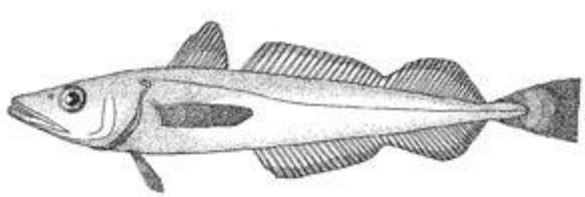
Status of the Pacific hake (whiting) stock in U.S. and Canadian waters in 2013



International Joint Technical Committee for Pacific hake

Final Document
3/4/2013

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

Authors of this document are (In no particular order):

Allan C. Hicks[1,2]
Nathan Taylor[1,3]
Chris Grandin[1,3]
Ian G. Taylor[1,2]
Sean Cox[1,4]

[1]*Official member of the 2013 Joint Technical Committee*

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

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

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

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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. In years with warmer water temperatures the stock tends to move farther to the North during the summer and older hake tend to migrate farther than younger fish in all years. Separate, and much smaller, populations of hake occurring in the major inlets of the northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California, are not included in this analysis.

Catches

Coast-wide fishery landings of Pacific hake averaged 222,000 mt from 1966 to 2012, with a low of 90,000 mt in 1980 and a peak of 363,000 mt in 2005. Prior to 1966 the total removals were negligible relative to the modern fishery. The fishery in U.S. waters has averaged 166,000 mt, or 74.7% of the average total landings over the time series, with the catch from Canadian waters averaging 56,000 mt. During the fishery's first 25 years, the majority of removals were from foreign or joint-venture fisheries. In this stock assessment, the terms catch and landings are used interchangeably; estimates of discard within the target fishery are included, but discarding of Pacific hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings and therefore is likely to be negligible with regard to the population dynamics.

Recent coast-wide landings from 2008–2012 have been above the long term average, at 243,000 mt. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal from that cohort exceeding an estimated 1.2 million mt. In 2008, the fishery began harvesting considerable numbers of the then emergent 2005 year class. Catches in 2009 were again dominated by the 2005 year class with some contribution from an emergent 2006 year class and relatively small numbers of the 1999 cohort. The 2010 and 2011 fisheries encountered very large numbers of the 2008 year-class, while continuing to see some of the 2005 and 2006 year-classes as well as a small proportion of the 1999 year class. In 2012, U.S. fisheries caught mostly 2 and 4-year old fish from the 2008 and 2010 year classes, while the Canadian fisheries encountered older fish from the 2005, 2006, and 2008 year classes. A considerable number of 2-year old fish were caught by the U.S. at-sea fleet later in the year.

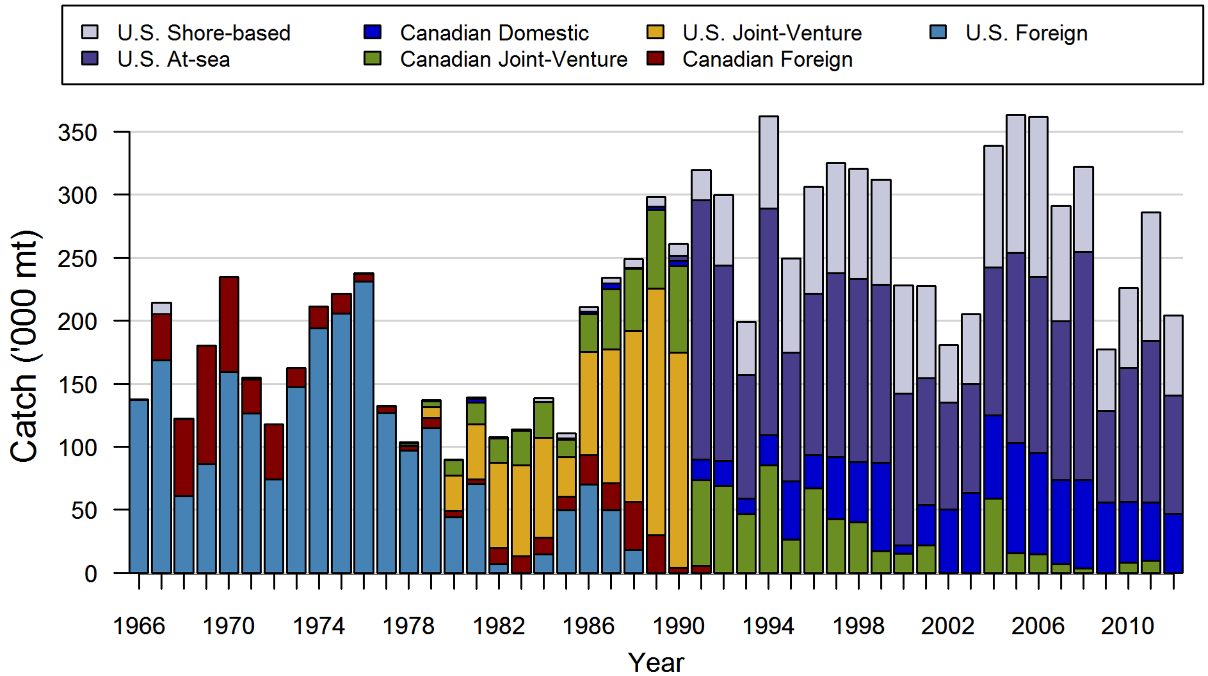


Figure a. Total Pacific hake catch used in the assessment by sector, 1966-2012. Tribal catches are included.

Table a. Recent commercial fishery catch (1,000's mt). Tribal catches are included where applicable.

Year	US at-sea	US shore-based	US total	Canadian joint-venture	Canadian domestic	Canadian total	Total
2003	87	55	142	0	63	63	205
2004	117	97	214	59	66	125	339
2005	151	109	260	16	87	103	363
2006	140	127	267	14	80	95	362
2007	126	91	218	7	67	73	291
2008	181	68	248	4	70	74	322
2009	72	49	122	0	56	56	177
2010	106	64	170	8	48	56	217
2011	128	102	230	10	46	56	286
2012	94	63	157	0	47	47	204

Data and assessment

Data have been updated for the 2013 assessment with the addition of new ages into the 2011 age distribution, the addition of a new age distribution from the 2012 fishery and acoustic survey, and addition of the 2012 acoustic survey biomass estimate to the abundance index.

This assessment reports a single base-case model representing the collective work of the Joint Technical Committee (JTC), and depends primarily upon nine years of an acoustic survey biomass index as well as catches for information on the scale of the current hake stock. The 2011 survey index value is the lowest in the time-series, and the 2012 index is more than 2.5 times greater. The age-composition data from the aggregated fisheries (1975-2012) and the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts. Both sources indicate a strong 2008 cohort in the 2011 and 2012 data, and a strong 2010 cohort in the 2012 data, which may partially explain the recent increase in the survey index.

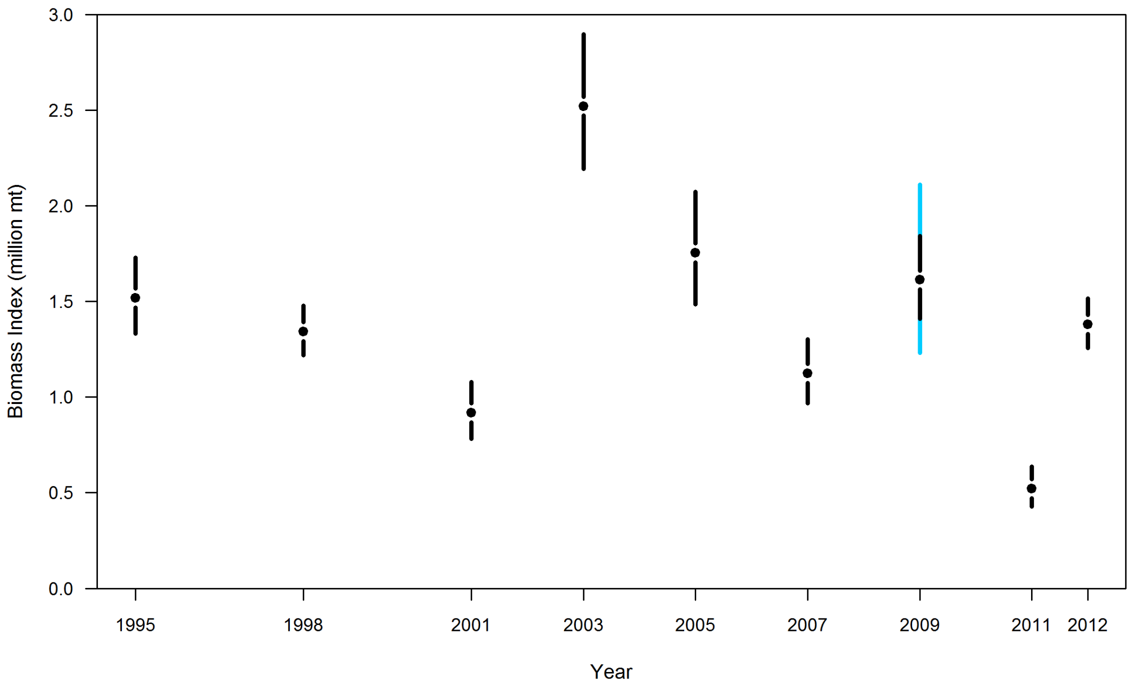


Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2012) in addition to squid/hake apportionment uncertainty (2009, in blue).

The assessment uses Bayesian methods to incorporate prior information on two key parameters (natural mortality, *M*, and steepness of the stock-recruit relationship, *h*) and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty is not limited to parameter uncertainty as structural uncertainty is investigated through sensitivity analyses.

Stock biomass

The base-case stock assessment model indicates that Pacific hake female spawning biomass was below the unfished equilibrium in the 1960s and 1970s. The stock is estimated to have increased rapidly 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 (a median female spawning biomass estimate of 1.34 million mt in the SS model) as the large 1999 year class matured. The stock is then estimated to have declined with the aging 1999 year class to a female spawning biomass time-series low of 0.42 million mt in 2009. This recent decline is similar to that estimated in the 2012 assessment, but at a slightly greater absolute value. The current (2013) median posterior spawning biomass is estimated to be 72.3% of the estimated unfished equilibrium level (SB_0) with 95% posterior credibility intervals ranging from 34.7% to 159.7%. The estimate of 2013 female spawning biomass is 1.50 million mt, which is more than double the projected spawning biomass from the 2012 assessment (0.64 million mt). The difference in projected biomass is largely driven by increases in the estimated size of the 2008 and 2010 year classes.

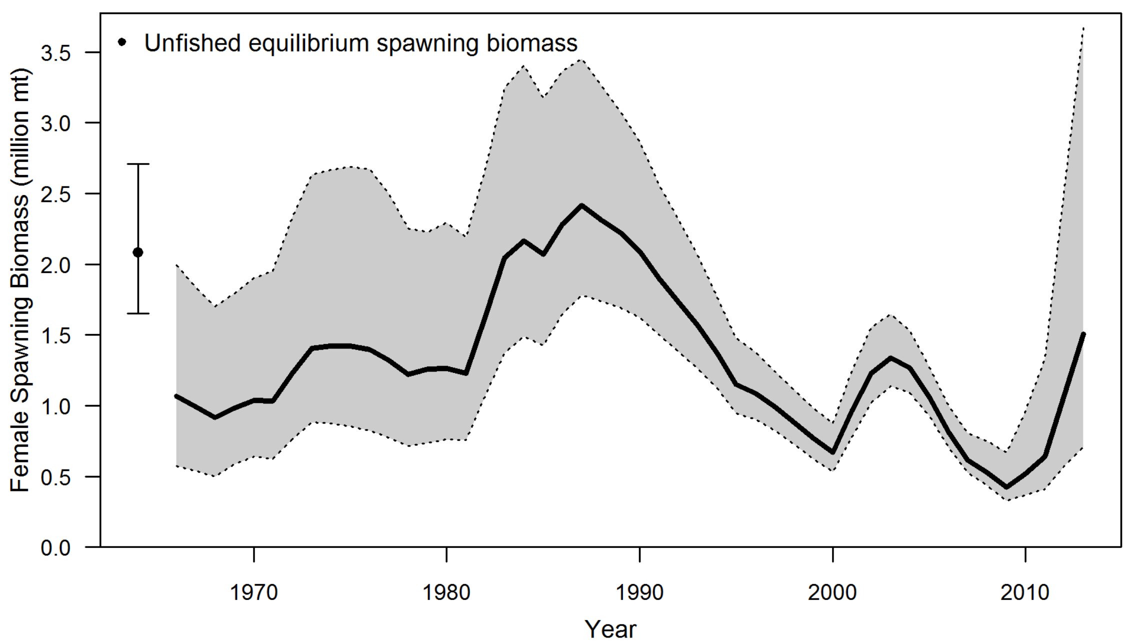


Figure c. Median of the posterior distribution for female spawning biomass through 2013 (solid line) with 95% posterior credibility intervals (shaded area).

Table b. Recent trends in estimated Pacific hake female spawning biomass (million mt) and depletion level relative to estimated unfished equilibrium.

	Spawning biomass (mt)			Depletion (SB_t/SB_0)		
Year	2.5^{th} percentile	Median	97.5^{th} percentile	2.5^{th} percentile	Median	97.5^{th} percentile
2004	1.093	1.268	1.530	0.475	0.605	0.769
2005	0.929	1.064	1.277	0.401	0.508	0.640
2006	0.705	0.811	1.000	0.307	0.390	0.491
2007	0.527	0.617	0.808	0.236	0.297	0.384
2008	0.436	0.529	0.751	0.199	0.255	0.345
2009	0.327	0.424	0.670	0.152	0.204	0.303
2010	0.371	0.520	0.964	0.172	0.255	0.418
2011	0.409	0.642	1.333	0.194	0.315	0.579
2012	0.575	1.078	2.542	0.275	0.516	1.109
2013	0.709	1.504	3.676	0.347	0.723	1.597

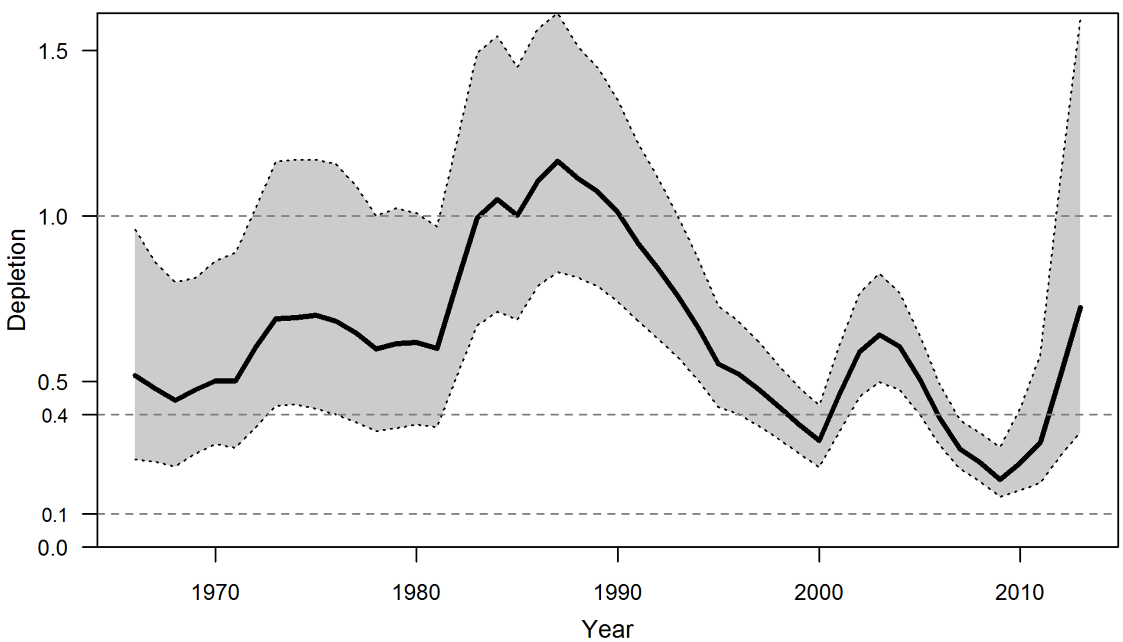


Figure d. Median (solid line) of the posterior distribution for spawning depletion (SB_t/SB_0) through 2013 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% depletion levels.

Recruitment

Recruitment is highly variable for Pacific hake. Large year classes in 1980, 1984, and 1999 have been a major component of the fishery in the 1980's and early 1990's, and the early 2000's. Recently, strong year classes are estimated in 2008 and 2010, although the uncertainty about 2010 year class strength is large given the limited exposure to fisheries. In the last decade, estimated recruitment has been at some of the lowest values in the time-series as well some of the highest.

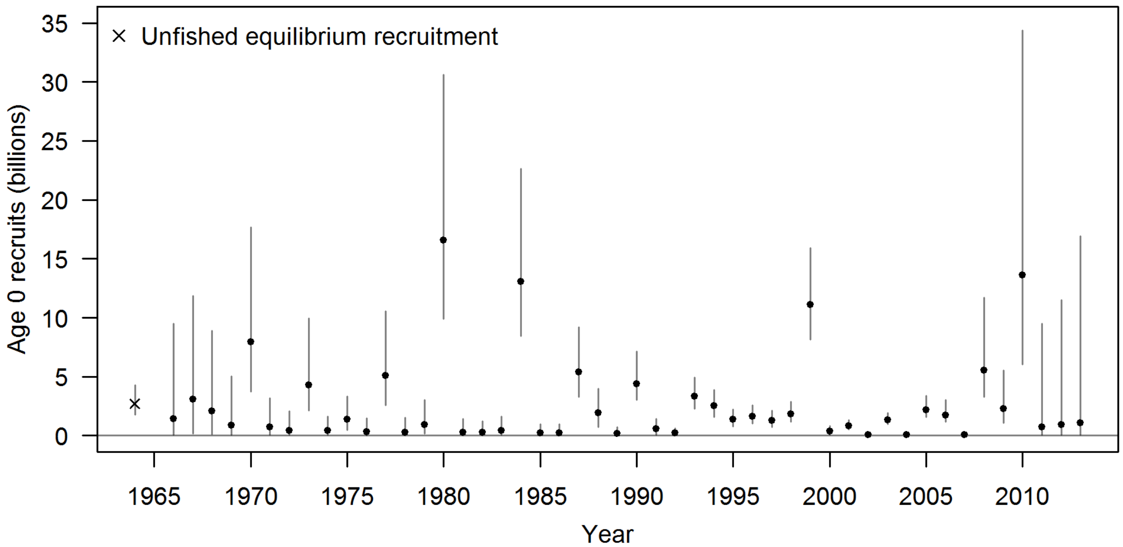


Figure e. Medians (solid circles) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (gray lines). Unfished equilibrium recruitment is shown as an X.

Table c. Estimates of recent Pacific hake recruitment (billions of age-0).

Year	2.5th percentile	Median	97.5th percentile
2004	0.012	0.069	0.228
2005	1.557	2.172	3.379
2006	1.151	1.721	3.048
2007	0.017	0.088	0.295
2008	3.288	5.526	11.720
2009	1.088	2.269	5.519
2010	6.037	13.606	34.396
2011	0.060	0.737	9.509
2012	0.054	0.916	11.500
2013	0.054	1.061	16.926

Exploitation status

Fishing intensity on the Pacific hake stock is estimated to have been below the $F_{40\%}$ target until 2007. The base-case model estimates of prior fishing intensity indicate that the target was likely exceeded in three of the last five years. (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 at the time.) The exploitation fraction does not necessarily correspond to fishing intensity because fishing intensity accounts for the age-structure of the population. For example, the fishing intensity remained nearly constant and above target from 2010 to 2011. However, the exploitation fraction declined in these years because of many estimated 1 year old fish.

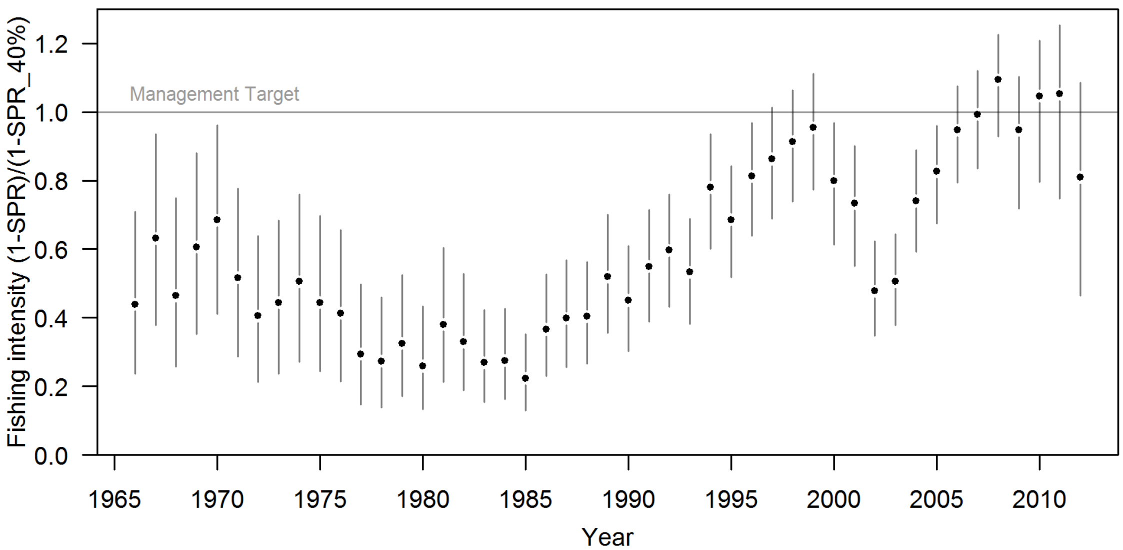


Figure f. Trend in median fishing intensity (relative to the SPR management target) through 2012 with 95% posterior credibility intervals. The management target define in the Agreement is shown as a horizontal line at 1.0.

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

	Fishing intensity			Exploitation fraction		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2003	37.8%	50.6%	64.4%	5.1%	6.3%	7.5%
2004	59.2%	74.1%	88.9%	10.6%	12.8%	14.8%
2005	67.5%	82.7%	96.0%	15.6%	18.7%	21.4%
2006	79.4%	94.7%	107.6%	18.3%	22.7%	26.0%
2007	83.5%	99.3%	112.0%	21.2%	27.5%	32.2%
2008	92.8%	109.4%	122.5%	20.8%	29.2%	35.2%
2009	71.7%	94.7%	110.3%	11.7%	18.4%	23.8%
2010	79.6%	104.7%	120.9%	18.2%	30.7%	42.3%
2011	74.8%	105.2%	125.3%	10.5%	21.5%	33.5%
2012	46.4%	81.0%	108.5%	6.3%	14.5%	26.4%

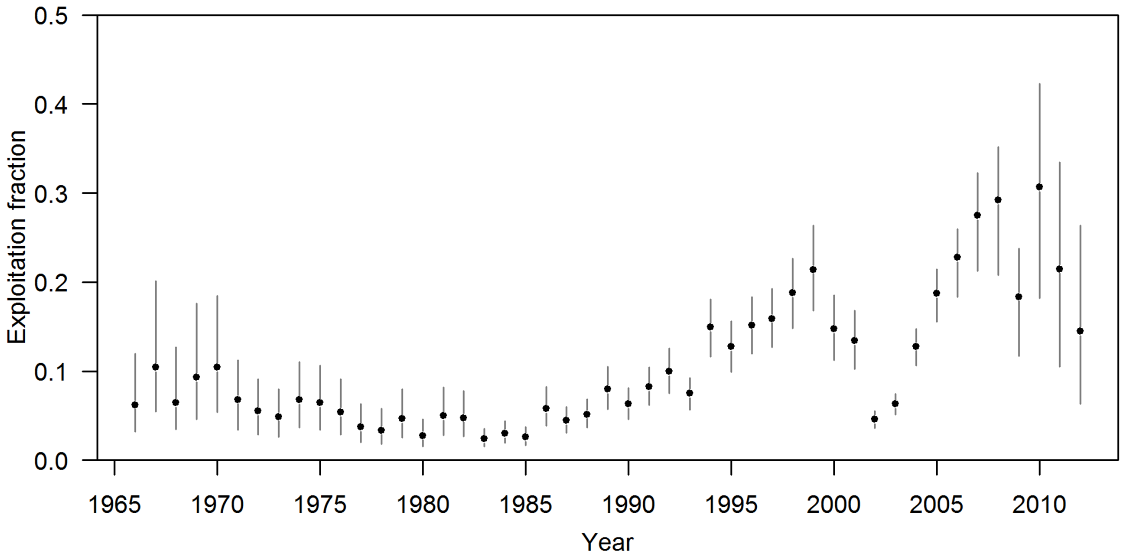


Figure g. Trend in median exploitation fraction through 2012 with 95% posterior credibility intervals.

Management Performance

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 by foreign and domestic fisheries. During the 1990s, however, disagreement between the U.S. and Canada on the division of the total catch led to quota overruns; 1991-1992 quotas summed to 128% of the limit and overruns averaged 114% from 1991-1999. Since 1999, catch targets have been determined using an $F_{40\%}$ default harvest rate with a 40:10 control rule (the default harvest policy) that decreases the catch linearly from a depletion of 40% to a depletion of 10%. Further considerations have often resulted in catch targets to be set lower than the recommended catch limit. 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.

Total catches last exceeded the coastwide catch target in 2002, when landings were 112% of the catch target. Over the last ten years, the average utilization has been 87%. From 2009 to 2012 much of the U.S. tribal allocation remained uncaught and Canadian catches have also been below the limit even though in retrospect the target harvest rate was surpassed in some years. The exploitation history in terms of both the biomass and *F*-target reference points, portrayed graphically via a phase-plot in Figure h, shows that historically the fishing intensity has been low and the biomass has been high. Recently, the estimated depletion level has been below 40% and the fishing intensity high, until 2012 when fishing intensity was below target and depletion was above 40%. Uncertainty is the 2012 estimates of fishing intensity and depletion show a 9% joint probability of being above the target fishing intensity and below 40% depletion.

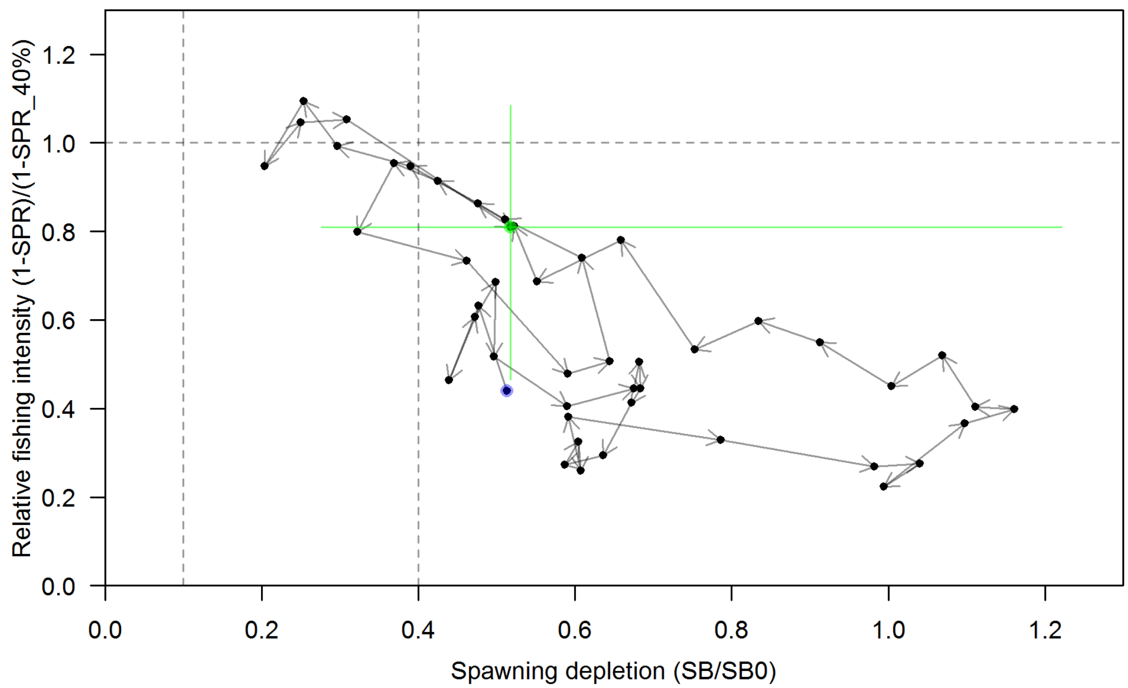


Figure h. Temporal pattern (phase plot) of posterior median fishing intensity vs. posterior median depletion through 2012. The blue circle indicates 1966 and the green circle denotes 2012. Green bars indicatethe 95% posterior credibility intervals along both axes. Arrows indicate the temporal progression of years and the dashed lines indicate the fishing intensity target (vertical) and the 40:10 control rule limits (vertical, 10% and 40%).

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

Year	Total Landings (mt)	Coast-wide (US+Canada) catch target (mt)
2003	205,177	228,000
2004	338,654	501,073
2005	363,157	364,197
2006	361,761	364,842
2007	291,129	328,358
2008	322,145	364,842
2009	177,459	184,000
2010	226,202	262,500
2011	286,055	393,751
2012	204,040	251,809

Reference points

The estimated unfished equilibrium spawning biomass estimate was 2,081 thousand mt, which is 10% greater than the estimate reported in the 2012 stock assessment. The 95% posterior credibility interval ranges from 1,653 to 2,709 thousand mt and encompasses the estimate from the 2012 assessment. The spawning biomass that is 40% of the unfished equilibrium spawning biomass ($SB_{40\%}$) is estimated to be 833 thousand mt, which is slightly larger than the equilibrium spawning biomass implied by the $F_{40\%}$ default harvest rate target, 36% of SB_0 (744 thousand mt). *MSY* is estimated to occur at 24% of SB_0 (500 thousand mt) with a yield of 357 thousand mt; only slightly higher than the equilibrium yield at the biomass target ($SB_{40\%}$), 328 thousand mt, and at the $F_{40\%}$ target, 337 thousand mt. The full set of reference points, with posterior credibility intervals for the base case is reported in Table f.

Table f.. Summary of Pacific hake reference points for the base-case model.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female *SB* (SB_0, thousand mt)	1,653	2,081	2,709
Unfished recruitment (R_0, billions)	1.761	2.687	4.303
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	556	744	942
$SPR_{MSY\text{-}proxy}$	–	40%	–
Exploitation fraction corresponding to SPR	18.4%	21.8%	25.9%
Yield at $SB_{F40\%}$ (thousand mt)	243	337	479
Reference points based on $SB_{40\%}$			
Female spawning biomass ($SB_{40\%}$ thousand mt)	661	833	1,084
$SPR_{SB40\%}$	40.6	43.2	51.4
Exploitation fraction resulting in $SB_{40\%}$	14.4%	19.2%	23.3%
Yield at $SB_{40\%}$ (thousand mt)	238	328	469
Reference points based on estimated MSY			
Female spawning biomass (SB_{MSY} thousand mt)	328	500	840
SPR_{MSY}	18.3%	28.2%	46.5%
Exploitation fraction corresponding to SPR_{MSY}	17.6%	34.5%	59.5%
MSY (thousand mt)	248	357	524

Unresolved problems and major uncertainties

Measures of uncertainty in this assessment underestimate the true uncertainty in current stock status and future projections because they do not account for 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 distribution choices.

The JTC investigated a broad range of alternative models, and we present a subset of key sensitivity analyses in the main document. A major source of uncertainty in the 2013 status and target catch is in the estimate of the size of the 2010 year class. The posterior distribution of derived parameters from the base model encompasses the median estimates of most sensitivity models.

Pacific hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. 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 future stock trajectory. Uncertainty in this assessment is largely a function of the potentially large 2010 year class being observed once in the acoustic survey and twice in the fishery, although with low and uncertain selectivity. The supplemental acoustic survey performed in 2012 helped reduce the uncertainty of the strength of this year class, which is an expected result of increasing the survey frequency. However, with recruitment being a main source of uncertainty in the projections and the survey not quantifying hake until they are 2 years old, short term forecasts are very uncertain.

At the direction of the JMC, the JTC developed a Management Strategy Evaluation (MSE) in 2012 to explore the basic performance of the default harvest policy in the context of annual vs. biennial surveys. The results of these explorations showed that biomass levels and average catch are variable, mainly because of the high recruitment variability seen with Pacific hake coupled with potentially large stock assessment estimation biases. Even though the Pacific hake fishery is relatively data-rich, with a directed fishery-independent survey program, substantial biological sampling for both commercial fisheries and the acoustic survey, and reliable estimates of catch, the data are less informative about incoming recruitment which is partially responsible for large differences between the simulated abundance and the estimated abundance.

The MSE simulations show two main results. First, the current $F_{40\%}$-40:10 management strategy with perfect knowledge of current biomass resulted in a median long-term average depletion of less than 30%. Second, there was little difference in median values between strategies involving annual and biennial surveys. At the present time, we consider these conclusions preliminary because our simulations involved a limited range of uncertain processes that are known or suspected to occur for Pacific hake. For example, the structure and assumptions of the stock assessment model used in the annual the assessment-management cycle matched the assumptions of the operating model used to generate stock dynamics and assessment data. Such a match typically underepresents the potential range of future outcomes possible under any combination of harvest policy and survey frequency. In the MSE (Appendix A), we identify several factors that may lead to incorrect assumptions in the stock assessment model.

The JTC recommends continuing work on the MSE by expanding the operating model to investigate the performance of a suite of assessment models with more complicated hypotheses about actual Pacific hake life-history and fishery dynamics. 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

A decision table showing predicted status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base-case model. The decision table (split into Tables g.1 and 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 (g.1) shows projected depletion outcomes, and the second (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.

An additional table is presented containing a set of management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP) in 2012. These metrics summarize the probability of various outcomes from the base case model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values. Figure i shows the depletion trajectory through 2015 for several of these management actions.

The median spawning stock biomass is projected to remain constant with a 2013 catch of 650,000 mt, which is greater than the catch determined using the default harvest rate (626,364 mt). A catch of approximately 603,000 mt results in an equal probability of the stock increasing or decreasing from 2013 to 2014, based on individual trajectories from samples of the posterior distribution. The median values show slightly different results than the individual trajectories, which is not unexpected. Catches of less than 600,000 mt result in a slight increase in the median 2014 spawning biomass. However, the posterior distribution is highly uncertain, and either increasing or decreasing trends are possible over a broad range of 2012 catch levels. A 2013 catch of 696,000 mt results in the same projected catch of 696,000 mt in 2014 when applying the default harvest policy ($F_{40\%}$ – 40:10).

Table g.3 shows the same catch alternatives for 2013 and probabilities based on individual samples from the posterior distribution. The probability that the spawning stock biomass in 2014 remains above the 2013 level is 50% with a catch of 603,000 mt, the probability that the fishing intensity is above target in 2013 is 50% with a catch of 626,364 mt, and the probability that the predicted 2014 catch target is the same as a set value in 2013 is 50% for a set value of 696,000 mt in 2013. There is less than a 12% probability that the spawning stock will drop below 40% in 2014 for all catch levels considered.

Until cohorts are five or six years old, the model's ability to resolve cohort strength is poor. For many of the recent above average cohorts (2005, 2006, and 2008), the size of the year class was overestimated when it was age 2, compared to updated estimates as the cohort aged and more observations were available from the fishery and survey. Given this trend, a very uncertain 2010 year class, and a projected 2013 catch target that is both more than 1.5 times the highest catch in the time series and 1.75 times the median MSY, additional forecast decision tables were created given three states of nature about the size of the 2010 year class. These states of nature are low 2010 recruitment, medium 2010 recruitment, and high 2010 recruitment, and each state of nature is defined to have a probability of 10%, 80%, and 10%, respectively. Table g.4 shows the median depletion and fishing intensity within each state of nature, and it can be seen that in the low-recruitment state of nature the fishing intensity would be at target with a 2013 catch between 300,000 and 350,000 mt. Table g.5 shows the probability metrics for each state of nature. In the low-recruitment state of nature there is an equal probability that the spawning biomass in 2014 will be less than or greater than the spawning biomass in 2013 with a catch between 300,000 and 350,000 mt. There is an equal probability that the spawning biomass will be below 40% of unfished equilibrium spawning biomass with a catch near 400,000 mt.

Table g.1. Posterior distribution quantiles for forecasts of Pacific hake relative depletion (at the beginning of the year before fishing takes place) from the base model. Catch alternatives are based on: 1) arbitrary constant catch levels (rows a–g), 2) the catch level that results in an equal probability of the population increasing or decreasing from 2013 to 2014 (row h), 3) the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base case (row i), 4) the catch level that results in the median spawning biomass to remain unchanged from 2013 to 2014 (row j), and 5) the catch level that results in a 50% probability that the median projected catch will remain the same in 2014 (row k).

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year depletion**				
	Year	Catch (mt)					
a	2013	0	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	0	47.7%	68.3%	88.1%	114.4%	169.8%
b	2013	250,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	250,000	41.8%	62.5%	82.1%	108.8%	163.2%
c	2013	300,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	300,000	40.5%	61.5%	81.1%	107.7%	162.1%
d	2013	350,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	350,000	39.3%	60.3%	79.9%	106.6%	161.0%
e	2013	400,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	400,000	38.3%	59.2%	78.6%	105.6%	159.7%
f	2013	450,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	450,000	37.0%	58.0%	77.3%	104.4%	158.7%
g	2013	500,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	500,000	35.8%	56.8%	76.0%	103.2%	157.7%
h	2013	603,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	603,000	33.9%	54.3%	73.5%	100.7%	155.7%
i	2013	626,364	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	715,041	33.4%	53.8%	72.9%	100.2%	155.3%
j	2013	650,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	650,000	32.8%	53.2%	72.4%	99.7%	154.8%
k	2013	696,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	696,000	31.7%	52.1%	71.3%	98.7%	153.9%

Table g.2. Posterior distribution quantiles for forecasts of Pacific hake fishing intensity (spawning potential ratio; (1-SPR)/(1-SPR$_{40\%}$); values greater than 100% denote fishing in excess of the $F_{40\%}$ default harvest rate) from the base model. Catch alternatives are explained in Table g.1.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Fishing Intensity**				
	Year	Catch (mt)					
a	2013	0	0%	0%	0%	0%	0%
	2014	0	0%	0%	0%	0%	0%
b	2013	250,000	37%	50%	63%	75%	91%
	2014	250,000	29%	42%	53%	64%	82%
c	2013	300,000	42%	57%	70%	82%	98%
	2014	300,000	34%	48%	61%	72%	90%
d	2013	350,000	47%	63%	76%	88%	105%
	2014	350,000	38%	54%	67%	80%	98%
e	2013	400,000	52%	68%	82%	94%	110%
	2014	400,000	42%	59%	74%	86%	104%
f	2013	450,000	57%	73%	87%	98%	114%
	2014	450,000	47%	64%	79%	92%	110%
g	2013	500,000	61%	77%	91%	102%	117%
	2014	500,000	50%	69%	84%	97%	115%
h	2013	603,000	68%	85%	99%	109%	123%
	2014	603,000	58%	78%	93%	106%	123%
i	2013	626,364	69%	87%	100%	111%	124%
	2014	715,041	65%	85%	100%	112%	129%
j	2013	650,000	71%	88%	101%	112%	125%
	2014	650,000	61%	81%	97%	109%	127%
k	2013	696,000	74%	91%	104%	114%	127%
	2014	696,000	64%	84%	100%	113%	129%

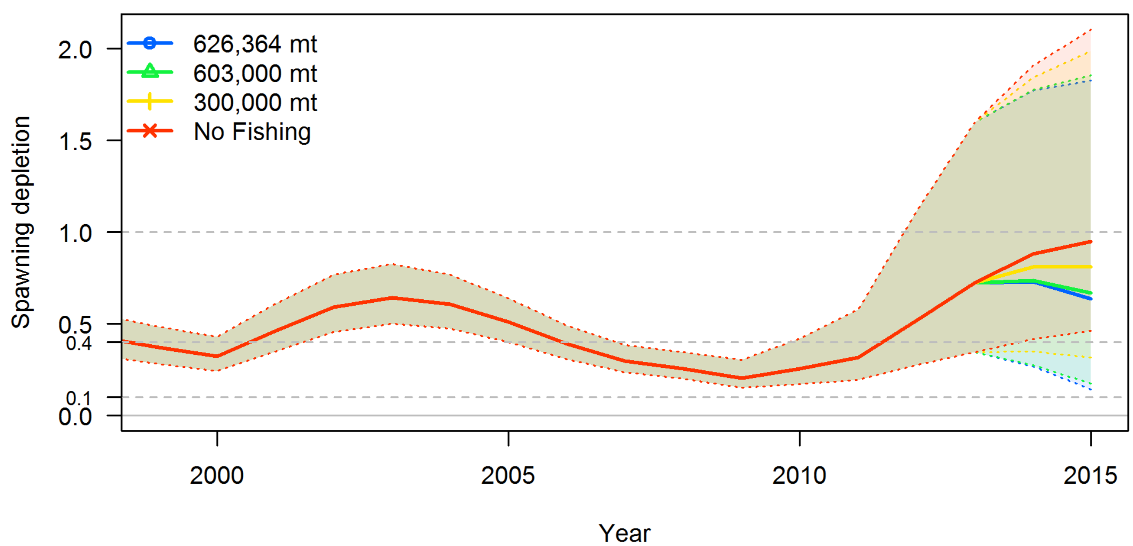


Figure i. Time-series of estimated spawning depletion to 2013 from the base-case model, and forecast trajectories to 2015 for several several management options from the decision table, with 95% posterior credibility intervals. The 2013 catch of 626,364 mt was calculated using the default harvest policy, as defined in the Agreement, which updates future catches (see Table g.1).

Table g.3. Probabilities of various management metrics given different catch alternatives. Catch alternatives are explained in Table g.1.

Catch	Probability $SB_{2014}<SB_{2013}$	Probability $SB_{2014}<SB_{40\%}$	Probability $SB_{2014}<SB_{25\%}$	Probability $SB_{2014}<SB_{10\%}$	Probability Fishing intensity in 2013 > 40% Target	Probability 2014 Catch Target < 2013 Catch
0	0%	2%	0%	0%	0%	0%
250,000	2%	4%	0%	0%	2%	1%
300,000	6%	5%	1%	0%	4%	2%
350,000	11%	6%	1%	0%	9%	4%
400,000	18%	6%	1%	0%	15%	9%
450,000	25%	7%	1%	0%	22%	14%
500,000	33%	8%	1%	0%	30%	20%
603,000	50%	9%	2%	0%	45%	36%
626,364	53%	10%	2%	0%	50%	39%
650,000	57%	10%	2%	0%	55%	42%
696,000	62%	11%	3%	0%	59%	50%

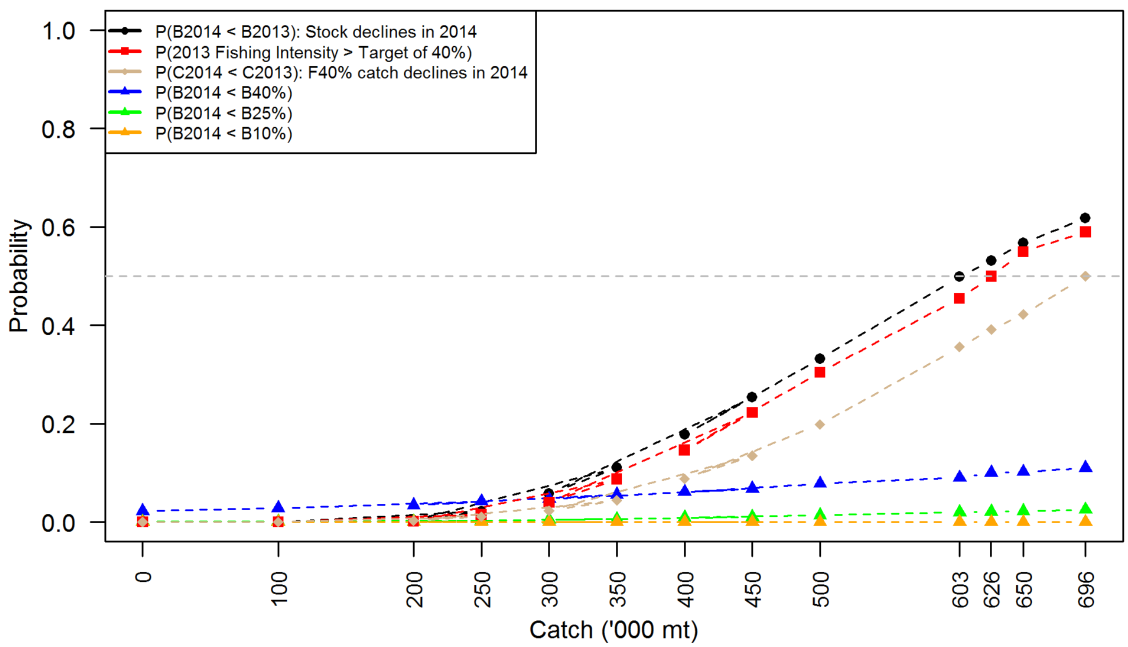


Figure j: Probabilities of various management metrics given different catch alternatives as defined in Table g.3. The points show these specific catch levels and lines interpolate between the points.

Table g.4. Median forecasts of Pacific hake depletion and fishing intensity (FI) for three different states of nature based on 2010 recruitment: 1) Low 2010 recruitment uses the lowest 10% of 2010 recruitment estimates, 2) Mid 2010 recruitment uses the middle 80% of 2010 recruitment estimates, and 3) High 2010 recruitment uses the highest 10% of 2010 recruitment estimates. Catch alternatives are explained in Table g.1.

	State Probability	Low 2010 recruitment 10%		Mid 2010 recruitment 80%		High 2010 recruitment 10%	
Year	Catch	Depletion	FI	Depletion	FI	Depletion	FI
2013	0	41.1%	0%	72.4%	0%	141.0%	0%
2014	0	49.3%	0%	88.2%	0%	165.8%	0%
2013	250,000	41.1%	91%	72.4%	63%	141.0%	37%
2014	250,000	43.9%	82%	82.2%	53%	160.3%	29%
2013	300,000	41.1%	98%	72.4%	70%	141.0%	42%
2014	300,000	42.8%	90%	81.1%	61%	159.3%	34%
2013	350,000	41.1%	104%	72.4%	76%	141.0%	47%
2014	350,000	41.6%	98%	79.9%	67%	158.3%	38%
2013	400,000	41.1%	109%	72.4%	82%	141.0%	52%
2014	400,000	40.3%	104%	78.6%	73%	157.2%	42%
2013	450,000	41.1%	113%	72.4%	87%	141.0%	57%
2014	450,000	39.0%	110%	77.3%	79%	156.2%	47%
2013	500,000	41.1%	117%	72.4%	91%	141.0%	61%
2014	500,000	37.6%	115%	76.0%	84%	155.1%	51%
2013	603,000	41.1%	123%	72.4%	98%	141.0%	68%
2014	603,000	35.1%	123%	73.5%	93%	153.0%	58%
2013	626,364	41.1%	124%	72.4%	100%	141.0%	69%
2014	626,364	34.6%	128%	73.0%	100%	152.5%	65%
2013	650,000	41.1%	125%	72.4%	101%	141.0%	71%
2014	650,000	34.0%	126%	72.4%	97%	152.0%	61%
2013	696,000	41.1%	127%	72.4%	104%	141.0%	74%
2014	696,000	32.9%	129%	71.3%	100%	151.0%	64%

Table g.5. Probabilities of various management metrics given different catch alternatives for three different states of nature based on 2010 recruitment: 1) the lower 10% of 2010 recruitment estimates, 2) the middle 80% of 2010 recruitment estimates, and 3) the highest 10% of 2010 recruitment estimates.. Catch alternatives are explained in Table g.1.

Catch	Probability $SB_{2014}<SB_{2013}$	Probability $SB_{2014}<SB_{40\%}$	Probability $SB_{2014}<SB_{25\%}$	Probability $SB_{2014}<SB_{10\%}$	Probability Fishing intensity in 2013 > 40% Target	Probability 2014 Catch Target < 2013 Catch
			Lower 10% of 2010 recruitment			
0	0%	21%	1%	0%	0%	0%
250,000	16%	34%	3%	0%	15%	11%
300,000	31%	39%	5%	0%	40%	23%
350,000	56%	46%	6%	0%	74%	42%
400,000	65%	49%	9%	0%	93%	74%
450,000	69%	54%	10%	0%	99%	90%
500,000	77%	59%	14%	0%	100%	97%
603,000	89%	64%	20%	0%	100%	100%
626,364	91%	68%	20%	0%	100%	100%
650,000	92%	68%	21%	0%	100%	100%
696,000	93%	71%	24%	0%	100%	100%
			Middle 80% of 2010 recruitment			
0	0%	0%	0%	0%	0%	0%
250,000	1%	1%	0%	0%	0%	0%
300,000	3%	1%	0%	0%	0%	0%
350,000	7%	1%	0%	0%	2%	0%
400,000	14%	2%	0%	0%	7%	2%
450,000	23%	2%	0%	0%	15%	6%
500,000	32%	2%	0%	0%	26%	13%
603,000	51%	3%	0%	0%	44%	32%
626,364	55%	4%	0%	0%	50%	36%
650,000	59%	4%	0%	0%	56%	40%
696,000	65%	5%	0%	0%	61%	50%
			Upper 10% of 2010 recruitment			
0	0%	0%	0%	0%	0%	0%
250,000	0%	0%	0%	0%	0%	0%
300,000	0%	0%	0%	0%	0%	0%
350,000	0%	0%	0%	0%	0%	0%
400,000	0%	0%	0%	0%	0%	0%
450,000	0%	0%	0%	0%	0%	0%
500,000	0%	0%	0%	0%	0%	0%
603,000	0%	0%	0%	0%	0%	0%
626,364	1%	0%	0%	0%	0%	0%
650,000	2%	0%	0%	0%	0%	0%
696,000	3%	0%	0%	0%	0%	0%

Research and data needs

There are many areas of research that could improve stock assessment efforts, however we focus here on those efforts that might appreciably reduce the uncertainty (both perceived and unknown) in short-term forecasts of Pacific hake for management decision-making. This list is in prioritized order:

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. 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. Review the proposed design of the joint hake/sardine (SaKe) acoustic survey to determine whether an optimized survey design could satisfy the needs of management for both Pacific hake and sardines. Included in this review should be a list of necessities that must be met to provide a consistent, accurate, and useful survey for Pacific hake.

3. 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.

4. Analyze recently collected maturity samples and explore ways to include new data in the assessment.

5. Routinely collect and analyze life-history data, including maturity and fecundity for Pacific hake. Explore possible relationships among these life history traits as well as with body growth and population density. Currently available information is limited and outdated.

6. 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.

7. Conduct an annual acoustic survey if the necessary research to continue advancing acoustic survey techniques is not compromised (e.g., see item 6 above).

8. Apply bootstrapping methods to the acoustic survey time-series in order to bring more of the relevant components into the 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.

9. Continue to explore process-based assessment modeling methods that may be able to use the large quantity of length observations to reduce model uncertainty and better propagate life-history variability into future projections.

10. Evaluate the quantity and quality of historical biological data (prior to 1988 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use in developing age-composition data.

11. 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.

12. Investigate meta-analytic methods for developing a prior on degree of recruitment variability (σ_r), and for refining existing priors for natural mortality (M) and steepness of the stock-recruitment relationship (h).

1 Introduction

Prior to 1997, separate Canadian and U.S. assessments for Pacific hake were submitted to each nation's assessment review process. This practice resulted in differing yield options being forwarded to each country's managers. Multiple interpretations of Pacific hake status made it difficult to coordinate an overall management policy. Since 1997, the Stock Assessment and Review (STAR) process for the Pacific Fishery Management Council (PFMC) has evaluated assessment models and the Pacific Council process, including NOAA Fisheries, has generated management advice that has been largely utilized by both nations.

The Joint US-Canada Agreement for Pacific hake (called the Agreement) was formally ratified in 2006 (signed in 2007) by the United States as part of the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act. Although the Agreement has been considered to be in force by Canada since June 25, 2008, an error in the original U.S. text required that the Agreement be ratified again before it could be implemented. This second ratification occurred in 2010. Under the Agreement, Pacific hake 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), with national representatives to both groups appointed by their respective governemnts. Additionally, the Agreement calls for both of these bodies to include industry- nominated scientists, who are selected and appointed jointly by both nations..

This stock assessment document represents the work of a joint U.S. and Canadian JTC and their associates. Extensive modeling efforts conducted from 2010 to 2012, as well as highly productive discussions among analysts have resulted in unified documents for the assessments from 2011 to the present (2013).

This assessment reports a single base-case model representing the collective work of the JTC. The assessment depends primarily upon the acoustic survey biomass index (1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011 and 2012) for information on the scale of the current hake stock. The 2011 index was the lowest in the time-series but the 2012 index was much greater. The aggregate fishery age-composition data (1975–2012) and the age-composition data from the acoustic survey contribute to the models ability to resolve strong and weak cohorts. Both sources show a somewhat strong 2008 cohort and a strong 2010 cohort, but the 2011 and 2012 age compositions differ slightly regarding the relative magnitude of the weaker 2005 and 2006 cohorts.

The assessment is fully Bayesian, with the base-case model incorporating prior information on two key parameters (natural mortality, M, and steepness of the stock-recruit relationship, h) and integrating over estimation and 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 the base case. These sensitivity models are thoroughly described in this assessment document.

The current document highlights progress made during 2012, residual areas of needed research, as well as ongoing scientific uncertainties in modeling choices, such that future technical working groups will enjoy a much easier working environment which fosters collaborative solutions to these difficult issues.

1.1 Stock structure and life history

Pacific hake (*Merluccius productus*), 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. It is among 18 species of hake from four genera (being the majority of the family *Merluccidae)*, which are distributed worldwide in both hemispheres of the Atlantic and Pacific oceans which have generated recent catches of around 1.25 million mt, annually (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 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 southern Alaska, with the northern boundary related to fluctuations in annual migration. However, a recent genetic and parasite-load study found evidence of some summer mixing with inshore stocks in Queen Charlotte Sound (King et al. 2012). Distributions of eggs, larvae, and infrequent observations of spawning aggregations indicate that Pacific hake spawning occurs off south-central California during January–March. Due to the difficulty of locating major offshore spawning concentrations, details of hake spawning behavior remains poorly understood (Saunders and McFarlane 1997). 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). Pacific hake feed on euphausiids, pandalid shrimp, and pelagic schooling fish (such as eulachon and Pacific herring) (Livingston and Bailey 1985). Larger Pacific hake become increasingly piscivorous, and Pacific herring are commonly a large component of hake diet off Vancouver Island. Although Pacific hake are cannibalistic, the geographic separation of juveniles and adults usually prevents cannibalism from being an important factor in their population dynamics (Buckley and Livingston 1997).

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). El Niño conditions also result in range extensions to the north, as evidenced by reports of hake off of southeast Alaska during these warm water years. Throughout the warm period experienced in 1990s, there were changes in typical patterns of hake distribution. Spawning activity was recorded north of California. Frequent reports of unusual numbers of juveniles off of Oregon to British Columbia suggest that juvenile settlement patterns also shifted northwards in the late 1990s (Benson et al. 2002, Phillips et al. 2007). Because of this shift, juveniles may have been subjected to increased cannibalistic predation and fishing mortality. However, the degree to which this was significant, and the proportion of the spawning and juvenile settlement that was further north than usual is unknown. Subsequently, La Nina conditions (colder water) in 2001 resulted in a southward shift in the stock's distribution, with a much smaller proportion of the population found in Canadian waters in the 2001 survey. Hake were distributed across the entire range of the survey in 2003, 2005, 2007 (Figures 1 and 2) after displaying a very southerly distribution in 2001. Although a few adult hake (primarily from the 1999 cohort) were observed north of the Queen Charlotte Islands in 2009 most of the stock appears to have been distributed off Oregon and Washington. The 2011 acoustic survey observed what appears to have been the most southerly distribution of Pacific hake since 2001. Some adult hake were observed in the

Quatsino area (northwest Vancouver Island), but most of the stock was found off the coasts of Washington, Oregon, and California (Figure 2).

1.2 Ecosystem Considerations

Pacific hake are an important contributor 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. The role of hake predation in the population dynamics of other groundfish species is likely to be important (Harvey et al. 2008), although difficult to quantify. Hake migrate farther north during the summer during relatively warm water years and their local ecosystem role therefore differs year-to-year depending on environmental conditions. Recent research indicates that hake distributions may be growing more responsive to temperature, and that spawning and juvenile hake may be occurring farther North (Phillips et al. 2007; Ressler et al. 2007). Given long-term climate-change projections and changing distributional patterns, considerable uncertainty exists in any forward projections of stationary stock productivity and dynamics.

Hake are also important prey items for many piscivorous species including lingcod (*Ophiodon elongatus*) and Humboldt squid (also known as jumbo flying squid, *Dosidicus gigas*). In recent years, the coastal U.S. lingcod stock has rebuilt rapidly from an overfished level and jumbo flying squid have intermittently extended their range northward from more tropical waters to the west coast of North America. Recent Humboldt squid observations in the hake fishery, recreational fisheries, and scientific surveys in the U.S. and Canada reflect a very large increase in squid abundance as far north as southeast Alaska (e.g., Gilly et al., 2006; Field et al., 2007) during the same portions of the year that hake are present, although the number and range vary greatly between years. While the relative biomass of these squid and the cause of such range extensions are not completely known, squid predation on Pacific hake is likely to have increased substantially in some years. There is evidence from the Chilean hake (a similar gadid species) fishery that squid may have a large and adverse impact on abundance, due to direct predation on individuals of all sizes (Alarcón-Muñoz et al., 2008). Squid predation as well as secondary effects on schooling behavior and distribution of Pacific hake may become important for future assessments. However, it is unlikely that the current data sources will be able to detect squid-related changes in hake population dynamics (such as an increase in natural mortality) until well after they have occurred, if at all. There is considerable ongoing research to document relative abundance, diet composition and habitat utilization of Humboldt squid in the California current ecosystem (e.g., J. Field, SWFSC, and J. Stewart, Hopkins Marine Station, personal communication, 2010; Gilly et al., 2006; Field et al., 2007) which should be considered in future assessments. However, there were few Humboldt squid present in the California Current during 2010, 2011, and 2012, despite the great abundance in 2009. Given the volatility of squid populations, future presence and abundance trends are impossible to predict.

1.3 Fisheries

The fishery for the coastal population of Pacific hake occurs along the coasts of northern California, Oregon, Washington, and British Columbia primarily during June–November in recent years. The fishery is conducted almost exclusively with mid-water trawls. Most fishing activity occurs over bottom depths of 100-500 m, while offshore extensions of fishing activity have occurred in recent years to reduce bycatch of depleted rockfish and salmon. The history of the coastal hake fishery is characterized by rapid changes brought about by the development of substantial foreign fisheries in 1966, joint-venture fisheries by the early 1980s, and domestic fisheries in 1990s (Table 1, Figure 3).

Large-scale harvesting of Pacific hake in the U.S. zone began in 1966, when factory trawlers from the Soviet Union began targeting Pacific hake. During the mid-1970s, factory trawlers from Poland, Federal Republic of Germany, the German Democratic Republic and Bulgaria also participated in the fishery. During 1966-1979, the catch in U.S. waters is estimated to have averaged 137,000 t per year (Table 1, Figure 3). A joint-venture fishery was initiated in 1978 between two U.S. trawlers and Soviet factory trawlers acting as mother-ships (the practice where the catch from several boats is brought back to the larger, slower ship for processing and storage until the return to land). By 1982, the joint-venture catch surpassed the foreign catch, and by 1989, the U.S. fleet capacity had grown to a level sufficient to harvest the entire quota, and no further foreign fishing was allowed, although joint-venture fisheries continued for another two years. In the late 1980's, joint ventures involved fishing companies from Poland, Japan, the former Soviet Union, the Republic of Korea and the People's Republic of China.

Historically, the foreign and joint-venture fisheries produced fillets as well as headed and gutted products. In 1989, Japanese mother-ships began producing surimi from Pacific hake using a newly developed process to inhibit myxozoan-induced proteolysis. In 1990, domestic catcher-processors and mother ships entered the Pacific hake fishery in the U.S. zone. These vessels had previously engaged in Alaskan walleye pollock (*Theragra chalcogramma*) fisheries, and have continued to do so ever since. The development of surimi production techniques for pollock was expanded to include Pacific hake as a viable alternative. Similarly, shore-based processors of Pacific hake had been constrained by a limited domestic market for Pacific hake fillets and headed and gutted products. The construction of surimi plants in Newport and Astoria, Oregon, led to a rapid expansion of shore-based landings in the U.S. fishery in the early 1990's, when the Pacific Council set aside an allocation for that sector. In 1991, the joint-venture fishery for Pacific hake in the U.S. zone ended because of the increased level of participation by domestic catcher-processors and mother ships, and the growth of shore-based processing capacity. In contrast, Canada, at its discretion, allocates a portion of the Pacific hake catch to joint-venture operations once shore-side capacity is filled.

The sectors involved in the Pacific hake fishery in Canada exhibit a similar historical pattern, although phasing out of the foreign and joint-venture fisheries has proceeded more slowly relative to the U.S. (Table 1). Since 1968, more Pacific hake have been landed than any other species in the groundfish fishery on Canada's west coast. Prior to 1977, the fishing vessels from the former Soviet Union caught the majority of Pacific hake in the Canadian zone, with Poland and Japan accounting for much smaller landings. After declaration of the 200-mile extended fishing zone in 1977, the Canadian fishery was divided among shore-based, joint-venture, and foreign fisheries. In 1992, the foreign fishery ended, but the demand of Canadian shore-based processors remained below the available yield, thus the joint-venture fishery continues today, although no joint-venture fishery took place in 2002, 2003, 2009 or 2012. The majority of the shore-based landings of the coastal hake stock is processed into fillets for human consumption, surimi, or mince by processing plants at Ucluelet, Port Alberni, and Delta, British Columbia. Although significant aggregations of hake are found as far north as Queen Charlotte Sound, in most years the fishery has been concentrated below 49° N. latitude off the south coast of Vancouver Island, where there have been sufficient quantities of fish in proximity to processing plants.

1.4 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 by foreign and domestic fisheries. 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 quotas summed to 128% of the 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 the harvest targets reasonably closely (Table 2). Since 1999, catch targets have been determined using an $F_{SPR=40\%}$ default harvest rate with a 40:10 control rule that decreases the catch linearly from a depletion of 40% to a depletion of 10% (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 2002, after Pacific hake was declared overfished by the U.S., the catch of 181 thousand mt exceeded the target; however it was still below the limit of 208 thousand mt. In 2004, after Pacific hake was declared rebuilt, and when the large 1999 cohort was near-peak biomass, the catch fell well short of the catch target of 501 thousand mt, which is larger than the largest catch ever realized. Constraints imposed by bycatch of canary and widow rockfishes limited the commercial U.S. catch target to 259 thousand mt. Neither the U.S. portion nor the total catch has substantially exceeded the harvest guidelines in any recent year, indicating that management procedures have been effective.

1.4.1 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. More recently, yields in the U.S. zone have been restricted to levels below optimum yields due to bycatch of overfished rockfish species, primarily widow and canary rockfishes, in the Pacific hake fishery. At-sea processing and night fishing (midnight to one hour after official sunrise) are prohibited south of 42° N. latitude. Fishing is prohibited in the Klamath and Columbia River Conservation zones, and a trip limit of 10,000 pounds is established for Pacific hake caught inside the 100-fathom contour in the Eureka INPFC area. During 1992-1995, the U.S. fishery opened on April 15; however in 1996 the opening date was changed to May 15. Shore-based fishing is allowed after April 1 south of 42° N. latitude, but is limited to 5% of the shore-based allocation being taken prior to the opening of the main shore-based fishery. The main shore-based fishery opens on June 15. Prior to 1997, at-sea processing was prohibited by regulation when 60 percent of the harvest guideline was reached. The current allocation agreement, effective since 1997, divides the U.S. non-tribal harvest guideline among factory trawlers (34%), vessels delivering to at-sea processors (24%), and vessels delivering to shore-based processing plants (42%). Since 1996, the Makah Indian Tribe has conducted a separate fishery with a specified allocation in its "usual and accustomed fishing area", and beginning in 2009 there has also been a Quileute tribal allocation. 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 to cooperatives in the at-sea mothership and catcher-processor sectors.

1.4.2 Industry actions

Shortly after the 1997 allocation agreement was approved by the PFMC, fishing companies owning factory trawlers with U.S. west coast groundfish permits established the Pacific Whiting Conservation Cooperative (PWCC). The primary role of the PWCC is to distribute the factory trawler allocation among its members in order to achieve greater efficiency by the member fishing companies in their resource allocation, processing efficiency and product quality, as well aspromoting reductions in waste and bycatch rates relative to the former “derby” fishery in which all vessels competed for a fleet-wide quota. The PWCC also initiated recruitment research to support hake stock assessment. As part of this effort, PWCC sponsored a juvenile recruit survey for a number of years. In 2009, the PWCC contracted a review of the 2009 stock assessment which was discussed in the 2010 stock assessment and was one of the contributing factors to the extensive re-analysis of historical data and modeling methods subsequent to that assessment.

1.5 Overview of recent fisheries

1.5.1 United States

In 2005 and 2006, the coast-wide ABCs were 531,124 and 661,680 mt respectively. The OYs for these years were set at 364,197 and 364,842 and were nearly fully utilized with the abundant 1999 year-class comprising a large proportion of the catch. For the 2007 fishing season the PFMC adopted a 612,068 mt ABC and a coast-wide OY of 328,358 mt. This coast-wide OY continued to be set considerably below the ABC in order to avoid exceeding bycatch limits for overfished rockfish. In 2008, the PFMC adopted an ABC of 400,000 mt and a coast-wide OY of 364,842 mt, based upon the 2008 stock assessment. This ABC was set below the overfishing level indicated by the stock assessment, and therefore the difference between the ABC and OY was substantially less than in prior years. However, the same bycatch constraints caused a mid-season closure in the U.S. in both 2007 and 2008 and resulted in final landings being below the OY in both years. Based on the 2009 assessment, the Pacific Council adopted a U.S.-Canada coast-wide ABC of 253,582 mt, and a U.S. ABC of 187,346 mt. The Pacific Council adopted a U.S.-Canada coast-wide OY of 184,000 mt and a U.S. OY of 135,939 mt, reflecting the agreed-upon 73.88% of the OY apportioned to U.S. fisheries and 26.12% to Canadian fisheries. Bycatch limits were assigned to each sector of the fishery for the first time in 2009, preventing the loss of opportunity for all sectors if one sector exceeded the total bycatch limit. This greatly reduced the ‘race for fish’ as bycatch accumulated during the season. In total, the 2009 U.S. fishery caught 121,110 mt, or 89.1% of the U.S. OY, without exceeding bycatch limits. In 2010 the Pacific Council adopted a U.S.-Canada coast-wide ABC of 455,550 mt, a U.S.-Canada coast-wide OY of 262,500 mt and a U.S. OY of 190,935 mt, reflecting the agreed-upon apportionment. As in 2009, tribal fisheries did not harvest the full allocation granted to them (49,939 mt in 2010), and two reapportionments were made to other sectors during the fishing season. In total, the 2010 U.S. fishery caught 170,109 mt, or 89.1% of the U.S. OY. Bycatch rates were generally not a problem, although known areas of high historical bycatch were still (anecdotally) being avoided. In certain areas of the coasts, many fishermen found it difficult to avoid the large schools of age-2 hake (200-300 grams) present off the U.S. coast. The shore-side fishery opted for a voluntary stand-down between June 30 to July 20 due to the presence of these small fish and to avoid bycatch of canary rockfish.

The Pacific Council adopted a U.S.-Canada coast-wide overfishing level (OFL) of 973,700 mt in 2011, with an annual catch limit (ACL) of 393,751 mt. The U.S. annual catch limit was 290,903 mt, after apportioning the coast-wide ACL by the agreed upon U.S.-Canada apportionment. The 2011 U.S. fisheries caught 78.7% of their catch limit (229,067 mt) and were below the 2011 catch limit mainly due to smaller tribal catches. This year was the first time that motherships participated under the co-op system, thus were able to pool bycatch limits. Remaining mothership bycatch allocations were transferred to the catcher/processor sector in mid-December. This was also the first year that the shore-based fleet operated under the new catch shares program with individual fishing quotas (IFQ). All U.S. sectors encountered smaller fish in the 35–40 cm range, dominated by the 2008 year class. In previous years, the fishery may have avoided these small fish, but markets for smaller fish were developing in 2011. The at-sea fleet encountered larger fish in May, which were encountered less often in June and rarely after then. The at-sea fleet additionally encountered even smaller fish in October through December, ranging in size from 24–34 cm, corresponding to the 2009 and 2010 year classes.

The Joint Management Committee (JMC) decided on a coastwide catch target of 251,809 mt for 2012, with a U.S. allocation of 186,037 mt. After the tribal allocation of 17.5% plus 16,000 mt, and a 2,000 mt allocation for research catch and bycatch in non-groundfish fisheries, the 2012 non-tribal U.S. catch limit of 135,481 mt was allocated to the catcher/processor (34%), mothership (24%), and shore-based (42%) commercial sectors. Therefore, the at-sea fleet (catcher/processors and motherships) was allocated 78,579 mt and the shore-based fleet was allocated 56,902 mt. The at-sea fleet encountered larger fish in May and mainly smaller fish from the 2010 year class late in the year. The shore-based fleet mainly caught a combination of the 2008 and 2010 year classes. Area closures and bycatch limits limited kept the at-sea fleet from fishing the locations where the shore-based fleet was encountering larger fish from the 2008 year class. Tribal fisheries had very few landings (less than 1,000 mt) because Pacific hake were not present in large numbers in tribal areas. Therefore, 28,000 mt were reapportioned from the tribal fisheries to the non-tribal fisheries on October 4, 2012. Both the at-sea and shore-based fleets nearly caught their respective total catch targets, leaving 28,773 mt, 84.5%, of the catch target uncaught.

1.5.2 Canada

The Canadian fishery has operated under an Individual Vessel Quota (IVQ) management system since 1997. Groundfish trawl vessels are allocated a set percentage of the Canadian TAC that is fully transferable among vessels within the trawl sector. Additionally, the IVQ management regime allows an opportunity for vessel owners to exceed license holding by up to 15% and have these overages deducted from their quota for the subsequent year. Conversely, if less than the quota is taken, up to 15% can be carried over into the next year. The maximum 15% overage allowance for the 2012 fishery, 15,427 mt, was allotted due to the 2011 fishery failing to capture its allocation. The assessment-based allocation for 2012 was 50,345 mt; with the additional overage carried forward from 2011 this became 65,772 mt. The fishery caught 46,776 mt, 92.9% of the 2012 allocation or 71.1% of the total allocation including the overages from 2011. Since the catch was only 71.1% of the total, the fishery will again be allowed the maximum 15% overage for the 2013 season. The 2012 catch was taken solely by the shore-based fishery; the JV fishery was not opened. The 2012 fishery followed the same spatial pattern as in the last several years with older, larger fish caught in Queen Charlotte Sound later in the year and a large portion of the total caught in the vicinity of La Perouse Sound throughout the summer and fall months. Quatsino Sound and Brooks Peninsula have also become popular hotspots for the fishery in the last two years.

For an overview of all catch and allocations by year, country, and fleet, see Table 1 and Table 2. For 2002, 2003, 2009, and 2012 there was no JV fishery opened and this is reflected as zero catch for those years in Table 1.

2 Data

Nearly all of the data sources available for Pacific hake were re-evaluated during 2010. That process included obtaining the original raw data, reprocessing the entire time-series with standardized methods, and summarizing the results for use in the 2011 and 2012 stock assessments. These sources have been updated with all newly available information in 2013. Primary fishery-dependent and -independent data sources used here (Figure 4) include:

- Total catch from all U.S. and Canadian fisheries (1966-2012).
- Age compositions composed of data from the U.S. fishery (1975-2012) and the Canadian fishery (1990-2012).
- 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 and 2012).

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, 1975-2012.
- Aging-error matrices based on cross-read and double-blind-read otoliths.
- Proportion of individual female hake mature by size and/or age from a sample collected in 1995.

Some sources were not included but have been explored, used for sensitivity analyses, or discarded in recent stock assessments (these data are discussed in more detail below):

- 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 2010 & 2012 NWFSC bottom trawl surveys, and the 2012 acoustic survey.

2.1 Fishery-dependent data

2.1.1 Total catch

The catch of Pacific hake for 1966-2012 by nation and fishery sector is shown in Table 1. 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 Stewart et al. 2011). Although the application of monthly bycatch rates differed from previous, simpler analyses, it resulted in less than a 0.3% change in aggregate catch over the time-series. 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 1991–2012 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 2007 from the Pacific Harvest

Trawl (PacHarvTrawl) database, and from April 2007 to present from the Fisheries Operations System (FOS) database. Discards are nominal relative to the total fishery catch. The majority of vessels in the U.S. shore-based fishery have operated under experimental fishing permits that required them to retain all catch and bycatch for sampling by plant observers. All U.S. at-sea vessels and Canadian joint-venture catches are monitored by at-sea observers. Observers use volume/density methods to estimate total catch. Domestic Canadian landings are recorded by dockside monitors using total catch weights provided by processing plants.

One of the concerns identified in recent assessments has been the presence of shifts in the within-year distribution of catches during the time series. Subsequent to the ascension of the domestic fleet in the U.S. and both the domestic and Joint-Venture fleets in Canada, the fishery shifted most of the catch to the early spring during the 1990s (Table 1). This fishery gradually spread out over the summer and fall, and in recent years has seen some of the largest catches in the fall through early winter (Figure 5). This pattern has allowed the fishery to reduce the impact of some bycatch constraints and is likely to continue in U.S. waters under the individual trawl quota system adopted in 2011, as long as bycatch quotas remain stable.

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 1991–2012. 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, 1991–2012, 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 fish are randomly selected for otolith extraction. The Canadian domestic fishery is subject to 100% observer coverage on the two processing vessels *Viking Enterprise* and *Osprey*, which together make up 25% of the coast-wide catch. The joint-venture fishery has 100% observer coverage on their processing vessels, which in 2011 made up 16% of the Canadian catch, but was non-existent in 2012. On observed trips, otoliths (for ageing) and lengths are sampled from Pacific hake caught in the first haul of the trip, with length samples taken on subsequent hauls. Sampled weight from which biological information is collected must be inferred from year-specific length-weight relationships. For unobserved 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 weight-length relationship applied to all lengths taken and summed over 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, samples 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 3.

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. In general, the analytical steps can be summarized as follows:

1. Count the number of fish (or lengths) at each age (or length bin) within each trip (or haul), generating "raw" frequency data.
2. Expand the raw frequencies from the trip (or haul) based on the fraction of the total haul sampled.
3. Weight the summed frequencies by fishery sector landings and aggregate.
4. Calculate sample sizes (number of trips or hauls) and normalize to proportions that sum to unity within each year.

To complete step (2), the expansion factor was calculated for each trip or haul based on the ratio of the total estimated catch weight divided by the total weight from which biological samples were taken. In cases where there was not an estimated sample weight, a predicted sample weight was computed by multiplying the count of fish in the sample by a mean individual weight, or by applying a year-specific length-weight relationship to the length of each fish in the sample, then summing these predicted weights. Anomalies can emerge when very small numbers of fish are sampled from very large landings; these were avoided by constraining expansion factors to not exceed the 95^{th} percentile of all expansion factors calculated for each year and fishery. The total number of trips or hauls sampled is used as either the initial multinomial sample size input to the SS stock assessment model (prior to iterative reweighting) or as a relative weighting factor among years. Motivated by a recent downward trend in fishery sampling for ages in the Canadian sector, the method of weighting the fleet-specific proportions (Step 3) was revised in 2012 to be based on the estimated numbers in the total sector catch using mean weight-at-age across many years, rather than the number of samples collected from that catch. This allows for adequate representation of even sparsely sampled sectors. In 2013, this was further revised to use year specific mean weight-at-age to determine the estimated numbers in the total sector catch, resulting in consistent historical age compositions that do not need to be updated in future years unless new data for that year are added.

The aggregate fishery age-composition data (1975–2012) confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999, with a small proportion from the 1999 year class (13 years old in 2012) 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 2012 fishery (Figure 6). The previously strong 2005 and 2006 year classes declined in proportion in the 2011 fishery samples, but remained persistent in the 2012 fishery. 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 absolute size of incoming cohorts cannot be precisely determined until they have been observed several times.

Both the weight- and length-at-age information suggest that hake growth has changed markedly over time. 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 section 2.3.3 and 2.3.4 below. Although length composition data are not fit explicitly in the base case assessment models presented here, the presence of the 2008 and 2010 year classes are clearly observed in both of the U.S. fishery sectors.

2.1.3 Catch per unit effort

Catch-per-unit-effort (CPUE) is a common source of information about relative population trend in stock assessments world-wide, although numerous studies question its utility. Calculation of a reliable CPUE metric is particularly problematic for Pacific hake and it has never been used as a tuning index for assessment of this stock. This is mainly because the basic concept of "effort" is difficult to define for the hake fishery, as the use of acoustics, communication among vessels, extensive time spent searching and transit time between fishing ports and known areas of recurrent hake aggregations means that, by the time a trawl net is put in the water, catch rates can be predicted by the fishing vessel reasonably well. Factory trawlers may continue to fish the same aggregation for days, while shore-based sectors may be balancing running time with hold capacity and therefore opt for differing catch rates. Further, during the last decade, the hake fishery has been severely constrained in some areas due to avoidance of rockfish bycatch. Periodic voluntary 'stand-downs', and temporary in-season closures have resulted from high bycatch rates, and in some years fishermen have changed their fishing behavior and fishing areas, in order to reduce bycatch of overfished rockfish species. Furthermore, the US at-sea fleet generally leaves the hake fishing grounds for a period during the season to participate in the Bering Sea pollock fishery. It is unlikely that such fleet dynamics and inter-species effects can be dealt with adequately in order to produce a reliable index for Pacific hake based on fishery CPUE data.

2.2 Fishery-independent data

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. Coast-wide surveys were carried out jointly by the Alaska Fisheries Science Center (AFSC) and the Pacific Biological Station (PBS) of the Canadian Department of Fisheries and Oceans (DFO) in 1995, 1998, and 2001. Following 2001, the responsibility for the U.S. portion of the survey was transferred to the Fishery Resource Analysis and Monitoring (FRAM) Division of NOAA's Northwest Fisheries Science Center (NWFSC). The survey was scheduled on a biennial basis, with joint acoustic surveys conducted by NWFSC and PBS from 2003 to 2011. In 2012 a supplemental survey was added due to concerns about the depletion level of the stock and to investigate the size of the incoming 2008 year class. Between 1977 and 1992, acoustic surveys of Pacific hake were conducted every three years by the AFSC. However, these early surveys (1977–1992) covered only a reduced depth range and focused on U.S. waters. Therefore, they are not used in the current assessment because of concerns over bias due to arbitrary expansion factors used to extrapolate findings to the entire depth and latitudinal range of the survey. More details are given in Stewart et al (2011). Only acoustic surveys performed in 1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, and 2012 were used in this assessment (Table 4). The acoustic survey includes all waters off the coasts of the U.S. and Canada thought to contain all portions of the hake stock older than age-1. Age-0 and age-1 hake have been historically excluded from the survey efforts, due to largely different schooling behavior relative to older hake and concerns over markedly different catchability by the trawl gear.

The distribution of Pacific hake can vary greatly between years. It appears that northward migration patterns are related to the strength of subsurface flow of the California Current (Agostini et al. 2006) and upwelling conditions (Benson et al. 2002). Distributions of hake backscatter plotted for each acoustic survey since 1995 illustrate the variable spatial patterns of age-2+ hake among years (Figure 1). 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 Nino. 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. Pacific hake also tend to migrate farther north as they age.

Figure 2 shows the mean location of Pacific hake observed in the acoustic survey by age and year. Age-2 hake are located in the southern portion of the summer range, while older age classes are found in more northerly locations within the same year. The mean locations of Pacific hake age-6 and older tend to be more similar among years than those for the younger ages. With the aging of the strong 1999 year class causing a reduction in the number of older fish, and the presence of recent strong cohorts, a more southerly distribution of the hake stock has been observed in recent surveys.

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 & Rose 2005; Simmonds and MacLenann, 2005). Advantages to the kriging approach are: 1) it simultaneously provides the estimates of the hake biomass and associated sample variability while properly accounting for spatial correlation along and between transects; 2) it provides biomass estimates in the area beyond transect lines but within the correlation distance; 3) it provides maps of hake biomass and estimation variance that take into account the heterogeneous and patchy hake distribution; and 4) it allows for greater flexibility (and potentially efficiency) in survey transect design, in that transects do not need to be parallel to each other. A comparison of the kriged estimates to previous conventional design-based estimates was presented in Stewart et al. (2011), and showed a reasonable degree of consistency between the two methods. 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 4 for the number of trawls in each survey year).

Biological samples collected from these trawls are post-stratified, based on similarity in size composition. Results from research done in 2010 on representativeness of the biological data (i.e. repeated trawls 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). The composite length frequency developed from the biological sampling 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 $TS_{db} = 20\log L - 68$ at 38 kHz (Traynor 1996). Recent target strength work (Henderson and Horne 2007), based on in-situ and ex-situ measurements, estimated a regression intercept of 4–6 dB lower than that of Traynor (1996), suggesting that an individual hake reflects less acoustic energy, resulting in a larger estimated biomass than when using Traynor's (1996) equation. This difference would be accounted for directly in estimates of acoustic catchability within the assessment model, but variability in the estimated biomass due to uncertainty in target strength is not explicitly accounted for.

The 2012 acoustic survey was a supplemental survey that was implemented based on recommendations from the JTC, SRG, and JMC after observing results from the 2012 assessment. To acquire enough ship time for a coastwide survey similar to past surveys, the SWFSC and NWFSC developed a joint design to survey Pacific hake and Pacific sardine (*Sardinops sagax*). The NOAA Ship *Bell M. Shimada* was to survey from central California to the north end of Vancouver Island and the Canadian Coast Guard Ship *W.E. Ricker* surveyed the northern areas in Canada (Figure 7). Additionally, it was necessary to use a catcher vessel to sample backscatter for species identification and the collection of biological samples, for which industry volunteered the F/V *Forum Star*. The *Forum Star* is a 29 meter long, 7.8 meter wide commercial trawler, and there were many times when weather did not permit it to meet up with the 63.8 meter long, 15 meter wide *Bell Shimada* in a timely fashion to perform the required hauls on backscatter aggregations. In addition to weather, having the *Forum Star* stop to fish while the *Bell Shimada* continued sounding resulted in the ships sometimes being rather far apart, which at times also made it difficult to perform the required hauls The Forum Star has an ES60 echo sounder system (38 and 120 kHz) on board which allowed for comparable identification of aggregations with the Bell Shimada, which has an EK60 (18, 38, 70, 120, 200 kHz).

The *W.E. Ricker* was slated to take over the survey at the North end of Vancouver Island this year instead of central Vancouver Island. This was due to the SWFSC's requirement to survey the entire west coast sardine stock, which is believed to extend to Northern Vancouver Island. However, the *Forum Star* had some mechanical and safety issues which did not allow it to continue into Canadian waters, and the Chief Scientists on the *Bell Shimada* and the *W.E. Ricker* decided during the survey that the *W.E. Ricker* would start at the U.S./Canadian border. Therefore, transects in Canada were redesigned to allow coverage of the additional area off Vancouver Island. If the *Bell Shimada* were to catch up to it, the plan was to have the *Bell Shimada* run the acoustic transects and the *W.E. Ricker* to convert to a fishing vessel only to be called upon by the *Bell Shimada* to trawl on aggregations seen by the echo sounders. The *Bell Shimada* did not catch up to the *W.E. Ricker* during its voyage up the West Coast of Vancouver Island, so the *W.E. Ricker* acoustic data and ground-truth (haul) data were used for this part of the survey. The extra transects that the *W.E. Ricker* had to run on the West Coast of Vancouver Island resulted in dropping of some transects in the north, mainly in Queen Charlotte Sound and Dixon Entrance.

The 2012 survey was successful at providing a useful biomass estimate of Pacific hake as well as age composition, but because of joint hake and sardine operations there were the following major differences from the past survey protocols.

- *Some planned transects were randomly selected for removal from the survey design in order to make up time lost to weather delays.* The hake biomass is estimated using spatial kriging which interpolates a biomass for these omitted areas using spatial correlation, and the variability is appropriately increased to account for this.

- *A change in ping rate and vessel speed resulted in false indication of the bottom and it was not always possible to confirm hake at the end of transects. Twelve transects were stopped while hake was still present.* The change in ping rate and vessel speed was to allow for the detection of small sardine schools in shallow water. While this worked for the hake program much of the time, there were quite often false bottoms generated on the echograms at the shelf drop-off. These false bottoms were due to the high ping rate which worked fairly well for shallow depths (<750m) but as the depth increased, the pings could not make it back to the ship before the next ping was sent, resulting in ping interference which manifested itself as a false bottom in the water column. These artifacts appeared as strong backscatter on the echogram and on several transects they overlaid actual hake aggregations. In past surveys the hake acoustic team changed the ping rate to avoid these artifacts but the sardine program was resistant to changing this as it would result in 'No Data' areas for their analysis. While at-sea it was believed that the transects were all stopped after the end of the hake school, upon further inspection post-survey, it was determined that hake were still present. The kriging estimates biomass beyond the end of the transect and appropriately inflates the variance, therefore the biomass estimate used in this assessment is the best possible estimate given the data available. To investigate the possible worst-case bias, data were sampled from nearby transects and arbitrarily inserted onto the end of these twelve transect, extending them from 1 to 12 nautical miles. This worst-case scenario resulted in a 5% increase in the biomass for the 1 mile extension, up to a 30% increase with a 12 mile extension. The length of schools of hake was commonly less than 6 nm, and this analysis suggests that the potential bias is likely to be small, especially when compared to other potential sources of uncertainty and bias.

- *The identification of hake was performed using a catcher vessel for the U.S. portion of the survey*. The JTC is grateful to the U.S. hake industry for supplying a catcher vessel to the survey and ensuring that a valid design could be completed. This was the first year that a separate catcher vessel has been used in this acoustic survey, and many challenges were faced and overcome. Ideally the *Bell Shimada* and *Forum Star* would be in close proximity to identify and ensure that the correct aggregation was fished upon, but the difference in size and speed did not always allow for this. At times, the Forum Star was many hours behind the Shimada and recorded a different backscatter signal than what the Forum Star did. The Forum Star also had significant pitch and roll which resulted in the dropping out of signal, which may have made the aggregations appear differently to the acousticians on board. In addition, the difference in number of echo sounder frequencies also made the identification of fish aggregation more difficult on Forum Star. In addition to issues such as communication and identifying the echo that was to be trawled on, there may be differences from previous surveys, such as vessel catchability. However, a large number of tows were performed relative to recent surveys and standardization of nets and methods reassures the JTC that mark identification was valid. The JTC does recommend that more research is done on mark identification and verification, though (see research recommendations).

- *Performing a joint survey results in the loss of some data collection.* Accomplishing two objectives in one survey means that some data collection will be lost and there may be sacrifices made to one or both objectives. The NWFSC and SWFSC are commended for their hard work in coming up with a design that satisfied the objective of both species, and the JTC is grateful for a valid Pacific hake survey biomass estimate in 2012. However, the JTC realizes that additional research and ecosystem data collection were sacrificed, both of which mmight have proven to be useful in the future. Additionally, the 2012 joint survey did not have the time to survey as far south for age-1 hake, as has been done in the past, and personnel and other resources were not available, due to necessary staffing of the supplemental survey, to convert and continue the age-1 index. Preliminary analyses, discussed below, of an age-1 index of hake developed from the surveys in past years showed that it may be useful to predict incoming year classes. This is a high priority research recommendation that would likely improve the assessment and management of Pacific hake.

Figure 7 shows the relative backscatter of age-2+ hake as observed in the 2012 survey. Many hake observed between Monterey Bay and Cape Mendocino, and off of the Oregon coast. There were few locations in Canada with assigned hake backscatter, mainly off of the northern portion of West Vancouver Island, Quatsino Sound, Brooks Peninsula, and Northeast Queen Charlotte sound. Although small numbers of hake were sampled in some trawls in areas far north of Vancouver Island, it was determined that, as in the 2011 survey, these hake were a very small part of the observed backscatter due to mixing with smaller species such as euphausiids or eulachon, and occasionally no backscatter was assigned to the regions on these transects (Figure 7). Comparing the distribution of backscatter in 2011 and 2012 to the distribution of backscatter in previous surveys (Figure 1) shows that the stock was distributed more southerly in 2011 and 2012. The distribution of hake in 2011 and 2012 was most similar to the distribution of hake in 2001, when the population was also dominated by young fish. The 2012 survey biomass estimate is 1,380,724 metric tons, which is approximately 2.65 times the 2011 acoustic survey biomass estimate of 521,476 metric tons (Figure 8). Only 8.69% of this biomass was observed in Canadian waters in 2012. No Humboldt squid were observed in 2012, although considerable numbers were caught in both the survey and fishery in 2009.

The variability of the 2012 biomass estimate, measured as a coefficient of variance (CV), is 4.75%, half of the 10.2% calculated for the 2011 survey (Figure 8 and Table 4). These estimates of uncertainty account for sampling variability (and the variability due to squid in 2009), but several additional sources of observation error are also possible. For example, haul-to-haul variation in size and age, target strength uncertainty of hake as well as the presence of other species in the backscatter and inter-annual differences in catchability likely comprise additional sources of uncertainty in the acoustic estimates. In the future, it is possible that a bootstrapping analysis that incorporates of many of these sources of variability can be conducted and the estimation of variance inflation constants in the assessment may become less important (O'Driscoll 2004). At present, though, there is strong reason to believe that all survey variance estimates are underestimated relative to the true variability.

As it was with the fishery data, age-composition data were used to describe the age structure of hake observed by this survey. Proportions-at-age for the eight acoustic surveys are summarized in Figure 6 and show large proportions of the 1999, 2008, and 2010 year classes. The 2012 survey attributed 63.7% of the estimated number of hake observed to the 2010 year-class. The acoustic survey data in this assessment do not include age-1 fish, although a separate age-1 index has been developed in the past.

2.2.2 Bottom trawl surveys

The Alaska Fisheries Science Center conducted a triennial bottom trawl survey along the west coast of North America from 1977 to 2001 (Wilkins et al. 1998). This survey was repeated for a final time by the Northwest Fisheries Science Center in 2004, but did not go into Canadian waters. In 1999, the Northwest Fisheries Science Center began to take responsibility for bottom trawl surveys off of the U.S. west coast, and, in 2003, the Northwest Fisheries Science Center survey was extended shoreward to a depth of 55 m to match the shallow limit of the triennial survey (Keller et al., 2008). Despite similar seasonal timing of the two surveys, the 2003 and subsequent annual surveys differ from the triennial survey in size/horsepower of the chartered fishing vessels and bottom trawl gear used. As such, the two were determined (at a workshop on the matter in 2006) to be separate surveys which cannot be combined into one. In addition, the presence of significant densities of hake, both offshore and to the North of the area covered by the trawl survey, coupled with the questionable effectiveness of bottom trawls in catching mid-water schooling hake, limits the usefulness of this survey to assess the hake population. For these reasons neither the triennial, nor the Northwest Fisheries Science Center shelf trawl survey, have been used in recent assessments. With the growing time-series length of the NWFSC survey (now 9 years), future assessments should re-evaluate the use of the survey as an index of the adult and/or juvenile (age 0-1) hake population.

2.2.3 Pre-recruit survey

From 1999-2009, the NWFSC and Pacific Whiting Conservation Cooperative (PWCC), in coordination with the SWFSC Rockfish survey have conducted an expanded survey (relative to historical efforts) targeting of juvenile hake and rockfish. The SWFSC/NWFSC/PWCC pre-recruit survey used a mid-water trawl with an 86' headrope and ½" codend with a 1/4" liner to obtain samples of juvenile hake and rockfish (identical to that used in the SWFSC Juvenile Rockfish Survey). Trawling was done at night with the head rope at 30 m at a speed of 2.7 kt. Some trawls were made before dusk to compare day/night differences in catch. Trawl tows of 15 minutes duration at target depth were conducted along transects at 30 nm intervals along the coast. Stations were located along each transect, at bottom depths of 50, 100, 200, 300, and 500 m. Since 2001, side-by-side comparisons were made between the vessels used for the survey.

Trends in the coast-wide index have shown very poor correlations with estimated year-class strengths in recent assessment models for year classes that were consistently observed in the fishery and survey. Therefore, this index has not been used in any assessment. Because the pre-recruit survey has not been conducted since 2009, it has not been revisited in subsequent stock assessments.

2.2.4 Age-1 Index from the acoustic survey

The acoustic survey has historically focused its at-sea and analysis efforts on the age-2+ portion of the Pacific hake stock. The rationale for this included: inshore and southerly distribution of age-1 fish required additional survey time to provide adequate geographic coverage; relatively lower catchability of age-1 fish in the trawl net used by the survey; and perhaps greater difficulty in identifying these schools from other small pelagic fish. This choice was also consistent with the needs of early stock assessments, where recruitments were modeled as at age-2. Despite these reasons for excluding age-1 fish historically, a reliable index of age-1 hake would now be extremely valuable for this stock assessment. An age-1 index could potentially reduce uncertainty around the strength of incoming cohorts much more rapidly than only the biennial survey estimates for age-2+ fish and the annual commercial fishery data.

During 2011, the acoustic survey team re-processed all echogram data available, spanning the period from 1995 to 2011. All age-1 aggregations were identified and the backscatter integrated following the simple polygon methods that were used for the adult stock prior to development of the kriging method currently employed. The number of data points is currently very small. Unfortunately, correlation analysis for the index and assessment-estimated year-class strengths is hampered by low variability among the years for which age-1 hake have been enumerated by the acoustic survey. However, the results are generally consistent with large 2008 and 2010 cohorts (Figure 9). This index was not used in the 2013 assessment, but the JTC encourages a continuation of this effort, which, in addition to an annual survey could reduce assessment model uncertainty in the future.

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 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-one 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. Less than 10% of the fish smaller than 32 cm are predicted to be mature, while 100% maturity is predicted by 45 cm.

Histological samples have been collected during the 2009 U.S. bottom trawl survey and were analyzed in early 2012. Preliminary analysis of the 2009 data suggest the presence of yearly variation and that some larger fish may skip spawning, although they are likely mature. Additional ovaries were collected from the 2012 bottom trawl survey and the 2012 acoustic survey to investigate differences between hake caught in mid-water and those caught near the bottom, as well as variability between years. The number of samples by length bin is shown in Table 5. The JTC expects to complete the analysis of 2012 samples in 2013 for consideration in the 2014 hake assessment.

2.3.2 Aging 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 data while neighboring year-classes are under-represented.

To account for these observation errors in the model, year-specific ageing-error matrices (or 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. This approach has been unchanged since the 2011 assessment and has been retained for 2013, with the ageing-error reduced for the 1980, 1984, 1999, 2008, and 2010 cohorts.

2.3.3 Weight-at-age

A matrix of empirically derived population weight at age is required as input for the current assessment models. Mean weight at age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2012 (Figure 10). Ages 15 and over were pooled and assumed to have the same weight at age. For ages 2 to 15+, 99% of the combinations of year and age had samples from which to calculate mean weight at age. At age 1, 58% of the years had samples available. 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.

2.3.4 Length-at-age

In 2011 assessment models, 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. Von Bertalanffy growth models fit externally to data collected prior to 1990 and afterward show the same dramatically different rates of growth when it has been estimated inside the assessment model in recent years. Hake show very rapid growth at younger ages, and the length-at-age trajectories of individual cohorts also vary greatly, as has been documented in previous assessments. In addition, there are bioenergetic effects (Walters and Essington 2010), the interactions of selectivity at length, fishing and natural mortality that can make estimating unbiased growth curves difficult (Taylor et al. 2005). Most statistical methods for estimating growth curves perform poorly (Gwinn et al. 2010).

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 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 6. Several important distributions are discussed in detail below.

2.4.1 Natural Mortality

In recent stock assessments, the natural mortality rate for Pacific hake has either been fixed at a value of 0.23 per year, or estimated using an informative prior to constrain the probability distribution to a reasonable range of values. The 0.23 estimate was originally obtained via tracking the decline in abundance of individual year classes (Dorn et. al 1994). Pacific hake longevity data, natural mortality rates reported for Merluciids in general, and previously published estimates for Pacific hake natural mortality indicate that natural morality rates in the range 0.20-0.30 could be considered plausible for Pacific hake (Dorn 1996).

Beginning in the 2008 assessment, Hoenig's (1983) method for estimating natural mortality (*M*), was applied to hake, assuming a maximum age of 22. The relationship between maximum age and *M* was recalculated using data available in Hoenig (1982) and assuming a log-log relationship (Hoenig, 1983), while forcing the exponent on maximum age to be -1. The recalculation was done so that uncertainty about the relationship could be evaluated, and the exponent was forced to be -1 because theoretically, given any proportional survival, the age at which that proportion is reached is inversely related to M (when free, the exponent is estimated to be -1.03). The median value of *M* via this method was 0.193. Two measures of uncertainty about the regression at the point estimate were calculated. The standard error, which one would use assuming that all error about the regression is due to observation error (and no bias occurred) and the standard deviation, which one would use assuming that the variation about the regression line was entirely due to actual variation in the relationship (and no bias occurred). The truth is likely to be between these two extremes (the issue of bias not withstanding). The value of the standard error in log space was 0.094, translating to a standard error in normal space of about 0.02. The value of the standard deviation in log space was 0.571, translating to a standard deviation in normal space of about 0.1. Thus Hoenig's method suggests that a prior distribution for *M* with mean of 0.193 and standard deviation between 0.02 and 0.1 would be appropriate if it were possible to accurately estimate *M* from the data, all other parameters and priors were correctly specified, and all correlation structure was accounted for.

In several previous assessments (2008-2010) natural mortality has been allowed to increase with age after age 13, to account for the relative scarcity of hake at age 15+ in the observed data. This choice was considered a compromise between using dome-shaped selectivity - and assuming the oldest fish were extant but unavailable to the survey or fishery - and specifying increasing natural mortality over all ages, which tended to create residual patterns for ages with far more fish in them. The reliability of this approach has been questioned repeatedly, and it makes little difference to current assessment results, so in the interest of parsimony, natural mortality is considered to be constant across age and time for all models reported in this assessment document.

Since the 2011 assessment and again this year, a combination of the informative prior used in recent Canadian assessments and the results from Hoenig's method described above support the use of a log-normal distribution with a median of 0.2 and a log-standard deviation of 0.1. Sensitivity to this prior is evaluated by examination of the posterior distribution, as updated by the data, as well as the use of alternate priors, specifically a larger standard deviation about the point estimate (see Section 3.4.7).

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. Sensitivity to this prior was evaluated using various values for the mean (see Section 3.4.7).

3 Assessment

3.1 Modeling history

Age-structured assessment models of various forms have been used to assess Pacific hake since the early 1980s, using total fishery landings, fishery length and age compositions, and abundance indices. Modeling approaches have evolved as new analytical techniques have been developed. 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 (Francis and Hollowed 1985, Hollowed et al. 1988a). In 1989, the hake population was modeled using a statistical catch-at-age model (Stock Synthesis) that utilized fishery catch-at-age data and survey estimates of population biomass and age-composition data (Dorn and Methot, 1991). The model was then converted to AD Model Builder (ADMB; Fournier et al. 2012) in 1999 by Dorn et al. (1999), using the same basic population dynamics equations. This allowed the assessment to take advantage of ADMB's post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest. Beginning in 2001, Helser et al. (2001, 2003, and 2004) used the same ADMB model to assess the hake stock and examine important assessment modifications and assumptions, including the time-varying nature of the acoustic survey's selectivity and catchability. The acoustic survey catchability coefficient (q) was one of the major sources of uncertainty in the model. The 2004 and 2005 assessments presented uncertainty in the final model result as a range of biomass. The lower end of the biomass range was based upon the conventional assumption that the acoustic survey q was equal to 1.0, while the higher end of the range represented a q=0.6 assumption.

In 2006, the coastal hake stock was modeled using the SS2, an earlier version of the Stock Synthesis (SS) modeling framework written in AD Model Builder (Methot and Wetzel 2012). Conversion of the previous hake model into SS2 was guided by three principles: 1) incorporate less *derived* data, favoring the inclusion of unprocessed data where possible, 2) explicitly model the underlying hake growth dynamics, and 3) pursue parsimony in model complexity. "Incorporating less *derived* data" entailed fitting observed data in their most elemental form. For instance, no pre-processing to convert length data to age-compositional data was performed. Also, incorporating conditional age-at-length data for each fishery and survey allowed explicit estimation of expected growth, dispersion about that expectation, and its temporal variability, all conditioned on selectivity. In both 2006 and 2007, as in 2004 and 2005, assessments presented two models (which were assumed equally likely) in an attempt to bracket the range of uncertainty in the acoustic survey catchability coefficient, q. The lower end of the biomass range was again based upon the conventional assumption that the acoustic survey q was equal to 1.0, while the higher end of the range allowed estimation of q with a fairly tight prior about q = 1.0 (estimated q = 0.6 - 0.7). The 2006 and 2007 assessments were collaborative, including both U.S. and Canadian scientists.

During 2008, three separate stock assessments were prepared independently by U.S. and Canadian scientists. The U.S. model was reviewed during the STAR panel process, and both the VPA and TINSS models were presented directly to the SSC, but were not formally included in the U.S. assessment review and management process. The post-STAR-panel U.S. model freely estimated q for the first time, and this resulted in very large relative stock size and yield estimates. In 2009, the U.S. assessment model incorporated further uncertainty in the degree of recruitment variability (σ_R), more flexible time-varying fishery selectivity, and a separate *M* for older hake. Additionally, the 2009 assessment incorporated further refinements to the ageing-error matrices, including both updated data and cohort-specific reductions in ageing error to reflect "lumping" effects due to strong year classes. The 2009 U.S. model continued to integrate uncertainty in acoustic survey *q* and selectivity and in *M* for older fish. Residual patterns that had been present in the age and length data were discussed at length, and efforts were undertaken to build the tools necessary to re-evaluate input data to allow more flexibility in potential modeling approaches.

In 2010, two competing models (one built using TINSS, Martell 2010; and one in SS, Stewart and Hamel 2010) were presented to the STAR panel. The SS model was similar in structure to the 2009 assessment. Estimates of absolute stock size and yields differed greatly between the two models, and the causes of these differences went largely unidentified. The SSC recommended that the Pacific Council base management advice on both models.

In 2011, two models were again put forward by a joint stock assessment team comprised of U.S. and Canadian scientists collaborating in the spirit of the as-yet unimplemented Agreement. Results from both models were presented in a single document (Stewart et al. 2011). Considerable efforts were made to refine both models to better understand the reasons for previous differences among models and to better present the uncertainty in current stock status. The exercise resulted in two models that were structurally very similar, although they still contained some fundamental differences in underlying assumptions about certain likelihood components and prior assumptions about the productivity and scale of the population. During model development, a wide range of model complexities were explored, which led to the conclusion that relatively simple model structures were able to provide results consistent with more complex models. The final models achieved a much greater degree of parsimony compared with some earlier assessments. Notably, neither model attempted to fit to observed lengths at age. Annual variability in length at age was instead captured through use of empirically-derived estimates of weight at age in the data files (discussed above). Both models were deemed equally plausible by the STAR panel, in terms of their ability to capture the dynamics of the Pacific hake stock and provide advice for management in the face of considerable scientific uncertainty.

In 2012 the Pacific whiting Agreement was officially enacted and members of a provisional Joint Technical Committee (JTC), comprised of Canadian and U.S. scientists, continued to collaborate in the production of a single stock assessment document. Members of the provisional JTC agreed on a single base-case model, using the SS modeling platform configured almost identically to that used in the 2011 assessment. Sensitivity to structural and parameter uncertainty was analyzed using this model and a new statistical catch at age model (CCAM), originally developed at the University of British Columbia (Martell 2011) and customized by members of the JTC.

The 2013 stock assessment presented here carries on the collaboration between U.S. and Canadian scientists making up the JTC. As in 2012, the SS model was used to represent a base model, but a separate Canadian model was not developed and SS was also used to characterize structural and parameter uncertainty.

3.2 Response to recent review recommendations

3.2.1 2013 Scientific Review Group (SRG) review

The Scientific Review Group was held in Vancouver, British Columbia from February 19–22, 2013. The SRG investigated many aspects of the model, but 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. The SRG also reviewed the Management Strategy Evaluation (MSE), and felt that it was a great start to this important process, but was limited in scope and in its current state was not completely adequate to provide management guidance.

Many recommendations were made by the SRG and three were given high priority: 1) continue work on the MSE, 2) improve our understanding of Pacific hake life-history by collecting and analyzing data related to growth, maturity, and fecundity, and 3) continue acoustic research, especially with regard to an age-1 index and target identification.

3.2.2 2012 SRG review

The 2012 SRG panel (21–24 February, 2011) conducted a thorough review of the data, analyses and modeling conducted by the JTC (a full summary can be found in the STAR panel report). The SRG endorsed the use of these revised models for 2012. Other recommendations for this assessment made during the SRG review were: inclusion of a table of management metrics that were of particular interest to meeting participants and several adjustments to some technical terms to improve the readability of the assessment results. These suggestions are incorporated in this document as well and an additional column was added to the table of metrics. Specific responses are given below.

3.2.3 2012 SRG recommendations and responses from the JTC

High priority recommendations

1. Increase frequency of survey to annual

   Response: The JTC supports this recommendation, and especially supported an interim survey in 2012. However, the results from the MSE show that on average, there is little difference in average catch, average annual variability of the catch, and stock status between an annual and a biennial survey. Furthermore, there is concern that an annual survey would jeopardize future research on improving survey techniques. On the other hand, the 2012 assessment incorporated an acoustic survey biomass estimate from 2009 that was very high, and an acoustic survey biomass estimate in 2011 that was very low. Along with the incoming 2008 year class and signs of a potentially strong 2010 year class, the 2013 assessment benefited from a supplemental 2012 acoustic survey. Results below present a hypothetical assessment where there was no 2012 survey to determine the usefulness of this interim survey.

2. Management strategy evaluation (MSE)

   Response: The JTC supports this recommendation, and began work on an MSE in the summer of 2012. Results of this MSE are provided in Appendix A and the JTC recommends future work on the MSE with input from the JMC, SRG, and AP.

Other recommendations

- Inter-vessel calibrations

  Response: Inter-vessel calibration has not been performed at this time. However, transects off of Vancouver Island in the 2012 survey were done by both the Bell Shimada and the CCGS W.E Ricker. It is uncertain if this data may be used to investigate the differences between vessels due to timing, but it may be possible.

- Age-1 or -0 index development

  Response: The JTC supports the development of an age-1 index, especially because the preliminary age-1 index from the acoustic survey indicates recent strong year classes estimated by the base model (Figure 9).

- Life-history data improvements

  Response: Ovaries have been collected from hake caught during the 2012 bottom trawl and 2012 acoustic surveys. These collections are currently being analyzed and will hopefully be available for consideration in the 2014 assessment. Numbers of samples collected are shown in Table 5.

- Survey extent

  Response: One long transect in 2012 was performed on the W.E. Ricker with an industry representative on board to investigate the presence of hake in deep water. No conclusive evidence of hake in deep water was found.

- Survey variance

  Response: There has been no additional work on the inclusion of additional sources of error in the survey estimate. Work on this topic was halted due to time constraints given a supplemental 2012 survey.

- The use of commercial vessels in acoustic or biological sampling be explored as one way to expand sampling

  Response: A catcher vessel was used in the 2012 acoustic survey, and many challenges were identified. No additional work has been done to determine the utility of acoustic sampling with commercial vessels, but as learned from the 2012 survey and the use of a catcher vessel, calibration of echo sounders would be necessary.

- Target characterization and verification

  Response: The use of a catcher vessel in the 2012 survey increased the number of hauls that typically occur in a normal survey year. However, other difficulties may negate the benefits seen from the increased number of tows. No additional work has been done due to time constraints imposed by the supplemental 2012 survey.

- Exploration of separability assumption in the assessment model; i.e., the assumption that selectivity is constant over time.

  Response: Two sensitivities are presented in this document showing the effect of introducing a flexible form of time-varying selectivity. Little difference in the results was seen.

3.3 Model Description

3.3.1 Base model

The base-case model reported in this assessment uses SS version 3.24j (Methot and Wetzel 2012), which provides a general framework for modeling fish stocks that permits the complexity of population dynamics to vary in response to the quantity and quality of available data. In the base model, both the complexity of the data and the dynamics of the model are intended to be quite simple, and efforts have been made to be as consistent with the 2012 assessment and with the model structure that was tested this year using the MSE. Additional complexity is explored via sensitivity analysis using the SS platform.

The basic model structure, aggregation-level, treatment of data, as well as parameterizations for key processes remain unchanged from the 2011 and 2012 assessments. The Pacific hake population is assumed to be a single coast-wide stock along the Pacific coast of the United States and Canada. Sexes are combined within all data sources, including fishery and survey age compositions, as well as in the model dynamics. The accumulator age for the internal dynamics of the population is set at 20 years, well beyond the expectation of asymptotic growth. The modeled period includes the years 1966–2012 (the last year of available data), with forecasts extending to 2015. The population was assumed to be in unfished equilibrium 20 years prior to the first year of the model, allowing a 'burn-in' of recruitment estimates such that the age structure in the first year of the model was free of equilibrium assumptions. Since there were no large-scale commercial fisheries for hake until the arrival of foreign fleets in the mid- to late 1960s, no fishing mortality is assumed prior to 1966.

The base model structure, including parameter specifications, bounds and prior distributions (where applicable) is summarized in Table 6. The assessment model includes a single fishery representing the aggregate catch from all sectors in both nations). The effect of modeling the U.S. foreign, joint-venture, at-sea and shore-based fisheries, as well as the Canadian foreign, joint-venture and domestic fisheries as separate fleets was explored in the 2011 assessment. It was assumed that selectivity for both the acoustic survey and commercial fishery does not change over time, but time-varying selectivity was explored as part of the sensitivity analysis. 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 as small numbers are observed in some years. Selectivity is forced to be constant after age-6, although this assumption is also explored in the sensitivity analysis.

Growth is represented via the externally derived matrix of weight-at-age described above. Alternate models, including a time-varying von Bertalanffy function, dimorphic growth and seasonally explicit growth within years were compared via sensitivity analyses during the 2011 assessment but did not provide substantially different results.

For the base model, the instantaneous rate of natural mortality (*M*) is estimated with a lognormal prior having a median of 0.2 and σ (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 Beta-distributed prior for stock-recruit steepness (*h*) applied to previous assessments and described above. Year-specific recruitment deviations were estimated from 1946–2012. 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 2012. Maturity and fecundity relationships are assumed to be time-invariant and fixed values remain unchanged from recent assessments.

The acoustic survey index of abundance was fit via a log-normal likelihood function, using the observed sampling variability, estimated via kriging as year-specific weighting (and additional uncertainty in 2009 due to the presence of Humboldt squid). An additional constant and additive log(SD) component is included, which was freely estimated to accommodate unaccounted for sources of process and observation error. Survey catchability was freely estimated with a uniform (noninformative) prior in log-space. 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 were unchanged from the 2012 assessment.

3.4 Modeling results

3.4.1 Changes from 2012

A set of 'bridging' models in SS was constructed to clearly illustrate the component-specific effects of all changes to the base-case model from 2012 to 2013. The first link in this bridge analysis was to update to the most recent version of the Stock Synthesis software (version 3.24j; 27 November, 2012). This change produced no observable differences in the model results (not shown).

The second change involved updating the 2011 catches and data to reflect any changes in the underlying databases and to get final estimates of catch and age compositions for 2011 to replace the preliminary estimates available at the time the 2012 stock assessment. The 2011 catch decreased slightly and due to late arriving ages collected late in 2011, the proportions at ages 1 and 2 increased slightly while the proportions at ages older than 3 decreased slightly (Figure 11). Other changes in this step were to update the mean weight-at-age matrix using 2012 data and to combine the fleet specific age compositions using year-specific mean weight-at-age (discussed above). This produced very small differences throughout the time series of fishery compositions. These changes resulted in similar historical trends, but a slightly more depleted stock in recent years mainly due to fewer 2005, 2006, and 2008 recruits (Table 7 and Figure 12).

The third change included adding the 2012 fishery age-composition data and 2012 catches. This is basically an assessment without a 2012 acoustic survey. The stock status improved greatly in 2012 due to a larger estimate of 2008 recruitment and a much larger, but uncertain, estimate of 2010 recruitment (Table 7 and Figure 12). The uncertainty interval on 2012 depletion is quite large, extending from just below 10% to slightly less than 100%.

The final change in the bridging was to add in the 2012 acoustic survey biomass estimate and age-compositions. The MLE estimates of spawning biomass, depletion, and recruitment showed little change, except for a slight reduction in the 2010 year class, indicating that the 2012 fishery and 2012 survey predict similar trends, which has not always been the case in past years. The largest change was that uncertainty was reduced, especially at the lower end (although MLE estimates may not accurately estimate the tails of uncertainty due to asymmetry). Without the acoustic data, the 2013 assessment would be much more uncertain.

3.4.2 Model selection and evaluation

The JTC focused on a small subset of structural choices for 2013. There were extensive structural explorations conducted during the 2011 stock assessment (see Stewart et al. 2011 for a thorough description of these analyses, ranging from simple production models to seasonal, sex- fleet/sector-specific approaches incorporating time-varying growth). The JTC devoted their efforts instead to a few structural uncertainties, and to the development of a management strategy evaluation in 2012. Of the models investigated, only a small subset representing those with the best estimation behavior was selected for sensitivity analyses, which are reported below.

Iterative reweighting of the composition data in the base case SS model did not produce large changes in the results, and the JTC found that the same down-weighting values for fishery and acoustic survey age compositions as used in the 2012 assessment produced reasonable results (12% and 94%, respectively, of the observed number of trips/hauls, while retaining the relative differences in sampling among years). As noted in the 2012 assessment, this is consistent with the high degree of correlation among fishery tows for the at-sea fleet and the much greater temporal and spatial spread of the acoustic hauls. The additional variance component for the acoustic survey was estimated to be 0.42 at the median of the posterior distribution, indicating substantial additional process error beyond simple sampling variability was present (as expected). This estimate is slightly less than the median estimate in the 2012 assessment (0.46), but much larger than that from the 2011 assessment (0.26) reflecting the *post hoc* deduction that the 2009 survey observation is largely inconsistent with the trend over adjacent years. Despite the relatively large amount of combined process and observation error for the acoustic time-series, fit to this data source still provides the strongest information available in the assessment on the scale of the current Pacific hake stock.

A summary of the fit to the age-composition data (for the base case) and survey index (for both models) can be found in the model results section below

3.4.3 Assessment model results

For the base model, the MCMC chain was run for 10,000,000 iterations with the first 10,000 discarded to eliminate 'burn-in' effects. Each 10,000th value thereafter was retained, resulting in 999 samples from the posterior distributions for model parameters and derived quantities. Stationarity of the posterior distribution for model parameters was 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 13 and Figure 14). 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 15). Correlations among key parameters were generally low, with the exception of natural mortality and the average unexploited equilibrium recruitment level (R_0). Recent recruitment (2008 and 2010), depletion in 2013, and predicted catch in 2013 were all positively correlated (Figure 16).

The modeled time series fit to the acoustic survey biomass index is shown in Figure 17 and is quite reasonable, given the sum of the input and estimated variance components. The 2001 data point was well below the predictions made by any model we evaluated, and no direct cause for this is known, however it was conducted about one month earlier than all other surveys between 1995 and 2009 (Table 4), which may explain some portion of the anomaly. 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. Additional uncertainty has been accounted for in both the data and the models.

Selectivity at age for both the fishery and survey is relatively uncertain (better reflected when using the non-parametric selectivity option as compared to parametric forms) but generally consistent with the observation that fish are fully selected by the time they reach their full size (Figure 18). Fits to the age-composition data are also reasonably good, with close correspondence to the dominant cohorts observed in the data and also identification of small cohorts, where the data give a consistent signal (Figure 19 through Figure 21). Residual patterns to the fishery and survey age data do not show particularly evident trends that would indicate systematic bias in model predictions, but there is a reversal in trend of over-fitting between years 2011 and 2012 (Figure 22).

Posterior distributions for model parameters showed that for both steepness and natural mortality the prior distributions strongly influenced the posterior (Figure 23). The posterior for steepness was not updated much by the data 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. All other parameters showed substantial updating from noninformative priors to stationary posterior distributions.

The base-case stock assessment model indicates that the Pacific hake female spawning biomass was well below the average unfished equilibrium level at the start of the fishery and during the 1970s (Figure 24 and Table 8 and Table 9). The model predicts that the stock increased rapidly after two or more large recruitment events in the early 1980s and then declined rapidly after a peak in the mid- to-late 1980s to a low in 2000 (Figure 25, Figure 26 and Table 10). This long period of decline was followed by a brief increase to a peak in 2003 (median estimate of 1.34 million mt) as the exceptionally large 1999 year class matured. The stock is then estimated to have declined with the ageing 1999 year class to a time-series low of 0.42 million mt in 2009. Since 2009, the model predicts that biomass is increasing based on the strength of the 2008 and 2010 year classes and is at 72.3% of the average unfished equilibrium level, with a 95% probability of being between 34.7% and 159.7% (Figure 27).

Stock size estimates are quite uncertain throughout the time series, and are typically largest at the end of the time series. Figure 28 compares the three assessments performed with a similar model since 2011 in terms of estimated depletion and recruitment. The estimated depletion is similar for the 2012 and 2013 assessment models (up to 2011), but the 2011 assessment model significantly departs in 2007 due to differences in the estimated size of the 2005, 2006, and 2008 recruitments. The uncertainty intervals for the estimated 2011 spawning biomass overlap from all three models, but the median spawning biomass from the 2011 assessment model is not contained within the uncertainty intervals of the 2012 and 2013 assessment models, and vice versa. The uncertainty interval for 2011 spawning biomass is smallest in the 2013 assessment, indicating that additional data has been interpreted as informative by the model.

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980 and 1999 in both assessment models, with 1970, 1984 and 2010 accounting for the other three of the five largest estimated to have occurred in the last 40 years. The strength of the 2008 cohort is estimated to be large (5.5 billion) and is the sixth largest in the time-series. The 2010 cohort is estimated as the second largest, but most uncertain, cohort at 13.6 billion individuals. In both the U.S. fishery and acoustic age compositions, the 2008 and 2010 year classes comprise a very large proportion of the recent observations. Uncertainty in estimated recruitments is substantial, especially for 2010, as indicated by the broad posterior intervals (Figure 25). The stock-recruit estimates are provided in Figure 29, showing both the extremely large variability about the expectation and the lack of relationship between spawning stock and subsequent recruitment.

The large recruitments are especially important to the Pacific hake fishery. Figure 30 shows that more than 1.2 million metric tons have been harvested from the 1999 year class, which is about 12% of the entire catch since 1966. The 1980, 1984, and 1999 year classes have been the largest contributors to catch over the entire time-series, making up 30% of the approximately 10 million tons of hake that have been harvested since 1966.

Using the estimated natural mortality and selectivity from the base Bayesian model, yield-per-recruit and spawner-per-recruit curves were calculated external to SS3 (Figure 31). Yield-per recruit curves show that it is maximized near age 3 at the exploitation rates recently observed (around 0.15–0.3). Spawner-per-recruit shows that knife-edge selectivity at age 3 would reduce the spawners-per-recruit to between 20% and 40% at these same exploitation rates. The estimated selectivity curve from the base model does not fully select fish until age 6, thus the yield-per-recruit and spawner-per-recruit curves are most similar to the age 5+ knife-edge selectivity. Although, not shown in this document, there was little change in these general results over the range of uncertainty in natural mortality. At a higher natural mortality the, yield-per-recruit was maximized at a first age of selectivity closer to 2.

3.4.4 Model uncertainty

The base case assessment model integrates over the substantial uncertainty associated with several important model parameters including: acoustic survey catchability (q), the productivity of the stock (via the steepness parameter, h, of the stock-recruitment relationship), the rate of natural mortality (M), and recruitment deviations. Although the Bayesian results presented include estimation uncertainty, this within-model uncertainty is likely an underestimate of the true uncertainty in current stock status and future projections, since it does not include structural modeling choices, data-weighting uncertainty and scientific uncertainty in selection of prior probability distributions. However, 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 (see Stewart et al 2012 for further discussion and examples). Table 11 compares the median of the posterior to the MLE, showing that median biomass, recruitment, and depletion estimates from the posterior distribution are all higher. Figure 32 shows the MLE and Bayesian estimates as well as the skewed uncertainty in the posterior distributions for spawning biomass and recruitment.

The JTC investigated a broad range of alternate models, and we present a subset of key sensitivity analyses using the Stock Synthesis (SS) modeling platform in order to provide a broad qualitative comparison of structural uncertainty with the base case. However, a major source of uncertainty in the 2013 status and target catch is in the estimate of the size of the 2010 year class, and the within model uncertainty captures the median trend of most sensitivity models.

Pacific hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. 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 continue to result in highly uncertain estimates of current stock status and even less-certain projections of future stock trajectory. Currently uncertainty in this assessment is largely a function of the potentially large 2010 year class being observed once in the acoustic survey and being observed twice by the fishery, although with reduced and uncertain selectivity. The supplemental acoustic survey performed in 2012 helped reduce the uncertainty in the strength of this year class, which is a likely result when increasing the frequency of the survey. However, the survey does not quantify hake until they are 2 years old, leaving a lag in the ability to forecast even one year.

Given the uncertainty in stock status and magnitude, the JTC developed a Management Strategy Evaluation (MSE) to explore topics including testing of the basic performance of the default harvest policy and the effect of annual vs. biennial surveys. The results of these explorations showed that biomass levels and average catch was variable, mainly because of the high recruitment variability seen with Pacific hake. Even though the Pacific hake fishery is relatively data-rich, with a directed fishery-independent survey program, substantial biological sampling for both commercial fisheries and the acoustic survey, and reliable estimates of catch, the data are less informative about incoming recruitment which results in large differences between the simulated abundance and the estimated abundance.

3.4.5 Reference points

The unexploited equilibrium spawning biomass estimate was 2.08 million mt (Table 12), larger than the estimates reported in the 2011 and 2012 stock assessments (Stewart et al. 2011, JTC 2012). However, the uncertainty is broad, with the 95% posterior credibility interval ranging from 1.65 to 2.71 million mt. The equilibrium spawning biomass resulting from fishing at the $F_{40\%}$ default harvest rate target was 0.74 million mt. *MSY* is estimated occur at a smaller stock size, 0.50 million mt, with a yield of 357 thousand mt; only slightly higher than the equilibrium yield when fishing at the $F_{40\%}$ target, 337 thousand mt. The full set of reference points with uncertainty intervals for the base case and among alternate sensitivity models are reported in Table 12.

The median fishing intensity on the Pacific hake stock is estimated to have been below the $F_{40\%}$ target until 2008 (Figure 33). Uncertainty in the recent SPR estimates is large, and the estimates from the base-case model indicate that the catch has exceeded the target in three of the last five years, although the fishing intensity in 2012 was very likely to be below target. The exploitation history, in terms of both the biomass and *F* targets, is portrayed graphically via a phase-plot (Figure 34).

3.4.6 Model projections

The main source of uncertainty in the current status of Pacific hake comes from the estimate of recent year classes. Therefore, a decision table showing predicted status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base-case model (Table 13 and Table 14). The uncertainty in the final and projected years of the assessment are broad and expected to encompass the uncertainty due to different structural assumptions. The decision table is organized such that the projected implications for each potential management action (the rows, containing a range of potential catch levels) can be evaluated across the quantiles of the posterior distribution for the base-case model (the columns). For clarity, the implications are divided into two tables: the first table projects the depletion estimates, and the second predicts the fishing intensity relative to the target fishing intensity (based on the SPR; see table legend). Fishing intensity exceeding 100% indicates fishing in excess of the $F_{40\%}$ default harvest rate.

An additional table (Table 15) is presented containing a set of management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP). These metrics summarize the probability of various outcomes from the base case model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values.

The median spawning stock estimate from the base-case model is projected to remain constant with a 2013 catch of 650,000 mt, which is greater than the catch determined using the default harvest rate (626,364 mt, Table 13 and Table 14). A catch of approximately 603,000 mt results in an equal probability of the stock increasing or decreasing from 2013 to 2014, based on individual trajectories from samples of the posterior distribution (Table 15). The median values show slightly different results than the individual trajectories because increases in the projected biomass tend to be greater in magnitude than the decreases in projected biomass. Catches less than 600,000 mt result in a slight increase in the median 2014 spawning biomass, relative to 2013. However, the posterior distribution is highly uncertain, and either increasing or decreasing trends are possible over a broad range of 2012 catch levels. A catch of 696,000 mt results in the base model to predict the same catch of 696,000 mt in 2014, and a declining spawning biomass. Forecasts of depletion under fixed catch levels are graphically displayed in Figure 35.

Table 15 shows the same catch alternatives for 2013 and probabilities based on individual samples from the posterior distribution, and Figure 36 displays this graphically. As catch increases, the probability of each metric increases, and the various catch levels that produce a defined probability can be found be reading horizontally across from the y-axis. At the highest catch considered, there is an 11% probability that the spawning biomass would be less than 40% of unfished equilibrium biomass.

The median of the catch for 2013 based on the default harvest policy ($F_{40\%}$ – 40:10) is 626,364 mt, but has a wide range of uncertainty (Figure 37). The 95% posterior credibility interval ranges from 268,351 mt to 1,626,550 mt.

Given this uncertainty, the projected 2013 catch target being more than 1.5 times the highest catch in the time series as well as 1.75 times MSY, and that for many of the recent above average cohorts, the size of the year class was overestimated when it was age 2 compared to updated estimates as the cohort aged and more observations were available, additional forecast decision tables were created given three states of nature about the size of the 2010 year class. These states of nature are low 2010 recruitment, medium 2010 recruitment, and high 2010 recruitment, and each state of nature is defined to have a probability of 10%, 80%, and 10%, respectively. Table 16 shows the median depletion and fishing intensity within each state of nature, and it can be seen that in the low recruitment state of nature the fishing intensity would be at target with a 2013 catch between 300,000 and 350,000 mt. Table 17 shows the probability metrics for each state of nature. In the low recruitment state of nature there is an equal probability that the spawning biomass in 2014 will be less than or greater than the spawning biomass in 2013 with a catch between 300,000 and 350,000 mt. There is an equal probability that the spawning biomass will be below 40% of unfished equilibrium spawning biomass with a catch near 400,000 mt. The probabilities are conditional probabilities given that the state of nature occurs (i.e., there may be a 50% probability that depletion falls below 40%, but that is conditioned on there being a 10% probability that a low recruitment occurs).

3.4.7 Sensitivity analyses

Sensitivity analyses were conducted to investigate the structural uncertainty of the base model by examining the effect of changing parameter priors and assumptions. The sensitivities included the following:

1. Increasing the standard deviation on the prior for natural mortality (M),
2. Decreasing the mean of the prior on steepness (h) or increasing steepness to 1.0,
3. Increasing or decreasing the recruitment variability assumption (σ_R),
4. Increasing or decreasing the maximum age for which selectivity was estimated, and
5. Allowing fishery selectivity to change from year to year.

Using larger standard deviations for the prior on M increased the median posterior estimates for this parameter, from 0.224 in the base case to 0.278 with a three-fold increase in the SD of the prior distribution, from 0.1 to 0.3 (Figure 38). In all cases, the median of the prior was 0.2. Higher values of M in this sensitivity were associated with a larger stock sizes with greater uncertainty (Figure 39, Table 18). In combination, this changed the upper range of estimated stock status much more than the lower, with the upper limit of the 95% interval for depletion in 2013 shifting from 160% of SB_0 in the base case to 220% of SB_0 with the widest prior on M. The lower limit of this interval on 2013 depletion showed less sensitivity and increased from 35% to 37%.

Alternative assumptions about the mean steepness had a large effect on the posterior parameter estiamtes, but relatively little effect on model results. Decreasing the prior mean from 0.777 in the base case to 0.5, resulted in a decrease in the median of the posterior from 0.823 to 0.576 (Figure 40, Table 19). However, the time-series of depletion and recruitment was not substantially impacted by this change, and thus the stock status was also relatively unchanged (Figure 41). Over the range of depletion estimated to have occurred for hake, the very large variability in recruitment overwhelms the influence of any decline in mean recruitment implied by the spawner-recruit relationship (Figure 29).

Increasing or decreasing σ_R from 1.4 to either 1.0 or 2.0 had a small impact on the estimated recruitments or spawning biomass, but a larger impact on the equilibrium spawning biomass (Figure 42, Table 20). With an increase in σ_R from 1.4 to 2.0, the posterior median of SB_0 increases from 2,081 to 5,097 thousand mt while the estimated change in SB_{2013} only changes from 1,504 to 1,690 thousand mt. The 2013 depletion values, representing the ratio of these two quantities, changes dramatically, with a much lower stock status in the case with σ_R = 2.0. Decreasing σ_R has an opposite, though less substantial, impact on the relationship between estimated equilibrium spawning biomass and the estimated spawning biomass within the time-series. These changes are attributable to properties of the lognormal distribution that is used to model recruitment. At σ_R = 1.4, the median is 38% of the mean, while at σ_R = 1.0 and 2.0, this ratio is 61% and 14% respectively. However, the changes in σ_R do not result in equal changes in the variability of the estimated recruitments. Over the years 1971–2010 which have good information about which recruitments are high or low, changing σ_R from 1.4 to 1.0 or 2.0 results in a change in the standard deviation of the median recruitment deviations from 1.49 to 1.30 or 1.77, respectively (Figure 42, Table 20). The good match between the assumed and realized varability in recruitment for the base case, as recommended by Methot and Taylor (2012), results in a mean recruitment over the time-series that is similar to the equilibrium value. Changing the assumptions about about σ_R results in a mismatch between assumed and realized values of recruitment which leads to a time-series of recruitments that are inconstant with the equilibrium assumption and large changes in estimated stock status.

The sensitivity to changes in assumption about the maximum age for which selectivity was estimated had little influence on model results (Figure 43, Table 21). The assessment in 2012 showed much greater sensitivity at the end of the time-series due to uncertainty in the 2008 year class. This assessment was not as variable because incoming recruitment was more certain due to repeat observations from the fishery and survey.. As the maximum estimated age at selectivity increased, the selectivity at younger ages slightly decreased (Figure 44). Increasing the maximum age estimated beyond age 7 produced very uncertain estimates of selectivity at older ages (not shown).

Two sensitivity analyses were performed to investigate time-varying selectivity. Both cases were implemented by allowing all of the estimated selectivity parameters (controlling changes in selectivity from ages 1–6) to vary annually according to a random walk process over the years 1980 to 2012 (Figure 45). This required 165 additional parameters, more than tripling the number of estimated quantities in the model. The Flexible Fishery case assumed a more strict deviation penalty in the random walk (0.05) than the Very Flexible Fishery case (0.2). See Appendix C for more information on the nonparametric selectivity option. Due to the much greater computational burden of models with time-varying selectivity and potential issues with MCMC convergence, both sensitivity cases were conducted using the MLE estimates, rather than doing the full posterior integration.

Allowing time-varying fishery selectivity reduced the estimates of the 2008 and 2010 recruitment, relative to the base case model, by approximately 30% (Table 22), but otherwise had relatively little influence on the depletion time-series (Figure 46). Strong cohorts that were observed repeatedly in the fishery and the survey age-composition data were well estimated regardless of the amount of flexibility in survey selectivity, whereas the appearance of strong cohorts in the most recent years could be attributable to changes in fishing patterns instead of good recruitment. However, the consistency between the 2012 age compositions from the fishery and survey limits the extent to which the model can reduce the strength of the 2008 and 2010 year classes, even in the presence of time-varying selectivity. Although selectivity may indeed be expected to change over time, the base case model is more parsimonious, provides very similar results to models with time-varying selectivity, and is more computationally stable. An exploration of the effects of time-varying selectivity within the context of an MSE would be a valuable step toward better understanding the trade-offs related to the use of such assumptions in a stock assessment.

3.4.8 Retrospective analyses

Retrospective analyses were conducted by systematically removing the terminal year's data sequentially for ten years. For the base model, the effect of the 2012 data is dramatic, as was observed in the bridge analysis, and was a mainly a result of the estimates of the 2008 and 2010 year classes (Figure 47). A retrospective pattern is not apparent in estimates of spawning biomass over the last decade, but the large amount of variability and a pattern of low spawning biomass predicted immediately after a strong recruitment event, followed by a large biomass when the year class is finally observed suggests that the model is unable to accurately predict recruitment until has been observed a few times. Parameter estimates showed no clear patterns except that the additional variability on the acoustic survey index increased in 2011 due to the contrast in 2009 and 2011 survey biomass estimates (Table 23). However, some recruitment-deviation estimates showed retrospective patterns, especially while the corresponding cohort was young and observed only a few times (Figure 48).

In general, the model captures the direction of cohort-specific recruitment deviations (i.e. positive or negative), but it cannot determine their magnitude until several years of catch and age-composition data have been collected. Figure 48 shows the retrospective pattern in recruitment deviation estimates. As data are removed, less information is available to accurately estimate these deviations, and they move towards zero. Figure 48 shows that cohort-specific recruitment deviations do not follow a predictable retrospective pattern: some grow larger with more data (1999, 2001); some grow smaller (2002, 2004 and 2007); while still others alternate between increasing and decreasing (2000, 2001, 2005, 2006, and 2008). This is a further illustration of how multiple observations are needed to accurately determine the strength of the largest cohorts.

A comparison of the models put forward for management since 1991 (a retrospective among assessment models) shows that there has been considerable uncertainty in the Pacific hake stock biomass and status (Figure 49). Model-to-model variability (especially in the early portion of the time-series) is larger than the uncertainty reported in any single model, and this pattern does not appear to dampen as subsequent assessments are developed. An important aspect of this historical perspective is the inclusion of alternate values for survey catchability during 2004-2007, and then subsequently freely estimated values from 2008-the present. Prior to that period, catchability was ubiquitously assumed to be equal to 1.0. The 2013 base model estimates of spawning biomass appear to be consistent with many previous time-series, and the uncertainty intervals bracket a large proportion of those historical estimates.

4 Acknowledgments

This assessment relies heavily on text and analyses from previous assessments spanning the last several decades, we thank those authors for the use of their work, including Ian Stewart, Owen Hamel, Robyn Forrest, Steve Martell, Tom Helser, and Martin Dorn. We are grateful for the hard work of the U.S. and Canadian acoustics teams, including Alicia Billings, Dezhang Chu, Julia Clemons, Ken Cooke, George Cronkite, Steve Deblois, Stephane Gauthier, Larry Hufnagle, John Pohl, and Rebecca Thomas, as well as the crews of the NOAA ship *Bell Shimada*, CCGS *W. E. Ricker*, and F/V *Forum Star*. We thank the following individuals who contributed technical assistance, analysis tools, data, or comments to this assessment: Cassandra Donavan, Melissa Haltuch, Jim Hastie, Rob Kronlund, Lisa Lacko, Shayne MacLennan, Patrick McDonald, Joanne Groot, Chelsea Stanley, Brad Stenberg, and Vanessa Tuttle. Rick Methot was very helpful with insight into SS3 as well as the assessment. We also thank the many attendees at the two official JTC meetings who provided valuable insight into the 2012 commercial fisheries in Canada and the U.S., as well as additional perspective on the acoustic survey. And, a final thanks to the members of the SRG (Greg Workman, Rick Methot, Robyn Forrest, Michael Prager, Dave Sampson, Rod Moore, and Mike Buston) who gave the model and MSE a thorough review and made some very useful recommendations for future work.

5 Literature Cited

Agostini, V.N., R.C. Francis, A.B. Hollowed, S.D. Pierce, C. Wilson, and A.N. Hendrix. 2006. The relationship between Pacific hake (*Merluccius productus*) distribution and poleward subsurface flow in the California Current system. Can. J. Fish. Aquat. Sci. 63:2648-2659.

Alarcón-Muñoz, R., L. Cubillos, and C. Gatica. 2008. Jumbo squid (*Dosidicus gigas*) biomass off central Chile: Effects on Chilean hake (*Merluccius gayi*). Calif. Coop. Oceanic Fish. Invest. Rep. 49: 157-166.

Alheit J. and T.J. Pitcher. 1995. Hake: biology, fisheries, and markets. Chapman and Hall. London. 477 p.

A'Mar, Z.T., Punt, A.E., and Dorn, M.W. 2009. The evaluation of two management strategies for the Gulf of Alaska walleye pollock fishery under climate change. ICES Journal of Marine Science. 66: 1614-1632.

A'Mar, Z.T., Punt, A.E., and Dorn, M.W. 2010. Incorporating ecosystem forcing through predation into a management strategy evaluation for the Gulf of Alaska walleye pollock (*Theragra chalcogramma*) fishery. Fisheries Research 102: 98-114.

Anon, 1993. “Report of the workshop on the applicability of spatial techniques to acoustic survey data,” ICES Coop. Res. Rep. 195, 87pp.

Bailey, K.M., R.C. Francis, and E.R. Stevens. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. Calif. Coop. Oceanic Fish. Invest. Rep. 23:81-98.

Benson, A.J., G.A. McFarlane, S.E. Allen, and J.F. Dowler. 2002. Changes in Pacific hake (*Merluccius productus*) migration patterns and juvenile growth related to the 1989 regime shift. Can. J. Fish. Aquat. Sci. 59: 1969-1979.

Bentley, N., Breen, P.A., Kim, S.W., and Starr, P.J. 2005. Can additional abundance indices improve harvest control rules for New Zealand rock lobster (*Jasus edwardsii*) fis heries? New Zealand journal of marine and freshwater research 39: 629-644.

Buckley, T.W. and P. A. Livingston. 1997. Geographic variation in the diet of Pacific hake, with a note on cannibalism. Calif. Coop. Oceanic Fish. Invest. Rep. 38:53-62.

Butterworth, D.S. 2007. Why a management procedure approach? Some positives and negatives. *ICES J. Mar. Sci.* 64: 613-617.

Cox, S.P., and Kronlund, A.R. 2008. Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia, Canada. Fisheries Research 94: 224-237.

de La Mare, W.K. 1986. Simulation studies on management procedures. Reports of the International Whaling
Commission.. 36: 429-450.

de La Mare, W.K. 1998. Tidier fisheries management requires a new MOP (management-oriented paradigm). Reviews in Fish Biology and Fisheries 8: 349-356.

Deriso, R. B., M. N. Maunder, and J.R. Skalski. 2007. Variance estimation in integrated assessment models and its importance for hypothesis testing. Can. J. Fish. Aquat. Sci. 64: 187-197.

Dorn, M.W. 1991. Spatial and temporal patterns in the catch of Pacific whiting in the U.S. management zone during 1978-88. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-205, 68 p.

Dorn, M.W. and R.D. Methot. 1991. Status of the coastal Pacific whiting resource in 1990. U.S. Dept. Commer., NOAA Tech. Memo. NMFS F/AFSC-47, 101 p.

Dorn, M.W. 1992. Detecting environmental covariates of Pacific whiting (*Merluccius productus*) growth using a growth-increment regression model. Fish. Bull. U.S. 90: 260-275.

Dorn, M.W. 1995. The effects of age composition and oceanographic conditions on the annual migration of Pacific whiting *Merluccius productus*. Calif. Coop. Oceanic Fish. Invest. Rep. 36:97-105

Dorn, M.W. 1996. Status of the coastal Pacific whiting resource in 1996. In Pacific Fishery Management Council, Appendix Volume I: Status of the Pacific Coast groundfish fishery through 1996 and recommended acceptable biological catches in 1997, p. A1-A77.

(Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Dorn, M.W., E.P. Nunnallee, C.D. Wilson and M.E. Wilkins. 1994. Status of the coastal Pacific whiting resource in 1993. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/AFSC-47, 101 p.

Dorn, M.W. and M.W. Saunders. 1997. Status of the coastal Pacific whiting stock in U.S. and Canada in 1997. In Pacific Fishery Management Council, Appendix: Status of the Pacific Coast groundfish fishery through 1997 and recommended acceptable biological catches in 1998: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Dorn, M.W., M.W. Saunders, C.D. Wilson, M.A. Guttormsen, K. Cooke, R. Kieser, and M.E. Wilkins. 1999. Status of the coastal Pacific hake/whiting stock in U.S. and Canada in 1998. In Pacific Fishery Management Council, Appendix: Status of the Pacific Coast groundfish fishery through 1998 and recommended acceptable biological catches in 1999: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Fay, G., A. E. Punt, and A. D. M. Smith. 2011. Impacts of spatial uncertainty on performance of age structure-based harvest strategies for blue eye trevalla (Hyperoglyphe antarctica). Fisheries Research 110:391-407.

Field, J.C., K. Baltz, A.J. Phillips, and W.A. Walker. 2007. Range expansion and trophic interactions of the jumbo squid, *Dosidicus gigas*, in the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 48: 131-146.

Fleischer, G.W., K.D. Cooke, P.H. Ressler, R.E. Thomas, S.K. de Blois, L.C. Hufnagle, A.R. Kronlund, J.A. Holmes, and C.D. Wilson. 2005. The 2003 integrated acoustic and trawl survey of Pacific hake, Merluccius productus, in U.S. and Canadian waters off the Pacific coast. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-65, 45 p.

Forrest, R.E., S.J.D. Martell, M.C. Melnychuk and C.J. Walters. 2008. An age-structured model with leading management parameters, incorporating age-specific selectivity and maturity. . Can. J. Fish. Aquat. Sci 65, 286-296.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249

Francis, R.C., G.L. Swartzman, W.M. Getz, R. Harr, and K. Rose. 1982. A management analysis of the Pacific whiting fishery. U.S. Dep. Commer., NWAFC Processed Report 82-06. 48 p.

Francis, R.C., and A.B. Hollowed. 1985. History and management of the coastal fishery for Pacific whiting, *Merluccius productus*. Mar. Fish. Rev. 47(2):95-98.

Gelman, A., Carlin, J.B., Stern, H.S., and Rubin, D.B. 2004. Bayesian data analysis, 2nd Edition. Chapman and Hall, New York.

Gilly, W.F., U. Markaida, C.H. Baxter, B.A. Block, A. Boustany, L. Zeidberg, K. Reisenbichler, B. Robison, G. Bazzino and C. Salinas. 2006. Vertical and horizontal migrations by the jumbo squid *Dosidicus gigas* revealed by electronic tagging. Mar. Eco. Prog. Ser. 324: 1-17.

Hamel, O.S. and I.J. Stewart. 2009. Stock assessment of the Pacific hake, *Merluccius productus*, (a.k.a. whiting) in the U.S. and Canadian waters in 2009. Pacific Fishery Management Council, Portland, OR. 246 p.

Hannah, R.W. and S. Jones. 2009. 20th Annual pink shrimp review. Oregon Department of Fish and Wildlife, 2040 S.E. Marine Science Dr., Newport, OR 97365. 12 p.

Harvey, C.J., K. Gross, V.H. Simon, and J. Hastie. 2008. Trophic and fishery interactions between Pacific hake and rockfish: effect on rockfish population rebuilding times. Marine Ecology-Progress Series 365:165-176.

Helser, T.E, M.W. Dorn, M.W. Saunders, and R.D. Methot. 2001. Pacific whiting assessment update for 2000. In Pacific Fishery Management Council, Status of the Pacific Coast groundfish fishery through 2001 and recommended acceptable biological catches in 2002 (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Helser, T.E. , M.W. Dorn, M.W. Saunders, C.D. Wilson, M.A. Guttormsen, K. Cooke and M.E. Wilkins. 2002. Stock assessment of Pacific whiting in U.S. and Canadian waters in 2001. In: Status of the Pacific Coast groundfish fishery through 2001 and recommended acceptable biological catches in 2002 (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Helser, T.E, R.D. Methot, and G.W. Fleischer. 2004. Stock assesment of Pacific hake (whiting) in U.S. and Canadian waters in 2003. In: Status of the Pacific Coast groundfish fishery through 2004 and stock assessment and fishery evaluation (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Helser, T.E., M.W. Fleisher, S. Martell and N. Taylor. 2005. Stock assessment of Pacific hake (whiting) in U.S. and Canadian waters in 2004. In: Status of the Pacific Coast Groundfish Fishery Through 2005, Stock Assessment and Fishery Evaluation: Stock Assessments and Rebuilding Analyses (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Helser, T.E, I. J. Stewart, G.W. Fleischer, and S. Martell. 2006. Stock assessment of Pacific hake (whiting) in U.S. and Canadian waters in 2006. In: Status of the Pacific Coast Groundfish Fishery Through 2005, Stock Assessment and Fishery Evaluation: Stock Assessments and Rebuilding Analyses (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Helser, T.E. and S. Martell. 2007. Stock assessment of Pacific hake (whiting) in U.S. and Canadian waters in 2007. In: Status of the Pacific Coast groundfish fishery through 200 and recommended acceptable biological catches in 2006 (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Helser, T.E., I.J. Stewart, and O.S. Hamel. 2008. Stock Assessment of Pacific Hake, *Merluccius productus*, (a.k.a Whiting) in U.S. and Canadian Waters in 2008. *In*: Status of the Pacific Coast groundfish fishery through 2008, Stock Assessment and Fishery evaluation: Stock Assessments, STAR Panel Reports, and Rebuilding Analyses. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR.

Henderson, M.J., and J.K. Horne. 2007. Comparison of in situ, ex situ, and backscatter model estimates of Pacific hake (Merluccius productus) target strength. Can. J. Fish. Aquat. Sci. 64: 1781-1794.

Hilborn, R., and Walters, C.J. 1992. Quantitative Fisheries Stock Assessment Choice, Dynamics and Uncertainty. Routledge, Chapman and Hall.

Hoenig, J.M. 1982. A compilation of mortality and longevity estimates for fish, mollusks, and cetaceans, with a bibliography of comparative life history studies. Technical Report No. 82-2. Narragansett Marine Laboratory, University of Rhode Island.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82:898-903.

Hollowed, A.B., S.A. Adlerstein, R.C. Francis, M. Saunders, N.J. Williamson, and T.A. Dark. 1988a. Status of the Pacific whiting resource in 1987 and recommendations to management in 1988. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-138, 54 p.

Ishimura, G., A. E. Punt, and D. D. Huppert. 2005. Management of fluctuating fish stocks: the case of Pacific whiting. Fisheries Research 73:201-216.

Iwamoto, E., M. J. Ford, and R. G. Gustafson. 2004. Genetic population structure of Pacific hake, Merluccius productus, in the Pacific Northwest. Environmental Biology of Fishes 69:187-199.

JTC. 2012. Status of the Pacific hake (Whiting) stock in U.S. and Canadian Waters in 2012. Prepared for the Joint U.S.-Canada Pacific hake treaty process. 195 p.

Jolly, G.M., and I. Hampton. 1990. A stratified random transect design for acoustic surveys of fish stocks. Can. J. Fish. Aquat. Sci. 47:1282–1291.

Jow, T. 1973. Pacific hake length frequencies at California ports, 1963-1970. Marine Resources Technical Report No. 2. California Department of Fish and Game.

Kell, L. T., A. A. Pastoors, R. D. Scott, M. T. Smith, F. A. Van Beek, C. M. O'Brien, and G. M. Pilling. 2005. Evaluation of multiple management objectives for Northeast Atlantic flatfish stocks: sustainability vs. stability of yield. Ices Journal of Marine Science 62:1104-1117.

Keller, A. A., B.H. Horness, E.L. Fruh, V.H. Simon, V.J. Tuttle, K.L. Bosley, J.C. Buchanan, D. J. Kamikawa, and J.R. Wallace. 2008. The 2005 U.S. West Coast bottom trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition., U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-93, 136 p.

King, J.R., MacFarlane, G.A., Jones, S.R.M., Gilmore, S.R., and Abbott, C.L. 2012. *Stock delineation of* migratory and resident Pacific hake in Canadian waters. Fisheries Research 114: 19-30.

Kurota, H., Hiramatsu, K., Takahashi, N., Shono, H., Itoh, T., and Tsuji, S. 2010. Developing a management procedure robust to uncertainty for southern bluefin tuna: a somewhat frustrating struggle to bridge the gap between ideals and reality. Popul. Ecol 52: 359-372.

Livingston, P.A. and K.M. Bailey. 1985. Trophic role of the Pacific whiting, Merluccius productus. Mar. Fish. Rev. 47(2):16-22-34.

Lo, N.C.H. 2007. Daily larval production of Pacific hake (*Merluccius productus*) off California in 1951-2006. CalCOFI rep. Vol. 48:147-164.

Ludwig, D. and R. Hilborn. 1983. Adaptive probing strategies for age structured fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 40:559-569.

Martell, S. J. D. 2010. Assessment and management advice for Pacific hake in U.S. and Canadian waters in 2010. Pacific Fishery Management Council. Portland, Oregon. 80 p.

Martell, S. J. D. 2011. iSCAM User's Guide. Version 1.0. University of British Columbia, Vancouver. 34 pp. Available online at http://code.google.com/p/iscam-project/source/checkout.

Mello, L. G. S. and Rose, G. A. 2005. Using geostatistics to quantify seasonal distribution and aggregation patterns of fishes: an example of Atlantic cod (Gadus morhua). Can. J. Fish. Aquat. Sci. 62: 659–670.

Mendelssohn, R. 1980. A systematic approach to determining mean-variance tradeoffs when managing randomly varying populations. Mathematical Biosciences 50:75-84.

Methot, R.D. 1989. Synthetic estimates of historical abundance and mortality for northern anchovy. In E.F. Edwards and B.A. Megrey, (eds.), Mathematical Analysis of Fish Stock Dynamics: Reviews. Evaluations, and Current Applications, p. 66-82. Am. Fish. Soc. Symp. Ser. No. 6.

Methot, R. D. Jr., C. R. Wetzel, Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management, Fisheries Research, Available online 17 December 2012, ISSN 0165-7836, 10.1016/j.fishres.2012.10.012. http://www.sciencedirect.com/science/article/pii/S0165783612003293

Myers, R.A, K.G. Bowen, and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56: 2404-2419.

Northwest Fisheries Science Center (NWFSC). 2009. Data report and summary analyses of the California and Oregon pink shrimp trawl fisheries. West Coast Groundfish Observer Program. NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112. 33 p.

O'Driscoll, R. L. 2004. Estimating the uncertainty associated with acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) in Cook Strait, New Zealand. ICES J. of Mar. Sci. 61:84–97.

Pennington, M., 1983. Efficient estimators of abundance for fish and plankton surveys. Biometrics 39, 281–286.

Petitgas, P., 1993. Geostatistics for fish stock assessments: a review and an acoustic application, ICES J. Mar. Sci. 50: 285:298.

Phillips, A.J., S. Ralston, R.D. Brodeur, T.D. Auth, R.L. Emmett, C. Johnson, and V.G. Wespestad. 2007. Recent pre-recruit Pacific hake (*Merluccius productus*) occurrences in the northern California current suggest a northward expansion of their spawning area. CalCOFI Reps. Vol. 48: 215-229.

PFMC. 1998. Final Environmental Assesment/Regulatory Impact Review for Amendment 11 to the Pacific Coast Groundfish Fishery Management Plan.in P. F. M. Council, editor., Portland, Oregon.

Punt, A.E. and D.S. Butterworth. 1993. Variance estimates for fisheries assessment: their importance and how best to evaluate them. p. 145-162. *In*: S.J. Smith, J.J. Hunt and D. Rivard [Ed.] Risk evaluation and biological reference points for fisheries management. Can. J. Fish. Aquat. Sci. Spec. Publ. 120.

Punt, A.E., Dorn, M.W., and Haltuch, M.A. 2008. Evaluation of threshold management strategies for groundfish off the US West Coast. Fisheries Research 94: 251-266.

Punt, A. E. and R. Hilborn. 1996. Biomass dynamics models. FAO, Rome.

Punt, A.E. and R. Hilborn. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Rev. Fish. Biol. Fish. 7:35-63.

Punt, A. E. and D. Hobday. 2009. Management strategy evaluation for rock lobster, Jasus edwardsii, off Victoria, Australia: accounting for uncertainty in stock structure. New Zealand Journal of Marine and Freshwater Research 43:485-509.

Punt, A.E., and Ralston, S. 2007. A Management Strategy Evaluation of Rebuilding Revision Rules for Overfished Rockfish Stocks. Biology, Assessment, and Management of North Pacific Rockfishes AK-SG-07-01: 329-351.

Punt, A.E., and Smith, A.D.M. 1999. Harvest strategy evaluation for the eastern stock of gemfish (*Rexea solandri*). ICES J. of Mar. Sci. 56: 860-875.

Punt, A. E., D. C. Smith, K. KrusicGolub, and S. Robertson. 2008. Quatifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Can. J. Fish. Aquat. Sc. 65:1991-2005.

Ralston, S. 2007. Coast-wide Pre-Recruit Indices from SWFSC and PWCC/NWFSC Midwater Trawl Surveys (2001-2006). Southwest Fisheries Science Center, Santa Cruz, California

Ralston, S., Punt, A.E., Hamel, O.S., DeVore, J.D., and Conser, R.J. 2011. A meta-analytic approach to quantifying scientific uncertainty in stock assessments. Fish. Bull. 109: 217-231.

Ressler, P.H., J.A. Holmes, G.W. Fleischer, R.E. Thomas, and K.C. Cooke. 2007. Pacific hake, *Merluccius productus*, autecology: a timely review. Mar. Fish. Rev. 69:1-24.

Richards, L. J., J. T. Schnute, and N. Olsen. 1997. Visualizing catch-age analysis: a case study. Can. J. Fish. Aquat. Sci. 54:1646-1658.

Richards, L. J. and J. T. Schnute. 1998. Model complexity and catch-age analysis. Can. J. Fish. Aquat. Sci. 55:949-957.

Ricker, W. E. 1958. Maximum sustained yields from fluctuating environments and mixed stocks. Journal of the Fisheries Research Board of Canada 15:991-1006.

Rivoirard, J., E.J. Simmonds, K. Foote, P.G. Fernandes, and N. Bez, 2000. Geostatistics for Estimating Fish Abundance. Blackwell Science Ltd, Oxford.

Sakuma, K.M., S. Ralston, and V.G. Wespestad. 2006. Interannual and spatial variation in the distribution of young-of-the-year rockfish (*Sebastes* spp.): expanding and coordinating the survey sampling frame. Calif. Coop. Oceanic Fish. Invest. Rep. 47:127–139.

Saunders, M.W. and G.A. McFarlane. 1997. Observation on the spawning distribution and biology of offshore Pacific hake. Calif. Coop. Oceanic Fish. Invest. Rep. 38:147:160.

Simmonds, J. and D. MacLennan, 2005. Fisheries Acoustics: Theory and practice. 2nd ed. Blackwell Science Ltd, Oxford, 437p.

Spiegelhalter, D.J., Thomas, A., and Best, N.G. 1999. WinBUGS Version 1.2 User Manual. Medical Research Council Biostatistics Unit, Institute of Public Health, Cambridge, U.K.

Stefánsson, G., 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES J. Mar. Sci. 53, 577–588.

Stewart, I. J. and O. S. Hamel. 2010. Stock Assessment of Pacific Hake, Merluccius productus, (a.k.a. Whiting) in U.S. and Canadian Waters in 2010. Pacific Fishery Management Council. Portland, Oregon. 290 p.

Stewart, I. J., A. C. Hicks, I. G. Taylor, J. T. Thorson, C. Wetzel, S. Kupschus, A comparison of stock assessment uncertainty estimates using maximum likelihood and Bayesian methods implemented with the same model framework, Fisheries Research, Available online 16 July 2012, ISSN 0165-7836, 10.1016/j.fishres.2012.07.003

Stewart, I. J., R. E. Forrest, C.J. Grandin, O.S. Hamel, A.C. Hicks, S.J.D. Martell and I.G. Taylor. 2011. Status of the Pacific hake (whiting) stock in U.S. and Canadian waters in 2011, *In* Status of the Pacific Coast Groundfish Fishery through 2011, Stock Assessment and Fishery Evaluation: Stock Assessments, STAR Panel Reports, and rebuilding analyses. Pacific Fishery Management Council, Portland, Oregon. 217 p.

Thomas, A., Spiegelhalter, D.J, and Gilks, W.R. 1992. BUGS: a program to perform Bayesian statistical inference using Gibbs sampling. *In* Bayesian statistics 4. Edited by J.M. Bernardo, J.O. Berger, A.P. Dawid, and A.F.M. Smith. Oxford University Press, Oxford, U.K. pp. 837-842.

Traynor, J.J. 1996. Target-strength measurements of walleye pollock (*Theragra chalcogramma*) and Pacific whiting (*Merluccius productus*). ICES J. of Mar. Sci. 53:253-258.

Utter, F.M. 1971. Biochemical polymorphisms in Pacific hake (*Merluccius productus*). Cons. Perm. Int. Explor. Mer Rapp. P.-V. Reun. 161:87-89.

Vrooman, A.M. and P.A. Paloma. 1977. Dwarf hake off the coast of Baja California, Mexico. Calif. Coop. Oceanic Fish. Invest. Rep. 19:67-72.

Walters, C. J. 1975. Optimal harvest strategies for salmon in relation to environmental variability and uncertain production parameters. Journal of the Fisheries Research Board of Canada 32:1777-1784.

Walters, C.J. 1986. Adaptive management of renewable resources. Macmillian Publishing Co., New York.

Walters, C.J., and Hilborn, R. 1978. Ecological optimization and adaptive management. Ann. Rev. Ecol.Syst. 9: 157-188.

Walters, C. J. and D. Ludwig. 1994. Calculation of Bayes posterior probability distributions for key population parameters. Canadian Journal of Fisheries and Aquatic Sciences 51: 713-722.

Walters, C.J., and Martell, S.J.D. 2004. Fisheries Ecology and Management. Princeton University Press, Princeton, New Jersey.

Wilkins, M.E. 1998. The 1995 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length and age composition. NOAA Tech. Memo. NMFS-AFSC-89.

6 Tables

Table 1: Annual catches of Pacific hake (1000s mt) in U.S. and Canadian waters by sector, 1966-2011. Tribal catches are included in the sector totals.

	U.S.					Canada				
Year	Foreign	JV	At-sea	Shore -based	Total U.S.	Foreign	JV	Domestic	Total Canada	Total
1966	137.00	0.00	0.00	0.00	137.00	0.70	0.00	0.00	0.70	137.70
1967	168.70	0.00	0.00	8.96	177.66	36.71	0.00	0.00	36.71	214.37
1968	60.66	0.00	0.00	0.16	60.82	61.36	0.00	0.00	61.36	122.18
1969	86.19	0.00	0.00	0.09	86.28	93.85	0.00	0.00	93.85	180.13
1970	159.51	0.00	0.00	0.07	159.58	75.01	0.00	0.00	75.01	234.59
1971	126.49	0.00	0.00	1.43	127.92	26.70	0.00	0.00	26.70	154.62
1972	74.09	0.00	0.00	0.04	74.13	43.41	0.00	0.00	43.41	117.54
1973	147.44	0.00	0.00	0.07	147.51	15.13	0.00	0.00	15.13	162.64
1974	194.11	0.00	0.00	0.00	194.11	17.15	0.00	0.00	17.15	211.26
1975	205.65	0.00	0.00	0.00	205.65	15.70	0.00	0.00	15.70	221.35
1976	231.33	0.00	0.00	0.22	231.55	5.97	0.00	0.00	5.97	237.52
1977	127.01	0.00	0.00	0.49	127.50	5.19	0.00	0.00	5.19	132.69
1978	96.83	0.86	0.00	0.69	98.38	3.45	1.81	0.00	5.26	103.64
1979	114.91	8.83	0.00	0.94	124.68	7.90	4.23	0.30	12.43	137.11
1980	44.02	27.54	0.00	0.79	72.35	5.27	12.21	0.10	17.58	89.93
1981	70.36	43.56	0.00	0.88	114.80	3.92	17.16	3.28	24.36	139.16
1982	7.09	67.46	0.00	1.03	75.58	12.48	19.68	0.00	32.16	107.74
1983	0.00	72.10	0.00	1.05	73.15	13.12	27.66	0.00	40.78	113.93
1984	14.77	78.89	0.00	2.72	96.38	13.20	28.91	0.00	42.11	138.49
1985	49.85	31.69	0.00	3.89	85.44	10.53	13.24	1.19	24.96	110.40
1986	69.86	81.64	0.00	3.47	154.97	23.74	30.14	1.77	55.65	210.62
1987	49.66	106.00	0.00	4.80	160.45	21.45	48.08	4.17	73.70	234.15
1988	18.04	135.78	0.00	6.87	160.69	38.08	49.24	0.83	88.15	248.84
1989	0.00	195.64	0.00	7.41	203.05	29.75	62.72	2.56	95.03	298.08
1990	0.00	170.97	4.54	9.63	185.14	3.81	68.31	4.02	76.14	261.29
1991	0.00	0.00	205.82	23.97	229.79	5.61	68.13	16.17	89.92	319.71
1992	0.00	0.00	154.74	56.13	210.87	0.00	68.78	20.04	88.82	299.69
1993	0.00	0.00	98.04	42.11	140.15	0.00	46.42	12.35	58.77	198.92
1994	0.00	0.00	179.87	73.62	253.48	0.00	85.16	23.78	108.94	362.42
1995	0.00	0.00	102.31	74.96	177.27	0.00	26.19	46.18	72.37	249.64
1996	0.00	0.00	128.11	85.13	213.24	0.00	66.78	26.36	93.14	306.38
1997	0.00	0.00	146.05	87.42	233.47	0.00	42.57	49.23	91.79	325.26
1998	0.00	0.00	145.16	87.86	233.01	0.00	39.73	48.07	87.80	320.81
1999	0.00	0.00	141.02	83.47	224.49	0.00	17.20	70.16	87.36	311.84
2000	0.00	0.00	120.92	85.85	206.77	0.00	15.06	6.38	21.44	228.21
2001	0.00	0.00	100.53	73.41	173.94	0.00	21.65	31.94	53.59	227.53
2002	0.00	0.00	84.75	45.71	130.46	0.00	0.00	50.24	50.24	180.70
2003	0.00	0.00	86.61	55.34	141.95	0.00	0.00	63.23	63.23	205.18
2004	0.00	0.00	117.07	96.50	213.57	0.00	58.89	66.19	125.08	338.65
2005	0.00	0.00	151.07	109.05	260.12	0.00	15.69	87.34	103.04	363.16
2006	0.00	0.00	139.79	127.17	266.96	0.00	14.32	80.49	94.80	361.76
2007	0.00	0.00	126.24	91.44	217.68	0.00	6.78	66.67	73.45	291.13
2008	0.00	0.00	180.64	67.76	248.40	0.00	3.59	70.16	73.75	322.14
2009	0.00	0.00	72.35	49.22	121.57	0.00	0.00	55.88	55.88	177.46
2010	0.00	0.00	106.31	63.79	170.10	0.00	8.08	48.01	56.09	226.20
2011	0.00	0.00	128.07	102.15	230.22	0.00	9.72	45.91	55.63	285.85
2012	0.00	0.00	93.78	63.49	157.26	0.00	0.00	46.78	46.78	204.04
Mean					165.73				56.11	221.84

Table 2: Recent trend in Pacific hake landings and management.

Year	Total Landings (mt)	Coast-wide (US+Canada) catch target (mt)
2003	205,177	228,000
2004	338,654	501,073
2005	363,157	364,197
2006	361,761	364,842
2007	291,129	328,358
2008	322,145	364,842
2009	177,459	184,000
2010	226,202	262,500
2011	286,055	393,751
2012	204,040	251,809

Table 3: 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.

	U.S.				Canada		
Year	Foreign	Joint-venture	At-sea	Shore-based	Foreign	Joint-venture	Domestic
1975	13	—	—	—	—	—	—
1976	142	—	—	—	—	—	—
1977	320	—	—	—	—	—	—
1978	336	5	—	—	—	—	—
1979	99	17	—	—	—	—	—
1980	191	30	—	—	—	—	—
1981	113	41	—	—	—	—	—
1982	52	118	—	—	—	—	—
1983	0	117	—	—	—	—	—
1984	49	74	—	—	—	—	—
1985	37	19	—	—	—	—	—
1986	88	32	—	—	—	—	—
1987	22	34	—	—	—	—	—
1988	39	42	—	—	—	—	—
1989	—	77	—	—	—	—	—
1990	—	143	—	15	—	5	—
1991	—	—	116	26	—	18	—
1992	—	—	164	46	—	33	—
1993	—	—	108	36	—	25	—
1994	—	—	143	50	—	41	—
1995	—	—	61	51	—	35	—
1996	—	—	123	35	—	28	—
1997	—	—	127	65	—	27	3
1998	—	—	149	64	—	21	9
1999	—	—	389	80	—	14	31
2000	—	—	413	91	—	25	—
2001	—	—	429	82	—	28	2
2002	—	—	342	71	—	—	37
2003	—	—	358	78	—	—	21
2004	—	—	381	72	—	20	28
2005	—	—	499	58	—	11	45
2006	—	—	549	83	—	21	67
2007	—	—	524	68	—	1	36
2008	—	—	680	63	—	—	51
2009	—	—	594	66	—	—	26
2010	—	—	774	75	—	—	24
2011	—	—	987	81	—		13
2012	—	—	460	65	—	—	144

Table 4: Summary of the acoustic surveys from 1995 to 2012.

Year	Start date	End date	Vessels	Biomass index (million mt)	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

[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 5: Number of Pacific hake ovaries sampled for histological analysis. The 2009 numbers reflect useable samples, while the 2012 sample are total number of samples which have not been analyzed. The 2012 trawl survey samples sizes (italics) are approximate and have yet to be finalized.

Length bin (cm)	**Trawl Survey 2009**	**Trawl Survey 2012**	**Acoustic Survey 2012**	**Total**
<20	12	*0*	0	12
20-21	6	*0*	0	6
22-23	17	*0*	0	17
24-25	16	*2*	3	21
26-27	8	*2*	7	17
28-29	4	*2*	11	17
30-31	5	*3*	22	30
32-33	13	*5*	12	30
34-35	4	*2*	24	30
36-37	9	*4*	15	28
38-39	19	*3*	8	30
40-41	17	*3*	14	34
42-43	17	*1*	9	27
44-45	13	*3*	11	27
46-47	18	*5*	8	31
48-49	19	*5*	6	30
50-51	15	*3*	9	27
52-53	4	*7*	10	21
54-55	9	*1*	9	19
56-57	5	*6*	6	17
58-59	5	*2*	7	14
60-61	7	*1*	4	12
>61	19	*6*	6	31
Total	**261**	***66***	**201**	**528**

Table 6: Summary of estimated model parameters and priors in the base-case 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		
Ln(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
Ln(Rec. deviations): 1946-2012	67	(-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	(0.0, 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
Total: 14 + 67 recruitment deviations = 81 estimated parameters. See Appendix A for all parameter estimates.			

Table 7: Estimates of important quantities (MLE) from the models bridging the 2012 base model to the 2013 base model.

MLE results	2012 base model	Update 2011 data and weight-at-age	Add 2012 fishery data	Add 2012 acoustic data (2013 base)
SB0 (thousand mt)	1,766	1,732	1,907	1,924
Spawning biomass 2012 (thousand mt)	483	372	949	932
Spawning biomass 2013 (thousand mt)	566	459	1,370	1,313
Depletion 2011	26.1%	18.8%	28.9%	29.7%
Depletion 2012	27.4%	21.5%	49.8%	48.4%
Depletion 2013	32.1%	26.5%	71.8%	68.2%
Age-0 recruits 2008 (billions)	4.058	2.915	4.751	4.766
Age-0 recruits 2010 (billions)	2.076	3.384	12.808	11.624

Table 8: Time-series of median posterior population estimates from the base-case model

Year	Female spawning biomass (millions mt)	Depletion	Age-0 recruits (billions)	(1-SPR) / (1-$SPR_{40\%}$)	Exploitation fraction
1966	1.068	NA	1.430	44.0%	6.2%
1967	0.992	47.9%	3.071	63.1%	10.4%
1968	0.915	44.3%	2.084	46.4%	6.4%
1969	0.983	47.6%	0.854	60.7%	9.3%
1970	1.038	50.3%	7.957	68.5%	10.4%
1971	1.033	50.3%	0.729	51.7%	6.8%
1972	1.228	60.4%	0.434	40.5%	5.5%
1973	1.406	69.0%	4.307	44.5%	4.9%
1974	1.420	69.4%	0.413	50.5%	6.8%
1975	1.422	70.0%	1.352	44.5%	6.4%
1976	1.398	68.3%	0.319	41.3%	5.4%
1977	1.323	64.6%	5.063	29.4%	3.7%
1978	1.222	59.9%	0.294	27.3%	3.4%
1979	1.258	61.4%	0.943	32.6%	4.6%
1980	1.264	61.8%	16.550	25.9%	2.8%
1981	1.231	60.1%	0.294	38.0%	5.0%
1982	1.636	80.0%	0.266	33.0%	4.7%
1983	2.044	99.5%	0.434	26.9%	2.4%
1984	2.166	105.0%	13.053	27.5%	3.0%
1985	2.070	100.2%	0.201	22.4%	2.6%
1986	2.285	110.3%	0.219	36.6%	5.8%
1987	2.416	116.7%	5.407	39.8%	4.4%
1988	2.313	111.4%	1.929	40.4%	5.2%
1989	2.225	107.4%	0.173	51.9%	8.0%
1990	2.090	101.2%	4.395	45.1%	6.3%
1991	1.900	91.9%	0.547	55.0%	8.2%
1992	1.737	84.2%	0.196	59.7%	10.0%
1993	1.567	75.8%	3.317	53.3%	7.5%
1994	1.370	66.3%	2.508	78.0%	14.9%
1995	1.149	55.5%	1.360	68.6%	12.7%
1996	1.087	52.3%	1.601	81.3%	15.2%
1997	0.990	47.7%	1.277	86.3%	15.9%
1998	0.884	42.6%	1.802	91.4%	18.8%
1999	0.768	37.0%	11.104	95.4%	21.4%
2000	0.670	32.3%	0.352	79.9%	14.7%
2001	0.962	46.2%	0.839	73.4%	13.4%
2002	1.230	58.9%	0.070	47.8%	4.6%
2003	1.340	64.1%	1.335	50.6%	6.3%
2004	1.268	60.5%	0.069	74.1%	12.8%
2005	1.064	50.8%	2.172	82.7%	18.7%
2006	0.811	39.0%	1.721	94.7%	22.7%
2007	0.617	29.7%	0.088	99.3%	27.5%
2008	0.529	25.5%	5.526	109.4%	29.2%
2009	0.424	20.4%	2.269	94.7%	18.4%
2010	0.520	25.5%	13.606	104.7%	30.7%
2011	0.642	31.5%	0.737	105.2%	21.5%
2012	1.078	51.6%	0.916	81.0%	14.5%
2013	1.504	72.3%	1.061	NA	NA

Table 9: Time-series of ~95% posterior credibility intervals for female spawning biomass, relative depletion estimates, age-0 recruits, relative spawning potential ratio[(1-SPR)/(1-SPRTarget=0.4)] and exploitation fraction from the base-case model

Year	Female spawning Biomass (millions mt)	Depletion	Age-0 recruits (billions)	(1-SPR) / (1-SPR_{target})	Exploitation fraction
1966	0.57-1.99	NA-NA	0.06-9.48	0.24-0.71	0.03-0.12
1967	0.54-1.83	0.26-0.86	0.17-11.87	0.38-0.93	0.05-0.20
1968	0.50-1.70	0.24-0.80	0.12-8.89	0.26-0.75	0.03-0.13
1969	0.58-1.79	0.28-0.81	0.06-5.02	0.35-0.88	0.05-0.18
1970	0.64-1.90	0.31-0.87	3.75-17.68	0.41-0.96	0.05-0.18
1971	0.62-1.95	0.30-0.89	0.06-3.19	0.29-0.78	0.03-0.11
1972	0.76-2.33	0.36-1.02	0.05-2.07	0.21-0.64	0.03-0.09
1973	0.88-2.63	0.43-1.16	2.14-9.93	0.24-0.68	0.03-0.08
1974	0.88-2.67	0.43-1.17	0.05-1.63	0.27-0.76	0.04-0.11
1975	0.85-2.69	0.42-1.17	0.46-3.33	0.24-0.70	0.03-0.11
1976	0.83-2.67	0.40-1.16	0.03-1.47	0.21-0.66	0.03-0.09
1977	0.77-2.50	0.38-1.09	2.57-10.54	0.15-0.50	0.02-0.06
1978	0.71-2.26	0.35-1.00	0.03-1.51	0.14-0.46	0.02-0.06
1979	0.74-2.23	0.36-1.02	0.16-3.03	0.17-0.53	0.03-0.08
1980	0.76-2.29	0.37-1.01	9.89-30.61	0.13-0.43	0.02-0.05
1981	0.76-2.19	0.36-0.97	0.04-1.44	0.21-0.60	0.03-0.08
1982	1.08-2.68	0.52-1.23	0.04-1.21	0.19-0.53	0.03-0.08
1983	1.37-3.24	0.67-1.49	0.05-1.64	0.15-0.42	0.02-0.04
1984	1.49-3.41	0.71-1.54	8.44-22.65	0.16-0.43	0.02-0.04
1985	1.43-3.17	0.69-1.45	0.03-0.97	0.13-0.35	0.02-0.04
1986	1.65-3.36	0.79-1.56	0.03-0.96	0.23-0.53	0.04-0.08
1987	1.78-3.45	0.83-1.61	3.29-9.22	0.26-0.57	0.03-0.06
1988	1.74-3.27	0.81-1.51	0.72-3.98	0.27-0.56	0.04-0.07
1989	1.69-3.08	0.79-1.45	0.02-0.72	0.36-0.70	0.06-0.10
1990	1.62-2.87	0.74-1.35	3.02-7.16	0.30-0.61	0.05-0.08
1991	1.50-2.56	0.68-1.22	0.09-1.40	0.39-0.71	0.06-0.10
1992	1.39-2.32	0.63-1.11	0.03-0.64	0.43-0.76	0.08-0.13
1993	1.26-2.06	0.57-1.00	2.30-4.95	0.38-0.69	0.06-0.09
1994	1.13-1.77	0.50-0.87	1.56-3.90	0.60-0.94	0.12-0.18
1995	0.95-1.47	0.42-0.73	0.77-2.25	0.52-0.84	0.10-0.16
1996	0.90-1.38	0.40-0.68	1.03-2.59	0.64-0.97	0.12-0.18
1997	0.83-1.24	0.37-0.62	0.70-2.12	0.69-1.01	0.13-0.19
1998	0.73-1.11	0.33-0.55	1.17-2.90	0.74-1.06	0.15-0.23
1999	0.63-0.98	0.28-0.48	8.17-15.91	0.77-1.11	0.17-0.26
2000	0.53-0.88	0.24-0.43	0.08-0.81	0.61-0.97	0.11-0.19
2001	0.78-1.25	0.35-0.61	0.52-1.30	0.55-0.90	0.10-0.17
2002	1.02-1.56	0.45-0.77	0.01-0.24	0.35-0.62	0.04-0.06
2003	1.14-1.65	0.50-0.83	0.97-1.93	0.38-0.64	0.05-0.07
2004	1.09-1.53	0.47-0.77	0.01-0.23	0.59-0.89	0.11-0.15
2005	0.93-1.28	0.40-0.64	1.56-3.38	0.67-0.96	0.16-0.21
2006	0.71-1.00	0.31-0.49	1.15-3.05	0.79-1.08	0.18-0.26
2007	0.53-0.81	0.24-0.38	0.02-0.29	0.84-1.12	0.21-0.32
2008	0.44-0.75	0.20-0.34	3.29-11.72	0.93-1.22	0.21-0.35
2009	0.33-0.67	0.15-0.30	1.09-5.52	0.72-1.10	0.12-0.24
2010	0.37-0.96	0.17-0.42	6.04-34.40	0.80-1.21	0.18-0.42
2011	0.41-1.33	0.19-0.58	0.06-9.51	0.75-1.25	0.10-0.33
2012	0.57-2.54	0.27-1.11	0.05-11.50	0.46-1.09	0.06-0.26
2013	0.71-3.68	0.35-1.60	0.05-16.93	0.98-1.00	0.13-0.20

Table 10: Estimated numbers at age at the beginning of the year from the base model (MLE; billions).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1966	1.63	1.20	0.78	0.57	0.44	0.36	0.30	0.26	0.22	0.19	0.17	0.14	0.12	0.10	0.09	0.38
1967	2.95	1.31	0.97	0.62	0.45	0.34	0.27	0.23	0.19	0.17	0.14	0.12	0.11	0.09	0.08	0.35
1968	2.15	2.38	1.06	0.77	0.48	0.33	0.25	0.19	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.30
1969	1.05	1.74	1.92	0.85	0.60	0.36	0.25	0.18	0.14	0.12	0.10	0.09	0.07	0.06	0.06	0.27
1970	6.48	0.84	1.40	1.53	0.65	0.44	0.27	0.18	0.13	0.10	0.08	0.07	0.06	0.05	0.05	0.23
1971	0.81	5.23	0.68	1.11	1.15	0.47	0.31	0.18	0.12	0.09	0.07	0.06	0.05	0.04	0.04	0.19
1972	0.48	0.66	4.22	0.54	0.86	0.87	0.35	0.23	0.13	0.09	0.06	0.05	0.04	0.04	0.03	0.16
1973	3.69	0.39	0.53	3.38	0.42	0.66	0.66	0.26	0.17	0.10	0.06	0.05	0.04	0.03	0.03	0.14
1974	0.42	2.98	0.31	0.42	2.62	0.32	0.49	0.48	0.19	0.12	0.07	0.05	0.03	0.03	0.02	0.12
1975	1.17	0.34	2.40	0.25	0.33	1.97	0.24	0.36	0.35	0.14	0.09	0.05	0.03	0.03	0.02	0.11
1976	0.34	0.95	0.27	1.92	0.19	0.25	1.48	0.18	0.26	0.26	0.10	0.07	0.04	0.03	0.02	0.09
1977	4.45	0.28	0.76	0.22	1.50	0.15	0.19	1.10	0.13	0.19	0.19	0.07	0.05	0.03	0.02	0.08
1978	0.28	3.59	0.22	0.61	0.17	1.17	0.11	0.14	0.84	0.10	0.15	0.15	0.06	0.04	0.02	0.08
1979	0.93	0.23	2.89	0.18	0.48	0.13	0.90	0.09	0.11	0.64	0.08	0.11	0.11	0.04	0.03	0.08
1980	14.56	0.75	0.19	2.32	0.14	0.37	0.10	0.69	0.07	0.08	0.49	0.06	0.09	0.08	0.03	0.08
1981	0.32	11.75	0.61	0.15	1.84	0.11	0.29	0.08	0.53	0.05	0.06	0.38	0.04	0.07	0.07	0.09
1982	0.26	0.26	9.47	0.49	0.12	1.41	0.08	0.22	0.06	0.40	0.04	0.05	0.28	0.03	0.05	0.11
1983	0.44	0.21	0.21	7.60	0.38	0.09	1.08	0.06	0.17	0.04	0.30	0.03	0.04	0.21	0.03	0.12
1984	11.81	0.36	0.17	0.17	6.01	0.30	0.07	0.83	0.05	0.13	0.03	0.23	0.02	0.03	0.16	0.11
1985	0.21	9.53	0.29	0.14	0.13	4.69	0.23	0.05	0.64	0.04	0.10	0.03	0.18	0.02	0.02	0.21
1986	0.22	0.17	7.69	0.23	0.11	0.10	3.68	0.18	0.04	0.50	0.03	0.08	0.02	0.14	0.01	0.18
1987	4.92	0.18	0.13	6.16	0.18	0.08	0.08	2.76	0.14	0.03	0.37	0.02	0.06	0.02	0.10	0.15
1988	1.90	3.97	0.15	0.11	4.81	0.14	0.06	0.06	2.06	0.10	0.02	0.28	0.02	0.04	0.01	0.19
1989	0.19	1.54	3.20	0.12	0.08	3.69	0.11	0.05	0.04	1.54	0.08	0.02	0.21	0.01	0.03	0.15
1990	4.04	0.15	1.24	2.55	0.09	0.06	2.72	0.08	0.03	0.03	1.11	0.05	0.01	0.15	0.01	0.13
1991	0.59	3.26	0.12	0.99	1.99	0.07	0.05	2.01	0.06	0.02	0.02	0.82	0.04	0.01	0.11	0.10
1992	0.20	0.47	2.63	0.10	0.76	1.48	0.05	0.03	1.43	0.04	0.02	0.02	0.58	0.03	0.01	0.15
1993	3.09	0.16	0.38	2.10	0.07	0.56	1.07	0.04	0.02	1.00	0.03	0.01	0.01	0.41	0.02	0.11
1994	2.31	2.49	0.13	0.31	1.61	0.06	0.41	0.77	0.03	0.02	0.72	0.02	0.01	0.01	0.29	0.09
1995	1.27	1.86	2.01	0.10	0.23	1.13	0.04	0.27	0.49	0.02	0.01	0.46	0.01	0.01	0.01	0.25
1996	1.49	1.02	1.50	1.60	0.08	0.16	0.79	0.03	0.18	0.33	0.01	0.01	0.31	0.01	0.00	0.17
1997	1.19	1.20	0.83	1.19	1.17	0.05	0.11	0.50	0.02	0.11	0.21	0.01	0.00	0.20	0.01	0.11
1998	1.67	0.96	0.97	0.65	0.86	0.79	0.03	0.07	0.30	0.01	0.07	0.13	0.00	0.00	0.12	0.07
1999	10.12	1.35	0.77	0.76	0.46	0.56	0.50	0.02	0.04	0.18	0.01	0.04	0.07	0.00	0.00	0.11
2000	0.37	8.16	1.09	0.60	0.53	0.30	0.34	0.27	0.01	0.02	0.10	0.00	0.02	0.04	0.00	0.06
2001	0.78	0.30	6.58	0.86	0.44	0.37	0.20	0.22	0.17	0.01	0.01	0.06	0.00	0.01	0.03	0.04
2002	0.07	0.63	0.24	5.22	0.64	0.31	0.26	0.13	0.14	0.11	0.00	0.01	0.04	0.00	0.01	0.04
2003	1.24	0.06	0.51	0.19	4.04	0.48	0.23	0.19	0.10	0.10	0.08	0.00	0.01	0.03	0.00	0.04
2004	0.07	1.00	0.05	0.40	0.15	3.04	0.36	0.17	0.14	0.07	0.08	0.06	0.00	0.00	0.02	0.03
2005	1.95	0.06	0.80	0.04	0.30	0.11	2.10	0.24	0.11	0.09	0.05	0.05	0.04	0.00	0.00	0.03
2006	1.54	1.58	0.05	0.63	0.03	0.21	0.07	1.31	0.15	0.07	0.06	0.03	0.03	0.03	0.00	0.02
2007	0.09	1.24	1.27	0.04	0.45	0.02	0.13	0.04	0.74	0.08	0.04	0.03	0.02	0.02	0.01	0.01
2008	4.77	0.08	1.00	0.99	0.02	0.28	0.01	0.07	0.02	0.39	0.04	0.02	0.02	0.01	0.01	0.01
2009	1.95	3.85	0.06	0.77	0.65	0.01	0.14	0.00	0.03	0.01	0.17	0.02	0.01	0.01	0.00	0.01
2010	11.62	1.58	3.10	0.05	0.54	0.41	0.01	0.08	0.00	0.02	0.01	0.09	0.01	0.01	0.00	0.01
2011	1.84	9.38	1.27	2.40	0.03	0.32	0.22	0.00	0.04	0.00	0.01	0.00	0.04	0.00	0.00	0.01
2012	2.21	1.49	7.55	0.98	1.58	0.02	0.17	0.10	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00

Table 11: Select parameters, derived quantities, and reference point estimates for the base case MLE and posterior medians

	MLE	Posterior median
Parameters		
R_0 (billions)	2.31	2.69
Steepness (*h*)	0.86	0.82
Natural mortality (*M*)	0.21	0.22
Acoustic catchability (*Q*)	1.10	1.01
Additional acoustic survey SD	0.34	0.42
Derived Quantities		
2008 recruitment (billions)	4.77	5.53
2010 recruitment (billions)	11.62	13.61
SB_0 (thousand mt)	1,924	2,081
2013 Depletion	68.2%	72.3%
2012 Fishing intensity: (1-SPR)/(1-SPR40%)	88.7%	81.0%
Reference points based on $F_{40\%}$		
Female spawning biomass ($SB_{F40\%}$ million mt)	721	744
$SPR_{MSY\text{-}proxy}$	40%	40%
Exploitation fraction corresponding to SPR	20.9%	21.8%
Yield at $SB_{F40\%}$ (million mt)	315	337
Reference points based on $SB_{40\%}$		
Female spawning biomass ($SB_{40\%}$ million mt)	770	833
$SPR_{SB40\%}$	42.4%	43.2
Exploitation fraction resulting in $SB_{40\%}$	19.2%	19.2%
Yield at $SB_{40\%}$ (million mt)	308	328
Reference points based on estimated MSY		
Female spawning biomass (SB_{MSY} million mt)	434	500
SPR_{MSY}	25.6%	28.2%
Exploitation fraction corresponding to SPR_{MSY}	37.1%	34.5%
MSY (million mt)	340	357

Table 12: Summary of Pacific hake reference points from the base-case model

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female *SB* (SB_0, thousand mt)	1,653	2,081	2,709
Unfished recruitment (R_0, billions)	1.761	2.687	4.303
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	556	744	942
$SPR_{MSY\text{-}proxy}$	–	40%	–
Exploitation fraction corresponding to SPR	18.4%	21.8%	25.9%
Yield at $SB_{F40\%}$ (thousand mt)	243	337	479
Reference points based on $SB_{40\%}$			
Female spawning biomass ($SB_{40\%}$ thousand mt)	661	833	1,084
$SPR_{SB40\%}$	40.6	43.2	51.4
Exploitation fraction resulting in $SB_{40\%}$	14.4%	19.2%	23.3%
Yield at $SB_{40\%}$ (thousand mt)	238	328	469
Reference points based on estimated MSY			
Female spawning biomass (SB_{MSY} thousand mt)	328	500	840
SPR_{MSY}	18.3%	28.2%	46.5%
Exploitation fraction corresponding to SPR_{MSY}	17.6%	34.5%	59.5%
MSY (thousand mt)	248	357	524

Table 13: Posterior distribution quantiles for forecasts of Pacific hake relative depletion (at the beginning of the year before fishing takes place) from the base model. Numbers for 2013 are greyed because they are the same for every catch alternative since beginning of the year quantities are given. Catch alternatives are based on: 1) arbitrary constant catch levels of 0, 300,000, and 500,000 mt (rows a–c), 2) the catch level that results in an equal probability of the population increasing or decreasing from 2013 to 2014 (row d), 3) the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base case (row e), 4) the catch level that results in the median spawning biomass to remain unchanged from 2013 to 2014 (row f), and 5) the catch level that results in a 50% probability that the median predicted catch will remain the same in 2014 (row g).

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year depletion**				
	Year	Catch (mt)					
a	2013	0	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	0	47.7%	68.3%	88.1%	114.4%	169.8%
b	2013	250,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	250,000	41.8%	62.5%	82.1%	108.8%	163.2%
c	2013	300,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	300,000	40.5%	61.5%	81.1%	107.7%	162.1%
d	2013	350,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	350,000	39.3%	60.3%	79.9%	106.6%	161.0%
e	2013	400,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	400,000	38.3%	59.2%	78.6%	105.6%	159.7%
f	2013	450,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	450,000	37.0%	58.0%	77.3%	104.4%	158.7%
g	2013	500,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	500,000	35.8%	56.8%	76.0%	103.2%	157.7%
h	2013	603,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	603,000	33.9%	54.3%	73.5%	100.7%	155.7%
i	2013	626,364	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	715,041	33.4%	53.8%	72.9%	100.2%	155.3%
j	2013	650,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	650,000	32.8%	53.2%	72.4%	99.7%	154.8%
k	2013	696,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	696,000	31.7%	52.1%	71.3%	98.7%	153.9%

Table 14: Posterior distribution quantiles for forecasts of Pacific hake fishing intensity (spawning potential ratio; (1-SPR)/(1-SPR$_{40\%}$); values greater than 100% denote fishing in excess of the $F_{40\%}$ default harvest rate) from the base model. Catch alternatives are explained in Table 13.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Fishing Intensity**				
	Year	Catch (mt)					
a	2013	0	0%	0%	0%	0%	0%
	2014	0	0%	0%	0%	0%	0%
b	2013	250,000	37%	50%	63%	75%	91%
	2014	250,000	29%	42%	53%	64%	82%
c	2013	300,000	42%	57%	70%	82%	98%
	2014	300,000	34%	48%	61%	72%	90%
d	2013	350,000	47%	63%	76%	88%	105%
	2014	350,000	38%	54%	67%	80%	98%
e	2013	400,000	52%	68%	82%	94%	110%
	2014	400,000	42%	59%	74%	86%	104%
f	2013	450,000	57%	73%	87%	98%	114%
	2014	450,000	47%	64%	79%	92%	110%
g	2013	500,000	61%	77%	91%	102%	117%
	2014	500,000	50%	69%	84%	97%	115%
h	2013	603,000	68%	85%	99%	109%	123%
	2014	603,000	58%	78%	93%	106%	123%
i	2013	626,364	69%	87%	100%	111%	124%
	2014	715,041	65%	85%	100%	112%	129%
j	2013	650,000	71%	88%	101%	112%	125%
	2014	650,000	61%	81%	97%	109%	127%
k	2013	696,000	74%	91%	104%	114%	127%
	2014	696,000	64%	84%	100%	113%	129%

Table 15: Probabilities of various management metrics given different catch alternatives. Catch alternatives are explained in Table 13.

Catch	Probability SB_{2014}<SB_{2013}	Probability SB_{2014}<$SB_{40\%}$	Probability SB_{2014}<$SB_{25\%}$	Probability SB_{2014}<$SB_{10\%}$	Probability Fishing intensity in 2013 > 40% Target	Probability 2014 Catch Target < 2013 Catch
0	0%	2%	0%	0%	0%	0%
250,000	2%	4%	0%	0%	2%	1%
300,000	6%	5%	1%	0%	4%	2%
350,000	11%	6%	1%	0%	9%	4%
400,000	18%	6%	1%	0%	15%	9%
450,000	25%	7%	1%	0%	22%	14%
500,000	33%	8%	1%	0%	30%	20%
603,000	50%	9%	2%	0%	45%	36%
626,364	53%	10%	2%	0%	50%	39%
650,000	57%	10%	2%	0%	55%	42%
696,000	62%	11%	3%	0%	59%	50%

Table 16: Median forecasts of Pacific hake depletion and fishing intensity (FI) for three different states of nature based on 2010 recruitment: 1) Low 2010 recruitment uses the lowest 10% of 2010 recruitment estimates, 2) Mid 2010 recruitment uses the middle 80% of 2010 recruitment estimates, and 3) High 2010 recruitment uses the highest 10% of 2010 recruitment estimates. Catch alternatives are explained in Table 13.

	State Probability	Low 2010 recruitment 10%		Mid 2010 recruitment 80%		High 2010 recruitment 10%	
Year	Catch	Depletion	FI	Depletion	FI	Depletion	FI
2013	0	41.1%	0%	72.4%	0%	141.0%	0%
2014	0	49.3%	0%	88.2%	0%	165.8%	0%
2013	250,000	41.1%	91%	72.4%	63%	141.0%	37%
2014	250,000	43.9%	82%	82.2%	53%	160.3%	29%
2013	300,000	41.1%	98%	72.4%	70%	141.0%	42%
2014	300,000	42.8%	90%	81.1%	61%	159.3%	34%
2013	350,000	41.1%	104%	72.4%	76%	141.0%	47%
2014	350,000	41.6%	98%	79.9%	67%	158.3%	38%
2013	400,000	41.1%	109%	72.4%	82%	141.0%	52%
2014	400,000	40.3%	104%	78.6%	73%	157.2%	42%
2013	450,000	41.1%	113%	72.4%	87%	141.0%	57%
2014	450,000	39.0%	110%	77.3%	79%	156.2%	47%
2013	500,000	41.1%	117%	72.4%	91%	141.0%	61%
2014	500,000	37.6%	115%	76.0%	84%	155.1%	51%
2013	603,000	41.1%	123%	72.4%	98%	141.0%	68%
2014	603,000	35.1%	123%	73.5%	93%	153.0%	58%
2013	626,364	41.1%	124%	72.4%	100%	141.0%	69%
2014	626,364	34.6%	128%	73.0%	100%	152.5%	65%
2013	650,000	41.1%	125%	72.4%	101%	141.0%	71%
2014	650,000	34.0%	126%	72.4%	97%	152.0%	61%
2013	696,000	41.1%	127%	72.4%	104%	141.0%	74%
2014	696,000	32.9%	129%	71.3%	100%	151.0%	64%

Table 17: Probabilities of various management metrics given different catch alternatives for three different states of nature based on 2010 recruitment: 1) the lower 10% of 2010 recruitment estimates, 2) the middle 80% of 2010 recruitment estimates, and 3) the highest 10% of 2010 recruitment estimates.. Catch alternatives are explained in Table 13.

Catch	Probability $SB_{2014}<SB_{2013}$	Probability $SB_{2014}<SB_{40\%}$	Probability $SB_{2014}<SB_{25\%}$	Probability $SB_{2014}<SB_{10\%}$	Probability Fishing intensity in 2013 > 40% Target	Probability 2014 Catch Target < 2013 Catch
Lower 10% of 2010 recruitment						
0	0%	21%	1%	0%	0%	0%
250,000	16%	34%	3%	0%	15%	11%
300,000	31%	39%	5%	0%	40%	23%
350,000	56%	46%	6%	0%	74%	42%
400,000	65%	49%	9%	0%	93%	74%
450,000	69%	54%	10%	0%	99%	90%
500,000	77%	59%	14%	0%	100%	97%
603,000	89%	64%	20%	0%	100%	100%
626,364	91%	68%	20%	0%	100%	100%
650,000	92%	68%	21%	0%	100%	100%
696,000	93%	71%	24%	0%	100%	100%
Middle 80% of 2010 recruitment						
0	0%	0%	0%	0%	0%	0%
250,000	1%	1%	0%	0%	0%	0%
300,000	3%	1%	0%	0%	0%	0%
350,000	7%	1%	0%	0%	2%	0%
400,000	14%	2%	0%	0%	7%	2%
450,000	23%	2%	0%	0%	15%	6%
500,000	32%	2%	0%	0%	26%	13%
603,000	51%	3%	0%	0%	44%	32%
626,364	55%	4%	0%	0%	50%	36%
650,000	59%	4%	0%	0%	56%	40%
696,000	65%	5%	0%	0%	61%	50%
Upper 10% of 2010 recruitment						
0	0%	0%	0%	0%	0%	0%
250,000	0%	0%	0%	0%	0%	0%
300,000	0%	0%	0%	0%	0%	0%
350,000	0%	0%	0%	0%	0%	0%
400,000	0%	0%	0%	0%	0%	0%
450,000	0%	0%	0%	0%	0%	0%
500,000	0%	0%	0%	0%	0%	0%
603,000	0%	0%	0%	0%	0%	0%
626,364	1%	0%	0%	0%	0%	0%
650,000	2%	0%	0%	0%	0%	0%
696,000	3%	0%	0%	0%	0%	0%

Table 18: Select parameters, derived quantities, and reference point estimates for sensitivity analyses to alternative priors natural mortality (*M*).

	Base case	Natural mortality prior SD = 0.2	Natural mortality prior SD = 0.3
Parameters			
R_0 (billions)	2.69	4.04	4.79
Steepness (*h*)	0.823	0.809	0.800
Natural mortality (*M*)	0.224	0.263	0.278
Acoustic catchability (*Q*)	NA	NA	NA
Additional acoustic survey SD	0.416	0.434	0.444
Derived Quantities			
2008 recruitment (billions)	5.53	7.82	8.79
2010 recruitment (billions)	13.61	19.92	23.17
SB_0 (thousand mt)	2,081	2,313	2,452
2013 Depletion	72.3%	83.0%	87.0%
2012 Fishing intensity (1-SPR/1-SPR40%)	81.0%	63.9%	58.1%
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	744	815	857
Equilibrium exploitation fraction corresponding to SPR	21.8%	25.5%	27.0%
Yield at $SB_{F40\%}$ (thousand mt)	337	427	481

Table 19: Select parameters, derived quantities, and reference point estimates for sensitivity analyses to alternative priors on steepness (h).

	Base case	Steepness prior mean = 0.5	Steepness = 1.0
Parameters			
R_0 (billions)	2.69	3.13	2.55
Steepness (h)	0.823	0.576	1.000
Natural mortality (M)	0.224	0.230	0.223
Acoustic catchability (Q)	NA	NA	NA
Additional acoustic survey SD	0.416	0.421	0.414
Derived Quantities			
2008 recruitment (billions)	5.53	5.56	5.50
2010 recruitment (billions)	13.61	13.92	13.70
SB_0 (thousand mt)	2,081	2,298	1,999
2013 Depletion	72.3%	65.6%	76.5%
2012 Fishing intensity (1-SPR/1-SPR40%)	81.0%	79.2%	80.4%
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	744	596	800
Equilibrium exploitation fraction corresponding to SPR	21.8%	22.3%	21.6%
Yield at $SB_{F40\%}$ (thousand mt)	337	270	361

Table 20: Select parameters, derived quantities, and reference point estimates for sensitivity analyses to alternative values for the standard deviation of recruitment variability (σ_r).

	Base case	Less recruitment variability (σ_r = 1.0)	More recruitment variability (σ_r = 2.0)
Parameters			
R_0 (billions)	2.69	1.83	6.83
Steepness (h)	0.823	0.823	0.843
Natural mortality (M)	0.224	0.220	0.230
Acoustic catchability (Q)	NA	NA	NA
Additional acoustic survey SD	0.416	0.408	0.438
Derived Quantities			
2008 recruitment (billions)	5.53	4.89	6.19
2010 recruitment (billions)	13.61	11.35	15.45
SB_0 (thousand mt)	2,081	1,465	5,097
2013 Depletion	72.3%	86.9%	33.7%
2012 Fishing intensity (1-SPR/1-SPR40%)	81.0%	87.2%	75.4%
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	744	528	1878
Equilibrium exploitation fraction corresponding to SPR	21.8%	21.4%	22.3%
Yield at $SB_{F40\%}$ (thousand mt)	337	233	869
Recruitment variability			
Assumed SD for recruitment variability (σ_r)	1.40	1.00	2.00
SD of median estimated recruitment deviations for years with good information about cohort strength (1971-2010)	1.49	1.30	1.77

Table 21: Select parameters, derived quantities, and reference point estimates for sensitivity analyses to alternative numbers of ages for which selectivity is estimated.

	Base case	Selectivity estimated to age 5	Selectivity estimated to age 7
Parameters			
R_0 (billions)	2.69	2.70	2.69
Steepness (*h*)	0.823	0.822	0.823
Natural mortality (*M*)	0.224	0.224	0.225
Acoustic catchability (*Q*)	NA	NA	NA
Additional acoustic survey SD	0.416	0.431	0.436
Derived Quantities			
2008 recruitment (billions)	5.53	5.38	5.90
2010 recruitment (billions)	13.61	12.77	14.79
SB_0 (thousand mt)	2,081	2,124	2,069
2013 Depletion	72.3%	67.6%	78.6%
2012 Fishing intensity (1-SPR/1-SPR40%)	81.0%	83.0%	77.4%
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	744	758	744
Equilibrium exploitation fraction corresponding to SPR	21.8%	21.6%	21.9%
Yield at $SB_{F40\%}$ (thousand mt)	337	340	338

Table 22: Select parameters, derived quantities, and reference point estimates for sensitivity analyses to two levels of time-varying fishery selectivity. Results are MLE values in all cases.

	Base case MLE	Flexible fishery selectivity	Very flexible fishery selectivity
Parameters			
R_0 (billions)	2.31	2.20	2.22
Steepness (*h*)	0.861	0.861	0.861
Natural mortality (*M*)	0.215	0.212	0.212
Acoustic catchability (*Q*)	1.105	1.131	1.133
Additional acoustic survey SD	0.338	0.322	0.329
Derived Quantities			
2008 recruitment (billions)	4.77	4.17	4.38
2010 recruitment (billions)	11.62	8.99	8.98
SB_0 (thousand mt)	1,924	1,882	1,894
2013 Depletion	68.2%	56.9%	57.7%
2012 Fishing intensity (1-SPR/1-SPR40%)	88.7%	92.0%	93.7%
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	721	705	710
Equilibrium exploitation fraction corresponding to SPR	20.9%	20.4%	20.5%
Yield at $SB_{F40\%}$ (thousand mt)	315	301	304

Table 23: Select parameters, derived quantities, and reference point estimates for retrospective analyses using the base case. Values in italics are implied since they occur after the ending year of the respective retrospective analysis.

	Base case	-1 year	-2 years	-3 years	-4 years	-5 years
Parameters						
R_0 (billions)	2.69	2.37	3.18	2.93	2.92	2.85
Steepness (*h*)	0.823	0.808	0.812	0.806	0.804	0.797
Natural mortality (*M*)	0.224	0.217	0.226	0.223	0.226	0.222
Acoustic catchability (*Q*)	NA	NA	NA	NA	NA	NA
Additional acoustic survey SD	0.416	0.486	0.293	0.293	0.319	0.315
Derived Quantities						
2008 recruitment (billions)	5.53	3.54	14.83	1.19	*0.87*	*0.89*
2010 recruitment (billions)	13.61	1.66	*1.12*	*1.01*	*1.01*	*0.92*
SB_0 (thousand mt)	2,081	1,948	2,391	2,301	2,281	2,222
2013 Depletion	72.3%	*24.8%*	*83.3%*	*44.8%*	*36.0%*	*33.5%*
2012 Fishing intensity (1-SPR/1-SPR40%)	81.0%	*111.8%*	*41.8%*	*58.9%*	*73.5%*	*76.9%*
Reference points based on $F_{40\%}$						
Female spawning biomass ($SB_{F40\%}$ thousand mt)	744	693	851	819	800	790
Equilibrium exploitation fraction corresponding to SPR	21.8%	21.2%	22.0%	21.8%	21.9%	21.6%
Yield at $SB_{F40\%}$ (thousand mt)	337	304	389	369	363	354

7 Figures

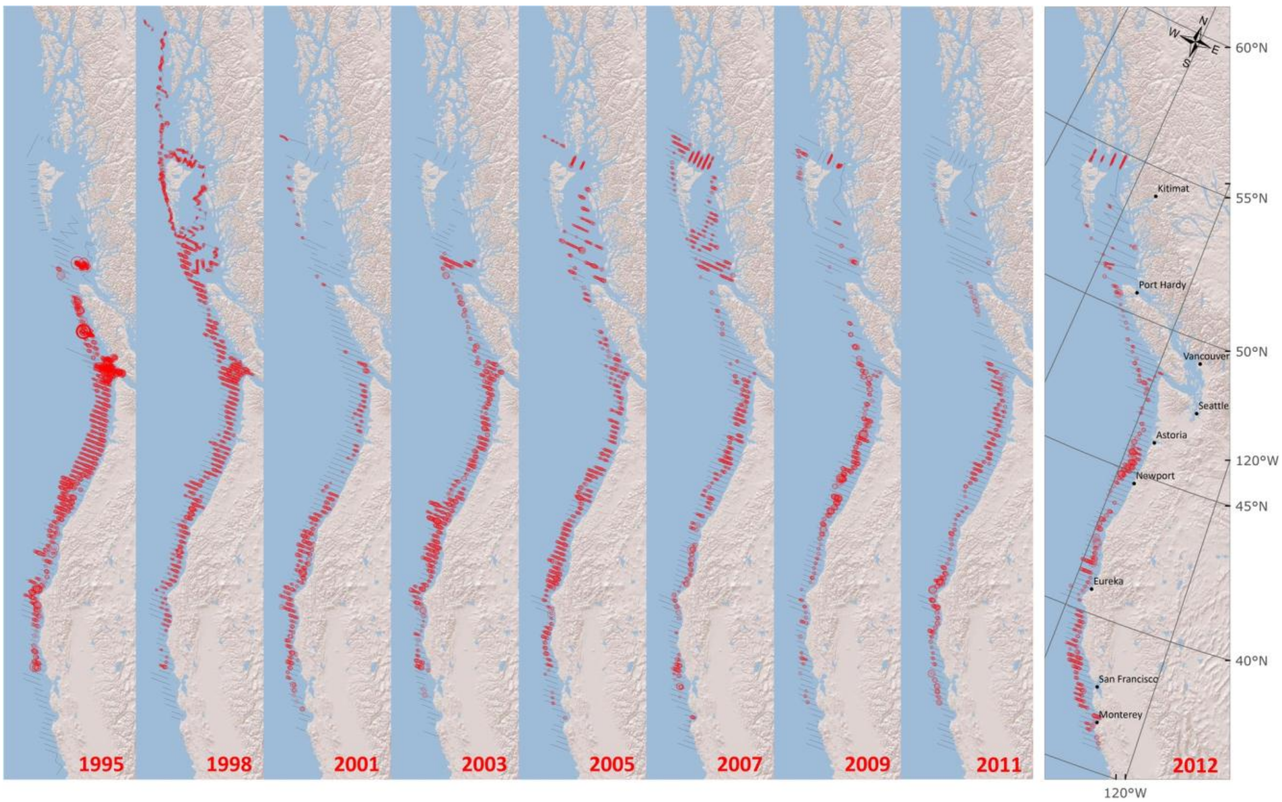


Figure 1: Spatial distribution of acoustic backscatter attributable to Pacific hake from joint US-Canada acoustic surveys 1995-2011. Area of the circles is roughly proportional to observed backscatter.

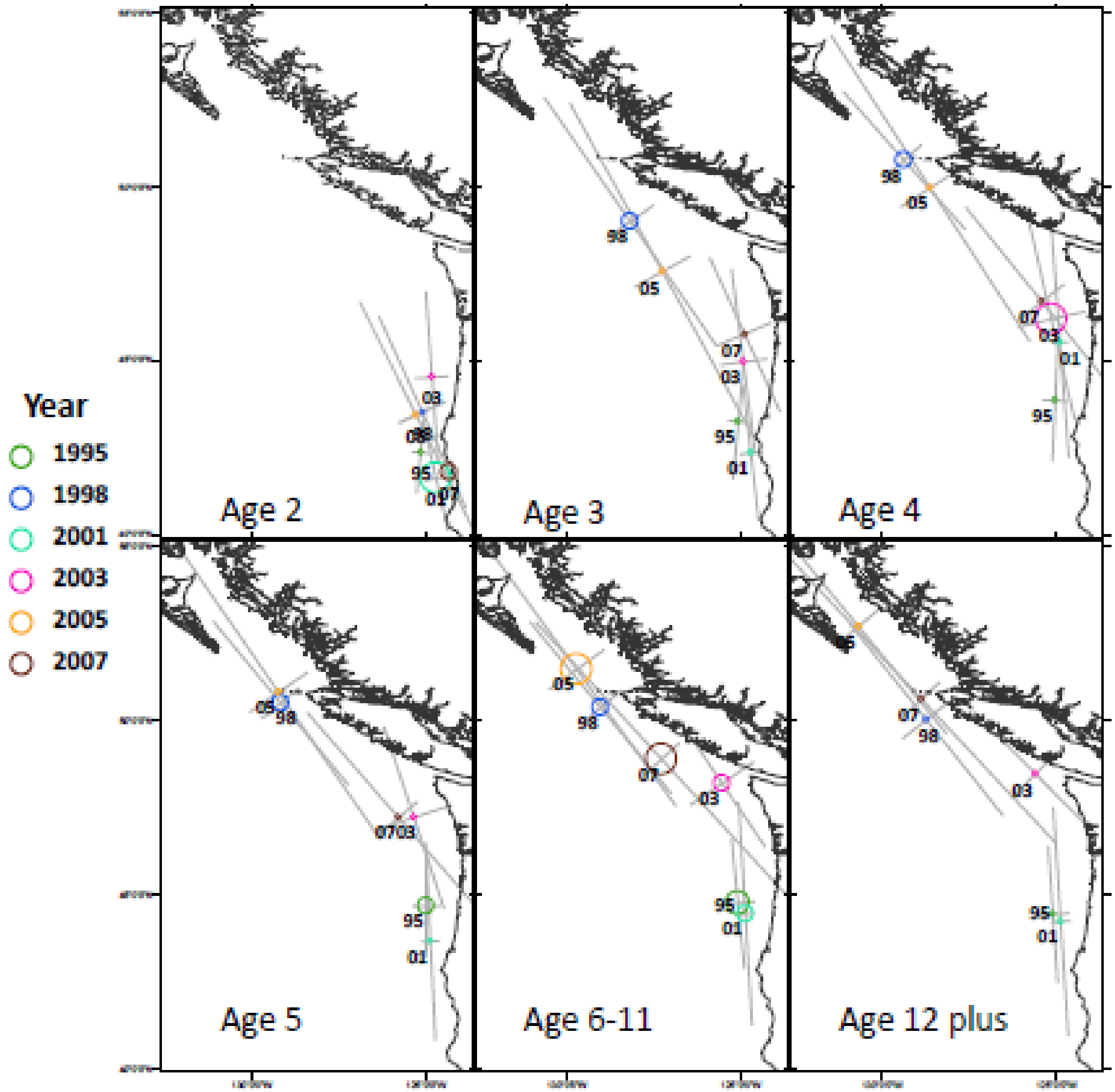


Figure 2: The mean spatial location of the hake stock (circles are proportional to biomass) and variance (grey lines) by age group and year based on acoustic survey observations 1995-2007 (Figure courtesy of O'Conner and Haltuch from preliminary results of the ongoing Fisheries And The Environment project investigating the links between ocean conditions and Pacific hake distribution).

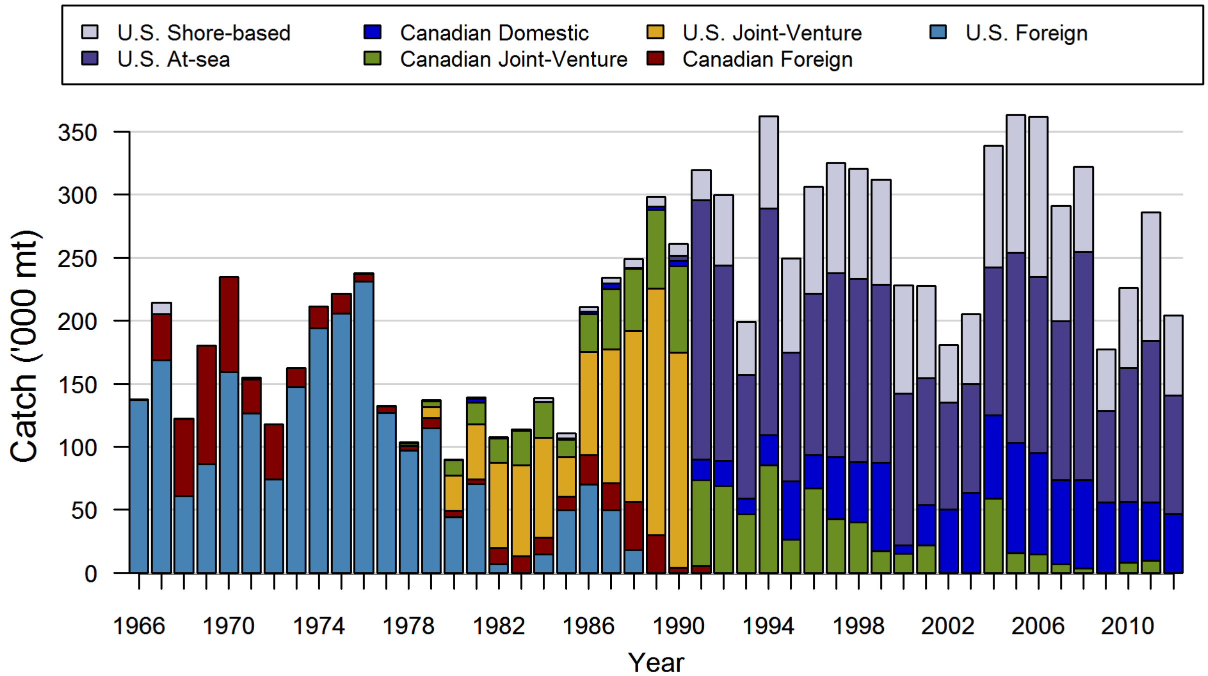


Figure 3: Total Pacific hake landings used in the assessment by sector, 1966-2011

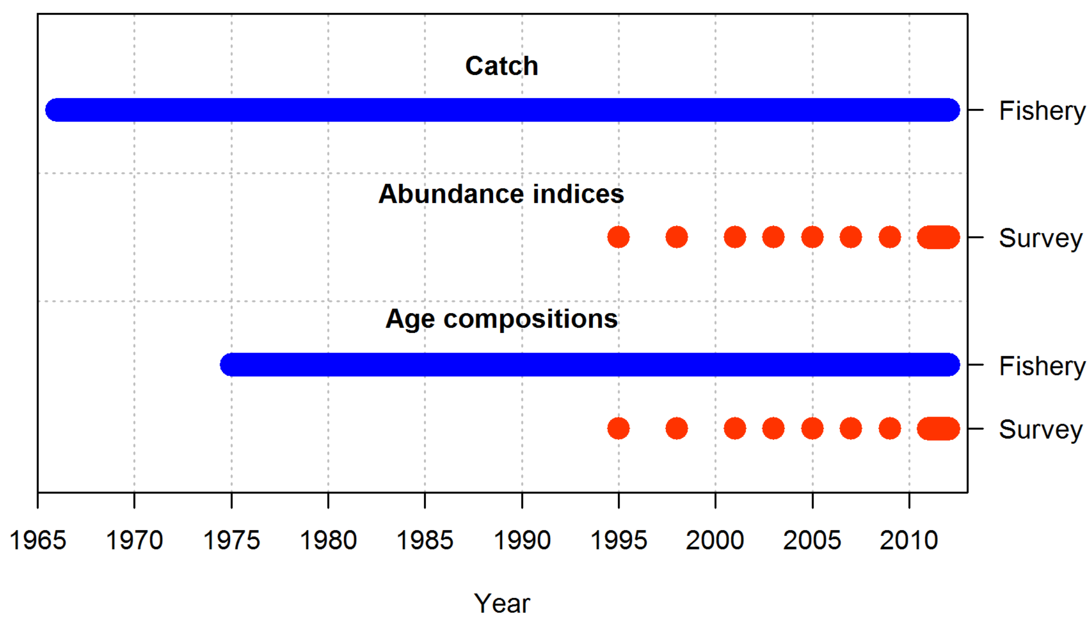


Figure 4: Overview of data used in this assessment, 1966-2012.

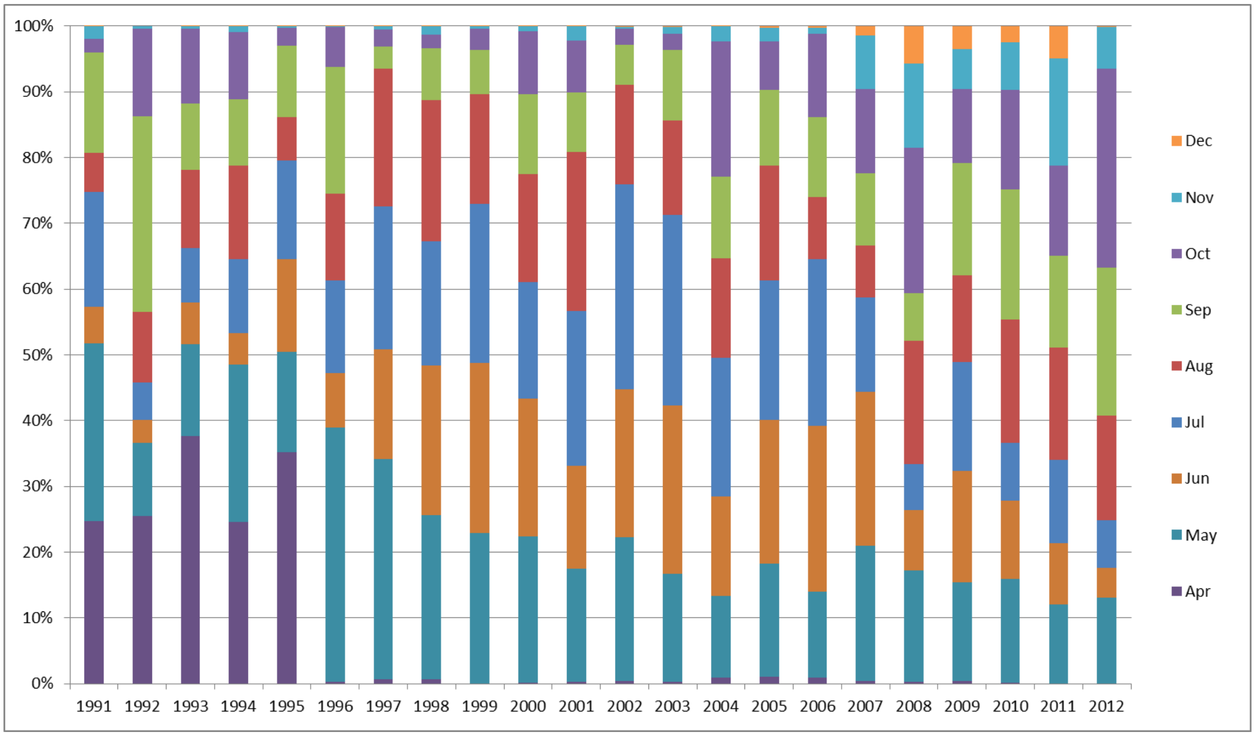


Figure 5: Proportion of catch for U.S. and Canadian combined occurring in each of the months from April through December.

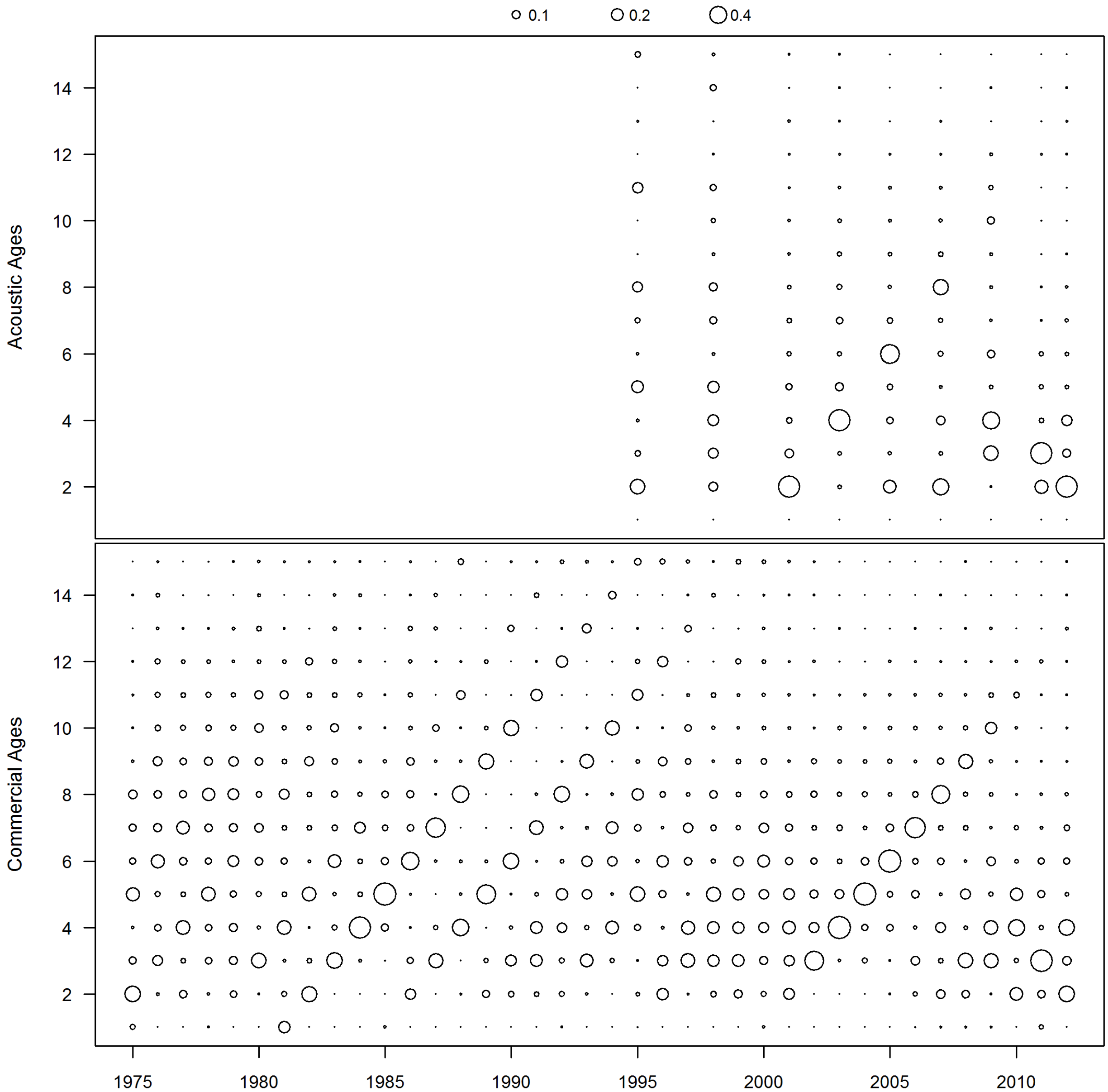


Figure 6: Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2011. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top).

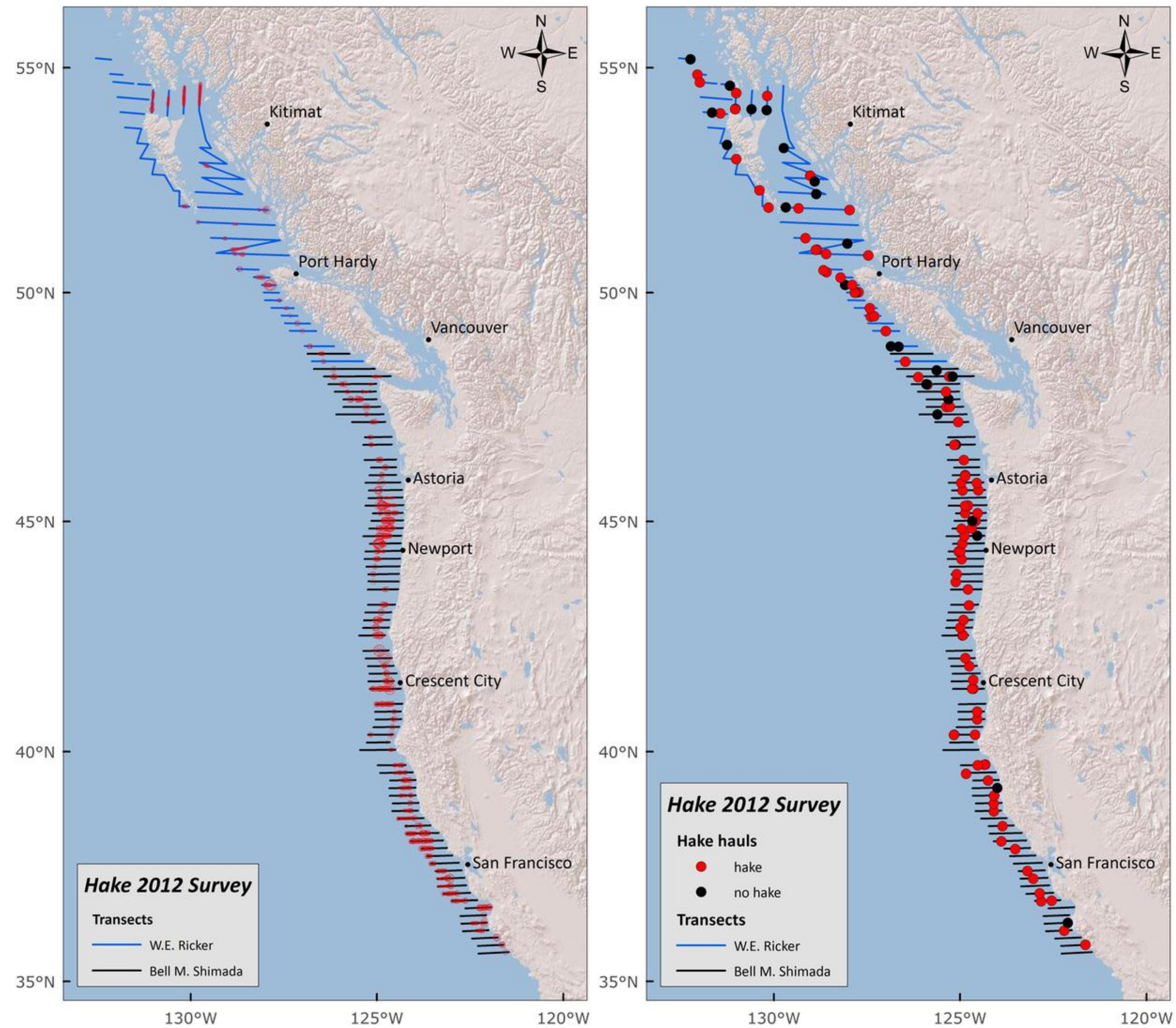


Figure 7: Acoustic survey transects surveyed in 2012 with backscatter proportional to the area of the circle (left panel) and hauls that caught or did not catch Pacific hake (right panel).

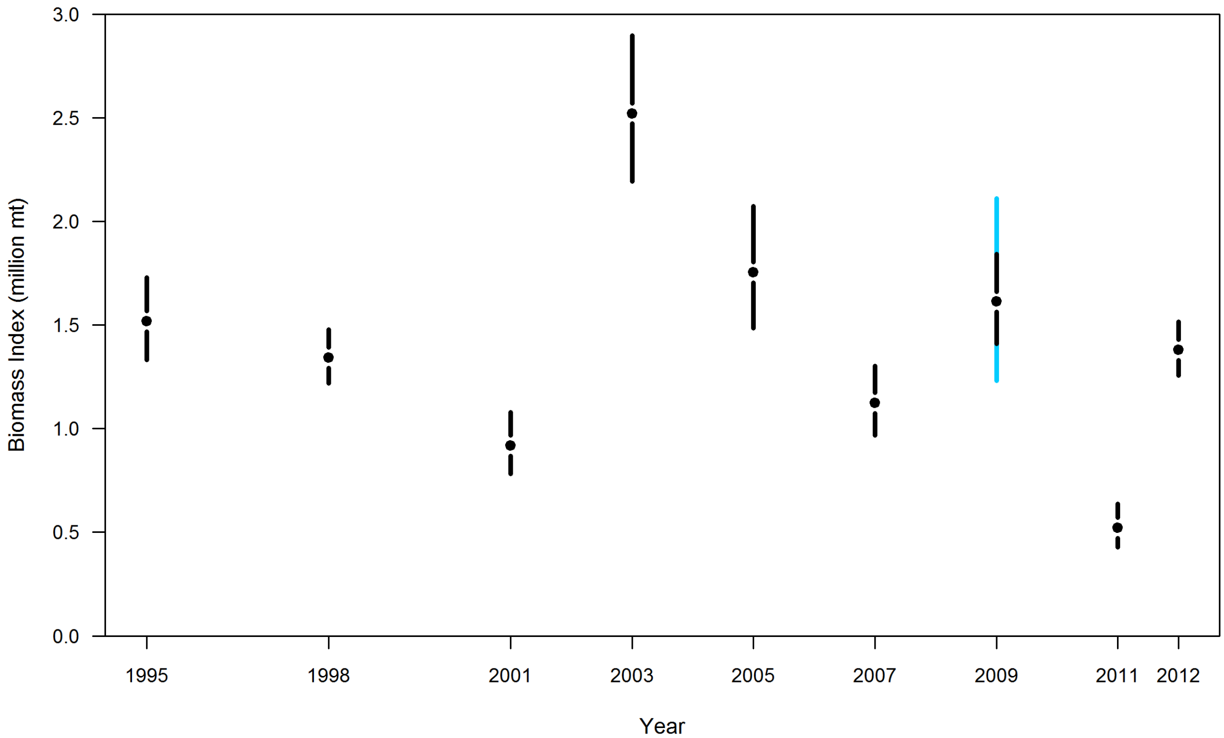


Figure 8: Acoustic survey biomass indices (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995-2007, 2011, 2012) and sampling variability as well as squid/hake apportionment uncertainty (2009).

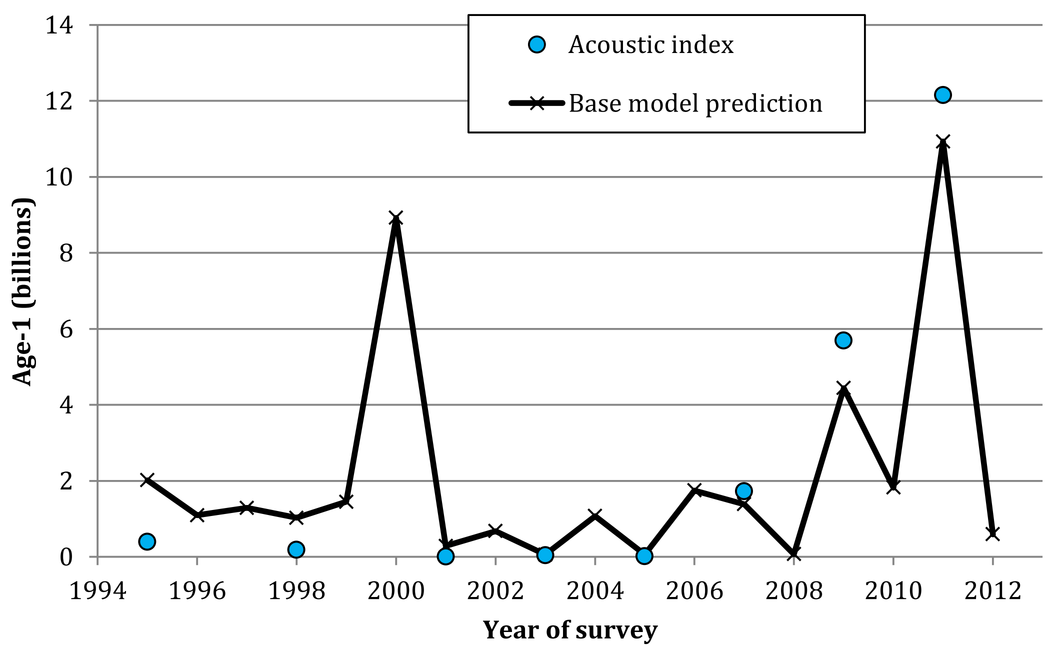


Figure 9: Preliminary acoustic survey age-1 index (scaled to have the same mean as the mean from base model recruitment for the same years) and base-case model predicted posterior median numbers at age-1. This figure represents a comparison with, not a fit to the preliminary data.

Mean weight at age with interpolation & extrapolation (all data)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2012	**0.02**	0.13	0.21	0.35	0.41	0.49	0.66	0.69	0.78	0.92	0.96	0.96	0.97	0.99	0.99	0.94
2011	**0.02**	0.08	0.25	0.32	0.39	0.51	0.60	0.69	0.86	0.93	0.97	1.07	1.05	1.03	1.06	0.92
2010	**0.02**	0.11	0.23	0.25	0.43	0.53	0.66	0.83	1.08	1.03	0.94	0.88	0.84	1.13	0.72	0.90
2009	**0.02**	0.07	0.24	0.34	0.47	0.64	0.67	0.69	0.75	0.82	0.77	0.81	1.01	0.85	0.96	1.03
2008	**0.02**	0.14	0.24	0.41	0.56	0.64	0.69	0.68	0.71	0.72	0.75	0.81	0.85	0.78	0.88	0.83
2007	0.02	0.05	0.23	0.38	0.54	0.55	0.61	0.63	0.65	0.71	0.77	0.76	0.81	0.87	0.80	0.87
2006	**0.02**	0.13	0.38	0.46	0.53	0.57	0.59	0.60	0.66	0.70	0.73	0.72	0.78	0.66	0.64	0.96
2005	**0.02**	0.12	0.26	0.43	0.51	0.54	0.57	0.63	0.65	0.70	0.80	0.81	0.81	0.76	1.14	0.97
2004	**0.02**	**0.11**	**0.26**	0.44	0.48	0.53	0.65	0.71	0.66	0.71	0.81	0.86	0.77	0.97	0.86	0.90
2003	**0.03**	0.10	0.26	0.44	0.52	0.59	0.76	0.69	0.75	0.82	0.77	0.89	0.93	0.79	0.84	1.00
2002	**0.03**	**0.08**	0.36	0.46	0.61	0.82	0.76	0.85	0.98	0.93	0.92	1.00	0.99	0.92	1.13	1.06
2001	**0.03**	0.05	0.29	0.48	0.65	0.66	0.75	0.86	0.86	0.88	0.96	0.98	1.01	1.05	0.99	0.98
2000	**0.03**	0.19	0.32	0.47	0.58	0.66	0.72	0.73	0.75	0.84	0.82	0.88	0.86	0.94	0.87	0.93
1999	**0.03**	**0.14**	0.25	0.35	0.43	0.53	0.56	0.57	0.61	0.70	0.67	0.80	0.76	0.88	0.73	0.82
1998	**0.03**	0.08	0.21	0.35	0.50	0.52	0.54	0.64	0.61	0.68	0.81	0.72	0.81	0.77	0.75	0.77
1997	**0.03**	**0.09**	0.36	0.43	0.49	0.55	0.55	0.58	0.59	0.61	0.63	0.86	0.59	0.71	0.66	0.87
1996	**0.03**	**0.10**	0.29	0.40	0.47	0.53	0.57	0.65	0.60	0.64	0.60	0.75	0.68	**0.81**	1.49	0.75
1995	**0.04**	0.11	0.27	0.34	0.49	0.54	0.65	0.62	0.66	0.76	0.67	0.74	0.80	0.91	0.68	0.80
1994	**0.04**	**0.12**	0.30	0.36	0.45	0.45	0.53	0.57	0.62	0.56	0.63	0.48	0.65	0.73	0.70	0.75
1993	**0.04**	**0.13**	0.25	0.34	0.40	0.45	0.49	0.50	0.49	0.55	0.51	1.26	1.02	0.61	0.60	0.69
1992	**0.04**	0.14	0.23	0.35	0.47	0.53	0.58	0.62	0.64	0.65	0.63	0.72	0.74	0.85	0.98	1.03
1991	**0.04**	**0.14**	0.28	0.37	0.46	0.51	0.54	0.59	0.72	0.85	1.10	0.72	0.64	**1.02**	1.21	2.38
1990	**0.04**	**0.14**	0.24	0.35	0.39	0.51	0.55	0.61	0.67	0.53	0.77	0.83	2.20	1.18	**1.02**	1.47
1989	**0.04**	**0.14**	0.27	0.30	0.29	0.51	0.44	0.41	0.52	0.63	0.66	0.60	0.88	0.67	0.83	1.13
1988	**0.04**	0.14	0.19	0.32	0.47	0.37	0.37	0.52	0.65	0.69	0.72	0.92	1.09	1.02	1.45	1.45
1987	**0.04**	**0.15**	0.14	0.38	0.28	0.29	0.36	0.58	0.60	0.64	0.76	0.98	0.92	1.24	1.20	1.42
1986	**0.04**	0.16	0.28	0.29	0.30	0.37	0.54	0.57	0.64	0.82	0.94	1.19	1.19	1.39	1.68	1.61
1985	**0.05**	0.17	0.23	0.27	0.44	0.55	0.55	0.60	0.75	0.69	0.72	0.86	0.87	0.95	0.68	1.12
1984	**0.05**	0.13	0.16	0.25	0.44	0.41	0.44	0.59	0.58	0.68	0.70	0.95	1.14	1.03	1.28	1.88
1983	**0.05**	0.13	0.14	0.34	0.37	0.33	0.52	0.50	0.62	0.71	0.88	0.93	1.04	1.03	1.32	1.48
1982	**0.05**	**0.12**	0.25	0.33	0.31	0.55	0.40	0.53	0.56	0.76	0.68	0.85	1.07	0.88	1.02	1.17
1981	**0.05**	0.11	0.21	0.34	0.53	0.39	0.53	0.55	0.75	0.72	0.82	1.04	1.10	1.34	1.49	1.21
1980	**0.05**	0.08	0.22	0.45	0.39	0.49	0.52	0.66	0.71	0.87	1.06	1.16	1.29	1.30	1.27	1.40
1979	**0.05**	**0.09**	0.24	0.26	0.58	0.69	0.77	0.89	0.91	1.04	1.20	1.25	1.53	1.55	1.80	1.98
1978	**0.05**	0.10	0.14	0.47	0.53	0.60	0.64	0.74	0.84	0.98	1.10	1.23	1.30	1.48	1.74	2.34
1977	0.06	**0.10**	0.40	0.49	0.59	0.67	0.75	0.83	0.98	1.11	1.23	1.31	1.41	1.75	2.04	2.21
1976	**0.06**	0.10	0.24	0.50	0.52	0.69	0.80	0.92	1.21	1.34	1.45	1.65	1.81	1.86	1.96	2.74
1975	**0.06**	0.16	0.30	0.37	0.61	0.63	0.79	0.87	0.97	0.91	0.97	1.69	1.50	1.90	**1.96**	**2.74**
mean	0.03	0.09	0.25	0.38	0.49	0.54	0.59	0.66	0.72	0.79	0.86	0.93	0.97	1.07	1.00	1.02

Age

Figure 10: Empirical weight-at-age (kg) used in the assessment. Numbers shown in bold were interpolated or extrapolated from adjacent years.

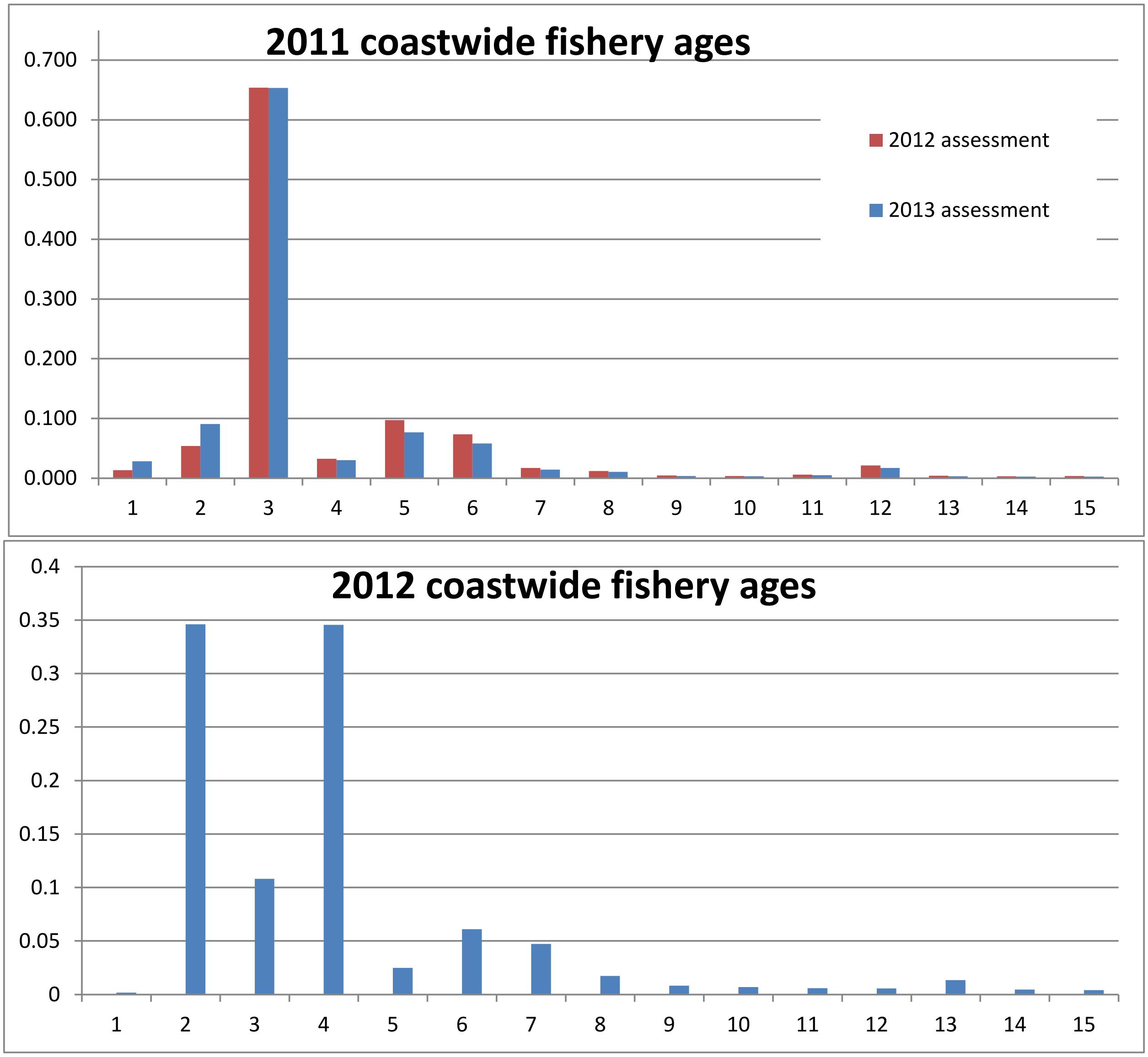


Figure 11: Fishery age compositions for 2011 (top) and 2012 (bottom). The 2011 proportions-at-age show the difference between those used in the 2012 assessment (red) and those used in the 2013 assessment (blue) containing additional ages collected late in 2011.

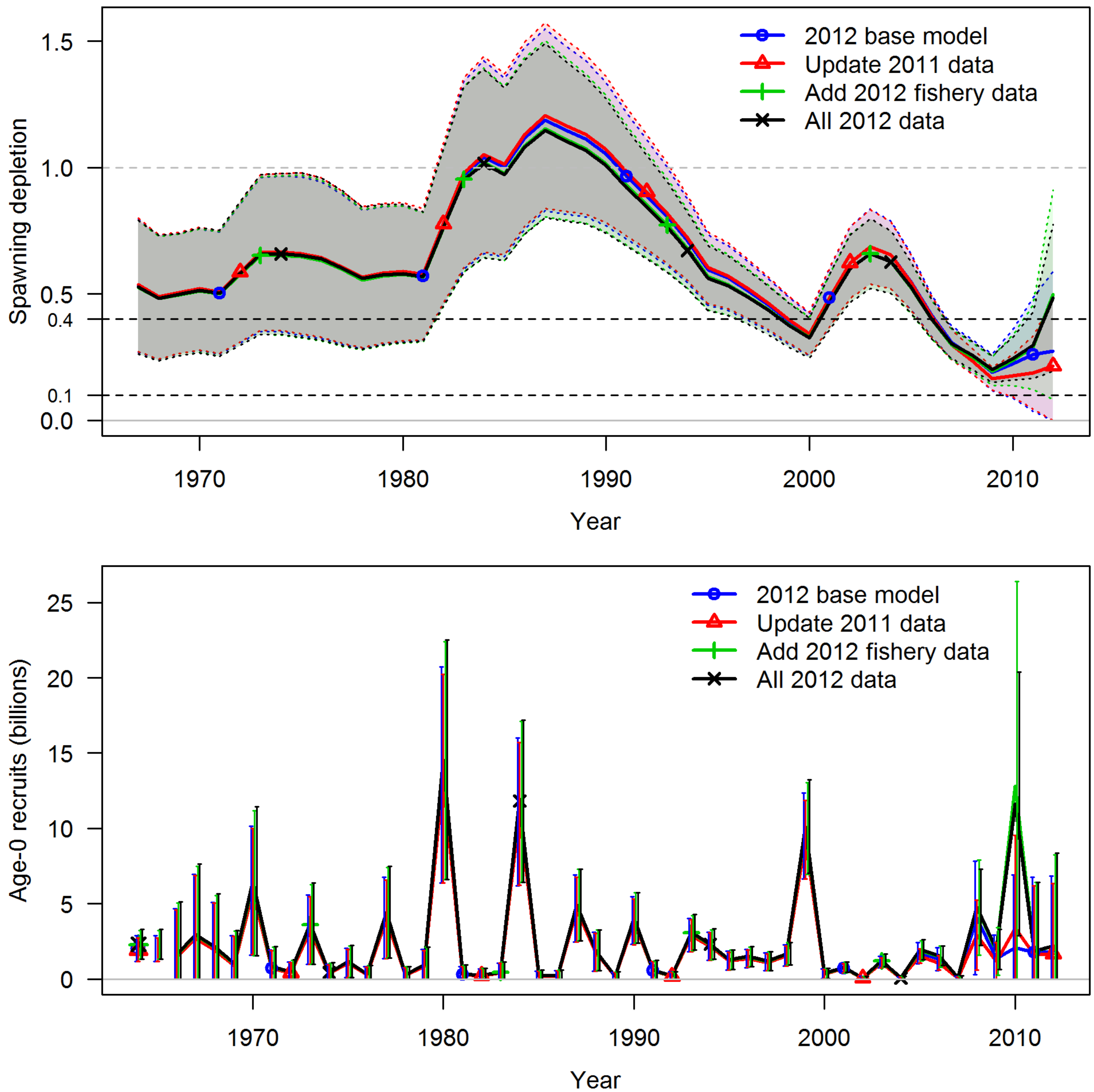


Figure 12: Bridge models from the 2012 base model to the 2013 base model (All 2012 data).

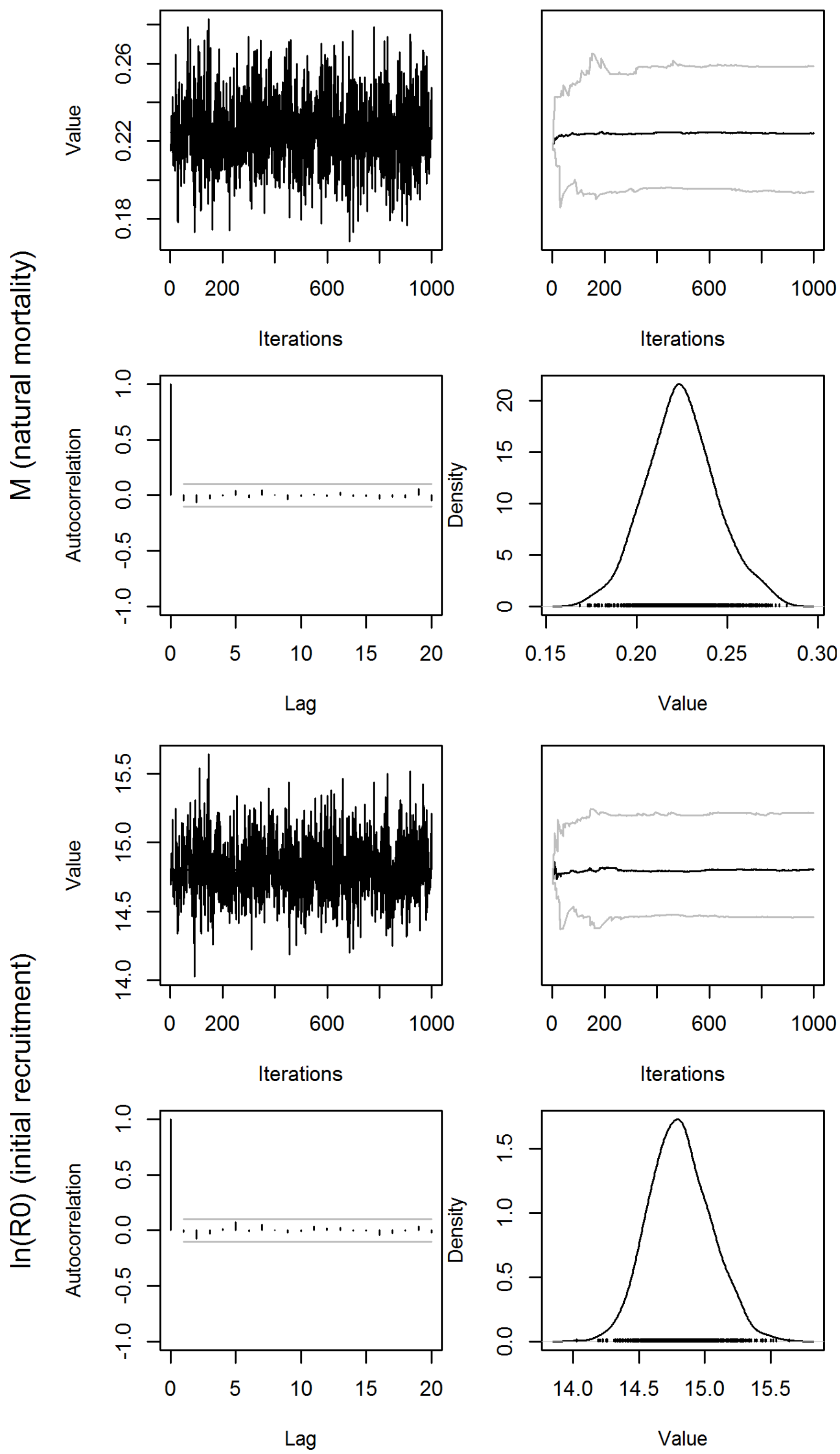


Figure 13: Summary of MCMC diagnostics for natural mortality (upper panels) and log(R0) (lower panels) in the base-case model.

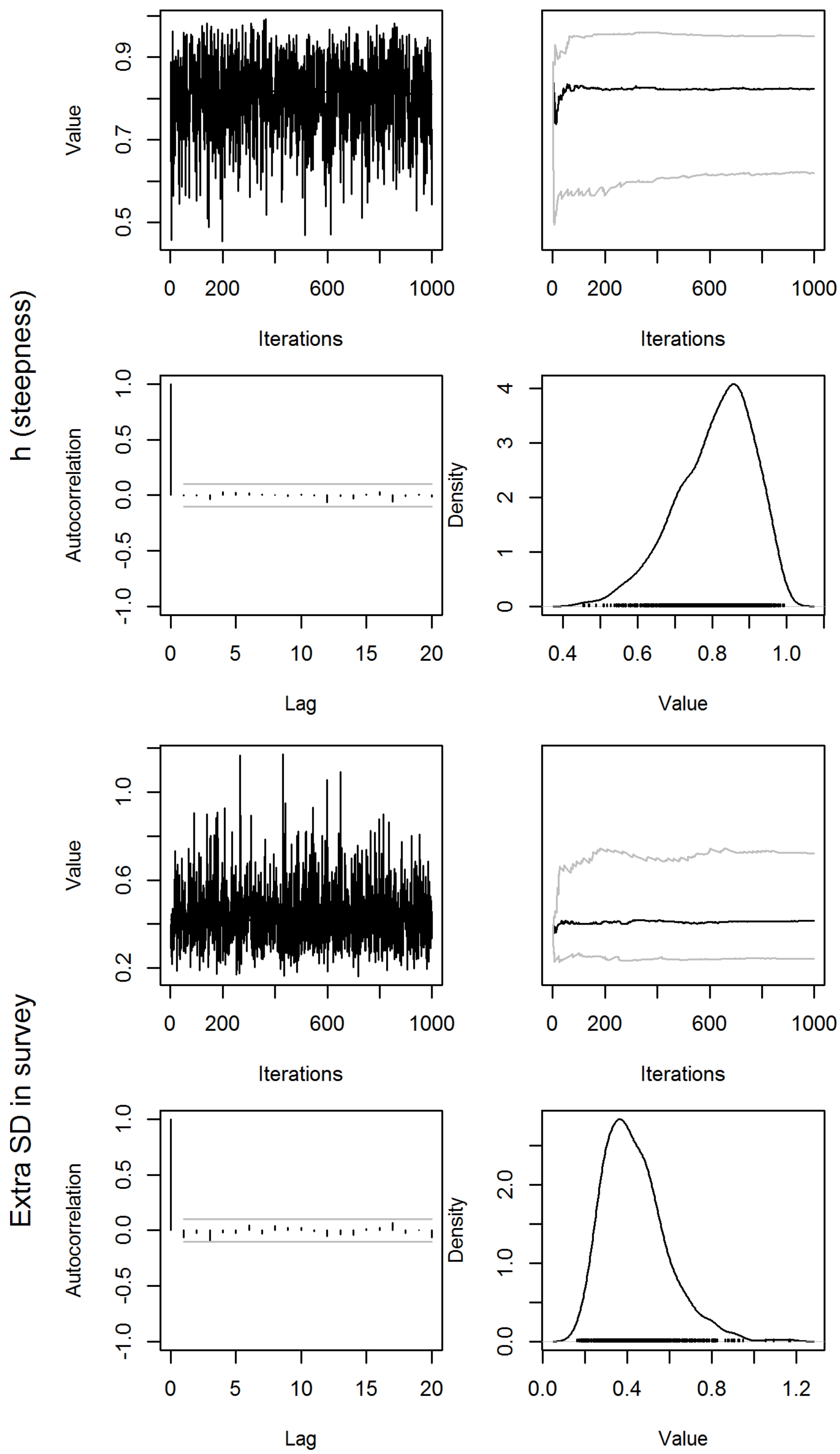


Figure 14: Summary of MCMC diagnostics for steepness (upper panels) and the additional SD for the acoustic survey index (lower panels) in the base-case model.

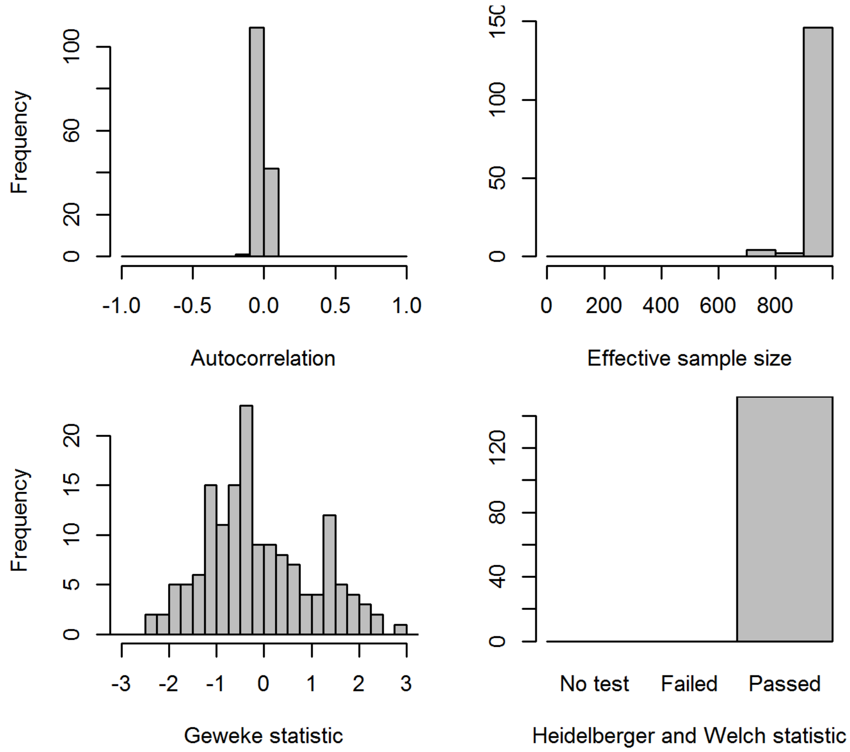


Figure 15: Summary histograms of MCMC diagnostics for all base-case model parameters and derived quantities including the recruitment, spawning biomass, and depletion time-series.

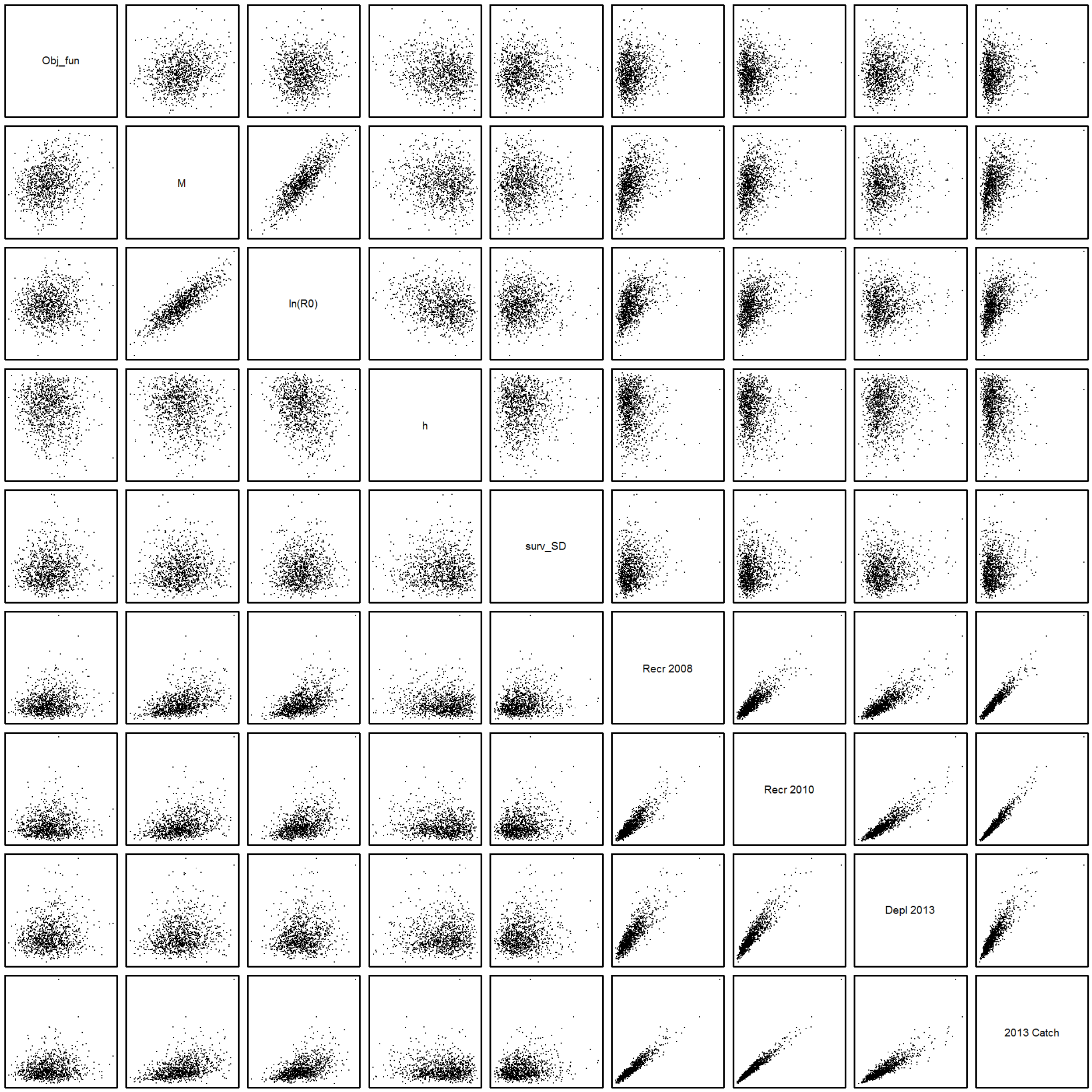


Figure 16: Posterior correlations among key base-case model parameters and derived quantities. From the top left the posteriors plotted are: objective function, natural mortality, ln(R0), steepness, the process-error SD for the acoustic survey, the 2008 recruitment deviation, the 2010 recruitment deviation, the depletion level in 2012, and the default harvest rate yield for 2013.

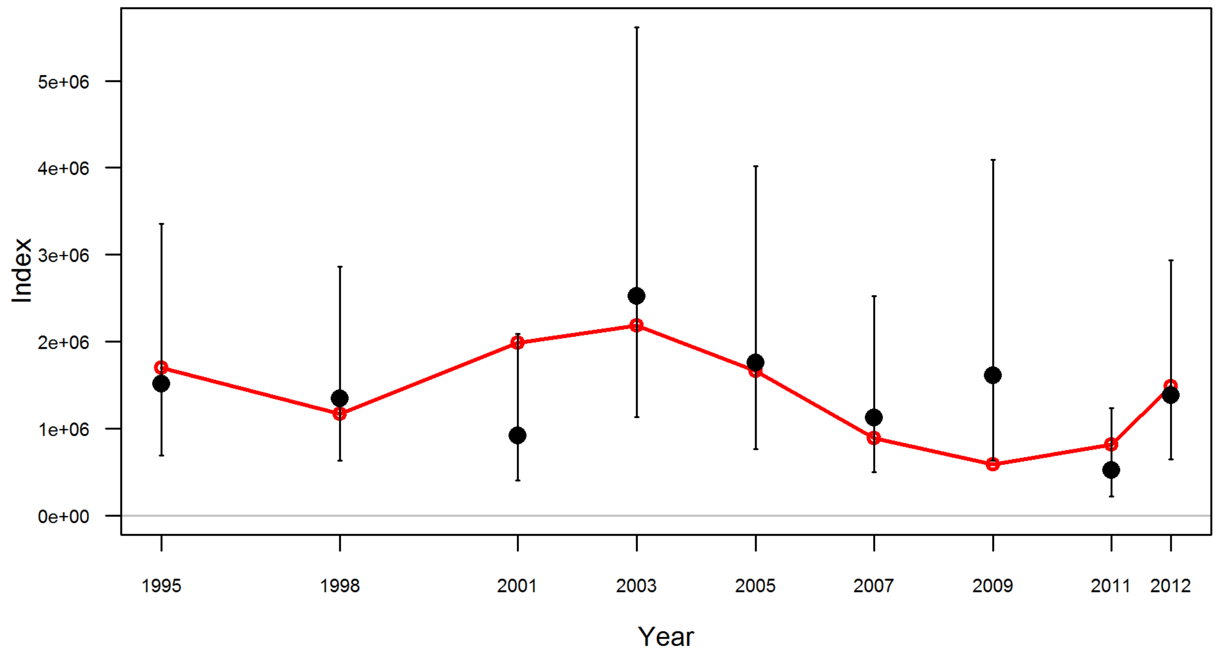


Figure 17: Predicted MLE fits to the acoustic survey with 95% confidence intervals around the index points.

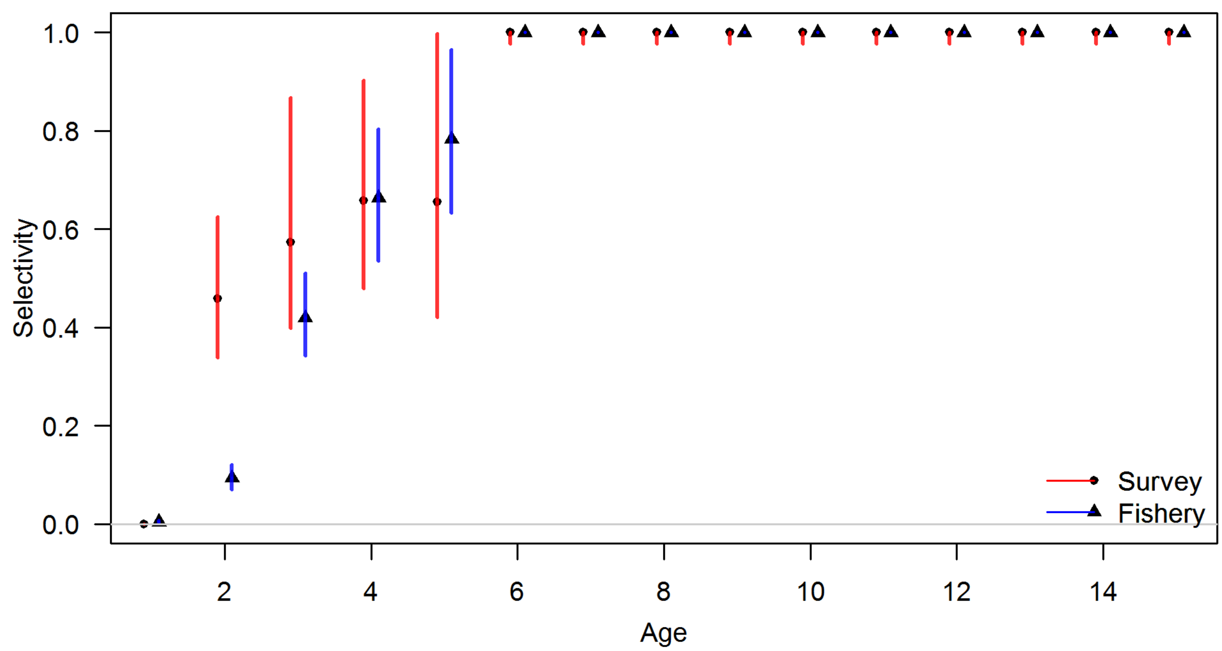


Figure 18: Estimated selectivity with 95% posterior credibility intervals for the acoustic survey and the fishery.

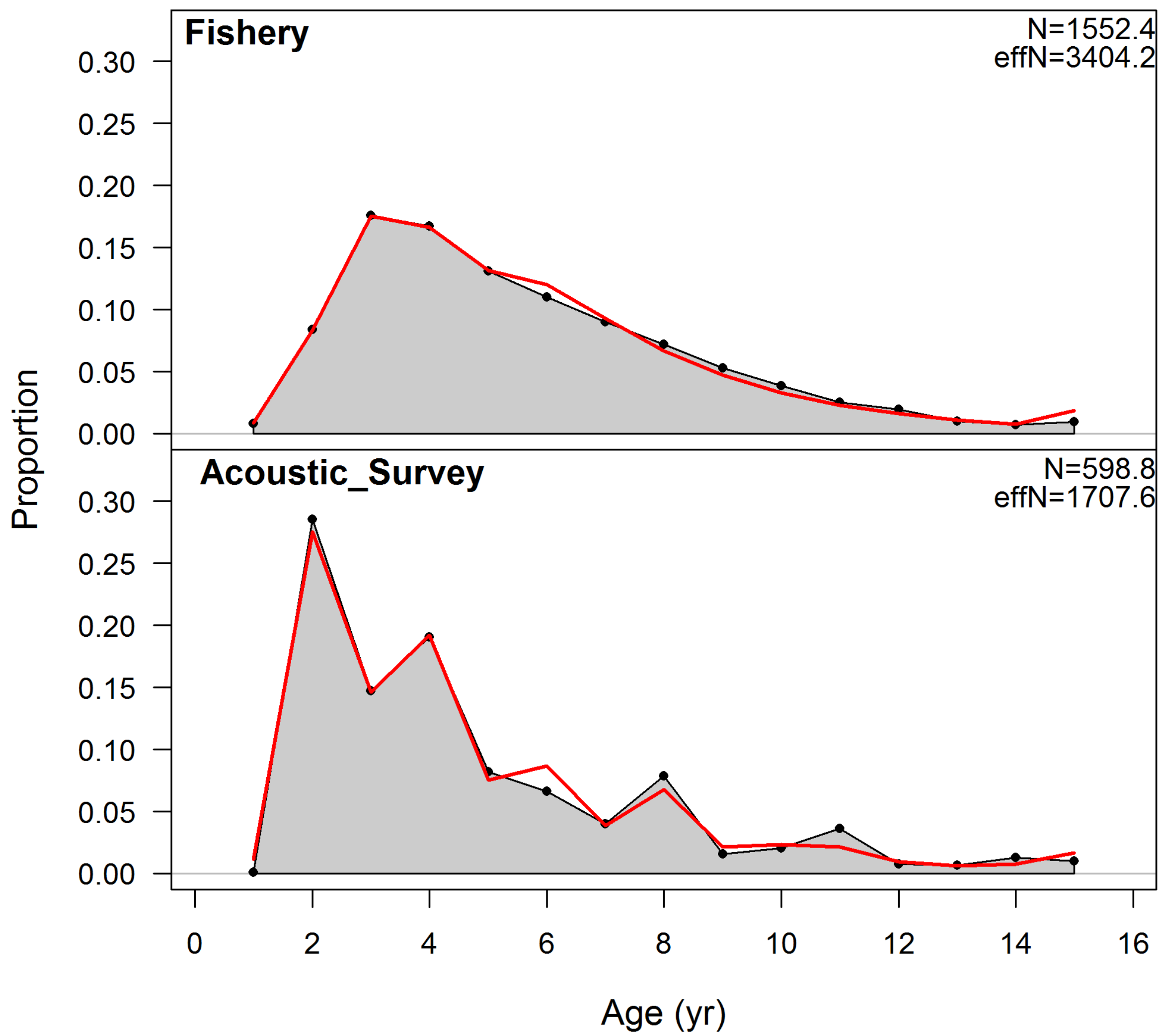


Figure 19: Base-case model fit to the aggregate fishery and acoustic age composition data.

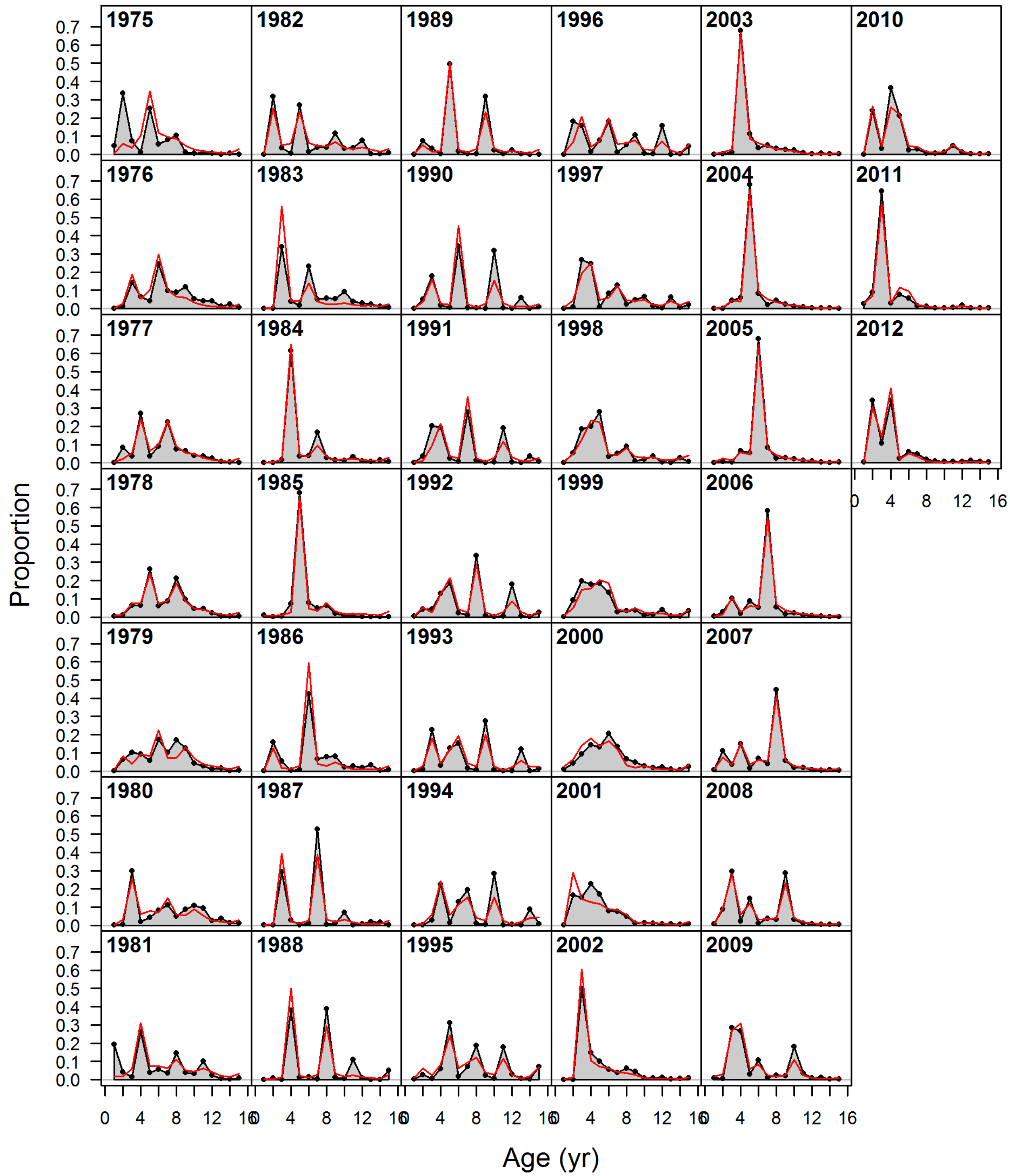


Figure 20: Base-case model fit to the observed fishery age composition data.

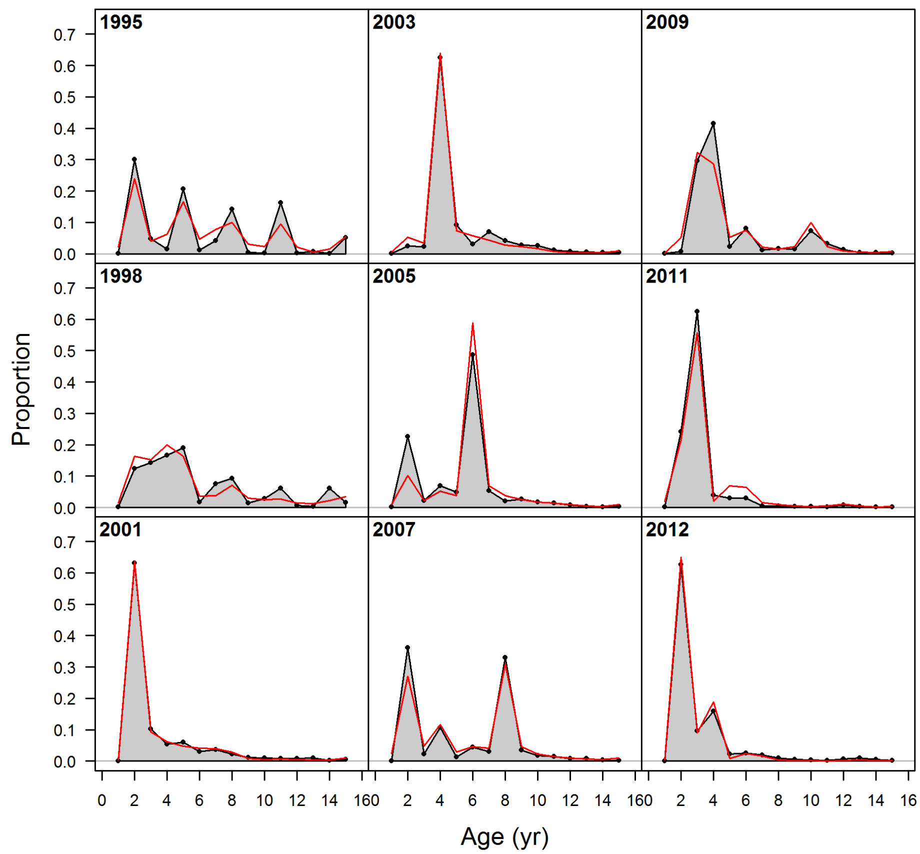


Figure 21: Base model fit to the observed acoustic survey age composition data.

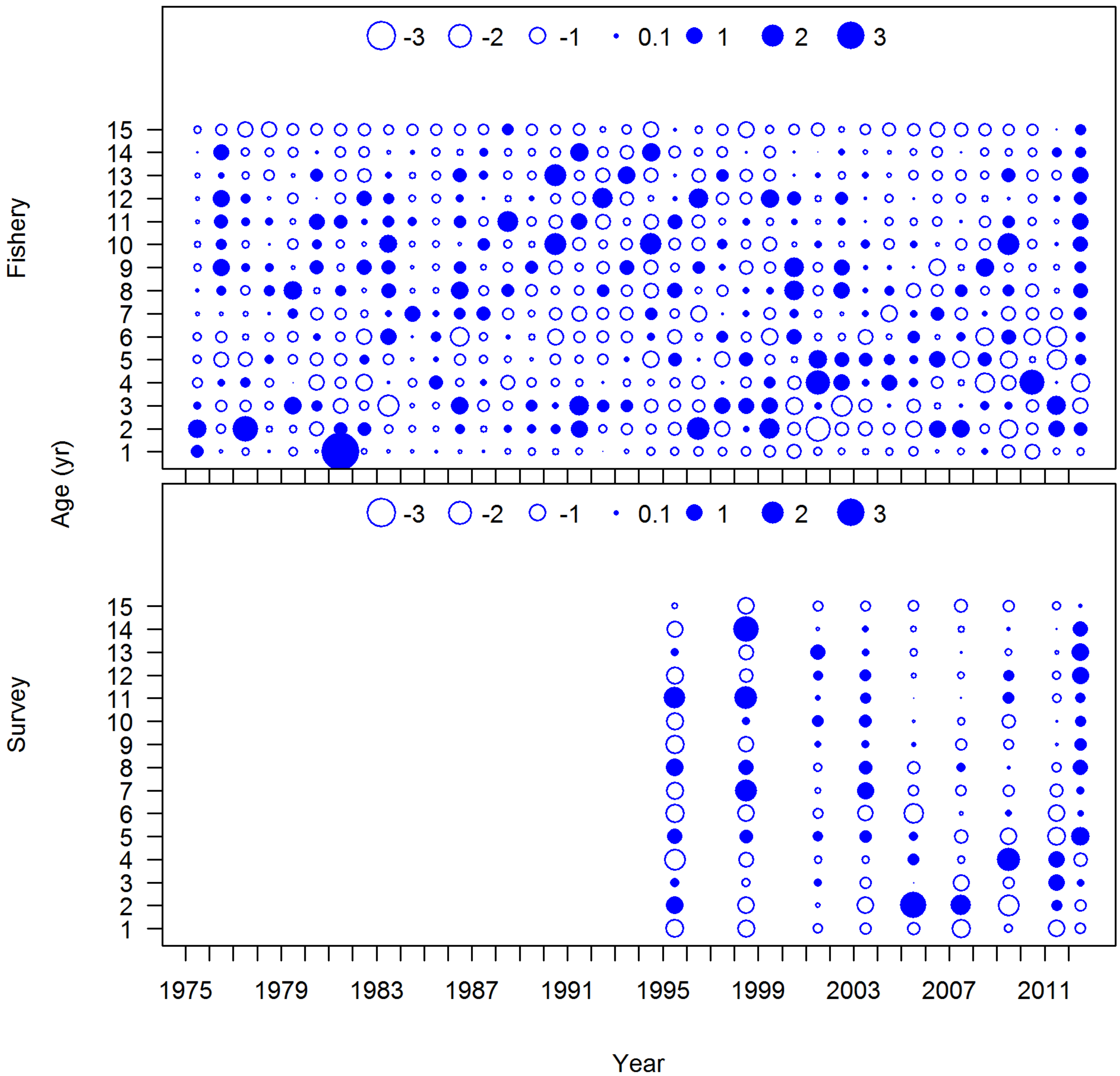


Figure 22: Pearson standardized residuals (observed - predicted) for base-case model fits to the fishery age composition data. Filled circles represent positive values.

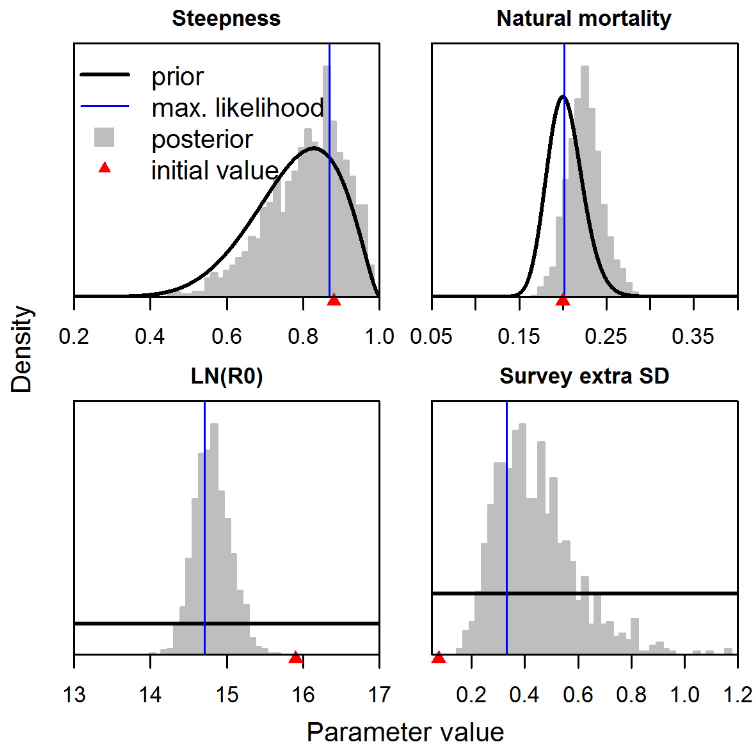


Figure 23: Prior and posterior probability distributions for key parameters in the base model. From the top left, the parameters are: steepness (h), Natural mortality (M), ln(R0), and the additional process-error SD for the acoustic survey.

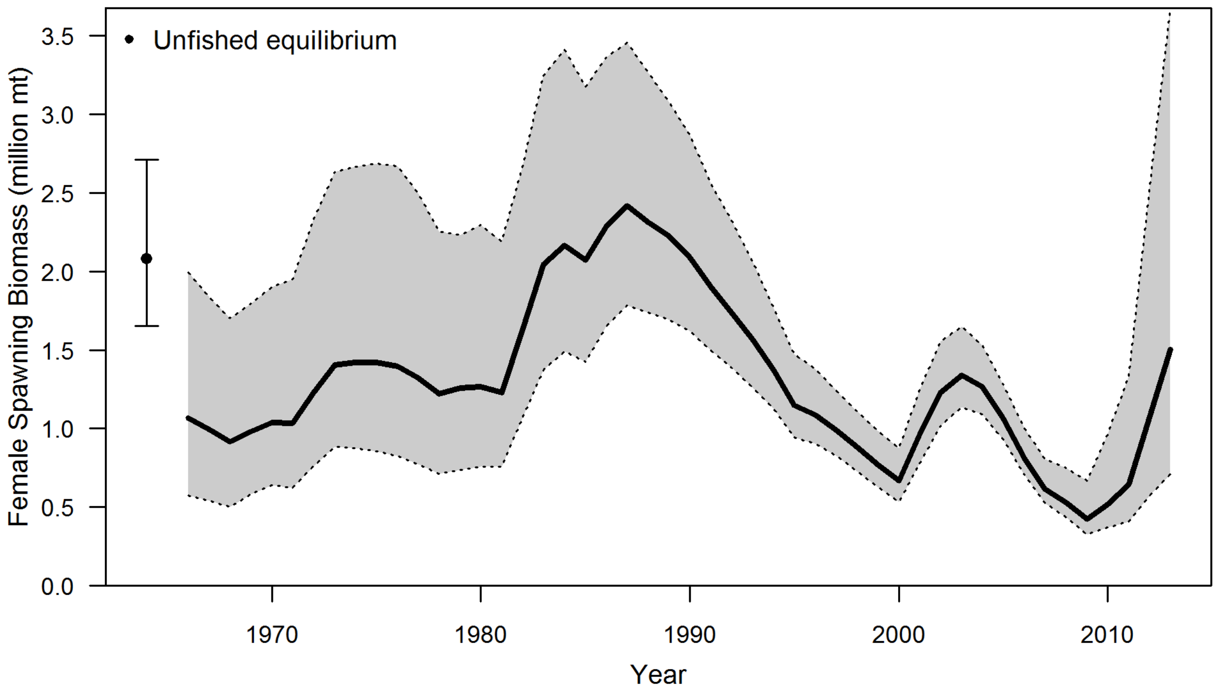


Figure 24: Posterior female spawning biomass time-series with 95% posterior credibility intervals.

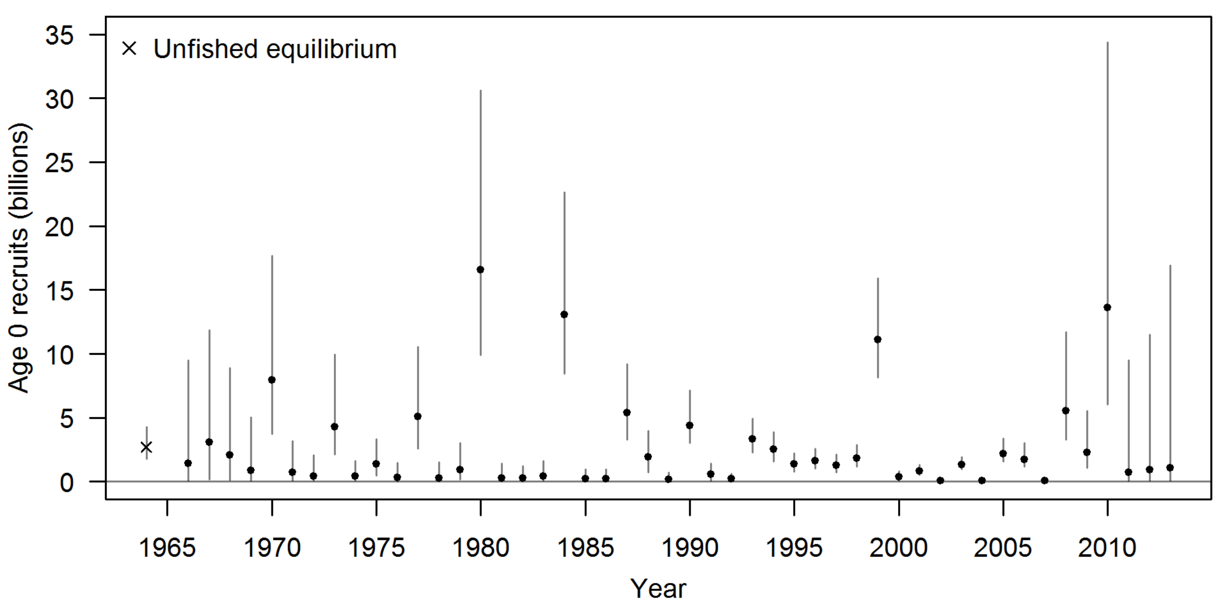


Figure 25: Posterior age-0 recruitment time-series for the base-case model with 95% posterior credibility intervals.

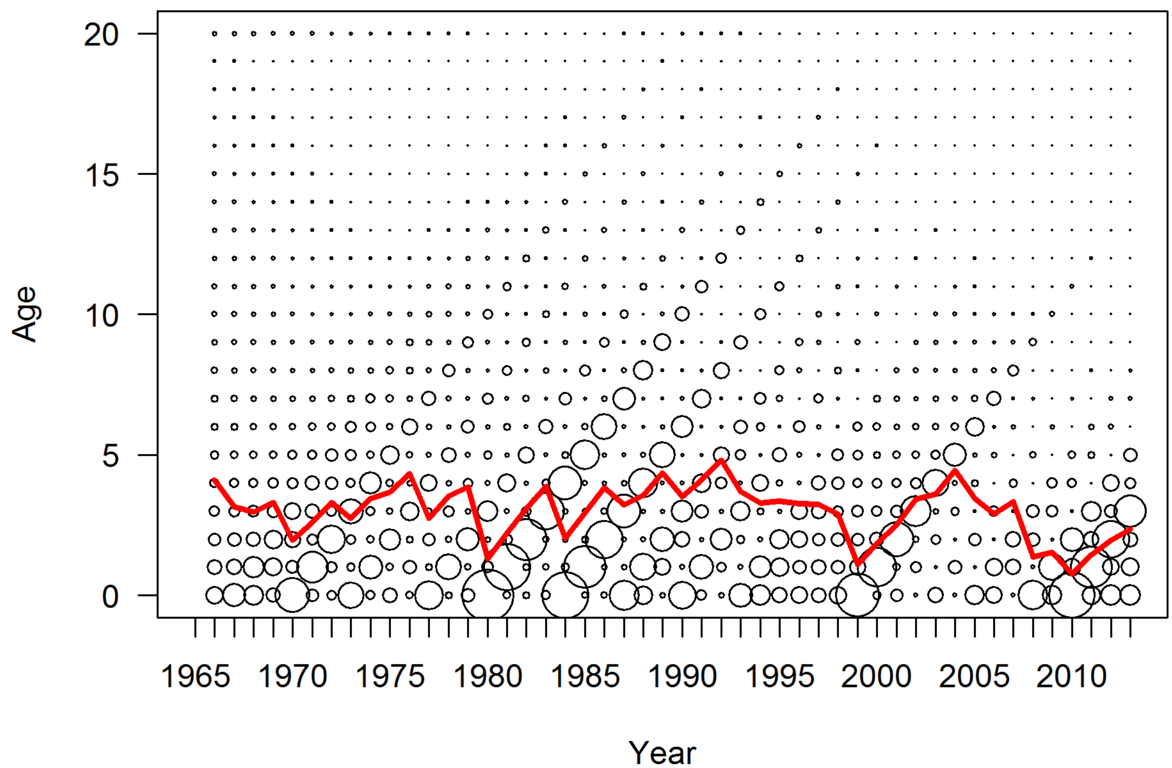


Figure 26: Estimated numbers at age (MLE) from the base-case model. Solid line indicates the average age during the time-series.

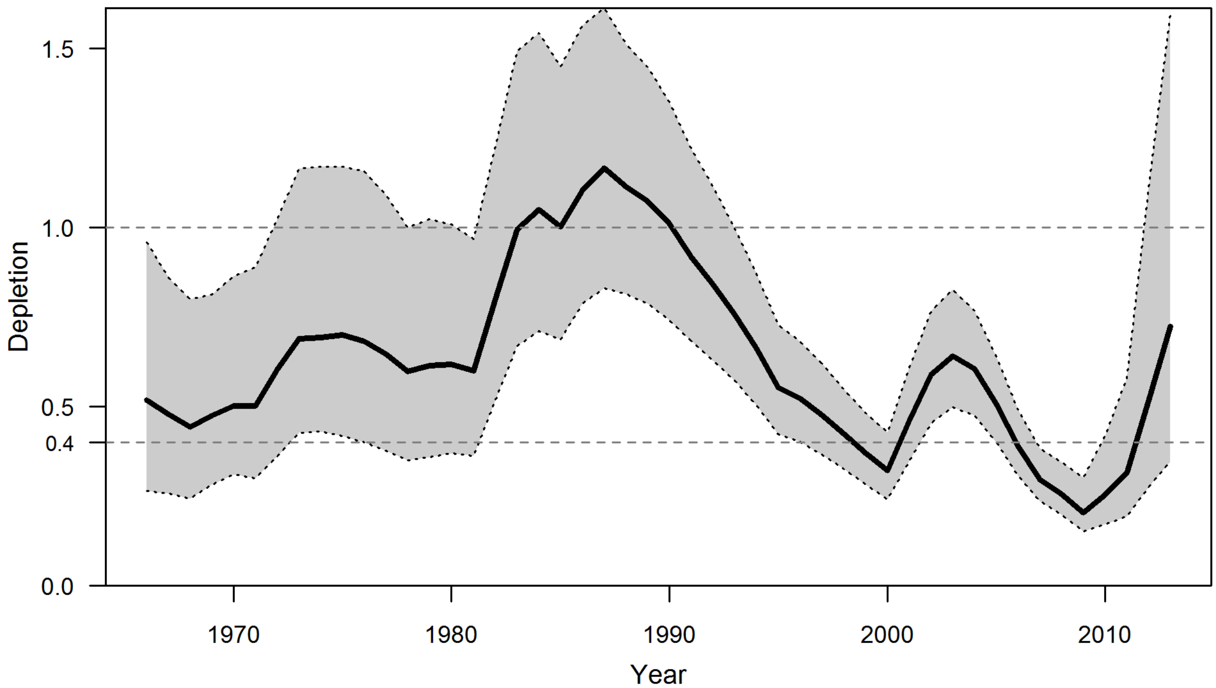


Figure 27: Time-series of posterior relative depletion with 95% posterior credibility intervals for the base model.

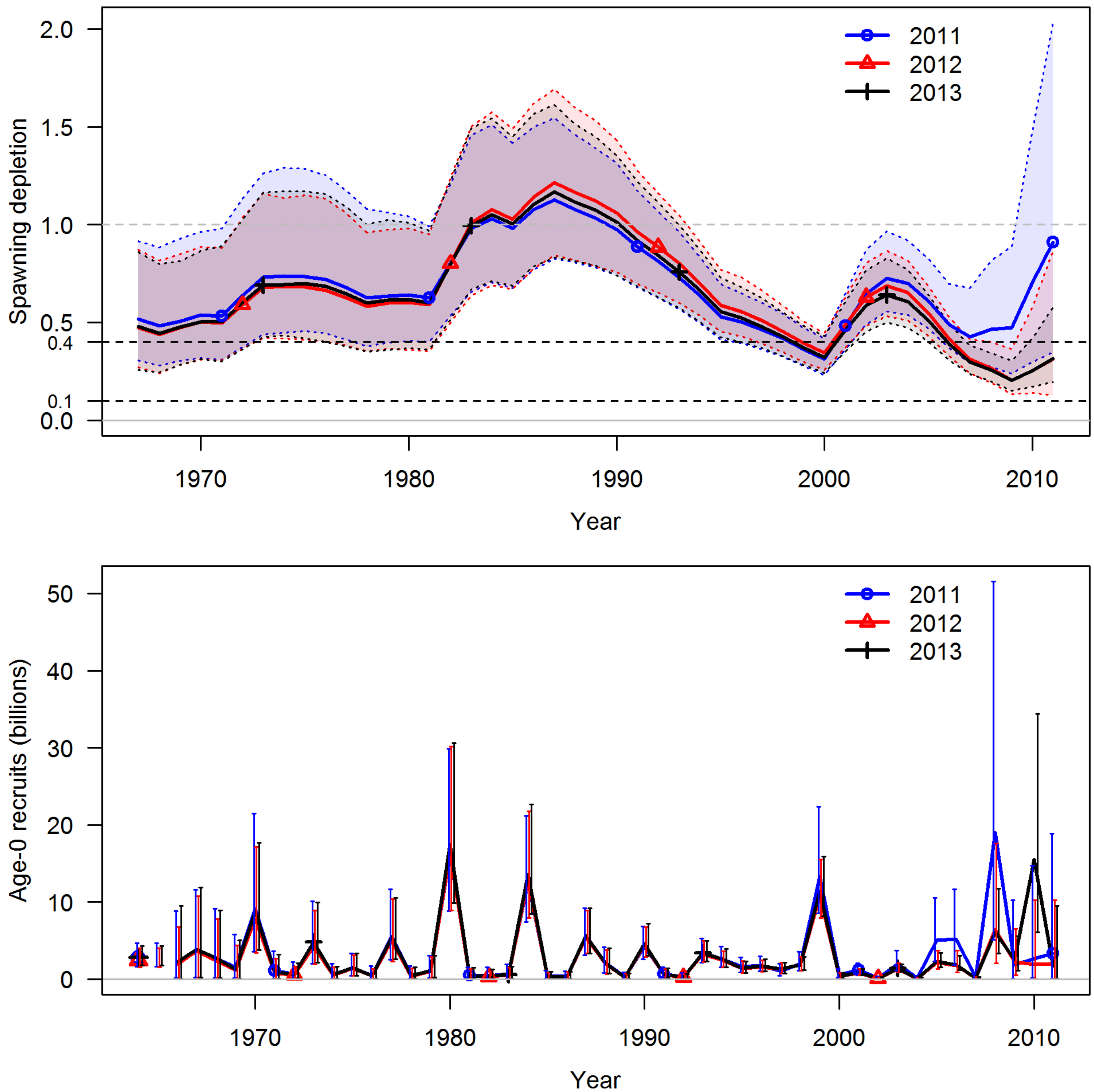


Figure 28: Estimated depletion and recruitments up to 2011, with 95% posterior credibility intervals, for the base assessment models from 2011, 2012, and 2013.

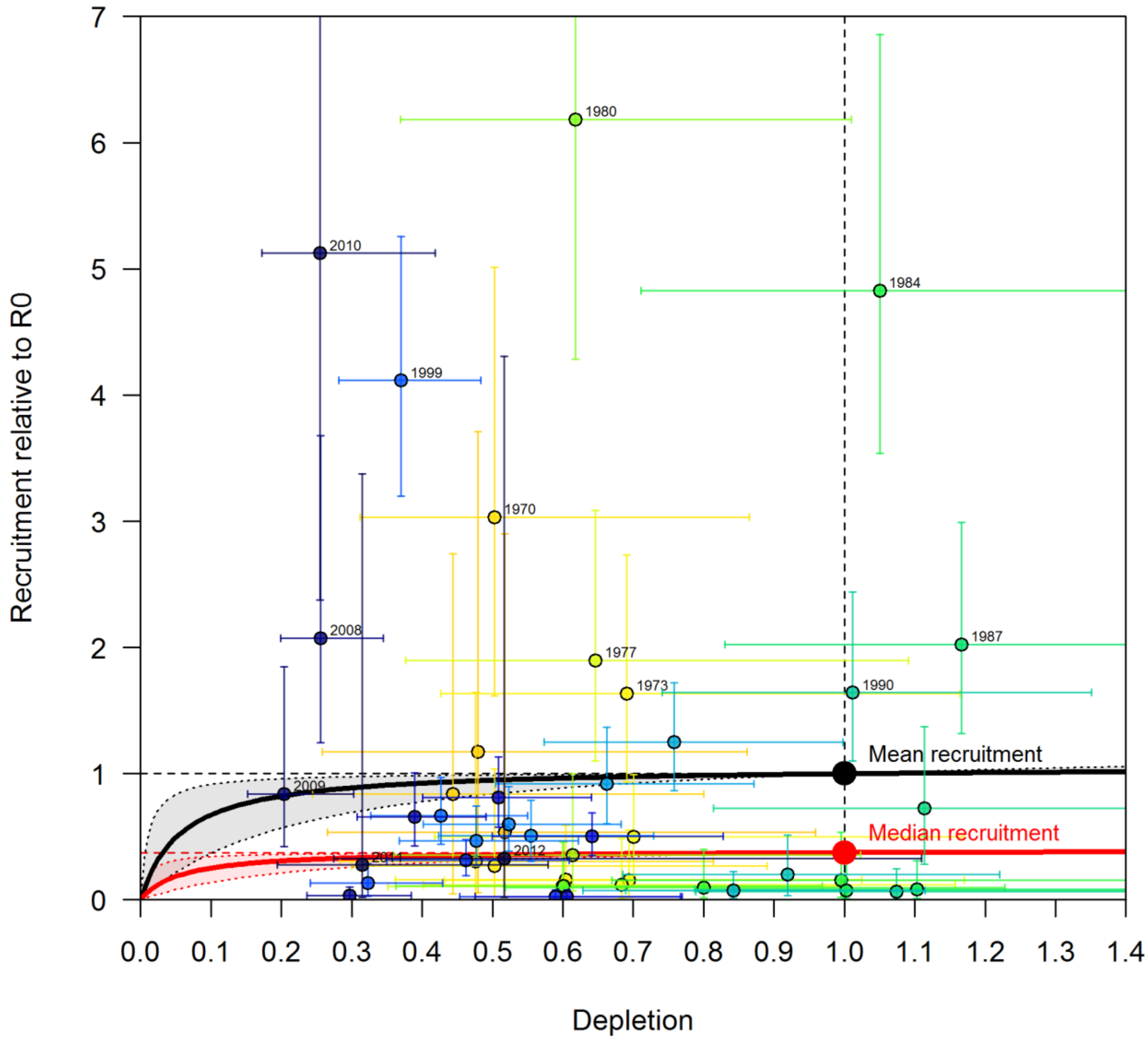


Figure 29: Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. The thick solid black line indicates the central tendency (mean) and the red line the central tendency after bias correcting for the log-normal distribution (median).

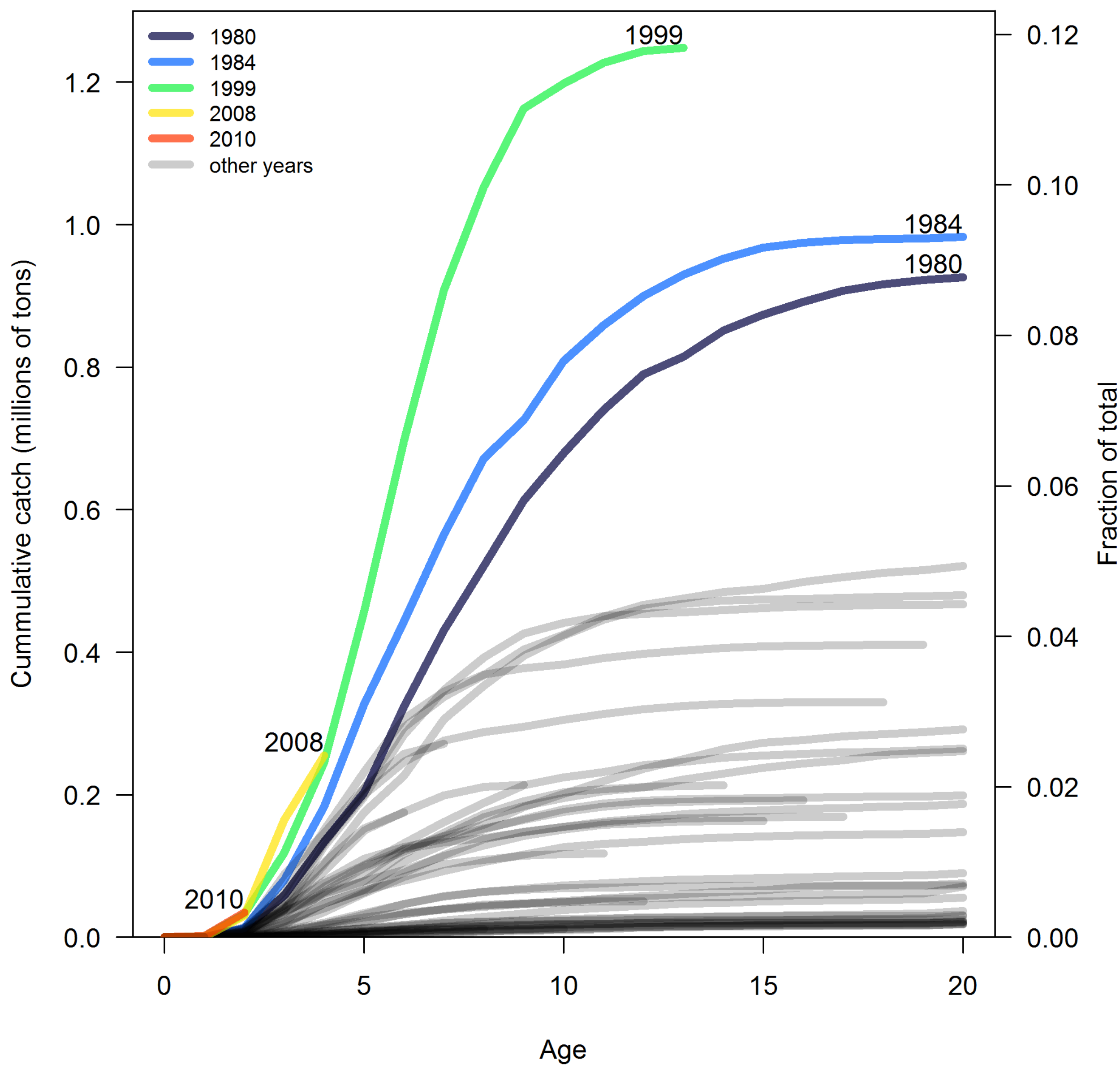


Figure 30: Model estimates of cumulative catch-at-age of each cohort. Cumulative catch in millions of metric tons is shown on the left axis and the percentage of the approximately 10 millions metric tons harvested since 1966 is shown on the right axis.

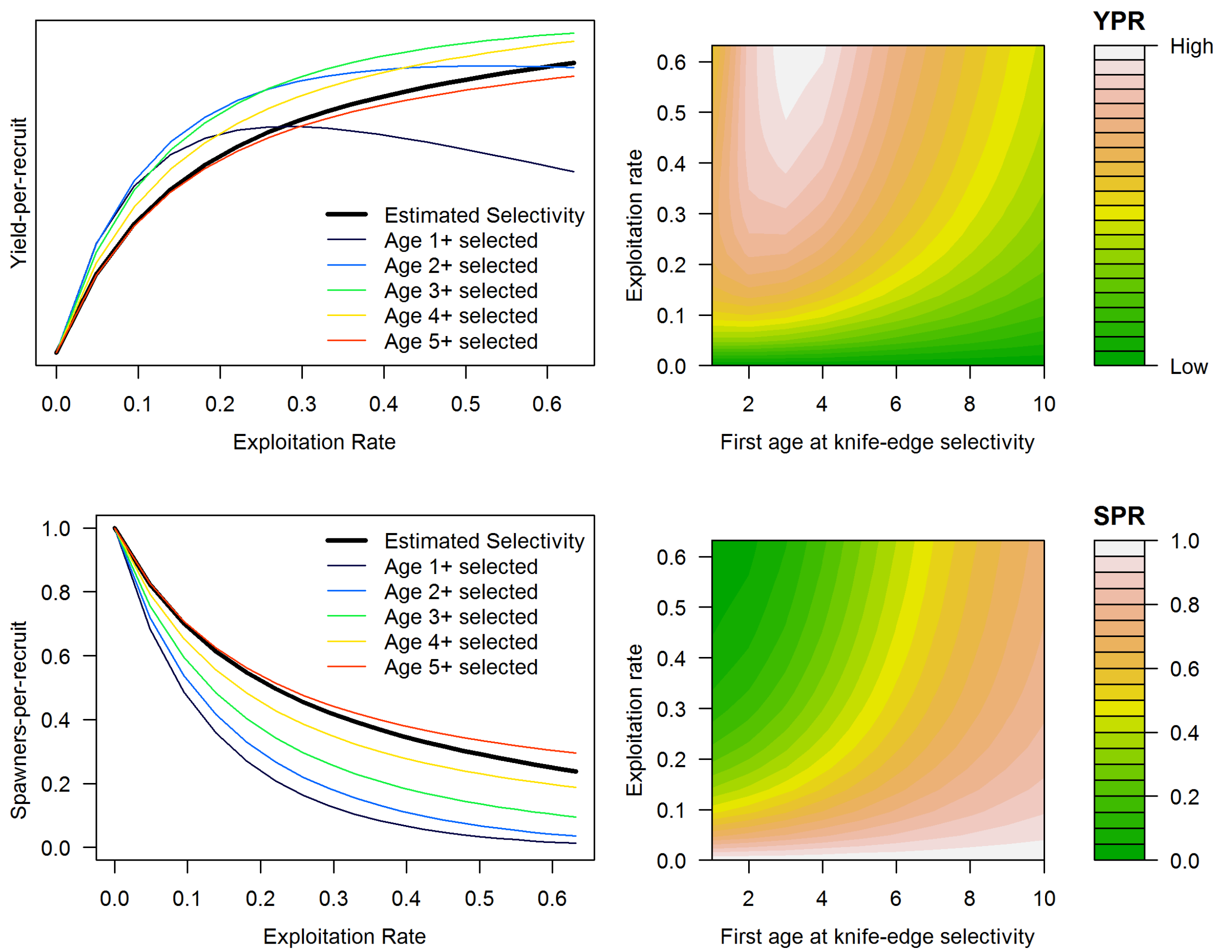


Figure 31: Equilibrium yield-per-recruit (top panels) and spawner-per-recruit (bottom panels) for Pacific hake using the estimated natural mortality from the base Bayesian model. Estimated selectivity is also from the base model, otherwise knife-edge selectivity was used.

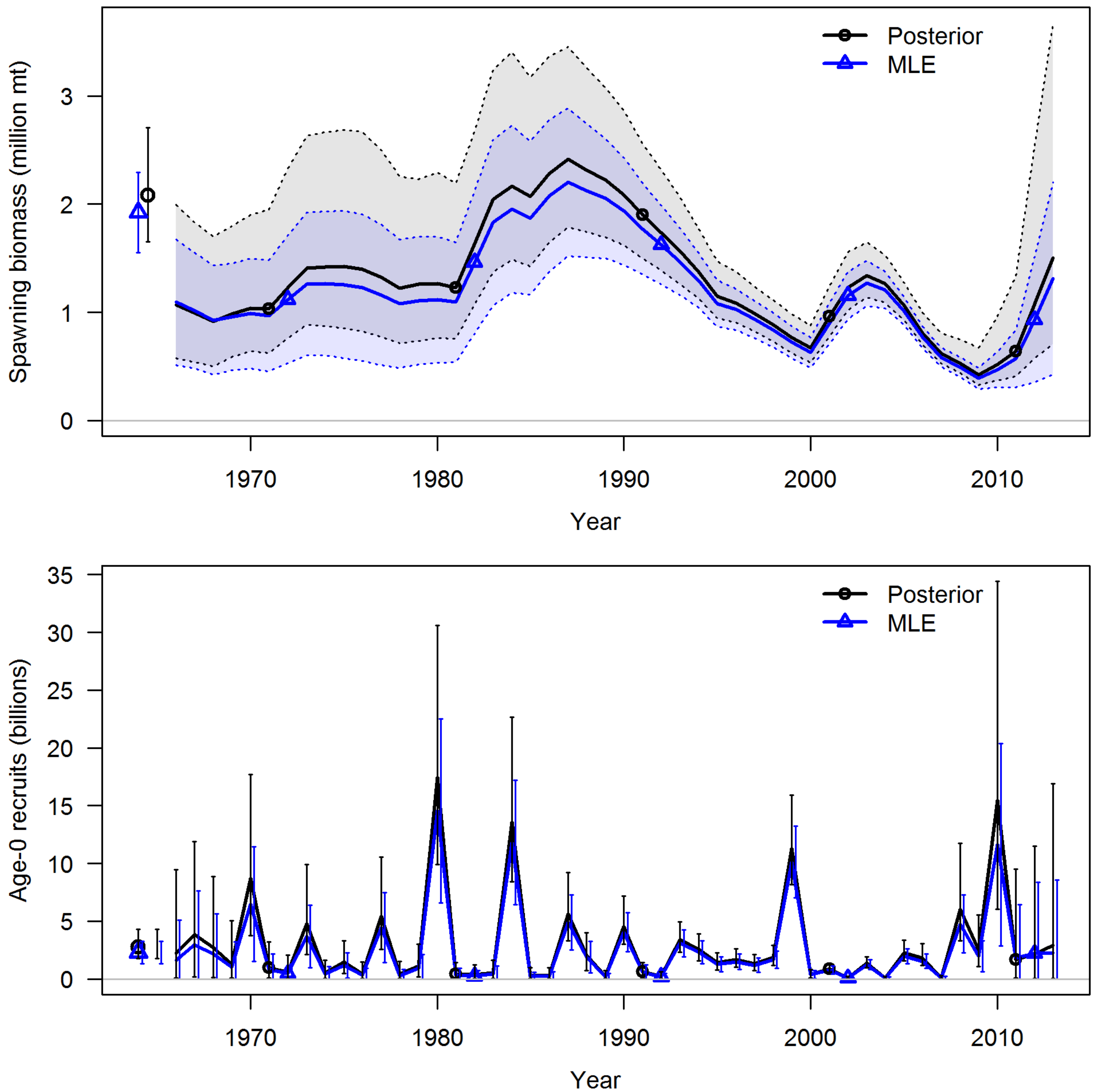


Figure 32: Comparison of MLE and Bayesian estimates (posterior) of spawning biomass and recruitment, with 95% asymptotic confidence intervals for the MLE, and 95% posterior credibility intervals for the Bayesian results.

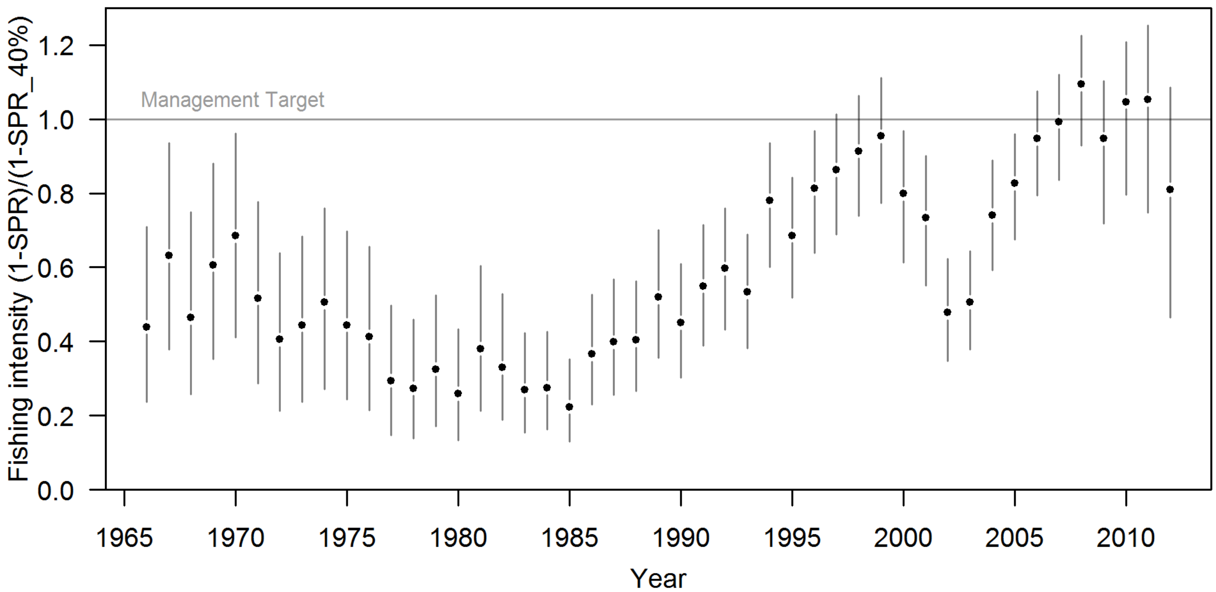


Figure 33: Trend in fishing intensity (relative SPR) through 2012.

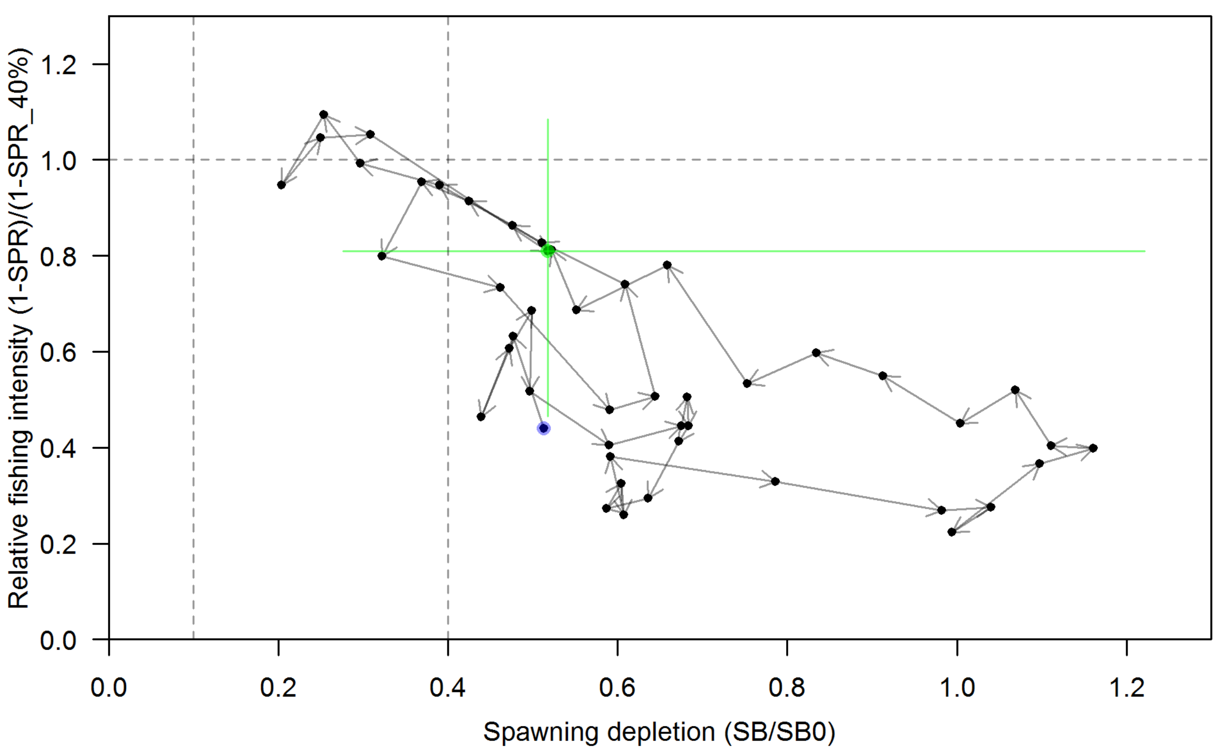


Figure 34: Temporal pattern (phase plot) of posterior median fishing intensity vs. relative posterior median spawning depletion through 2012. The blue circle indicates the start of fishing in 1966. The green circle denotes 2012 and the 95% posterior credibility intervals are shown along both axes. The arrows connects years through the time-series and the dashed lines indicate the fishing intensity target on the y-axis and the control rule limits along the x-axis (10% and 40%).

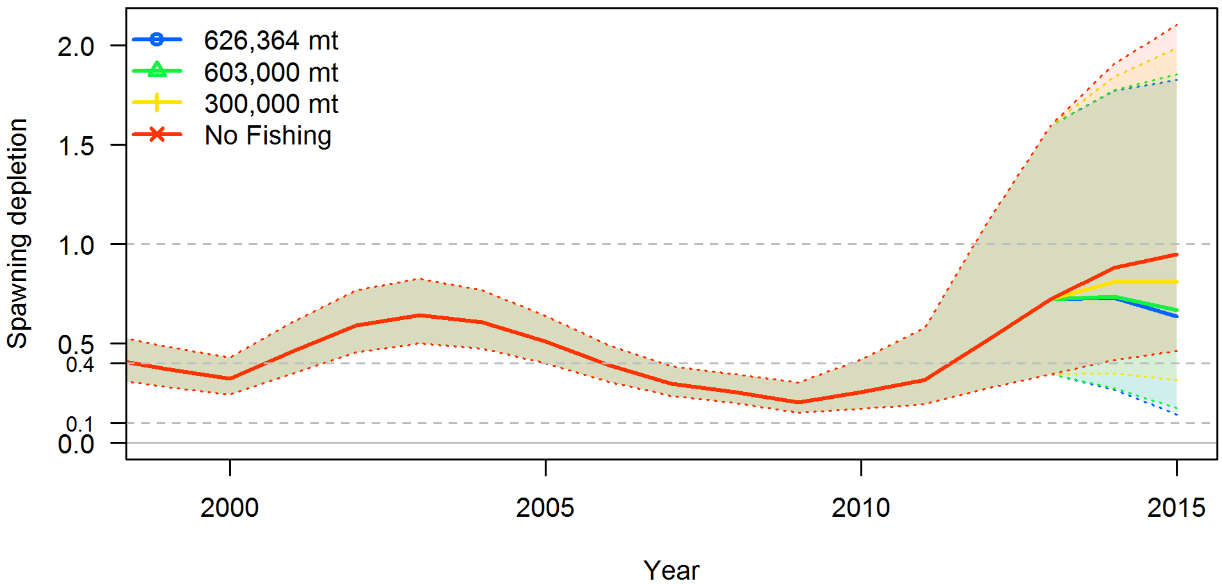


Figure 35: Time-series of estimated spawning depletion to 2013 from the base-case model, and forecast trajectories to 2015 for several several management options from the decision table, with 95% posterior credibility intervals. The 2013 catch of 626,364 mt was calculated using the default harvest policy, as defined in the Agreement, which updates future catches (see Table 13)..

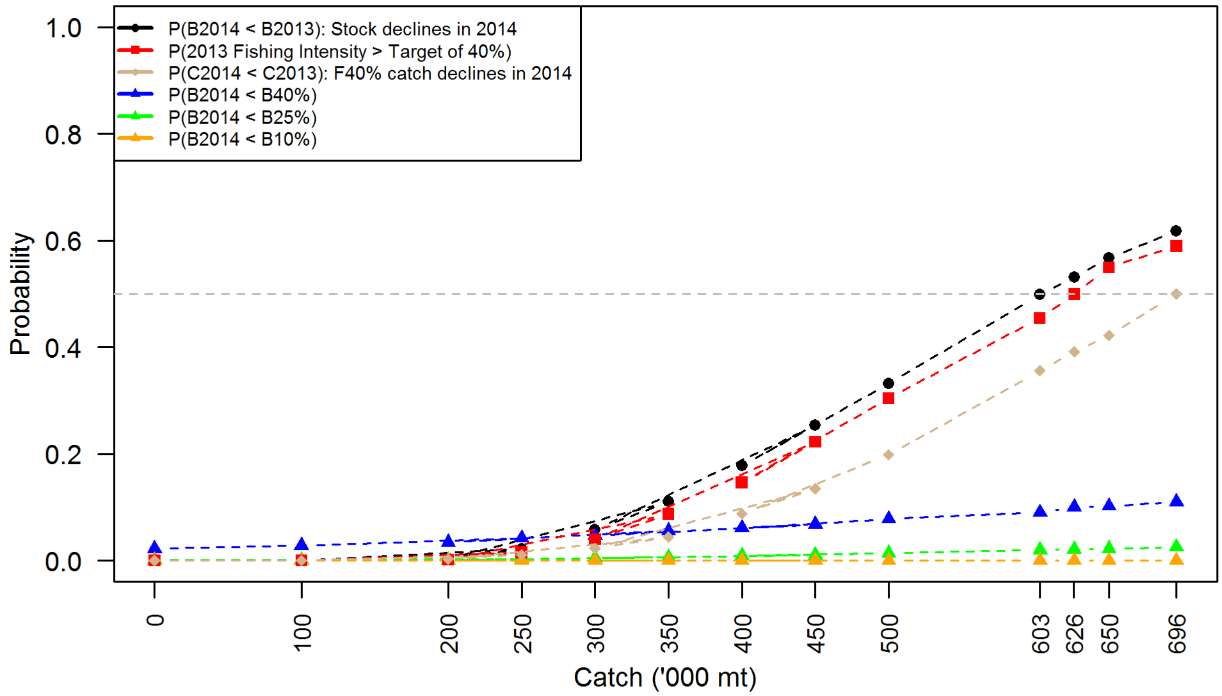


Figure 36: Probabilities of various management metrics given different catch alternatives. Catch alternatives are described in Table 13. The points show these specific catch levels and lines interpolate between the points.

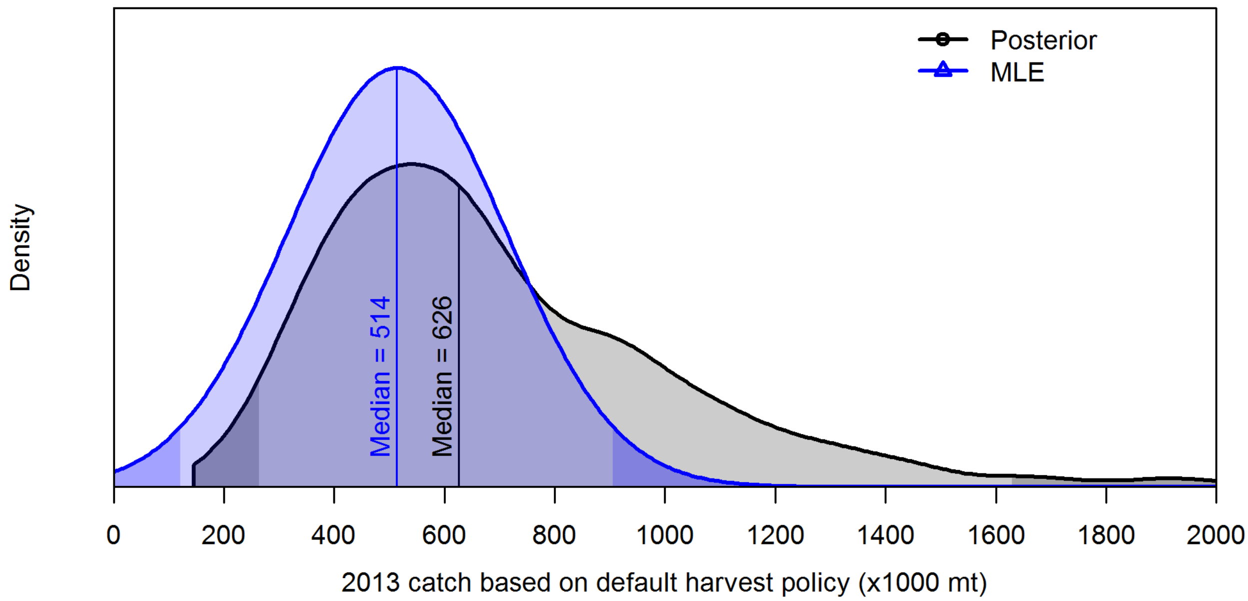


Figure 37: The MLE prediction and the posterior distribution of 2013 catch using the default harvest policy ($F_{40\%}$-40:10).

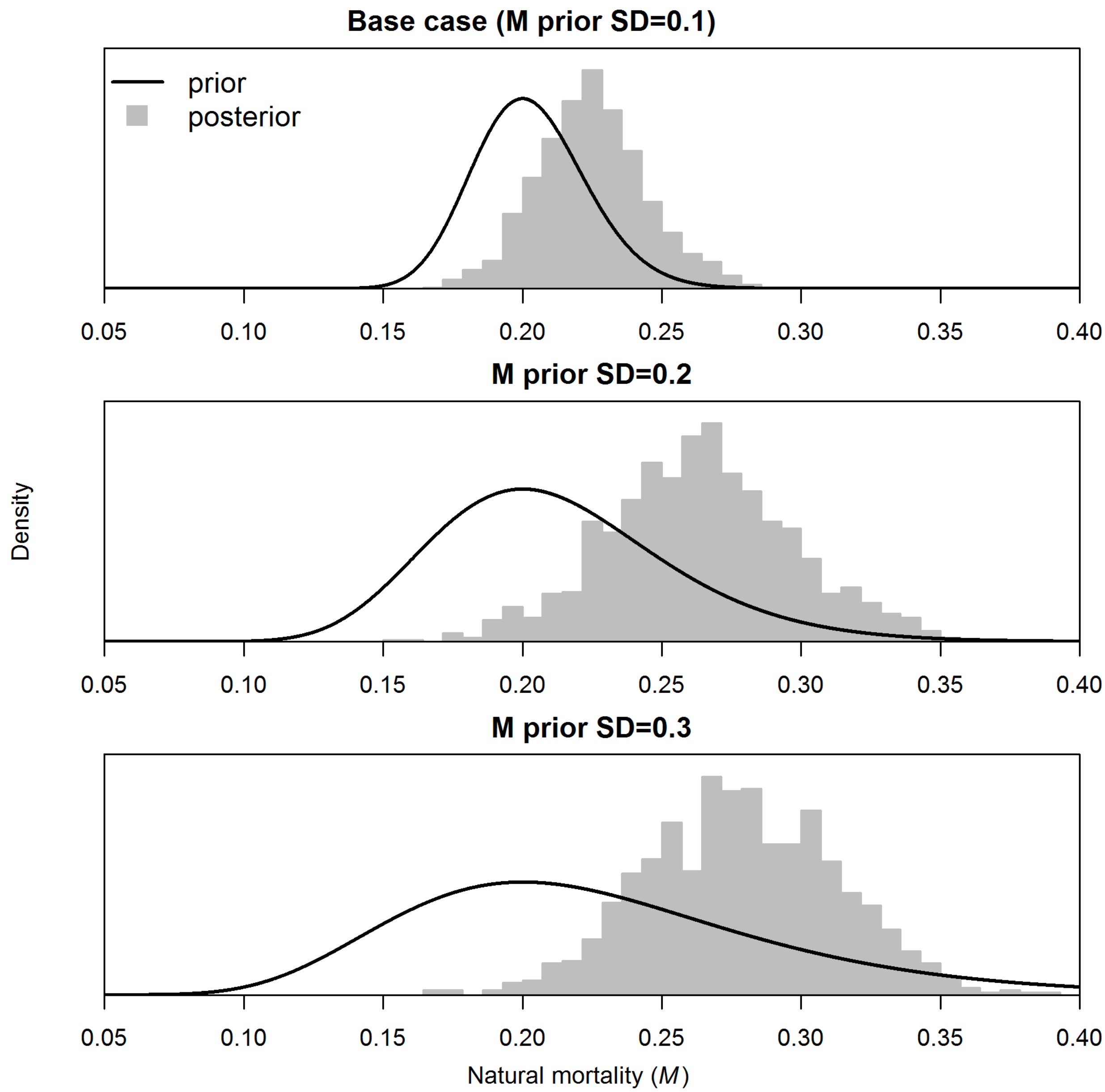


Figure 38: Alternative prior distributions for natural mortality (black lines), with resulting posterior distributions (gray histograms).

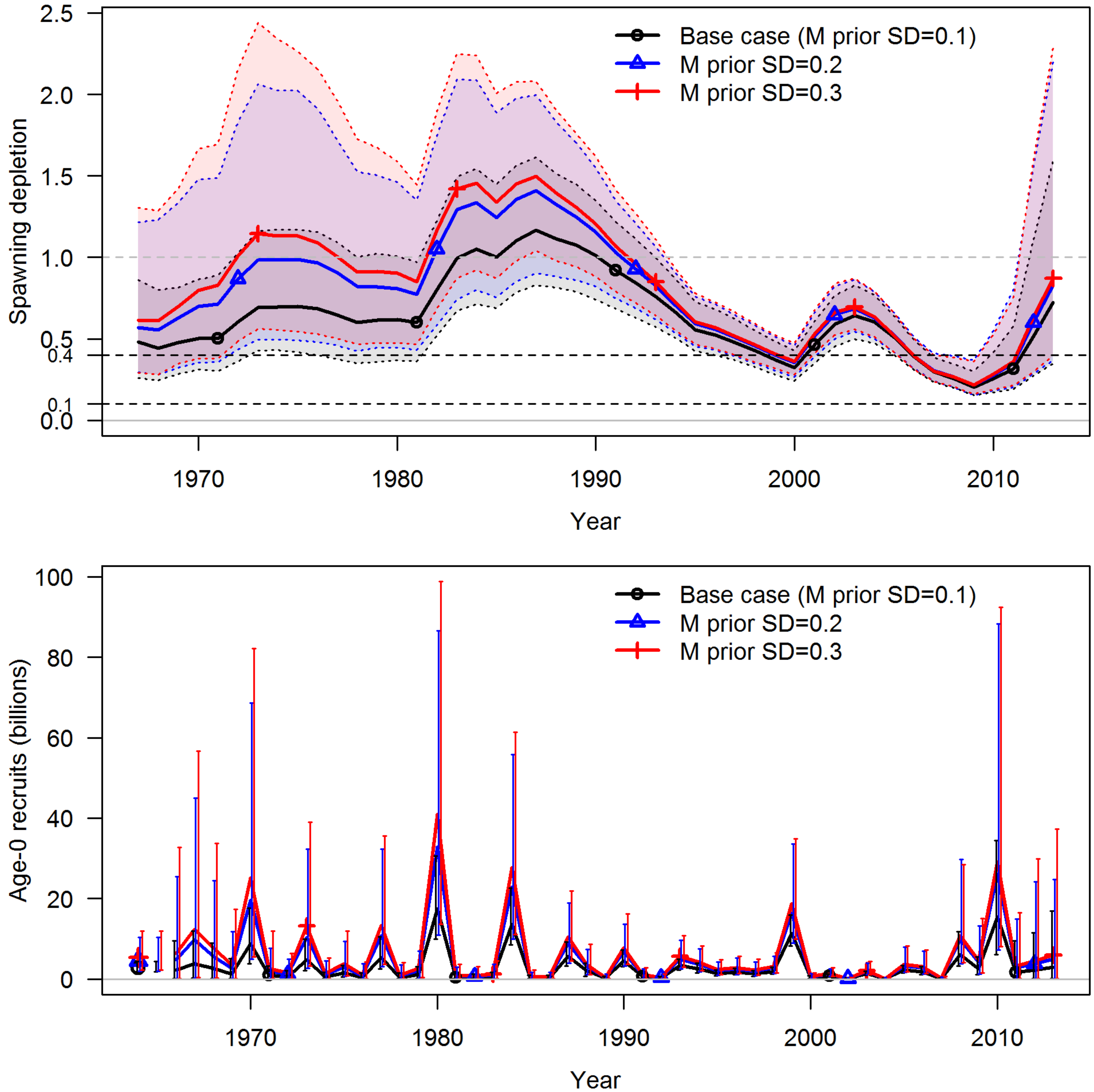


Figure 39: Sensitivity analysis to the mean of the width of the natural mortality prior.

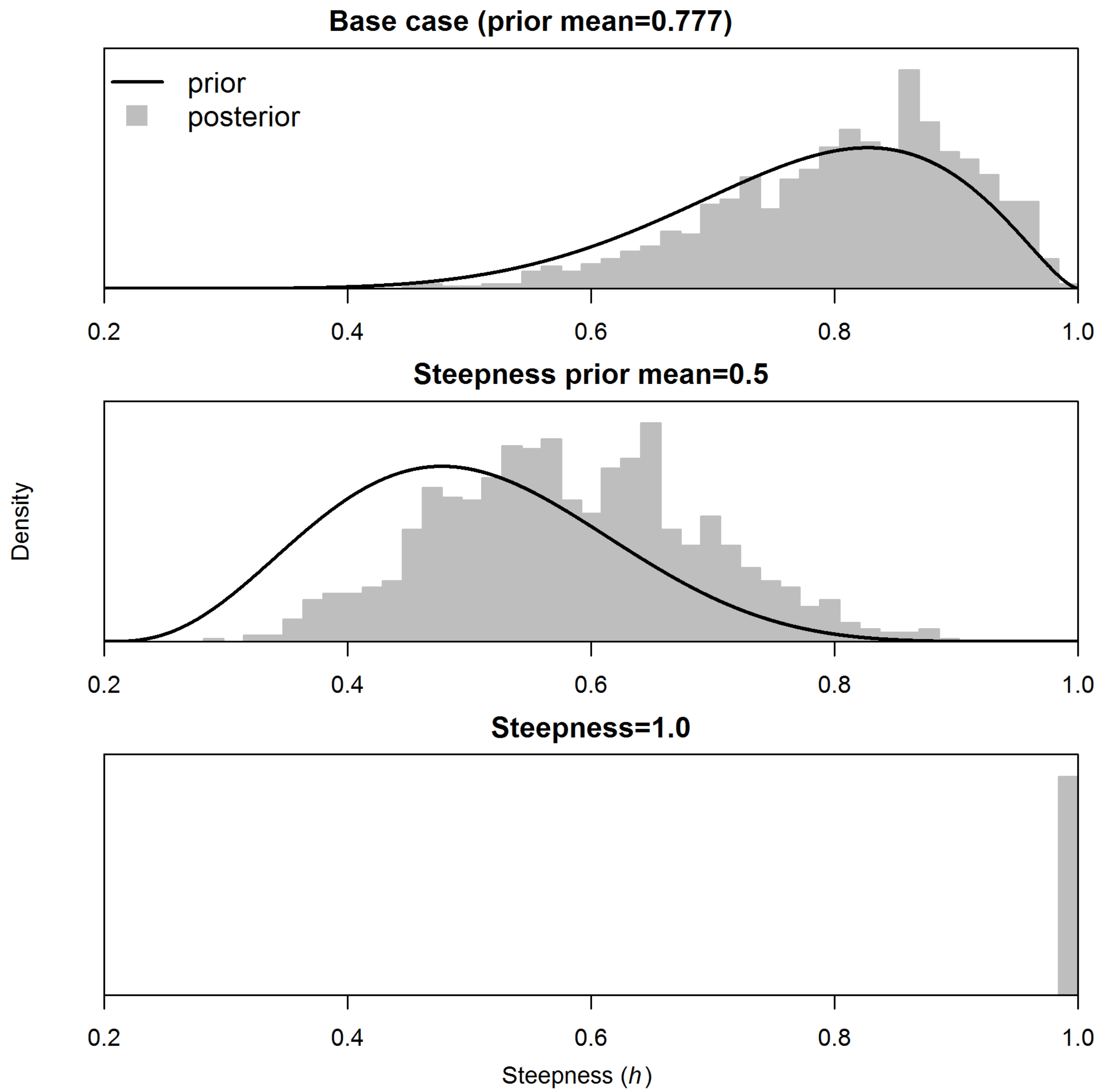


Figure 40: Alternative prior distributions for steepness (black lines), with resulting posterior distributions (gray histograms).

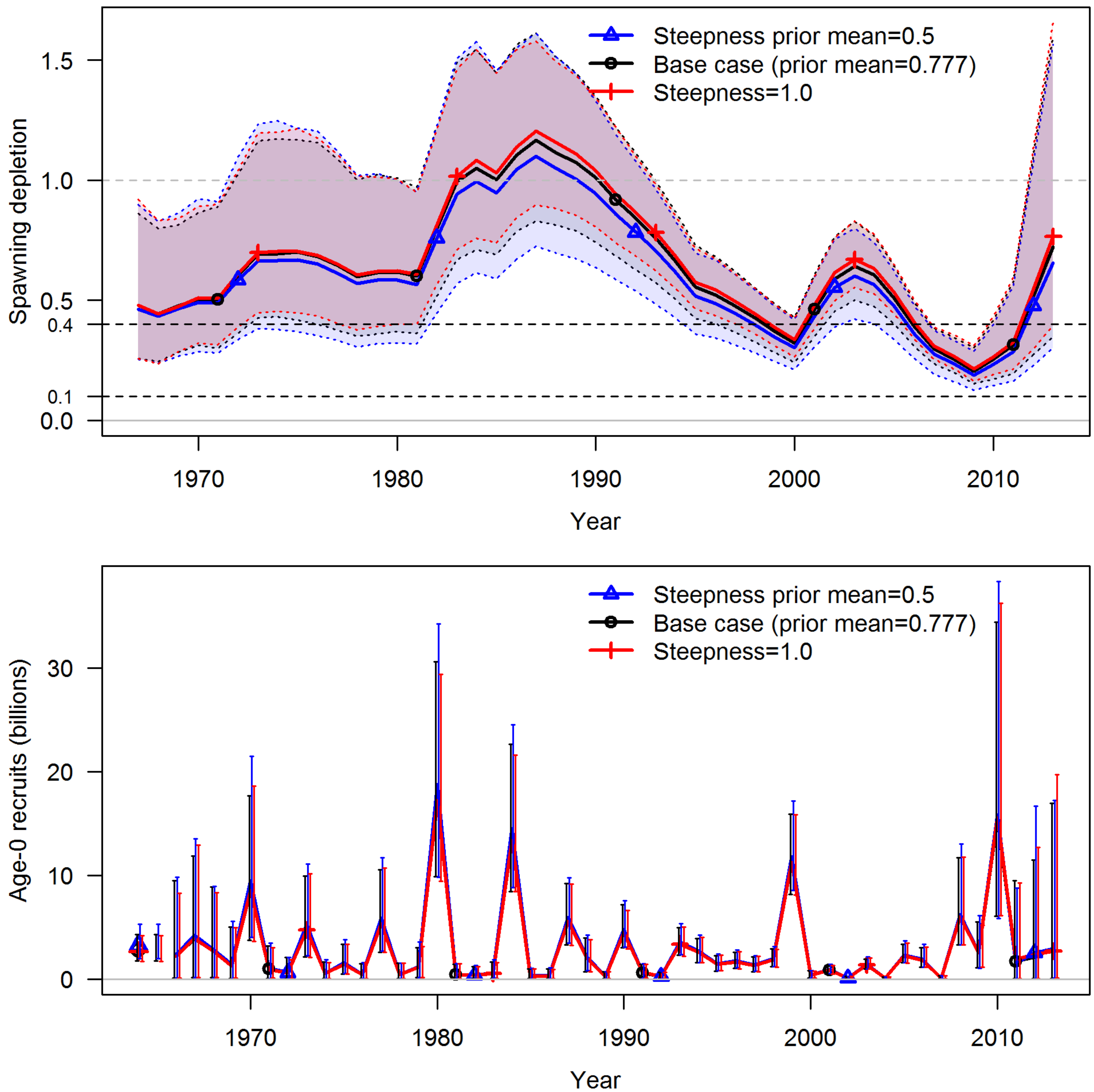


Figure 41: Sensitivity analysis to the mean of the steepness prior.

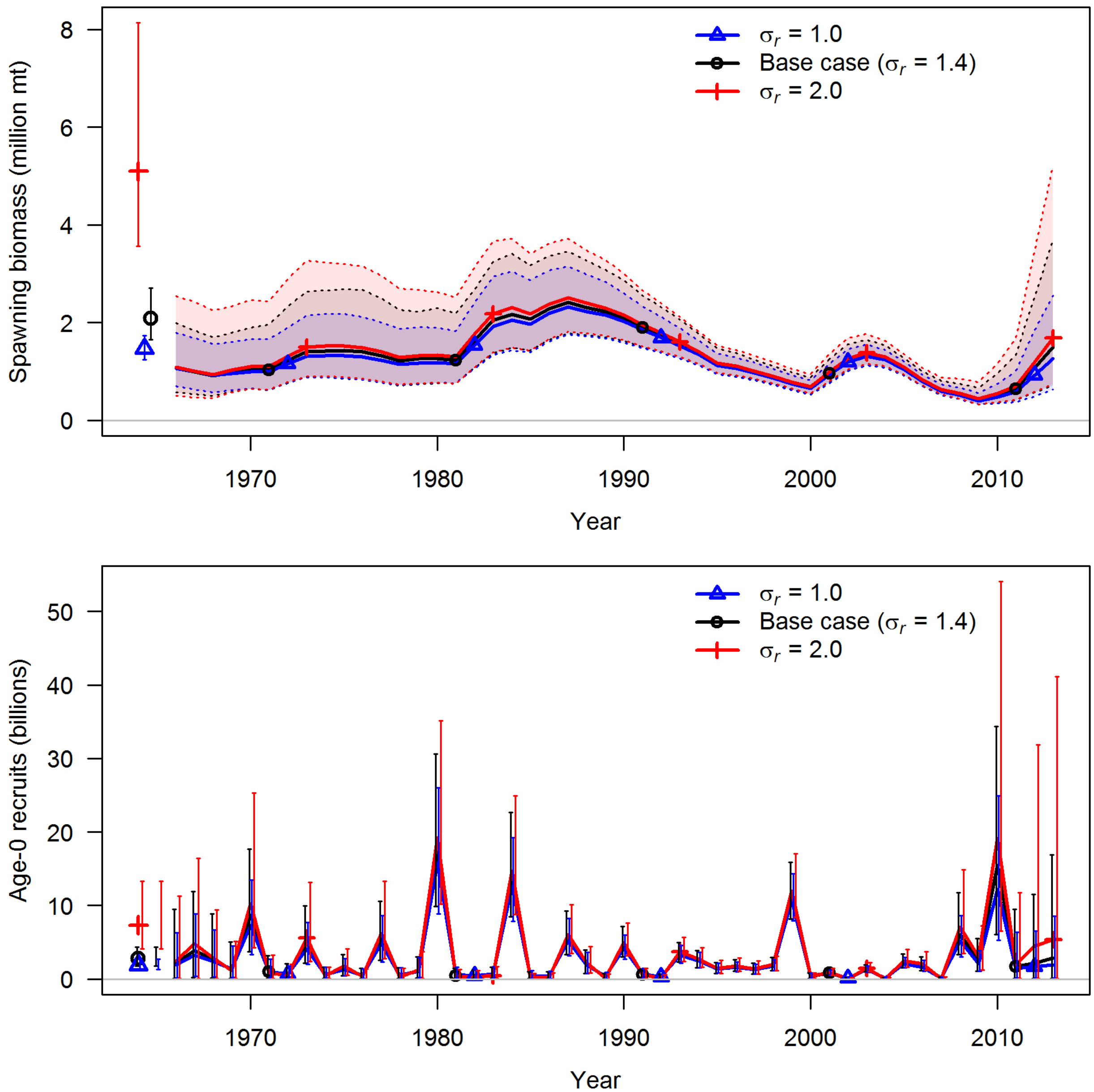


Figure 42: Sensitivity analysis to the alternative assumptions about the standard deviation of recruitment variability (σ_R). Note that upper plot shows spawning biomass rather than depletion.

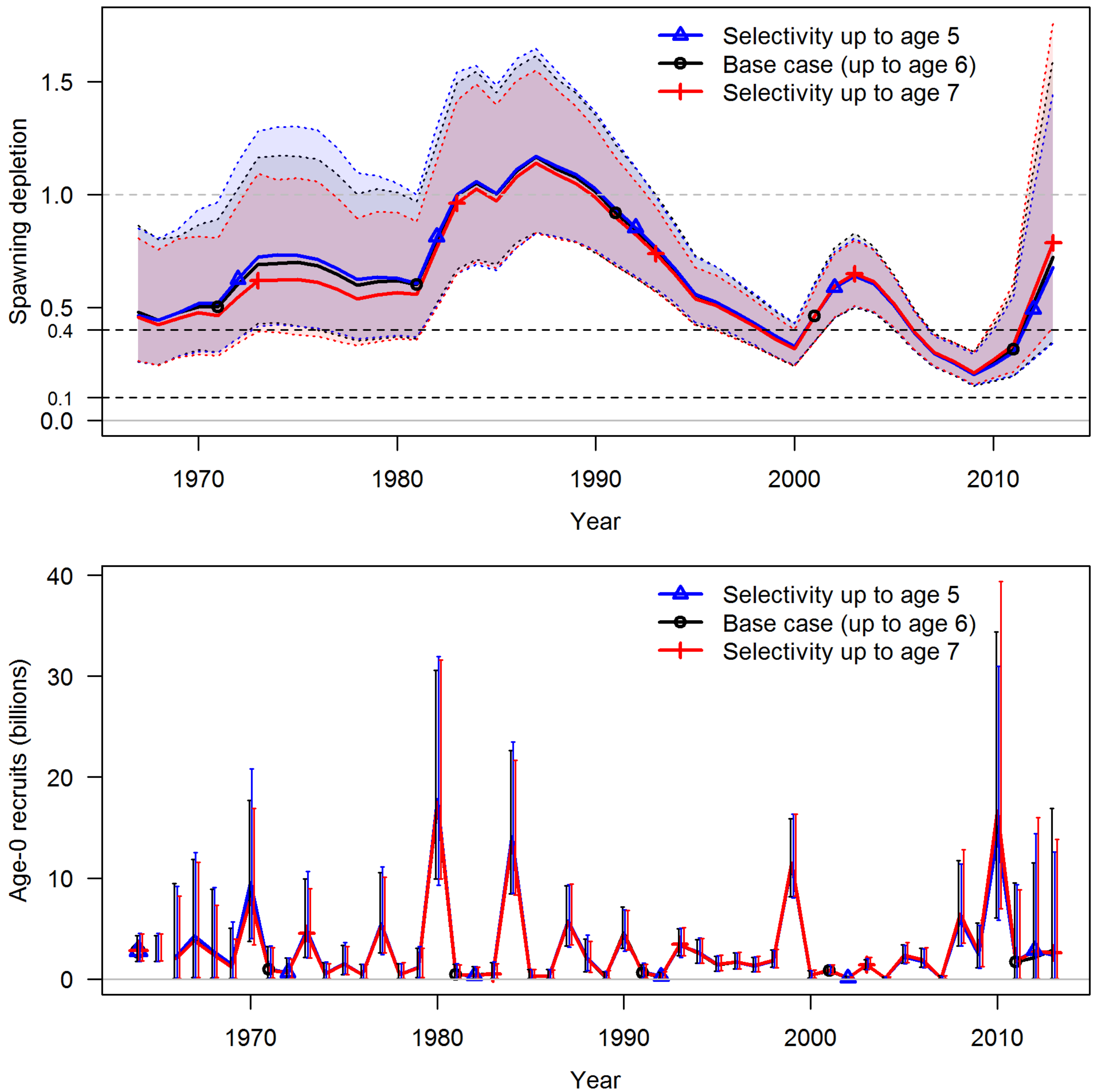


Figure 43: Sensitivity analysis to the range of ages for which selectivity is estimated.

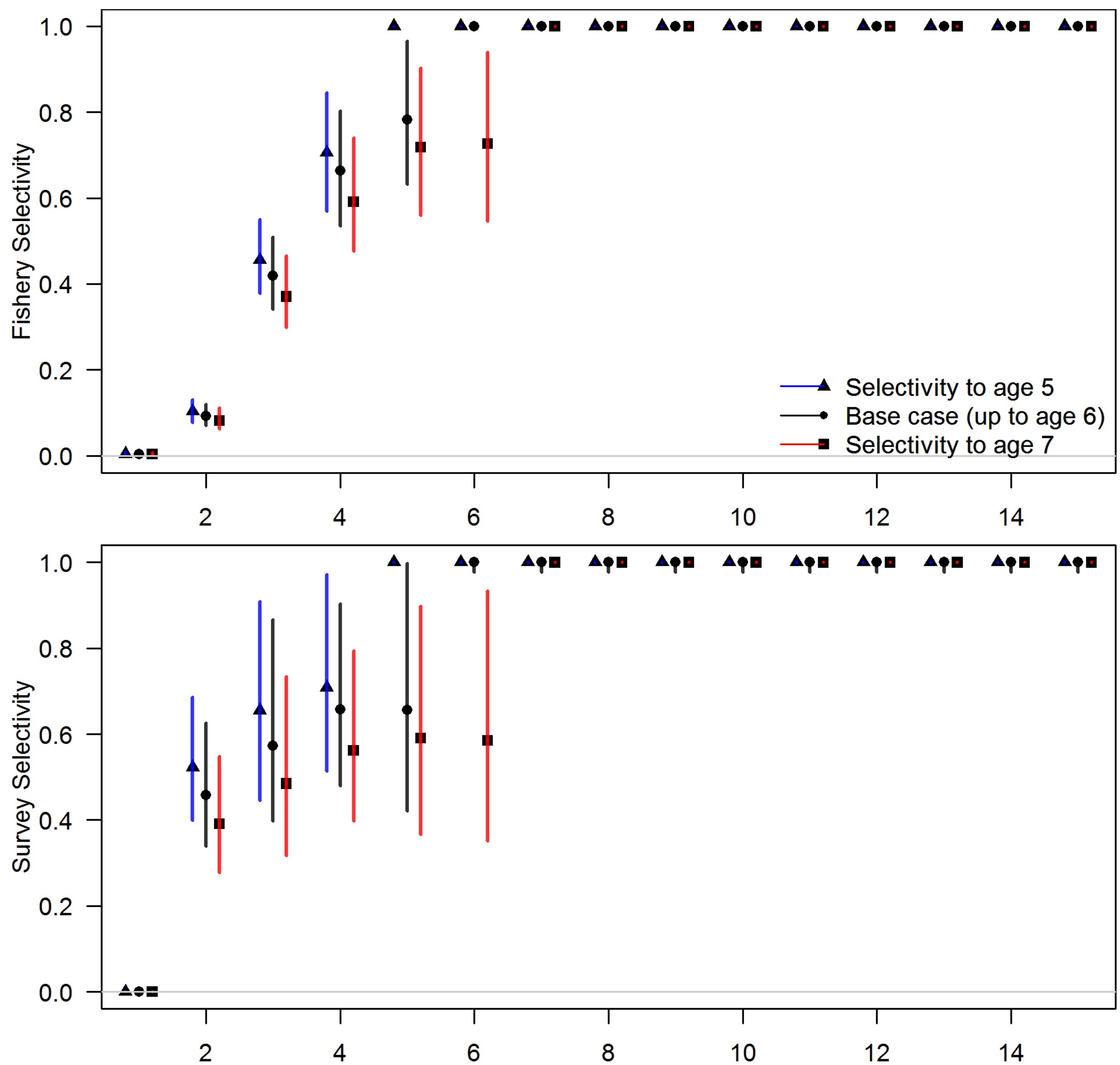


Figure 44: Estimated selectivity at age with 95% posterior credibility intervals for the base case (black) and estimating selectivity up to age 5 or age 7 (blue and red, respectively). Fishery selectivity is shown in the top panel and survey selectivity is shown in the bottom panel.

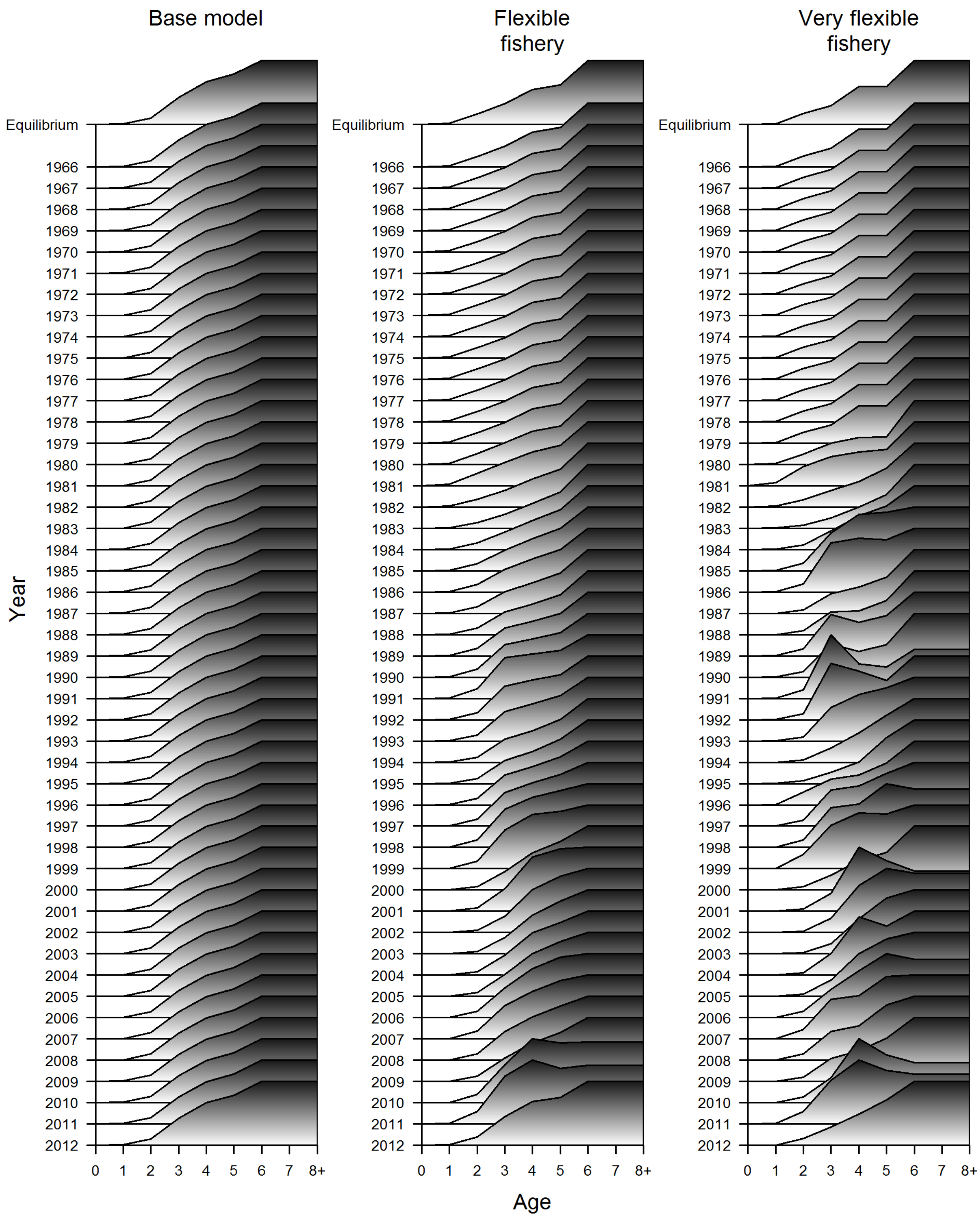


Figure 45: Estimated fishery selectivity for each year of the model under different assumptions about the flexibility of the changes.

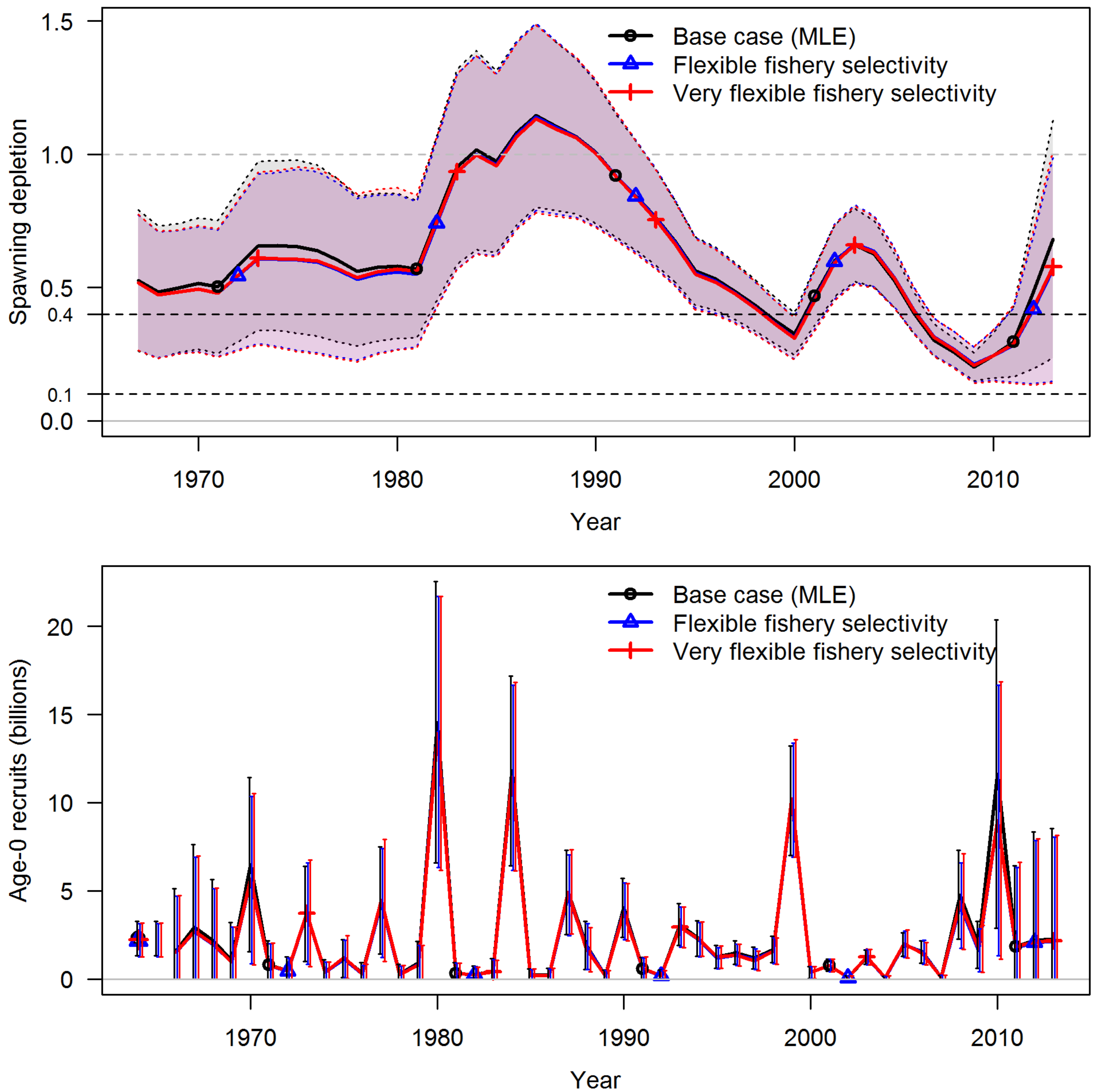
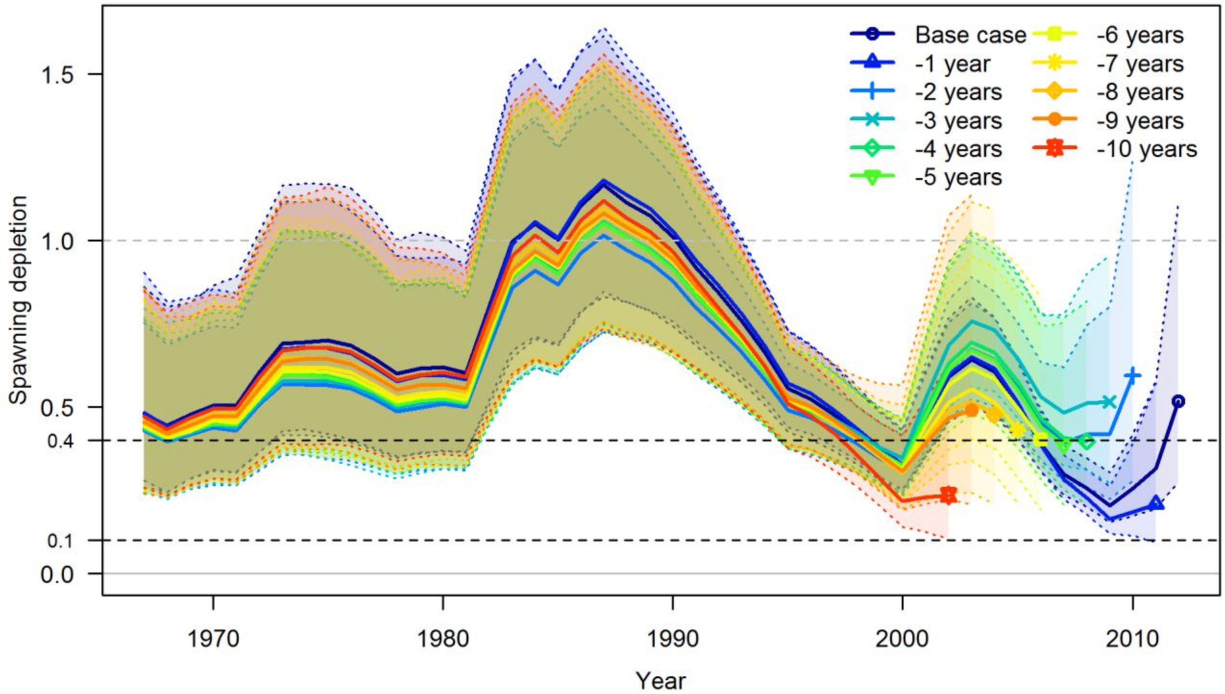


Figure 46: Sensitivity analysis to allowing fishery selectivity to change from year to year.



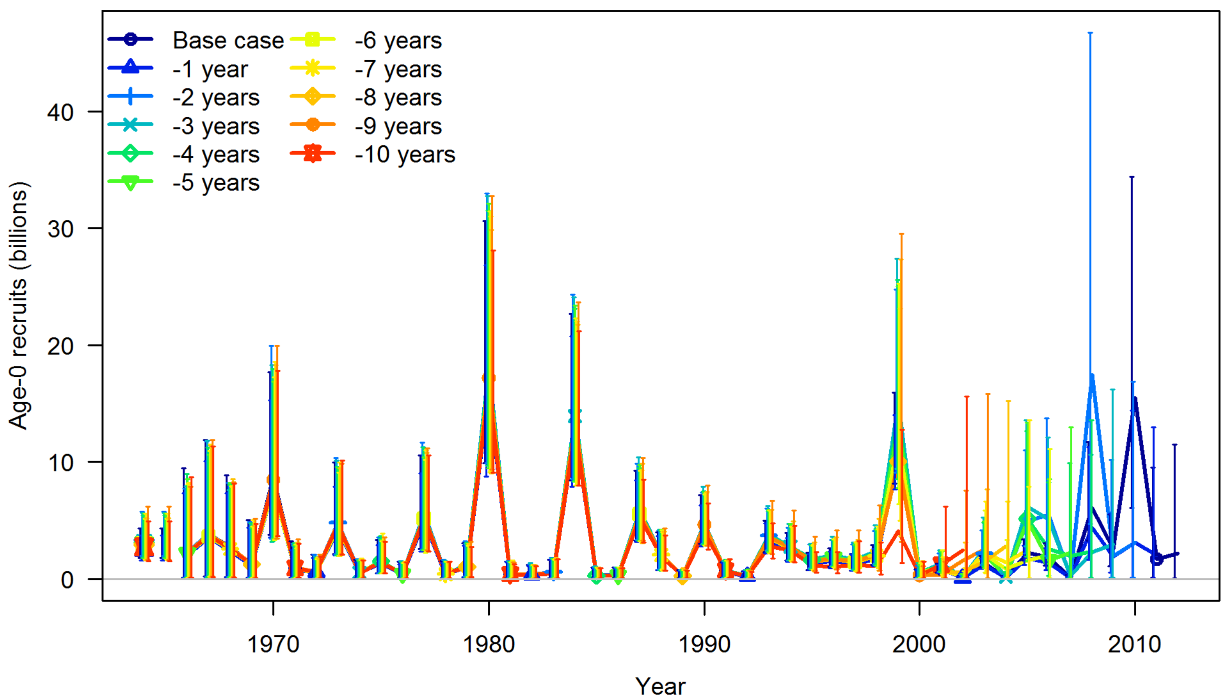


Figure 47: Retorspective analysis over the last ten years.

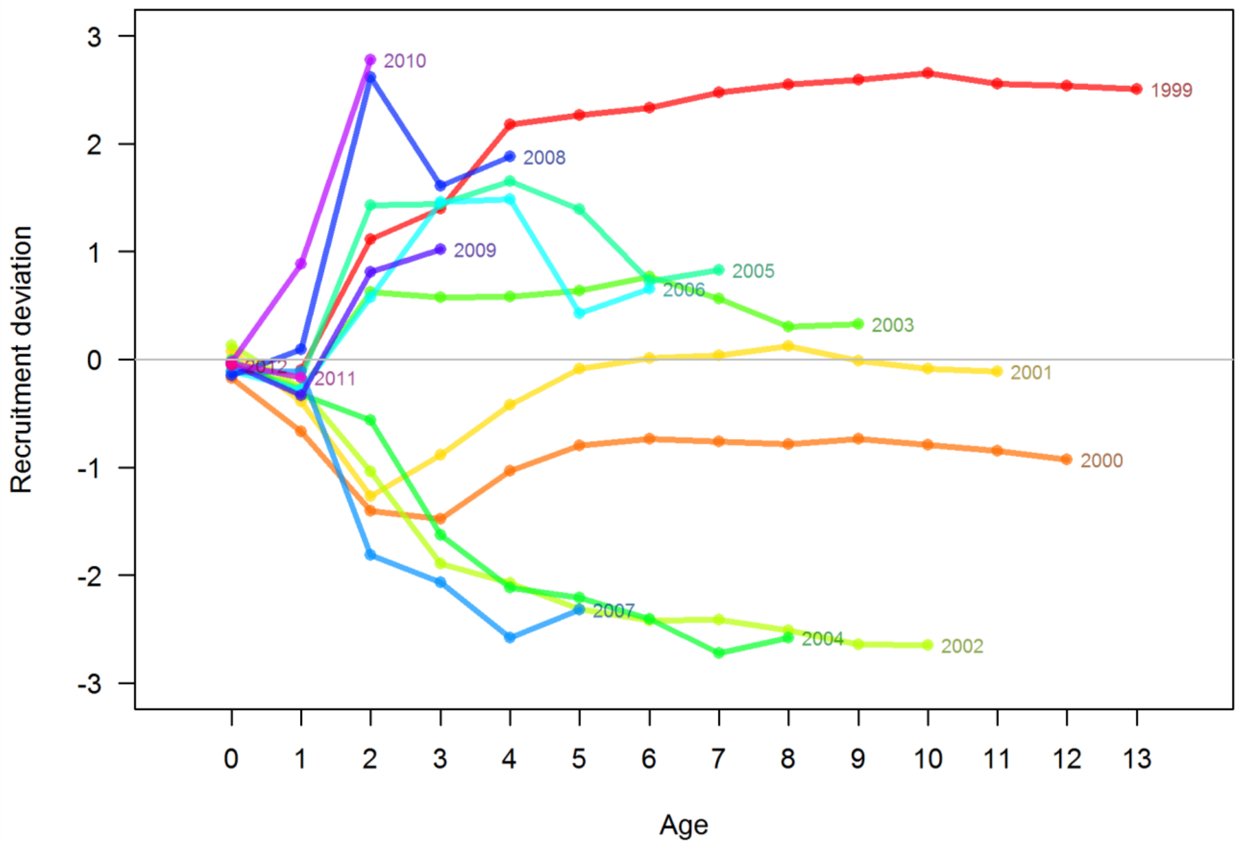


Figure 48: Retrospective analysis of recruitment estimates over the last twelve years. Lines represent estimated deviations in recruitment for cohorts starting in 1999 (with cohort birth year marked at the right of each line). Values are estimated in models with data available only up to the year in which each cohort was a given age. Recruitment deviations are log-scale difference between estimated recruitment and spawner-recruit expectation.

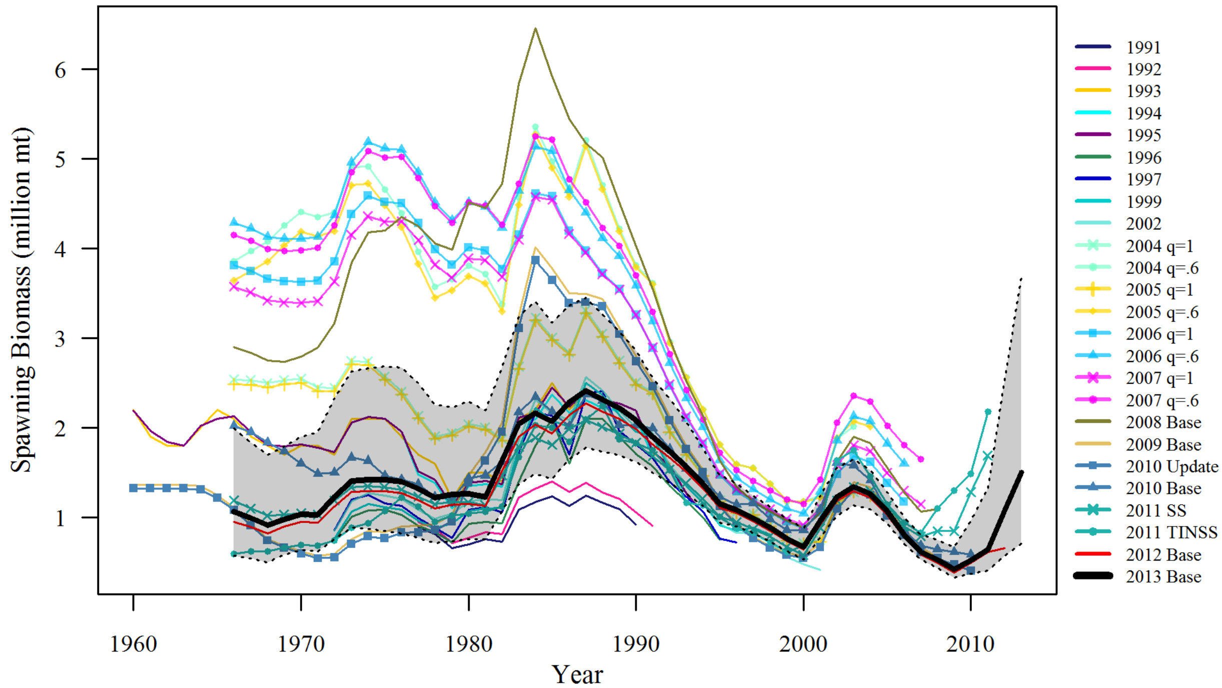


Figure 49: Posterior medians for the base 2013 assessment model (thick black line with 95% posterior credibility intervals notated with dashed lines and shading) in a retrospective comparing model results from previous stock assessments since 1991 (updates in 1998, 2000, 2001, 2003 are not included).

Appendix A. Management Strategy Evaluation (MSE)

Appendix A.1. Introduction

The Agreement between the Government of the United States of America and the Government of Canada on Pacific Hake/Whiting (The Agreement) was officially implemented in 2011. Part of this agreement defines a harvest control rule for setting Pacific Hake catches. The harvest control rule specifies an $F_{40\%}$ fishing mortality rate target combined with a 40:10 adjustment (default harvest policy). At equilibrium, the $F_{40\%}$ fishing mortality rate would reduce spawners-per-recruit (SPR) to 40% of the unfished equilibrium level. Target fishing mortality is then reduced linearly when the estimated spawning biomass depletion (i.e., SB/SB_0) is between 40% and above 10% of the estimated unfished level and then is set to zero when the estimated population falls below 10%. This harvest control rule is commonly referred to as the $F_{40\%}$-40:10 rule and it has been applied by the Pacific Fisheries Management Council since 1998 (PFMC 1998).

For Pacific Hake, estimates of depletion used for applying the 40:10 rule, and the corresponding predictions of sustainable harvest levels, have been very volatile. Harvest levels have changed as estimates have varied with data updates, but also because of several alternative assessment models that have been used since Pacific Hake assessments began (see Fig. 45 JTC (2012)). For example, the 2010 prediction of a sustainable harvest level was 455,550 mt. When forecasts were completed in 2011 using only commercial age-composition data, the model prediction increased to 973,700 mt. The high predicted 2011 biomass was followed by a 2011 acoustic survey biomass estimate that was the lowest in the survey index series; this led to a predicted sustainable harvest level from the 2012 assessment of 251,809 mt.

Large differences in the 2010 to 2012 predictions of sustainable harvest levels and the low 2011 survey biomass estimate produced at least two specific concerns for Pacific Hake management. The first concern was how well the $F_{40\%}$-40:10 rule performed at meeting conservation and yield objectives. Secondly, that the survey biomass was indicating an immediate conservation concern since it was the lowest ever observed since the survey began.

To deal with these concerns the Scientific Review Group (SRG) and the Joint Management Committee (JMC), bodies defined by The Agreement, recommended both a 2012 survey and a Management Strategy Evaluation (MSE). The 2012 survey was intended to help bolster the stock assessment's predictions, with the hope that an annual survey would provide more stock-status information than commercial age-composition data alone (the only data typically available in non-survey years). The MSE had two main objectives: i) to evaluate the expected performance of the $F_{40\%}$-40:10 rule and ii) evaluate the relative improvement that was gained by using annual instead of biennial surveys.

MSE is an iterative prospective evaluation of the full management system using computer simulation. his type of analysis is also called Harvest Strategy Evaluation (Punt and Smith 1999), Management Procedure Evaluation (Butterworth 2007), and the Management Oriented Paradigm, MOP (de la Mare 1998). MSE uses computer models to represent the underlying fish population, data gathering, stock assessment analysis, and harvest control rule application as well as measures of management strategy performance. The choice of a particular management strategy from a set of candidates is made by evaluating their ability to satisfy a hierarchy of measurable objectives, given practical and economic constraints, at a cost that is commensurate with the benefits (de la Mare 1998). The MSE approach has been used in a variety of fisheries including: Blue Eye Trevalla (Fay et al. 2011), Northeast Atlantic flatfish stocks (Kell et al. 2005), Rock Lobster (Punt and Hobday 2009) and Southern Bluefin Tuna (Kurota et al. 2010). Regionally it has been used to evaluate rebuilding revision rules for overfished rockfish stocks (Punt and Ralston 2007) and applied for several years in the B.C. Sablefish fishery (Cox and Kronlund 2008). There are typically several iterations in an MSE, with various approaches to management being simulated, modified and re-evaluated as objectives are developed and reconsidered (de la Mare 1998).

Management Strategy Evaluations have only been possible to perform in recent years due to the large amount of computer processing power, memory resources, and storage space that they require. For example, this MSE has an operating model that runs 1000 simulations, each of these has an 18 year projection, and there are 2 cases with assessments. The number of assessments run was 999x18x2 = 35,964 assessments. The output data from this MSE takes up nearly 45 GB of disk space.

For MSE, measurable management objectives typically fall into three categories: i) Conservation - to avoid deleterious changes to the stocks and the environment; ii) Socio-economic – to maximize benefits derived from fishery yield, and iii) Variability – to minimize large changes in year-to-year catch (de la Mare 1998). To make objectives measurable, performance statistics are calculated. For each statistic, time frames and probabilities are imposed, for example, the proportion of times in 2021–2030 that the depletion dropped below 10%.

In practice, one cannot maximize conservation, yield and catch stability simultaneously. Conservation and yield trade off against each other (Ricker 1958, de la Mare 1998, Kell et al. 2005, Cox and Kronlund 2008); maximizing yield may require frequent large adjustments of catch limits including complete closures in response to variability in stock assessments and recruitment (Ricker 1958, de la Mare 1998), as has been the case in Pacific Hake. In addition expected average catch is typically inversely proportional to expected final depletion (Punt and Smith 1999). In many situations, management objectives exist in a hierarchy as well. For example, there can be legal or policy constraints for avoiding small stock sizes that take precedence over other objectives, such as reducing the catch variability.

MSE is a process not a product. MSE is more than just closed-loop simulation software that is delivered to managers and stakeholders from scientists. Among other things, managers must define objectives; stakeholders must define costs/benefits associated with a range of potential outcomes; scientists must define credible hypothesis about the stock and identify assessment methods and tool available for management. All participants must communicate these elements to each other and adapt the process as need and available resources require.

Below we describe the MSE methodology as it was applied to Pacific Hake. Because, the full set of consultation activities is ongoing, the analysis we present in this paper is not yet a fully-fledged MSE. It is a first round of closed-loop simulation aimed at addressing two issues, testing the performance of the $F_{40\%}$-40:10 rule, and the relative performance of annual, vs. biennial, acoustic surveys. We also provide performance analyses of alternative rules that use different target harvest rates i.e., $F_{SPR\%}$-40:10 rules.

Appendix A.2. Materials and methods

The closed loop simulation proceeded as described in Figure A.1:

1. From the operating model, data were generated that were generally comparable to the real data collection system (for the Annual Survey Case, the survey index and age composition were generated every year, for the Biennial Survey every second year).
2. The simulated data were fit by the stock assessment model, from which
3. The control rule was applied.

4. The catch specified by the control rule was input back into the operating model to feedback into the future stock dynamics represented by the operating model.
5. Steps 1-4 were projected forward for eighteen years
6. Steps 1-5 were repeated 999 times (one for every posterior sample of the 2012 base case assessment model). The realized performance represented using performance statistics.

Operating model

We used the JTC (2012) Bayesian age-structured model stock assessment model (JTC 2012) as the operating model for Pacific hake. The model was built in Stock Synthesis version 3.23b (SS) (Methot and Wetzel 2012). The model was conditioned (i.e., fitted to) on the 1966-2012 data (Figure A.2), which resulted in approximate posterior distributions for a selected set of parameters including fishery and acoustic survey selectivity-at-age, survey catchability (q), natural mortality (M), steepness (h), unfished equilibrium biomass (B_0), and annual recruitment deviations (Table A.1). Markov Chain Monte Carlo (MCMC) was used to characterize the variability of the population by sampling every 10,000th point from a chain of 10,000,000, and discarding the first sample as a burn-in, as was done in the 2012 assessment (JTC 2012). This left 999 samples from the posterior distribution, where each sample consisted of a vector of parameters that was used to simulate the population into the future. The posterior distribution of parameters resulted in a median 2012 depletion of 33% with 2.5th-% and 97.5th-% percentiles of 9% and 102%, respectively.

Data generation

We simulated survey abundance index and age-composition data for the years 2012–2030 from the operating model to reflect the typical data available for stock assessments. The acoustic survey index of abundance was assumed to be log-normally distributed according to

$$I_{i.y} = \mathrm{LN}\left(median = q_i e^{-0.5M} B_{i,y}^{\mathrm{survey}}, \sigma_{\ln(I)}\right) \tag{1}$$

where the median is the mid-season biomass selected by the survey, adjusted by catchability.

$$B_{i.y}^{survey} = \sum_{a=1}^{A} N_{i,y,a} s_{i,a}^{\mathrm{survey}} \overline{w}_a \tag{2}$$

Age-based selectivity for the survey s^{survey} is taken from the posterior distribution, which means it is different for each of the 999 simulations. The beginning of year numbers-at-age, $N_{i,y,a}$, were from the operating model population, and , $\overline{w}_a$, , is the average of weight-at-age over the years from 1975 to 2011 (Table A.2). The maximum age, A was set to 15 years in the operating model.

The standard error in log-space was a combination of the intra- and inter-year standard errors.

$$\sigma_{\ln(I)} = \sqrt{\sigma^2_{\ln(\mathrm{intra-year}),y} + \sigma^2_{\ln(\mathrm{inter-year}),i}} \tag{3}$$

The intra-year standard error for the survey was fixed at a value of 0.085 and was the input into SS (see Table A.3 for a history of acoustic survey estimates). This standard error represents the mean of the observed standard errors determined from an analysis of the year-specific survey data. The inter-year standard error represents the additional year-to-year observation error in the survey that is not explained by the measurable sampling variability. These values are simulation specific because the assessment model estimated a value to be added to the intra-year standard error as in the 2012 assessment (JTC 2012) We chose to use a total standard error of 0.42, similar to that estimated from the 2012 assessment model. With an intra-year standard error of 0.085, the inter-year standard error, from equation 3, was approximately 0.41.

We simulated proportion-at-age data for the fishery and survey using a multinomial distribution with probabilities

$$n_{i.y,a} = N_{i,y,a} s_{i,a} \Omega \quad (4)$$

given by the product of numbers-at-age (N), selectivity (s) and ageing error Ω. Effective sample sizes for the fishery and survey were assumed to be the same as the recent estimates from the 2012 assessment (JTC 2012) and are shown in Table A.1.

The ageing error matrix (Ω) contains the probabilities of assigned ages for each true age, where the probabilities are determined from a normal distribution centered on the true age with standard deviation increasing with true age (Table A.2). Ageing error was applied before the sampling process, but in retrospect, we believe that the ageing error should be applied after the sampling process. However, in the interest of time, we were unable to rerun the simulations with this change. Initial runs suggest that the MSE results were not very sensitive to ageing error.

Assessment model

Simulated assessments were used to provide catch recommendations based on a control rule for each management strategy considered. The simulated assessments estimated spawning stock and exploitable biomass by fitting each year's simulated index and age-composition data. The stock assessment model was set up similarly to the 2012 SS base model (JTC 2012), and was therefore structurally identical to the operating model. Estimation was done by maximizing the joint posterior density. For each simulated assessment, model parameters were initialized at values estimated in the previous year and convergence was acceptable if the final maximum gradient was less than 0.1. If convergence was not acceptable, the starting parameters were jittered and the assessment was repeated. This was repeated 3 times, after which the final assessment was accepted, regardless of convergence. The majority of assessments had a maximum final gradient less than 0.001, and only one simulation in each case failed to meet the above criteria. The maximum posterior density (MPD) estimates of spawning stock biomass depletion and exploitable biomass were used for applying the $F_{40\%}$-40:10 rule to determine the year's catch.

Management strategies

For the 2013 hake MSE, we only consider a narrow range of management strategies. A management strategy is the combination of data collected (e.g., frequency and quality), the stock assessment, and the control rule which assists in determining catch. We limit the number of management strategies we consider in two key ways. First, we keep the structural form of the operating and assessment models identical. Second, out of a large universe of possible harvest control rules, we only consider one, the

40:10 rule. We do consider some alternative $F_{SPR\%}$ default harvest rates presented in the Additional Analyses section below.

We investigated four main management strategies (Table A.4). First, the management strategy of no fishing was simulated as a comparison to other cases and to determine the trajectory of the simulated (operating model) population with no catch (No Fishing). Second, perfect information from the operating model was used in the control rule to set the catch for next year (Perfect Information); data and an assessment model were not needed in this case. The third and fourth management strategies used simulated survey and fishery data, as described above, and the assessment model to estimate a population trajectory and an associated catch. Catch and fishery catch-at-age were available every year, so the only difference between these two management strategies was survey frequency. The Biennial Survey management strategy assumed that an index of abundance as well as survey and commercial catch-at-age data were available for alternate years starting in 2013 but that in non-survey years there were only catch and commercial catch-at-age data. The Annual Survey management strategy assumed that catch, commercial age-composition, the survey index, and the survey age-composition data were available every year. Surveys completed prior to 2012 are listed in Table A.3. For the hake MSE survey data were always generated for 2012 even for the Biennial Survey management strategy since the survey was underway when this analysis was being done.

The No Fishing management strategy provides a baseline measure of the stock. In this case, the operating model was run into the future with catches of zero in every year. We do not provide a full series of performance statistics for the No Fishing management strategy because there are no catch-based statistics in this instance. Accordingly, we confine our presentation of the No Fishing management strategy to plots of the depletion time series (Figure A.3) and the kernel density for depletion (Figure A.4).

The Perfect Information management strategy involved applying the catch given by the operating model's harvest control rule calculation. This case illustrates the fundamental properties of management procedures absent assessment errors. Because the Perfect Information management strategy does not have any assessment errors, it is important for disentangling the effects of assessment errors from the intrinsic properties of the default harvest policy.

Assessment errors can occur when assessment models represent the true stock dynamics improperly due to incorrect structural forms or assumptions. There are also ways such errors can be introduced even when the operating and assessment model are structurally identical, for example if there is insufficient contrast in catch and fishing mortality to generate reliable estimates of the productive potential of the stock (Ludwig and Hilborn 1983). To evaluate the effect of assessment errors, the Annual and Biennial Survey cases evaluate harvest control rule performance with more realistic data assumptions. Together with the Perfect Information management strategy, these two management strategies attempt to cover a spectrum of harvest control rule performance as a function of information quality. On one end of the spectrum the Perfect Information management strategy illustrates the theoretical limit of not needing information because the manager has perfect knowledge of what the quantities needed, and on the other; the Biennial Survey illustrates the lowest information case, with the Annual Survey case in between.

Analysis and performance measures

With MSE, performance is measured using performance statistics. We chose seven key performance metrics over (2013-2015), medium (2016-2020) and long (2021-2030) time frames (for some definitions see Table A.5). We divide performance statistics into those that measure the proportion of years within a given time period that the stock is in a particular state, and the medians of quantities that measure catch, stock-status, and variability in yield performance (Table A.6 and Table A.7, respectively). With the exception of the proportion of years that a management strategy closes the fishery all performance statistics in Table A.6 refer to the stock status given by the operating model. The second group is the medians of average depletion and average catch as well as AAV (Table A.7). For those readers wishing to consider a broader set performance measures we provide a full set of performance metrics in Table A.8.

We chose performance statistics to help illustrate if particular strategies have met conservation/legal, catch, or variability objectives. To illustrate if management procedures meet conservation objectives, we use the percentage of years that depletion is: below 10%, 10-40% and above 40% as well as the median average depletion. For yield objectives we consider the median of the average catch and for variability in yield we present use the average annual variability in catch, AAV. We also illustrate these same quantities using a range of graphics of the time series of depletion, catch as well as the long-term probability distributions of depletion, catch and AAV.

Additional Analyses

We considered an additional set of simulations in order to illustrate the general effects of varying the default harvest rate. Specifically, we applied the harvest control rule, with perfect information to a range of alternative default harvest rates. The aim of these additional simulations was to illustrate the tradeoffs between depletion, yield and catch stability.

Appendix A.3. Results

The MSE predicts that the default harvest control rule keeps the stock above 40% for a minority of years (Table A.6). The proportion of years that depletion is above 40% declines from the short to the long term in all management strategies with the highest proportion of years above 40% depletion using the Biennial Survey strategy. Within each management strategy, the proportion of years that the stock is in the 10-40% range increases as time frames extend from short to long for all management strategies (Table A.6). The proportion of years that the stock spends above 40% depletion decreases with data quality and quantity; it is lowest in the Perfect Information, Annual Survey, Biennial Survey strategies, respectively (Table A.6).

How often the operating model predicts the simulated stock to be below 10% differs between strategies, time frames, and survey frequencies. In the Perfect Information case, the MSE predicts that the stock will be below 10% depletion less than 5% of the time in the short term. In the short term, the stock has not come to equilibrium with the management strategy and is therefore sensitive to the starting conditions of the simulation period i.e. for some random simulations, the stock starts below 10% depletion. However, in the Perfect Information case, the proportion of years that the stock is predicted to be below 10% is less than 1% over the medium and long term (Table A.6 and Figure A.3). While the proportion of years that depletion is less than 10% decreases over time in the Perfect Information case, it is highest in the medium term for both Annual and Biennial Survey management strategies (Table A.6 and Figure A.3).
For all management strategies that we considered, the actual (given by the operating model) and perceived (given by the assessment model) proportion of years that the stock is below 10% depletion differed. All management strategies suffered from both false positives (i.e. they closed the fishery when the stock is above 10% depletion) and false negatives (they did not close the fishery when the stock is below 10% depletion). In the short term, the Perfect Information management strategy did not result in fishery closures even though the operating model predicts depletion to be below 10% approximately 5% of the time; this paradoxical observation is because all simulations applied the actual 2012 catch, and in some of these instances this catch was sufficiently large to deplete the simulated stock to below 10%. Similarly, over the long and medium terms, the Perfect Information management strategy essentially never closed the fishery; in these instances, the operating model predicted the frequency that the stock is

below 10% is less than 1% (Table A.6). The Annual and Biennial Survey management procedures close the fishery less frequently than the proportion of years that the simulated stock was actually below 10% in the short term (Table A.6). However, in the long term, the Annual Survey strategy closed the fishery more frequently than the proportion of years that the operating model predicted the stock to be below 10% depletion, and the Biennial Survey management strategy even more so.

The predicted distribution of long-term depletion for all management strategies considered is summarized in Figure A.4. The No Fishing case shows that in the long term, the stock is still settling to an unfished equilibrium with a mean depletion approaching unity (Figure A.3) and a long-term median depletion of approximately 75% (Figure A.4). For those instances where harvest was applied, the default harvest control rule did not produce median average depletion levels of 40% regardless of survey frequency or information quality (Table A.7). In the long term, all management strategies except No Fishing, had median depletion levels well below 40% with the means slightly higher (Figure A.4). The Perfect Information management procedure shows that the $F_{40\%}$ default harvest rate with a 40:10 control rule eventually brings the median average depletion of the stock to just below 30% and it reduces the median average depletion over the short, to the medium and long terms, settling eventually at 28% (Table A.6 and Figure A.4).

In general the median of the average catch declines from the short to the medium and long term. In the short term, the median of average catch is higher in the Annual and Biennial Survey management strategies than it is in the Perfect Information case (Table A.7). However, as the population comes to equilibrium with each of the management strategies in the long term, the median average catch in the Perfect Information case is highest and in all cases there is a very broad distribution of catch applied for every management procedure (Figure A.5).

AAV is similar between the Perfect Information, Annual Survey, and Biennial Survey only in the short term (Table A.7). In the medium and long terms, the median AAV is higher for the Annual Survey, and Biennial Survey management strategies. AAV is similar between the Annual Survey and Biennial Survey management strategies in the medium term and slightly higher in the Biennial Survey case in the long term. In all management strategies, there is a large distribution of AAV values in the long term (Figure A.6).

It bears repeating that summary statistics of central tendencies such as the median or mean, do not capture the range of possible outcomes for any given performance measure. For each summary statistics, there is considerable variability about any median (or mean) performance measure (see Figures A.4-A.6). Extreme events such as low or high catches or depletion levels are not rare. For those readers wishing to examine a more complete set of statistics, Table A.8 provides a summary table of all the statistics that we examined.

Additional Analyses

Different default harvest rates result in different median and mean depletion levels. We illustrate this by running the Perfect-Information simulations using a range of different default harvest rate ($F_{SPR\%}$) values ranging from 0.30 to 0.50. Recall that $F_{SPR\%}$ is the fishing mortality that would reduce the spawners-per-recruit to xx% of the unfished equilibrium spawners-per-recruit. Accordingly, as $F_{SPR\%}$ decreases, the actual fishing mortality increases. Figure A.14 depicts the discrete fishing mortalities associated with each of these $F_{SPR\%}$ values; note that for each $F_{SPR\%}$, there is uncertainty in the corresponding discreet exploitation rate caused by the uncertainty in selectivity and natural mortality. Note also that there is a non-linear increase in exploitation rate with linear increases in SPR% (Figure A.14). As the value of $F_{SPR\%}$ ranges from 50% to 30%, median depletions range from approximately 0.4 to 0.25. Given the asymmetry of the resultant depletion probability distributions for each $F_{SPR\%}$, the mean depletion is higher than the median.

As the default harvest rate increases ($F_{SPR\%}$ decreases), there are diminishing marginal returns in median average catches (Figure A.8) but increasing marginal AAV (Figure A.9). Increasing the default harvest rate (declining $F_{SPR\%}$) results in progressively declining mean catch increases per unit increase in target F (Figure A.8). Mean and median AAVs in catch appear to increase in a non-linear way with increases in the target harvest rate (Figure A.9).

Changes in median depletion, yield and AAV with increasing target harvest rates show that (i) depletion decreases as yield increases, as expected (Figure A.10), and (ii) relatively small increases in yield correspond to large increases in yield variability as target fishing mortality increases (Figure A.11).

Appendix A.4. Discussion

The MSE shows that the $F_{40\%}$-40:10 rule reduces the median average depletion of the stock to just below 30%. Median average depletion levels are consistent across all management strategies considered, including the Perfect Information case. While the median average depletion levels are similar between all management strategies, the probability of extreme depletion values increases with decreased information. While, for example, the biennial survey management strategy has the highest long-term proportion of years where depletion is greater than 40%, it also closes the fishery more frequently, has a higher proportion of years that depletion is less than 10%, and has the highest AAV. Summary statistics notwithstanding, a wide range of stock sizes can be expected from any management strategy, even the No Fishing case, due to high recruitment variability.

Because of the way that catches were simulated in the MSE, they may reflect different tonnages than would be taken in practice. Firstly there are statistical differences between how the MSE simulated catches and how it is done in practice. The MSE used the MPD estimate of the catch predicted by the harvest control rule. In practice, we do a full posterior integration using MCMC and there are statistical differences between this, and the multivariate normal approximation of the posterior given at the posterior mode (Stewart et al. 2012). However, the large number of assessment models run in the MSE required us to use the MPD estimates due to time constraints. Secondly, managers make decisions based on a richer set of objectives, constraints and hedging activities (Walters and Hilborn 1978); some of these constraints may include upper limits on target catches or bycatch considerations. Finally, actual catches taken in the Pacific hake fishery have recently been below the recommended TAC. The MSE does not capture these additional complexities. The actual management strategy has a potentially large unpredictable component to it.

During consultations we were asked to consider a different operating model that would be more consistent with what was anticipated to be a more optimistic 2013 assessment. For practical reasons, it was not possible to re-run the simulations. However, it is important to note that while the MSE's results may differ according to the initial state of the operating model in the short and medium terms, the long term predictions should be similar. In these simulations, 95% of the operating model initial depletion values for 2012 ranged between 9.4 and 102.2%, with a median depletion of 32.6% (see table b in JTC (2012)). Had we used a more optimistic operating model, it is likely that the short and medium term MSE performance statistics for each management strategy would be different. However, we assume that predictions for 2021-2030 will be similar. If the operating model starts simulations with a stock that is assumed have high depletion levels, then the harvest control rule will apply high catches (and vice versa if the stock size is assumed to be relatively low) so that depletion (and corresponding catches) should be similar over longer time horizons.

While there are differences between the performance statistics for annual, and biennial survey strategies, the absolute magnitude of these differences is very small. This observation holds whether the performance statistic measures average catch, depletion or AAV. We caution that the MSE we present here may paint an optimistic picture of the small improvement offered by annual, over biennial surveys. One reason is that in non-survey years, only catch and commercial age composition are available for assessment-model fitting while both operating and assessment models assume time-invariant selectivity. Previous assessments gave us reason to be suspicious of using catch and commercial age-composition data alone: using 2010 data, the 2011 assessment model predicted that a very optimistic sustainable harvest level of 973,700 mt; this prediction was followed by a 2011 survey biomass estimate was the lowest on record at 521,476 mt. There are several situations where commercial age-composition data may be inconsistent with this assumption. For example, it is possible that spatial management measures limit fishing to certain areas to produce very-rapid changes in selectivity, because the fleet is confined to fishing in areas where there are distorted proportions of younger, or older, fish. In such situations, applying an assessment model where such effects are not considered (or cannot be) may result in a poor actual biennial survey management strategy performance because the commercial age-composition data used to estimate non-survey-year stock status are inconsistent with the assessment model's time invariant selectivity assumption.

It is important to test the performance of management strategies using more realistic operating models. The example of time-varying selectivity identified above is one of large number of possible ways that the current stock assessment model structure is an over-simplification of the true state dynamics. Other parameterizations that consider spatial structure, multiple fleets, or growth type groups may provide more accurate representations of the biology as well occasional extreme survey errors like that caused by Humboldt squid. MSE is a suitable instrument to determine if alternative assessment models result in improved management performance. But the assessment model is only one management-strategy component; improvements can also be sought by considering alternative harvest control rules.

If further MSE is to be pursued for Pacific hake, then choosing between alternative management strategies will mean defining a measurable set of objectives. In this instance, only a narrow range of management strategies was considered, but if the process is expanded by new operating models then choosing between candidate management strategies becomes difficult because of the potentially large number of scenarios considered. Measurable objectives help eliminate candidate management strategies.

MSE has been applied to Pacific hake in the past. For instance, Ishimura et al (2005) examined a very comprehensive set of management strategies and showed how each performed in terms of average catch, variation in catch, the probability of closing the fishery, and a variety of other conservation-related performance measures. They considered the 40:10 rule and a comprehensive set of fixed escapement strategies in which the catch limit is the maximum of zero and a pre-specified fraction of the difference between the estimate of the current biomass and a minimum biomass for a fishery to occur. There are some important technical differences between the Ishimura et al. (2005)'s study and the JTC's MSE that make direct comparisons inappropriate. Among other things, they applied a 40:10 rule that scaled down fishing mortality, not catch, as the Agreement's harvest control rule does; and instead of simulating data collection and assessments, they used the method suggested by Punt and Hilborn (1996) and approximate the monitoring of the resource by generating the estimate of this biomass based on the true 3+ biomass, allowing for correlation in assessment errors. In spite of the methodological differences, the general tradeoff patterns between conservation, yield and catch stability they illustrate are similar to the JTC's MSE.

Conservation, yield and catch stability tradeoffs identified here are not unique to Pacific hake. The tradeoff between mean catch and variability is well known in fisheries. W.E. Ricker (1958) showed that increases in mean catch occur at the expense of increased variability in yield in part because for highly variable stocks there can be occasional cessation of fishing in order to get the long-term maximum. Before MSE existed in its current form, others identified similar tradeoffs (Walters 1975, Mendelssohn 1980). Since then, full MSE analyses have identified the same set of conservation, yield, and catch stability tradeoffs (de la Mare 1998, Punt and Smith 1999, Cox and Kronlund 2008).

Two key things have been learned from this exercise that could not have been examined using other studies like Ishimura et al (2005) and general relationships. The first is that the $F_{40\%}$-40:10 rule reduces the median average depletion of the stock to below 30%. Ishimura et al (2005) suggested that the 40:10 rule leaves the 3+ biomass on average at 52% of unfished. Unfortunately, their approach was invalid because it applied the 40:10 rule in a way that is inconsistent with the hake treaty and because they did not explicitly model stock assessments. Secondly, the marginal improvement of annual over biennial surveys is very specific to the hake case, due to the interaction of data, the assessment and the harvest control rule interacting with a stock having high recruitment variability.

The gain of pursuing MSE for hake is that it places decisions about the relative superiority of alternative management strategies (whether these be assessment model, survey frequency or harvest control rule choice), into the hands of those who bear the consequences of these choices. To continue using MSE, managers, scientists and stakeholders will have to first define measurable management objectives. The challenge will then be how to define good performance given the tradeoffs and potentially conflicting objectives among stakeholder groups.

Appendix A.5. References

Butterworth, D. S. 2007. Why a management procedure approach? Some positives and negatives. Ices Journal of Marine Science 64:613-617.

Cox, S. P. and A. R. Kronlund. 2008. Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia, Canada. Fisheries Research 94:224-237.

de la Mare, W. K. 1998. Tidier fisheries management requires a new MOP (management-oriented paradigm). Reviews in Fish Biology and Fisheries 8:349-356.

Fay, G., A. E. Punt, and A. D. M. Smith. 2011. Impacts of spatial uncertainty on performance of age structure-based harvest strategies for blue eye trevalla (Hyperoglyphe antarctica). Fisheries Research 110:391-407.

Ishimura, G., A. E. Punt, and D. D. Huppert. 2005. Management of fluctuating fish stocks: the case of Pacific whiting. Fisheries Research 73:201-216.

JTC. 2012. Status of the Pacific hake (Whiting) stock in U.S. and Canadian Waters in 2012. Prepared for the Joint U.S.-Canada Pacific hake treaty process. 195 p.

Kell, L. T., A. A. Pastoors, R. D. Scott, M. T. Smith, F. A. Van Beek, C. M. O'Brien, and G. M. Pilling. 2005. Evaluation of multiple management objectives for Northeast Atlantic flatfish stocks: sustainability vs. stability of yield. Ices Journal of Marine Science 62:1104-1117.

Kurota, H., K. Hiramatsu, N. Takahashi, H. Shono, T. Itoh, and S. Tsuji. 2010. Developing a management procedure robust to uncertainty for southern bluefin tuna: a somewhat frustrating struggle to bridge the gap between ideals and reality. Population Ecology 52:359-372.

Ludwig, D. and R. Hilborn. 1983. Adaptive probing strategies for age structured fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 40:559-569.

Mendelssohn, R. 1980. A systematic approach to determining mean-variance tradeoffs when managing randomly varying populations. Mathematical Biosciences 50:75-84.

Methot, R. D. J. and C. R. Wetzel. 2012. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research.

PFMC. 1998. Final Environmental Assesment/Regulatory Impact Review for Amendment 11 to the Pacific Coast Groundfish Fishery Management Plan.*in* P. F. M. Council, editor., Portland, Oregon.
Punt, A. E. and R. Hilborn. 1996. Biomass dynamics models. FAO, Rome.
Punt, A. E. and D. Hobday. 2009. Management strategy evaluation for rock lobster, Jasus edwardsii, off Victoria, Australia: accounting for uncertainty in stock structure. New Zealand Journal of Marine and Freshwater Research 43:485-509.
Punt, A. E. and S. Ralston. 2007. A Management Strategy Evaluation of Rebuilding Revision Rules for Overfished Rockfish Stocks. Biology, Assessment and Management of North Pacific Rockfishes, Alaska Sea Grant College Program AK-SG-07-01:329-351.
Punt, A. E. and A. D. M. Smith. 1999. Harvest strategy evaluation for the eastern stock of gemfish (Rexea solandri). Ices Journal of Marine Science 56:860-875.
Ricker, W. E. 1958. Maximum sustained yields from fluctuating environments and mixed stocks. Journal of the Fisheries Research Board of Canada 15:991-1006.
Stewart, I. J., A. C. Hicks, I. G. Taylor, J. T. Thorson, C. Wetzel, and S. Kupschus. A comparison of stock assessment uncertainty estimates using maximum likelihood and Bayesian methods implemented with the same model framework. Fisheries Research.
Walters, C. J. 1975. Optimal harvest strategies for salmon in relation to environmental variability and uncertain production parameters. Journal of the Fisheries Research Board of Canada 32:1777-1784.
Walters, C. J. and R. Hilborn. 1978. Ecological optimization and adaptive management. Ann. Rev. Ecol. Syst. 9:157-188.

Appendix A.6. Tables

Table A.1: Parameters used in the operating model and for data generation. The median and 95% confidence interval (CI) are provided for the parameters estimated in the 2012 stock assessment (JTC 2012), other than recruitment deviations. These estimated parameters vary across simulations in the operating model. Fixed parameters are also given.

Parameter	Median	95% CI
Stock Dynamics		
Ln(R_0)	14.66	14.25 – 15.16
Steepness (h)	0.81	0.57 – 0.96
Recruitment variability (σ_R)	1.40	—
Natural mortality (M)	0.22	0.18 – 0.26
Acoustic catchability (q)	1.11	0.75 – 1.49
Data generation		
Within year SE for acoustic survey in log space	0.085	—
Total SE for acoustic survey in log space	0.420	—
Number of age samples for fishery	96	—
Number of age samples for acoustic survey	65	—
Derived parameters		
B_0	3,807,210	3,001,948 – 4,800,112
Yield at 40%SPR (metric tons)	299,987	208,426 – 428,620
Depletion at 40%SPR	0.36	0.26 – 0.39
$F_{40\%SPR}$	0.21	0.18 – 0.26

Table A.2: Age-specific parameters for the true population used in the operating model. Weight-at-age varied across years and only the mean across all years is shown below. Selectivity was variable for age 6 and held constant for all older ages, thus a few simulations had selectivity less than 1 for ages 6+.

Age	Mean Weight	Maturity	Acoustic Selectivity	Fishery selectivity	Ageing Error SD
0	0.0300	0.0000	0	0	0.3292
1	0.0885	0.0000	0	0.00 (0.00–0.01)	0.3292
2	0.2562	0.1003	0.49 (0.35–0.67)	0.08 (0.06–0.11)	0.3469
3	0.3799	0.2535	0.53 (0.35–0.81)	0.40 (0.32–0.48)	0.3686
4	0.4913	0.3992	0.70 (0.51–0.98)	0.67 (0.55–0.83)	0.3953
5	0.5434	0.5180	0.64 (0.40–1.00)	0.79 (0.63–0.98)	0.4281
6	0.5906	0.6131	1*	1*	0.4684
7	0.6620	0.6895	1*	1*	0.5178
8	0.7215	0.7511	1*	1*	0.5786
9	0.7910	0.8007	1*	1*	0.6533
10	0.8629	0.8406	1*	1*	0.7451
11	0.9315	0.8724	1*	1*	0.8578
12	0.9681	0.8979	1*	1*	0.9963
13	1.0751	0.9181	1*	1*	1.1665
14	1.0016	0.9342	1*	1*	1.3756
15	1.0202	0.9469	1*	1*	1.6324
16	1.0202	0.9569	1*	1*	1.8580
17	1.0202	0.9649	1*	1*	2.1720
18	1.0202	0.9711	1*	1*	2.5300
19	1.0202	0.9761	1*	1*	2.9340
20	1.0202	0.9830	1*	1*	3.3880

*A few simulations (less than 2.5%) showed values less than 1.

Table A.3: Acoustic survey estimates for years prior to 2012. The standard error is related to the natural log of the estimate.

Year	Estimate (mt)	Standard error
1995	1517948	0.0666
1998	1342740	0.0492
2001	918622	0.0823
2003	2520641	0.0709
2005	1754722	0.0847
2007	1122809	0.0752
2009	1612027	0.1375
2011	521476	0.1015

Table A.4: Description of the four management strategies simulated.

Case	**Description**
No Fishing	No catch from 2013 to 2030
Perfect Information	Catch determine from true status of stock. No data or assessment.
Annual Survey	Catch determined from an annual assessment. An annual survey from 2013 to 2030 informs the assessment.
Biennial Survey	Catch determined from an annual assessment. A survey in odd numbered years from 2013 to 2030 informs the assessment.

Table A.5: Metrics used to investigate performance of the simulations.

Metric	Description	**Formula**
Depletion (D_t)	The ratio of the estimated beginning of the year female spawning biomass to estimated average unfished equilibrium female spawning biomass. Thus, lower values of relative depletion are associated with fewer mature female fish.	$D_t = \frac{B_t}{B_0}$
Median average depletion	The median of the average status of the stock over a defined period of time	$Median\left(\frac{1}{n+1}\sum_{i=t}^{t+n} D_t\right)$
P(Threshold1< D_t <Threshold2)	The probability that depletion is between two threshold values (i.e., 0.1 and 0.4) at any point of the defined period of time	$\frac{N_{within}}{N_{total}}$ where N_{within} is the total number of observations satisfying the criteria and N_{total} is the total number of observations
Median average catch	The median of the average catch over the time period defined.	$Median\left(\frac{1}{n+1}\sum_{i=t}^{t+n} C_i\right)$
Average annual variability (AAV)	The percent average change in catch divided by the average catch over the time period defined.	$AAV = \frac{1/n\sum_y \lvert C_y - C_{y-1}\rvert}{1/n\sum_y C_y}$

Table A.6: Summary of key stock status statistics in the short (2013-2015), medium (Med, 2016-2020), and long (2021-2030) time frames for the following management strategies: perfect information (Perf), the annual survey (Ann) and the biennial survey (Bien).

	Short Term			Medium Term			Long Term		
Percentage of years:	*Per*	*Ann*	*Bie*	*Per*	*Ann*	*Bie*	*Per*	*Ann*	*Bie*
Depletion above 40%	34.30%	35.90%	35.64%	28.95%	31.29%	32.67%	27.07%	29.54%	31.06%
Depletion below 10%	4.44%	6.61%	6.87%	0.94%	7.17%	8.59%	0.39%	5.39%	7.04%
Depletion between 10 and 40%	61.26%	57.49%	57.49%	70.11%	61.54%	58.74%	72.54%	65.08%	61.90%
MS closes fishery	0.00%	4.70%	3.90%	0.00%	8.51%	8.21%	0.00%	10.11%	13.61%

Table A.7: Median of key statistics for the perfect information (Per), Annual Survey (Ann) and Biennial Survey (Bie) management strategies in the short, medium and long term.

	Short Term			Medium Term			Long Term		
Medians of:	*Per*	*Ann*	*Bie*	*Per*	*Ann*	*Bie*	Per	Ann	Bie
Average catch	251	284	273	216	226	217	230	217	218
Average depletion	31.71	31.45	31.58	27.89	26.92	27.84	27.60	27.27	28.00
AAV in catch (%)	36.57	35.46	32.55	23.09	34.14	34.68	23.35	32.54	33.24

Table A.8: Complete set of performance statistics

Quantity	Short	Medium	Long	case
Start year corresponding to time period	2013	2016	2021	Perfect Information
End year corresponding to time period	2015	2020	2030	Perfect Information
Median average depletion	31.71%	27.89%	27.60%	Perfect Information
First quartile depletion	20.95%	20.14%	19.74%	Perfect Information
Third quartile depletion	47.57%	43.61%	41.60%	Perfect Information
Median final depletion	30.16%	27.94%	26.67%	Perfect Information
Median of lowest depletion	26.58%	21.59%	17.71%	Perfect Information
Median of lowest perceived depletion	NA	NA	NA	Perfect Information
First quartile of lowest depletion	17.86%	16.25%	14.54%	Perfect Information
Third quartile of lowest depletion	37.55%	29.97%	22.95%	Perfect Information
Median Average Annual Variability (AAV) in catch	36.57%	23.09%	23.35%	Perfect Information
First quartile of AAV in catch	23.34%	16.80%	18.47%	Perfect Information
Third quartile of AAV in catch	62.17%	32.20%	29.43%	Perfect Information
Median average catch	251	216	230	Perfect Information
First quartile of average catch	124	133	148	Perfect Information
Third quartile of average catch	422	392	356	Perfect Information
Median of lowest catch levels	193	139	97	Perfect Information
First quartile of lowest catch levels	91	79	57	Perfect Information
Third quartile of lowest catch levels	336	237	155	Perfect Information
Proportion with any depletion below SB10%	7.31%	2.00%	2.00%	Perfect Information
Proportion perceived to have any depletion below SB10%	NA	NA	NA	Perfect Information
Proportion of years below SB10%	4.44%	0.94%	0.39%	Perfect Information
Proportion of years between SB10% and SB40%	61.26%	70.11%	72.54%	Perfect Information
Proportion of years above SB40%	34.30%	28.95%	27.07%	Perfect Information
Start year corresponding to time period	2013	2016	2021	Annual
End year corresponding to time period	2015	2020	2030	Annual
Median average depletion	31.45%	26.92%	27.27%	Annual
First quartile depletion	19.09%	17.02%	17.69%	Annual
Third quartile depletion	50.22%	47.45%	44.19%	Annual
Median final depletion	29.65%	27.37%	27.51%	Annual
Median of lowest depletion	25.66%	19.46%	15.82%	Annual
Median of lowest perceived depletion	28.20%	20.47%	16.21%	Annual
First quartile of lowest depletion	15.30%	12.40%	10.71%	Annual
Third quartile of lowest depletion	40.69%	31.76%	22.49%	Annual
Median Average Annual Variability (AAV) in catch	35.46%	34.14%	32.54%	Annual
First quartile of AAV in catch	24.31%	25.54%	26.62%	Annual
Third quartile of AAV in catch	54.39%	50.75%	40.87%	Annual
Median average catch	284	226	217	Annual
First quartile of average catch	164	120	138	Annual

Third quartile of average catch	396	380	341	Annual
Median of lowest catch levels	192	113	66	Annual
First quartile of lowest catch levels	99	41	27	Annual
Third quartile of lowest catch levels	300	215	118	Annual
Proportion with any depletion below SB10%	11.21%	16.12%	20.42%	Annual
Proportion perceived to have any depletion below SB10%	4.70%	8.51%	10.11%	Annual
Proportion of years below SB10%	6.61%	7.17%	5.39%	Annual
Proportion of years between SB10% and SB40%	57.49%	61.54%	65.08%	Annual
Proportion of years above SB40%	35.90%	31.29%	29.54%	Annual
Start year corresponding to time period	2013	2016	2021	Biennial
End year corresponding to time period	2015	2020	2030	Biennial
Median average depletion	31.58%	27.84%	28.00%	Biennial
First quartile depletion	19.17%	17.18%	17.45%	Biennial
Third quartile depletion	50.02%	49.13%	46.02%	Biennial
Median final depletion	29.52%	28.42%	28.97%	Biennial
Median of lowest depletion	25.80%	19.73%	15.59%	Biennial
Median of lowest perceived depletion	28.94%	20.37%	16.18%	Biennial
First quartile of lowest depletion	15.59%	12.27%	10.33%	Biennial
Third quartile of lowest depletion	40.34%	32.86%	23.47%	Biennial
Median Average Annual Variability (AAV) in catch	32.55%	34.68%	33.24%	Biennial
First quartile of AAV in catch	22.80%	25.45%	27.15%	Biennial
Third quartile of AAV in catch	49.68%	51.05%	42.34%	Biennial
Median average catch	273	217	218	Biennial
First quartile of average catch	168	127	137	Biennial
Third quartile of average catch	401	357	328	Biennial
Median of lowest catch levels	206	110	60	Biennial
First quartile of lowest catch levels	110	43	20	Biennial
Third quartile of lowest catch levels	320	208	123	Biennial
Proportion with any depletion below SB10%	11.61%	16.72%	22.92%	Biennial
Proportion perceived to have any depletion below SB10%	3.90%	8.21%	13.61%	Biennial
Proportion of years below SB10%	6.87%	8.59%	7.04%	Biennial
Proportion of years between SB10% and SB40%	57.49%	58.74%	61.90%	Biennial
Proportion of years above SB40%	35.64%	32.67%	31.06%	Biennial

Appendix A.7. Figures

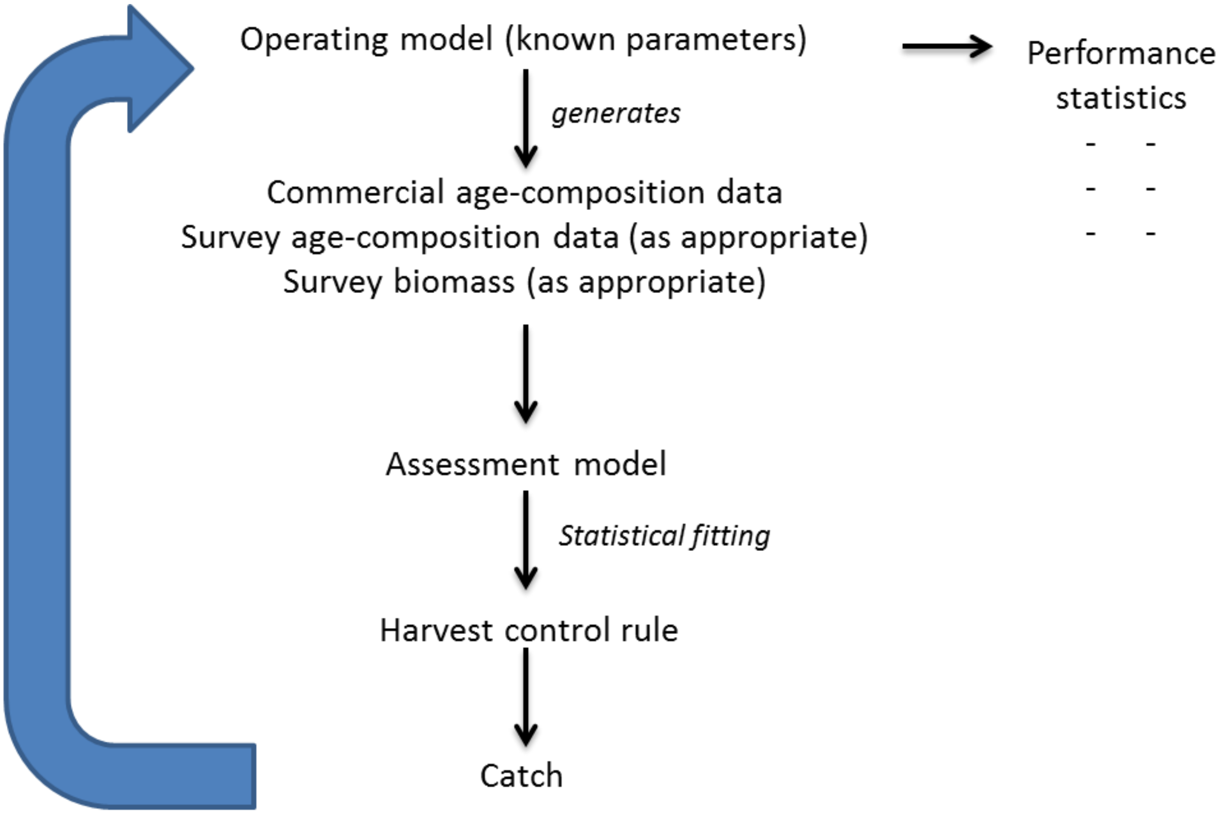


Figure A.1: Schematic of a closed-loop simulation.

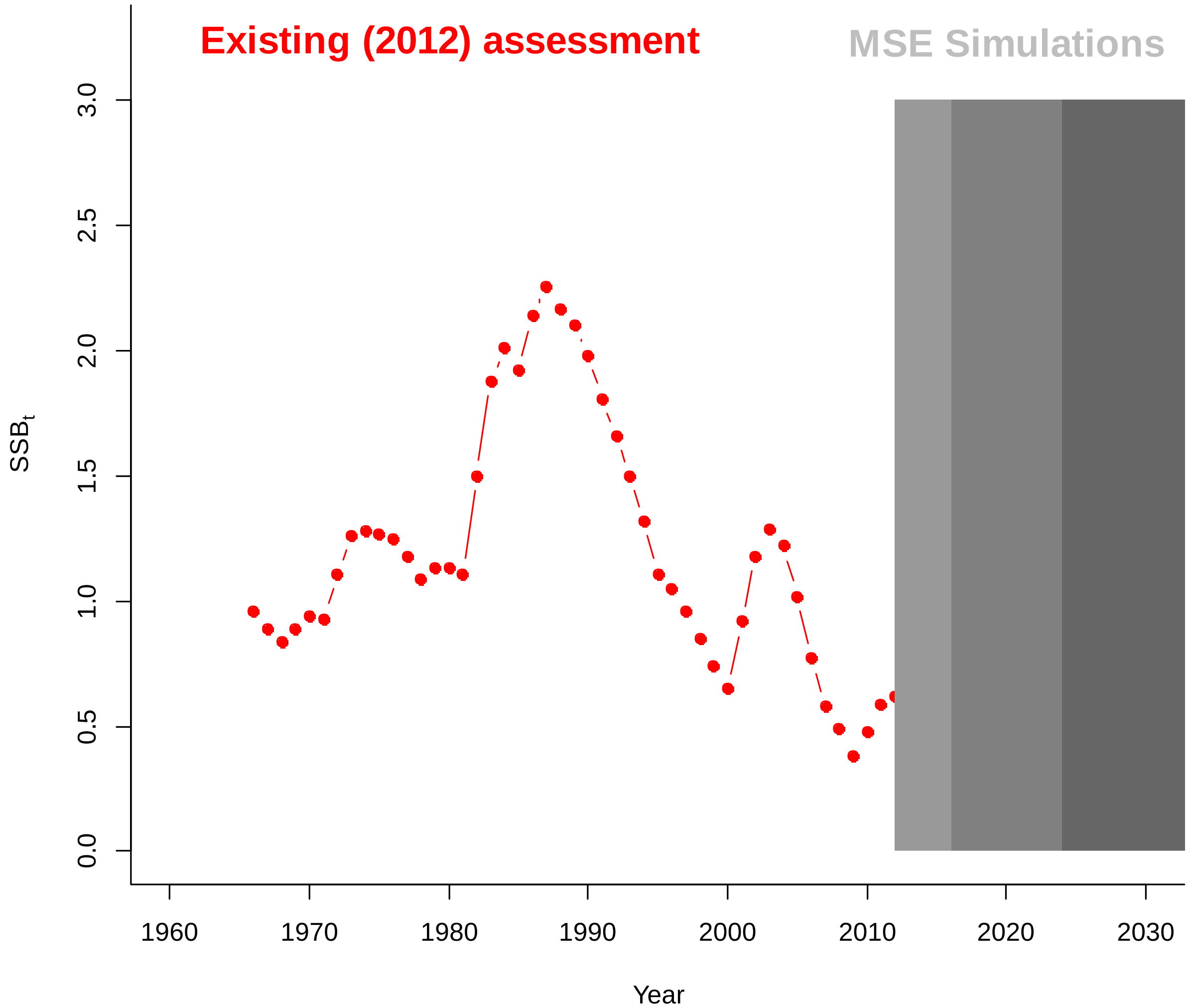


Figure A.2: Schematic of hake operating model conditioning (Existing 2012 assessment) and simulation periods (MSE Simulations)

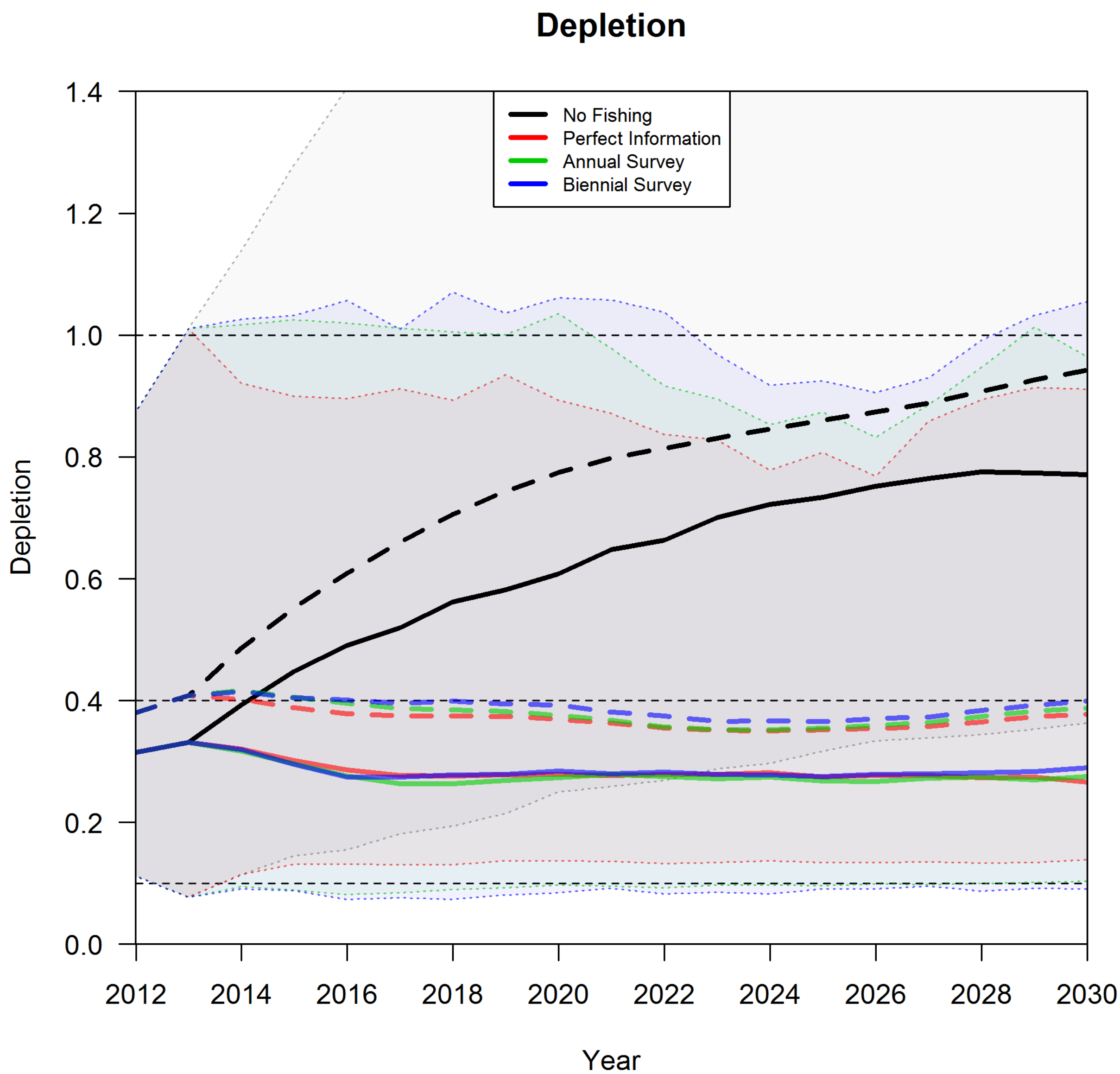


Figure A.3: Predicted depletion for each simulated management strategy. Colored shading represents the 95% credibility intervals, solid lines represent the median and dashed lines represent the means.

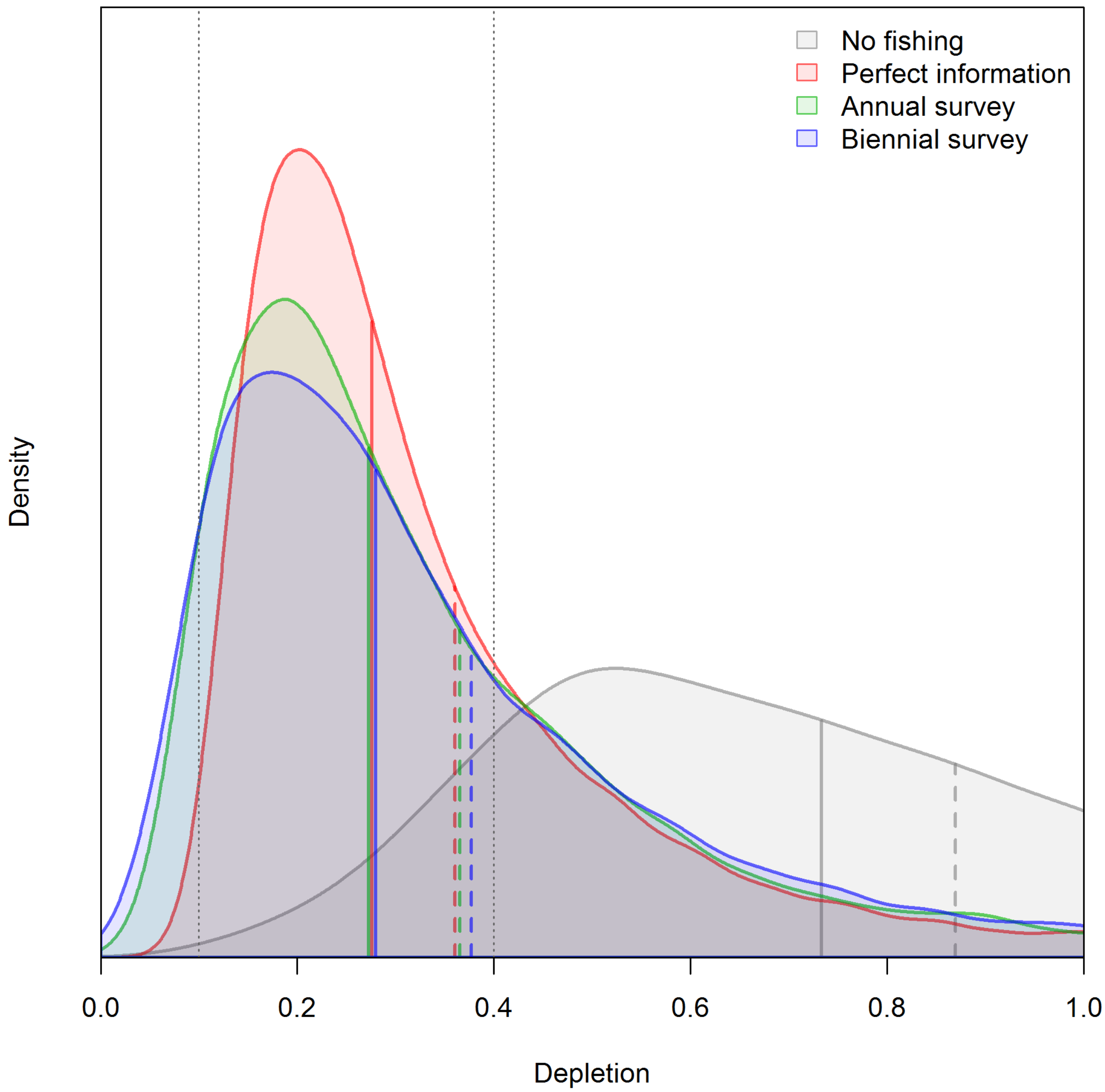


Figure A.4: Plot of kernel density estimate for depletion (B_y/B_0) for the No Fishing, Perfect Information, Annual and Biennial Survey management strategies over the long term (2021-2030). Solid vertical lines are medians. Dashed vertical lines are means.

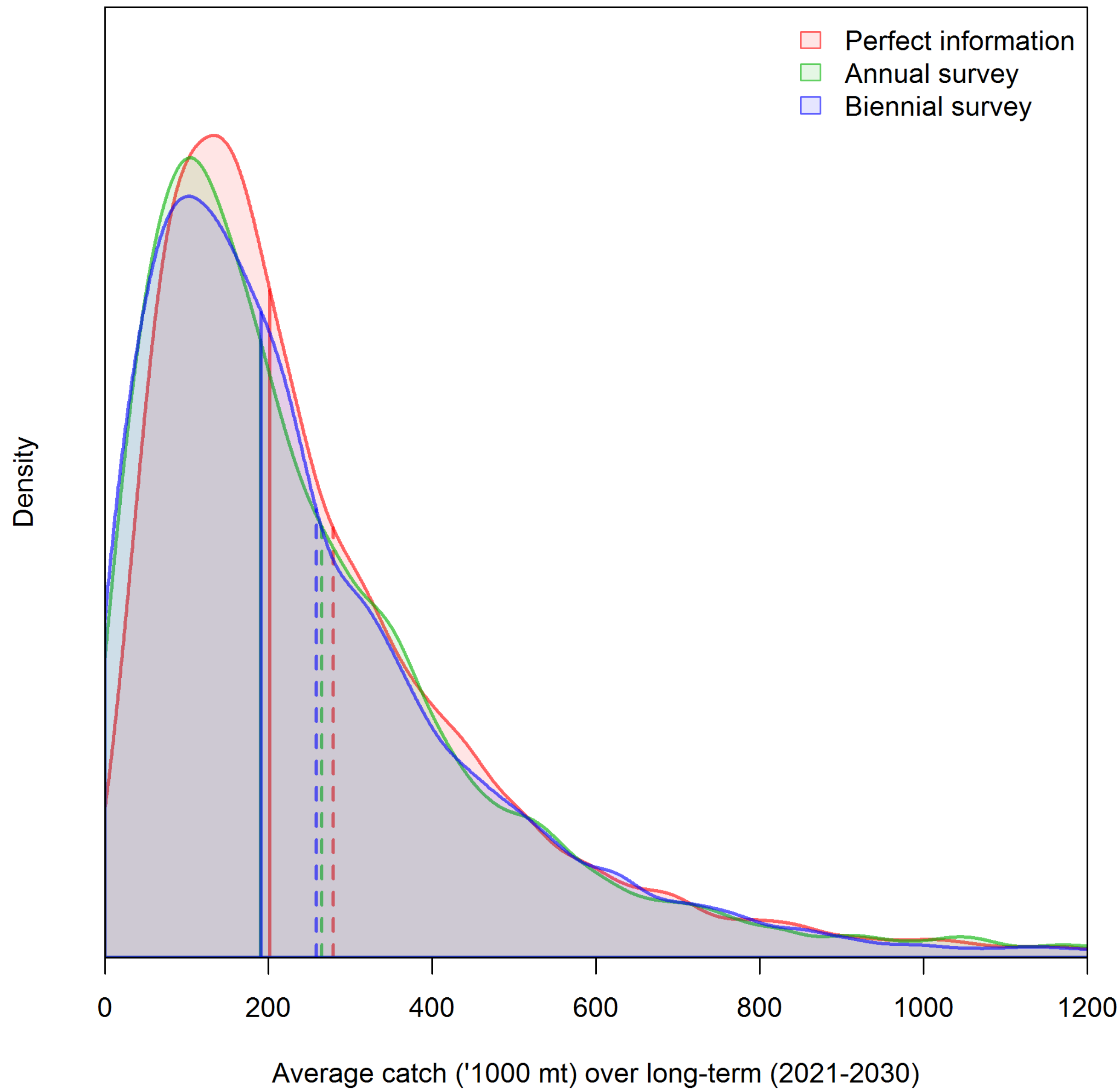


Figure A.5: Plot of kernel density estimate for catches for perfect information, annual and biennial survey management strategies in the long term (2021-2030). Solid vertical lines are medians. Dashed vertical lines are means.

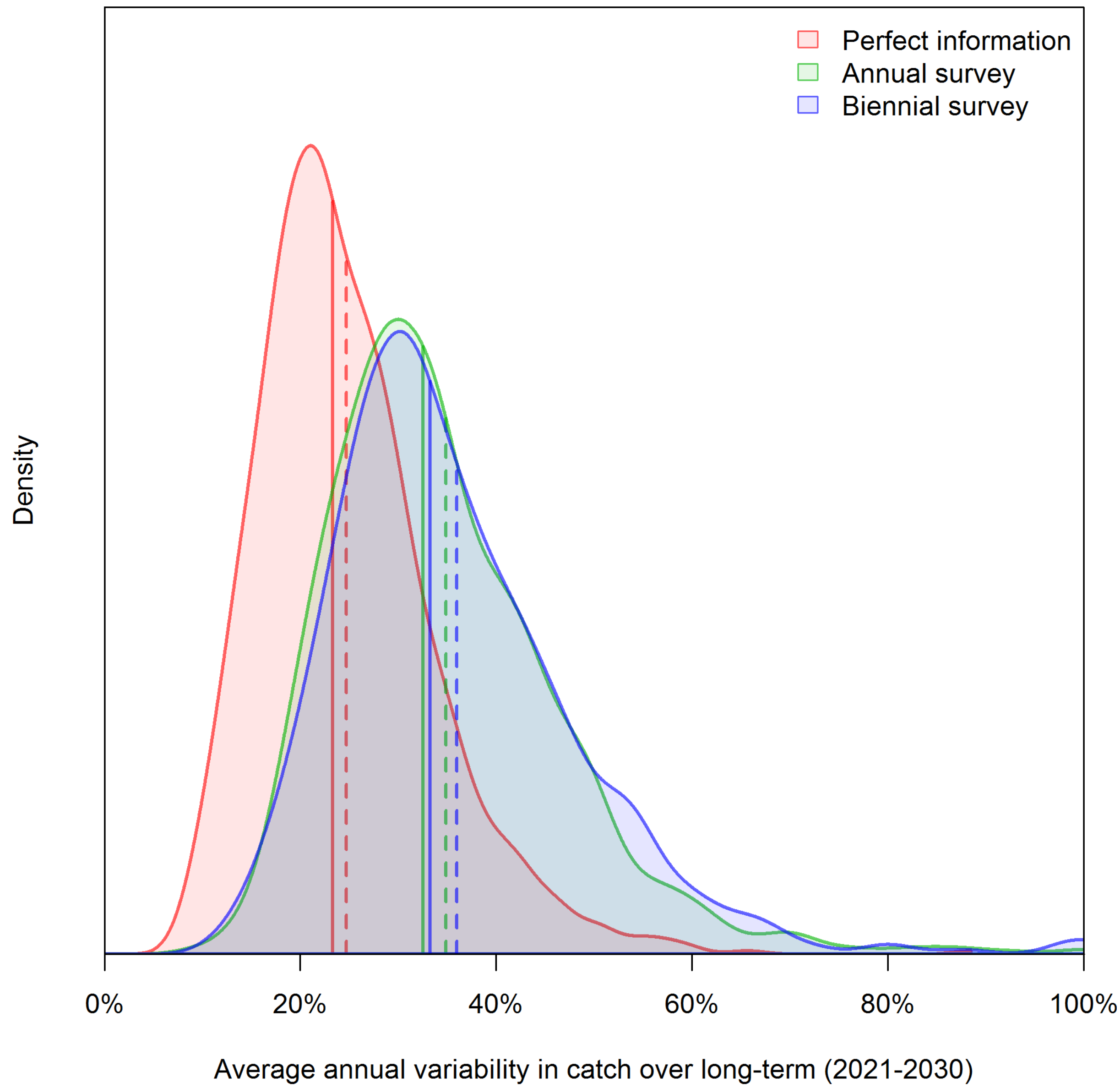


Figure A.6: Plot of kernel density estimate for average annual variability in catch (AAV) for Perfect Information, Annual and Biennial survey management strategies in the long term (2021-2030). Solid lines are medians. Dashed lines are means.

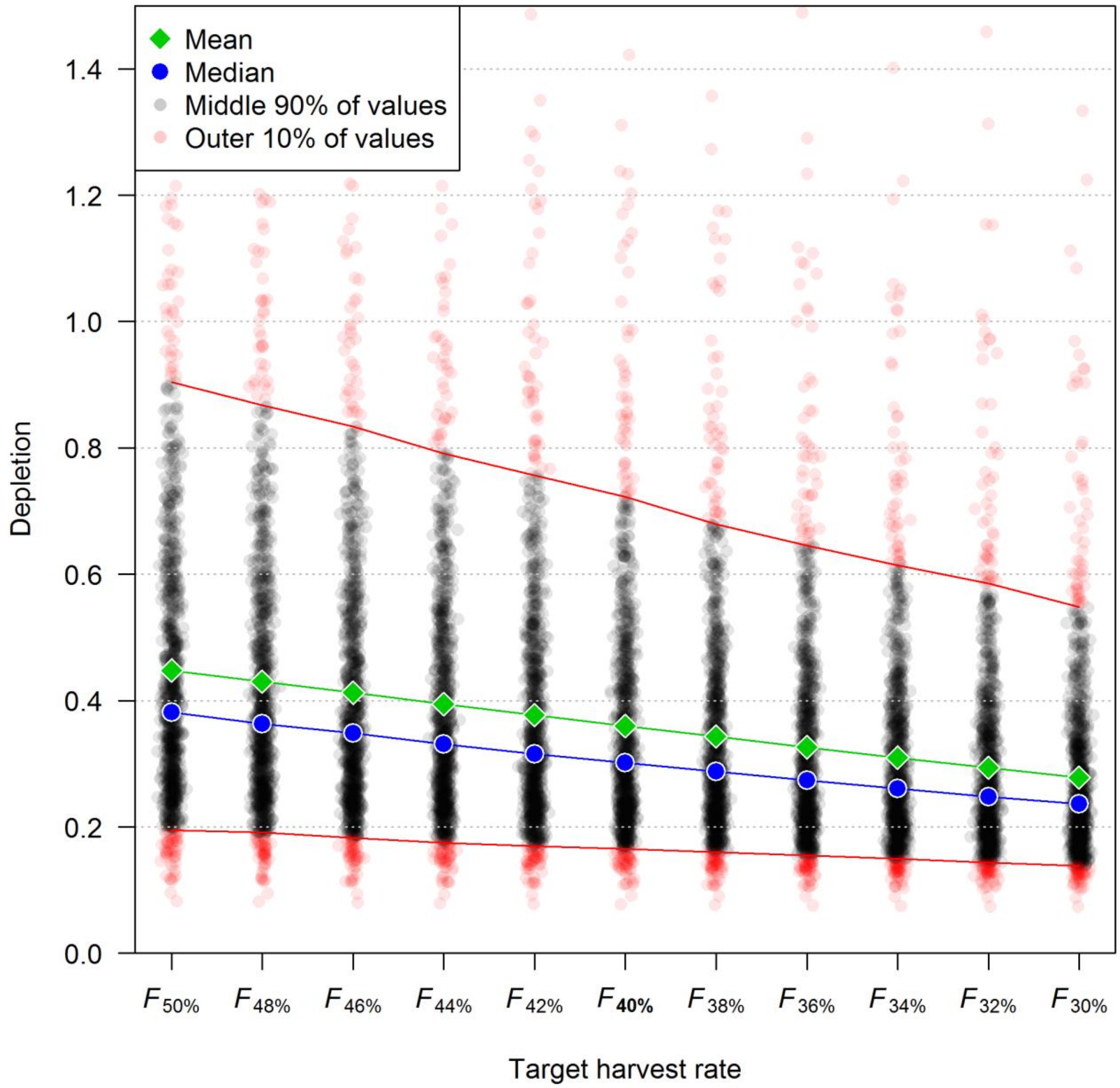


Figure A.7: Long term (2021-2030) depletion (y) as a function of the default harvest rate ($F_{SPR\%}$, x) for the perfect information case. The blue line is the median, the green line is the mean. Each dot is the MSE's simulated estimate of depletion. Horizontal positions are jittered to better illustrate distribution of individual points.

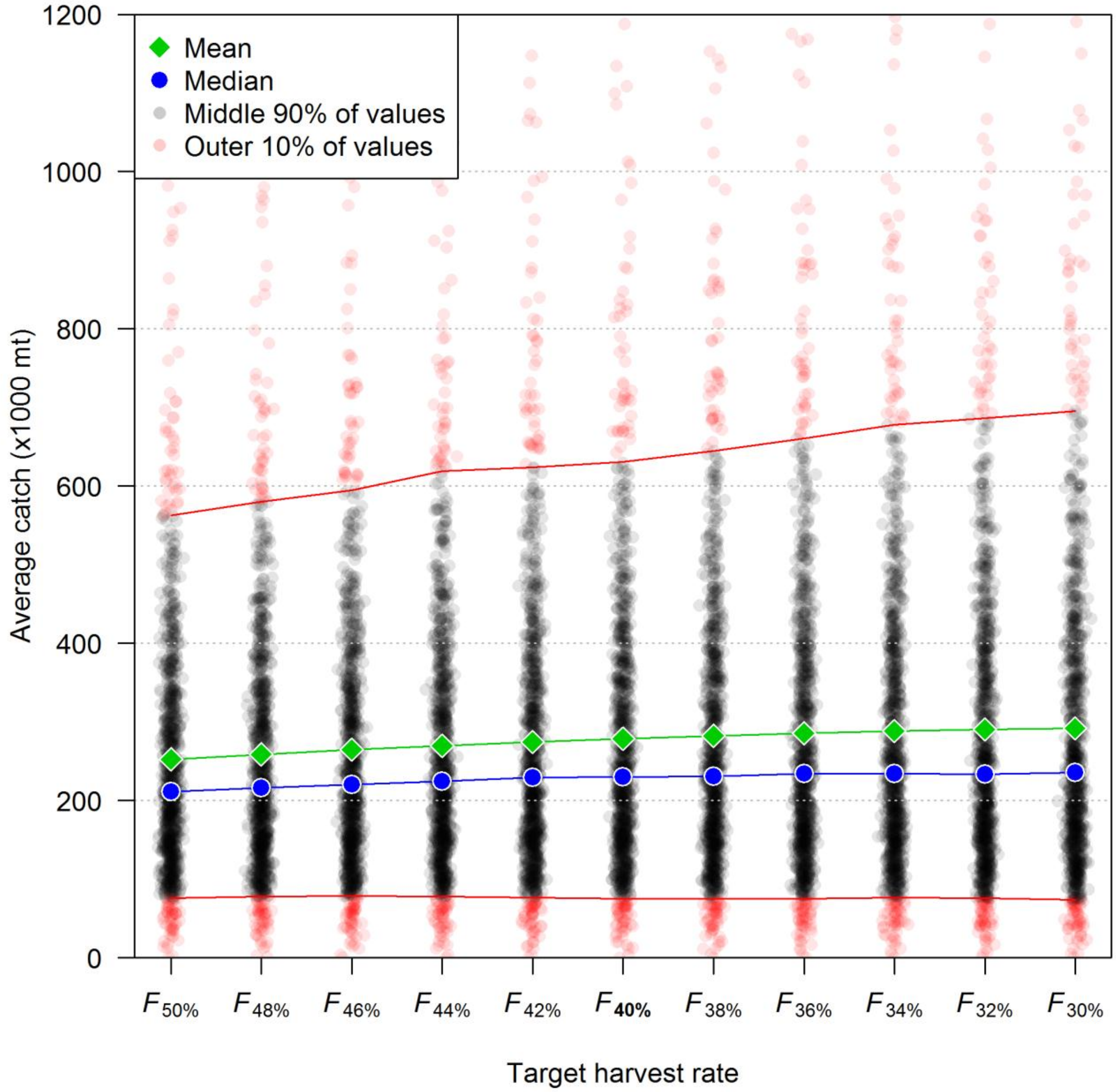


Figure A.8: Long term (2021-2030) average catch as a function of default harvest rate. Horizontal positions are jittered to better illustrate distribution of individual points

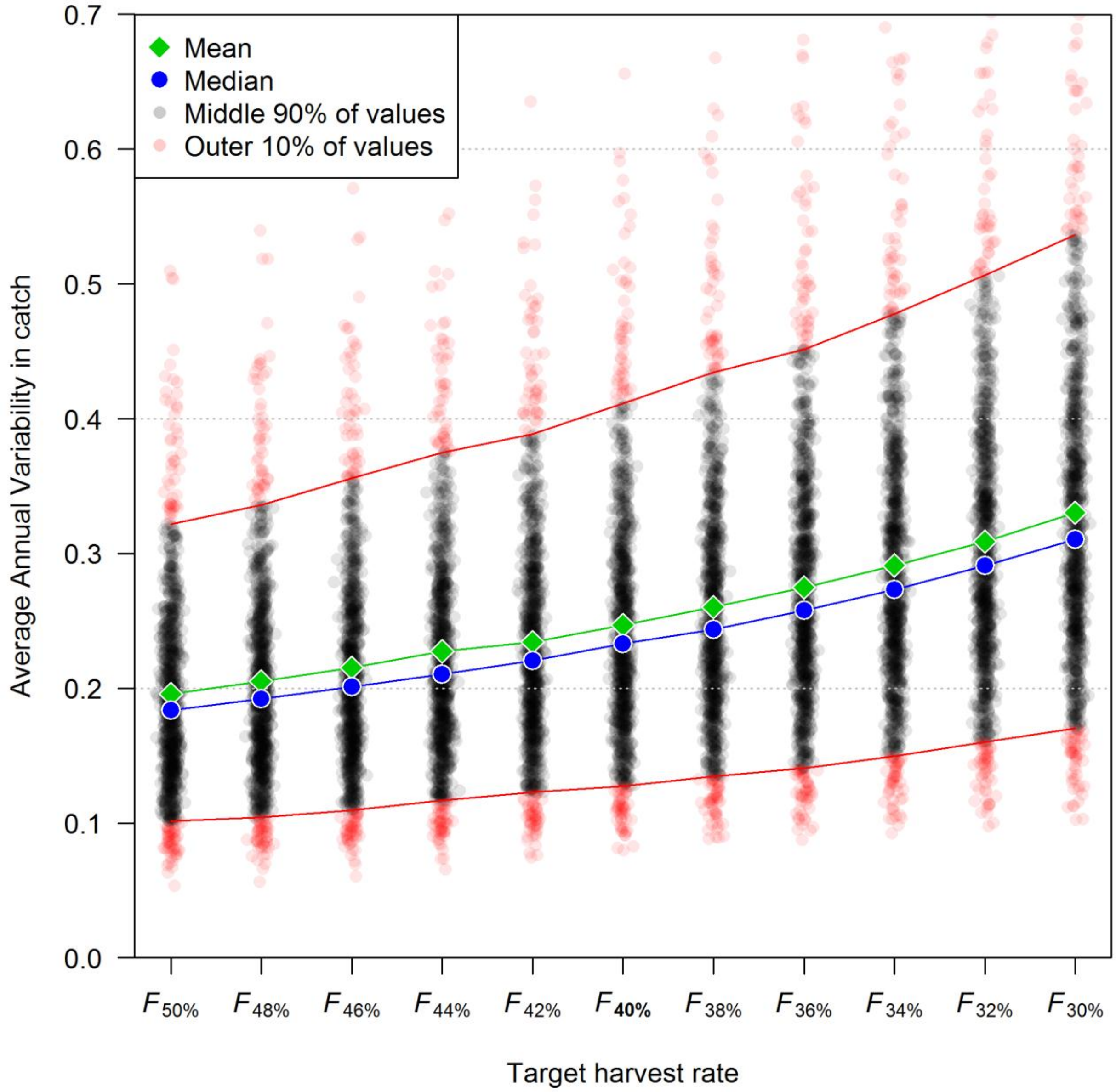


Figure A.9: Long term (2021-2030) average annual variability (AAV) as a function of the target harvest rate Fxx%. Note that F increases from left to right (see Figure A.14). Horizontal positions are jittered to better illustrate distribution of individual points.

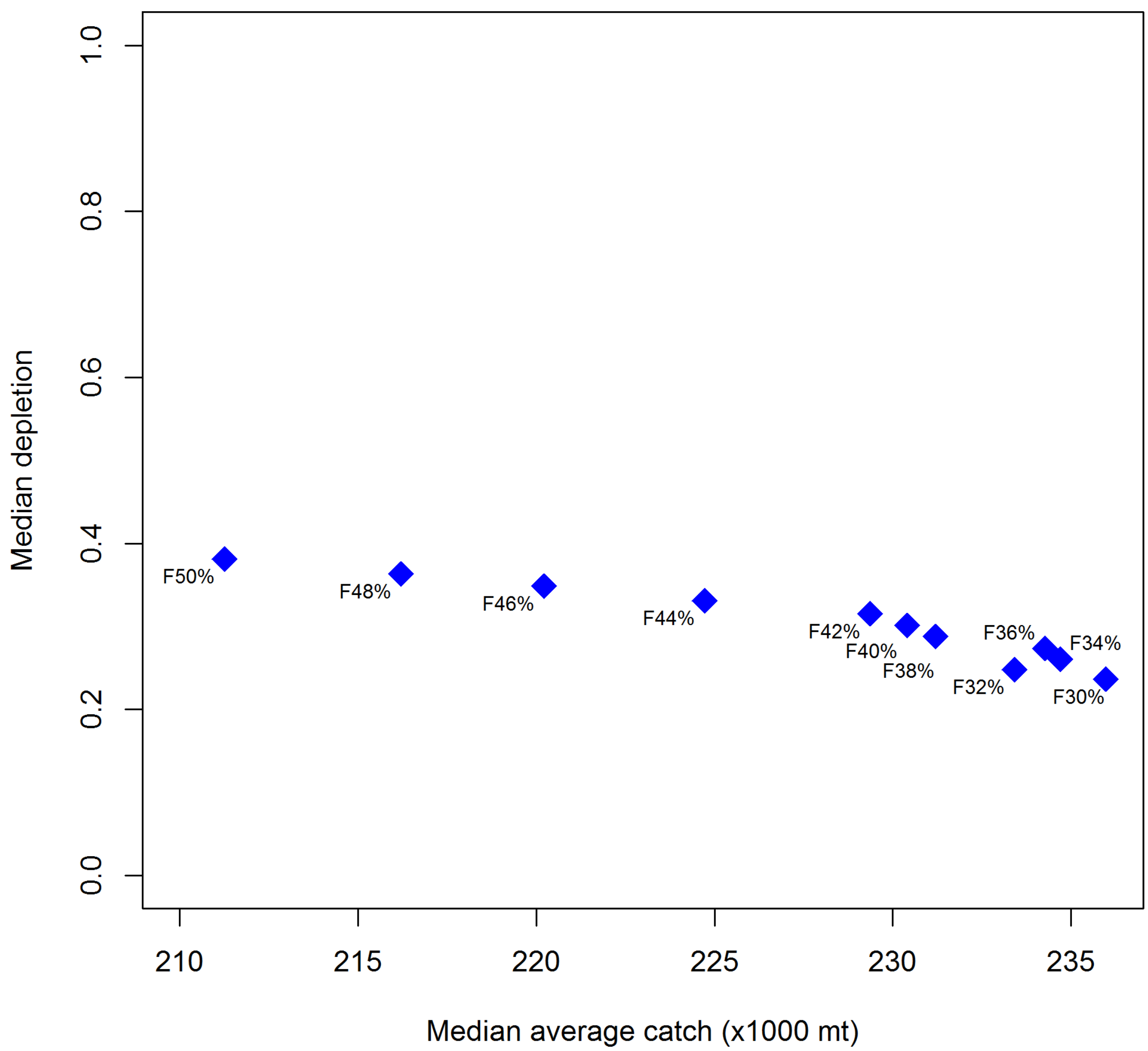


Figure A.10: Long term (2021-2030) median average depletion (y) vs. median average catch (x, mt) given by exploring alternative $F_{xx\%}$ values.

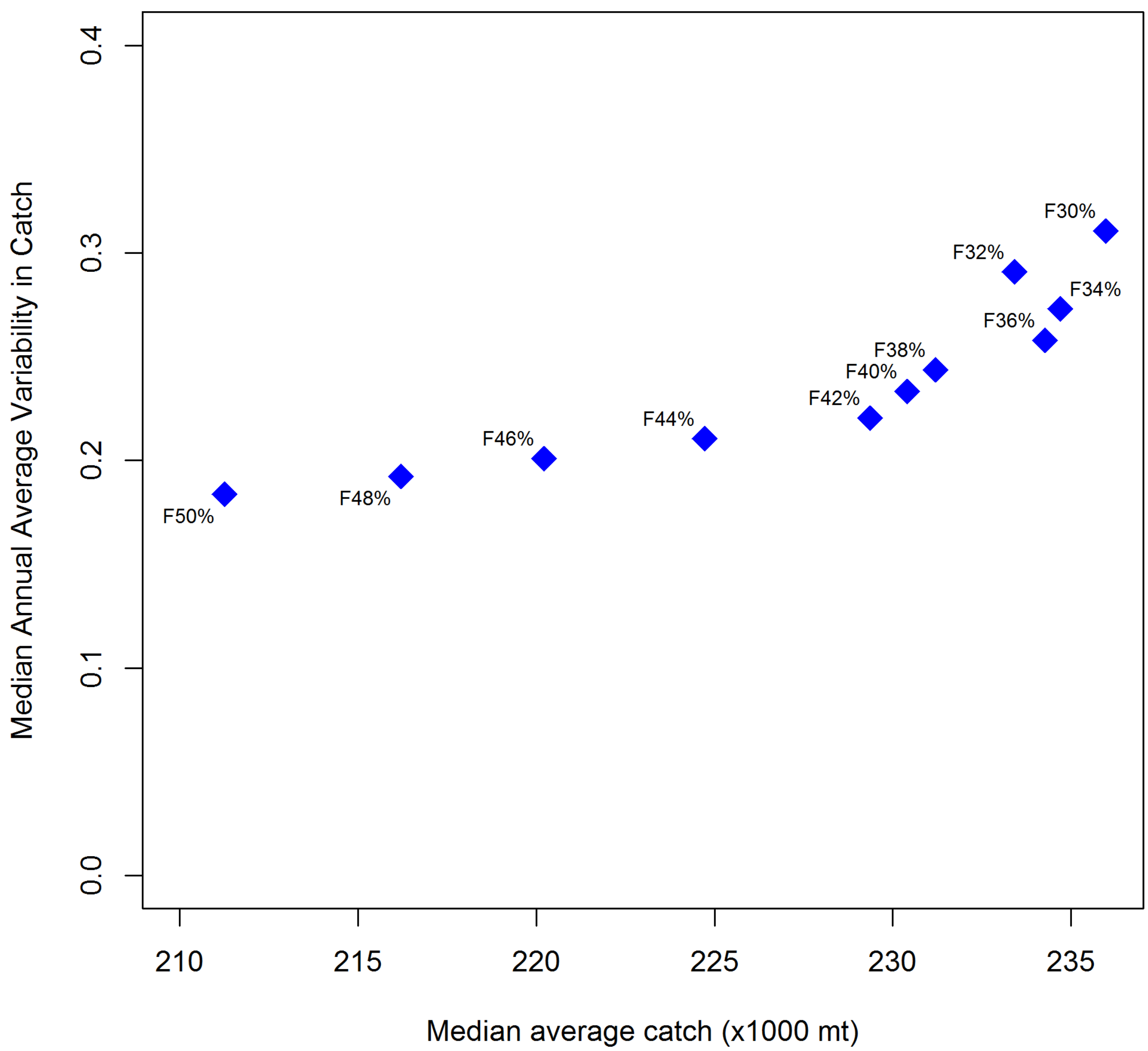


Figure A.11: Long term (2021-2030) median AAV (y) vs median average catch (x) given by alternative $F_{xx\%}$ values.

Appendix A.8. Supporting MSE Figures

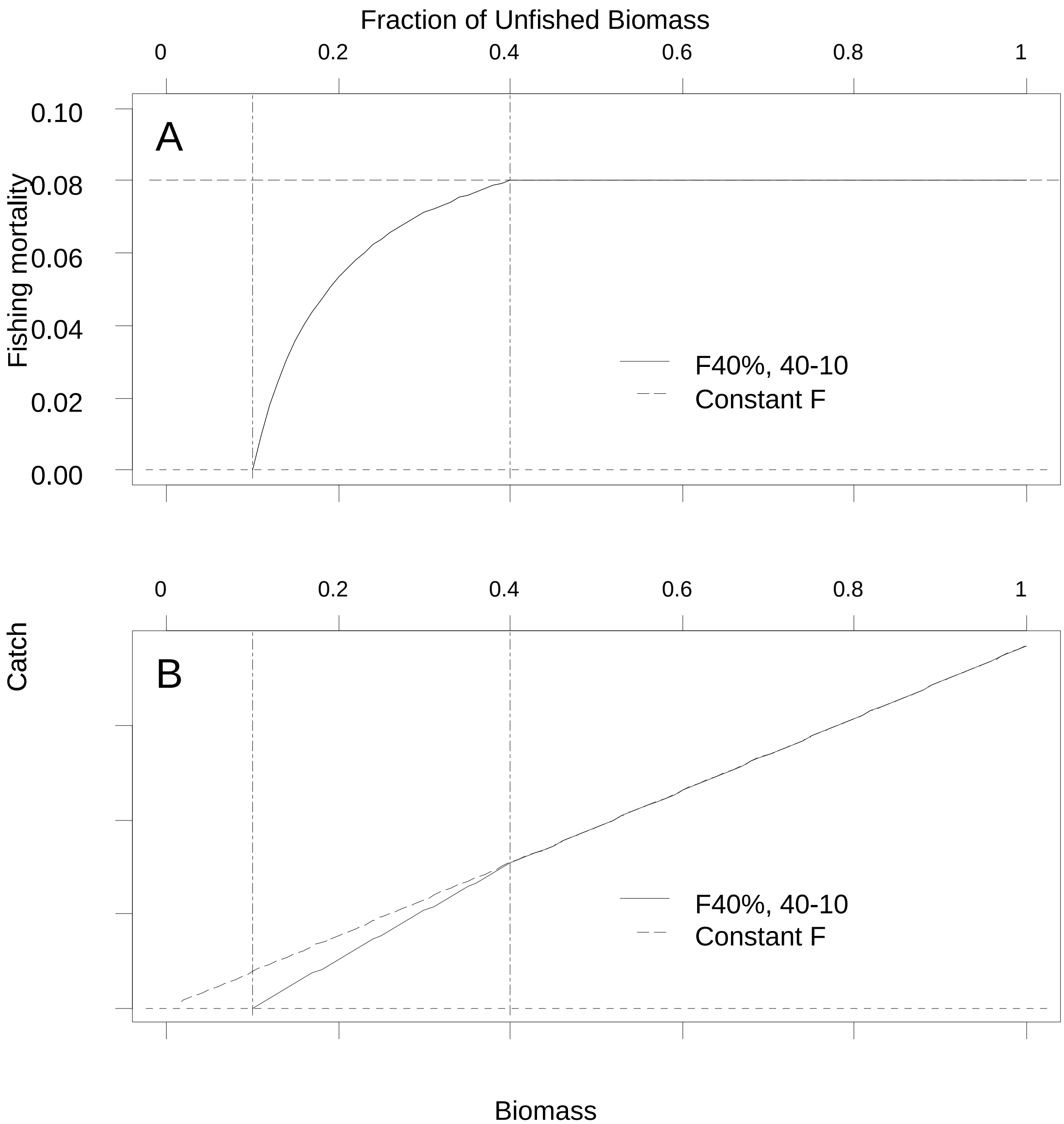


Figure A.12: The 40:10 control rule in relation to fishing mortality (top panel) and catch (bottom panel).

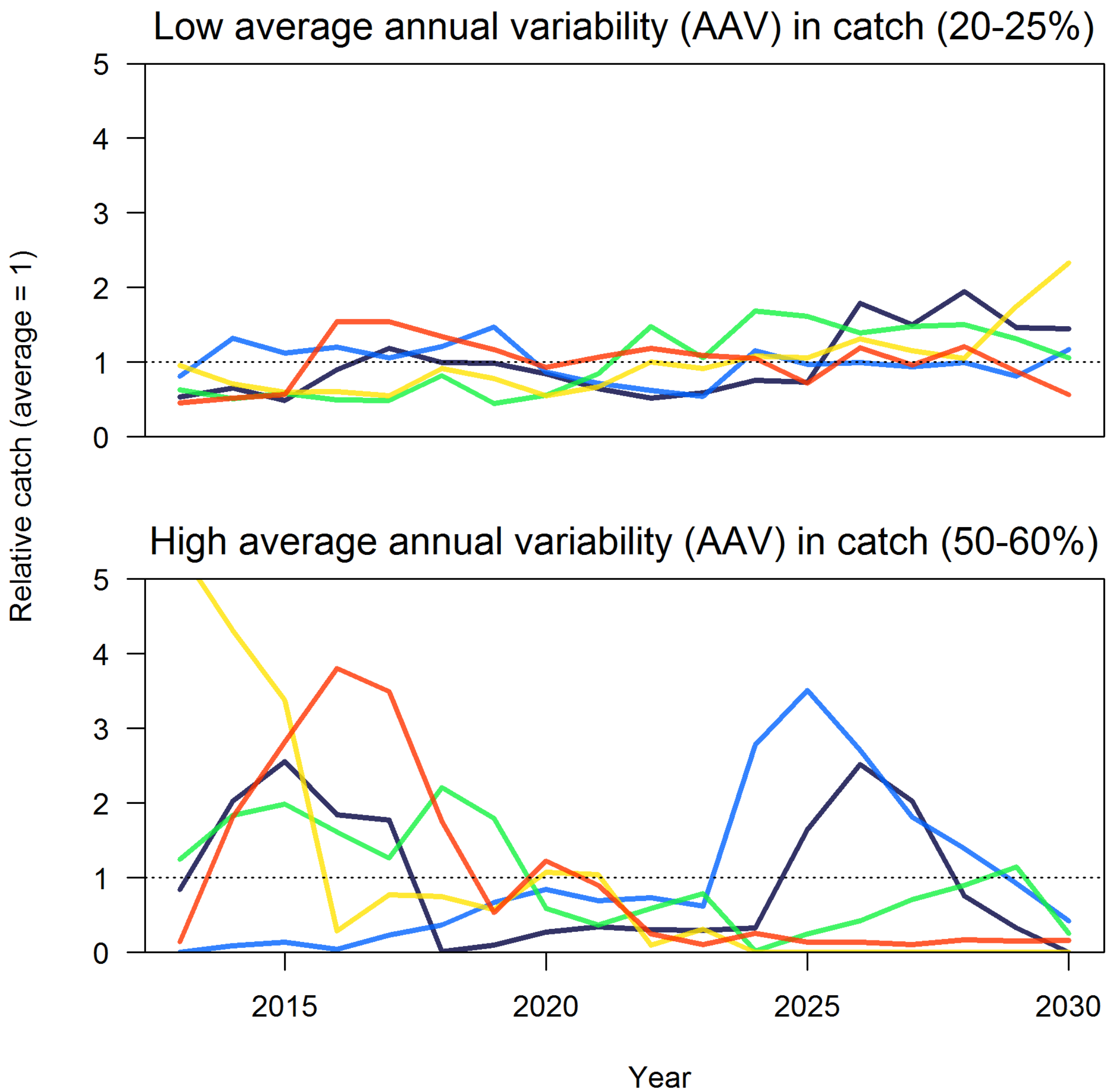


Figure A.13: Illustration of relative catch as a function of AAV in catch.

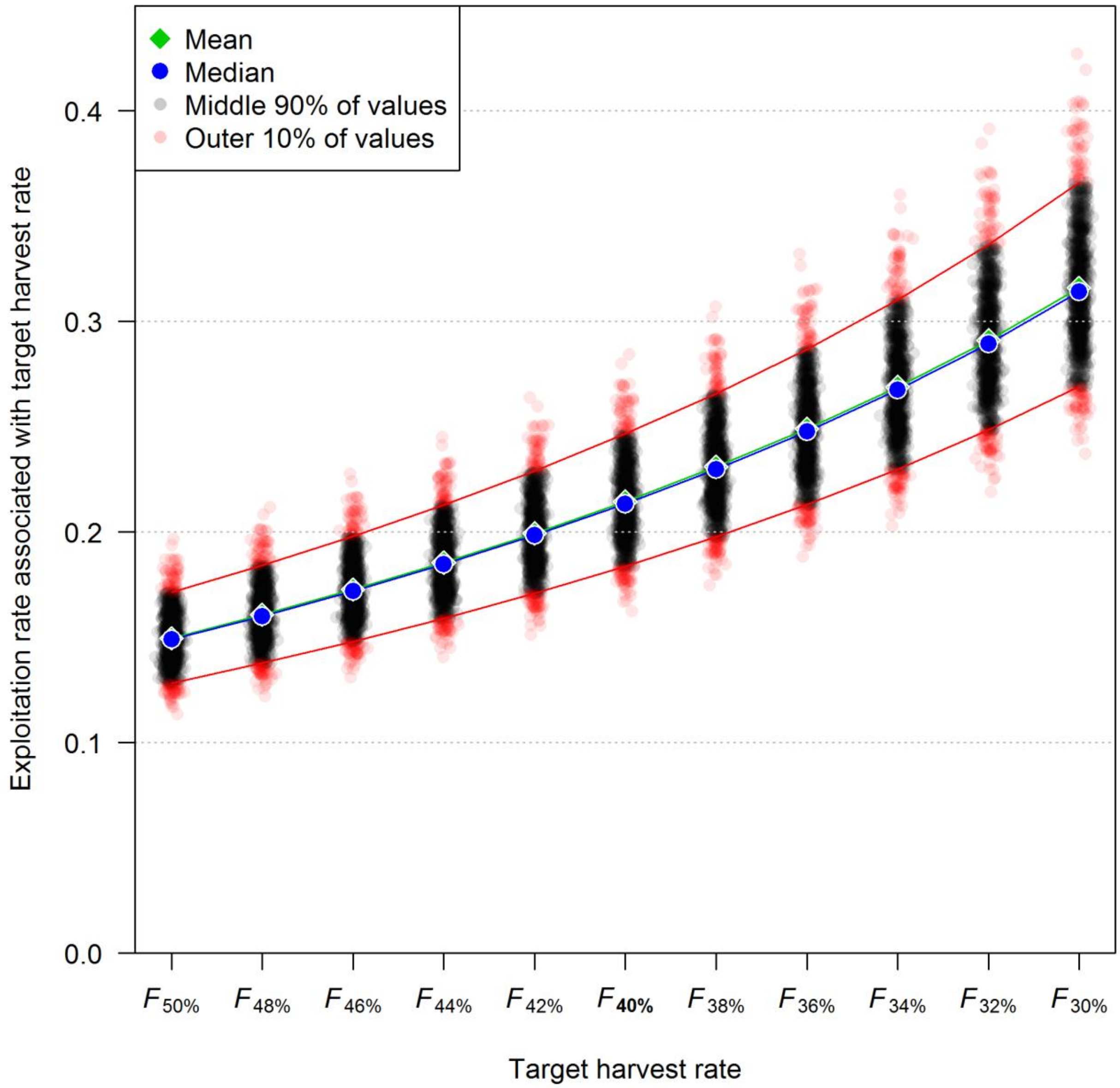


Figure A.14: Samples (dots) of discreet exploitation rates that correspond to the each random draw associated with target harvest rates expressed at Fspr%

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 $SB_{40\%}$ (see below) to a value of 0 at $SB_{10\%}$.

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.

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 formally established in 2011.

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

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.

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 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: Abbreviated term for relative depletion (see below).

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.

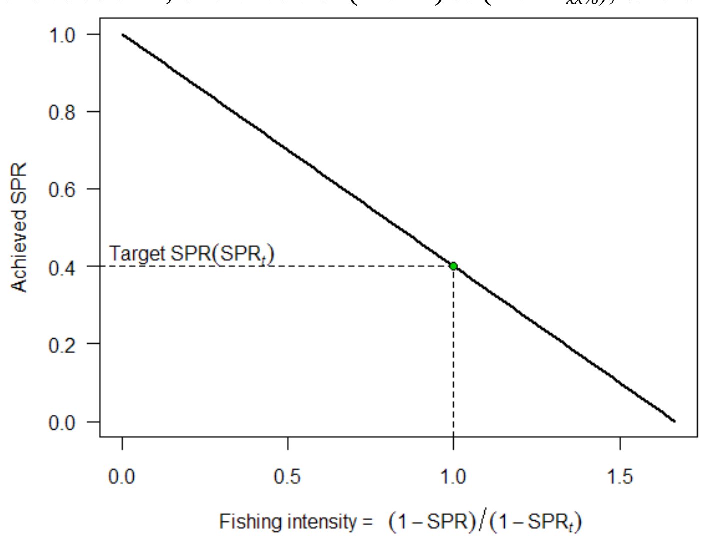
Exploitation fraction: A metric of fishing intensity that represents the total annual catch divided by the estimated population biomass over a range of ages assumed to be vulnerable to the fishery. This value is not equivalent to the instantaneous rate of fishing mortality (see below) or the Spawning 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.

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

Joint Technical Committee (JTC): The joint technical committee established by the Agreement.

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.

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.

MSE: Management Strategy Evaluation. A simulation procedure that 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.

MSY: Maximum sustainable yield. See above.

mt: Metric ton(s). A unit of mass (often referred to as weight) equal to 1000 kilograms or 2,204.62 pounds.

NA: Not available.

National Marine Fisheries Service: A division of the U.S. Department of Commerce, National Ocean and Atmospheric Administration (NOAA). NMFS is responsible for conservation and management of offshore fisheries (and inland salmon).

NMFS: National Marine Fisheries Service. See above.

NOAA: National Oceanic and Atmospheric Administration. The parent agency of the National Marine Fisheries Service.

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

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

Operating Model: 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.

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 SB_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 depletion: The ratio of the estimated beginning of the year female spawning biomass to estimated average unfished equilibrium female spawning biomass (SB_0, see below). Thus, lower values of relative depletion are associated with fewer mature female fish.

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.

$SB_{10\%}$: The level of female spawning biomass (output) corresponding to 10% of average unfished equilibrium female spawning biomass (SB_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.

$SB_{40\%}$: The level of female spawning biomass (output) corresponding to 40% of average unfished equilibrium female spawning biomass (SB_0, size of fish stock without fishing; see below).

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

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 $SB_{40\%}$. 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 SB_0 (i.e., when relative depletion 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. Explanation of nonparametric selectivity

For all ages in the population beginning with A_{min} = 1 for the fishery and 2 for the survey, there is a corresponding set of selectivity parameters for each fleet, p_a. The selectivity at age a is computed as,

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

where S'_a is the sum of parameters for ages up to a,

$$S'_a = \sum_{i=A_{min}}^{a} p_a$$

and S'_{max} is the maximum of the S'_a,

$$S'_{max} = \max(S'_a)$$

Selectivity is fixed at $S_a = 0$ for $a < A_{min}$. This formulation has the properties that the maximum selectivity is equal to 1, positive p_a values are associated with increasing selectivity between ages a-1 and a, and negative values are associated with decreasing selectivity between those ages. The parameters beyond the maximum age for which selectivity is estimated (6 in the base model, and 5 or 7 in the in a sensitivity analysis) are fixed at $p_a = 0$, resulting in constant selectivity beyond the last estimated value. The condition that maximum selectivity is equal to 1 results in one fewer degree of freedom than the number of estimated selectivity values. Therefore, the parameter corresponding to the first age of estimated selectivity (1 for the fishery and 2 for the survey), is fixed at 1.0.

In addition to a sensitivity considering changes in the maximum age of estimated selectivity, a sensitivity was conducted to examine the effect of two alternatives for time-varying selectivity. In these cases, the estimated parameters for the fishery selectivity, p_a for a in the range (2, 6) were assumed to follow a random walk over the years 1980-2012. This is formulated as

$$p_{a,y} = p_{a,y-1} + \varepsilon_{a,y}$$

where the $\varepsilon_{a,y}$ are additional parameters estimated in the model. The values of $\varepsilon_{a,y}$ are included in an additional likelihood component with negative log likelihood proportional to

$$-\log(L) \propto \frac{1}{2}\sum_{a=2}^{6}\sum_{y=1980}^{2012}\frac{{\varepsilon_{a,y}}^2}{{\sigma_a}^2}$$

The “flexible fishery” sensitivity analysis set all $\sigma_a = 0.05$ while the “very flexible fishery” case set all $\sigma_a = 0.2$. This sensitivity is intended to explore the effect of two degrees of time-varying selectivity on quantities of interest, but by no means does it represent the full range of possibilities. The statistical properties of this time-varying selectivity formulation have not been adequately explored, and many other parameterizations for time-varying selectivity are available. These options would benefit from further testing in a simulation or MSE context before being applied in an assessment model for application to management.

Appendix D. Estimated parameters in the base assessment model

Parameter	Posterior median
NatM_p_1_Fem_GP_1	0.2241
SR_LN.R0.	14.8037
SR_BH_steep	0.8226
Early_InitAge_20	-0.0757
Early_InitAge_19	-0.0905
Early_InitAge_18	0.0209
Early_InitAge_17	-0.0526
Early_InitAge_16	-0.0862
Early_InitAge_15	-0.1652
Early_InitAge_14	-0.1605
Early_InitAge_13	-0.0377
Early_InitAge_12	-0.1694
Early_InitAge_11	-0.1689
Early_InitAge_10	-0.2427
Early_InitAge_9	-0.2728
Early_InitAge_8	-0.2677
Early_InitAge_7	-0.4053
Early_InitAge_6	-0.3155
Early_InitAge_5	-0.4272
Early_InitAge_4	-0.3362
Early_InitAge_3	-0.2177
Early_InitAge_2	-0.1348
Early_InitAge_1	-0.0005
Early_RecrDev_1966	0.4151
Early_RecrDev_1967	1.1946
Early_RecrDev_1968	0.8858
Early_RecrDev_1969	-0.1398
Main_RecrDev_1970	2.1488
Main_RecrDev_1971	-0.2683
Main_RecrDev_1972	-0.7791
Main_RecrDev_1973	1.5022
Main_RecrDev_1974	-0.8386
Main_RecrDev_1975	0.3090
Main_RecrDev_1976	-1.0886
Main_RecrDev_1977	1.6587
Main_RecrDev_1978	-1.1963
Main_RecrDev_1979	-0.0167
Main_RecrDev_1980	2.8446
Main_RecrDev_1981	-1.1399
Main_RecrDev_1982	-1.3179
Main_RecrDev_1983	-0.8634

Parameter	Posterior median
Main_RecrDev_1984	2.5546
Main_RecrDev_1985	-1.5977
Main_RecrDev_1986	-1.5325
Main_RecrDev_1987	1.6785
Main_RecrDev_1988	0.6563
Main_RecrDev_1989	-1.7773
Main_RecrDev_1990	1.4786
Main_RecrDev_1991	-0.6191
Main_RecrDev_1992	-1.6213
Main_RecrDev_1993	1.2251
Main_RecrDev_1994	0.9293
Main_RecrDev_1995	0.3562
Main_RecrDev_1996	0.5235
Main_RecrDev_1997	0.2963
Main_RecrDev_1998	0.6651
Main_RecrDev_1999	2.5040
Main_RecrDev_2000	-0.9257
Main_RecrDev_2001	-0.1107
Main_RecrDev_2002	-2.6462
Main_RecrDev_2003	0.3274
Main_RecrDev_2004	-2.5835
Main_RecrDev_2005	0.8272
Main_RecrDev_2006	0.6522
Main_RecrDev_2007	-2.3190
Main_RecrDev_2008	1.8795
Late_RecrDev_2009	1.0208
Late_RecrDev_2010	2.7750
Late_RecrDev_2011	-0.1653
Late_RecrDev_2012	-0.0548
ForeRecr_2013	0.0416
ForeRecr_2014	-0.0121
ForeRecr_2015	0.0760
Q_extraSD_2_Acoustic_Survey	0.4162
AgeSel_1P_3_Fishery	3.1936
AgeSel_1P_4_Fishery	1.5091
AgeSel_1P_5_Fishery	0.4566
AgeSel_1P_6_Fishery	0.1701
AgeSel_1P_7_Fishery	0.2452
AgeSel_2P_4_Acoustic_Survey	0.2330
AgeSel_2P_5_Acoustic_Survey	0.1322
AgeSel_2P_6_Acoustic_Survey	-0.0039
AgeSel_2P_7_Acoustic_Survey	0.4220

Appendix E. SS data file

```
#C 2013 Hake data file

### Global model specifications ###
1966    # Start year
2012    # 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

47 # 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
103640  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
319710  1991    1
299687  1992    1
198924  1993    1
362422  1994    1
249644  1995    1
306383  1996    1
325257  1997    1
320815  1998    1
311844  1999    1
228214  2000    1
227531  2001    1
180698  2002    1
205177  2003    1
338654  2004    1
363157  2005    1
361761  2006    1
291129  2007    1
322145  2008    1
177459  2009    1
226202  2010    1
285850  2011    1
204040  2012    1

9 # 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

# Year seas index obs se(log)
# Acoustic survey
1995    1       2       1517948 0.0666
1998    1       2       1342740 0.0492
2001    1       2       918622  0.0823
2003    1       2       2520641 0.0709
2005    1       2       1754722 0.0847
2007    1       2       1122809 0.0752
2009    1       2       1612027 0.1375
2011    1       2       521476  0.1015
2012    1       2       1380724 0.0475

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

40 # N_ageerror_definitions
# Annual keys with cohort effect
#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   0.1810831  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
with adjustments for age 1
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
with adjustments for age 2
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
with adjustments for age 3
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
with adjustments for age 4
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   0.1810831  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
with adjustments for ages 1,5
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
with adjustments for ages 2,6
```

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
with adjustments for ages 3,7											
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
with adjustments for ages 4,8											
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
with adjustments for ages 5,9											
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
with adjustments for ages 6,10											
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
with adjustments for ages 7,11											
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
with adjustments for ages 8,12											
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
with adjustments for ages 9,13											
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
with adjustments for ages 10,14											

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
with adjustments for ages 11,15											
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
with adjustments for ages 12,16											
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
with adjustments for ages 13,17											
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
with adjustments for ages 14,18											
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
with adjustments for ages 15,19											
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	# 2000	def28	expected
ages											
0.329242	0.1810831	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
with adjustments for ages 1,16,20											
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
with adjustments for ages 2,17											
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
with adjustments for ages 3,18											

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
with adjustments for ages 4,19											
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
with adjustments for ages 5,20											
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
with adjustments for age 6											
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
with adjustments for age 7											
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
with adjustments for age 8											
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
with adjustments for age 9											
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	0.1810831	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
with adjustments for ages 1,10											
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	0.19080435	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
with adjustments for ages 2,11											

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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      # 2011    def39     expected
ages
0.329242  0.1810831 0.346917  0.202748  0.395312  0.42809   0.468362  0.517841  0.57863   0.653316  0.745076  0.857813
0.547977  1.1665    1.37557   1.63244   1.858     2.172     2.53      2.934     3.388     # 2011    def39     SD of age
with adjustments for ages 1,3,12
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 0.2174216 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
with adjustments for ages 2,4,13

47      # 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=8)
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

#Aggregate marginal fishery age comps (n=38)                                            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	0.621	0.036	0.038	0.168	0.028
0.015	0.012	0.033	0.009	0.006	0.014	0.005										
1985	1	1	0	0	13	-1	-1	56	0.010	0.001	0.003	0.073	0.688	0.080	0.049	0.063
0.018	0.006	0.006	0.002	0.000	0.000	0.000										
1986	1	1	0	0	14	-1	-1	120	0.000	0.160	0.056	0.005	0.008	0.428	0.067	0.080
0.083	0.022	0.028	0.018	0.033	0.005	0.007										
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
0.012	0.071	0.000	0.007	0.019	0.018	0.000										
1988	1	1	0	0	16	-1	-1	81	0.000	0.008	0.000	0.384	0.011	0.015	0.002	0.394
0.011	0.005	0.111	0.008	0.000	0.000	0.051										
1989	1	1	0	0	17	-1	-1	77	0.000	0.073	0.032	0.003	0.501	0.016	0.003	0.001
0.321	0.023	0.001	0.023	0.001	0.000	0.000										
1990	1	1	0	0	18	-1	-1	163	0.000	0.052	0.179	0.017	0.006	0.347	0.003	0.002
0.000	0.321	0.003	0.001	0.060	0.000	0.009										
1991	1	1	0	0	19	-1	-1	160	0.000	0.035	0.204	0.196	0.025	0.007	0.278	0.011
0.001	0.002	0.192	0.004	0.000	0.036	0.007										
1992	1	1	0	0	20	-1	-1	243	0.005	0.042	0.042	0.130	0.187	0.022	0.010	0.340
0.008	0.001	0.003	0.181	0.004	0.000	0.024										
1993	1	1	0	0	21	-1	-1	175	0.000	0.010	0.230	0.032	0.127	0.156	0.015	0.008
0.278	0.007	0.001	0.000	0.121	0.001	0.014										
1994	1	1	0	0	22	-1	-1	234	0.000	0.000	0.029	0.228	0.012	0.131	0.197	0.010
0.003	0.286	0.001	0.003	0.000	0.089	0.008										
1995	1	1	0	0	23	-1	-1	147	0.002	0.025	0.005	0.058	0.315	0.018	0.072	0.190
0.024	0.006	0.180	0.030	0.005	0.001	0.071										
1996	1	1	0	0	24	-1	-1	186	0.000	0.182	0.158	0.014	0.078	0.183	0.010	0.054
0.109	0.004	0.003	0.159	0.000	0.001	0.045										
1997	1	1	0	0	25	-1	-1	222	0.000	0.008	0.272	0.250	0.010	0.084	0.130	0.024
0.049	0.065	0.015	0.002	0.064	0.006	0.022										
1998	1	1	0	0	26	-1	-1	243	0.000	0.053	0.188	0.203	0.283	0.032	0.050	0.091
0.010	0.017	0.037	0.003	0.001	0.026	0.005										
1999	1	1	0	0	27	-1	-1	514	0.000	0.095	0.198	0.181	0.187	0.136	0.028	0.034
0.036	0.009	0.014	0.040	0.004	0.003	0.035										
2000	1	1	0	0	28	-1	-1	529	0.010	0.044	0.094	0.147	0.134	0.210	0.137	0.067
0.048	0.027	0.020	0.022	0.011	0.008	0.024										
2001	1	1	0	0	29	-1	-1	541	0.000	0.168	0.154	0.231	0.174	0.081	0.078	0.049
0.012	0.013	0.012	0.007	0.007	0.005	0.009										
2002	1	1	0	0	30	-1	-1	450	0.000	0.000	0.505	0.149	0.102	0.056	0.039	0.063
0.045	0.007	0.007	0.012	0.002	0.004	0.009										
2003	1	1	0	0	31	-1	-1	457	0.000	0.001	0.012	0.690	0.115	0.035	0.049	0.031
0.026	0.022	0.007	0.003	0.005	0.002	0.003										
2004	1	1	0	0	32	-1	-1	501	0.000	0.000	0.046	0.061	0.690	0.084	0.022	0.044
0.025	0.011	0.009	0.003	0.002	0.002	0.001										
2005	1	1	0	0	33	-1	-1	613	0.000	0.006	0.004	0.066	0.053	0.690	0.083	0.023
0.028	0.022	0.011	0.010	0.002	0.001	0.002										

```
2006	1	1	0	0	34	-1	-1	720	0.003	0.028	0.103	0.018	0.089	0.052	0.589	0.055
0.015	0.022	0.011	0.008	0.004	0.001	0.001
2007	1	1	0	0	35	-1	-1	629	0.008	0.113	0.037	0.151	0.015	0.071	0.039	0.451
0.057	0.019	0.018	0.008	0.004	0.006	0.003
2008	1	1	0	0	36	-1	-1	794	0.008	0.089	0.299	0.023	0.149	0.011	0.037	0.033
0.290	0.031	0.010	0.009	0.005	0.003	0.004
2009	1	1	0	0	37	-1	-1	686	0.007	0.005	0.287	0.270	0.030	0.109	0.010	0.024
0.019	0.182	0.034	0.008	0.012	0.002	0.003
2010	1	1	0	0	38	-1	-1	873	0.000	0.243	0.033	0.369	0.214	0.024	0.029	0.006
0.006	0.011	0.047	0.011	0.001	0.001	0.002
2011	1	1	0	0	39	-1	-1	1081	0.028	0.091	0.653	0.030	0.077	0.058	0.014	0.011
0.004	0.003	0.005	0.017	0.003	0.003	0.003
2012	1	1	0	0	40	-1	-1	669	0.002	0.346	0.108	0.345	0.025	0.061	0.047	0.017
0.008	0.007	0.006	0.006	0.013	0.005	0.004

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 F. SS control file

```
#C 2013 Hake control file

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

# 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
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 length at age 0
0.03   0.16  0.062 0.1   -1     99     -5     0      0      0   0 0 0 0 # CV of length at age inf
# W-L, maturity and fecundity parameters
# Female placeholders
-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
2008    # 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
# the following 5 bias adjustment settings are not used in the MCMC
1965    # Last recruit dev with no bias_adjustment
1971    # First year of full bias correction (linear ramp from year above)
2009    # Last year for full bias correction in_MPD
2010    # First_recent_yr_nobias_adj_in_MPD
0.86    # 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
# Create one par for each entry > 0 by row in cols A-D
0       0       0       0        # US_Foreign
0       0       1       0        # Acoustic_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 0 0 0 0 0 0 # Change to age 2
  -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        0.1    -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

# Acoustic survey - nonparametric age-based selectivity
# Acoustic Survey double non-parametric 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

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
# Component codes:
#  1=Survey, 2=discard, 3=mean body weight
#  4=length frequency, 5=age frequency, 6=Weight frequency
```

```
#  7=size at age, 8=catch, 9=initial equilibrium catch
#  10=rec devs, 11=parameter priors, 12=parameter devs
#  13=Crash penalty
# Component fleet/survey  phase  value  wtfreq_method

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 G. SS starter file (starter.ss

```
#C 2013 Hake starter file

2013hake_data.SS     # Data file
2013hake_control.SS  # Control file

0       # 0=use init values in control file; 1=use ss3.par
1       # run display detail (0,1,2)
2       # detailed age-structured reports in REPORT.SSO (0,1)
0       # write detailed checkup.sso file (0,1)
0  # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms; 
4=every,active)
0       # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
0       # Include prior_like for non-estimated parameters (0,1)
0       # Use Soft Boundaries to aid convergence (0,1) (recommended)
1     # Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd and higher are 
bootstrap
25      # Turn off estimation for parameters entering after this phase
1       # MCeval burn interval
1       # MCeval thin interval
0       # jitter initial parm value by this fraction
-1      # min yr for sdreport outputs (-1 for styr)
-2      # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0       # N individual STD years
0.00001 # final convergence criteria (e.g. 1.0e-04)
0       # retrospective year relative to end year (e.g. -4)
3       # min age for calc of summary biomass
1       # Depletion basis:  denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel X*B_styr
1.0     # Fraction (X) for Depletion denominator (e.g. 0.4)
1       # SPR_report_basis:  0=skip; 1=(1-SPR)/(1-SPR_tgt); 2=(1-SPR)/(1-SPR_MSY); 3=(1-SPR)/(1-
SPR_Btarget); 4=rawSPR
1       # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num); 3=sum(Frates); 4=true F 
for range of ages
0       # F_report_basis: 0=raw; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
999     # check value for end of file
```

Appendix H. SS forecast file (forecast.ss)

```
#C 2013 Hake forecast file

# for all year entries except rebuilder; enter either: actual year, -999 for styr, 0 for endyr, neg
number for rel. endyr
1       # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2       # 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)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actual year, or
values of 0 or -integer to be rel. endyr)
 -999 -999 -999 -999 -999 -999
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 (uses first-last relF yrs);
5=input annual F scalar
3       # N forecast years
1       # F scalar (only used for Do_Forecast==5)
#_Fcast_years:  beg_selex, end_selex, beg_relF, end_relF  (enter actual year, or values of 0 or -
integer to be rel. endyr)
-5 0 -5 0
1       # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0.4     # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no
F level below)
0.1     # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
1       # Control rule target as fraction of Flimit (e.g. 0.75)
3       #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with allocations
applied)
3       #_First forecast loop with stochastic recruitment
-1      #_Forecast loop control #3 (reserved for future bells&whistles)
0       #_Forecast loop control #4 (reserved for future bells&whistles)
0       #_Forecast loop control #5 (reserved for future bells&whistles)
2011    #FirstYear for caps and allocations (should be after years with fixed inputs)
0       # stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause active
impl_error)
0       # Do West Coast gfish rebuilder output (0/1)
1999    # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
2002    # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
1       # fleet relative F:  1=use first-last alloc year; 2=read seas(row) x fleet(col) below
# Note that fleet allocation is used directly as average F if Do_Forecast=4
2       # basis for fcast catch tuning and for fcast catch caps and allocation  (2=deadbio;
3=retainbio; 5=deadnum; 6=retainnum)
# Conditional input if relative F choice = 2
# Fleet relative F:  rows are seasons, columns are fleets
#_Fleet:  Fishery
#  1
# max totalcatch by fleet (-1 to have no max) must enter value for each fleet
 -1
# max totalcatch by area (-1 to have no max); must enter value for each fleet
 -1
# fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an
alloc group)
 1
# allocation fraction for each of: 1 allocation groups
1
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 I. Weight-at-age file (wtatage.ss)

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2013-01-08 18:04:48
###################################################
157 # 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 0.0300 0.0900 0.2481 0.3798 0.4859 0.5433 0.5919 0.6625 0.7220 0.7918 0.8636 0.9318 0.9707 1.0708
1.0023 1.0191 1.0191 1.0191 1.0191 1.0191 1.0191
  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 0.4973 0.5188 0.6936 0.8041 0.9166 1.2097 1.3375 1.4498 1.6532 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 0.1006 0.4021 0.4870 0.5902 0.6650 0.7493 0.8267 0.9781 1.1052 1.2349 1.3148 1.4058 1.7511
2.0367 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1      1  1     1    -1 0.0539 0.1026 0.1360 0.4699 0.5300 0.6027 0.6392 0.7395 0.8391 0.9775 1.0971 1.2349 1.3028 1.4814
1.7419 2.3379 2.3379 2.3379 2.3379 2.3379 2.3379
  1979    1      1  1     1    -1 0.0528 0.0913 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 0.0517 0.0800 0.2236 0.4529 0.3922 0.4904 0.5166 0.6554 0.7125 0.8740 1.0616 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 0.0506 0.1079 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 0.0494 0.1183 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 0.0483 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 0.0472 0.1315 0.1642 0.2493 0.4385 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 0.0461 0.1740 0.2297 0.2679 0.4414 0.5497 0.5474 0.6014 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 0.0450 0.1555 0.2771 0.2909 0.3024 0.3735 0.5425 0.5717 0.6421 0.8209 0.9403 1.1860 1.1900 1.3864
1.6800 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
  1987    1      1  1     1    -1 0.0439 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 0.0428 0.1400 0.1870 0.3189 0.4711 0.3689 0.3731 0.5163 0.6474 0.6851 0.7183 0.9167 1.0924 1.0225
1.4500 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
```

```
  1989    1       1  1     1    -1 0.0417 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 0.0406 0.1378 0.2435 0.3506 0.3906 0.5111 0.5462 0.6076 0.6678 0.5300 0.7691 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 0.0394 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 0.0383 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 0.0372 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 0.0361 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 0.0350 0.1108 0.2682 0.3418 0.4876 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7442 0.7998 0.9101
0.6804 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
  1996    1       1  1     1    -1 0.0339 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 0.0328 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 0.0317 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 0.7714 0.7714 0.7714 0.7714 0.7714 0.7714
  1999    1       1  1     1    -1 0.0306 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 0.0294 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 0.0283 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 0.0272 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 0.0261 0.1000 0.2551 0.4355 0.5225 0.5879 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 0.0250 0.1081 0.2577 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 0.0239 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 0.0228 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 0.0217 0.0461 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 0.0217 0.1403 0.2445 0.4081 0.5630 0.6371 0.6865 0.6818 0.7084 0.7210 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 0.0217 0.0667 0.2448 0.3431 0.4712 0.6371 0.6702 0.6942 0.7463 0.8226 0.7672 0.8115 1.0147 0.8503
0.9582 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
  2010    1       1  1     1    -1 0.0217 0.1089 0.2325 0.2535 0.4335 0.5293 0.6577 0.8349 1.0828 1.0276 0.9409 0.8763 0.8373 1.1253
0.7200 0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
  2011    1       1  1     1    -1 0.0217 0.0844 0.2457 0.3219 0.3864 0.5142 0.5967 0.6914 0.8620 0.9294 0.9742 1.0691 1.0451 1.0268
1.0578 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1       1  1     1    -1 0.0217 0.1270 0.2073 0.3516 0.4085 0.4934 0.6574 0.6930 0.7802 0.9151 0.9633 0.9639 0.9713 0.9935
0.9924 0.9425 0.9425 0.9425 0.9425 0.9425 0.9425

#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 0.0300 0.0900 0.2481 0.3798 0.4859 0.5433 0.5919 0.6625 0.7220 0.7918 0.8636 0.9318 0.9707 1.0708
1.0023 1.0191 1.0191 1.0191 1.0191 1.0191 1.0191
  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 0.4973 0.5188 0.6936 0.8041 0.9166 1.2097 1.3375 1.4498 1.6532 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 0.1006 0.4021 0.4870 0.5902 0.6650 0.7493 0.8267 0.9781 1.1052 1.2349 1.3148 1.4058 1.7511
2.0367 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1      1  1     1     0 0.0539 0.1026 0.1360 0.4699 0.5300 0.6027 0.6392 0.7395 0.8391 0.9775 1.0971 1.2349 1.3028 1.4814
1.7419 2.3379 2.3379 2.3379 2.3379 2.3379 2.3379
  1979    1      1  1     1     0 0.0528 0.0913 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 0.0517 0.0800 0.2236 0.4529 0.3922 0.4904 0.5166 0.6554 0.7125 0.8740 1.0616 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 0.0506 0.1079 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 0.0494 0.1183 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 0.0483 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 0.0472 0.1315 0.1642 0.2493 0.4385 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 0.0461 0.1740 0.2297 0.2679 0.4414 0.5497 0.5474 0.6014 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 0.0450 0.1555 0.2771 0.2909 0.3024 0.3735 0.5425 0.5717 0.6421 0.8209 0.9403 1.1860 1.1900 1.3864
1.6800 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
  1987    1      1  1     1     0 0.0439 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 0.0428 0.1400 0.1870 0.3189 0.4711 0.3689 0.3731 0.5163 0.6474 0.6851 0.7183 0.9167 1.0924 1.0225
1.4500 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
  1989    1      1  1     1     0 0.0417 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 0.0406 0.1378 0.2435 0.3506 0.3906 0.5111 0.5462 0.6076 0.6678 0.5300 0.7691 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 0.0394 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 0.0383 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 0.0372 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 0.0361 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 0.0350 0.1108 0.2682 0.3418 0.4876 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7442 0.7998 0.9101
0.6804 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
  1996    1      1  1     1     0 0.0339 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 0.0328 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
```

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  1998    1      1  1     1     0 0.0317 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 0.7714 0.7714 0.7714 0.7714 0.7714 0.7714
  1999    1      1  1     1     0 0.0306 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 0.0294 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 0.0283 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 0.0272 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 0.0261 0.1000 0.2551 0.4355 0.5225 0.5879 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 0.0250 0.1081 0.2577 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 0.0239 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 0.0228 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 0.0217 0.0461 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 0.0217 0.1403 0.2445 0.4081 0.5630 0.6371 0.6865 0.6818 0.7084 0.7210 0.7488 0.8073 0.8483 0.7755
0.8834 0.8332 0.8332 0.8332 0.8332 0.8332 0.8332
  2009    1      1  1     1     0 0.0217 0.0667 0.2448 0.3431 0.4712 0.6371 0.6702 0.6942 0.7463 0.8226 0.7672 0.8115 1.0147 0.8503
0.9582 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
  2010    1      1  1     1     0 0.0217 0.1089 0.2325 0.2535 0.4335 0.5293 0.6577 0.8349 1.0828 1.0276 0.9409 0.8763 0.8373 1.1253
0.7200 0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
  2011    1      1  1     1     0 0.0217 0.0844 0.2457 0.3219 0.3864 0.5142 0.5967 0.6914 0.8620 0.9294 0.9742 1.0691 1.0451 1.0268
1.0578 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1      1  1     1     0 0.0217 0.1270 0.2073 0.3516 0.4085 0.4934 0.6574 0.6930 0.7802 0.9151 0.9633 0.9639 0.9713 0.9935
0.9924 0.9425 0.9425 0.9425 0.9425 0.9425 0.9425

#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 0.0300 0.0900 0.2481 0.3798 0.4859 0.5433 0.5919 0.6625 0.7220 0.7918 0.8636 0.9318 0.9707 1.0708
1.0023 1.0191 1.0191 1.0191 1.0191 1.0191 1.0191
  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 0.4973 0.5188 0.6936 0.8041 0.9166 1.2097 1.3375 1.4498 1.6532 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 0.1006 0.4021 0.4870 0.5902 0.6650 0.7493 0.8267 0.9781 1.1052 1.2349 1.3148 1.4058 1.7511
2.0367 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1      1  1     1     1 0.0539 0.1026 0.1360 0.4699 0.5300 0.6027 0.6392 0.7395 0.8391 0.9775 1.0971 1.2349 1.3028 1.4814
1.7419 2.3379 2.3379 2.3379 2.3379 2.3379 2.3379
  1979    1      1  1     1     1 0.0528 0.0913 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 0.0517 0.0800 0.2236 0.4529 0.3922 0.4904 0.5166 0.6554 0.7125 0.8740 1.0616 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 0.0506 0.1079 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 0.0494 0.1183 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 0.0483 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 0.0472 0.1315 0.1642 0.2493 0.4385 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 0.0461 0.1740 0.2297 0.2679 0.4414 0.5497 0.5474 0.6014 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 0.0450 0.1555 0.2771 0.2909 0.3024 0.3735 0.5425 0.5717 0.6421 0.8209 0.9403 1.1860 1.1900 1.3864
1.6800 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
  1987    1      1  1     1     1 0.0439 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 0.0428 0.1400 0.1870 0.3189 0.4711 0.3689 0.3731 0.5163 0.6474 0.6851 0.7183 0.9167 1.0924 1.0225
1.4500 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
  1989    1      1  1     1     1 0.0417 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 0.0406 0.1378 0.2435 0.3506 0.3906 0.5111 0.5462 0.6076 0.6678 0.5300 0.7691 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 0.0394 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 0.0383 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 0.0372 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 0.0361 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 0.0350 0.1108 0.2682 0.3418 0.4876 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7442 0.7998 0.9101
0.6804 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
  1996    1      1  1     1     1 0.0339 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 0.0328 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 0.0317 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 0.7714 0.7714 0.7714 0.7714 0.7714 0.7714
  1999    1      1  1     1     1 0.0306 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 0.0294 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 0.0283 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 0.0272 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 0.0261 0.1000 0.2551 0.4355 0.5225 0.5879 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 0.0250 0.1081 0.2577 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 0.0239 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 0.0228 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
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  2007    1      1  1     1     1 0.0217 0.0461 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 0.0217 0.1403 0.2445 0.4081 0.5630 0.6371 0.6865 0.6818 0.7084 0.7210 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 0.0217 0.0667 0.2448 0.3431 0.4712 0.6371 0.6702 0.6942 0.7463 0.8226 0.7672 0.8115 1.0147 0.8503
0.9582 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
  2010    1      1  1     1     1 0.0217 0.1089 0.2325 0.2535 0.4335 0.5293 0.6577 0.8349 1.0828 1.0276 0.9409 0.8763 0.8373 1.1253
0.7200 0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
  2011    1      1  1     1     1 0.0217 0.0844 0.2457 0.3219 0.3864 0.5142 0.5967 0.6914 0.8620 0.9294 0.9742 1.0691 1.0451 1.0268
1.0578 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1      1  1     1     1 0.0217 0.1270 0.2073 0.3516 0.4085 0.4934 0.6574 0.6930 0.7802 0.9151 0.9633 0.9639 0.9713 0.9935
0.9924 0.9425 0.9425 0.9425 0.9425 0.9425 0.9425

#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 0.0300 0.0900 0.2481 0.3798 0.4859 0.5433 0.5919 0.6625 0.7220 0.7918 0.8636 0.9318 0.9707 1.0708
1.0023 1.0191 1.0191 1.0191 1.0191 1.0191 1.0191
  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 0.4973 0.5188 0.6936 0.8041 0.9166 1.2097 1.3375 1.4498 1.6532 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 0.1006 0.4021 0.4870 0.5902 0.6650 0.7493 0.8267 0.9781 1.1052 1.2349 1.3148 1.4058 1.7511
2.0367 2.2094 2.2094 2.2094 2.2094 2.2094 2.2094
  1978    1      1  1     1     2 0.0539 0.1026 0.1360 0.4699 0.5300 0.6027 0.6392 0.7395 0.8391 0.9775 1.0971 1.2349 1.3028 1.4814
1.7419 2.3379 2.3379 2.3379 2.3379 2.3379 2.3379
  1979    1      1  1     1     2 0.0528 0.0913 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 0.0517 0.0800 0.2236 0.4529 0.3922 0.4904 0.5166 0.6554 0.7125 0.8740 1.0616 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 0.0506 0.1079 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 0.0494 0.1183 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 0.0483 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 0.0472 0.1315 0.1642 0.2493 0.4385 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 0.0461 0.1740 0.2297 0.2679 0.4414 0.5497 0.5474 0.6014 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 0.0450 0.1555 0.2771 0.2909 0.3024 0.3735 0.5425 0.5717 0.6421 0.8209 0.9403 1.1860 1.1900 1.3864
1.6800 1.6142 1.6142 1.6142 1.6142 1.6142 1.6142
  1987    1      1  1     1     2 0.0439 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 0.0428 0.1400 0.1870 0.3189 0.4711 0.3689 0.3731 0.5163 0.6474 0.6851 0.7183 0.9167 1.0924 1.0225
1.4500 1.4537 1.4537 1.4537 1.4537 1.4537 1.4537
  1989    1      1  1     1     2 0.0417 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 0.0406 0.1378 0.2435 0.3506 0.3906 0.5111 0.5462 0.6076 0.6678 0.5300 0.7691 0.8312 2.2000 1.1847
1.0166 1.4668 1.4668 1.4668 1.4668 1.4668 1.4668
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  1991    1      1  1     1     2 0.0394 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 0.0383 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 0.0372 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 0.0361 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 0.0350 0.1108 0.2682 0.3418 0.4876 0.5367 0.6506 0.6249 0.6597 0.7560 0.6670 0.7442 0.7998 0.9101
0.6804 0.8008 0.8008 0.8008 0.8008 0.8008 0.8008
  1996    1      1  1     1     2 0.0339 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 0.0328 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 0.0317 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 0.7714 0.7714 0.7714 0.7714 0.7714 0.7714
  1999    1      1  1     1     2 0.0306 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 0.0294 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 0.0283 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 0.0272 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 0.0261 0.1000 0.2551 0.4355 0.5225 0.5879 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 0.0250 0.1081 0.2577 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 0.0239 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 0.0228 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 0.0217 0.0461 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 0.0217 0.1403 0.2445 0.4081 0.5630 0.6371 0.6865 0.6818 0.7084 0.7210 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 0.0217 0.0667 0.2448 0.3431 0.4712 0.6371 0.6702 0.6942 0.7463 0.8226 0.7672 0.8115 1.0147 0.8503
0.9582 1.0334 1.0334 1.0334 1.0334 1.0334 1.0334
  2010    1      1  1     1     2 0.0217 0.1089 0.2325 0.2535 0.4335 0.5293 0.6577 0.8349 1.0828 1.0276 0.9409 0.8763 0.8373 1.1253
0.7200 0.9021 0.9021 0.9021 0.9021 0.9021 0.9021
  2011    1      1  1     1     2 0.0217 0.0844 0.2457 0.3219 0.3864 0.5142 0.5967 0.6914 0.8620 0.9294 0.9742 1.0691 1.0451 1.0268
1.0578 0.9212 0.9212 0.9212 0.9212 0.9212 0.9212
  2012    1      1  1     1     2 0.0217 0.1270 0.2073 0.3516 0.4085 0.4934 0.6574 0.6930 0.7802 0.9151 0.9633 0.9639 0.9713 0.9935
0.9924 0.9425 0.9425 0.9425 0.9425 0.9425 0.9425
# End of wtatage.ss file
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