Agenda Item F.2
Attachment 1
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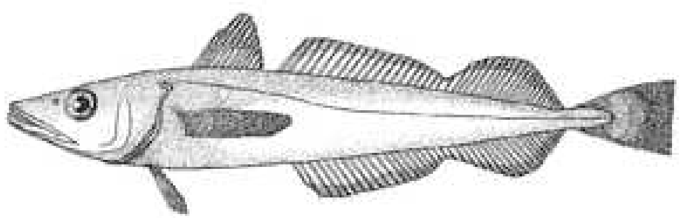
April 2016

Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2016



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

March 1st, 2016

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

Authors of this document are (in no particular order):
Chris J. Grandin[1]
Allan C. Hicks[2]
Aaron M. Berger[3]
Andrew M. Edwards[1]
Nathan Taylor[1]
Ian G. Taylor[2]
Sean Cox[4]

[1]*Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, Canada*

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

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

[4]*School of Resource and Environmental Management, Simon Fraser University, TASC I – Room #8405, 8888 University Drive, Burnaby, B.C. V5A-1S6, Canada*

This document should be cited as follows:
Grandin, C.J., A.C. Hicks, A.M. Berger, A.M. Edwards, N. Taylor, I.G. Taylor, and S. Cox. 2016. Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2016. Prepared by the Joint Technical Committee of the U.S. and Canada Pacific Hake/Whiting Agreement, National Marine Fisheries Service and Fisheries and Oceans Canada. 165 p.

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ONE-PAGE SUMMARY

- The stock assessment model for 2016 is similar in structure to the 2015 model with the addition of fishery age compositions from 2015, new acoustic survey biomass and age composition estimates for 2015, reanalyzed acoustic survey biomass and age compositions from 1998–2013, and minor refinements to data including catch estimates from earlier years.

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

- Coastwide catch in 2015 was 190,663 t, out of a TAC (adjusted for carryovers) of 440,000 t. Attainment in the U.S. was 47.4% of its quota; in Canada it was 31.8%. A variety of factors influenced the attainment of the quota.

- The stock is estimated to be near its highest biomass level since 1990 as a result of estimated large 2010 and 2014 cohorts. The 2014 cohort has only been observed once by the commercial fishery, thus its size is highly uncertain. The survey observed high numbers of age-1 hake in 2015, but those data are not used in the base assessment model.

- The median estimate of 2016 relative spawning biomass (spawning biomass at the start of 2016 divided by that at unfished equilibrium, B_0) is 78.9% but is highly uncertain (with 95% interval from 35.6% to 174.1%).

- The median estimate of 2016 female spawning biomass is 1.885 million t (with 95% interval from 0.791 to 4.781 million t).

- The spawning biomass in 2016 is estimated to have increased from 2015 due to the 2014 year-class likely being well above average size.

- Based on the default harvest rule, the estimated median catch limit for 2016 is 830,124 t (with 95% interval from 309,329 to 1,958,126 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 2016 and 2017 catch equal to the 2015 TAC of 440,000 t show the estimated median relative spawning biomass increasing from 79% in 2016 to 87% in 2017 and again in 2018 to 89%. However, due to uncertainty there is an estimated 10% chance of the spawning biomass falling below 40% of B_0 in two years (2018). There is an estimated 33% chance of the spawning biomass declining from 2016 to 2017, and a 45% chance of it declining from 2017 to 2018 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 2016. 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 224,376 t from 1966 to 2015, 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 168,983 t, or 75.3% of the average total landings, while catch from Canadian waters averaged 55,393 t. Over the last 10 years, 2006–2015 (Table a), the average coastwide catch was 265,707 t

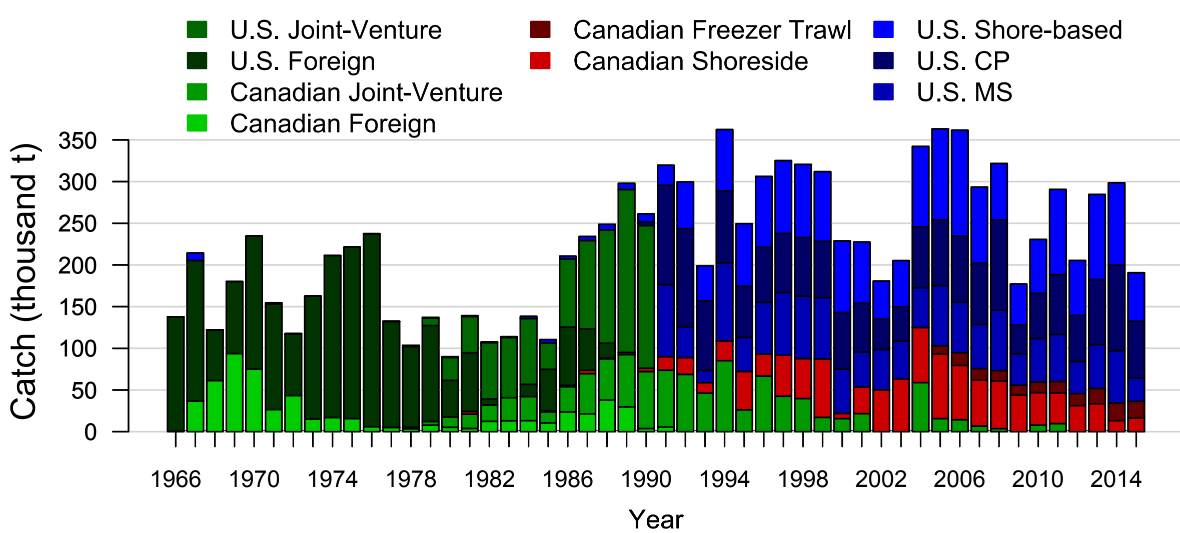

Figure a. Total Pacific Hake catch used in the assessment by sector, 1966–2015. U.S. tribal catches are included in the sectors where they are represented.

Table a. Recent commercial fishery catch (t). Tribal catches are included where applicable.

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	55,390	13,537	75,707	293,389
2008	72,440	108,195	67,760	0	248,395	3,592	57,197	12,517	73,306	321,701
2009	37,550	34,552	49,223	0	121,325	0	43,774	12,073	55,847	177,172
2010	52,022	54,284	64,654	0	170,961	8,081	38,780	12,850	59,712	230,672
2011	56,394	71,678	102,147	1,042	231,262	9,717	36,632	14,060	60,409	291,671
2012	38,512	55,264	65,920	448	160,145	0	31,164	14,478	45,642	205,787
2013	52,470	77,950	102,143	1,018	233,581	0	33,451	18,583	52,033	285,614
2014	62,102	103,203	98,638	197	264,139	0	13,184	21,380	34,563	298,703
2015	27,661	68,484	58,010	0	154,155	0	16,451	20,057	36,507	190,663

with U.S. and Canadian catches averaging 206,860 t and 58,847 t, respectively.

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 (224,376 t) in 2011, 2013 and 2014, 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 from that cohort estimated at apporximately 1.24 million t. Through 2015, the total catch of the 2010 year class is estimated to be about 0.53 million t.

DATA AND ASSESSMENT

The biomass estimate and age composition from the acoustic survey conducted in 2015 have been added to the survey time series (Figure b); earlier survey data (1998–2013) were re-analyzed and updated this year. The only other new data for this 2016 assessment, that were not in the 2015 assessment, are the 2015 fishery age compositions (and minor refinements to historical catch estimates were made). Total catch and empirical weight-at-age for 2015 are also added to the assessment model this year, but are fixed and not included in the model fitting procedure. 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 (1966–2015), acoustic survey biomass estimates (Figure b) and age-compositions (1998–2015), as well as fishery age-compositions (1975–2015). 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, 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

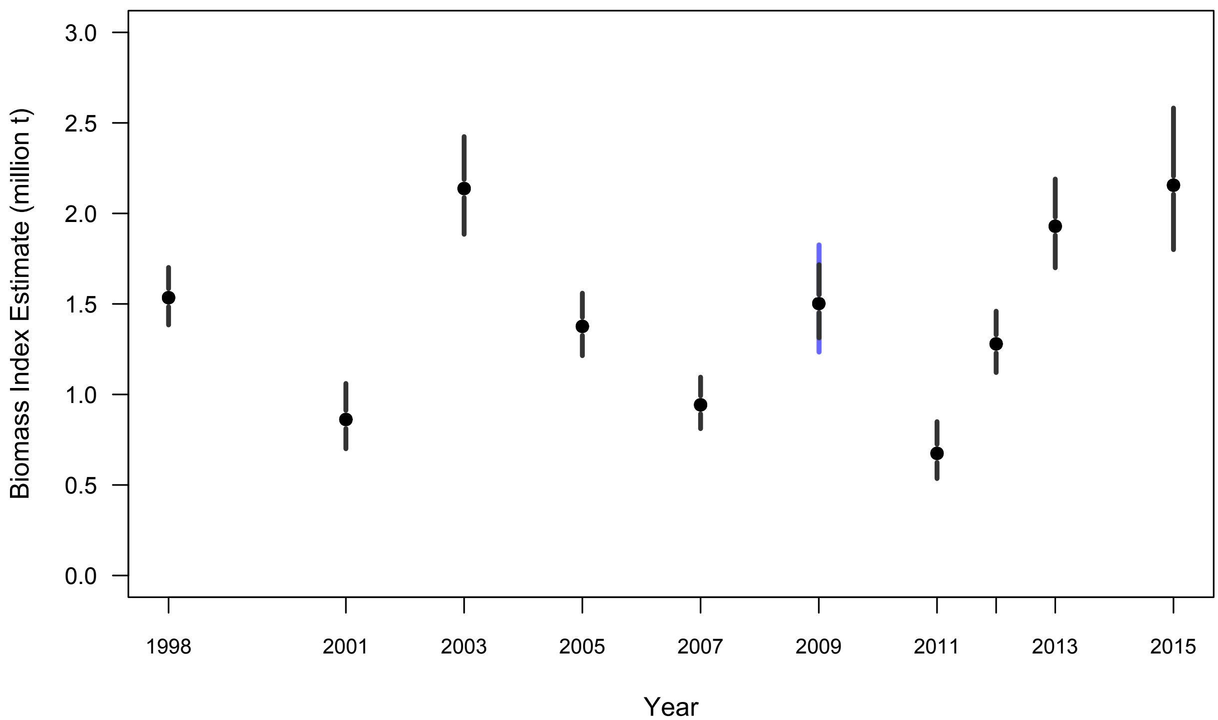

Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1998–2007, 2011–2015) in addition to squid/hake apportionment uncertainty (2009, in blue).

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 Markov Chain Monte Carlo simulation) 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. In past assessments, closed-loop simulations have provided an insight 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 2016 assessment retains the structural form of the base assessment model from 2015 and retains many of the previous elements as configured in Stock Synthesis (SS). Analyses conducted in 2014 showed that using time-varying (rather than fixed) selectivity reduced the magnitude of extreme cohort strength estimates. In closed-loop simulations, management based upon assessment models with 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 with time-invariant fishery selec-

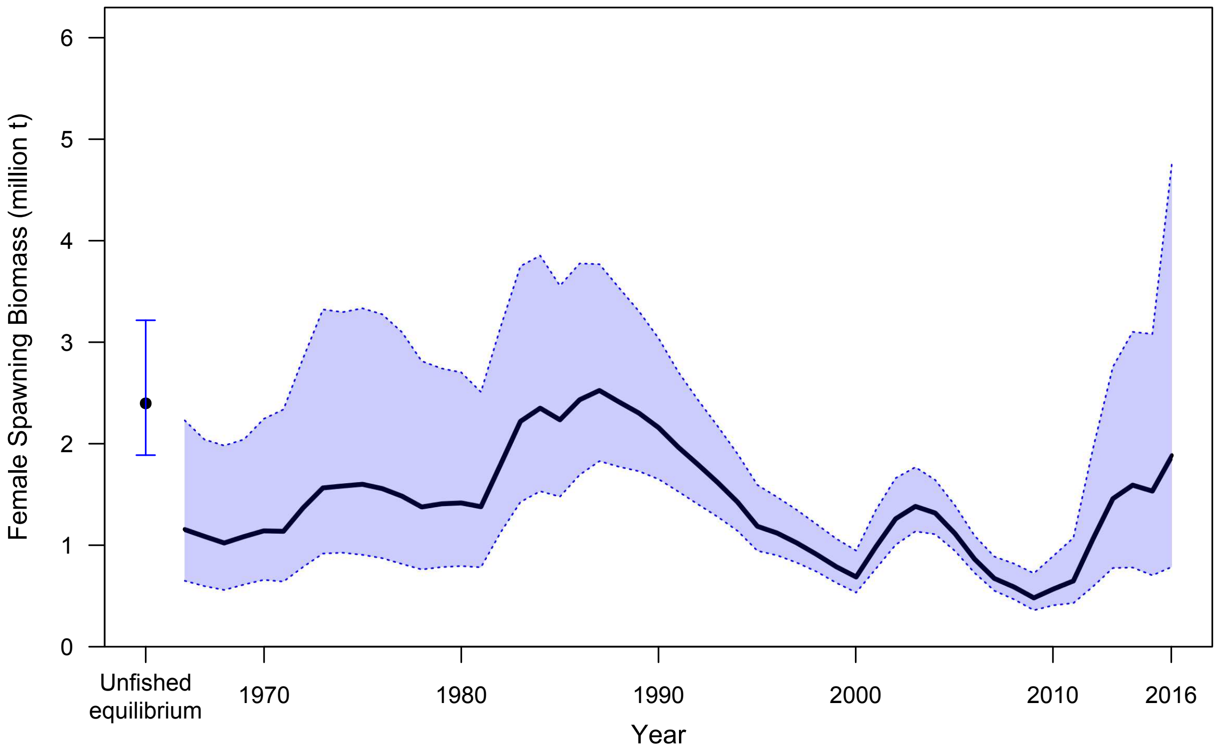

Figure c. Median of the posterior distribution for beginning of the year female spawning biomass through 2016 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

tivity. It was found that 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.

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 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 0.484 million t in 2009. The assessment model estimates that spawning biomass declined from 2014 to 2015 after five years of increases from 2009 to 2014. The estimated increases were the result of a large 2010 cohort and an above-average 2008 cohort surpassing the age at which gains in biomass from growth are greater than the

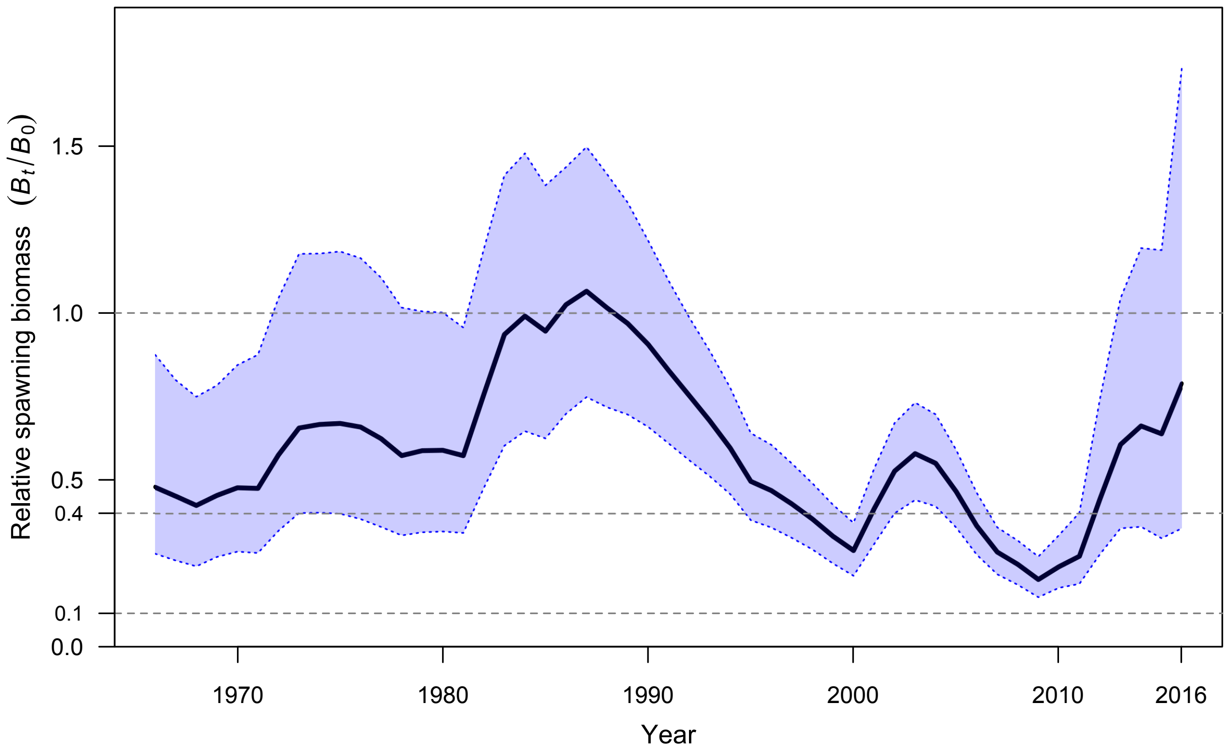

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2016 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

loss in biomass from natural mortality. The model then estimates an increase from 2015 to 2016 due to an 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 2016 relative spawning biomass (spawning biomass at the start of 2016 divided by that at unfished equilibrium, B_0) is 78.9% but is highly uncertain (with a 95% posterior credibility interval from 35.6% to 174.1%; Table b). The median estimate of the 2016 beginning-of-the-year female spawning biomass is 1.885 million t (with a 95% posterior credibility interval from 0.791 to 4.781 million t). The estimated 2015 female spawning biomass is 1.536 (0.706–3.082) million t.

RECRUITMENT

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

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

Year	Spawning Biomass (thousand t)			Relative spawning biomass (B_t/B_0)		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2007	554.8	675.4	891.0	21.8%	28.5%	35.9%
2008	469.3	590.9	821.3	18.7%	24.8%	31.9%
2009	362.8	484.1	726.1	15.0%	20.3%	27.2%
2010	411.9	572.4	900.1	17.8%	24.1%	33.5%
2011	432.8	650.8	1,075.3	19.0%	27.2%	40.3%
2012	597.3	1,067.5	1,959.9	27.8%	44.4%	74.4%
2013	778.4	1,461.1	2,758.8	35.6%	60.7%	104.4%
2014	783.5	1,594.3	3,103.3	36.1%	66.2%	119.5%
2015	706.1	1,536.0	3,082.3	32.6%	63.9%	118.9%
2016	790.6	1,884.8	4,780.9	35.6%	78.9%	174.1%

Table c. Estimates of recent recruitment (millions of age-0) and recruitment deviations (deviations below zero indicate less than median recruitment and deviations above zero indicate above median recruitment).

Year	Absolute recruitment (millions)			Recruitment deviations		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2006	1,196.8	1,852.8	3,115.7	0.217	0.576	0.906
2007	9.2	57.6	207.0	-4.613	-2.875	-1.673
2008	3,498.3	5,426.4	9,670.7	1.390	1.722	2.104
2009	506.7	1,097.7	2,456.0	-0.494	0.178	0.754
2010	7,634.0	14,784.7	30,731.6	2.230	2.719	3.226
2011	123.8	514.7	1,543.3	-1.956	-0.656	0.235
2012	507.1	1,582.4	4,381.2	-0.573	0.373	1.225
2013	150.9	932.9	3,840.2	-1.888	-0.195	1.079
2014	444.6	13,070.7	83,006.3	-0.928	2.427	4.182
2015	59.3	1,103.4	22,330.0	-2.825	0.012	2.878

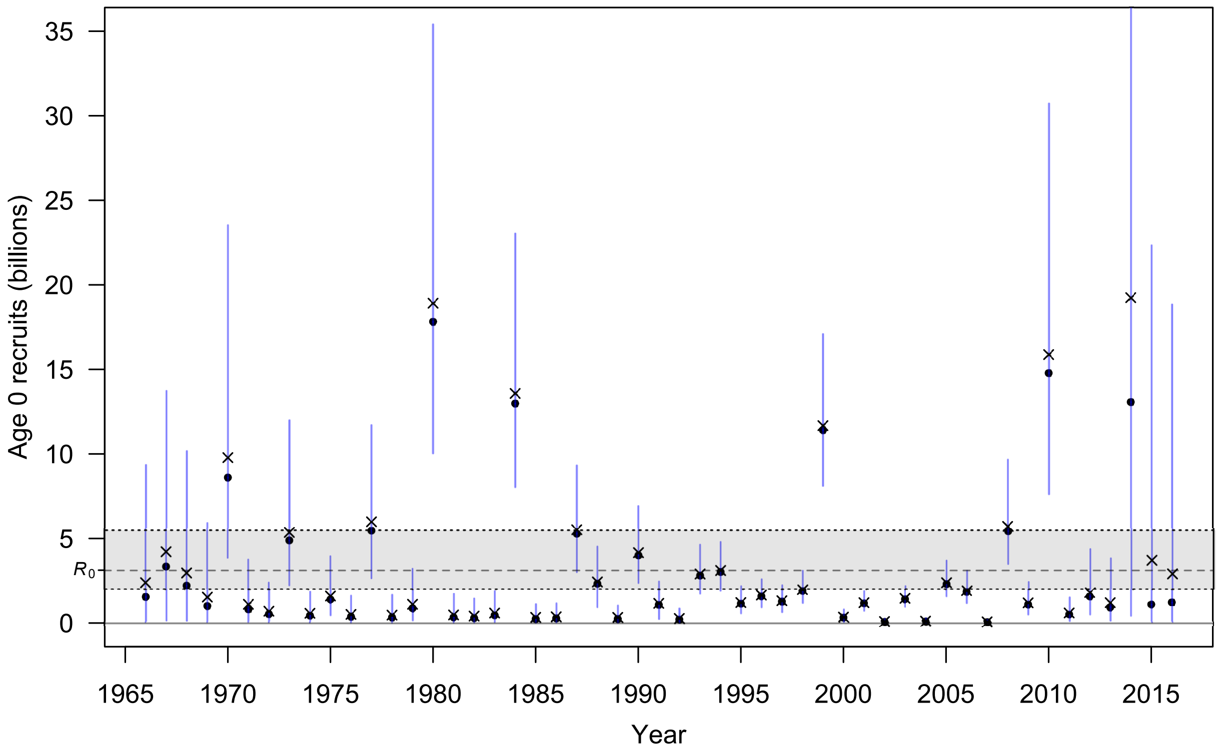

Figure e. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with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

comprising 70% of the coast-wide commercial catch in 2013, 67% of the 2014 catch, and 67% of the 2015 catch. The size of the 2010 year class is more uncertain than older cohorts (other than the 1980 year class), but the median estimate is the second highest in the time series (after the 1980 recruitment estimate). The model currently estimates a small 2011 year class, and smaller than average 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 2015 and 2016 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.

EXPLOITATION STATUS

Median fishing intensity on the stock is estimated to have been below the target except for the years 2008 and 2010 when spawning biomass was low (Table d and Figure f). Exploitation fraction (catch divided by biomass of fish of age 3 and above) has shown relatively similar patterns (Figure g and Table d). Median fishing intensity is estimated to have declined from 102.5% in 2010 to 49.0% in 2015, while the exploitation fraction has decreased from 0.27 in 2010 to 0.07 in 2015. Although there is a considerable amount of uncertainty around these recent estimates, the 95% posterior

Table d. Recent trend in fishing intensity (relative spawning potential ratio; (1-SPR)/(1-$SPR_{40\%}$)) and exploitation fraction (catch divided by age 3+ biomass).

Year	Fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2006	0.743	0.928	1.091	0.167	0.212	0.250
2007	0.795	0.984	1.153	0.193	0.252	0.305
2008	0.854	1.053	1.196	0.188	0.262	0.329
2009	0.658	0.886	1.069	0.108	0.162	0.215
2010	0.785	1.025	1.209	0.174	0.271	0.377
2011	0.710	0.991	1.204	0.124	0.205	0.304
2012	0.497	0.779	1.051	0.089	0.161	0.272
2013	0.416	0.681	0.976	0.041	0.077	0.143
2014	0.365	0.643	0.978	0.044	0.085	0.171
2015	0.257	0.490	0.849	0.033	0.067	0.148

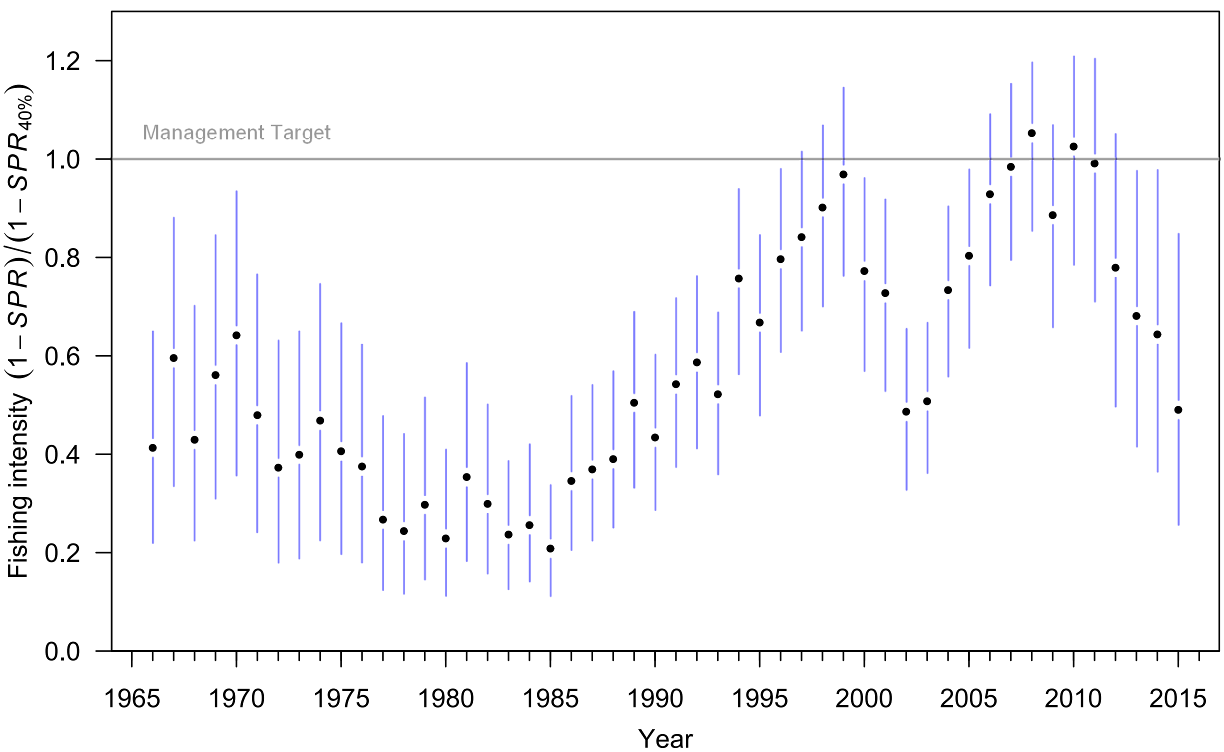

Figure f. Trend in median fishing intensity (relative to the SPR management target) through 2015 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

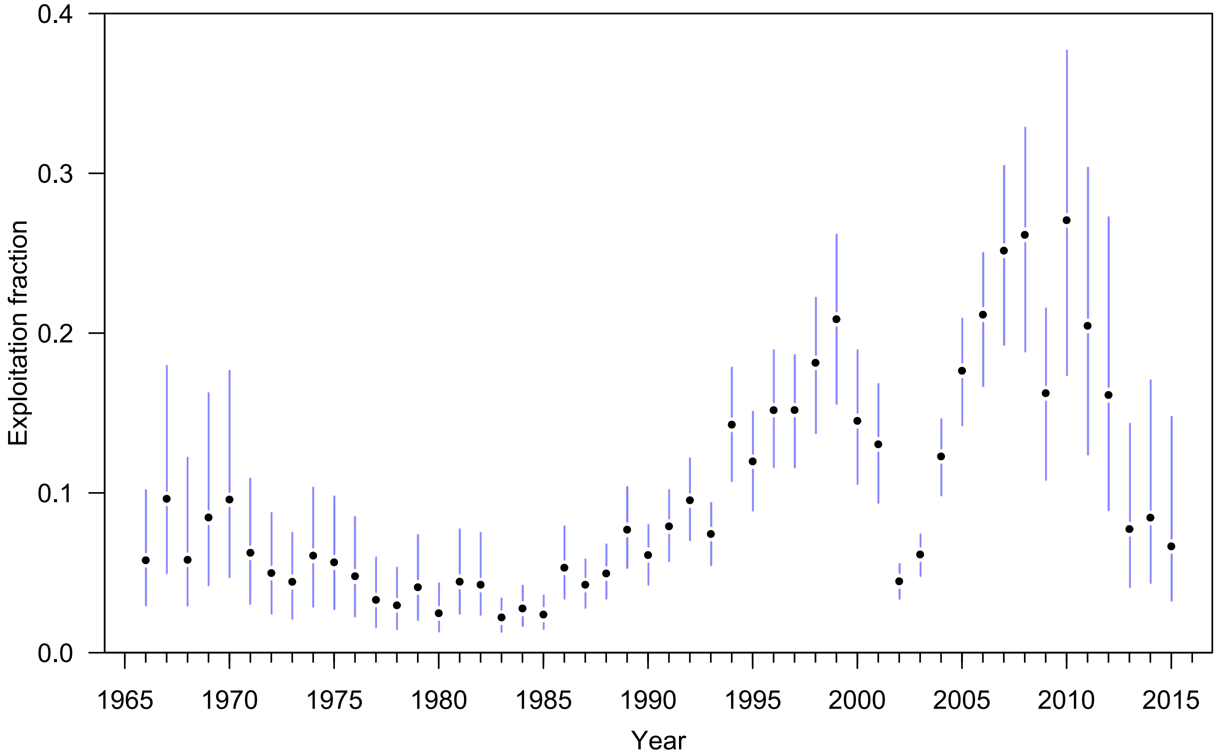

Figure g. Trend in median exploitation fraction through 2015 with 95% posterior credibility intervals.

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)	Canada catch target (t)	US catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2006	266,955	94,744	361,699	364,842	95,297	269,545	99.0%	99.4%	99.1%
2007	217,682	75,707	293,389	328,358	85,767	242,591	89.7%	88.3%	89.4%
2008	248,395	73,306	321,701	364,842	95,297	269,545	92.2%	76.9%	88.2%
2009	121,325	55,847	177,172	184,000	48,061	135,939	89.2%	116.2%	96.3%
2010	170,961	59,712	230,672	262,500	68,565	193,935	88.2%	87.1%	87.9%
2011	231,262	60,409	291,671	393,751	102,848	290,903	79.5%	58.7%	74.1%
2012	160,145	45,642	205,787	251,809	65,773	186,036	86.1%	69.4%	81.7%
2013	233,581	52,033	285,614	365,112	95,367	269,745	86.6%	54.6%	78.2%
2014	264,139	34,563	298,703	428,000	111,794	316,206	83.5%	30.9%	69.8%
2015	154,155	36,507	190,663	440,000	114,928	325,072	47.4%	31.8%	43.3%

credibility interval of fishing intensity is below the SPR management target for the last three years (Figure f).

MANAGEMENT PERFORMANCE

Over the last decade (2006–2015), the mean coast-wide utilization rate (i.e., landings/quota) has been 80.8% (Table e). From 2011 to 2015, the mean utilization rates differed between the United States (76.6%) and Canada (49.1%). Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

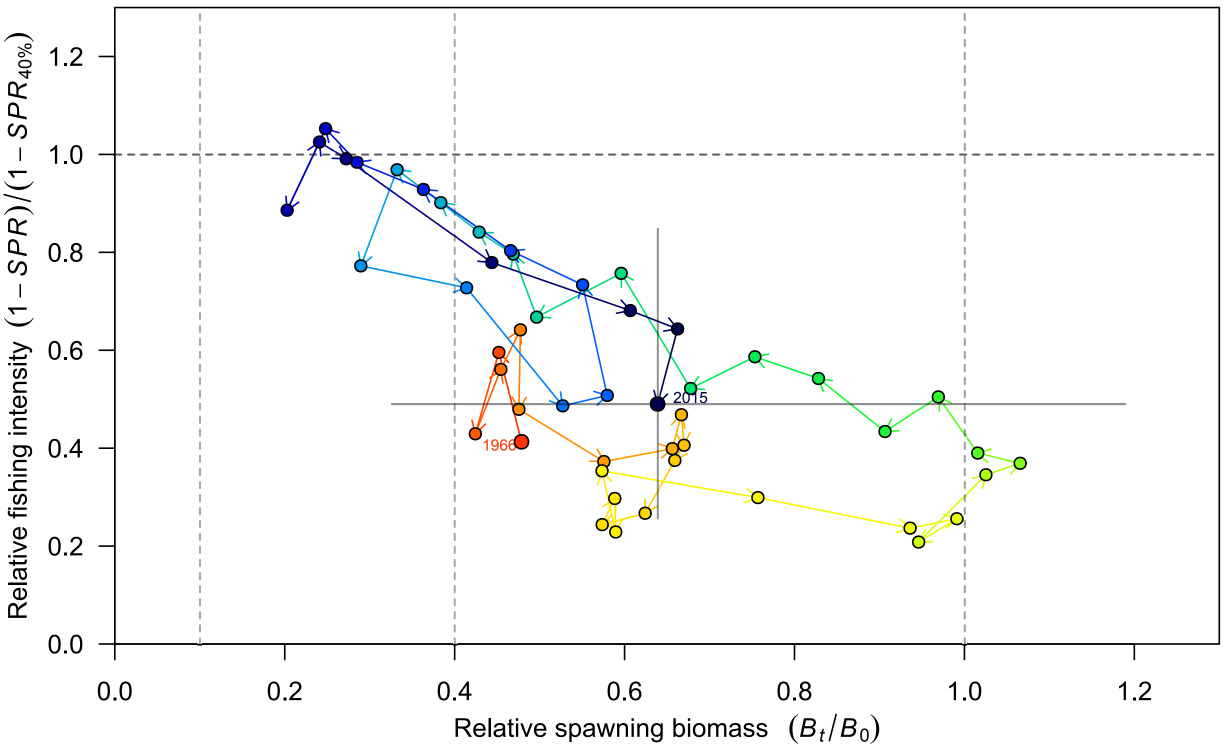

Figure h. Estimated historical path followed by fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years. Gray bars span the 95% credibility intervals for 2015 fishing intensity (vertical) and relative spawning biomass (horizontal).

The median fishing intensity was below target in all years except 2008 and 2010 (Figure f). The median female spawning biomass was above target until 1998 and was below target from 1998-2000 and 2006-2011 (Figure d).

The joint history of biomass and F-target reference points shows that before 2007, median fishing intensity was below target and female spawning biomass was mostly above target (Figure h). Between 2007 and 2011, however, median fishing intensity ranged from 89% to 105% and median relative spawning biomass between 0.20 and 0.28. Biomass has risen recently with the 2008 and 2010 recruitments and, correspondingly, fishing intensity has fallen below targets. Relative spawning biomass has been above the target since 2012.

While there is large uncertainty in the 2015 estimates of fishing intensity and relative spawning biomass, the model predicts a less than 1% joint probability of being both above the target fishing intensity in 2015 and below the target relative spawning biomass at the start of 2016.

REFERENCE POINTS

Estimates of the 2016 base model reference points with posterior credibility intervals are in Table f. The estimates are slightly different than those in the 2015 assessment, with slightly greater sustainable yields and reference biomasses estimated in this assessment.

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 1966–2015 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)	1,887	2,397	3,216
Unfished recruitment (R_0, millions)	2,021	3,125	5,484
Reference points (equilibrium) based on $F_{SPR=40\%}$			
Female spawning biomass at $F_{SPR=40\%}$ ($B_{SPR=40\%}$, thousand t)	644	856	1,117
SPR at $F_{SPR=40\%}$	–	40%	–
Exploitation fraction corresponding to SPR	18.3%	21.9%	26.1%
Yield at $B_{SPR=40\%}$ (thousand t)	277	382	569
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	755	959	1,286
SPR at $B_{40\%}$	40.6%	43.4%	50.7%
Exploitation fraction resulting in $B_{40\%}$	14.6%	19%	23.8%
Yield at $B_{40\%}$ (thousand t)	271	372	550
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	367	586	962
SPR at MSY	18%	28.9%	45.4%
Exploitation fraction corresponding to SPR at MSY	17.9%	33.2%	61.1%
MSY (thousand t)	286	406	615

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 know until it is at least age 3).

The JTC presented results from closed-loop simulations evaluating the effect of including potential age-1 indices on management outcomes at the May 6-7 2015 JMC meeting in Victoria, B.C. They 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. How-

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), the TAC from 2015 (row d), the catch values that result in a median SPR ratio of 1.0 (row f), the median values estimated via the default harvest policy ($F_{SPR=40\%}$–40:10) for the base (row g), and the catch level that results in a 50% probability that the median projected catch will remain the same in 2016 and 2017 (row h).

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2016	0	41%	61%	79%	101%	152%
	2017	0	47%	73%	96%	128%	224%
	2018	0	51%	77%	107%	147%	267%
b:	2016	180,000	41%	61%	79%	101%	152%
	2017	180,000	43%	69%	92%	124%	219%
	2018	180,000	43%	70%	99%	139%	262%
c:	2016	350,000	41%	61%	79%	101%	152%
	2017	350,000	39%	66%	89%	121%	214%
	2018	350,000	36%	64%	92%	132%	255%
d:	2016	440,000	41%	61%	79%	101%	152%
2015	2017	440,000	38%	64%	87%	119%	212%
TAC	2018	440,000	32%	60%	89%	129%	251%
e:	2016	500,000	41%	61%	79%	101%	152%
	2017	500,000	36%	62%	86%	118%	210%
	2018	500,000	29%	57%	86%	127%	249%
f:	2016	785,000	41%	61%	79%	101%	152%
FI=	2017	900,000	30%	56%	80%	112%	203%
100%	2018	825,000	16%	44%	73%	114%	235%
g:	2016	830,124	41%	61%	79%	101%	152%
default	2017	955,423	28%	55%	79%	111%	201%
HR	2018	837,352	15%	42%	71%	112%	233%
h:	2016	928,100	41%	61%	79%	101%	152%
C2016=	2017	928,100	27%	53%	77%	109%	200%
C2017	2018	820,224	14%	41%	69%	111%	231%

ever, 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.

FORECAST DECISION TABLES

The median catch limit for 2016 based on the default $F_{SPR=40\%}$–40:10 harvest policy is 830,124 t, but has a wide range of uncertainty, with the 2.5% to 97.5% range being 309,329–1,958,126 t.

Decision tables give the projected population status (relative spawning biomass) and the fishing intensity under different catch alternatives for the base model (Tables g and h). The tables are

Table h. Forecast quantiles of Pacific Hake fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2016–2018 catch alternatives presented in Table g. Values greater than 100% indicate fishing intensities greater than the $F_{SPR=40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile			5%	25%	50%	75%	95%
Management Action			Fishing Intensity				
	Year	Catch (t)					
a:	2016	0	0%	0%	0%	0%	0%
	2017	0	0%	0%	0%	0%	0%
	2018	0	0%	0%	0%	0%	0%
b:	2016	180,000	23%	33%	41%	51%	70%
	2017	180,000	14%	24%	33%	43%	60%
	2018	180,000	12%	22%	31%	42%	60%
c:	2016	350,000	40%	55%	66%	78%	99%
	2017	350,000	25%	42%	56%	70%	92%
	2018	350,000	22%	40%	54%	72%	97%
d:	2016	440,000	48%	64%	75%	88%	108%
2015	2017	440,000	31%	51%	66%	82%	104%
TAC	2018	440,000	27%	48%	65%	84%	111%
e:	2016	500,000	53%	69%	81%	94%	113%
	2017	500,000	34%	56%	72%	88%	111%
	2018	500,000	31%	53%	71%	92%	119%
f:	2016	785,000	71%	88%	100%	112%	129%
FI=	2017	900,000	55%	83%	100%	117%	136%
100%	2018	825,000	47%	79%	100%	123%	140%
g:	2016	830,124	73%	90%	103%	114%	131%
default	2017	955,423	57%	86%	103%	120%	136%
HR	2018	837,352	48%	80%	102%	125%	140%
h:	2016	928,100	78%	95%	107%	119%	134%
C2016=	2017	928,100	56%	85%	103%	120%	137%
C2017	2018	820,224	48%	80%	102%	125%	140%

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.

Fishing intensity exceeding 100% indicates fishing in excess of the $F_{SPR=40\%}$ default harvest rate catch limit. This can happen for the median 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 fishing intensity is 100% for three years of projections is provided for comparison (scenario f: FI=100%).

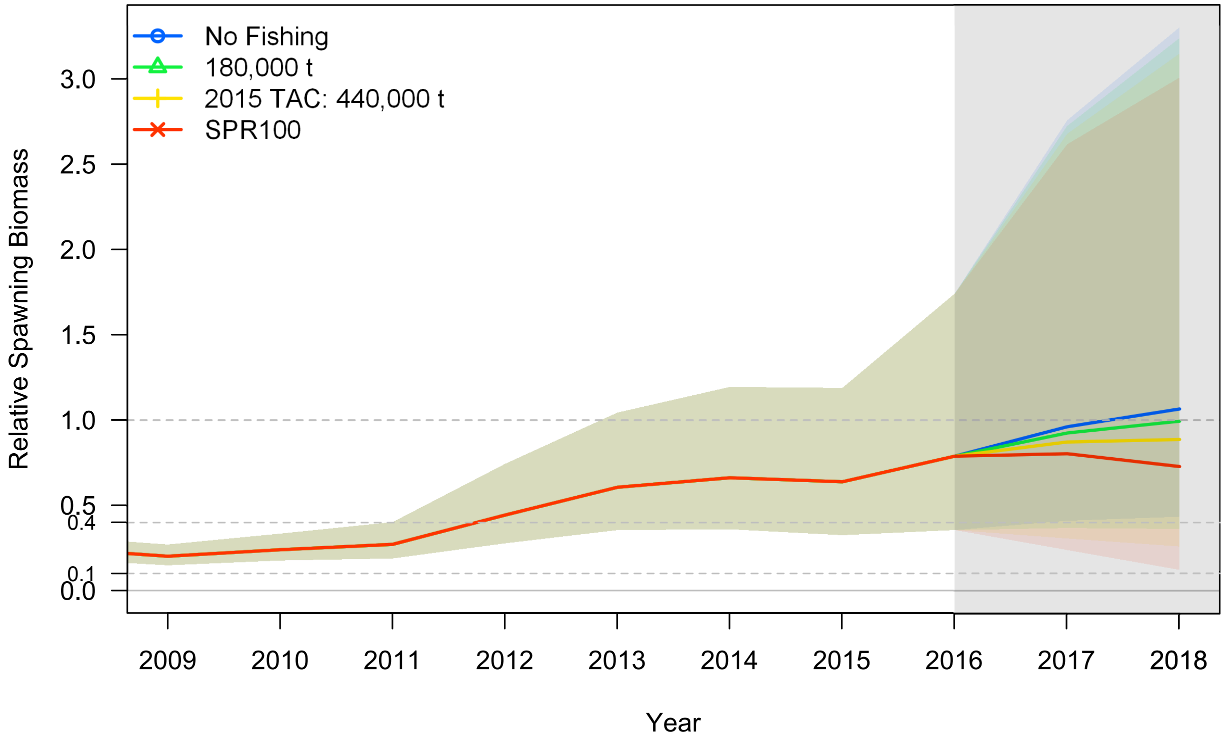

Figure i. Time series of estimated relative spawning biomass to 2016 from the base model, and forecast trajectories to 2018 for several management options from the decision table, with 95% posterior credibility intervals. The 2016 catch of 785,000 t was calculated using the default harvest policy, as defined in the Agreement.

Table i. Probabilities related to spawning biomass, fishing intensity, and 2017 catch limits for alternative 2016 catch options (catch options explained in Table g).

Catch in 2016	Probability $B_{2017}<B_{2016}$	Probability $B_{2017}<B_{40\%}$	Probability $B_{2017}<B_{25\%}$	Probability $B_{2017}<B_{10\%}$	Probability Fishing intensity in 2016 >40% Target	Probability 2017 Catch Target <2016 Catch
a: 0	7%	2%	0%	0%	0%	0%
b: 180,000	17%	4%	0%	0%	0%	0%
c: 350,000	27%	5%	1%	0%	5%	3%
d: 440,000	33%	7%	1%	0%	10%	7%
e: 500,000	36%	7%	1%	0%	15%	11%
f: 785,000	49%	11%	3%	0%	51%	38%
g: 830,124	51%	12%	3%	0%	54%	42%
h: 928,100	55%	13%	4%	0%	66%	50%

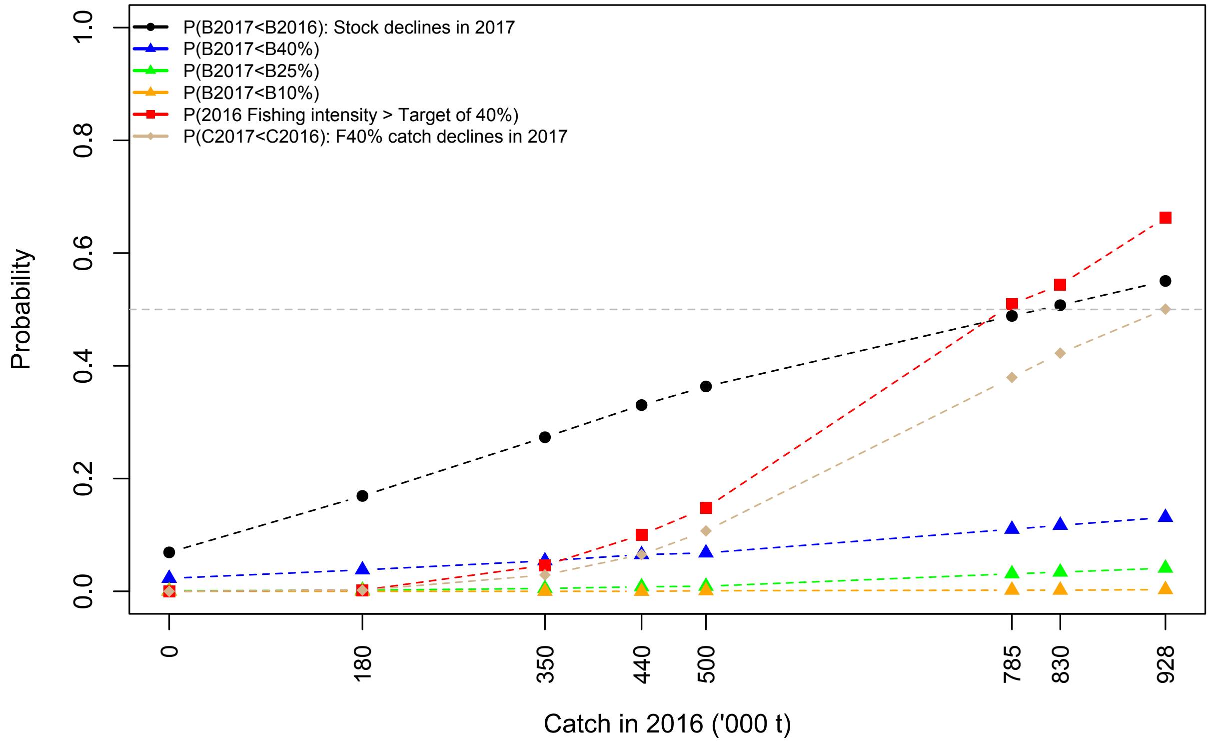

Figure j. Graphical representation of the probabilities related to spawning biomass, fishing intensity, and 2017 catch limits for alternative 2016 catch options (catch options explained in Table g) as listed in Table i. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

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 2017 and 2018 (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 this table for intermediate catch values. Figure i shows the predicted relative spawning biomass trajectory through 2018 for several of these management actions. With zero catch for the next two years, the biomass has a 7% probability of decreasing from 2016 to 2017, and a 14% probability of decreasing from 2017 to 2018

The population is predicted to decrease from 2016 to 2017 with a less than 50% probability for all catch levels investigated up to 440,000 t (Table i and Figure j). The model predicts high biomass levels and the predicted probability of dropping below $B_{10\%}$ (10% of B_0) in 2017 is less than 1% and the maximum probability of dropping below $B_{40\%}$ is 13% for all catches explored. 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 2017 spawning biomass will be less than the 2016 spawning biomass is less than 55% for all catch levels. (Table i and Figure j).

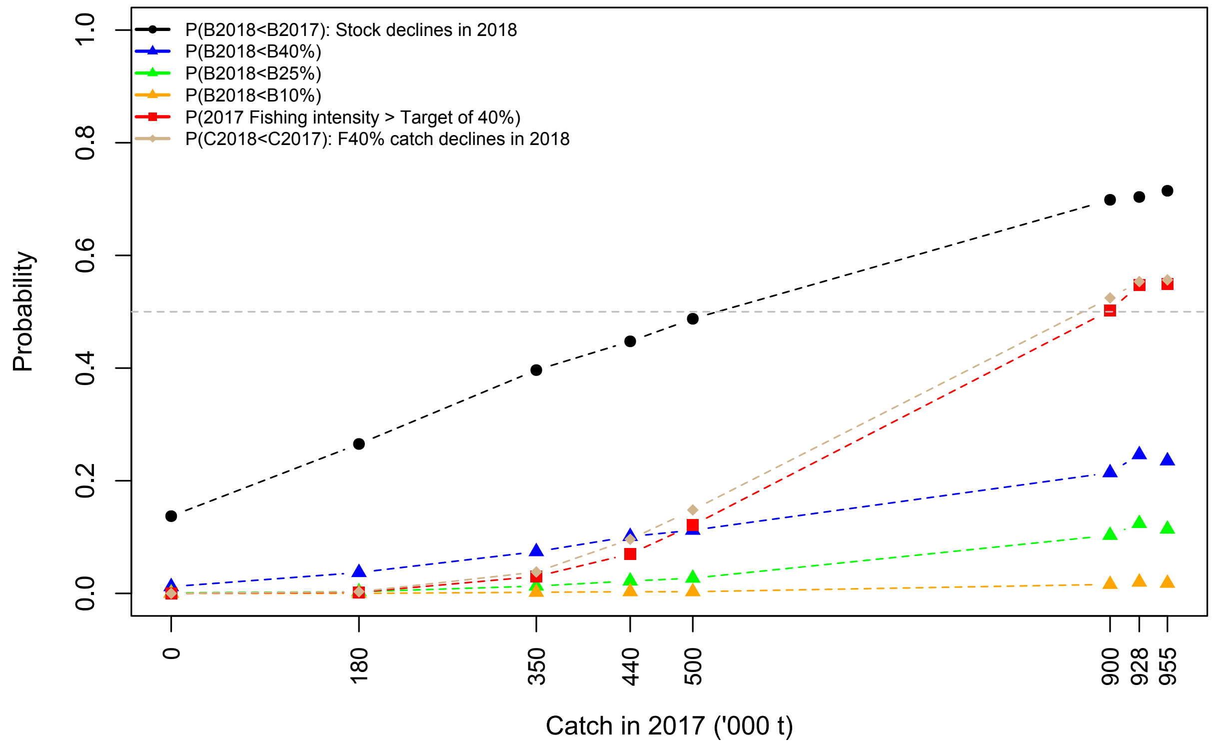

Figure k. Graphical representation of the probabilities related to spawning biomass, fishing intensity, and 2018 catch limits for alternative 2017 catch options (catch options explained in Table g) as listed in Table j. The symbols indicate points that were computed directly from model output and lines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

Table j. Probabilities related to spawning biomass, fishing intensity, and 2018 catch limits 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 Fishing intensity in 2017 >40% Target	Probability 2018 Catch Target <2017 Catch
a: 0	14%	1%	0%	0%	0%	0%
b: 180,000	27%	4%	0%	0%	0%	0%
c: 350,000	40%	7%	1%	0%	3%	4%
d: 440,000	45%	10%	2%	0%	7%	10%
e: 500,000	49%	11%	3%	0%	12%	15%
f: 900,000	70%	21%	10%	2%	50%	52%
g: 955,423	71%	24%	11%	2%	55%	56%
h: 928,100	70%	25%	12%	2%	55%	55%

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. 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, making 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 Hake/Sardine 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 and went into force in 2008 but could not be implemented until 2010. The committees defined by the Agreement were first formed in 2011 and catch advice in 2012 was the first year for which the process defined by the Agreement was followed. This is the fifth annual stock assessment conducted under the Agreement process.

Under the Agreement, Pacific Hake (or Pacific whiting *Merluccius productus*) 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 as well as fishery and survey 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. Annual fishery catch is not considered data in the sense that it does not contribute to the likelihood. However, 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 2016 base model are effectively the same as the 2015 base model, including time-varying fishery selectivity.

1.1 STOCK STRUCTURE AND LIFE HISTORY

Pacific Hake also referred to as Pacific whiting is a semi-pelagic schooling species distributed along the west coast of North America generally ranging from 25° N. to 55° N. latitude (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). 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 107% of the limit, on average. 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 $F_{\text{SPR}=40\%}$ default harvest rate with a 40:10 adjustment that 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, but harvest rates have approached the $F_{\text{SPR}=40\%}$ target and, in retrospect, may have exceeded the target in 2008 and 2010 as estimated from this assessment. 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 predicted by 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 that is 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. 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 2015, Canadian hake fishermen were allocated a TAC of 114,928 t, including 14,793 t of uncaught carryover fish from 2014. Canadian priority lies with the domestic fishery, but when there is determined to be an excess of fish for which there is not enough shoreside 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 2015, 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, including 2015.

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 2015

The Joint Management Committee (JMC) determined an adjusted (for carryovers) coast-wide catch target of 440,000 t for 2015, with a U.S. allocation of 325,072 t (73.88%) and a Canadian allocation of 114,928 t (26.12%). A review of the 2015 fishery is given below.

United States

The U.S. adjusted allocation (i.e. adjusted for carryovers) of 325,072 t was further divided to research, tribal, catcher-processor, mothership, and shore-based sectors. After the tribal allocation of 17.5% (56,888 t), and a 1,500 t allocation for research catch and bycatch in non-groundfish fisheries, the 2015 non-tribal U.S. catch limit of 266,684 t was allocated to the catcher/processor (34%), mothership (24%), and shore-based (42%) commercial sectors. After reallocation of 30,000 t of tribal quota to non-tribal sectors on Sep-21, the catcher/processor, mothership, and shore-based sectors total quotas were 100,873 t, 71,204 t, and 124,607 t, respectively.

Catch in the at-sea sectors was dominated by age-5 fish from the 2010 year class, making up more than 70% of the total catch. While the catch from the shore-based sector had a higher proportion of age-7 fish from the 2008 year class (5%), more than 65% of this sector's catch was from the 2010 year class.

The overall catch of Pacific Hake in U.S. waters was much less than anticipated. Tribal fisheries did not land any hake in 2015. The catcher-processor, mothership, and shore-based fleets caught 67.9%, 38.8%, and 46.6% of their reallocated quotas, respectively. Overall, 170,917 t (52.6%) of the total U.S. adjusted TAC was not caught.

The midwater fishery for Pacific Hake began on May 15 for the shorebased and at-sea fisheries. In previous 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. In 2015, the shorebased fishery was 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 don't allow at-sea processing south of 42° N. latitude at any time during the year.

The spring fishery began in May with high catch rates and fish mostly found off Oregon, although some fish were caught off of Westport, WA. The fleets sometimes fished in deeper water than observed in past years (Figure 5). As time progressed, the fishery slowed with periods (typically several days) of slow fishing. During July and August, the at-sea fishery did not fish hake, but these were the months that the shorebased fishery had the largest monthly catches of the year. When the at-sea fleet returned in September, the catch rates for the at-sea fleet had declined considerably. From May through November, catch-rates declined consistently from approximately 50 t/hr to about 5 t/hr (Figure 6). Due to the low catch-rates in the fall (for all U.S. fleets), the U.S. utilization rate was 47.4%.

Canada

The 2015 Canadian Pacific Hake domestic fishery removed 36,507 t from Canadian waters, which was 31.8% of the Canadian TAC of 114,928 t.

The shoreside component, made up of vessels landing fresh round product onshore, landed 16,451 t. The freezer trawler component, made up of four vessels which freezes headed and gutted product while at sea, landed 20,057 t. The year 2014 was the first in which the freezer trawler component of the Canadian fleet landed more hake than the shoreside component.

The Canadian fishery began in early May, approximately a week earlier than in 2014, and the last delivery for the Freezer trawler vessels was in late November. Shoreside deliveries continued to the end of December. In late May, the vessels made a move westward, further offshore, to avoid large aggregations of age-1 hake that were appearing on the shelf. Many fishermen reported that these aggregations were the largest, acoustically, that they had seen in years. Gradually, these aggregations covered more and more of the southwest of the fishing grounds off the West coast of Vancouver Island, so fishing vessels moved North, into deeper water, to avoid the small fish. Industry reported an overall larger hake biomass in Canada compared to the last two years.

In mid-August, at the request of industry, DFO permitted the harvest of offshore hake for the production of fish meal. This required special permission from the Minister of Fisheries and Oceans, as the production of fish meal is usually disallowed according to the Fisheries and Oceans act. This request was made in response to poor market conditions in 2014, which were expected to continue into 2015. However, the markets were better than expected, and with poor prices for landed fish meal, the fleet processed only 68 t for this fishery.

The most abundant year classes in the Canadian Freezer trawler catch were age 5 at 58.4%, age 6 at 12.3%, age 7 at 11.7%, and age 9 at 3.9%. The most abundant year classes in the Canadian Shoreside catch were age 5 at 63.5%, age 7 at 11.5%, age 6 at 8.1%, and age 9 at 5.6%. The distribution of catch by month remained similar to other years, with the summer months showing the greatest catch.

For an overview of Canadian catch by year and fleet, see Table 2. For 2002, 2003, 2009, 2012, 2013, 2014 and 2015 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.

The total U.S, Canadian and coastwide catches of Pacific Hake are shown in Table 3, together with the percentage of the total catch that came from each country.

2 DATA

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

- Total catch from all U.S. and Canadian target fisheries (1966–2015).
- Age compositions composed of data from the U.S. fishery (1975–2015) and the Canadian fishery (1990–2015).
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012, 2013 and 2015).

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

- Mean observed weight-at-age from fishery and survey catches, (1975-2015).
- Ageing-error matrices based on cross-read and double-blind-read otoliths.
- Proportion of female hake maturity by age (Dorn and Saunders, 1997).

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 1977–2015).
- NWFSC/SWFSC/PWCC coast-wide juvenile hake and rockfish surveys (2001–2015).
- 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.
- Histological analysis of ovary samples collected during the 2009, and 2012–2015 NWFSC bottom trawl surveys, the 2012, 2013, and 2015 acoustic surveys, and the at-sea fishery from 2013 through 2015.

2.1 FISHERY-DEPENDENT DATA

2.1.1 Total catch

The catch of Pacific Hake for 1966–2015 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 1991–2015 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 1991–2015. 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 1991–2015 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 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 (23.6% in 2015). Their catch exceeded that of the Shoreside vessels for the first time in 2014. 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. 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 (1975–2015) confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999 (Figure 7). The more recent age-composition data consisted of high proportions of 2008 and 2010 year classes in the 2012 to 2015 fisheries (Figure 7). In 2015, the 2012 and 2014 cohorts showed up as significant proportions given a large 2010 year class. 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 2015.

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, pre-recruit, and age-1 acoustic data sources were not used. 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 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 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012, 2013 and 2015 were used in this assessment (Table 6). 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.

A survey was completed in 2015 that covered U.S. and Canadian waters from the U.S./Mexico border to north of Haida Gwaii (Figure 2). This was the first year that the Southern California Bight was covered by this survey. The NOAA ship Bell M. Shimada completed the U.S. and met with the C.C.G.S. W. E. Ricker to interleave acoustic transects off of Vancouver Island before the Ricker completed the rest of the survey around Haida Gwaii. The Ricker was able to complete additional transects off of Vancouver Island after the survey was complete. The Shimada performed the Pacific Hake survey in collaboration with the SWFSC to collect data for coastal pelagic species (CPS). Trawling for hake was done during the day while trawling for CPS was performed at night. Environmental data were collected along the transect and CTD casts were completed at various locations along the coast.

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. El Niño conditions were prevalent in 2015, but an extreme northern distribution was not observed by the survey. More Pacific Hake were observed in Canadian waters, but a large amount of backscatter was observed off Oregon and Washington during the period of time that the survey took place.

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 6 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.

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 this assessment, the data from all surveys since 1998 were scrutinized and reanalyzed using the same geostatistical techniques as in the 2015 assessment (Taylor et al., 2015), but with more robust assumptions and some corrections. These include:

- fixing the minimum (k_{min}) and maximum (k_{max}) number of points used to calculate the value in a cell;
- 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.

The net result of these changes is a consistent approach applied to all survey years from 1998 onwards (Table 7). Therefore, the biomass indices (Table 6 and Figure 8) and age compositions (Figure 7, top) are new for this assessment and differ from the 2015 assessment (Taylor et al., 2015).

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 estimate is 2.156 million metric tons, which is 1.69 times the 2012 survey biomass estimate and 3.19 times the 2011 acoustic survey biomass estimate (Table 6 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 6) 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 has been the subject of some debate in recent reviews, hence the reanalysis of the entire time series using a more robust parameterization in the kriging analysis. However, a time series without extrapolation is used as a sensitivity. The series without extrapolation is shown in Table 8 and Figure 9 along with the extrapolated time series. The largest percentage of extrapolated biomass in any year occurred in 2005 and was 25.18% (with a minimum of 0.52% in 2011 and an average of 8.89%).

The extrapolated survey time series was used in this assessment for a number of reasons. First, some surveys have observed hake at or near the western (offshore) edge of some transects. Second, in 2014 and 2015, the U.S. at-sea fishery has caught a significant amount of hake farther offshore than where the survey normally covers, and a small amount of hake where caught at a location more than 100 miles off of the coast in 2015. Finally, the hake distribution is dynamic and changes each year depending on the size of the population, the age-structure, and environmental conditions. These inter-annual differences in distribution result in a varying proportion of biomass outside of the survey area, and by including an estimate of the biomass outside of the survey area, it will hopefully reduce the amount of annual variation in estimated survey catchability.

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. 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 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).

The JTC has also been using the simulation software developed for recent Management Strategy Evaluation (MSE) work (Taylor et al., 2014) to test the potential benefit of an age-1 index under alternative scenarios for the precision of this index relative to the survey of ages 2 and above. These simulations showed that there is a small benefit to including an age-1 index, but improving the age-2+ survey had larger gains in achieving fishery and management goals. However, the costs of improving the precision on the age-2+ biomass estimates are much greater than the cost of analyzing the age-1 data that are already available.

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 mature, by size and age, is based on data reported in Dorn and Saunders (1997) and has remained unchanged in the base models since the 2006 stock assessment. These data consisted of 782 individual ovary collections based on visual maturity determinations by observers. The highest variability in the percentage of each length bin that was mature within an age group occurred at ages 3 and 4, with virtually all age-1 fish immature and age 4+ hake mature. Within ages 3 and 4, the proportion of mature hake increased with larger sizes, such that only 25% were mature at 31 cm while 100% were mature at 41 cm.

Histological samples have been collected during the 2009, 2012, 2013, 2014, and 2015 U.S. bottom trawl surveys, during the 2012, 2013, and 2015 joint U.S/Canada Hake/Sardine acoustic surveys, and from At-Sea hake Observer Program (ASHOP) observers aboard at-sea fishing vessels in 2013, 2014, and 2015 (Table 9). In the course of the surveys, length bins were targeted for ovary collection to ensure an even coverage. The protocol for collection from at-sea fishery vessels was to randomly sample one ovary from the three fish randomly sampled for otoliths. Fish were randomly sampled for otoliths every third haul. A fin clip was also collected with most histological samples for genetic determination of stock structure.

Tissue from each individual ovary was embedded in paraffin, thin-sectioned to 4 μm, mounted on slides, and stained with hematoxylin and eosin (H&E) stain. Microscopic examination was done to determine oocyte development and maturity (pers. comm., Melissa Head, NWFSC). Ovary samples were marked as mature when yolk was present in a healthy viable oocyte. The presence of various oocyte stages was recorded, and a visual estimate of the percentage of the sample that showed atresia was also noted. Size and age of the fish were not used in the determination of maturity.

Oocytes exhibiting atresia were noted with a visual estimate of the percent atresia. If an ovary sample did not have yolk present in a healthy viable oocyte, then it was marked as immature. Specimens were classified as mature if they contained large oocytes with dark-stained vitellogenin yolk or characteristics associated with more advanced stages. Spent ovaries characterized by the presence of large numbers of post ovulatory follicles (POFs) and immature oocytes were also defined as mature. Fish that did not have yolk present but were large or older were not changed to a mature status because of these biological factors. Reader error in the determination of maturity for Pacific Hake was negligible (pers. comm., Melissa Head). Slides of ovary sections from the trawl survey were re-evaluated to ensure consistency in maturity determination.

Developing oocytes that indicated mature and possibly spawning fish were present in samples collected throughout the year. This suggests that Pacific Hake are batch spawners with multiple spawning events in a year. It is uncertain the extent to which viable eggs are produced throughout the year and more investigation is required to determine when spawning that contributes to recruitment actually occurs. A trawl/acoustic survey beginning in January 2016 collected histological samples from hake observations, which may help determine the spawning state of Pacific Hake. Male hake spawning state may also be useful to investigate to learn more about this.

No additional analysis of maturity samples collected in 2015 have been done, but results reported in the Pacific Hake assessment from 2015 (Taylor et al., 2015) indicated that maturity-at-age and length observations show differences across years. It has been difficult to determine if these difference are due to the source (bottom trawl, acoustic survey, or ASHOP) or the year. Investigating data through 2014 showed that Pacific Hake south of 34.5 degrees latitude (approximately Point Conception) mature at a smaller size (Figure 11). The trawl survey is the only source of the three analyzed here that samples in that area, and genetic samples were collected in 2015 to determine if there is any stock structure that could help to explain this. Another interesting observation from the maturity data is that there are large, old fish classified as immature (Taylor et al., 2015). It is believed that these fish may be mature, but are “skip spawners” and will not be spawning in the upcoming year.

It is unclear how the smaller size at maturity south of Point Conception fits into the determination of spawning biomass for Pacific Hake. Additionally, fecundity-at-age is ultimately the desired metric to determine spawning biomass. Therefore, we hesitate to move forward with defining a new maturity curve until we complete the following:

1. read ages and histological sample from the 2015 collections,
2. further investigate the smaller maturity-at-length south of Point Conception,
3. determine the significance of batch spawning and viability of spawning events throughout the year,
4. study fecundity as a function of size, age, weight, and batch spawning.

Hopefully, samples collected during the winter 2016 trawl/acoustic survey for Pacific Hake will help to address these tasks.

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 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, and 2010. 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 2015 (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. (2015) 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-at-age in 2015 was typically slightly less than the mean weight-at-age over all years.

2.3.4 Length-at-age

In the 2011 assessment models (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 10. 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 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 and was modelled with yearly deviations applied individually to the parameters for selectivity-at-age (more detail on the parameterization is provided in Appendix C of Taylor et al. 2014). 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.

A standard deviation of $\phi = 0.03$ for this penalty function was used for each age and 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 estimation procedure was not repeated for this assessment and $\phi = 0.03$ was used again.

This parameterization allows for the estimation of time-varying selectivity without allowing large year-to-year changes. However, the current selectivity parameterization is limiting because each individual selectivity-at-age is correlated with the selectivity of other ages. Research into alternative non-parametric time-varying selectivity configurations 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 spatial 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: $F_{\text{SPR}=35\%}$, $F_{\text{SPR}=40\%}$, $F_{\text{SPR}=40\%}$–40:10, $F_{\text{SPR}=45\%}$, $F_{\text{SPR}=45\%}$–40:10 and $F_{\text{SPR}=50\%}$ (e.g., Dorn 1996; Hicks et al. 2013). The above is only a small fraction of the number of management procedures that have actually been investigated. There have been many others combinations of data, assessment model and harvest control rule. 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 $F_{\text{SPR}=40\%}$–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 2015 SCIENTIFIC REVIEW GROUP (SRG) REVIEW

The Scientific Review Group (SRG) meeting was held from February 24–27, 2015, at Simon Fraser University, Vancouver, B.C, Canada.

The following are the Assessment Recommendations from the 2015 SRG report, as listed from highest to lowest priority, and associated responses from the JTC:

- Given the information and analyses presented to the SRG at this meeting, the 2016 base assessment model should be fitted to a survey biomass index series (starting in 1995) with no extrapolation. Sensitivity runs can be conducted to assess the effect of extrapolation in the survey index on the assessment, if extrapolation is supported by compelling evidence.

  Response – The acoustic survey biomass index included in the 2016 base model includes an estimate of extrapolated 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. A more robust (and intuitive) parameterization in the kriging analysis was completed in 2015, resulting in a new survey time series that did not show as large of an extrapolated biomass when compared to the old method, and incorporated a tapering function to ensure extrapolated biomass became zero the further the prediction was from observed data. A time series without extrapolation is used as a sensitivity (see Section 3.8). The extrapolated survey time series was used in *this assessment for a number of reasons (see Section 2.2.1 for specifics). In short, inter-annual differences in distribution result in a varying proportion of biomass outside of the survey area, and by including an estimate of the biomass outside of the survey area, it will hopefully reduce the amount of annual variation in estimated survey catchability.*

- Age-1 index – The SRG recommends that the next assessment include a sensitivity run incorporating the age-1 acoustic index (which begins in 1995) shown in Figure 8 of the draft 2015 assessment document. Results of this run could be used to facilitate an MSE evaluation of the value of developing a formal age-1 index.

  Response – The addition of a separate age-1 acoustic index is included as a sensitivity run to the 2016 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. The JTC presented results from closed-loop MSE simulations evaluating the effect of including potential age-1 indices on management outcomes at the May 6-7 2015 JMC meeting in Victoria, B.C.

- The SRG recommends that future stock assessments include sensitivity analyses that help communicate more of the key structural uncertainties in the current assessment modelling framework. Two key sensitivities in previous Hake assessments are the prior distributions on natural mortality and recruitment variation. The JTC should define a list of additional uncertainties to be examined regularly.

  Response – The JTC identified several key underlying structural model assumptions that have persisted across previous hake assessments, and thus warrant revisiting periodically as a set of reference sensitivity examinations to new base models. Those identified here include the prior distribution specified for 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). Additional sensitivity runs will always be necessary and should be developed according to the specifics of each assessment.

- High uncertainty about species/stock composition of the developing Hake fishery in Mexico and of Hake found south of Point Conception in the southern California Bight does not support the inclusion of these fish in the assessment at this time. The SRG encourages ongoing monitoring and collaborative research on stock structure to resolve stock status. Anecdotal reports that Mexican catches of Hake have increased substantially in recent years are a concern, especially should these catches come from the same offshore stock of Hake covered by this assessment.

  Response – The JTC supports this recommendation and has initialized contacts with Mexican counterparts.

- The SRG supports continued collection of ovaries across the range of Hake and analysis of maturity schedules using histological techniques. Analyses conducted in 2014 show that maturity-at-length differs between northern and southern areas of the stock (based on a break-point at Point Conception, 34^{o}N). The SRG notes that the maturity-at-length curve for the northern region is similar to the relationship used in the current stock assessment (based on Dorn and Saunders 1997). Since most of the catch and estimated survey biomass occurs above 34^{o}N, further work on defining the apparent difference between northern and southern regions is expected to have low relevance to the stock assessment. However, further investigation into the source of this difference, including the possibility of a separate southern stock or sub-species, is of interest for increasing our understanding of Hake species.

Response – Samples from Pacific Hake ovaries were collected in 2015 from the NWFSC bottom trawl survey, the acoustic survey, and the At-Sea Hake Observer Program (U.S. catcher-processors and motherships). In addition, fin clips were collected from these same fish for future genetic studies. These new data are being prepared and maturation state is being determined. It is expected that these data will be available soon for analysis, but it is not known when genetic analysis of the fin clips can be completed.

3.3 DESCRIPTION OF BASE MODEL

The 2016 base model is structurally an update of the base model in the 2015 stock assessment. Stock Synthesis version 3.24U (R. Methot, pers. comm.) was used, the same as for the previous assessment (Taylor et al., 2015). The largest change between the 2016 and 2015 stock assessments is the use of an updated acoustic survey index time-series in the base model. 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). At the time of this assessment, the reanalysis of 1995 acoustic data was incomplete and thus is omitted from the 2016 base model. Time-varying fishery selectivity is retained in the 2016 base model as it has been applied since 2014. The parameterization of selectivity was also 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 2015 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 1.10 (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). Year-specific recruitment deviations were estimated from 1946–2016 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 and 2015. 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 had previously not changed since the 2012 assessment, however additional tuning was required 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 3.2.2 (2015-08-14) (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.

3.4 MODELING RESULTS

3.4.1 Changes from 2015

A set of 'bridging' models was constructed to evaluate the component-specific effects of all changes to the base model from 2015 to 2016. These changes included updating historic (pre-2015) catch, fishery age-composition, and weight-at-age data; reanalyzing and updating the acoustic survey index time series and age-composition data; adding 2015 catch and fishery age-composition data; and 'tuning' the 2016 base model given the new survey time series and additional year of fishery data. Updating pre-2015 catch, fishery age-compositions and weight-at-age data had no observable effects on spawning biomass (Figure 13).

The next bridging steps were to add the new acoustic survey data and then insert the 2015 fishery data (Figure 14). The new survey time series spanned the years 1998 through 2015, excluding 1995 because these data were unavailable for re-analysis prior to the completion of this assessment. The main difference from the addition of the new survey time series is a slight increase in spawning biomass resulting from a higher estimate of B_0 and recruitment from the 2011 and 2012 year classes. The overall trend and fit to the new survey index is similar to that used in the previous assessment (Figure 14, lower right panel). The addition of 2015 fishery data affected estimates of recent recruitment (2012–2014). In particular, a relatively large proportion of age-1 fish were caught in the 2015 fishery, providing some evidence to the population model that 2014 could be a large year-class (Figure 14, middle right panel).

The final bridging steps were to 'tune' the 2016 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 small differences in 2012 and 2013 recruitment deviations and hence spawning biomass during recent years. 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 2016 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 2015 assessment (Taylor et al., 2015). 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 relative spawning biomass in 2016 and the default harvest catch in 2016 were more 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 (0.79) between the 2008 and 2010 recruitment deviations. This is 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 2015 base model, despite the inclusion of the reanalyzed time series this year. The 2001 data point continues to be well below any model predictions that were evaluated, and no direct cause for this is known. Although, the survey was conducted about one month earlier that year than all other surveys between 1995 and 2009 (Table 6), 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 2015 age composition was dominated by age-5 fish from the 2010 year-class (70% of the catch in the fishery; 59% in the survey), with age-3 fish from the 2012 year-class making up the second largest cohort in the observations. This pattern was expected given the strength of the 2010 cohort from the 2012 fishery composition data onwards, and thus are fit well by the model. Residual patterns to the fishery and survey age data do not show patterns that would indicate systematic bias in model predictions (Figure 23).

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.

Fishery selectivity continues to have the largest estimated deviations in 2010 and 2011 (Figures 25 and 26). Fishery selectivity in 2010 and 2011 show a more rapid increase in selectivity-at-age than most other years (almost fully selected by age-4 in 2010 and age-3 in 2011). 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 11 and 12). 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 0.484 million t in 2009. The assessment model estimates that spawning biomass declined from 2014 to 2015 after five years of increases from 2009 to 2014. The estimated increases were the result of a large 2010 cohort and an above-average 2008 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 increase from 2015 to 2016 due to an 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 2016 relative spawning biomass (spawning biomass at the start of 2016 divided by that at unfished equilibrium, B_0) is 78.9% but is highly uncertain (with a 95% posterior credibility interval from 35.6% to 174.1%; see Tables 11 and 12). The median estimate of the 2016 beginning of the year female spawning biomass is 1.885 million t (with a 95% posterior credibility interval from 0.791 to 4.781 million t). The estimated 2015 female spawning biomass is 1.536 (0.706–3.082) 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 11 and 12). 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 relatively 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, 67% of the 2014 catch, and 67% of the 2015 catch. The size of the 2010 year class is still more uncertain than cohorts that have been observed for more years but the median estimate is the second highest in the time series (after the 1980 recruitment estimate). The model currently estimates a small 2011 year class, and smaller than average 2012 and 2013 year classes (median recruitment below the mean of all median recruitments). The 2014 year class appears to be larger than average, but is still highly uncertain. There is little or no information in the data to estimate the sizes of the 2015 and 2016 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 recruitment has 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 1971-2012, which are well informed by the age compositions, is 1.43. This value is consistent with the base model value of $\sigma_r = 1.4$.

Exploitation status

Median fishing intensity on the stock is estimated to have been below the target except for the years 2008 and 2010 when spawning biomass was low (Figure 34 and Tables 11 and 12). It should be noted, however, that the 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 11 and 12). Although similar patterns, the exploitation fraction (catch divided by biomass of ages 3 and above) does not necessarily correspond to fishing intensity because fishing intensity more directly accounts for the age-structure. For example, fishing intensity remained nearly constant from 2010 to 2011 but the exploitation fraction declined in these years because of the large estimated proportion of 1-year-old fish in the latter year. Median fishing intensity is estimated to have declined from 102.5% in 2010 to 49.0% in 2015, while the exploitation fraction has decreased from 0.27 in 2010 to 0.07 in 2015. 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 fishing intensity is below the SPR management target for the last three years.

Management performance

Over the last decade (2006–2015), the mean coast-wide utilization rate (i.e., landings/quota) has been 80.8% and catches have generally been below coast-wide targets (Table 4). From 2011 to 2015, the mean utilization rates differed between the United States (76.6%) and Canada (49.1%). In 2015, the utilization rate for the fishery was the lowest in the previous decade (43.3%) 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. Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

The median fishing intensity was below target in all years except 2008 and 2010 (Figure 34). The female spawning biomass was above target until 1998 and was below target from 1998-2000 and 2006-2011.

The joint history of biomass and F-target reference points shows that before 2007, median fishing intensity was below target and female spawning biomass was mostly above target (Figure 36). Between 2007 and 2011, however, median fishing intensity ranged from 89% to 105% and median relative spawning biomass between 0.20 and 0.28. Biomass has risen recently with the 2008 and 2010 recruitments and, correspondingly, fishing intensity has fallen below targets. Relative spawning biomass has been above the target since 2012. While there is large uncertainty in the 2015 estimates of fishing intensity and relative spawning biomass, the model predicts a less than 1% joint probability of being both above the target fishing intensity in 2015 and below the target relative spawning biomass at the start of 2016.

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 maximum likelihood estimates (MLE) because it allows for asymmetry (Figure 24; also see Stewart et al. (2012) for further discussion and examples). Table 14 shows that the median biomass, recruitment, and 2009 relative spawning biomass estimates from the posterior distribution are larger than their respective MLEs, however some estimates (e.g., 2016 relative spawning biomass) are significantly smaller. Figure 37 shows the MLE and Bayesian 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 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 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 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. 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 with posterior credibility intervals in Table 15. The estimates are slightly different than the estimates in the previous 2015 assessment with slightly greater yields and biomasses estimated in this assessment.

3.7 MODEL PROJECTIONS

The median catch limit for 2016 based on the default $F_{\text{SPR}=40\%}$–40:10 harvest policy is 830,124 t, but has a wide range of uncertainty (Figure 38), with the 2.5% to 97.5% range being 309,329–1,958,126 t.

Decision tables give projected population status (relative spawning biomass) and fishing intensity under different catch alternatives for the base model (Tables 16 and 17). 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 16 shows projected relative spawning biomass outcomes, and Table 17 shows projected fishing intensity outcomes relative to 100% target (based on SPR; see table legend).

Fishing intensity exceeding 100% indicates fishing in excess of the $F_{\text{SPR}=40\%}$ default harvest rate catch limit. This can happen for the median fishing intensity in 2016, 2017 and 2018 because the $F_{\text{SPR}=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of overfishing. An alternative catch level where median 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 2017 and 2018 (Tables 18 and 19). 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 2018 for several of these management actions. With zero catch for the next two years, the biomass has a probability of 7% of decreasing from 2016 to 2017 (Table 18 and Figure 40), and a probability of 14% of decreasing from 2017 to 2018 (Table 19 and Figure 41).

The population is predicted to increase from 2016 to 2017 with a greater than 50% probability for all catch levels investigated up to 440,000 t (Table 16 and Figure 39). The model predicts high biomass levels and the predicted probability of dropping below 10% in 2017 is less than 1% and the maximum probability of dropping below $B_{40\%}$ is 13% for all catches explored (Table 18). 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 2017 spawning biomass will be less than the 2016 spawning biomass is 55% or less for all catch levels (Table 18 and Figure 40).

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 21 and 20 for a set of comparisons of the base model to MLE estimates from the following sensitivity models). The sensitivities include the following:

1. Change the external analysis used to develop the age-2+ input survey biomass index time-series from an approach of using the K-S stratified kriging method with extrapolation to using the K-S stratified kriging method without extrapolation;

2. Include the age-1 survey index as an additional source of information;

3. Assume no cohort-based ageing error (i.e., time invariant ageing error);

4. Consideration of alternative maximum age assumptions for estimating selectivity;

5. Consideration of a higher standard deviation on the prior distribution for natural mortality;

6. Assume higher/lower variation about the stock-recruitment curve (σ_r); and

7. 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.

The sensitivity of the base model to changes in the survey biomass estimates as a result of not using the new extrapolation algorithm was conducted to evaluate the impact of assuming negligible biomass outside the surveyed area, or equally, that the population dynamics in the survey area are representative of the stock as a whole (see discussion in Section 2.2.1 above). The results of this model relative to the base model are shown in Table 20 and Figures 42 and 43. In general, the estimated population dynamics are similar, regardless of extrapolation, throughout most of the time series. However, there is some divergence in recent year estimates; e.g., the estimated relative spawning biomass in 2016 is 79.6% for the base model (with extrapolation) and 83.2% for the model without extrapolation. The 2016 default harvest control catch limit coming from the base model is 715,183 t compared to 761,441 t for the model using no extrapolation (using MLE values).

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 early in the time series are slightly lower than the base model due to the lower estimate of equilibrium unfished spawning biomass, yet are similar during the middle of the time series before diverging again towards the end of the time series (Figure 42; 2016 estimates at 79.6% of unfished biomass for the base model and 93.7% 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 (Figure 43). The most prominent of these reductions is for the 2014 year-class, where the estimated standard error is reduced by 25%.

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). 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.

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 12) 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 44). However, absolute levels of spawning biomass are different, particularly for the age-12 case, mainly as a result of scaling the population through estimated B_0 and R_0 parameters (Table 20). 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, 12) selectivity patterns (Figure 44). This feature is 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 sensitivity of the base model to changes in the input σ_r and to the prior distributions for natural mortality and steepness were explored. The standard deviation of the prior distribution on natural mortality was increased from 0.1 (as in the base model) to 0.2 and 0.3. The mean of the prior distribution on steepness was decreased from 0.777 (base) to 0.500, and steepness was also fixed at 1.0. The value of σ_r was changed from a value of 1.4 (base) to alternative high (2.0) and low (1.0) states. These key sensitivities had little effect on the overall estimated population trend throughout the time series (Figure 45), but they do have a significant impact on the estimated scale of the population (quite different estimates of B_0 and R_0 parameters; Table 21). The least influential in terms of relative spawning biomass (Figure 46) as compared to the base model is fixing steepness to 1.0, changing the prior mean on steepness, and moderately changing the prior standard deviation on natural mortality (0.2). The greatest difference in stock status compared to the base model results from changing the input for σ_r. Estimates of natural mortality increased from 0.215 for the base model (prior standard deviation of 0.1) to 0.250 for the sensitivity run with the prior standard deviation set to 0.3. When the mean of the prior distribution for steepness was changed from 0.777 (base model) to 0.5, the estimate for steepness decreased from 0.861 to 0.602.

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 47).

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 48 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. The variability among cohort estimates relative to their estimated size in the base model (Figure 49) further indicates that the estimates start to improve as early as age 3, but some may not stabilize until the cohort approaches 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 50. 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 2016 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, making 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 Hake/Sardine 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.

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

8. 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.

9. 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.

10. 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.

11. Evaluate the quantity and quality of historical biological data (prior to 1989 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use as age-composition and weight-at-age data, and/or any historical indications of abundance fluctuations.

12. Consider alternative methods for treatment of recruitment variability (σ_r) including the use of prior distributions derived from meta-analytic methods, and for refining existing prior for natural mortality (M).

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

5 ACKNOWLEDGMENTS

We thank the authors of previous assessments whose work, and words, remain an influential part of this assessment. We are grateful for the hard work of the U.S. and Canadian acoustics teams, including (in alphabetical order) Alicia Billings, Dezhang Chu, Julia Clemons, Steve Deblois, Stephane Gauthier, Larry Hufnagle, Jessica Nephin, Sandy Parker-Stetter, John Pohl, Chelsea Stanley, and Rebecca Thomas, as well as the crews of the NOAA ship Bell Shimada, and CCGS W. E. Ricker. We thank the following individuals who contributed technical assistance, analysis tools, data, or comments to this assessment: Chelsea Cooke, Cassandra Donavan, Joanne Groot, Rowan Haigh, Owen Hamel, Jim Hastie, Melissa Head, Patrick McDonald, Brad Stenberg, Vanessa Tuttle and Steve Wischniowski. Rick Methot was very helpful with insight into Stock Synthesis as well as the assessment. We also thank the many attendees at the two official JTC meetings who provided valuable insight into the 2015 commercial fisheries in Canada and the U.S., as well as additional perspective on the acoustic survey. We appreciate the input form the AP and other industry members including Barry Ackerman, Shannon Mann, Mike Okoniewski, Brent Paine, Dave Smith, Dan Waldeck, and Teresa Williams to name a few. And, we are very thankful to Miako Ushio, who has been coordinating all of the meetings and logistics related to the assessment and management of Pacific Hake. Finally, we would like to acknowledge the past, current, and future contributions of Ian Taylor. Ian is a member of the JTC and has been unable to contribute to this assessment as much as we would like him to due to personal reasons. Our thoughts are with Ian and his family, and we look forward to working with him in the future.

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7 TABLES

Table 1. Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2015. Tribal catches are included in the sector totals.

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	96,504	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	67,760	0	248,395
2009	0	0	37,550	34,552	49,223	0	121,325
2010	0	0	52,022	54,284	64,654	0	170,961
2011	0	0	56,394	71,678	102,147	1,042	231,262
2012	0	0	38,512	55,264	65,920	448	160,145
2013	0	0	52,470	77,950	102,143	1,018	233,581
2014	0	0	62,102	103,203	98,638	197	264,139
2015	0	0	27,661	68,484	58,010	0	154,155

Table 2. Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2015.

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	55,390	13,537	75,707
2008	0	3,592	57,197	12,517	73,306
2009	0	0	43,774	12,073	55,847
2010	0	8,081	38,780	12,850	59,712
2011	0	9,717	36,632	14,060	60,409
2012	0	0	31,164	14,478	45,642
2013	0	0	33,451	18,583	52,033
2014	0	0	13,184	21,380	34,563
2015	0	0	16,451	20,057	36,507

Table 3. Total U.S., Canadian and coastwide catches of Pacific Hake (t) from 1966-2015. 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	249,496	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	75,707	293,389	74.2	25.8
2008	248,395	73,306	321,701	77.2	22.8
2009	121,325	55,847	177,172	68.5	31.5
2010	170,961	59,712	230,672	74.1	25.9
2011	231,262	60,409	291,671	79.3	20.7
2012	160,145	45,642	205,787	77.8	22.2
2013	233,581	52,033	285,614	81.8	18.2
2014	264,139	34,563	298,703	88.4	11.6
2015	154,155	36,507	190,663	80.9	19.1

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)	Canada catch target (t)	US catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2006	266,955	94,744	361,699	364,842	95,297	269,545	99.0%	99.4%	99.1%
2007	217,682	75,707	293,389	328,358	85,767	242,591	89.7%	88.3%	89.4%
2008	248,395	73,306	321,701	364,842	95,297	269,545	92.2%	76.9%	88.2%
2009	121,325	55,847	177,172	184,000	48,061	135,939	89.2%	116.2%	96.3%
2010	170,961	59,712	230,672	262,500	68,565	193,935	88.2%	87.1%	87.9%
2011	231,262	60,409	291,671	393,751	102,848	290,903	79.5%	58.7%	74.1%
2012	160,145	45,642	205,787	251,809	65,773	186,036	86.1%	69.4%	81.7%
2013	233,581	52,033	285,614	365,112	95,367	269,745	86.6%	54.6%	78.2%
2014	264,139	34,563	298,703	428,000	111,794	316,206	83.5%	30.9%	69.8%
2015	154,155	36,507	190,663	440,000	114,928	325,072	47.4%	31.8%	43.3%

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	–	490	64	–	–	26	79
2015	–	–	203	–	431	79	–	–	6	74

Table 6. 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	–	–	–
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	0.092	78

Table 7. Summary of key kriging parameters for the acoustic survey as used in the 2015 and 2016 assessments. Search radius is the distance in the transformed space from which observations are drawn to calculate weights in the kriging. Parameters k_{min} and k_{max} are the minimum and maximum number of data points used to calculate a kriged value. Length scale is a parameter estimated from the variogram for each year. For the 2016 assessment the search radius was calculated as three times the length scale for each year.

Year	Search radius	k_{min}	k_{max}
2015 assessment			
1995	0.03	1	10
1998	0.03	1	10
2001	0.03	1	10
2003	0.03	1	10
2005	0.03	1	10
2007	0.03	1	10
2009	0.03	1	10
2011	0.30	10	30
2012	0.30	10	30
2013	0.30	10	30
2016 assessment			
1998-2015	0.018–0.024	3	10

Table 8. Biomass index estimates from the acoustic survey (million t) using kriging with extrapolation, kriging without extrapolation, and design-based methods.

Year	Biomass with extrapolation (million t)	Sampling CV with extrapolation	Biomass no extrapolation (million t)	Sampling CV no extrapolation	Biomass Design-based (million t)
1995	–	–	–	–	–
1998	1.535	5.3%	1.305	1.8%	1.371
2001	0.862	10.6%	0.787	4.6%	0.738
2003	2.138	6.4%	1.880	2.7%	1.807
2005	1.376	6.4%	1.030	3.3%	0.931
2007	0.943	7.7%	0.894	3.3%	0.853
2009	1.502	10.0%	1.448	3.9%	1.338
2011	0.675	11.8%	0.671	3.9%	0.662
2012	1.279	6.7%	1.174	2.9%	1.124
2013	1.929	6.5%	1.803	3.1%	1.830
2015	2.156	9.2%	2.072	4.0%	2.128

Table 9. Number of Pacific Hake ovaries collected for histological analysis with maturity determined from different years and different sources. Numbers for 2015 are preliminary and may be reduced when preparation of the samples is completed.

Year	NWFSC Trawl Survey	Acoustic Survey	At-Sea Hake Observer Program
2009	259	–	–
2012	71	199	–
2013	70	254	209
2014	271	–	105
2015	293	193	210

Table 10. 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 Rec. deviations: 1946–2016	71	(-6,6)	Lognormal(0,σ_r)
Natural mortality (M)	–	(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 (1991–2015, ages 2–6)	125	NA	Normal(0,0.03)

Table 11. Time-series of median posterior population estimates from the base model. Relative spawning biomass is spawning biomass relative to the unfished equilibrium (B_0). Exploitation fraction is total catch divided by total age-3+ biomass. (1-SPR)/(1-$SPR_{40\%}$) is the fishing intensity relative to the default harvest rate.

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Age-0 recruits (millions)	(1-SPR) / (1-$SPR_{40\%}$)	Exploitation fraction
1966	1,157	47.9%	1,552	41.3%	5.8%
1967	1,090	45.2%	3,354	59.6%	9.6%
1968	1,025	42.4%	2,235	42.9%	5.8%
1969	1,088	45.4%	1,014	56.1%	8.5%
1970	1,144	47.7%	8,607	64.2%	9.6%
1971	1,140	47.6%	808	47.9%	6.3%
1972	1,372	57.6%	531	37.3%	5.0%
1973	1,567	65.6%	4,887	39.9%	4.4%
1974	1,586	66.7%	444	46.8%	6.1%
1975	1,603	67.0%	1,399	40.6%	5.7%
1976	1,560	65.9%	378	37.5%	4.8%
1977	1,486	62.4%	5,462	26.7%	3.3%
1978	1,379	57.4%	336	24.4%	3.0%
1979	1,410	58.8%	876	29.7%	4.1%
1980	1,419	59.0%	17,827	22.9%	2.5%
1981	1,382	57.3%	342	35.4%	4.4%
1982	1,800	75.7%	299	29.9%	4.3%
1983	2,222	93.6%	465	23.7%	2.2%
1984	2,352	99.1%	12,984	25.6%	2.8%
1985	2,237	94.6%	243	20.8%	2.4%
1986	2,435	102.5%	283	34.6%	5.3%
1987	2,526	106.6%	5,278	36.9%	4.3%
1988	2,412	101.6%	2,347	39.0%	5.0%
1989	2,304	96.9%	246	50.5%	7.7%
1990	2,160	90.7%	4,010	43.4%	6.1%
1991	1,967	82.8%	1,086	54.2%	7.9%
1992	1,795	75.3%	212	58.7%	9.5%
1993	1,618	67.8%	2,828	52.2%	7.4%
1994	1,426	59.6%	3,038	75.7%	14.3%
1995	1,189	49.7%	1,151	66.8%	12.0%
1996	1,122	46.9%	1,590	79.6%	15.2%
1997	1,025	42.9%	1,273	84.1%	15.2%
1998	912	38.4%	1,908	90.1%	18.1%
1999	790	33.2%	11,412	96.9%	20.9%
2000	690	29.0%	321	77.2%	14.5%
2001	987	41.4%	1,169	72.8%	13.0%
2002	1,263	52.7%	71	48.6%	4.5%
2003	1,385	58.0%	1,413	50.8%	6.1%
2004	1,320	55.1%	94	73.4%	12.3%
2005	1,118	46.6%	2,325	80.3%	17.6%
2006	865	36.3%	1,853	92.8%	21.2%
2007	675	28.5%	58	98.4%	25.2%
2008	591	24.8%	5,426	105.3%	26.2%
2009	484	20.3%	1,098	88.6%	16.2%
2010	572	24.1%	14,785	102.5%	27.1%
2011	651	27.2%	515	99.1%	20.5%
2012	1,067	44.4%	1,582	77.9%	16.1%
2013	1,461	60.7%	933	68.1%	7.7%
2014	1,594	66.2%	13,071	64.3%	8.5%
2015	1,536	63.9%	1,103	49.0%	6.7%
2016	1,885	78.9%	1,223	–	–

Table 12. Time-series of 95% posterior credibility intervals for the quantities shown in Table 11.

Year	Female spawning biomass (thousand t)	Relative spawning biomass	Age-0 recruits (millions)	(1-SPR) / (1-$SPR_{40\%}$)	Exploitation fraction
1966	653-2,232	28.0- 87.5%	69- 9,345	22.0- 65.0%	2.9-10.2%
1967	600-2,044	26.0- 79.9%	156-13,734	33.6- 88.0%	5.0-18.0%
1968	562-1,984	24.2- 75.0%	140-10,178	22.5- 70.2%	2.9-12.2%
1969	615-2,044	27.0- 78.4%	66- 5,912	31.0- 84.5%	4.2-16.2%
1970	662-2,247	28.6- 84.5%	3,862-23,527	35.7- 93.4%	4.7-17.6%
1971	645-2,339	28.2- 87.6%	69- 3,768	24.1- 76.6%	3.1-10.9%
1972	790-2,846	34.9-104.5%	58- 2,421	18.0- 63.1%	2.4- 8.8%
1973	921-3,324	40.2-117.7%	2,248-12,000	18.8- 65.0%	2.1- 7.5%
1974	929-3,298	40.3-117.8%	45- 1,873	22.5- 74.6%	2.9-10.3%
1975	908-3,335	40.0-118.5%	472- 3,964	19.7- 66.7%	2.7- 9.8%
1976	876-3,276	38.4-116.5%	40- 1,631	18.0- 62.3%	2.3- 8.5%
1977	818-3,101	36.0-110.6%	2,663-11,712	12.4- 47.8%	1.6- 6.0%
1978	764-2,815	33.5-101.7%	32- 1,678	11.6- 44.2%	1.5- 5.3%
1979	787-2,744	34.4-100.5%	165- 3,230	14.6- 51.5%	2.1- 7.4%
1980	797-2,705	34.7-100.2%	10,036-35,390	11.2- 41.0%	1.3- 4.4%
1981	785-2,511	34.2- 95.7%	35- 1,735	18.3- 58.6%	2.4- 7.7%
1982	1,130-3,154	47.7-119.2%	36- 1,462	15.8- 50.1%	2.4- 7.5%
1983	1,428-3,750	60.3-141.3%	62- 1,918	12.6- 38.7%	1.3- 3.4%
1984	1,534-3,854	64.7-147.8%	8,034-23,045	14.2- 42.0%	1.7- 4.2%
1985	1,481-3,557	62.5-138.2%	27- 1,144	11.2- 33.8%	1.5- 3.6%
1986	1,696-3,777	69.9-143.7%	40- 1,187	20.5- 51.9%	3.4- 7.9%
1987	1,830-3,769	74.9-149.7%	3,022- 9,316	22.4- 54.1%	2.8- 5.9%
1988	1,775-3,536	71.8-141.6%	938- 4,530	25.0- 56.9%	3.4- 6.8%
1989	1,731-3,307	69.7-133.1%	29- 1,048	33.2- 69.0%	5.3-10.4%
1990	1,653-3,039	66.0-121.7%	2,386- 6,932	28.7- 60.3%	4.3- 8.0%
1991	1,531-2,707	61.0-109.7%	241- 2,484	37.4- 71.8%	5.7-10.2%
1992	1,404-2,431	56.0- 98.7%	25- 869	41.2- 76.2%	7.0-12.2%
1993	1,281-2,172	51.2- 88.7%	1,735- 4,639	35.9- 68.9%	5.5- 9.4%
1994	1,143-1,901	45.8- 77.6%	1,911- 4,799	56.3- 93.9%	10.8-17.9%
1995	948-1,596	38.0- 64.1%	570- 2,208	47.9- 84.5%	8.9-15.1%
1996	903-1,477	35.8- 60.6%	932- 2,615	60.8- 98.0%	11.6-18.9%
1997	831-1,350	32.7- 55.0%	634- 2,266	65.1-101.5%	11.6-18.6%
1998	743-1,209	29.3- 49.1%	1,204- 3,115	70.1-106.9%	13.8-22.2%
1999	632-1,067	25.1- 42.7%	8,126-17,091	76.3-114.5%	15.6-26.2%
2000	537- 950	21.4- 37.2%	65- 819	56.9- 96.1%	10.6-18.9%
2001	771-1,350	30.9- 53.4%	739- 1,917	52.8- 91.8%	9.4-16.8%
2002	1,007-1,663	40.1- 67.1%	12- 265	32.8- 65.5%	3.4- 5.6%
2003	1,139-1,771	44.1- 73.2%	959- 2,212	36.2- 66.7%	4.8- 7.4%
2004	1,111-1,646	42.2- 69.7%	18- 293	55.8- 90.4%	9.8-14.6%
2005	947-1,396	35.8- 59.1%	1,600- 3,710	61.6- 97.9%	14.2-20.9%
2006	730-1,096	27.7- 46.2%	1,197- 3,116	74.3-109.1%	16.7-25.0%
2007	555- 891	21.8- 35.9%	9- 207	79.5-115.3%	19.3-30.5%
2008	469- 821	18.7- 31.9%	3,498- 9,671	85.4-119.6%	18.8-32.9%
2009	363- 726	15.0- 27.2%	507- 2,456	65.8-106.9%	10.8-21.5%
2010	412- 900	17.8- 33.5%	7,634-30,732	78.5-120.9%	17.4-37.7%
2011	433-1,075	19.0- 40.3%	124- 1,543	71.0-120.4%	12.4-30.4%
2012	597-1,960	27.8- 74.4%	507- 4,381	49.7-105.1%	8.9-27.2%
2013	778-2,759	35.6-104.4%	151- 3,840	41.6- 97.6%	4.1-14.3%
2014	784-3,103	36.1-119.5%	445-83,006	36.5- 97.8%	4.4-17.1%
2015	706-3,082	32.6-118.9%	59-22,330	25.7- 84.9%	3.3-14.8%
2016	791-4,781	35.6-174.1%	80-18,851	–	–

Table 13. 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	1,743	1,257	833	619	487	399	337	289	250	216	187	161	138	118	100	433
1967	3,062	1,406	1,014	668	483	376	305	254	218	189	163	141	121	104	89	402
1968	2,319	2,470	1,134	809	509	360	276	218	182	156	135	117	101	87	74	351
1969	1,176	1,871	1,992	908	629	391	274	207	164	136	117	101	88	76	65	319
1970	7,084	949	1,509	1,590	693	472	289	198	149	118	98	84	73	63	54	277
1971	909	5,716	765	1,200	1,195	508	339	201	138	104	82	68	59	51	44	231
1972	543	734	4,609	611	924	906	381	249	147	101	76	60	50	43	37	202
1973	4,062	438	592	3,693	477	712	692	287	187	111	76	57	45	38	32	180
1974	472	3,277	353	474	2,868	365	540	516	214	140	83	57	43	34	28	158
1975	1,228	381	2,643	282	364	2,169	273	395	377	156	102	61	41	31	25	136
1976	398	991	307	2,115	219	279	1,642	203	294	281	116	76	45	31	23	120
1977	4,697	321	799	246	1,647	168	212	1,233	152	221	211	87	57	34	23	108
1978	327	3,790	259	642	194	1,288	131	164	949	117	170	162	67	44	26	101
1979	953	264	3,057	208	507	152	1,005	101	126	734	91	131	126	52	34	98
1980	15,406	769	213	2,453	164	395	118	769	77	97	561	69	101	96	40	101
1981	357	12,430	620	171	1,941	129	309	91	596	60	75	435	54	78	74	109
1982	287	288	10,025	497	133	1,499	98	233	69	450	45	57	328	41	59	139
1983	472	231	232	8,044	390	104	1,158	75	178	53	344	35	43	251	31	151
1984	11,485	381	187	187	6,361	307	81	897	58	138	41	266	27	34	194	141
1985	255	9,267	307	150	147	4,983	239	63	692	45	106	31	205	21	26	259
1986	283	206	7,475	247	119	116	3,911	186	49	539	35	83	24	160	16	222
1987	4,654	228	166	5,992	193	92	89	2,960	141	37	408	27	63	19	121	180
1988	2,276	3,755	184	133	4,671	149	70	67	2,227	106	28	307	20	47	14	227
1989	267	1,836	3,028	147	103	3,588	113	53	50	1,667	79	21	230	15	35	180
1990	3,589	216	1,480	2,417	113	78	2,659	82	38	36	1,207	57	15	167	11	156
1991	1,113	2,896	174	1,184	1,870	86	59	1,968	61	28	27	894	43	11	123	123
1992	215	898	2,335	139	897	1,391	63	42	1,418	44	20	19	644	31	8	178
1993	2,621	173	724	1,860	105	664	1,013	45	30	1,000	31	14	14	454	22	131
1994	2,752	2,115	140	578	1,420	79	491	732	32	22	723	22	10	10	328	110
1995	1,096	2,221	1,705	111	427	1,011	54	316	471	21	14	465	14	7	6	282
1996	1,477	884	1,790	1,356	83	312	718	37	215	320	14	9	316	10	5	196
1997	1,158	1,191	712	1,411	977	58	211	459	23	137	205	9	6	202	6	128
1998	1,750	934	960	561	1,000	664	38	131	286	15	86	128	6	4	126	84
1999	10,269	1,412	752	752	389	662	421	23	79	172	9	51	77	3	2	126
2000	350	8,285	1,137	583	497	244	407	246	13	46	101	5	30	45	2	75
2001	1,069	282	6,679	903	432	354	166	255	155	8	29	63	3	19	28	48
2002	74	862	227	5,319	675	309	243	108	166	101	5	19	41	2	12	50
2003	1,303	60	695	182	4,135	513	230	176	78	120	73	4	14	30	2	45
2004	98	1,052	48	556	140	3,124	380	167	127	57	87	53	3	10	22	34
2005	2,102	79	848	38	409	100	2,166	253	111	85	38	58	35	2	7	37
2006	1,667	1,696	64	671	28	285	67	1,370	160	70	53	24	37	22	1	27
2007	56	1,345	1,366	50	467	18	177	39	795	93	41	31	14	21	13	17
2008	4,729	45	1,083	1,061	33	295	11	99	22	443	52	23	17	8	12	16
2009	1,008	3,815	36	838	689	20	163	5	49	11	218	25	11	9	4	14
2010	12,428	813	3,074	29	592	463	13	96	3	29	6	128	15	7	5	10
2011	504	10,027	655	2,378	18	343	266	7	54	2	16	4	72	8	4	9
2012	1,363	407	8,069	502	1,431	11	213	163	4	33	1	10	2	44	5	8
2013	950	1,100	328	6,329	355	971	7	141	108	3	22	1	7	1	29	8
2014	17,590	766	886	260	4,684	255	683	5	93	71	2	14	0	4	1	25
2015	2,594	14,193	618	704	194	3,426	181	461	3	63	48	1	10	0	3	18
2016	2,639	2,093	11,443	493	537	146	2,523	132	335	2	46	35	1	7	0	15

Table 14. 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 (2015) base model.

	MLE	Posterior median	Posterior median from 2015 base model
Parameters			
Natural Mortality (M)	0.215	0.226	0.223
Unfished recruitment (R_0, millions)	2,666	3,125	2,923
Steepness (h)	0.861	0.814	0.814
Additional acoustic survey SD	0.271	0.338	0.376
Catchability (q)	1.137	1.029	0.915
Derived Quantities			
2008 recruitment (millions)	4,729	5,426	5,987
2010 recruitment (millions)	12,428	14,785	14,799
2014 recruitment (millions)	17,590	13,071	1,062
Unfished female spawning biomass (B_0, thousand t)	2,226	2,397	2,269
2009 Relative Spawning Biomass	20.0%	20.3%	22.0%
2016 Relative Spawning Biomass	79.6%	78.9%	–
2015 Fishing intensity: (1-SPR)/(1-$SPR_{40\%}$)	56.1%	49.0%	103.5%
Female spawning biomass at $F_{SPR=40\%}$ ($B_{SPR=40\%}$, thousand t)	834	856	814
Reference Points (equilibrium) based on $F_{SPR=40\%}$			
SPR at $F_{SPR=40\%}$	40.0%	40.0%	40.0%
Exploitation Fraction corresponding to SPR	20.8%	21.9%	21.6%
Yield at $B_{SPR=40\%}$ (thousand t)	361	382	362

Table 15. Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2015 averages for mean size at age and selectivity at age.

Quantity	2.5^{th} percentile	Median	97.5^{th} percentile
Unfished female spawning biomass (B_0, thousand t)	1,887	2,397	3,216
Unfished recruitment (R_0, millions)	2,021	3,125	5,484
Reference points (equilibrium) based on $F_{SPR=40\%}$			
Female spawning biomass at $F_{SPR=40\%}$ ($B_{SPR=40\%}$, thousand t)	644	856	1,117
SPR at $F_{SPR=40\%}$	–	40%	–
Exploitation fraction corresponding to SPR	18.3%	21.9%	26.1%
Yield at $B_{SPR=40\%}$ (thousand t)	277	382	569
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	755	959	1,286
SPR at $B_{40\%}$	40.6%	43.4%	50.7%
Exploitation fraction resulting in $B_{40\%}$	14.6%	19%	23.8%
Yield at $B_{40\%}$ (thousand t)	271	372	550
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	367	586	962
SPR at MSY	18%	28.9%	45.4%
Exploitation fraction corresponding to SPR at MSY	17.9%	33.2%	61.1%
MSY (thousand t)	286	406	615

Table 16. Decision tables 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), the TAC from 2015 (row d), the catch values that result in a median SPR ratio of 1.0 (row f), the median values estimated via the default harvest policy ($F_{SPR=40\%}$–40:10) using the base model (row g), and the catch level that results in a 50% probability that the median projected catch will remain the same in 2016 and 2017 (row h). Catch in 2018 does not impact the beginning of the year biomass in 2018.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2016	0	41%	61%	79%	101%	152%
	2017	0	47%	73%	96%	128%	224%
	2018	0	51%	77%	107%	147%	267%
b:	2016	180,000	41%	61%	79%	101%	152%
	2017	180,000	43%	69%	92%	124%	219%
	2018	180,000	43%	70%	99%	139%	262%
c:	2016	350,000	41%	61%	79%	101%	152%
	2017	350,000	39%	66%	89%	121%	214%
	2018	350,000	36%	64%	92%	132%	255%
d:	2016	440,000	41%	61%	79%	101%	152%
2015	2017	440,000	38%	64%	87%	119%	212%
TAC	2018	440,000	32%	60%	89%	129%	251%
e:	2016	500,000	41%	61%	79%	101%	152%
	2017	500,000	36%	62%	86%	118%	210%
	2018	500,000	29%	57%	86%	127%	249%
f:	2016	785,000	41%	61%	79%	101%	152%
FI=	2017	900,000	30%	56%	80%	112%	203%
100%	2018	825,000	16%	44%	73%	114%	235%
g:	2016	830,124	41%	61%	79%	101%	152%
default	2017	955,423	28%	55%	79%	111%	201%
HR	2018	837,352	15%	42%	71%	112%	233%
h:	2016	928,100	41%	61%	79%	101%	152%
C2016=	2017	928,100	27%	53%	77%	109%	200%
C2017	2018	820,224	14%	41%	69%	111%	231%

Table 17. Decision tables of forecast quantiles of Pacific Hake fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2016 – 2018 catch alternatives presented in Table 16. 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			**Fishing Intensity**				
	Year	Catch (t)					
a:	2016	0	0%	0%	0%	0%	0%
	2017	0	0%	0%	0%	0%	0%
	2018	0	0%	0%	0%	0%	0%
b:	2016	180,000	23%	33%	41%	51%	70%
	2017	180,000	14%	24%	33%	43%	60%
	2018	180,000	12%	22%	31%	42%	60%
c:	2016	350,000	40%	55%	66%	78%	99%
	2017	350,000	25%	42%	56%	70%	92%
	2018	350,000	22%	40%	54%	72%	97%
d:	2016	440,000	48%	64%	75%	88%	108%
2015	2017	440,000	31%	51%	66%	82%	104%
TAC	2018	440,000	27%	48%	65%	84%	111%
e:	2016	500,000	53%	69%	81%	94%	113%
	2017	500,000	34%	56%	72%	88%	111%
	2018	500,000	31%	53%	71%	92%	119%
f:	2016	785,000	71%	88%	100%	112%	129%
FI=	2017	900,000	55%	83%	100%	117%	136%
100%	2018	825,000	47%	79%	100%	123%	140%
g:	2016	830,124	73%	90%	103%	114%	131%
default	2017	955,423	57%	86%	103%	120%	136%
HR	2018	837,352	48%	80%	102%	125%	140%
h:	2016	928,100	78%	95%	107%	119%	134%
C2016=	2017	928,100	56%	85%	103%	120%	137%
C2017	2018	820,224	48%	80%	102%	125%	140%

Table 18. Probabilities related to spawning biomass, fishing intensity, and 2017 catch limits for alternative 2016 catch options (catch options explained in Table 16).

Catch in 2016	Probability $B_{2017}<B_{2016}$	Probability $B_{2017}<B_{40\%}$	Probability $B_{2017}<B_{25\%}$	Probability $B_{2017}<B_{10\%}$	Probability Fishing intensity in 2016 >40% Target	Probability 2017 Catch Target <2016 Catch
a: 0	7%	2%	0%	0%	0%	0%
b: 180,000	17%	4%	0%	0%	0%	0%
c: 350,000	27%	5%	1%	0%	5%	3%
d: 440,000	33%	7%	1%	0%	10%	7%
e: 500,000	36%	7%	1%	0%	15%	11%
f: 785,000	49%	11%	3%	0%	51%	38%
g: 830,124	51%	12%	3%	0%	54%	42%
h: 928,100	55%	13%	4%	0%	66%	50%

Table 19. Probabilities related to spawning biomass, fishing intensity, and 2018 catch limits for alternative 2017 catch options (catch options explained in Table 16).

Catch in 2017	Probability $B_{2018}<B_{2017}$	Probability $B_{2018}<B_{40\%}$	Probability $B_{2018}<B_{25\%}$	Probability $B_{2018}<B_{10\%}$	Probability Fishing intensity in 2017 >40% Target	Probability 2018 Catch Target <2017 Catch
a: 0	14%	1%	0%	0%	0%	0%
b: 180,000	27%	4%	0%	0%	0%	0%
c: 350,000	40%	7%	1%	0%	3%	4%
d: 440,000	45%	10%	2%	0%	7%	10%
e: 500,000	49%	11%	3%	0%	12%	15%
f: 900,000	70%	21%	10%	2%	50%	52%
g: 955,423	71%	24%	11%	2%	55%	56%
h: 928,100	70%	25%	12%	2%	55%	55%

Table 20. Maximum likelihood estimates (MLE) of select parameters, derived quantities, and reference points for the base model and sensitivity runs.

	Base model	No extrapolation on survey	Include age-1 index	Max. age of selectivity 5	Max. age of selectivity 7	Max. age of selectivity 12
Parameters						
Natural Mortality (M)	0.215	0.215	0.214	0.214	0.214	0.211
R_0 (millions)	2,666	2,707	2,672	2,655	2,577	2,450
Steepness (h)	0.861	0.861	0.860	0.858	0.864	0.869
Additional acoustic survey SD	0.271	0.350	0.265	0.272	0.254	0.248
Derived Quantities						
2008 recruitment (millions)	4,729	4,931	5,218	4,533	4,640	4,893
2010 recruitment (millions)	12,428	12,954	14,371	11,008	12,078	12,780
2014 recruitment (millions)	17,590	18,292	19,871	16,629	17,330	17,987
B_0 (thousand t)	2,226	2,246	2,238	2,230	2,169	2,104
2009 Relative Spawning Biomass	20.0%	20.4%	20.9%	20.0%	19.9%	20.3%
2016 Relative Spawning Biomass	79.6%	83.2%	93.7%	71.7%	79.9%	89.0%
Reference Points based on $F_{\text{SPR}=40\%}$						
2015 Fishing intensity: (1-SPR)/(1-$\text{SPR}_{40\%}$)	56.1%	53.8%	49.7%	58.4%	56.7%	56.8%
Female Spawning Biomass ($B_{F_{40\%}}$; thousand t)	834	842	838	834	814	792
$\text{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation Fraction corresponding to SPR	20.8%	20.9%	20.8%	20.7%	20.8%	20.7%
Yield at $B_{F_{40\%}}$ (thousand t)	361	365	362	359	352	340

Table 21. 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	Sigma R 1.0	Sigma R 2.0	Steepness prior mean 0.5	Steepness fixed mean 1.0	Natural mortality SD 0.2	Natural mortality SD 0.3
Parameters							
Natural Mortality (M)	0.215	0.209	0.224	0.222	0.213	0.237	0.250
R_0 (millions)	2,666	1,830	6,521	3,267	2,513	3,395	3,880
Steepness (h)	0.861	0.852	0.894	0.602	1.000	0.850	0.845
Additional acoustic survey SD	0.271	0.271	0.271	0.272	0.271	0.272	0.272
Derived Quantities							
2008 recruitment (millions)	4,729	4,424	5,206	4,984	4,665	5,703	6,340
2010 recruitment (millions)	12,428	11,368	14,059	13,086	12,268	15,419	17,391
2014 recruitment (millions)	17,590	8,128	32,382	18,612	17,298	22,085	25,053
B_0 (thousand t)	2,226	1,600	5,040	2,562	2,134	2,350	2,443
2009 Relative Spawning Biomass	20.0%	27.1%	9.2%	17.9%	20.7%	21.0%	21.5%
2016 Relative Spawning Biomass	79.6%	86.4%	46.7%	70.8%	82.6%	86.9%	90.7%
Reference Points based on $F_{\mathrm{SPR}=40\%}$							
2015 Fishing intensity: (1-SPR)/(1-$\mathrm{SPR}_{40\%}$)	56.1%	60.3%	50.7%	54.0%	56.7%	47.3%	43.0%
Female Spawning Biomass ($B_{F_{40\%}}$; thousand t)	834	597	1,924	720	854	875	907
$\mathrm{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation Fraction corresponding to SPR	20.8%	20.3%	21.7%	21.5%	20.6%	23.0%	24.1%
Yield at $B_{F_{40\%}}$ (thousand t)	361	252	867	322	366	418	454

Table 22. 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.

	Base model	-1 year	-2 years	-3 years	-4 years	-5 years
Parameters						
Natural Mortality (*M*)	0.215	0.215	0.214	0.214	0.210	0.217
R_0 (millions)	2,666	2,681	2,571	2,515	2,266	2,744
Steepness (*h*)	0.861	0.863	0.862	0.865	0.859	0.856
Additional acoustic survey SD	0.271	0.290	0.299	0.370	0.485	0.281
Derived Quantities						
2008 recruitment (millions)	4,729	5,025	5,133	4,949	3,758	9,003
2010 recruitment (millions)	12,428	12,287	13,046	10,167	2,669	853
2014 recruitment (millions)	17,590	1,972	1,897	1,832	1,427	1,969
B_0 (thousand t)	2,226	2,235	2,157	2,116	1,970	2,243
2009 Relative Spawning Biomass	20.0%	20.0%	19.5%	16.5%	14.4%	35.4%
2016 Relative Spawning Biomass	79.6%	59.6%	60.9%	49.2%	13.4%	37.8%
Reference Points based on $F_{\text{SPR}=40\%}$						
2015 Fishing intensity: (1-SPR)/(1-$\text{SPR}_{40\%}$)	56.1%	57.0%	57.8%	65.9%	122.4%	67.7%
Female Spawning Biomass ($B_{F_{40\%}}$; thousand t)	834	839	809	795	737	838
$\text{SPR}_{\text{MSY-proxy}}$	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Exploitation Fraction corresponding to SPR	20.8%	20.9%	20.8%	20.8%	20.5%	21.2%
Yield at $B_{F_{40\%}}$ (thousand t)	361	363	350	344	314	369

8 FIGURES

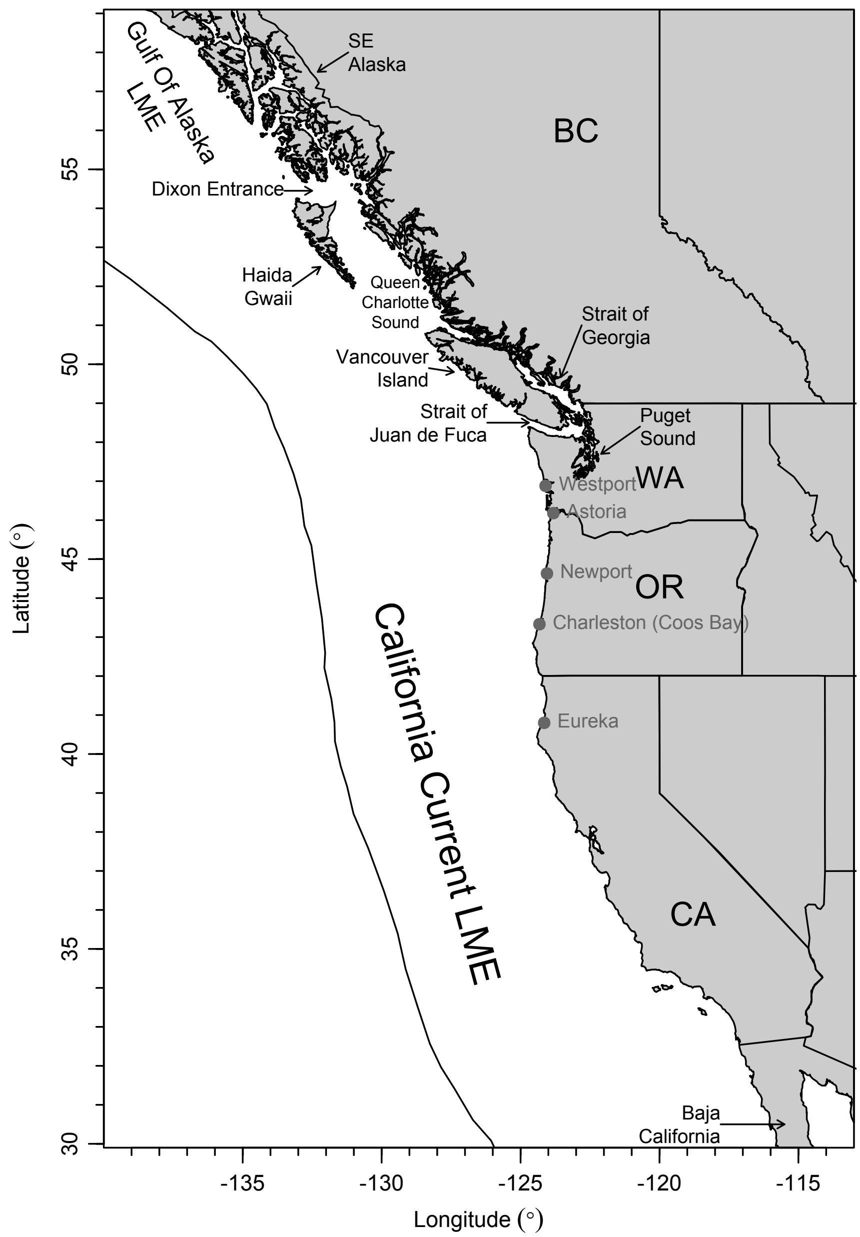


Figure 1. Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.

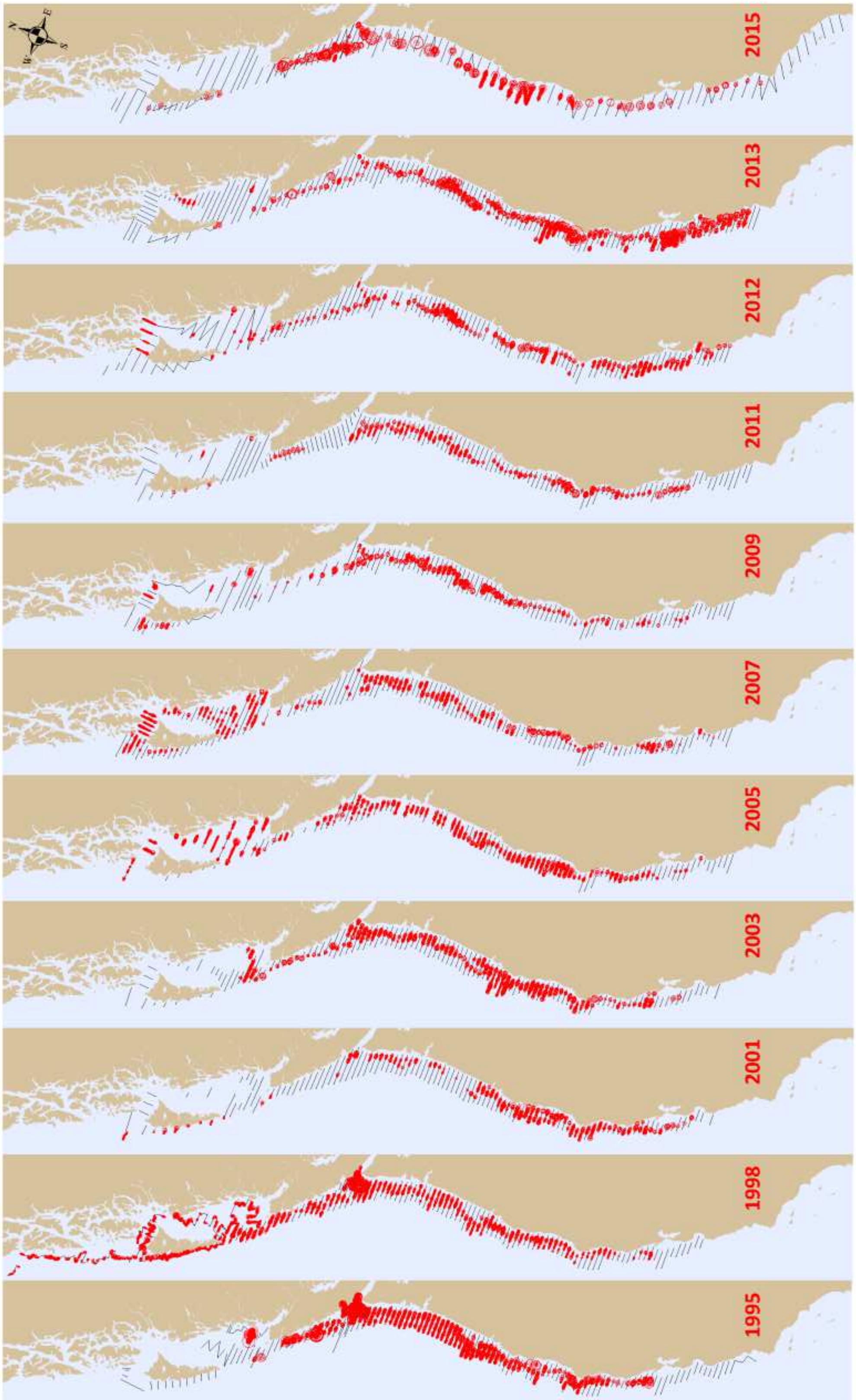


Figure 2. Spatial distribution of acoustic backscatter attributable to Pacific Hake from joint US-Canada acoustic surveys 1998–2015. Area of the circle is roughly proportional to observed backscatter.

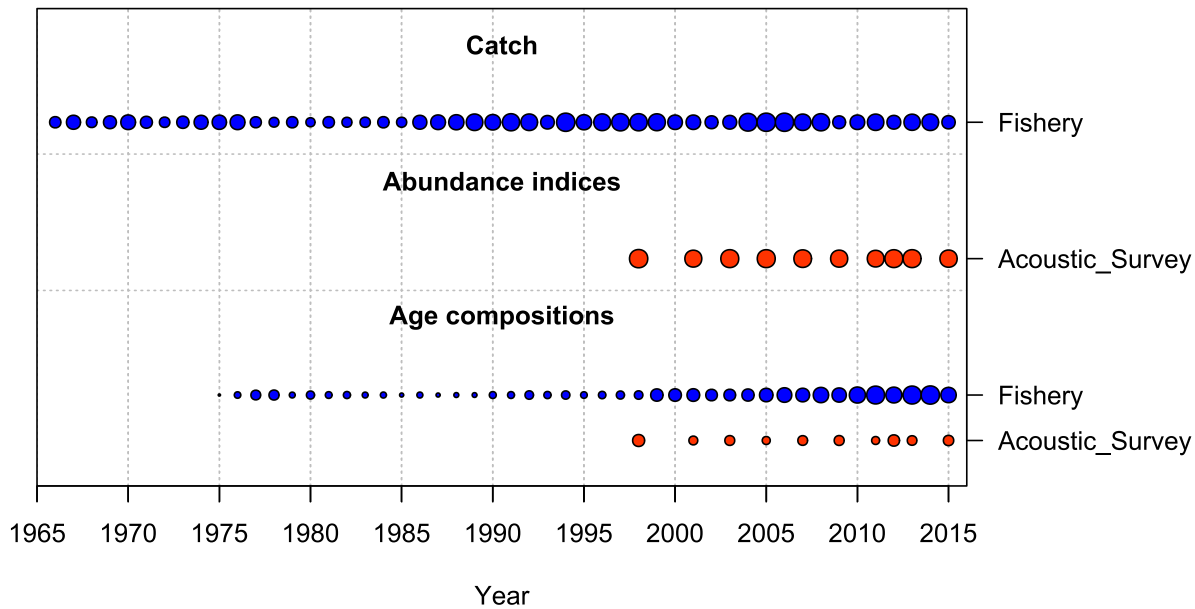


Figure 3. Overview of data used in this assessment, 1966–2015.

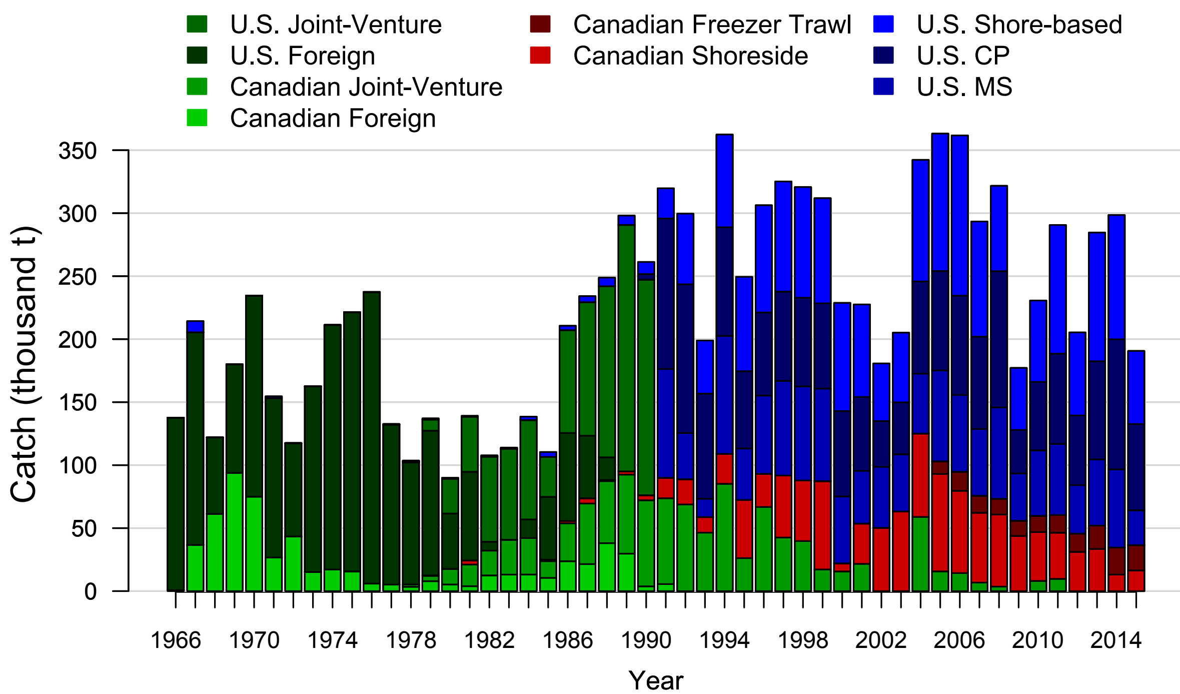


Figure 4. Total Pacific Hake catch used in the assessment by sector, 1966–2015. U.S. tribal catches are included in the appropriate sector.

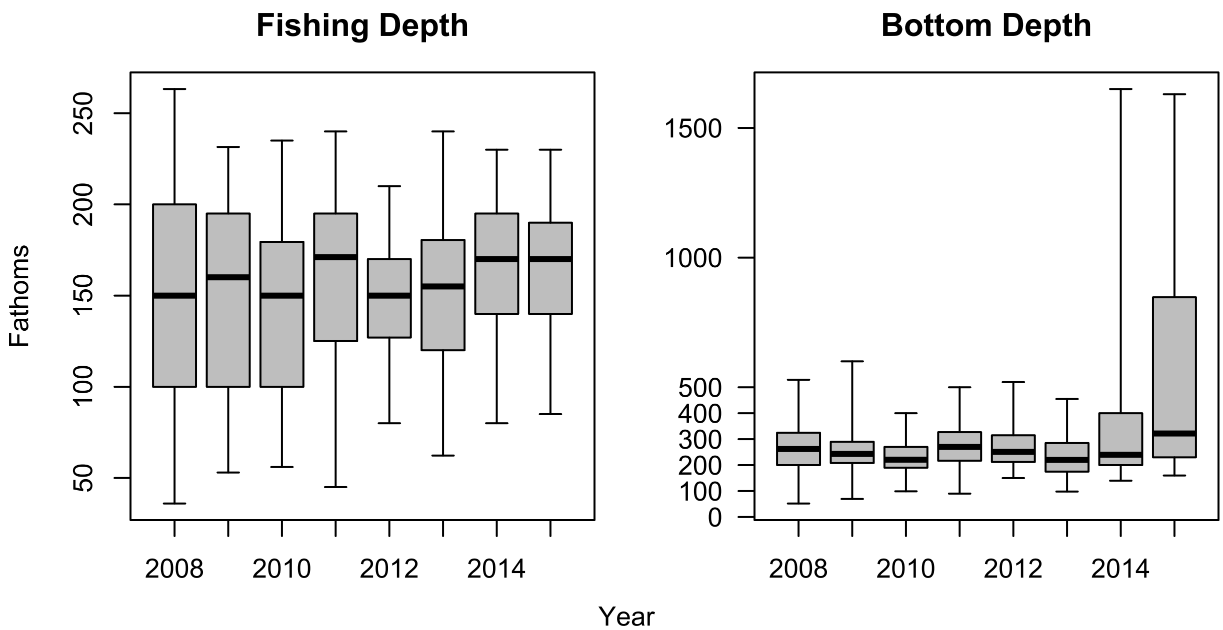


Figure 5. Distribution of fishing depths (left) and bottom depths (right), in fathoms, of Pacific Hake catches in the U.S. at-sea fleet from 2008–2015.

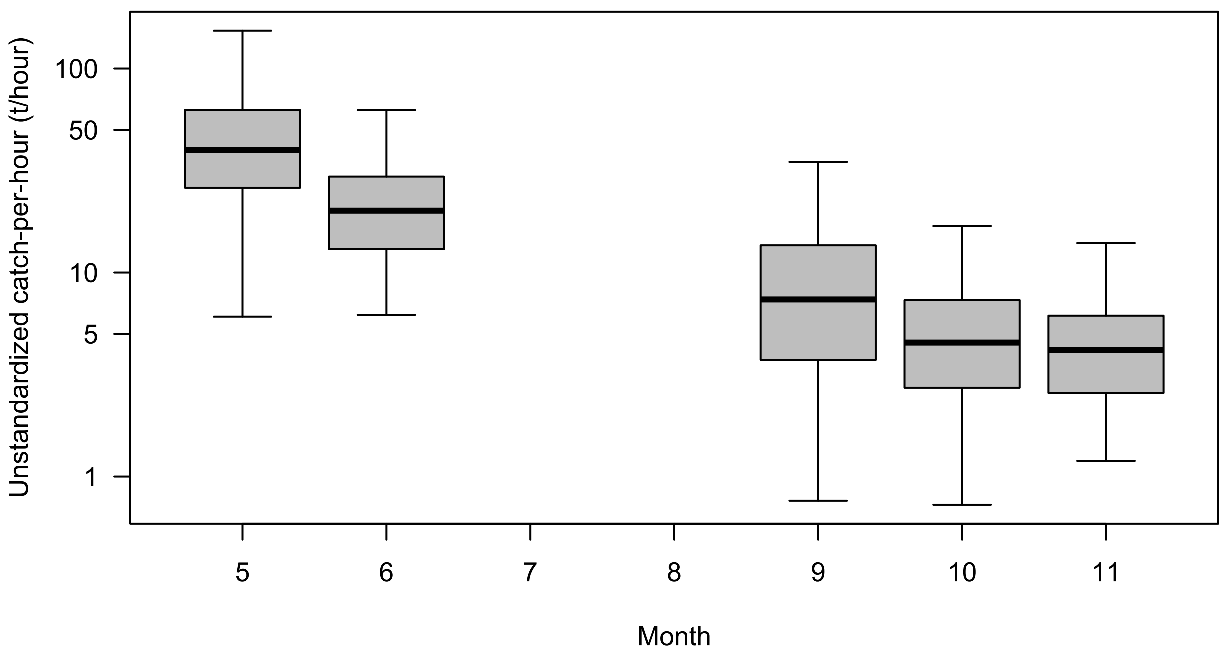


Figure 6. Unstandardized (raw) catch-rates (t/hr) of Pacific Hake catches by tow in the U.S. at-sea fleet in 2015.

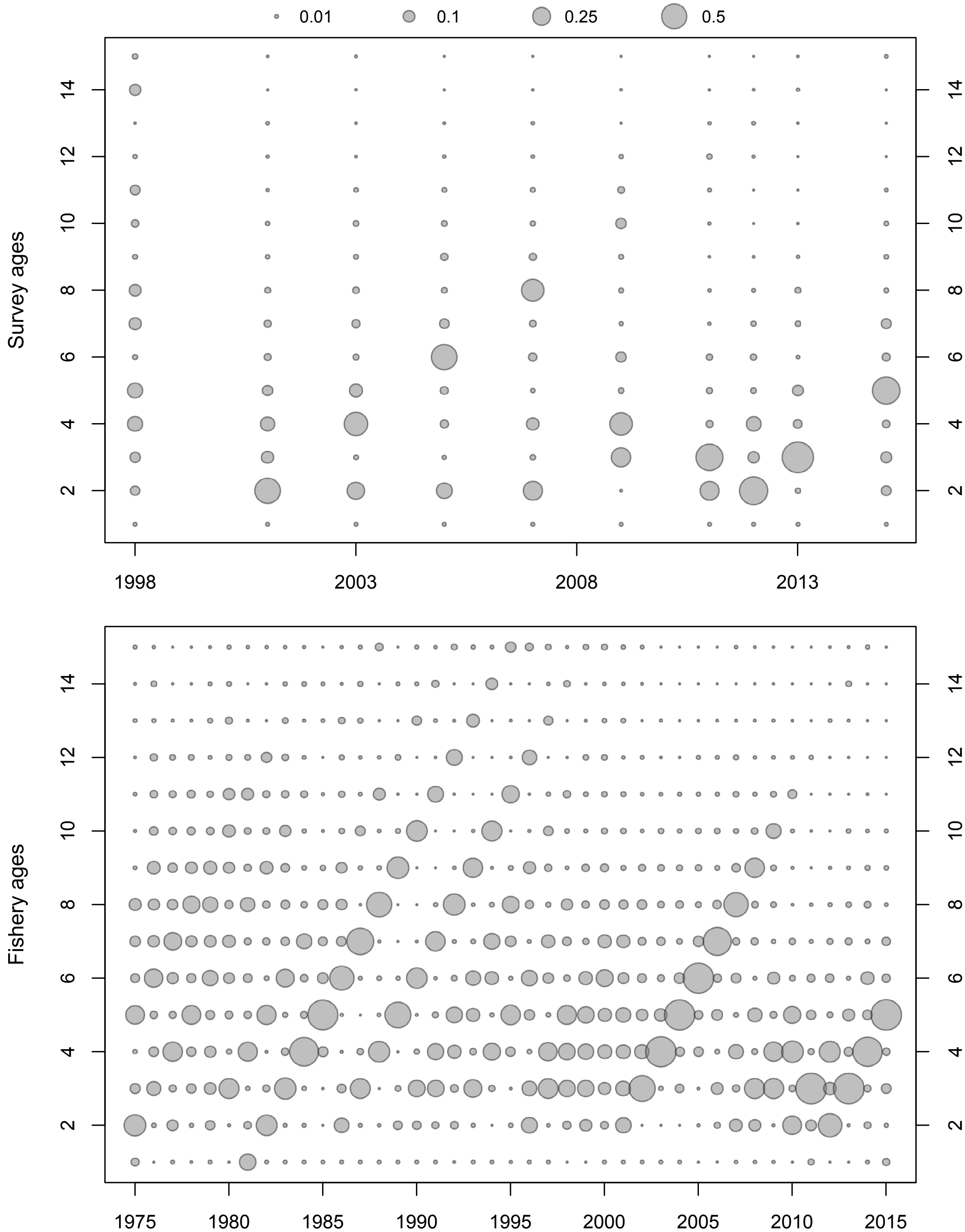


Figure 7. Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2015. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble in the survey data is 0.75 for age 3 in 2013 and in the fishery is 0.71 for age 3 in 2011.

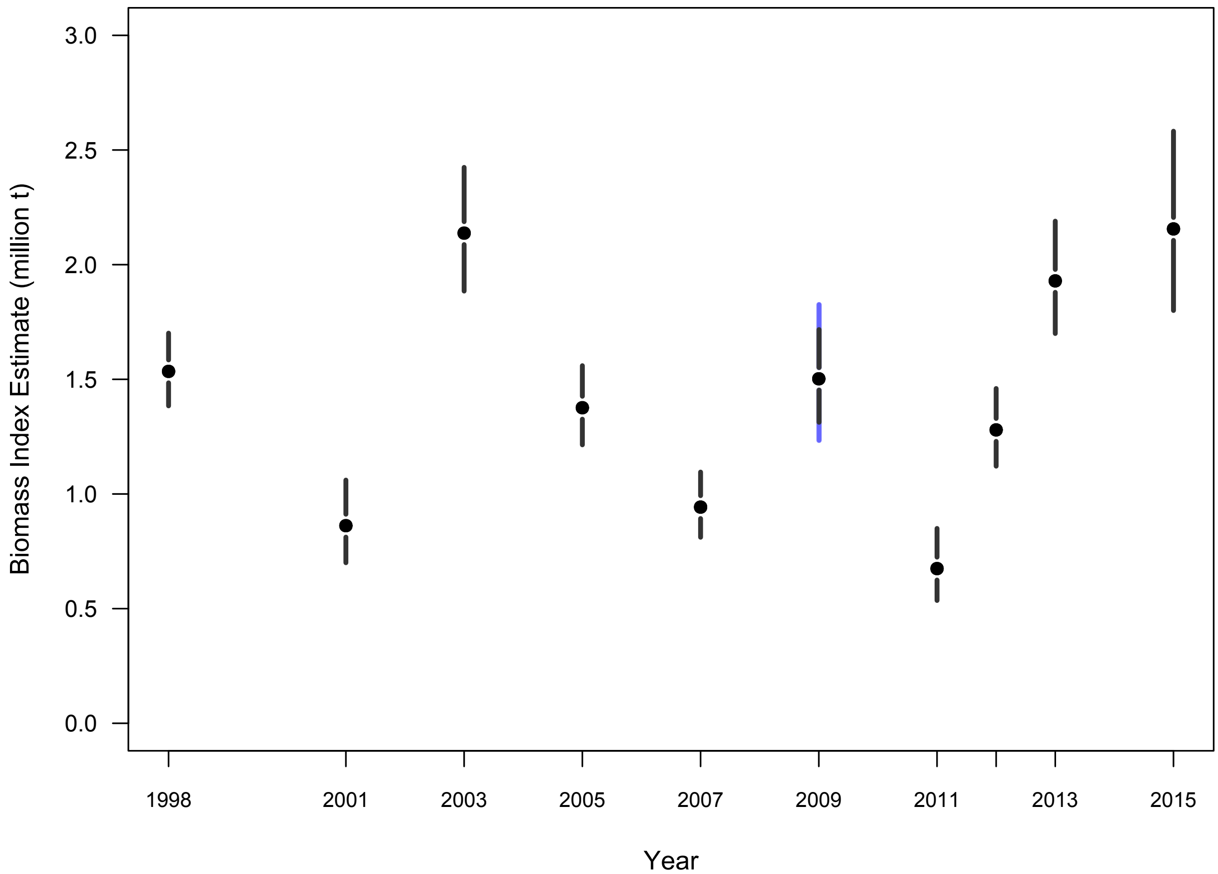


Figure 8. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1998–2007, 2011–2015) in addition to squid/hake apportionment uncertainty (2009, in blue).

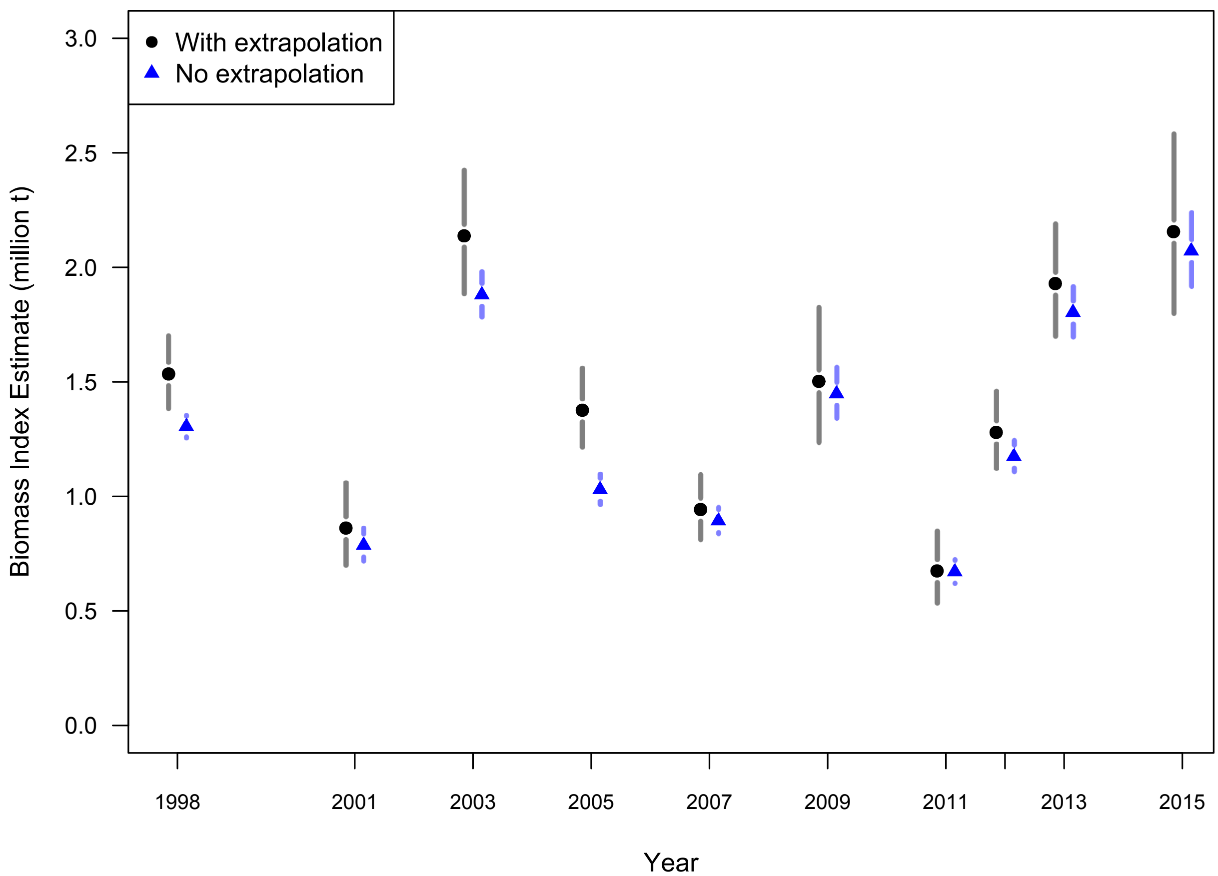


Figure 9. Acoustic survey biomass indices with and without extrapolation (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (and squid/hake apportionment uncertainty in 2009).

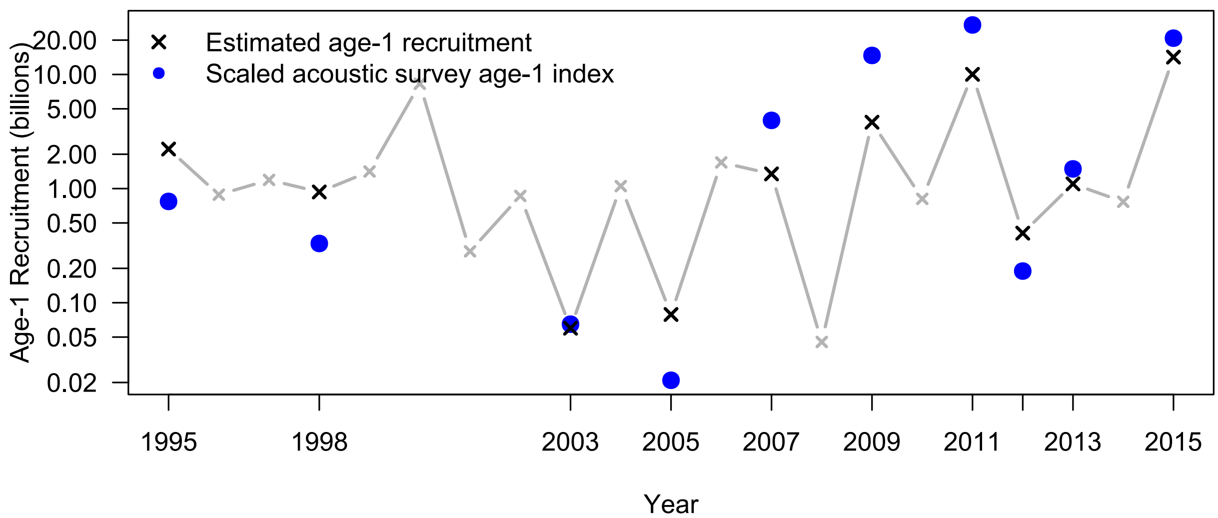


Figure 10. Preliminary acoustic survey age-1 index overlaid on estimated numbers of age-1 fish (MLE from the base model).

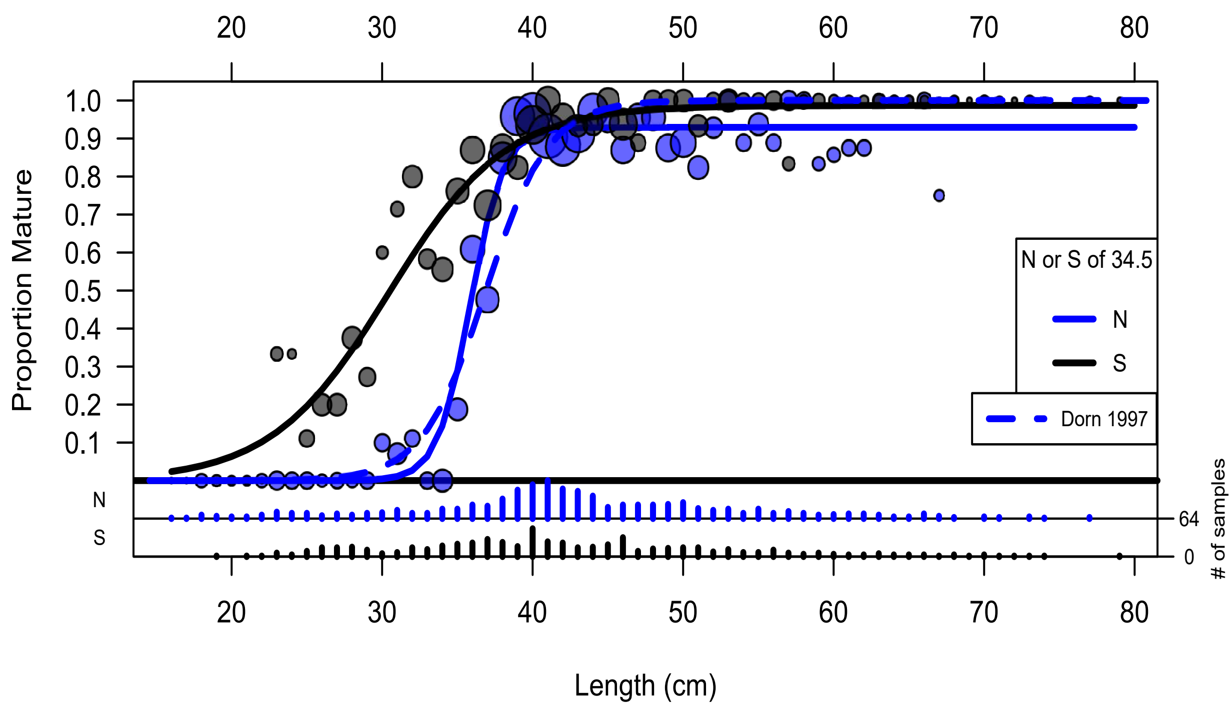


Figure 11. Observed proportion mature-at-length (bubbles with circle size relative to number of samples at length), fitted proportion mature-at-length with an estimated asymptote (lines), and number of samples at length (barplots beneath each panel). Panels show categories of source (top left), year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

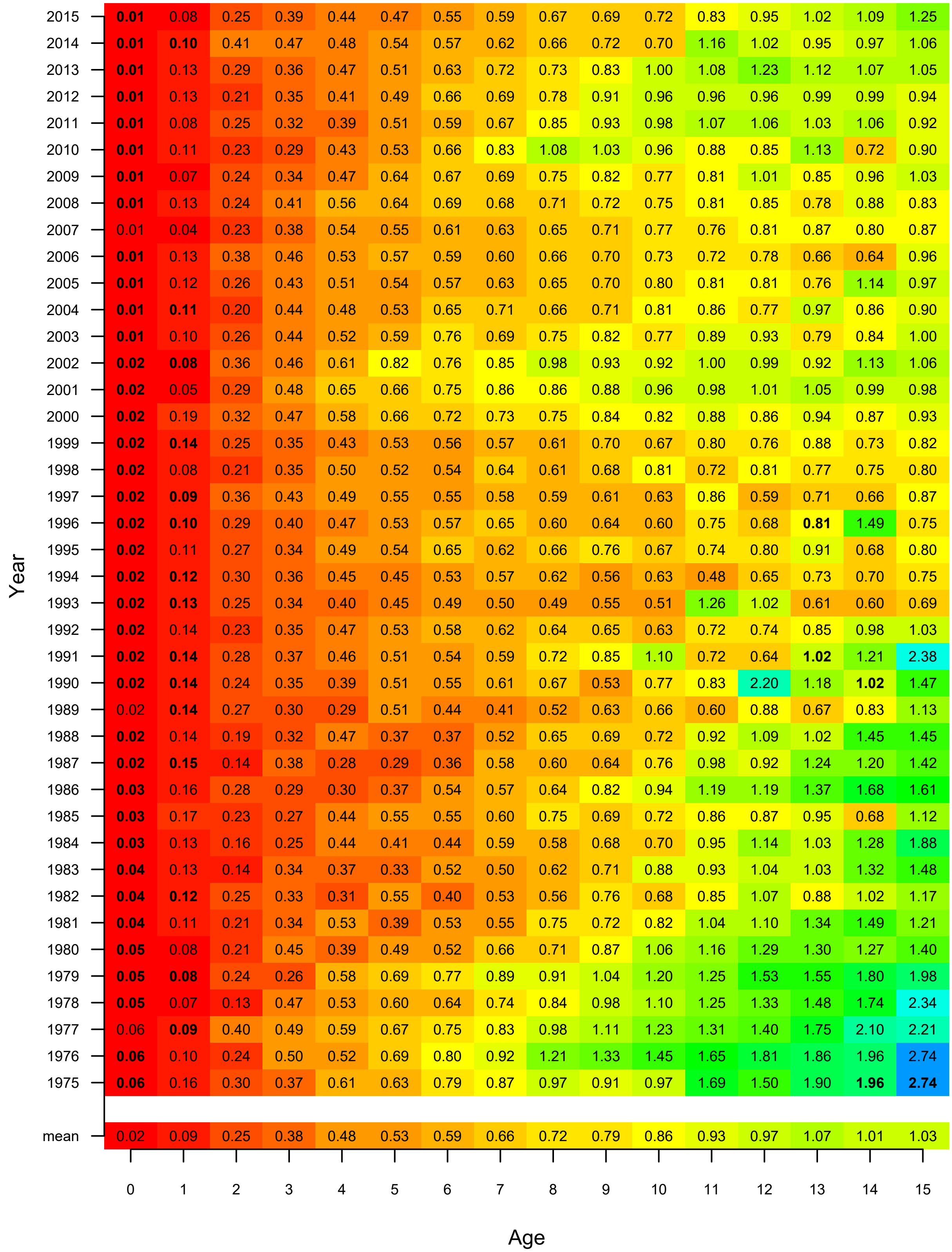


Figure 12. Empirical weight-at-age (kg) used in the assessment (numbers, with colors given by the scale at the bottom). Numbers shown in bold were interpolated or extrapolated from adjacent areas.

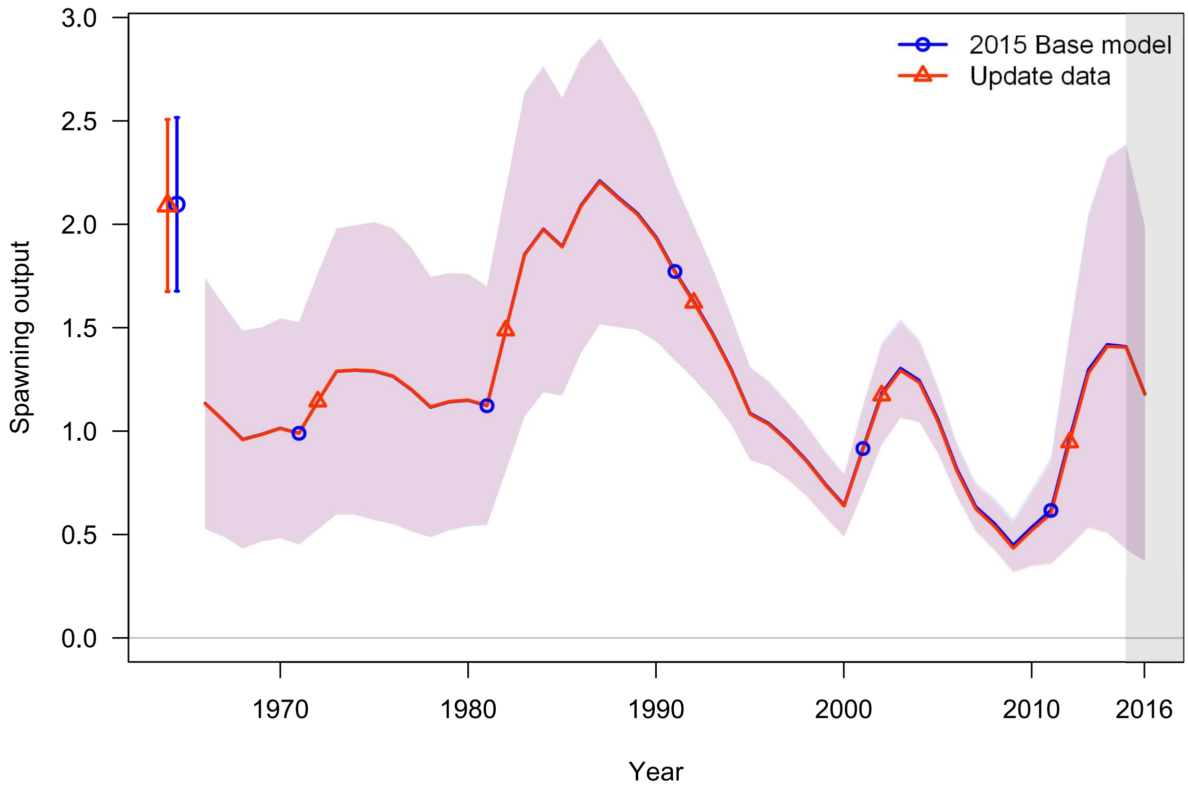


Figure 13. Bridging models comparison showing the 2015 base model and the terminal model from sequentially updating all pre-2015 data. This included updating fishery catch and age-compositions as well as weight-at-age information. The points disconnected from the time-series on the left side show the unfished equilibrium spawning biomass estimates.

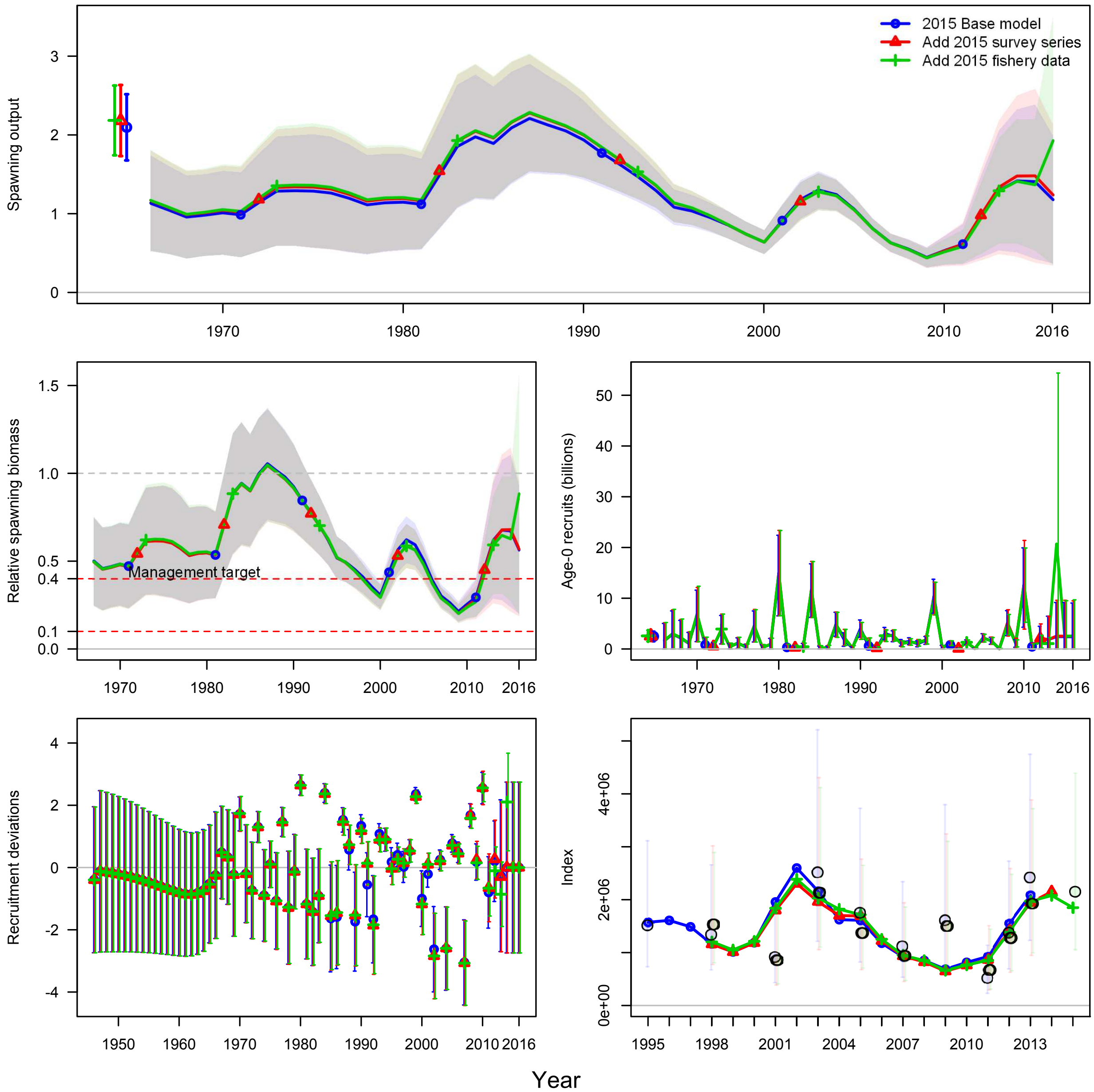


Figure 14. Bridging models showing the difference between the 2015 base model and the sequential addition of the new acoustic survey time-series (1998–2015) and then the new 2015 fishery data. Spawning biomass (upper panel), relative spawning biomass (spawning biomass in each year relative to the unfished equilibrium spawning biomass, middle left), absolute recruitment (middle right), recruitment deviations (lower left), and survey index (lower right) are shown.

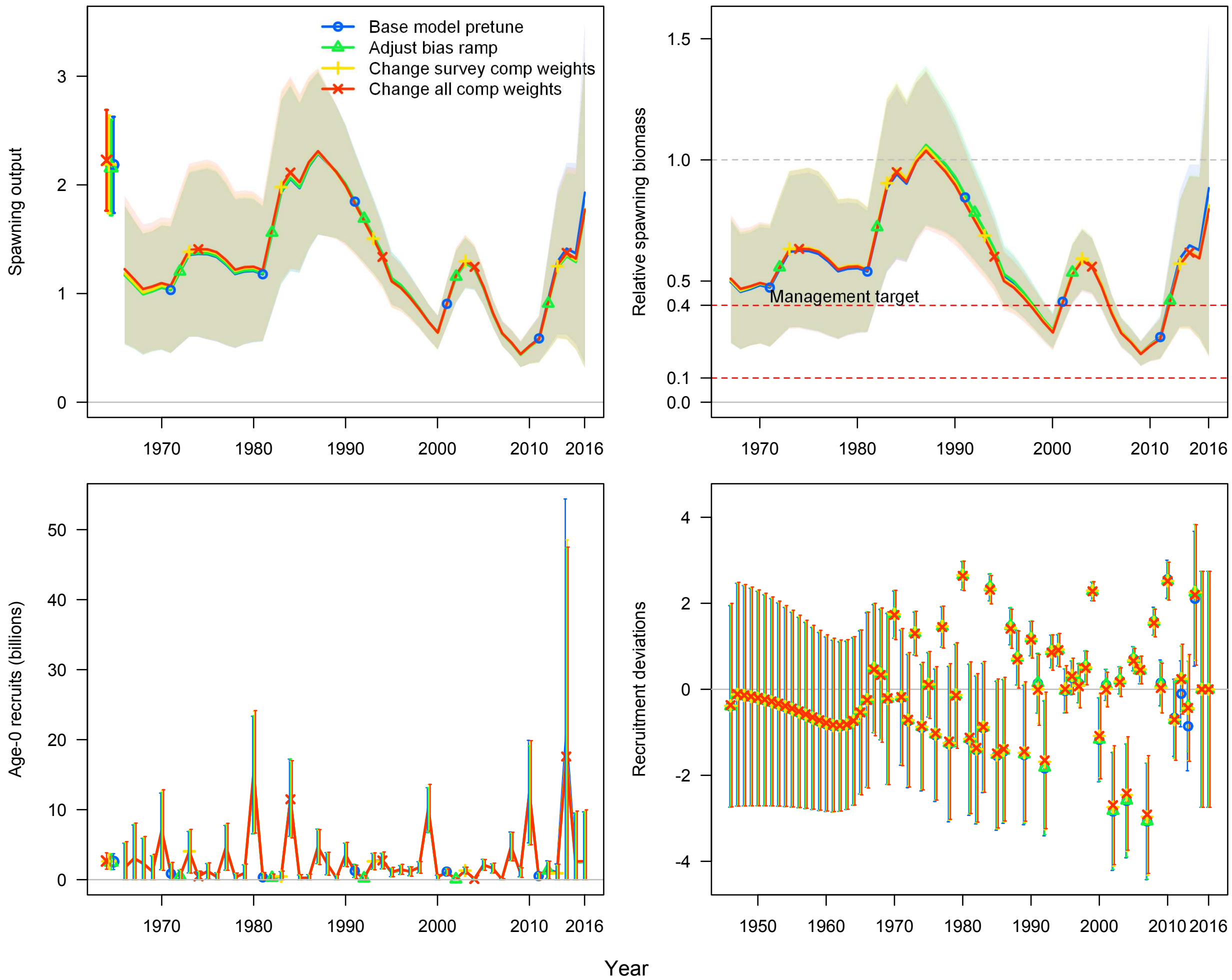


Figure 15. Bridging models showing the difference between the 2016 pre-tuned base model and the sequential addition of the main base model tuning runs (adjusting time periods and levels for recruitment bias and reweighting the survey and fishery compositional data). The red line is equivalent to the 2016 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.

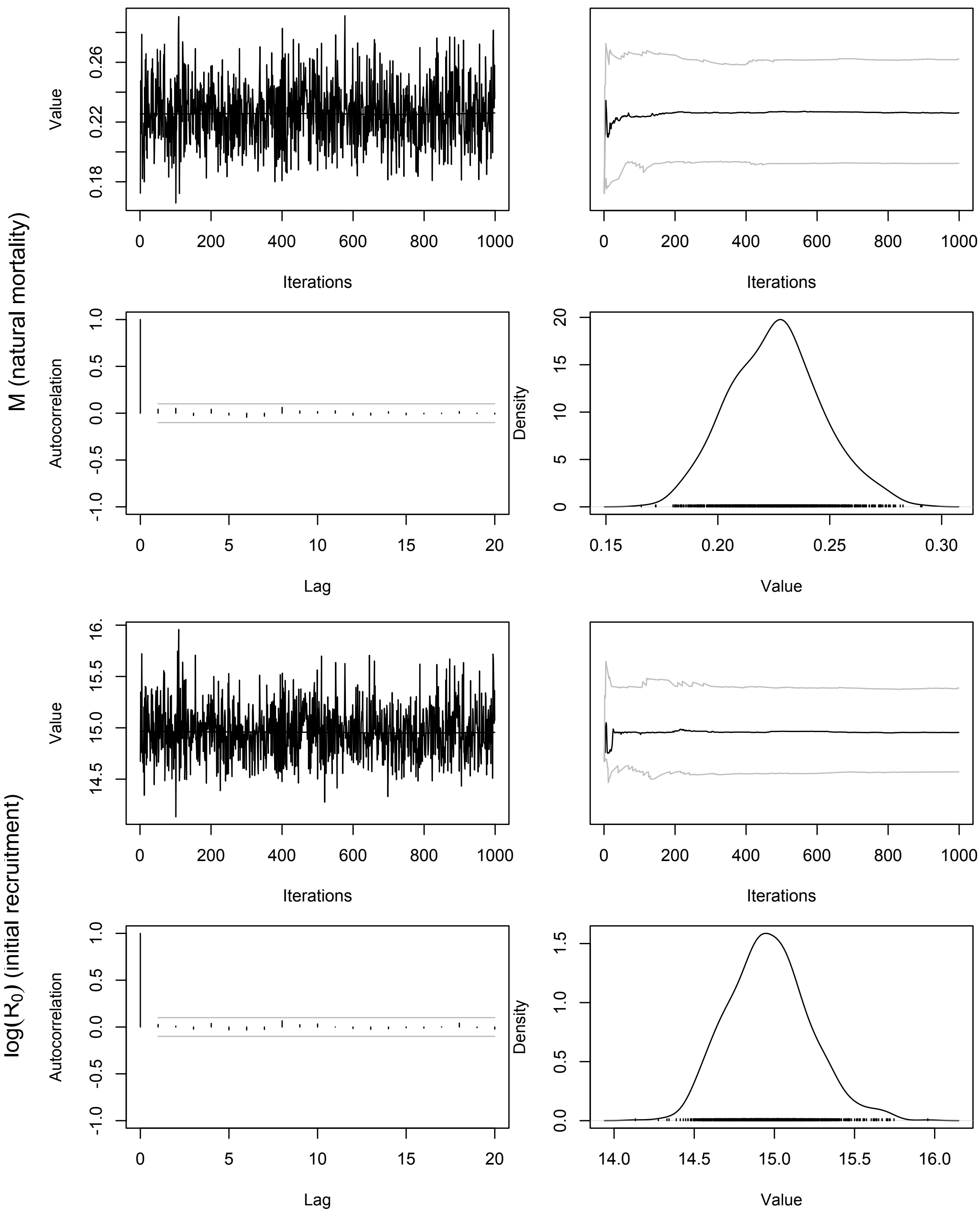


Figure 16. Summary of MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels) in the base model.

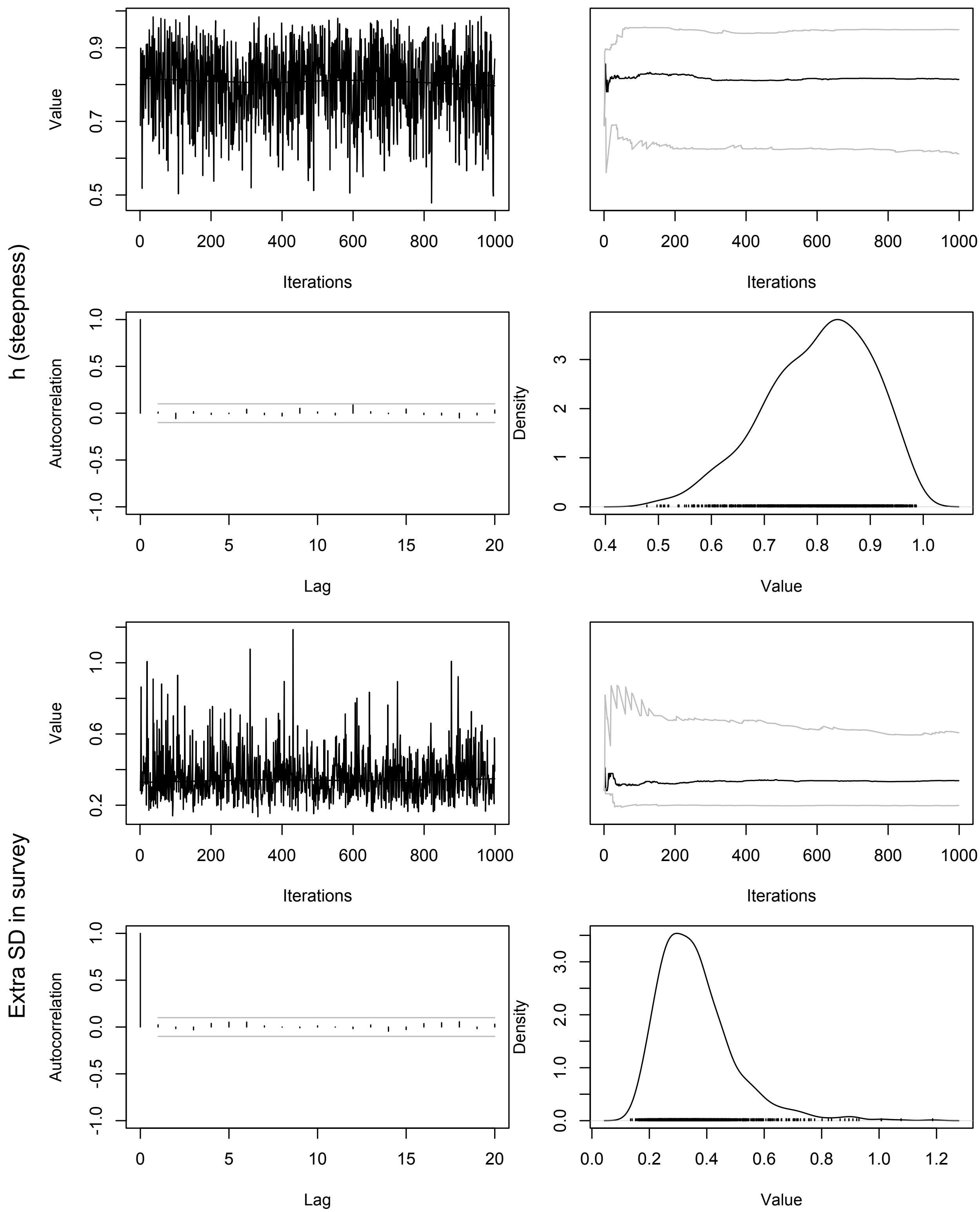


Figure 17. Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) in the survey index (lower panels) in the base model.

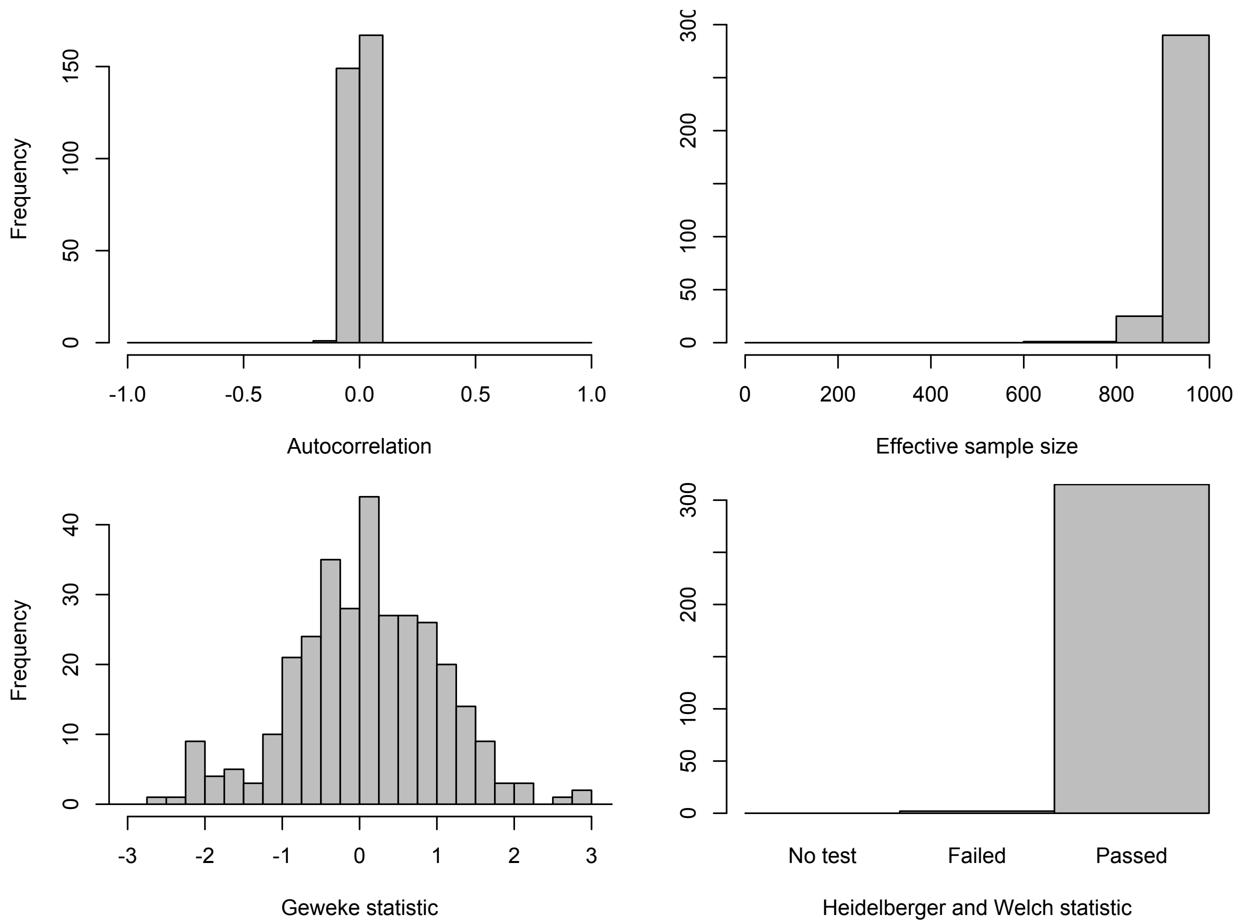


Figure 18. Summary histograms of MCMC diagnostics for all base model parameters along with derived quantities for the time-series of spawning biomass, and relative spawning biomass.

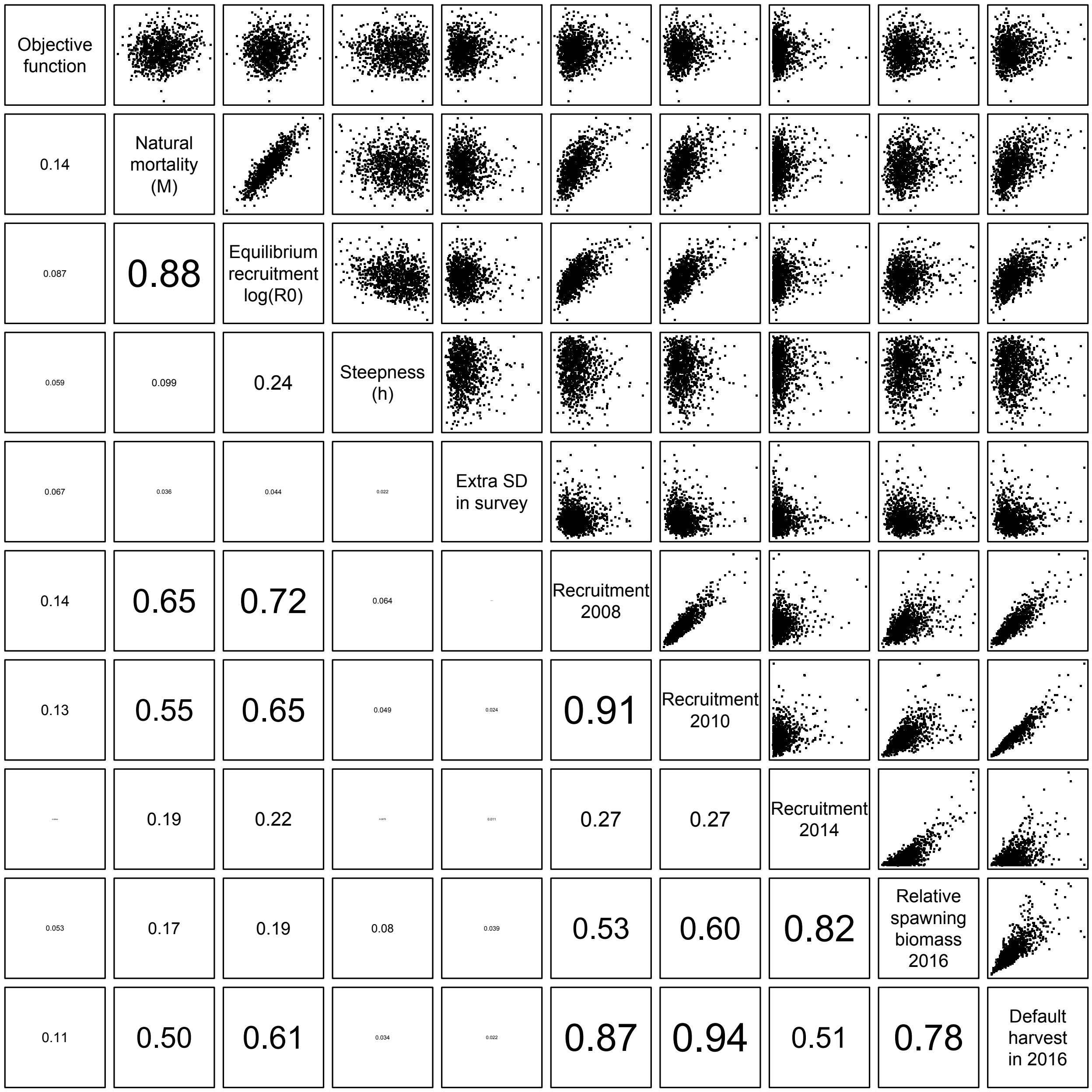


Figure 19. Posterior correlations among key base-model parameters and derived quantities. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

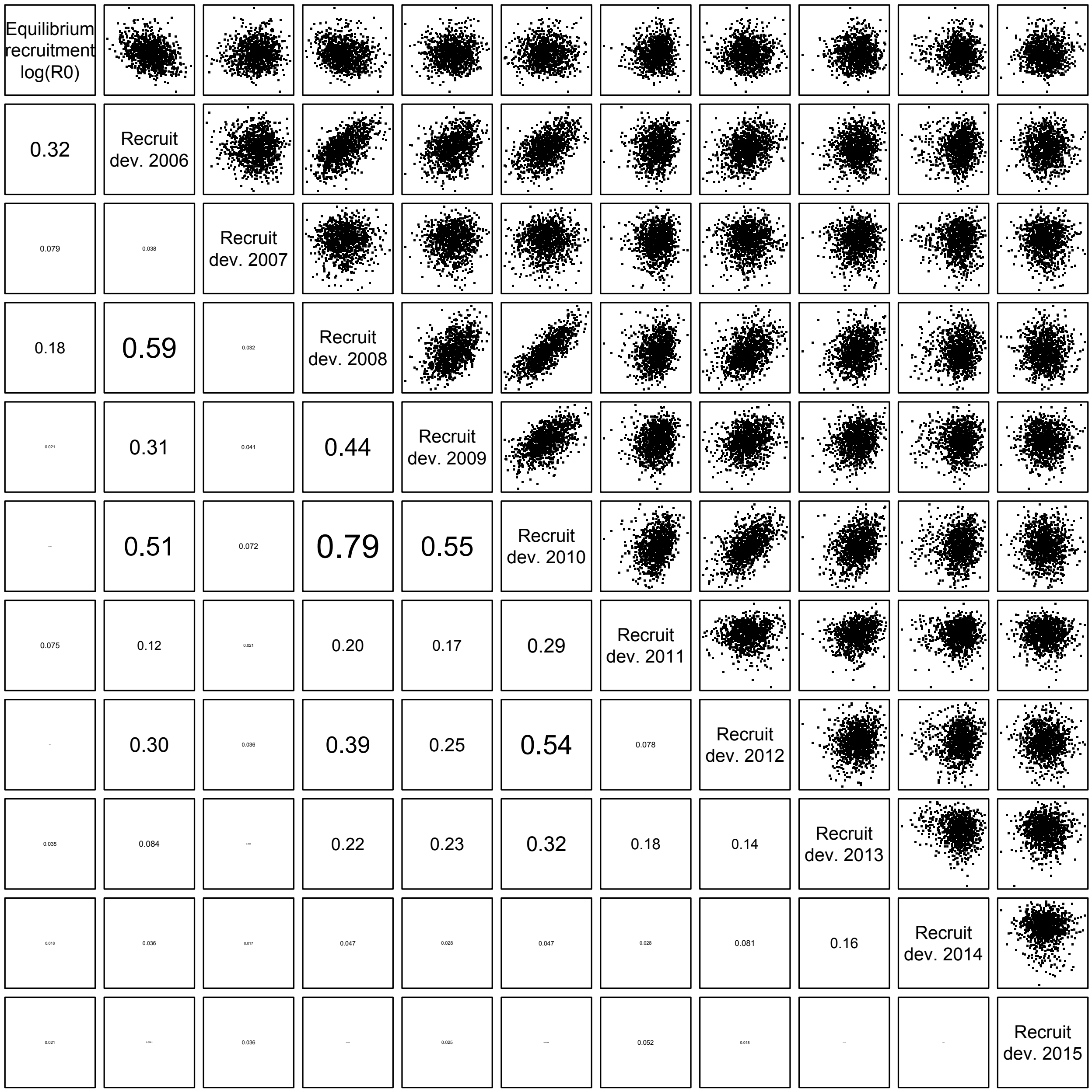


Figure 20. Posterior correlations among recruitment deviations from recent years. Numbers refer to the absolute correlation coefficients, with font size proportional to the square root of the coefficient.

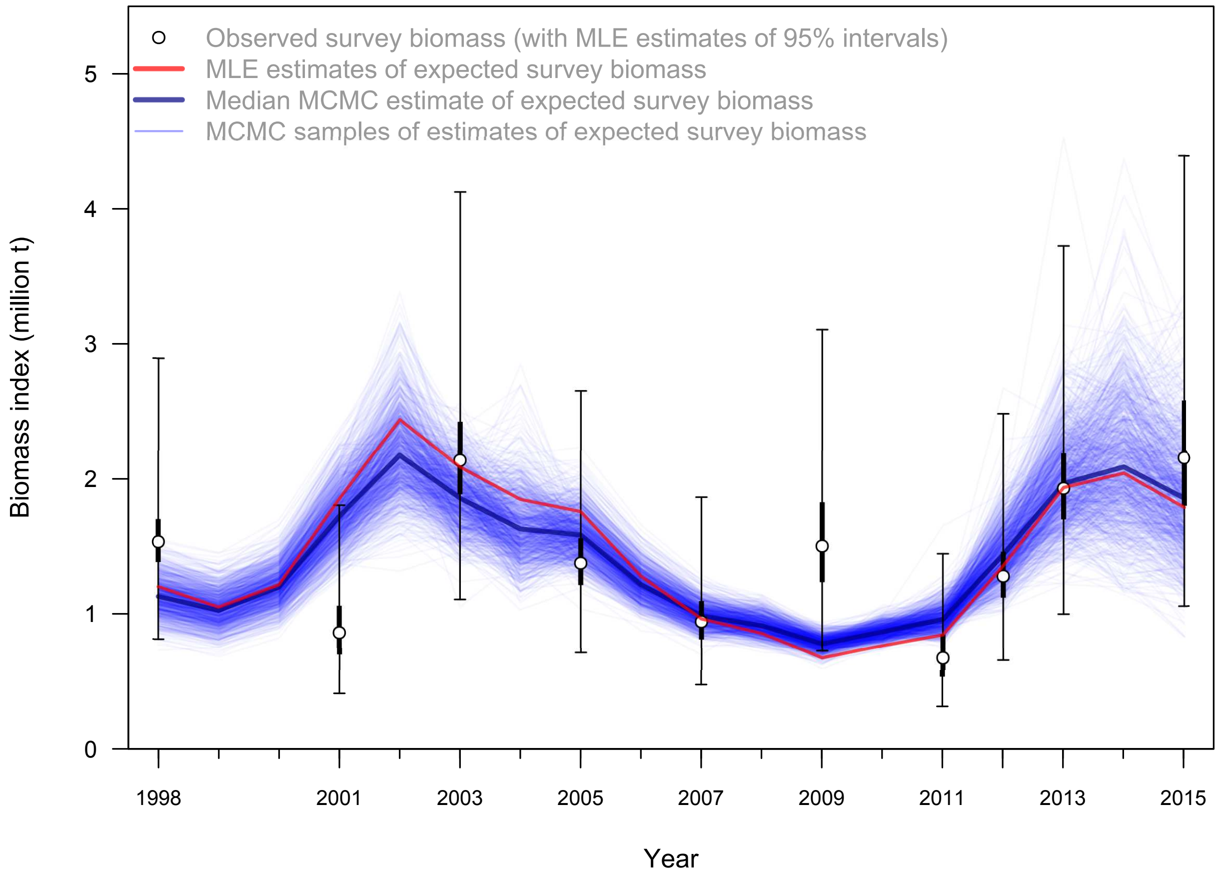
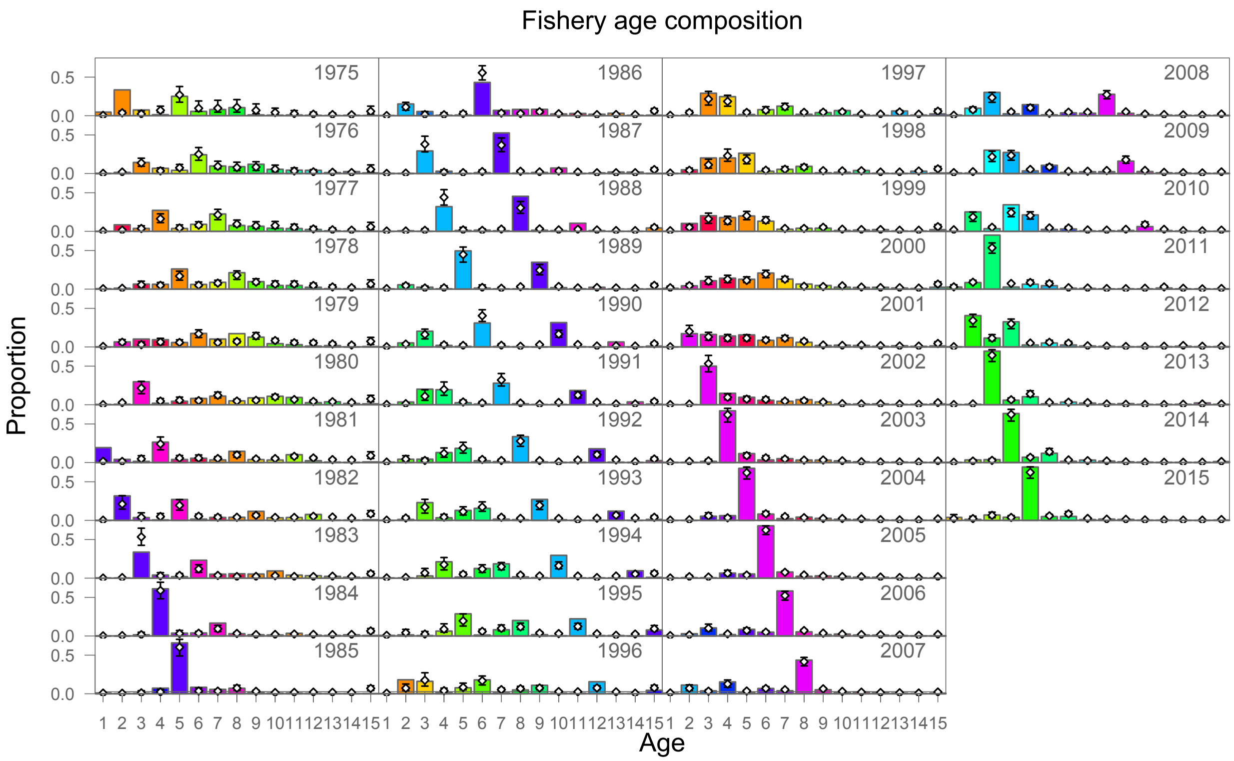


Figure 21. Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker 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.



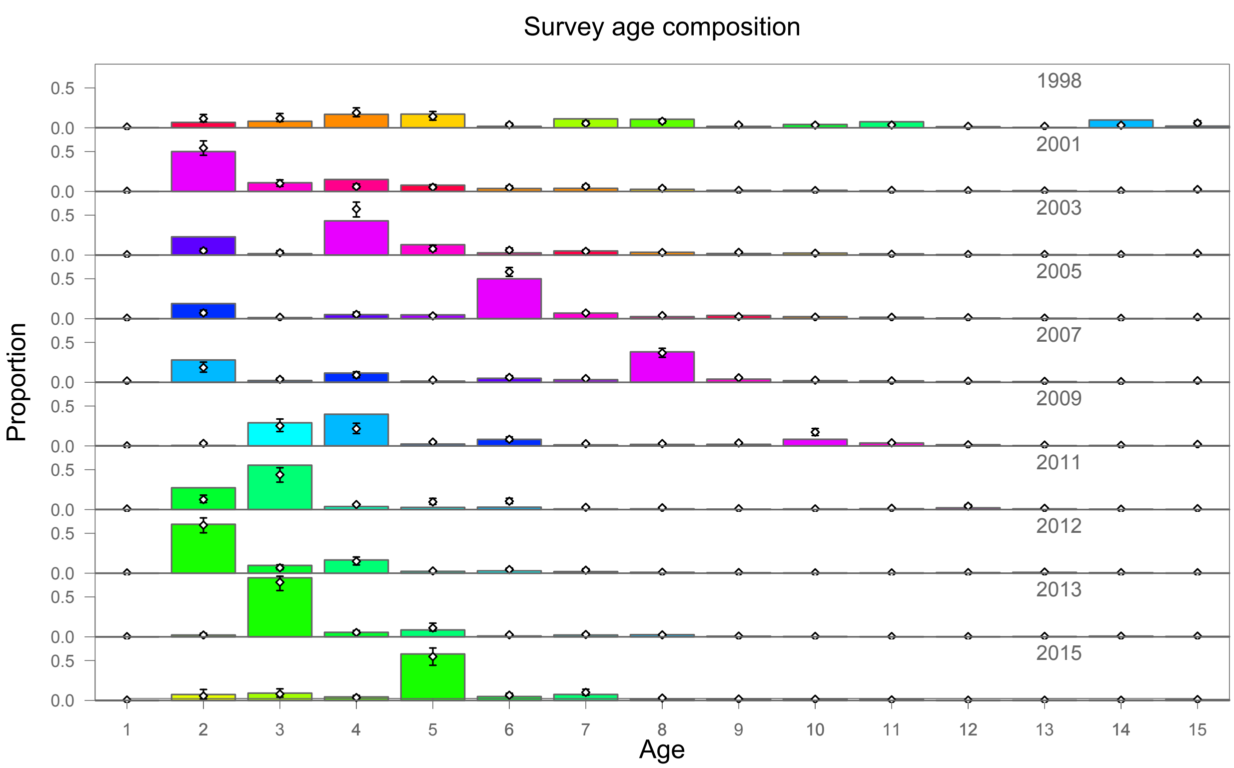


Figure 22. Base model fit to the observed fishery (top) and acoustic survey (bottom) age composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% uncertainty intervals from the MCMC.

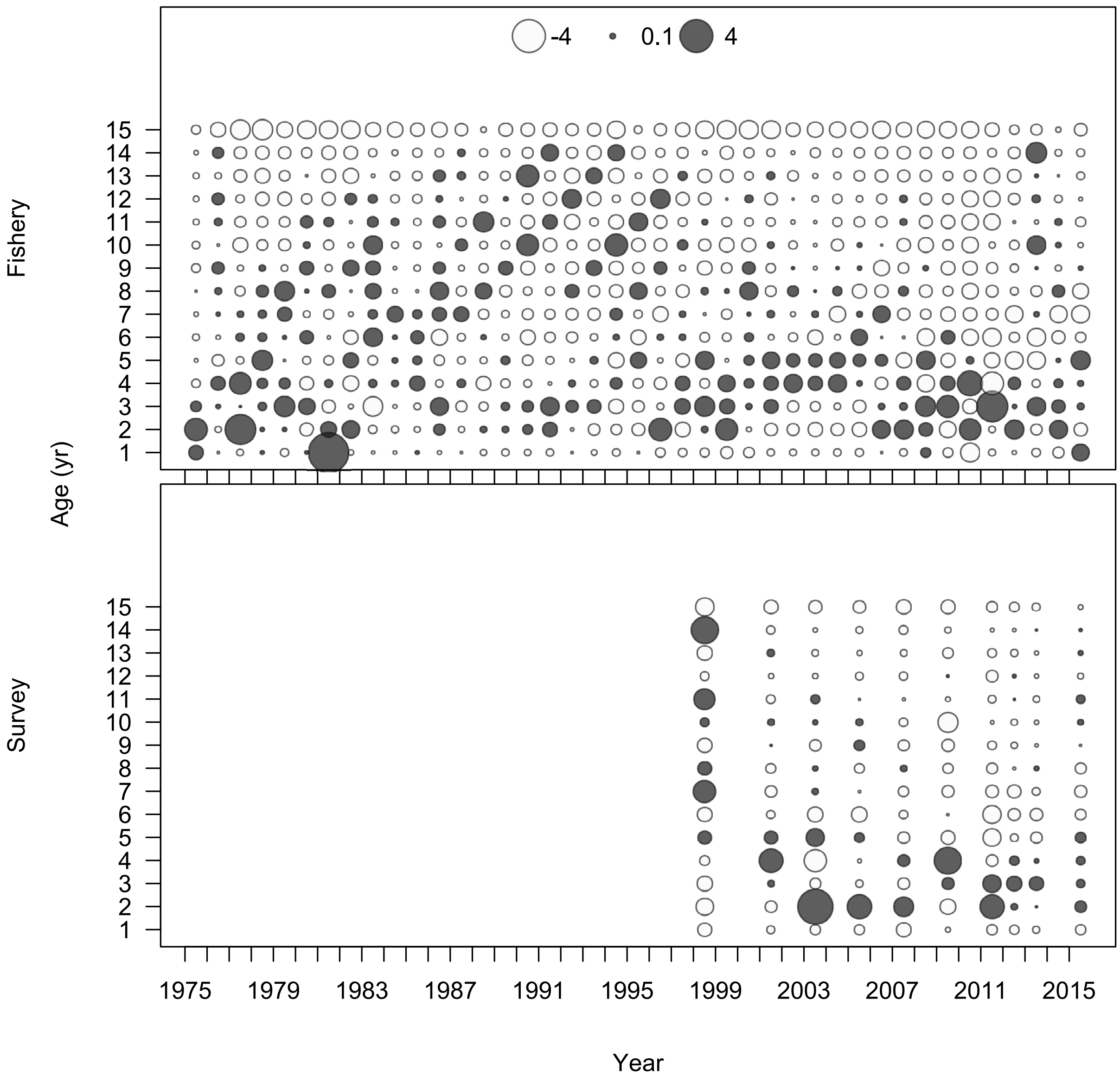


Figure 23. Pearson residuals for base model MLE fits to the fishery age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

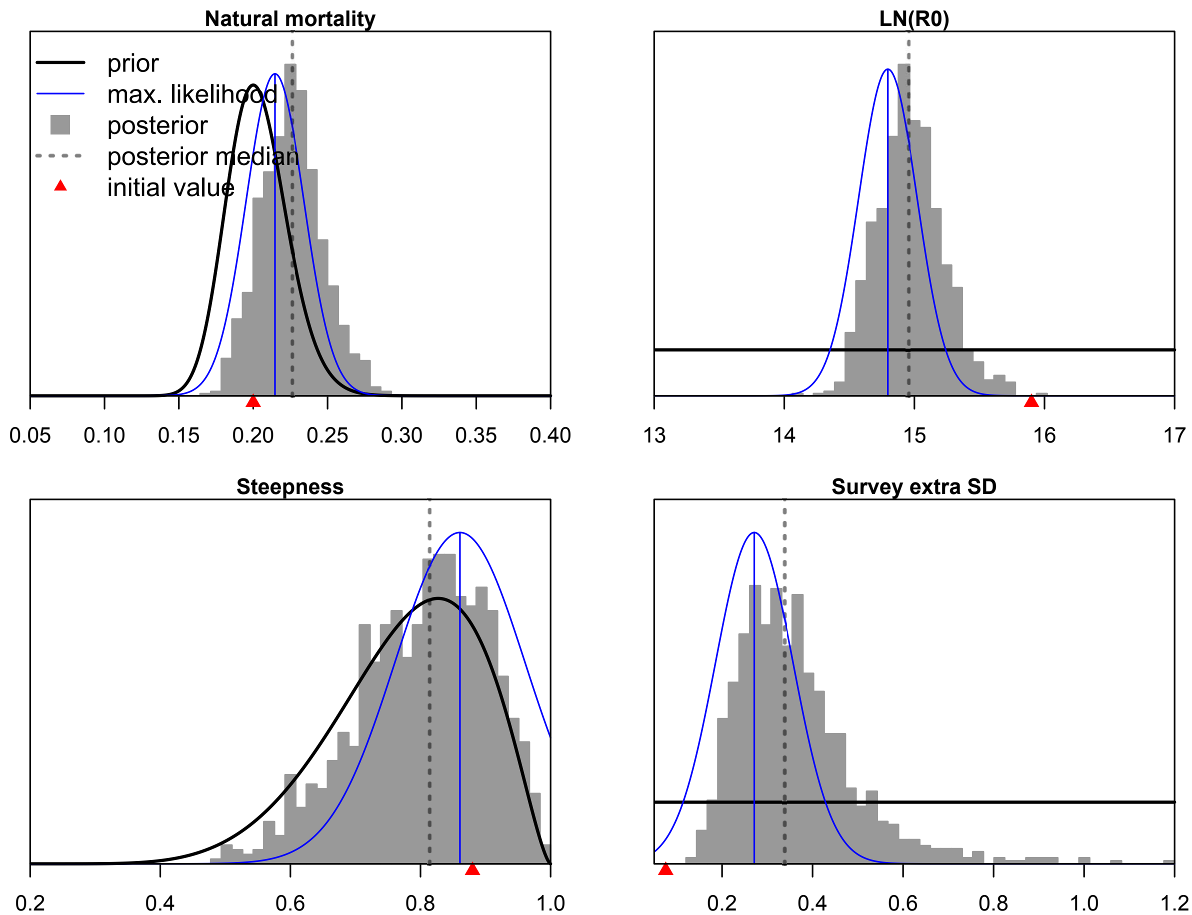


Figure 24. Prior (black lines) and posterior (gray histograms) probability distributions for key parameters in the base model. The parameters are: natural mortality (M), equilibrium log recruitment $\log(R_0)$, steepness (h), and the additional process-error standard deviation for the acoustic survey.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

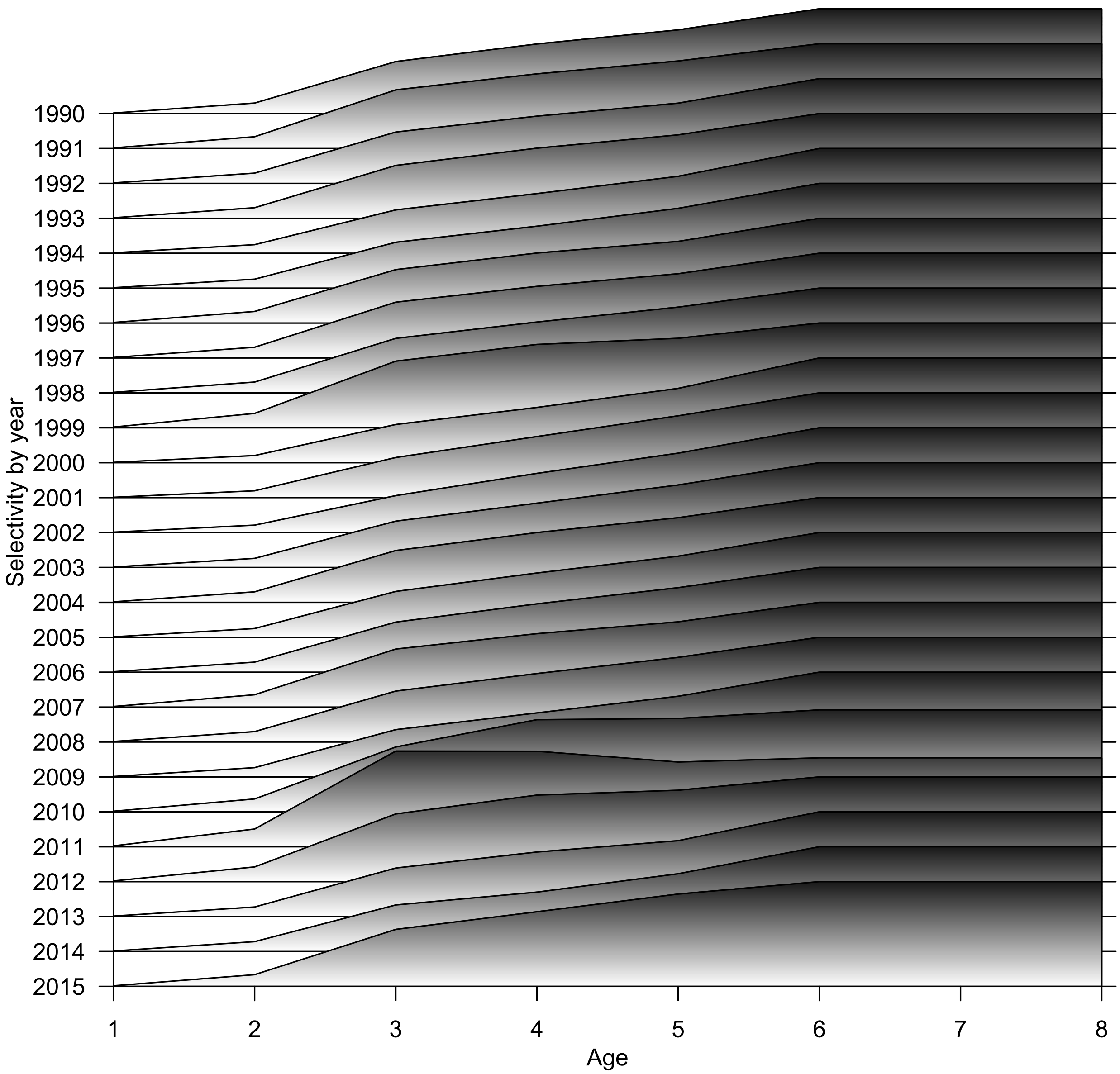


Figure 25. Mountains plot of time varying fishery selectivity for the base model. Range of selectivity is 0 to 1 in each year.

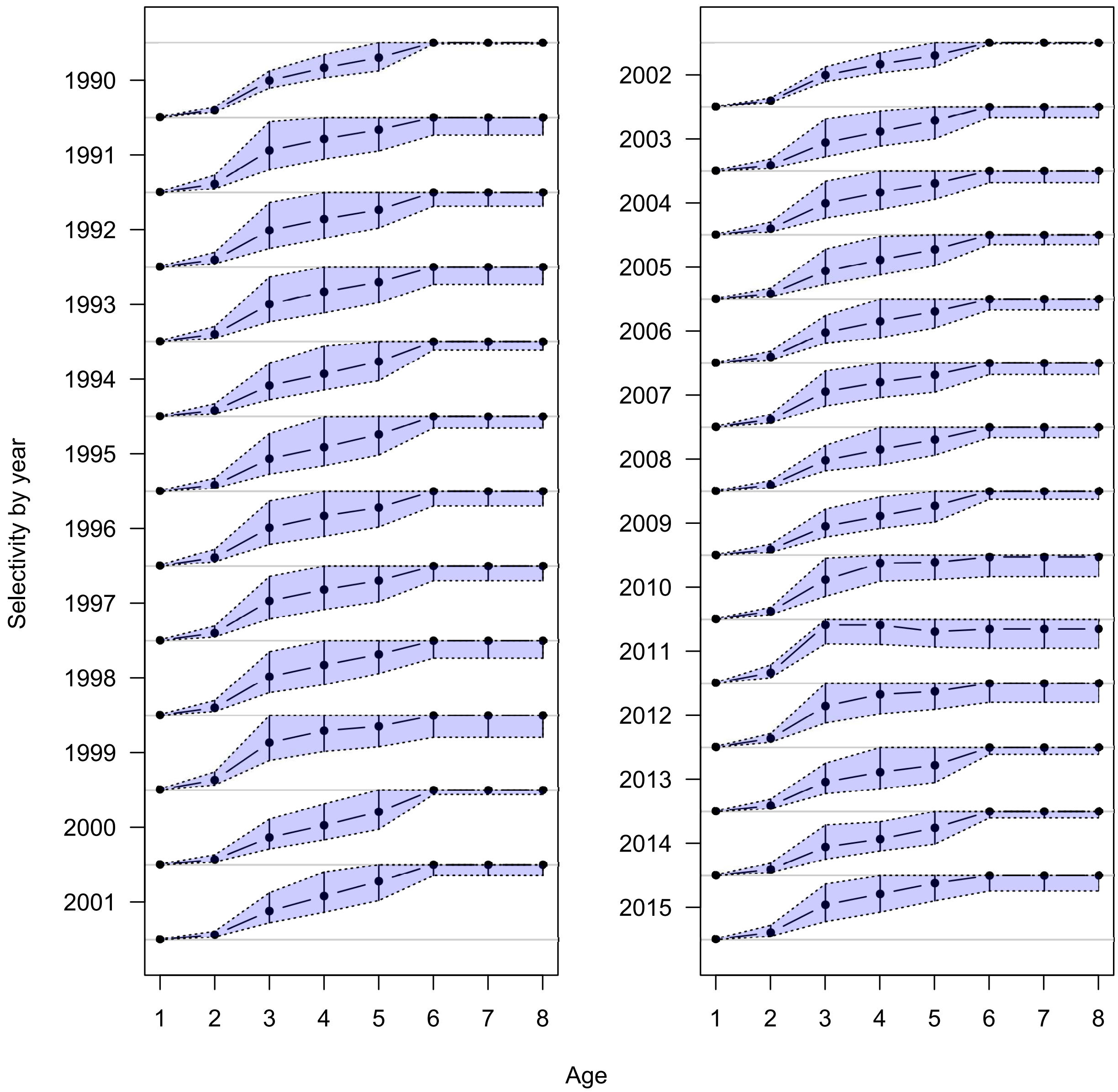


Figure 26. Fishery selectivity sampled from posterior probability distribution by year. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared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

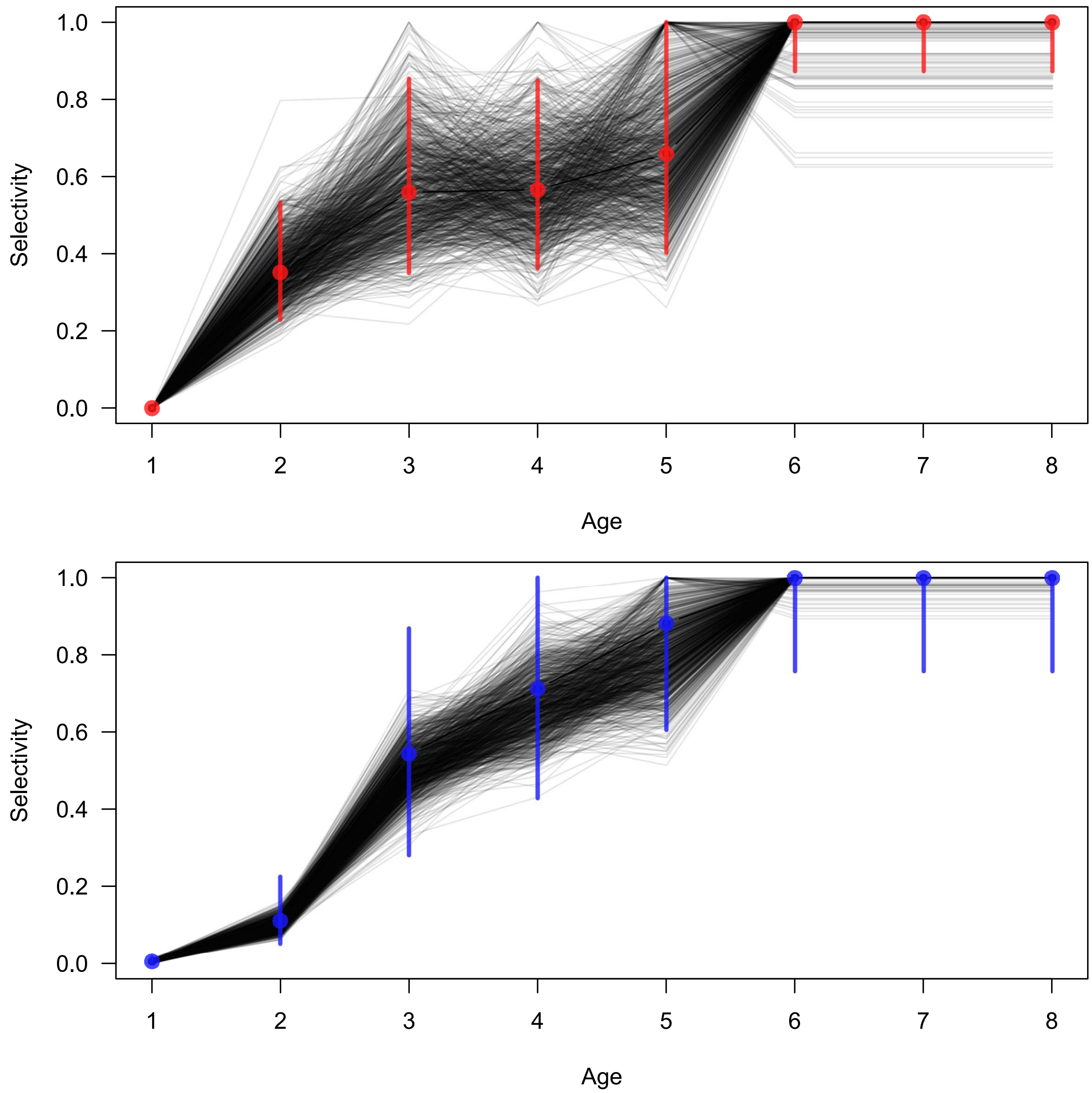


Figure 27. Estimated acoustic (top) and fishery (bottom) selectivity (2015) ogives from the posterior distribution.

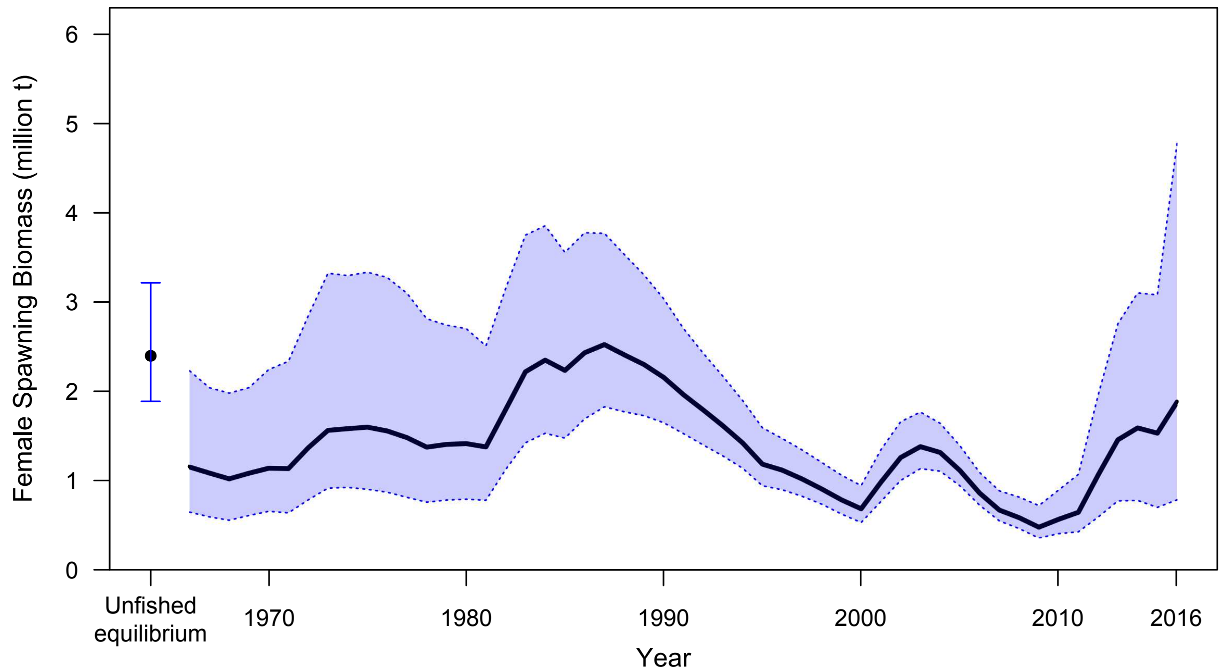


Figure 28. Median of the posterior distribution for female spawning biomass at the start of each year (B_t) up to 2016 (solid line) with 95% posterior credibility intervals (shaded area).

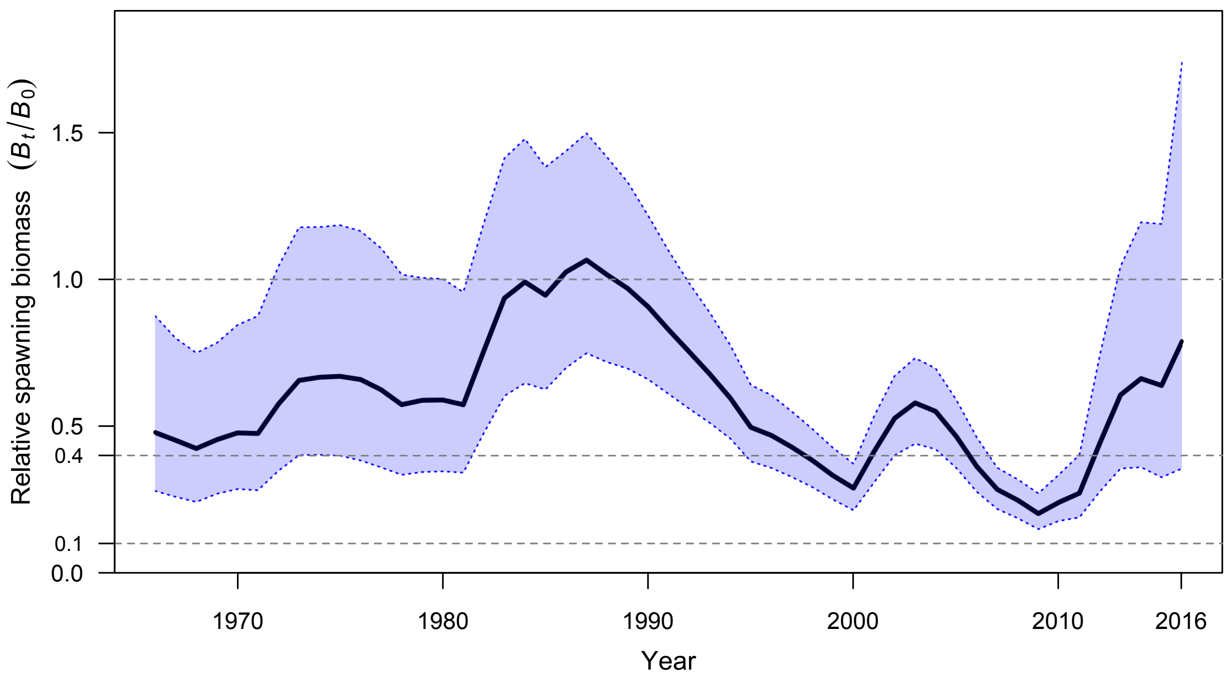


Figure 29. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2016 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

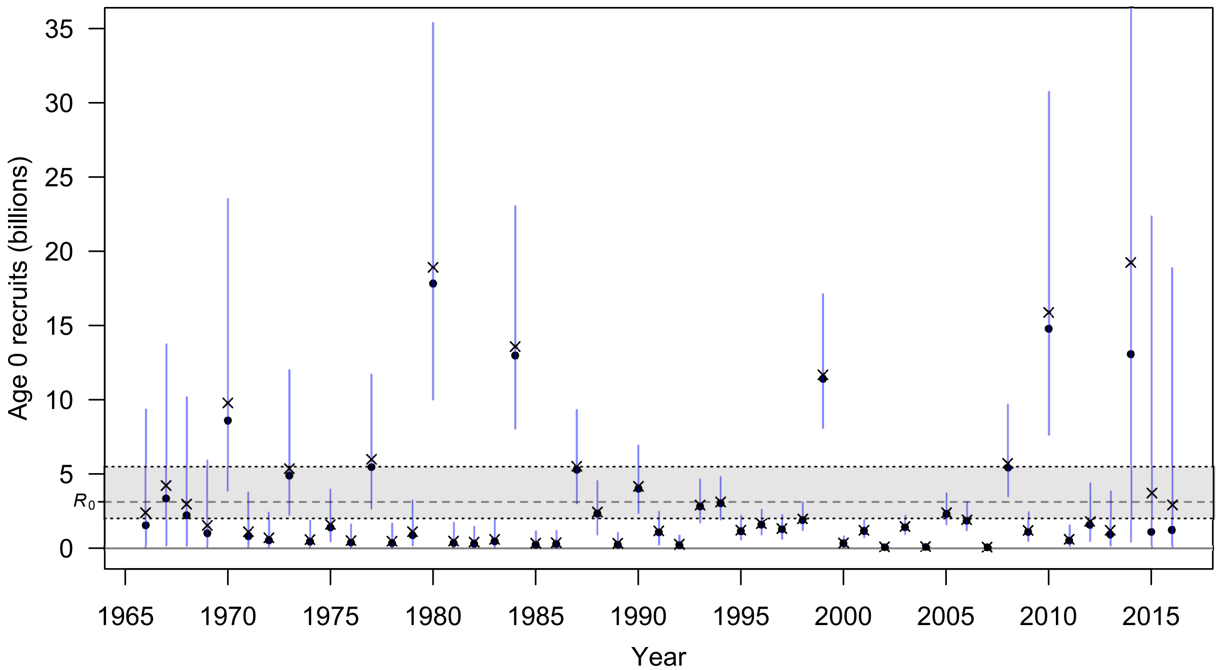


Figure 30. Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with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

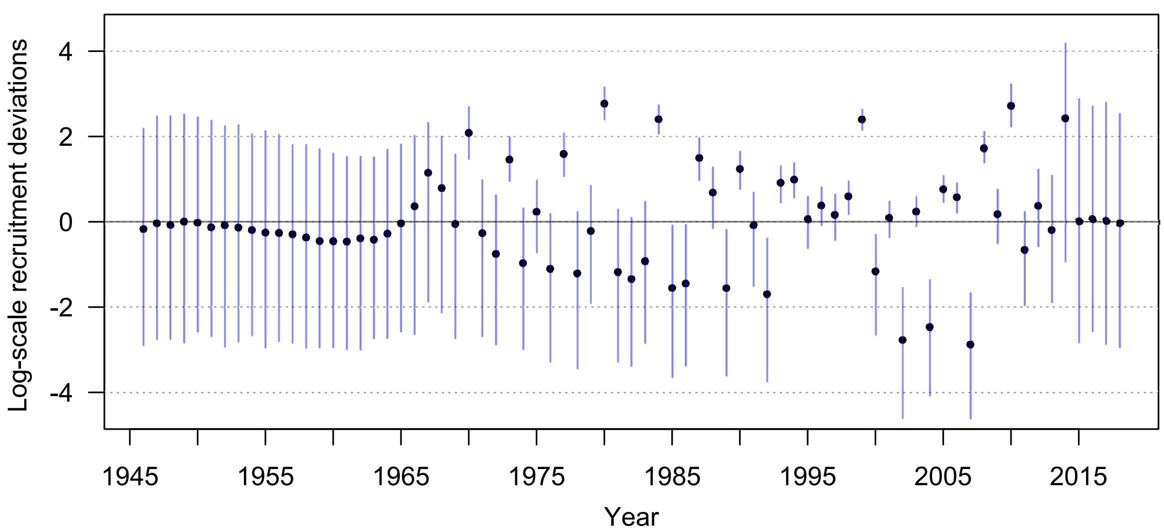


Figure 31. Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model. Deviations for the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

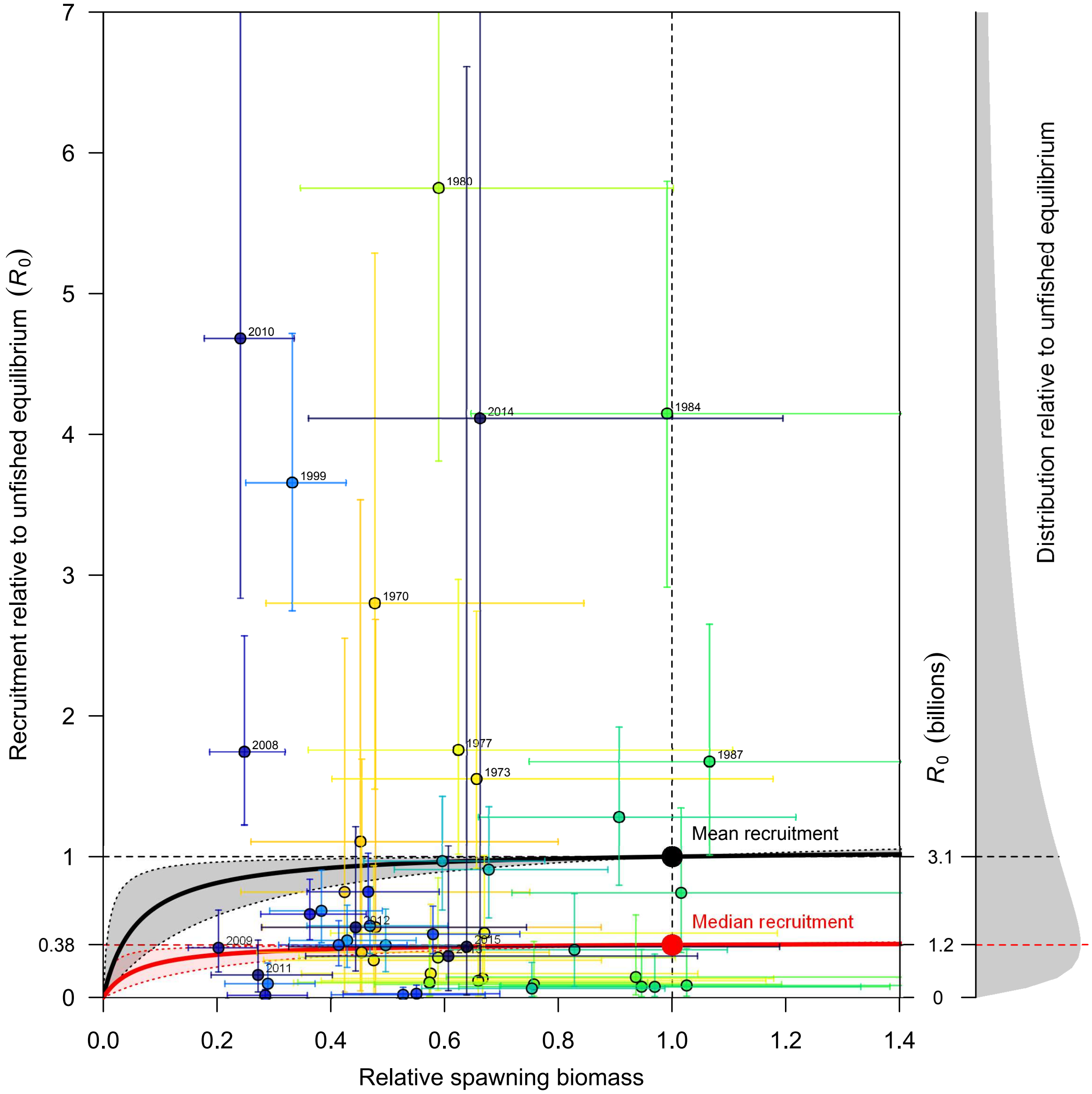


Figure 32. Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (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.

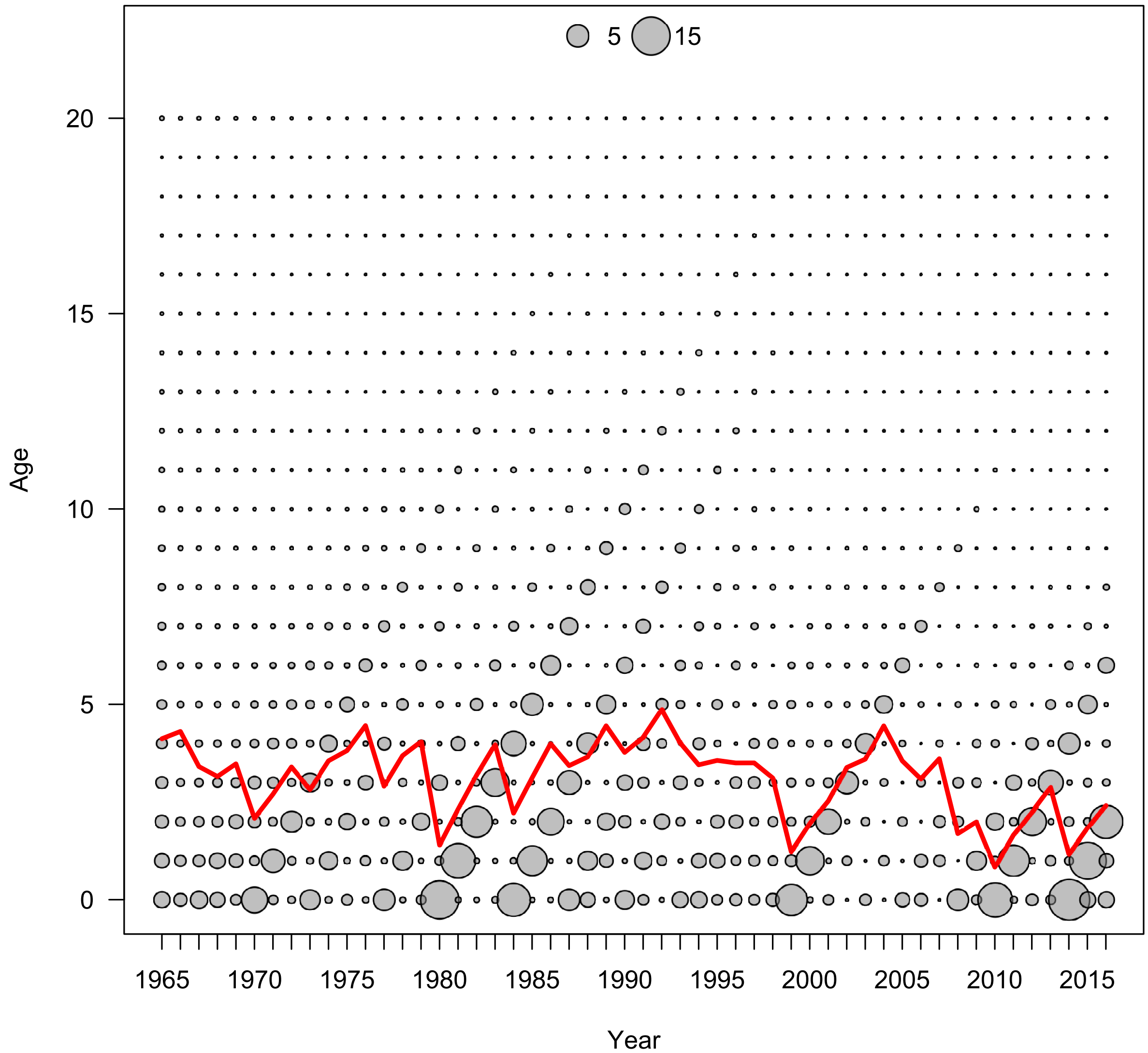


Figure 33. Bubble plot of maximum likelihood (MLE) estimates of population numbers at age at the beginning of each year, where diagonals follow each year-class through time. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish (with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

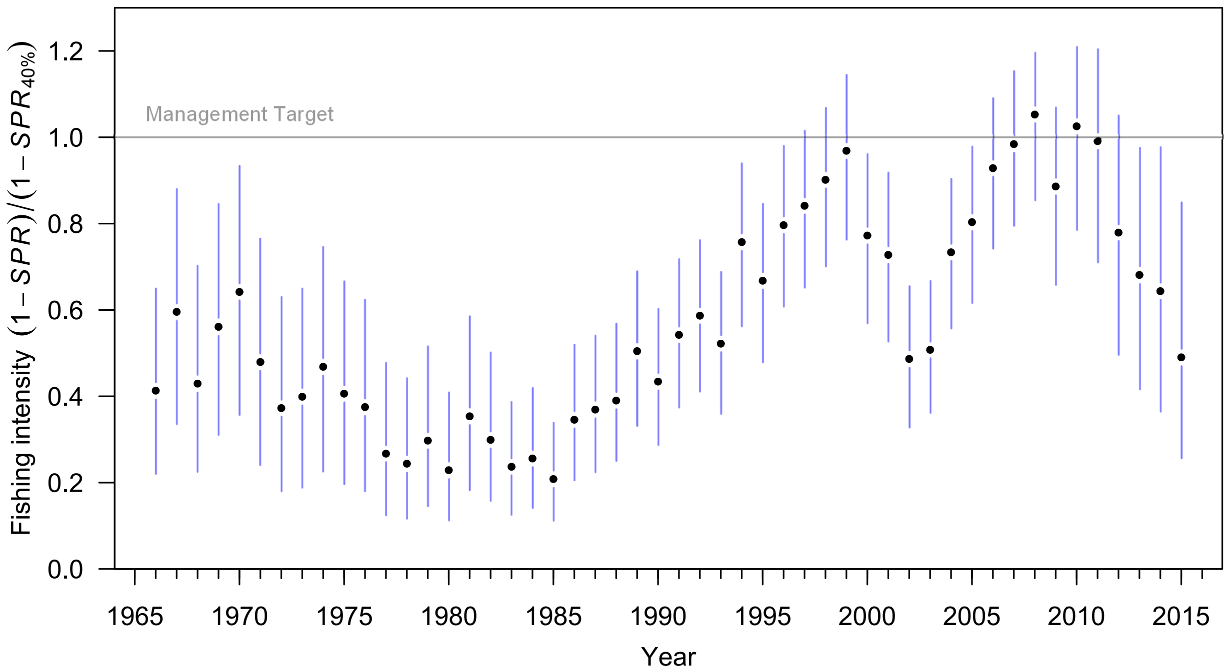


Figure 34. Trend in median fishing intensity (relative to the SPR management target) through 2015 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

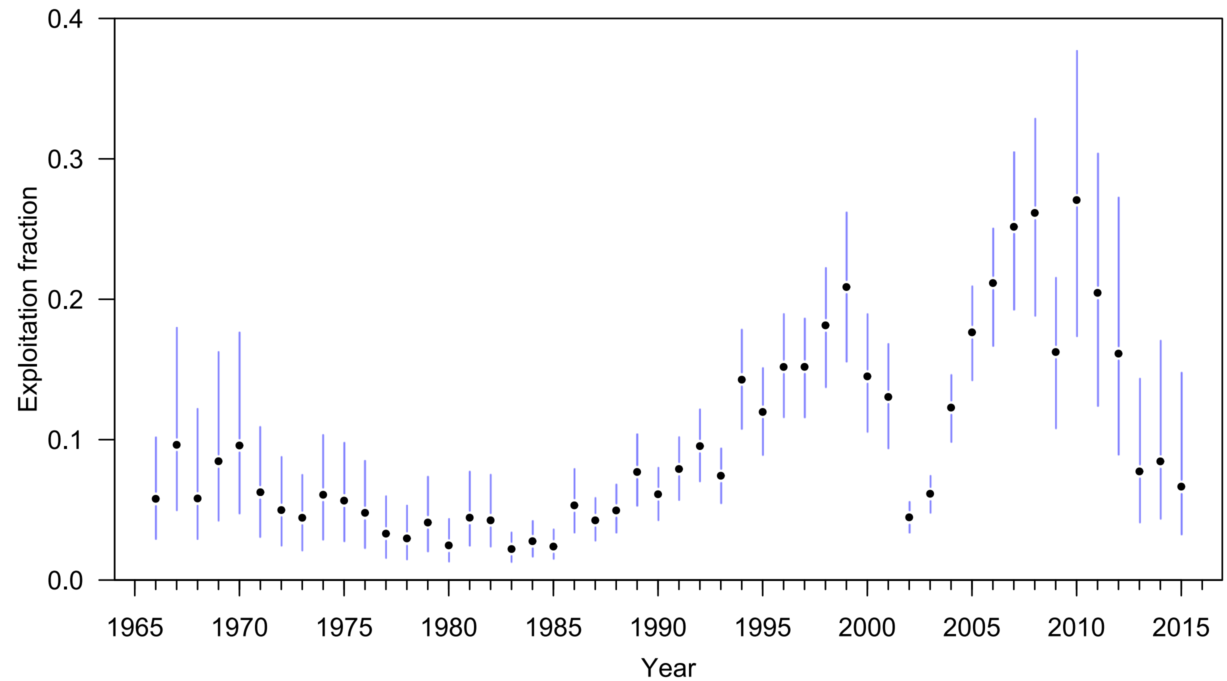


Figure 35. Trend in median exploitation fraction through 2015 with 95% posterior credibility intervals.

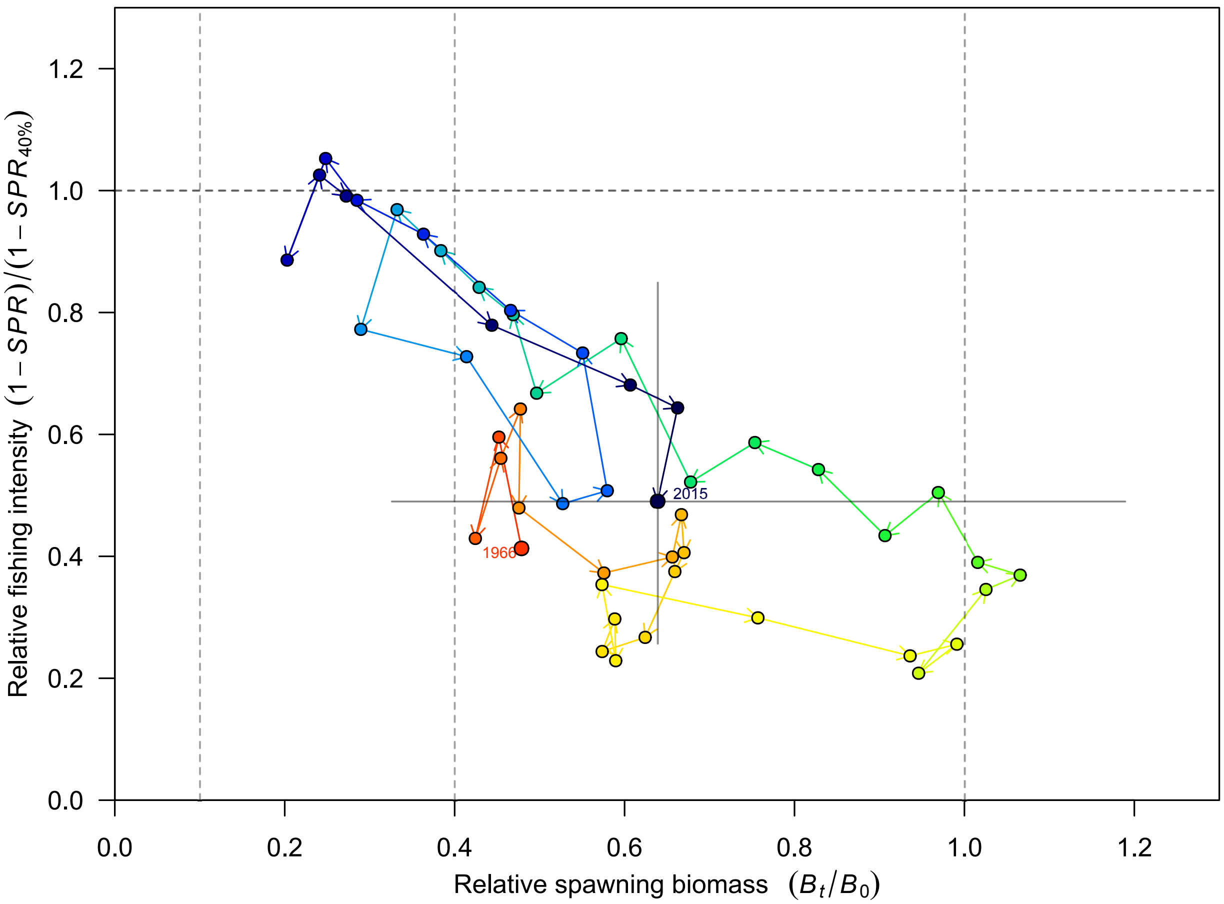


Figure 36. Estimated historical path followed by fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years. Gray bars span the 95% credibility intervals for 2015 fishing intensity (vertical) and relative spawning biomass (horizontal).

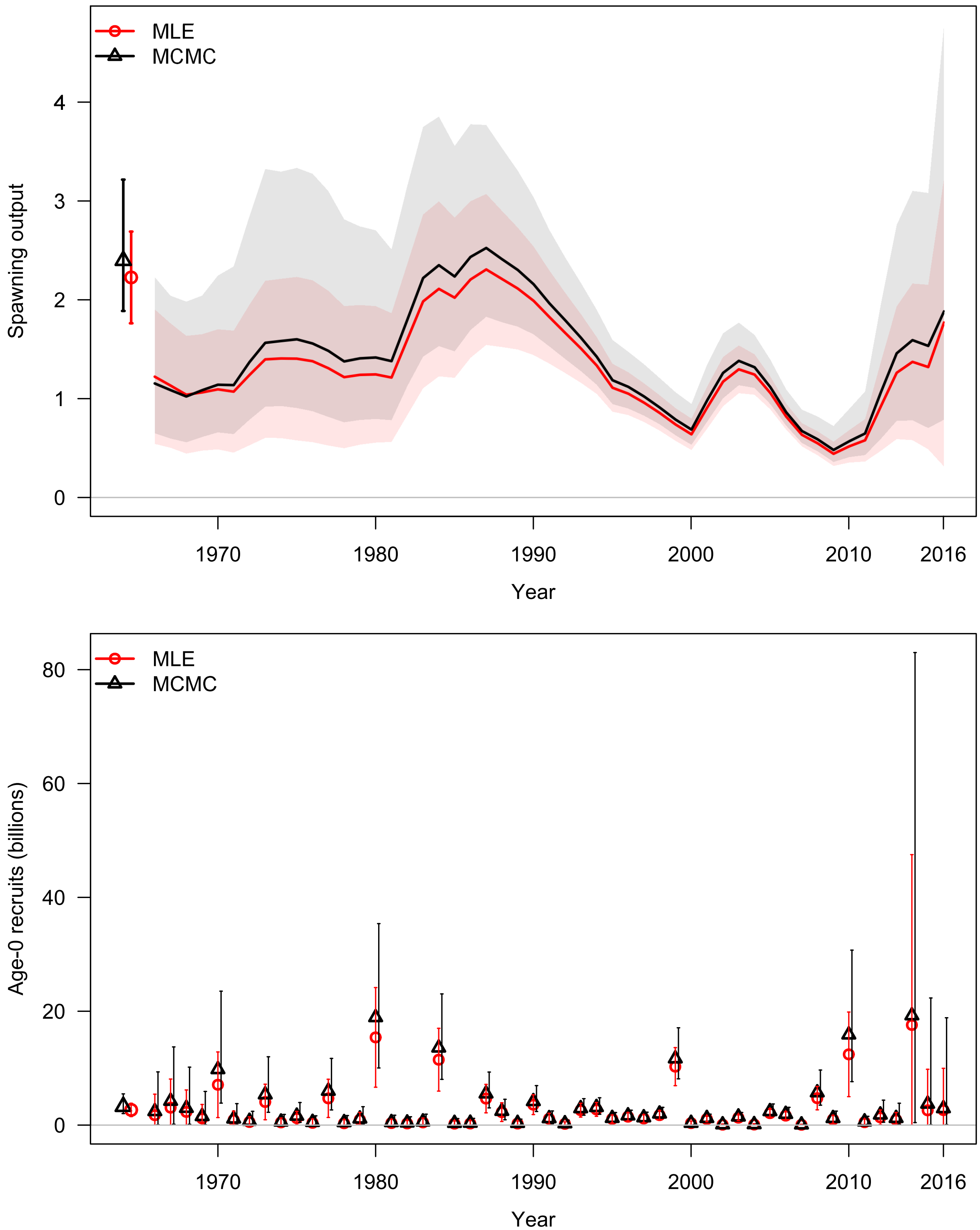


Figure 37. A comparison of maximum likelihood estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the posterior distribution with 95% credibility intervals (black). The posterior median is shown for spawning output while the posterior mean recruitment is displayed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

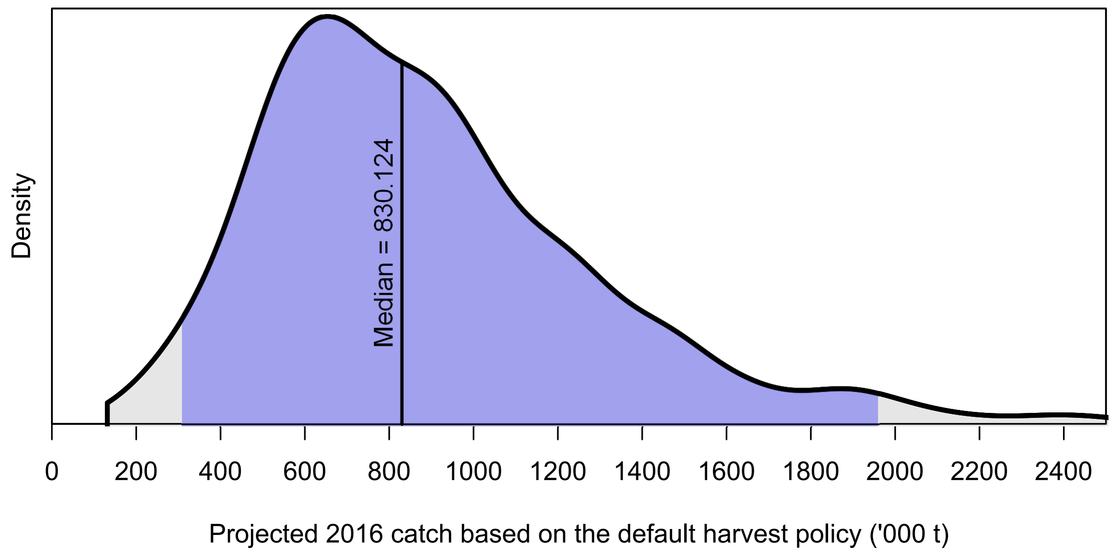


Figure 38. The posterior distribution of the default 2016 catch limit calculated using the default harvest policy ($F_{\text{SPR}=40\%}$–40:10). The median is 830,124 t (vertical line), with the dark shaded area ranging from the 2.5% quantile to the 97.5% quantile, covering the range 309,329–1,958,126 t.

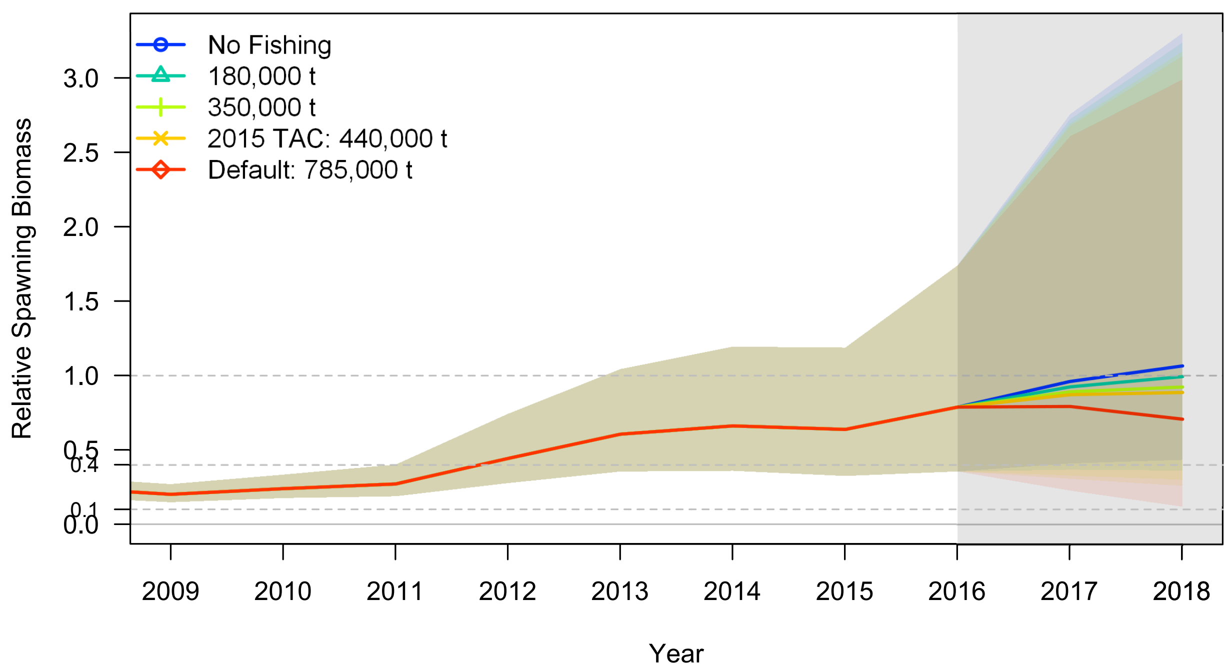


Figure 39. Time series of relative spawning biomass at the start of each year until 2016 as estimated from the base model, and forecast trajectories to the start of 2018 for several management options from the decision table, with 95% posterior credibility intervals. The 2016 catch of 785,000 t was calculated using the default harvest policy, as defined in the Agreement.

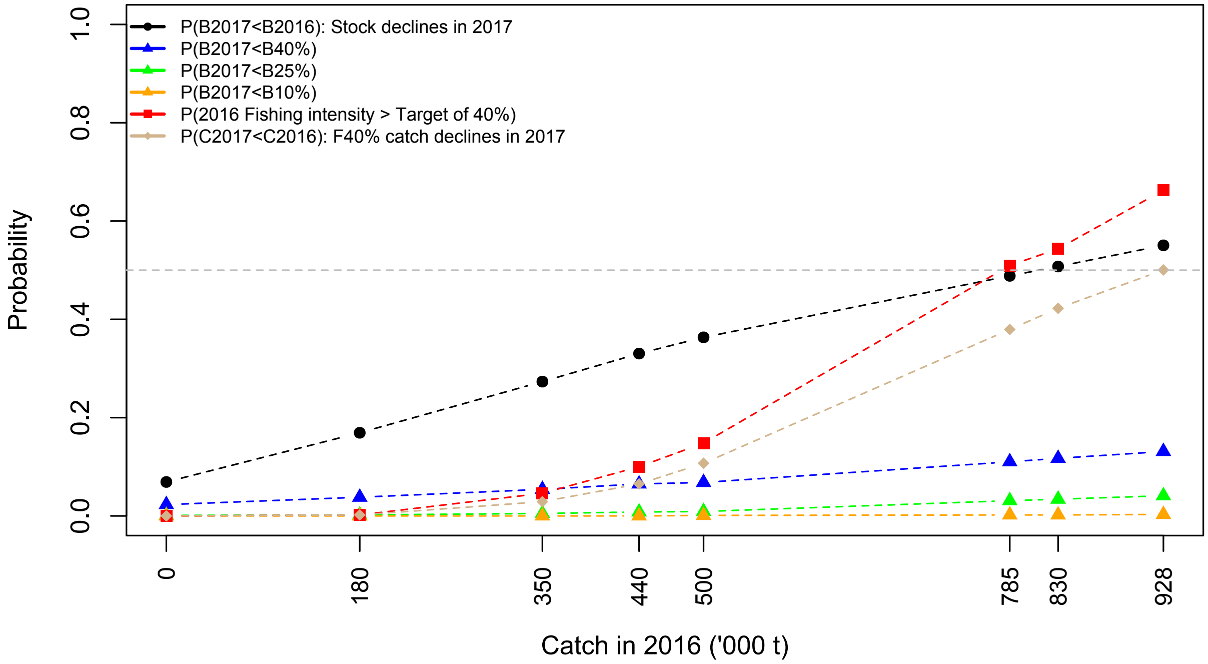


Figure 40. Graphical representation of the base model results presented in Table 18 for various catches in 2016. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

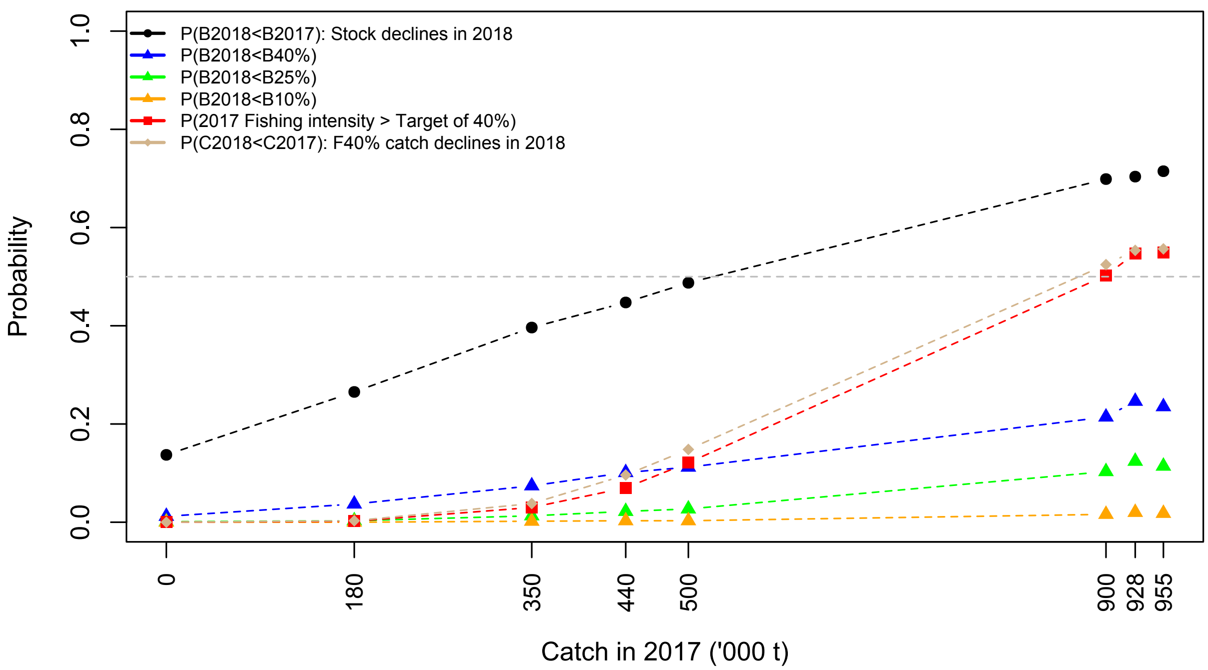


Figure 41. Graphical representation of the base model results presented in Table 19 for catch in 2017. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

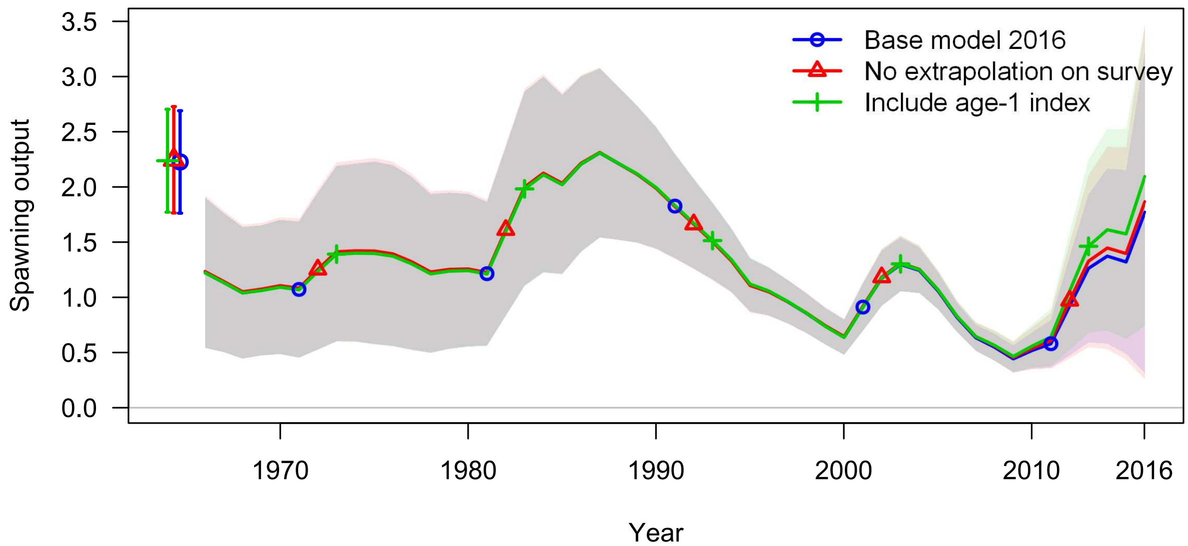


Figure 42. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing no extrapolation on the acoustic survey estimate and inclusion of an age-1 index.

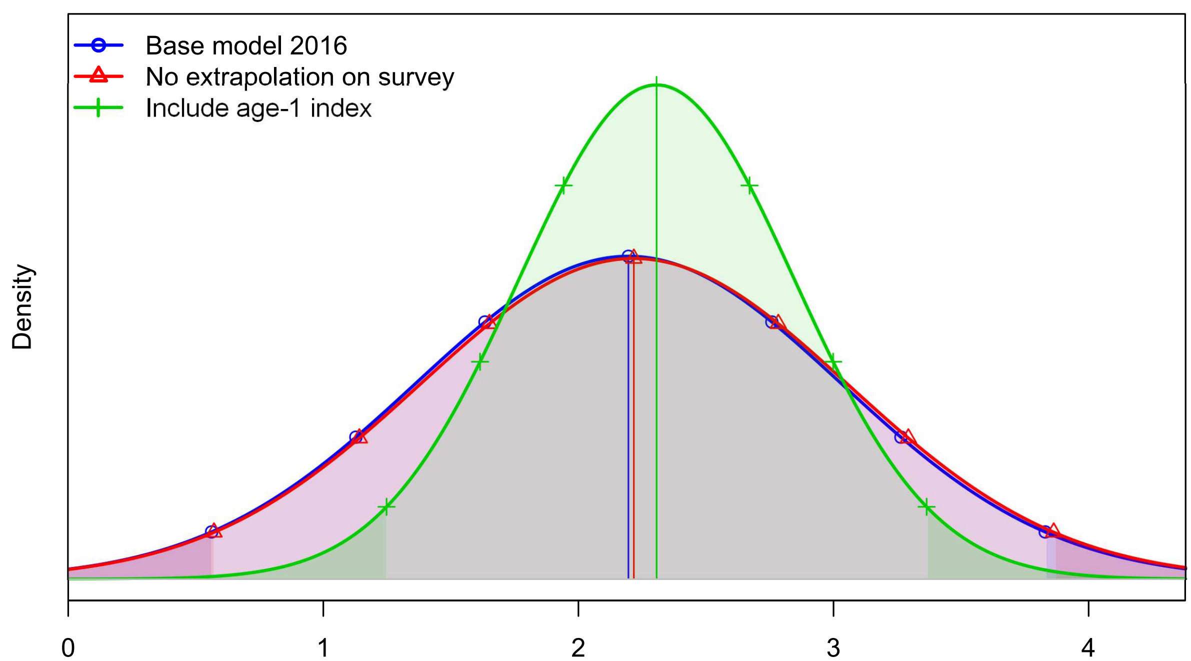


Figure 43. Density plot showing the MLE recruitment deviate estimates for the 2014 cohort for the base model and alternative sensitivity runs representing no extrapolation on the acoustic survey estimate and inclusion of an age-1 index.

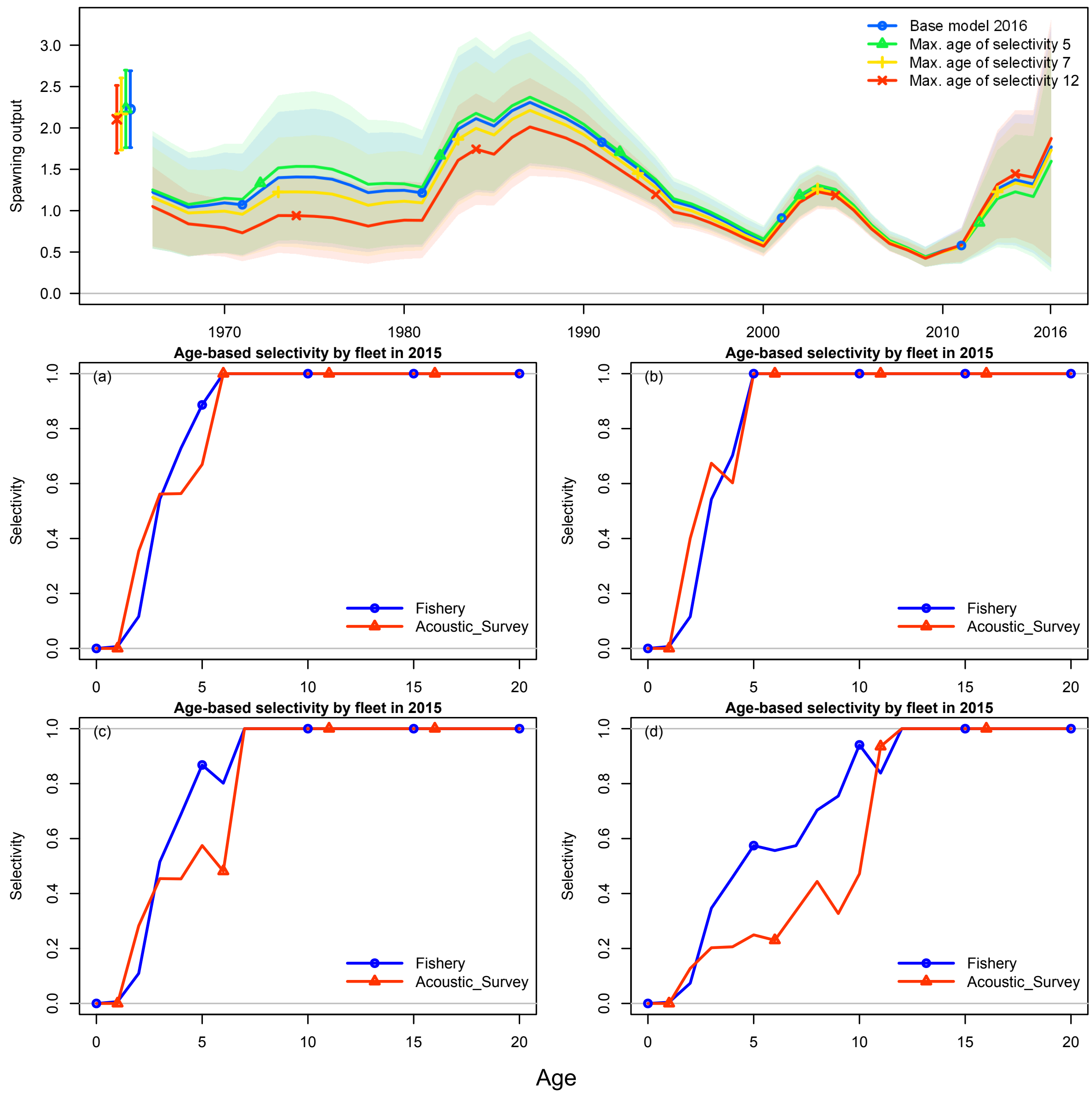


Figure 44. Maximum likelihood estimates of spawning biomass and selectivity for the base model and alternative sensitivity runs representing changes in the age of maximum selectivity from the value of 6 in the base model. Selectivity panels are a) Base model, b) Max. age of selectivity 5, c) Max. age of selectivity 7, and d) Max. age of selectivity 12.

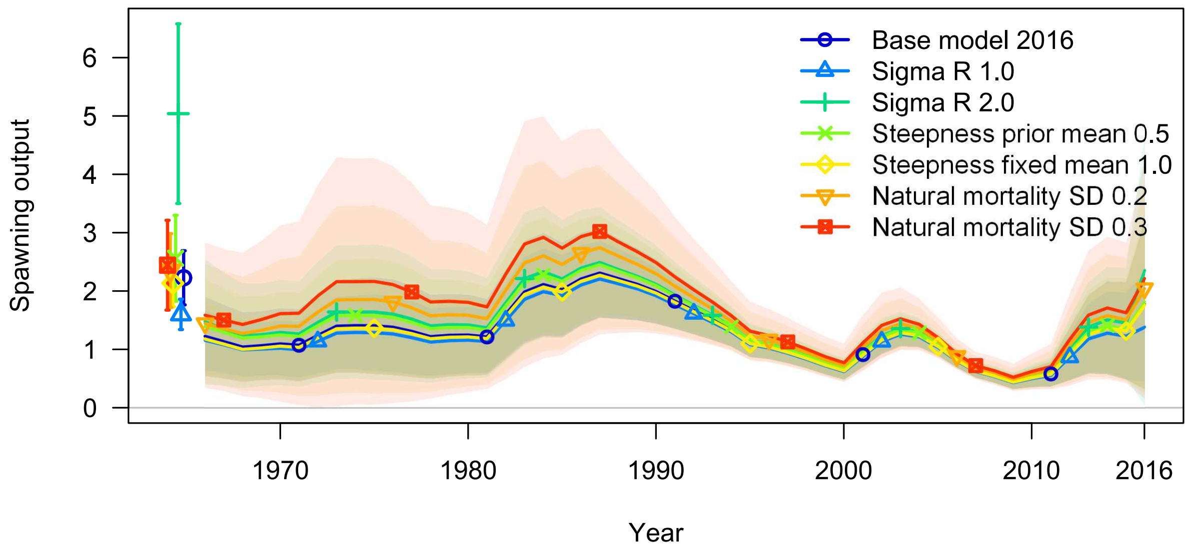


Figure 45. Maximum likelihood estimates of spawning biomass for the base model and alternative sensitivity runs representing changes to σ_r, steepness, and natural mortality parameters.

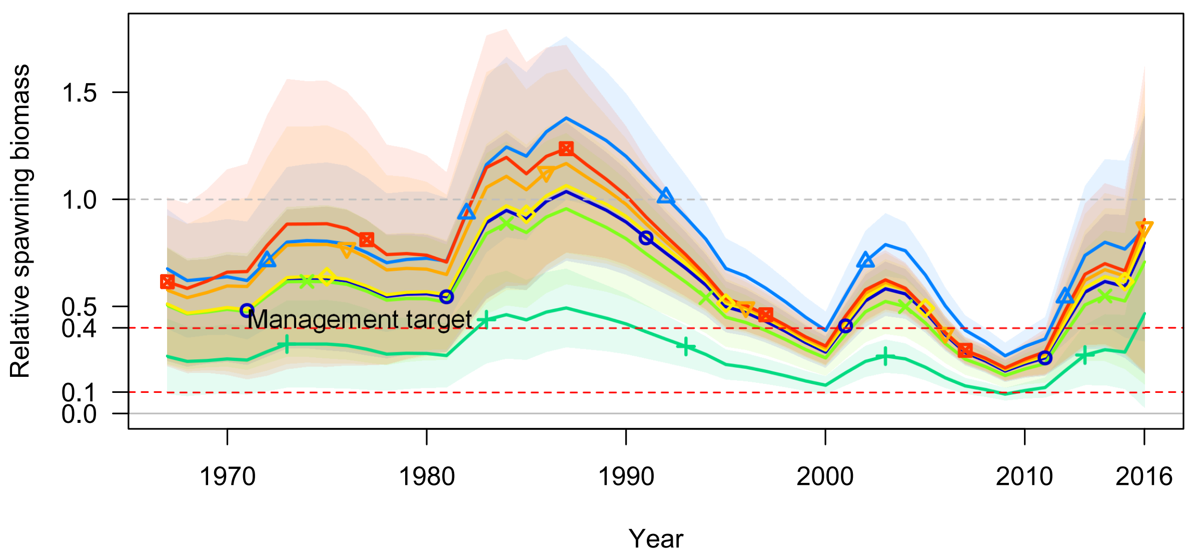


Figure 46. Maximum likelihood estimates of stock status (relative spawning biomass) for the base model and alternative sensitivity runs representing changes to σ_r, steepness, and natural mortality parameters. See Figure 45 for legend.

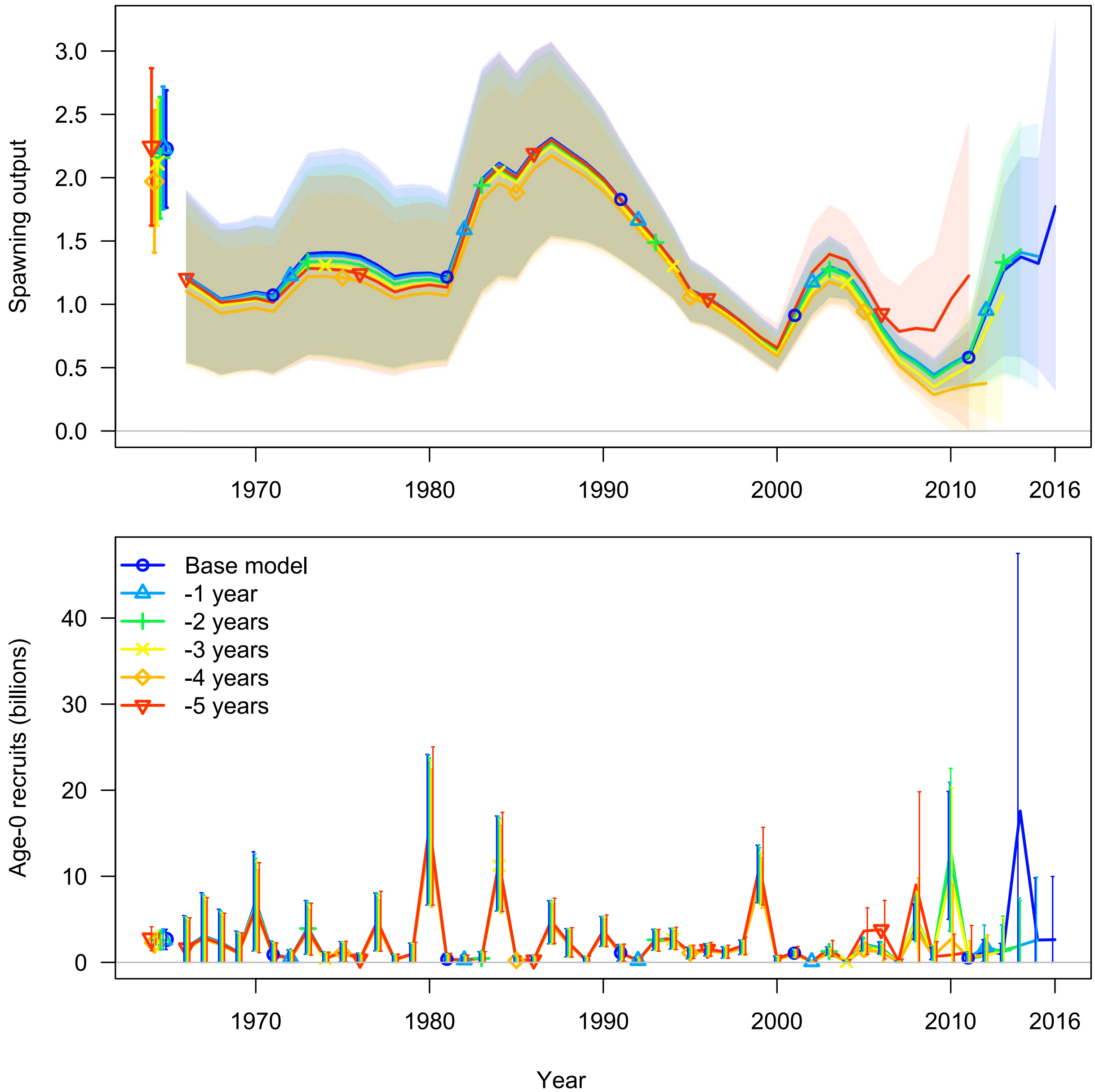


Figure 47. Estimates of spawning biomass at the start of each year (top) and recruitment (bottom) for the base model and retrospective runs (based on MLE model runs).

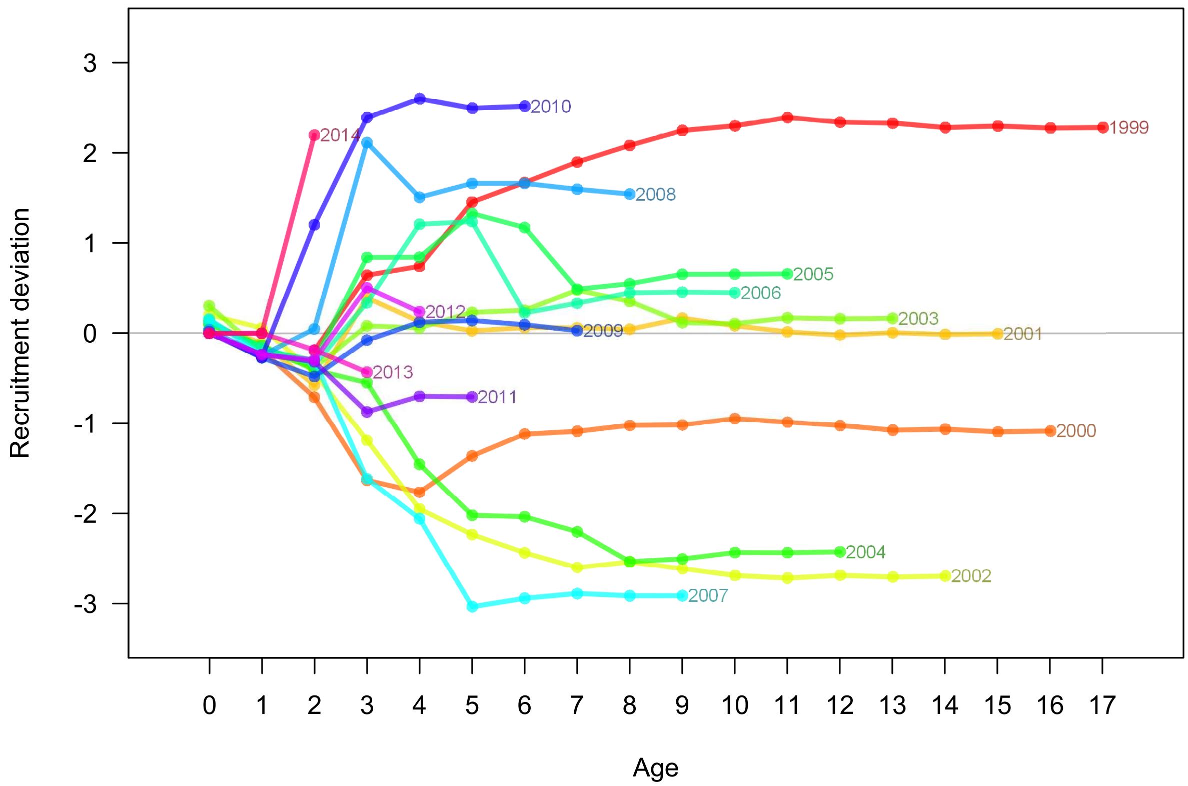


Figure 48. Retrospective analysis of recruitment deviations from maximum likelihood estimate (MLE) models over the last 16 years. Recruitment deviations are the log-scale differences between recruitment estimated by the model and expected recruitment from the spawner-recruit relationship. Lines represent 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.

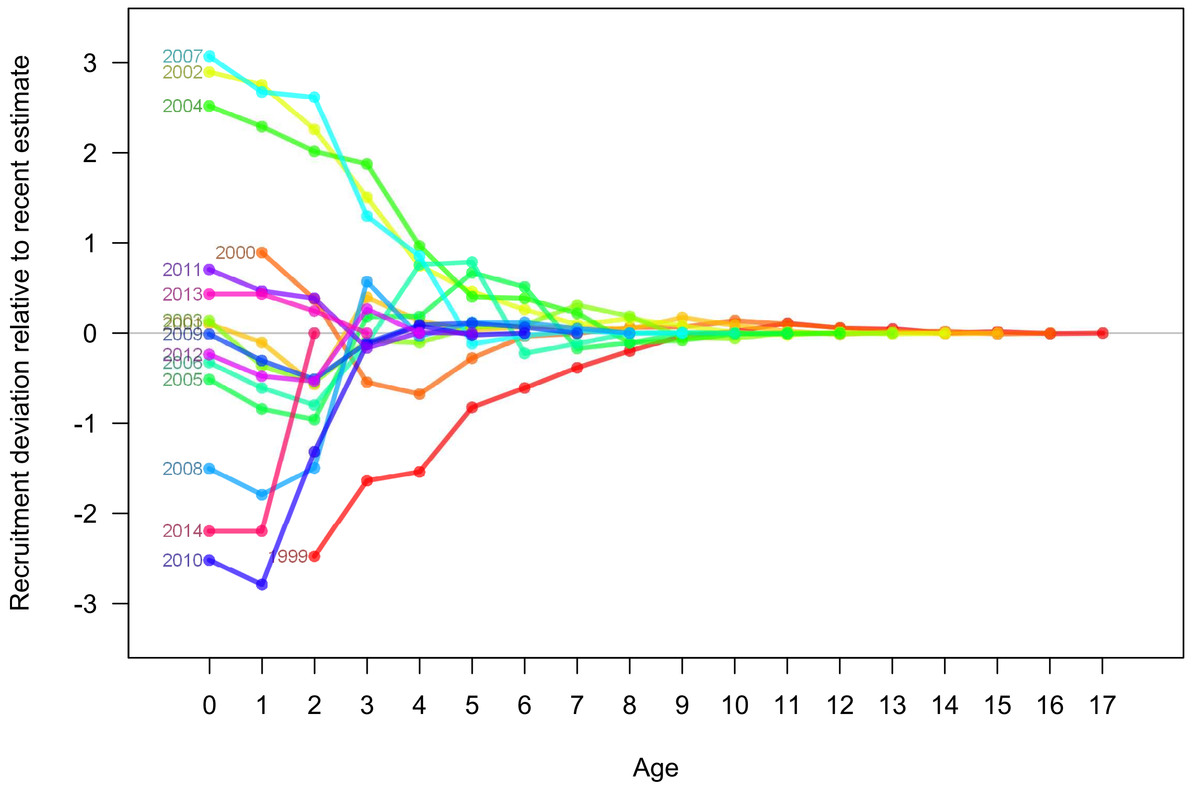


Figure 49. Retrospective recruitment estimates shown in Figure 48 scaled relative to the most recent estimate of the strength of each cohort.

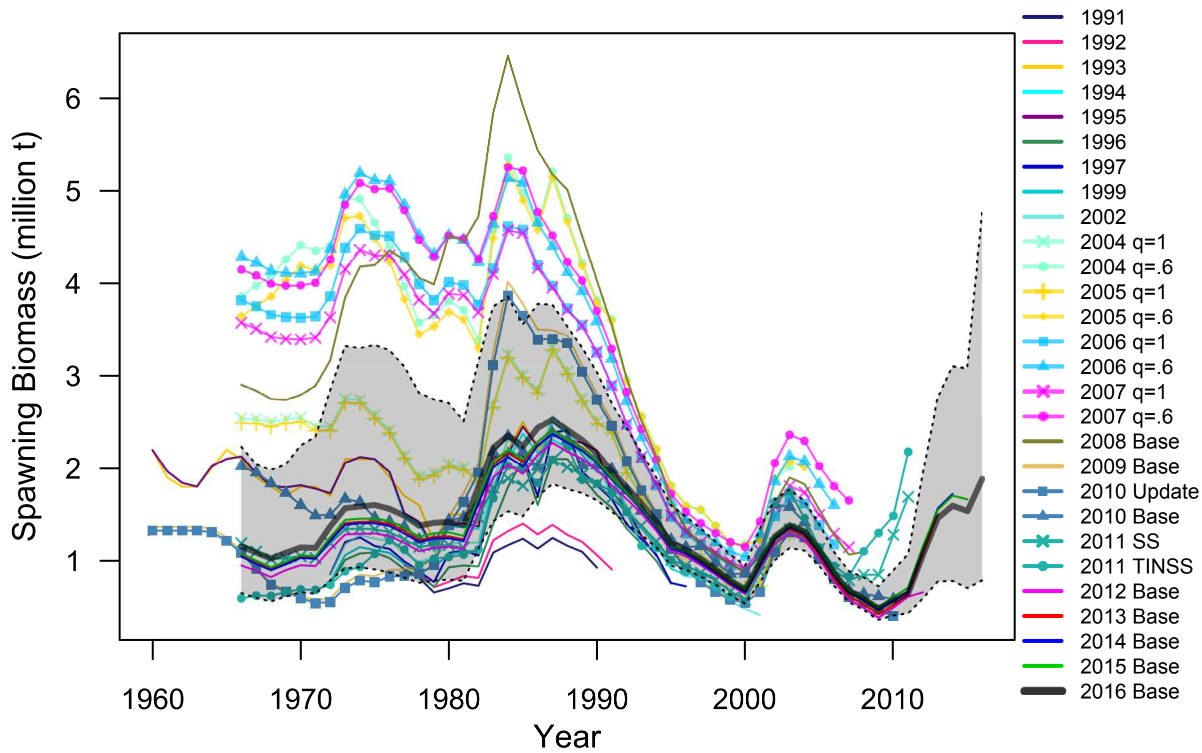


Figure 50. Summary of historical Pacific Hake assessment estimates of spawning biomass. Shading represents the approximate 95% confidence range from the 2016 base model.

A GLOSSARY OF TERMS AND ACRONYMS USED IN THIS DOCUMENT

Note: Many of these definitions are relevant to the historical management of Pacific Hake and the U.S. Pacific Fishery Management Council process, and are included here only to improve interpretability of previous assessment and background documents.

40:10 harvest control rule: The calculation leading to the ABC catch level (see below) for future years. This calculation decreases the catch linearly (given a constant age structure in the population) from the catch implied by the F_{MSY} (see below) harvest level when the stock declines below $B_{\text{SPR}=40\%}$ (see below) to a value of 0 at $B_{\text{SPR}=10\%}$.

40:10 adjustment: a reduction in the overall total allowable catch that is triggered when the biomass falls below 40% of its average equilibrium level in the absence of fishing. 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 stock is at 10% of its average equilibrium level in the absence of fishing.

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 TAC 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 estimated average unfished equilibrium female spawning biomass or spawning output if not directly proportional to spawning biomass.

$B_{\text{SPR}=10\%}$: The level of female spawning biomass (output) corresponding to 10% of average unfished equilibrium female spawning biomass (B_0, size of fish stock without fishing; see above). This is the level at which the calculated catch based on the 40:10 harvest control rule (see above) is equal to 0.

$B_{\text{SPR}=40\%}$: The level of female spawning biomass (output) corresponding to 40% of average unfished equilibrium female spawning biomass (B_0, size of fish stock without fishing; see above).

B_{MSY}: The estimated female spawning biomass (output) that produces the maximum sustainable yield (MSY). Also see $B_{\text{SPR}=40\%}$.

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, denoted by SA) 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."

Case: A combination of the harvest policy (F_{SPR} and control rule) and simulation assumptions regarding the survey. Cases considered in the MSE are "Annual", "Biennial", "Perfect information", and "No Fishing".

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 range: A term used in the MSE to describe simulations in which the JMC decision-making process is modeled very simplistically as replacing any TAC outside of a particular range with the limit of the range, even when this differs from the Default harvest policy (see below). The catch may fall outside the range if the available biomass is insufficient to support such removals.

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: One of many ways of setting catch in the MSE. In this case, the catch is set equal to a fixed value in all years unless the available biomass is insufficient to support such removals.

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

DOC: United States Department of Commerce. Parent organization of the National Marine Fisheries Service (NMFS).

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.

Estimation model: A single run of Stock Synthesis within a combination of Case, Simulation and Year. The directories containing these results are named "assess2012" through "assess2030" where the year value in this case represents the last year of real or simulated data. The amount of data available to these models is therefore consistent with the stock assessments conducted in the years 2013-2031. There are 18 Estimation Models for each of 999 Simulations within each of 4 Management strategies for a total of 71,928 model results. The estimation models use maximum likelihood estimation, not MCMC.

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.

$F_{\text{SPR}=40\%}$ (F-40 Percent): The rate of fishing mortality estimated to reduce the spawning potential ratio (SPR, see below) to 40%.

$F_{\text{SPR}=40\%}$–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. Occasionally, especially in reference points, this term is used to mean spawning output (expected egg production, see below) when this is not proportional to spawning biomass. See also spawning biomass.

Fishing intensity: A measure of the magnitude of fishing relative to a specified target. In this assessment it is defined as:

$$\text{relative SPR} = \frac{1-\text{SPR}}{1-\text{SPR}_{xx\%}}, \qquad \text{(A.1)}$$

where *xx*% is the 40% proxy. See Figure A.1.

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 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. (See “40:10 harvest control rule” 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.

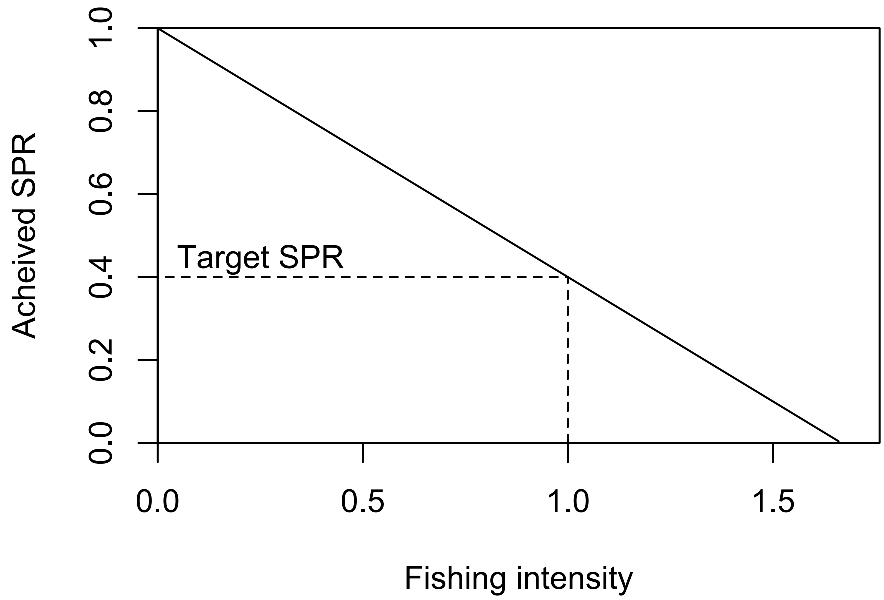


Figure A.1. Achieved SPR as a function of fishing intensity for a target SPR of 40%, using the inverse of (A.1).

The full formal name is "Joint Technical Committee of the Pacific Hake/whiting Agreement Between the Governments of the United States and Canada".

kt: Knots (nautical miles per hour).

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).

MAP: maximum *a posteriori* probability. See below.

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 above), 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 *a posteriori* probability (MAP) estimate: mode of the posterior distribution used as a point estimate which is similar to the penalized MLE.

Maximum likelihood estimate (MLE): Sometimes used interchangeably with “maximum posterior density estimate” or MPD. A numerical 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 characterized.

Maximum posterior density (MPD) estimate: mode of the posterior distribution used as a point estimate which is similar to the penalized MLE. This is also known as the “maximum *a posterior* probability” (MAP).

Maximum sustainable yield (MSY): An estimate of the largest average annual catch that can be continuously taken over a long period of time from a stock under prevailing 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 agency was previously 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 division of NOAA Fisheries 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).

Optimum yield: The amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems. The OY is developed based on the acceptable biological catch from the fishery, taking into account relevant economic, social, and ecological factors. In the case of overfished fisheries, the OY provides for rebuilding to the target stock abundance.

OY: Optimum yield (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/whiting: *Merluccius productus* are located in the offshore waters of the United States and Canada (not including smaller stocks located in Puget Sound and the Strait of Georgia).

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 average level of annual recruitment occurring at B_0 (see above).

Recruits/recruitment: A group of fish born in the same year, or the estimated production of new members to a fish population of the same age. Recruitment is reported at a specific life stage, often age 0 or 1, but sometimes corresponding to the age at which the fish first become vulnerable to the fishery. 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 spawning biomass: The ratio of the estimated beginning-of-the-year female spawning biomass to estimated average unfished equilibrium female spawning biomass (B_0, see above). Thus, lower values are associated with fewer mature female fish. This term has been introduced in the 2015 stock assessment as a replacement for “depletion” which was a source of some confusion.

Relative SPR: A measure of fishing intensity transformed to have an interpretation more like F: as fishing increases the metric increases. Relative SPR is the ratio of $(1-\text{SPR})$ to $(1-\text{SPR}_{xx\%})$, where “xx” is the proxy or estimated SPR rate that produces MSY.

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: State of nature, including combination of parameters controlling stock productivity, stock status, and time series of recruitment deviations. There are 999 simulations for each case, numbered 2-1000. These simulation models are samples from the MCMC calculations associated with a previous assessment model.

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

Spawning output: The total production of eggs (or possibly viable egg equivalents if egg quality is taken into account) given the number of females-at-age (and maturity- and fecundity-at-age).

Spawning potential ratio (SPR): A metric of fishing intensity. The ratio of the spawning output per recruit under a given level of fishing to the estimated spawning output per recruit in the absence of fishing. It achieves a value of one in the absence of fishing and declines toward zero as fishing intensity increases.

Spawning stock biomass (SSB): Alternative term for female spawning biomass (see above).

SPR: Spawning potential ratio(see above).

SPR_{MSY}: The estimated spawning potential ratio that produces the largest sustainable harvest (MSY).

$\text{SPR}_{40\%}$: The estimated spawning potential ratio that stabilizes the female spawning biomass at the MSY-proxy target of $B_{\text{SPR}=40\%}$. Also referred to as SPR_{MSY}-proxy.

SS: Stock Synthesis (see below).

SSC: Scientific and Statistical Committee (see above).

STAR Panel: Stock Assessment Review Panel. A panel set up to provide independent review of all stock assessments used by the Pacific Fishery Management Council.

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%). This parameter can be thought of one important component to the productivity of the stock.

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

Target strength: 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'.

B REPORT OF THE 2015 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 16th, 2015.

The 2015/16 Offshore Pacific TAC for Canada was 114,925.5 t with a combined harvest of 37,138.21 t (32.3%) by the shoreside and freezer vessel fleets. The freezer vessels led the way with 68% of the total harvest for Canada. Although a Joint Venture allocation of 29,622.2 t was approved, there was no JV fishery conducted in 2015/16. While the fleet caught slightly more fish in 2015, the size of the fish was smaller on average (estimated by industry as 4 or 5 year old fish) compared to 2014.

In mid-August DFO permitted, at the request of industry, the harvest of offshore hake for the production of meal (this required special permission from the Minister of Fisheries). The Canadian fleet made this request in response to the previous year's poor market conditions, similar market expectations for this season, and the general lack by foreign interests in a Joint Venture fishery that wouldn't compete with shoreside markets. However, better than expected markets, hake distributions and timing, and poor landed prices for meal resulted in only 68 t being landed for meal.

Fishing in the Canadian zone started in early May (a week to 10 days earlier than in 2014) with the last delivery occurring November 18, 2015. The early fishery was in the southern area of Vancouver Island but the vessels were pushed westward due to large bodies of small juvenile hake, which many fishermen reported as acoustically the largest biomass of hake witnessed in years. Vessels noticed a lot of small hake (200–250 g) South of Barclay Canyon early in the season. This body of small fish gradually covered the southern West Coast of Vancouver Island grounds (Clayquot area and south). Industry had agreed not to target hake under 300 g, so vessels moved west or north or into deeper water in search of larger fish. Unlike 2014, some vessels fished almost exclusively on the lower West Coast of Vancouver island in 2015. In 2014 a majority of the effort and catch was from the upper West Coast of Vancouver Island.

A majority of the Canadian production was HGT (by both shoreside and freezer vessels) with a very small amount of mince and whole round produced shoreside. The Canadian hake shoreside TAC is harvested by freezer vessels and vessels delivering fresh to shoreside plants. Overall fleet participation was down in 2015 due to hake distribution, the absence of a JV fishery, market conditions, ex-vessel pricing, an expanded shrimp fishery, and fewer shoreside processors taking hake.

In many ways, the Canadian hake fleet believes the 2015/16 hake fishery was encouraging, with fish present most time along the shelf break and at times on the shelf off the West Coast of Vancouver Island, with many different year classes, and a strong presence of juvenile hake in the south. Hake were present along the shelf break well past the Tide Marks north of Vancouver Island (it was communicated to some Canadian fishermen that SE Alaskan fishermen were intercepting hake in longline fisheries). There appeared to be a larger hake biomass in Canada compared to the two previous years (2013 and 2014). There was also warm water pushing all the way up the coast, perhaps 3 to 4 degrees higher than normal (signs of a strong El Niño). At times, the fleet found large dense schools (more so than in recent years), which at times of the day on certain tides was amplified. The hake were aggregating by size, with smaller fish in the 130–170 fathoms depth and larger fish outside 200 fathoms (where the water was cooler). Early in the season (June and July) it was reported by some vessels that hake were soft (possibly something to do with the feed) and needed to be processed quickly to maintain quality.

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 537 g (based on 1,472 sampled fish), with a maximum weight of 1,477 g and a minimum weight of 300 g. In 2014, the same vessel sampled 1,108 fish and had an average hake weight of 727 g, with a maximum weight of 1,509 g and a minimum weight of 317 g. On another freezer vessel the average size of round hake caught in 2015 was 600 g (in 2014 the hake this vessel caught primarily off Winter Harbor was around 200 g larger).

C ESTIMATED PARAMETERS IN THE BASE ASSESSMENT MODEL

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

Parameter	Posterior median
NatM_p_1_Fem_GP_1	0.2262
SR_LN.R0.	14.9550
SR_BH_steep	0.8141
Q_extraSD_2_Acoustic_Survey	0.3378
Early_InitAge_20	-0.1689
Early_InitAge_19	-0.0355
Early_InitAge_18	-0.0755
Early_InitAge_17	0.0058
Early_InitAge_16	-0.0192
Early_InitAge_15	-0.1268
Early_InitAge_14	-0.0833
Early_InitAge_13	-0.1348
Early_InitAge_12	-0.1953
Early_InitAge_11	-0.2538
Early_InitAge_10	-0.2610
Early_InitAge_9	-0.2912
Early_InitAge_8	-0.3689
Early_InitAge_7	-0.4517
Early_InitAge_6	-0.4547
Early_InitAge_5	-0.4628
Early_InitAge_4	-0.3901
Early_InitAge_3	-0.4192
Early_InitAge_2	-0.2768
Early_InitAge_1	-0.0364
Early_RecrDev_1966	0.3638
Early_RecrDev_1967	1.1490
Early_RecrDev_1968	0.7910
Early_RecrDev_1969	-0.0527
Main_RecrDev_1970	2.0820
Main_RecrDev_1971	-0.2666
Main_RecrDev_1972	-0.7532
Main_RecrDev_1973	1.4567
Main_RecrDev_1974	-0.9685
Main_RecrDev_1975	0.2336
Main_RecrDev_1976	-1.1013
Main_RecrDev_1977	1.5896
Main_RecrDev_1978	-1.2067
Main_RecrDev_1979	-0.2160
Main_RecrDev_1980	2.7703
Main_RecrDev_1981	-1.1751
Main_RecrDev_1982	-1.3409
Main_RecrDev_1983	-0.9246
Main_RecrDev_1984	2.4039
Main_RecrDev_1985	-1.5500
Main_RecrDev_1986	-1.4479
Main_RecrDev_1987	1.4968
Main_RecrDev_1988	0.6836
Main_RecrDev_1989	-1.5548
Main_RecrDev_1990	1.2397
Main_RecrDev_1991	-0.0816
Main_RecrDev_1992	-1.6944
Main_RecrDev_1993	0.9153
Main_RecrDev_1994	0.9882
Main_RecrDev_1995	0.0568
Main_RecrDev_1996	0.3796
Main_RecrDev_1997	0.1643
Main_RecrDev_1998	0.5976
Main_RecrDev_1999	2.3984
Main_RecrDev_2000	-1.1599

Continued on next page

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

Parameter	Posterior median
Main_RecrDev_2001	0.0921
Main_RecrDev_2002	-2.7704
Main_RecrDev_2003	0.2381
Main_RecrDev_2004	-2.4648
Main_RecrDev_2005	0.7649
Main_RecrDev_2006	0.5756
Main_RecrDev_2007	-2.8746
Main_RecrDev_2008	1.7223
Main_RecrDev_2009	0.1782
Main_RecrDev_2010	2.7192
Main_RecrDev_2011	-0.6564
Main_RecrDev_2012	0.3729
Late_RecrDev_2013	-0.1946
Late_RecrDev_2014	2.4267
Late_RecrDev_2015	0.0120
ForeRecr_2016	0.0615
ForeRecr_2017	0.0226
ForeRecr_2018	-0.0312
AgeSel_1P_3_Fishery	2.9721
AgeSel_1P_4_Fishery	1.5945
AgeSel_1P_5_Fishery	0.2895
AgeSel_1P_6_Fishery	0.1719
AgeSel_1P_7_Fishery	0.2244
AgeSel_2P_4_Acoustic_Survey	0.4690
AgeSel_2P_5_Acoustic_Survey	0.0243
AgeSel_2P_6_Acoustic_Survey	0.1556
AgeSel_2P_7_Acoustic_Survey	0.4153
AgeSel_1P_3_Fishery_DEVadd_1991	0.0008
AgeSel_1P_3_Fishery_DEVadd_1992	0.0006
AgeSel_1P_3_Fishery_DEVadd_1993	0.0011
AgeSel_1P_3_Fishery_DEVadd_1994	0.0008
AgeSel_1P_3_Fishery_DEVadd_1995	0.0013
AgeSel_1P_3_Fishery_DEVadd_1996	0.0000
AgeSel_1P_3_Fishery_DEVadd_1997	0.0006
AgeSel_1P_3_Fishery_DEVadd_1998	-0.0003
AgeSel_1P_3_Fishery_DEVadd_1999	0.0014
AgeSel_1P_3_Fishery_DEVadd_2000	0.0016
AgeSel_1P_3_Fishery_DEVadd_2001	-0.0017
AgeSel_1P_3_Fishery_DEVadd_2002	0.0011
AgeSel_1P_3_Fishery_DEVadd_2003	0.0021
AgeSel_1P_3_Fishery_DEVadd_2004	0.0014
AgeSel_1P_3_Fishery_DEVadd_2005	-0.0012
AgeSel_1P_3_Fishery_DEVadd_2006	0.0000
AgeSel_1P_3_Fishery_DEVadd_2007	0.0007
AgeSel_1P_3_Fishery_DEVadd_2008	0.0000
AgeSel_1P_3_Fishery_DEVadd_2009	0.0037
AgeSel_1P_3_Fishery_DEVadd_2010	0.0027
AgeSel_1P_3_Fishery_DEVadd_2011	0.0065
AgeSel_1P_3_Fishery_DEVadd_2012	-0.0002
AgeSel_1P_3_Fishery_DEVadd_2013	-0.0013
AgeSel_1P_3_Fishery_DEVadd_2014	0.0018
AgeSel_1P_3_Fishery_DEVadd_2015	-0.0070
AgeSel_1P_4_Fishery_DEVadd_1991	-0.0004
AgeSel_1P_4_Fishery_DEVadd_1992	0.0014
AgeSel_1P_4_Fishery_DEVadd_1993	0.0008
AgeSel_1P_4_Fishery_DEVadd_1994	0.0000
AgeSel_1P_4_Fishery_DEVadd_1995	0.0030
AgeSel_1P_4_Fishery_DEVadd_1996	-0.0101
AgeSel_1P_4_Fishery_DEVadd_1997	0.0057
AgeSel_1P_4_Fishery_DEVadd_1998	0.0014
AgeSel_1P_4_Fishery_DEVadd_1999	-0.0090

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

Parameter	Posterior median
AgeSel_1P_4_Fishery_DEVadd_2000	0.0101
AgeSel_1P_4_Fishery_DEVadd_2001	0.0244
AgeSel_1P_4_Fishery_DEVadd_2002	0.0027
AgeSel_1P_4_Fishery_DEVadd_2003	0.0043
AgeSel_1P_4_Fishery_DEVadd_2004	0.0003
AgeSel_1P_4_Fishery_DEVadd_2005	0.0076
AgeSel_1P_4_Fishery_DEVadd_2006	-0.0003
AgeSel_1P_4_Fishery_DEVadd_2007	-0.0083
AgeSel_1P_4_Fishery_DEVadd_2008	0.0005
AgeSel_1P_4_Fishery_DEVadd_2009	0.0051
AgeSel_1P_4_Fishery_DEVadd_2010	0.0036
AgeSel_1P_4_Fishery_DEVadd_2011	0.0105
AgeSel_1P_4_Fishery_DEVadd_2012	-0.0104
AgeSel_1P_4_Fishery_DEVadd_2013	0.0029
AgeSel_1P_4_Fishery_DEVadd_2014	-0.0063
AgeSel_1P_4_Fishery_DEVadd_2015	-0.0072
AgeSel_1P_5_Fishery_DEVadd_1991	-0.0062
AgeSel_1P_5_Fishery_DEVadd_1992	-0.0001
AgeSel_1P_5_Fishery_DEVadd_1993	-0.0015
AgeSel_1P_5_Fishery_DEVadd_1994	0.0064
AgeSel_1P_5_Fishery_DEVadd_1995	0.0031
AgeSel_1P_5_Fishery_DEVadd_1996	-0.0024
AgeSel_1P_5_Fishery_DEVadd_1997	-0.0043
AgeSel_1P_5_Fishery_DEVadd_1998	-0.0048
AgeSel_1P_5_Fishery_DEVadd_1999	-0.0119
AgeSel_1P_5_Fishery_DEVadd_2000	0.0114
AgeSel_1P_5_Fishery_DEVadd_2001	0.0218
AgeSel_1P_5_Fishery_DEVadd_2002	0.0264
AgeSel_1P_5_Fishery_DEVadd_2003	0.0061
AgeSel_1P_5_Fishery_DEVadd_2004	0.0014
AgeSel_1P_5_Fishery_DEVadd_2005	0.0067
AgeSel_1P_5_Fishery_DEVadd_2006	0.0036
AgeSel_1P_5_Fishery_DEVadd_2007	-0.0080
AgeSel_1P_5_Fishery_DEVadd_2008	-0.0013
AgeSel_1P_5_Fishery_DEVadd_2009	0.0037
AgeSel_1P_5_Fishery_DEVadd_2010	0.0082
AgeSel_1P_5_Fishery_DEVadd_2011	-0.0445
AgeSel_1P_5_Fishery_DEVadd_2012	-0.0066
AgeSel_1P_5_Fishery_DEVadd_2013	-0.0027
AgeSel_1P_5_Fishery_DEVadd_2014	-0.0072
AgeSel_1P_5_Fishery_DEVadd_2015	-0.0002
AgeSel_1P_6_Fishery_DEVadd_1991	-0.0075
AgeSel_1P_6_Fishery_DEVadd_1992	-0.0017
AgeSel_1P_6_Fishery_DEVadd_1993	-0.0019
AgeSel_1P_6_Fishery_DEVadd_1994	0.0102
AgeSel_1P_6_Fishery_DEVadd_1995	0.0098
AgeSel_1P_6_Fishery_DEVadd_1996	-0.0019
AgeSel_1P_6_Fishery_DEVadd_1997	-0.0031
AgeSel_1P_6_Fishery_DEVadd_1998	0.0011
AgeSel_1P_6_Fishery_DEVadd_1999	-0.0177
AgeSel_1P_6_Fishery_DEVadd_2000	0.0172
AgeSel_1P_6_Fishery_DEVadd_2001	0.0155
AgeSel_1P_6_Fishery_DEVadd_2002	0.0155
AgeSel_1P_6_Fishery_DEVadd_2003	0.0089
AgeSel_1P_6_Fishery_DEVadd_2004	-0.0011
AgeSel_1P_6_Fishery_DEVadd_2005	0.0085
AgeSel_1P_6_Fishery_DEVadd_2006	0.0039
AgeSel_1P_6_Fishery_DEVadd_2007	-0.0061
AgeSel_1P_6_Fishery_DEVadd_2008	0.0031
AgeSel_1P_6_Fishery_DEVadd_2009	0.0050
AgeSel_1P_6_Fishery_DEVadd_2010	-0.0252

Continued on next page

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

Parameter	Posterior median
AgeSel_1P_6_Fishery_DEVadd_2011	-0.0412
AgeSel_1P_6_Fishery_DEVadd_2012	-0.0215
AgeSel_1P_6_Fishery_DEVadd_2013	-0.0018
AgeSel_1P_6_Fishery_DEVadd_2014	0.0128
AgeSel_1P_6_Fishery_DEVadd_2015	0.0026
AgeSel_1P_7_Fishery_DEVadd_1991	-0.0085
AgeSel_1P_7_Fishery_DEVadd_1992	0.0070
AgeSel_1P_7_Fishery_DEVadd_1993	-0.0016
AgeSel_1P_7_Fishery_DEVadd_1994	0.0132
AgeSel_1P_7_Fishery_DEVadd_1995	0.0072
AgeSel_1P_7_Fishery_DEVadd_1996	0.0013
AgeSel_1P_7_Fishery_DEVadd_1997	-0.0016
AgeSel_1P_7_Fishery_DEVadd_1998	-0.0055
AgeSel_1P_7_Fishery_DEVadd_1999	-0.0148
AgeSel_1P_7_Fishery_DEVadd_2000	0.0178
AgeSel_1P_7_Fishery_DEVadd_2001	0.0032
AgeSel_1P_7_Fishery_DEVadd_2002	0.0090
AgeSel_1P_7_Fishery_DEVadd_2003	0.0028
AgeSel_1P_7_Fishery_DEVadd_2004	-0.0013
AgeSel_1P_7_Fishery_DEVadd_2005	0.0045
AgeSel_1P_7_Fishery_DEVadd_2006	-0.0033
AgeSel_1P_7_Fishery_DEVadd_2007	-0.0030
AgeSel_1P_7_Fishery_DEVadd_2008	-0.0020
AgeSel_1P_7_Fishery_DEVadd_2009	0.0054
AgeSel_1P_7_Fishery_DEVadd_2010	-0.0274
AgeSel_1P_7_Fishery_DEVadd_2011	-0.0306
AgeSel_1P_7_Fishery_DEVadd_2012	-0.0203
AgeSel_1P_7_Fishery_DEVadd_2013	0.0150
AgeSel_1P_7_Fishery_DEVadd_2014	0.0114
AgeSel_1P_7_Fishery_DEVadd_2015	-0.0163

D STOCK SYNTHESIS DATA FILE

../models/55_2016base/2016hake_data.ss

```
#C 2016 Hake data file - survey data, K-S, with extrapolation
###################################################

### Global model specifications ###
1966    # Start year
2015    # 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

50 # 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
249496   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
321701   2008    1
177172   2009    1
230672   2010    1
291671   2011    1
205787   2012    1
285614   2013    1
298703   2014    1
190663   2015    1


18 # 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)
1998     1       2       1534604   0.0526
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   0.0920
```

```
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

43 # 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.
   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.
   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
```

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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
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
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         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     def42      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    0.897842   1.858      2.172      2.53
        2.934      3.388      # 2015     def42      SD of age.
   0.55*age4, 0.55*age15

#Age comps updated 1/11/2016
51   # 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
```

```
1998  1     2     0  0         26     -1     -1     105     0
   6.78    8.20    17.04   17.28   1.77    11.30   10.76   1.72    4.12
      7.58    1.28    0.33    9.80    2.04
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  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
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  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      56       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      81       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      77       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      175      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      234      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      222      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   20.348  20.288  26.595  2.869   5.401   9.311   0.917
  1.557   3.900   0.352   0.092   2.941   0.627
1999  1     1     0   0          27      -1      -1      514      0.062
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   10.230   20.364   17.982   20.066   13.201   2.688    3.930    4.010
   0.990    1.543    2.141    0.392    0.335    2.067
2000  1      1      0   0          28      -1      -1      529      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      541      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      450      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      457      0.000
   0.105    1.397    67.891   11.642   3.339    4.987    3.193    3.138
   2.107    0.875    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    68.720   7.955    2.358    2.909
   2.207    1.177    1.091    0.250    0.090    0.248
2006  1      1      0   0          34      -1      -1      720      0.326
   2.808    10.443   1.673    8.565    4.878    59.030   5.278    1.717
   2.377    1.136    1.017    0.428    0.136    0.188
2007  1      1      0   0          35      -1      -1      629      0.759
   11.295   3.732    15.445   1.596    6.851    3.839    44.103   5.187
   1.724    2.290    1.790    0.507    0.185    0.699
2008  1      1      0   0          36      -1      -1      794      0.760
   9.716    30.568   2.402    14.451   1.030    3.640    3.176    28.092
   3.045    1.146    0.735    0.494    0.314    0.431
2009  1      1      0   0          37      -1      -1      686      0.643
   0.520    30.584   27.605   3.353    10.705   1.302    2.265    2.298
   16.168   2.473    0.867    0.592    0.282    0.342
2010  1      1      0   0          38      -1      -1      873      0.028
   25.395   3.341    34.816   21.488   2.344    3.008    0.440    0.577
   0.976    6.085    0.927    0.307    0.106    0.159
2011  1      1      0   0          39      -1      -1      1081     2.639
   8.505    70.919   2.650    6.388    4.420    1.133    0.819    0.294
   0.390    0.116    1.343    0.170    0.109    0.107
2012  1      1      0   0          40      -1      -1      851      0.182
   41.085   11.563   32.934   2.480    5.029    2.501    1.130    0.658
   0.231    0.327    0.348    0.866    0.285    0.383
2013  1      1      0   0          41      -1      -1      1094     0.030
   0.545    70.348   5.896    10.454   1.123    3.401    2.058    0.907
   1.363    0.264    0.334    0.529    2.284    0.464
2014  1      1      0   0          42      -1      -1      1130     0.000
   3.319    3.733    64.376   6.916    12.121   1.580    3.147    1.808
   0.819    0.458    0.121    0.183    0.280    1.137
2015  1      1      0   0          43      -1      -1      793      3.727
   1.149    6.949    3.985    70.003   4.827    5.023    0.948    1.520
   1.081    0.199    0.204    0.060    0.051    0.276

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
```

E STOCK SYNTHESIS CONTROL FILE

../models/55_2016base/2016hake_control.ss

```
#C 2016 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
2012    # 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)
2012    # Last year for full bias correction in_MPD
2015    # 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 2015
   0.03 0 0 # Change to age 2
  -5    9         0.1     -1       -1       0.01     2        0 2 1991 2015
   0.03 0 0 # Change to age 3
  -5    9         0.1     -1       -1       0.01     2        0 2 1991 2015
   0.03 0 0 # Change to age 4
  -5    9         0.1     -1       -1       0.01     2        0 2 1991 2015
   0.03 0 0 # Change to age 5
  -5    9         0.0     -1       -1       0.01     2        0 2 1991 2015
   0.03 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
 0.11 0.51 # 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
```

F STOCK SYNTHESIS STARTER FILE

../models/55_2016base/starter.ss

```
#C 2016 Hake starter file
###################################################

2016hake_data.SS        # Data file
2016hake_control.SS     # Control file

0       # Read initial values from .par file: 0=no,1=yes
0       # 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
402       # MCMC burn-in
2       # 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
```

G STOCK SYNTHESIS FORECAST FILE

../models/55_2016base/forecast.ss

```
#C 2016 Bridge2 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
```

H STOCK SYNTHESIS WEIGHT-AT-AGE FILE

../models/55_2016base/wtatage.ss

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2016-01-10 16:32:30
###################################################
169 # 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 0.0864 0.2495 0.3778 0.4847
   0.5335 0.5914 0.6621 0.7219 0.7912 0.8630 0.9335 0.9740 1.0706 1.0102
   1.0315 1.0315 1.0315 1.0315 1.0315 1.0315
  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

#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 0.0864 0.2495 0.3778 0.4847
   0.5335 0.5914 0.6621 0.7219 0.7912 0.8630 0.9335 0.9740 1.0706 1.0102
   1.0315 1.0315 1.0315 1.0315 1.0315 1.0315
  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

#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 0.0864 0.2495 0.3778 0.4847
  0.5335 0.5914 0.6621 0.7219 0.7912 0.8630 0.9335 0.9740 1.0706 1.0102
  1.0315 1.0315 1.0315 1.0315 1.0315 1.0315
 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
```

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  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

#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 0.0864 0.2495 0.3778 0.4847
   0.5335 0.5914 0.6621 0.7219 0.7912 0.8630 0.9335 0.9740 1.0706 1.0102
   1.0315 1.0315 1.0315 1.0315 1.0315 1.0315
  1975    1       1  1     1     2 0.0550 0.1575 0.2987 0.3658 0.6143
   0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555
   2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
  1976    1       1  1     1     2 0.0550 0.0986 0.2359 0.4990 0.5188
   0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507 1.8066 1.8588 1.9555
   2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
  1977    1       1  1     1     2 0.0550 0.0855 0.4020 0.4882 0.5902
   0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148 1.4027 1.7511 2.1005
   2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1       1  1     1     2 0.0517 0.0725 0.1275 0.4699 0.5302
```

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 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
```

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 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
# End of wtatage.ss file
```