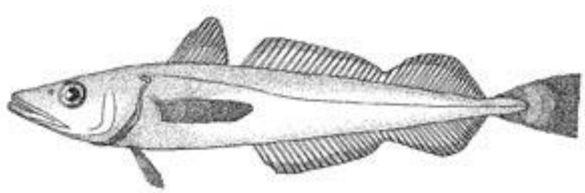
Agenda Item E.9
Attachment 1
(FULL Assessment Electronic Only)
April 2015

Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2015



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

FINAL Document
4 March, 2015

This document reports the collaborative efforts of the official U.S. and Canadian JTC members.

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ONE PAGE SUMMARY

- The stock assessment model for 2015 is similar in structure to the 2014 model with addition of fishery data from 2014 and minor refinements to data including catch estimates from earlier years.

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

- There was no survey conducted in 2014. Therefore the most recent survey information remains from the one conducted in 2013.

- Coastwide catch in 2014 was 301,573 t, out of a TAC (adjusted for carryovers) of 428,000 t. Attainment of the quota was higher in the US at 83.5% relative to Canada at 33.5% of their respective allocations. A variety of factors influenced the attainment of the quota.

- The stock is estimated to be near its highest biomass level since the early 1990s as a result of an above average 2008 cohort and a very large 2010 cohort. Recruitment in 2011 is estimated to have been below average. Cohorts from the years 2012-2014 have not been observed long enough in the data to estimate their size or even if they are likely to be above or below average.

- The 2015 median relative spawning biomass (current spawning biomass divided by unfished equilibrium, B_0) is estimated to be 73.6% but is highly uncertain (with 95% interval from 34.3% to 149.8%).

- The median estimate of 2015 female spawning biomass is 1.663 million t (with 95% interval from 0.750 to 3.551 million t).

- The spawning biomass in 2015 is estimated to have declined from 2014 due to fishery removals and natural mortality of the 2008 and 2010 cohorts which are now fully mature and no longer growing as rapidly as in previous years.

- The catch limit based upon the median default harvest rate calculated for 2015 is 804,576 t.

- As in the past, forecasts are highly uncertain due to lack of information about recruitment in the most recent years. Forecasts were conducted across a range of catch levels.

- Projections setting 2015 and 2016 catch equal to the 2014 TAC of 428,000 t show the median spawning relative biomass estimates declining from 74% of B_0 in 2015 to 68% in 2016 and 60% in 2017. However, this projection is highly uncertain and shows a 5% chance of falling below 25% of B_0 in 2 years (by 2017) and a 5% chance of increasing above 129% in that same time frame.

- Spawning biomass in 2017 is likely to be less than spawning biomass in 2016 given any catch level. There is a 40% probability that the relative spawning biomass in 2017 will be less than 40% if the entire predicted default harvest catch is taken in 2015 (804,576 t) and 2016 (682,782 t).

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. 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. The northern extent of migration is dependent upon both ocean conditions and age although the mechanisms and relationships are not well understood. Catches in the Canadian zone typically consist of older fish than those in the United States. 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. The potential for catches of *Merluccius productus* in Mexican waters is being investigated but no catches from Mexico are included in this analysis.

Catches

Coast-wide Pacific Hake landings averaged 224,982 t from 1966 through 2014, with a low of 89,930 t in 1980 and a peak of 363,135 t in 2005. 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 169,231 t, or 75.2% of the average total landings, while catch from Canadian waters averaged 55,324 t. Over the last 10 years, 2005–2014, the total average catch was 282,549 with U.S. and Canadian catches averaging 217,186 t and 65,093 t, respectively.

In this stock assessment, we use the terms catch and landings 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. In 2013, mortality of hake from non-hake fisheries was estimated at 337 t which represents less than 0.2% of the landings (Somers, 2014). Recent coast-wide landings from 2010–2014 have been above the long term average of 224,982 t. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal estimated to have come from that cohort exceeding 1.2 million t. Coast-wide catches in recent years have depended on the 2008 and 2010 year-classes, with the 2008 cohort being 70% of the 2011 catch and 33% of the 2012 catch, while the 2010 cohort accounted for 40% of the 2012 catch, 70% of the 2013 catch, and 64% of the 2014 catch. This is despite the fact that catches in Canada have had relatively small proportions of these two cohorts.

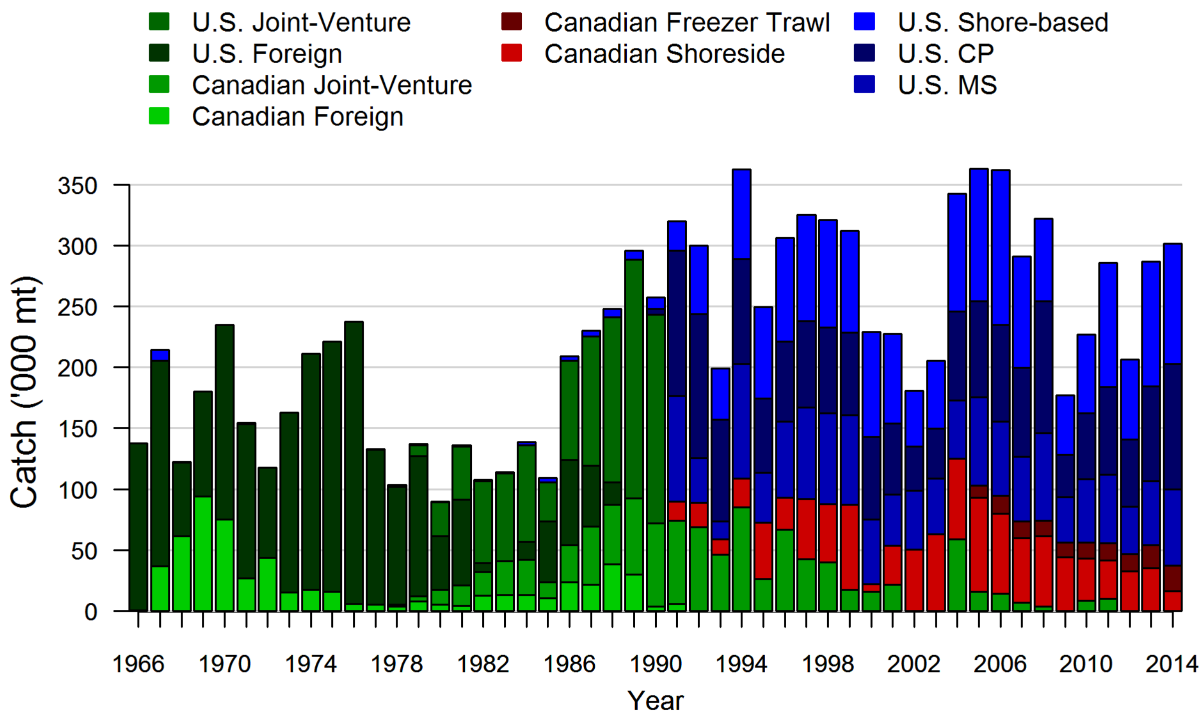

Figure a. Total Pacific Hake catch used in the assessment by sector, 1966-2013. U.S. tribal catches are included in the sectors where they are represented.

Table a. Recent commercial fishery catch (t). U.S. tribal catches are included where applicable. US research catch does not include any acoustic or trawl surveys in the U.S. or Canada.

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
2005	72,178	78,890	109,052	0	260,120	15,695	77,335	9,985	103,014	363,135
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	53,055	13,537	73,373	291,054
2008	72,440	108,195	67,760	0	248,395	3,592	57,640	12,517	73,749	322,144
2009	37,550	34,552	49,223	0	121,325	0	43,811	12,073	55,885	177,209
2010	52,022	54,284	64,654	0	170,961	8,081	35,162	12,850	56,094	227,054
2011	56,394	71,678	102,147	1,042	231,262	9,717	31,504	14,409	55,630	286,892
2012	38,512	55,264	65,920	448	160,145	0	32,434	14,478	46,913	207,057
2013	52,470	77,950	102,143	1,018	233,581	0	35,303	18,793	54,096	287,677
2014	62,102	103,203	98,635	197	264,137	0	16,056	21,381	37,437	301,573

Data and assessment

No new acoustic survey was conducted in 2014, so the only new data included in the stock assessment are the 2014 fishery age composition and total catch. Various other data types, including data on maturity, have been explored since the 2014 stock assessment, but are not included in the base model for this year.

The Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2014), acoustic survey biomass estimates and age-composition (1995–2013; Figure b), as well as fishery age-composition. While the 2011 survey index value was the lowest in the time-series, the index increased steadily over the three surveys conducted in 2011, 2012, and 2013. Age-composition data from the aggregated fisheries (1975–2014) 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 closed-loop simulations to evaluate the potential consequences of parameter uncertainty, alternative structural models, and management system performance, respectively. The Bayesian approach combines prior knowledge about natural mortality, stock-recruitment steepness (a parameter for stock productivity), and several other parameters with likelihoods for acoustic survey biomass indices and age-composition, as well as 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. Finally, the closed-loop simulations provide an assessment of 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.

This 2015 assessment retains the structural form of the base assessment model from 2014. The model retains many of the previous elements as configured in Stock Synthesis (SS). Analyses conducted in 2014 showed that the time-varying selectivity assessment model 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 selectivity. 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.

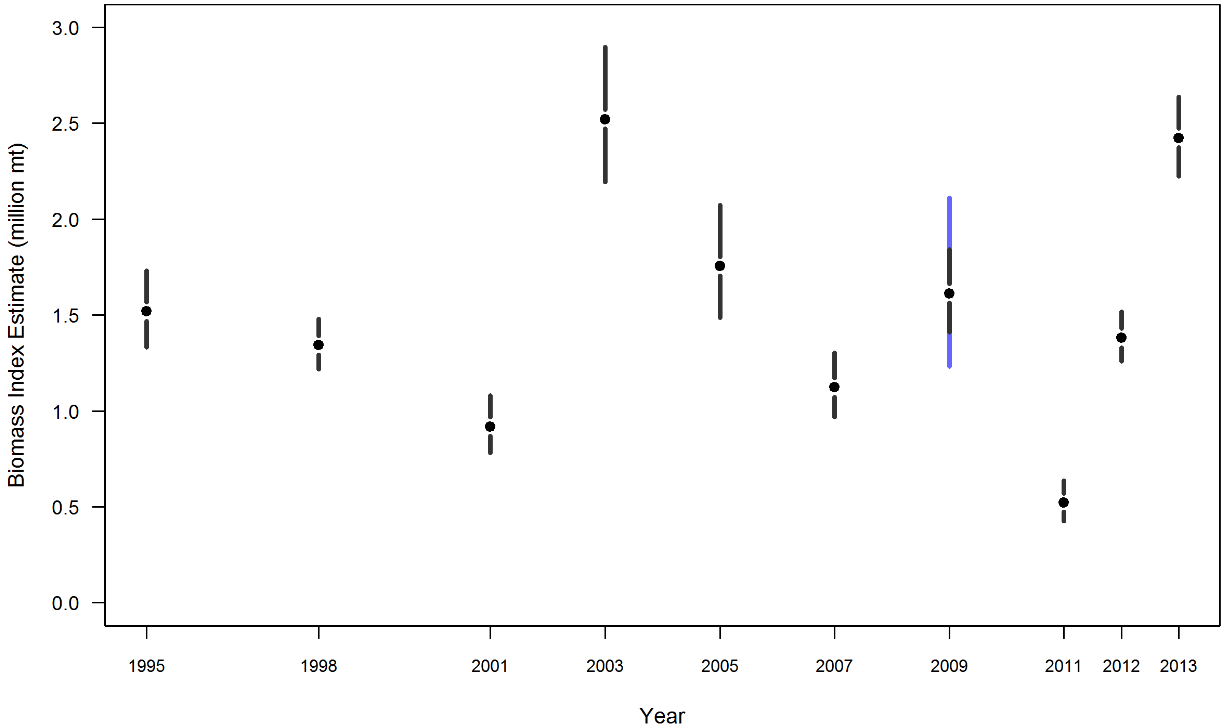

Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2013) in addition to squid/hake apportionment uncertainty (2009, in blue). No new acoustic survey was conducted in 2014.

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. 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 entering the fishery to replace catches being removed during this period. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.497 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 increase was the result of a large 2010 and an above-average 2008 cohort. The 2015 median posterior spawning biomass is estimated to be 73.6% of the unfished equilibrium level (B_0) with 95% posterior credibility intervals ranging from 34.3% to 149.8%. The median estimates of 2014 and 2015 female spawning biomass values are 1.703 and 1.663 million t, respectively.

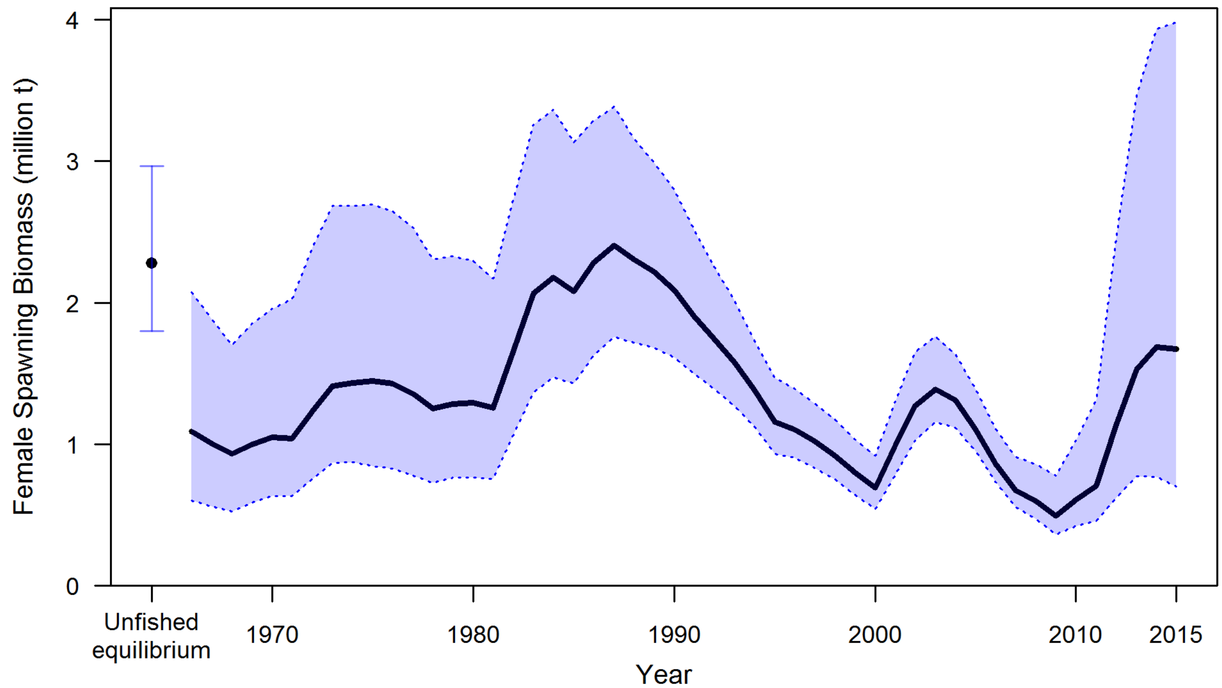

Figure c. Median of the posterior distribution for female spawning biomass through 2013 (solid line) with 95% posterior credibility intervals (shaded area).

Table b. Recent trends in estimated Pacific Hake female spawning biomass (thousand t) and relative spawning biomass level relative to estimated unfished equilibrium.

	Spawning biomass (thousand t)			Relative spawning biomass (B_t/B_0)		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2006	735.7	866.6	1,098.7	30.5%	38.3%	48.8%
2007	561.1	680.5	902.0	23.7%	30.2%	39.5%
2008	478.4	602.0	858.2	20.5%	26.7%	36.3%
2009	370.2	496.8	772.1	16.4%	22.0%	31.6%
2010	426.9	609.8	1,005.8	19.0%	26.8%	41.8%
2011	466.3	712.9	1,251.6	20.5%	31.4%	51.3%
2012	638.3	1,161.9	2,221.2	29.3%	50.7%	91.3%
2013	800.9	1,549.2	3,068.4	36.5%	68.9%	129.8%
2014	794.4	1,703.3	3,466.1	36.6%	75.2%	145.6%
2015	749.6	1,663.0	3,550.6	34.3%	73.6%	149.8%

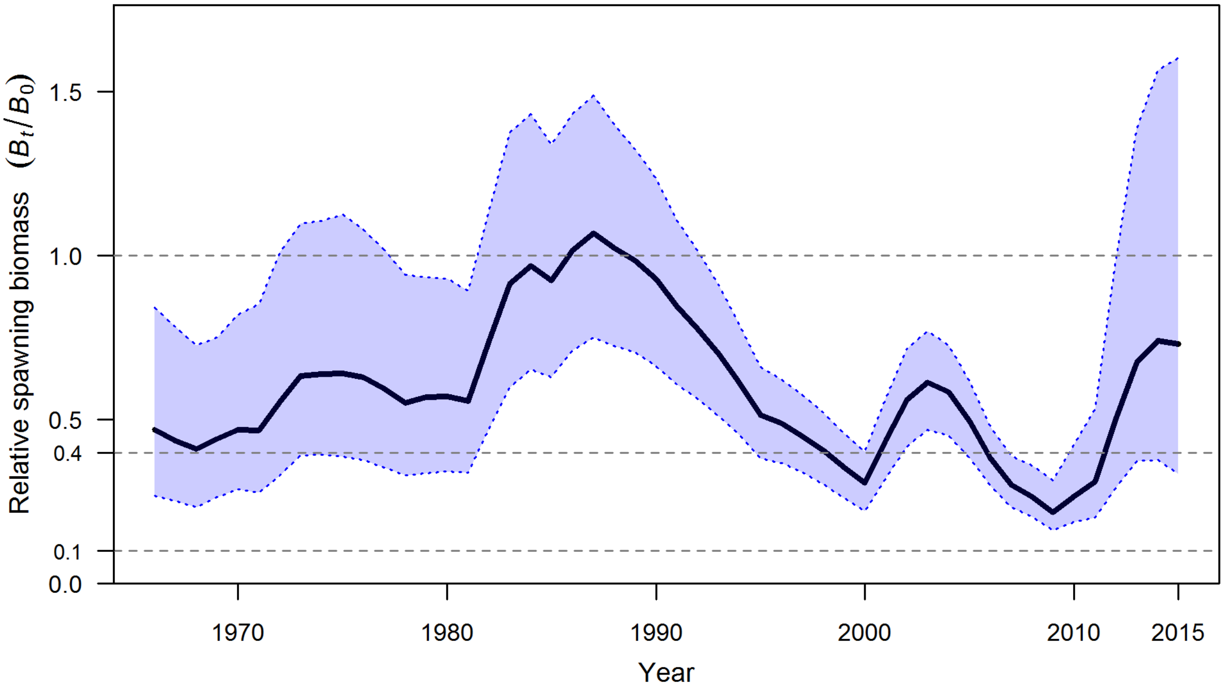

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2015 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

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. 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 comprising 70% of the coast-wide commercial catch in 2013 and 64% of the 2014 catch. Its size 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. There is little or no information in the data to estimate the sizes of the 2014 and 2015 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.

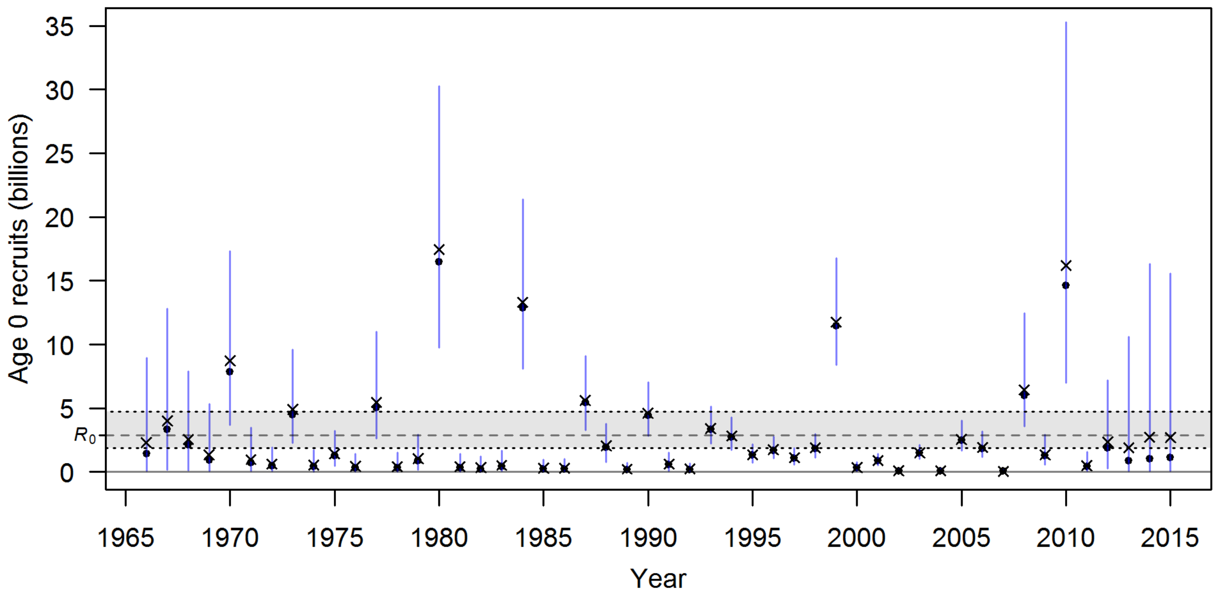

Figure e. Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with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

Table c. Estimates of recent Pacific Hake 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) 2.5th percentile	Absolute recruitment (millions) Median	Absolute recruitment (millions) 97.5th percentile	Recruitment deviation 2.5th percentile	Recruitment deviation Median	Recruitment deviation 97.5th percentile
2005	1,715.5	2,465.3	3,950.7	0.5830	0.8850	1.2085
2006	1,173.4	1,852.6	3,249.5	0.2768	0.6312	1.0182
2007	8.4	48.2	168.5	-4.6515	-2.9765	-1.8000
2008	3,696.0	5,987.2	11,245.9	1.4758	1.8774	2.3222
2009	575.5	1,289.5	2,926.6	-0.3111	0.3571	0.9655
2010	7,1816	14,799.4	31,733.8	2.1916	2.7669	3.3551
2011	85.4	447.3	1,533.2	-2.3368	-0.7656	0.3604
2012	311.4	1,818.1	7,954.9	-1.1171	0.5594	1.9011
2013	52.5	833.3	9,911.5	-2.9862	-0.2248	2.1849
2014	67.0	1,062.1	19,282.9	-2.7434	0.0411	2.7690

Exploitation status

Median fishing intensity on the stock is estimated to have been consistently below the $F_{40\%}$ target with the exception of the periods in the late 1990s and late 2000s when the spawning biomass was the lowest. In retrospect, the target was exceeded slightly in 2008 and 2010. Exploitation fraction (catch divided by biomass of ages 3 and above) has shown relatively similar patterns. Fishing intensity is estimated to have declined from 100.3% in 2010 to 61.6% in 2014 while exploitation fraction has decreased from about 0.25 in the late 2000s to less than 0.10 in 2013 and 2014. The uncertainty around these estimates is largest in the most recent years due to uncertainty in recruitment and spawning biomass.

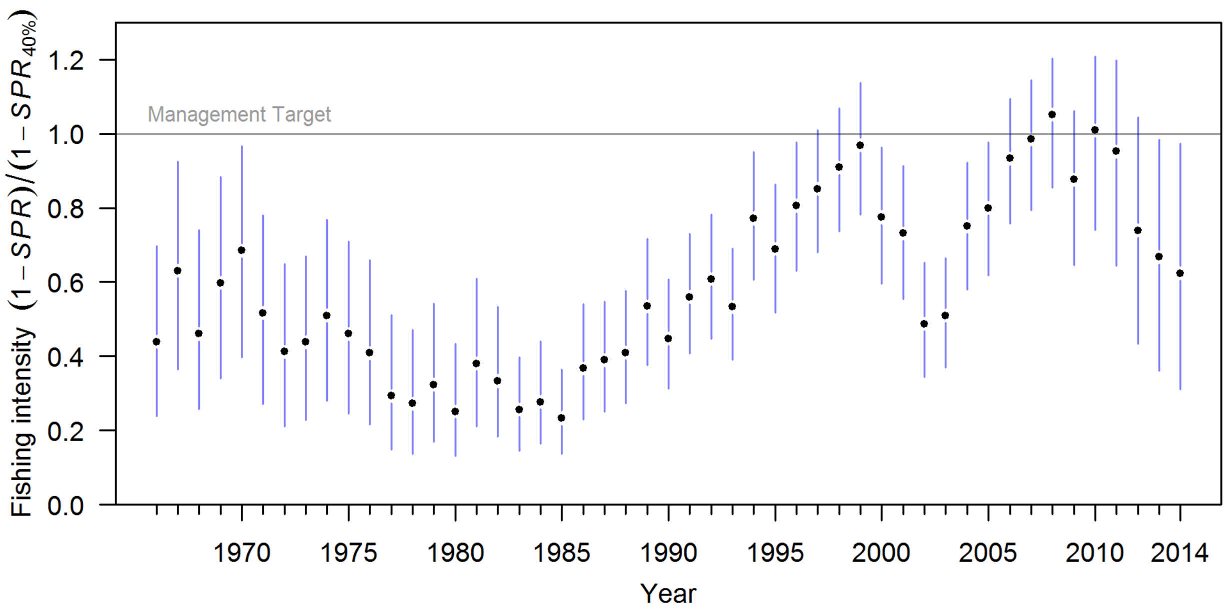

Figure f. Trend in median fishing intensity (relative to the SPR management target) through 2014 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

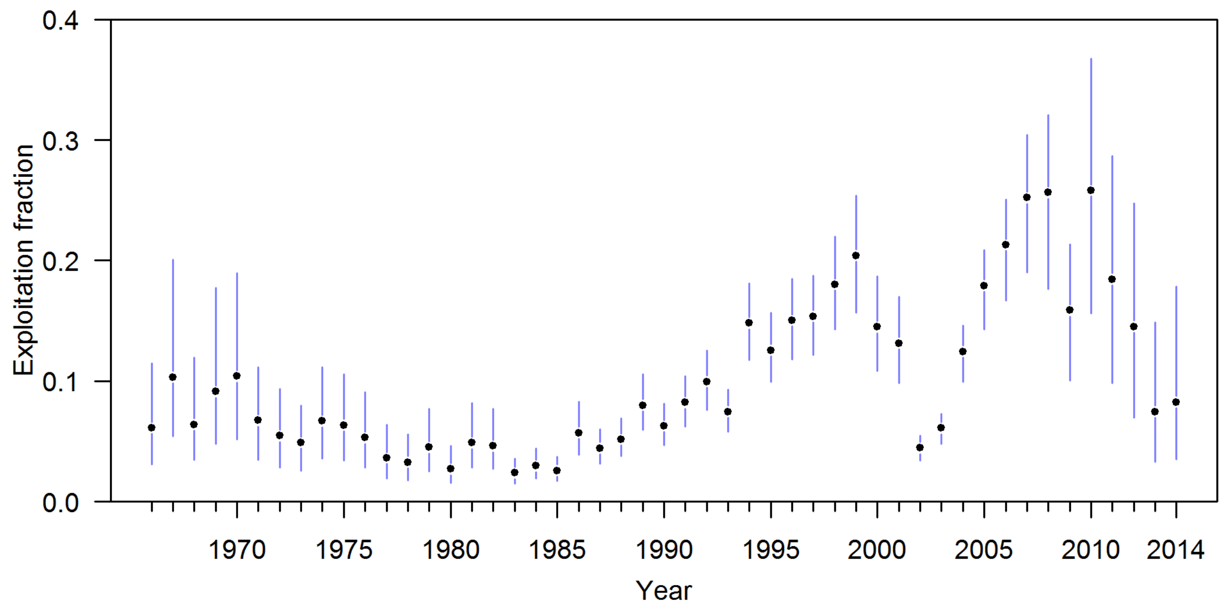

Figure g. Trend in median exploitation fraction through 2014 with 95% posterior credibility intervals.

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

	Fishing intensity			Exploitation fraction		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2005	0.6242	0.8008	0.9603	0.142	0.1778	0.2070
2006	0.7509	0.9275	1.0918	0.1661	0.212	0.2488
2007	0.7921	0.9813	1.139	0.1898	0.2507	0.3005
2008	0.8581	1.0453	1.1994	0.1799	0.2562	0.3198
2009	0.6433	0.8712	1.0511	0.1022	0.1573	0.2105
2010	0.7311	1.0026	1.1974	0.1589	0.2569	0.3623
2011	0.6609	0.9489	1.1791	0.1042	0.1839	0.2774
2012	0.4506	0.7399	1.0120	0.0752	0.1432	0.2466
2013	0.3797	0.6600	0.9736	0.0369	0.0743	0.1430
2014	0.3422	0.6158	0.9422	0.0391	0.0815	0.1724

Management performance

Over the last decade, the average coast-wide utilization rate (i.e., utilization = landings/quota) has been 86%. From 2010 to 2014, the mean utilization rates differed between the United States (85%) and Canada (60%). Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

Exploitation history in terms of joint biomass and *F*-target reference points shows that before 2007, median fishing intensity was below target and female spawning biomass was near or above target (Figure h). Between 2007 and 2011, however, fishing intensity ranged from 87% to 105% and relative spawning biomass between 0.22 and 0.31. Biomass has risen recently with the 2008 and 2010 recruitments and correspondingly, fishing intensity has fallen below targets, and relative spawning biomass above targets for 2012 through 2014. While uncertainty in the 2014 fishing intensity estimates and relative spawning biomass is large, the model predicts a 1.4% joint probability of being both above the target fishing intensity in 2014 and below 40% relative spawning biomass at the start of 2015.

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

Year	Total Landings (t)	Coast-wide (US+Canada) catch target (t)	Proportion of catch target removed
2005	363,135	364,197	99.7%
2006	361,699	364,842	99.1%
2007	291,054	328,358	88.6%
2008	322,144	364,842	88.3%
2009	177,209	184,000	96.3%
2010	227,054	262,500	86.5%
2011	286,892	393,751	72.9%
2012	207,057	251,809	82.2%
2013	287,677	365,112	78.8%
2014	301,573	428,000	70.5%

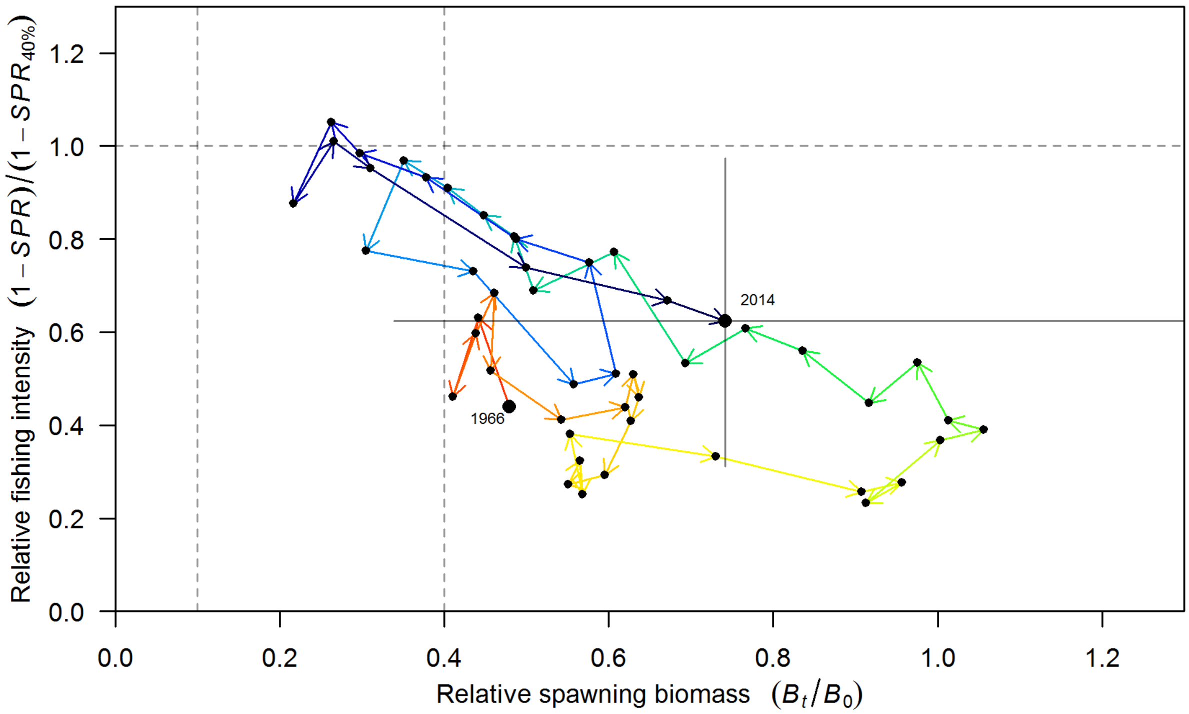

Figure h. Estimated historical path followed by fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years. Gray bars span the 95% credibility intervals for 2014 fishing intensity (vertical) and relative spawning biomass (horizontal).

Reference points

We report estimates of the 2015 base model reference points with posterior credibility intervals in Table f. The estimates are slightly different than the estimates in the 2014 assessment with slightly greater yields and 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 1966-2013 averages for mean size at age and selectivity at age.

Quantity	2.5^{th} percentile	Median	97.5^{th} percentile
Unfished female *B* (B_0, thousand t)	1,828	2,269	2,897
Unfished recruitment (R_0, millions)	1,932	2,923	4,812
Reference points (equilibrium) based on $F_{40\%}$			
Female spawning biomass ($B_{F40\%}$ thousand t)	613	814	1,025
$SPR_{MSY\text{-}proxy}$	–	40%	–
Exploitation fraction corresponding to SPR	18.5%	21.6%	25.6%
Yield at $B_{F40\%}$ (thousand t)	270	362	513
Reference points (equilibrium) based on $B_{40\%}$			
Female spawning biomass ($B_{40\%}$ thousand t)	731	907	1,159
$SPR_{B40\%}$	40.7%	43.4%	50.5%
Exploitation fraction resulting in $B_{40\%}$	14.4%	18.9%	23.2%
Yield at $B_{40\%}$ (thousand t)	264	352	503
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY} thousand t)	357	561	895
SPR_{MSY}	18.5%	29.0%	44.7%
Exploitation fraction corresponding to SPR_{MSY}	17.6%	33.3%	59.6%
MSY (thousand t)	277	384	563

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. Uncertainty in the best method for calculating acoustic survey biomass is a particular focus and results from a model fit to an alternative set of survey biomass values are presented in the decision tables alongside the base model results.

The Pacific Hake stock displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid biomass changes. This volatility adds to the uncertainty in estimates of current stock status and stock projections because of the dynamic fishery, which potentially targets strong cohorts resulting in time-varying fishery selectivity and limited data to estimate incoming recruitment in a timely manner (i.e., until the cohort is age 2 or greater).

The JTC was active doing MSE in 2014-15. We divided MSE research activities into short and long term projects. The short term plan was to evaluate the system performance with and without an age-1 index. The design of the age-1 index simulations is described below and simulations will be completed soon. The age-1 index simulations and our efforts to elicit feedback on management objectives from the JMC and MSE Steering Group for the purposes of operating model development are described in Appendix A below.

Developing alternative operating dynamics complicates analyses greatly. For example last year's closed-loop simulations only examined a single implementation of time-varying selectivity: there are many possible hypotheses about how this process is best modelled and statistical methods with which to estimate parameters describing these dynamics. How to determine estimation and simulation methods for time-varying selectivity is only a small subset of choices that are possible for modeling Pacific Hake; other hypotheses that might change our perception of stock status (spatial dynamics, time-varying changes in life-history parameters) will also involve complicated and difficult analyses. Decisions about what operating models to pursue with MSE will have to be made carefully. Furthermore, the JTC would like to continue the involvement of the JMC, SRG, and AP to further refine management objectives, as well as, determine scenarios of interest, management actions to investigate, and hypotheses to simulate.

Forecast decision table

The median catch for 2015 based on the default harvest policy ($F_{40\%}$ – 40:10) is 804,576 t, but has a wide range of uncertainty; the 95% posterior credibility interval ranges from 307,435 t to1,920,296 t.

A decision table showing predicted population status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base model. The decision table (split into Table g.1 and Table g.2) is organized such that the projected outcomes for each potential catch level (rows) can be evaluated across the quantiles (columns) of the posterior distribution. The first table (Table g.1) shows projected relative spawning biomass outcomes, and the second (Table g.2) shows projected fishing intensity outcomes relative to the target fishing intensity (based on SPR; see table legend). Fishing intensity exceeding 100% indicates fishing in excess of the $F_{40\%}$ default harvest rate catch limit. The default harvest rate catch limit results in a median fishing intensity above 100% in 2015, 2016, and 2017 because the $F_{40\%}$ default harvest rate catch limit is calculated using baseline selectivity from all years and the forecasted catches are removed using selectivity averaged over the last 5 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.

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 2016 and 2017 (Tables g.3 & g.4 and Figures j & 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 2017 for several of these management actions. With zero catch for the next two years, the median biomass is predicted to remain stable from 2016 to 2017, with a 39% probability of decreasing from 2015 to 2016 and a 51% probability of decreasing from 2016 to 2017.

At all catch levels 180,000 t per year or greater, the spawning biomass is predicted to decline from 2015 to 2016 with greater than 68% probability (Table g.3 and Figure j). The model predicts high biomass levels and the predicted probability of dropping below 10% in 2016 is less than 1% and the maximum probability of dropping below B40% is 21% for all catches explored. It should be noted that in addition to the natural mortality rate overtaking the growth rate for the 2010 year class, the model estimated below average recruitment for the 2011 and 2013 cohorts entering the 2016 spawning biomass, which also contributes to the relatively low catch that will result in a reduction in spawning biomass from 2015 to 2016. The probability that the 2017 spawning biomass will be less than the 2016 spawning biomass is greater than 50% for any catch level (including zero catch).

Table g.1. Forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Quantiles from the base model are shown in the center of the table with median (50% quantile) in bold. "Alt. Survey" values on the right side are median values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e, g), the TAC from 2014 (row f), the catch level that results in a 50% probability that the median projected catch will remain the same in 2015 (row h), the catch values that result in a median SPR ratio of 1.0 (row i), and the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base (row j). Catch in 2017 is not given because it does not impact the beginning of the year biomass in 2017.

Within model quantile			5%	25%	**50%**	75%	95%		**50%**
Management Action			Beginning of year relative spawning biomass						**Alt. Survey**
	Year	Catch (t)							
a: No catch	2015	0	40%	58%	**74%**	93%	132%		**60%**
	2016	0	42%	61%	**77%**	97%	138%		**62%**
	2017		44%	62%	**78%**	100%	147%		**64%**
b:	2015	180,000	40%	58%	**74%**	93%	132%		**60%**
	2016	180,000	37%	57%	**74%**	94%	134%		**58%**
	2017		36%	55%	**70%**	92%	139%		**56%**
c:	2015	300,000	40%	58%	**74%**	93%	132%		**60%**
	2016	300,000	35%	54%	**71%**	91%	132%		**56%**
	2017		31%	50%	**65%**	87%	134%		**51%**
d:	2015	350,000	40%	58%	**74%**	93%	132%		**60%**
	2016	350,000	33%	53%	**70%**	90%	130%		**55%**
	2017		29%	48%	**63%**	85%	133%		**49%**
e:	2015	400,000	40%	58%	**74%**	93%	132%		**60%**
	2016	400,000	32%	52%	**69%**	89%	130%		**53%**
	2017		26%	46%	**61%**	83%	130%		**47%**
f: 2014 TAC	2015	428,000	40%	58%	**74%**	93%	132%		**60%**
	2016	428,000	32%	51%	**68%**	88%	129%		**53%**
	2017		25%	45%	**60%**	82%	129%		**46%**
g:	2015	500,000	40%	58%	**74%**	93%	132%		**60%**
	2016	500,000	30%	50%	**66%**	86%	128%		**51%**
	2017		22%	42%	**57%**	79%	126%		**43%**
h: highest	2015	710,000	40%	58%	**74%**	93%	132%		**60%**
C2015=	2016	710,000	26%	45%	**62%**	82%	123%		**46%**
C2016	2017		13%	33%	**48%**	70%	117%		**34%**
i: fishing	2015	730,000	40%	58%	**74%**	93%	132%		**60%**
intensity	2016	650,000	25%	45%	**61%**	81%	122%		**46%**
=100%	2017		14%	34%	**49%**	72%	118%		**35%**
j: default	2015	804,576	40%	58%	**74%**	93%	132%		**60%**
harvest	2016	682,782	24%	43%	**60%**	79%	120%		**44%**
rule	2017		12%	32%	**47%**	69%	116%		**32%**

Table g.2. Forecast quantiles of Pacific Hake fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2015-2017 catch alternatives presented in Table g.1 Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy calculated using baseline selectivity. "Alt. Survey" values on the right side are median values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document.

Within model quantile			5%	25%	**50%**	75%	95%		**50%**
Management Action			Fishing Intensity						**Alt. Survey**
	Year	Catch (t)							
a:	2015	0	0%	0%	**0%**	0%	0%		**0%**
No catch	2016	0	0%	0%	**0%**	0%	0%		**0%**
	2017	0	0%	0%	**0%**	0%	0%		**0%**
	2015	180,000	24%	35%	**43%**	53%	71%		**51%**
b:	2016	180,000	23%	33%	**41%**	51%	70%		**49%**
	2017	180,000	23%	33%	**42%**	53%	72%		**51%**
	2015	300,000	37%	51%	**62%**	74%	93%		**72%**
c:	2016	300,000	35%	49%	**61%**	74%	96%		**72%**
	2017	300,000	36%	51%	**64%**	78%	102%		**76%**
	2015	350,000	42%	57%	**69%**	81%	100%		**79%**
d:	2016	350,000	40%	55%	**68%**	81%	104%		**79%**
	2017	350,000	41%	58%	**72%**	87%	112%		**84%**
	2015	400,000	46%	62%	**74%**	87%	105%		**84%**
e:	2016	400,000	44%	61%	**74%**	88%	111%		**86%**
	2017	400,000	46%	64%	**79%**	95%	120%		**92%**
	2015	428,000	49%	65%	**77%**	90%	108%		**87%**
f: 2014 TAC	2016	428,000	47%	64%	**78%**	91%	115%		**89%**
	2017	428,000	49%	68%	**83%**	99%	123%		**96%**
	2015	500,000	54%	71%	**84%**	96%	114%		**94%**
g:	2016	500,000	53%	71%	**86%**	99%	122%		**97%**
	2017	500,000	55%	76%	**92%**	108%	132%		**106%**
h: highest	2015	710,000	68%	87%	**99%**	111%	127%		**109%**
C2015=	2016	710,000	68%	89%	**104%**	117%	137%		**115%**
C2016	2017	710,000	72%	96%	**113%**	129%	141%		**127%**
i: fishing	2015	730,000	69%	88%	**100%**	112%	128%		**110%**
intensity	2016	650,000	65%	85%	**100%**	114%	136%		**113%**
=100%	2017	520,000	60%	82%	**100%**	118%	139%		**121%**
j: default	2015	804,576	73%	92%	**104%**	115%	131%		**114%**
harvest	2016	682,782	67%	88%	**104%**	118%	138%		**116%**
rule	2017	547,280	62%	86%	**104%**	122%	140%		**120%**

Table g.3. Probabilities of related to spawning biomass, fishing intensity, and 2016 catch limits for alternative 2015 catch options (catch options explained in Table g.1). “Alternative survey” values in the lower section are values from a model fit to an alternative set of acoustic survey biomass values as described in the “Sensitivity analyses” section of the document.

Catch in 2015	Probability B2016<B2015	Probability B2016<B40%	Probability B2016<B25%	Probability B2016<B10%	Probability Fishing intensity in 2015 > 40% Target	Probability 2016 Catch Target < 2015 Catch
a: 0	39%	4%	0%	0%	0%	0%
b: 180,000	68%	6%	1%	0%	0%	1%
c: 300,000	80%	8%	1%	0%	3%	4%
d: 350,000	83%	9%	2%	0%	5%	6%
e: 400,000	85%	9%	2%	0%	8%	9%
f: 428,000	86%	10%	2%	0%	10%	11%
g: 500,000	89%	12%	3%	0%	18%	20%
h: 710,000	94%	18%	5%	1%	47%	50%
i: 730,000	94%	19%	5%	1%	50%	53%
j: 804,576	95%	21%	6%	1%	58%	62%
Alternative survey indices in 2012 and 2013						
a: 0	33%	12%	1%	0%	0%	0%
b: 180,000	71%	19%	3%	0%	1%	2%
c: 300,000	83%	23%	5%	0%	8%	11%
d: 350,000	85%	24%	6%	0%	15%	17%
e: 400,000	87%	26%	6%	0%	24%	26%
f: 428,000	88%	28%	7%	0%	28%	29%
g: 500,000	90%	31%	8%	0%	39%	41%
h: 710,000	95%	41%	14%	2%	67%	68%
i: 730,000	95%	41%	15%	2%	70%	71%
j: 804,576	96%	43%	18%	2%	76%	77%

Table g.4. Probabilities of related to spawning biomass, fishing intensity, and 2017 catch limits for alternative 2016 catch options conditioned on specific catches in 2014 (catch options explained in Table g.1). "Alternative survey" values in the lower section are values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document.

Catch in 2016	Probability B2017<B2016	Probability B2017<B40%	Probability B2017<B25%	Probability B2017<B10%	Probability Fishing intensity in 2016 > 40% Target	Probability 2017 Catch Target < 2016 Catch
a: 0	51%	4%	0%	0%	0%	0%
b: 180,000	71%	8%	1%	0%	0%	1%
c: 300,000	78%	13%	3%	0%	4%	5%
d: 350,000	81%	15%	4%	0%	6%	10%
e: 400,000	83%	18%	5%	1%	11%	16%
f: 428,000	84%	19%	5%	1%	14%	19%
g: 500,000	86%	23%	7%	1%	24%	32%
h: 710,000	91%	38%	16%	3%	57%	64%
i: 650,000	90%	36%	15%	3%	51%	58%
j: 682,782	90%	40%	17%	4%	57%	63%
Alternative survey indices in 2012 and 2013						
a: 0	48%	9%	1%	0%	0%	0%
b: 180,000	72%	21%	4%	0%	1%	3%
c: 300,000	79%	31%	8%	1%	11%	18%
d: 350,000	82%	35%	10%	1%	20%	26%
e: 400,000	83%	39%	13%	2%	29%	34%
f: 428,000	84%	41%	15%	2%	33%	40%
g: 500,000	87%	46%	20%	3%	45%	53%
h: 710,000	89%	59%	36%	11%	74%	79%
i: 650,000	88%	58%	34%	9%	69%	75%
j: 682,782	89%	60%	39%	12%	73%	78%

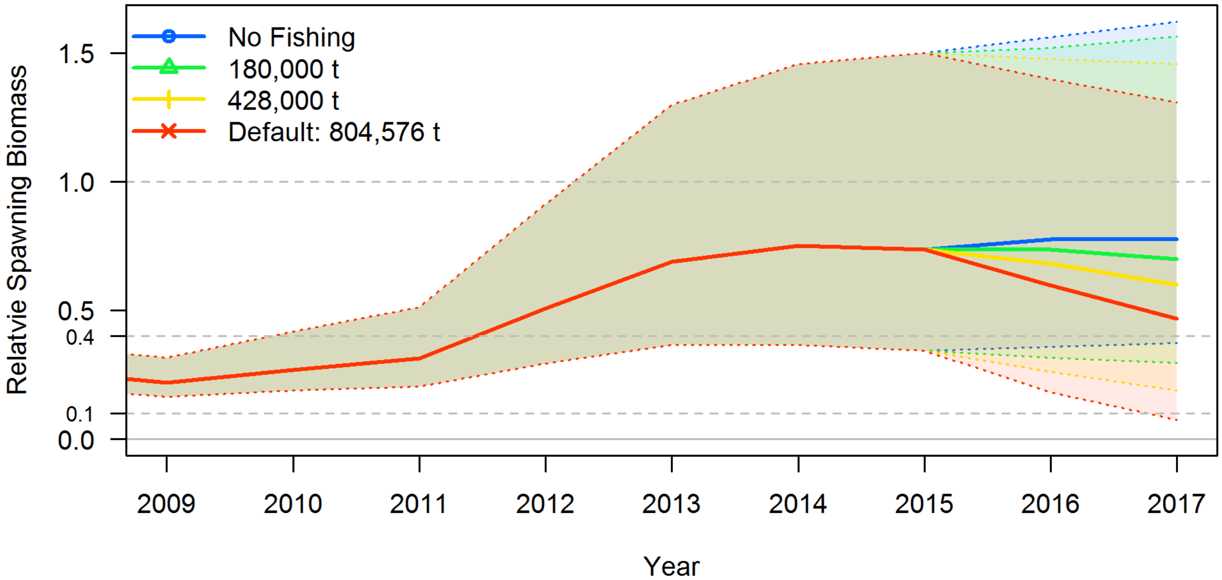

Figure i: Time-series of estimated relative spawning biomass to 2015 from the base model, and forecast trajectories to 2017 for several management options from the decision table, with 95% posterior credibility intervals. The 2015 catch of 804,576 t was calculated using the default harvest policy, as defined in the Agreement.

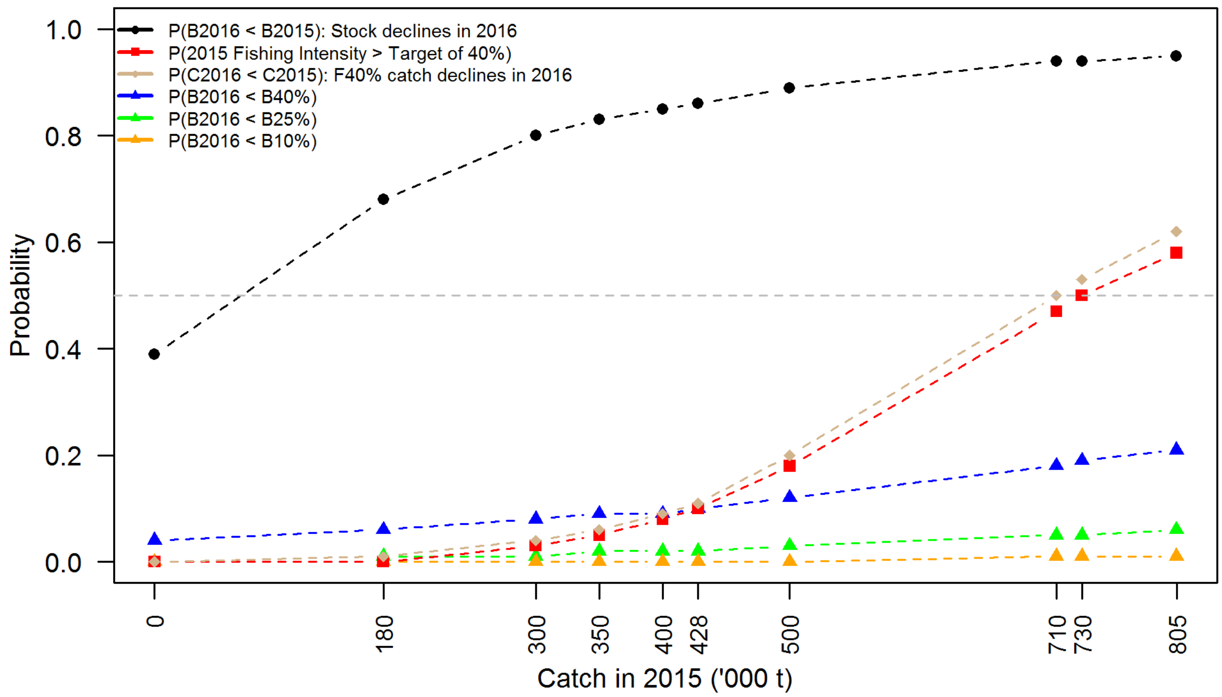

Figure j: Graphical representation of the base model results presented in the upper portion of Table g.3 for catch in 2015. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

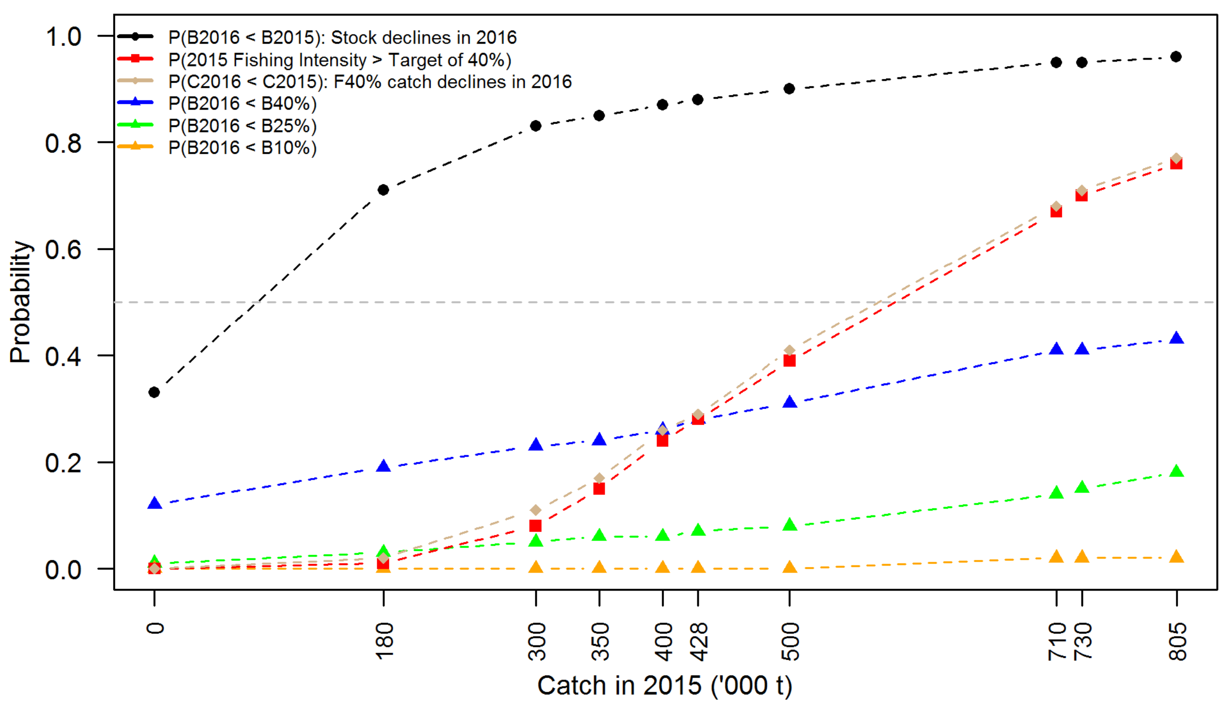

Figure k: Graphical representation of the alternative survey model results presented in the lower portion of Table g.3 for catch in 2015. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

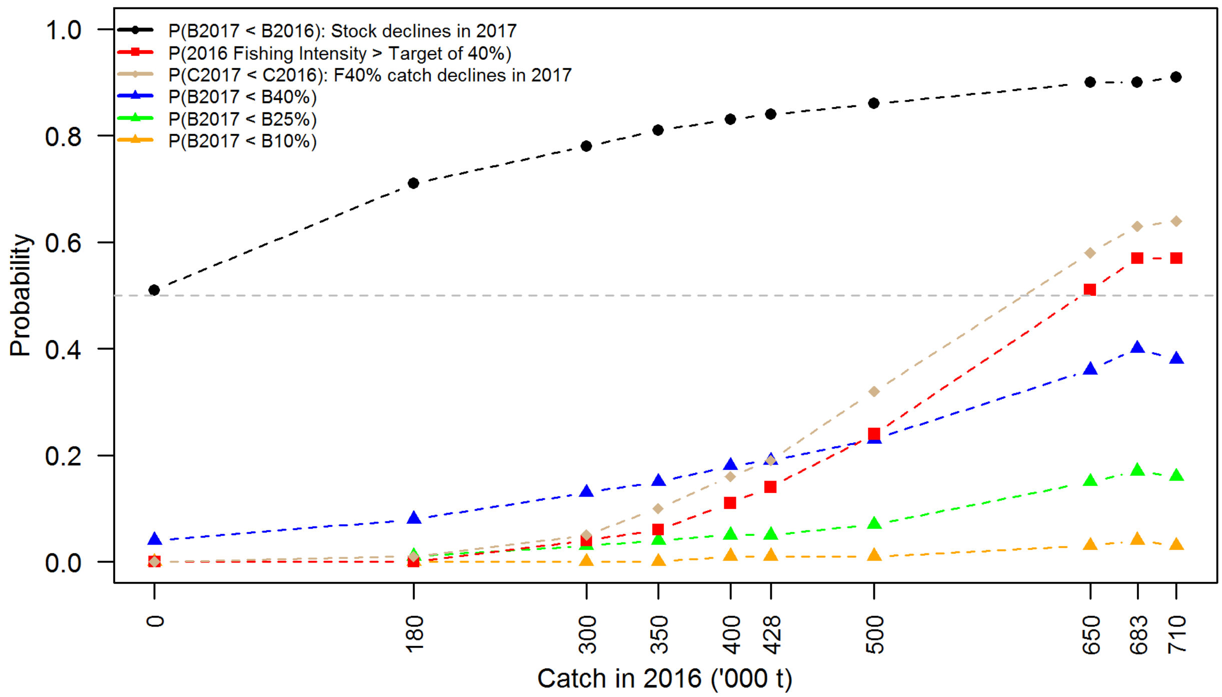

Figure l: Graphical representation of the base model results presented in the upper portion of Table g.4 for catch in 2016. The symbols indicate points that were computed directly from model output and lines interpolate between the points. These catches are conditional on the catch in 2015, and 2015 catch levels corresponding to the 2016 catches of 650 and 683 thousand t were higher (see Table g.1).

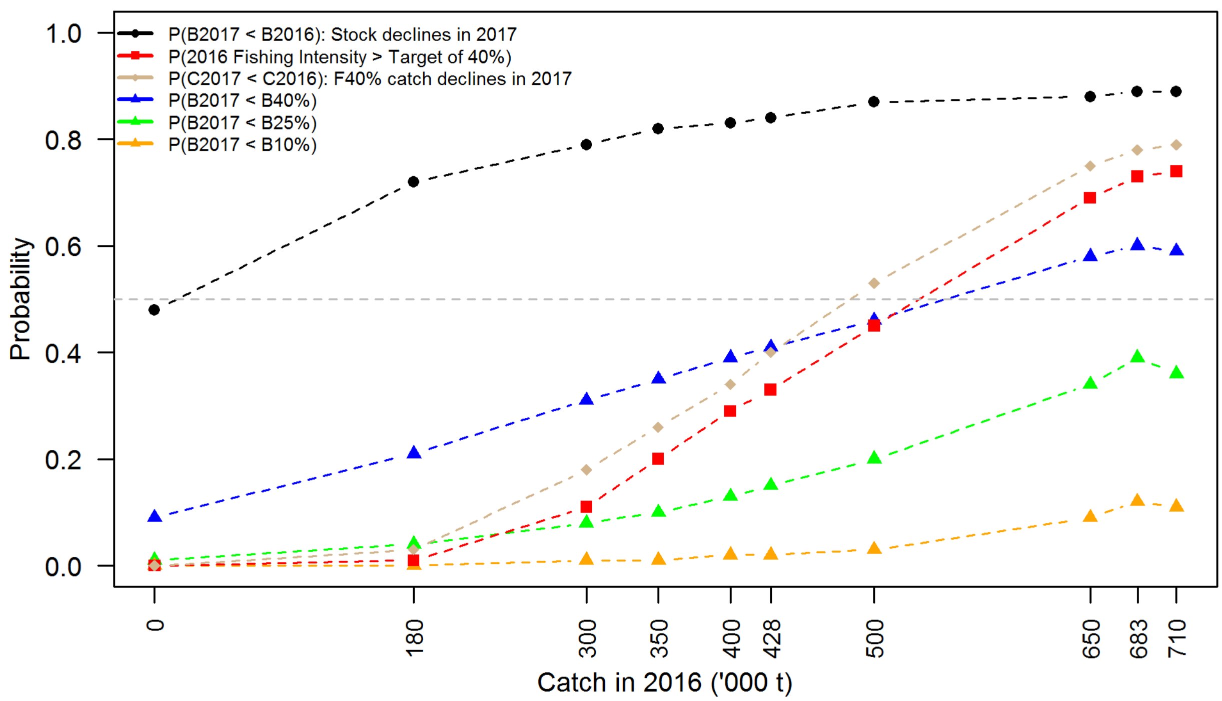

Figure m: Graphical representation of the alternative survey model results presented in the lower portion of Table g.4 for catch in 2016. The symbols indicate points that were computed directly from model output and lines interpolate between the points. These catches are conditional on the catch in 2015, and 2015 catch levels corresponding to the 2016 catches of 650 and 683 thousand t were higher (see Table g.1).

Research and data needs

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

1. Continue development of the management strategy evaluation (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 Panel 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 to best to model these dynamics to capture seasonal effects and potential climate forcing influences in the simulations.

2. 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.

3. Continue to explore and develop statistical methods to parameterize time-varying fishery selectivity in assessment and forecasting.

4. 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. Having ages read for the 2014 trawl samples
    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

5. Investigate links between hake spatial distribution and dynamics with ocean conditions and ecosystem variables such as temperature and prey availability. These investigations have the potential to improve the scenarios considered in future MSE work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.

6. 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.

7. Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific Hake. This would include completing ongoing MSE analyses to investigate whether an age-1 index could reduce stock assessment and management uncertainty enough to improve overall management performance.

8. 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.

9. 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.

10. 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.

11. 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).

12. 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.

13. Continue to coordinate our MSE research with other scientists in the region engaging in similar research.

14. Continue to investigate alternative ways to model and forecast recruitment. Use MSE simulations to investigate the impact of making incorrect assumptions about the underlying recruitment process.

15. 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.

16. 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.

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. This is the fourth annual stock assessment conducted under the treaty process. Under the Agreement, Pacific Hake or 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 are 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. Both sources show a very strong 2010 cohort dominating the age compositions in recent years. 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 2015 base model are effectively the same as the 2014 base model. These models differ from the 2013 base model primarily through the addition of time-varying selectivity in the fishery.

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 body size and seasonal migratory behavior.

The coastal stock of Pacific Hake typically ranges from the waters off southern California to northern British Columbia and in some years to 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 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), 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 (JTC 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 (JTC 2013). Recent research has developed an index of abundance for Humboldt Squid and suggested links between squid and hake abundance (Stewart et al., 2014). This document includes a sensitivity analysis where hake mortality was linked to the Humboldt Squid index (Section 3.5 below) 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 U.S. 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 Subcommittee of the Canada-U.S. Groundfish Committee (TSC), and there were informal agreements on the adoption of annual fishing policies. During the 1990s, however, disagreements between the U.S. and Canada on the allotment of the catch limits between U.S. and Canadian fisheries led to quota overruns; 1991-1992 national quotas summed to 128% of the coast-wide limit, while the 1993-1999 combined quotas were 107% of the limit, on average. The Agreement between the United States 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 $F_{SPR=40\%}$ 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 $F_{SPR=40\%}$ target and in retrospect, may have exceeded the target as estimated from this assessment. Overall, management appears to be effective at maintaining a sustainable stock size, in spite of uncertain stock assessments. 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 Canada

Canadian groundfish managers distribute their portion (26.12%) of the Total Allowable Catch (TAC) as quota to individual license holders. In 2014, the Canadian Hake was allocated a TAC of 98,621 t plus 13,172t of uncaught carryover fish from 2013. 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 2014, 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.

1.3.2 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 1 south of 42° N. latitude, but only 5% of the shore-based allocation is released prior to the opening of the main shore-based fishery (June 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 PFMC, 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 cooperative where bycatch allocations are pooled and shared among the vessels. The individual cooperatives have internal systems of in-season monitoring and spatial closures to avoid and reduce bycatch of salmon and rockfish. The shore-based fishery is managed with Individual Fishing Quotas (IFQ).

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 above 200,000 t prior to 1986, and have been mostly above that level since.

A more detailed description of the history of the fishery is provided in the 2013 Pacific Hake stock assessment (JTC 2013).

1.4.1 Overview of the fisheries in 2014

The Joint Management Committee (JMC) determined an adjusted coast-wide catch target of 428,000 t for 2014, with a U.S. allocation of 316,206 t (73.88%) and a Canadian allocation of 111,794 t (26.12%). A review of the 2014 fishery is given below.

1.4.1.1 Canada

The 2014 Canadian Pacific Hake domestic fishery removed 37,437 t from Canadian waters, or 33.5% of the allowable Canadian TAC of 111,794 t.[1] The shoreside component, made up of vessels landing fresh round product onshore, landed 16,056 t. The freezer trawler component, made up of four vessels which freezes headed and gutted product while at sea, landed 21,381 t. This was the first year in which the freezer trawler component of the Canadian fleet landed more Hake than the shoreside component.

The fishery started optimistically in third week of May with a good showing of large fish off lower West Coast of Vancouver Island (WCVI). Catches dropped off significantly by early June, and the lack of fish continued for the remainder of the season. The Canadian shoreside fleet operations ended earlier than usual, in early October. Stakeholders reported that there was a scarcity of hake throughout the season, as has been the case for the past number of years. This scarcity of hake was the main factor in Canadian fleet being unable to fully prosecute the fishery and catch the available Canadian allocation. The freezer trawlers had greater catches than the shoreside vessels due to their higher horsepower and larger nets, which provided them the ability to target non-typical less-aggregated acoustic targets.

Contributing to the failure of the Canadian fishery was the loss of the primary head and gutted (H&G) market for Canadian hake caused by the Russian Federation imposing a ban on fish imports as of early August 2014. The loss of this market forced all hake producers to seek new sales opportunities, which focused primarily in China/Asia. This new market was quickly saturated with product and lead to reduced prices and margins for the industry. This uncertainty in markets coupled with scarcity of fish on the grounds, forced some processors to alter operational plans. In late August to early September, the Shoreside fleet shifted fishing/processing effort away from a marginal hake fishery to focus on Sockeye Salmon in anticipation of a large fishery. The availability of fish in Canadian waters and market conditions both contributed to lower Hake catches and Canadian utilization of only 33.5% of the available quota.

The most abundant year classes in the Canadian catch were age 6 at 23.7%, age 4 at 15.3%, age 8 at 15.2%, age 5 at 12.6%, and age 7 at 9.0%. The large 1999 cohort, now age 15, accounted for 7.7% of the catch in Canada. The distribution of catch by month remained similar to other years, with the summer months showing the greatest catch. The fishery's spatial distribution changed significantly in 2008, with many vessels taking more of their catch than usual from Queen Charlotte Sound (Area 5A/5B). Since 2012, there has been a marked reversal of that trend, and a regrowth of the fishery off the WCVI, which is the traditional area in which the Hake fishery operates. All of the 2014 Canadian catch/effort occurred in waters off the WCVI. In addition, fishermen reported a change in the spatial distribution of the fish than traditionally occurred off the WCVI. Hake were not found in high concentrations on the continental shelf but rather in smaller pockets in canyons and off the shelf break.

For an overview of catch by year and fleet, see Table 1. For 2002, 2003, 2009, 2012, 2013, and 2014 there was no Joint-Venture fishery operating in Canada and this is reflected as zero catch in that sector for those years in Table 1.

[1] During the review meeting, it was discovered that the Canadian catch used in this assessment possibly included some catch from the Strait of Georgia, which is believed to be a separate stock. The largest amount of this extra catch was 2,653 t in 2014, representing about 7% of the catch in Canada for that year. Removing that 2014 catch from the model resulted in a 1% increase in the estimated 2015 spawning biomass. The algorithms for estimating catch have been revised to avoid this error in future assessments.

1.4.1.2 United States

The U.S. adjusted allocation (i.e. adjusted for carryovers) of 316,206 t was further divided to research, tribal, catcher-processor, mothership, and shore-based sectors. After the tribal allocation of 17.5% (55,336 t), and a 1,500 t allocation for research catch and bycatch in non-groundfish fisheries, the 2014 non-tribal U.S. catch limit of 259,370 t was allocated to the catcher/processor (34%, 88,186 t), mothership (24%, 62,249 t), and shore-based (42%, 108,935 t) commercial sectors. Catch in the at-sea sectors was dominated by age-4 fish from the 2010 year class (>70% of the catch). While the catch from the shore-based sector had a higher proportion of age 6 fish from the 2008 year class, more than 60% of this sector's catch was from the 2010 year class. Tribal fisheries landed less than 1,000 t, and a total of 45,000 t of tribal hake quota was reapportioned to the non-tribal sectors on September 11 and October 23. The catcher-processor, mothership, and shore-based fleets caught 99.7%, 85.0%, and 77.2% of their reallocated quotas, respectively. Overall, 52,069 t (16.5%) of the total U.S. adjusted TAC was not caught.

The mothership sector started the season fishing in the north, but moved to waters off southern Oregon and Northern California after some high Pacific Ocean Perch bycatch events. Although the fleet encountered some older fish in the North, they fished predominantly on 4 year old fish in the South. Later in the season, high bycatch of darkblotched rockfish briefly halted fishing in the mothership sector. Coastwide catch of darkblotched rockfish was below target harvest levels, which provided industry and fishery managers the ability to transfer darkblotched rockfish quota to the mothership sector in order for them to continue utilizing their uncaught hake quota. Ultimately, the mothership fishery reopened, but with additional restrictions imposed on them intended to reduce salmon and rockfish bycatch. These restrictions also limited access for many of the harvesters to productive hake grounds. The 85.0% utilization of the mothership quota was a result of factors other than being able to catch fish (e.g., scheduled maintenance).

The catcher-processor fleet mainly fished in southern waters throughout the year and industry reported catching fish that weighed 470-540 grams (likely age 4 fish). It appeared that most of the fish was further south in fall 2014 than previous years and fishing effort was concentrated in the same general area, starting north of Hecate Bank working southward to below Coos Bay (Oregon). Fishing depth was reported to be along the edge of the continental shelf, mostly in the 200-280 fathom range; however, the CP fleet spent several days fishing well off the edge in waters 800 fathoms and deeper. The industry reported that weather and sea temperatures (in their area of operation) were fairly normal during the fall fishery.

Chinook salmon protected under the Endangered Species Act (ESA) occurs as bycatch in the whiting fishery, which operates under an Incidental Take Statement. The amount of salmon bycatch allowed under this Incidental Take Statement was exceeded in October, and consequently, an Ocean Salmon Conservation Zone (where whiting fishing was prohibited) was implemented shoreward of 100 fathoms. The at-sea sectors fished in water deeper than 150 fathoms, and in October and November, some catches occurred far offshore in water deeper than 1,000 fathoms (Figure 5).

2 Data

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

- Total catch from all U.S. and Canadian target fisheries (1966-2014).
- Age compositions composed of data from the U.S. fishery (1975-2014) and the Canadian fishery (1990-2014).
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011–2013).

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, 1975-2014.
- 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 (these data are discussed in more detail in the 2013 stock assessment document (JTC 2013)).

- 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, 1992).
- NWFSC/SWFSC/PWCC coast-wide juvenile hake and rockfish survey (2001–2009).
- Bycatch of Pacific Hake in the trawl fishery for pink shrimp off the coast of Oregon, 2004–2005, 2007–2008.
- 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, 2012, 2013, and 2014 NWFSC bottom trawl surveys, the 2012 and 2013 acoustic surveys, and the at-sea fishery in 2013 and 2014.

2.1 Fishery-dependent data

2.1.1 Total catch

The catch of Pacific Hake for 1966–2014 by nation and fishery sector is shown in Table 1 and Figure 4. 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 JTC 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 1991–2014 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 1991–2014. 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, 1991–2014, 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. In 2014, their catch exceeded that of the Shoreside vessels for the first time. 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. Sampled weight from which biological information is collected must be inferred from length-weight relationships. For electronically observed shoreside trips, port samplers obtain biological data from the landed catch. Observed domestic haul-level information is then aggregated to the trip level to be consistent with the unobserved trips that are sampled in ports. For the Canadian Joint-Venture fishery, an observer aboard the factory ship estimates the codend weight by measuring the diameter of the codend and doing a spherical volume calculation for each delivery from a companion catcher boat. Length samples are collected every second day of fishing operations, and otoliths are collected once a week. Length and age samples are taken randomly from a given codend. Since the weight of the sample from which biological information is taken is not recorded, sample weight must be inferred from a length-weight relationship applied to all lengths taken and summed over each haul.

The sampling unit for the shore-based fisheries is the trip, while the haul is the primary unit for the at-sea fisheries. Since detailed haul-level information is not recorded on trip landings documentation in the shore-based fishery, and hauls sampled in the at-sea fishery cannot be aggregated to a comparable trip level, there is no least common denominator for aggregating at-sea and shore-based fishery samples. As a result, 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 (JTC 2013, JTC 2014).

The aggregate fishery age-composition data (1975–2014) confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999, with a small proportion from the 1999 year class (15 years old in 2014) still present in the fishery (Figure 6). The more recent age-composition data consisted of high proportions of 2008 and 2010 year classes in the 2014 fishery (Figure 6). 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 they were overwhelmed by the strong 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. The estimated absolute size of incoming cohorts 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 length-at-age and weight-at-length 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 are clearly observed in length data from both of the U.S. fishery sectors.

2.1.3 Catch per unit effort

Calculation of a reliable fishery 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 (JTC 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 (JTC 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 1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012 and 2013 were used in this assessment (Table 6). The acoustic survey includes all waters off the coasts of the U.S. and Canada thought to contain all portions of the 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 places.

Distributions of hake backscatter plotted for each acoustic survey since 1995 illustrate the variable spatial patterns of age-2+ hake among years (Figure 2). 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, and 2012 the majority of the hake distribution was again found in U.S. waters, which is more likely due to age-composition than the environment. The 2013 survey found similar distribution of hake as in 2012, except that few aggregations of fish were found north of Vancouver Island. Older Pacific Hake tend to migrate farther north, but the distribution is variable among years.

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 (JTC 2013).

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 Pacific 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 biomass due to uncertainty in target strength is not explicitly accounted for.

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).

No survey was conducted in 2014 and the index of acoustic biomass in this assessment is unchanged from that used in the base model of the previous assessment (JTC, 2014). Estimated age-2+ biomass in the survey had increased steadily over the three surveys conducted in 2011–2013, with the 2013 survey biomass estimate at approximately 2.4 million metric tons, which is 1.8 times the 2012 survey biomass estimate and 4.6 times the 2011 acoustic survey biomass estimate (Figure 9). The 2013 survey age composition was made up of 76.2% age-3 fish from the 2010 year-class.

The acoustic survey biomass index include 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 (see JTC 2014 for maps of estimated biomass). The method of extrapolation has been the subject of some debate so alternative values have been proposed for consideration in a sensitivity analysis. The survey index could not be recalculated for all years in time for this assessment, so the changes were made only to the most recent two biomass estimates in 2012 and 2013. Therefore, the alternative values are a short-term approach to bracketing the uncertainty associated with the extrapolation rather than elements of a consistent time series. The index used in the base model has values of 1.381 and 2.423 million t for these years (Table 6). Alternative values chosen for consideration during the SRG meeting in February 2015 were 1.207 and 1.648 for these same years. The modified value for 2013 is lower than the unkriged survey biomass estimate of 1.840 million t, indicating that this value is likely a lower bound of plausible values.

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 has not been used in the stock assessment because more time is needed to develop and investigate the index, but preliminary estimates seem to track the estimated recruitment reasonably well (Figure 8). The JTC has also been using the simulation software developed for recent MSE work (JTC 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. That simulation work could not be completed in time for this document. The 2013 stock assessment provides a more detailed description of the age-1 index (JTC 2013).

2.2.2 Other fishery-independent data

Fishery-independent data from the Alaska Fisheries Science Center (AFSC) bottom trawl survey, the Northwest Fishery Science Center (NWFSC) bottom trawl survey, the NWFSC and Pacific Whiting Conservation Cooperative (PWCC) pre-recruit survey were not used in this assessment. More information on these data sources is given in the 2013 stock assessment (JTC 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, and 2014 U.S. bottom trawl surveys, during the 2012 and 2013 joint U.S/Canada Hake/Sardine acoustic surveys, and from At-Sea hake Observer Program (ASHOP) observers aboard at-sea fishing vessels in 2013 and 2014 (Table 7). 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 significant amount of work went into completing the determination of maturity for these samples, but unfortunately all of the tow specific data were not available at the time of this assessment for analysis.

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 was 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. Although not encountered, spent ovaries would also be defined as mature and would be characterized by the presence of large numbers of post ovulatory follicles (POFs), atresia, and typically small groups of immature oocytes. Fish that did not have yolk present but were large or older were not changed to a mature status because of these biological factors (Fig. 4). 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. Male hake spawning state may be useful to investigation to learn more about this.

Maturity-at-age and length observations show differences across years (Figure 9), but it has been difficult to determine if these difference are due to the source (bottom trawl, acoustic survey, or ASHOP) or the year. With the addition of 2014 data from the trawl survey, and looking at source/year specifics estimates of maturity, it is apparent that the trawl survey samples estimate a smaller size at maturity. Looking at samples by month for the trawl survey specifically (Figure 9, bottom right), there is a shift to smaller maturity-at-length from May to July and August to October. However, the trawl survey operates in two passes, with each pass moving from north to south. Therefore, this pattern by month could actually be a latitudinal cline in maturity. Figure 10 shows that hake sampled south of 34.5 degrees latitude (approximately Point Conception) mature at a smaller size. The trawl survey is the only source of the three analyzed here that sample in that area.

Another interesting observation in Figure 9 and Figure 10 is that there are large, old fish classified as immature. It is believed that these fish may be mature, but are “skip spawners” and will not be spawning in the upcoming year. Therefore, maturity-at-length is estimated with a third parameter to allow the asymptote to be less than one.

It is unclear how the smaller size at maturity south of Pont 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 for the 2014 trawl samples,
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.

2.3.2 Ageing error

The large inventory of Pacific Hake age determinations include 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 to 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 (JTC, 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 it was not included. 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. Sensitivity analyses (not presented here) indicated very little difference in model results associated with alternative assumptions about the 2008 cohort or the treatment of ageing error for age-1 fish. An alternative approach was also explored (not presented here) in which cohort-specific ageing error was only applied to the combination of cohort and year that represented at least 40% of the age-composition data for that year. That approach also produced very similar results to the other methods while increasing model complexity and was therefore not chosen for the base model.

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. Mean weight at age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2014 (Figure 11). 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.

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 2014 was similar to this mean so alternative treatments of the weight at age in the forecast would not be likely to make a large difference in the results.

2.3.4 Length-at-age

In 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 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 8. 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 method (Hoenig 1983) 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 is discussed in the 2013 stock assessment (JTC 2013). Sensitivity to this prior has been evaluated extensively in many previous hake assessments (JTC 2013). 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 and the sensitivities have not been repeated this year.

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. (1999) meta-analysis of the family Gadidae, and has been used in previous 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 2013 and 2012 assessments (JTC 2013, JTC 2012).

2.4.3 Variability on fishery selectivity deviations

Time-varying fishery selectivity was introduced in this 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 JTC, 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 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). The estimation procedure was repeated but the resulting value remained unchanged from the 2014 stock assessment (JTC, 2014).

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 (J. Thorson, pers. comm.) 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 west coast of the US 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, Helser et al. 2004, 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); multinomial sample size on age-composition (Dorn et al. 1999, Helser et al. 2002, Helser et al. 2005, Stewart et al. 2011) and survey variance assumptions. 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 explicitly spatial forms (Dorn 1994, Dorn and Saunders 1997), spatially implicit forms (Helser et al. 2006) and single-area models (JTC 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 Fmsy/MSY (Martell 2010), and using several alternative steepness priors (JTC 2012, 2013). Selectivity has also been modeled in several ways: It has been both time varying with a random walk (Helser et al. 2002) and without (Dorn 1994, Dorn and Saunders 1997, JTC 2012, 2013) and invariant (JTC 2012, 2013); and it has been age-based (Dorn 1994, Dorn and Saunders 1997, JTC 2012, 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: $F_{35\%}$, $F_{40\%}$, $F_{40\%}$-40:10, $F_{45\%}$, F45%-40:10, $F_{50\%}$ (e.g., Dorn 1996, JTC 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 modelling 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 $F_{40\%}$-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 (JTC, 2013), none of these management procedure changes has been evaluated in simulation and quantitatively compared with performance measures.

3.2 Response to recent review recommendations

3.2.1 2015 Scientific Review Group (SRG) review

To be added after 2015 review.

3.2.2 2014 Scientific Review Group (SRG) review

The Scientific Review Group (SRG) was held in Seattle, WA from February 18–21, 2014. The SRG investigated many aspects of the 2013 acoustic survey estimate and the model. The base model presented by the JTC was unchanged and endorsed by the SRG for use by the JMC when considering the 2013 catch quota, with the understanding that the 2013 acoustic survey biomass estimate was potentially biased due to extrapolation into unsurveyed areas. A sensitivity to a lower survey estimate resulted in a 16% reduction in the default harvest rate catch. The SRG also reviewed the Management Strategy Evaluation (MSE), and felt that progress has been made and it is proving to be a useful tool to investigate assessment model behavior and potentially could be used to understand management decisions.

Many recommendations were made by the SRG and are summarized in their 2014 report. A few of the high priority recommendations were to continue research on the acoustic survey including research on the methods to calculate a biomass estimate, continuing research on hake biology and ecology, and expanding the MSE operating model to test how the assessment model performs under alternative stock and recruitment assumptions.

3.3 Model description

3.3.1 Base model

The 2015 base model is effectively an update of the base model in the 2014 stock assessment. The software was updated from Stock Synthesis (SS) version 3.24s (Methot and Wetzel 2012) used in 2014 to SS version 3.24u (R. Methot, pers. comm.) although no changes made between these versions were expected to impact this model and indeed the results were effectively identical. The largest change between the 2013 and 2014 stock assessments was the addition of time-varying fishery selectivity in the base model and that feature was retained for 2015. The parameterization of the 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 (since age-1 fish are excluded included from the design) and age-1 for the fishery.

Prior probability distributions remained unchanged from 2014 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 0.2 and a standard deviation (in log-space) of 0.1 (described above). 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, JTC 2012, 2013). Year-specific recruitment deviations were estimated from 1946–2014 as well as the years 2015 and 2016 for purposes of forecasting. The standard deviation, σ_r, for recruitment variability, serving as both a recruitment deviation constraint and bias-correction, 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 and 2014. Survey catchability was set at the median unbiased estimate calculated analytically as shown by Ludwig & 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 log(SD) 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, and tuning quantities have been unchanged since the 2012 assessment, even with the inclusion of time-varying selectivity.

3.4 Modeling results

3.4.1 Changes from 2014

A set of 'bridging' models was constructed to clearly illustrate the component-specific effects of all changes to the base model from 2014 to 2015. Updating the 2013 catch, proportions at age and weight at age had no observable effects on relative spawning biomass (Figure 12). Likewise, updating from SS version 3.24S used in 2013 to 3.24U caused no change in the results.

The next bridging step was to include 2014 catches and fishery age-composition data (Figure 13). The biggest difference is in the final year with the previous model predicting a decrease in spawning biomass because it assumed that the full default harvest rate catch was taken. The 2014 catch was much less than the default harvest rate catch, and the biomass remained nearly stable. Uncertainty in 2014 was reduced slightly, likely because uncertainty in 2010 recruitment was reduced (Figure 13, lower left). The estimate of 2010 recruitment was a very small amount less than predicted in the previous model. Overall, the 2015 base model with 2014 catch and fishery age compositions is similar to the updated 2014 model. More information about the 2015 base model is given below.

3.4.2 Model selection and evaluation

3.4.3 Assessment model results

Model Fit

For the base model, the MCMC chain was of equal length as in the 2014 assessment (JTC, 2014). 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 (Figure 14 and Figure 15). Correlation-corrected effective sample sizes were sufficient to summarize the posterior distributions and neither the Geweke nor the Hiedelberger and Welch statistics for these parameters exceeded critical values more frequently than expected via random chance (Figure 16). Correlations among key parameters were generally low, with the exception of natural mortality, M, and the unexploited equilibrium recruitment level, log(R_0). Derived quantities for Recruitment in 2008 and 2010 as well as relative spawning biomass in 2015 and the default harvest catch in 2015 were more highly correlated as expected given the dependencies among these quantities. (Figure 17). An examination of deviations in recruitment (log-scale differences between estimated and expected recruitment values) from recent years (Figure 18) indicates the highest correlation (0.83) 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 19 remains similar to the 2014 base model. The 2001 data point continues to be well below any model predictions that we evaluated, and no direct cause for this is known, although it was conducted about one month earlier 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 slightly underfits the 2013 survey index.

Fits to the age-composition data continue to show close correspondence to the dominant cohorts observed in the data and also identification of small cohorts, where the data give a consistent signal (Figure 20). 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. As noted above, the 2014 age composition was dominated by age-4 fish from the 2010 year-class, with age-6 fish from the 2008 year-class making up the second largest cohort in the observations. These patterns were expected given the strength of these two cohorts in the 2013 fishery composition data 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 21).

Posterior distributions for both steepness and natural mortality are strongly influenced by priors (Figure 22). 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 substantial updating from non-informative priors to stationary posterior distributions.

Fishery selectivity had the largest estimated deviations in 2010 and 2011 (Figure 23 and Figure 24). Fishery selectivity in 2010 shows a high (almost 100%) selectivity on age-4 fish, corresponding to the 2006 year class, and in 2011 age-3 selectivity is increased (again almost to 100%), corresponding to the 2008 year class. Even though the survey selectivity is time invariant, the posterior shows a broad band of uncertainty between ages 2 and 5 (Figure 25). The fishery selectivity is likewise very uncertain (Figure 24 and Figure 25), but in spite of this uncertainty, changes in year to year patterns in the estimates are still evident, particularly for age 3 and 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 (Figure 26 and Figure 27). The model predicts that it was below the unfished equilibrium in the 1960s and 1970s (due to low recruitment). The stock is estimated to have increased rapidly after two or more large recruitments in the early 1980s to near unfished equilibrium, 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 entering the fishery to replace catches being removed during this period. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.497 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 increase was the result of a large 2010 and above-average 2008 cohorts. The 2015 median posterior spawning biomass is estimated to be 73.6% of the unfished equilibrium level (B_0) with 95% posterior credibility intervals ranging from 34.3% to 149.8% (Table 9 and Table 10). The median estimates of 2014 and 2015 female spawning biomass values are 1.703 and 1.663 million t, respectively (Table 9).

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 (Figure 28). 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 has been at some of the lowest values in the time-series as well some of the highest (Figure 28). The current assessment estimates a strong 2010 year class comprising 70% of the coast-wide commercial catch in 2013 and 64% of the 2014 catch. Its size is still more uncertain than cohorts that were 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. There is little or no information in the data to estimate the sizes of the 2014 and 2015 year classes so they are given by the underlying stock recruitment relationship assumptions (Figure 30). 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 (JTC 2013).

The estimated recruitments with uncertainty for each predicted point and the overall stock recruit relationship are provided in Figure 30. Extremely large variability about the expectation and about the joint uncertainty of individual recruitment and spawning biomass pairs are clearly evident in this plot. High and low recruitment has been produced throughout the range of observed spawning biomass (Figure 30).

The standard deviation of the time series of median recruitment deviation estimates for the years 1971–2011, which are well informed by the age compositions, is 1.51. The standard deviation of the MCMC samples of all recruitment deviations for the years 1946–2014 (69 years with 999 samples per year, combining both the variability among years and the uncertainty within each year), is 1.51. These values are roughly consistent with the base model value of σ_r = 1.4 and suggest that, if anything, σ_r could be even higher.

Exploitation status

Median fishing intensity on the stock is estimated to have been consistently below the $F_{40\%}$ target (Figure 32) with the exception of the periods in the late 1990s and late 2000s when the spawning biomass was the lowest. The base model estimates of fishing intensity indicate that the SPR target was exceeded with a greater than 50% chance in 2008 and 2010. 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. The exploitation fraction (catch divided by biomass of ages 3 and above) does not necessarily correspond to fishing intensity because fishing intensity 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. The median estimates of fishing intensity have declined from 100.3% in 2010 to 61.6% in 2014. The uncertainty around these estimates is largest in the most recent years due to uncertainty in recruitment and spawning biomass, but the 2014 fishing intensity is estimated to have a 98.6% probability of being below the target (Figure 32).

Management performance

Recent catches have generally been below coast-wide targets (Table 4). Total catches last exceeded the coast-wide catch target in 2002 when landings were 112% of the catch target. Over the last ten years, the average coast-wide utilization rate has been 86%. In the last five years (2010–2014), mean utilization rates between have differed between the United States and Canada at 85% and 60%, respectively. The underutilization in the United States is mostly a result of unrealized catch in the tribal apportionment, while reports from stakeholders in Canada suggest that hake are less aggregated in Canada and availability has declined in recent years. The Canadian fishery has changed in recent years with an increase in the number of Freezer Trawlers which have more horsepower and larger nets than their Shoreside counterparts.

Exploitation history in terms of joint biomass and *F*-target reference points shows that before 2007, median fishing intensity was below target and female spawning biomass was near or above target (Figure 26 and Figure 32 and Figure 34). Between 2007 and 2011, however, fishing intensity ranged from 87% to 105% and relative spawning biomass between 0.22 and 0.31 (Table 9). Biomass has risen recently with the 2008 and 2010 recruitments (Figure 26) and correspondingly, fishing intensity has fallen below targets, and relative spawning biomass above targets for 2012 through 2014 (Figure 34). While uncertainty in the 2014 fishing intensity estimates and relative spawning biomass is large, the model predicts a 1.4% joint probability of being both above the target fishing intensity in 2014 and below 40% relative spawning biomass at the start of 2015.

3.4.4 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), the selectivities, 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 22; also see Stewart et al 2012 for further discussion and examples). Table 12 compares the median of the posterior to the MLE, showing that median biomass, recruitment, and relative spawning biomass estimates from the posterior distribution are all larger in value. Figure 35 shows the MLE and Bayesian estimates as well as the skewed uncertainty in the posterior distributions for spawning biomass and recruitment

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. Uncertainty in the best method for calculating acoustic survey biomass is a particular focus and results from a model fit to an alternative set of survey biomass values are presented in the decision tables alongside the base model results.

The Pacific Hake stock displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid biomass changes. This volatility, coupled with a dynamic fishery, which 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 was active doing MSE in 2014-15. We divided MSE research activities into short and long term projects. The short term plan was to evaluate the system performance with and without an age-1 index. The design of the age-1 index simulations are described below and simulations will be completed soon. The age-1 index simulations and our efforts to elicit feedback on management objectives from the JMC and MSE Steering Group for the purposes of operating model development are described in Appendix A below.

Developing alternative operating dynamics complicates analyses greatly. For example last year's closed-loop simulations only examined a single implementation of time-varying selectivity: there are many possible hypotheses about how this process is best modelled and statistical methods with which to estimate parameters describing these dynamics. How to determine estimation and simulation methods for time-varying selectivity is only a small subset of choices that are possible for modeling for Pacific Hake; other hypotheses that might change our perceptions of stock status (spatial dynamics, time-varying changes in life-history parameters) will also involve complicated and difficult analyses. Decisions about what operating models to pursue with MSE will have to be made carefully. Furthermore, the JTC would like to continue the involvement of the JMC, SRG, and AP to further refine management objectives, as well as determine scenarios of interest, management actions to investigate, and hypotheses to simulate.

3.4.5 Reference points

We report estimates of the 2014 base reference points with posterior credibility intervals in Table 13. The estimates are slightly different than the estimates in the 2014 assessment with slightly greater yields and biomasses estimated in this assessment.

3.4.6 Model projections

The median catch for 2015 based on the default harvest policy ($F_{40\%}$ – 40:10) is 804,576 t, but has a wide range of uncertainty (Figure 36). The 95% posterior credibility interval ranges from 307,435 t to 1,920,296 t.

A decision table showing predicted population status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base model. The decision table (split into Table 14 and Table 15) is organized such that the projected outcomes for each potential catch level (rows) can be evaluated across the quantiles (columns) of the posterior distribution. The first table (Table 14) shows projected relative spawning biomass outcomes, and the second (Table 15) shows projected fishing intensity outcomes relative to the target fishing intensity (based on SPR; see table legend). Fishing intensity exceeding 100% indicates fishing in excess of the $F_{40\%}$ default harvest rate catch limit. The default harvest rate catch limit results in a median fishing intensity above 100% in 2015, 2016, and 2017 because the $F_{40\%}$ default harvest rate catch limit is calculated using baseline selectivity from all years and the forecasted catches are removed using selectivity averaged over the last 5 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.

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 2016 and 2017 (Table 16 and Table 17). 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 37 shows the predicted relative spawning biomass trajectory through 2017 for several of these management actions. With zero catch for the next two years, the median biomass is predicted to remain stable from 2016 to 2017, with a 51% probability of decreasing from 2016 to 2017 (Figure 37 and Table 17).

At all catch levels 180,000 t per year or greater, the spawning biomass is predicted to decline with greater than 68% probability (Figure 38 and Table 16). The model predicts high biomass levels and the predicted probability of dropping below 10% in 2016 is less than 1% and the maximum probability of dropping below B40% is 21% for all catches explored. It should be noted that in addition to the natural mortality rate overtaking the growth rate for the 2010 year class, the model estimated below average recruitment for the 2011 and 2013 cohorts entering the 2016 spawning biomass, which also contributes to the relatively low catch that will result in a reduction in spawning biomass from 2015 to 2016. Probabilities for these same metrics given specific catches in 2016 are shown in Table 17 and Figure 40. The probability that the 2017 spawning biomass will be less than the 2016 spawning biomass is greater than 50% for any catch level (including zero catch).

3.5 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 Table 12 for a set of comparisons of the base model to corresponding MLE estimates). The sensitivities include the following:

1. Change the survey biomass for 2012 and 2013 based to values discussed at the SRG
2. Assume natural mortality declines with age rather than remain constant across ages,
3. Link natural mortality for young hake with an index of abundance for Humboldt Squid,
4. Have mean weight at age remain constant across years,
5. Include autocorrelation in recruitment deviations,

In general, none of the sensitivities resulted in any significant departure from the population dynamics of the base model: all models showed large estimated increases in spawning biomass in recent years driven by a large 2010 cohort.

The sensitivity of the base model to changes in the survey biomass estimates was conducted to bracket the uncertainty associated with the extrapolation of estimated biomass outside the survey area (see discussion in section 2.2.1 above). The index used in the base model has values of 1.381 and 2.423 million t for 2012 and 2013. Alternative values calculated during the SRG meeting in February 2015 were 1.207 and 1.648 for these same years, which are lower by 12.6% and 32.0%, respectively. This analysis was conducted using MCMC while the other sensitivity analyses were based on comparisons of MLE values. The results of this analysis are shown in Table 18 and Figure 42 through Figure 45. The early part of the time series of biomass remains relatively unchanged, but the lower survey numbers result in smaller estimates of the 2008 and 2010 cohorts (Figure 44) and a slower increase in biomass resulting from those cohorts (Figure 43). The estimated 2015 relative spawning biomass is 60.2% with the lower survey values compared to 73.6% in the base model. This is a change of 18%, which is smaller than the magnitude of the change in survey biomass due to the base model expectation not being as high as the original 2013 acoustic survey biomass estimate (Figure 42). The median default harvest control catch limit coming from the model with lower survey values is 628,361 t compared to 804,576 t for the base model, a difference of 22% (Figure 45).

Two sensitivities related to natural mortality were explored, one related to natural mortality varying with age according to a rescaled Lorenzen curve (Lorenzen, 1996) and another linking natural mortality to an estimated index of abundance for Humboldt Squid (Stewart et al. 2014; J. Field, pers. comm.).

The Lorenzen curve links natural mortality to fish size. As implemented in Stock Synthesis, the function is scaled by an estimated parameter for natural mortality at a chosen age (Methot and Wetzel, 2009). For this sensitivity, age 5 was arbitrarily chosen and the prior distribution used in the base model for all ages was applied to this age. The base model is configured to use an empirical mean weight-at-age matrix rather than model growth explicitly, so the Lorenzen curve was based on a von Bertalanffy growth curve that approximates recent patterns of hake growth but was not fit to length and age data. The intention of this sensitivity is therefore to explore the impact of natural mortality declining with age rather than propose a specific set of mortality estimates for the population.

Preliminary sensitivities with Humboldt Squid index linked to hake natural mortality at all ages resulted in a negative relationship between squid abundance and hake mortality, which is contrary to the hypothesized interaction. The sensitivity presented here has natural mortality for hake split into two parameters, one for ages 0–4 and one for ages 5+. The natural mortality prior distribution from the base model was applied to both parameters. The parameter for the younger hake mortality was then linked to the Humboldt Squid abundance under the assumption that the distribution of Humboldt Squid has greater overlap with younger hake.

The patterns of natural mortality resulting from these two sensitivities differ from base model (Figure 46) but MLE estimates of spawning biomass at both initial equilibrium and in recent years are very similar among these three models (Figure 47). Recruitment is much higher in the Lorenzen M model to account for the higher mortality at young ages but since these ages are not commonly selected in the fishery and there is a flexible selectivity pattern for these ages, the fit to the data and key model outputs are very similar (Table 19).

In order to understand the sensitivity of the model results to assumptions about the estimates of weight at age (Figure 11), a sensitivity was conducted in which the matrix of weight-at-age values for each year with the vector of mean weight-at-age across all years. There was relatively little impact of this change on assessment results, with the estimate of 2015 relative spawning biomass at 63.6% instead of 67.2% of B0 (Table 18). This results suggests that there would be little impact of alternative assumptions about how weights are treated for year/age combinations with missing data or small sample sizes.

The sensitivity with the smallest impact on model results involved estimating an autocorrelation parameter for recruitment deviations. The estimated value was -0.12, reflecting the negative relationship between recruitments in adjacent years (large cohorts typically followed by small cohorts). The additional parameter reduces the negative log-likelihood by only 0.6 units and has negligible effects on model estimates (Table 19), as well as forecast quantities. Exploration of alternative ways to model and forecast recruitment is included in the list of suggested research needs, and future MSE operating models can include more flexible options for treatment of recruitment autocorrelations (beyond the lag-1 autocorrelation implemented in Stock Synthesis). The MSE could explore trade-offs associated with more complex treatment of recruitment in an assessment model.

3.6 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 the high 2009 acoustic survey as the final point in the index of abundance and therefore predicted a higher biomass than models which included any of the surveys conducted in 2011, 2012, and 2013 (Figure 48).

Overall, there is little retrospective change to the relative spawning biomass trajectory up to the early 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 3 years, the stock assessment has retrospectively underestimated the status, but removing 3 or more years of data resulted in the assessment over-estimating the status in the terminal year, which is likely related to the high 2009 acoustic survey estimate.

Figure 49 shows the retrospective patterns of estimated recruitment deviations for various cohorts. The magnitude of the deviation is not well estimated until several years of catch-at-age data have been collected, incorporated into the model, and the cohort is older The variability among cohort estimates relative to their estimated size in the base model (Figure 50) indicate that the estimates improve significantly at age 3 and begin to stabilize when the cohort is approximately 4 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 51. There has been a large difference in the models 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% C.I.) 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; and in the following years 2008 to present, it was allowed to be freely estimated by the model. In all the years prior to 2004, the 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 what we see today. The 2015 estimates of spawning biomass are consistent with recent assessments, although the model structure has remained consistent, and the uncertainty intervals associated with them bracket the majority of the historical estimates.

4 Research and data needs

4.1 Progress on past "Research and data needs" topics

Examine statistical methods to parameterize time-varying fishery selectivity in assessment and forecasting (#1 on list from 2014).
Jim Thorson (NOAA NWFSC) has been leading a project with participation from the JTC (Allan Hicks and Ian Taylor) looking at alternative selectivity parameterizations to be included in Stock Synthesis. The approach is being informed by methods presented at a CAPAM workshop on selectivity, the results of which were published in October 2014.

Continue development of the management strategy evaluation (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. Work with the JMC, SRG, and AP to develop scenarios to investigate, management performance metrics to evaluate the scenarios, and hypotheses related to the life-history, fishery, spatial dynamics, and management of Pacific Hake (#2 on list from 2014)
Progress on the MSE is summarized in Appendix A of this document.

Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific Hake. Initially, the MSE should be used to investigate whether an age-0 or -1 index could reduce stock assessment and management uncertainty enough to improve overall management performance (#3 on list from 2014).
The JTC has explored the use of the preliminary time series of age-1 abundance derived from past acoustic surveys and is currently conducting simulations to investigate the utility of an age-1 index in the assessment of Pacific Hake. It is expected that these results will be available in late 2015 and presented to the MSE steering committee.

Finalize the analysis of recently collected maturity samples and explore ways to include new maturity estimates in the assessment (#4 from 2014).
Analysis of those samples has been completed (see Section 2.3.1 above). However, the resulting patterns are complex and the best approach for including these results in the stock assessment is not yet clear. The JTC continues to work with biologists to better understand the spawning behavior of Pacific Hake.

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 and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods. (#8 from 2014)
The NWFSC and DFO acoustic survey teams consulted with the JTC on specific research to be conducted in 2014. This research will be presented at the February 2015 SRG meeting.

Coordinate our MSE research with other scientists in the region engaging in similar research. (#13 from 2014)
A JTC representative was included in a recent IPHC meeting on the MSE work being conducted by that agency and an IPHC representative attended the December 2014 JTC meeting. The JTC continues to be well connected to the ongoing MSE process for B.C. Sablefish.

Examine alternative ways to model and forecast recruitment (#15 from 2014).
Elizabeth Councill, a post-doctoral researcher working with Jim Thorson at the NOAA NWFSC, is investigating issues related to recruitment autocorrelations and forecasting. She is expecting to have results available in time to benefit from them in the 2016 hake stock assessment. A second avenue that we are pursuing is the examination of stock recruitment models that have for example the Larkin extension (Larkin 1971) of the Ricker stock recruitment model that has lag terms at t-1, t-2,...t-n): in this way, some of the apparent lag-4 autocorrelation in recruitment can be captured in predictions. Using simulation to test if there is improved management performance by employing alternative recruitment model formulations will be a key tool for choosing amongst alternatives.

Investigate the utility of additional data sources (bottom trawl surveys, length data, etc.) for use in assessment and simulation models (#16 from 2014)
The JTC (Allan and Ian) have been consulting with NWFSC scientists on a paper investigating the information about Pacific Hake contained in acoustic survey, trawl survey, and observer data. Additionally, the JTC continues to investigate the utility of the NWFSC trawl survey with regard to assessing and understanding Pacific Hake. In 2014, more than 1500 Pacific Hake collected from the NWFSC trawl survey from different years were aged to assist this investigation.

4.2 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 might appreciably improve biological understanding and decision-making:

1. Continue development of the management strategy evaluation (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 Panel 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 to best to model these dynamics in order to capture seasonal effects and potential climate forcing influences in the simulations.

2. 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.

3. Continue to explore and develop statistical methods to parameterize time-varying fishery selectivity in assessment and forecasting.

4. 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. Having ages read for the 2014 trawl samples
   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

5. Investigate links between hake spatial distribution and dynamics with ocean conditions and ecosystem variables such as temperature and prey availability. These investigations have the potential to improve the scenarios considered in future MSE work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.

6. 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.

7. Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific Hake. This would include completing ongoing MSE analyses to investigate whether an age-1 index could reduce stock assessment and management uncertainty enough to improve overall management performance.

8. 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.

9. 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.

10. 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.

11. 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).

12. 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.

13. Continue to coordinate our MSE research with other scientists in the region engaging in similar research.

14. Continue to investigate alternative ways to model and forecast recruitment. Use MSE simulations to investigate the impact of making incorrect assumptions about the underlying recruitment process.

15. 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.

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

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7 Tables

Table 1: Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2014. Tribal catches are included in the sector totals.

Year	Foreign	JV	Mothership	Catcher-processor	Shore-based	Research
1966	137,000	0	0	0	0	0
1967	168,700	0	0	0	8,960	0
1968	60,660	0	0	0	160	0
1969	86,190	0	0	0	90	0
1970	159,510	0	0	0	70	0
1971	126,490	0	0	0	1,430	0
1972	74,090	0	0	0	40	0
1973	147,440	0	0	0	70	0
1974	194,110	0	0	0	0	0
1975	205,650	0	0	0	0	0
1976	231,330	0	0	0	220	0
1977	127,010	0	0	0	490	0
1978	96,827	860	0	0	690	0
1979	114,910	8,830	0	0	940	0
1980	44,023	27,537	0	0	790	0
1981	70,365	43,557	0	0	838	0
1982	7,089	67,465	0	0	1,027	0
1983	0	72,100	0	0	1,051	0
1984	14,772	78,889	0	0	2,721	0
1985	49,853	31,692	0	0	3,894	0
1986	69,861	81,640	0	0	3,465	0
1987	49,656	105,997	0	0	4,795	0
1988	18,041	135,781	0	0	6,867	0
1989	0	195,636	0	0	7,414	0
1990	0	170,972	0	4,537	9,632	0
1991	0	0	86,408	119,411	23,970	0
1992	0	0	36,721	117,981	56,127	0
1993	0	0	14,558	83,466	42,108	0
1994	0	0	93,610	86,251	73,616	0
1995	0	0	40,805	61,357	74,962	0
1996	0	0	62,098	65,933	85,128	0
1997	0	0	75,128	70,832	87,416	0
1998	0	0	74,686	70,377	87,856	0
1999	0	0	73,440	67,655	83,470	0
2000	0	0	53,110	67,805	85,854	0
2001	0	0	41,901	58,628	73,412	0
2002	0	0	48,404	36,342	45,708	0
2003	0	0	45,396	41,214	55,335	0
2004	0	0	47,561	73,176	96,504	0
2005	0	0	72,178	78,890	109,052	0
2006	0	0	60,926	78,864	127,165	0
2007	0	0	52,977	73,263	91,441	0
2008	0	0	72,440	108,195	67,760	0
2009	0	0	37,550	34,552	49,223	0
2010	0	0	52,022	54,284	64,654	0
2011	0	0	56,394	71,678	102,147	1,042
2012	0	0	38,512	55,264	65,920	448
2013	0	0	52,470	77,950	102,143	1,018
2014	0	0	62,102	103,203	98,635	197

Table 2: Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2014.

Year	Foreign	JV	Shoreside	Freezer-trawl
1966	700	0	0	0
1967	36,710	0	0	0
1968	61,360	0	0	0
1969	93,850	0	0	0
1970	75,010	0	0	0
1971	26,700	0	0	0
1972	43,410	0	0	0
1973	15,130	0	0	0
1974	17,150	0	0	0
1975	15,700	0	0	0
1976	5,970	0	0	0
1977	5,190	0	0	0
1978	3,450	1,810	0	0
1979	7,900	4,230	300	0
1980	5,270	12,210	100	0
1981	3,920	17,160	3,280	0
1982	12,480	19,680	0	0
1983	13,120	27,660	0	0
1984	13,200	28,910	0	0
1985	10,530	13,240	1,190	0
1986	23,740	30,140	1,770	0
1987	21,450	48,080	4,170	0
1988	38,080	49,240	830	0
1989	29,750	62,718	2,562	0
1990	3,810	68,314	4,021	0
1991	5,610	68,133	16,174	0
1992	0	68,779	20,043	0
1993	0	46,422	12,352	0
1994	0	85,154	23,776	0
1995	0	26,191	46,181	0
1996	0	66,779	26,360	0
1997	0	42,544	49,227	0
1998	0	39,728	48,074	0
1999	0	17,201	70,121	0
2000	0	15,625	6,382	0
2001	0	21,650	31,935	0
2002	0	0	50,244	0
2003	0	0	63,217	0
2004	0	58,892	66,175	0
2005	0	15,695	77,335	9,985
2006	0	14,319	65,289	15,136
2007	0	6,780	53,055	13,537
2008	0	3,592	57,640	12,517
2009	0	0	43,811	12,073
2010	0	8,081	35,162	12,850
2011	0	9,717	31,504	14,409
2012	0	0	32,434	14,478
2013	0	0	35,303	18,793
2014	0	0	16,056	21,381

Table 3: Total U.S., Canadian, and coastwide catches of pacific Hake from 1966–2014. The percentage of catch from each countries 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	73,373	291,054	74.8%	25.2%
2008	248,395	73,749	322,144	77.1%	22.9%
2009	121,325	55,885	177,209	68.5%	31.5%
2010	170,961	56,094	227,054	75.3%	24.7%
2011	231,262	55,630	286,892	80.6%	19.4%
2012	160,145	46,913	207,057	77.3%	22.7%
2013	233,581	54,096	287,677	81.2%	18.8%
2014	264,137	37,437	301,573	87.6%	12.4%

Table 4: Recent trend in Pacific Hake landings and management.

Year	Total Landings (t)	Coast-wide (US+Canada) catch target (t)	Proportion of catch target removed
2004	342,307	501,073	68.3%
2005	363,135	364,197	99.7%
2006	361,699	364,842	99.2%
2007	291,054	328,358	88.7%
2008	322,144	364,842	88.3%
2009	177,209	184,000	96.3%
2010	227,054	262,500	86.2%
2011	286,892	393,751	72.6%
2012	207,057	251,809	82.0%
2013	287,677	365,112	77.7%
2014	301,573	428,000	70.5%

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).

Year	U.S.					Canada			
	Foreign (hauls)	Joint-venture (hauls)	Mother-ship (hauls	Catcher-processor (hauls)	Shore-based (trips)	Foreign	Joint-venture (hauls)	Shoreside (trips)	Freezer-trawl (hauls)
1975	13	—	—		—	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

Table 6: Summary of the acoustic surveys from 1995 to 2013.

Year	Start date	End date	Vessels	Biomass index (million t)	Sampling CV[1]	Number of hauls with bio. samples
1995	1 July	1 Sept.	Miller Freeman, Ricker	1.518	0.067	69
1998	6 July	27 Aug.	Miller Freeman, Ricker	1.343	0.049	84
2001	15 June	18 Aug	Miller Freeman, Ricker	0.919	0.082	49
2003	29 June	1 Sept.	Ricker	2.521	0.071	71
2005	20 June	19 Aug.	Miller Freeman	1.755	0.085	49
2007	20 June	21 Aug.	Miller Freeman	1.123	0.075	130
2009	30 June	7 Sept.	Miller Freeman, Ricker	1.612	0.137[2]	61
2011	26 June	10 Sept	Bell Shimada, Ricker	0.521	0.1015	59
2012	23 June	7 Sept	Bell Shimada, Ricker, F/V Forum Star	1.381	0.0475	94
2013	13 June	11 Sept	Bell Shimada, Ricker	2.423	0.0433	68

[1]Sampling CV includes only error associated with kriging of transect-based observations.
[2]Also includes bootstrapped estimates of uncertainty associated with delineation of Humboldt squid from hake.

Table 7: Number of Pacific Hake ovaries collected for histological analysis with maturity determined from different years and different sources.

Length bin (cm)	Acoustic Survey 2012	Acoustic Survey 2013	ASHOP 2013	ASHOP 2014	Trawl Survey 2009	Trawl Survey 2012	Trawl Survey 2013	Trawl Survey 2014	Total
<20	0	0	0	0	12	0	0	1	13
20-21	0	0	0	0	6	0	0	1	7
22-23	0	0	0	0	17	0	2	5	24
24-25	3	4	0	0	16	2	1	4	30
26-27	7	8	0	0	8	2	1	17	43
28-29	11	10	0	0	4	2	3	12	42
30-31	21	1	0	0	5	2	1	6	36
32-33	12	5	0	0	11	4	3	10	45
34-35	24	15	6	0	4	1	3	18	71
36-37	14	36	20	0	7	4	4	11	96
38-39	8	15	52	3	19	3	4	18	122
40-41	14	51	63	22	17	3	5	19	194
42-43	9	14	21	46	17	1	3	24	135
44-45	11	14	16	17	13	3	1	19	94
46-47	8	23	8	4	18	5	8	13	87
48-49	6	10	8	8	20	5	2	16	75
50-51	9	17	7	5	15	4	4	13	74
52-53	10	13	3	0	5	7	5	7	50
54-55	9	6	4	0	9	2	3	7	40
56-57	6	7	1	0	5	7	3	9	38
58-59	7	2	0	0	5	2	2	7	25
60-61	4	0	0	0	7	3	1	7	22
>61	6	3	0	0	19	9	11	27	75
Total	199	254	209	105	259	71	70	271	1438

Table 8: 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 (LN) 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	(0.2,1.0)	~Beta(0.777,0.113)
Recruitment variability (σ_r)	-	NA	1.40
Log(Rec. deviations): 1946–2015	70	(-6, 6)	~LN(0, σ_r)
Natural mortality (M)	1	(0.05,0.4)	~LN(0.2,0.1)
	Catchability and selectivity (double normal)		
Acoustic survey:			
Catchability (q)	1	NA	Analytic solution
Additional value for acoustic survey log(SE)	1	(0.05, 1.2)	Uniform
Non parametric age-based selectivity: ages 3–6	4	(-5,9)	Uniform in scaled logistic space
Fishery:			
Non parametric age-based selectivity: ages 2–6	5	(-5,9)	Uniform in scaled logistic space
Selectivity deviations (1991–2014, ages 2-6)	120	NA	Normal(0,0.03)

Total: 14 + 70 recruitment deviations+120 selectivity deviations = 204 estimated parameters. Additional parameters for Log(Recruitment deviations) in 2016 and 2017 are used for forecasting. See Appendix A for all parameter estimates.

Table 9: 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-SPR40%) is the fishing intensity relative to the default harvest control catch limit.

Year	Female spawning biomass (thousand t)	Relative Spawning Biomass	Age-0 recruits (millions)	(1-SPR) / ($1-SPR_{40\%}$)	Exploitation fraction
1966	1,076	47.3%	1,380	43.7%	6.2%
1967	1,003	43.9%	3,289	62.8%	10.3%
1968	931	41.3%	2,096	45.9%	6.4%
1969	990	44.2%	918	59.8%	9.2%
1970	1,062	47.0%	7,955	67.8%	10.3%
1971	1,050	46.7%	742	51.4%	6.7%
1972	1,257	55.7%	472	40.3%	5.4%
1973	1,441	63.6%	4,604	43.0%	4.8%
1974	1,455	64.2%	411	50.3%	6.6%
1975	1,454	64.7%	1,301	44.9%	6.2%
1976	1,430	63.4%	346	40.1%	5.3%
1977	1,355	60.0%	5,162	29.0%	3.6%
1978	1,259	55.4%	289	26.8%	3.2%
1979	1,297	56.7%	915	31.9%	4.5%
1980	1,308	57.5%	16,558	24.6%	2.7%
1981	1,269	55.9%	274	37.6%	4.8%
1982	1,688	74.6%	251	32.7%	4.6%
1983	2,077	92.0%	393	25.3%	2.4%
1984	2,200	97.1%	12,740	27.3%	3.0%
1985	2,096	92.1%	206	23.1%	2.6%
1986	2,286	100.8%	210	36.7%	5.7%
1987	2,412	106.1%	5,454	39.0%	4.4%
1988	2,310	101.5%	1,912	40.6%	5.2%
1989	2,217	97.8%	182	53.4%	8.0%
1990	2,082	91.9%	4,453	45.0%	6.3%
1991	1,896	83.7%	563	55.9%	8.3%
1992	1,738	76.6%	192	61.0%	10.0%
1993	1,570	69.3%	3,355	53.1%	7.5%
1994	1,378	60.8%	2,748	77.1%	14.9%
1995	1,155	51.0%	1,309	68.6%	12.6%
1996	1,101	48.9%	1,648	80.3%	15.0%
1997	1,014	44.9%	1,127	85.2%	15.4%
1998	914	40.4%	1,848	91.0%	18.2%
1999	794	35.1%	11,449	97.1%	20.6%
2000	693	30.4%	335	77.5%	14.5%
2001	994	43.8%	900	73.0%	13.1%
2002	1,274	56.3%	73	48.8%	4.4%
2003	1,391	61.6%	1,445	51.0%	6.1%
2004	1,322	58.5%	73	74.7%	12.4%
2005	1,118	49.5%	2,465	80.1%	17.8%
2006	867	38.3%	1,853	92.8%	21.2%
2007	681	30.2%	48	98.1%	25.1%
2008	602	26.7%	5,987	104.5%	25.6%
2009	497	22.0%	1,289	87.1%	15.7%
2010	610	26.8%	14,799	100.3%	25.7%
2011	713	31.4%	447	94.9%	18.4%
2012	1,162	50.7%	1,818	74.0%	14.3%
2013	1,549	68.9%	833	66.0%	7.4%
2014	1,703	75.2%	1,062	61.6%	8.1%
2015	1,663	73.6%	1,103	103.5%	23.0%

Table 10: Time-series of ~95% posterior credibility intervals for the quantities shown in Table 9.

Year	Female spawning Biomass (millions t)	Relative Spawning Biomass	Age-0 recruits (billions)	(1-SPR) / (1-SPR_{target})	Exploitation fraction
1966	594-2025	26-82%	58-8740	24-69%	3-12%
1967	566-1908	25-77%	191-10704	37-90%	5-20%
1968	528-1820	23-74%	131-8568	25-71%	3-12%
1969	598-1891	27-77%	67-5001	34-86%	5-17%
1970	643-2011	29-82%	3856-18196	40-94%	5-18%
1971	628-1995	29-80%	68-3493	28-78%	3-12%
1972	748-2398	35-98%	54-1948	21-65%	3-9%
1973	890-2741	40-109%	2330-10325	22-67%	3-8%
1974	904-2785	40-111%	50-1758	27-75%	3-11%
1975	885-2851	40-114%	448-3328	23-69%	3-10%
1976	856-2793	39-112%	39-1410	21-64%	3-9%
1977	798-2630	36-105%	2515-10745	14-49%	2-6%
1978	743-2394	34-96%	28-1542	13-46%	2-5%
1979	785-2386	36-96%	146-2824	16-52%	2-8%
1980	787-2361	36-93%	9589-30512	13-42%	1-4%
1981	771-2220	36-89%	30-1592	21-60%	3-8%
1982	1087-2804	49-112%	28-1327	18-53%	3-8%
1983	1375-3372	61-135%	42-1638	14-40%	1-4%
1984	1483-3507	65-143%	8116-21012	16-43%	2-4%
1985	1439-3240	63-134%	27-960	13-36%	2-4%
1986	1649-3426	71-143%	30-832	22-54%	4-8%
1987	1790-3510	75-148%	3222-9015	25-54%	3-6%
1988	1746-3298	73-139%	773-3897	27-56%	4-7%
1989	1729-3103	72-131%	22-666	36-71%	6-10%
1990	1644-2876	67-123%	2902-7011	30-60%	5-8%
1991	1516-2555	62-111%	83-1424	40-73%	6-10%
1992	1411-2297	57-102%	28-671	44-78%	8-12%
1993	1276-2017	52-91%	2310-5277	39-68%	6-9%
1994	1129-1756	46-78%	1833-4257	60-94%	12-18%
1995	937-1473	39-66%	757-2274	52-85%	10-16%
1996	908-1398	37-62%	1050-2628	63-98%	12-18%
1997	843-1290	35-58%	571-1961	68-100%	12-19%
1998	754-1173	31-52%	1129-2887	73-106%	14-22%
1999	647-1038	27-46%	8373-16745	78-113%	16-25%
2000	547-920	23-40%	80-808	59-95%	11-18%
2001	793-1307	33-57%	561-1427	55-90%	10-17%
2002	1031-1639	43-72%	12-255	35-64%	3-5%
2003	1166-1759	48-79%	1029-2203	36-66%	5-7%
2004	1126-1654	46-74%	11-242	58-91%	10-15%
2005	959-1403	39-62%	1715-3951	62-96%	14-21%
2006	736-1099	31-49%	1173-3250	75-109%	17-25%
2007	561-902	24-39%	8-169	79-114%	19-30%
2008	478-858	20-36%	3696-11246	86-120%	18-32%
2009	370-772	16-32%	575-2927	64-105%	10-21%
2010	427-1006	19-42%	7182-31734	73-120%	16-36%
2011	466-1252	20-51%	85-1533	66-118%	10-28%
2012	638-2221	29-91%	311-7955	45-101%	8-25%
2013	801-3068	36-130%	53-9911	38-97%	4-14%
2014	794-3466	37-146%	67-19283	34-94%	4-17%
2015	750-3551	34-150%	71-17121	97-109%	17-30%

Table 11: 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	1,622	1,186	778	573	449	366	309	266	230	199	172	149	128	110	93	410
1967	2,909	1,311	958	625	447	346	280	232	199	173	150	129	112	96	82	378
1968	2,156	2,352	1,059	765	475	332	254	199	165	142	123	106	92	79	68	326
1969	1,069	1,742	1,900	850	595	364	253	190	148	123	106	91	79	68	59	294
1970	6,522	864	1,408	1,518	648	444	269	181	135	106	88	75	65	56	49	252
1971	826	5,272	698	1,121	1,137	472	319	185	124	93	73	60	52	45	39	207
1972	490	668	4,260	558	862	859	353	232	134	90	68	53	44	38	33	179
1973	3,797	396	540	3,418	435	663	656	264	174	101	68	51	40	33	28	158
1974	420	3,069	320	433	2,652	333	503	487	196	129	75	50	38	29	24	138
1975	1,142	339	2,480	256	332	1,998	248	365	353	142	93	54	36	27	21	118
1976	352	923	274	1,987	198	253	1,511	183	269	260	105	69	40	27	20	102
1977	4,436	285	746	220	1,546	152	193	1,128	137	201	194	78	51	30	20	91
1978	280	3,586	230	600	173	1,208	118	148	866	105	154	149	60	39	23	86
1979	903	227	2,898	185	474	136	943	91	114	667	81	119	115	46	30	84
1980	14,470	730	183	2,329	146	369	105	719	70	87	508	62	91	88	35	87
1981	315	11,697	590	147	1,844	114	289	81	556	54	67	393	48	70	68	95
1982	249	255	9,452	473	115	1,421	88	217	61	418	40	51	296	36	53	122
1983	420	202	206	7,596	372	89	1,099	67	165	47	318	31	38	225	27	133
1984	11,511	339	163	166	6,011	292	70	850	52	128	36	246	24	30	174	124
1985	204	9,305	274	131	131	4,708	228	54	655	40	98	28	189	18	23	229
1986	215	165	7,521	221	104	103	3,698	177	42	509	31	76	22	147	14	196
1987	4,872	174	133	6,039	173	80	79	2,791	134	32	384	23	58	16	111	159
1988	1,863	3,939	140	107	4,712	133	62	59	2,095	100	24	288	17	43	12	202
1989	185	1,506	3,183	113	83	3,620	102	46	44	1,565	75	18	215	13	32	160
1990	4,012	149	1,217	2,545	86	63	2,690	73	33	32	1,127	54	13	155	9	139
1991	602	3,243	121	975	1,971	66	47	1,988	54	24	24	833	40	9	115	109
1992	198	486	2,620	96	739	1,466	49	34	1,429	39	18	17	599	29	7	161
1993	3,053	160	393	2,091	73	545	1,072	34	24	1,003	27	12	12	420	20	118
1994	2,509	2,468	129	314	1,600	55	406	774	25	17	724	20	9	9	303	99
1995	1,214	2,028	1,994	103	232	1,141	38	259	494	16	11	462	13	6	5	257
1996	1,521	982	1,639	1,589	77	169	814	25	174	332	11	7	311	8	4	177
1997	1,024	1,229	793	1,294	1,150	54	116	519	16	111	212	7	5	198	5	115
1998	1,686	828	993	626	920	782	36	72	322	10	69	132	4	3	123	75
1999	10,386	1,363	668	780	435	608	503	21	43	192	6	41	78	2	2	118
2000	356	8,395	1,100	519	516	273	381	295	12	25	112	4	24	46	1	70
2001	811	287	6,782	875	385	368	188	239	185	8	16	71	2	15	29	45
2002	74	655	232	5,412	654	275	256	123	156	121	5	10	46	1	10	48
2003	1,322	60	530	186	4,218	498	206	185	89	113	87	4	7	33	1	42
2004	76	1,069	48	424	144	3,194	372	149	134	64	82	63	3	5	24	31
2005	2,202	61	863	38	312	102	2,227	245	98	88	42	54	42	2	4	36
2006	1,619	1,780	50	685	28	218	69	1,410	155	62	56	27	34	26	1	25
2007	46	1,309	1,437	39	477	18	138	40	817	90	36	32	16	20	15	15
2008	5,096	37	1,056	1,119	26	301	11	77	22	456	50	20	18	9	11	17
2009	1,097	4,119	30	821	733	16	170	6	37	11	222	24	10	9	4	14
2010	12,106	887	3,326	24	582	496	10	100	3	22	6	131	14	6	5	11
2011	432	9,786	715	2,587	15	339	294	6	57	2	12	4	74	8	3	9
2012	1,887	349	7,897	554	1,618	9	215	180	4	35	1	8	2	45	5	7
2013	1,856	1,525	282	6,211	395	1,117	6	144	120	2	23	1	5	1	30	8
2014	2,424	1,500	1,232	224	4,602	286	800	4	96	80	2	15	0	3	1	26
2015	2,423	1,960	1,212	982	169	3,374	206	546	3	65	54	1	11	0	2	18

Table 12: Select parameters, derived quantities, and reference point estimates for the base model MLE and posterior median (MCMC) estimates with comparison to posterior median estimates from the 2014 base model.

	MLE	Posterior median	Posterior median from 2014 base model
Parameters			
R_0 (millions)	2,470	2,923	2,3488
Steepness (h)	0.862	0.814	0.826
Natural mortality (M)	0.213	0.223	0.222
Acoustic catchability (Q)	1.012	—	—
Additional acoustic survey SD	0.300	0.376	0.360
Derived Quantities			
2008 recruitment (millions)	5,096	5,987	5,148
2010 recruitment (millions)	12,106	14,799	15,364
B_0 (thousand t)	2,096	2,268	2,132
2009 Relative Spawning Biomass	21.4%	22.0%	22.8%
2015 Relative Spawning Biomass	67.2%	73.6%	—
2014 Fishing intensity: (1-SPR)/(1-SPR40%)	70.8%	61.6%	—
Reference points based on $F_{40\%}$			
Female spawning biomass ($B_{F40\%}$ thousand t)	786	813	769
$SPR_{MSY\text{-}proxy}$	40%	40%	40%
Exploitation fraction corresponding to SPR	20.7%	21.6%	21.6%
Yield at $B_{F40\%}$ (thousand t)	339	362	342

Table 13: Summary of median and 95% credibility base reference points for Pacific Hake. Mean size at age was averaged from 1966-2014 and selectivity was averaged from 2010-2014.

Quantity	2.5^{th} percentile	Median	97.5^{th} percentile
Unfished female *B* (B_0, thousand t)	1,828	2,269	2,897
Unfished recruitment (R_0, billions)	1,932	2,923	4,812
Reference points based on $F_{40\%}$			
Female spawning biomass ($B_{F40\%}$ thousand t)	613	814	1,025
$SPR_{MSY\text{-}proxy}$	–	40%	–
Exploitation fraction corresponding to SPR	18.5%	21.6%	25.6%
Yield at $B_{F40\%}$ (thousand t)	270	362	513
Reference points based on $B_{40\%}$			
Female spawning biomass ($B_{40\%}$ thousand t)	731	907	1,159
$SPR_{B40\%}$	40.7%	43.4%	50.5%
Exploitation fraction resulting in $B_{40\%}$	14.4%	18.9%	23.2%
Yield at $B_{40\%}$ (thousand t)	264	352	503
Reference points based on estimated MSY			
Female spawning biomass (B_{MSY} thousand t)	357	561	895
SPR_{MSY}	18.5%	29.0%	44.7%
Exploitation fraction corresponding to SPR_{MSY}	17.6%	33.3%	59.6%
MSY (thousand t)	277	384	563

Table 14: Forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Quantiles from the base model are shown in the center of the table with median (50% quantile) in bold. "Alt. Survey" values on the right side are median values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e, g), the TAC from 2014 (row f), the catch level that results in a 50% probability that the median projected catch will remain the same in 2015 (row h), the catch values that result in a median SPR ratio of 1.0 (row i), and the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base (row j). Catch in 2017 is not given because it does not impact the beginning of the year biomass in 2017.

Within model quantile			5%	25%	**50%**	75%	95%		**50%**
Management Action			Beginning of year relative spawning biomass						**Alt. Survey**
	Year	Catch (t)							
a: No catch	2015	0	40%	58%	**74%**	93%	132%		**60%**
	2016	0	42%	61%	**77%**	97%	138%		**62%**
	2017		44%	62%	**78%**	100%	147%		**64%**
b:	2015	180,000	40%	58%	**74%**	93%	132%		**60%**
	2016	180,000	37%	57%	**74%**	94%	134%		**58%**
	2017		36%	55%	**70%**	92%	139%		**56%**
c:	2015	300,000	40%	58%	**74%**	93%	132%		**60%**
	2016	300,000	35%	54%	**71%**	91%	132%		**56%**
	2017		31%	50%	**65%**	87%	134%		**51%**
d:	2015	350,000	40%	58%	**74%**	93%	132%		**60%**
	2016	350,000	33%	53%	**70%**	90%	130%		**55%**
	2017		29%	48%	**63%**	85%	133%		**49%**
e:	2015	400,000	40%	58%	**74%**	93%	132%		**60%**
	2016	400,000	32%	52%	**69%**	89%	130%		**53%**
	2017		26%	46%	**61%**	83%	130%		**47%**
f: 2014 TAC	2015	428,000	40%	58%	**74%**	93%	132%		**60%**
	2016	428,000	32%	51%	**68%**	88%	129%		**53%**
	2017		25%	45%	**60%**	82%	129%		**46%**
g:	2015	500,000	40%	58%	**74%**	93%	132%		**60%**
	2016	500,000	30%	50%	**66%**	86%	128%		**51%**
	2017		22%	42%	**57%**	79%	126%		**43%**
h: highest	2015	710,000	40%	58%	**74%**	93%	132%		**60%**
C2015=	2016	710,000	26%	45%	**62%**	82%	123%		**46%**
C2016	2017		13%	33%	**48%**	70%	117%		**34%**
i: fishing	2015	730,000	40%	58%	**74%**	93%	132%		**60%**
intensity	2016	650,000	25%	45%	**61%**	81%	122%		**46%**
=100%	2017		14%	34%	**49%**	72%	118%		**35%**
j: default	2015	804,576	40%	58%	**74%**	93%	132%		**60%**
harvest	2016	682,782	24%	43%	**60%**	79%	120%		**44%**
rule	2017		12%	32%	**47%**	69%	116%		**32%**

Table 15: Forecast quantiles of Pacific Hake fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2014-2016 catch alternatives presented in Table 14 Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy calculated using baseline selectivity. "Alt. Survey" values on the right side are median values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document.

Within model quantile			5%	25%	**50%**	75%	95%		**50%**
Management Action			Fishing Intensity						**Alt. Survey**
	Year	Catch (t)							
a: No catch	2015	0	0%	0%	**0%**	0%	0%		**0%**
	2016	0	0%	0%	**0%**	0%	0%		**0%**
	2017	0	0%	0%	**0%**	0%	0%		**0%**
b:	2015	180,000	24%	35%	**43%**	53%	71%		**51%**
	2016	180,000	23%	33%	**41%**	51%	70%		**49%**
	2017	180,000	23%	33%	**42%**	53%	72%		**51%**
c:	2015	300,000	37%	51%	**62%**	74%	93%		**72%**
	2016	300,000	35%	49%	**61%**	74%	96%		**72%**
	2017	300,000	36%	51%	**64%**	78%	102%		**76%**
d:	2015	350,000	42%	57%	**69%**	81%	100%		**79%**
	2016	350,000	40%	55%	**68%**	81%	104%		**79%**
	2017	350,000	41%	58%	**72%**	87%	112%		**84%**
e:	2015	400,000	46%	62%	**74%**	87%	105%		**84%**
	2016	400,000	44%	61%	**74%**	88%	111%		**86%**
	2017	400,000	46%	64%	**79%**	95%	120%		**92%**
f: 2014 TAC	2015	428,000	49%	65%	**77%**	90%	108%		**87%**
	2016	428,000	47%	64%	**78%**	91%	115%		**89%**
	2017	428,000	49%	68%	**83%**	99%	123%		**96%**
g:	2015	500,000	54%	71%	**84%**	96%	114%		**94%**
	2016	500,000	53%	71%	**86%**	99%	122%		**97%**
	2017	500,000	55%	76%	**92%**	108%	132%		**106%**
h: highest	2015	710,000	68%	87%	**99%**	111%	127%		**109%**
C2015=	2016	710,000	68%	89%	**104%**	117%	137%		**115%**
C2016	2017	710,000	72%	96%	**113%**	129%	141%		**127%**
i: fishing	2015	730,000	69%	88%	**100%**	112%	128%		**110%**
intensity	2016	650,000	65%	85%	**100%**	114%	136%		**113%**
=100%	2017	520,000	60%	82%	**100%**	118%	139%		**121%**
j: default	2015	804,576	73%	92%	**104%**	115%	131%		**114%**
harvest	2016	682,782	67%	88%	**104%**	118%	138%		**116%**
rule	2017	547,280	62%	86%	**104%**	122%	140%		**120%**

Table 16: Probabilities related to spawning biomass, fishing intensity, and 2016 catch limits for alternative 2015 catch options (catch options explained in Table 14). "Alternative survey" values in the lower section are values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document.

Catch in 2015	Probability B2016<B2015	Probability B2016<B40%	Probability B2016<B25%	Probability B2016<B10%	Probability Fishing intensity in 2015 > 40% Target	Probability 2016 Catch Target < 2015 Catch
a: 0	39%	4%	0%	0%	0%	0%
b: 180,000	68%	6%	1%	0%	0%	1%
c: 300,000	80%	8%	1%	0%	3%	4%
d: 350,000	83%	9%	2%	0%	5%	6%
e: 400,000	85%	9%	2%	0%	8%	9%
f: 428,000	86%	10%	2%	0%	10%	11%
g: 500,000	89%	12%	3%	0%	18%	20%
h: 710,000	94%	18%	5%	1%	47%	50%
i: 730,000	94%	19%	5%	1%	50%	53%
j: 804,576	95%	21%	6%	1%	58%	62%
Alternative survey indices in 2012 and 2013						
a: 0	33%	12%	1%	0%	0%	0%
b: 180,000	71%	19%	3%	0%	1%	2%
c: 300,000	83%	23%	5%	0%	8%	11%
d: 350,000	85%	24%	6%	0%	15%	17%
e: 400,000	87%	26%	6%	0%	24%	26%
f: 428,000	88%	28%	7%	0%	28%	29%
g: 500,000	90%	31%	8%	0%	39%	41%
h: 710,000	95%	41%	14%	2%	67%	68%
i: 730,000	95%	41%	15%	2%	70%	71%
j: 804,576	96%	43%	18%	2%	76%	77%

Table 17: Probabilities related to spawning biomass, fishing intensity, and 2017 catch limits for alternative 2016 catch options (catch options explained in Table 14). "Alternative survey" values in the lower section are values from a model fit to an alternative set of acoustic survey biomass values as described in the "Sensitivity analyses" section of the document.

Catch in 2016	Probability B2017<B2016	Probability B2017<B40%	Probability B2017<B25%	Probability B2017<B10%	Probability Fishing intensity in 2016 > 40% Target	Probability 2017 Catch Target < 2016 Catch
a: 0	51%	4%	0%	0%	0%	0%
b: 180,000	71%	8%	1%	0%	0%	1%
c: 300,000	78%	13%	3%	0%	4%	5%
d: 350,000	81%	15%	4%	0%	6%	10%
e: 400,000	83%	18%	5%	1%	11%	16%
f: 428,000	84%	19%	5%	1%	14%	19%
g: 500,000	86%	23%	7%	1%	24%	32%
h: 710,000	91%	38%	16%	3%	57%	64%
i: 650,000	90%	36%	15%	3%	51%	58%
j: 682,782	90%	40%	17%	4%	57%	63%
Alternative survey indices in 2012 and 2013						
a: 0	48%	9%	1%	0%	0%	0%
b: 180,000	72%	21%	4%	0%	1%	3%
c: 300,000	79%	31%	8%	1%	11%	18%
d: 350,000	82%	35%	10%	1%	20%	26%
e: 400,000	83%	39%	13%	2%	29%	34%
f: 428,000	84%	41%	15%	2%	33%	40%
g: 500,000	87%	46%	20%	3%	45%	53%
h: 710,000	89%	59%	36%	11%	74%	79%
i: 650,000	88%	58%	34%	9%	69%	75%
j: 682,782	89%	60%	39%	12%	73%	78%

Table 18: Select parameters, derived quantities, and reference point estimates for the base model posterior median (MCMC) estimates with comparison to alternative model with lower 2012 and 2013 survey biomass values. The base model values match those shown in Table 12.

	Base model posterior median	Alternative survey posterior median
Parameters		
R_0 (millions)	2,923	2,834
Steepness (h)	0.814	0.809
Natural mortality (M)	0.223	0.223
Acoustic catchability (Q)	—	—
Additional acoustic survey SD	0.376	0.357
Derived Quantities		
2008 recruitment (millions)	5,987	5,337
2010 recruitment (millions)	14,799	12,133
B_0 (thousand t)	2,268	2,215
2009 Relative Spawning Biomass	22.0%	21.2%
2015 Relative Spawning Biomass	73.6%	60.2%
2014 Fishing intensity: (1-SPR)/(1-SPR40%)	61.6%	70.2%
Default harvest catch limit for 2015 (t)	804,576	628,361
Reference points based on $F_{40\%}$		
Female spawning biomass ($B_{F40\%}$ thousand t)	813	788
$SPR_{MSY\text{-}proxy}$	40%	40%
Exploitation fraction corresponding to SPR	21.6%	21.6%
Yield at $B_{F40\%}$ (thousand t)	362	352

Table 19: Maximum likelihood estimates (MLE) of select parameters, derived quantities, and reference points for the base model and sensitivity runs of (1) estimating natural mortality following a Lorenzen function, (2) natural mortality linked to Humboldt Squid abundance, (3) time-invariant weight at age, and (4) autocorrelated recruitments.

	Base case MLE	Lorenzen M	M linked to Humboldt Squid	Time-invariant weight-at-age	Auto-correlated recruits
Parameters					
R_0 (billions)	2.47	6.14	2.39	2.30	2.47
Steepness (h)	0.862	0.875	0.864	0.861	0.865
Natural mortality (M) at age 5	0.213	0.215	0.214	0.211	0.215
Acoustic catchability (Q)	1.012	1.121	1.012	1.034	1.009
Additional acoustic survey SD	0.300	0.295	0.294	0.274	0.300
Derived Quantities					
2008 recruitment (millions)	5,096	13,565	5,303	4,589	5,136
2010 recruitment (millions)	12,106	32,382	11,525	10,934	12,123
B_0 (thousand t)	2,096	2,082	2,146	1,990	2,061
2015 relative spawning biomass	67.2%	64.4%	66.1%	63.6%	67.8%
2014 Fishing intensity (1-SPR/1-SPR40%)	70.8%	79.1%	70.9%	75.2%	70.6%
Reference points based on $F_{40\%}$					
Female spawning biomass ($B_{F40\%}$ thousand t)	786	786	806	746	774
Equilibrium exploitation fraction corresponding to SPR	20.7%	18.6%	20.7%	20.5%	20.8%
Yield at $B_{F40\%}$ (thousand t)	339	300	348	319	337

Table 20: Select parameters, derived quantities, and reference point estimates for retrospective analyses using the base model. Values in italics 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						
R_0 (billions)	2.92	2.90	2.73	2.47	3.04	2.88
Steepness (*h*)	0.814	0.818	0.818	0.814	0.812	0.805
Natural mortality (*M*)	0.223	0.223	0.222	0.219	0.226	0.223
Acoustic catchability (*Q*)	-	-	-	-	-	-
Additional acoustic survey SD	0.376	0.375	0.421	0.496	0.280	0.282
Derived Quantities						
2008 recruitment (millions)	5,987	6,150	5,633	5,499	11,975	1,066
2010 recruitment (millions)	14,799	15,498	11,215	1,824	921	*1,030*
B_0 (thousand t)	2,269	2,259	2,140	1,988	2,345	2,248
2009 relative spawning biomass	22.0%	21.1%	17.9%	17.0%	43.3%	50.7%
2015 relative spawning biomass	73.6%	*77.1%*	*64.2%*	*30.4%*	*68.3%*	*38.7%*
2014 Fishing intensity (1-SPR/1-SPR40%)	61.6%	*58.9%*	*70.2%*	*100.4%*	*56.6%*	*82.3%*
Reference points based on $F_{40\%}$						
Female spawning biomass ($B_{F40\%}$ thousand t)	814	803	770	707	824	793
Equilibrium exploitation fraction corresponding to SPR	21.6%	21.6%	21.6%	21.3%	22.0%	21.7%
Yield at $B_{F40\%}$ (thousand t)	362	361	345	315	378	358

8 Figures

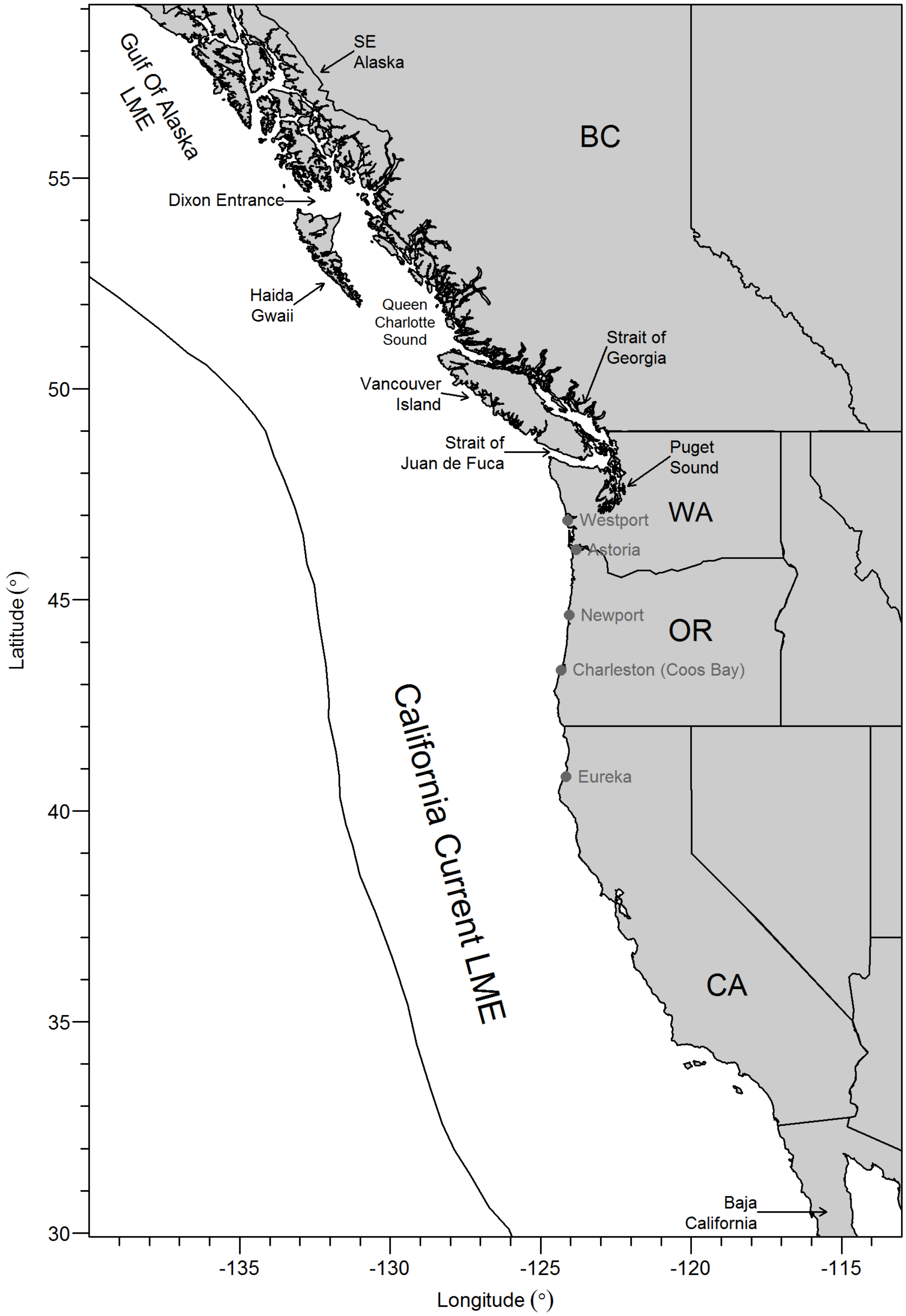


Figure 1: Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.

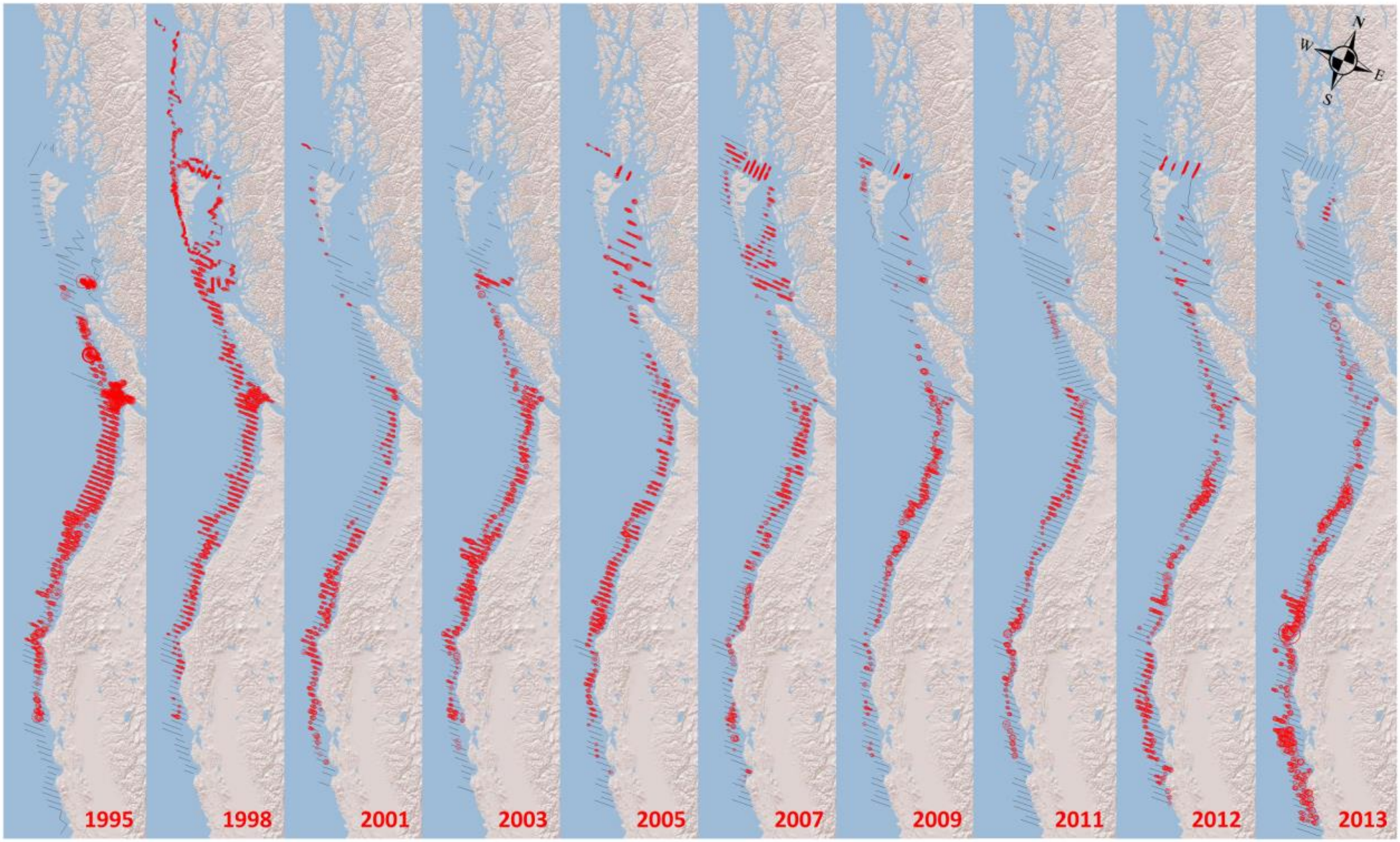


Figure 2: Spatial distribution of acoustic backscatter attributable to Pacific Hake from joint US-Canada acoustic surveys 1995-2013. Area of the circle is roughly proportional to observed backscatter.

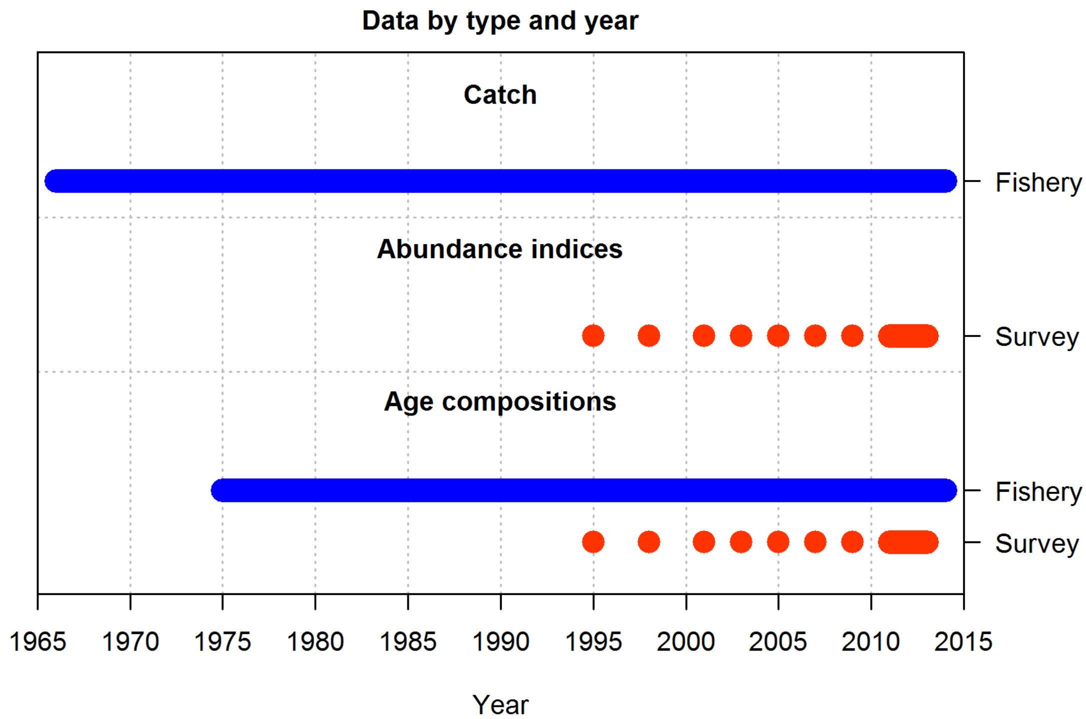


Figure 3: Overview of data used in this assessment, 1966-2014.

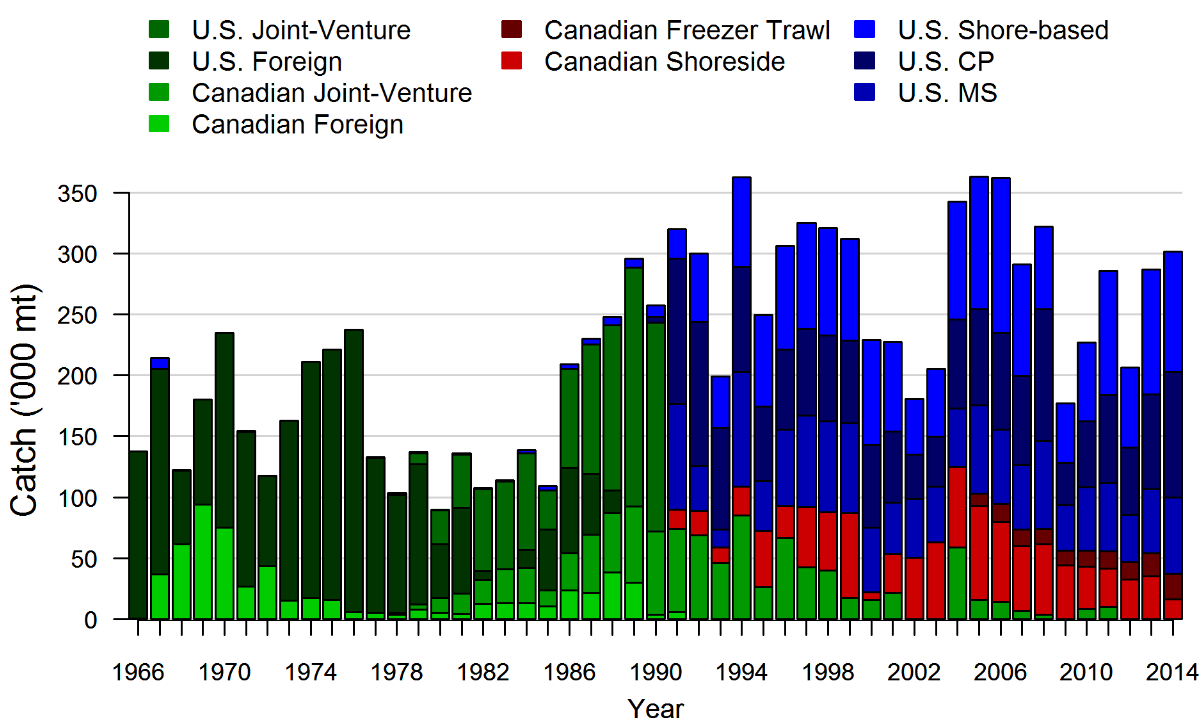


Figure 4: Total Pacific Hake landings used in the assessment by sector, 1966–2014

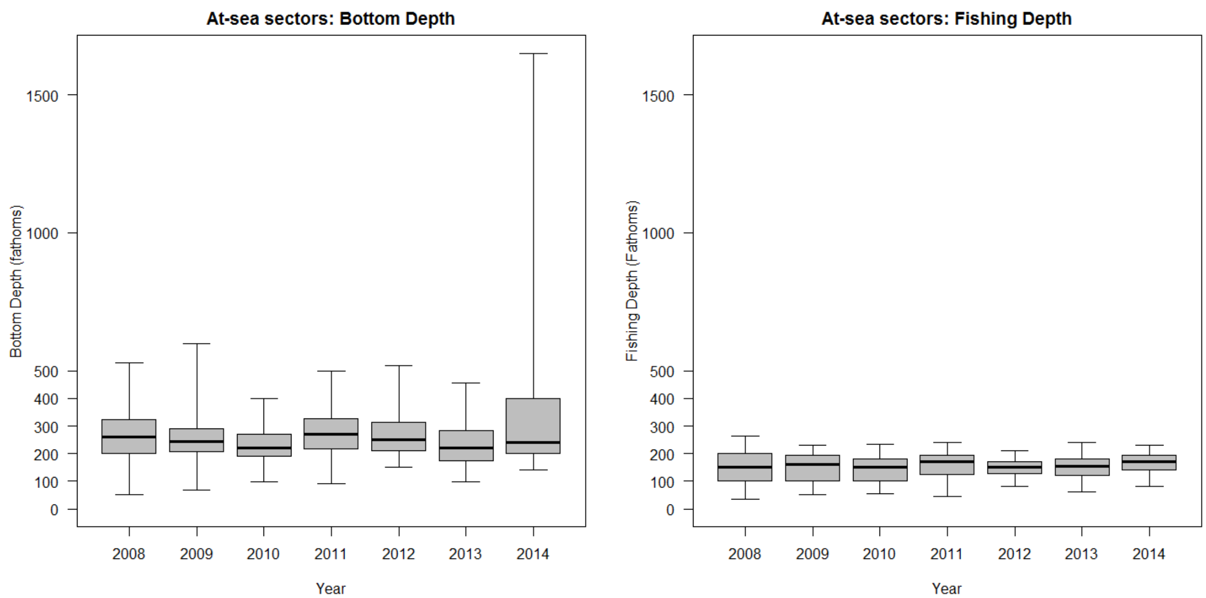


Figure 5: Distribution of bottom depths (left) and fishing depth (right) in fathoms of Pacific Hake catches in the U.S. at-sea fleet from 2008 to 2014.

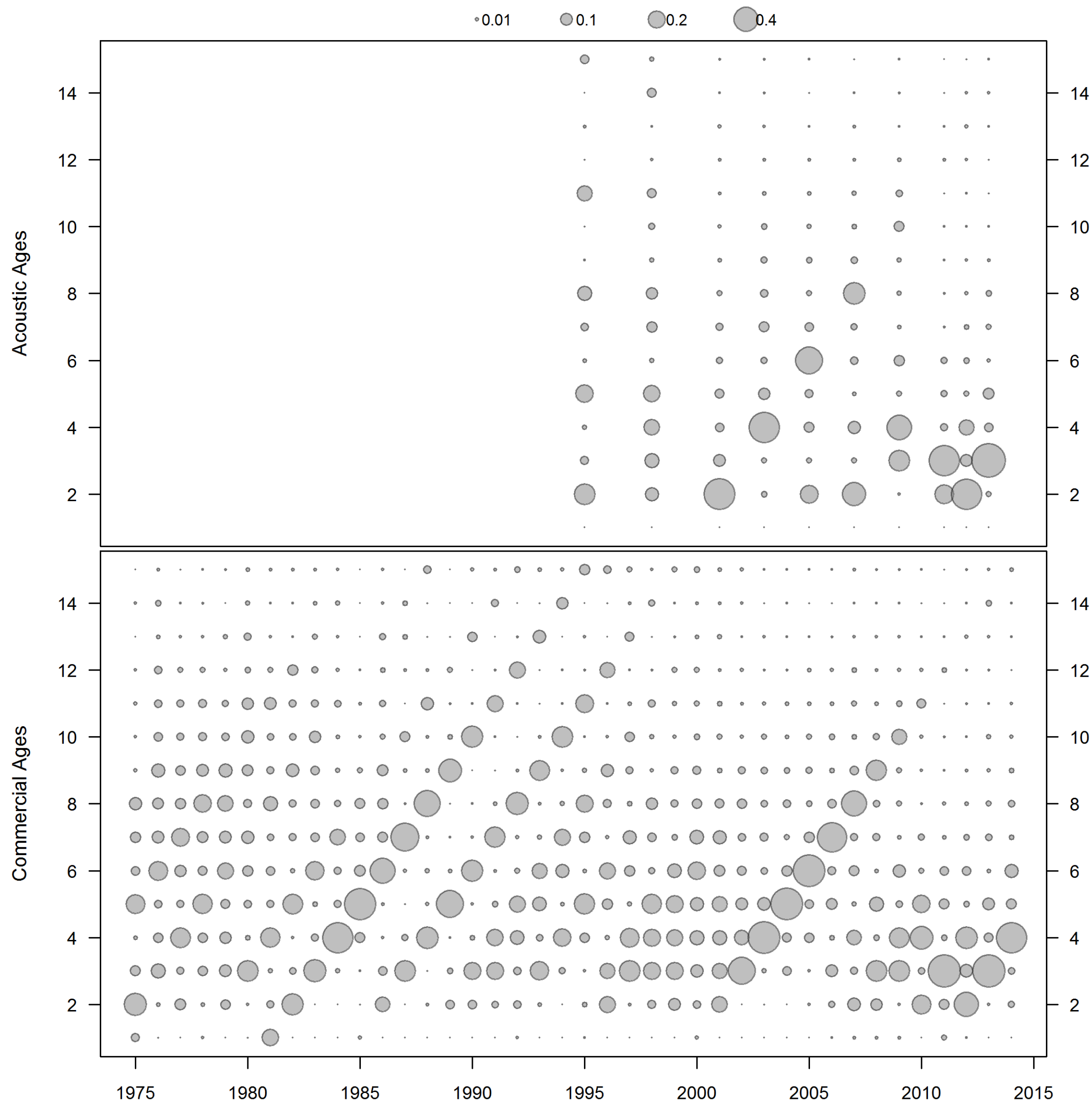


Figure 6: Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2014. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top). The largest bubble is 0.76 for age 3 in the 2013 acoustic survey.

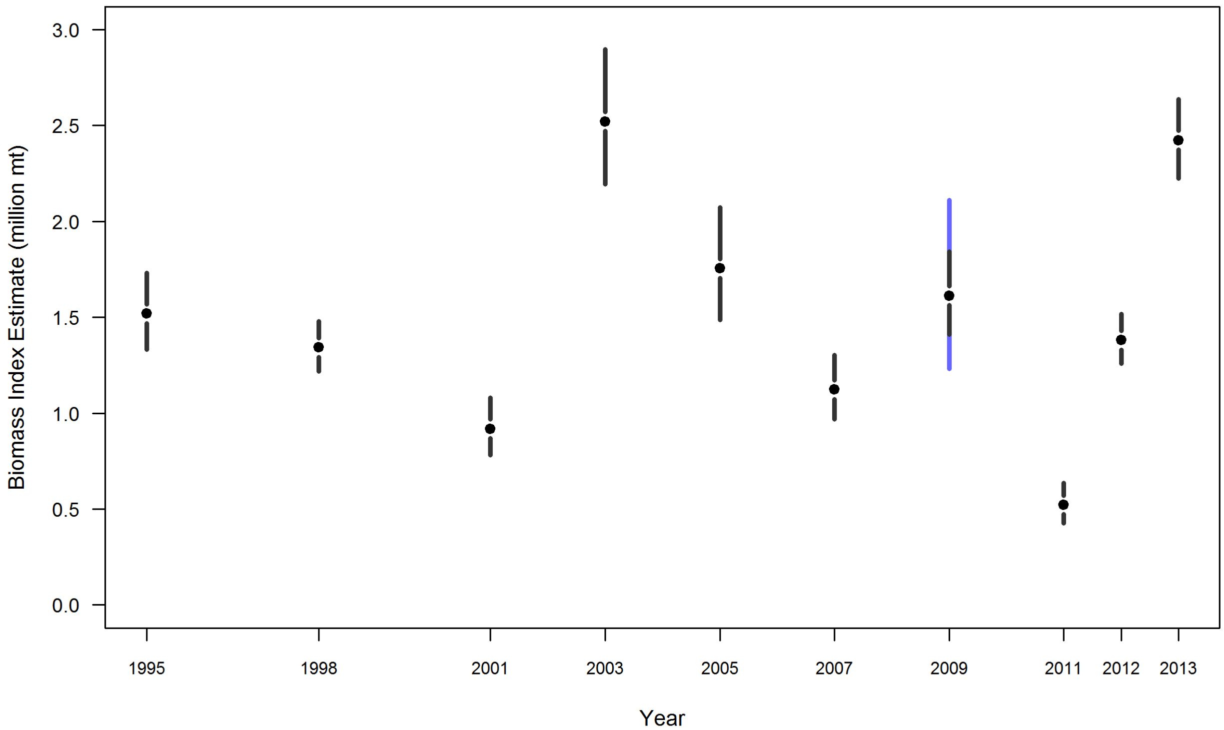


Figure 7: Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995-2007, 2011–2013) and sampling variability as well as squid/hake apportionment uncertainty (blue bars, 2009). No new acoustic survey was conducted in 2014.

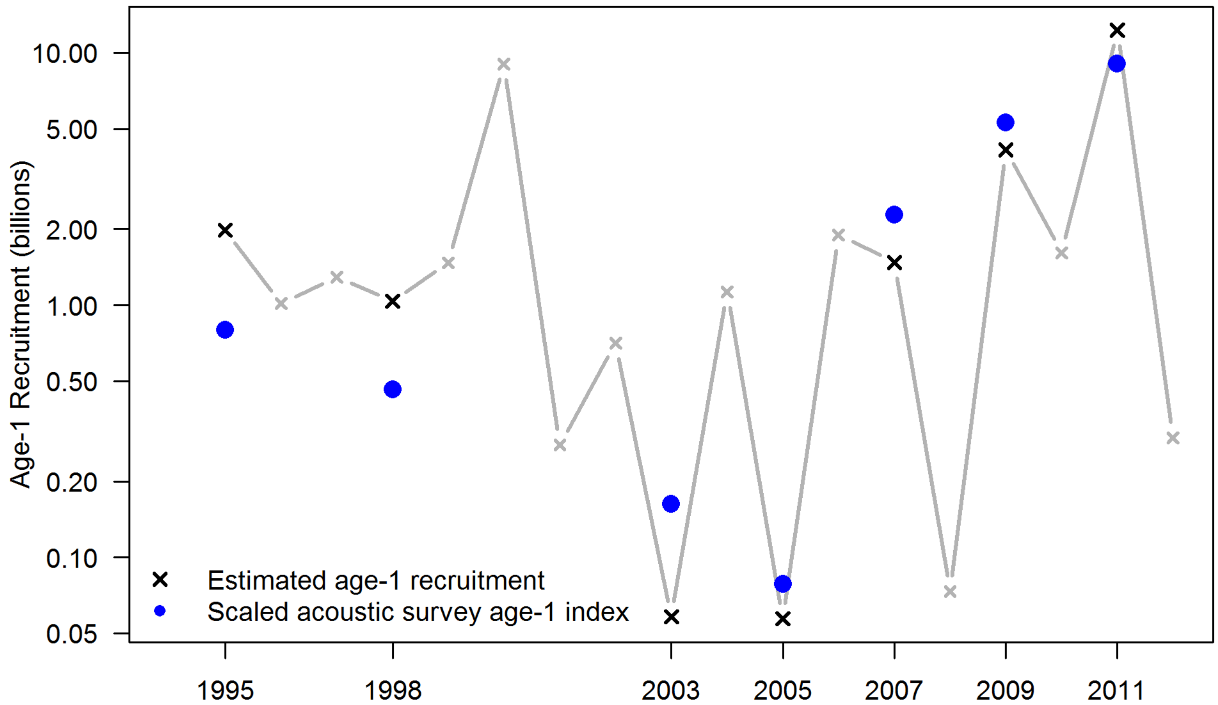


Figure 8: Preliminary acoustic survey age-1 index overlaid on the base model predicted posterior median numbers at age-1. The y-axis is on a log scale with labels in real space. This figure represents a comparison with, not a fit to, the preliminary age-1 index data.

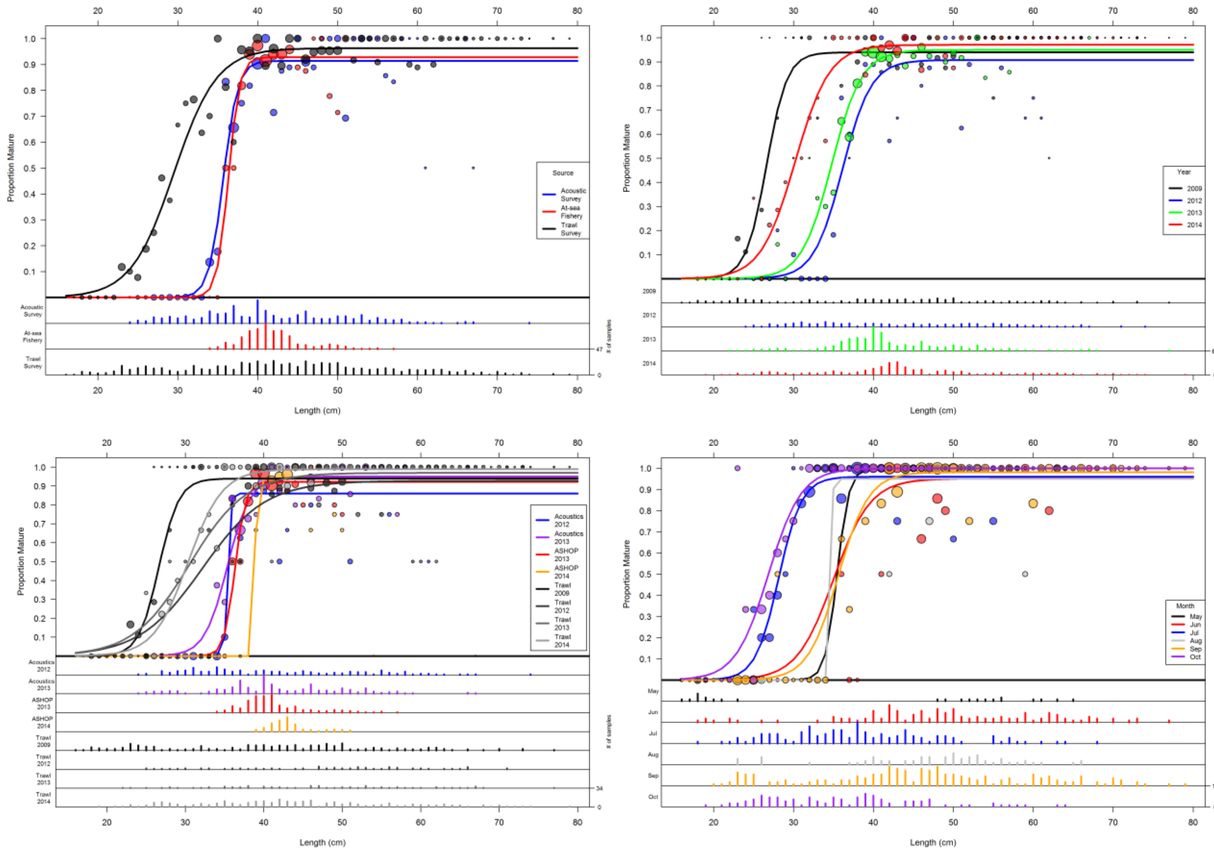


Figure 9: Maturity observations of the proportion mature at length (bubbles with circle size relative to number of samples at length), fitted lines for proportion mature at length with an estimated asymptote, and number of samples at length below for categories of source (top left), year (top right), source and year (bottom left), and month for the trawl survey only (bottom right).

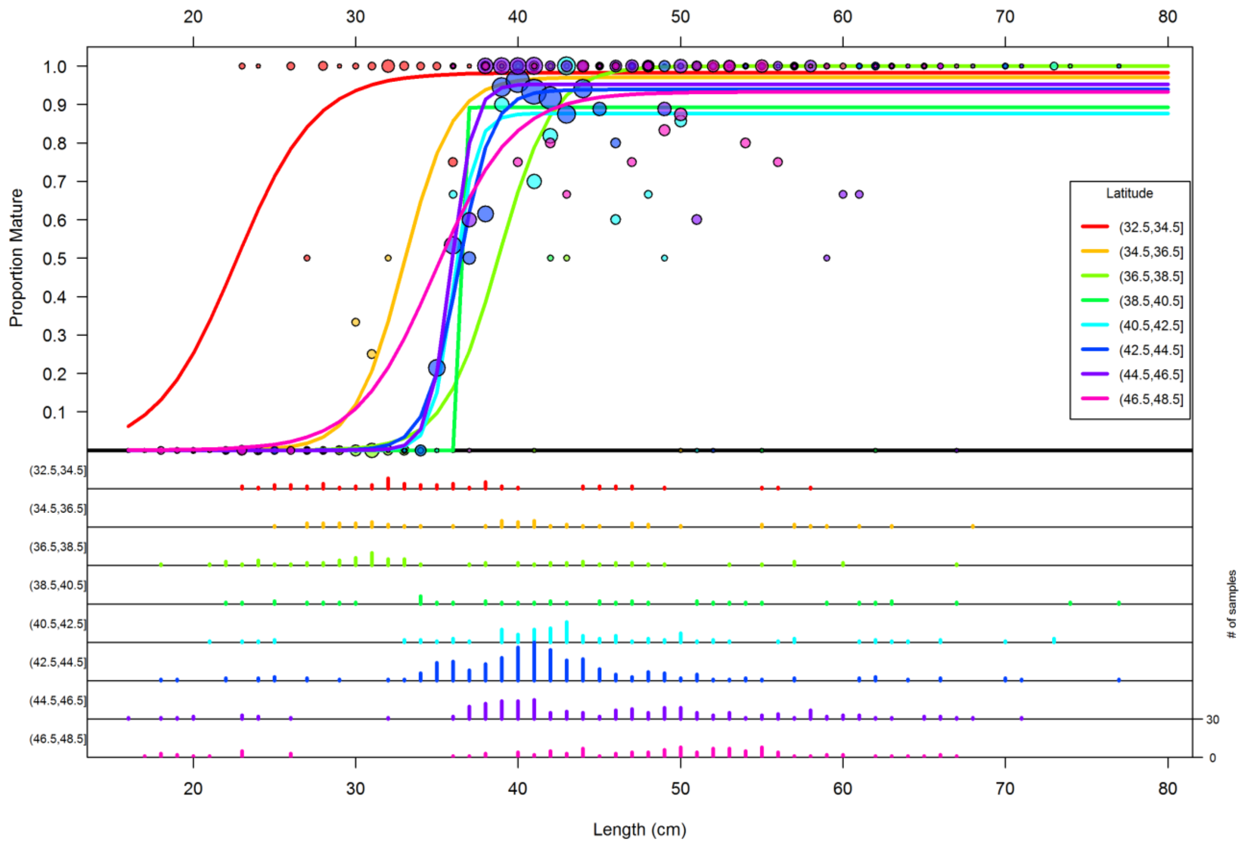


Figure 10: Maturity observations of the proportion mature at length (bubbles with circle size relative to number of samples at length), fitted lines for proportion mature at length with an estimated asymptote (upper panel), and number of samples at length below by two degree latitude bins (bottom panel).

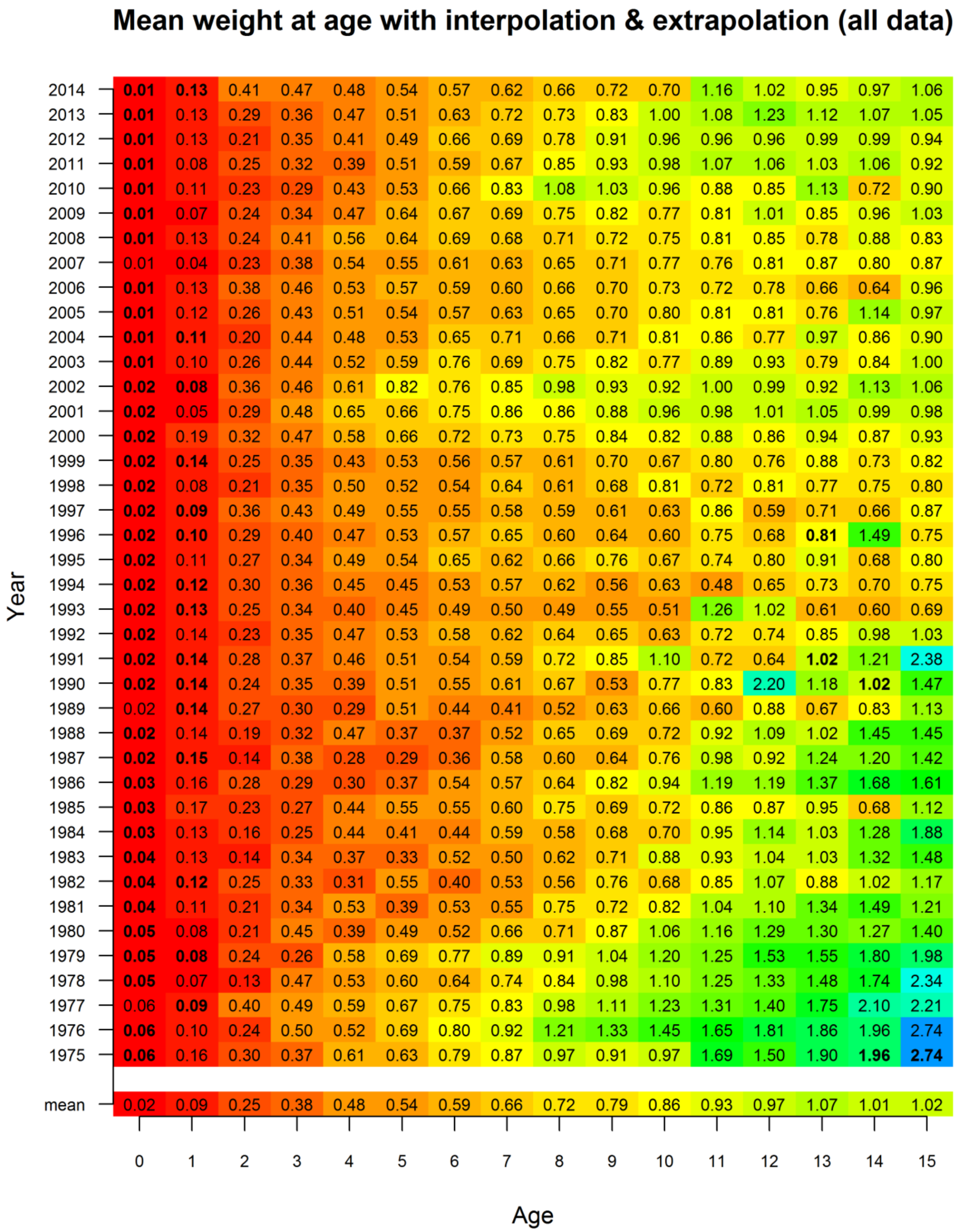


Figure 11: Empirical weight-at-age (kg) used in the assessment. Numbers shown in bold were interpolated or extrapolated from adjacent years.

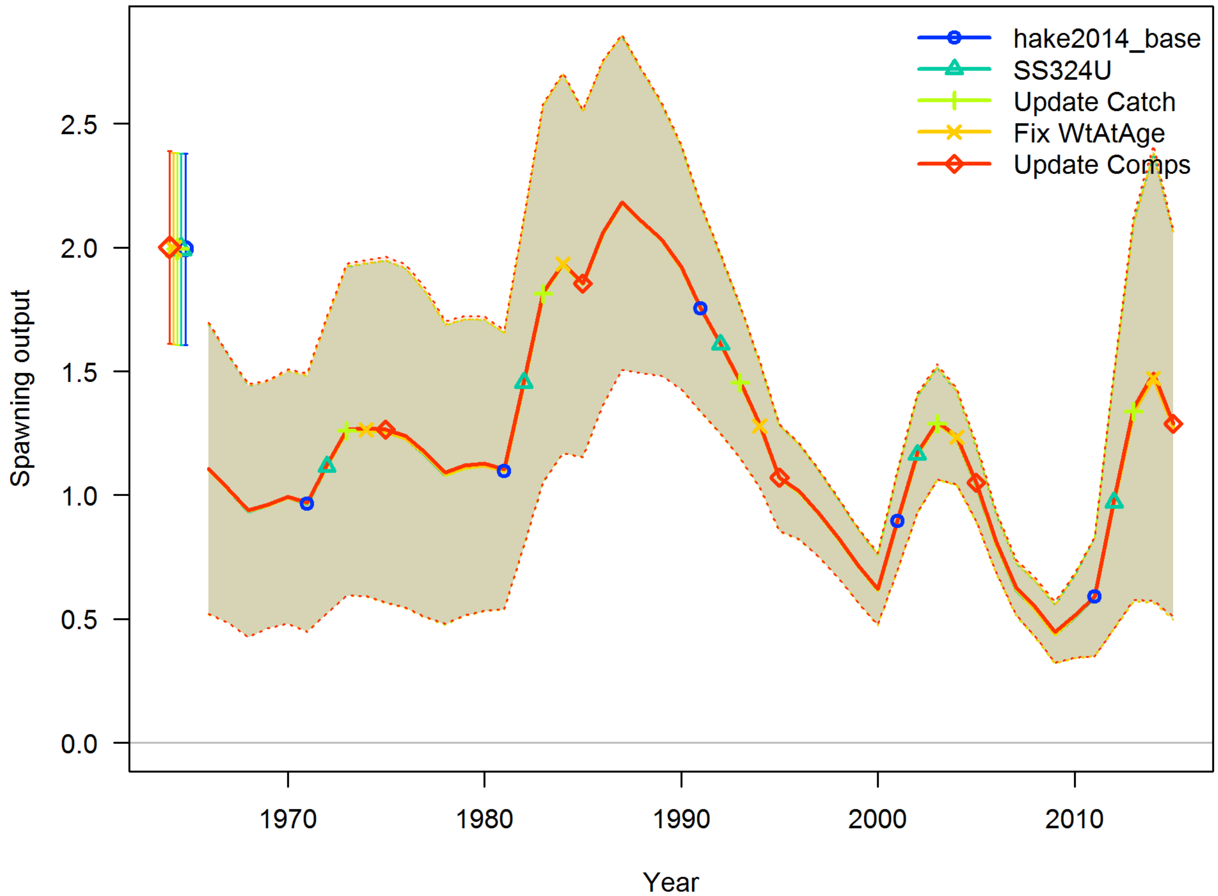


Figure 12: Sequential bridge models from the 2014 base model (hake2014_base) to a new version of Stock Synthesis (SS324U), updating the 2013 catches (Update Catch), fixing a minor error in the calculation of weight-at-age (Fix WtAtAge), and updating the 2013 composition data (Update Comps). The points disconnected from the time-series on the left side show the unfished equilibrium spawning biomass estimates.

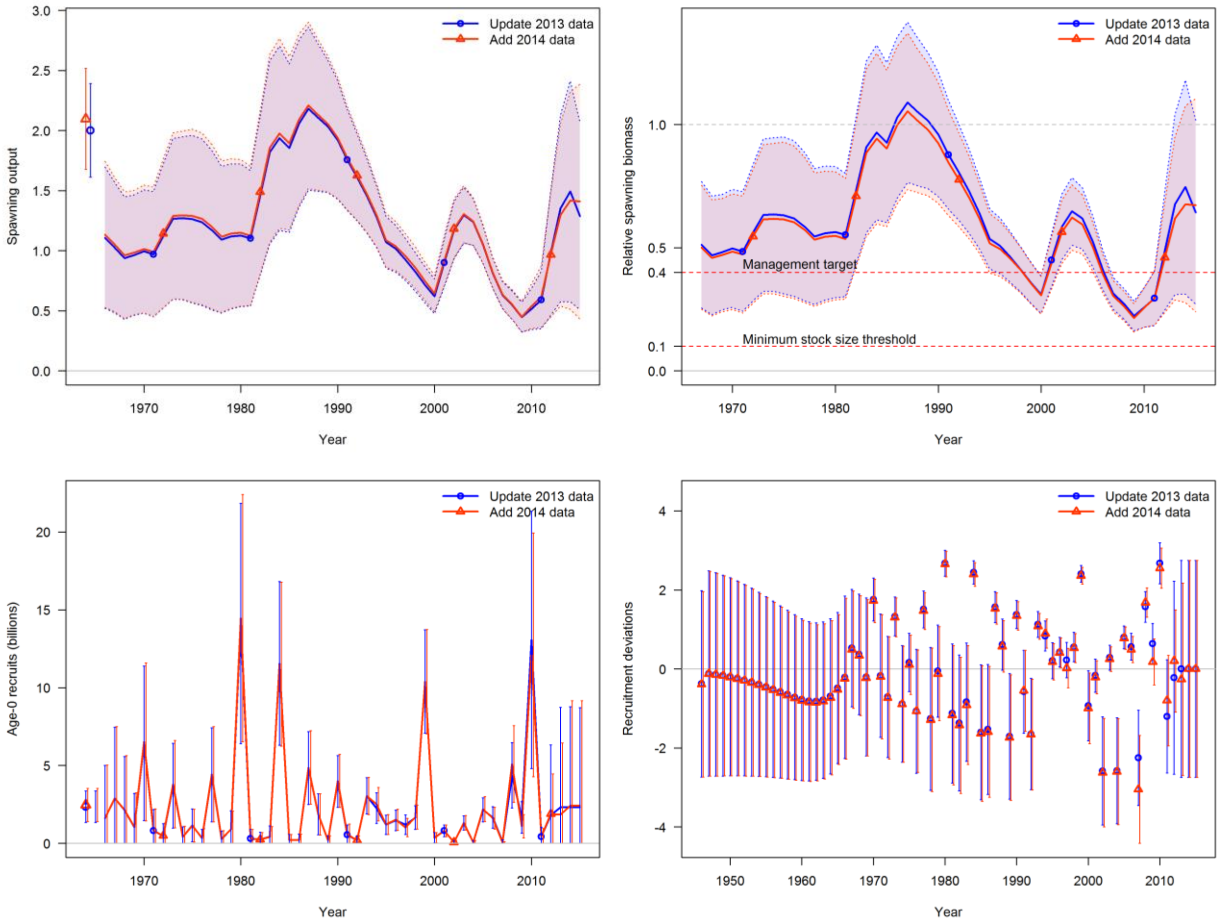


Figure 13: Bridge models showing the difference between the model with updated 2013 data (blue) and the base model with all new 2014 data (red). Spawning biomass (upper left), relative spawning biomass (spawning biomass in each year relative to the unfished equilibrium spawning biomass, upper right), absolute recruitment (lower left), and recruitment deviations (lower right) are shown.

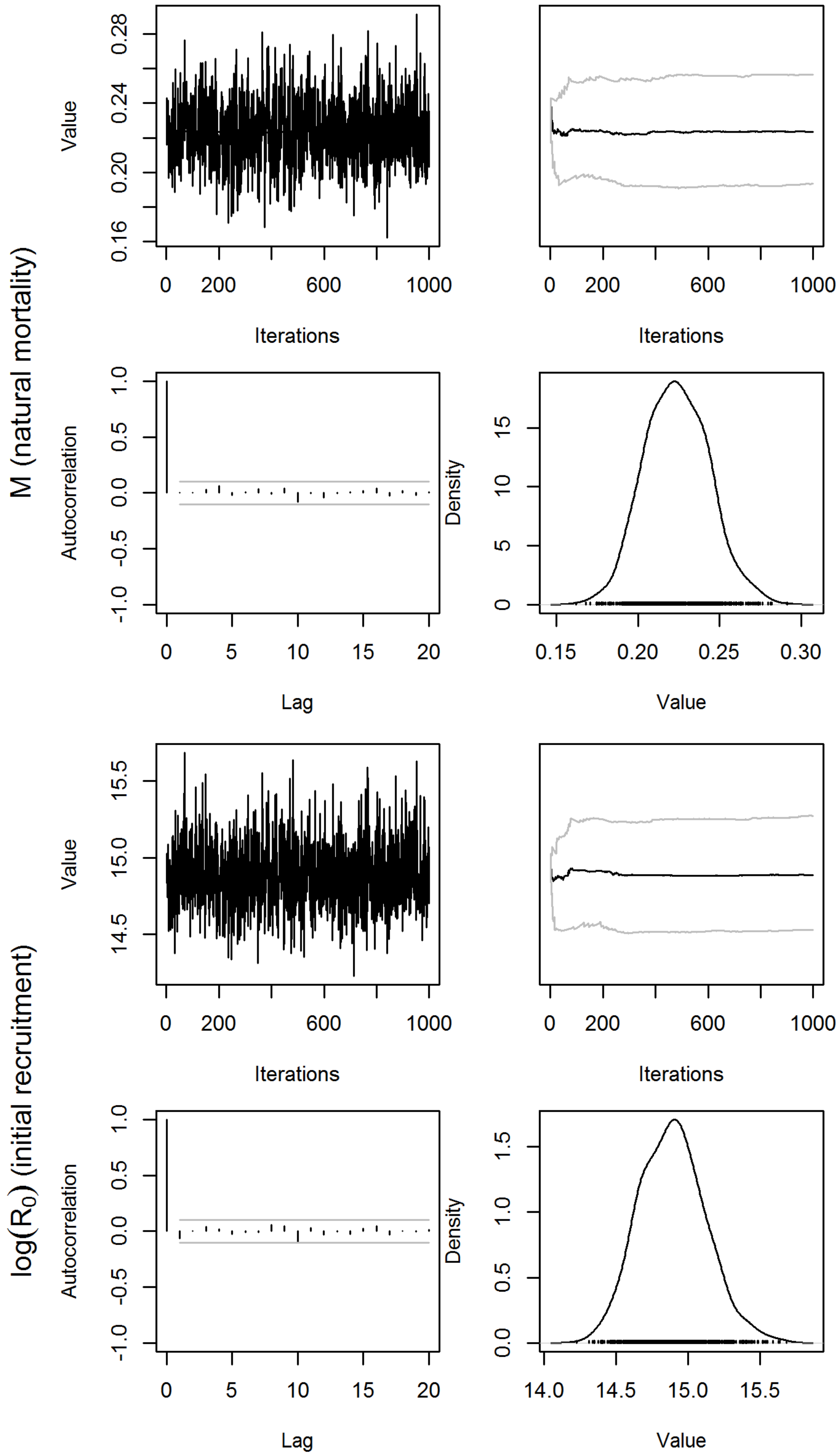


Figure 14: Summary of MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels) in the base model.

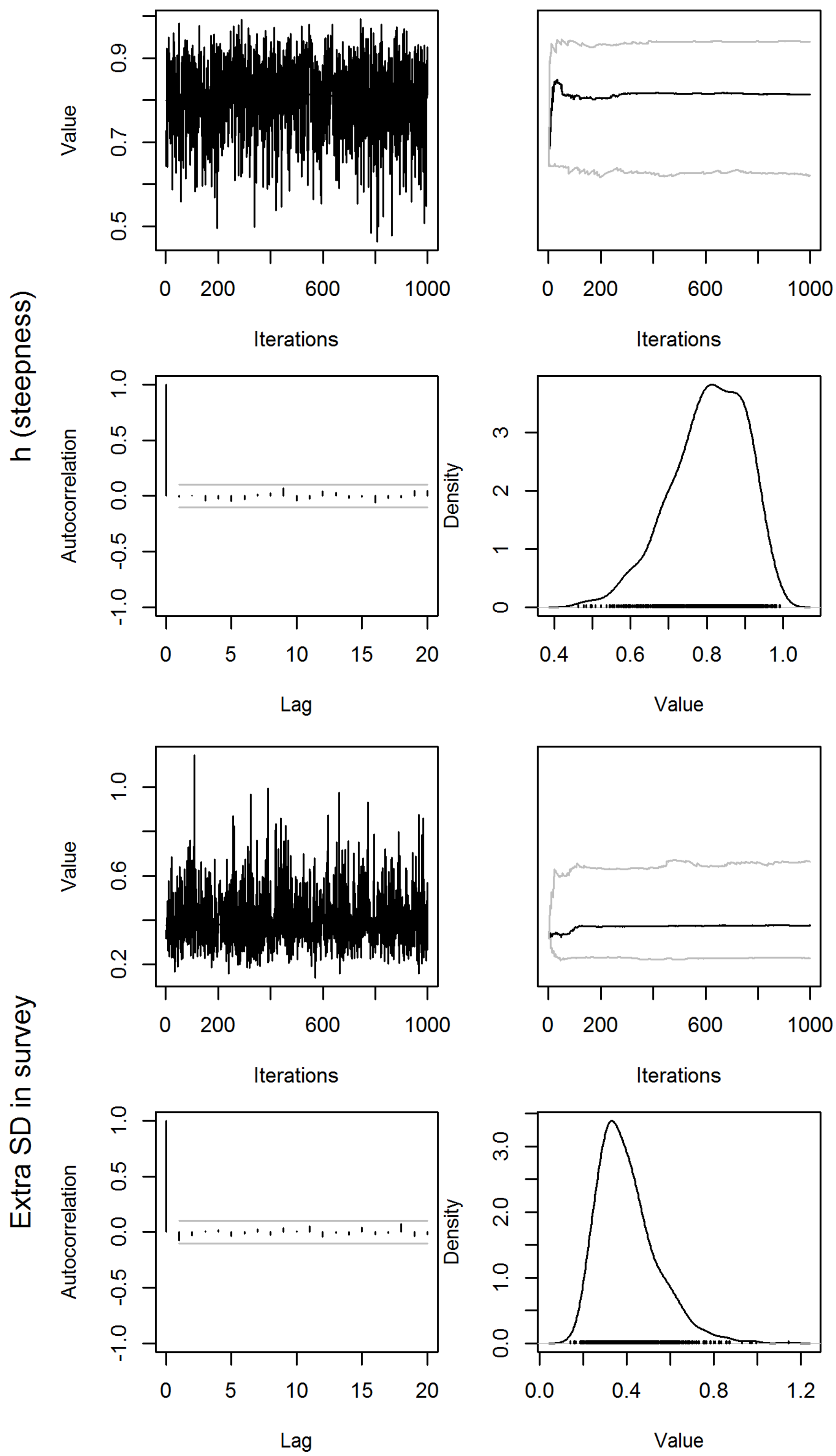


Figure 15: Summary of MCMC diagnostics for steepness (upper panels) and the additional standard deviation (SD) for the acoustic survey index (lower panels) in the base model.

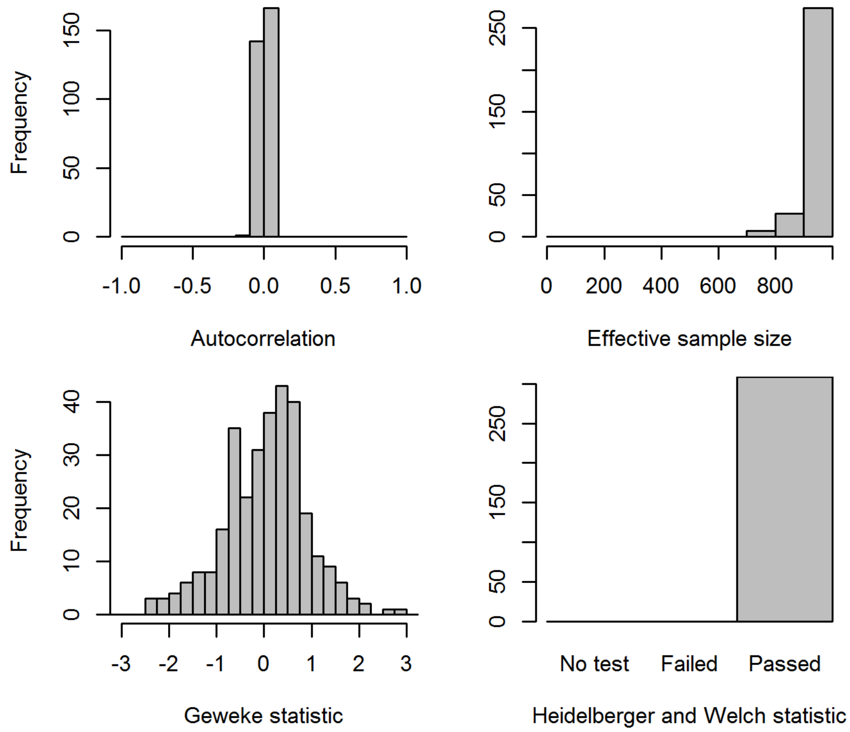


Figure 16: Summary histograms of MCMC diagnostics for all base model parameters along with derived quantities for the time-series of spawning biomass, and relative spawning biomass.

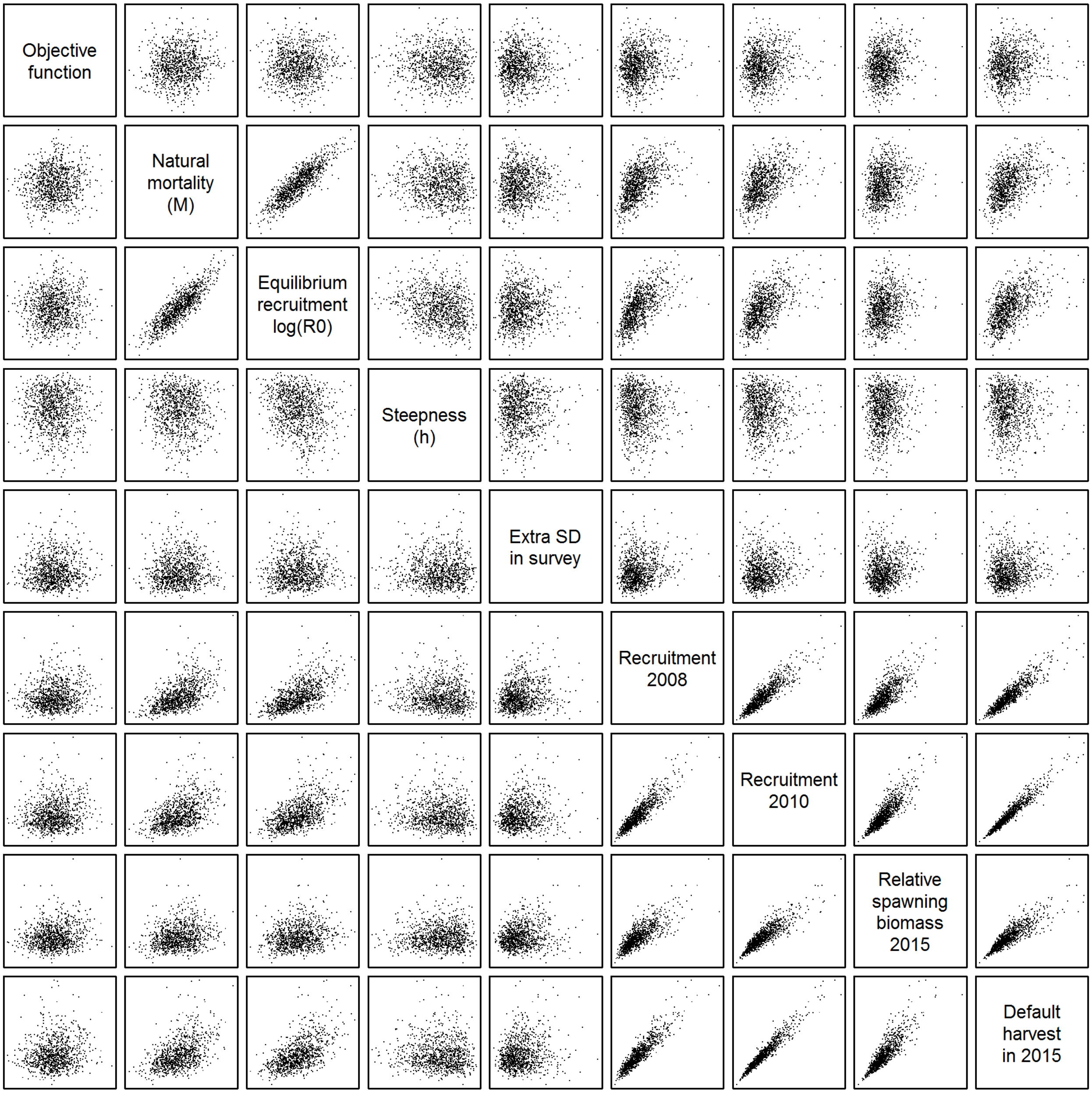


Figure 17: Posterior correlations among key base-model parameters and derived quantities.

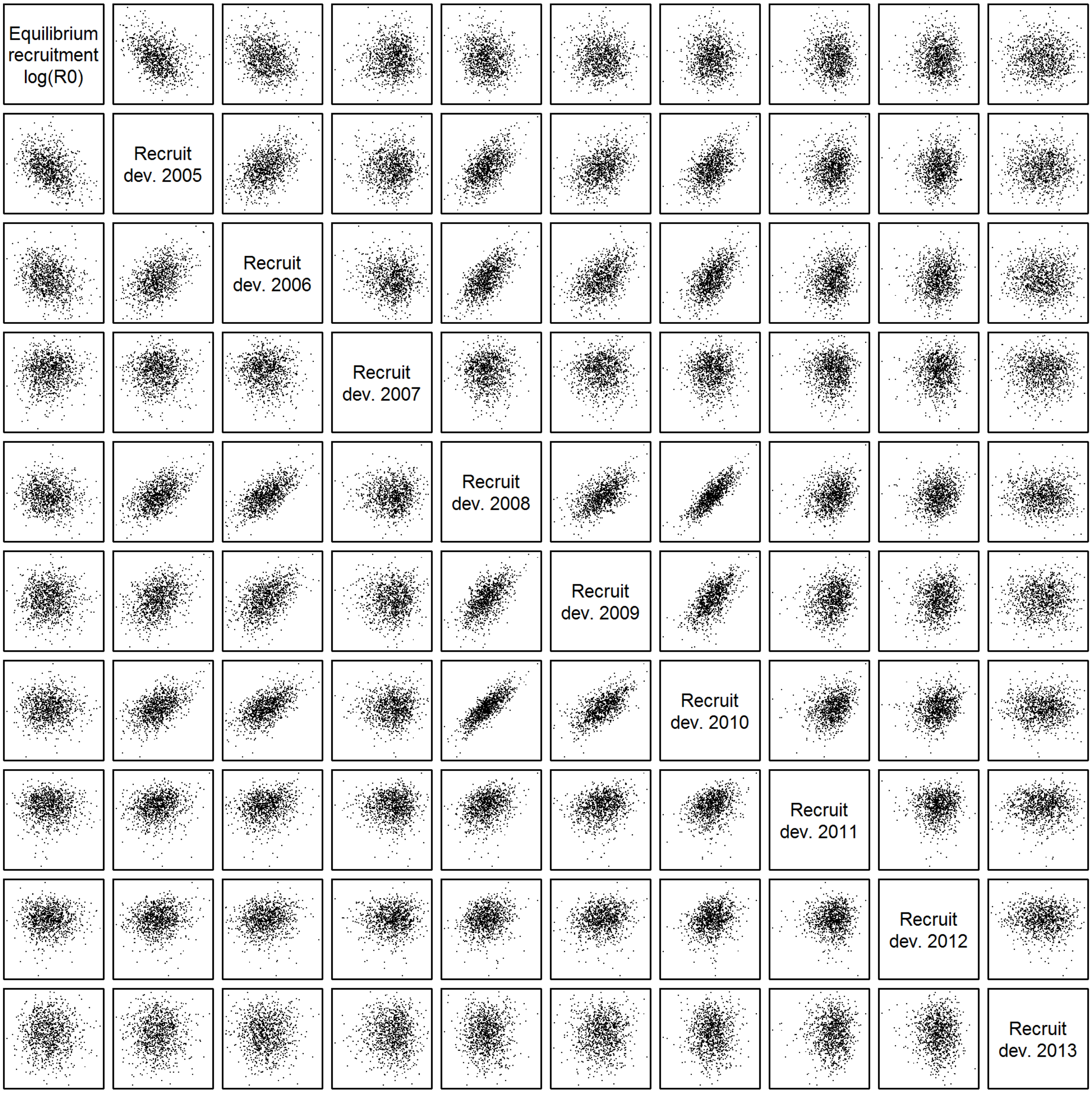


Figure 18: Posterior correlations among recruitment deviations from recent years.

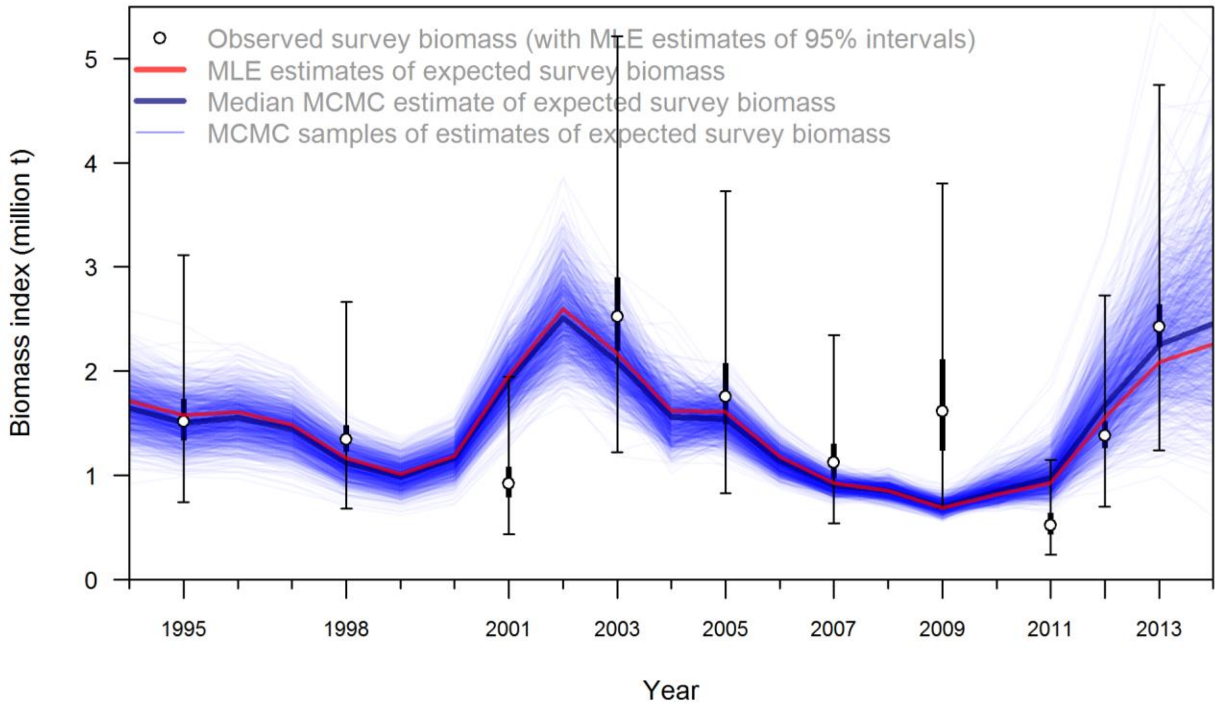


Figure 19: Fits to the acoustic survey with 95% confidence intervals around the index points. Red and blue thick lines are MLE and median MCMC expected survey estimates in every year, including years without a survey. Thin blue lines show individual MCMC samples of the expected survey biomass. Thicker 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.

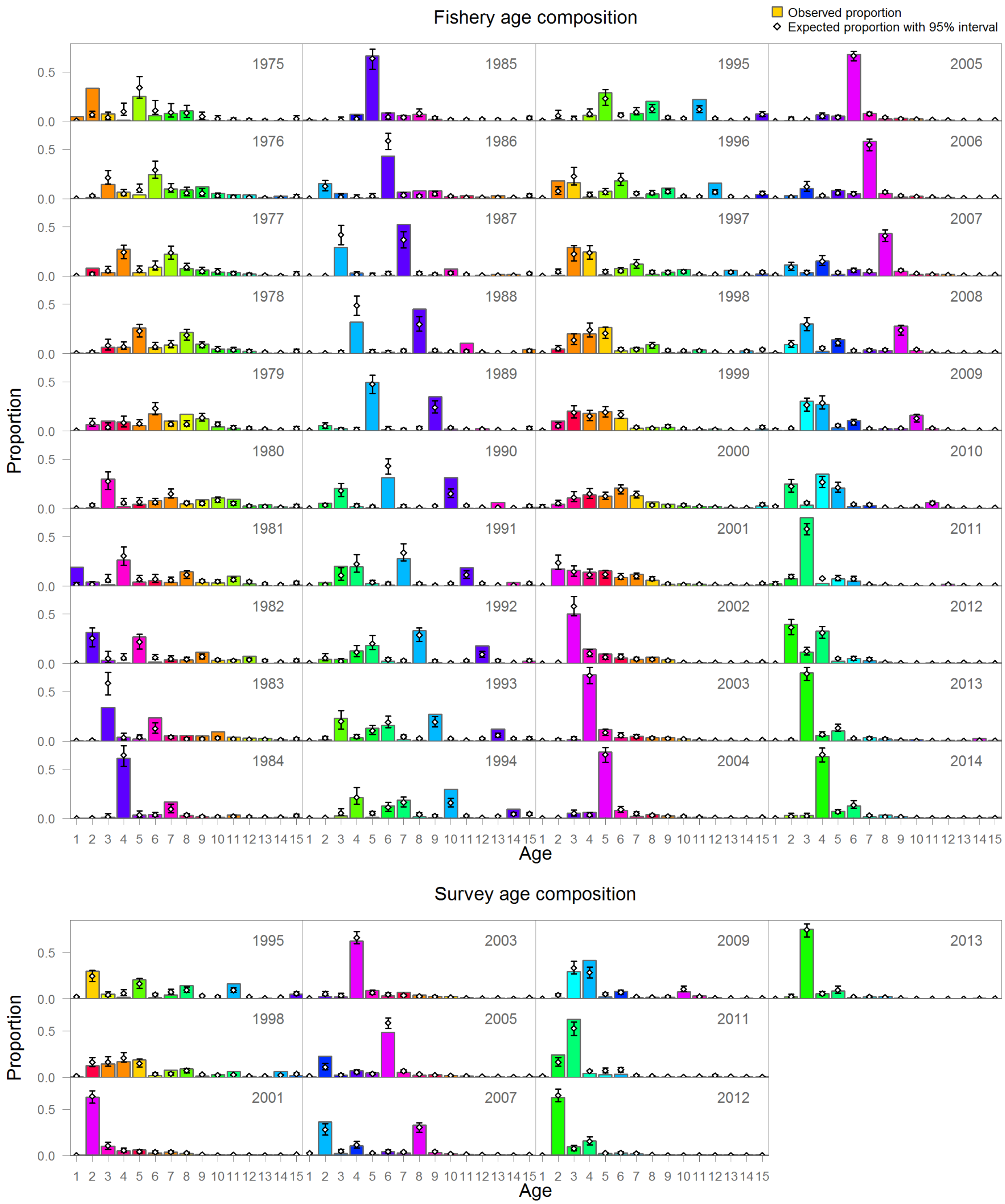


Figure 20: Base model fit to the observed fishery (top) and acoustic survey (bottom) age composition data. Colored bars show observed proportions with colors following each cohort across years. Points with intervals indicate median expected proportions and 95% uncertainty intervals from the MCMC.

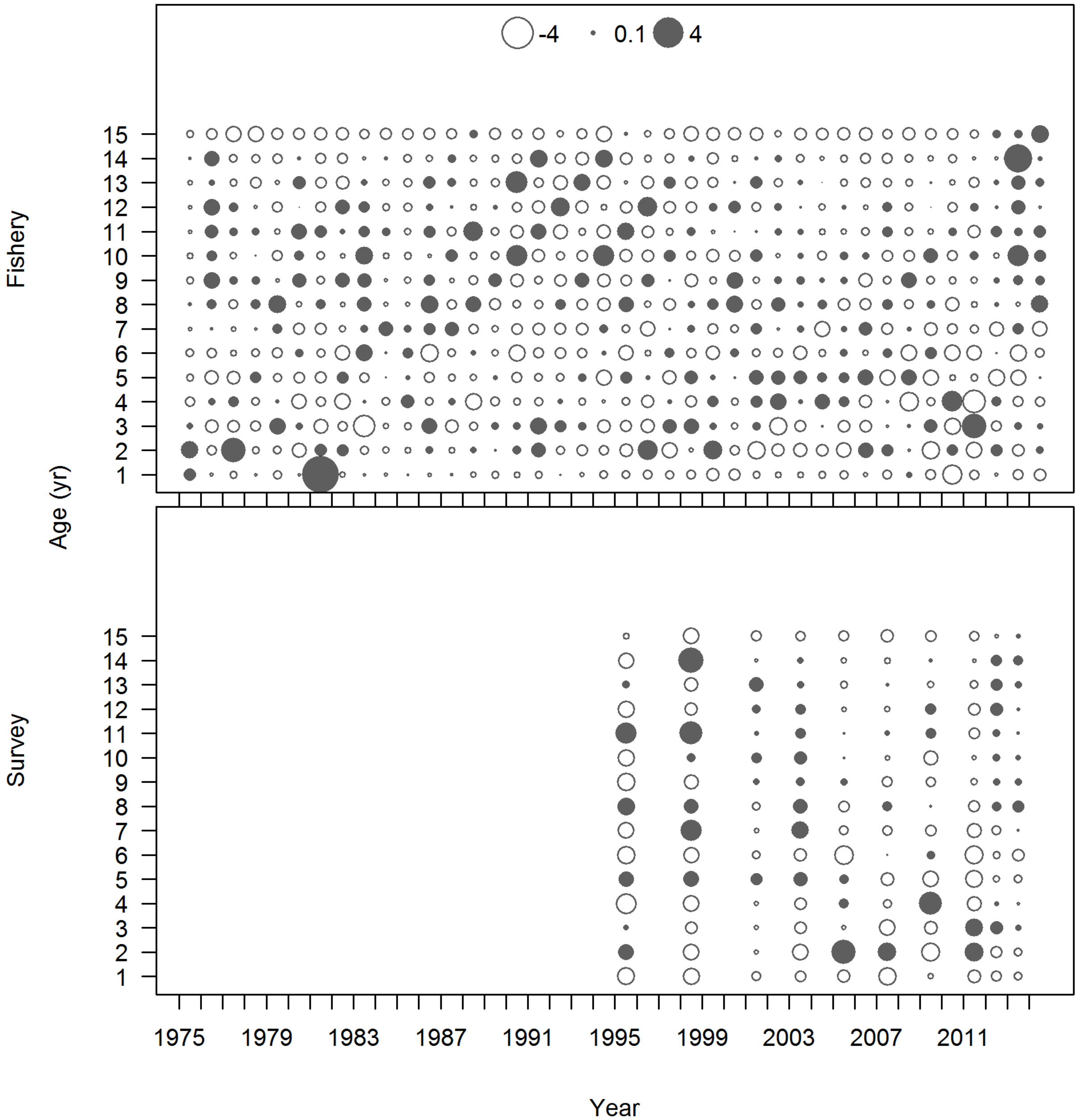


Figure 21: Pearson residuals for base model MLE fits to the fishery age composition data. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

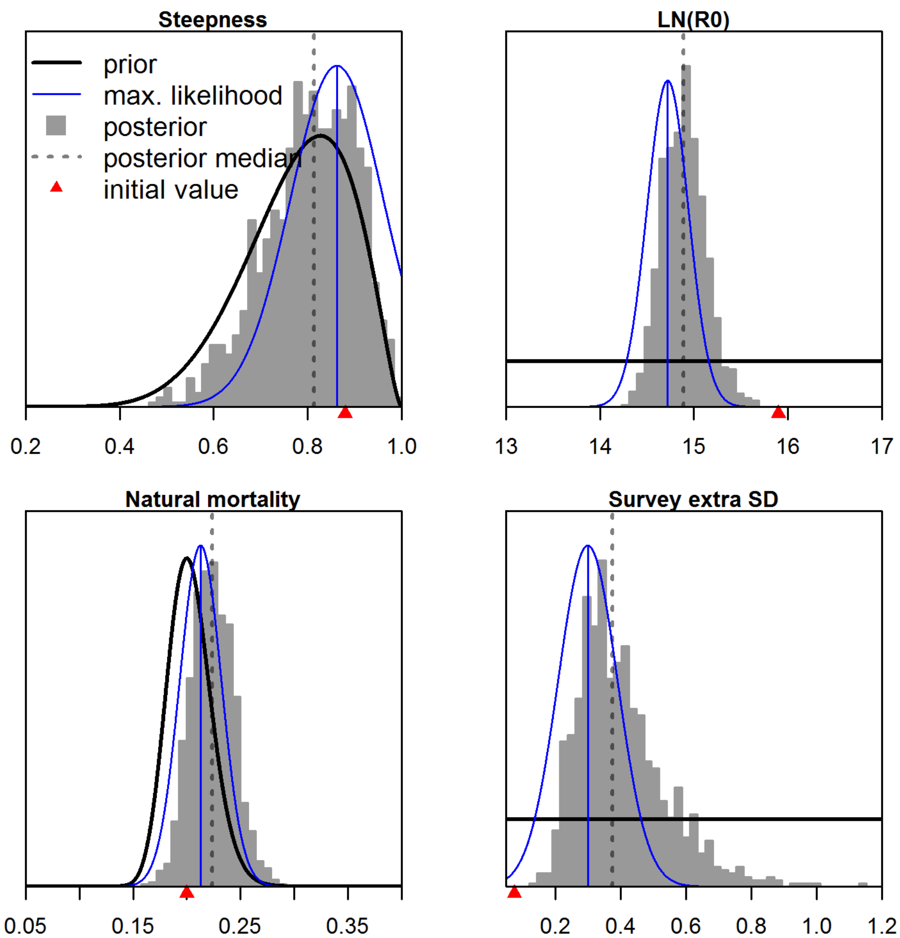


Figure 22: Prior (black lines) and posterior (gray polygons) probability distributions for key parameters in the base model. From the top left, the parameters are: steepness (*h*), Natural mortality (*M*), equilibrium log recruitment log(R_0), and the additional process-error SD for the acoustic survey. The maximum likelihood estimates and associated symmetric uncertainty intervals are also shown (blue lines)

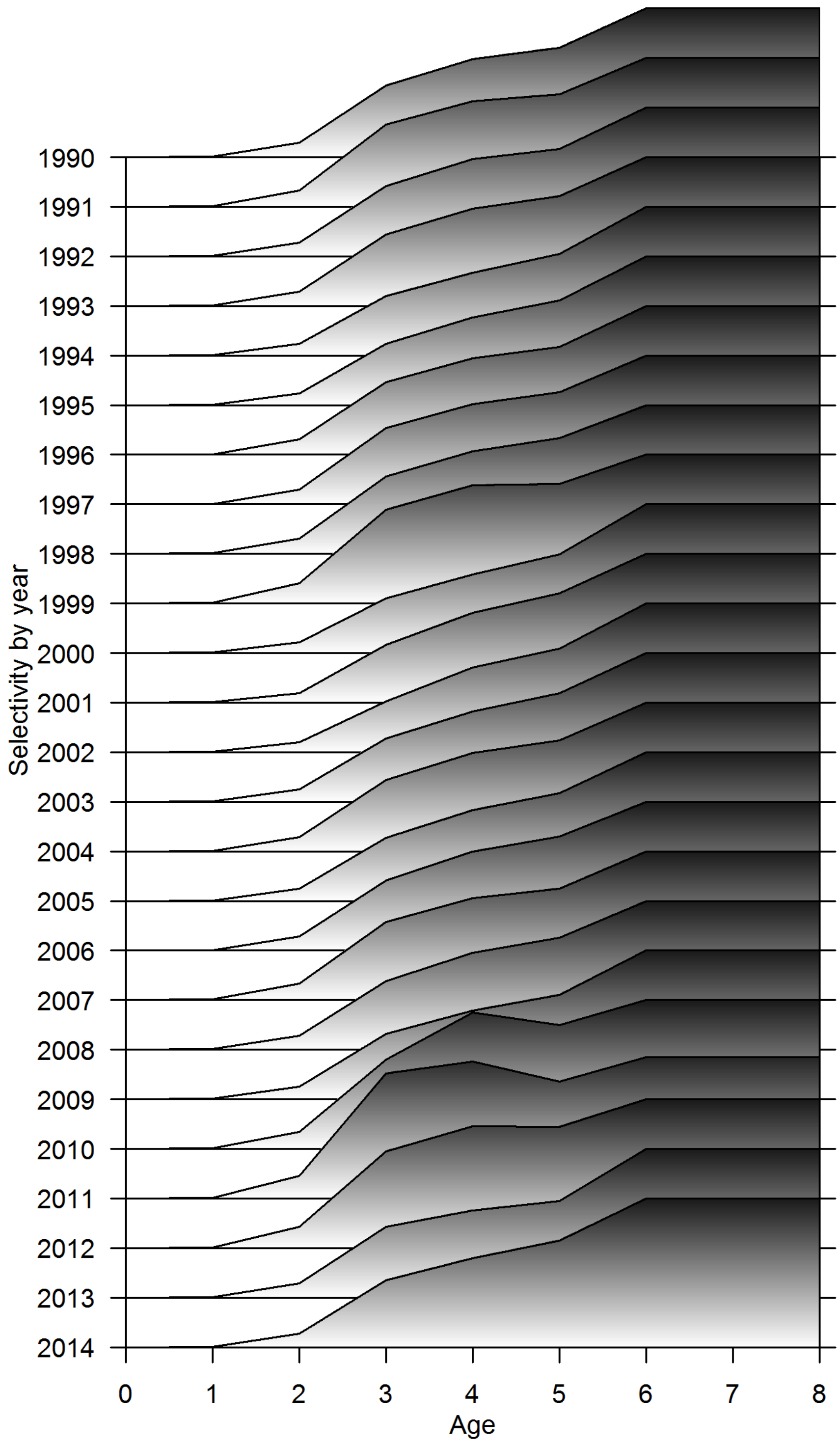


Figure 23: Mountains plot of time varying fishery selectivity for the base model. Range of selectivity is 0 to 1 in each year.

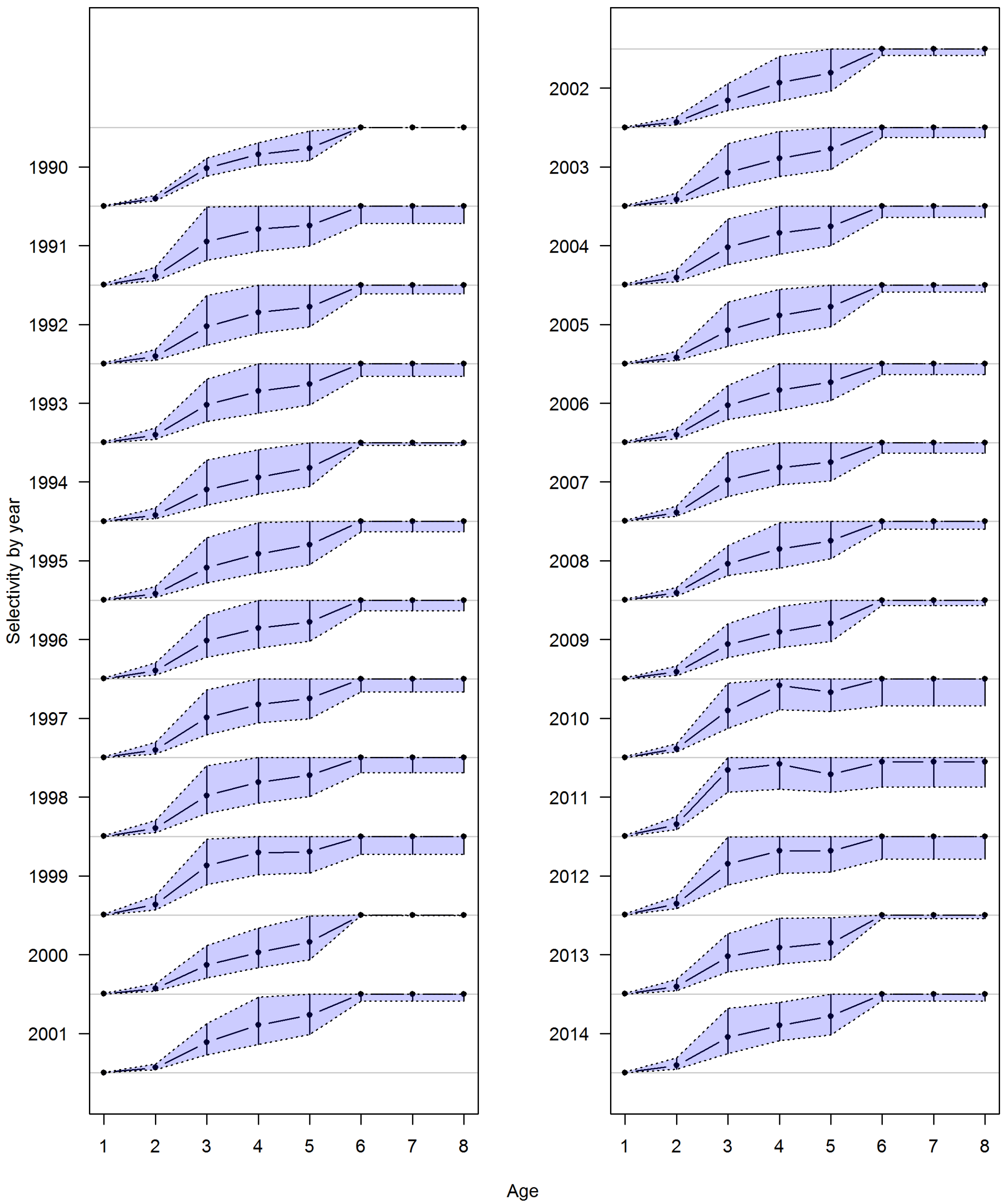


Figure 24: Fishery selectivity sampled from posterior probability distribution by year. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval. Range is from 0 to 1 within each year. Selectivity for 1990 is shared for all years from 1966 to 1990.

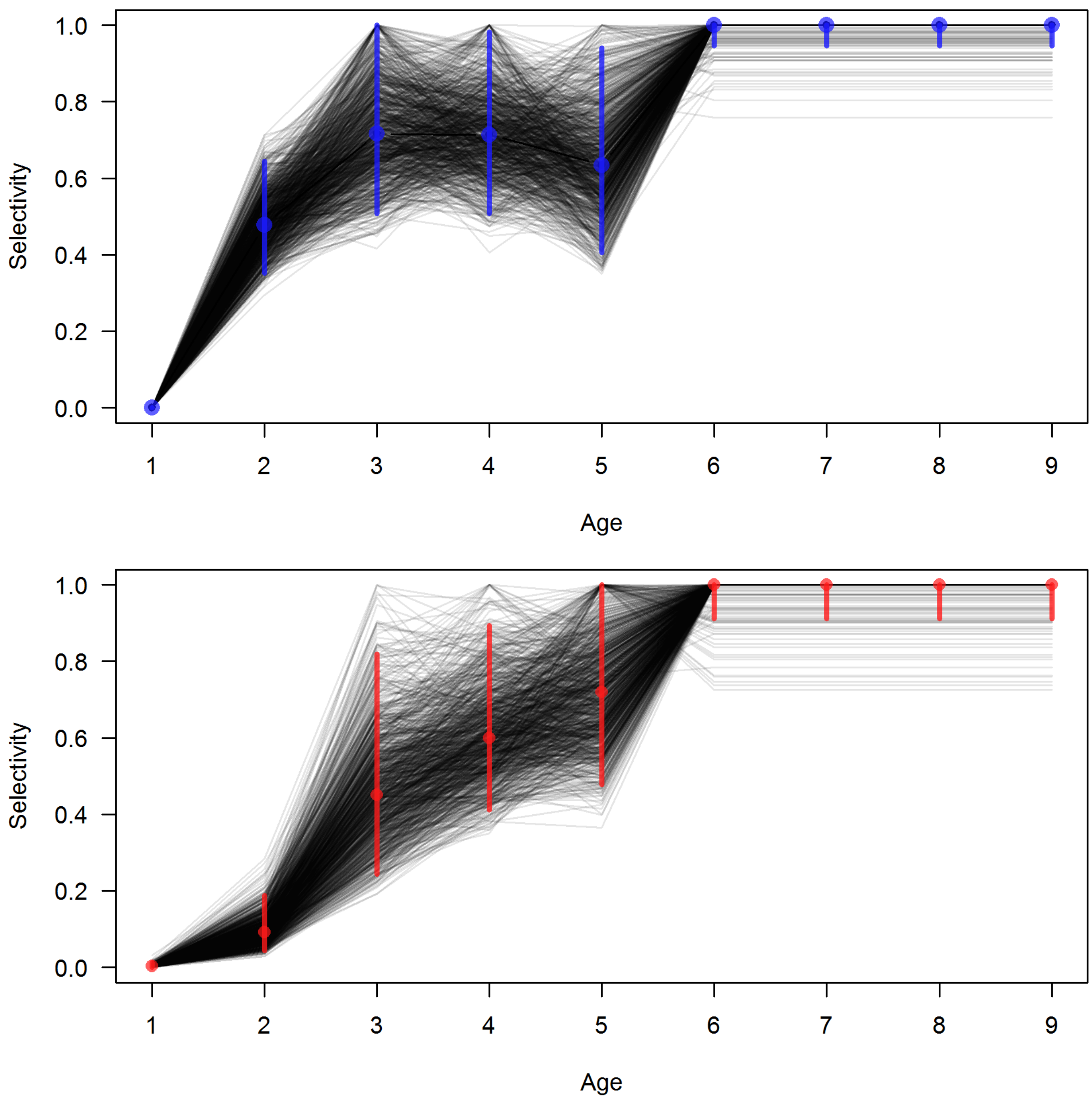


Figure 25: Estimated acoustic (top) and fishery (bottom) selectivity (2014) ogives from the posterior distribution

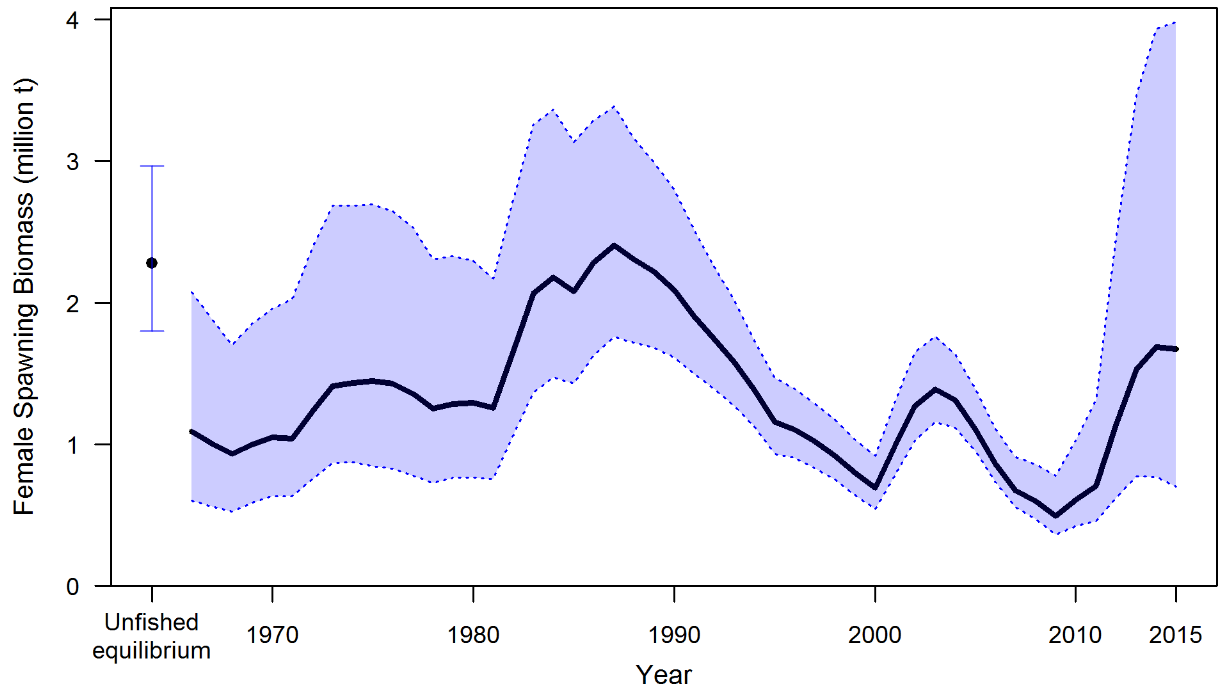


Figure 26: Median of the posterior distribution for female spawning biomass (solid line) with 95% posterior credibility intervals (shaded area).

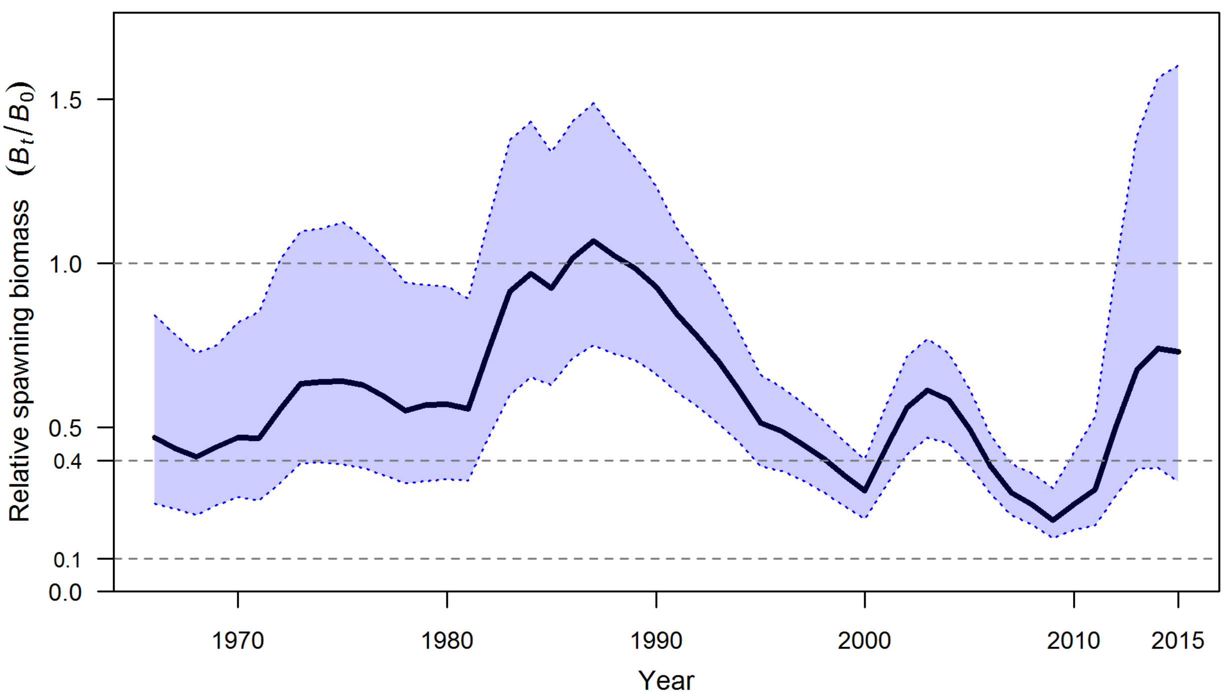


Figure 27: Median (solid line) of the posterior distribution for relative spawning biomass (B_t /B_0) with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

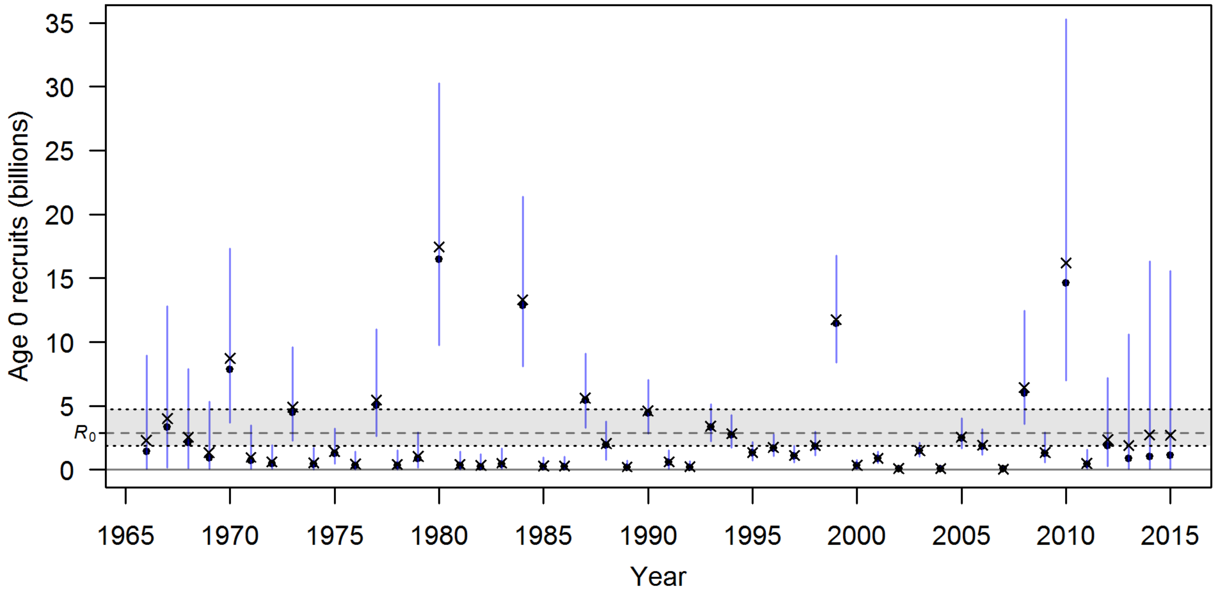


Figure 28: Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment is shown as the horizontal dashed line with a 95% posterior credibility shaded on either side of the median.

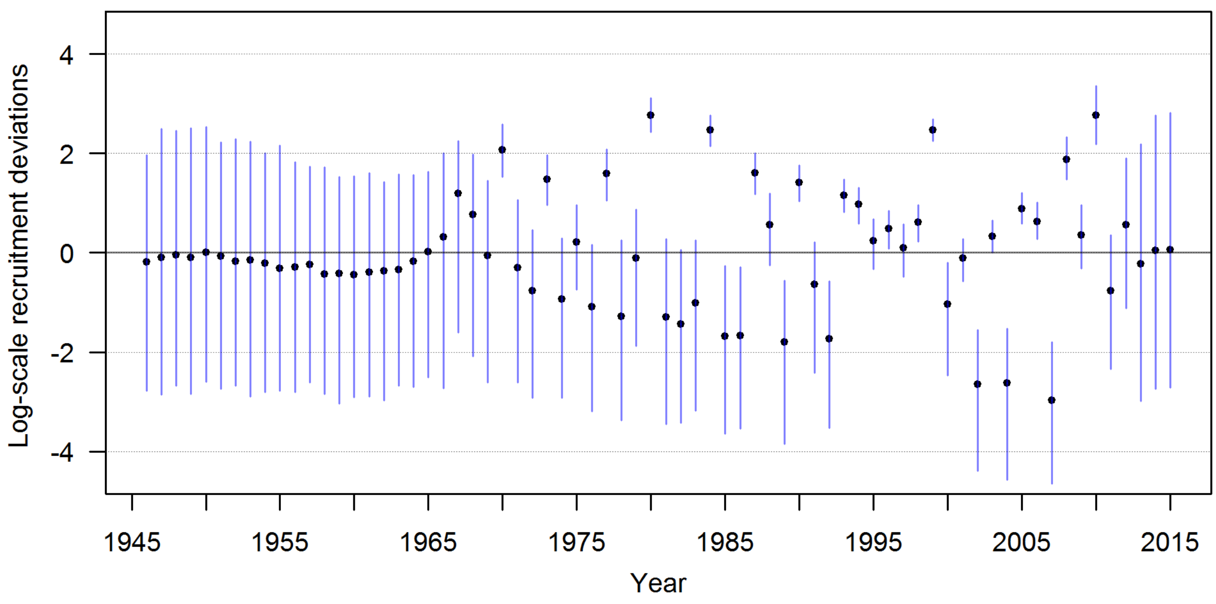


Figure 29: Medians (solid circles) of the posterior distribution for log-scale recruitment deviations with 95% posterior credibility intervals (blue lines). Recruitment deviations for the years 1946–1965 are used to calculate the numbers at age in 1966, the initial year of the model. Deviations for the years 1970–2010 are constrained to sum to zero while deviations outside this range do not have a constraint. All deviations are influenced by the

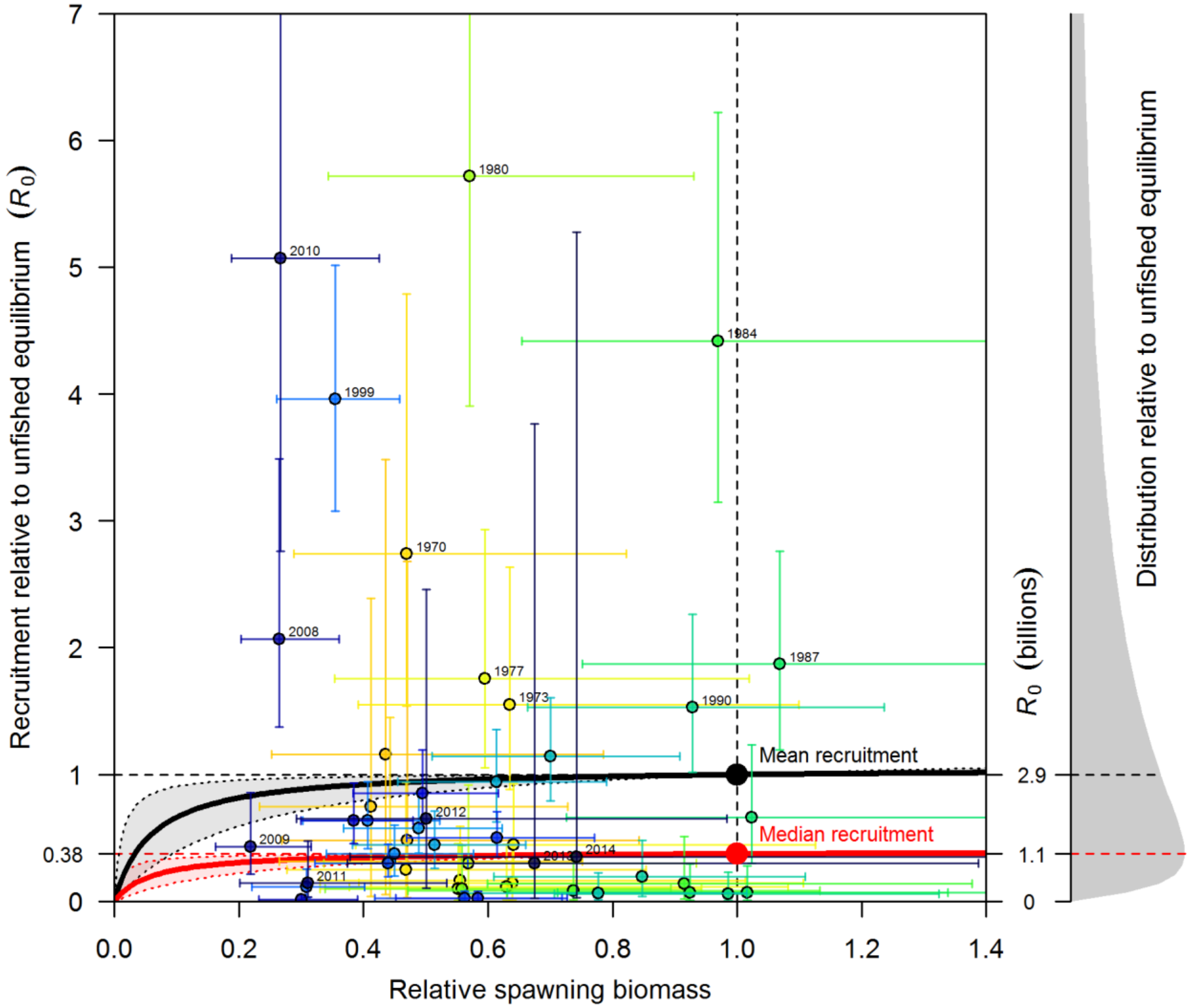


Figure 30: Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. Colors indicate time-period, with yellow colors in the early years and blue colors in the recent years. The thick solid black line indicates the central tendency (mean) and the red line the central tendency after bias correcting for the log-normal distribution (median). Shading around stock-recruit curves indicates uncertainty in shape associated with distribution of the steepness parameter (*h*). The gray polygon on the right indicates the expected distribution of recruitments relative to the unfished equilibrium.

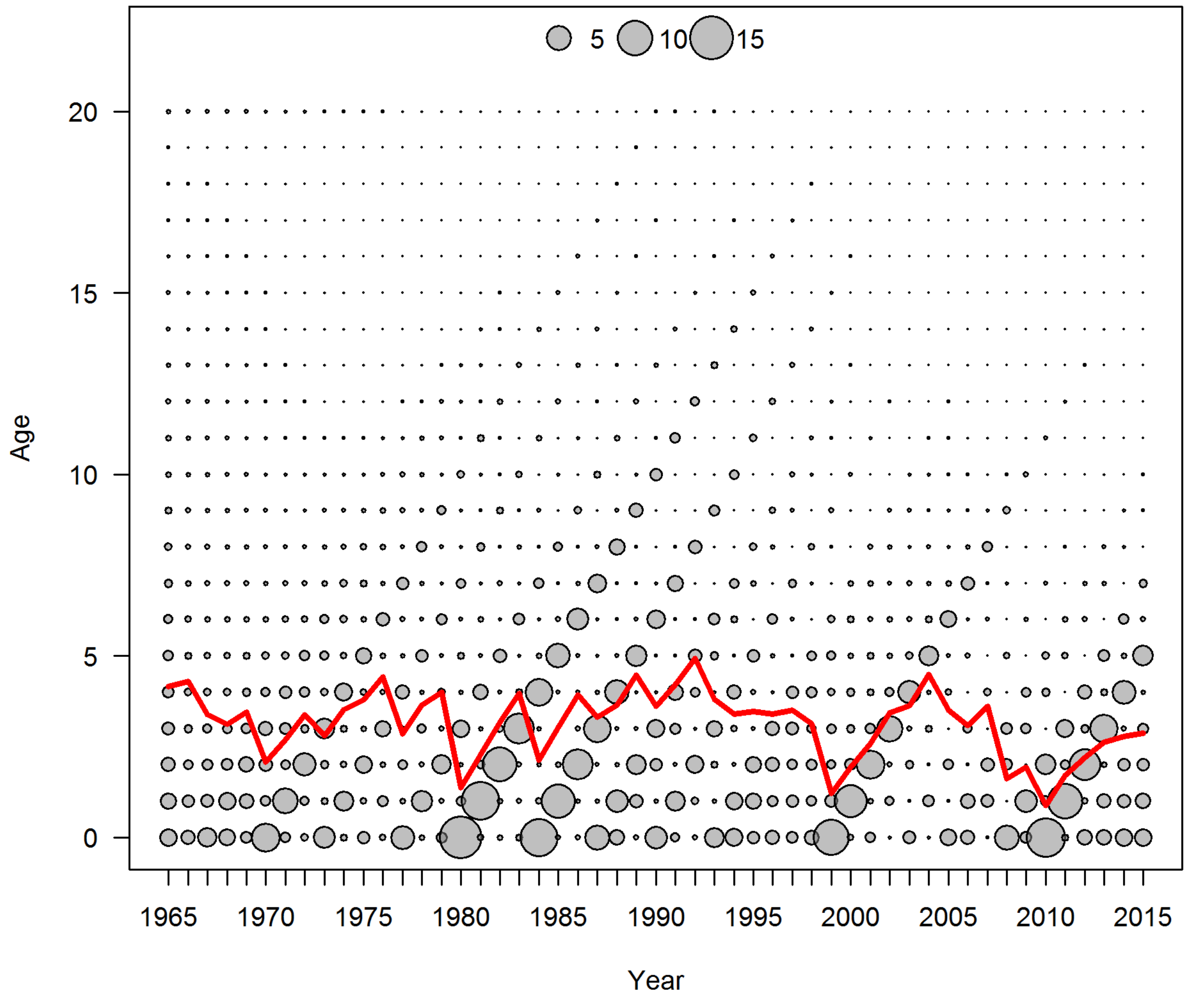


Figure 31: Bubble plot of maximum likelihood (MLE) estimates of population numbers at age at the beginning of each year. The red line represents the mean age. The scale of the bubbles is represented in the key where the units are billions of fish (with the largest bubble representing about 14 billion age 0 recruits in 1980).

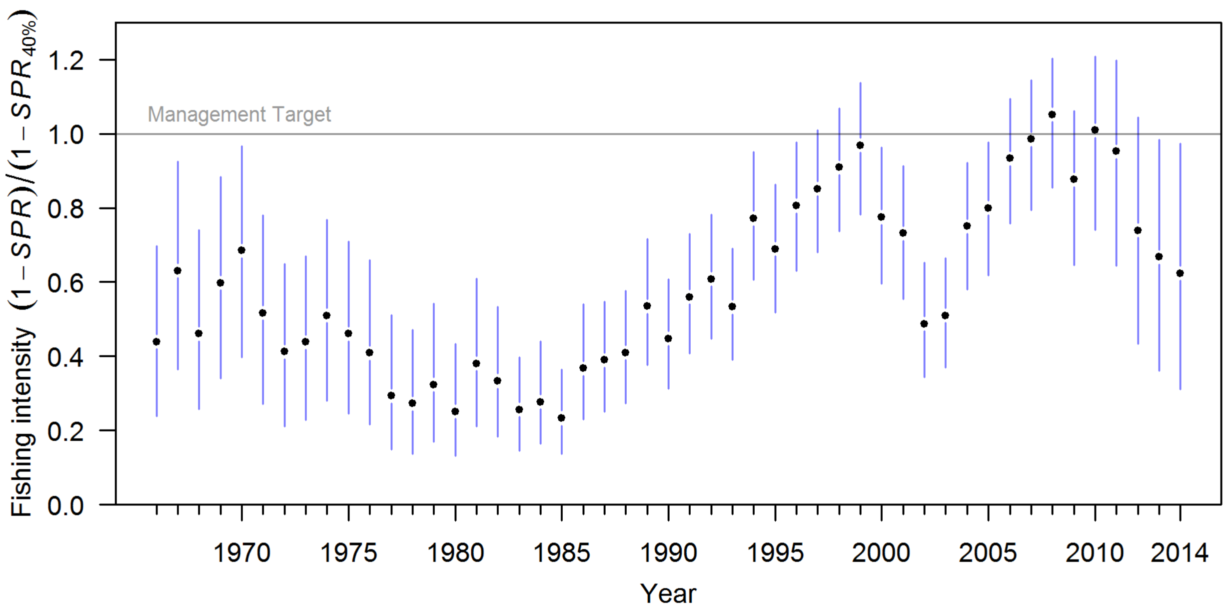


Figure 32: Trend in median fishing intensity (relative to the SPR management target) with 95% posterior credibility intervals. The management target define in the Agreement is shown as a horizontal line at 1.0.

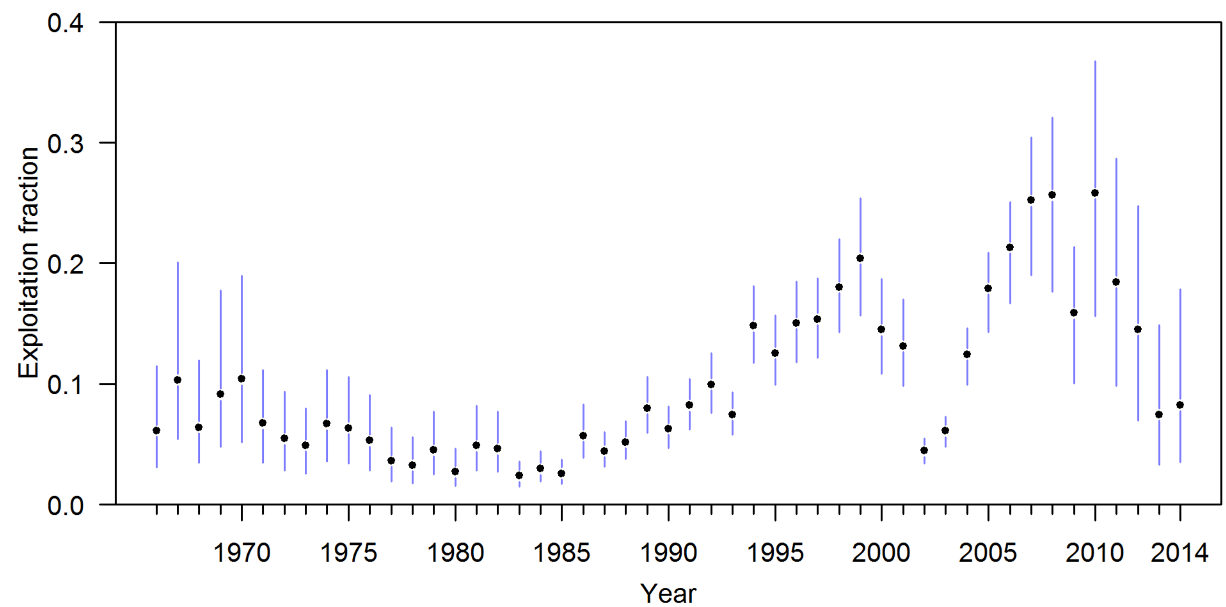


Figure 33: Trend in median exploitation fraction with 95% posterior credibility intervals.

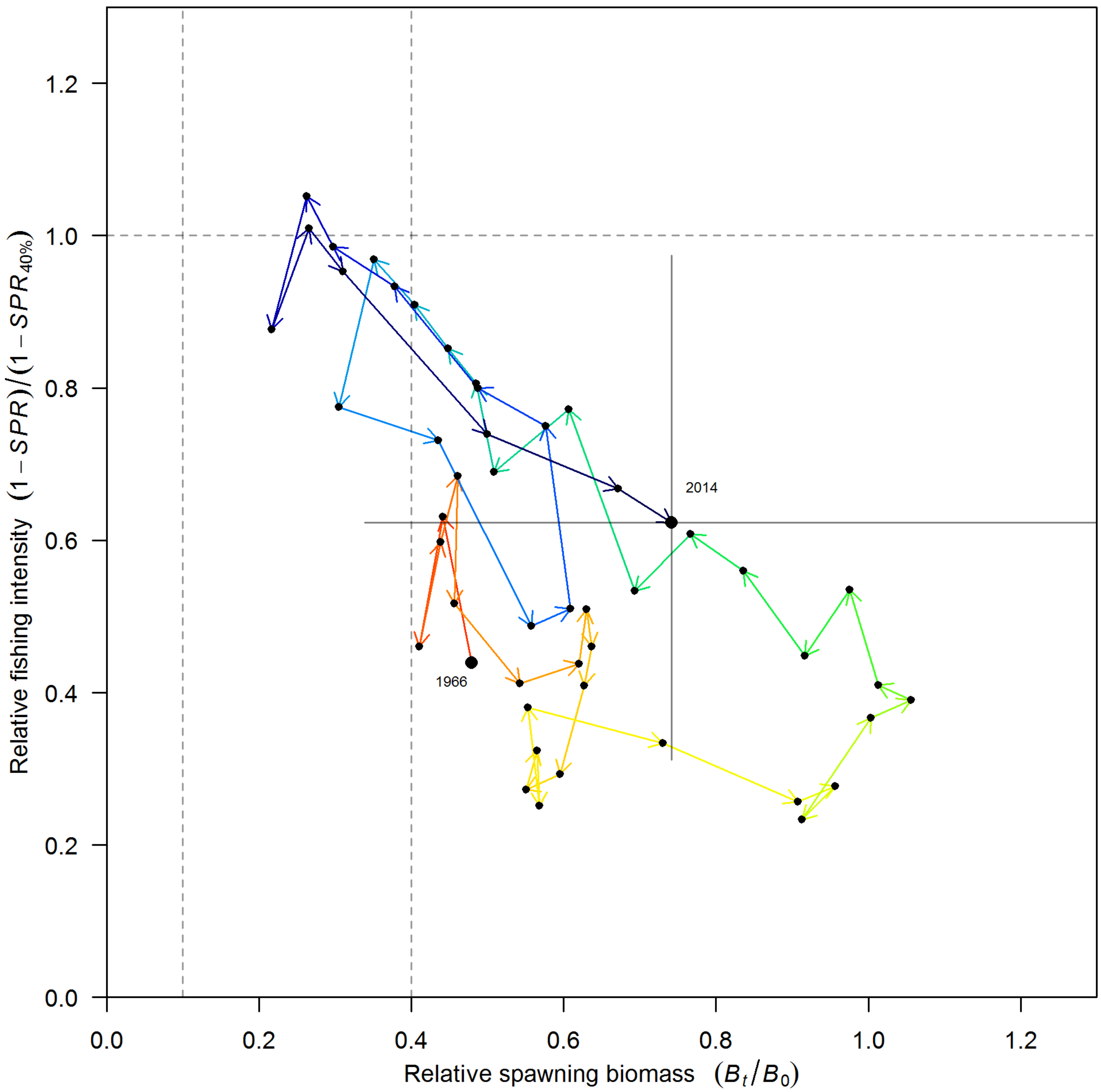


Figure 34: Estimated historical path followed by fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years. Gray bars span the 95% credibility intervals for 2014fishing intensity (vertical) and relative spawning biomass (horizontal).

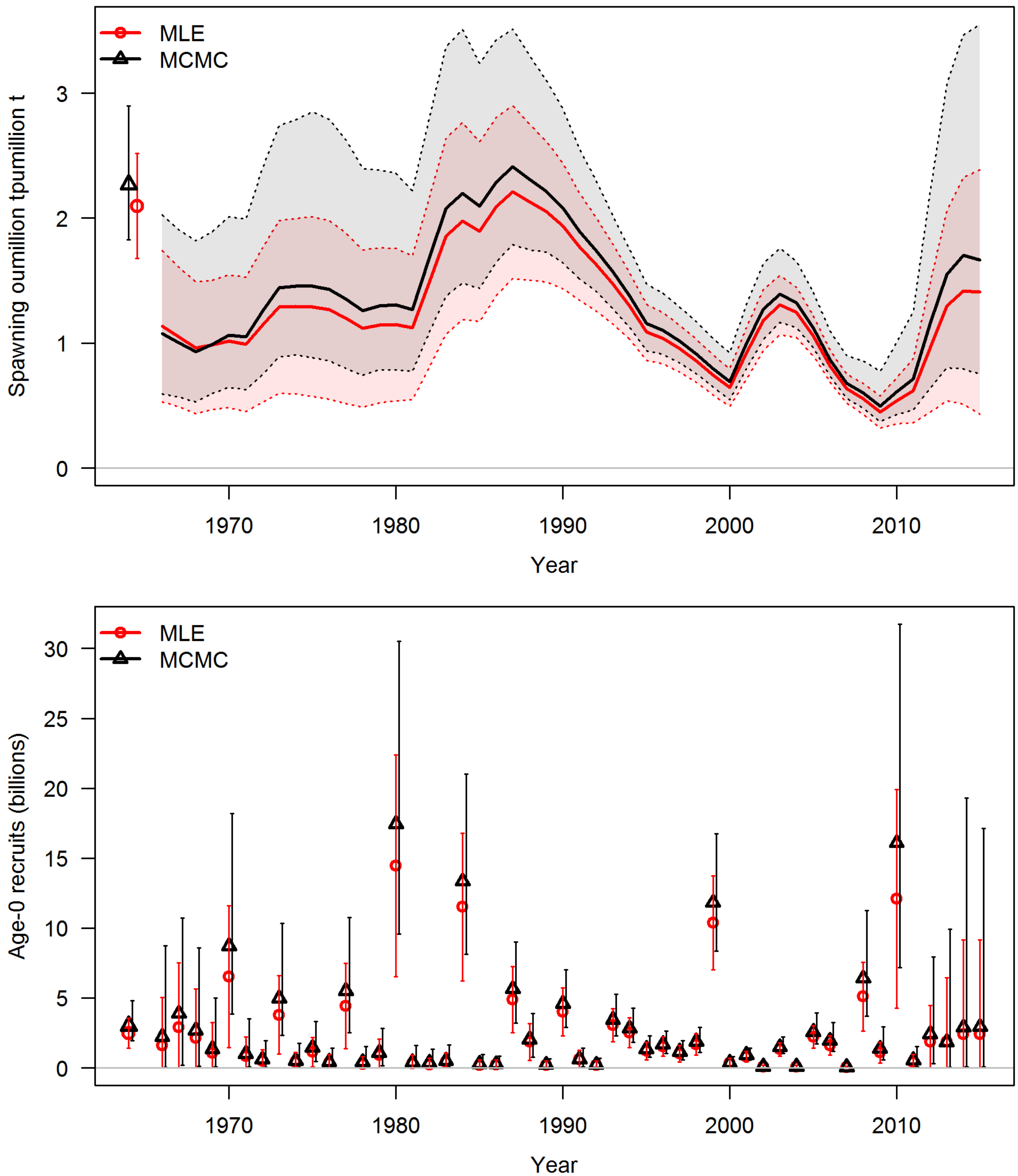


Figure 35: A comparison of MLE estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the median of the posterior distribution with 95% credibility intervals (black).

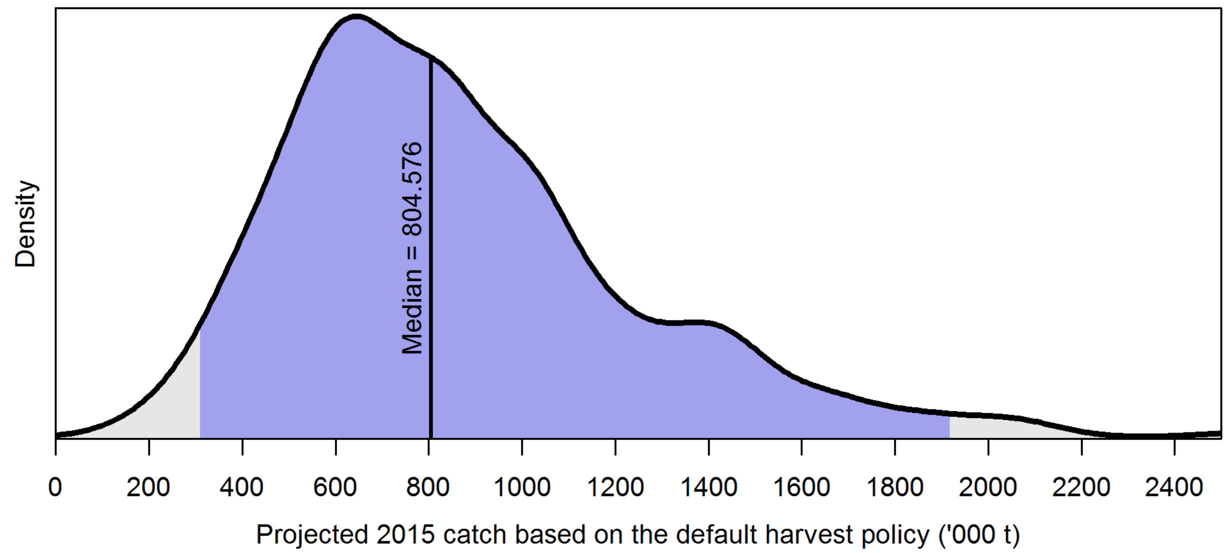


Figure 36: The posterior distribution of the default 2015 catch limit calculated using the default harvest policy ($F_{40\%}$ - 40:10). The dark shaded area ranges from the 2.5% quantile to the 97.5% quantile.

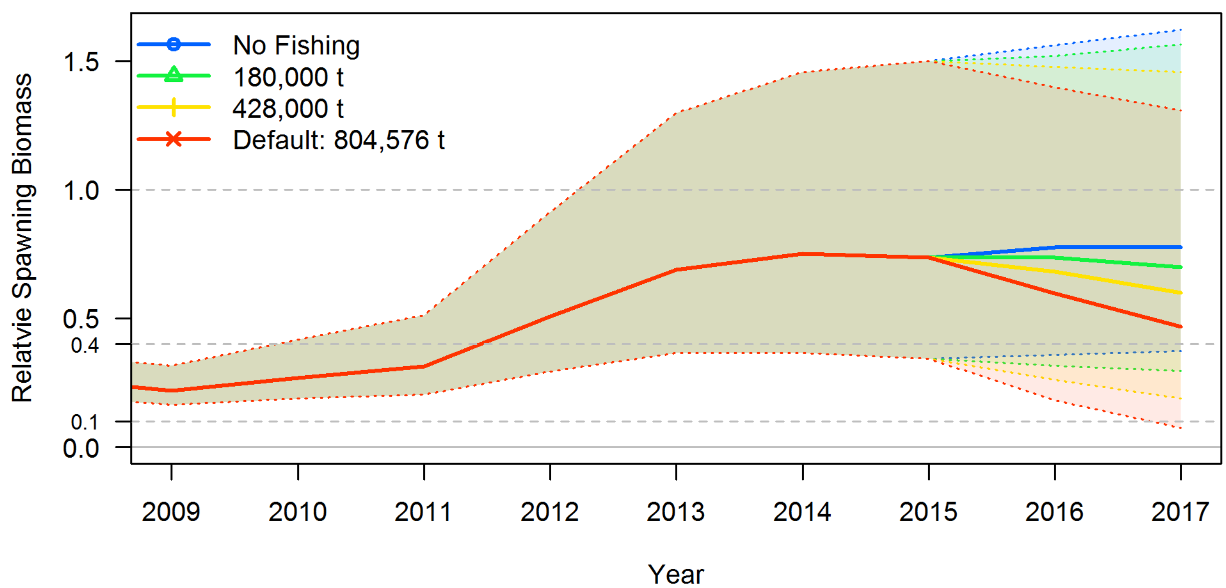


Figure 37: Time-series of estimated relative spawning biomass to 2015 from the base model, and forecast trajectories to 2016 for several management options from the decision table, with 95% posterior credibility intervals. The 2015 catch of 804,576 t was calculated using the default harvest policy, as defined in the Agreement.

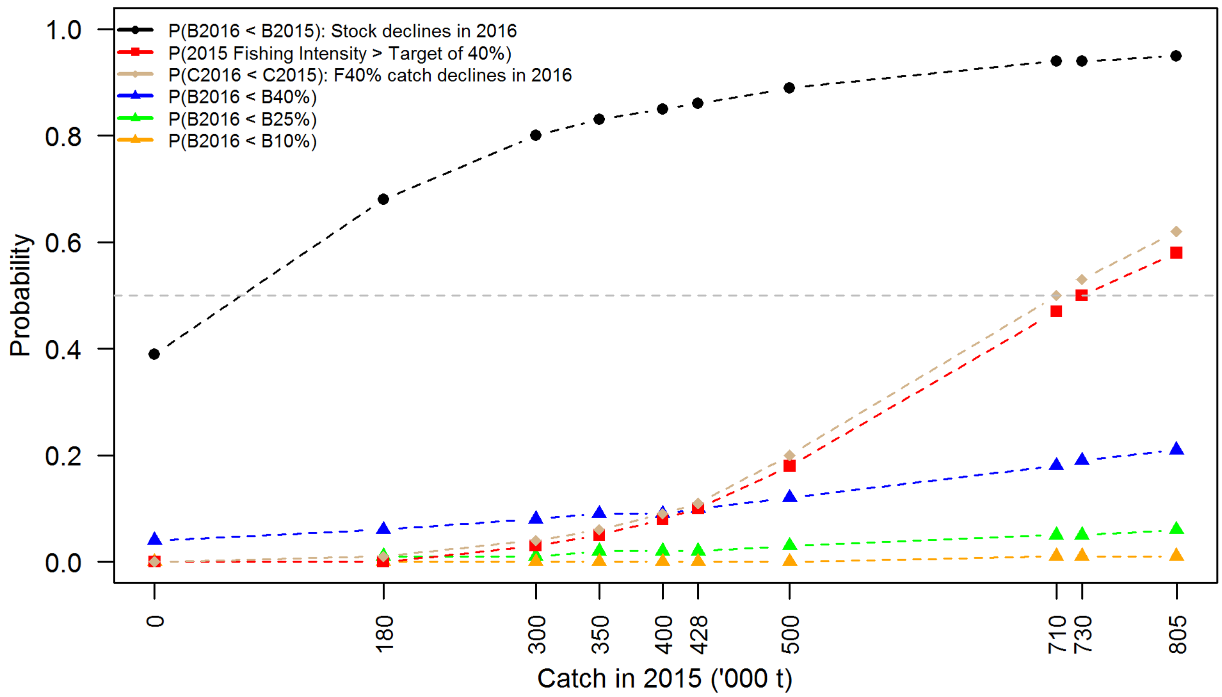


Figure 38: Graphical representation of the base model results presented in the upper portion of Table 16 for catch in 2015. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

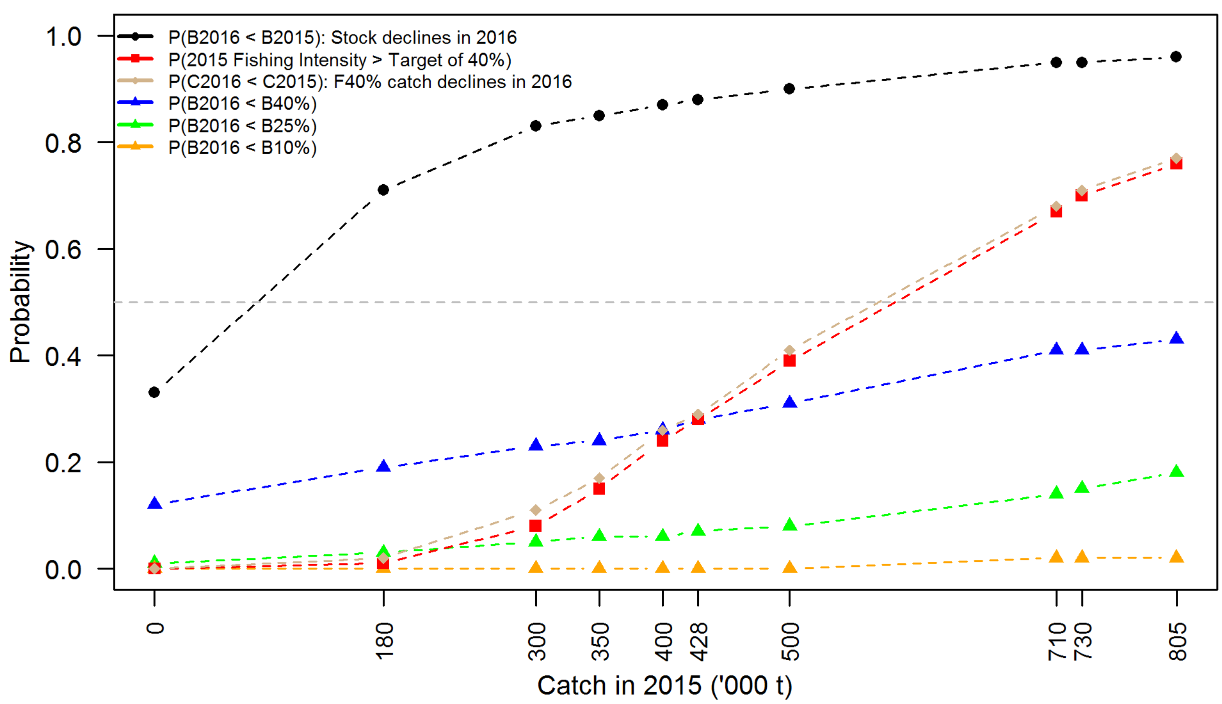


Figure 39: Graphical representation of the alternative survey model results presented in the lower portion of Table 16 for catch in 2015. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

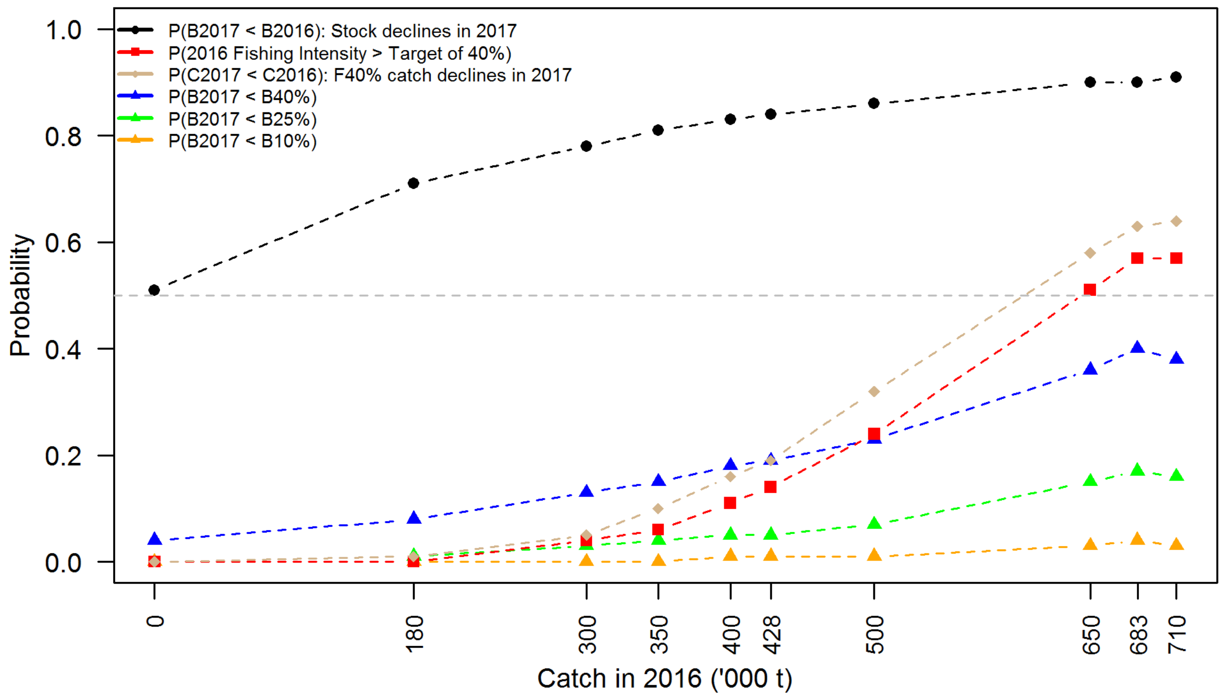


Figure 40: Graphical representation of the base model results presented in the upper portion of Table 17 for catch in 2016. The symbols indicate points that were computed directly from model output and lines interpolate between the points. These catches are conditional on the catch in 2015, and 2015 catch levels corresponding to the 2016 catches of 650 and 683 thousand t were higher (see Table g.1).

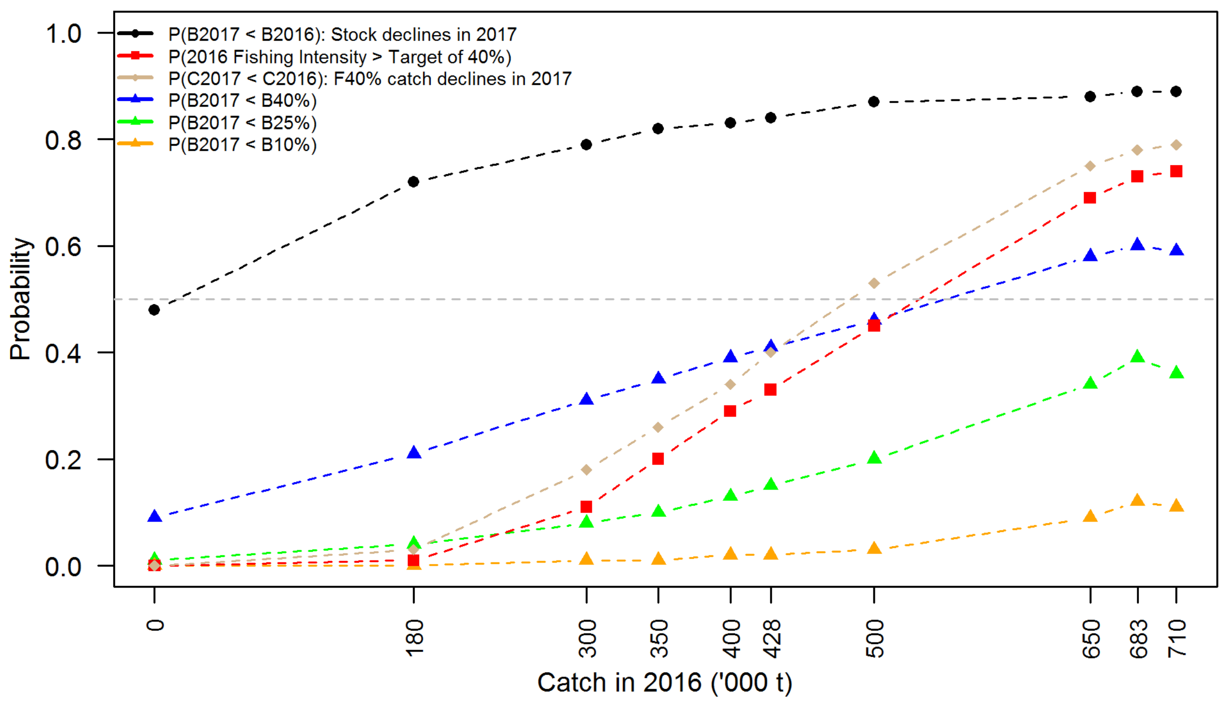


Figure 41: Graphical representation of the alternative survey model results presented in the lower portion of Table 17 for catch in 2016. The symbols indicate points that were computed directly from model output and lines interpolate between the points. These catches are conditional on the catch in 2015, and 2015 catch levels corresponding to the 2016 catches of 650 and 683 thousand t were higher (see Table g.1).

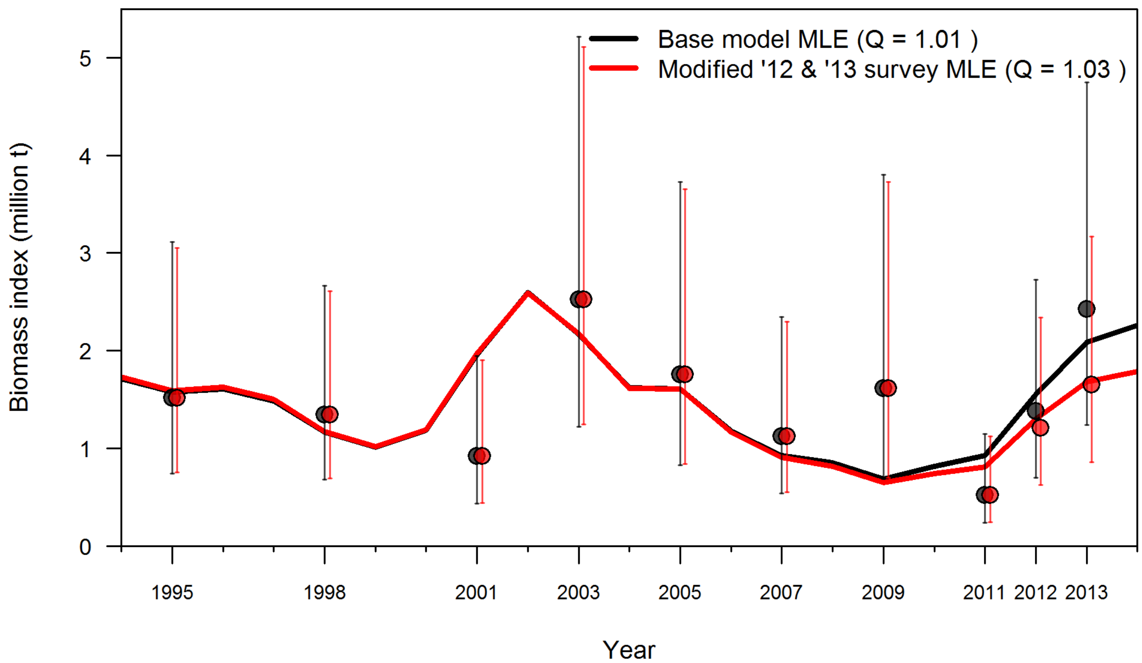


Figure 42: MLE predictions comparing base model (black) to alternative model (red) for expected survey biomass for sensitivity runs with modified acoustic survey biomass estimates for 2012 and 2013. The black line for the base model MLE is the same as the red line in Figure 19.

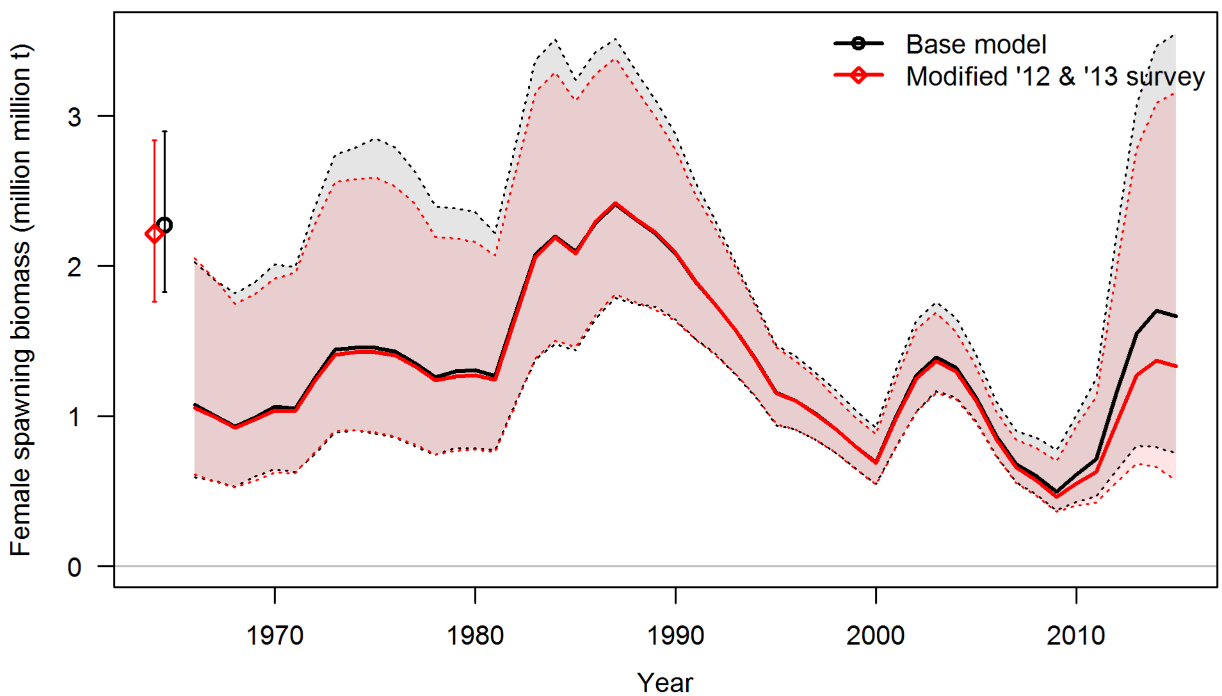


Figure 43: Posterior (MCMC) predictions of spawning biomass for sensitivity runs with modified acoustic survey biomass estimates for 2012 and 2013. The base model lines in black are partly obscured by the red lines.

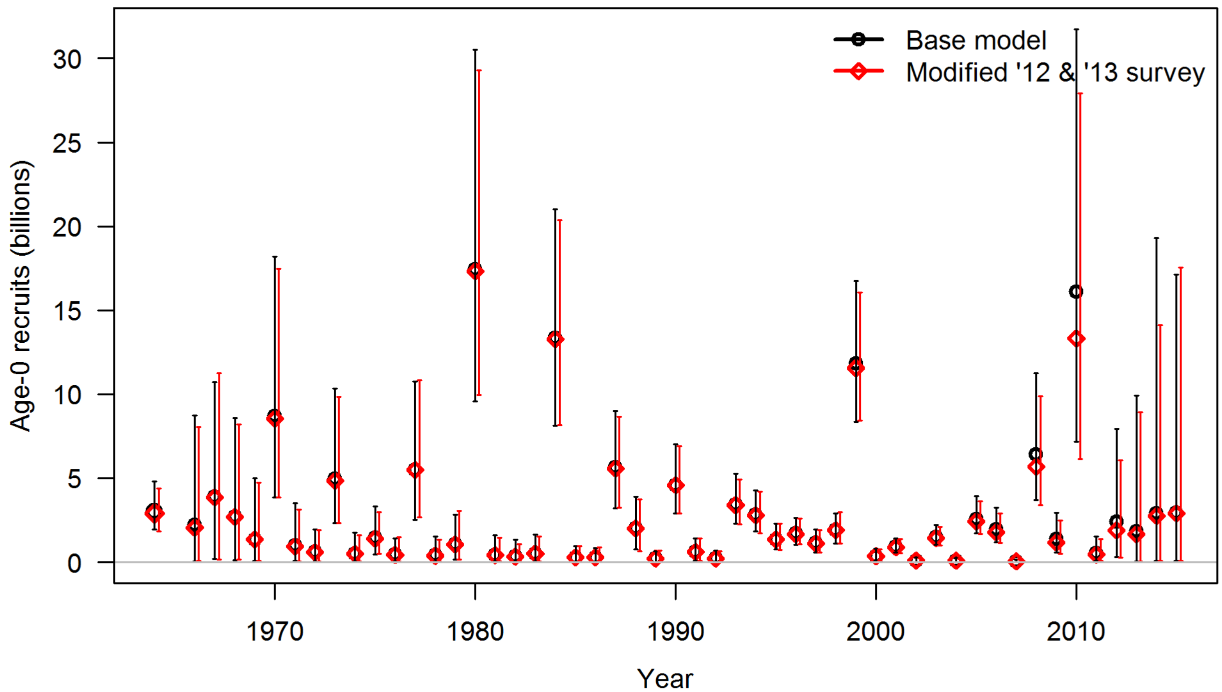


Figure 44: Posterior (MCMC) predictions of recruitment sensitivity runs with modified acoustic survey biomass estimates for 2012 and 2013.

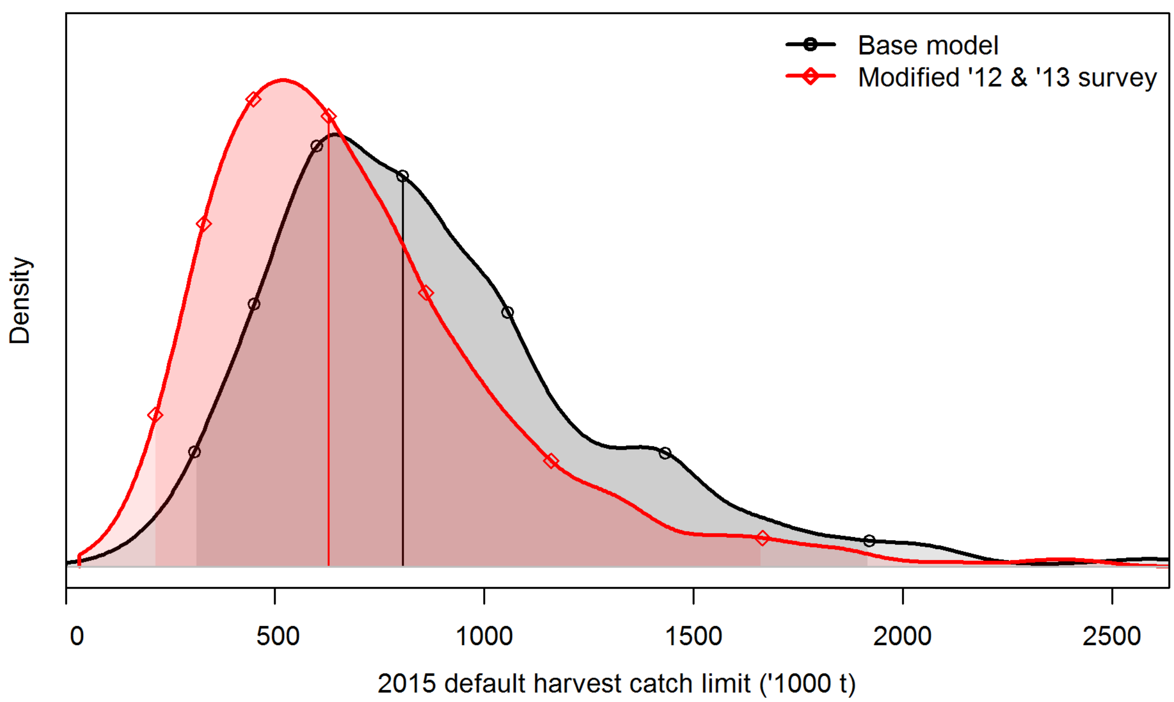


Figure 45: The posterior distribution of the default 2015 catch limit calculated using the default harvest policy ($F_{40\%}$ - 40:10). The dark shaded area ranges from the 2.5% quantile to the 97.5% quantile. The distribution for the base model matches that shown in Figure 36 with median at 804,576 t. The median of the distribution for the model with modified survey values is 628,361 t.

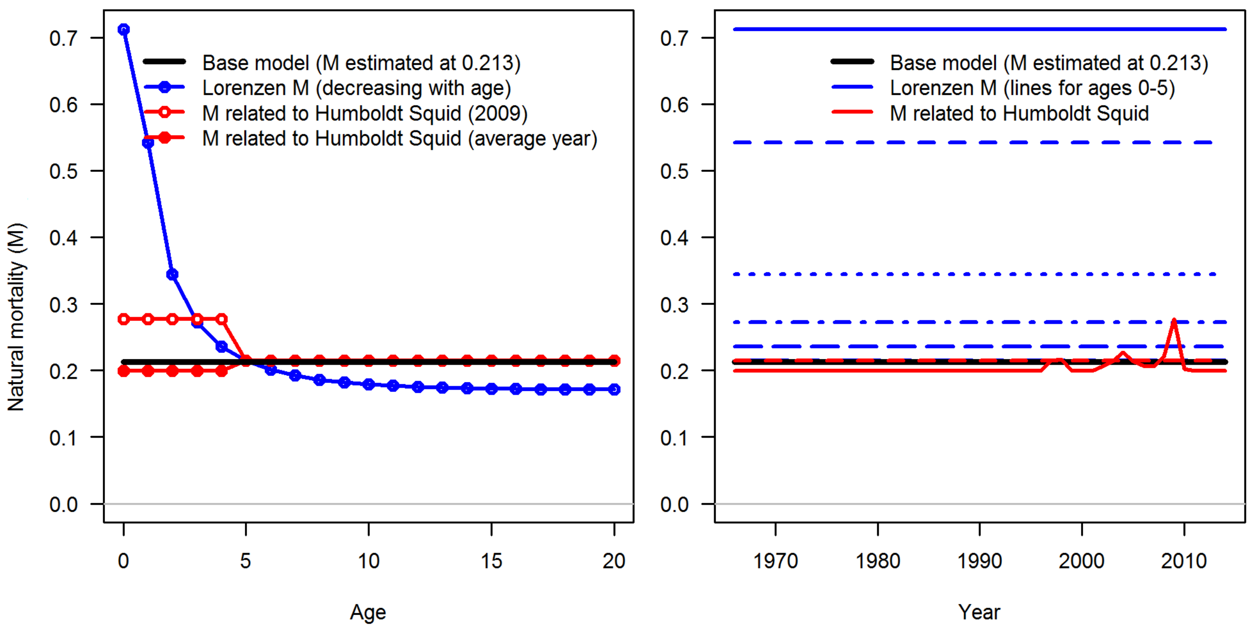


Figure 46: Natural mortality as a function of age and year for two sensitivities analyses compared to base model.

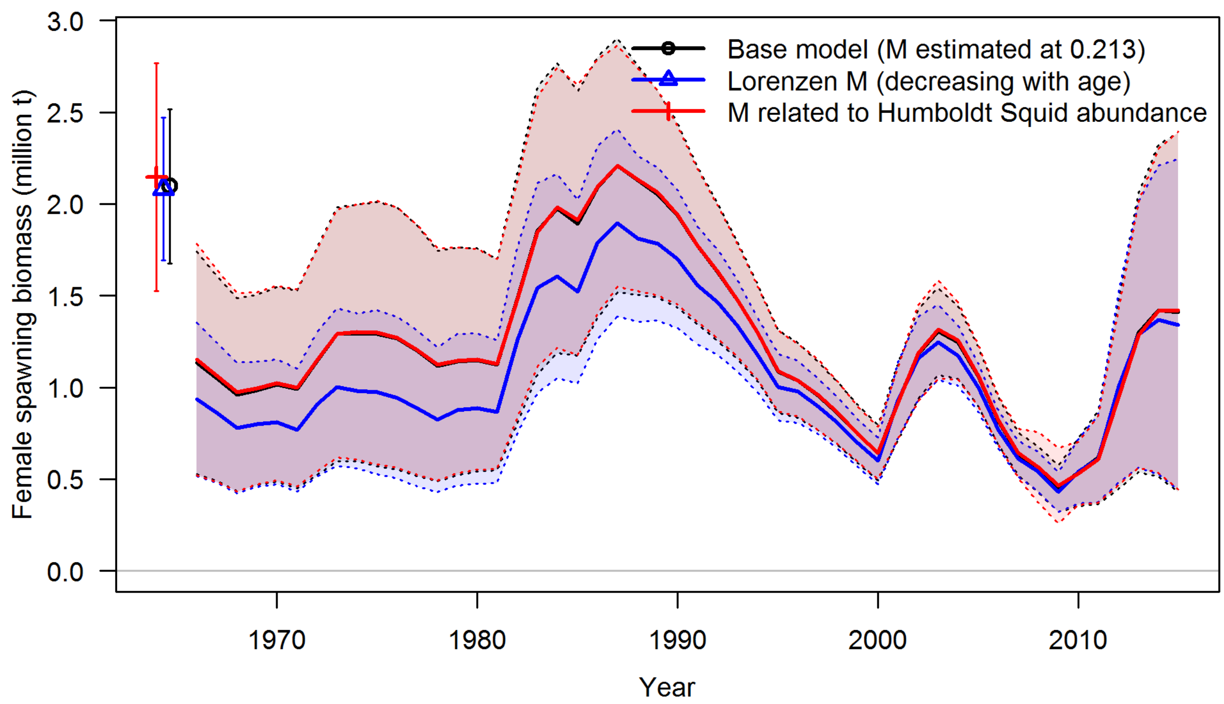
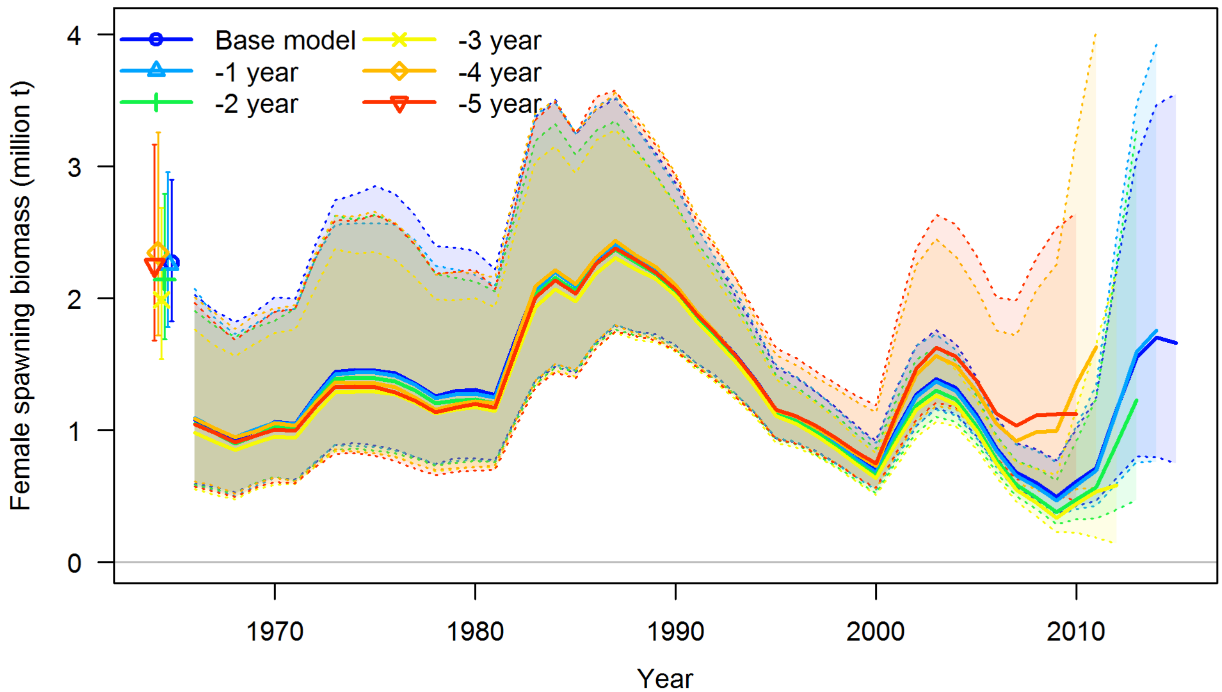


Figure 47: Maximum likelihood (MLE) predictions of spawning biomass for sensitivity runs with alternative assumptions about natural mortality (M). The base model lines in black are mostly obscured by the red lines.



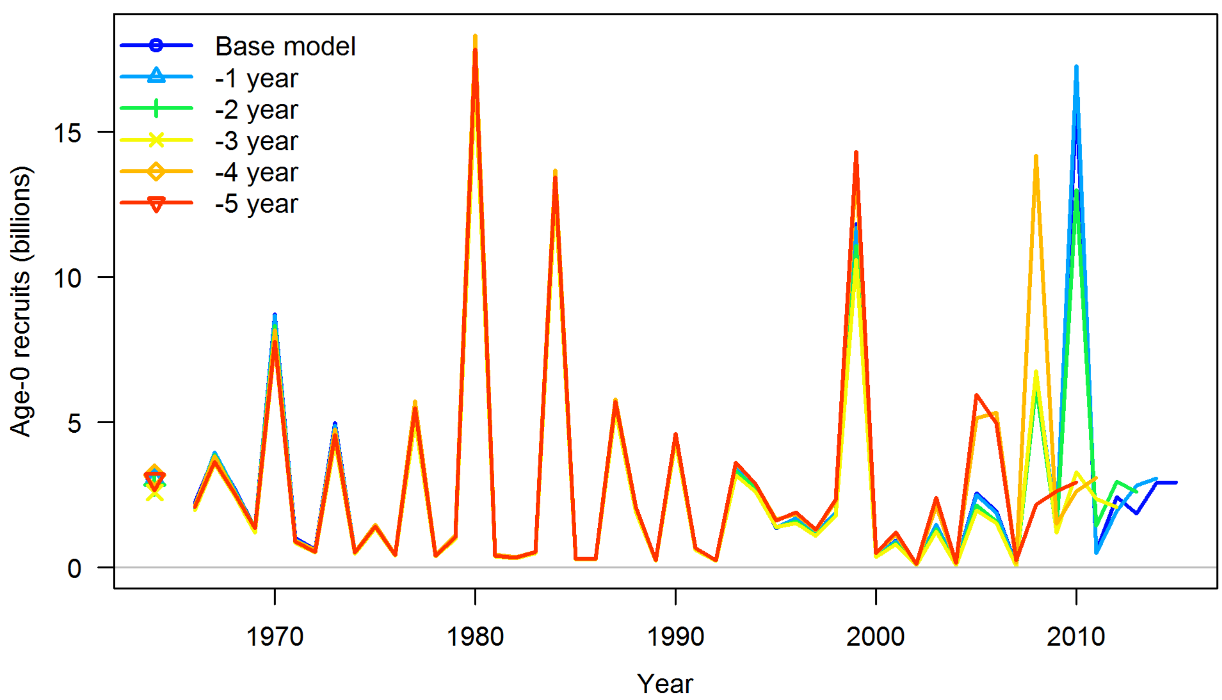


Figure 48: Spawning biomass estimates (top) and recruitment estimates (bottom) for the base model and retrospective runs (all based on MCMC posteriors).

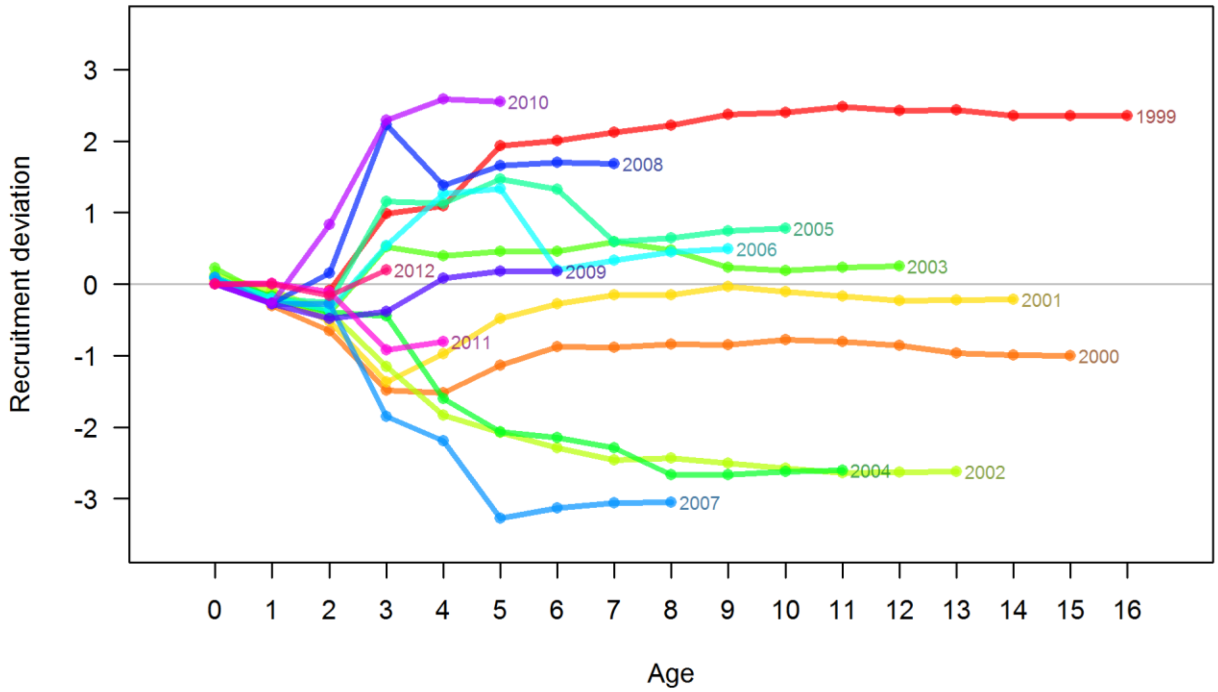


Figure 49: Retrospective analysis of recruitment estimates from MLE models over the last 15 years. Lines represent estimated deviations in recruitment for cohorts starting in 1999 (with cohort birth year marked at the right of each line). Values are estimated in models with data available only up to the year in which each cohort was a given age. Recruitment deviations are log-scale difference between estimated recruitment and spawner-recruit expectation.

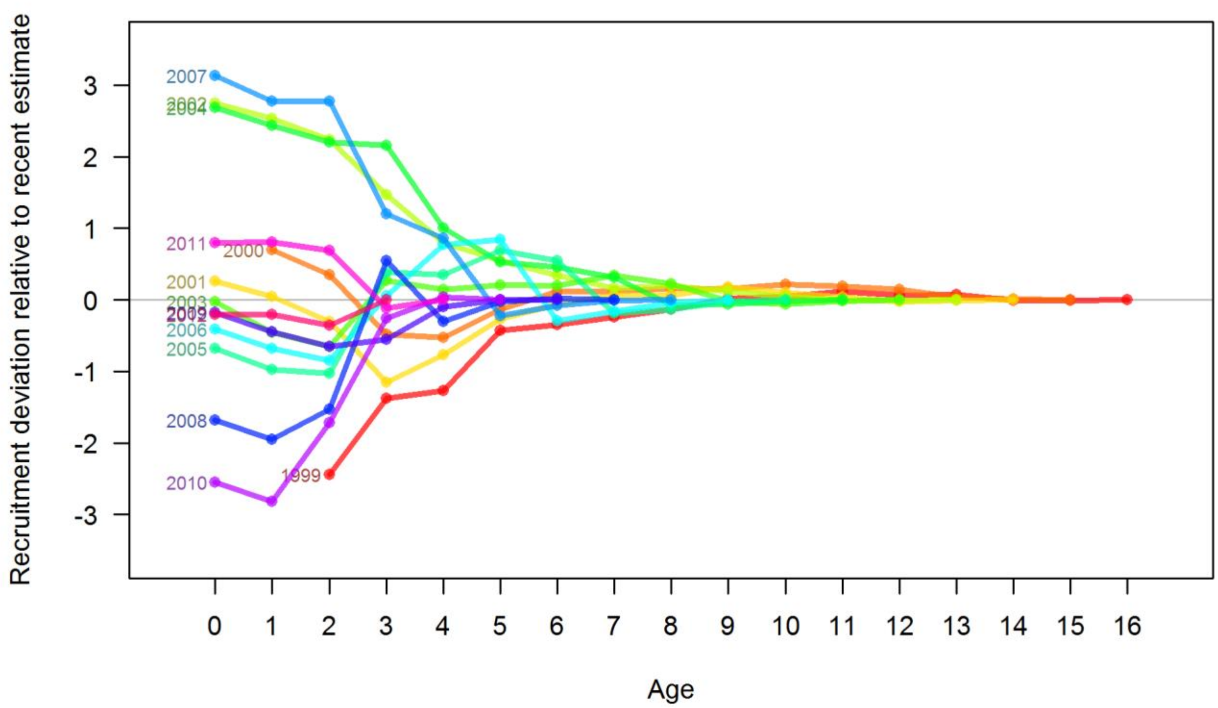


Figure 50: Retrospective recruitment estimates shown Figure 49 scaled relative to the most recent estimate of the strength of each cohort.

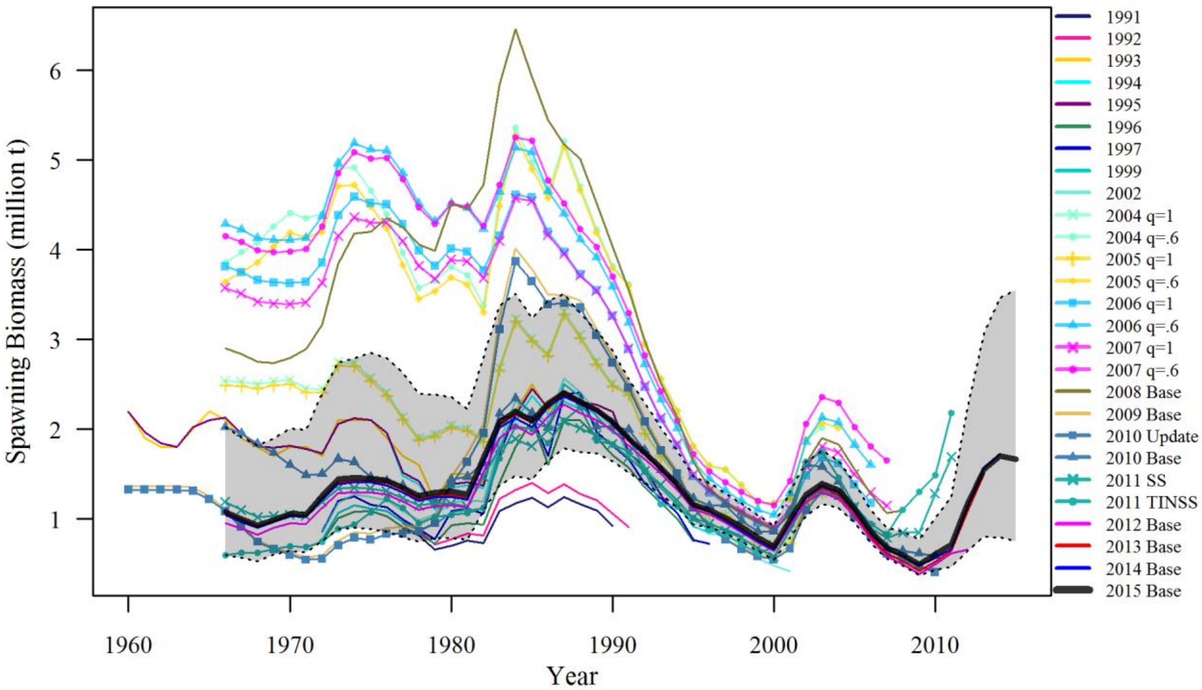


Figure 51: Summary of historical Pacific Hake assessment estimates of spawning biomass. The 2013 and 2014 assessment estimated trajectories (red and blue lines) are almost completely covered by the 2015 estimated trajectory.

Appendix A. Summary of MSE activities in 2014

In 2014-15 the JTC compiled the MSE results to date as a book chapter (Hicks et al. 2015). The chapter describes the methodological approach taken for MSE simulations done in 2012-2014. It then reports the conservation and yield performance of four harvest control rules that we have explored as part of the Pacific hake MSE: (1) the F40% harvest control rule; (2–3) partially constrained F40% rules in which TACs ceilings are limited to either (2) 375,000 or (3) 500,000 mt; and (4) a fully constrained F40% rule with a TAC floor of 180,000 mt and ceiling of 375,000 mt similar to the realized range of TACs based on historical decisions. The chapter's key conclusion is that the simulations indicated that limiting TACs to levels below those suggested by the F40%-40:10 rule benefitted both long-term fishery yield and spawning biomass conservation. When applied literally, the F40% rule (with 40:10 adjustment) led to the highest interannual variability in yield, as well as the highest probability that biomass would be below biological reference points such as B40% and B10%. A draft of the book chapter will be circulated at SRG 2015 for your reading pleasure.

SRG 2014 made several recommendations for the continued work on the MSE which are paraphrased below:

1. Having the JTC and the JMC to engage in discussions that will better define the objectives for managing the fishery so that performance can be defined objectively and quantitatively in the context of the MSE.
2. That the JTC continue to pursue exploring the potential benefits and risks of different harvest control rules and overall harvest strategies with input from the JMC, the AP and the MSE steering committee.
3. Development of a more complex operating model that will enable the evaluation of structural mis-matches between the operating and assessment model.
4. Explore the effects of harvest on different ages on overall sustainability of the stock and distribution across the U.S. and Canadian fisheries. As additional information about drivers of migration and recruitment is developed, the potential for including spatial components in the MSE would be worth investigation.
5. Using a more complex operating model, evaluate the system performance under scenarios with different survey designs, for example annual versus biennial surveys, and surveys with and without an age-1 abundance index.
6. Explore which stock assessment uncertainties have the greatest relative impact on management performance, notably natural mortality.
7. Explore variation in recruitment in the short and long term. In the short term, we suggest that the current recruitment patterns be modeled and generally to consider ongoing and future studies in its development of future MSE operating models.

To address the items above and also the management principles presented at JMC 2014 the JTC developed a workplan presented to the MSE Steering Committee on July 31, 2014. In it, we documented how we would address the SRG's recommendations above. The JTC's MSE workplan divided MSE research activities into short and long term projects. The short term plan was to address one element of item 5 above, to evaluate the system performance with and without and age-1 index, although with the current operating model. The design of the age-1 index simulations is described below and simulations will be completed soon.

To elicit feedback on management objectives and to develop the MSE operating model specifications (item 1 above), the JTC drafted the text in Appendix A.2 below. In it, we provided our interpretation of the JMC's management principles (presented at the JMC meeting on May 12, 2014) and key paragraphs of The Agreement insofar as defining aspirational objectives (relatively broad, qualitative statements about overall management goals) and operational objectives (i.e. specific directions about what types of models and analyses scientists should do and what they should look for in the assessment and management strategy simulation output). A key task for continued MSE development will be for the JMC to define a set of operational/ends objectives, against which alternative management procedures could be tested.

The final component of JTC 2014c was a series of questions to help guide if the operating model for the MSE should be spatially structured or not. We have received very little feedback on the JTC 2014c from US MSE Advisory Panel members but are anxious to consider their feedback once it is available. In subsequent meetings with Canadian MSE Advisory panel members, it was clear that their key concern was to develop an MSE that could address how the application of the current management procedure may affect availability of hake in each country. Moreover, SRG 2014's recommendation 4 above, implies some evaluation of the effects of alternative harvest regimes on the distribution of the stock. To address these concerns, the JTC will need to build a spatially structured model that captures the stock's seasonal, and spatial population dynamics. We are currently investigating alternative options for modelling these dynamics. The JTC will likely develop its own operating model. While we intend to pursue collaborations with colleagues engaging in other MSE activities, we would like to maintain the flexibility to tailor the operating model to meet hake process needs as they arise.

Appendix A.1. Simulations looking at hake age-1 index in 2015

To investigate the usefulness of an age-1 index for the hake assessment, we modified the code used in previous MSE simulations (msess). The basic premise is that the age-1 index begins in 2013, when the first survey index is generated, and then the age-1 index is available only in the same years as the survey (this is even years in the MSE, which is slightly different than the odd-year biennial acoustic survey). The age-1 index is not added to the assessment until there are at least three values (the first assessment with it is 2016), since it estimates q. The index is generated from only simulated age-1 fish (no bias), is entered as biomass of age-1 fish with lognormal error, and is assumed in the assessment to be only age-1 fish (selectivity is 100% at only age 1). Only an index of abundance is associated with this new fleet in SS.

We chose to not use the historical age-1 index because it would require a new MCMC for the operating model, and we are only interesting in investigating the long-term effect of using the index.
We added code to do the following:

1. Read in two new values in scenarios.csv.
    a. Age1sd is the standard error (in log space) of the index. If this value is negative, an age-1 index is not included.
    b. qAge1 is the catchability coefficient for the index. We did not code in any check for this (such as error if negative).
2. Generate an age-1 index of abundance using the same assumptions as the generation of the survey index, except that selectivity is age-1 only. *simulateAge1Index*
3. Once there are three age-1 observations, it adds a third fleet to the assessment and fits to the age-1 index as well as the survey. The only newly estimated parameter is q for Age-1, which uses the analytical solution. *addAge1Fleet*

a. Dat file: Add survey fleet, a name, timing, area, and fleet units. Also add the three indices for age-1.
b. CTL file: catchability setup, selectivity setup, selectivity for age-1, variance adjustments. These changes are made to the assessment and simulation control files since they both use the same dat file.
c. PAR file: add two selectivity parameters at the end of the selectivity section. Both ss3.par files in the simulation and assessment directories.

We then did 12 cases crossing age-1 assumptions and survey assumptions. We used the same seed as before (and 1000 simulations) so that any previous results are comparable to these.

Appendix A.2. Fishery objectives, performance metrics, and operating models to support management strategy evaluation for the Pacific hake fishery

Report from the Joint Technical Committee to the MSE Steering Committee
8/22/2014

Explicit fishery objectives provide the critical link between fishery management and fisheries science. Basically, fishery objectives tell fisheries scientists what to do, and what to look for, when they are asked to provide advice about fishery management plans. Fishery objectives come in four general forms by cross-classifying aspirational/operational types with means/ends types. Aspirational objectives make relatively broad, qualitative statements about overall management goals and tend to look outward, for example, from a specific fishery toward broader regional, national, or international goals. The following management principle drafted by the Pacific Hake Joint Management Committee (JMC) is one example of an aspirational objective (throughout this document the prefix "P" refers to JMC management principles):

P.1 Manage the Pacific Whiting resource utilizing the best available science in a precautionary and sustainable manner
This statement is clearly important and is also consistent with national fishery policies of both the USA and Canada, as well as with international fishery agreements and eco-certification standards. As an objective, this statement therefore looks outward to the world rather than inward to help fisheries scientists identify what to look for in a stock assessment or simulation. The wording of this aspirational objective also identifies it as a means objective; that is, it tells those involved in managing the fishery what to do in general ("utilize best available science...") even though there may be an infinite number of specific ways doing it.

Although both aspirational and means objectives are needed to guide the general management of a fishery, operational/ends objectives imply specific directions about what types of models and analyses scientists should do and what they should look for in the assessment and management strategy simulation output. Operational objectives look inward by translating broad national fishery policies (aspirational/means objectives) into a specific set of criteria that define acceptable fishery performance. The following management principle, also drafted by the JMC is closer to an operational objective:

P.4 Manage the fishery to ensure that each country has the opportunity to receive the intended benefits contemplated in the treaty
This statement has an operational aspect because it suggests that the JTC might need to design a simulation model that separately tracks hake abundance and catch in the USA and Canada. The statement also is closer to an ends objective, than a means objective, because it only presents an outcome ("...each country has the opportunity to receive the intended benefits contemplated in the treaty"). Translating a

means objective into an ends objective is relatively simple – just read the aspirational objective and then ask "why is that important?" until you get a specific answer. For example, we can get from P.1 to P.4 by starting at P.1 and asking why that is important, to which we might answer "because managing in a precautionary way will ensure that hake abundance remains healthy". And why is that important? "Because we need high abundance of hake". And why is that important? "Because we (P.4) need to ensure the each country has the opportunity to receive the intended benefits contemplated in the treaty". And why is that important? "Because it is important!" – this answer defines an ends objective.

Finally, operational/ends objectives require at least three components. (1) a target or threshold value is needed for given quantity that can be represented in an operating model (e.g., hake abundance, proportional distribution between countries, inter-annual variation in catch, etc.). (2) a time horizon over which to measure the value is required: for instance, hake abundance might be measured over 2-3 generations, while catch or catch variability might be measured over shorter timeframes such as 5-10 years. Finally,(3) an acceptable probability of either achieving the target or avoiding a threshold (e.g., 50% chance of being above a target, 95% chance above a threshold) is required. Together these three components define performance with respect to a particular operational objective.

Ideally, the JMC would draft a set of operational/ends objectives from the five management principles presented in Table 1 as well as two possible objectives stated in the Agreement (Table 2). The JTC has provided some possible interpretation and guidance to help this task.

At the present time, the JTC requires these more specific objectives because we are considering whether to develop a more complex operating model for addressing operational objectives such as P.4. There are several considerations to account for in making those choices (see Table 3 for the presentation of some).

Aspirational objectives: The Agreement and Management Principles

The JMC drafted a list of Management Principles at the May 2014 JMC meeting, which provides guidance for defining objectives of the Pacific Hake fishery and metrics to gauge the performance of various management strategies. Table 1 (the letter "P" refers to elements of the Management Principles) lists these five principles along with an interpretation by the JTC of specific objectives that would be useful to consider in an MSE.

Paragraphs 1 and 2 of Article III in The Agreement for Pacific Hake/Whiting provide protocol for managing the Pacific Hake fishery in Canada and the U.S.A, but does not specifically state objectives. Table 2 shows the two paragraphs (the letter "A" followed by a number refers to elements of the Agreement) and the interpretation by the JTC that could guide the formation of objectives. Note that the JTC interprets "the Parties" in both the Agreement and the Management Principles to be U.S. and Canada.

Table 1: Management principles provided by the JMC and the JTC's interpretation of these principles with respect to defining objectives.

	Paragraph	JTC interpretation
P.1	Manage the Pacific Whiting resource utilizing the best available science in a precautionary and sustainable manner.	Similar to The Agreement, the aspirational objective of sustainability appears here. However, the aspirational objective "precautionary" also occurs, and is interpreted by the JTC as defined by the FAO with regard to fisheries management. http://www.fao.org/docrep/003/w3592e/w3592e07.htm) To summarize, "management involves explicit consideration to undesirable and potentially unacceptable outcomes", and "operational interpretations of the precautionary management will depend on the context." Defining undesirable and unacceptable would provide benchmarks to measure management procedures again.
P.2	Maintain a healthy stock status across a range of recruitment events and consider total allowable catch levels that spread the harvest of strong cohorts over multiple years.	The JTC believes that aspirational objectives here are to maintain a diversity of ages in the Pacific Hake population and maintain older age classes in adequate numbers to sustain harvest in both countries.
P.3	Manage the fishery resource in a manner that aims to provide the best long-term benefits to the Parties.	The aspirational objective here seems related to sustainability and is similar to P.1 and A.1. There is no specific guidance on what long-term is and what the benefits are.
P.4	Manage the fishery to ensure that each country has the opportunity to receive the intended benefits contemplated in the treaty.	The JTC is uncertain as to what the intended benefits are, therefore, we cannot define any operational objectives. We believe that defining "intended benefits" would greatly improve our ability to define operational objectives and measure outcomes from the MSE against those objectives.
P.5	These management principles are dynamic and shall be reviewed annually by the JMC and the AP to ensure they remain valid.	Although there do not appear to be objectives defined in the principle, this indicates the need to occasionally revisit the principles and objectives to make sure that they adequately captured the intentions of all Parties.

Table 2: Paragraphs from the Agreement from which objectives could be defined.

	Paragraph	JTC interpretation
A.1	[T]he default harvest rate shall be F-40 percent with a 40/10 adjustment. Having considered any advice provided by the JTC, the SRG or the Advisory Panel, the JMC may recommend to the Parties a different harvest rate if the scientific evidence demonstrates that a different rate is necessary to sustain the offshore hake/whiting resource.	The offshore Pacific Hake resource should be managed in a sustainable manner. The default method to manage this resource is to use an F-40% harvest rate with a 40-10 adjustment. Therefore, catch would be zero at stock sizes less than 10% of unfished biomass, and it implies that the catch would be maximized when the stock is at or above 40% of unfished biomass. Recent research conducted by the JTC suggests that this default harvest strategy is not optimal and there is likely a higher than desired probability of the stock declining to levels that would result in low catch levels. The Agreement, however, is not clear on target biomass levels.
A.2	The United States' share of the overall TAC shall be 73.88 percent. The Canadian share of the overall TAC shall be 26.12 percent.	The words "share of the overall TAC" is ambiguous to the JTC in regard to defining end objectives. Allocation is not purely a scientific decision, but is something we can evaluate given an objective. Using a spatial operating model, we can evaluate alternative management procedures against the defined objective.

To summarize the above, the JTC finds two aspirational objectives (as opposed to operational objectives) that can be defined for an MSE.

> **Aspirational Objective 1: The offshore Pacific Hake resource is above a certain threshold to allow for a sustainable population and sufficient numbers in a diversity of age classes. A threshold may be defined as a level that does not impair recruitment.**
>
> **Aspirational Objective 2: Both parties can achieve their intended benefits.**

In the context of an MSE, operational objectives are needed to measure the performance of different management procedures. However, these aspirational objectives are a good start to defining operational objectives.

The JTC has proposed the questions listed in Table 3 to help guide defining operational objectives and metrics for the MSE.

Questions and metrics

Table 3. Questions that would be useful to guide forming operational objectives and that could be asked of the MSE. Metrics are then provided that could address that question. Finally, an indication is given to whether the metric can be calculated with the current operating model (OM) and/or a potential future spatial operating model.

Stock Status

Question	Metrics	Current OM	Spatial OM
1) What is the desired status of the stock (i.e., abundance)?	The average stock status over a defined time period	Yes	Yes
	The probability that the stock is above, below, or within a defined range	Yes	Yes
2) What is the desired age structure?	The diversity of age classes	Yes	Yes
	The proportion of older fish to total numbers or biomass	Yes	Yes
	The amount of fish above a certain age are available in each country	No	Yes
	The harvest rate of specific age classes	Yes	Yes
	The age at which the median cumulative harvest occurred.	Yes	Yes
3) What is the desired proportion/availability of biomass or numbers in each country?	The proportion of spawning, exploitable, or other biomass in each country.	No	Yes

Yield:

The Agreement and the Management Principles do not specifically state any objectives related to yield other than possibly sustainability and intended benefits.

Question	Metrics	Current OM	Spatial OM
4) What is the desired level of catch	The average TAC over a specified time period	Yes	Yes
	The average TAC in each country	No	Yes
5) What is the maximum allowable change in TAC from year to year?	The average annual variability (AAV) of the TAC over a time period	Yes	Yes
	That AAV of the TAC in each country	No	Yes
6) What is the minimum acceptable TAC?	The proportion of times that the TAC was set below a threshold	Yes	Yes
	The proportion of times that the TAC was set below a threshold in each country	No	Yes
7) What is the availability of fish in each country after allocation?	The proportion of times that a specified percentage of exploitable biomass is less than the TAC for each country	No	Yes

Appendix B. List 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 $B_{40\%}$ (see below) to a value of 0 at $B_{10\%}$.

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, 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.

$B_{10\%}$: 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.

$B_{40\%}$: 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 below).

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

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 S_A) 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, 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: 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: 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. See CPUE below.

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. This is illustrated in Figure A.2.

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.

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.

Cohort: A group of fish born in the same year. Also see recruitment and year-class.

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 $F_{40\%}$ (see below) with the 40:10 adjustment (see above). Having considered any advice provided by the Joint Technical Committee, Scientific Review Group or Advisory Panel, the Joint Management Committee may recommend a different harvest rate if the scientific evidence demonstrates that a different rate is necessary to sustain the offshore 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.

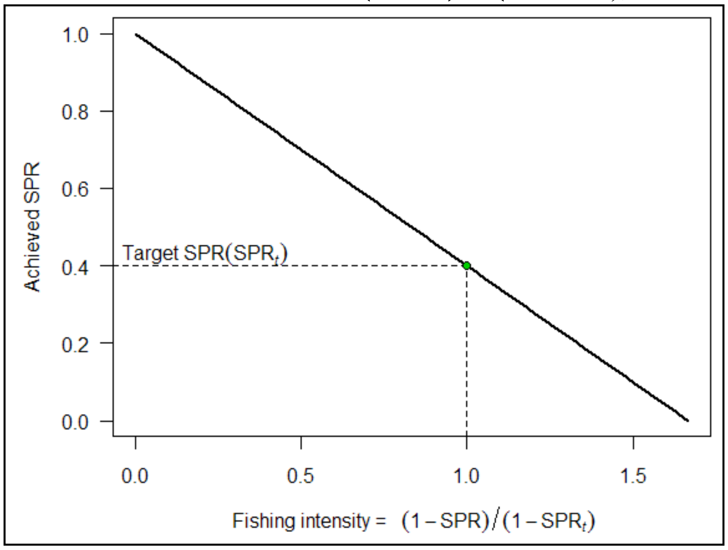
Exploitation fraction: A metric of fishing intensity that represents the total annual catch divided by the estimated population biomass over a range of ages assumed to be vulnerable to the fishery (set to ages 3+ in recent assessments, including this one). This value is not equivalent to the instantaneous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

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

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: relative SPR, or the ratio of (1-SPR) to (1-$SPR_{xx\%}$), where "*xx*" is the 40% proxy.



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.

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. 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.

MAP: maximum a posteriori probability. See below.

Maximum a posteriori probability (MAP) estimate: mode of the posterior distribution used as a point estimate which is similar to the penalized MLE. This is also referred to as the "maximum posterior density" (MPD) in this document.

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. 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 (MLE, see below), but provides a more accurate depiction of parameter uncertainty. See Stewart et al. (2012) for a discussion of issues related to differences between MCMC and MLE.

MLE: Maximum likelihood estimate. Sometimes used interchangeably with "maximum posterior density estimate" or MPD. A numerical method used to estimate a single value of the parameters and derived quantities. It is less computationally intensive than MCMC methods (see above), but parameter uncertainty is less well characterized.

MPD: maximum posterior density. See above.

MSE: Management Strategy Evaluation. A formal process for evaluating Harvest Strategies (see above). The elements of an MSE are illustrated in Figures A.1 and A.2.

MSY: Maximum sustainable yield. See above.

t: Metric ton(s). A unit of mass (often referred to as weight) equal to 1000 kilograms or 2,204.62 pounds. Previous stock assessments used the abbreviation "mt".

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 (see above) represent alternative configurations of the operating model.

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.

OM: Operating Model. See above.

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).

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

Pacific Hake/whiting ("Pacific Hake"): The stock of *Merluccius productus* 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 prior probability distributions (see below) 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 others, 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 below).

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 log 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-SPR) to (1-$SPR_{xx\%}$), where "*xx*" is the proxy or estimated SPR rate that produces MSY.

SB_0: The estimated average unfished equilibrium female spawning biomass or spawning output if not directly proportional to spawning biomass. See B_0.

$SB_{10\%}$: 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. See $B_{10\%.}$

$SB_{40\%}$: 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 below). See $B_{40\%.}$

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

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, 2012 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 the 2011 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 1.0 in the absence of fishing and declines toward 0.0 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*).

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

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: The age-structured stock assessment model applied in this stock assessment. For a more detailed description of this model, see Methot and Wetzel (2013).

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

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 the Canadian 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.

Appendix C. Estimated parameters in the base assessment model

Parameter	Posterior median
NatM_p_1_Fem_GP_1	0.2233
SR_LN.R0.	14.8882
SR_BH_steep	0.8139
Early_InitAge_20	-0.1903
Early_InitAge_19	-0.1027
Early_InitAge_18	-0.0469
Early_InitAge_17	-0.1005
Early_InitAge_16	0.0055
Early_InitAge_15	-0.0648
Early_InitAge_14	-0.1712
Early_InitAge_13	-0.1437
Early_InitAge_12	-0.2111
Early_InitAge_11	-0.3216
Early_InitAge_10	-0.2864
Early_InitAge_9	-0.2387
Early_InitAge_8	-0.4358
Early_InitAge_7	-0.4244
Early_InitAge_6	-0.4487
Early_InitAge_5	-0.3974
Early_InitAge_4	-0.3612
Early_InitAge_3	-0.3357
Early_InitAge_2	-0.1724
Early_InitAge_1	0.0203
Early_RecrDev_1966	0.3193
Early_RecrDev_1967	1.1993
Early_RecrDev_1968	0.7735
Early_RecrDev_1969	-0.0595
Main_RecrDev_1970	2.0662
Main_RecrDev_1971	-0.2987
Main_RecrDev_1972	-0.7670
Main_RecrDev_1973	1.4725
Main_RecrDev_1974	-0.9359
Main_RecrDev_1975	0.2076
Main_RecrDev_1976	-1.0937
Main_RecrDev_1977	1.5982
Main_RecrDev_1978	-1.2856
Main_RecrDev_1979	-0.1149
Main_RecrDev_1980	2.7661
Main_RecrDev_1981	-1.2952
Main_RecrDev_1982	-1.4326
Main_RecrDev_1983	-1.0168
Main_RecrDev_1984	2.4667
Main_RecrDev_1985	-1.6815

Parameter	Posterior median
Main_RecrDev_1986	-1.6722
Main_RecrDev_1987	1.6044
Main_RecrDev_1988	0.5671
Main_RecrDev_1989	-1.7991
Main_RecrDev_1990	1.4167
Main_RecrDev_1991	-0.6429
Main_RecrDev_1992	-1.7381
Main_RecrDev_1993	1.1481
Main_RecrDev_1994	0.9680
Main_RecrDev_1995	0.2378
Main_RecrDev_1996	0.4820
Main_RecrDev_1997	0.0969
Main_RecrDev_1998	0.6133
Main_RecrDev_1999	2.4720
Main_RecrDev_2000	-1.0325
Main_RecrDev_2001	-0.1067
Main_RecrDev_2002	-2.6569
Main_RecrDev_2003	0.3268
Main_RecrDev_2004	-2.6297
Main_RecrDev_2005	0.8850
Main_RecrDev_2006	0.6312
Main_RecrDev_2007	-2.9765
Main_RecrDev_2008	1.8774
Main_RecrDev_2009	0.3571
Main_RecrDev_2010	2.7669
Late_RecrDev_2011	-0.7656
Late_RecrDev_2012	0.5594
Late_RecrDev_2013	-0.2248
Late_RecrDev_2014	0.0411
ForeRecr_2015	0.0548
ForeRecr_2016	-0.1008
ForeRecr_2017	-0.0227
Q_extraSD_2_Acoustic_Survey	0.3762
AgeSel_1P_3_Fishery	3.2661
AgeSel_1P_4_Fishery	1.6072
AgeSel_1P_5_Fishery	0.3080
AgeSel_1P_6_Fishery	0.1153
AgeSel_1P_7_Fishery	0.3046
AgeSel_2P_4_Acoustic_Survey	0.4207
AgeSel_2P_5_Acoustic_Survey	-0.0133
AgeSel_2P_6_Acoustic_Survey	-0.1195
AgeSel_2P_7_Acoustic_Survey	0.4549

AgeSel Parameters	Posterior median
3_Fishery_DEVadd_1991	-0.0013
3_Fishery_DEVadd_1992	-0.0009
3_Fishery_DEVadd_1993	0.0000
3_Fishery_DEVadd_1994	-0.0002
3_Fishery_DEVadd_1995	0.0005
3_Fishery_DEVadd_1996	-0.0002
3_Fishery_DEVadd_1997	-0.0007
3_Fishery_DEVadd_1998	0.0002
3_Fishery_DEVadd_1999	0.0013
3_Fishery_DEVadd_2000	0.0025
3_Fishery_DEVadd_2001	-0.0005
3_Fishery_DEVadd_2002	0.0025
3_Fishery_DEVadd_2003	-0.0002
3_Fishery_DEVadd_2004	-0.0011
3_Fishery_DEVadd_2005	-0.0007
3_Fishery_DEVadd_2006	-0.0012
3_Fishery_DEVadd_2007	0.0012
3_Fishery_DEVadd_2008	0.0005
3_Fishery_DEVadd_2009	0.0036
3_Fishery_DEVadd_2010	0.0016
3_Fishery_DEVadd_2011	0.0042
3_Fishery_DEVadd_2012	0.0019
3_Fishery_DEVadd_2013	0.0013
3_Fishery_DEVadd_2014	0.0023
4_Fishery_DEVadd_1991	-0.0001
4_Fishery_DEVadd_1992	0.0015
4_Fishery_DEVadd_1993	0.0009
4_Fishery_DEVadd_1994	0.0004
4_Fishery_DEVadd_1995	0.0058
4_Fishery_DEVadd_1996	-0.0086
4_Fishery_DEVadd_1997	0.0055
4_Fishery_DEVadd_1998	0.0012
4_Fishery_DEVadd_1999	-0.0095
4_Fishery_DEVadd_2000	0.0069
4_Fishery_DEVadd_2001	0.0249
4_Fishery_DEVadd_2002	0.0032
4_Fishery_DEVadd_2003	0.0029
4_Fishery_DEVadd_2004	-0.0006
4_Fishery_DEVadd_2005	0.0077
4_Fishery_DEVadd_2006	0.0005
4_Fishery_DEVadd_2007	-0.0067
4_Fishery_DEVadd_2008	-0.0019
4_Fishery_DEVadd_2009	0.0040

AgeSel Parameters	Posterior median
4_Fishery_DEVadd_2010	0.0077
4_Fishery_DEVadd_2011	0.0115
4_Fishery_DEVadd_2012	-0.0174
4_Fishery_DEVadd_2013	0.0012
4_Fishery_DEVadd_2014	-0.0028
5_Fishery_DEVadd_1991	-0.0089
5_Fishery_DEVadd_1992	0.0007
5_Fishery_DEVadd_1993	0.0015
5_Fishery_DEVadd_1994	0.0029
5_Fishery_DEVadd_1995	0.0059
5_Fishery_DEVadd_1996	-0.0042
5_Fishery_DEVadd_1997	-0.0047
5_Fishery_DEVadd_1998	-0.0028
5_Fishery_DEVadd_1999	-0.0136
5_Fishery_DEVadd_2000	0.0100
5_Fishery_DEVadd_2001	0.0214
5_Fishery_DEVadd_2002	0.0282
5_Fishery_DEVadd_2003	0.0055
5_Fishery_DEVadd_2004	0.0032
5_Fishery_DEVadd_2005	0.0077
5_Fishery_DEVadd_2006	0.0051
5_Fishery_DEVadd_2007	-0.0084
5_Fishery_DEVadd_2008	0.0030
5_Fishery_DEVadd_2009	0.0006
5_Fishery_DEVadd_2010	0.0087
5_Fishery_DEVadd_2011	-0.0393
5_Fishery_DEVadd_2012	-0.0110
5_Fishery_DEVadd_2013	-0.0115
5_Fishery_DEVadd_2014	-0.0026
6_Fishery_DEVadd_1991	-0.0064
6_Fishery_DEVadd_1992	-0.0022
6_Fishery_DEVadd_1993	0.0029
6_Fishery_DEVadd_1994	0.0132
6_Fishery_DEVadd_1995	0.0070
6_Fishery_DEVadd_1996	-0.0007
6_Fishery_DEVadd_1997	-0.0043
6_Fishery_DEVadd_1998	-0.0006
6_Fishery_DEVadd_1999	-0.0174
6_Fishery_DEVadd_2000	0.0143
6_Fishery_DEVadd_2001	0.0101
6_Fishery_DEVadd_2002	0.0149
6_Fishery_DEVadd_2003	0.0106
6_Fishery_DEVadd_2004	-0.0020

AgeSel Parameters	Posterior median
6_Fishery_DEVadd_2005	0.0067
6_Fishery_DEVadd_2006	0.0056
6_Fishery_DEVadd_2007	-0.0053
6_Fishery_DEVadd_2008	0.0045
6_Fishery_DEVadd_2009	0.0048
6_Fishery_DEVadd_2010	-0.0266
6_Fishery_DEVadd_2011	-0.0340
6_Fishery_DEVadd_2012	-0.0171
6_Fishery_DEVadd_2013	-0.0059
6_Fishery_DEVadd_2014	0.0071
7_Fishery_DEVadd_1991	-0.0067
7_Fishery_DEVadd_1992	0.0026
7_Fishery_DEVadd_1993	-0.0015
7_Fishery_DEVadd_1994	0.0124
7_Fishery_DEVadd_1995	0.0063
7_Fishery_DEVadd_1996	0.0037
7_Fishery_DEVadd_1997	-0.0028
7_Fishery_DEVadd_1998	-0.0088
7_Fishery_DEVadd_1999	-0.0148
7_Fishery_DEVadd_2000	0.0161
7_Fishery_DEVadd_2001	0.0022
7_Fishery_DEVadd_2002	0.0078
7_Fishery_DEVadd_2003	0.0012
7_Fishery_DEVadd_2004	-0.0004
7_Fishery_DEVadd_2005	0.0040
7_Fishery_DEVadd_2006	-0.0062
7_Fishery_DEVadd_2007	-0.0038
7_Fishery_DEVadd_2008	-0.0037
7_Fishery_DEVadd_2009	0.0067
7_Fishery_DEVadd_2010	-0.0292
7_Fishery_DEVadd_2011	-0.0259
7_Fishery_DEVadd_2012	-0.0195
7_Fishery_DEVadd_2013	0.0200
7_Fishery_DEVadd_2014	0.0048

Appendix D. SS data file

```
#C 2015 Hake data file - pre-SRG
###################################################

### Global model specifications ###
1966    # Start year
2014    # 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

49 # 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
#new extraction from different pacFIN table for 1994 US and beyond.
362407   1994    1   #updated 1/8/2015
249496   1995    1   #updated 1/8/2015
#new extraction for Canadian catches resulted in difference from 1996 onward
306299   1996    1   #updated 1/8/2015
325147   1997    1   #updated 1/8/2015
320722   1998    1
311887   1999    1   #updated 1/8/2015
228777   2000    1   #updated 1/8/2015
227525   2001    1   #updated 1/8/2015
180697   2002    1   #updated 1/8/2015
205162   2003    1   #updated 1/8/2015
342307   2004    1   #updated 1/8/2015
363135   2005    1   #updated 1/8/2015
361699   2006    1   #updated 1/8/2015
291054   2007    1   #updated 1/8/2015
322144   2008    1
177209   2009    1
227054   2010    1   #updated 1/8/2015
286892   2011    1   #updated 1/8/2015
207057   2012    1   #updated 1/8/2015
287677   2013    1   #updated 1/8/2015
301573   2014    1   #added 1/9/2015


19 # 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
# Year  seas    fleet   obs       se(log)
1995    1       2       1517948   0.0666
1996    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
1997    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
```

```
1998    1       2       1342740   0.0492
1999    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2000    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2001    1       2        918622   0.0823
2002    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2003    1       2       2520641   0.0709
2004    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2005    1       2       1754722   0.0847
2006    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2007    1       2       1122809   0.0752
2008    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2009    1       2       1612027   0.1375
2010    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence )
2011    1       2        521476   0.1015
2012    1       2       1380724   0.0475
2013    1       2       2422661   0.0433    #updated from 12/25/13 results on 1/7/2014

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

42 # 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
```

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0.329242   0.329242   0.346917   0.368632   0.395312   0.42809    0.468362   0.517841   0.57863    0.653316   0.745076
0.857813   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
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
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0.5        1.5        2.5        3.5        4.5        5.5        6.5        7.5        8.5        9.5        10.5
11.5       12.5       13.5       14.5       15.5       16.5       17.5       18.5       19.5       20.5       # 2008
def36      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809    0.468362   0.517841   0.57863    0.3593238  0.745076
0.857813   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53       2.934      3.388      # 2008
def36      SD of age. 0.55*age9
0.5        1.5        2.5        3.5        4.5        5.5        6.5        7.5        8.5        9.5        10.5
11.5       12.5       13.5       14.5       15.5       16.5       17.5       18.5       19.5       20.5       # 2009
def37      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809    0.468362   0.517841   0.57863    0.653316   0.4097918
0.857813   0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53       2.934      3.388      # 2009
def37      SD of age. 0.55*age10
0.5        1.5        2.5        3.5        4.5        5.5        6.5        7.5        8.5        9.5        10.5
11.5       12.5       13.5       14.5       15.5       16.5       17.5       18.5       19.5       20.5       # 2010
def38      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809    0.468362   0.517841   0.57863    0.653316   0.745076
0.47179715 0.996322   1.1665     1.37557    1.63244    1.858      2.172      2.53       2.934      3.388      # 2010
def38      SD of age. 0.55*age11
0.5        1.5        2.5        3.5        4.5        5.5        6.5        7.5        8.5        9.5        10.5
11.5       12.5       13.5       14.5       15.5       16.5       17.5       18.5       19.5       20.5       # 2011
def39      Expected ages
0.329242   0.329242   0.346917   0.368632   0.395312   0.42809    0.468362   0.517841   0.57863    0.653316   0.745076
0.857813   0.5479771  1.1665     1.37557    1.63244    1.858      2.172      2.53       2.934      3.388      # 2011
def39      SD of age. 0.55*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

#Age comps updated 1/6/2014
50   # Number of age comp observations
```

```
1    # Length bin refers to: 1=population length bin indices; 2=data length bin indices
0    #_combine males into females at or below this bin number
# Acoustic survey ages (N=10)
#year   Season  Fleet   Sex     Partition       AgeErr  LbinLo  LbinHi  nTrips  a1      a2      a3      a4      a5
a6      a7      a8      a9      a10     a11     a12     a13     a14     a15
1995    1       2       0       0       23      -1      -1      68      0.000   0.304   0.048   0.014   0.209   0.012
0.042   0.144   0.003   0.001   0.165   0.001   0.007   0.000   0.051
1998    1       2       0       0       26      -1      -1      103     0.000   0.125   0.144   0.168   0.191   0.016
0.076   0.093   0.014   0.028   0.061   0.005   0.003   0.061   0.015
2001    1       2       0       0       29      -1      -1      57      0.000   0.641   0.104   0.054   0.060   0.030
0.037   0.022   0.011   0.010   0.008   0.008   0.010   0.002   0.004
2003    1       2       0       0       31      -1      -1      71      0.000   0.024   0.023   0.635   0.092   0.031
0.070   0.042   0.028   0.026   0.011   0.007   0.005   0.004   0.004
2005    1       2       0       0       33      -1      -1      47      0.000   0.229   0.021   0.069   0.048   0.492
0.053   0.020   0.027   0.016   0.013   0.007   0.002   0.001   0.002
2007    1       2       0       0       35      -1      -1      70      0.000   0.366   0.022   0.108   0.013   0.044
0.030   0.334   0.034   0.017   0.014   0.007   0.007   0.003   0.001
2009    1       2       0       0       37      -1      -1      66      0.000   0.006   0.299   0.421   0.023   0.082
0.012   0.016   0.015   0.073   0.032   0.013   0.003   0.004   0.002
2011    1       2       0       0       39      -1      -1      59      0.000   0.244   0.631   0.039   0.029   0.030
0.004   0.004   0.003   0.002   0.001   0.007   0.003   0.001   0.000
2012    1       2       0       0       40      -1      -1      96      0.000   0.637   0.097   0.161   0.022   0.026
0.019   0.01    0.005   0.003   0.002   0.006   0.009   0.005   0.001
2013    1       2       0       0       41      -1      -1      67      0.000   0.020   0.762   0.056   0.085   0.009
0.020   0.025   0.007   0.003   0.001   0.001   0.003   0.006   0.003

#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      0.046   0.338  0.074  0.012  0.254  0.055  0.080
        0.105  0.010  0.006  0.009  0.005  0.000  0.005  0.000
1976    1       1       0       0       4       -1      -1      142     0.001   0.013  0.145  0.067  0.041  0.246  0.098
        0.089  0.121  0.054  0.043  0.041  0.011  0.024  0.007
1977    1       1       0       0       5       -1      -1      320     0.000   0.084  0.037  0.275  0.036  0.091  0.227
        0.076  0.065  0.040  0.036  0.023  0.006  0.003  0.001
1978    1       1       0       0       6       -1      -1      341     0.005   0.011  0.065  0.063  0.264  0.061  0.089
        0.215  0.098  0.047  0.047  0.023  0.005  0.004  0.003
1979    1       1       0       0       7       -1      -1      116     0.000   0.065  0.102  0.094  0.057  0.177  0.103
        0.174  0.128  0.042  0.029  0.010  0.016  0.000  0.004
1980    1       1       0       0       8       -1      -1      221     0.001   0.005  0.301  0.019  0.045  0.082  0.112
        0.050  0.089  0.111  0.095  0.026  0.038  0.015  0.011
1981    1       1       0       0       9       -1      -1      154     0.195   0.040  0.014  0.267  0.039  0.055  0.034
        0.147  0.038  0.032  0.102  0.023  0.005  0.002  0.007
1982    1       1       0       0       10      -1      -1      170     0.000   0.321  0.035  0.005  0.273  0.015  0.037
        0.039  0.118  0.033  0.036  0.076  0.002  0.003  0.007
```

1983	1	1	0	0	11	-1	-1	117	0.000	0.000	0.341	0.040	0.018	0.235	0.051
	0.056	0.053	0.094	0.039	0.031	0.023	0.011	0.007							
1984	1	1	0	0	12	-1	-1	123	0.000	0.000	0.014	0.619	0.036	0.038	0.168
	0.029	0.015	0.012	0.033	0.009	0.006	0.014	0.006							
1985	1	1	0	0	13	-1	-1	56	0.009	0.001	0.003	0.072	0.668	0.084	0.056
	0.071	0.020	0.005	0.007	0.002	0.000	0.000	0.000							
1986	1	1	0	0	14	-1	-1	120	0.000	0.153	0.054	0.005	0.008	0.436	0.069
	0.082	0.083	0.022	0.028	0.018	0.031	0.005	0.006							
1987	1	1	0	0	15	-1	-1	56	0.000	0.000	0.296	0.029	0.001	0.010	0.533
	0.004	0.013	0.071	0.000	0.007	0.019	0.018	0.000							
1988	1	1	0	0	16	-1	-1	81	0.000	0.007	0.001	0.323	0.010	0.015	0.007
	0.460	0.013	0.008	0.105	0.008	0.001	0.001	0.043							
1989	1	1	0	0	17	-1	-1	77	0.000	0.056	0.024	0.003	0.502	0.013	0.003
	0.001	0.352	0.018	0.004	0.023	0.001	0.000	0.000							
1990	1	1	0	0	18	-1	-1	163	0.000	0.052	0.205	0.019	0.006	0.315	0.005
	0.002	0.000	0.319	0.003	0.001	0.064	0.000	0.010							
1991	1	1	0	0	19	-1	-1	160	0.000	0.035	0.204	0.196	0.025	0.008	0.283
	0.012	0.001	0.002	0.187	0.004	0.000	0.036	0.007							
1992	1	1	0	0	20	-1	-1	243	0.005	0.042	0.043	0.131	0.186	0.023	0.010
	0.339	0.008	0.001	0.003	0.180	0.004	0.000	0.024							
1993	1	1	0	0	21	-1	-1	175	0.000	0.011	0.232	0.033	0.130	0.157	0.015
	0.008	0.274	0.007	0.001	0.001	0.120	0.001	0.011							
1994	1	1	0	0	22	-1	-1	234	0.000	0.000	0.028	0.214	0.013	0.126	0.187
	0.016	0.006	0.299	0.003	0.003	0.000	0.096	0.009							
1995	1	1	0	0	23	-1	-1	147	0.002	0.017	0.005	0.063	0.290	0.011	0.080
	0.203	0.016	0.002	0.224	0.004	0.005	0.000	0.077							
1996	1	1	0	0	24	-1	-1	186	0.000	0.183	0.162	0.015	0.077	0.181	0.010
	0.049	0.110	0.006	0.003	0.157	0.000	0.001	0.044							
1997	1	1	0	0	25	-1	-1	222	0.000	0.007	0.295	0.250	0.015	0.078	0.125
	0.018	0.040	0.067	0.013	0.002	0.061	0.007	0.023							
1998	1	1	0	0	26	-1	-1	243	0.000	0.048	0.203	0.203	0.266	0.029	0.054
	0.093	0.009	0.016	0.039	0.004	0.001	0.029	0.006							
1999	1	1	0	0	27	-1	-1	514	0.000	0.102	0.204	0.180	0.201	0.132	0.027
	0.039	0.040	0.010	0.015	0.021	0.004	0.003	0.021							
2000	1	1	0	0	28	-1	-1	529	0.010	0.042	0.109	0.143	0.129	0.211	0.131
	0.065	0.046	0.025	0.021	0.023	0.013	0.007	0.024							
2001	1	1	0	0	29	-1	-1	541	0.000	0.173	0.162	0.142	0.157	0.086	0.121
	0.060	0.018	0.022	0.018	0.007	0.014	0.007	0.012							
2002	1	1	0	0	30	-1	-1	450	0.000	0.000	0.506	0.149	0.097	0.057	0.044
	0.066	0.036	0.009	0.008	0.010	0.002	0.005	0.010							
2003	1	1	0	0	31	-1	-1	457	0.000	0.001	0.014	0.679	0.116	0.033	0.050
	0.032	0.032	0.021	0.009	0.004	0.005	0.001	0.002							
2004	1	1	0	0	32	-1	-1	501	0.000	0.000	0.053	0.061	0.683	0.082	0.022
	0.042	0.025	0.013	0.011	0.004	0.003	0.002	0.002							

```
2005   1    1    0    0    33   -1   -1    613    0.000   0.006 0.005 0.066 0.054 0.687 0.080
       0.024 0.029 0.022 0.012 0.011 0.003 0.001 0.002
2006   1    1    0    0    34   -1   -1    720    0.003   0.028 0.104 0.017 0.086 0.049 0.590
       0.053 0.017 0.024 0.011 0.010 0.004 0.001 0.002
2007   1    1    0    0    35   -1   -1    629    0.008   0.114 0.038 0.155 0.016 0.069 0.038
       0.440 0.052 0.017 0.023 0.017 0.005 0.002 0.007
2008   1    1    0    0    36   -1   -1    794    0.007   0.094 0.306 0.024 0.145 0.011 0.036
       0.032 0.282 0.031 0.012 0.007 0.005 0.003 0.004
2009   1    1    0    0    37   -1   -1    686    0.007   0.005 0.307 0.277 0.033 0.106 0.013
       0.023 0.023 0.162 0.025 0.009 0.006 0.003 0.004
2010   1    1    0    0    38   -1   -1    873    0.000   0.251 0.033 0.354 0.213 0.023 0.030
       0.004 0.006 0.010 0.061 0.010 0.003 0.001 0.002
2011   1    1    0    0    39   -1   -1    1081   0.020   0.071 0.701 0.027 0.074 0.052 0.013
       0.009 0.003 0.004 0.001 0.018 0.002 0.001 0.001
2012   1    1    0    0    40   -1   -1    851    0.002   0.402 0.116 0.334 0.025 0.051 0.026
       0.012 0.007 0.002 0.004 0.004 0.009 0.003 0.004
2013   1    1    0    0    41   -1   -1    1094   0.000   0.005 0.699 0.059 0.104 0.011 0.035
       0.021 0.010 0.014 0.003 0.004 0.006 0.024 0.005
2014   1    1    0    0    42   -1   -1    1038   0.000   0.030 0.032 0.636 0.070 0.128 0.017
       0.034 0.019 0.009 0.005 0.001 0.002 0.002 0.013

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
```

Appendix E. SS control file

```
#C 2015 Hake control file - pre-SRG
####################################################

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
2010    # 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)
2011    # Last year for full bias correction in_MPD
```

```
2013    # 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 2014 0.03 0 0 # Change to age 2
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2014 0.03 0 0 # Change to age 3
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2014 0.03 0 0 # Change to age 4
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2014 0.03 0 0 # Change to age 5
  -5    9        0.0    -1      -1      0.01    2       0 2 1991 2014 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
 0.12 0.94 # 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
```

Appendix F. SS starter file (starter.ss)

```
#C 2015 Hake starter file - pre-SRG
###################################################

2015hake_data.SS        # Data file
2015hake_control.SS # Control file

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

999 # end of file marker
```

Appendix G. SS forecast file (forecast.ss)

```
#C 2015 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)
2017    # 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
```

Appendix H. SS weight-at-age file (wtatge.ss)

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2014-01-06 21:21:44
###################################################
165 # 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 0.0918 0.2495 0.3776 0.4850 0.5421 0.5918 0.6631 0.7221 0.7919 0.8645 0.9340
0.9741 1.0708 1.0095 1.0227 1.0227 1.0227 1.0227 1.0227 1.0227
  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
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  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
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  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 0.1297 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

#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 0.0918 0.2495 0.3776 0.4850 0.5421 0.5918 0.6631 0.7221 0.7919 0.8645 0.9340
0.9741 1.0708 1.0095 1.0227 1.0227 1.0227 1.0227 1.0227 1.0227
  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
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  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
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  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 0.1297 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

#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 0.0918 0.2495 0.3776 0.4850 0.5421 0.5918 0.6631 0.7221 0.7919 0.8645 0.9340
0.9741 1.0708 1.0095 1.0227 1.0227 1.0227 1.0227 1.0227 1.0227
  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
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  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
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  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 0.1297 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

#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 0.0918 0.2495 0.3776 0.4850 0.5421 0.5918 0.6631 0.7221 0.7919 0.8645 0.9340
0.9741 1.0708 1.0095 1.0227 1.0227 1.0227 1.0227 1.0227 1.0227
  1975    1      1  1     1     2 0.0550 0.1575 0.2987 0.3658 0.6143 0.6306 0.7873 0.8738 0.9678 0.9075 0.9700 1.6933
1.5000 1.9000 1.9555 2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
  1976    1      1  1     1     2 0.0550 0.0986 0.2359 0.4990 0.5188 0.6936 0.8038 0.9165 1.2063 1.3335 1.4495 1.6507
1.8066 1.8588 1.9555 2.7445 2.7445 2.7445 2.7445 2.7445 2.7445
  1977    1      1  1     1     2 0.0550 0.0855 0.4020 0.4882 0.5902 0.6650 0.7489 0.8272 0.9779 1.1052 1.2341 1.3148
1.4027 1.7511 2.1005 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1      1  1     1     2 0.0517 0.0725 0.1275 0.4699 0.5302 0.6026 0.6392 0.7397 0.8422 0.9811 1.0997 1.2459
1.3295 1.4814 1.7419 2.3353 2.3353 2.3353 2.3353 2.3353 2.3353
  1979    1      1  1     1     2 0.0484 0.0763 0.2410 0.2587 0.5821 0.6868 0.7677 0.8909 0.9128 1.0369 1.1987 1.2482
1.5326 1.5520 1.7950 1.9817 1.9817 1.9817 1.9817 1.9817 1.9817
  1980    1      1  1     1     2 0.0452 0.0800 0.2125 0.4529 0.3922 0.4904 0.5166 0.6554 0.7136 0.8740 1.0626 1.1623
1.2898 1.3001 1.2699 1.3961 1.3961 1.3961 1.3961 1.3961 1.3961
  1981    1      1  1     1     2 0.0419 0.1074 0.2137 0.3422 0.5264 0.3933 0.5254 0.5462 0.7464 0.7204 0.8231 1.0413
1.0989 1.3449 1.4926 1.2128 1.2128 1.2128 1.2128 1.2128 1.2128
  1982    1      1  1     1     2 0.0386 0.1181 0.2465 0.3336 0.3097 0.5496 0.3956 0.5275 0.5629 0.7606 0.6837 0.8539
1.0670 0.8793 1.0186 1.1693 1.1693 1.1693 1.1693 1.1693 1.1693
  1983    1      1  1     1     2 0.0353 0.1287 0.1357 0.3410 0.3694 0.3277 0.5200 0.5028 0.6179 0.7060 0.8800 0.9299
1.0356 1.0310 1.3217 1.4823 1.4823 1.4823 1.4823 1.4823 1.4823
  1984    1      1  1     1     2 0.0321 0.1315 0.1642 0.2493 0.4384 0.4113 0.4352 0.5872 0.5802 0.6758 0.7010 0.9513
1.1364 1.0258 1.2807 1.8800 1.8800 1.8800 1.8800 1.8800 1.8800
  1985    1      1  1     1     2 0.0288 0.1740 0.2297 0.2679 0.4414 0.5496 0.5474 0.6017 0.7452 0.6933 0.7231 0.8584
0.8698 0.9458 0.6759 1.1217 1.1217 1.1217 1.1217 1.1217 1.1217
  1986    1      1  1     1     2 0.0255 0.1555 0.2780 0.2906 0.3024 0.3735 0.5426 0.5720 0.6421 0.8209 0.9403 1.1860
1.1900 1.3737 1.6800 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
  1987    1      1  1     1     2 0.0222 0.1478 0.1388 0.3790 0.2786 0.2870 0.3621 0.5775 0.5975 0.6369 0.7638 0.9820
0.9250 1.2407 1.2031 1.4157 1.4157 1.4157 1.4157 1.4157 1.4157
  1988    1      1  1     1     2 0.0190 0.1400 0.1870 0.3189 0.4711 0.3689 0.3731 0.5163 0.6471 0.6884 0.7183 0.9211
1.0924 1.0225 1.4500 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
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  1989    1       1  1     1      2 0.0157 0.1389 0.2737 0.3047 0.2931 0.5134 0.4386 0.4064 0.5167 0.6263 0.6611 0.6027
0.8758 0.6686 0.8282 1.1264 1.1264 1.1264 1.1264 1.1264 1.1264
  1990    1       1  1     1      2 0.0156 0.1378 0.2435 0.3506 0.3906 0.5111 0.5462 0.6076 0.6678 0.5300 0.7697 0.8312
2.2000 1.1847 1.0166 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
  1991    1       1  1     1      2 0.0156 0.1367 0.2754 0.3697 0.4598 0.5138 0.5437 0.5907 0.7210 0.8497 1.0997 0.7185
0.6403 1.0174 1.2051 2.3828 2.3828 2.3828 2.3828 2.3828 2.3828
  1992    1       1  1     1      2 0.0155 0.1356 0.2316 0.3473 0.4743 0.5334 0.5817 0.6210 0.6406 0.6530 0.6330 0.7217
0.7354 0.8501 0.9750 1.0272 1.0272 1.0272 1.0272 1.0272 1.0272
  1993    1       1  1     1      2 0.0155 0.1274 0.2486 0.3384 0.3960 0.4539 0.4935 0.5017 0.4880 0.5491 0.5100 1.2630
1.0250 0.6135 0.5995 0.6850 0.6850 0.6850 0.6850 0.6850 0.6850
  1994    1       1  1     1      2 0.0154 0.1191 0.3000 0.3626 0.4469 0.4473 0.5262 0.5700 0.6218 0.5598 0.6341 0.4850
0.6491 0.7300 0.7013 0.7455 0.7455 0.7455 0.7455 0.7455 0.7455
  1995    1       1  1     1      2 0.0154 0.1108 0.2682 0.3418 0.4876 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7445
0.7998 0.9101 0.6804 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
  1996    1       1  1     1      2 0.0153 0.1007 0.2876 0.3982 0.4674 0.5317 0.5651 0.6509 0.5957 0.6362 0.6049 0.7500
0.6756 0.8109 1.4853 0.7509 0.7509 0.7509 0.7509 0.7509 0.7509
  1997    1       1  1     1      2 0.0153 0.0906 0.3555 0.4322 0.4931 0.5476 0.5453 0.5833 0.5855 0.6071 0.6315 0.8633
0.5946 0.7118 0.6618 0.8693 0.8693 0.8693 0.8693 0.8693 0.8693
  1998    1       1  1     1      2 0.0152 0.0805 0.2091 0.3539 0.5041 0.5172 0.5420 0.6412 0.6099 0.6769 0.8078 0.7174
0.8100 0.7733 0.7510 0.7979 0.7979 0.7979 0.7979 0.7979 0.7979
  1999    1       1  1     1      2 0.0152 0.1352 0.2502 0.3455 0.4251 0.5265 0.5569 0.5727 0.6117 0.7030 0.6650 0.7989
0.7554 0.8787 0.7348 0.8187 0.8187 0.8187 0.8187 0.8187 0.8187
  2000    1       1  1     1      2 0.0151 0.1899 0.3216 0.4729 0.5766 0.6598 0.7176 0.7279 0.7539 0.8378 0.8159 0.8814
0.8554 0.9391 0.8744 0.9336 0.9336 0.9336 0.9336 0.9336 0.9336
  2001    1       1  1     1      2 0.0151 0.0512 0.2867 0.4843 0.6527 0.6645 0.7469 0.8629 0.8555 0.8802 0.9630 0.9790
1.0054 1.0494 0.9927 0.9768 0.9768 0.9768 0.9768 0.9768 0.9768
  2002    1       1  1     1      2 0.0150 0.0756 0.3583 0.4575 0.6058 0.8160 0.7581 0.8488 0.9771 0.9322 0.9176 0.9974
0.9890 0.9236 1.1250 1.0573 1.0573 1.0573 1.0573 1.0573 1.0573
  2003    1       1  1     1      2 0.0150 0.1000 0.2551 0.4355 0.5225 0.5885 0.7569 0.6915 0.7469 0.8246 0.7692 0.8887
0.9266 0.7894 0.8414 0.9965 0.9965 0.9965 0.9965 0.9965 0.9965
  2004    1       1  1     1      2 0.0149 0.1081 0.2000 0.4360 0.4807 0.5319 0.6478 0.7068 0.6579 0.7094 0.8050 0.8581
0.7715 0.9704 0.8631 0.8959 0.8959 0.8959 0.8959 0.8959 0.8959
  2005    1       1  1     1      2 0.0149 0.1162 0.2603 0.4311 0.5086 0.5393 0.5682 0.6336 0.6550 0.7027 0.7962 0.8104
0.8109 0.7602 1.1449 0.9678 0.9678 0.9678 0.9678 0.9678 0.9678
  2006    1       1  1     1      2 0.0148 0.1324 0.3831 0.4575 0.5341 0.5740 0.5910 0.5979 0.6560 0.6997 0.7259 0.7220
0.7753 0.6580 0.6399 0.9550 0.9550 0.9550 0.9550 0.9550 0.9550
  2007    1       1  1     1      2 0.0148 0.0445 0.2272 0.3776 0.5352 0.5530 0.6073 0.6328 0.6475 0.7055 0.7723 0.7627
0.8137 0.8702 0.8008 0.8698 0.8698 0.8698 0.8698 0.8698 0.8698
  2008    1       1  1     1      2 0.0148 0.1346 0.2440 0.4079 0.5630 0.6365 0.6865 0.6818 0.7098 0.7211 0.7488 0.8073
0.8483 0.7755 0.8834 0.8332 0.8332 0.8332 0.8332 0.8332 0.8332
  2009    1       1  1     1      2 0.0148 0.0667 0.2448 0.3431 0.4712 0.6371 0.6702 0.6942 0.7463 0.8226 0.7674 0.8139
1.0147 0.8503 0.9582 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
  2010    1       1  1     1      2 0.0148 0.1089 0.2326 0.2918 0.4332 0.5302 0.6582 0.8349 1.0828 1.0276 0.9582 0.8763
0.8524 1.1253 0.7200 0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
```

```
  2011    1      1  1     1     2 0.0148 0.0844 0.2457 0.3219 0.3867 0.5142 0.5950 0.6746 0.8534 0.9294 0.9780 1.0749
1.0588 1.0279 1.0557 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1      1  1     1     2 0.0148 0.1290 0.2145 0.3536 0.4094 0.4889 0.6562 0.6907 0.7775 0.9072 0.9633 0.9639
0.9639 0.9889 0.9924 0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
  2013    1      1  1     1     2 0.0148 0.1297 0.2874 0.3595 0.4697 0.5104 0.6260 0.7165 0.7310 0.8313 0.9989 1.0752
1.2303 1.1187 1.0682 1.0545 1.0545 1.0545 1.0545 1.0545 1.0545
  2014    1      1  1     1     2 0.0148 0.1297 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
# End of wtatage.ss file
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