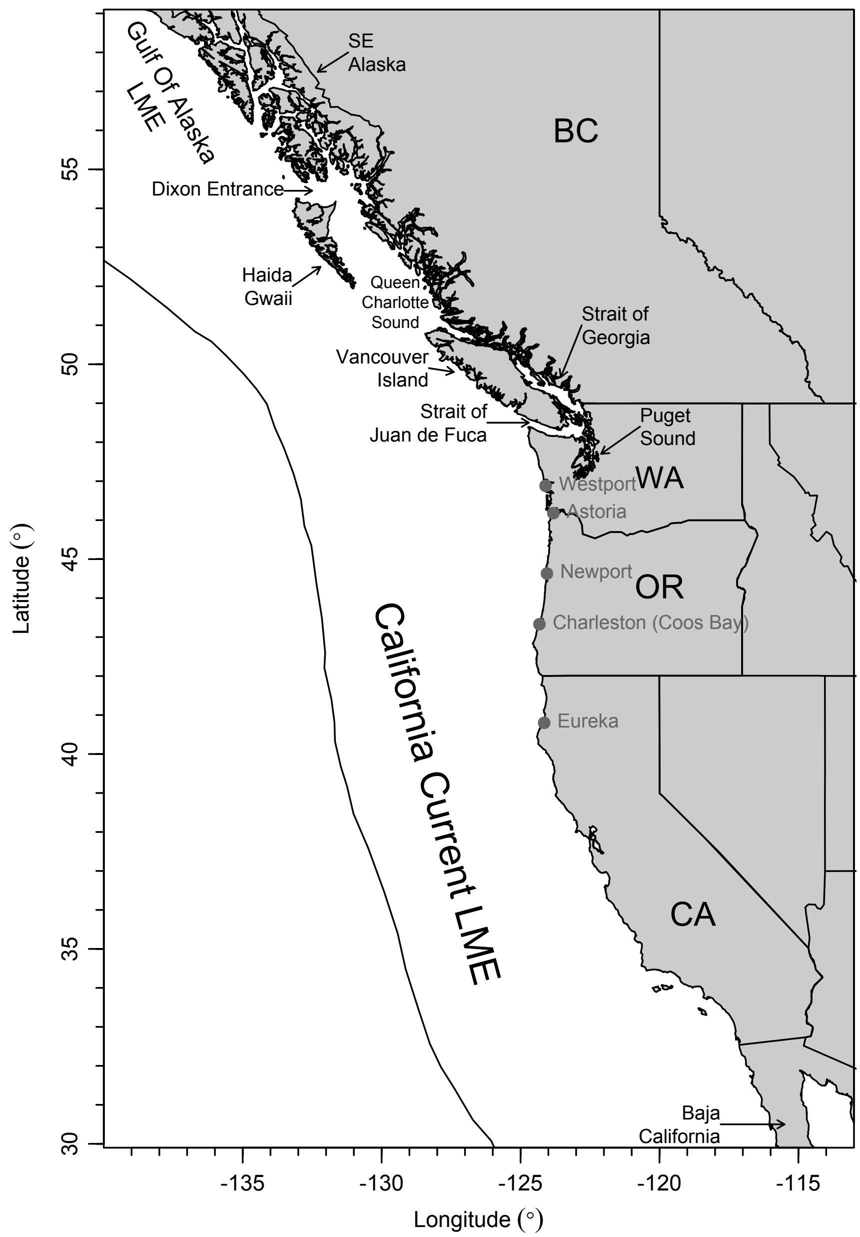


Figure 1. Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.

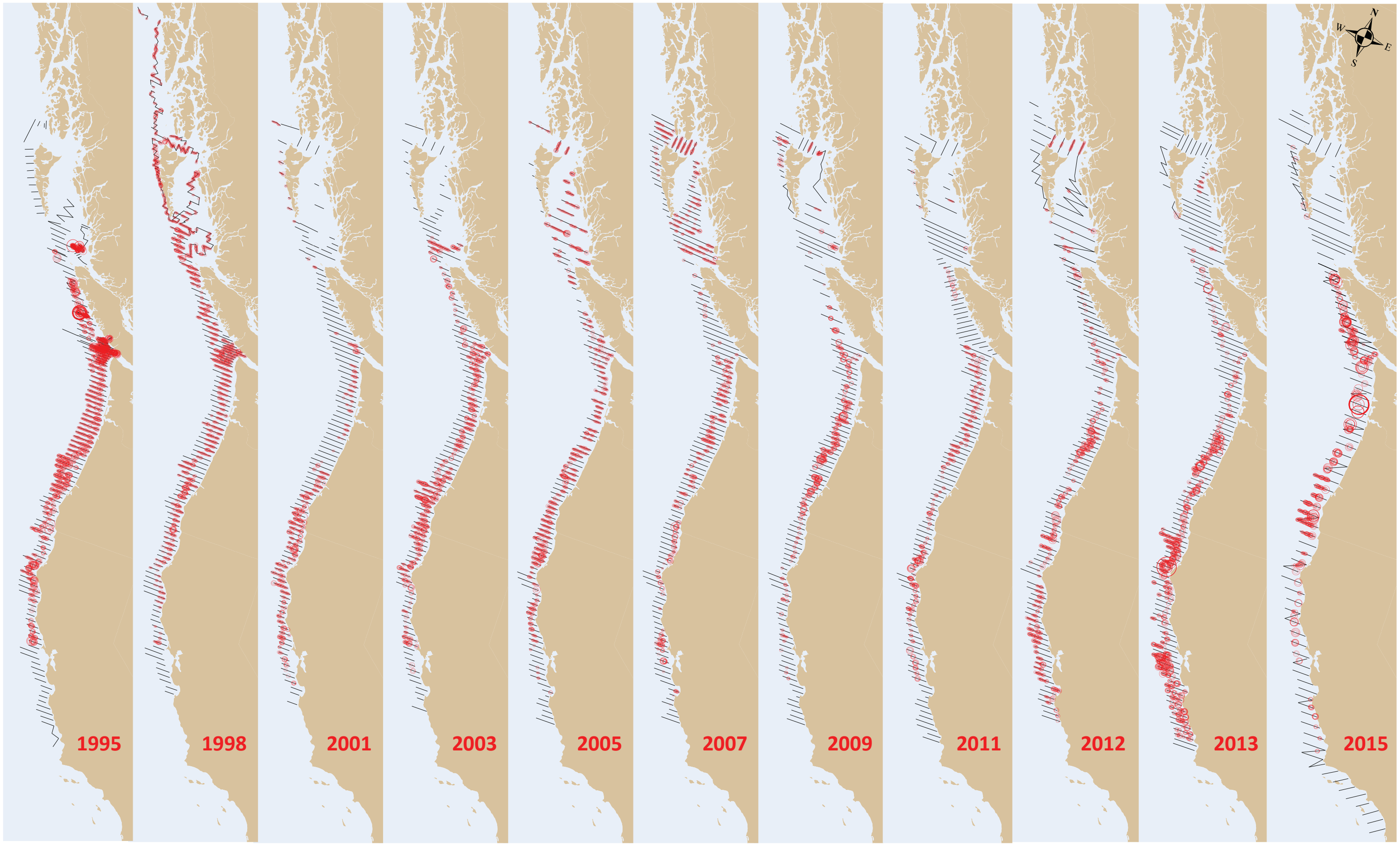


Figure 2. Spatial distribution of acoustic backscatter attributable to Pacific Hake from joint US-Canada acoustic surveys 1995–2015. Area of the circle is roughly proportional to observed backscatter.

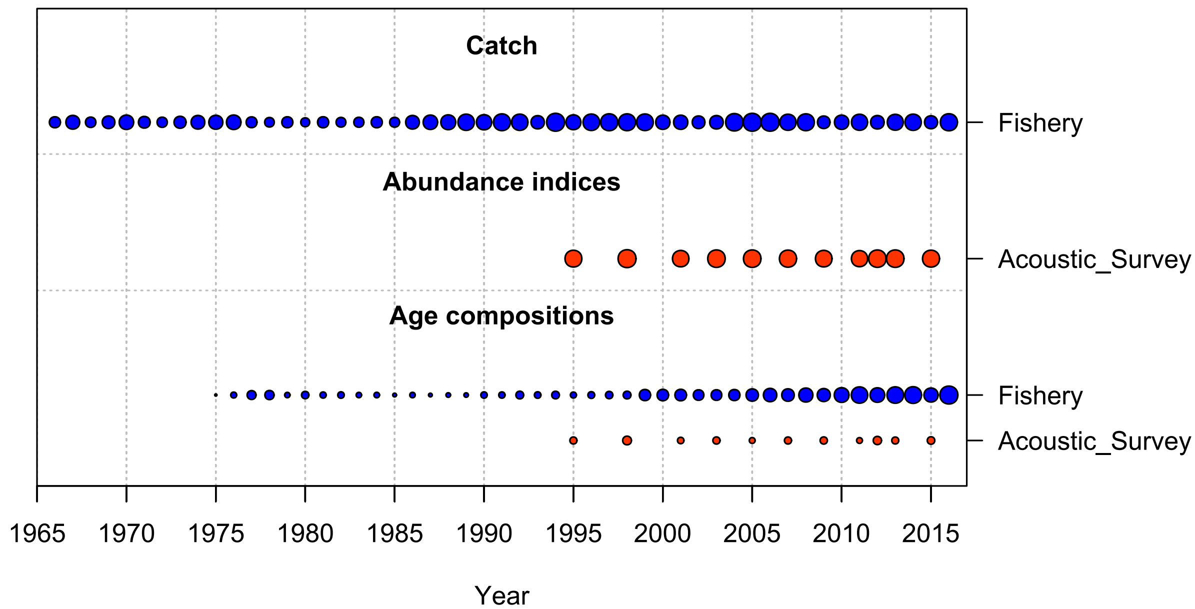


Figure 3. Overview of data used in this assessment, 1966–2016.

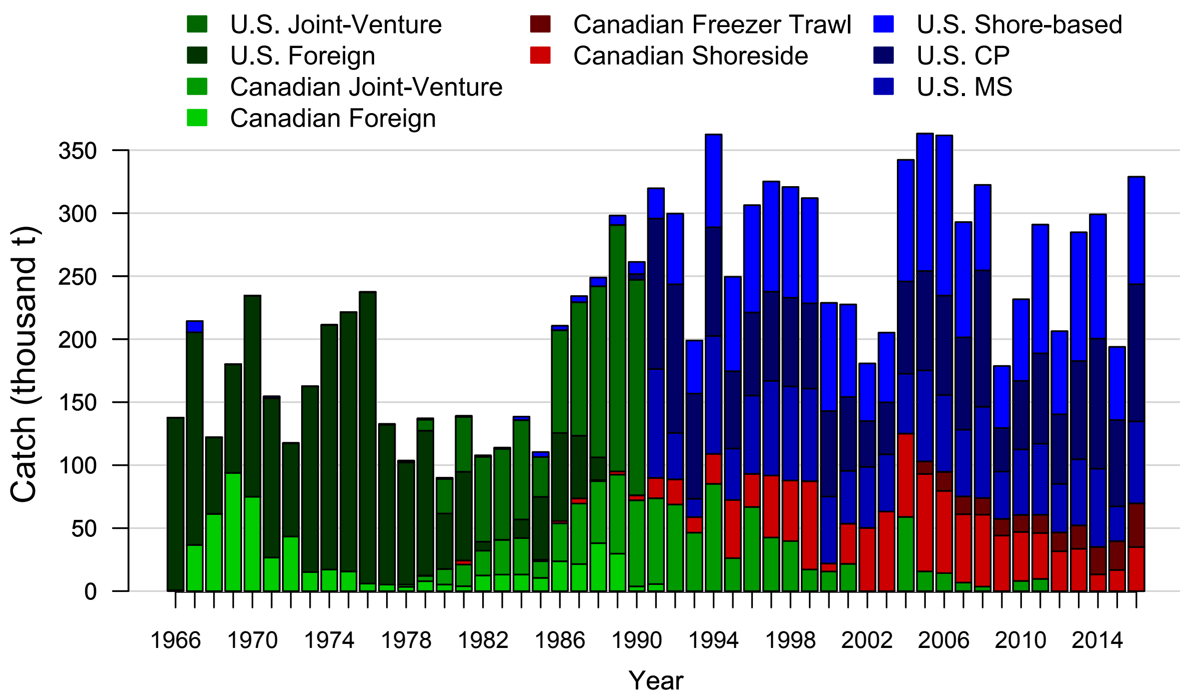


Figure 4. Total Pacific Hake catch used in the assessment by sector, 1966–2016. U.S. tribal catches are included in the appropriate sector.

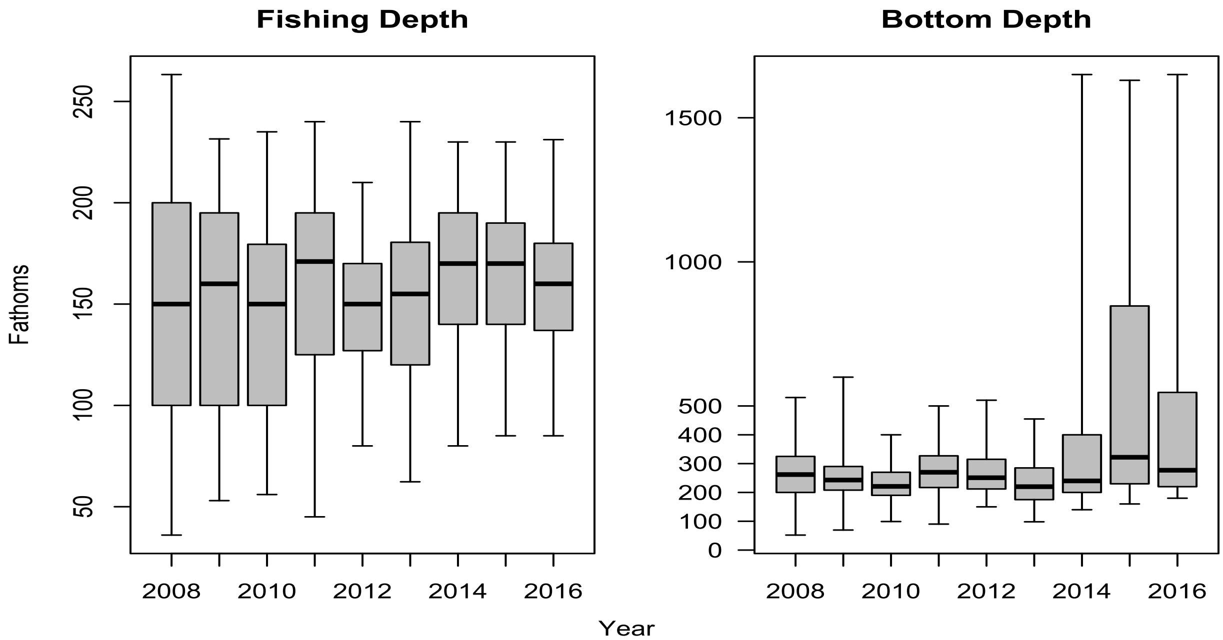


Figure 5. Distribution of fishing depths (left) and bottom depths (right), in fathoms, of Pacific Hake catches in the U.S. at-sea fleet from 2008–2016.

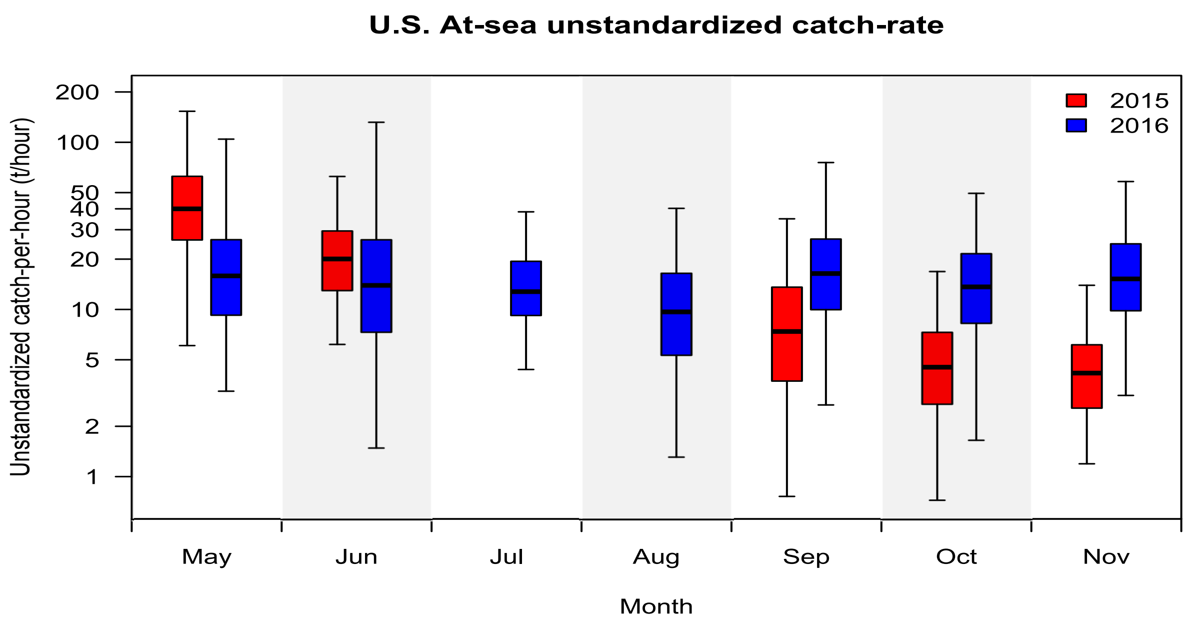


Figure 6. Unstandardized (raw) catch-rates (t/hr) of Pacific Hake catches by tow in the U.S. at-sea fleet in 2016.

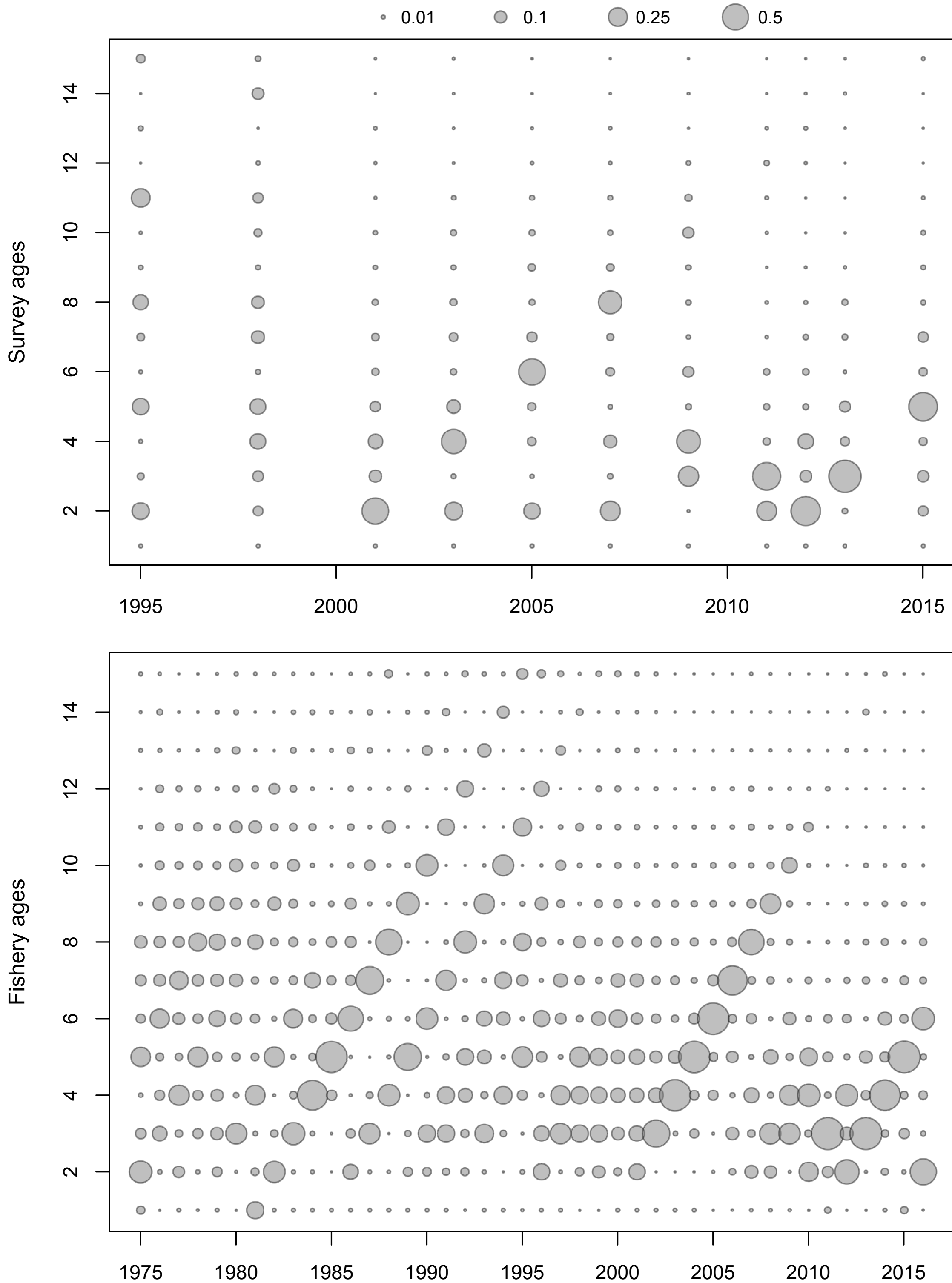


Figure 7. Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2016. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble in the survey data is 0.75 for age 3 in 2013 and in the fishery is 0.71 for age 3 in 2011.

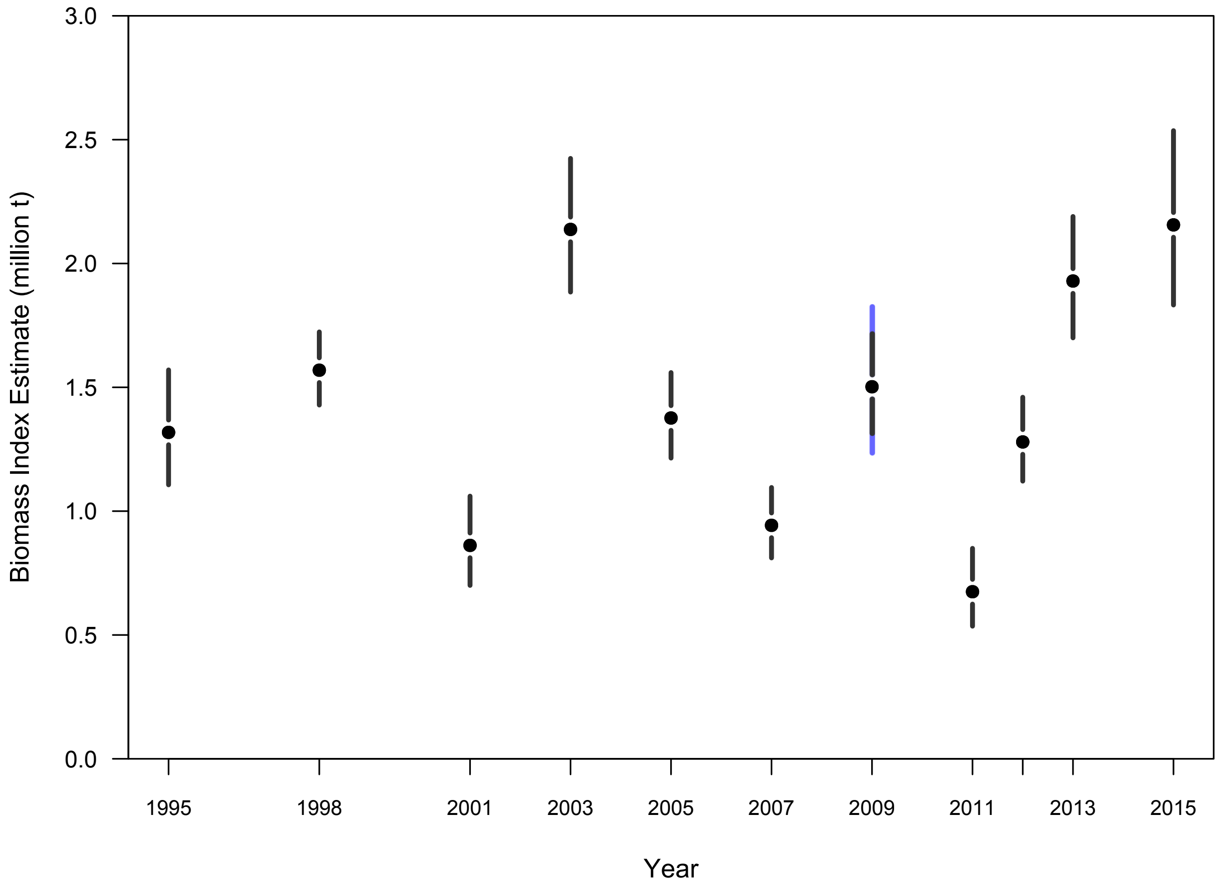


Figure 8. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2015) in addition to squid/hake apportionment uncertainty (2009, in blue).

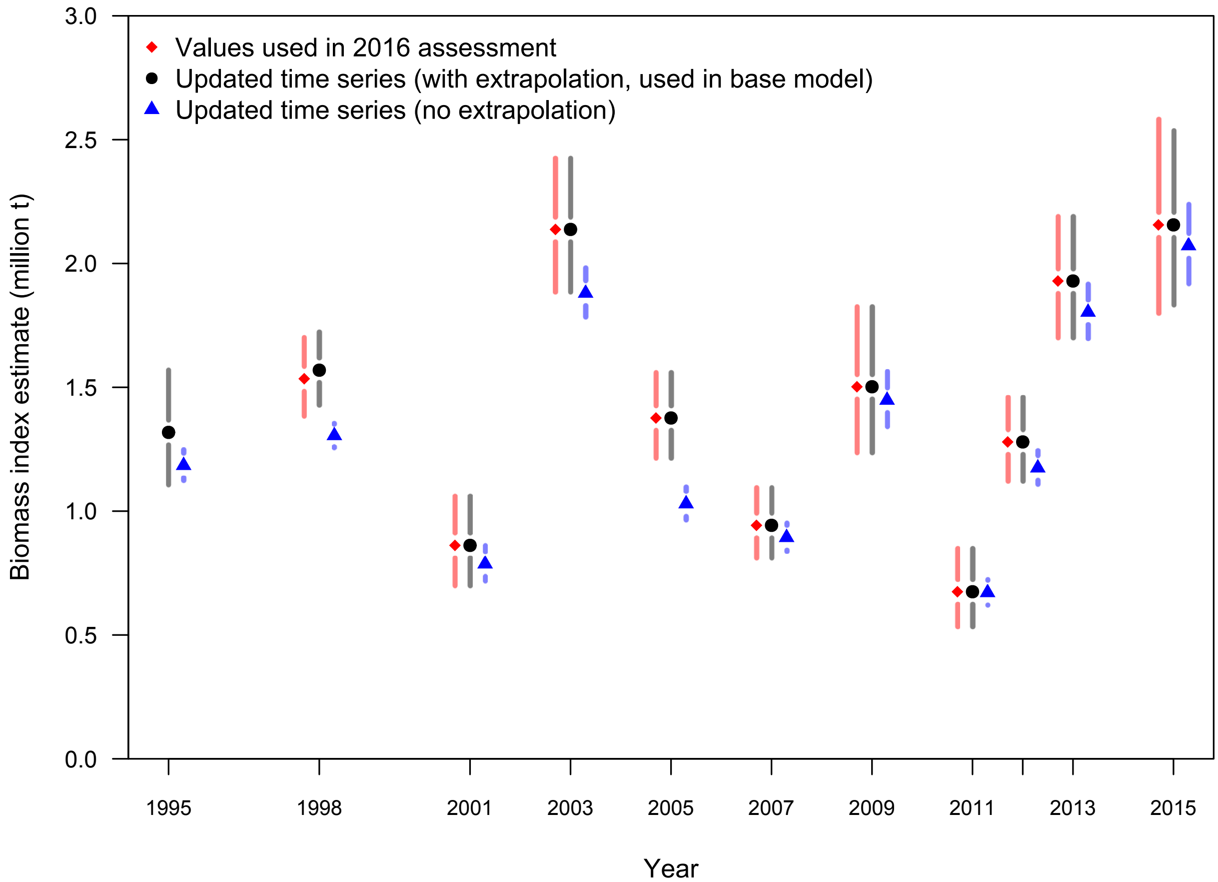


Figure 9. Updated acoustic survey biomass indices with and without extrapolation (millions of metric tons) relative to the index used 2016. Approximate 95% confidence intervals are based on only sampling variability (and squid/hake apportionment uncertainty in 2009). See Table 14 for values used in the base model and the 2016 assessment.

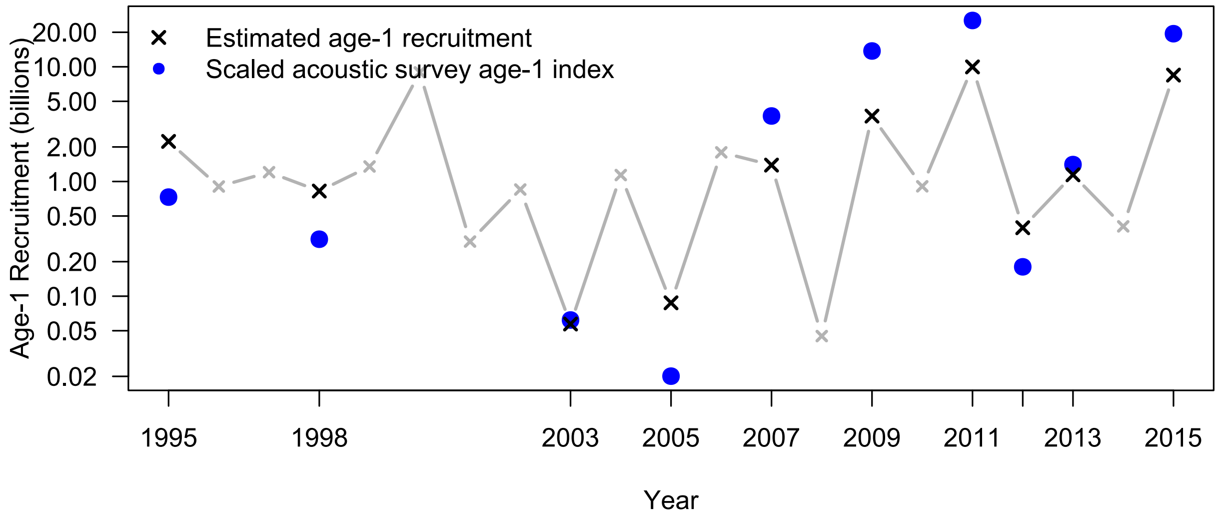


Figure 10. Preliminary acoustic survey age-1 index overlaid on estimated numbers of age-1 fish (MLE from the base model).

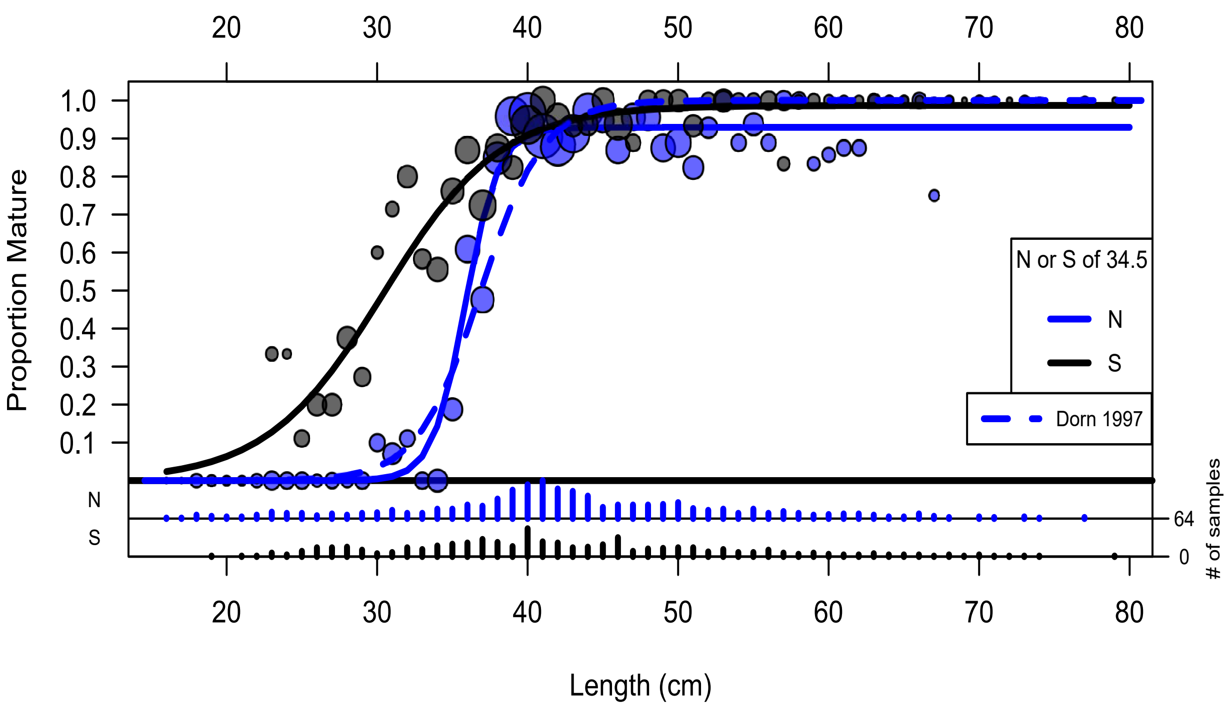


Figure 11. Observed proportion mature-at-length (bubbles with circle size relative to number of samples at length), fitted proportion mature-at-length with an estimated asymptote (lines), and number of samples at length (barplots beneath each panel). Panels show categories of source (top left), year (top right), source and year (bottom left), and month (for the trawl survey only, bottom right).

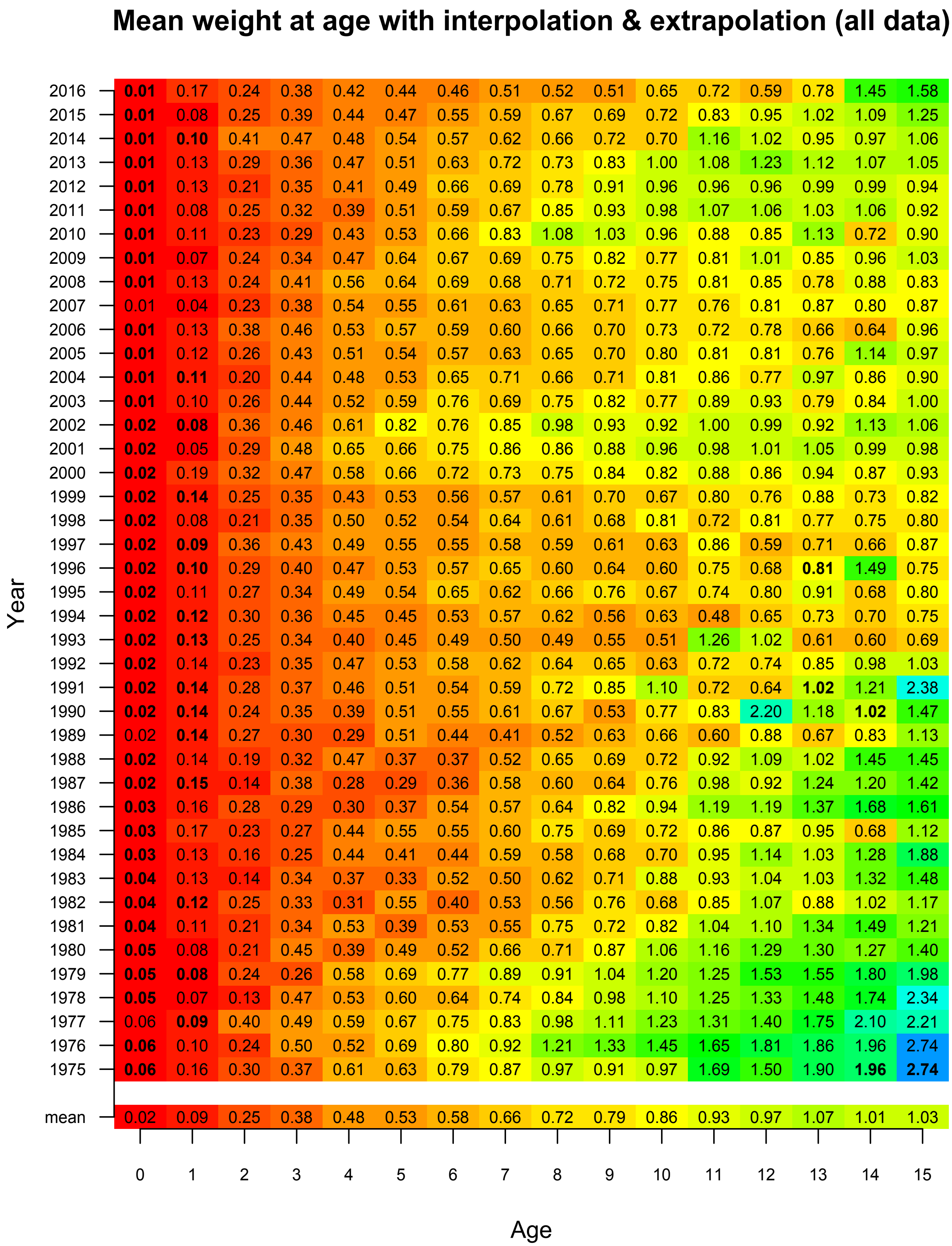


Figure 12. Empirical weight-at-age (kg) used in the assessment (numbers, with colors given by the scale at the bottom). Numbers shown in bold were interpolated or extrapolated from adjacent areas.

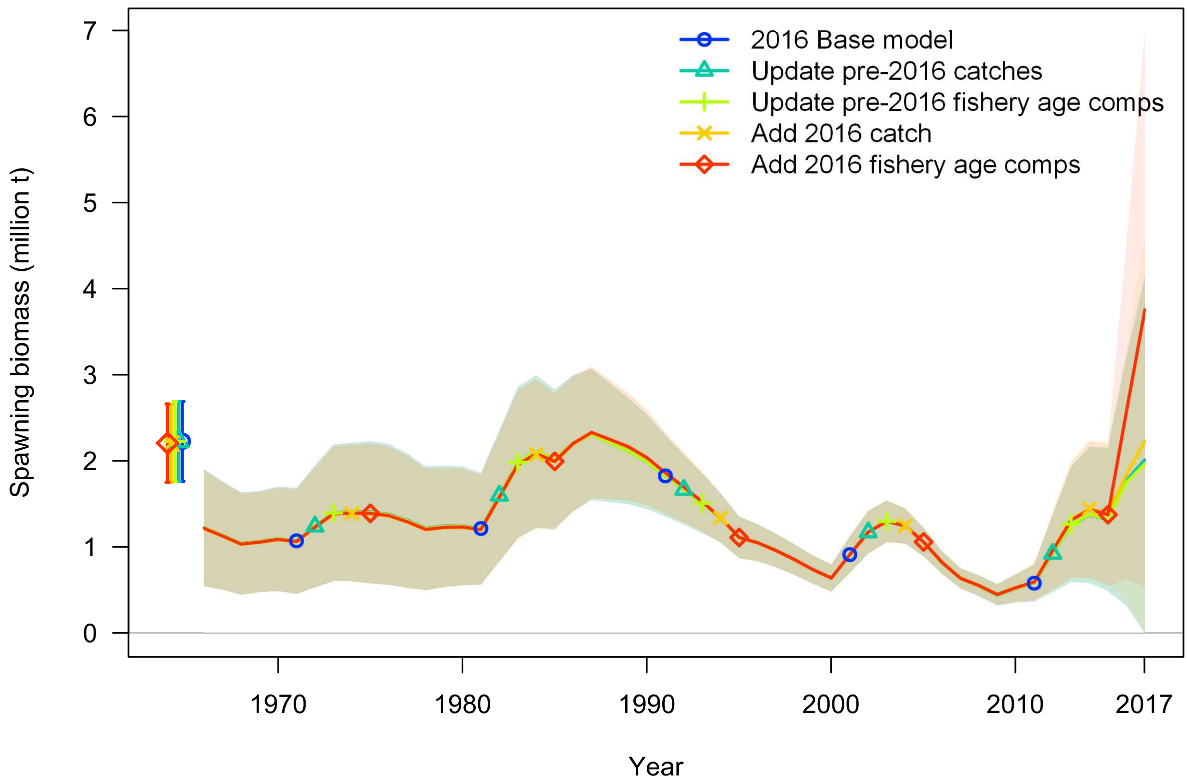


Figure 13. Bridging models comparison showing the 2016 base model and the terminal model from sequentially updating all pre-2016 data. This included updating fishery catch and age-compositions as well as weight-at-age information. The points disconnected from the time-series on the left side show the unfished equilibrium spawning biomass estimates.

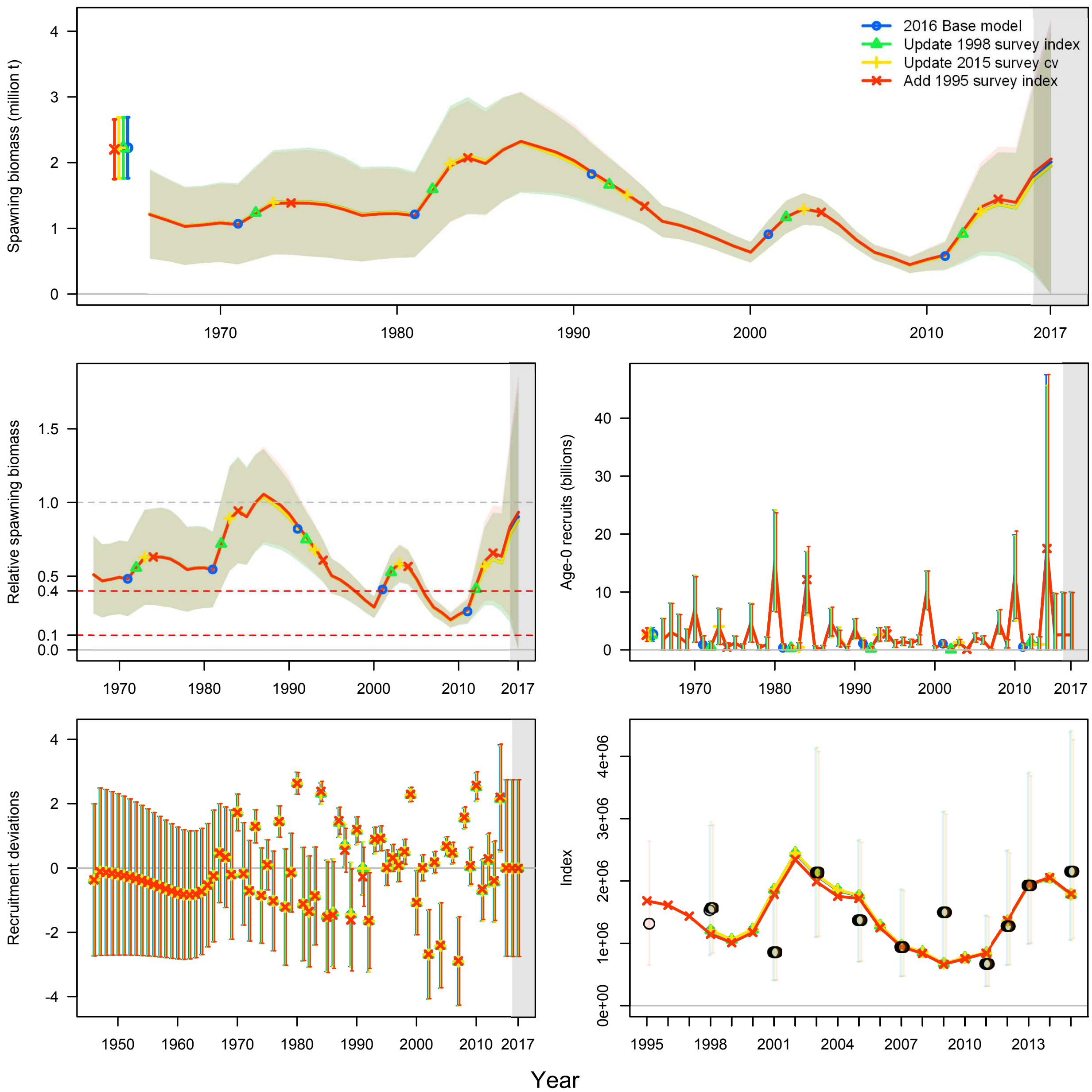


Figure 14. Bridging models showing the difference between the 2016 base model and the sequential addition of the new acoustic survey time-series (1995–2016) and then the new 2016 fishery data. Spawning biomass (upper panel), relative spawning biomass (spawning biomass in each year relative to the unfished equilibrium spawning biomass, middle left), absolute recruitment (middle right), recruitment deviations (lower left), and survey index (lower right) are shown.

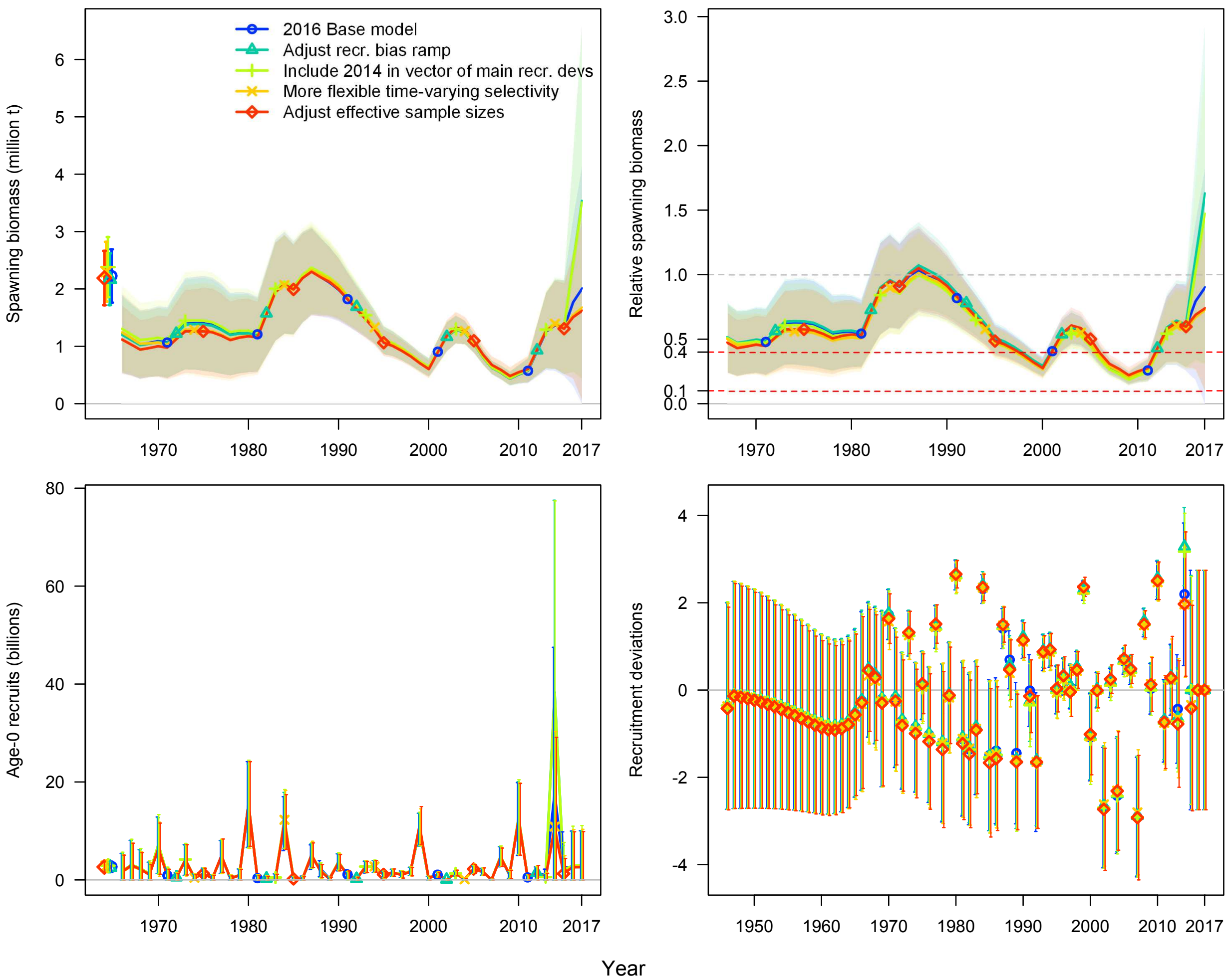


Figure 15. Bridging models showing the difference between the 2017 pre-tuned base model, the sequential addition of the main base model tuning runs (adjusting time periods and levels for recruitment bias and reweighting the survey and fishery compositional data), and increased flexibility associated with time-varying selectivity (larger standard deviation associated with temporal deviates). The red line is equivalent to the 2017 base model. Spawning biomass (upper left panel), relative spawning biomass (spawning biomass in each year relative to the unfished equilibrium spawning biomass, upper right), absolute recruitment (lower left), and recruitment deviations (lower right) are shown.

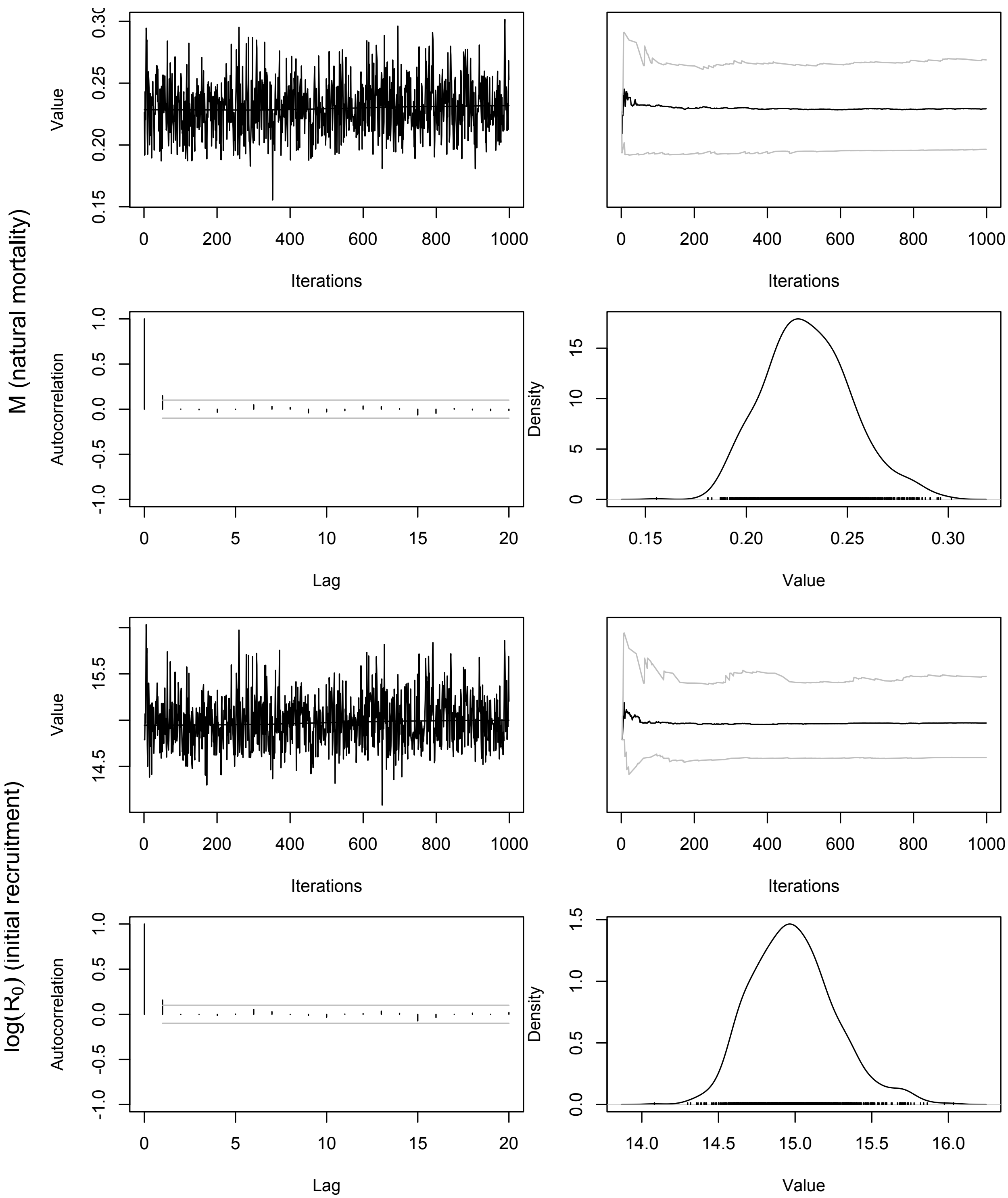


Figure 16. Summary of MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th percentiles, top right). The lower left sub-panel indicates the autocorrelation present in the chain at different lag times (i.e., distance between samples in the chain), and the lower right sub-panel shows the distribution of the values in the chain (i.e., the marginal density from a smoothed histogram of values in the trace plot).

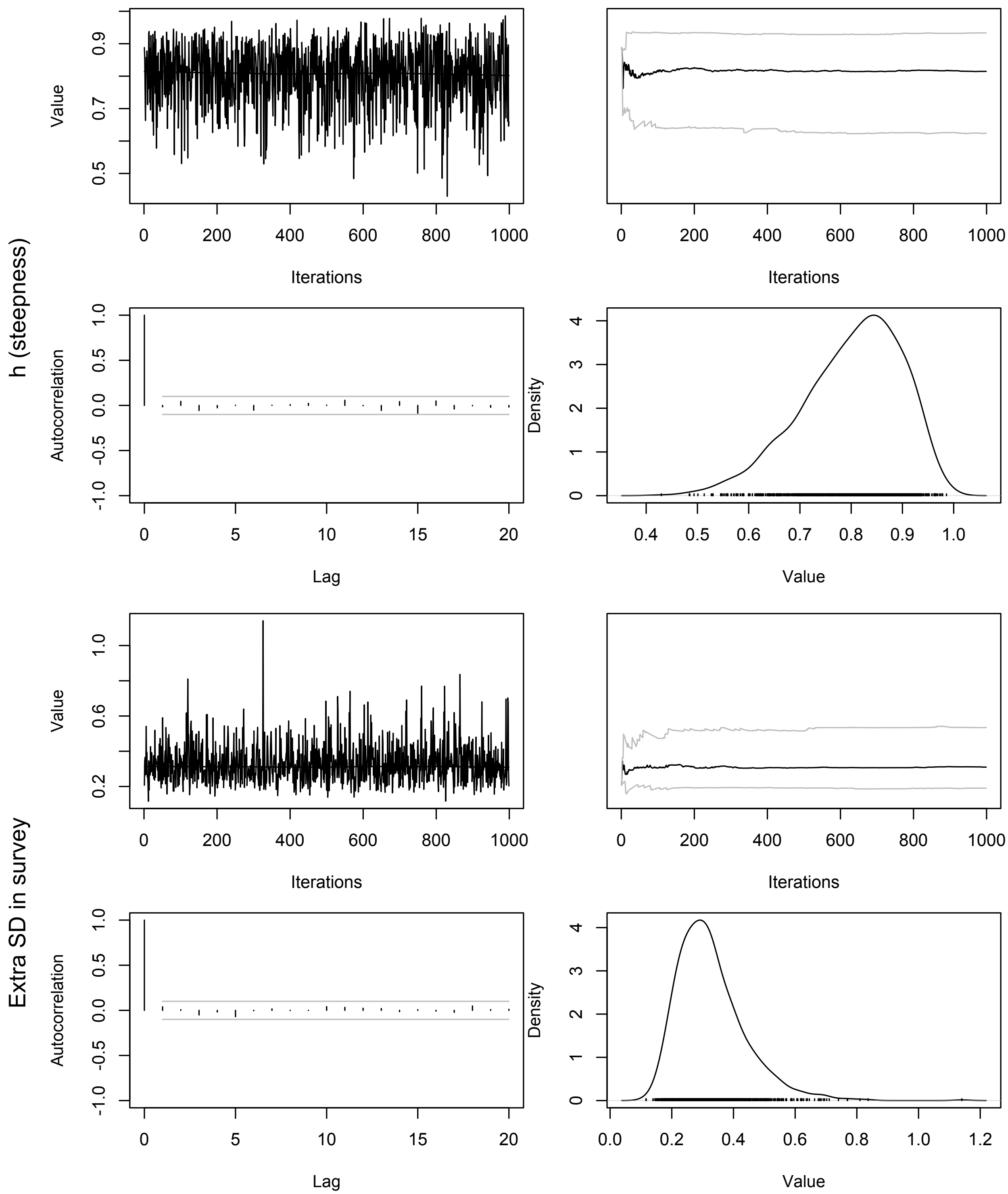


Figure 17. Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels) in the base model. Top sub-panels show the trace of the sampled values across iterations (absolute values, top left; cumulative running mean with 5th and 95th 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).

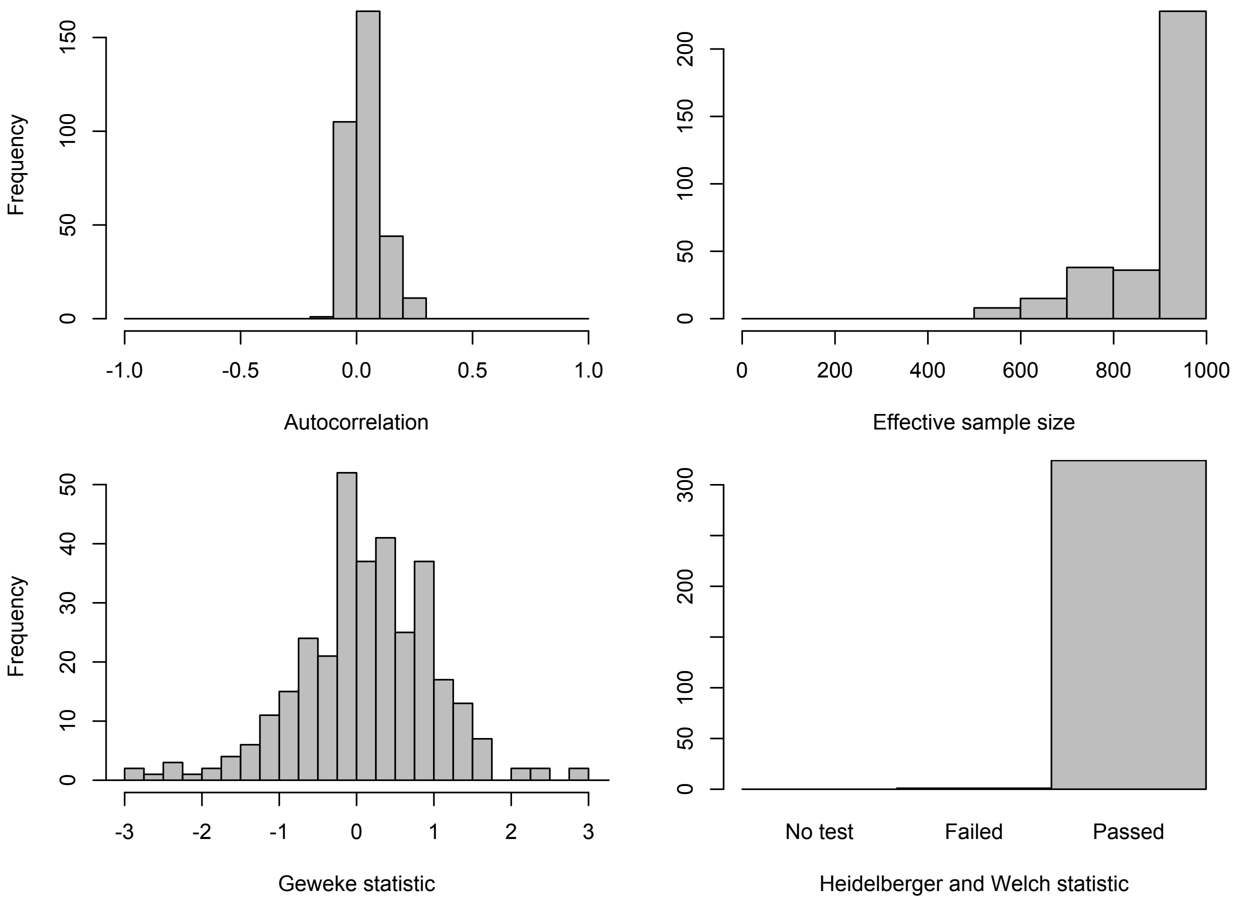


Figure 18. Summary histograms of MCMC diagnostics for all base model parameters together with the derived time series of spawning biomass and relative spawning biomass. The level of autocorrelation in the chain (distribution across lag times, i.e. distance between samples in the chain, shown in the top right panel) influences the effective sample size (top left 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 stationarity distribution by comparing different sections of the chain.

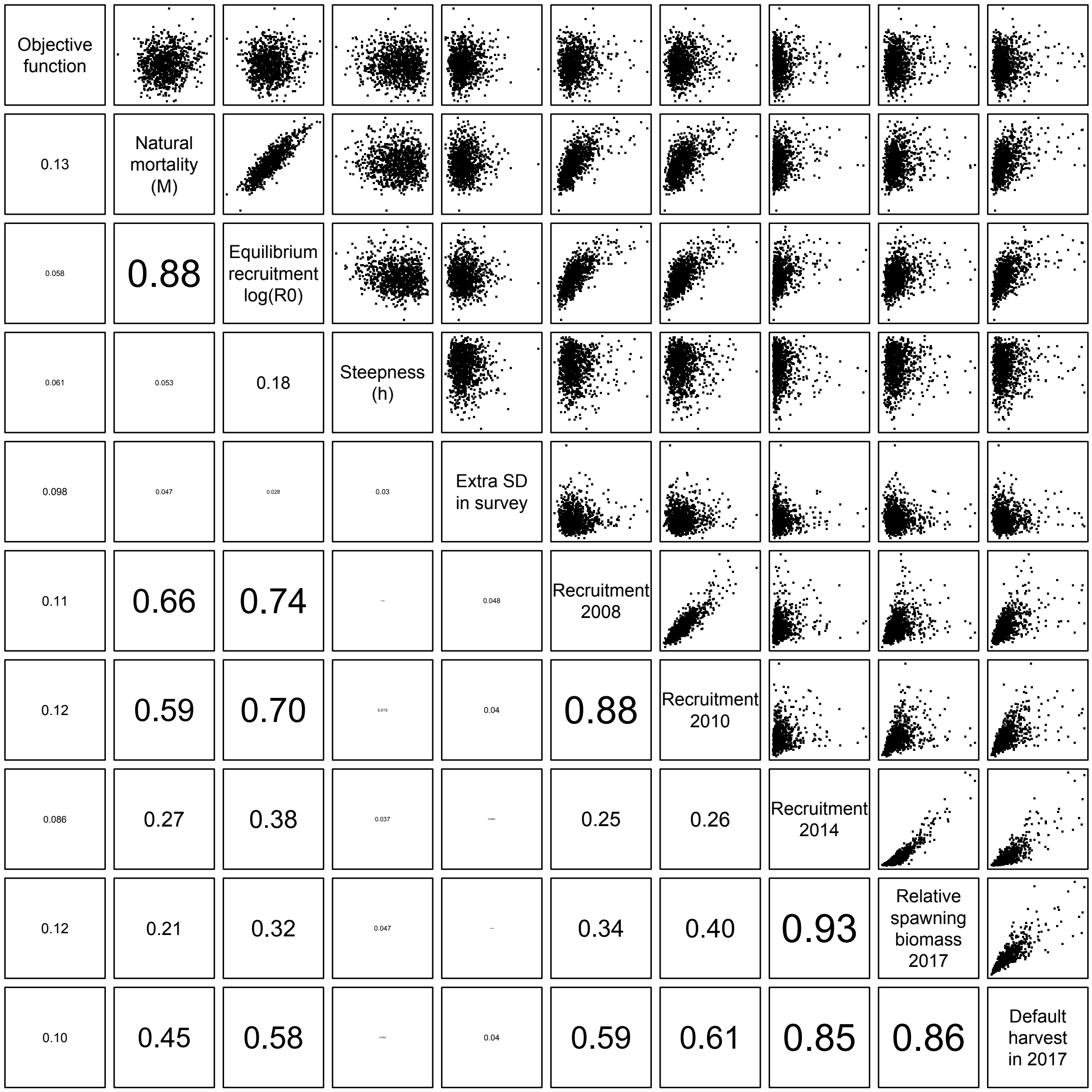


Figure 19. Posterior correlations among key base-model parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

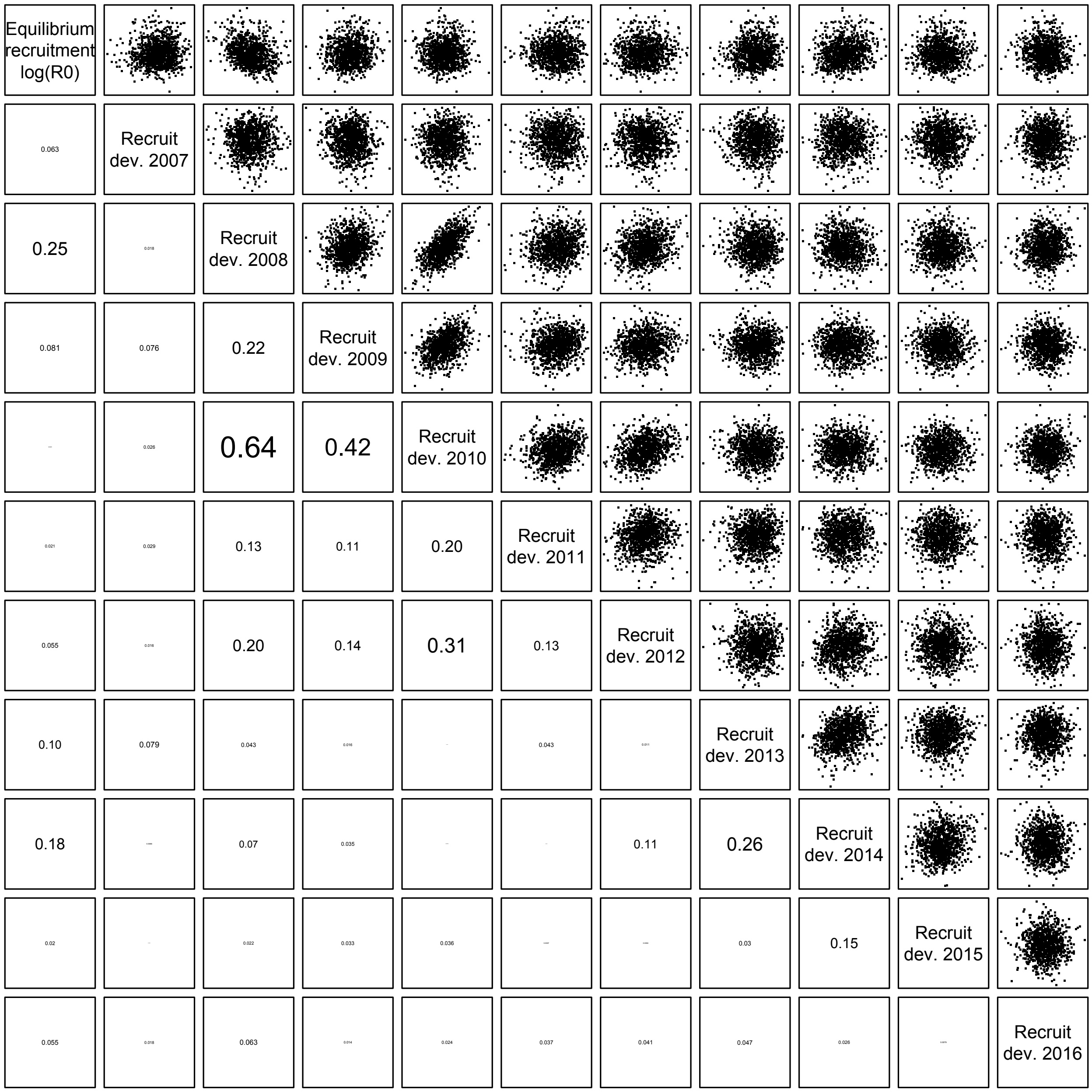


Figure 20. Posterior correlations among recruitment deviations from recent years. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

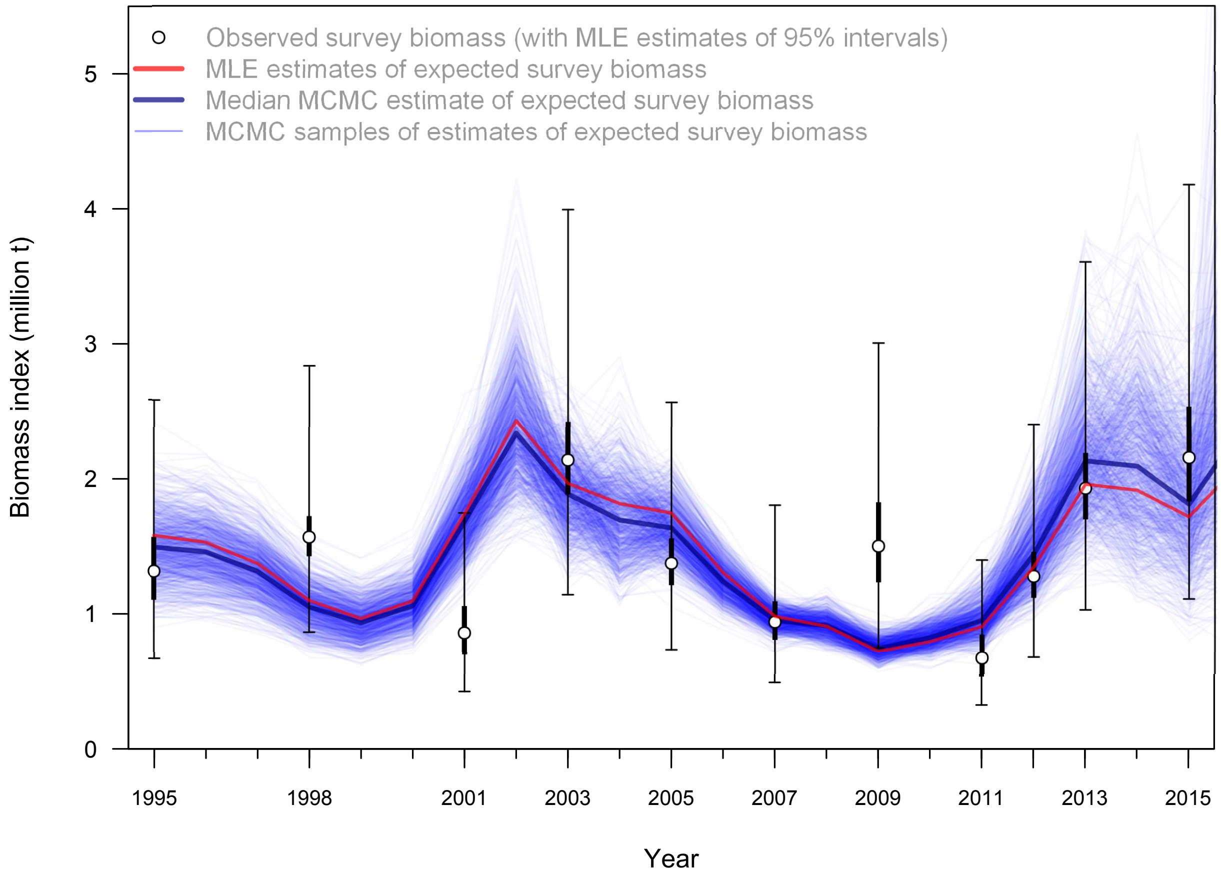


Figure 21. Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker bars on uncertainty intervals around observed survey points indicate 95% log-normal uncertainty intervals estimated by the kriging method. Longer bars indicate 95% uncertainty intervals with the MLE estimate of additional uncertainty.

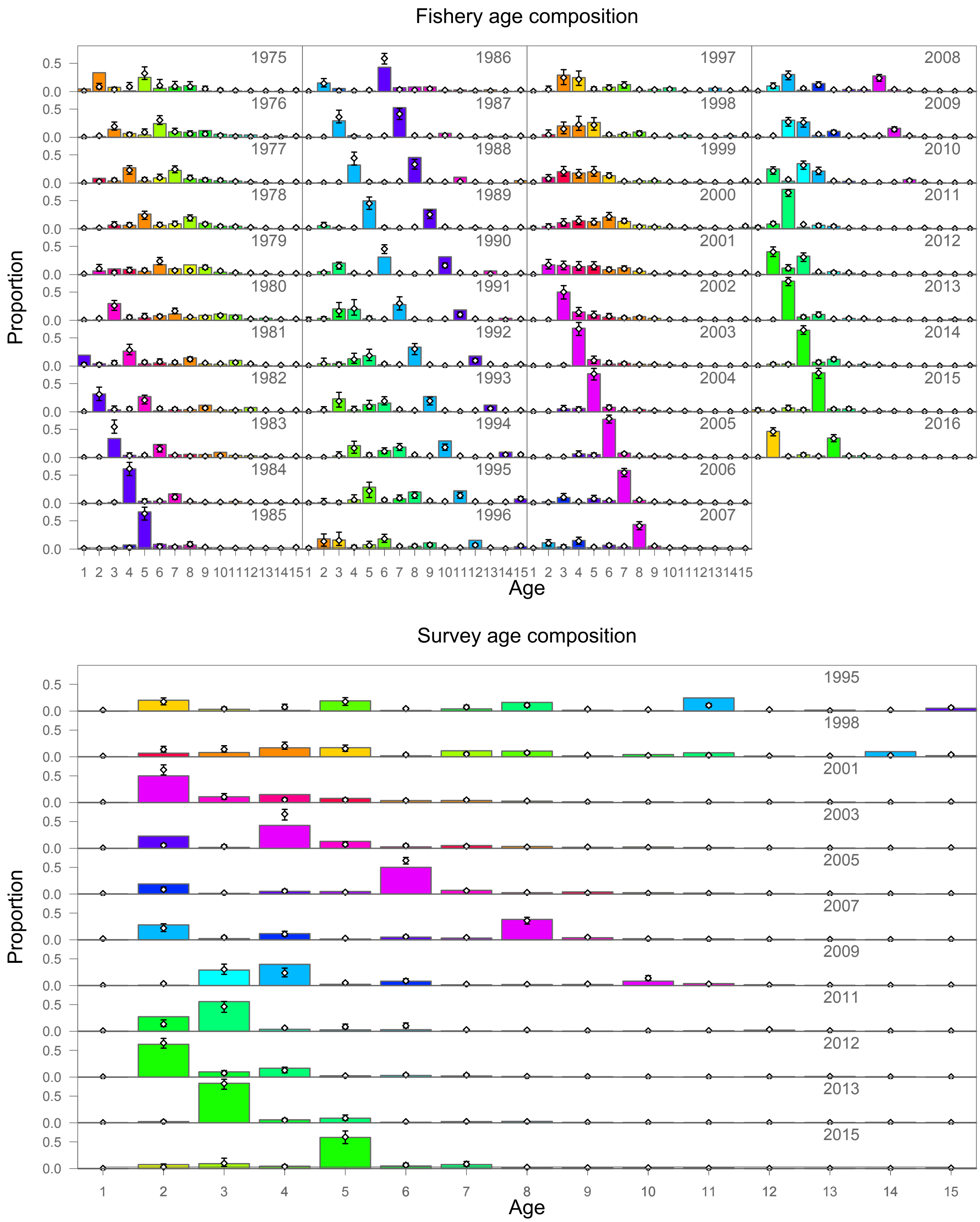


Figure 22. Base model fit to the observed fishery (top) and acoustic survey (bottom) age composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% uncertainty intervals from the MCMC.

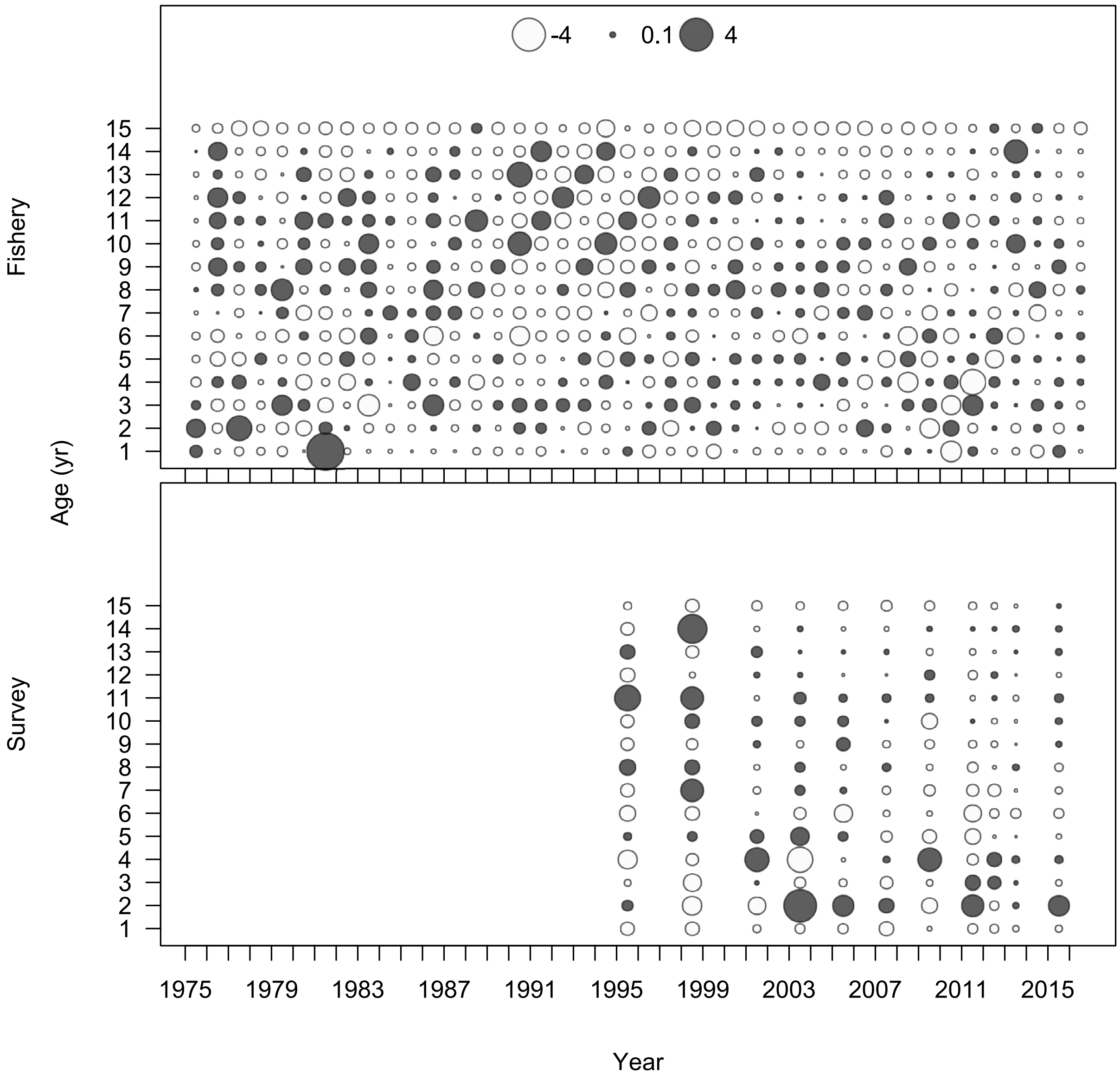


Figure 23. Pearson residuals for base model MLE fits to the fishery age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

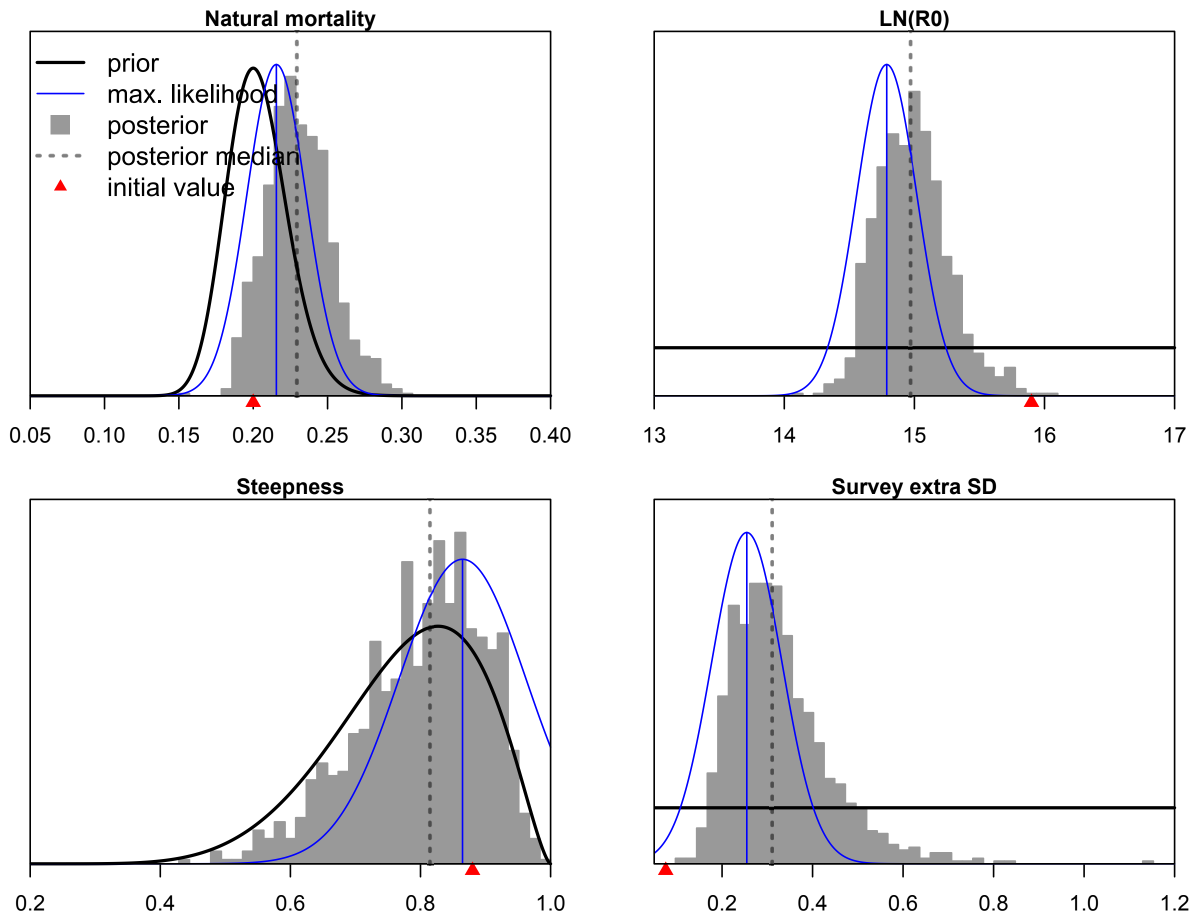


Figure 24. Prior (black lines) and posterior (gray histograms) probability distributions for key parameters in the base model. The parameters are: natural mortality (M), equilibrium log recruitment $\log(R_0)$, steepness (h), and the additional process-error standard deviation for the acoustic survey. The maximum likelihood estimates and associated symmetric uncertainty intervals are also shown (blue lines).

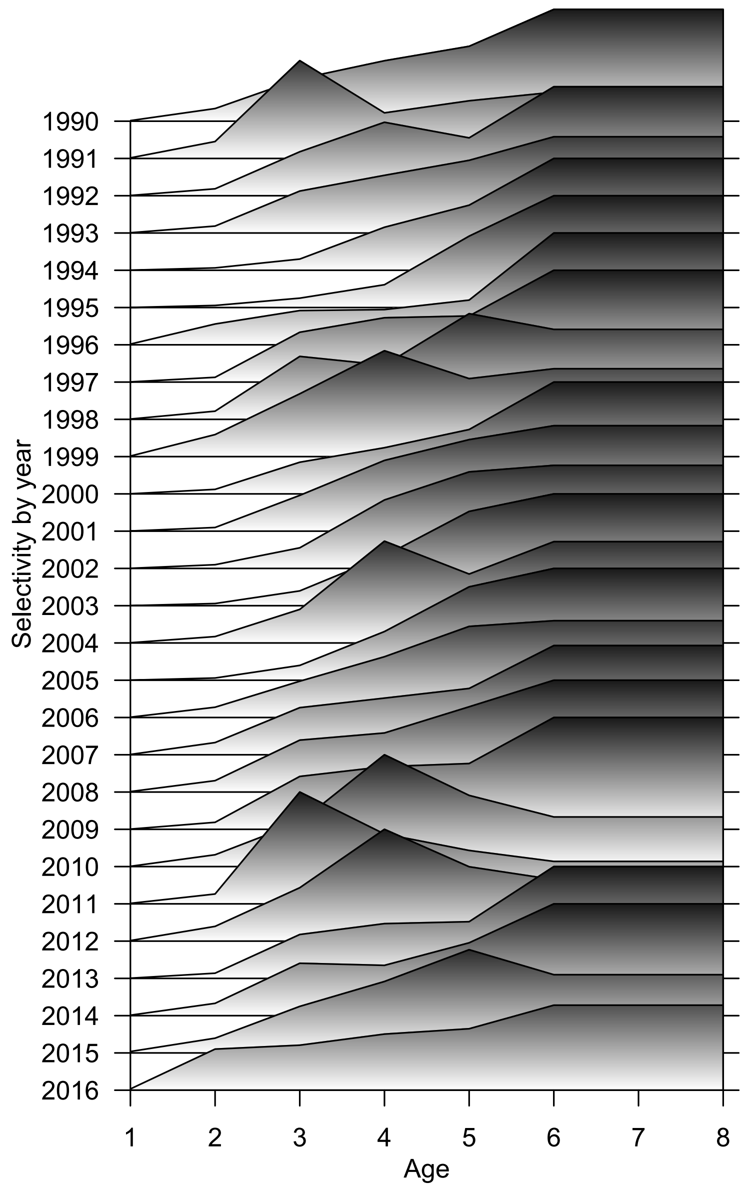


Figure 25. Mountains plot of median fishery selectivity in each year for the base model. Range of selectivity is 0 to 1 in each year.

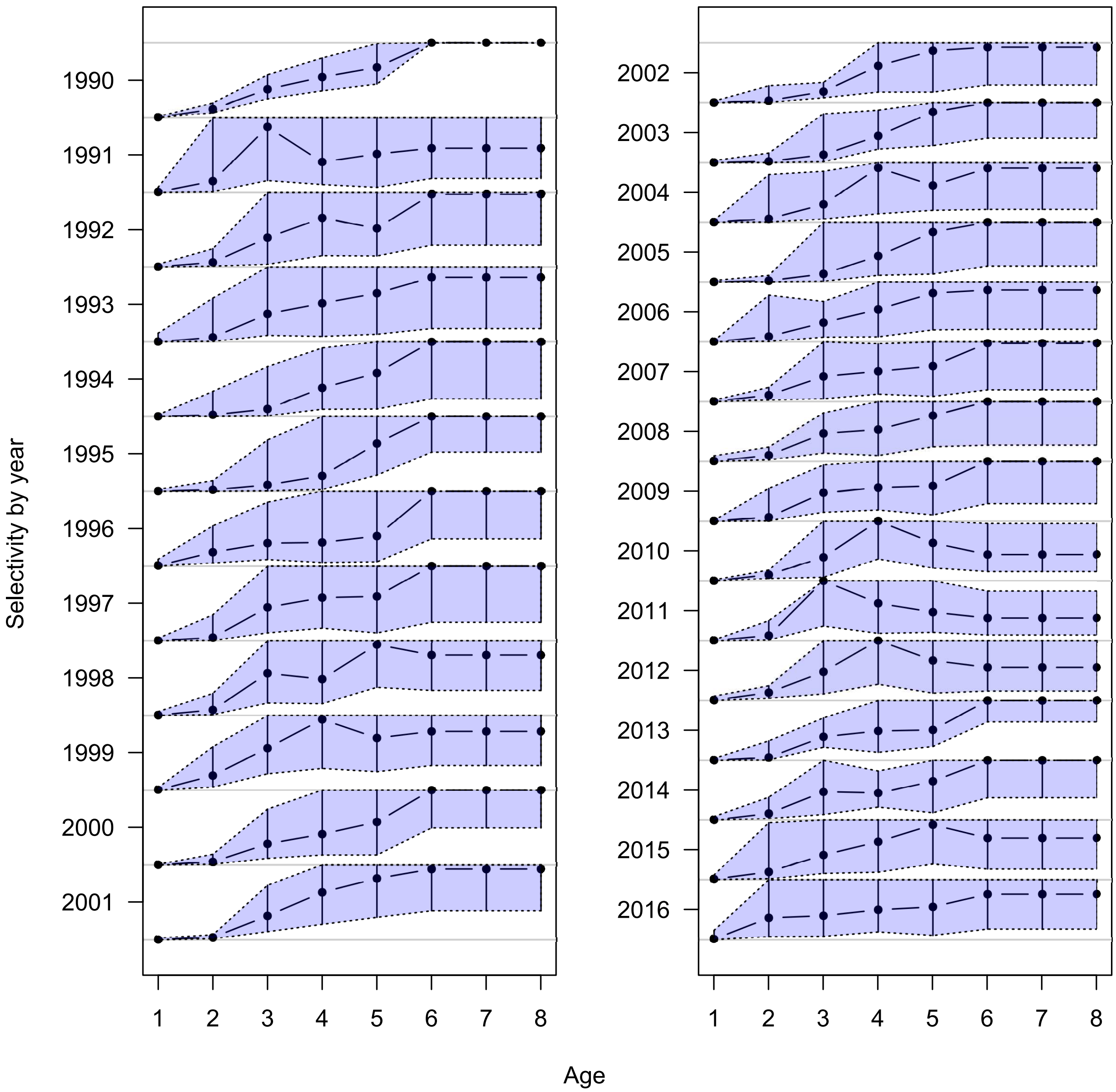
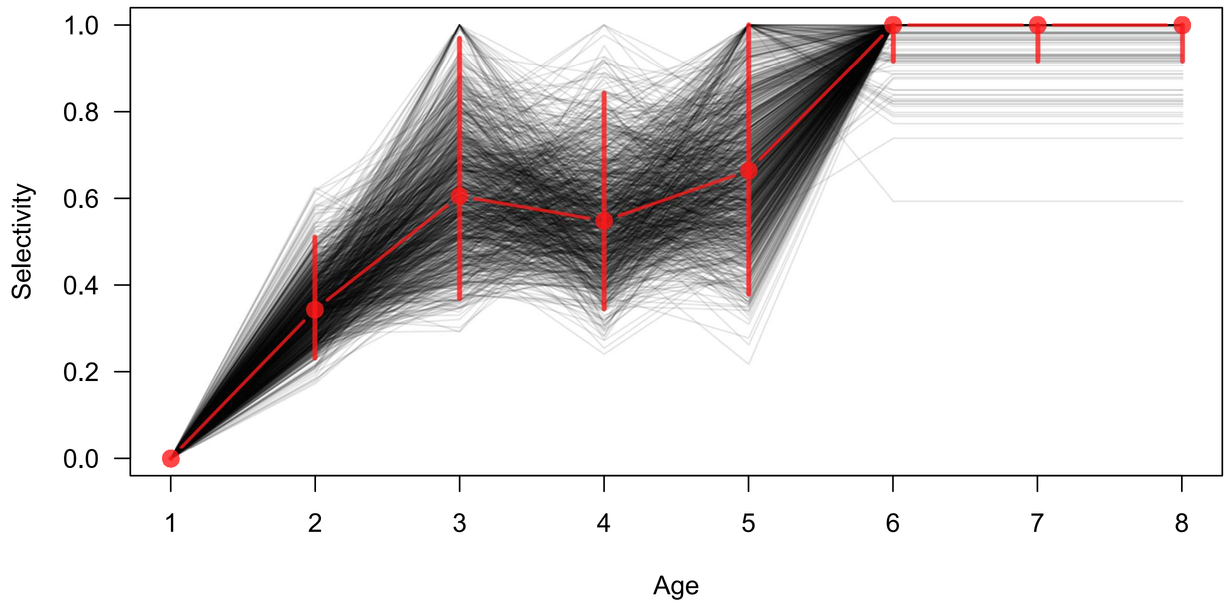


Figure 26. Fishery selectivity sampled from posterior probability distribution by year for the base model. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared for all years from 1966 to 1990.



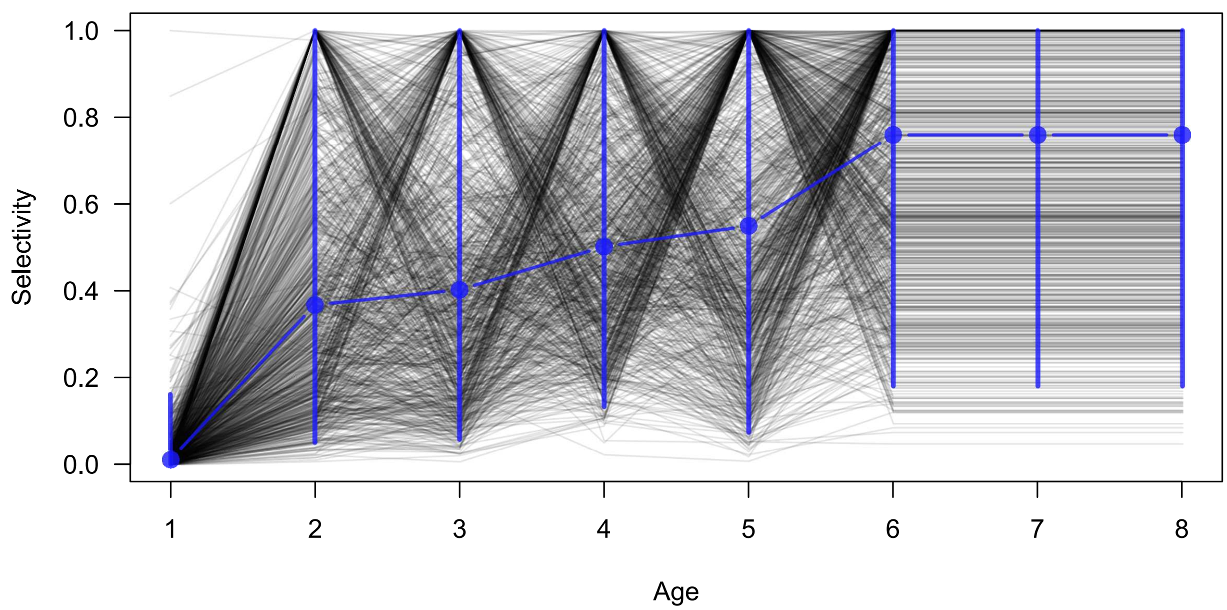


Figure 27. Estimated acoustic (top - for all years) and fishery selectivity (bottom - for 2016 only) ogives from the posterior distribution for the base model.

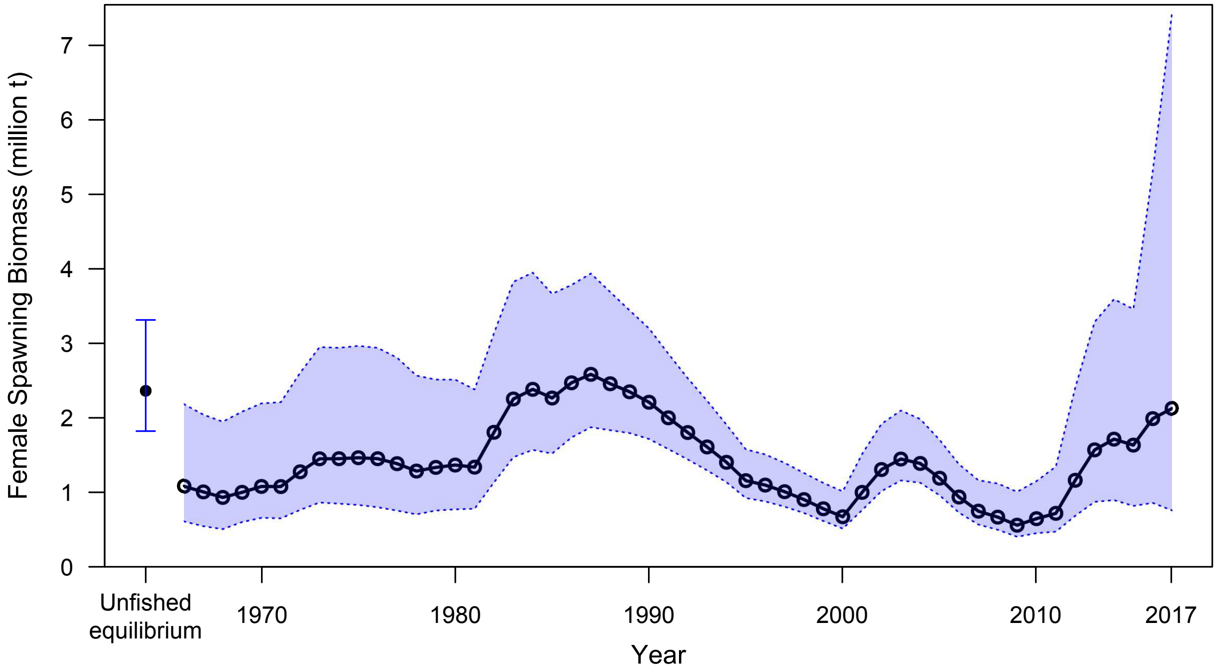


Figure 28. Median of the posterior distribution for female spawning biomass at the start of each year (B_t) for the base model up to 2017 (solid line) with 95% posterior credibility intervals (shaded area).

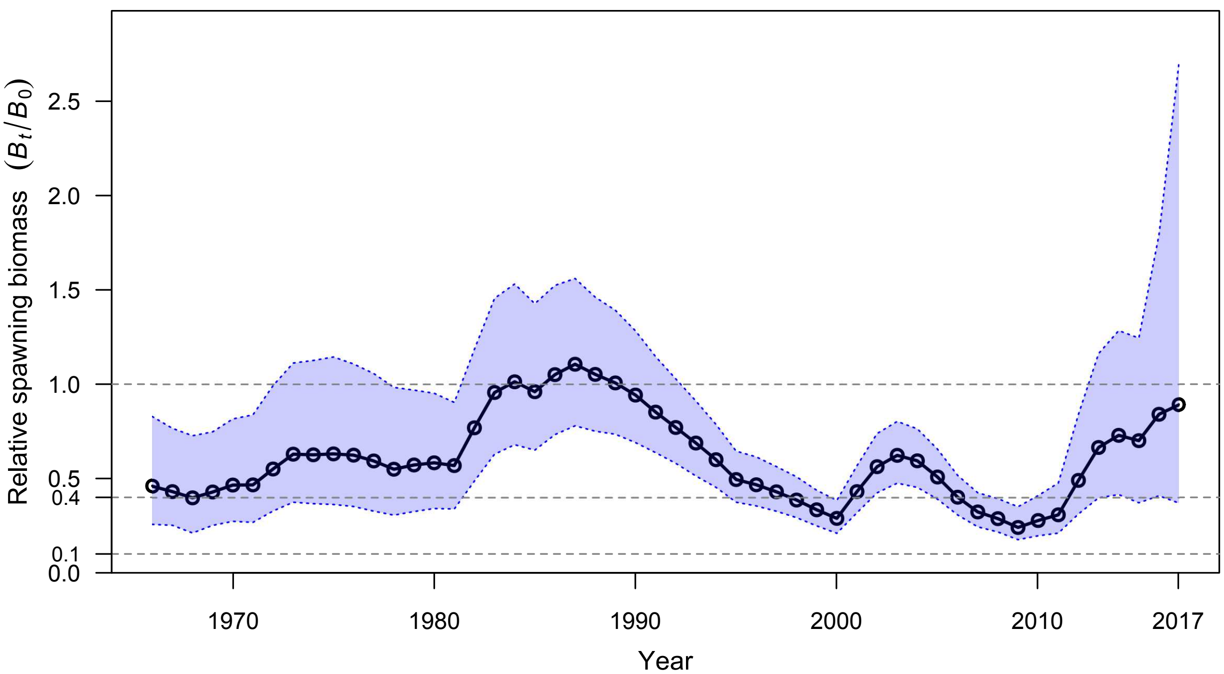


Figure 29. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) for the base model through 2017 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

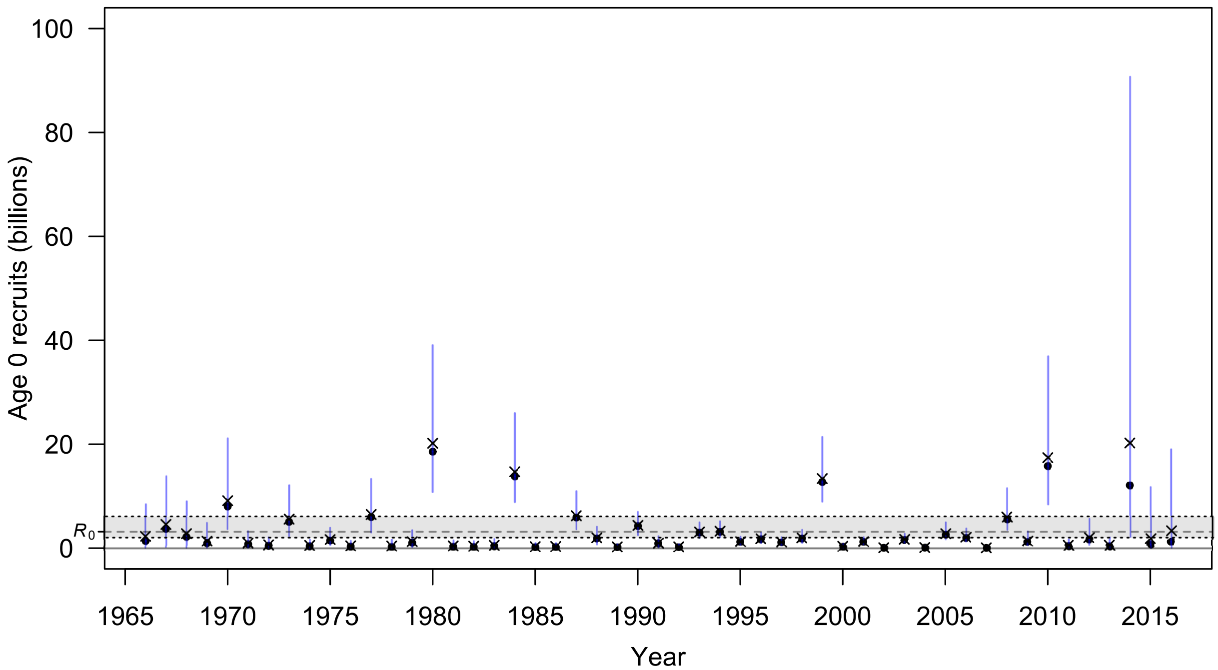


Figure 30. Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

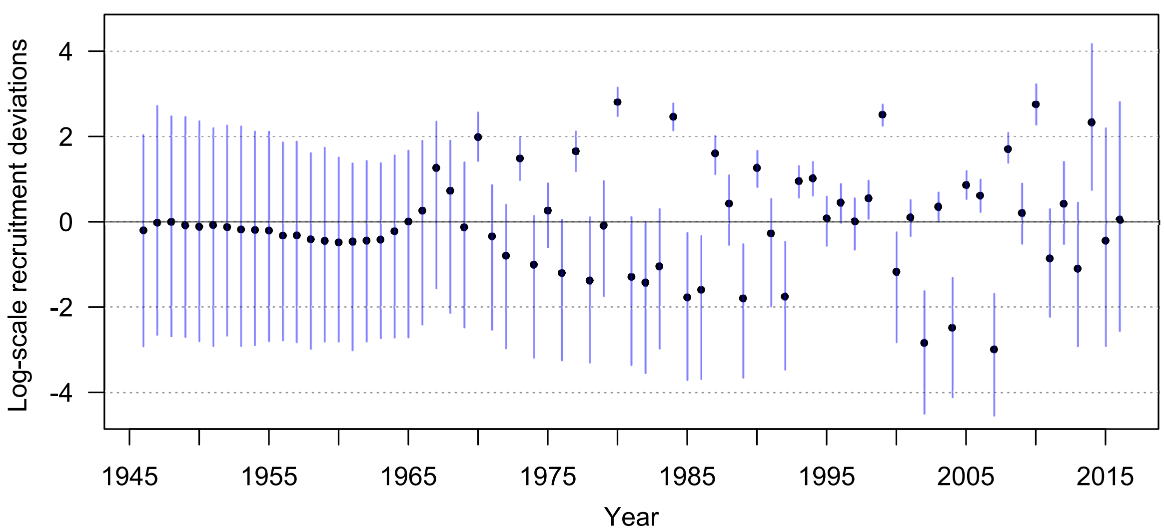


Figure 31. Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model. Deviations for the years 1970–2012 are constrained to sum to zero while deviations outside this range do not have a constraint.

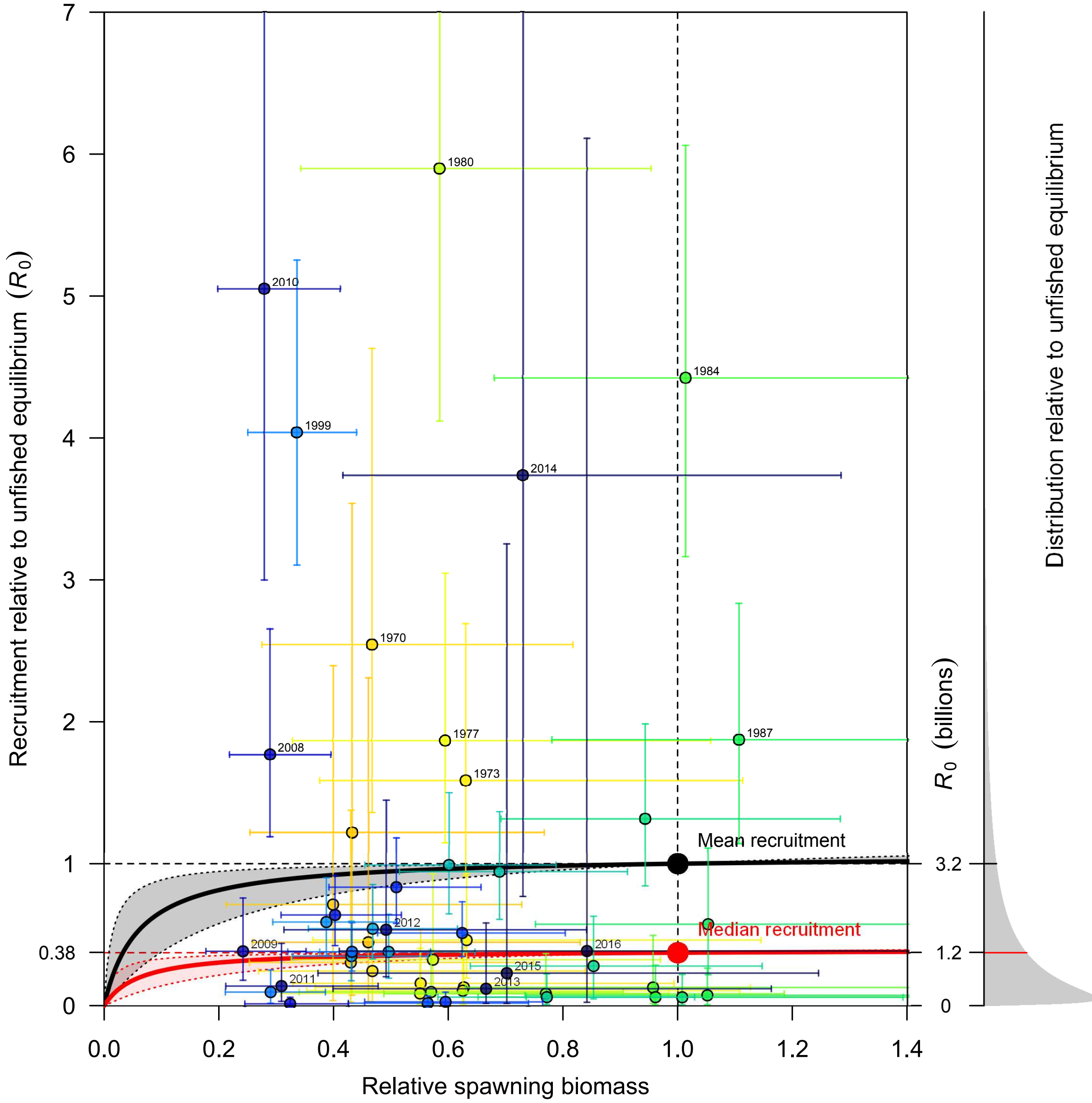


Figure 32. Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (mean) and the red line the central tendency after bias correcting for the log-normal distribution (median). Shading around stock-recruit curves indicates uncertainty in shape associated with distribution of the steepness parameter (h). The gray polygon on the right indicates the expected distribution of recruitments relative to the unfished equilibrium.

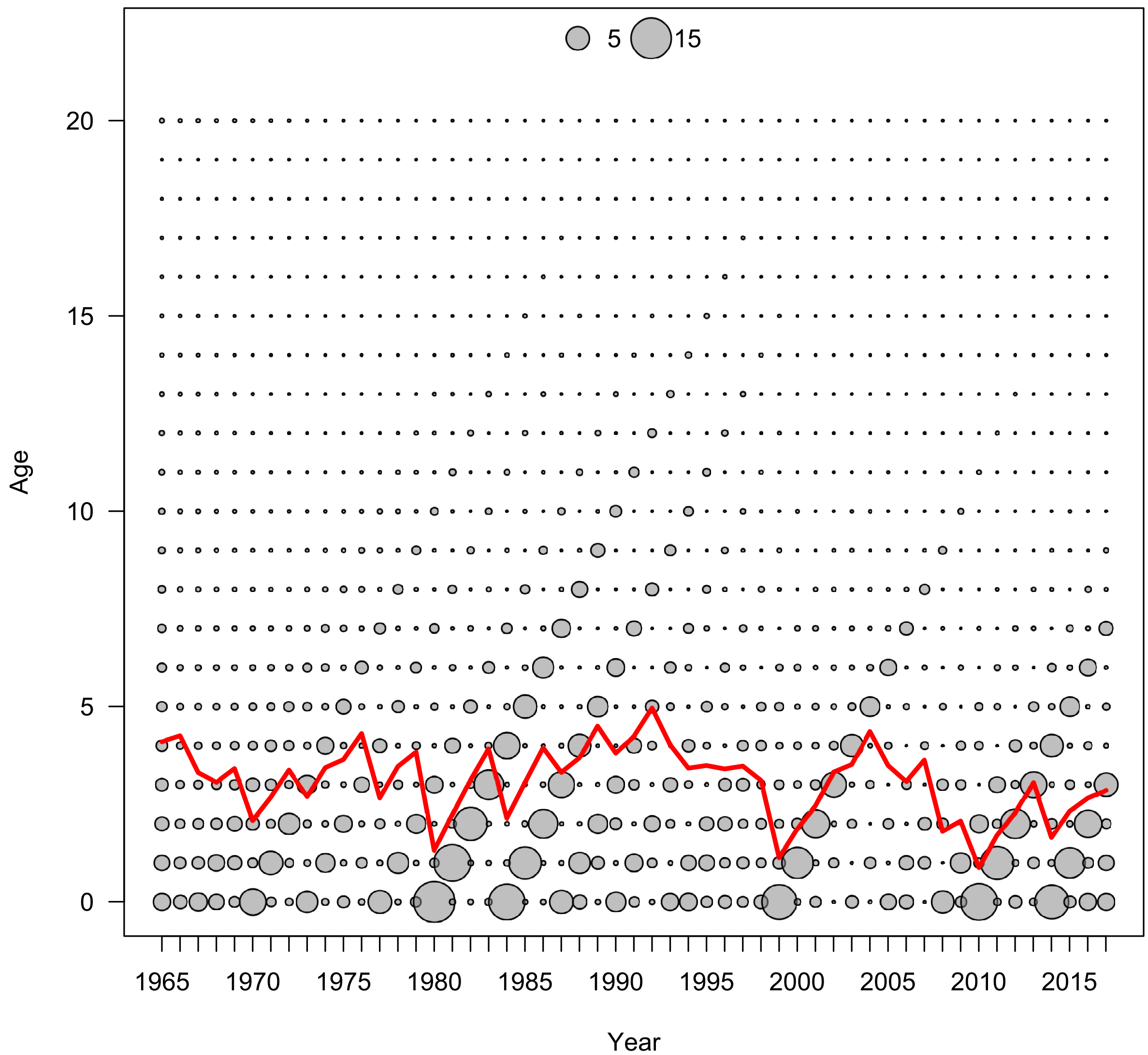


Figure 33. Bubble plot of maximum likelihood (MLE) estimates of population numbers at age at the beginning of each year, where diagonals follow each year-class through time. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish (with the largest bubble representing about 14 billion age-0 recruits in 1980). See Table 20 for values.

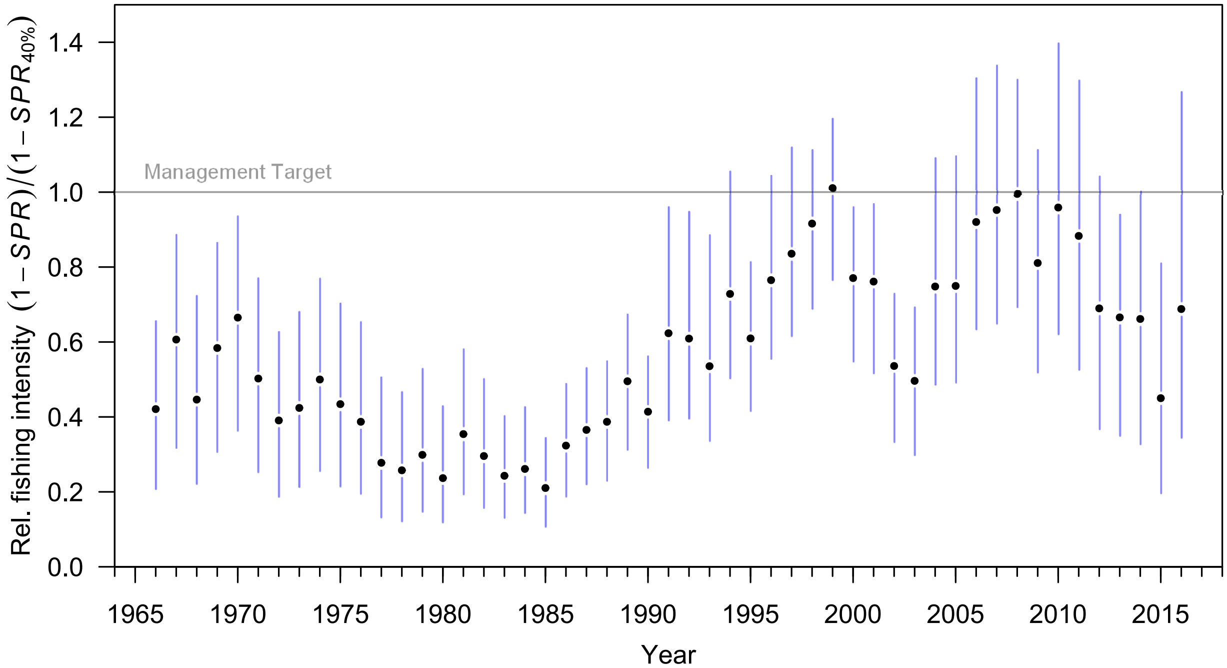


Figure 34. Trend in median fishing intensity (relative to the SPR management target) through 2016 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

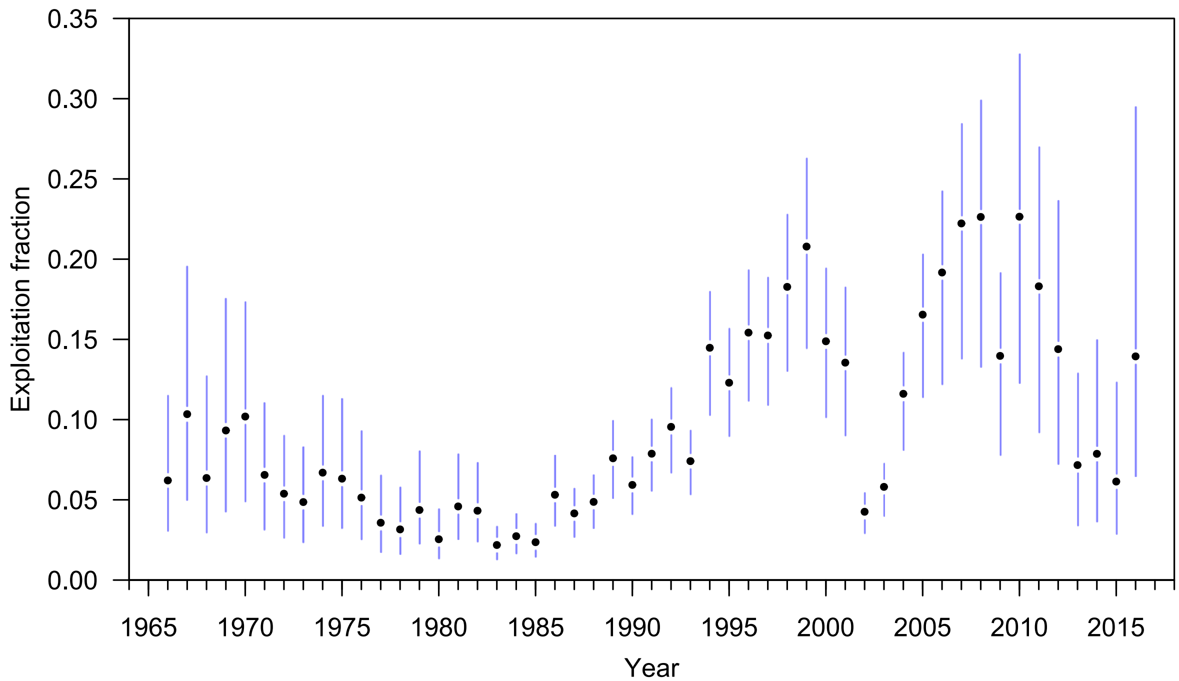


Figure 35. Trend in median exploitation fraction (catch divided by biomass of fish of age-3 and above) through 2016 with 95% posterior credibility intervals.

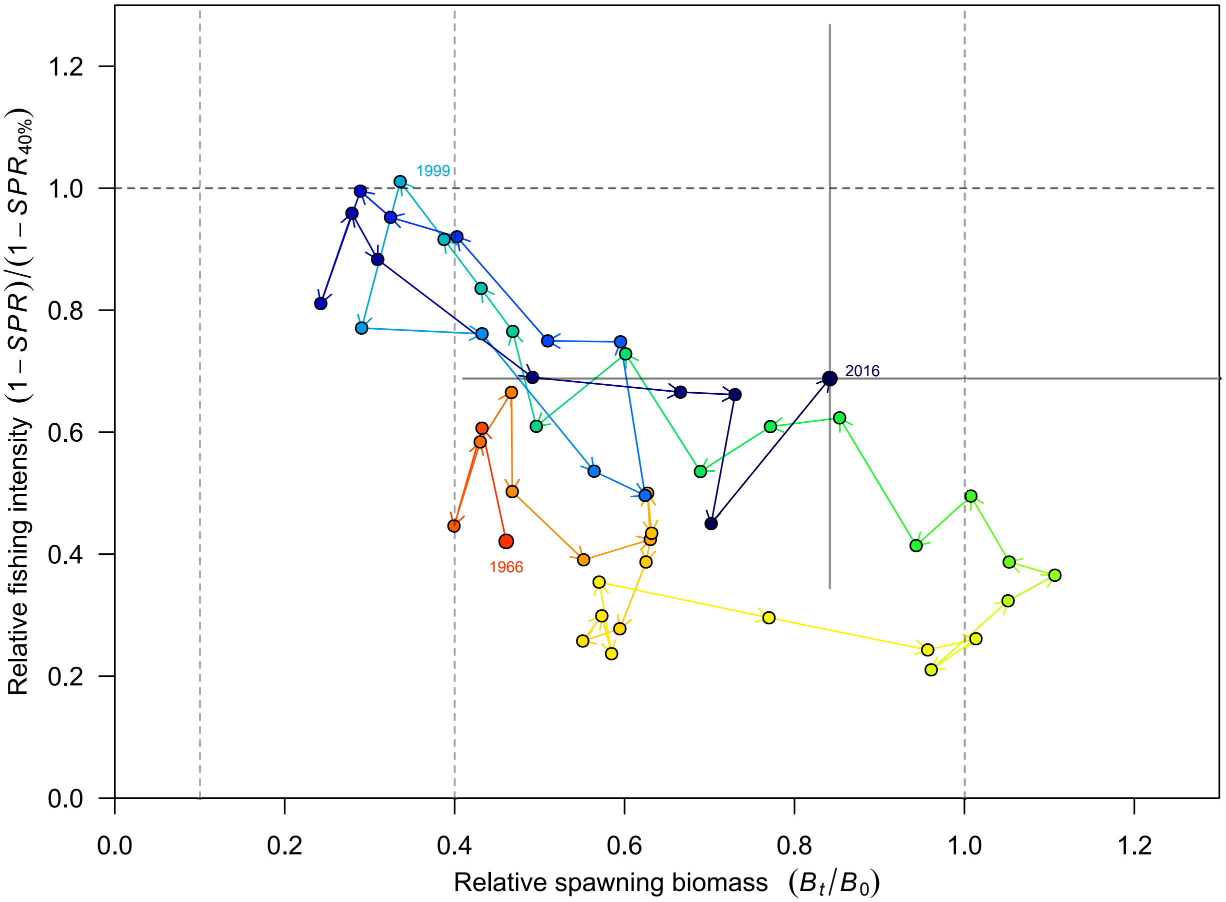


Figure 36. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2016 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

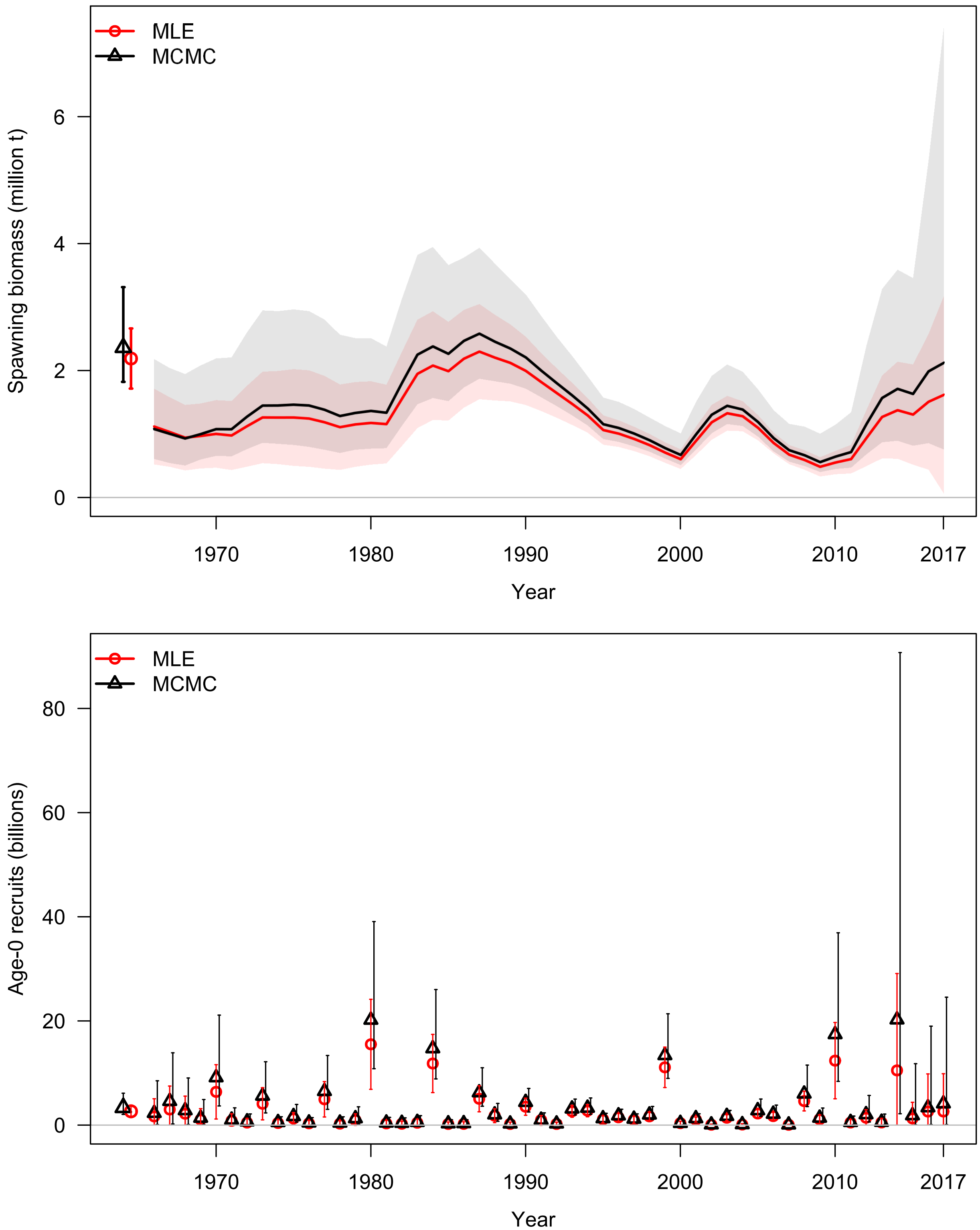


Figure 37. A comparison of maximum likelihood estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the posterior distribution with 95% credibility intervals (black). The posterior median is shown for spawning biomass while the posterior mean recruitment is displayed in the lower panel to be more comparable to the MLE value.

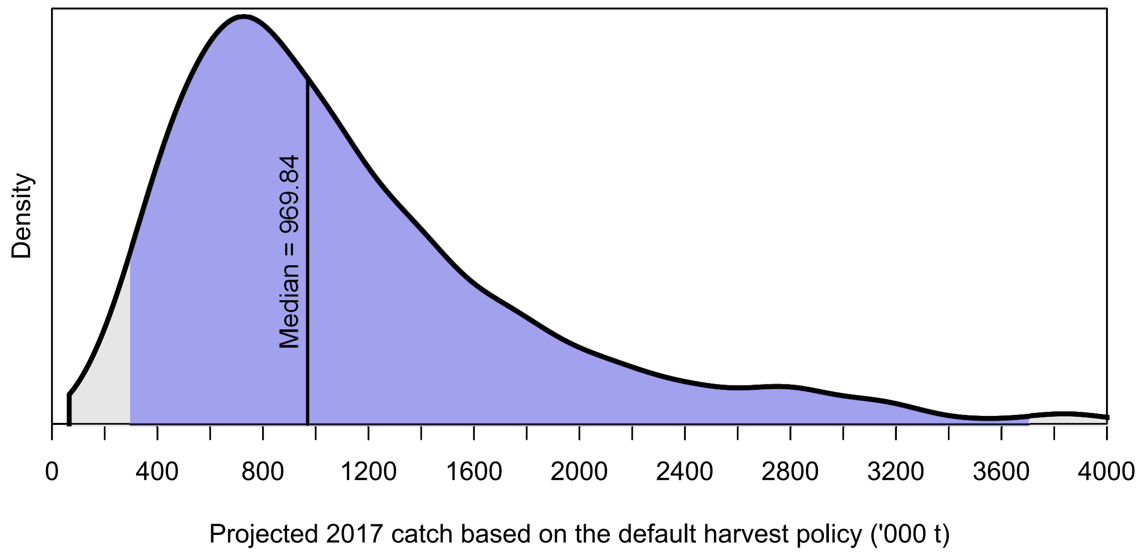


Figure 38. The posterior distribution of the default 2017 catch limit calculated using the default harvest policy ($F_{\mathrm{SPR}=40\%}$–40:10). The median is 969,840 t (vertical line), with the dark shaded area ranging from the 2.5% quantile to the 97.5% quantile, covering the range 293,697–3,710,305 t.

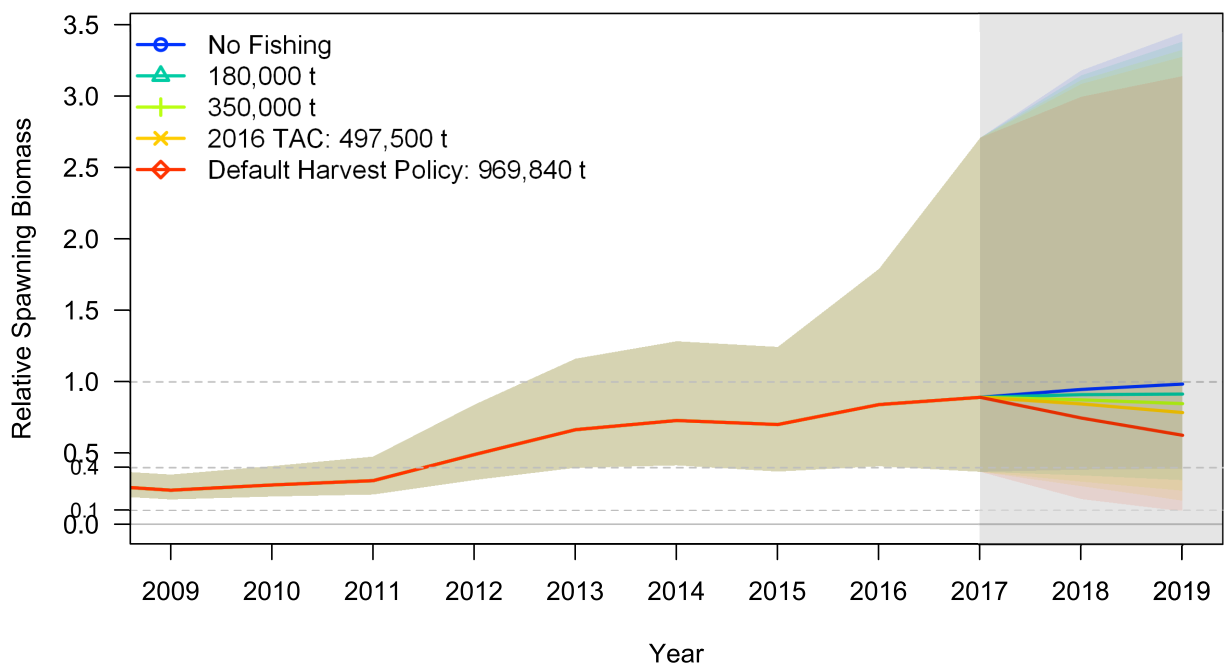


Figure 39. Time series of relative spawning biomass at the start of each year until 2017 as estimated from the base model, and forecast trajectories to the start of 2019 for several management options from the decision table (grey region), with 95% posterior credibility intervals. The 2017 catch of 969,840 t was calculated using the default harvest policy, as defined in the Agreement.

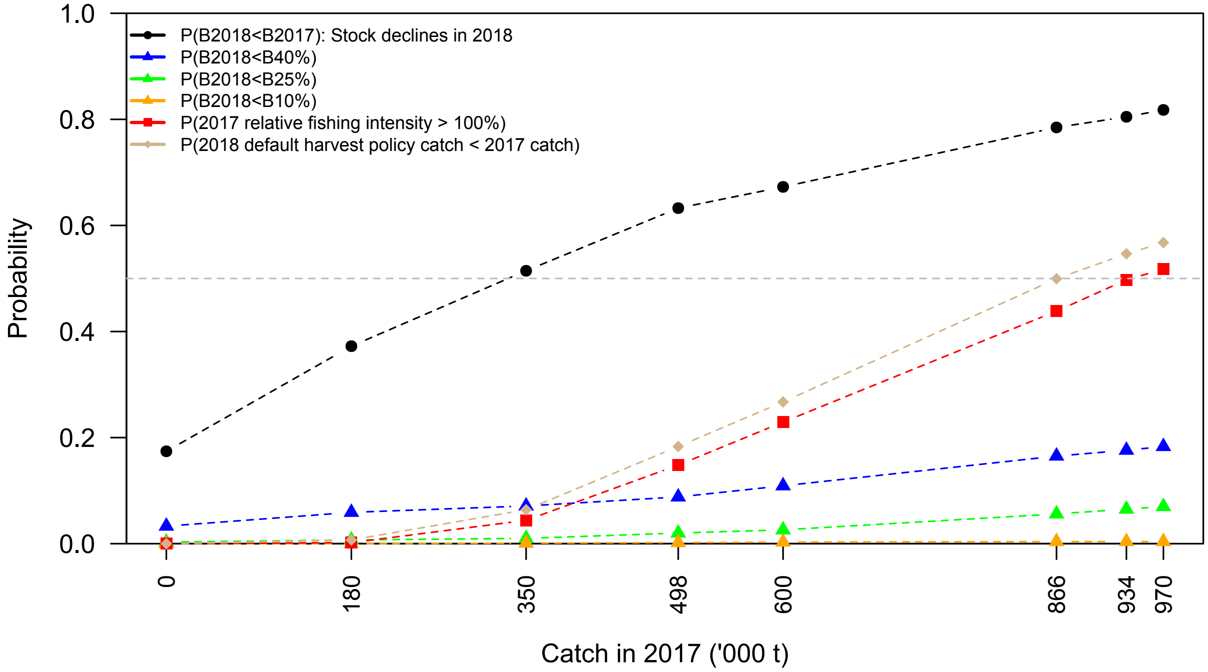


Figure 40. Graphical representation of the base model results presented in Table 30 for various catches in 2017. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

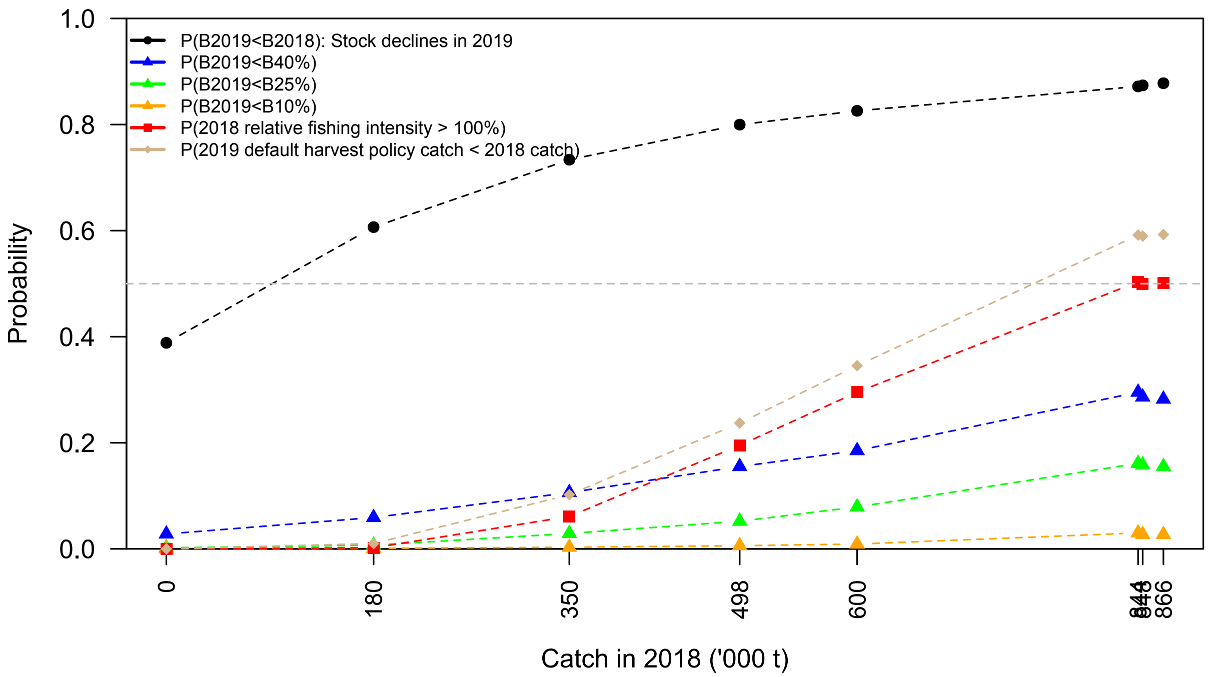


Figure 41. Graphical representation of the base model results presented in Table 31 for catch in 2018, given the 2017 catch level shown in Table 30. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

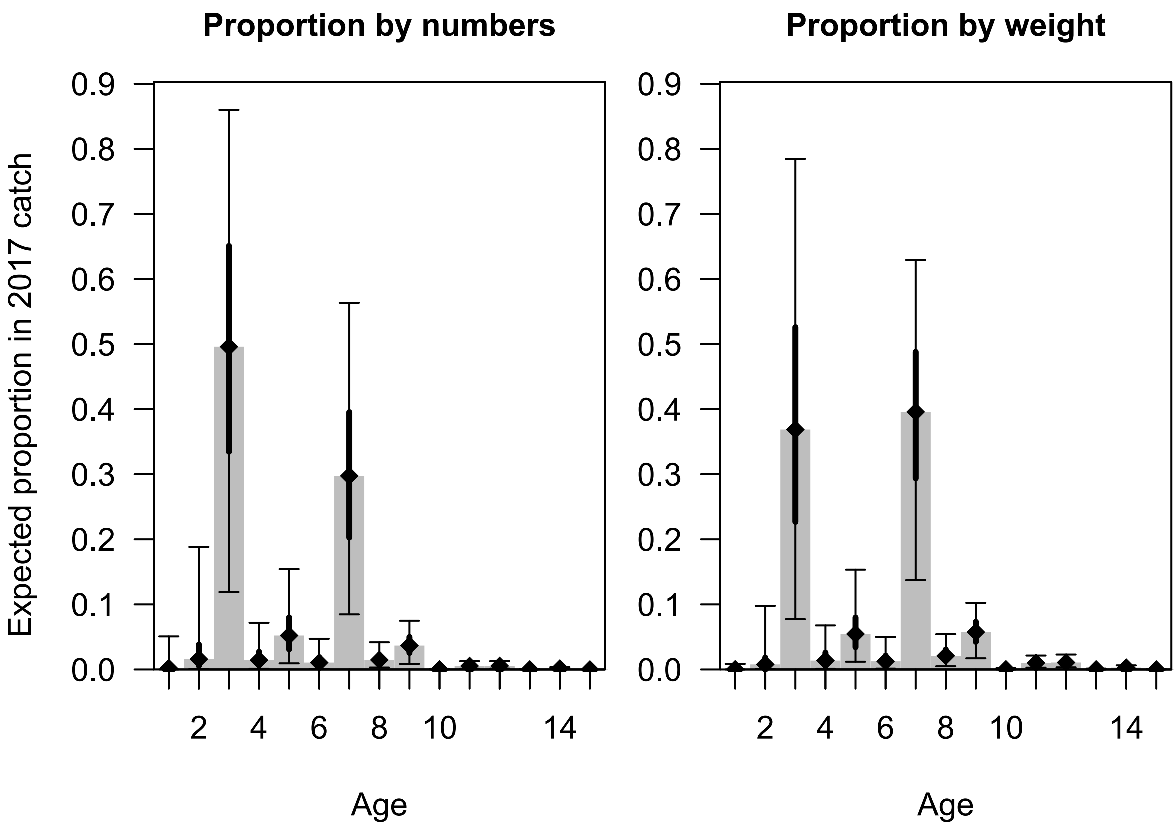


Figure 42. Forecast age compositions in numbers and in weight for the 2017 fishery catch (combined across all sectors in both countries). Gray bars show median estimates. Thick black lines show 50% credibility intervals and thin black lines show 95% credibility intervals. These estimates are based on the posterior distribution for selectivity averaged across the most recent 5 years and the distribution for expected numbers at age at the start of 2017 (see Table 20 for the MLEs for numbers-at-age for all years). The panel on the right is scaled based on the weight at each age averaged across all years.

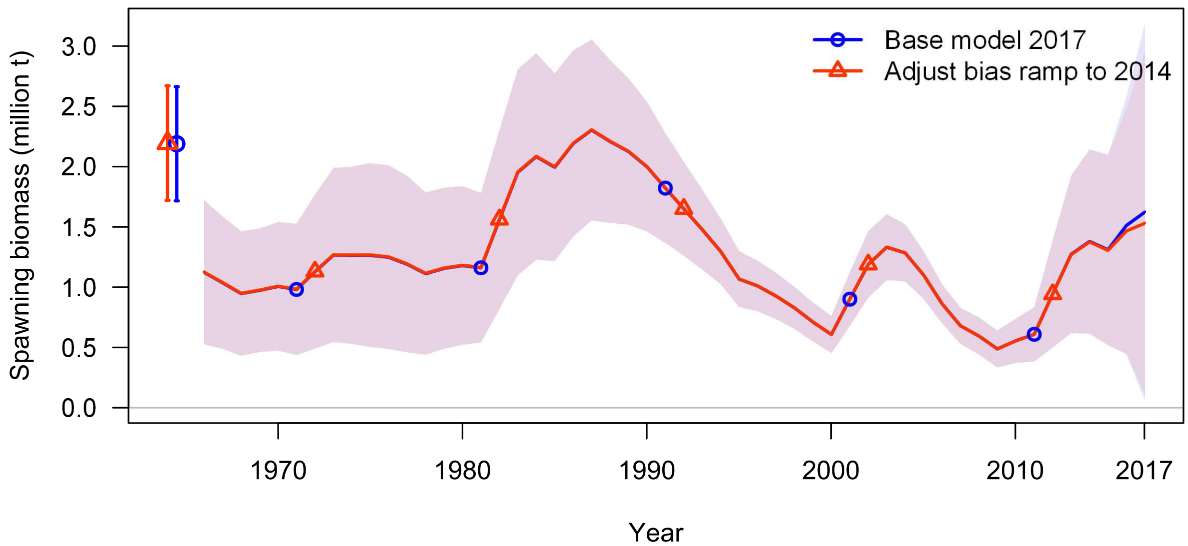


Figure 43. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity run that sets the full bias ramp adjust period to 2014 instead of 2013.

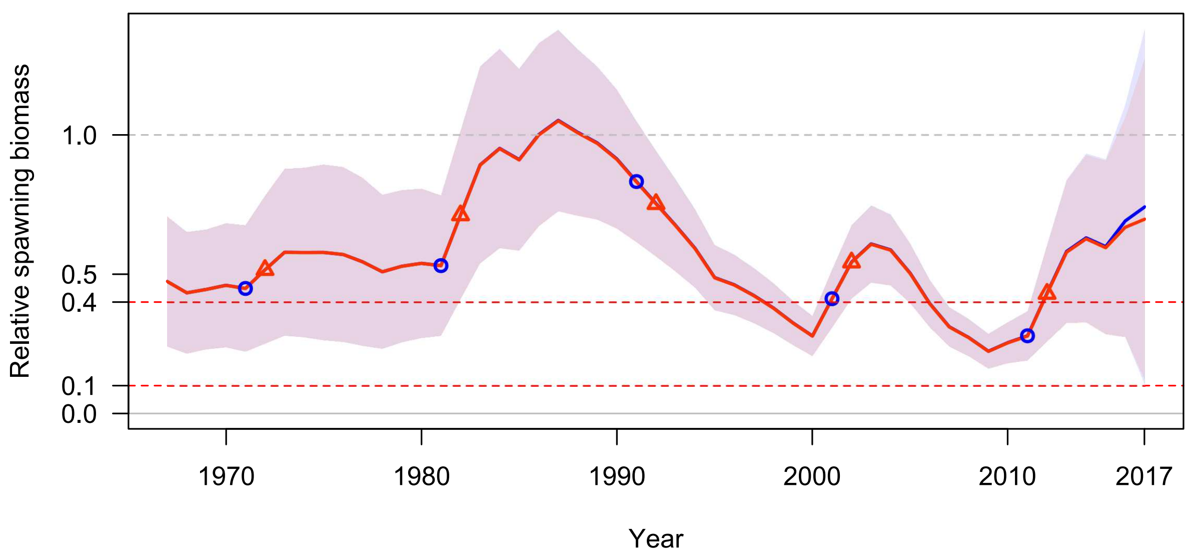


Figure 44. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity run that sets the full bias ramp adjust period to 2014 instead of 2013.

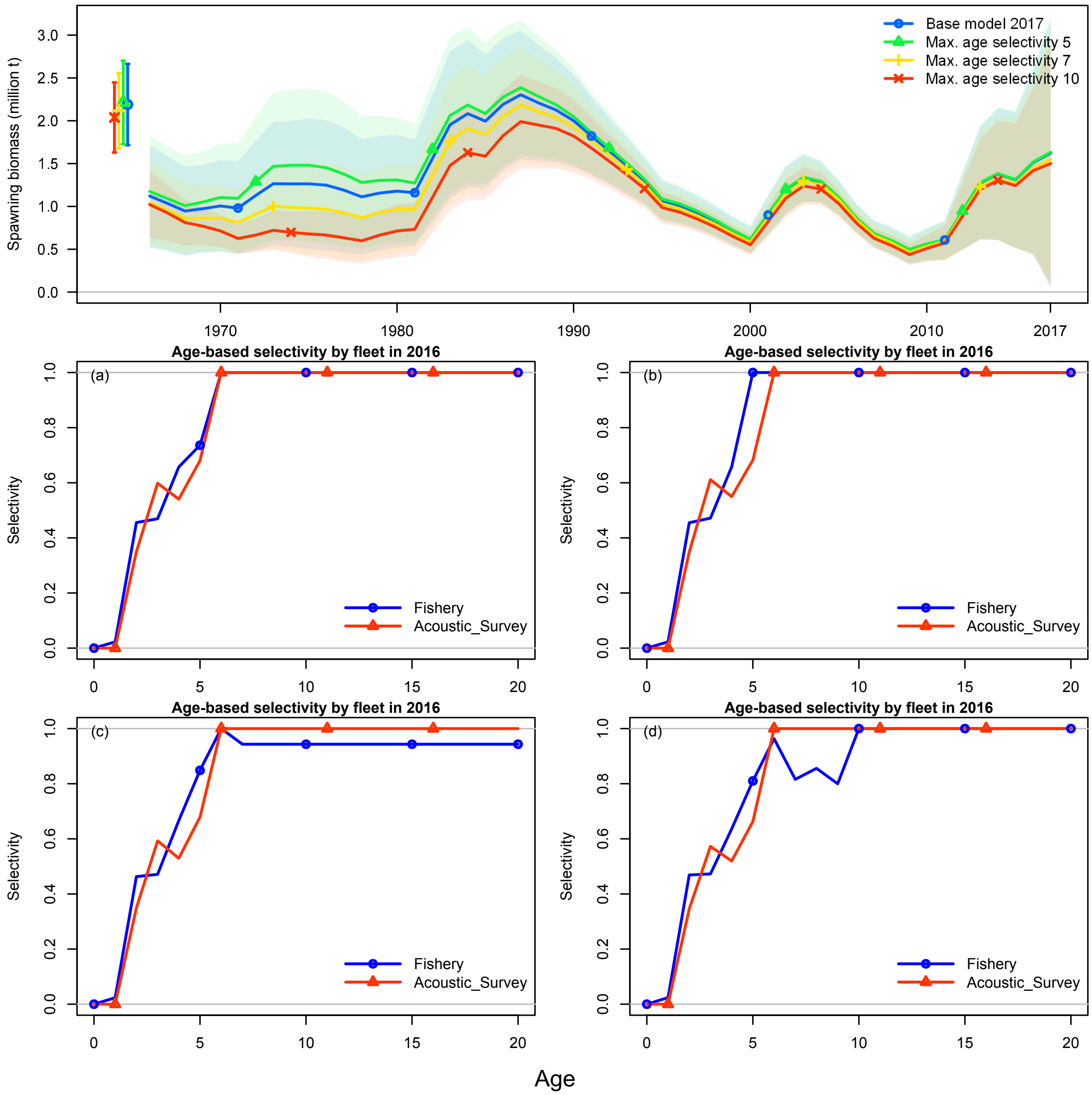


Figure 45. Maximum likelihood estimates of spawning biomass and selectivity for the base model and alternative sensitivity runs representing changes in the age of maximum selectivity from the value of 6 in the base model. Selectivity panels are a) Base model, b) Max. age selectivity 5, c) Max. age selectivity 7, and d) Max. age selectivity 10.

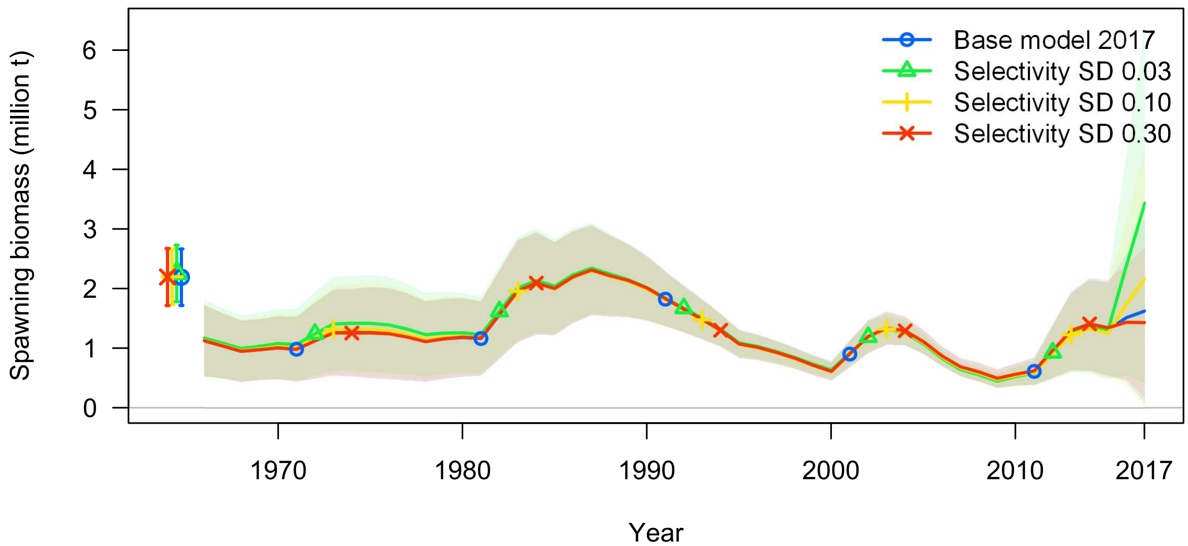


Figure 46. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity run representing changes in the standard deviation of the selectivity parameters from the base model's value of $\phi = 0.20$.

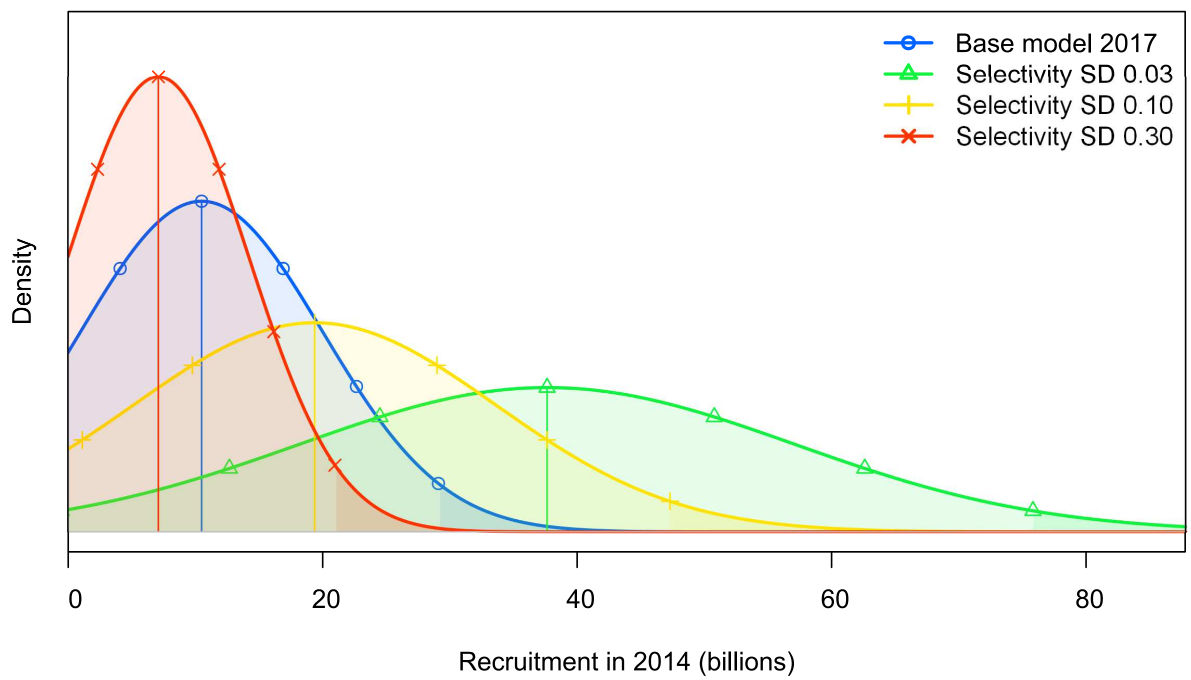


Figure 47. Density plot showing the MLE recruitment estimates for the 2014 cohort for the base model and alternative sensitivity run representing changes in the standard deviation of the selectivity parameters from the base model's value of $\phi = 0.20$.

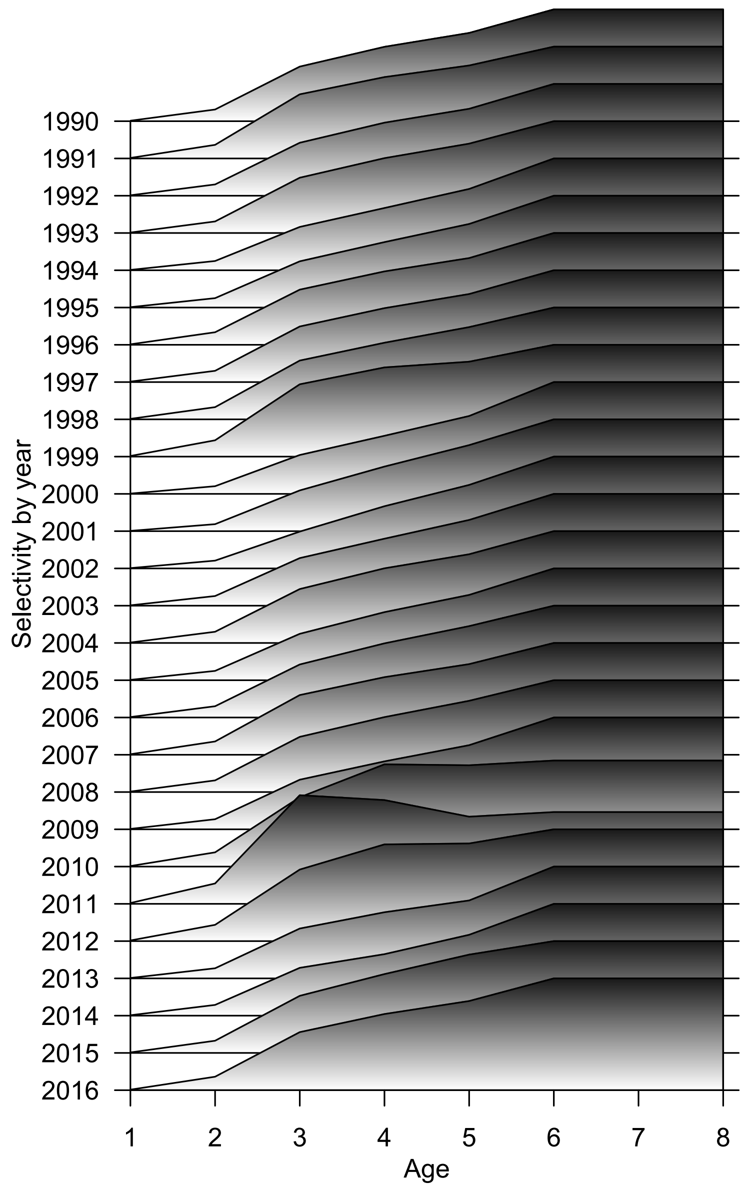


Figure 48. Mountains plot of median fishery selectivity in each year for the $\phi = 0.03$ sensitivity case. Range of selectivity is 0 to 1 in each year. See Figure 25 for the base model.

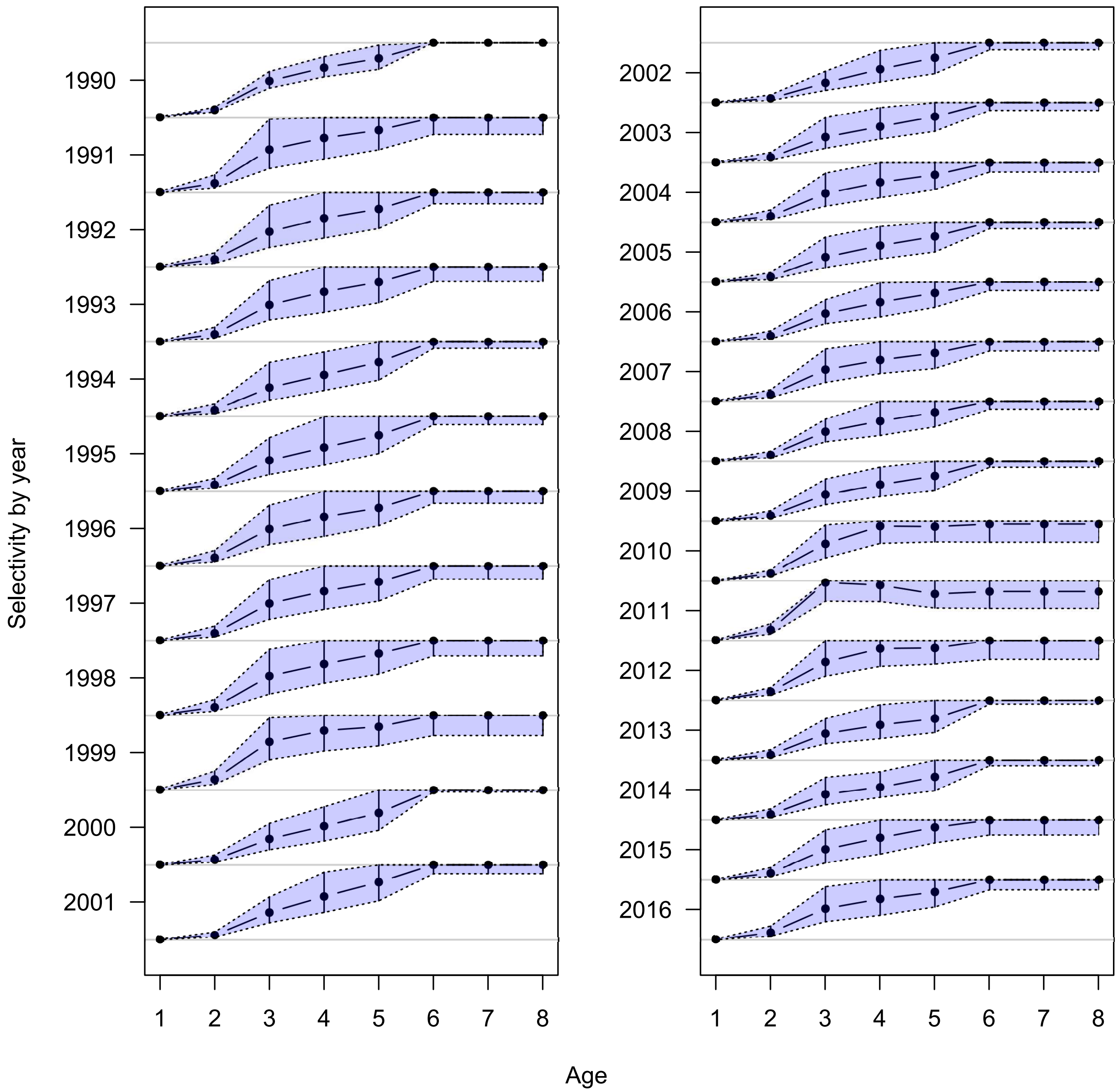


Figure 49. Fishery selectivity sampled from posterior probability distribution by year for the $\phi = 0.03$ sensitivity case. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared for all years from 1966 to 1990. See Figure 26 for the base model.

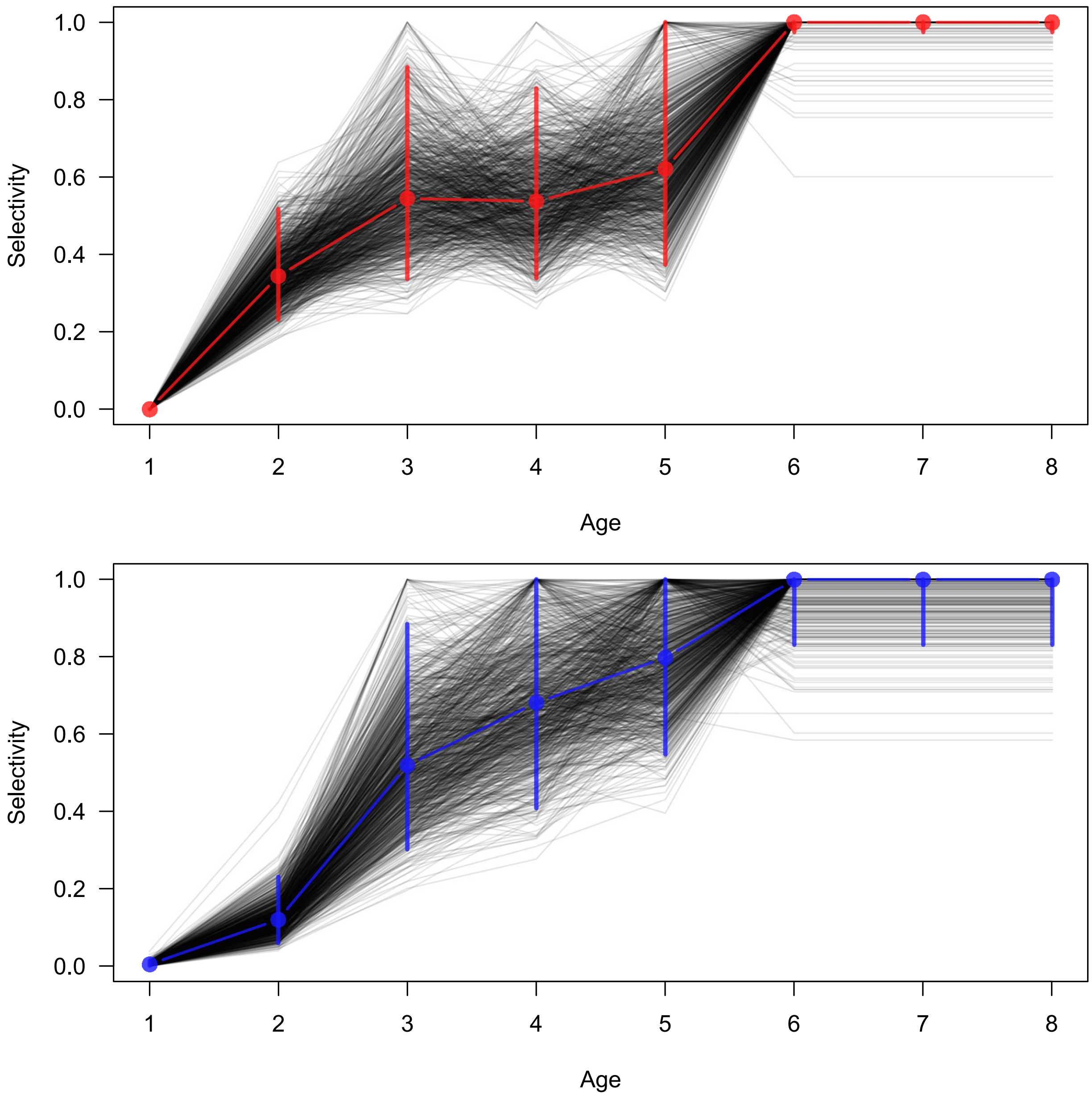


Figure 50. Estimated acoustic (top - for all years) and fishery selectivity (bottom - for 2016 only) ogives from the posterior distribution for the $\phi = 0.03$ sensitivity case. See Figure 27 for the base model.

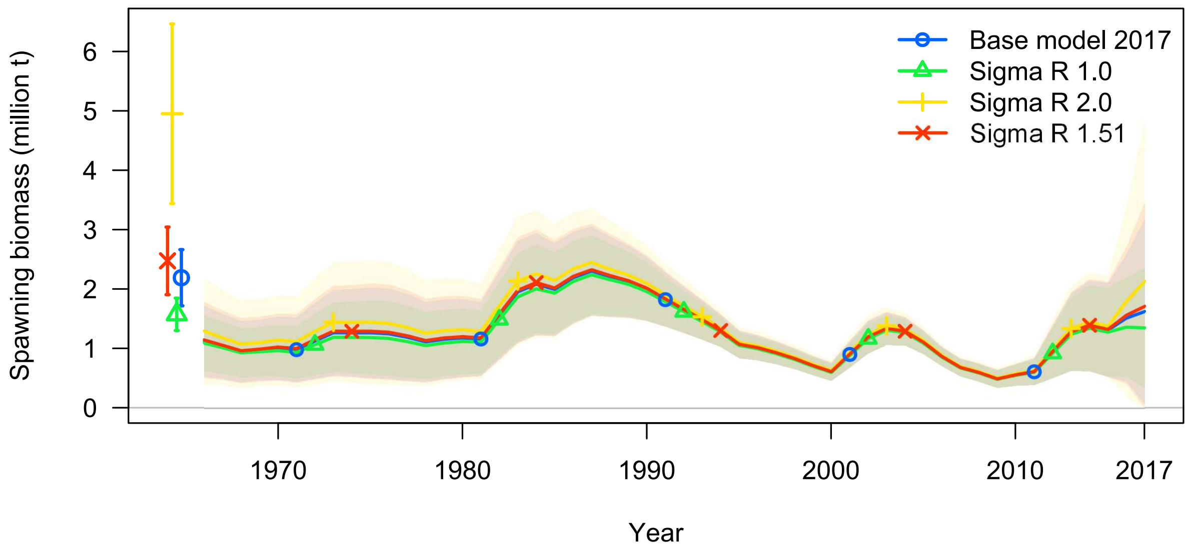


Figure 51. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing changes to the standard deviation of recruitment variability from the base model's σ_r =1.40.

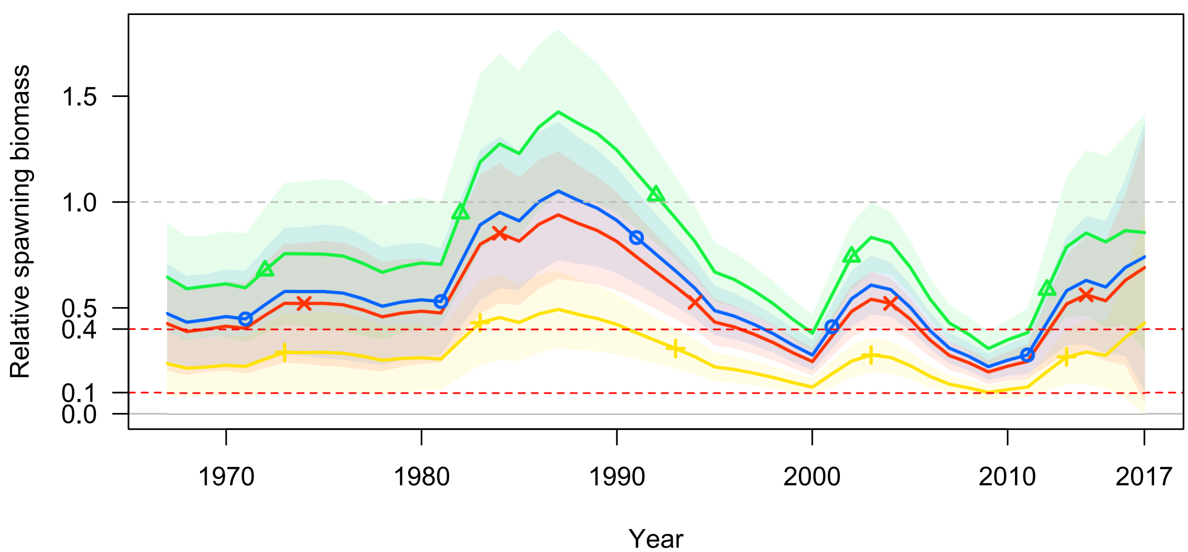


Figure 52. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changes to the standard deviation of recruitment variability from the base model's σ_r =1.40. See Figure 51 for legend.

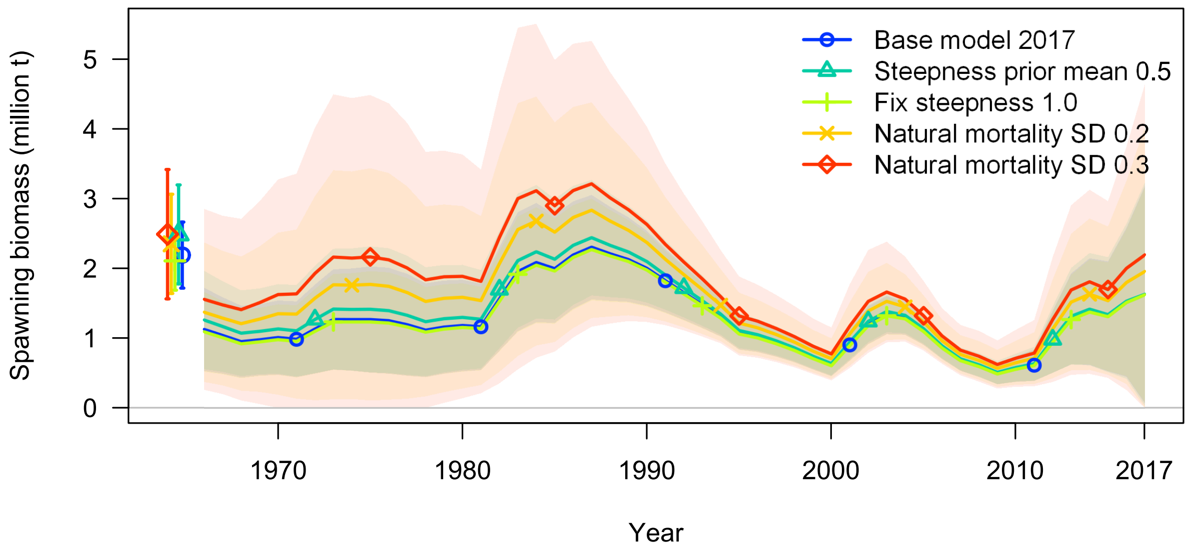


Figure 53. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3.

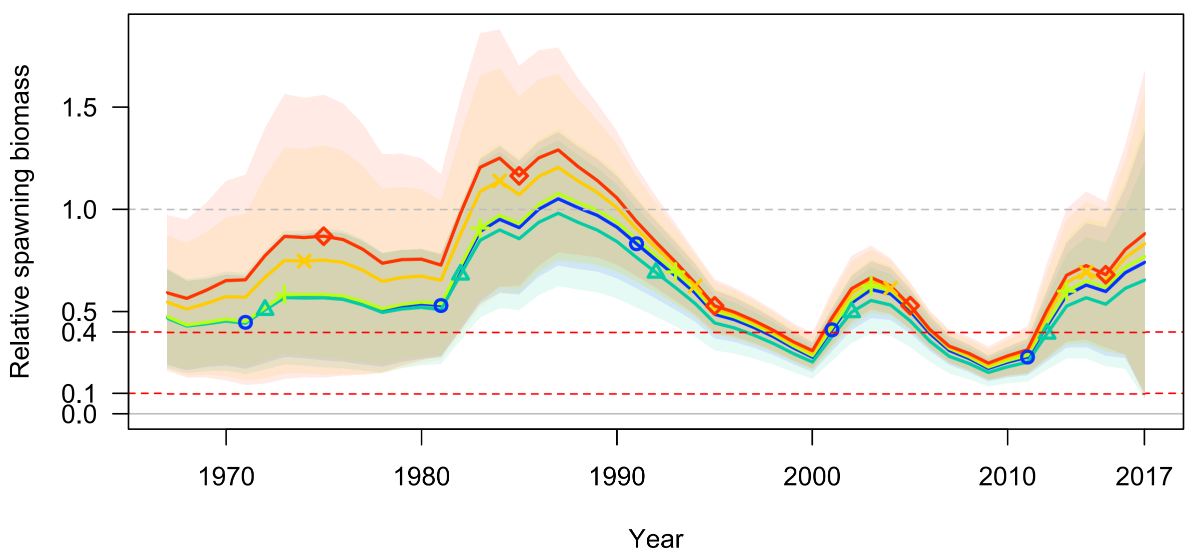


Figure 54. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changing the mean of the prior for steepness from 1.0 to 0.5, fixing steepness at 1.0, and changing the standard deviation of the prior for natural mortality from 0.1 to 0.2 or 0.3. See Figure 53 for legend.

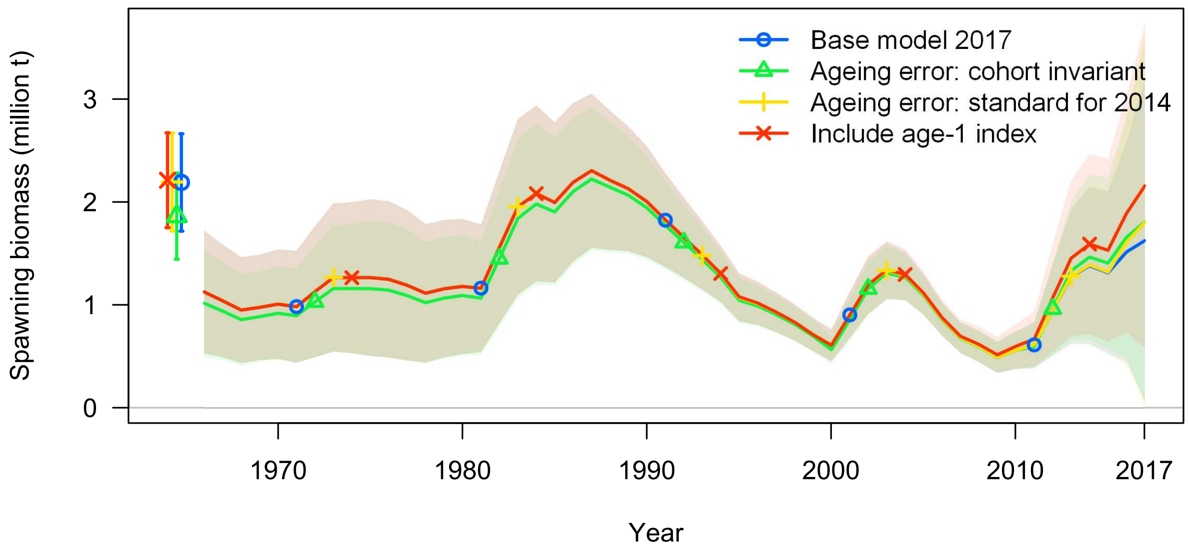


Figure 55. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing time/cohort-invariant ageing error (no downward adjustments for large labelled cohorts), not adjusting the 2014 cohort ageing error downwards (i.e., labelling it a not-very-large cohort at this point) and adding in the age-1 index as a separate data source on recruitment strength.

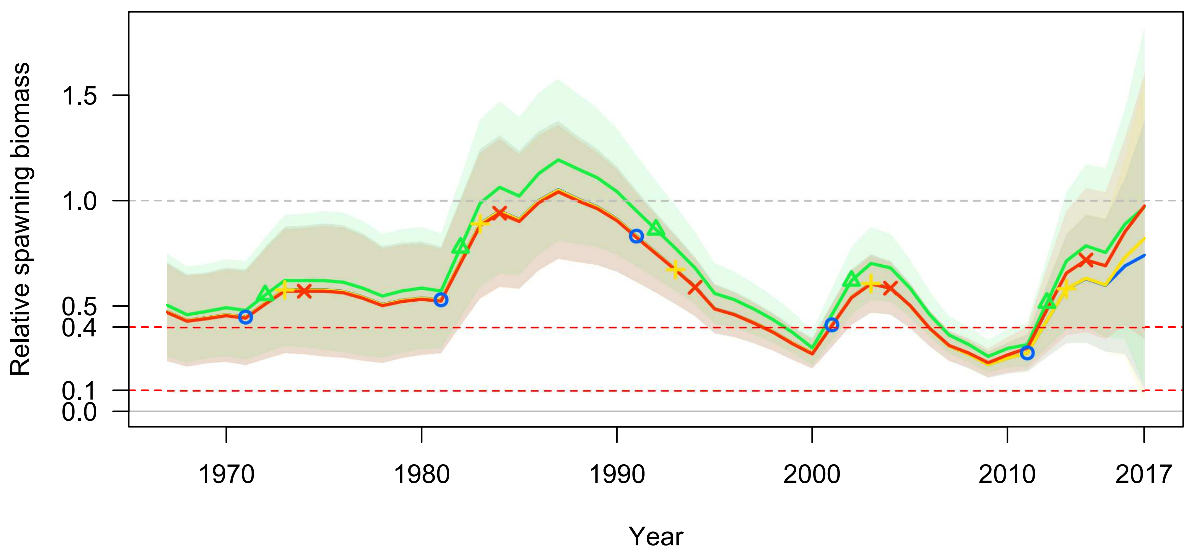


Figure 56. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing time/cohort-invariant ageing error (no downward adjustments for large labelled cohorts), not adjusting the 2014 cohort ageing error downwards (i.e., labelling it a not-very-large cohort at this point) and adding in the age-1 index as a separate data source on recruitment strength. See Figure 55 for legend.

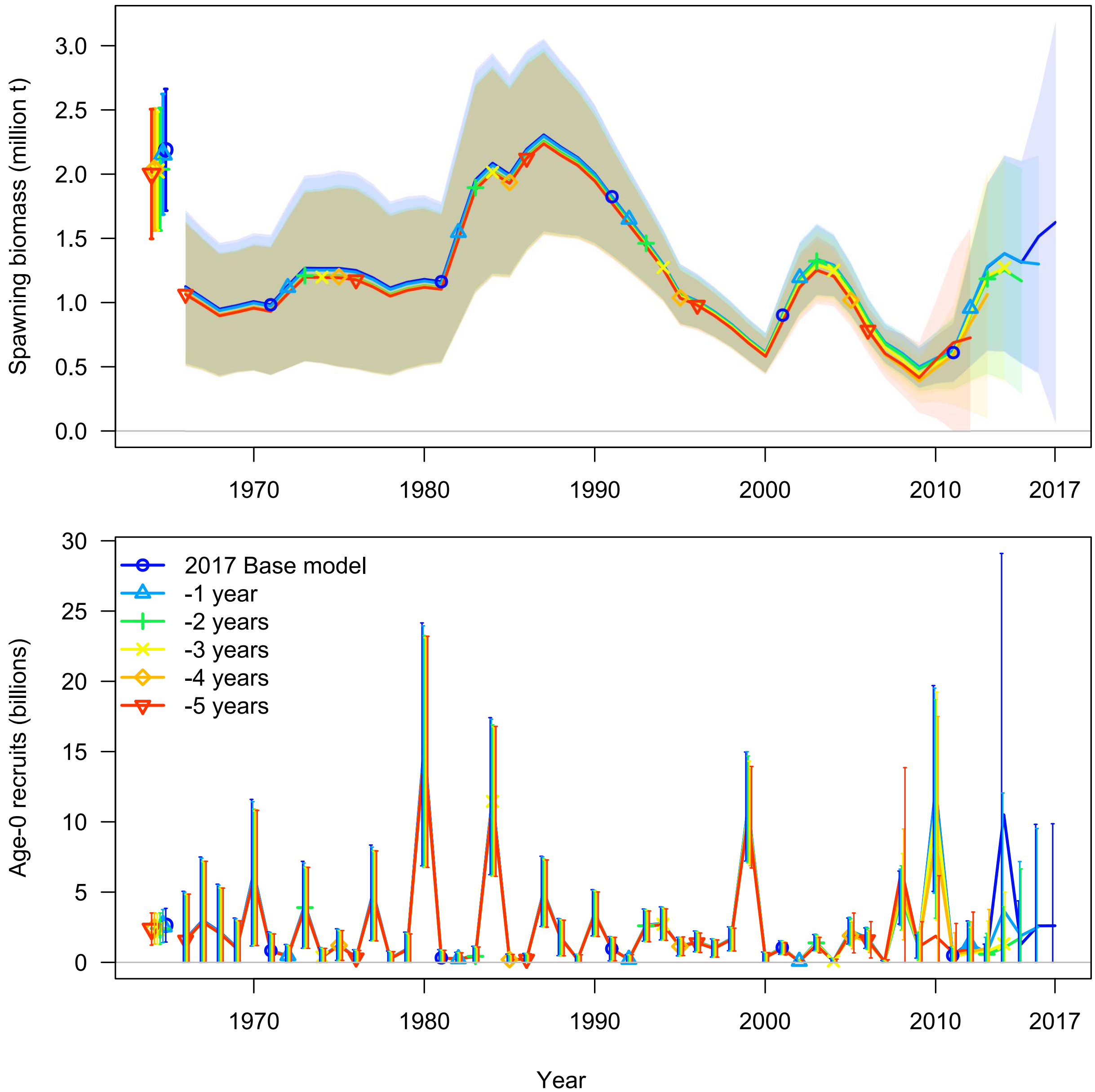


Figure 57. Estimates of spawning biomass at the start of each year (top) and recruitment (bottom) for the base model and retrospective runs (based on MLE model runs).

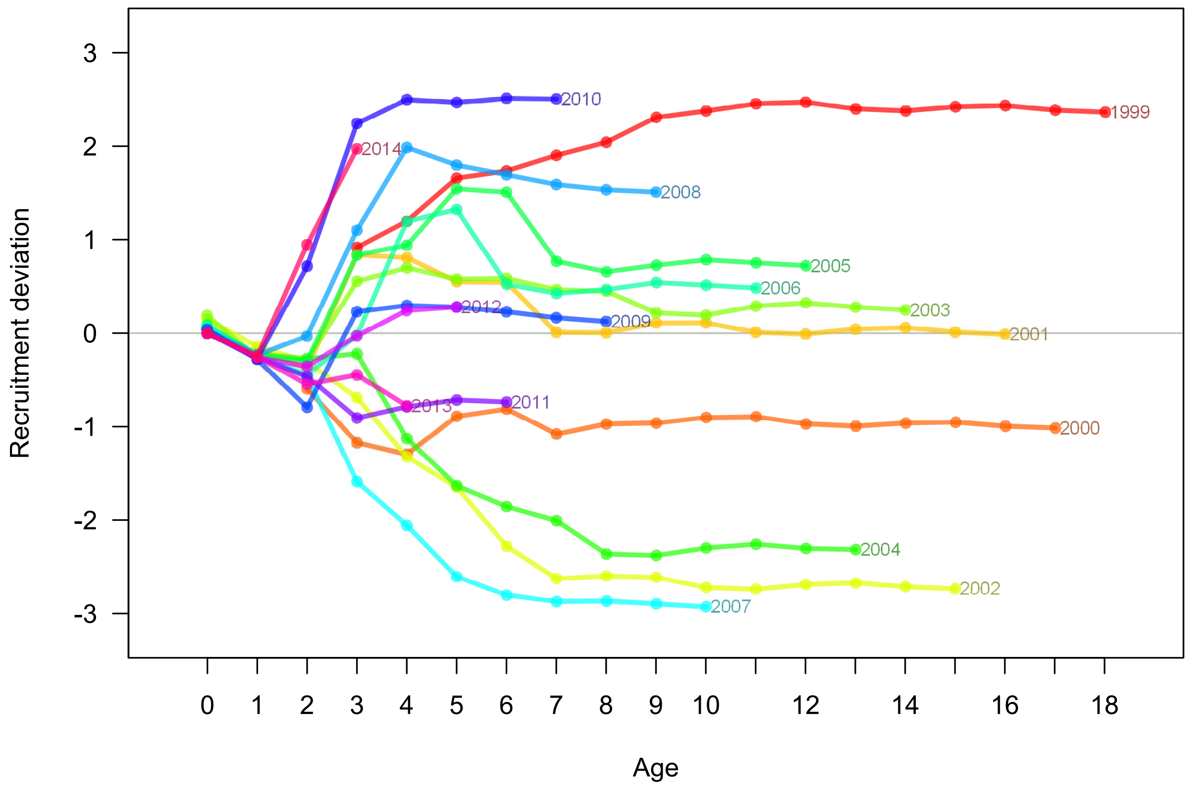


Figure 58. Retrospective analysis of recruitment deviations from maximum likelihood estimate (MLE) models over the last 16 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent estimated recruitment deviations for cohorts from 1999 to 2014, with cohort birth year marked at the right of each color-coded line. Values are estimated by models using data available only up to the year in which each cohort was a given age.

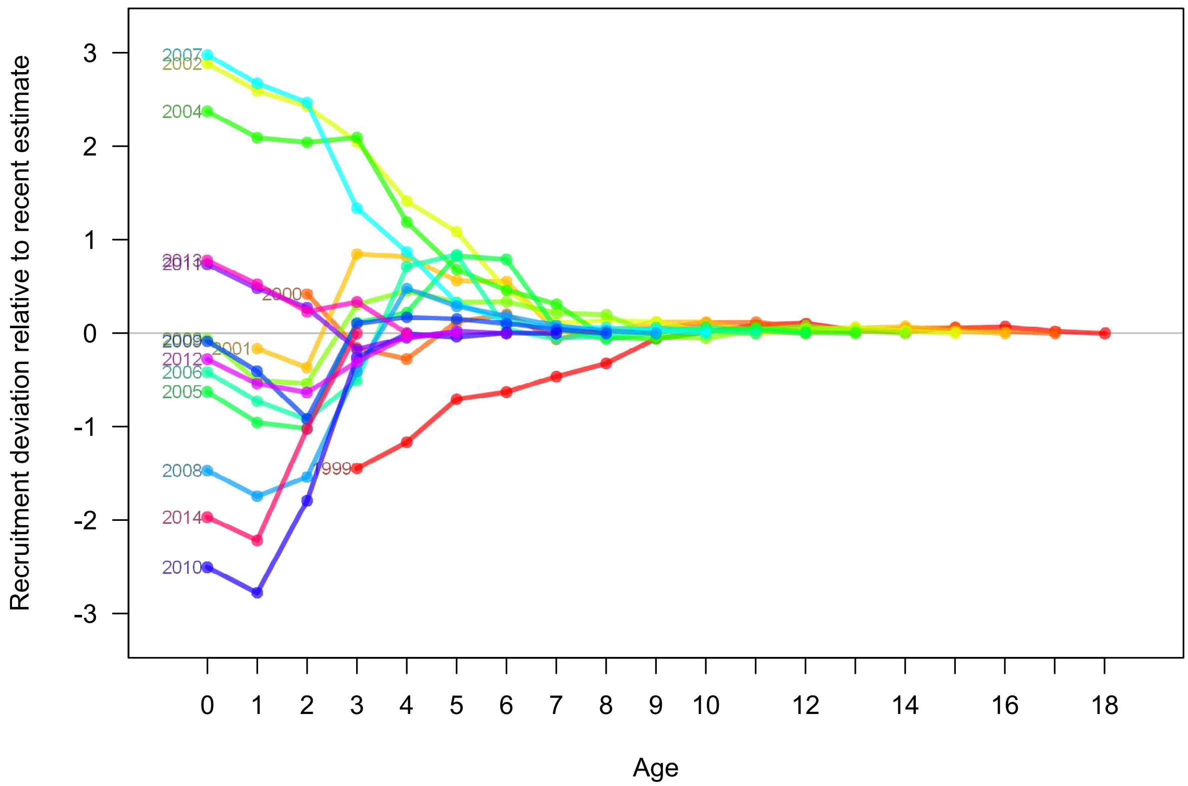


Figure 59. Retrospective recruitment estimates shown in Figure 58 scaled relative to the most recent estimate of the strength of each cohort.

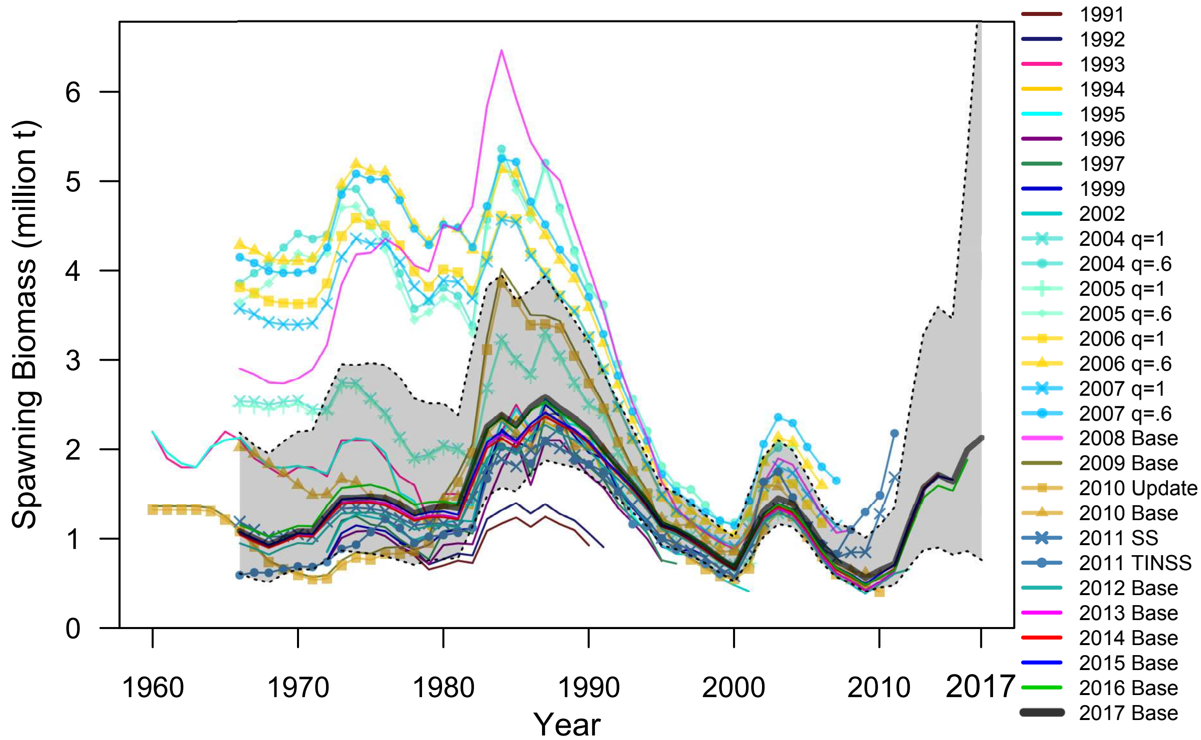


Figure 60. Summary of historical Pacific Hake assessment estimates of spawning biomass. Shading represents the approximate 95% confidence range from the 2017 base model.

A SCIENTIFIC REVIEW GROUP (SRG) REQUESTS

The SRG meeting took place on Feb 13-16, 2017 in Vancouver, B.C., Canada. The group had several requests for further model sensitivities, model convergence diagnostics, and data summary tables which are addressed here.

1. Conduct sensitivity analysis to the standard deviation associated with time-varying selectivity (phi) across a range of standard deviation values while including the age-1 index. The reason for this inclusion is that the age-1 index provides the only data-driven piece of information on cohort size currently available. Sensitivity runs were conducted and are shown in Figures A.1 and A.2.

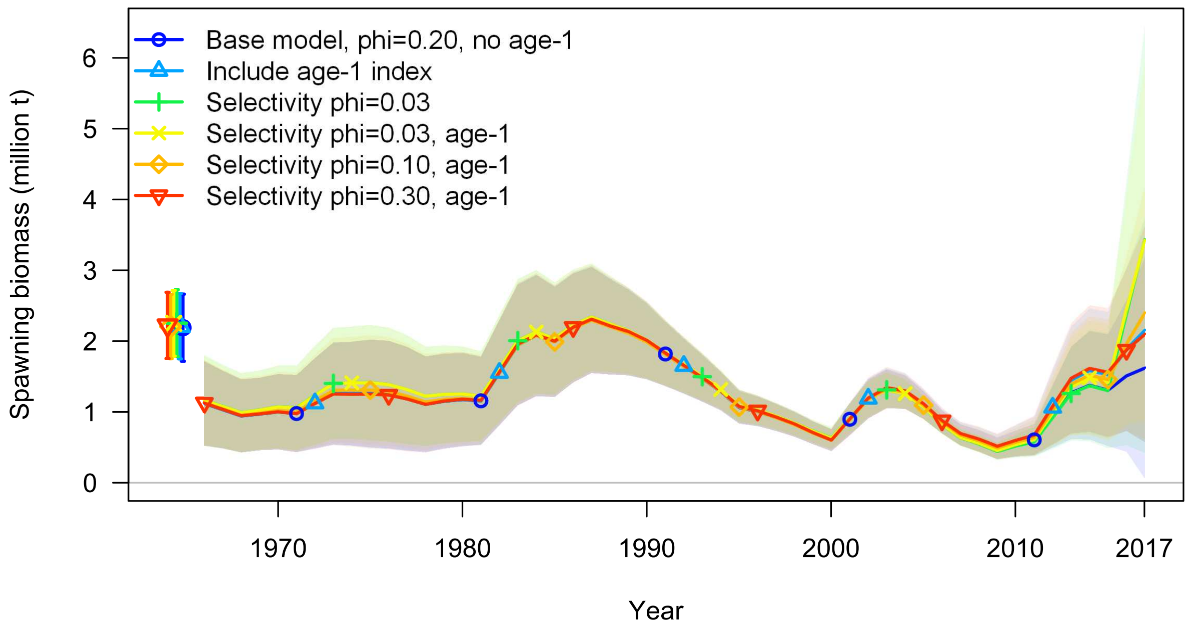
2. Conduct sensitivity analysis that includes deviations on selectivity parameters from 1991-2008 using a standard deviation value of 0.03 and 0.20 for 2009-2016. Sensitivity runs were conducted and are shown in Figures A.3 and A.5. For comparison, Figure A.4 shows the selectivity from a previous sensitivity run.

3. Conduct sensitivity analysis that includes deviations on selectivity parameters from 1991-2015 using a standard deviation value of 0.03 and 0.20 for 2016. Sensitivity runs were conducted and are shown in Figures A.3 and A.6.

4. Run the base model with a MCMC chain of 24,000,000. This request was made to run the MCMC chain out to a length double that of the presented model in an attempt to identify any improvement in the diagnostics of the chain. The resulting diagnostics are shown in Figures A.7-A.12, and are comparable to similar figures in the main document.

5. Prepare a table of exploitation rate by age and year for inclusion in the final assessment document going to the JMC. The requested values are shown in Table 22.

6. Prepare a table for the major cohorts of catch weight, natural mortality weight and surviving weight by age for inclusion in the final assessment document going to the JMC. Calculations for each age and year are shown for biomass (Table 21), exploitation rate (Table 22), catch numbers (Table 23) and catch weight (Table 24). The resulting requested values (including natural mortality) for the main cohorts are are shown in Table 25.



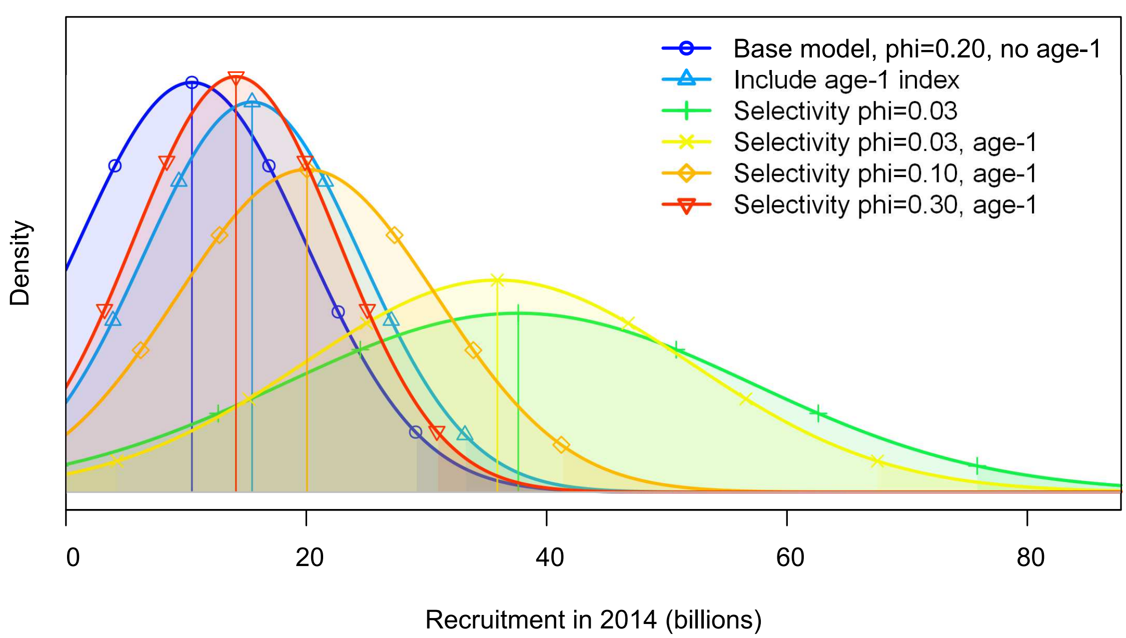
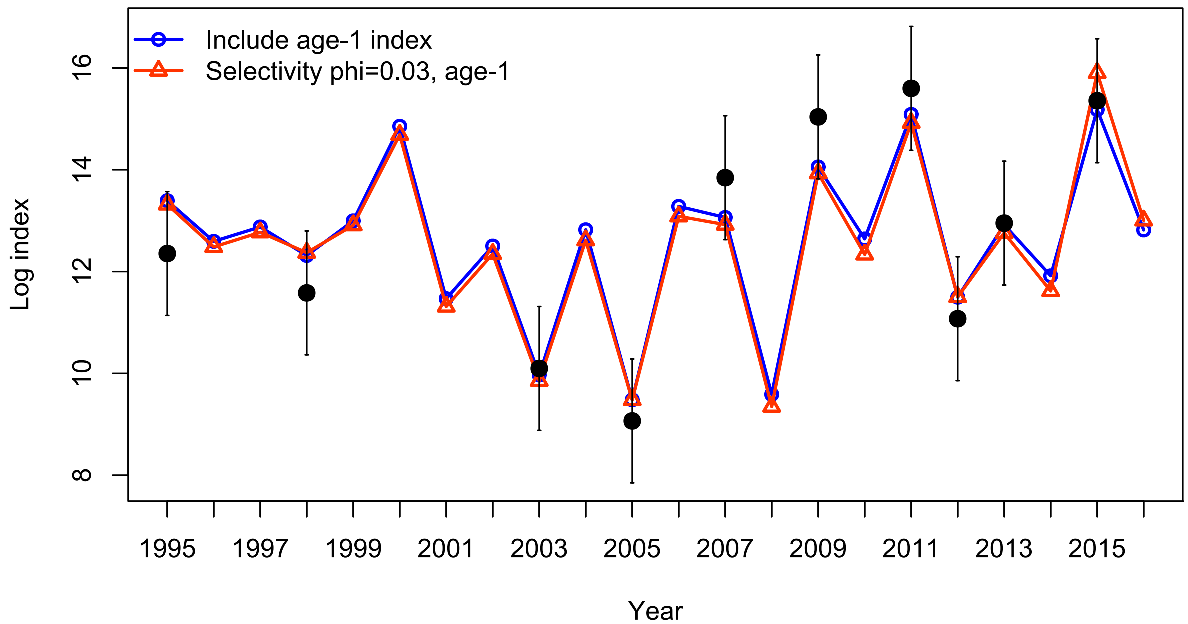


Figure A.1. Sensitivity to the standard deviation associated with time-varying selectivity (phi) across a range of standard deviation values while including the age-1 index.



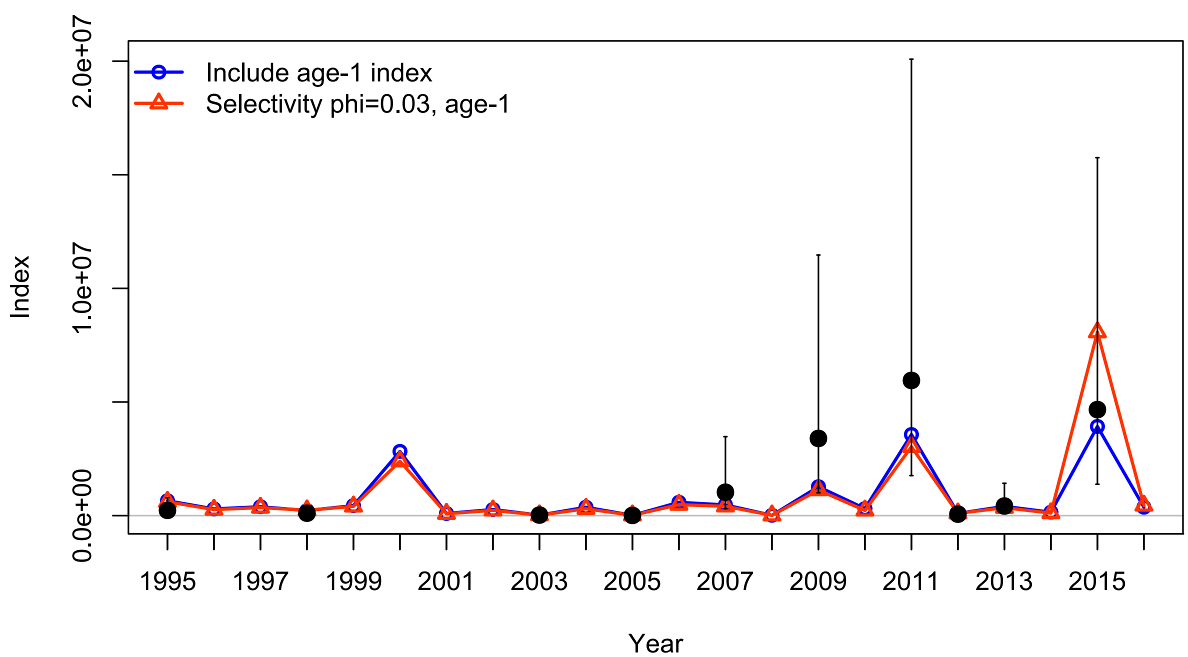


Figure A.2. Sensitivity to including the age-1 index when the standard deviation associated with time-varying selectivity (phi) is 0.03 or 0.20 as in the base model.

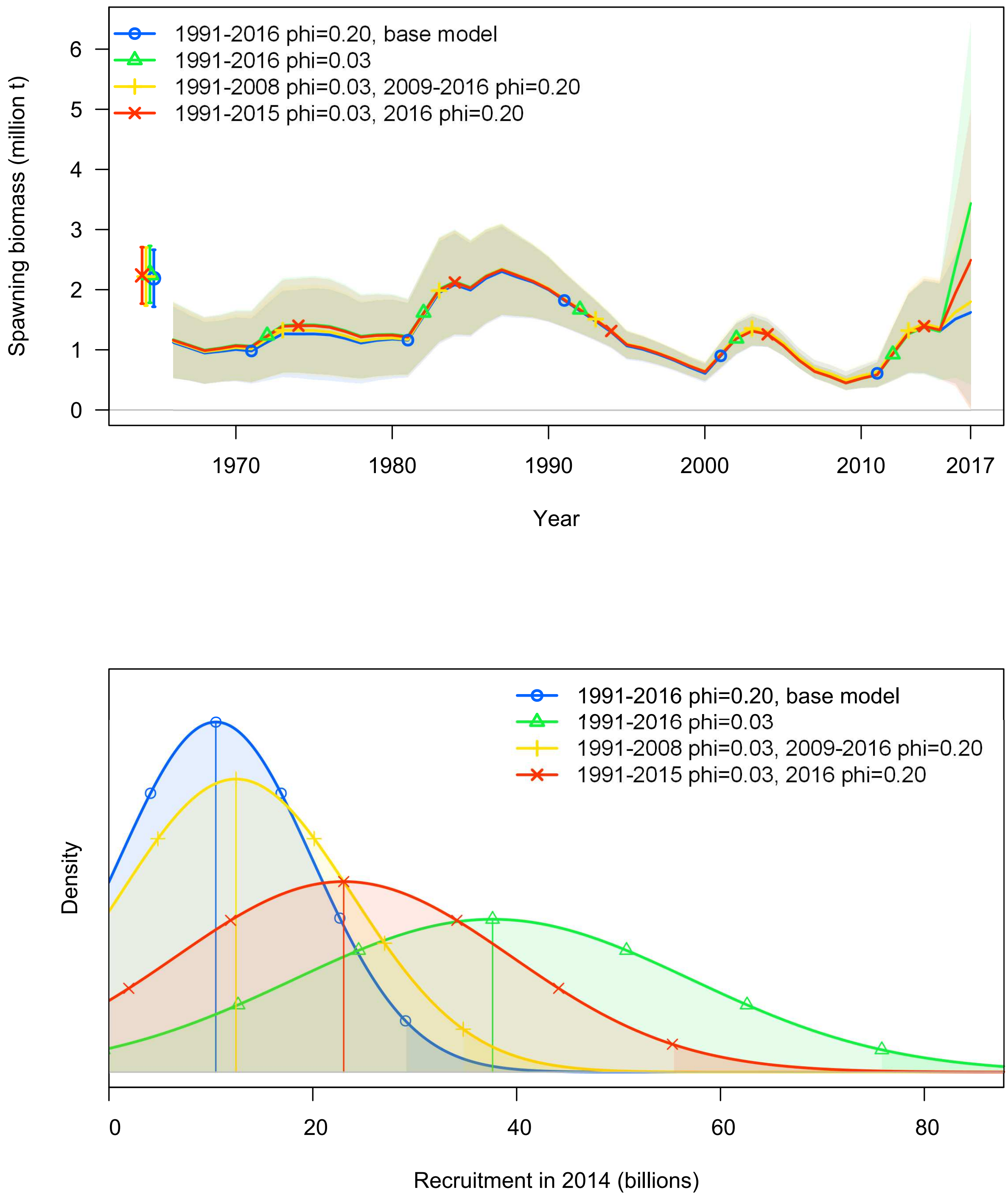


Figure A.3. Sensitivity analysis that includes deviations on selectivity parameters of 0.03 and 0.20 across different time periods as specified in the legend.

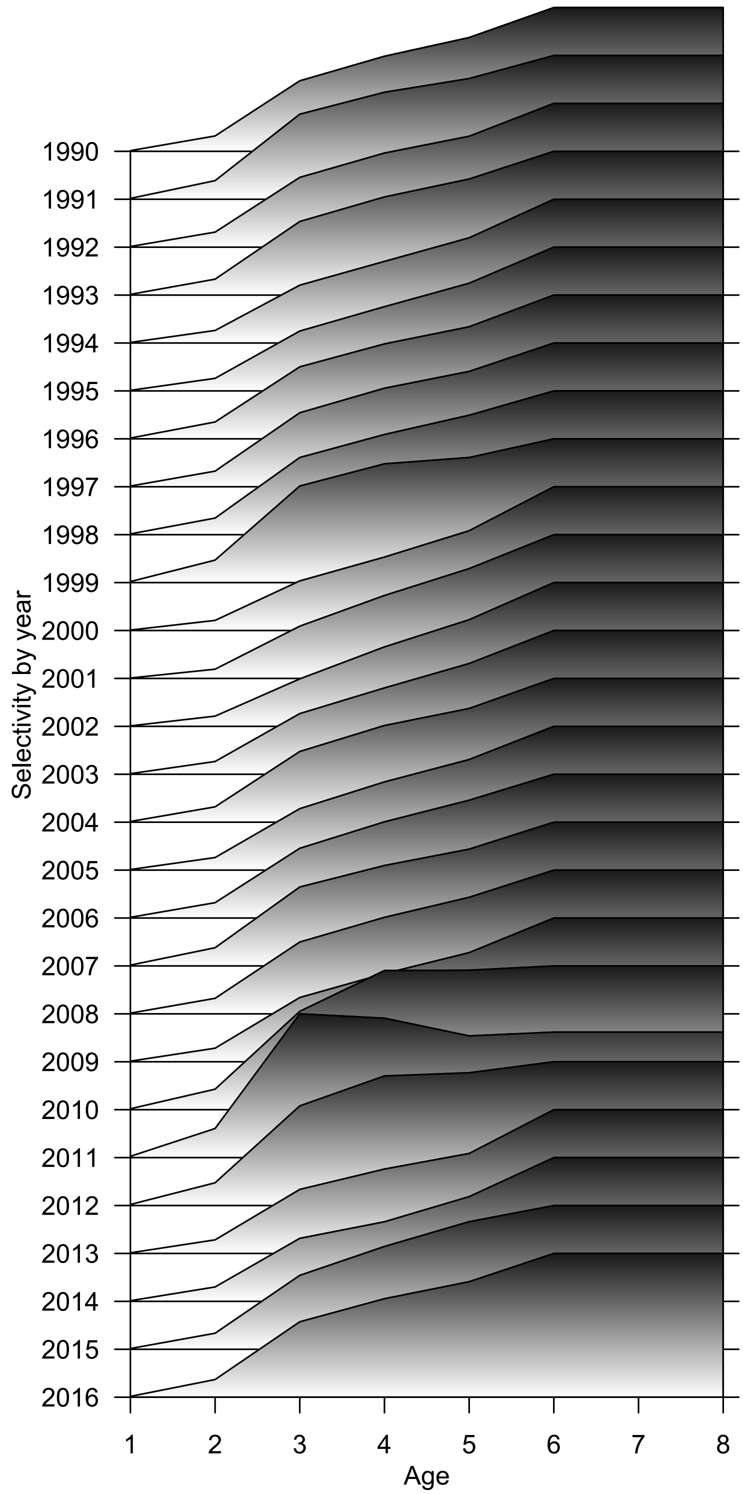


Figure A.4. Mountains plot of median fishery selectivity in recent years using deviations on selectivity parameters of 0.03 for all years.

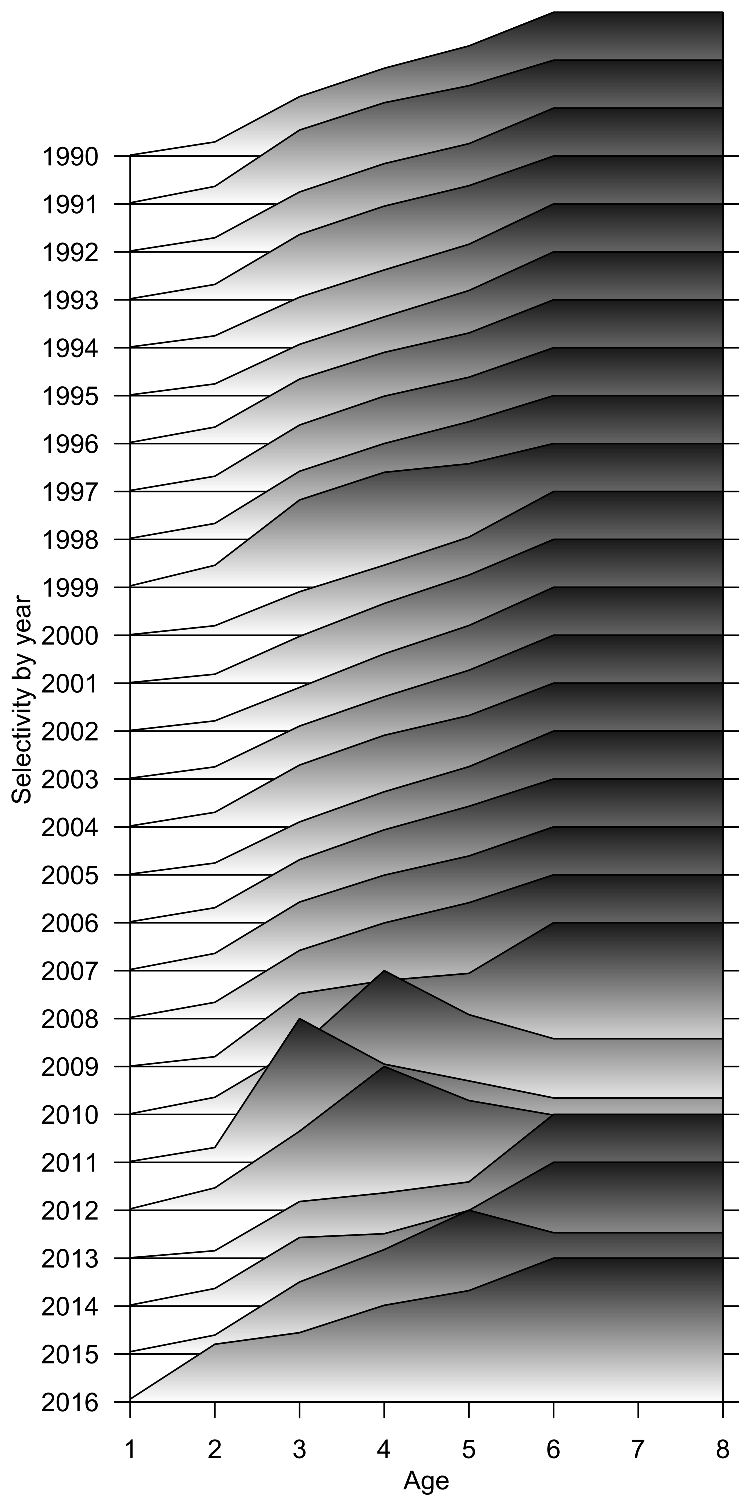


Figure A.5. Mountains plot of median fishery selectivity in recent years using deviations on selectivity parameters of 0.03 up to 2008 and 0.20 for 2009–2016.

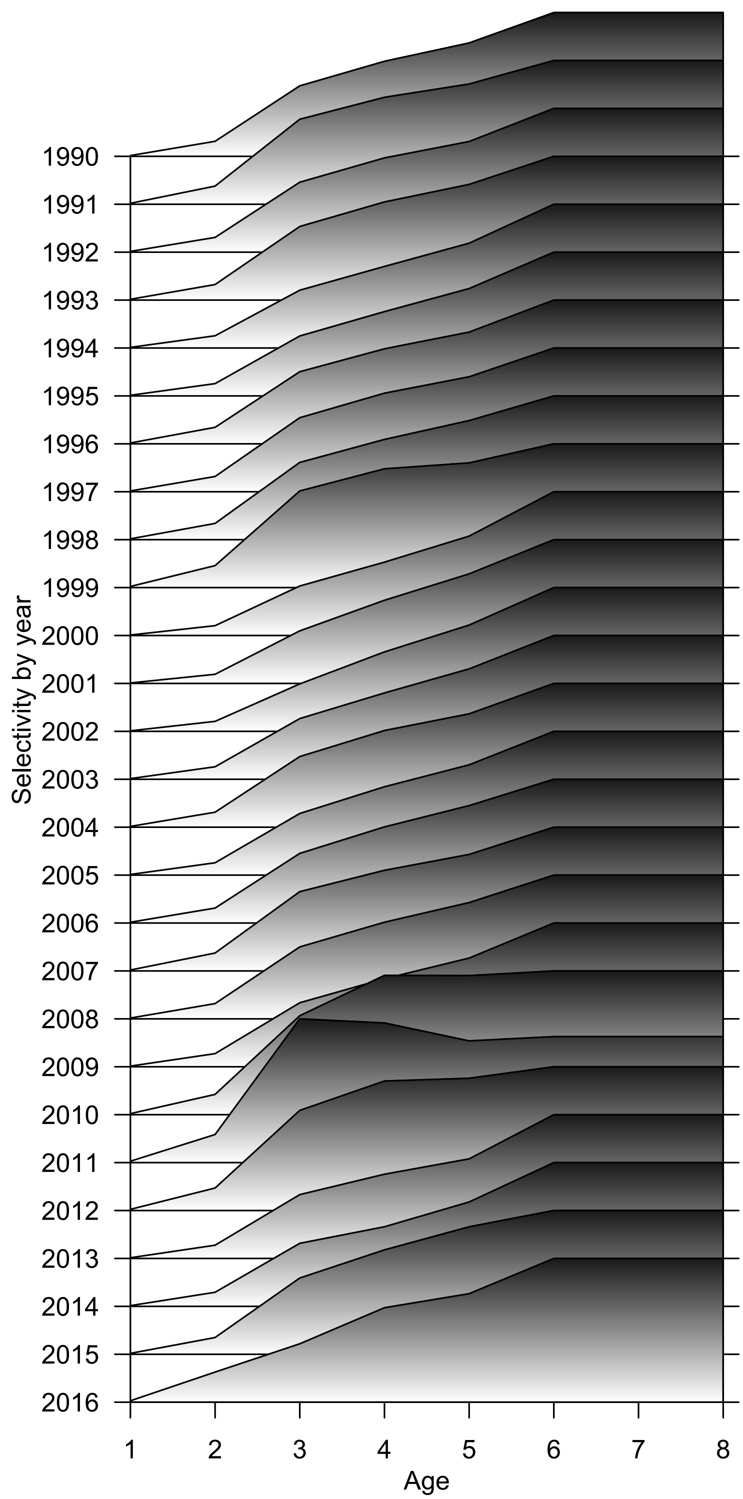


Figure A.6. Mountains plot of median fishery selectivity in recent years using deviations on selectivity parameters of 0.03 up to 2015 and 0.20 for 2016.

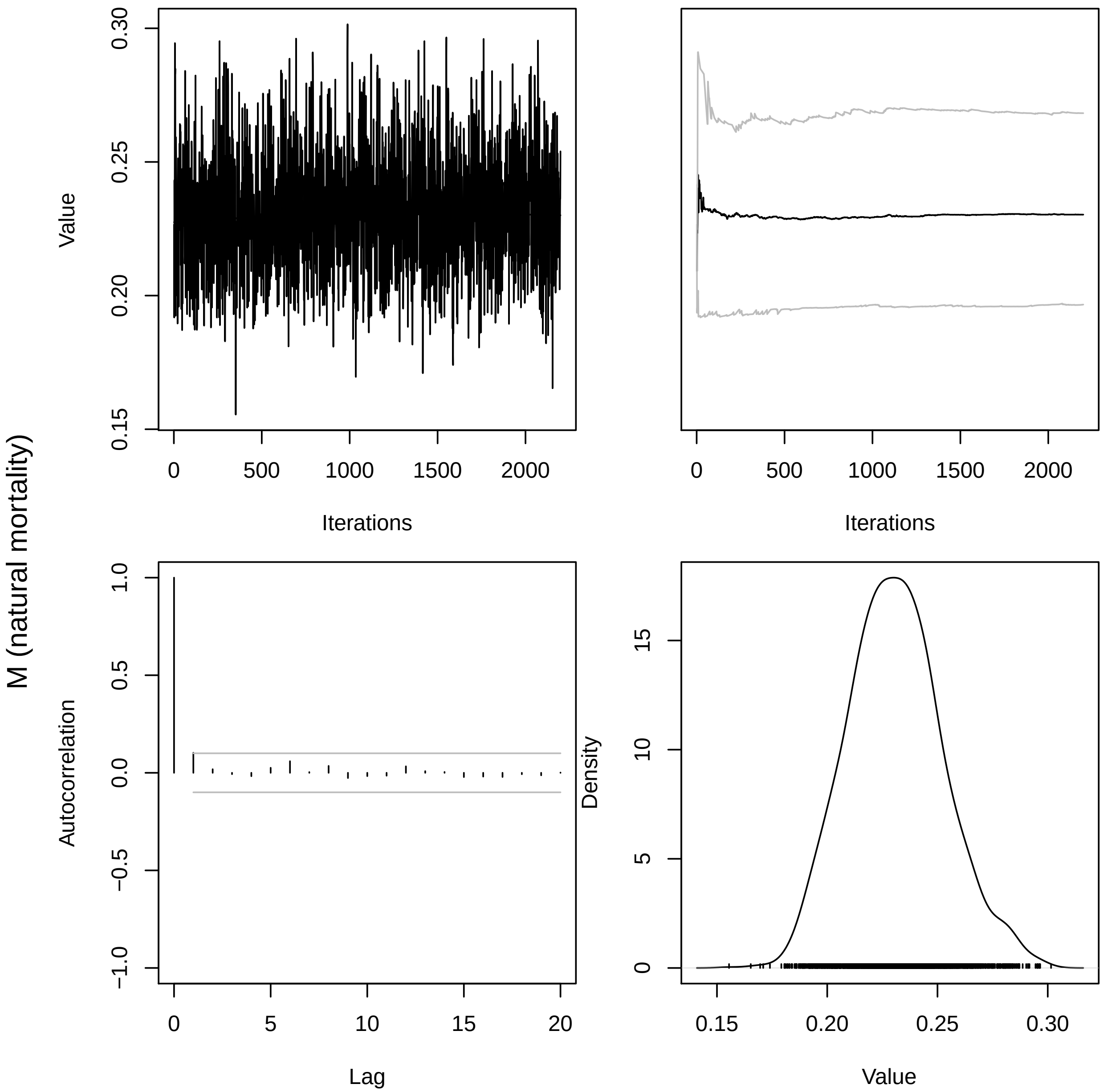


Figure A.7. MCMC diagnostics for the natural mortality parameter for a chain length of 24,000,000 and 1,998 samples. Figure 16 shows the same plot for the base model with a chain length of 12,000,000 and 999 samples.

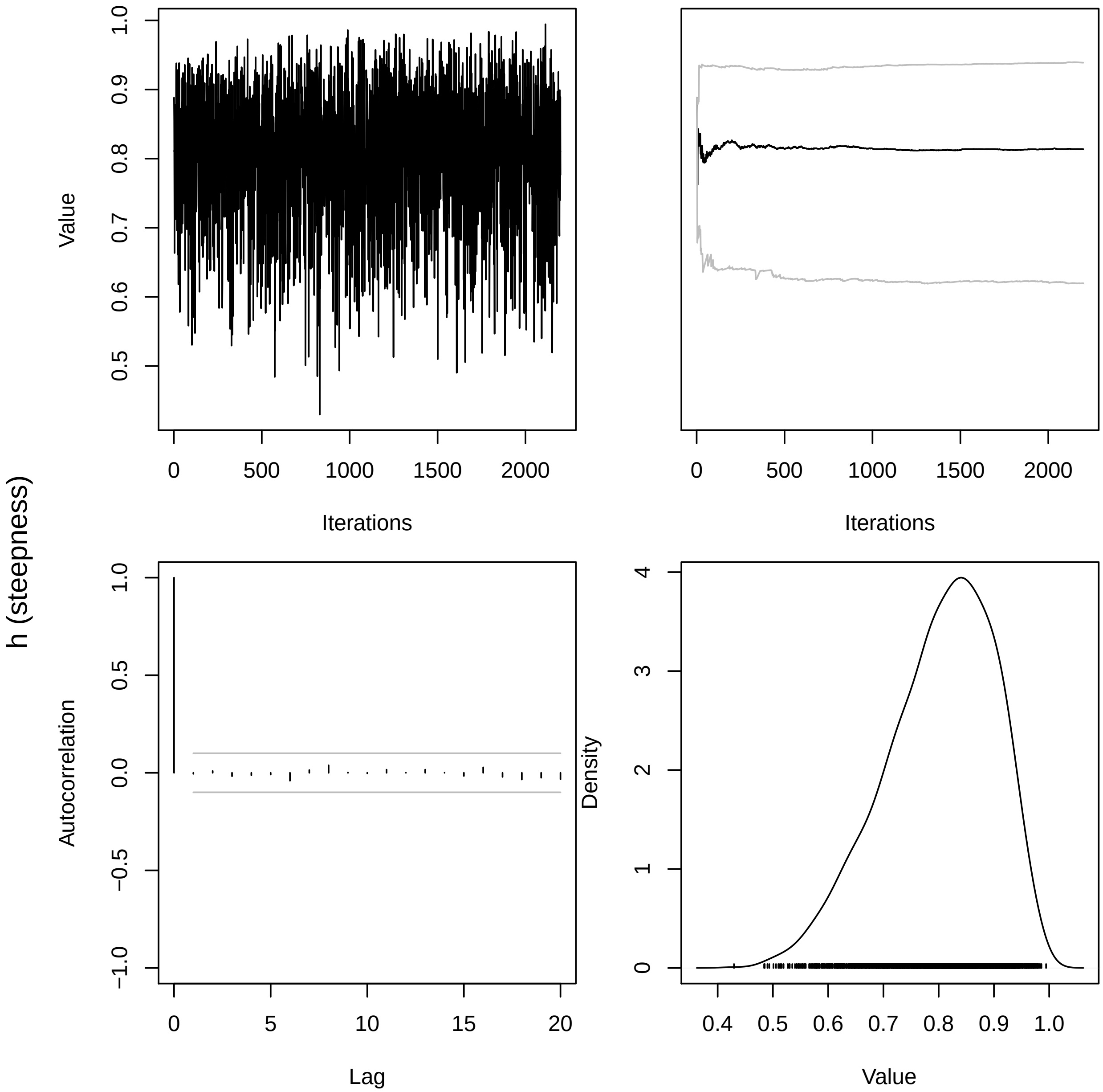


Figure A.8. MCMC diagnostics for the steepness parameter for a chain length of 24,000,000 and 1,998 samples. Figure 17 shows the same plot for the base model with a chain length of 12,000,000 and 999 samples.

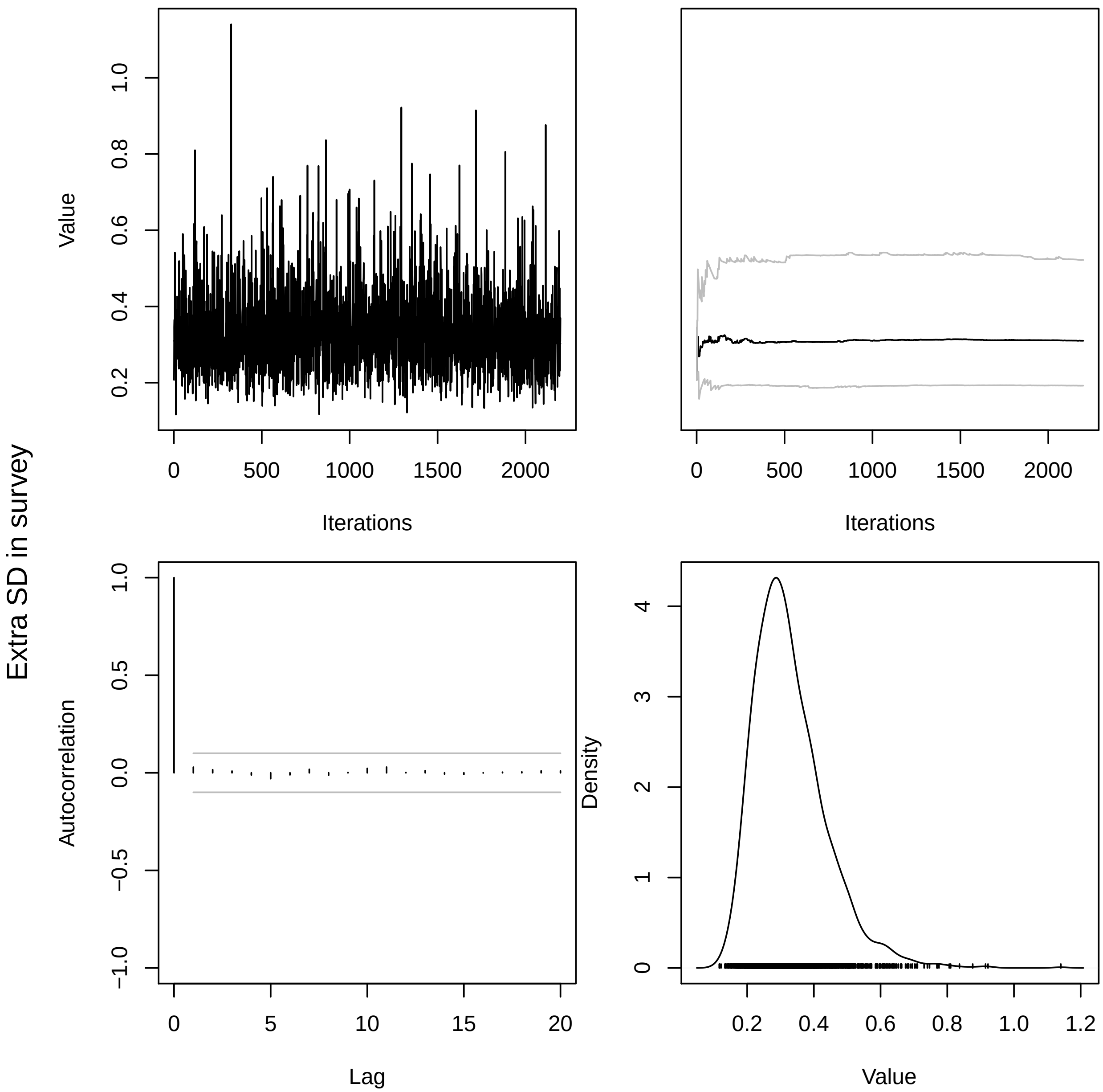


Figure A.9. MCMC diagnostics for the additional standard deviation (SD) in the survey index for a chain length of 24,000,000 and 1,998 samples. Figure 17 shows the same plot for the base model with a chain length of 12,000,000 and 999 samples.

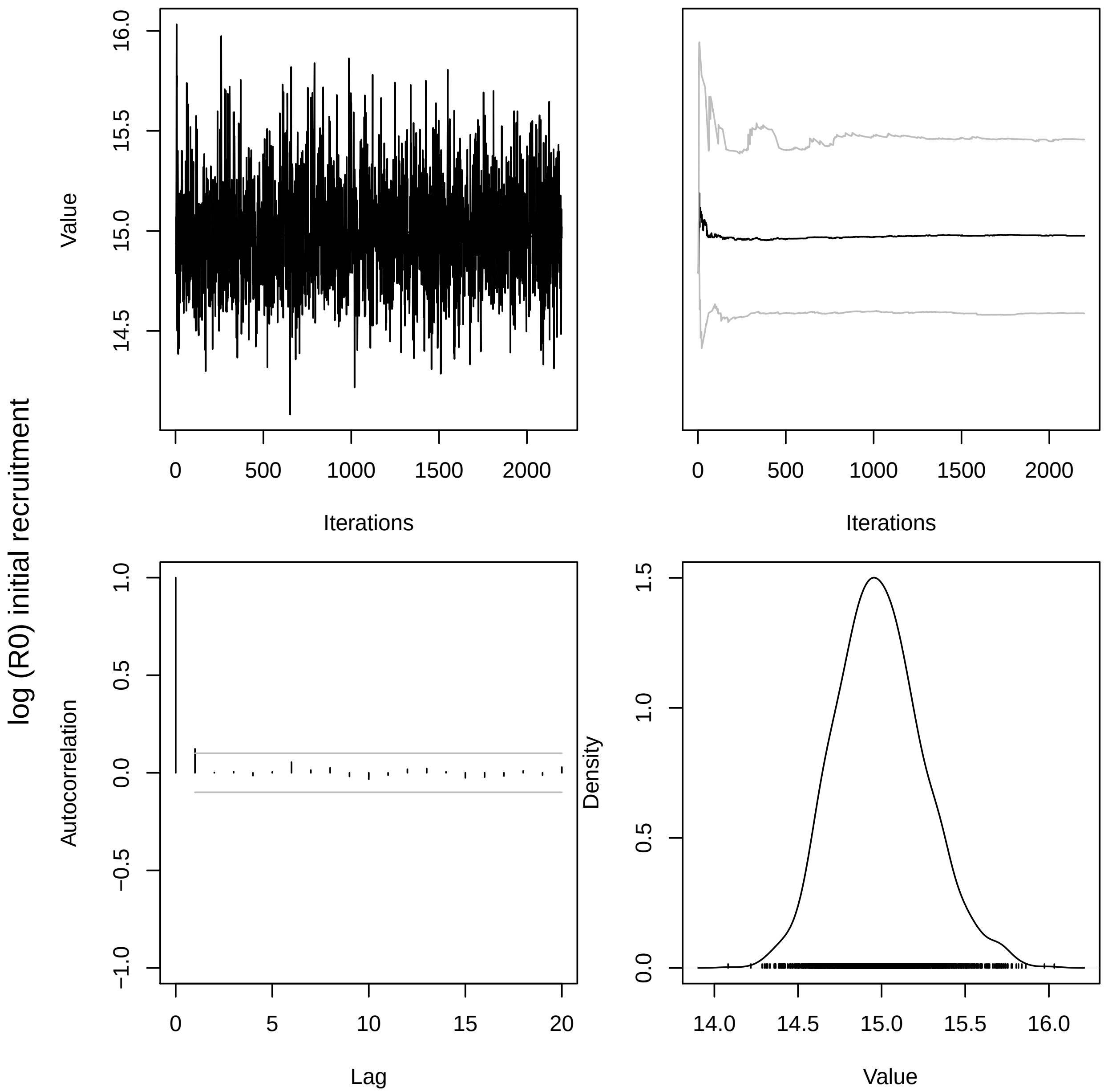


Figure A.10. MCMC diagnostics for the initial recruitment parameter for a chain length of 24,000,000 and 1,998 samples. Figure 16 shows the same plot for the base model with a chain length of 12,000,000 and 999 samples.

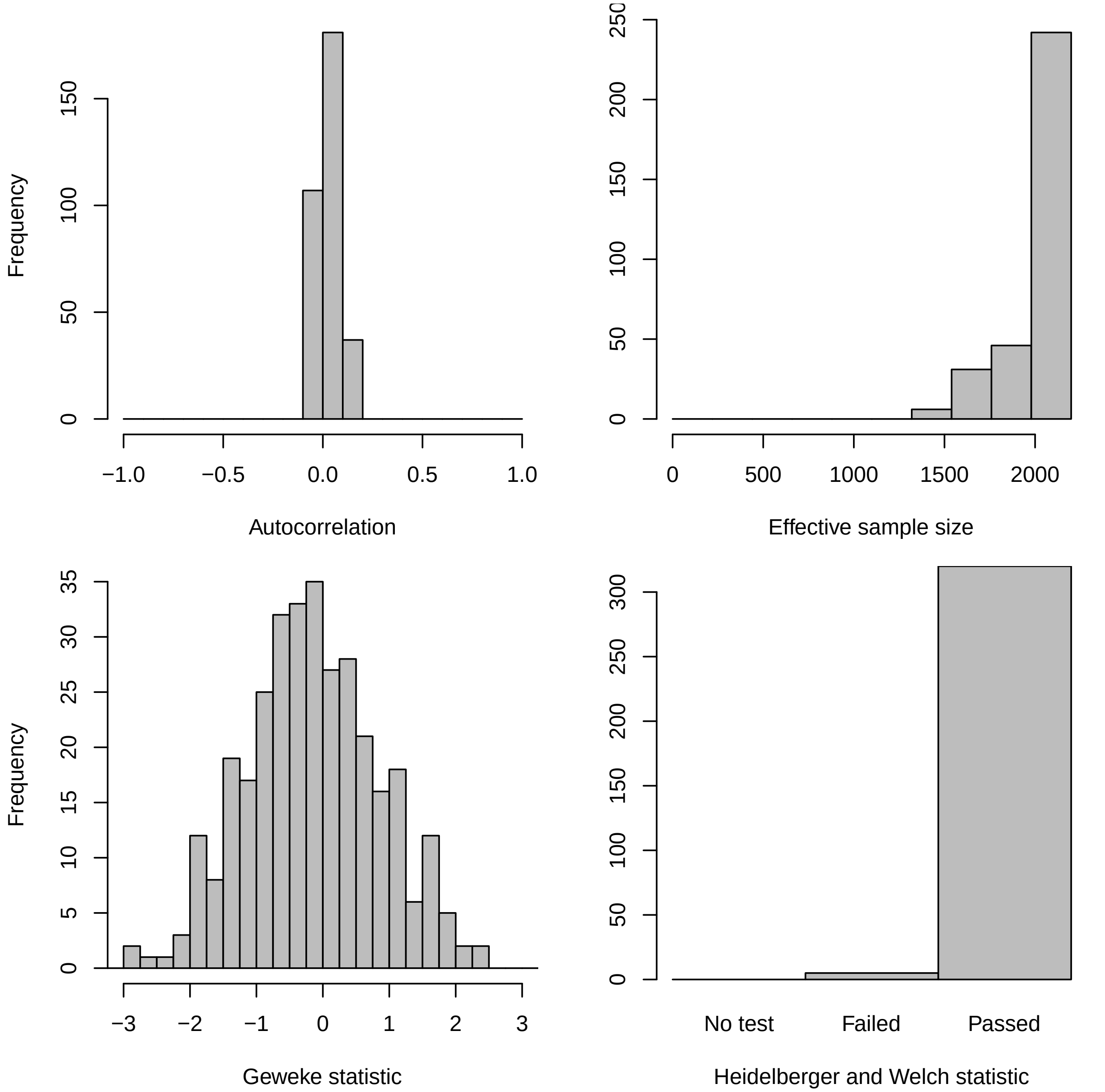


Figure A.11. Summary histograms of MCMC diagnostics for all base model parameters together with the derived time series of spawning biomass and relative spawning biomass. This is for a chain length of 24,000,000 with 1,998 samples; Figure 18 shows the same plot for the base model with a chain length of 12,000,000 and 999 samples.

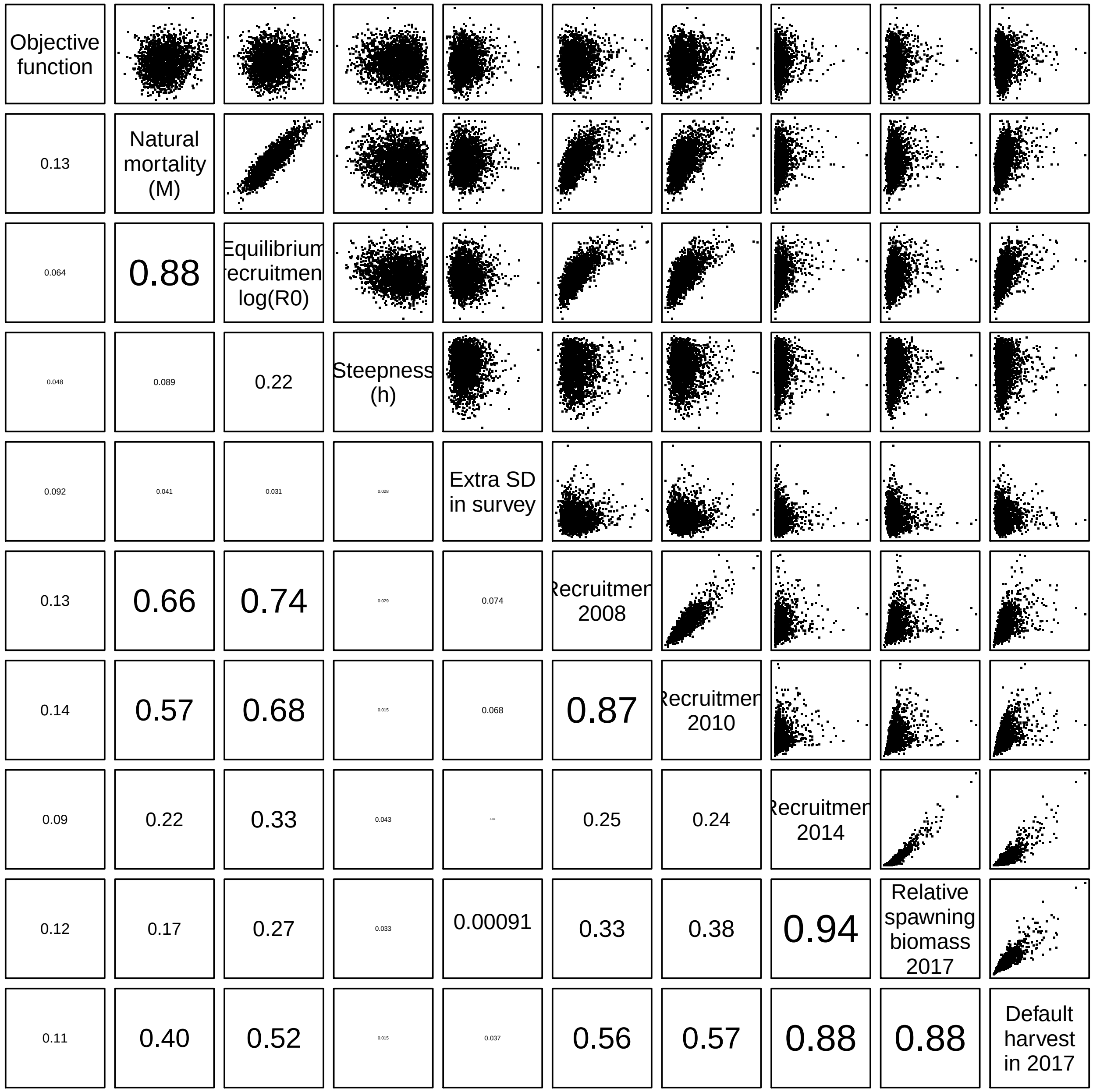


Figure A.12. Posterior correlations among key base-model parameters and derived quantities for a chain length of 24,000,000. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient. Figure 19 shows the same plot for the base model with a chain length of 12,000,000.

B GLOSSARY OF TERMS AND ACRONYMS USED IN THIS DOCUMENT

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

ABC: Acceptable biological catch. See below.

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

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

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

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

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

B_0: The unfished equilibrium female spawning biomass.

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

$B_{40\%}$: The level of female spawning biomass corresponding to 40% of unfished equilibrium female spawning biomass, i.e. $B_{40\%} = 0.4B_0$. This is the level below which the calculated TAC is decreased from the value associated with $F_{\text{SPR}=40\%}$, 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/whiting resource.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MLE: Maximum likelihood estimate (see above).

MSE: Management Strategy Evaluation (see above).

MSY: Maximum sustainable yield (see above).

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

NA: Not available.

National Marine Fisheries Service: See NOAA Fisheries below.

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

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

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

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

Operating Model (OM): A model used to simulate data for use in the MSE (see above). The operating model includes components for the stock and fishery dynamics, as well as the simulation of the data sampling process, potentially including observation error. Cases in the MSE represent alternative configurations of the operating model.

OM: Operating Model (see above).

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

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

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

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

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

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

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

q: Catchability (see above).

R_0: Estimated annual recruitment at unfished equilibrium.

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

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

Relative fishing intensity: See definition of fishing intensity.

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

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

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

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

Simulation: A model evaluation under a particular state of nature, including combinations of parameters controlling stock productivity, stock status, and the time series of recruitment deviations. In this assessment, there are 999 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 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

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

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

SPR: Spawning potential ratio (see above).

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

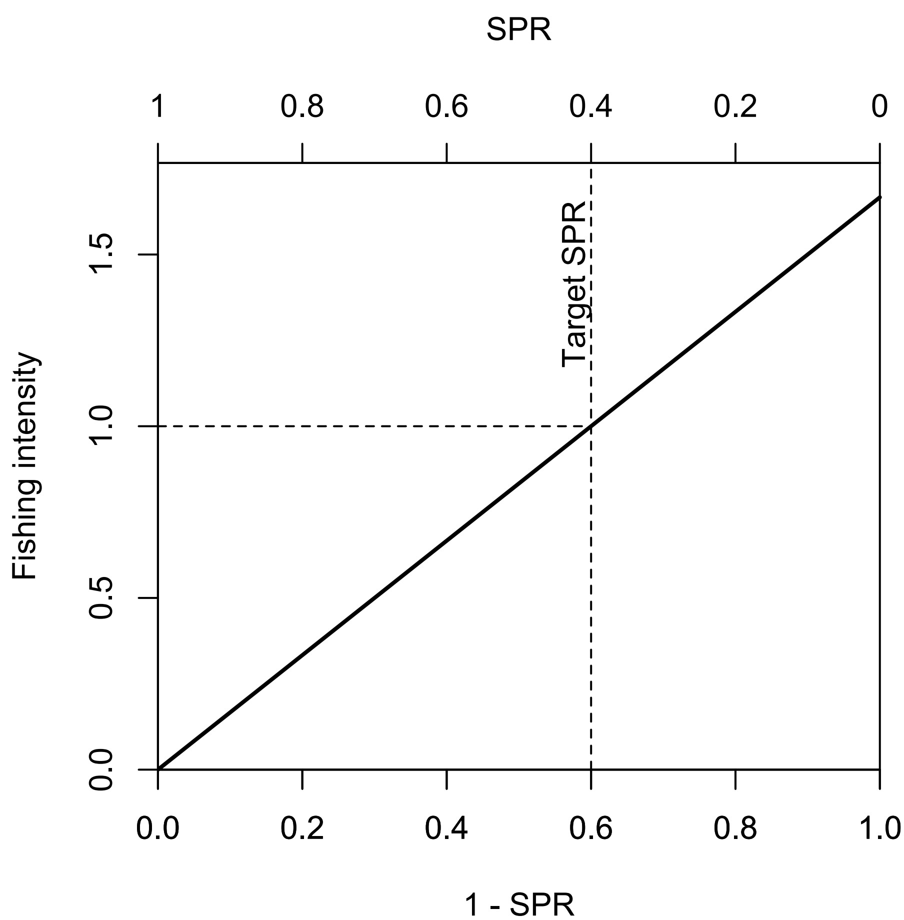


Figure B.1. Fishing intensity as a function of SPR (top axis) and 1-SPR (bottom axis); given the target SPR of 40%, the bold line is simply $1/0.6$, as shown in equation (B.5).

depends on the spawning biomass *per recruit*.

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

TAC: Total allowable catch (see below).

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

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

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

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

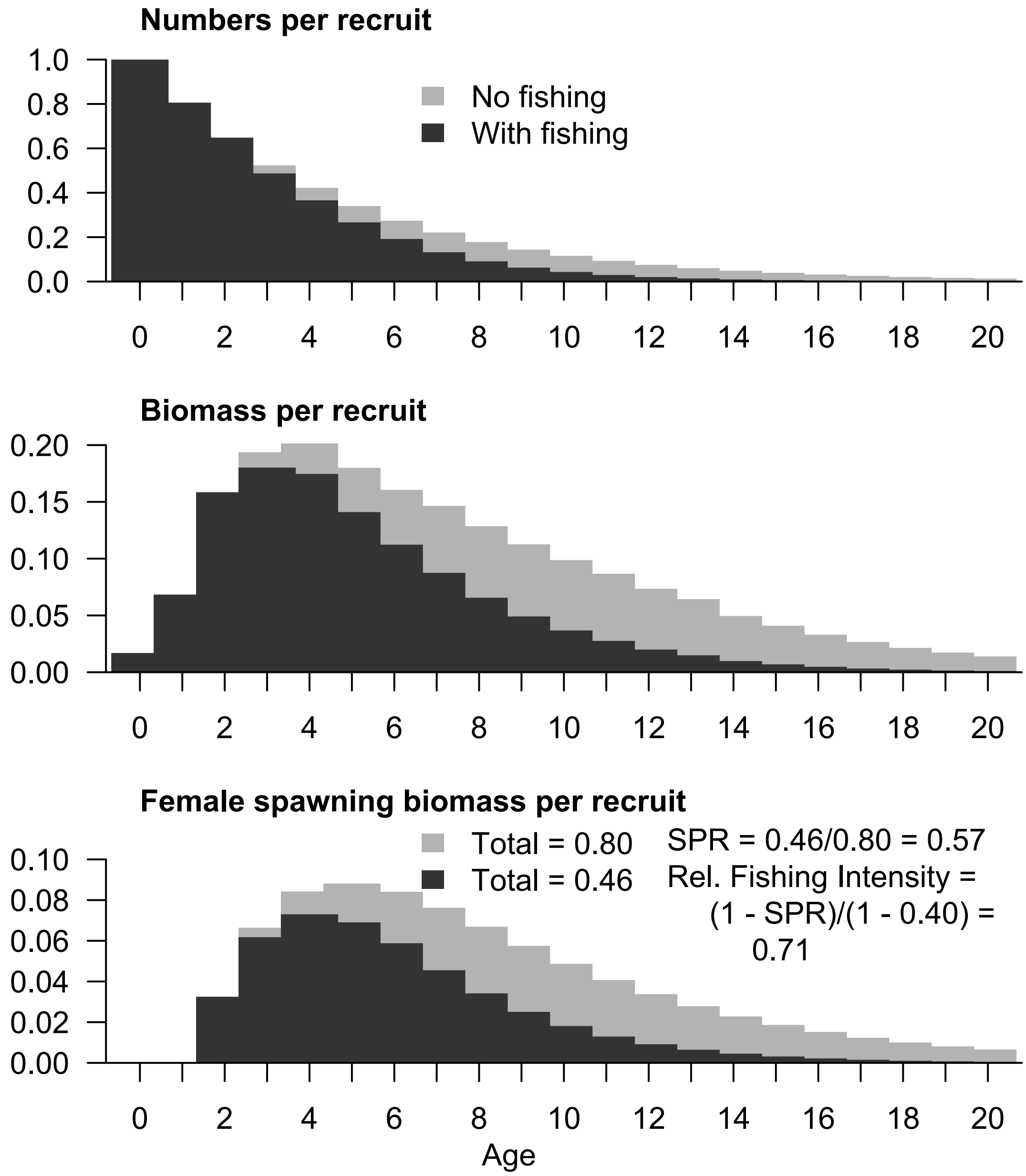


Figure B.2. Illustration of the spawning potential ratio (SPR) calculation based on the combination of maturity and fecundity used in the model, using the maximum likelihood estimates of natural mortality, selectivity, and fishing mortality in the final year of the base model.

C REPORT OF THE 2016 PACIFIC HAKE FISHERY IN CANADA

Prepared by the Canadian Advisory Panel and submitted for the Canada/US Joint Management Committee's and the Joint Technical Committee's consideration on December 6th, 2016.

The 2016/17 Offshore Pacific TAC for Canada was 129,947 mt with a combined harvest up to December 2, 2016 of 69,783.6 mt (53.7%) by the shoreside and freezer vessel fleets. The freezer vessels led the way with 48% of the total harvest for Canada. Although a Joint Venture allocation of 15,000 MT was approved, there was no JV fishery conducted in 2016/17. The Canadian fleet's catch increased by 88% from 2015, and the average size of the fish was similar to the previous year.

Fishing in the Canadian zone started in early March (Two months earlier than in 2015) with the last delivery occurring during the week of November 13, 2016. Freezer vessels started first with shoreside deliveries and processing commencing in early April. The early fishery was in the southern area of Vancouver Island (off Ucluelet). For the wet boat fleet delivering shoreside for processing, upwards of 90% of the fishing took place off Barkley Canyon west to Brooks Peninsula. The Freezer vessels started off Ucluelet but in July moved to western Clayoquot and Nootka and in late September moved north to Winter Harbour. In all areas, fishermen reported large bodies of hake. Vessels noticed small Hake (300 grams) in the south (Ucluelet, Tofino) in July and then again in Western Clayoquot in September.

A majority of the Canadian production was HGT (by both shoreside and freezer vessels) with a very small amount of mince and whole round produced shoreside. The Canadian hake shoreside TAC is harvested by freezer vessels and vessels delivering fresh to shoreside plants. Overall fleet participation was up slightly from 2015 due to good hake abundance and availability close to the processing facility in Ucluelet, an early closure to the West coast Vancouver Island shrimp trawl fishery, and more stable market conditions throughout the season. The market was strong in March and April but tailed off in July through September and partially recovered in October.

The Canadian hake fleet believes the 2016/17 hake fishery was positive, with fish present continuously along the shelf break and on the shelf off the West Coast of Vancouver Island throughout the season. Similar to 2015, there appeared to be a larger hake biomass in Canada compared to 2013 and 2014. Bycatch was seldom a problem throughout the year.

One freezer vessel that fished in areas 3C, 3D, and 5A sampled their catch after each trip throughout the year and recorded an average round weight for the season of 539 grams (based on 2,593 sampled fish), with a maximum weight of 1,254 grams and a minimum weight of 294 grams. In 2015, the same vessel sampled 1,472 fish and had an average hake weight of 537 grams, with a maximum weight of 1,477 grams and a minimum weight of 300 grams. On another freezer vessel the average size of round hake caught in 2016 was 500 grams off Ucluelet/Tofino in March through June, 550 grams off Western Clayoquot and Winter Harbour in July through October.

At the March 2016 meeting of the Canadian and US APs, an agreement was reached to try and avoid hake of 2 years or younger. The Canadian industry monitored the catch of small fish through sampling by at-sea observers and dockside monitors. Based on advice from science (correspondence from Ian Taylor dated May 27, 2016), everything less than 40 cm was assumed to be 2 years old or younger. Data was collected from two types of samples: 1) biological samples which sample for length, sex, age, and maturity; and 2) length frequency samples which only collect length information. Up to October 25, 2016 a total of 190 trips had been sampled (51 at-sea, 139 dockside), counting 17,094 hake weighing 20,943.85 lbs. The total number of 2 year old or younger hake counted was 1,722 (10.07% of all hake sampled) weighing 949.09 lbs (4.53% of the total weight sampled). The percentage of total calculated weight of 2 year old or younger hake in at-sea observer samples (Freezer Trawlers) was 3.81% compared to 5.14% for dockside monitoring samples (wet boats delivering to shoreside processors).

D REPORT OF THE 2016 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 January 31, 2017.

The US Pacific hake season started on May 15, 2016. All three sectors of the fishery – Shoreside (SS), Mothership (MS), and Catcher-Processor (CP) – commenced operations in mid-May. In general, participants in the at-sea sectors made one or two fishing trips before pausing hake operations to participate in the Alaska pollock B-season. In September, the MS and CP sectors re-entered the hake fishery. The MS sector finished at the end of October because of increasingly severe weather. The CP sector finished its hake season in mid-November. The SS hake fishery finished its season in early November. The Makah Tribe had a limited hake fishery in 2016. On September 14, 2016, 34,000 mt of tribal hake was re-apportioned to the non-tribal sectors (pro rata to initial allocation).

Table D.1. 2016 US Catch Summary (does not include US Research set-aside and catch; 1,500 mt and 572 mt, respectively)

	SS	CP	MS	Tribal	Total
Init. Alloc. (5/15)	126,727	102,589	72,415	64,322	367,553
Rev. Alloc. (9/14)	141,007	114,149	80,575	30,322	
Catch	85,293	108,786	65,035	2,470	261,584
Remaining	55,714	5,363	15,540	27,852	104,469
% Util Init. Alloc.	67%	100%	90%	4%	
% Util Rev. Alloc.	61%	95%	81%	8%	71%

Both the MS and CP sectors started the 2016 season in northern waters off Washington. The schools of hake were of larger size classes (e.g., 375-600 gram fish); however, encounter rates of rockfish species made fishing in this area too risky (that is, because of highly constraining bycatch limits, there was a risk of the sectors being closed prematurely) and the fleets moved to the south. The CP sector moved operations to the Oregon coast where bycatch rates were lower. The MS sector found good fishing in the Astoria Canyon area, but because of high encounter rates of Pacific Ocean perch, the sector relocated off of central and southern Oregon. The remainder of the spring and fall fisheries for the MS and CP sectors generally occurred off southern Oregon (that is, Heceta Bank and to the south) because of the need to avoid rockfish bycatch. The SS hake fishery occurred in areas near to shoreside processing facilities. Shoreside catcher vessels delivering to Washington and northern Oregon processors fished north of the Columbia River in two main areas North of Westport and between Long Beach and Westport, Washington. Vessels delivering to shore plants in Newport, Oregon generally fished in waters off central Oregon.

Product forms in the 2016 US hake fishery included surimi, mince, fillet, HGT, and fishmeal products. For the at-sea sectors, surimi appeared to be the predominant product in response to market conditions.

Ocean conditions and weather patterns during the 2016 season were more typical than 2015, although there were reports of areas where warm water persisted. There seemed to be more upwelling than 2015, and vessels reported areas of colder water where whiting schools tend to aggregate. However, the colder water areas tended to be closer to shore in areas with a higher occurrence of constraining rockfish species. Moreover, some captains reported variable temperatures at fishing depth that affected CPUE.

A mix of size classes was encountered by the US hake fishery during 2016. All sectors reported consistent encounters with large schools of smaller fish (ca 250 grams) throughout the season. The sectors aimed to target larger hake (that is, 350 grams and up), but schools of these larger fish were less concentrated, would break up as fishing pressure intensified, and were often mixed with large amounts of constraining rockfish species.

General observations are that, in 2016, there appeared to be good abundance of hake north of the Columbia River, but these fish were in areas of higher concentrations of constraining rockfish species. The at-sea sectors avoided these areas because of the risk of sector closure from attaining a bycatch limit. As a result, the MS and CP fisheries avoided good fishing off Washington and made do with scratchy fishing off southern Oregon where bycatch encounters were lower. The SS sector is somewhat less constrained by rockfish limits and, therefore, was able to remain in areas with consistent schools of hake. Larger fish were present in the US zone, and there were some days of high production, but the schools of larger hake tended to dis-aggregate and move. In contrast, there appeared to be a large, consistent presence of younger hake perhaps indicating strong recruitment into the fishery.

E ESTIMATED PARAMETERS IN THE BASE ASSESSMENT MODEL

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

Parameter	Posterior median
NatM_p_1_Fem_GP_1	0.2293
SR_LN.R0.	14.9692
SR_BH_steep	0.8146
Q_extraSD_2_Acoustic_Survey	0.3100
Early_InitAge_20	-0.2005
Early_InitAge_19	-0.0202
Early_InitAge_18	0.0006
Early_InitAge_17	-0.0815
Early_InitAge_16	-0.1130
Early_InitAge_15	-0.0742
Early_InitAge_14	-0.1222
Early_InitAge_13	-0.1794
Early_InitAge_12	-0.1916
Early_InitAge_11	-0.2048
Early_InitAge_10	-0.3235
Early_InitAge_9	-0.3178
Early_InitAge_8	-0.4098
Early_InitAge_7	-0.4456
Early_InitAge_6	-0.4809
Early_InitAge_5	-0.4606
Early_InitAge_4	-0.4402
Early_InitAge_3	-0.4181
Early_InitAge_2	-0.2206
Early_InitAge_1	0.0087
Early_RecrDev_1966	0.2616
Early_RecrDev_1967	1.2634
Early_RecrDev_1968	0.7279
Early_RecrDev_1969	-0.1258
Main_RecrDev_1970	1.9861
Main_RecrDev_1971	-0.3397
Main_RecrDev_1972	-0.7943
Main_RecrDev_1973	1.4867
Main_RecrDev_1974	-1.0030
Main_RecrDev_1975	0.2637
Main_RecrDev_1976	-1.1989
Main_RecrDev_1977	1.6562
Main_RecrDev_1978	-1.3742
Main_RecrDev_1979	-0.0881
Main_RecrDev_1980	2.8072
Main_RecrDev_1981	-1.2902
Main_RecrDev_1982	-1.4218
Main_RecrDev_1983	-1.0416
Main_RecrDev_1984	2.4630
Main_RecrDev_1985	-1.7709
Main_RecrDev_1986	-1.5934
Main_RecrDev_1987	1.6036
Main_RecrDev_1988	0.4277
Main_RecrDev_1989	-1.7933
Main_RecrDev_1990	1.2634
Main_RecrDev_1991	-0.2715
Main_RecrDev_1992	-1.7530
Main_RecrDev_1993	0.9532
Main_RecrDev_1994	1.0182
Main_RecrDev_1995	0.0807
Main_RecrDev_1996	0.4530
Main_RecrDev_1997	0.0128
Main_RecrDev_1998	0.5510
Main_RecrDev_1999	2.5119
Main_RecrDev_2000	-1.1696

Continued on next page

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

Parameter	Posterior median
Main_RecrDev_2001	0.1014
Main_RecrDev_2002	-2.8402
Main_RecrDev_2003	0.3524
Main_RecrDev_2004	-2.4838
Main_RecrDev_2005	0.8619
Main_RecrDev_2006	0.6167
Main_RecrDev_2007	-2.9929
Main_RecrDev_2008	1.7069
Main_RecrDev_2009	0.2072
Main_RecrDev_2010	2.7553
Main_RecrDev_2011	-0.8587
Main_RecrDev_2012	0.4220
Main_RecrDev_2013	-1.0983
Main_RecrDev_2014	2.3310
Late_RecrDev_2015	-0.4418
Late_RecrDev_2016	0.0466
ForeRecr_2017	0.1229
ForeRecr_2018	-0.0670
ForeRecr_2019	0.0442
AgeSel_1P_3_Fishery	3.0367
AgeSel_1P_4_Fishery	1.2095
AgeSel_1P_5_Fishery	0.3483
AgeSel_1P_6_Fishery	0.2258
AgeSel_1P_7_Fishery	0.4003
AgeSel_2P_4_Acoustic_Survey	0.5745
AgeSel_2P_5_Acoustic_Survey	-0.1115
AgeSel_2P_6_Acoustic_Survey	0.1902
AgeSel_2P_7_Acoustic_Survey	0.4062
AgeSel_1P_3_Fishery_DEVadd_1991	0.0569
AgeSel_1P_3_Fishery_DEVadd_1992	0.0110
AgeSel_1P_3_Fishery_DEVadd_1993	0.0129
AgeSel_1P_3_Fishery_DEVadd_1994	0.0201
AgeSel_1P_3_Fishery_DEVadd_1995	0.0032
AgeSel_1P_3_Fishery_DEVadd_1996	0.0365
AgeSel_1P_3_Fishery_DEVadd_1997	0.0170
AgeSel_1P_3_Fishery_DEVadd_1998	0.0149
AgeSel_1P_3_Fishery_DEVadd_1999	0.0847
AgeSel_1P_3_Fishery_DEVadd_2000	0.0850
AgeSel_1P_3_Fishery_DEVadd_2001	0.0091
AgeSel_1P_3_Fishery_DEVadd_2002	0.0276
AgeSel_1P_3_Fishery_DEVadd_2003	-0.0171
AgeSel_1P_3_Fishery_DEVadd_2004	0.0407
AgeSel_1P_3_Fishery_DEVadd_2005	0.0050
AgeSel_1P_3_Fishery_DEVadd_2006	0.0702
AgeSel_1P_3_Fishery_DEVadd_2007	0.0624
AgeSel_1P_3_Fishery_DEVadd_2008	-0.0014
AgeSel_1P_3_Fishery_DEVadd_2009	0.0800
AgeSel_1P_3_Fishery_DEVadd_2010	0.0869
AgeSel_1P_3_Fishery_DEVadd_2011	-0.0140
AgeSel_1P_3_Fishery_DEVadd_2012	0.0147
AgeSel_1P_3_Fishery_DEVadd_2013	0.0351
AgeSel_1P_3_Fishery_DEVadd_2014	0.0148
AgeSel_1P_3_Fishery_DEVadd_2015	-0.1079
AgeSel_1P_3_Fishery_DEVadd_2016	0.0460
AgeSel_1P_4_Fishery_DEVadd_1991	0.0401
AgeSel_1P_4_Fishery_DEVadd_1992	0.0845
AgeSel_1P_4_Fishery_DEVadd_1993	0.0785
AgeSel_1P_4_Fishery_DEVadd_1994	0.0355
AgeSel_1P_4_Fishery_DEVadd_1995	0.0464
AgeSel_1P_4_Fishery_DEVadd_1996	-0.1056
AgeSel_1P_4_Fishery_DEVadd_1997	0.1609

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

Parameter	Posterior median
AgeSel_1P_4_Fishery_DEVadd_1998	0.1200
AgeSel_1P_4_Fishery_DEVadd_1999	-0.0279
AgeSel_1P_4_Fishery_DEVadd_2000	0.1079
AgeSel_1P_4_Fishery_DEVadd_2001	0.1494
AgeSel_1P_4_Fishery_DEVadd_2002	0.0715
AgeSel_1P_4_Fishery_DEVadd_2003	0.1067
AgeSel_1P_4_Fishery_DEVadd_2004	0.0529
AgeSel_1P_4_Fishery_DEVadd_2005	0.1027
AgeSel_1P_4_Fishery_DEVadd_2006	-0.0046
AgeSel_1P_4_Fishery_DEVadd_2007	0.0130
AgeSel_1P_4_Fishery_DEVadd_2008	0.0401
AgeSel_1P_4_Fishery_DEVadd_2009	0.1123
AgeSel_1P_4_Fishery_DEVadd_2010	0.0130
AgeSel_1P_4_Fishery_DEVadd_2011	0.1509
AgeSel_1P_4_Fishery_DEVadd_2012	0.0126
AgeSel_1P_4_Fishery_DEVadd_2013	0.1267
AgeSel_1P_4_Fishery_DEVadd_2014	0.0228
AgeSel_1P_4_Fishery_DEVadd_2015	-0.0196
AgeSel_1P_4_Fishery_DEVadd_2016	-0.1717
AgeSel_1P_5_Fishery_DEVadd_1991	-0.1451
AgeSel_1P_5_Fishery_DEVadd_1992	0.0229
AgeSel_1P_5_Fishery_DEVadd_1993	-0.0120
AgeSel_1P_5_Fishery_DEVadd_1994	0.1428
AgeSel_1P_5_Fishery_DEVadd_1995	0.0799
AgeSel_1P_5_Fishery_DEVadd_1996	-0.0588
AgeSel_1P_5_Fishery_DEVadd_1997	-0.0114
AgeSel_1P_5_Fishery_DEVadd_1998	-0.0807
AgeSel_1P_5_Fishery_DEVadd_1999	0.0068
AgeSel_1P_5_Fishery_DEVadd_2000	0.0038
AgeSel_1P_5_Fishery_DEVadd_2001	0.0418
AgeSel_1P_5_Fishery_DEVadd_2002	0.1183
AgeSel_1P_5_Fishery_DEVadd_2003	0.1278
AgeSel_1P_5_Fishery_DEVadd_2004	0.0728
AgeSel_1P_5_Fishery_DEVadd_2005	0.1181
AgeSel_1P_5_Fishery_DEVadd_2006	0.0129
AgeSel_1P_5_Fishery_DEVadd_2007	-0.0199
AgeSel_1P_5_Fishery_DEVadd_2008	-0.0438
AgeSel_1P_5_Fishery_DEVadd_2009	-0.0270
AgeSel_1P_5_Fishery_DEVadd_2010	0.0774
AgeSel_1P_5_Fishery_DEVadd_2011	-0.1271
AgeSel_1P_5_Fishery_DEVadd_2012	0.0309
AgeSel_1P_5_Fishery_DEVadd_2013	-0.0313
AgeSel_1P_5_Fishery_DEVadd_2014	-0.0506
AgeSel_1P_5_Fishery_DEVadd_2015	-0.0064
AgeSel_1P_5_Fishery_DEVadd_2016	-0.0123
AgeSel_1P_6_Fishery_DEVadd_1991	-0.0171
AgeSel_1P_6_Fishery_DEVadd_1992	-0.0684
AgeSel_1P_6_Fishery_DEVadd_1993	-0.0087
AgeSel_1P_6_Fishery_DEVadd_1994	0.0082
AgeSel_1P_6_Fishery_DEVadd_1995	0.1381
AgeSel_1P_6_Fishery_DEVadd_1996	-0.0115
AgeSel_1P_6_Fishery_DEVadd_1997	-0.0479
AgeSel_1P_6_Fishery_DEVadd_1998	0.0474
AgeSel_1P_6_Fishery_DEVadd_1999	-0.0656
AgeSel_1P_6_Fishery_DEVadd_2000	0.0065
AgeSel_1P_6_Fishery_DEVadd_2001	-0.0018
AgeSel_1P_6_Fishery_DEVadd_2002	-0.0014
AgeSel_1P_6_Fishery_DEVadd_2003	0.0471
AgeSel_1P_6_Fishery_DEVadd_2004	-0.0650
AgeSel_1P_6_Fishery_DEVadd_2005	0.0316
AgeSel_1P_6_Fishery_DEVadd_2006	0.0238

Continued on next page

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

Parameter	Posterior median
AgeSel_1P_6_Fishery_DEVadd_2007	-0.0231
AgeSel_1P_6_Fishery_DEVadd_2008	0.0309
AgeSel_1P_6_Fishery_DEVadd_2009	-0.0398
AgeSel_1P_6_Fishery_DEVadd_2010	-0.0947
AgeSel_1P_6_Fishery_DEVadd_2011	-0.0636
AgeSel_1P_6_Fishery_DEVadd_2012	-0.0933
AgeSel_1P_6_Fishery_DEVadd_2013	-0.0188
AgeSel_1P_6_Fishery_DEVadd_2014	0.0074
AgeSel_1P_6_Fishery_DEVadd_2015	0.0211
AgeSel_1P_6_Fishery_DEVadd_2016	-0.0377
AgeSel_1P_7_Fishery_DEVadd_1991	-0.0217
AgeSel_1P_7_Fishery_DEVadd_1992	0.0120
AgeSel_1P_7_Fishery_DEVadd_1993	-0.0380
AgeSel_1P_7_Fishery_DEVadd_1994	0.0219
AgeSel_1P_7_Fishery_DEVadd_1995	0.0014
AgeSel_1P_7_Fishery_DEVadd_1996	0.0677
AgeSel_1P_7_Fishery_DEVadd_1997	0.0079
AgeSel_1P_7_Fishery_DEVadd_1998	-0.0744
AgeSel_1P_7_Fishery_DEVadd_1999	-0.0435
AgeSel_1P_7_Fishery_DEVadd_2000	0.0238
AgeSel_1P_7_Fishery_DEVadd_2001	-0.0446
AgeSel_1P_7_Fishery_DEVadd_2002	-0.0502
AgeSel_1P_7_Fishery_DEVadd_2003	-0.0398
AgeSel_1P_7_Fishery_DEVadd_2004	-0.0253
AgeSel_1P_7_Fishery_DEVadd_2005	-0.0394
AgeSel_1P_7_Fishery_DEVadd_2006	-0.0528
AgeSel_1P_7_Fishery_DEVadd_2007	0.0001
AgeSel_1P_7_Fishery_DEVadd_2008	-0.0333
AgeSel_1P_7_Fishery_DEVadd_2009	0.0122
AgeSel_1P_7_Fishery_DEVadd_2010	-0.1159
AgeSel_1P_7_Fishery_DEVadd_2011	-0.1003
AgeSel_1P_7_Fishery_DEVadd_2012	-0.0730
AgeSel_1P_7_Fishery_DEVadd_2013	0.0385
AgeSel_1P_7_Fishery_DEVadd_2014	-0.0034
AgeSel_1P_7_Fishery_DEVadd_2015	-0.0925
AgeSel_1P_7_Fishery_DEVadd_2016	-0.0122

F STOCK SYNTHESIS DATA FILE

../models/45_BasePreSRG_v4/2017hake_data.ss

```
#C 2017 Hake data file
#####################################################

### Global model specifications ###
1966    # Start year
2016    # End year
1       # Number of seasons/year
12      # Number of months/season
1       # Spawning occurs at beginning of season
1       # Number of fishing fleets
1       # Number of surveys
1       # Number of areas
Fishery%Acoustic_Survey
0.5 0.5 # fleet timing_in_season
1 1     # Area of each fleet
1       # Units for catch by fishing fleet: 1=Biomass(mt),2=Numbers(1000s)
0.01    # SE of log(catch) by fleet for equilibrium and continuous options
1       # Number of genders
20      # Number of ages in population dynamics

### Catch section ###
0  # Initial equilibrium catch (landings + discard) by fishing fleet

51 # Number of lines of catch
# Catch  Year    Season
137700  1966    1
214370  1967    1
122180  1968    1
180130  1969    1
234590  1970    1
154620  1971    1
117540  1972    1
162640  1973    1
211260  1974    1
221350  1975    1
237520  1976    1
132690  1977    1
103637  1978    1
137110  1979    1
89930   1980    1
139120  1981    1
107741  1982    1
113931  1983    1
138492  1984    1
110399  1985    1
210616  1986    1
234148  1987    1
248840  1988    1
298079  1989    1
261286  1990    1
```

```
319705  1991    1
299650  1992    1
198905  1993    1
362407  1994    1
249495  1995    1
306299  1996    1
325147  1997    1
320722  1998    1
311887  1999    1
228777  2000    1
227525  2001    1
180697  2002    1
205162  2003    1
342307  2004    1
363135  2005    1
361699  2006    1
293389  2007    1
321802  2008    1
177171  2009    1
230755  2010    1
291670  2011    1
205787  2012    1
285591  2013    1
298705  2014    1
190663  2015    1
329427  2016    1


22 # Number of index observations
# Units: 0=numbers,1=biomass,2=F; Errortype: -1=normal,0=lognormal,>0=T
# Fleet Units Errortype
1 1 0 # Fishery
2 1 0 # Acoustic Survey

# Acoustic survey  (all years updated with new acoustic team
   extrapolation analysis; 1995 unavailabe with new analysis)
# Year  seas    fleet   obs       se(log)
1995    1       2       1318035   0.0893
1996    1       -2      1         1
1997    1       -2      1         1
1998    1       2       1569148   0.0479
1999    1       -2      1         1
2000    1       -2      1         1
2001    1       2       861744    0.1059
2002    1       -2      1         1
2003    1       2       2137528   0.0642
2004    1       -2      1         1
2005    1       2       1376099   0.0638
2006    1       -2      1         1
2007    1       2       942721    0.0766
2008    1       -2      1         1
2009    1       2       1502273   0.0995
2010    1       -2      1         1
2011    1       2       674617    0.1177
```

```
2012    1       2       1279421   0.0673
2013    1       2       1929235   0.0646
2014    1       -2      1         1
2015    1       2       2155853   0.0829
2016    1       -2      1         1



0  #_N_fleets_with_discard
0  #_N_discard_obs
0  #_N_meanbodywt_obs
30 #_DF_for_meanbodywt_T-distribution_like

## Population size structure
2  # Length bin method: 1=use databins; 2=generate from binwidth,min,max
   below;
2  # Population length bin width
10 # Minimum size bin
70 # Maximum size bin

-1       # Minimum proportion for compressing tails of observed
   compositional data
0.001    # Constant added to expected frequencies
0        # Combine males and females at and below this bin number

26 # Number of Data Length Bins
# Lower edge of bins
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
0 #_N_Length_obs

15 #_N_age_bins
# Age bins
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

44 # N_ageerror_definitions
# No ageing error
#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
#0.001  0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
     0.001   0.001   0.001
# Baseline ageing error
#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
#0.329  0.329   0.347   0.369   0.395   0.428   0.468   0.518   0.579
   0.653   0.745   0.858   0.996   1.167   1.376   1.632   1.858   2.172
     2.530   2.934   3.388
# Annual keys with cohort effect
#
# NOTE: no adjustment for 2008, full adjustment for 2010
#
```

```
#age0      age1       age2       age3       age4       age5       age6
        age7       age8       age9       age10      age11      age12
        age13      age14      age15      age16      age17      age18
   age19      age20      yr         def        comment
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1973     def1       Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1973     def1       SD of age.
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1974     def2       Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1974     def2       SD of age.
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1975     def3       Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1975     def3       SD of age.
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1976     def4       Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1976     def4       SD of age.
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1977     def5       Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1977     def5       SD of age.
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1978     def6       Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1978     def6       SD of age.
0.5        1.5        2.5        3.5        4.5        5.5        6.5
        7.5        8.5        9.5        10.5       11.5       12.5
```

```
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1979    def7      Expected ages
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1979    def7      SD of age.
0.5       1.5       2.5       3.5       4.5       5.5       6.5
        7.5       8.5       9.5       10.5      11.5      12.5
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1980    def8      Expected ages
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1980    def8      SD of age.
0.5       1.5       2.5       3.5       4.5       5.5       6.5
        7.5       8.5       9.5       10.5      11.5      12.5
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1981    def9      Expected ages
0.329242  0.329242  0.346917  0.368632  0.395312  0.42809
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1981    def9      SD of age. 0.55*age1
0.5       1.5       2.5       3.5       4.5       5.5       6.5
        7.5       8.5       9.5       10.5      11.5      12.5
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1982    def10     Expected ages
0.329242  0.329242  0.19080435 0.368632  0.395312  0.42809
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1982    def10     SD of age. 0.55*age2
0.5       1.5       2.5       3.5       4.5       5.5       6.5
        7.5       8.5       9.5       10.5      11.5      12.5
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1983    def11     Expected ages
0.329242  0.329242  0.346917  0.2027476 0.395312  0.42809
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1983    def11     SD of age. 0.55*age3
0.5       1.5       2.5       3.5       4.5       5.5       6.5
        7.5       8.5       9.5       10.5      11.5      12.5
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1984    def12     Expected ages
0.329242  0.329242  0.346917  0.368632  0.2174216 0.42809
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1984    def12     SD of age. 0.55*age4
0.5       1.5       2.5       3.5       4.5       5.5       6.5
        7.5       8.5       9.5       10.5      11.5      12.5
        13.5      14.5      15.5      16.5      17.5      18.5
        19.5      20.5      # 1985    def13     Expected ages
0.329242  0.329242  0.346917  0.368632  0.395312  0.2354495
   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
   0.996322  1.1665    1.37557   1.63244   1.858     2.172     2.53
        2.934     3.388     # 1985    def13     SD of age.
```

```
   0.55*age1, 0.55*age5
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1986     def14      Expected ages
0.329242   0.329242   0.19080435 0.368632   0.395312   0.42809
   0.2575991  0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1986     def14      SD of age.
   0.55*age2, 0.55*age6
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1987     def15      Expected ages
0.329242   0.329242   0.346917   0.2027476  0.395312   0.42809
   0.468362   0.28481255 0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1987     def15      SD of age.
   0.55*age3, 0.55*age7
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1988     def16      Expected ages
0.329242   0.329242   0.346917   0.368632   0.2174216  0.42809
   0.468362   0.517841   0.3182465  0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1988     def16      SD of age.
   0.55*age4, 0.55*age8
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1989     def17      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.2354495
   0.468362   0.517841   0.57863    0.3593238  0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1989     def17      SD of age.
   0.55*age5, 0.55*age9
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1990     def18      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.2575991  0.517841   0.57863    0.653316   0.4097918  0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1990     def18      SD of age.
   0.55*age6, 0.55*age10
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1991     def19      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.28481255 0.57863    0.653316   0.745076   0.47179715
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1991     def19      SD of age.
```

```
   0.55*age7, 0.55*age11
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1992     def20      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.3182465  0.653316   0.745076   0.857813
   0.5479771  1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1992     def20      SD of age.
   0.55*age8, 0.55*age12
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1993     def21      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.3593238  0.745076   0.857813
   0.996322   0.641575   1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 1993     def21      SD of age.
   0.55*age9, 0.55*age13
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1994     def22      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.4097918  0.857813
   0.996322   1.1665     0.7565635  1.63244    1.858      2.172      2.53
        2.934      3.388      # 1994     def22      SD of age.
   0.55*age10, 0.55*age14
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1995     def23      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.47179715
   0.996322   1.1665     1.37557    0.897842   1.858      2.172      2.53
        2.934      3.388      # 1995     def23      SD of age.
   0.55*age11, 0.55*age15
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1996     def24      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.5479771  1.1665     1.37557    1.63244    1.0219     2.172      2.53
        2.934      3.388      # 1996     def24      SD of age.
   0.55*age12, 0.55*age16
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 1997     def25      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   0.641575   1.37557    1.63244    1.858      1.1946     2.53
        2.934      3.388      # 1997     def25      SD of age.
```

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   0.55*age13, 0.55*age17
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 1998     def26      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     0.7565635  1.63244    1.858      2.172
   1.3915     2.934      3.388      # 1998     def26      SD of age.
   0.55*age14, 0.55*age18
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 1999     def27      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    0.897842   1.858      2.172      2.53
         1.6137     3.388      # 1999     def27      SD of age.
   0.55*age15, 0.55*age19
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2000     def28      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.0219     2.172      2.53
         2.934      1.8634     # 2000     def28      SD of age.
   0.55*age1, 0.55*age16, 0.55*age20
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2001     def29      Expected ages
0.329242   0.329242   0.19080435 0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      1.1946     2.53
         2.934      3.388      # 2001     def29      SD of age.
   0.55*age2, 0.55*age17
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2002     def30      Expected ages
0.329242   0.329242   0.346917   0.2027476  0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172
   1.3915     2.934      3.388      # 2002     def30      SD of age.
   0.55*age3, 0.55*age18
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2003     def31      Expected ages
0.329242   0.329242   0.346917   0.368632   0.2174216  0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         1.6137     3.388      # 2003     def31      SD of age.
```

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   0.55*age4, 0.55*age19
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2004     def32      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.2354495
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         2.934      1.8634     # 2004     def32      SD of age.
   0.55*age5, 0.55*age20
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2005     def33      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.2575991  0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         2.934      3.388      # 2005     def33      SD of age. 0.55*age6
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2006     def34      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.28481255 0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         2.934      3.388      # 2006     def34      SD of age. 0.55*age7
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2007     def35      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.3182465  0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         2.934      3.388      # 2007     def35      SD of age. 0.55*age8
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2008     def36      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.3593238  0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         2.934      3.388      # 2008     def36      SD of age. 0.55*age9
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2009     def37      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.4097918  0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
         2.934      3.388      # 2009     def37      SD of age. 0.55*age10
0.5        1.5        2.5        3.5        4.5        5.5        6.5
          7.5        8.5        9.5        10.5       11.5       12.5
         13.5       14.5       15.5       16.5       17.5       18.5
         19.5       20.5       # 2010     def38      Expected ages
```

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0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.47179715
   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 2010     def38      SD of age. 0.55*age11
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 2011     def39      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.5479771  1.1665     1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 2011     def39      SD of age.
   0.55*age1, 0.55*age12
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 2012     def40      Expected ages
0.329242   0.329242   0.19080435 0.368632   0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   0.641575   1.37557    1.63244    1.858      2.172      2.53
        2.934      3.388      # 2012     def40      SD of age.
   0.55*age2, 0.55*age13
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 2013     def41      Expected ages
0.329242   0.329242   0.346917   0.2027476  0.395312   0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     0.7565635  1.63244    1.858      2.172      2.53
        2.934      3.388      # 2013     def41      SD of age.
   0.55*age3, 0.55*age14
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 2014     def42      Expected ages
0.329242   0.329242   0.346917   0.368632   0.2174216  0.42809
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    0.897842   1.858      2.172      2.53
        2.934      3.388      # 2014     def42      SD of age.
   0.55*age4, 0.55*age15
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 2015     def43      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.2354495
   0.468362   0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.0219     2.172      2.53
        2.934      3.388      # 2015     def43      SD of age.
   0.55*age5, 0.55*age16
0.5        1.5        2.5        3.5        4.5        5.5        6.5
         7.5        8.5        9.5        10.5       11.5       12.5
        13.5       14.5       15.5       16.5       17.5       18.5
        19.5       20.5       # 2016     def44      Expected ages
0.329242   0.329242   0.19080435 0.368632   0.395312   0.42809
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   0.2575991  0.517841   0.57863    0.653316   0.745076   0.857813
   0.996322   1.1665     1.37557    1.63244    1.858      1.1946     2.53
        2.934      3.388      # 2016     def44      SD of age.
   0.55*age2, 0.55*age6, 0.55*age17

#Age comps updated 1/11/2016
53   # Number of age comp observations
1    # Length bin refers to: 1=population length bin indices; 2=data
   length bin indices
0    #_combine males into females at or below this bin number
# Acoustic survey ages (N=10)
#year Season Fleet Sex Partition AgeErr LbinLo LbinHi nTrips  a1      a2
        a3      a4      a5      a6      a7      a8      a9      a10
   a11     a12     a13     a14     a15
1995  1      2     0   0          23     -1     -1     69      0
   20.48   3.26    1.06    19.33   1.03    4.03    16.37   1.44    0.72
      24.86   0.24    1.67    0.21    5.32
1998  1      2     0   0          26     -1     -1     105     0
   6.83    8.03    17.03   17.25   1.77    11.37   10.79   1.73    4.19
      7.60    1.27    0.34    9.74    2.06
2001  1      2     0   0          29     -1     -1     57      0
   50.62   10.95   15.12   7.86    3.64    3.84    2.60    1.30    1.34
      0.65    0.68    0.87    0.15    0.39
2003  1      2     0   0          31     -1     -1     71      0
   23.06   1.63    43.40   13.07   2.71    5.14    3.43    1.82    2.44
      1.44    0.49    0.43    0.42    0.52
2005  1      2     0   0          33     -1     -1     47      0
   19.07   1.23    5.10    4.78    50.67   6.99    2.50    3.99    2.45
      1.71    0.74    0.48    0.14    0.16
2007  1      2     0   0          35     -1     -1     69      0
   28.29   2.16    11.64   1.38    5.01    3.25    38.64   3.92    1.94
      1.70    0.83    0.77    0.34    0.12
2009  1      2     0   0          37     -1     -1     72      0
   0.55    29.33   40.21   2.29    8.22    1.25    1.79    1.93    8.32
      3.63    1.44    0.28    0.48    0.26
2011  1      2     0   0          39     -1     -1     46      0
   27.62   56.32   3.71    2.64    2.94    0.70    0.78    0.38    0.66
      0.97    2.10    0.76    0.31    0.11
2012  1      2     0   0          40     -1     -1     94      0
   62.12   9.78    16.70   2.26    2.92    1.94    1.01    0.50    0.23
      0.27    0.66    0.98    0.51    0.12
2013  1      2     0   0          41     -1     -1     67      0
   2.17    74.97   5.63    8.68    0.95    2.20    2.59    0.71    0.35
      0.10    0.13    0.36    0.77    0.38
2015  1      2     0   0          43     -1     -1     78      0
   7.45    9.19    4.38    58.98   4.88    7.53    1.69    1.68    1.64
      0.95    0.16    0.29    0.24    0.92

#Aggregate marginal fishery age comps (n=40)
#year Season Fleet Sex Partition AgeErr LbinLo LbinHi nTrips  a1      a2
        a3      a4      a5      a6      a7      a8      a9      a10
   a11     a12     a13     a14     a15
1975    1       1       0       0       3       -1      -1      13
   4.608   33.846  7.432   1.248   25.397  5.546   8.031   10.537
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   0.953    0.603    0.871    0.451    0.000    0.476    0.000
1976     1        1        0        0        4       -1       -1      142
   0.085    1.337    14.474   6.742    4.097    24.582   9.766    8.899
   12.099   5.431    4.303    4.075    1.068    2.355    0.687
1977     1        1        0        0        5       -1       -1      320
   0.000    8.448    3.683    27.473   3.594    9.106    22.682   7.599
   6.544    4.016    3.550    2.308    0.572    0.308    0.119
1978     1        1        0        0        6       -1       -1      341
   0.472    1.110    6.511    6.310    26.416   6.091    8.868    21.505
   9.776    4.711    4.680    2.339    0.522    0.353    0.337
1979     1        1        0        0        7       -1       -1      116
   0.000    6.492    10.241   9.382    5.721    17.666   10.256   17.370
   12.762   4.180    2.876    0.963    1.645    0.000    0.445
1980     1        1        0        0        8       -1       -1      221
   0.148    0.544    30.087   1.855    4.488    8.166    11.227   5.012
   8.941    11.075   9.460    2.628    3.785    1.516    1.068
1981     1        1        0        0        9       -1       -1      154
   19.492   4.031    1.403    26.726   3.901    5.547    3.376    14.675
   3.769    3.195    10.186   2.313    0.504    0.163    0.720
1982     1        1        0        0       10       -1       -1      170
   0.000    32.050   3.521    0.486    27.347   1.526    3.680    3.894
   11.764   3.268    3.611    7.645    0.241    0.302    0.664
1983     1        1        0        0       11       -1       -1      117
   0.000    0.000    34.144   3.997    1.825    23.458   5.126    5.647
   5.300    9.383    3.910    3.128    2.259    1.130    0.695
1984     1        1        0        0       12       -1       -1      123
   0.000    0.000    1.393    61.904   3.625    3.849    16.778   2.853
   1.509    1.239    3.342    0.923    0.586    1.439    0.561
1985     1        1        0        0       13       -1       -1       57
   0.925    0.111    0.348    7.241    66.754   8.407    5.605    7.106
   2.042    0.530    0.654    0.246    0.000    0.000    0.032
1986     1        1        0        0       14       -1       -1      120
   0.000    15.341   5.384    0.527    0.761    43.638   6.898    8.154
   8.260    2.189    2.817    1.834    3.133    0.457    0.609
1987     1        1        0        0       15       -1       -1       56
   0.000    0.000    29.583   2.904    0.135    1.013    53.260   0.404
   1.250    7.091    0.000    0.744    1.859    1.757    0.000
1988     1        1        0        0       16       -1       -1       84
   0.000    0.657    0.065    32.348   0.980    1.451    0.656    45.959
   1.343    0.835    10.498   0.791    0.054    0.064    4.301
1989     1        1        0        0       17       -1       -1       80
   0.000    5.616    2.431    0.288    50.206   1.257    0.292    0.084
   35.192   1.802    0.395    2.316    0.084    0.000    0.037
1990     1        1        0        0       18       -1       -1      163
   0.000    5.194    20.559   1.885    0.592    31.349   0.512    0.200
   0.043    31.901   0.296    0.067    6.411    0.000    0.992
1991     1        1        0        0       19       -1       -1      160
   0.000    3.464    20.372   19.632   2.522    0.790    28.260   1.177
   0.145    0.181    18.688   0.423    0.000    3.606    0.741
1992     1        1        0        0       20       -1       -1      243
   0.461    4.238    4.304    13.052   18.594   2.272    1.044    33.927
   0.767    0.078    0.340    18.049   0.413    0.037    2.426
1993     1        1        0        0       21       -1       -1      172
   0.000    1.051    23.240   3.260    12.980   15.666   1.500    0.810
```

```
   27.421  0.674   0.089   0.120   12.004  0.054   1.129
1994    1       1       0       0       22      -1      -1      235
   0.000   0.037   2.832   21.390  1.265   12.628  18.687  1.571
   0.573   29.906  0.262   0.282   0.022   9.634   0.909
1995    1       1       0       0       23      -1      -1      147
   0.619   1.281   0.467   6.309   28.973  1.152   8.051   20.271
   1.576   0.222   22.422  0.435   0.451   0.037   7.734
1996    1       1       0       0       24      -1      -1      186
   0.000   18.282  16.242  1.506   7.743   18.140  1.002   4.908
   10.981  0.576   0.347   15.716  0.009   0.108   4.439
1997    1       1       0       0       25      -1      -1      220
   0.000   0.737   29.476  24.952  1.468   7.838   12.488  1.798
   3.977   6.671   1.284   0.216   6.079   0.733   2.282
1998    1       1       0       0       26      -1      -1      243
   0.015   4.786   20.351  20.288  26.596  2.869   5.400   9.310
   0.917   1.557   3.899   0.352   0.092   2.940   0.627
1999    1       1       0       0       27      -1      -1      509
   0.062   10.242  20.364  17.981  20.062  13.199  2.688   3.930
   4.009   0.989   1.542   2.140   0.392   0.335   2.066
2000    1       1       0       0       28      -1      -1      530
   0.996   4.218   10.935  14.285  12.880  21.063  13.115  6.548
   4.648   2.509   2.070   2.306   1.292   0.720   2.414
2001    1       1       0       0       29      -1      -1      540
   0.000   17.338  16.247  14.250  15.685  8.559   12.100  5.989
   1.778   2.232   1.810   0.698   1.421   0.685   1.209
2002    1       1       0       0       30      -1      -1      449
   0.000   0.033   50.642  14.934  9.687   5.719   4.438   6.580
   3.546   0.871   0.845   1.036   0.242   0.475   0.953
2003    1       1       0       0       31      -1      -1      456
   0.000   0.105   1.397   67.896  11.642  3.339   4.987   3.191
   3.137   2.106   0.874   0.436   0.533   0.125   0.231
2004    1       1       0       0       32      -1      -1      501
   0.000   0.022   5.310   6.067   68.288  8.152   2.187   4.155
   2.512   1.281   1.079   0.350   0.268   0.160   0.170
2005    1       1       0       0       33      -1      -1      613
   0.018   0.569   0.464   6.562   5.381   68.723  7.953   2.358
   2.909   2.207   1.177   1.090   0.250   0.090   0.248
2006    1       1       0       0       34      -1      -1      720
   0.326   2.808   10.444  1.673   8.567   4.879   59.038  5.275
   1.716   2.376   1.134   1.015   0.426   0.135   0.188
2007    1       1       0       0       35      -1      -1      629
   0.761   11.311  3.737   15.471  1.594   6.855   3.834   44.109
   5.177   1.721   2.279   1.771   0.504   0.187   0.689
2008    1       1       0       0       36      -1      -1      794
   0.758   9.850   30.590  2.403   14.421  1.027   3.628   3.166
   28.014  3.039   1.142   0.732   0.491   0.313   0.429
2009    1       1       0       0       37      -1      -1      686
   0.637   0.519   30.626  27.548  3.356   10.705  1.305   2.259
   2.291   16.191  2.485   0.866   0.591   0.281   0.340
2010    1       1       0       0       38      -1      -1      874
   0.028   25.336  3.355   34.848  21.528  2.358   3.001   0.444
   0.579   0.974   6.056   0.926   0.306   0.104   0.157
2011    1       1       0       0       39      -1      -1      1081
   2.638   8.503   70.847  2.650   6.413   4.446   1.144   0.819
```

```
   0.294   0.390   0.118   1.348   0.171   0.110   0.108
2012    1       1       0       0       40      -1      -1      851
   0.181   40.949  11.556  32.991  2.490   5.083   2.516   1.132
   0.659   0.231   0.329   0.347   0.870   0.283   0.383
2013    1       1       0       0       41      -1      -1      1094
   0.030   0.544   70.309  5.906   10.473  1.123   3.413   2.059
   0.906   1.366   0.264   0.333   0.530   2.281   0.462
2014    1       1       0       0       42      -1      -1      1130
   0.000   3.314   3.731   64.297  6.926   12.169  1.587   3.141
   1.827   0.823   0.466   0.118   0.191   0.279   1.131
2015    1       1       0       0       43      -1      -1      798
   3.591   1.136   6.883   3.946   70.023  4.940   5.089   0.958
   1.551   1.088   0.202   0.205   0.061   0.054   0.273
2016    1       1       0       0       44      -1      -1      1300
   0.322   46.956  1.687   4.867   2.589   35.046  3.004   3.376
   0.868   0.471   0.402   0.220   0.073   0.041   0.078

0 # No Mean size-at-age data
0 # Total number of environmental variables
0 # Total number of environmental observations
0 # No Weight frequency data
0 # No tagging data
0 # No morph composition data

999 # End data file
```

G STOCK SYNTHESIS CONTROL FILE

../models/45_BasePreSRG_v4/2017hake_control.ss

```
#C 2017 Hake control file
###################################################

1       # N growth patterns
1       # N sub morphs within patterns
0       # Number of block designs for time varying parameters

# Mortality and growth specifications
0.5     # Fraction female (birth)
0       # M setup: 0=single
   parameter,1=breakpoints,2=Lorenzen,3=age-specific;4=age-specific,seasonal
   interpolation
1       # Growth model: 1=VB with L1 and L2, 2=VB with A0 and Linf,
   3=Richards, 4=Read vector of L@A
1       # Age for growth Lmin
20      # Age for growth Lmax
0.0     # Constant added to SD of LAA (0.1 mimics SS2v1 for compatibility
   only)
0       # Variability of growth: 0=CV~f(LAA), 1=CV~f(A), 2=SD~f(LAA),
   3=SD~f(A)
5       # maturity_option:  1=length logistic; 2=age logistic; 3=read
   age-maturity matrix by growth_pattern; 4=read age-fecundity; 5=read
   fec and wt from wtatage.ss
2       # First age allowed to mature
1       # Fecundity
   option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b
0       # Hermaphroditism option:  0=none; 1=age-specific fxn
1       # MG parm offset option: 1=none, 2= M,G,CV_G as offset from GP1,
   3=like SS2v1
1       # MG parm env/block/dev_adjust_method: 1=standard; 2=logistic
   transform keeps in base parm bounds; 3=standard w/ no bound check

# Lo     Hi     Init    Prior   Prior   Prior   Param   Env     Use
   Dev     Dev     Dev     Block   block
# bnd    bnd    value   mean    type    SD      phase   var     dev
   minyr   maxyr   SD      design  switch
### Mortality
0.05     0.4    0.2     -1.609438 3     0.1     4       0       0       0
         0       0       0       0       # M
### Growth parameters ignored in empirical input approach
2       15      5       32      -1      99      -5      0       0       0
         0       0       0       0       # A0
45      60      53.2    50      -1      99      -3      0       0       0
         0       0       0       0       # Linf
0.2     0.4     0.30    0.3     -1      99      -3      0       0       0
         0       0       0       0       # VBK
0.03    0.16    0.066   0.1     -1      99      -5      0       0       0
         0       0       0       0       # CV of len@age 0
0.03    0.16    0.062   0.1     -1      99      -5      0       0       0
         0       0       0       0       # CV of len@age inf
```

```
# W-L, maturity and fecundity parameters
# Female placeholders (wtatage overrides these)
-3      3       7.0E-06 7.0E-06 -1      99      -50     0       0       0
        0       0       0       0       # F W-L slope
-3      3       2.9624  2.9624  -1      99      -50     0       0       0
        0       0       0       0       # F W-L exponent
# Maturity ok from 2010 assessment
-3      43      36.89   36.89   -1      99      -50     0       0       0
        0       0       0       0       # L at 50% maturity
-3      3       -0.48   -0.48   -1      99      -50     0       0       0
        0       0       0       0       # F Logistic maturity slope
# No fecundity relationship
-3      3       1.0     1.0     -1      99      -50     0       0       0
        0       0       0       0       # F Eggs/gm intercept
-3      3       0.0     0.0     -1      99      -50     0       0       0
        0       0       0       0       # F Eggs/gm slope
# Unused recruitment interactions
0       2       1       1       -1      99      -50     0       0       0
        0       0       0       0       # placeholder only
0       2       1       1       -1      99      -50     0       0       0
        0       0       0       0       # placeholder only
0       2       1       1       -1      99      -50     0       0       0
        0       0       0       0       # placeholder only
0       2       1       1       -1      99      -50     0       0       0
        0       0       0       0       # placeholder only
0 0 0 0 0 0 0 0 0 0 # Unused MGparm_seas_effects

# Spawner-recruit parameters
3 # S-R function: 1=B-H w/flat top, 2=Ricker, 3=standard B-H, 4=no
   steepness or bias adjustment
# Lo    Hi      Init    Prior   Prior   Prior   Param
# bnd   bnd     value   mean    type    SD      phase
13      17      15.9    15      -1      99      1       # Ln(R0)
0.2     1       0.88    0.777   2       0.113   4       # Steepness with
   Myers' prior
1.0     1.6     1.4     1.1     -1      99      -6      # Sigma-R
-5      5       0       0       -1      99      -50     # Env link
   coefficient
-5      5       0       0       -1      99      -50     # Initial
   equilibrium recruitment offset
 0      2       0       1       -1      99      -50     # Autocorrelation
   in rec devs
0 # index of environmental variable to be used
0 # SR environmental target: 0=none;1=devs;_2=R0;_3=steepness
1 # Recruitment deviation type: 0=none; 1=devvector; 2=simple deviations

# Recruitment deviations
1970    # Start year standard recruitment devs
2014    # End year standard recruitment devs
1       # Rec Dev phase

1 # Read 11 advanced recruitment options: 0=no, 1=yes
1946    # Start year for early rec devs
3       # Phase for early rec devs
```

```
5       # Phase for forecast recruit deviations
1       # Lambda for forecast recr devs before endyr+1
1965    # Last recruit dev with no bias_adjustment
1971    # First year of full bias correction (linear ramp from year above)
2013    # Last year for full bias correction in_MPD
2016    # First_recent_yr_nobias_adj_in_MPD
0.87    # Maximum bias adjustment in MPD
0       # Period of cycles in recruitment (N parms read below)
-6      # Lower bound rec devs
6       # Upper bound rec devs
0       # Read init values for rec devs

# Fishing mortality setup
0.1     # F ballpark for tuning early phases
-1999   # F ballpark year
1       # F method:  1=Pope's; 2=Instan. F; 3=Hybrid
0.95    # Max F or harvest rate (depends on F_Method)

# Init F parameters by fleet
#LO     HI      INIT    PRIOR   PR_type SD      PHASE
0       1       0.0     0.01    -1      99       -50

# Catchability setup
# A=do power: 0=skip, survey is prop. to abundance, 1= add par for
   non-linearity
# B=env. link: 0=skip, 1= add par for env. effect on Q
# C=extra SD: 0=skip, 1= add par. for additive constant to input SE (in
   ln space)
# D=type: <0=mirror lower abs(#) fleet, 0=no par Q is median unbiased,
   1=no par Q is mean unbiased, 2=estimate par for ln(Q)
#          3=ln(Q) + set of devs about ln(Q) for all years. 4=ln(Q) + set
   of devs about Q for indexyr-1
#A      B       C       D
0       0       0       0        # Fishery
0       0       1       0        # Survey

#LO     HI      INIT    PRIOR   PR_type SD      PHASE
0.05    1.2     0.0755  0.0755  -1      0.1     4 # additive value for
   acoustic survey

#_SELEX_&_RETENTION_PARAMETERS
# Size-based setup
# A=Selex option: 1-24
# B=Do_retention: 0=no, 1=yes
# C=Male offset to female: 0=no, 1=yes
# D=Extra input (#)
# A B C D
# Size selectivity
0       0       0       0  # Fishery
0       0       0       0  # Acoustic_Survey
# Age selectivity
17      0       0       20  # Fishery
17      0       0       20  # Acoustic_Survey
```

```
# Selectivity parameters
# Lo    Hi      Init    Prior   Prior   Prior   Param   Env     Use
   Dev     Dev     Dev     Block   block
# bnd   bnd     value   mean    type    SD      phase   var     dev
   minyr   maxyr   SD      design  switch
# Fishery age-based
  -1002 3       -1000   -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   0.0 at age 0
  -1    1        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Age 1 is Reference
  -5    9        2.8    -1      -1      0.01    2       0 2 1991 2016
   0.20 0 0 # Change to age 2
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2016
   0.20 0 0 # Change to age 3
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2016
   0.20 0 0 # Change to age 4
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2016
   0.20 0 0 # Change to age 5
  -5    9        0.0    -1      -1      0.01    2       0 2 1991 2016
   0.20 0 0 # Change to age 6
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 7
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 8
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 9
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 10
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 11
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 12
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 13
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 14
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 15
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 16
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 17
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 18
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 19
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 20

# Acoustic survey - nonparametric age-based selectivity
  -1002 3       -1000   -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   0.0 at age 0
  -1002 3       -1000   -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   0.0 at age 1
```

```
  -1    1         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Age 2 is reference
  -5    9         0.1    -1      -1      0.01    2       0 0 0 0 0 0 0 #
   Change to age 3
  -5    9         0.1    -1      -1      0.01    2       0 0 0 0 0 0 0 #
   Change to age 4
  -5    9         0.0    -1      -1      0.01    2       0 0 0 0 0 0 0 #
   Change to age 5
  -5    9         0.0    -1      -1      0.01    2       0 0 0 0 0 0 0 #
   Change to age 6
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 7
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 8
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 9
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 10
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 11
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 12
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 13
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 14
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 15
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 16
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 17
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 18
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 19
  -5    9         0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 #
   Change to age 20

4 #selparm_dev_PH
2 #_env/block/dev_adjust_method (1=standard; 2=logistic trans to keep in
   base parm bounds; 3=standard w/ no bound check)
0 # Tagging flag: 0=no tagging parameters,1=read tagging parameters

### Likelihood related quantities ###
1 # Do variance/sample size adjustments by fleet (1)
# # Component
 0    0   # Constant added to index CV
 0    0   # Constant added to discard SD
 0    0   # Constant added to body weight SD
 1    1   # multiplicative scalar for length comps
 0.14 0.41 # multiplicative scalar for agecomps
 1    1   # multiplicative scalar for length at age obs
```

```
1  # Lambda phasing: 1=none, 2+=change beginning in phase 1
1  # Growth offset likelihood constant for Log(s): 1=include, 2=not
0  # N changes to default Lambdas = 1.0
1  # Extra SD reporting switch
2  2 -1 15 # selex type (fleet), len=1/age=2, year, N selex bins (4
   values)
1  1    # Growth pattern, N growth ages (2 values)
1 -1  1 # NatAge_area(-1 for all), NatAge_yr, N Natages (3 values)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 # placeholder for vector of selex
   bins to be reported
-1 # growth ages
-1 # NatAges

999 # End control file
```

H STOCK SYNTHESIS STARTER FILE

../models/45_BasePreSRG_v4/starter.ss

```
#C 2017 Hake starter file
###################################################

2017hake_data.SS        # Data file
2017hake_control.SS     # Control file

0       # Read initial values from .par file: 0=no,1=yes
1       # DOS display detail: 0,1,2
2       # Report file detail: 0,1,2
0       # Detailed checkup.sso file (0,1)
0       # Write parameter iteration trace file during minimization
0       # Write cumulative report: 0=skip,1=short,2=full
0       # Include prior likelihood for non-estimated parameters
0       # Use Soft Boundaries to aid convergence (0,1) (recommended)
1       # N bootstrap datafiles to create
25      # Last phase for estimation
1       # MCMC burn-in
1       # MCMC thinning interval
0       # Jitter initial parameter values by this fraction
-1      # Min year for spbio sd_report (neg val = styr-2, virgin state)
-2      # Max year for spbio sd_report (neg val = endyr+1)
0       # N individual SD years
0.00001 # Ending convergence criteria
0       # Retrospective year relative to end year
3       # Min age for summary biomass
1       # Depletion basis: denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy;
   3=rel X*B_styr
1.0     # Fraction (X) for Depletion denominator (e.g. 0.4)
1       # (1-SPR)_reporting:  0=skip; 1=rel(1-SPR); 2=rel(1-SPR_MSY);
   3=rel(1-SPR_Btarget); 4=notrel
1       # F_std reporting: 0=skip; 1=exploit(Bio); 2=exploit(Num);
   3=sum(frates)
0       # F_report_basis: 0=raw; 1=rel Fspr; 2=rel Fmsy ; 3=rel Fbtgt

999 # end of file marker
```

I STOCK SYNTHESIS FORECAST FILE

../models/45_BasePreSRG_v4/forecast.ss

```
#C 2017 Hake forecast file - pre-SRG
###################################################

1       # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2       # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set
   to F(endyr)
0.4     # SPR target (e.g. 0.40)
0.4     # Biomass target (e.g. 0.40)
# Enter either: actual year, -999 for styr, 0 for endyr, neg number for
   rel. endyr
-999 -999 -999 -999 -999 -999 # Bmark_years: beg_bio end_bio beg_selex
   end_selex beg_alloc end_alloc
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); 4=Ave F (use
   first-last alloc yrs); 5=input annual F
3       # N forecast years
1.0     # F scalar (only used for Do_Forecast==5)
# Enter either: actual year, -999 for styr, 0 for endyr, neg number for
   rel. endyr
-4 0 -4 0 # Fcast_years:  beg_selex end_selex beg_alloc end_alloc
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)
0.1     # Control rule Biomass level for no F (as frac of Bzero, e.g.
   0.10)
1.0     # Control rule target as fraction of Flimit (e.g. 0.75)
3       # N forecast loops (1-3) (fixed at 3 for now)
3       # First forecast loop with stochastic recruitment
-1      # Forecast loop control #3 (reserved)
0       #_Forecast loop control #4 (reserved for future bells&whistles)
0       #_Forecast loop control #5 (reserved for future bells&whistles)
2019    # FirstYear for caps and allocations (should be after any fixed
   inputs)
0.0     # stddev of log(realized catch/target catch) in forecast
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(row) x fleet(col) below
2       # basis for fcast catch tuning and for fcast catch caps and
   allocation  (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
-1      # max totalcatch by fleet (-1 to have no max)
-1      # max totalcatch by area (-1 to have no max)
1       # fleet assignment to allocation group (enter group ID# for each
   fleet, 0 for not included in an alloc group)
# assign fleets to groups
1.0
```

```
# allocation fraction for each of: 2 allocation groups
0 # Number of forecast catch levels to input (else calc catch from
   forecast F)
2 # basis for input Fcast catch:  2=dead catch; 3=retained catch;
   99=input Hrate(F) (units are from fleetunits; note new codes in
   SSV3.20)

999 # verify end of input
```

J STOCK SYNTHESIS WEIGHT-AT-AGE FILE

../models/45_BasePreSRG_v4/wtatage.ss

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2017-01-10 13:29:00
###################################################
173 # Number of lines of weight-at-age input to be read
20 # Maximum age

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

 #_#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 0.1003 0.2535 0.3992 0.518 0.6131
   0.6895 0.7511 0.8007 0.8406 0.8724 0.8979 0.9181 0.9342 0.9469 0.9569
   0.9649 0.9711 0.9761 0.983
#All matrices below use the same values, pooled across all data sources

#Weight at age for population in middle of the year: Fleet = -1
 #_#Yr seas gender GP bseas fleet     a0     a1     a2     a3     a4
   a5     a6     a7     a8     a9    a10    a11    a12    a13    a14
   a15    a16    a17    a18    a19    a20
 -1940    1      1  1     1    -1 0.0169 0.0848 0.2445 0.3698 0.4772
   0.5288 0.5853 0.6624 0.7212 0.7840 0.8524 0.9291 0.9760 1.0603 1.0126
   1.0391 1.0391 1.0391 1.0391 1.0391 1.0391
  1975    1      1  1     1    -1 0.0550 0.1575 0.2987 0.3658 0.6143
   0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555
   2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
  1976    1      1  1     1    -1 0.0550 0.0986 0.2359 0.4990 0.5188
   0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507 1.8066 1.8588 1.9555
   2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
  1977    1      1  1     1    -1 0.0550 0.0855 0.4020 0.4882 0.5902
   0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148 1.4027 1.7511 2.1005
   2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1      1  1     1    -1 0.0517 0.0725 0.1275 0.4699 0.5302
   0.6026 0.6392 0.7397 0.8422 0.9811 1.0997 1.2459 1.3295 1.4814 1.7419
   2.3353 2.3353 2.3353 2.3353 2.3353 2.3353
  1979    1      1  1     1    -1 0.0484 0.0763 0.2410 0.2587 0.5821
   0.6868 0.7677 0.8909 0.9128 1.0369 1.1987 1.2482 1.5326 1.5520 1.7950
   1.9817 1.9817 1.9817 1.9817 1.9817 1.9817
  1980    1      1  1     1    -1 0.0452 0.0800 0.2125 0.4529 0.3922
   0.4904 0.5166 0.6554 0.7136 0.8740 1.0626 1.1623 1.2898 1.3001 1.2699
   1.3961 1.3961 1.3961 1.3961 1.3961 1.3961
  1981    1      1  1     1    -1 0.0419 0.1074 0.2137 0.3422 0.5264
   0.3933 0.5254 0.5462 0.7464 0.7204 0.8231 1.0413 1.0989 1.3449 1.4926
   1.2128 1.2128 1.2128 1.2128 1.2128 1.2128
  1982    1      1  1     1    -1 0.0386 0.1181 0.2465 0.3336 0.3097
   0.5496 0.3956 0.5275 0.5629 0.7606 0.6837 0.8539 1.0670 0.8793 1.0186
   1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
  1983    1      1  1     1    -1 0.0353 0.1287 0.1357 0.3410 0.3694
```

```
 0.3277 0.5200 0.5028 0.6179 0.7060 0.8800 0.9299 1.0356 1.0310 1.3217
 1.4823 1.4823 1.4823 1.4823 1.4823 1.4823
1984    1     1  1    1    -1 0.0321 0.1315 0.1642 0.2493 0.4384
 0.4113 0.4352 0.5872 0.5802 0.6758 0.7010 0.9513 1.1364 1.0258 1.2807
 1.8800 1.8800 1.8800 1.8800 1.8800 1.8800
1985    1     1  1    1    -1 0.0288 0.1740 0.2297 0.2679 0.4414
 0.5496 0.5474 0.6017 0.7452 0.6933 0.7231 0.8584 0.8698 0.9458 0.6759
 1.1217 1.1217 1.1217 1.1217 1.1217 1.1217
1986    1     1  1    1    -1 0.0255 0.1555 0.2780 0.2906 0.3024
 0.3735 0.5426 0.5720 0.6421 0.8209 0.9403 1.1860 1.1900 1.3737 1.6800
 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
1987    1     1  1    1    -1 0.0222 0.1478 0.1388 0.3790 0.2786
 0.2870 0.3621 0.5775 0.5975 0.6369 0.7638 0.9820 0.9250 1.2407 1.2031
 1.4157 1.4157 1.4157 1.4157 1.4157 1.4157
1988    1     1  1    1    -1 0.0190 0.1400 0.1870 0.3189 0.4711
 0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989    1     1  1    1    -1 0.0157 0.1389 0.2737 0.3047 0.2931
 0.5134 0.4386 0.4064 0.5167 0.6263 0.6611 0.6027 0.8758 0.6686 0.8282
 1.1264 1.1264 1.1264 1.1264 1.1264 1.1264
1990    1     1  1    1    -1 0.0156 0.1378 0.2435 0.3506 0.3906
 0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991    1     1  1    1    -1 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1     1  1    1    -1 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993    1     1  1    1    -1 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994    1     1  1    1    -1 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995    1     1  1    1    -1 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996    1     1  1    1    -1 0.0153 0.1007 0.2876 0.3982 0.4674
 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997    1     1  1    1    -1 0.0153 0.0906 0.3555 0.4322 0.4931
 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998    1     1  1    1    -1 0.0152 0.0805 0.2091 0.3539 0.5041
 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999    1     1  1    1    -1 0.0152 0.1352 0.2502 0.3455 0.4251
 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000    1     1  1    1    -1 0.0151 0.1899 0.3216 0.4729 0.5766
 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001    1     1  1    1    -1 0.0151 0.0512 0.2867 0.4843 0.6527
```

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

#Weight at age for population at beginning of the year: Fleet = 0
 #_#Yr seas gender GP bseas fleet     a0     a1     a2     a3     a4
   a5     a6     a7     a8     a9    a10    a11    a12    a13    a14
   a15    a16    a17    a18    a19    a20
 -1940    1      1  1     1     0 0.0169 0.0848 0.2445 0.3698 0.4772
   0.5288 0.5853 0.6624 0.7212 0.7840 0.8524 0.9291 0.9760 1.0603 1.0126
```

```
 1.0391 1.0391 1.0391 1.0391 1.0391 1.0391
1975    1       1  1     1      0 0.0550 0.1575 0.2987 0.3658 0.6143
 0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555
 2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
1976    1       1  1     1      0 0.0550 0.0986 0.2359 0.4990 0.5188
 0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507 1.8066 1.8588 1.9555
 2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
1977    1       1  1     1      0 0.0550 0.0855 0.4020 0.4882 0.5902
 0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148 1.4027 1.7511 2.1005
 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
1978    1       1  1     1      0 0.0517 0.0725 0.1275 0.4699 0.5302
 0.6026 0.6392 0.7397 0.8422 0.9811 1.0997 1.2459 1.3295 1.4814 1.7419
 2.3353 2.3353 2.3353 2.3353 2.3353 2.3353
1979    1       1  1     1      0 0.0484 0.0763 0.2410 0.2587 0.5821
 0.6868 0.7677 0.8909 0.9128 1.0369 1.1987 1.2482 1.5326 1.5520 1.7950
 1.9817 1.9817 1.9817 1.9817 1.9817 1.9817
1980    1       1  1     1      0 0.0452 0.0800 0.2125 0.4529 0.3922
 0.4904 0.5166 0.6554 0.7136 0.8740 1.0626 1.1623 1.2898 1.3001 1.2699
 1.3961 1.3961 1.3961 1.3961 1.3961 1.3961
1981    1       1  1     1      0 0.0419 0.1074 0.2137 0.3422 0.5264
 0.3933 0.5254 0.5462 0.7464 0.7204 0.8231 1.0413 1.0989 1.3449 1.4926
 1.2128 1.2128 1.2128 1.2128 1.2128 1.2128
1982    1       1  1     1      0 0.0386 0.1181 0.2465 0.3336 0.3097
 0.5496 0.3956 0.5275 0.5629 0.7606 0.6837 0.8539 1.0670 0.8793 1.0186
 1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
1983    1       1  1     1      0 0.0353 0.1287 0.1357 0.3410 0.3694
 0.3277 0.5200 0.5028 0.6179 0.7060 0.8800 0.9299 1.0356 1.0310 1.3217
 1.4823 1.4823 1.4823 1.4823 1.4823 1.4823
1984    1       1  1     1      0 0.0321 0.1315 0.1642 0.2493 0.4384
 0.4113 0.4352 0.5872 0.5802 0.6758 0.7010 0.9513 1.1364 1.0258 1.2807
 1.8800 1.8800 1.8800 1.8800 1.8800 1.8800
1985    1       1  1     1      0 0.0288 0.1740 0.2297 0.2679 0.4414
 0.5496 0.5474 0.6017 0.7452 0.6933 0.7231 0.8584 0.8698 0.9458 0.6759
 1.1217 1.1217 1.1217 1.1217 1.1217 1.1217
1986    1       1  1     1      0 0.0255 0.1555 0.2780 0.2906 0.3024
 0.3735 0.5426 0.5720 0.6421 0.8209 0.9403 1.1860 1.1900 1.3737 1.6800
 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
1987    1       1  1     1      0 0.0222 0.1478 0.1388 0.3790 0.2786
 0.2870 0.3621 0.5775 0.5975 0.6369 0.7638 0.9820 0.9250 1.2407 1.2031
 1.4157 1.4157 1.4157 1.4157 1.4157 1.4157
1988    1       1  1     1      0 0.0190 0.1400 0.1870 0.3189 0.4711
 0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989    1       1  1     1      0 0.0157 0.1389 0.2737 0.3047 0.2931
 0.5134 0.4386 0.4064 0.5167 0.6263 0.6611 0.6027 0.8758 0.6686 0.8282
 1.1264 1.1264 1.1264 1.1264 1.1264 1.1264
1990    1       1  1     1      0 0.0156 0.1378 0.2435 0.3506 0.3906
 0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991    1       1  1     1      0 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1       1  1     1      0 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
```

```
 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993    1      1  1     1     0 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994    1      1  1     1     0 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995    1      1  1     1     0 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996    1      1  1     1     0 0.0153 0.1007 0.2876 0.3982 0.4674
 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997    1      1  1     1     0 0.0153 0.0906 0.3555 0.4322 0.4931
 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998    1      1  1     1     0 0.0152 0.0805 0.2091 0.3539 0.5041
 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999    1      1  1     1     0 0.0152 0.1352 0.2502 0.3455 0.4251
 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000    1      1  1     1     0 0.0151 0.1899 0.3216 0.4729 0.5766
 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001    1      1  1     1     0 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
 0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
2002    1      1  1     1     0 0.0150 0.0756 0.3583 0.4575 0.6058
 0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974 0.9890 0.9236 1.1250
 1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
2003    1      1  1     1     0 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887 0.9266 0.7894 0.8414
 0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
2004    1      1  1     1     0 0.0149 0.1081 0.2000 0.4360 0.4807
 0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581 0.7715 0.9704 0.8631
 0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
2005    1      1  1     1     0 0.0149 0.1162 0.2603 0.4311 0.5086
 0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104 0.8109 0.7602 1.1449
 0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
2006    1      1  1     1     0 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220 0.7753 0.6580 0.6399
 0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
2007    1      1  1     1     0 0.0148 0.0445 0.2272 0.3776 0.5352
 0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627 0.8137 0.8702 0.8008
 0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008    1      1  1     1     0 0.0148 0.1346 0.2440 0.4079 0.5630
 0.6365 0.6865 0.6818 0.7098 0.7211 0.7488 0.8073 0.8483 0.7755 0.8834
 0.8332 0.8332 0.8332 0.8332 0.8332 0.8332
2009    1      1  1     1     0 0.0148 0.0667 0.2448 0.3431 0.4712
 0.6371 0.6702 0.6942 0.7463 0.8226 0.7674 0.8139 1.0147 0.8503 0.9582
 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
2010    1      1  1     1     0 0.0148 0.1089 0.2326 0.2918 0.4332
 0.5302 0.6582 0.8349 1.0828 1.0276 0.9582 0.8763 0.8524 1.1253 0.7200
```

```
    0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
   2011    1       1  1      1      0 0.0148 0.0844 0.2457 0.3219 0.3867
    0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
    0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
   2012    1       1  1      1      0 0.0148 0.1290 0.2145 0.3536 0.4094
    0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
    0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
   2013    1       1  1      1      0 0.0148 0.1297 0.2874 0.3595 0.4697
    0.5104 0.6260 0.7165 0.7310 0.8313 0.9989 1.0752 1.2303 1.1187 1.0682
    1.0545 1.0545 1.0545 1.0545 1.0545 1.0545
   2014    1       1  1      1      0 0.0148 0.1028 0.4080 0.4686 0.4797
    0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
    1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
   2015    1       1  1      1      0 0.0148 0.0759 0.2471 0.3905 0.4445
    0.4708 0.5531 0.5948 0.6749 0.6879 0.7179 0.8337 0.9523 1.0185 1.0893
    1.2493 1.2493 1.2493 1.2493 1.2493 1.2493
   2016    1       1  1      1      0 0.0148 0.1653 0.2439 0.3831 0.4159
    0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
    1.5802 1.5802 1.5802 1.5802 1.5802 1.5802

#Weight at age for Fishery: Fleet = 1
 #_#Yr seas gender GP bseas fleet      a0      a1      a2      a3      a4
    a5      a6      a7      a8      a9     a10     a11     a12     a13     a14
    a15     a16     a17     a18     a19    a20
 -1940    1       1  1      1      1 0.0169 0.0848 0.2445 0.3698 0.4772
    0.5288 0.5853 0.6624 0.7212 0.7840 0.8524 0.9291 0.9760 1.0603 1.0126
    1.0391 1.0391 1.0391 1.0391 1.0391 1.0391
   1975    1       1  1      1      1 0.0550 0.1575 0.2987 0.3658 0.6143
    0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555
    2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
   1976    1       1  1      1      1 0.0550 0.0986 0.2359 0.4990 0.5188
    0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507 1.8066 1.8588 1.9555
    2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
   1977    1       1  1      1      1 0.0550 0.0855 0.4020 0.4882 0.5902
    0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148 1.4027 1.7511 2.1005
    2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
   1978    1       1  1      1      1 0.0517 0.0725 0.1275 0.4699 0.5302
    0.6026 0.6392 0.7397 0.8422 0.9811 1.0997 1.2459 1.3295 1.4814 1.7419
    2.3353 2.3353 2.3353 2.3353 2.3353 2.3353
   1979    1       1  1      1      1 0.0484 0.0763 0.2410 0.2587 0.5821
    0.6868 0.7677 0.8909 0.9128 1.0369 1.1987 1.2482 1.5326 1.5520 1.7950
    1.9817 1.9817 1.9817 1.9817 1.9817 1.9817
   1980    1       1  1      1      1 0.0452 0.0800 0.2125 0.4529 0.3922
    0.4904 0.5166 0.6554 0.7136 0.8740 1.0626 1.1623 1.2898 1.3001 1.2699
    1.3961 1.3961 1.3961 1.3961 1.3961 1.3961
   1981    1       1  1      1      1 0.0419 0.1074 0.2137 0.3422 0.5264
    0.3933 0.5254 0.5462 0.7464 0.7204 0.8231 1.0413 1.0989 1.3449 1.4926
    1.2128 1.2128 1.2128 1.2128 1.2128 1.2128
   1982    1       1  1      1      1 0.0386 0.1181 0.2465 0.3336 0.3097
    0.5496 0.3956 0.5275 0.5629 0.7606 0.6837 0.8539 1.0670 0.8793 1.0186
    1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
   1983    1       1  1      1      1 0.0353 0.1287 0.1357 0.3410 0.3694
    0.3277 0.5200 0.5028 0.6179 0.7060 0.8800 0.9299 1.0356 1.0310 1.3217
    1.4823 1.4823 1.4823 1.4823 1.4823 1.4823
```

```
1984    1       1  1     1     1 0.0321 0.1315 0.1642 0.2493 0.4384
 0.4113 0.4352 0.5872 0.5802 0.6758 0.7010 0.9513 1.1364 1.0258 1.2807
 1.8800 1.8800 1.8800 1.8800 1.8800 1.8800
1985    1       1  1     1     1 0.0288 0.1740 0.2297 0.2679 0.4414
 0.5496 0.5474 0.6017 0.7452 0.6933 0.7231 0.8584 0.8698 0.9458 0.6759
 1.1217 1.1217 1.1217 1.1217 1.1217 1.1217
1986    1       1  1     1     1 0.0255 0.1555 0.2780 0.2906 0.3024
 0.3735 0.5426 0.5720 0.6421 0.8209 0.9403 1.1860 1.1900 1.3737 1.6800
 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
1987    1       1  1     1     1 0.0222 0.1478 0.1388 0.3790 0.2786
 0.2870 0.3621 0.5775 0.5975 0.6369 0.7638 0.9820 0.9250 1.2407 1.2031
 1.4157 1.4157 1.4157 1.4157 1.4157 1.4157
1988    1       1  1     1     1 0.0190 0.1400 0.1870 0.3189 0.4711
 0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989    1       1  1     1     1 0.0157 0.1389 0.2737 0.3047 0.2931
 0.5134 0.4386 0.4064 0.5167 0.6263 0.6611 0.6027 0.8758 0.6686 0.8282
 1.1264 1.1264 1.1264 1.1264 1.1264 1.1264
1990    1       1  1     1     1 0.0156 0.1378 0.2435 0.3506 0.3906
 0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991    1       1  1     1     1 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1       1  1     1     1 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993    1       1  1     1     1 0.0155 0.1274 0.2486 0.3384 0.3960
 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994    1       1  1     1     1 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995    1       1  1     1     1 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996    1       1  1     1     1 0.0153 0.1007 0.2876 0.3982 0.4674
 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997    1       1  1     1     1 0.0153 0.0906 0.3555 0.4322 0.4931
 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998    1       1  1     1     1 0.0152 0.0805 0.2091 0.3539 0.5041
 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999    1       1  1     1     1 0.0152 0.1352 0.2502 0.3455 0.4251
 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000    1       1  1     1     1 0.0151 0.1899 0.3216 0.4729 0.5766
 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001    1       1  1     1     1 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
 0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
```

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

#Weight at age for Survey: Fleet = 2
 #_#Yr seas gender GP bseas fleet     a0     a1     a2     a3     a4
   a5     a6     a7     a8     a9    a10    a11    a12    a13    a14
   a15    a16    a17    a18    a19    a20
 -1940    1       1  1     1     2 0.0169 0.0848 0.2445 0.3698 0.4772
   0.5288 0.5853 0.6624 0.7212 0.7840 0.8524 0.9291 0.9760 1.0603 1.0126
   1.0391 1.0391 1.0391 1.0391 1.0391 1.0391
  1975    1       1  1     1     2 0.0550 0.1575 0.2987 0.3658 0.6143
```

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 0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555
 2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
1976    1      1  1    1     2 0.0550 0.0986 0.2359 0.4990 0.5188
 0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507 1.8066 1.8588 1.9555
 2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
1977    1      1  1    1     2 0.0550 0.0855 0.4020 0.4882 0.5902
 0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148 1.4027 1.7511 2.1005
 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
1978    1      1  1    1     2 0.0517 0.0725 0.1275 0.4699 0.5302
 0.6026 0.6392 0.7397 0.8422 0.9811 1.0997 1.2459 1.3295 1.4814 1.7419
 2.3353 2.3353 2.3353 2.3353 2.3353 2.3353
1979    1      1  1    1     2 0.0484 0.0763 0.2410 0.2587 0.5821
 0.6868 0.7677 0.8909 0.9128 1.0369 1.1987 1.2482 1.5326 1.5520 1.7950
 1.9817 1.9817 1.9817 1.9817 1.9817 1.9817
1980    1      1  1    1     2 0.0452 0.0800 0.2125 0.4529 0.3922
 0.4904 0.5166 0.6554 0.7136 0.8740 1.0626 1.1623 1.2898 1.3001 1.2699
 1.3961 1.3961 1.3961 1.3961 1.3961 1.3961
1981    1      1  1    1     2 0.0419 0.1074 0.2137 0.3422 0.5264
 0.3933 0.5254 0.5462 0.7464 0.7204 0.8231 1.0413 1.0989 1.3449 1.4926
 1.2128 1.2128 1.2128 1.2128 1.2128 1.2128
1982    1      1  1    1     2 0.0386 0.1181 0.2465 0.3336 0.3097
 0.5496 0.3956 0.5275 0.5629 0.7606 0.6837 0.8539 1.0670 0.8793 1.0186
 1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
1983    1      1  1    1     2 0.0353 0.1287 0.1357 0.3410 0.3694
 0.3277 0.5200 0.5028 0.6179 0.7060 0.8800 0.9299 1.0356 1.0310 1.3217
 1.4823 1.4823 1.4823 1.4823 1.4823 1.4823
1984    1      1  1    1     2 0.0321 0.1315 0.1642 0.2493 0.4384
 0.4113 0.4352 0.5872 0.5802 0.6758 0.7010 0.9513 1.1364 1.0258 1.2807
 1.8800 1.8800 1.8800 1.8800 1.8800 1.8800
1985    1      1  1    1     2 0.0288 0.1740 0.2297 0.2679 0.4414
 0.5496 0.5474 0.6017 0.7452 0.6933 0.7231 0.8584 0.8698 0.9458 0.6759
 1.1217 1.1217 1.1217 1.1217 1.1217 1.1217
1986    1      1  1    1     2 0.0255 0.1555 0.2780 0.2906 0.3024
 0.3735 0.5426 0.5720 0.6421 0.8209 0.9403 1.1860 1.1900 1.3737 1.6800
 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
1987    1      1  1    1     2 0.0222 0.1478 0.1388 0.3790 0.2786
 0.2870 0.3621 0.5775 0.5975 0.6369 0.7638 0.9820 0.9250 1.2407 1.2031
 1.4157 1.4157 1.4157 1.4157 1.4157 1.4157
1988    1      1  1    1     2 0.0190 0.1400 0.1870 0.3189 0.4711
 0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211 1.0924 1.0225 1.4500
 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
1989    1      1  1    1     2 0.0157 0.1389 0.2737 0.3047 0.2931
 0.5134 0.4386 0.4064 0.5167 0.6263 0.6611 0.6027 0.8758 0.6686 0.8282
 1.1264 1.1264 1.1264 1.1264 1.1264 1.1264
1990    1      1  1    1     2 0.0156 0.1378 0.2435 0.3506 0.3906
 0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312 2.2000 1.1847 1.0166
 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
1991    1      1  1    1     2 0.0156 0.1367 0.2754 0.3697 0.4598
 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 1.0174 1.2051
 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
1992    1      1  1    1     2 0.0155 0.1356 0.2316 0.3473 0.4743
 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750
 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
1993    1      1  1    1     2 0.0155 0.1274 0.2486 0.3384 0.3960
```

```
 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630 1.0250 0.6135 0.5995
 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
1994    1       1  1     1     2 0.0154 0.1191 0.3000 0.3626 0.4469
 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850 0.6491 0.7300 0.7013
 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
1995    1       1  1     1     2 0.0154 0.1108 0.2682 0.3418 0.4876
 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445 0.7998 0.9101 0.6804
 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
1996    1       1  1     1     2 0.0153 0.1007 0.2876 0.3982 0.4674
 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500 0.6756 0.8109 1.4853
 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
1997    1       1  1     1     2 0.0153 0.0906 0.3555 0.4322 0.4931
 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633 0.5946 0.7118 0.6618
 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
1998    1       1  1     1     2 0.0152 0.0805 0.2091 0.3539 0.5041
 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174 0.8100 0.7733 0.7510
 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
1999    1       1  1     1     2 0.0152 0.1352 0.2502 0.3455 0.4251
 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989 0.7554 0.8787 0.7348
 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
2000    1       1  1     1     2 0.0151 0.1899 0.3216 0.4729 0.5766
 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814 0.8554 0.9391 0.8744
 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
2001    1       1  1     1     2 0.0151 0.0512 0.2867 0.4843 0.6527
 0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790 1.0054 1.0494 0.9927
 0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
2002    1       1  1     1     2 0.0150 0.0756 0.3583 0.4575 0.6058
 0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974 0.9890 0.9236 1.1250
 1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
2003    1       1  1     1     2 0.0150 0.1000 0.2551 0.4355 0.5225
 0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887 0.9266 0.7894 0.8414
 0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
2004    1       1  1     1     2 0.0149 0.1081 0.2000 0.4360 0.4807
 0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581 0.7715 0.9704 0.8631
 0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
2005    1       1  1     1     2 0.0149 0.1162 0.2603 0.4311 0.5086
 0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104 0.8109 0.7602 1.1449
 0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
2006    1       1  1     1     2 0.0148 0.1324 0.3831 0.4575 0.5341
 0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220 0.7753 0.6580 0.6399
 0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
2007    1       1  1     1     2 0.0148 0.0445 0.2272 0.3776 0.5352
 0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627 0.8137 0.8702 0.8008
 0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
2008    1       1  1     1     2 0.0148 0.1346 0.2440 0.4079 0.5630
 0.6365 0.6865 0.6818 0.7098 0.7211 0.7488 0.8073 0.8483 0.7755 0.8834
 0.8332 0.8332 0.8332 0.8332 0.8332 0.8332
2009    1       1  1     1     2 0.0148 0.0667 0.2448 0.3431 0.4712
 0.6371 0.6702 0.6942 0.7463 0.8226 0.7674 0.8139 1.0147 0.8503 0.9582
 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
2010    1       1  1     1     2 0.0148 0.1089 0.2326 0.2918 0.4332
 0.5302 0.6582 0.8349 1.0828 1.0276 0.9582 0.8763 0.8524 1.1253 0.7200
 0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
2011    1       1  1     1     2 0.0148 0.0844 0.2457 0.3219 0.3867
```

```
    0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749 1.0588 1.0279 1.0557
    0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1      1  1    1     2 0.0148 0.1290 0.2145 0.3536 0.4094
    0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639 0.9639 0.9889 0.9924
    0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
  2013    1      1  1    1     2 0.0148 0.1297 0.2874 0.3595 0.4697
    0.5104 0.6260 0.7165 0.7310 0.8313 0.9989 1.0752 1.2303 1.1187 1.0682
    1.0545 1.0545 1.0545 1.0545 1.0545 1.0545
  2014    1      1  1    1     2 0.0148 0.1028 0.4080 0.4686 0.4797
    0.5362 0.5741 0.6198 0.6590 0.7174 0.6950 1.1645 1.0150 0.9491 0.9674
    1.0579 1.0579 1.0579 1.0579 1.0579 1.0579
  2015    1      1  1    1     2 0.0148 0.0759 0.2471 0.3905 0.4445
    0.4708 0.5531 0.5948 0.6749 0.6879 0.7179 0.8337 0.9523 1.0185 1.0893
    1.2493 1.2493 1.2493 1.2493 1.2493 1.2493
  2016    1      1  1    1     2 0.0148 0.1653 0.2439 0.3831 0.4159
    0.4406 0.4638 0.5141 0.5164 0.5127 0.6480 0.7198 0.5948 0.7756 1.4510
    1.5802 1.5802 1.5802 1.5802 1.5802 1.5802
# End of wtatage.ss file
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