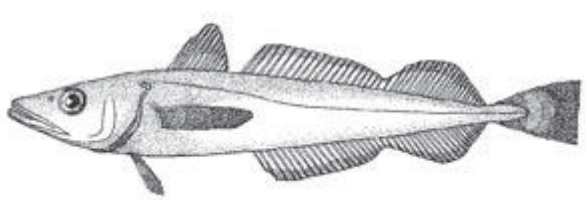
# Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2014 with a management strategy evaluation



International Joint Technical Committee for Pacific Hake

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

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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 with catches in the Canadian zone typically consisting of fish greater than four years old. Separate, and much smaller, populations of hake occurring in the major inlets of the northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California, are not included in this analysis.

## Catches

Coast-wide Pacific Hake landings averaged 223,238 mt from 1966 to 2013, with a low of 89,930 mt in 1980 and a peak of 363,157 mt in 2005. Prior to 1966, total removals were negligible compared to the modern fishery. Over the early period, 1966-1990, most removals were from foreign or joint-venture fisheries. Over all years, the fishery in U.S. waters averaged 167,171 mt, or 74.88% of the average total landings, while catch from Canadian waters averaged 56,067 mt.

In this stock assessment, the terms catch and landings are used interchangeably. Estimates of discard within the target fishery are included, but discarding of Pacific Hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings in recent years. Recent coast-wide landings from 2010–2013 have been above the long term average of 223,238 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 1.2 million mt.

Recent coast-wide catches have been dominated by a small number of year classes. Catches in 2009 were 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 caught 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. Of the 2013 total coast-wide catch, 67% came from the 2010 year class. However, catch age-composition differed between the U.S. and Canada: in 2012, U.S. fisheries caught mostly 4 and 2-year old fish from the 2008 and 2010 year classes, while the Canadian fisheries caught older fish from the 2005, 2006, and 2008 year classes. In 2013, more than 70% of the U.S. catch was from the 2010 year class whereas Canadian catches were dominated by older fish from 2008, 2006, 2005, and 1999 year classes.

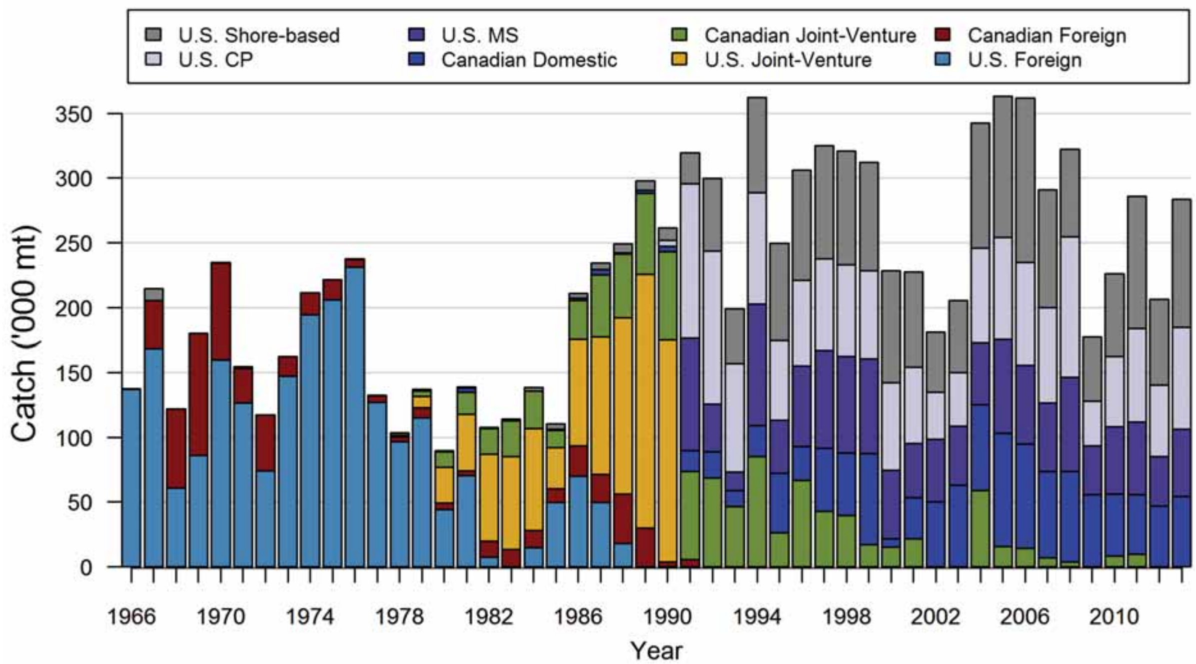


**Figure a. Total Pacific Hake catch used in the assessment by sector, 1966-2013. U.S. tribal catches are included.**

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

| Year | US Mothership | US Catcher-Processor | US shore-based | US Total | Canadian joint-venture | Canadian domestic | Canadian total | Total |
|---|---|---|---|---|---|---|---|---|
| 2004 | 48 | 73 | 97 | 217 | 59 | 66 | 125 | 342 |
| 2005 | 72 | 79 | 109 | 260 | 16 | 87 | 103 | 363 |
| 2006 | 61 | 79 | 127 | 267 | 14 | 80 | 95 | 362 |
| 2007 | 53 | 73 | 91 | 218 | 7 | 67 | 73 | 291 |
| 2008 | 72 | 108 | 68 | 248 | 4 | 70 | 74 | 322 |
| 2009 | 38 | 35 | 49 | 121 | 0 | 56 | 56 | 177 |
| 2010 | 52 | 54 | 64 | 170 | 8 | 48 | 56 | 226 |
| 2011 | 56 | 72 | 102 | 230 | 10 | 46 | 56 | 286 |
| 2012 | 39 | 55 | 66 | 160 | 0 | 47 | 47 | 206 |
| 2013 | 52 | 78 | 99 | 229 | 0 | 54 | 54 | 284 |

## Data and assessment

New data include the 2013 acoustic survey biomass estimate as well as the 2013 fishery and acoustic survey age compositions. In addition, some histological analyses of hake ovaries have been undertaken, contributing to a preliminary re-examination of the Dorn and Saunders (1997) maturity estimates that were based on visual maturity determinations by observers during 1990–1992.

The Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966-2013), acoustic survey biomass estimates and age-composition (1995-2013; Figure b), as well as fishery age-composition. While the 2011 survey index value was the lowest in the time-series, the index increased more than 2.5 times that value in 2012, and is now within 5% of the highest (2003) biomass estimate (2.42 million mt). Age-composition data from the aggregated fisheries (1975—2013) and the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts: over 65% of the proportions at age from each source consisted of 2010 year class fish.

The assessment uses a Bayesian estimation approach, sensitivity analyses, and closed-loop simulations to evaluate the potential consequences of uncertainty in parameter estimates, alternative structural models, and management system performance, respectively. The Bayesian approach combines prior knowledge about natural mortality, stock-recruitment steepness (a parameter for stock productivity), and several other parameters with likelihoods for acoustic survey biomass indices and age-composition, as well as fishery age composition data. Integrating the joint posterior distribution over model parameters (via Markov Chain Monte Carlo simulation) provides probabilistic inferences about uncertain model parameters and forecasts derived from those parameters. Sensitivity analyses are used to identify alternative structural models that may also be consistent with the data. Finally, the closed-loop simulations provide an assessment of how alternative combinations of survey frequency, assessment model selectivity assumptions, and harvest control rules affect expected management outcomes given repeated application of these procedures over the long-term.

For the 2013-14 assessment, the JTC changed the structural form of the base assessment model to include time-varying fishery selectivity. The model retains many of the previous elements as configured in Stock Synthesis (SS3). Time-varying fishery selectivity was implemented by estimating random annual deviations from the estimated base selectivity parameters. We used the Laplace approximation with SS3 to estimate the random effects variance, $\phi$, which controls the magnitude of year-to-year selectivity changes. In addition, we used both retrospective analysis and closed-loop simulations to compare expected performance of assessment models with or without time-varying selectivity.

Both retrospective and closed-loop simulation analyses support time-varying fishery selectivity as the new base assessment model. Retrospective analyses of estimated cohort strength (e.g., squid plots from 2013 assessment) showed that the time-varying selectivity assessment model reduced the magnitude of extreme cohort strength estimates. In closed-loop simulations, assessment models with time-varying fishery selectivity had higher median average catch, lower risk of falling below 10% of unfished biomass ($B_0$), smaller probability of fishery closures, and lower inter-annual variability in catch compared to assessment models with time-invariant fishery selectivity. It was found that even a small degree of flexibility in the assessment model fishery selectivity could reduce the effects of errors caused by assuming selectivity is constant over time.

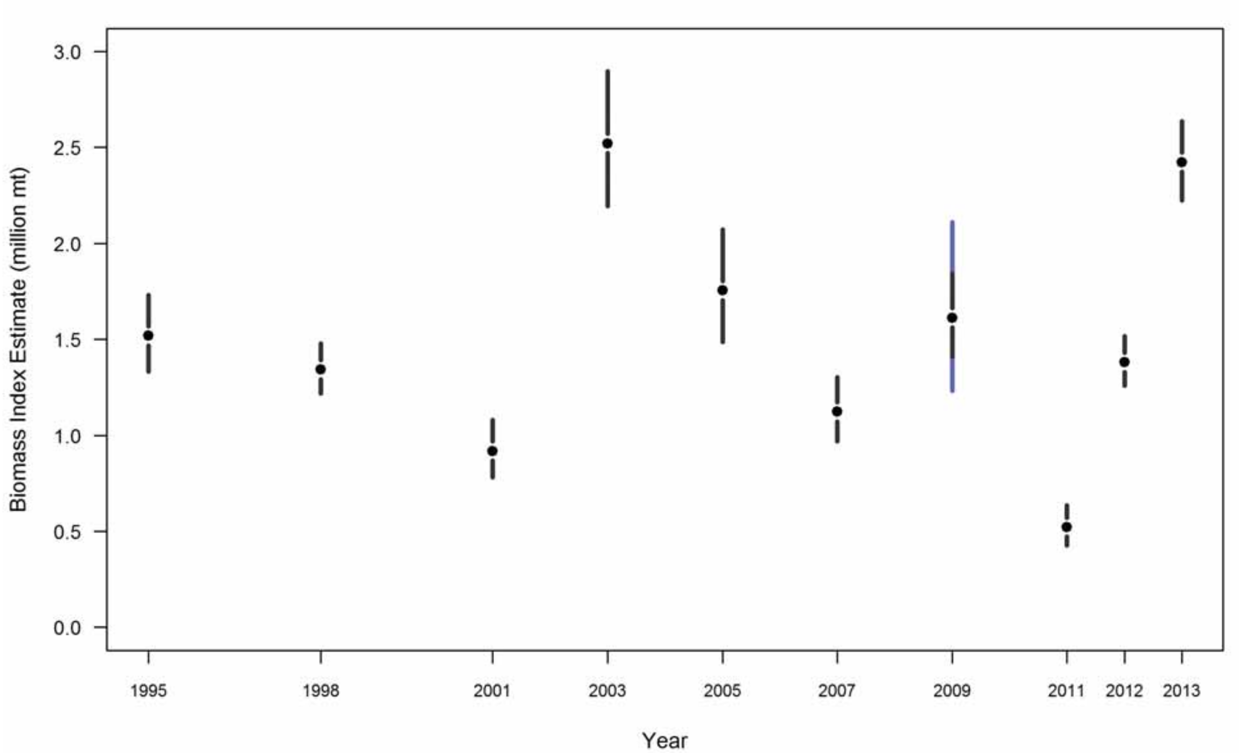


**Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2013) in addition to squid/hake apportionment uncertainty (2009, in blue).**

## Stock biomass

The base model estimates indicate that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium biomass. The model estimates that the stock was below the unfished equilibrium in the 1960s and 1970s, increased toward the unfished equilibrium after two or more large recruitments occurred in the early 1980s, and then declined steadily through the 1990s to a low in 2000. This long period of decline was followed by a brief peak in 2003 as the large 1999 year class matured and subsequently supported the fishery for several years. Estimated female spawning biomass declined to an all-time low of 0.479 million mt in 2009 because of low recruitment between 2000 and 2007, along with a declining 1999 year class. Spawning biomass estimates have increased since 2009 on the strength of a large 2010 cohort and above average 2008 and 2009 cohorts. The 2014 female spawning biomass is estimated to be 81.8% of the unfished equilibrium level ($B_0$) with 95% posterior credibility intervals ranging from 41.6% to 168%. The median of the forecast for 2014 female spawning biomass is 1.72 million mt.

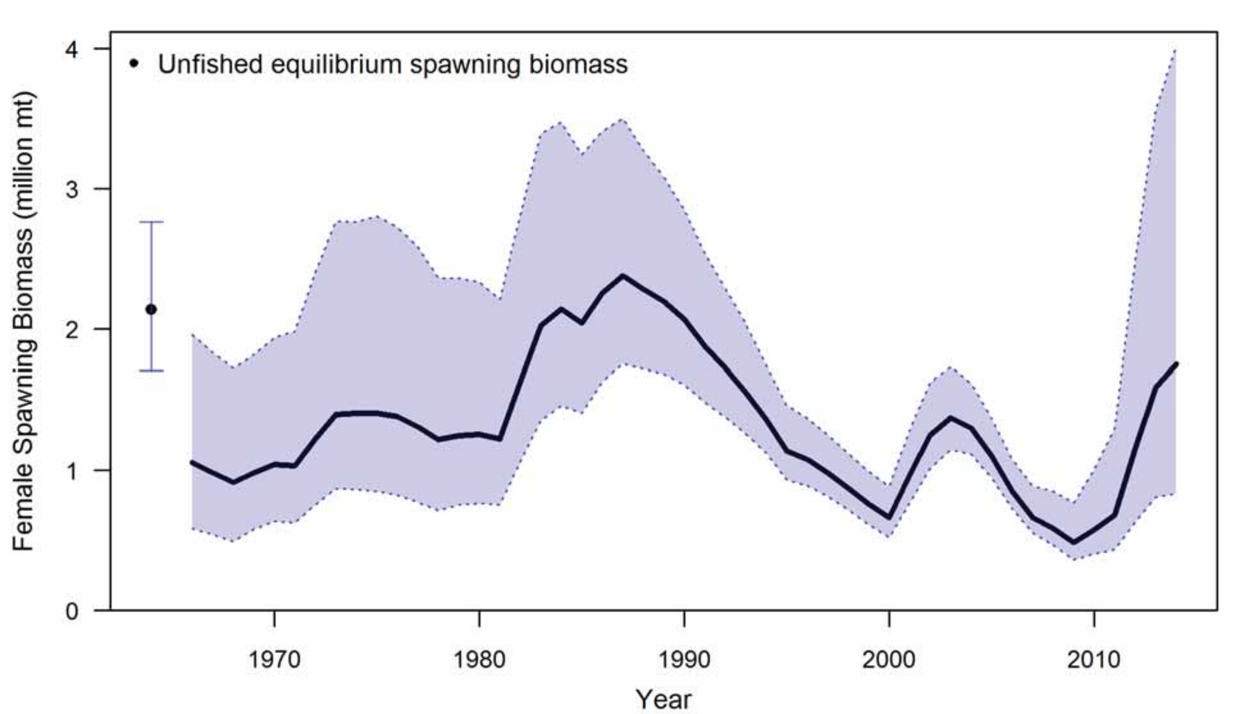


**Figure c. Median of the posterior distribution for female spawning biomass through 2013 (solid line) with 95% posterior credibility intervals (shaded area).**

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

| Year | Spawning biomass (mt) | | | Depletion ($B_t/B_0$) | | |
|---|---|---|---|---|---|---|
| | 2.5th percentile | Median | 97.5th percentile | 2.5th percentile | Median | 97.5th percentile |
| 2005 | 0.951 | 1.090 | 1.343 | 0.418 | 0.517 | 0.647 |
| 2006 | 0.726 | 0.843 | 1.052 | 0.323 | 0.400 | 0.503 |
| 2007 | 0.553 | 0.656 | 0.867 | 0.247 | 0.311 | 0.401 |
| 2008 | 0.470 | 0.579 | 0.825 | 0.211 | 0.274 | 0.366 |
| 2009 | 0.365 | 0.479 | 0.746 | 0.169 | 0.228 | 0.327 |
| 2010 | 0.406 | 0.568 | 0.964 | 0.193 | 0.269 | 0.420 |
| 2011 | 0.443 | 0.669 | 1.271 | 0.215 | 0.317 | 0.543 |
| 2012 | 0.635 | 1.139 | 2.445 | 0.316 | 0.540 | 1.042 |
| 2013 | 0.813 | 1.566 | 3.499 | 0.410 | 0.745 | 1.526 |
| 2014 | 0.835 | 1.722 | 3.932 | 0.416 | 0.818 | 1.688 |

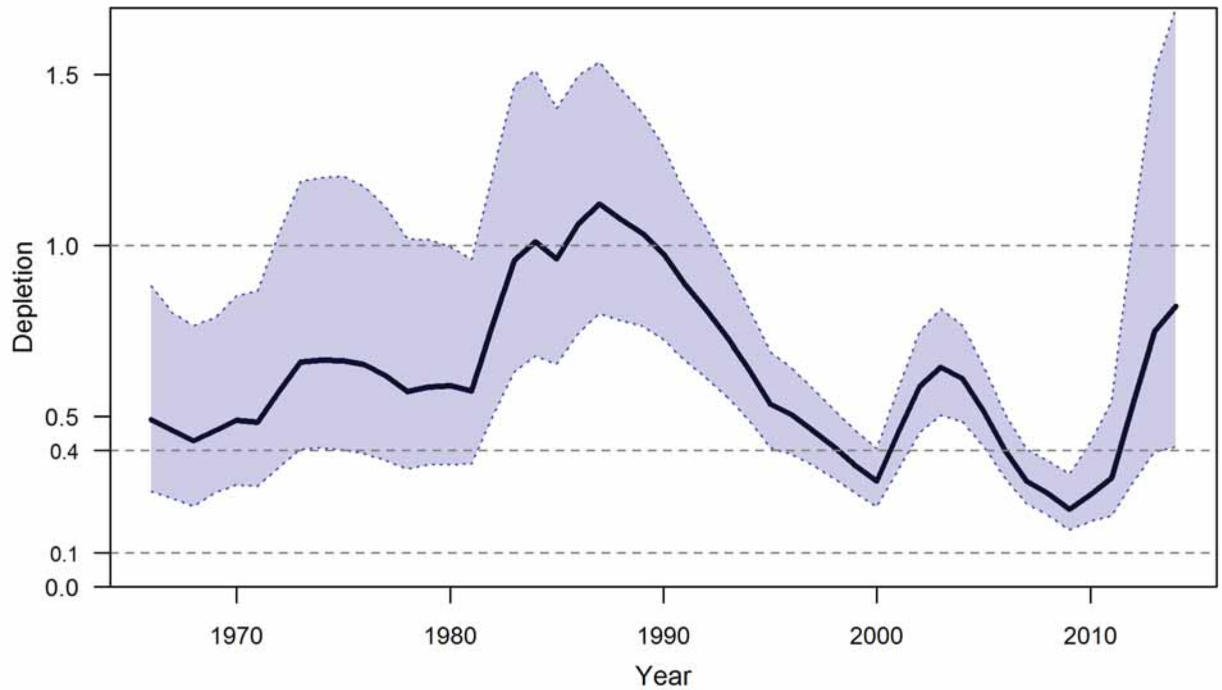


**Figure d. Median (solid line) of the posterior distribution for spawning depletion ($B_t/B_0$) through 2013 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% depletion levels.**

## Recruitment

Pacific Hake are estimated to have low average recruitment with occasional large year-classes. Very large year classes in 1980, 1984, and 1999 supported much of the commercial catch from the 1980's to the early 2000's. In the last decade, estimated recruitment has been at some of the lowest values in the time-series as well as some of the highest. The current assessment estimates a strong 2010 year class comprising 67% of the 2013 commercial catch. However, due to the small number of years it has been observed, its size is still uncertain. The model currently estimates a lower than average 2011 year class. The sizes of 2013 and 2014 year classes remain uninformed and are therefore characterized by the underlying stock recruitment assumption because these cohorts have not yet been observed in survey or commercial age-composition data. Retrospective analyses of year class strength for young fish consistently indicate that estimates of the most recent year classes are the least reliable.

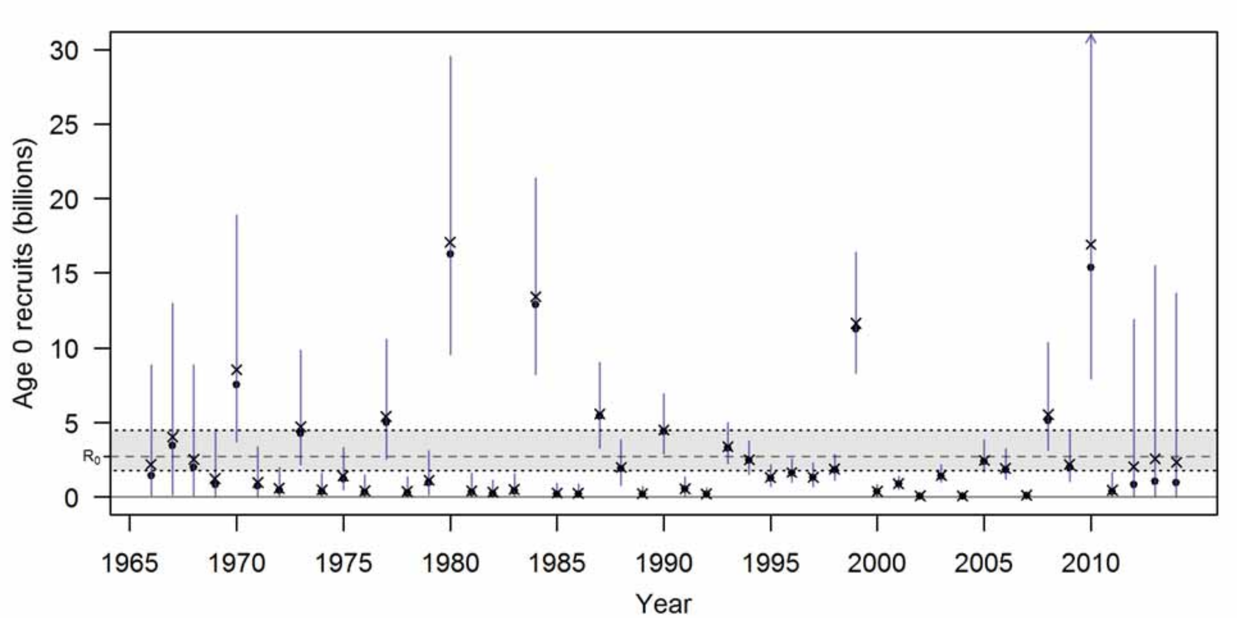


**Figure e. Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment ($R_0$) is shown as the horizontal dashed line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

**Table c. Estimates of recent Pacific Hake recruitment (billions of age-0) and recruitment deviations (deviations below zero indicate less than average recruitment and deviations above zero indicate above average recruitment).**

| | Absolute recruitment | | | Recruitment deviation | | |
|---|---|---|---|---|---|---|
| Year | 2.5th percentile | Median | 97.5th percentile | 2.5th percentile | Median | 97.5th percentile |
| 2003 | 0.99 | 1.41 | 2.16 | 0.02 | 0.36 | 0.67 |
| 2004 | 0.01 | 0.07 | 0.25 | -4.35 | -2.62 | -1.49 |
| 2005 | 1.68 | 2.37 | 3.86 | 0.60 | 0.91 | 1.21 |
| 2006 | 1.21 | 1.84 | 3.23 | 0.32 | 0.69 | 1.07 |
| 2007 | 0.01 | 0.09 | 0.30 | -4.11 | -2.28 | -1.12 |
| 2008 | 3.14 | 5.15 | 10.38 | 1.40 | 1.78 | 2.26 |
| 2009 | 1.06 | 2.01 | 4.37 | 0.34 | 0.87 | 1.42 |
| 2010 | 7.91 | 15.36 | 36.13 | 2.31 | 2.88 | 3.50 |
| 2011 | 0.04 | 0.37 | 1.64 | -3.07 | -0.90 | 0.49 |
| 2012 | 0.06 | 0.84 | 11.87 | -2.79 | -0.11 | 2.44 |

## Exploitation status

Estimated fishing intensity on the stock was consistently below the $F_{40\%}$ target until recently when the target was likely exceeded in 2008, 2010 and 2011. The exploitation fraction does not necessarily correspond to fishing intensity because fishing intensity accounts for the age-structure: for example, fishing intensity remained nearly constant and above target from 2010 to 2011 but exploitation fraction declined in these years because of high estimated abundances of 1 year old fish. Fishing intensity for 2013 is highly likely to be below the management target.

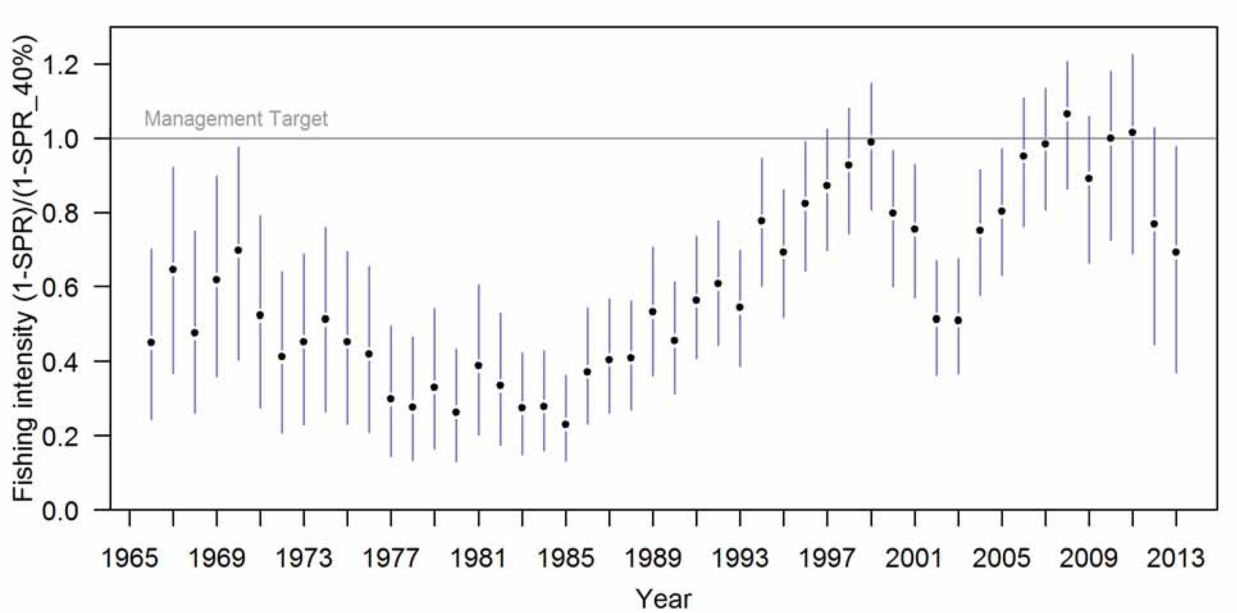


**Figure f. Trend in median fishing intensity (relative to the SPR management target) through 2013 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.**

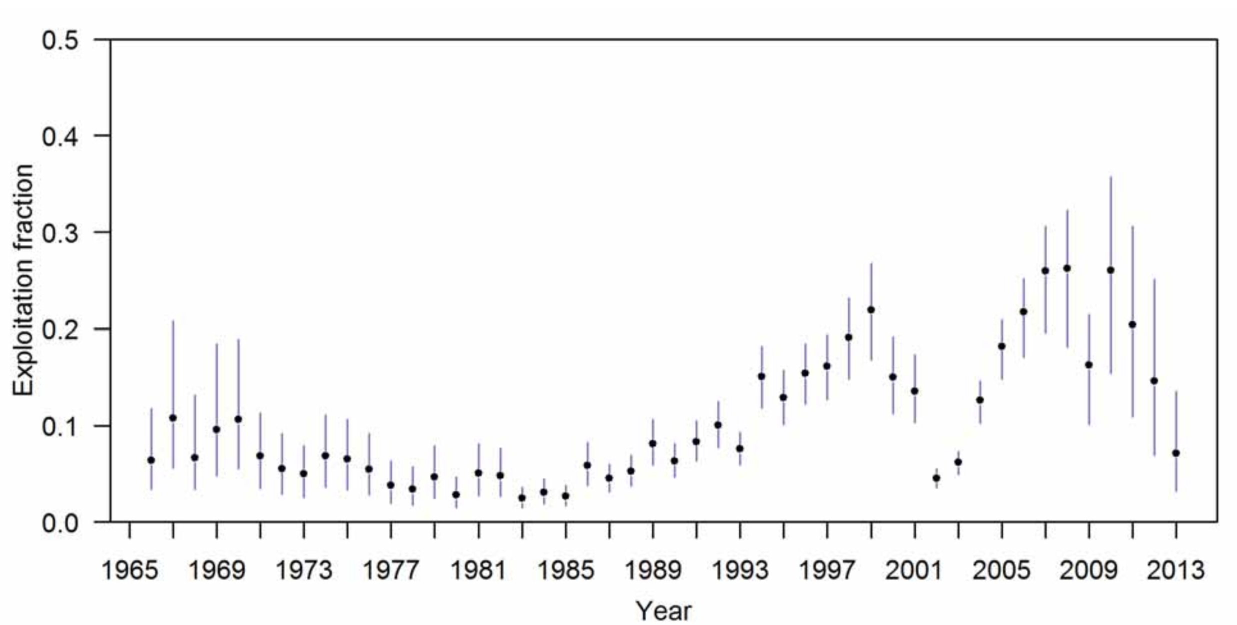


**Figure g. Trend in median exploitation fraction through 2013 with 95% posterior credibility intervals.**

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

| Year | Fishing intensity | | | Exploitation fraction | | |
|---|---|---|---|---|---|---|
| | 2.5th percentile | Median | 97.5th percentile | 2.5th percentile | Median | 97.5th percentile |
| 2004 | 57.71% | 74.95% | 90.97% | 10.31% | 12.62% | 14.59% |
| 2005 | 63.47% | 80.48% | 96.47% | 14.87% | 18.21% | 20.95% |
| 2006 | 76.35% | 95.26% | 110.68% | 17.18% | 21.73% | 25.23% |
| 2007 | 80.39% | 98.61% | 113.44% | 19.68% | 25.91% | 30.77% |
| 2008 | 87.22% | 106.41% | 120.58% | 18.62% | 26.19% | 32.42% |
| 2009 | 67.03% | 89.31% | 105.88% | 10.49% | 16.24% | 21.49% |
| 2010 | 73.82% | 100.00% | 118.09% | 15.78% | 26.06% | 35.87% |
| 2011 | 69.50% | 101.39% | 122.51% | 10.91% | 20.49% | 31.24% |
| 2012 | 45.60% | 76.88% | 103.69% | 6.97% | 14.63% | 25.18% |
| 2013 | 37.91% | 69.37% | 98.87% | 3.21% | 7.20% | 13.96% |

## Management performance

Over the last decade, the average coast-wide utilization rate (i.e., utilization = landings/quota) has been 86%. Over the 2009–2013 period, utilization rates differed between the United States (85%) and Canada (76%). Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

Before 2007, estimated fishing intensity and biomass were below and above their respective targets, respectively (Figure h). Between 2007 and 2011, fishing intensity ranged from 89 to 106% and spawning biomass depletion (relative spawning biomass) between 23% and 32% of unfished levels (Tables d and b, respectively). Recent biomass estimates are higher and fishing intensities are lower than 2011 levels mainly because of contributions by the 2008 and 2010 cohorts (Figure e., Figure h). For 2013, there is an estimated 1% chance that fishing intensity estimates will be above the 100% target and spawning biomass depletion below the 40% target.

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

| Year | Total Landings (mt) | Coast-wide (US+Canada) catch target (mt) | Proportion of catch target removed |
|---|---|---|---|
| 2004 | 342,323 | 501,073 | 68.3% |
| 2005 | 363,157 | 364,197 | 99.7% |
| 2006 | 361,760 | 364,842 | 99.2% |
| 2007 | 291,129 | 328,358 | 88.7% |
| 2008 | 322,144 | 364,842 | 88.3% |
| 2009 | 177,209 | 184,000 | 96.3% |
| 2010 | 226,195 | 262,500 | 86.2% |
| 2011 | 285,850 | 393,751 | 72.6% |
| 2012 | 206,350 | 251,809 | 82.0% |
| 2013 | 283,510 | 365,112 | 77.7% |

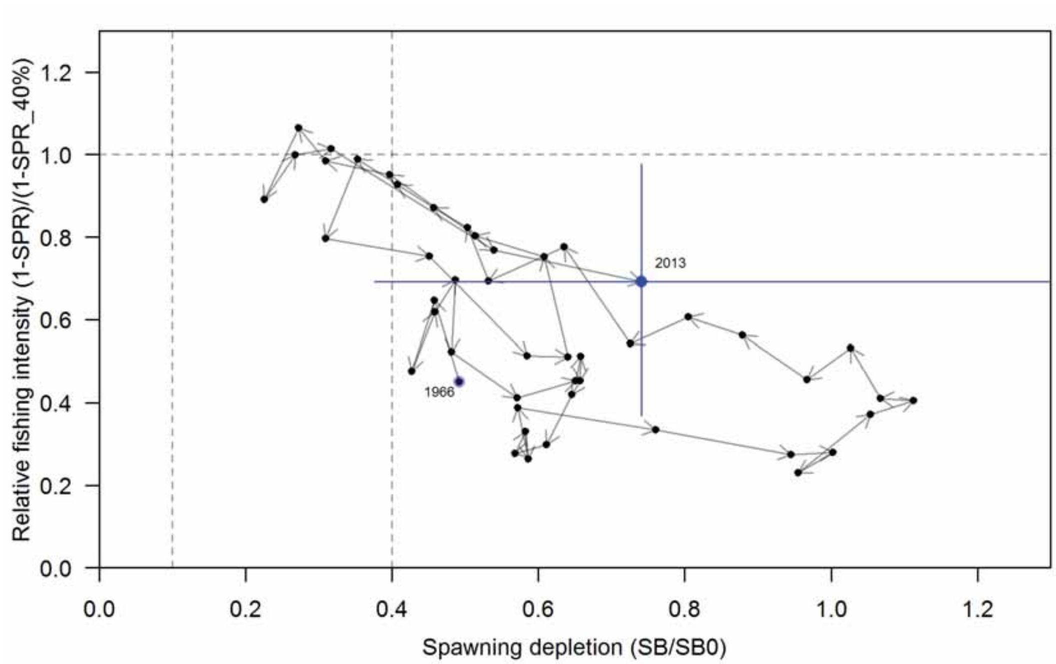


**Figure h. Estimated historical path followed by fishing intensity and spawning biomass depletion for Pacific Hake over years 1966-2013, inclusive. Blue bars span the 95% credibility intervals for 2013 fishing intensity (vertical) and spawning biomass depletion (horizontal). The dashed lines indicate the fishing intensity target (horizontal) and the 40:10 harvest control rule (vertical) 10% and 40% depletion points.**

## Reference points

We report estimates of the 2014 base model reference points with posterior credibility intervals in Table f. The estimates differ very little from the 2013 assessment: the maximum difference between the 2013 and 2014 median reference point estimates is 3.66%, for the $SB_{MSY}$ estimate.

**Table f. Summary of median and 95% credibility reference points for the Pacific Hake base assessment model. Reference points were computed using 1966-2013 averages for mean size at age and selectivity at age.**

| Quantity | $2.5^{th}$ percentile | Median | $97.5^{th}$ percentile |
|---|---|---|---|
| Unfished female *B* ($B_0$, thousand mt) | 1,690 | 2,132 | 2,748 |
| Unfished recruitment ($R_0$, billions) | 1,788 | 2,720 | 4,496 |
| **Reference points based on $F_{40\%}$** | | | |
| Female spawning biomass ($B_{F40\%}$ thousand mt) | 592 | 769 | 968 |
| $SPR_{MSY\text{-}proxy}$ | — | 40% | — |
| Exploitation fraction corresponding to SPR | 18.3% | 21.6% | 25.6% |
| Yield at $B_{F40\%}$ (thousand mt) | 252 | 342 | 489 |
| **Reference points based on $B_{40\%}$** | | | |
| Female spawning biomass ($B_{40\%}$ thousand mt) | 676 | 853 | 1,099 |
| $SPR_{B40\%}$ | 40.6% | 43.2% | 49.6% |
| Exploitation fraction resulting in $B_{40\%}$ | 14.9% | 19.1% | 23.2% |
| Yield at $B_{40\%}$ (thousand mt) | 248 | 334 | 479 |
| **Reference points based on estimated MSY** | | | |
| Female spawning biomass ($B_{MSY}$ thousand mt) | 347 | 519 | 844 |
| $SPR_{MSY}$ | 18.9% | 28.4% | 43.4% |
| Exploitation fraction corresponding to $SPR_{MSY}$ | 18.9% | 34.2% | 57.1% |
| *MSY* (thousand mt) | 263 | 363 | 524 |

## Unresolved problems and major uncertainties

Uncertainty measures in the base model underestimate the total uncertainty in the current stock status and projections because they do not account for alternative structural models for hake population dynamics and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distributions. To address structural uncertainties, the JTC investigated a broad range of alternative models, and we present a subset of key sensitivity analyses in the main document. The posterior distribution of derived parameters from the base model encompasses the median estimates of most sensitivity tests. We use the closed-loop simulation component of the Management Strategy Evaluation (MSE) to illustrate the long-term average management performance of alternative assessment models.

The Pacific Hake stock displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid biomass changes. This volatility adds to the uncertainty in estimates of current stock status and stock projections because of the dynamic fishery, which potentially targets strong cohorts resulting in time-varying fishery selectivity and limited data to estimate incoming recruitment in a timely manner (i.e., until the cohort is age 2 or greater). Within-model uncertainty in this assessment's spawning stock biomass is largely a function of the potentially large 2010 year class being observed twice in the acoustic survey and for the third year in the fishery data.

At the JMC's direction, we continued to develop the Management Strategy Evaluation (MSE) approach to explore the expected performance of alternative harvest policies involving annual or biennial surveys using more challenging operating models (Appendix A). Of the wide range of recommendations made by the 2013 SRG, the MSE steering group and the 2014 JTC meeting, we focused on: the effects of operating models with time-varying selectivity; increasing the frequency of a survey to annual from biennial, management procedures (MPs) using assessment models with and without time-varying selectivity, and the default harvest control rule with floors and ceilings on TAC recommendations. We also addressed last year's SRG recommendation of 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 the dynamics of the Pacific Hake fishery, but this topic remains germane.

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

## Forecast decision table

A decision table showing predicted population status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base model. The decision table (split into 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.

Management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP) in 2012 are presented for projections to 2015 and 2016 (Tables g.3 and g.4). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values.

At all catch levels above 190,000 mt, the spawning biomass is predicted to decline with greater than 50% probability. The model predicts high biomass levels and the predicted probability of dropping below 10% is effectively zero and the maximum probability of dropping below B40% is 13% for all catches explored. It should be noted that in addition to the effects of natural morality, another reason that the model predicts declining spawning biomass even at relatively low catch levels, is that the model estimates below average recruitment of the 2011 and 2012 cohorts that would begin maturing in 2014.

Until cohorts are five or six years old, the model's prediction of cohort strength is uncertain. The size of the 2010 year class is certainly above average, but is a major source of uncertainty in future projections of spawning biomass and catch. Therefore, following the 2013 assessment of Pacific Hake, additional forecast decision tables were created given three states of nature about the size of the 2010 year class: low 2010 recruitment, medium 2010 recruitment, and high 2010 recruitment. Each state of nature is defined to have a probability of 10%, 80%, and 10%, respectively, defined by the corresponding range of quantiles for estimates of 2010 recruitment.

Tables h.1 and h.2 show the median depletion and fishing intensity within each state of nature, and it can be seen that in the low-2010 recruitment state of nature the fishing intensity would be slightly above target with a 2014 catch of 375,000 mt, and a projected biomass of 40% in 2016. Median depletion is predicted to decline in 2016 across all states of nature for all catches above 190,000 mt.

Tables h.3 and h.4 show the probability metrics in 2015 and in 2016 for each state of nature. Across all states of nature there are approximately equal probabilities that the spawning biomass in 2015 will be less than or greater than the spawning biomass in 2014 with a catch near 190,000 mt. For the low state of nature, there is less than a 50% probability that the 2015 spawning biomass will be below 40% of unfished equilibrium spawning biomass with a catch near 500,000 mt, but a constant catch of 375,000 mt in 2014 and 2015 results in a 50% probability that the spawning biomass in 2016 is less than 50% of unfished equilibrium spawning biomass.

An additional source of uncertainty was the 2013 estimate of biomass from the acoustic survey. Due to the presence of hake schools extending far offshore, the survey biomass estimate included an extrapolated area that contained at least 25% of the estimated biomass. No observations occurred in this extrapolated area, thus there was a concern that the biomass was overestimated. A sensitivity run using a 2013 acoustic survey biomass estimate without the extrapolated area resulted in a lower 2014 spawning biomass and a 12% reduction in the predicted 2014 default harvest rate catch.

**Table g.1. Forecast quantiles of Pacific Hake spawning biomass depletion at the beginning of the year before fishing. Catch alternatives are based on: constant catch levels (rows a, e, g), the catch level that results in an equal probability of the population increasing or decreasing from 2014 to 2015 (row b), the approximate average catch over the last 5 years (row c), the catch level that results in the median spawning biomass to remain unchanged from 2014 to 2015 (row d), the approximate maximum historical catch (row f), the approximate maximum catch target (row h), the catch level that results in a 50% probability that the median projected catch will remain the same in 2015 (row i), the catch values that result in a median SPR ratio of 1.0 (row j), and the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base (row k).**

| Within model quantile | | | 5% | 25% | 50% | 75% | 95% |
|---|---|---|---|---|---|---|---|
| Management Action | | | Beginning of year depletion | | | | |
| | Year | Catch (mt) | | | | | |
| a: No catch | 2014 | 0 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 0 | 52% | 70% | 88% | 110% | 158% |
| | 2016 | 0 | 54% | 72% | 91% | 112% | 168% |
| b: B2014=B2015 | 2014 | 190000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 190000 | 47% | 65% | 84% | 105% | 154% |
| | 2016 | 190000 | 45% | 63% | 82% | 104% | 159% |
| c: average historical catch | 2014 | 235000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 235000 | 46% | 64% | 82% | 104% | 153% |
| | 2016 | 235000 | 43% | 61% | 80% | 102% | 157% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 275000 | 45% | 63% | 82% | 103% | 153% |
| | 2016 | 275000 | 41% | 59% | 78% | 100% | 156% |
| e | 2014 | 325000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 325000 | 44% | 62% | 80% | 102% | 151% |
| | 2016 | 325000 | 39% | 57% | 76% | 98% | 154% |
| f: near max historical catch | 2014 | 375000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 375000 | 43% | 61% | 79% | 101% | 150% |
| | 2016 | 375000 | 36% | 55% | 74% | 96% | 151% |
| g | 2014 | 425000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 425000 | 42% | 60% | 78% | 100% | 149% |
| | 2016 | 425000 | 33% | 52% | 71% | 94% | 149% |
| h: near max catch target | 2014 | 500000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 500000 | 40% | 58% | 76% | 98% | 147% |
| | 2016 | 500000 | 30% | 49% | 68% | 90% | 146% |
| i: highest C2014=C2015 | 2014 | 727000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 727000 | 35% | 53% | 71% | 94% | 141% |
| | 2016 | 727000 | 20% | 38% | 58% | 81% | 135% |
| j: fishing intensity = 100% | 2014 | 825000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 660000 | 32% | 51% | 69% | 91% | 139% |
| | 2016 | 600000 | 19% | 38% | 57% | 80% | 135% |
| k: default harvest rule | 2014 | 872424 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 691686 | 31% | 50% | 68% | 90% | 139% |
| | 2016 | 604762 | 17% | 36% | 55% | 78% | 133% |

**Table g.2. Forecast quantiles of Pacific Hake fishing intensity (1-SPR)/(1-SPR$_{40\%}$) for the 2014-2016 catch alternatives presented in Table g.1 Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy.**

| Within model quantile | | | 5% | 25% | 50% | 75% | 95% |
|---|---|---|---|---|---|---|---|
| Management Action | | | **Fishing Intensity** | | | | |
| | Year | Catch (mt) | | | | | |
| a: No catch | 2014 | 0 | 0% | 0% | 0% | 0% | 0% |
| | 2015 | 0 | 0% | 0% | 0% | 0% | 0% |
| | 2016 | 0 | 0% | 0% | 0% | 0% | 0% |
| b: B2014=B2015 | 2014 | 190000 | 23% | 34% | 42% | 50% | 66% |
| | 2015 | 190000 | 23% | 34% | 42% | 52% | 68% |
| | 2016 | 190000 | 21% | 32% | 40% | 50% | 67% |
| c: average historical catch | 2014 | 235000 | 27% | 40% | 49% | 59% | 75% |
| | 2015 | 235000 | 28% | 40% | 50% | 61% | 78% |
| | 2016 | 235000 | 26% | 39% | 48% | 60% | 78% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 31% | 45% | 55% | 65% | 82% |
| | 2015 | 275000 | 32% | 46% | 56% | 68% | 86% |
| | 2016 | 275000 | 30% | 44% | 55% | 67% | 87% |
| e | 2014 | 325000 | 36% | 51% | 61% | 72% | 89% |
| | 2015 | 325000 | 37% | 52% | 64% | 76% | 94% |
| | 2016 | 325000 | 34% | 51% | 62% | 76% | 96% |
| f: near max historical catch | 2014 | 375000 | 40% | 56% | 67% | 78% | 95% |
| | 2015 | 375000 | 41% | 58% | 70% | 83% | 102% |
| | 2016 | 375000 | 39% | 57% | 69% | 84% | 105% |
| g | 2014 | 425000 | 44% | 61% | 72% | 83% | 101% |
| | 2015 | 425000 | 46% | 63% | 76% | 89% | 108% |
| | 2016 | 425000 | 43% | 63% | 76% | 91% | 113% |
| h: near max catch target | 2014 | 500000 | 49% | 67% | 79% | 90% | 107% |
| | 2015 | 500000 | 52% | 71% | 84% | 97% | 115% |
| | 2016 | 500000 | 50% | 71% | 85% | 101% | 122% |
| i: highest C2014=C2015 | 2014 | 727000 | 63% | 83% | 95% | 105% | 121% |
| | 2015 | 727000 | 68% | 89% | 102% | 116% | 132% |
| | 2016 | 727000 | 67% | 92% | 107% | 124% | 138% |
| j: fishing intensity = 100% | 2014 | 825000 | 68% | 88% | 100% | 110% | 125% |
| | 2015 | 660000 | 65% | 86% | 100% | 114% | 132% |
| | 2016 | 600000 | 59% | 84% | 100% | 118% | 136% |
| k: default harvest rule | 2014 | 872424 | 71% | 91% | 102% | 112% | 127% |
| | 2015 | 691686 | 67% | 88% | 103% | 116% | 134% |
| | 2016 | 604762 | 60% | 85% | 102% | 120% | 137% |

**Table g.3. Probabilities of related to spawning biomass, fishing intensity, and 2015 catch limits for alternative 2014 catch options (catch options explained in Table g.1).**

| Catch in 2014 | Probability $B_{2015}<B_{2014}$ | Probability $B_{2015}<B_{40\%}$ | Probability $B_{2015}<B_{25\%}$ | Probability $B_{2015}<B_{10\%}$ | Probability Fishing intensity in 2014 > 40% Target | Probability 2015 Catch Target < 2014 Catch |
|---|---|---|---|---|---|---|
| 0 | 8% | 1% | 0% | 0% | 0% | 0% |
| 190,000 | 50% | 2% | 0% | 0% | 0% | 0% |
| 235,000 | 58% | 3% | 0% | 0% | 0% | 0% |
| 275,000 | 64% | 3% | 0% | 0% | 0% | 1% |
| 325,000 | 70% | 3% | 0% | 0% | 1% | 3% |
| 375,000 | 75% | 4% | 0% | 0% | 2% | 5% |
| 425,000 | 79% | 4% | 0% | 0% | 5% | 9% |
| 500,000 | 83% | 5% | 0% | 0% | 11% | 18% |
| 727,000 | 91% | 9% | 2% | 0% | 37% | 50% |
| 825,000 | 92% | 12% | 2% | 0% | 50% | 62% |
| 872,424 | 92% | 13% | 3% | 0% | 55% | 68% |

**Table g.4. Probabilities of related to spawning biomass, fishing intensity, and 2016 catch limits for alternative 2015 catch options conditioned on specific catches in 2014 (catch options explained in Table g.1).**

| Catch in 2015 | Probability $B_{2016}<B_{2015}$ | Probability $B_{2016}<B_{40\%}$ | Probability $B_{2016}<B_{25\%}$ | Probability $B_{2016}<B_{10\%}$ | Probability Fishing intensity in 2015 > 40% Target | Probability 2016 Catch Target < 2015 Catch |
|---|---|---|---|---|---|---|
| 0 | 46% | 1% | 0% | 0% | 0% | 0% |
| 190,000 | 73% | 3% | 0% | 0% | 0% | 0% |
| 235,000 | 75% | 4% | 0% | 0% | 0% | 0% |
| 275,000 | 77% | 5% | 1% | 0% | 1% | 2% |
| 325,000 | 80% | 6% | 1% | 0% | 3% | 4% |
| 375,000 | 83% | 7% | 1% | 0% | 6% | 7% |
| 425,000 | 85% | 10% | 2% | 0% | 10% | 13% |
| 500,000 | 87% | 14% | 3% | 0% | 21% | 24% |
| 727,000 | 92% | 27% | 9% | 1% | 55% | 58% |
| 660,000 | 91% | 28% | 10% | 2% | 50% | 54% |
| 691,686 | 91% | 30% | 12% | 2% | 54% | 57% |

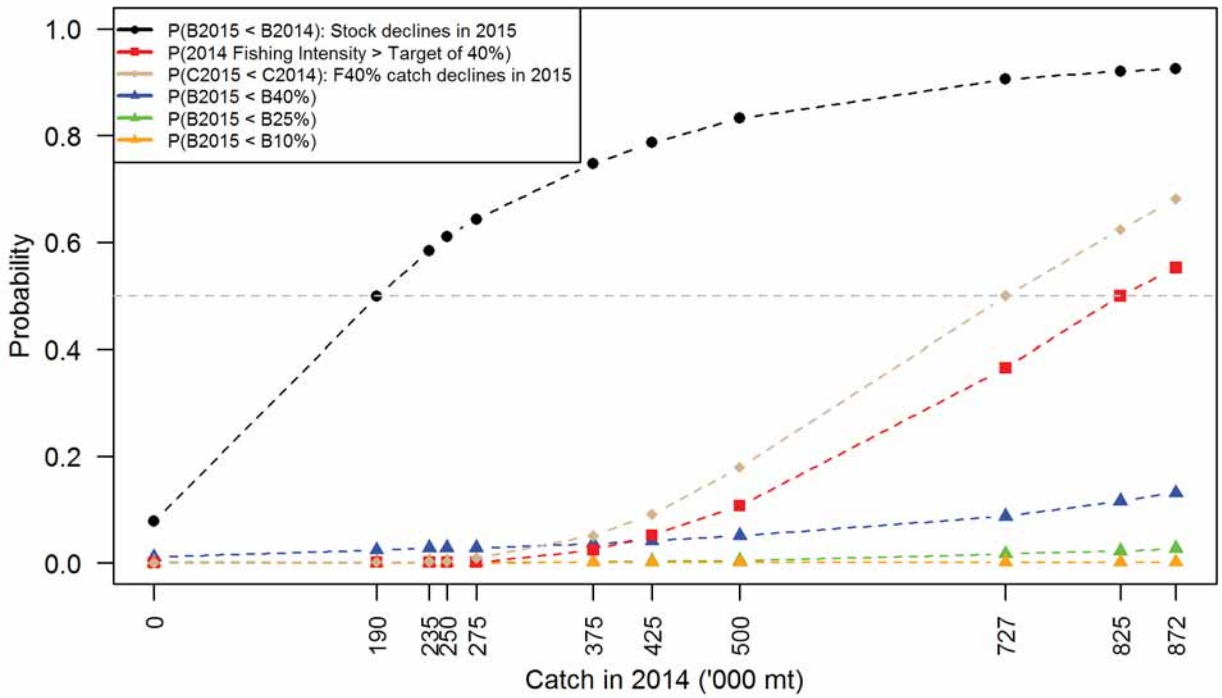


**Figure i: Graphical representation of the results presented in Table g.4 for catch in 2014. The symbols indicate points that were computed directly from model output and lines interpolate between the points.**

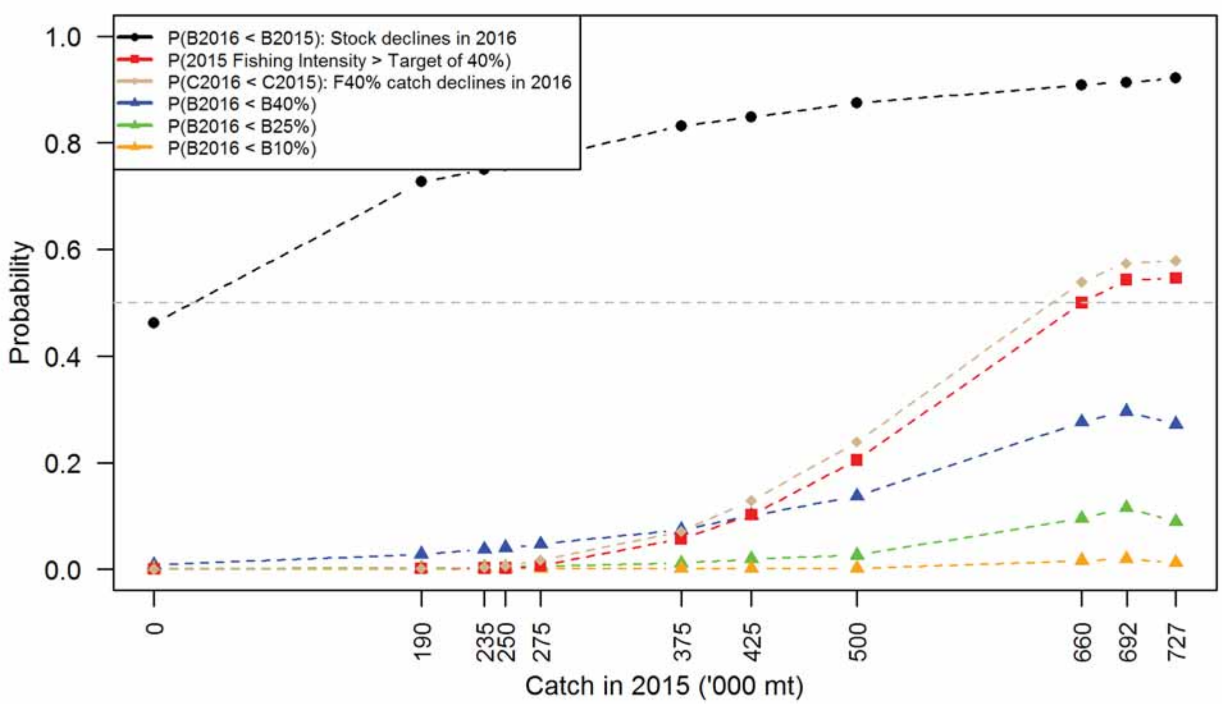


**Figure j: Graphical representation of the results presented in Table g.4 for catch in 2015. The symbols indicate points that were computed directly from model output and lines interpolate between the points. These catches are conditional on the catch in 2014, and 2014 catch levels corresponding to the 2015 catches of 660 and 692 were higher (see Table g.1).**

**Table h.1. Forecast quantiles of Pacific Hake beginning of year depletion for the 2014-2016 catch alternatives presented in Table g.1.**

| Quantile range of 2010 recruitment | | | 0–10% | 10–90% | 90–100% |
|---|---|---|---|---|---|
| Probability of state of nature | | | 10% | 80% | 10% |
| Management Action | | | **Median Beginning of year depletion** | | |
| | Year | Catch (mt) | | | |
| a: No catch | 2014 | 0 | 49% | 82% | 141% |
| | 2015 | 0 | 55% | 88% | 149% |
| | 2016 | 0 | 59% | 90% | 145% |
| b: B2014=B2015 | 2014 | 190000 | 49% | 82% | 141% |
| | 2015 | 190000 | 50% | 83% | 144% |
| | 2016 | 190000 | 49% | 82% | 138% |
| c: average historical catch | 2014 | 235000 | 49% | 82% | 141% |
| | 2015 | 235000 | 49% | 82% | 143% |
| | 2016 | 235000 | 47% | 80% | 136% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 49% | 82% | 141% |
| | 2015 | 275000 | 48% | 82% | 142% |
| | 2016 | 275000 | 45% | 78% | 135% |
| e | 2014 | 325000 | 49% | 82% | 141% |
| | 2015 | 325000 | 47% | 80% | 141% |
| | 2016 | 325000 | 43% | 76% | 133% |
| f: near max historical catch | 2014 | 375000 | 49% | 82% | 141% |
| | 2015 | 375000 | 46% | 79% | 140% |
| | 2016 | 375000 | 40% | 73% | 131% |
| g | 2014 | 425000 | 49% | 82% | 141% |
| | 2015 | 425000 | 44% | 78% | 139% |
| | 2016 | 425000 | 37% | 71% | 129% |
| h: near max catch target | 2014 | 500000 | 49% | 82% | 141% |
| | 2015 | 500000 | 43% | 76% | 138% |
| | 2016 | 500000 | 34% | 68% | 126% |
| i: highest C2014=C2015 | 2014 | 727000 | 49% | 82% | 141% |
| | 2015 | 727000 | 37% | 71% | 133% |
| | 2016 | 727000 | 22% | 57% | 117% |
| j: fishing intensity = 100% | 2014 | 825000 | 49% | 82% | 141% |
| | 2015 | 660000 | 34% | 69% | 130% |
| | 2016 | 600000 | 21% | 57% | 116% |
| k: default harvest rule | 2014 | 872424 | 49% | 82% | 141% |
| | 2015 | 691686 | 33% | 68% | 129% |
| | 2016 | 604762 | 19% | 55% | 115% |

**Table h.2. Forecast quantiles of Pacific Hake fishing intensity for the 2014-2016 catch alternatives presented in Table g.1 Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy.**

| Quantile range of 2010 recruitment | | | 0–10% | 10–90% | 90–100% |
|---|---|---|---|---|---|
| Probability of state of nature | | | 10% | 80% | 10% |
| Management Action | | | **Median Fishing Intensity** | | |
| | Year | Catch (mt) | | | |
| a: No catch | 2014 | 0 | 0% | 0% | 0% |
| | 2015 | 0 | 0% | 0% | 0% |
| | 2016 | 0 | 0% | 0% | 0% |
| b: B2014=B2015 | 2014 | 190000 | 66% | 42% | 23% |
| | 2015 | 190000 | 68% | 42% | 24% |
| | 2016 | 190000 | 66% | 41% | 22% |
| c: average historical catch | 2014 | 235000 | 75% | 49% | 27% |
| | 2015 | 235000 | 78% | 50% | 29% |
| | 2016 | 235000 | 77% | 48% | 27% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 82% | 55% | 31% |
| | 2015 | 275000 | 86% | 56% | 33% |
| | 2016 | 275000 | 86% | 55% | 31% |
| e | 2014 | 325000 | 89% | 61% | 36% |
| | 2015 | 325000 | 94% | 64% | 38% |
| | 2016 | 325000 | 96% | 63% | 36% |
| f: near max historical catch | 2014 | 375000 | 96% | 67% | 40% |
| | 2015 | 375000 | 102% | 70% | 42% |
| | 2016 | 375000 | 104% | 70% | 40% |
| g | 2014 | 425000 | 101% | 72% | 44% |
| | 2015 | 425000 | 108% | 76% | 46% |
| | 2016 | 425000 | 112% | 76% | 45% |
| h: near max catch target | 2014 | 500000 | 107% | 79% | 49% |
| | 2015 | 500000 | 116% | 84% | 52% |
| | 2016 | 500000 | 121% | 85% | 51% |
| i: highest C2014=C2015 | 2014 | 727000 | 121% | 95% | 63% |
| | 2015 | 727000 | 132% | 102% | 68% |
| | 2016 | 727000 | 137% | 108% | 69% |
| j: fishing intensity = 100% | 2014 | 825000 | 125% | 100% | 68% |
| | 2015 | 660000 | 132% | 100% | 65% |
| | 2016 | 600000 | 135% | 101% | 62% |
| k: default harvest rule | 2014 | 872424 | 127% | 102% | 70% |
| | 2015 | 691686 | 134% | 103% | 67% |
| | 2016 | 604762 | 136% | 102% | 62% |

**Table h.3. Probabilities related to spawning biomass, fishing intensity, and 2015 catch limits for alternative 2014 catch options (catch options explained in Table g.1) and low, mid, and high state of nature. States of nature are defined on the lower 10%, middle 80%, and high 10% quantiles of 2010 recruitment.**

| | Catch in 2014 | Probability SB2015< SB2014 | Probability SB2015< SB40% | Probability SB2015< SB25% | Probability SB2015< SB10% | Probability Fishing intensity in 2014 > 40% Target | Probability 2015 Catch Target < 2014 Catch |
|---|---|---|---|---|---|---|---|
| **Lower 10% of 2010 recruitment** | 0 | 0% | 10% | 1% | 0% | 0% | 0% |
| | 190,000 | 53% | 22% | 1% | 0% | 1% | 1% |
| | 235,000 | 65% | 26% | 1% | 0% | 1% | 2% |
| | 275,000 | 71% | 26% | 1% | 0% | 1% | 9% |
| | 325,000 | 78% | 28% | 1% | 0% | 5% | 26% |
| | 375,000 | 83% | 32% | 2% | 1% | 24% | 50% |
| | 425,000 | 88% | 35% | 3% | 1% | 52% | 75% |
| | 500,000 | 90% | 43% | 4% | 1% | 92% | 94% |
| | 727,000 | 93% | 60% | 16% | 1% | 100% | 99% |
| | 825,000 | 96% | 71% | 21% | 1% | 100% | 99% |
| | 872,424 | 96% | 75% | 26% | 1% | 100% | 99% |
| | | | | | | | |
| **Middle 80% of 2010 recruitment** | 0 | 7% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 49% | 0% | 0% | 0% | 0% | 0% |
| | 235,000 | 58% | 0% | 0% | 0% | 0% | 0% |
| | 275,000 | 64% | 0% | 0% | 0% | 0% | 0% |
| | 325,000 | 69% | 1% | 0% | 0% | 0% | 0% |
| | 375,000 | 74% | 1% | 0% | 0% | 0% | 0% |
| | 425,000 | 78% | 1% | 0% | 0% | 0% | 2% |
| | 500,000 | 84% | 1% | 0% | 0% | 2% | 11% |
| | 727,000 | 91% | 3% | 0% | 0% | 33% | 50% |
| | 825,000 | 92% | 6% | 0% | 0% | 50% | 66% |
| | 872,424 | 93% | 7% | 0% | 0% | 57% | 73% |
| | | | | | | | |
| **Upper 10% of 2010 recruitment** | 0 | 26% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 54% | 0% | 0% | 0% | 0% | 0% |
| | 235,000 | 59% | 0% | 0% | 0% | 0% | 0% |
| | 275,000 | 63% | 0% | 0% | 0% | 0% | 0% |
| | 325,000 | 68% | 0% | 0% | 0% | 0% | 0% |
| | 375,000 | 70% | 0% | 0% | 0% | 0% | 0% |
| | 425,000 | 73% | 0% | 0% | 0% | 0% | 0% |
| | 500,000 | 74% | 0% | 0% | 0% | 0% | 0% |
| | 727,000 | 84% | 0% | 0% | 0% | 0% | 0% |
| | 825,000 | 88% | 0% | 0% | 0% | 0% | 0% |
| | 872,424 | 88% | 0% | 0% | 0% | 0% | 0% |

**Table h.4. Probabilities related to spawning biomass, fishing intensity, and 2016 catch limits for alternative 2015 catch options (catch options explained in Table g.1) and low, mid, and high state of nature. States of nature are defined on the lower 10%, middle 80%, and high 10% quantiles of 2010 recruitment.**

| | Catch in 2015 | Probability SB2016< SB2015 | Probability SB2016< SB40% | Probability SB2016< SB25% | Probability SB2016< SB10% | Probability Fishing intensity in 2015 > 40% Target | Probability 2016 Catch Target < 2015 Catch |
|---|---|---|---|---|---|---|---|
| **Lower 10% of 2010 recruitment** | 0 | 23% | 7% | 1% | 0% | 0% | 0% |
| | 190,000 | 67% | 24% | 2% | 0% | 1% | 1% |
| | 235,000 | 70% | 30% | 3% | 1% | 2% | 4% |
| | 275,000 | 72% | 38% | 6% | 1% | 6% | 17% |
| | 325,000 | 74% | 45% | 7% | 1% | 30% | 35% |
| | 375,000 | 77% | 50% | 10% | 1% | 56% | 62% |
| | 425,000 | 80% | 60% | 18% | 1% | 80% | 78% |
| | 500,000 | 85% | 69% | 24% | 1% | 97% | 93% |
| | 727,000 | 93% | 90% | 58% | 12% | 99% | 98% |
| | 660,000 | 91% | 90% | 61% | 16% | 99% | 98% |
| | 691,686 | 91% | 90% | 62% | 19% | 99% | 98% |
| | | | | | | | |
| **Middle 80% of 2010 recruitment** | 0 | 46% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 73% | 1% | 0% | 0% | 0% | 0% |
| | 235,000 | 75% | 1% | 0% | 0% | 0% | 0% |
| | 275,000 | 77% | 1% | 0% | 0% | 0% | 0% |
| | 325,000 | 80% | 2% | 0% | 0% | 0% | 0% |
| | 375,000 | 84% | 3% | 0% | 0% | 0% | 1% |
| | 425,000 | 85% | 5% | 0% | 0% | 3% | 6% |
| | 500,000 | 88% | 9% | 0% | 0% | 14% | 18% |
| | 727,000 | 92% | 23% | 4% | 0% | 56% | 60% |
| | 660,000 | 91% | 23% | 4% | 0% | 50% | 55% |
| | 691,686 | 92% | 26% | 7% | 0% | 55% | 59% |
| | | | | | | | |
| **Upper 10% of 2010 recruitment** | 0 | 69% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 78% | 0% | 0% | 0% | 0% | 0% |
| | 235,000 | 81% | 0% | 0% | 0% | 0% | 0% |
| | 275,000 | 83% | 0% | 0% | 0% | 0% | 0% |
| | 325,000 | 84% | 0% | 0% | 0% | 0% | 0% |
| | 375,000 | 86% | 0% | 0% | 0% | 0% | 0% |
| | 425,000 | 87% | 0% | 0% | 0% | 0% | 0% |
| | 500,000 | 88% | 0% | 0% | 0% | 0% | 0% |
| | 727,000 | 92% | 0% | 0% | 0% | 0% | 0% |
| | 660,000 | 90% | 0% | 0% | 0% | 0% | 0% |
| | 691,686 | 91% | 0% | 0% | 0% | 0% | 0% |

## Research and data needs

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

1. Examine statistical methods to parameterize time-varying fishery selectivity in assessment and forecasting.

2. 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.

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. Finalize the analysis of recently collected maturity samples and explore ways to include new maturity estimates 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 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.

7. Continue to explore process-based operating and assessment models that may be able to capture more realistic life-history variability (changes in size at age, M, fecundity at size etc.), as well as future fishery selectivity patterns.

8. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods.

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

10. Evaluate the quantity and quality of historical biological data (prior to 1988 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use as age-composition and weight-at-age data, and/or any historical indications of abundance fluctuations.

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

12. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others.

13. Coordinate our MSE research with other scientists in the region engaging in similar research.

14. Examine variation (annual and seasonal) in key life-history quantities (i.e., length at age).

15. Examine alternative ways to model and forecast recruitment.

16. Investigate the utility of additional data sources (bottom trawl surveys, length data, etc.) for use in assessment and simulation models.

# 1 Introduction

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 or Whiting (*Merluccius productus*) stock assessments are to be prepared by the Joint Technical Committee (JTC) comprised of both U.S. and Canadian scientists, and reviewed by the Scientific Review Group (SRG), consisting of representatives from both nations. Additionally, the Agreement calls for both of these bodies to include industry-nominated scientists, who are selected and appointed jointly by both nations.

This assessment reports a base model representing the collective work of the JTC. The assessment depends primarily upon the acoustic survey biomass index time-series for information on the scale of the current hake stock. Age-composition data from the aggregated fishery and the acoustic survey provide additional information allowing the model to resolve strong and weak cohorts. Both sources show a moderately strong 2008 cohort and a very strong 2010 cohort.

This assessment is fully Bayesian, with the base model incorporating prior information on several key parameters (including natural mortality, *M*, and steepness of the stock-recruit relationship, *h*) and integrating over 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 respect to the base. These sensitivity analyses are thoroughly described in this assessment document. The structural assumptions of the 2014 base model are mostly similar to the 2013 base model. The most important change between the two is that the 2014 base model includes estimation of time-varying selectivity in the fishery.

## 1.1 Stock structure and life history

Pacific Hake, also referred to as Pacific Whiting, is a semi-pelagic schooling species distributed along the west coast of North America generally ranging from 25° N. to 55° N. latitude (see Figure 1 for an overview map). It is among 18 species of hake from four genera (being the majority of the family *Merluccidae)*, which are found in both hemispheres of the Atlantic and Pacific oceans (Alheit and Pitcher 1995, Lloris et al. 2005). The coastal stock of Pacific Hake is currently the most abundant groundfish population in the California Current system. Smaller populations of this species occur in the major inlets of the Northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California. Genetic studies indicate that the Strait of Georgia and the Puget Sound populations are genetically distinct from the coastal population (Iwamoto et al. 2004; King et al. 2012). Genetic differences have also been found between the coastal population and hake off the west coast of Baja California (Vrooman and Paloma 1977). The coastal stock is also distinguished from the inshore populations by larger body size and seasonal migratory behavior.

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

Older Pacific Hake exhibit the greatest northern migration each season, with two- and three-year old fish rarely observed in Canadian waters north of southern Vancouver Island. During El Niño events (warm ocean conditions, such as 1998), a larger proportion of the stock migrates into Canadian waters, apparently due to intensified northward transport during the period of active migration (Dorn 1995, Agostini et al. 2006). In contrast, La Niña conditions (colder water, such as in 2001) result in a southward shift in the stock's distribution, with a much smaller proportion of the population found in Canadian waters, as seen in the 2001 survey (Figure 2).

Additional information on the stock structure for Pacific Hake is available in the 2013 Pacific Hake Stock Assessment document (JTC 2013).

## 1.2 Ecosystem considerations

Pacific Hake are 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. A more detailed description of ecosystem considerations is given in the 2013 Pacific Hake stock assessment (JTC 2013).

## 1.3 Management of Pacific Hake

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

Throughout the last decade, the total coast-wide catch has tracked harvest targets reasonably well (Table 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 the catch target at a depletion (relative spawning biomass) of 40% and above, to zero catch at a depletion of 10% or less (called the default harvest policy in the Agreement). Further considerations have often resulted in catch targets to be set lower than the recommended catch limit. In the last decade, total catch has never exceeded the quota, but harvest rates have approached the $F_{SPR=40\%}$ target, and based upon this assessment, may have exceeded the target in a few years. Overall, management appears to be effective at maintaining a sustainable stock size, in spite of uncertain stock assessments. However, management has been precautionary in years when very large quotas were predicted by the stock assessment.

### 1.3.1 Management of Pacific Hake in Canada

Canadian groundfish managers distribute their portion (26.12%) of the Total Allowable Catch (TAC) as quota to individual license holders. In 2013, the Canadian Hake fleet was given its TAC plus 7,724 mt of uncaught carryover from the 2012 season. This total allocation was high enough that Canadian fisheries managers allotted a portion of it (19,230 mt) to a Joint Venture (JV) fishery. Despite the allocation of quota to the JV fishery, there was insufficient catch by domestic vessels to entice any JV motherships to enter Canadian waters in 2012 or 2013.

In 2013, all Canadian Pacific Hake trips remained subject to 100% observer coverage, by either electronic monitoring (EM) or on-board observer. All shoreside Hake landings are also subject to 100% coverage by the groundfish Dockside Monitoring Program (DMP). Retention of all catch, with the exception of prohibited species, is mandatory. The retention of groundfish other than Sablefish, Mackerel, Walleye Pollock, and Pacific Halibut on non-observed but electronically monitored, dedicated Pacific Hake trips cannot exceed 20% of the landed catch weight.

For the 2013 fishing season, the Canadian Hake industry asked that vessels document, in their logbooks, any instance of contact of their mid-water nets with the ocean bottom, in order to address a condition of the Marine Stewardship Certification (MSC).

### 1.3.2 Management of Pacific Hake in the United States

In the U.S. zone, participants in the directed fishery are required to use pelagic trawls with a codend mesh that is at least 7.5 cm (3 inches). Regulations also restrict the area and season of fishing to reduce the bycatch of Chinook salmon and several depleted rockfish stocks. The at-sea fisheries begin on May 15, but processing and night fishing (midnight to one hour after official sunrise) are prohibited south of 42° N. latitude (the Oregon-California border). Shore-based fishing is allowed after April 1 south of 42° N. latitude, but only 5% of the shore-based allocation is released prior to the opening of the main shore-based fishery (June 15). The current allocation agreement, effective since 1997, divides the U.S. non-tribal harvest guideline among catcher-processors (34%), motherships (24%), and the shore-based fleet (42%). Since 2011, the non-tribal U.S. fishery has been fully rationalized with allocations in the form of IFQs to the shore-based sector and group shares to cooperatives in the at-sea mothership and catcher-processor sectors. Starting in 1996, the Makah Indian Tribe has conducted a separate fishery with a specified allocation in its "usual and accustomed fishing area". Since 2009 there has also been a Quileute tribal allocation, which has never been fished.

Shortly after the 1997 allocation agreement was approved by the PFMC, fishing companies owning catcher-processor (CP) vessels with U.S. west coast groundfish permits established the Pacific Whiting Conservation Cooperative (PWCC). The primary role of the PWCC is to distribute the CP allocation among its members in order to achieve greater efficiency and product quality, as well as promoting reductions in waste and bycatch rates relative to the former "derby" fishery in which all vessels competed for a fleet-wide quota. The mothership fleet (MS) has also formed a cooperative where bycatch allocations are pooled and shared among the vessels.

## 1.4 Fisheries

The fishery for the coastal population of Pacific Hake occurs along the coasts of northern California, Oregon, Washington, and British Columbia primarily during May–November. The fishery is conducted almost exclusively with mid-water trawls. Foreign fleets dominated the fishery until 1991, when domestic fleets began taking the majority of the catch. Catches were occasionally above 200,000 mt prior to 1986, and have been mostly above that level since.

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

### 1.4.1 Overview of the fisheries in 2013

The Joint Management Committee (JMC) determined an adjusted coast-wide catch target of 365,112 mt for 2013, with a U.S. allocation of 269,745 mt (73.88%) and a Canadian allocation of 95,367 mt (26.12%). A review of the 2013 fishery is given below.

#### 1.4.1.1 Canada

The 2013 Pacific Hake domestic fishery removed 54,096 mt from Canadian waters, or 57% of the Canadian TAC. The low catches by the domestic fishery dissuaded the Joint Venture vessels from participating in the fishery, even though there was a quota allocated to them. The 2010 year class was nearly completely absent in Canada, where it only made up 0.9% of the catch numbers. The most abundant year classes (by number) in the Canadian catch were age 5 at 17.2%, age 7 at 18.2%, age 8 at 11.4%, and age 14 at 16.3%, being the 2008, 2006, 2005, and 1999 year classes, respectively. Remarkably, the 1999 cohort, now age 14, is still making up a significant portion of the catch in Canada.

The distribution of catch by month remained similar to other years, with the summer months showing the greatest catch. When compared to recent years, September 2013 was slightly more productive for vessels but the catches dropped off quickly in October and were all but finished in November, approximately a month earlier than in recent years (2008-2012).

In 2008 there was a significant change in the spatial distribution of the fishery, with many vessels taking more of their catch than usual from Queen Charlotte Sound (Area 5B). Since then, there has been a marked reversal of that trend, and a regrowth of the fishery off the West Coast of Vancouver Island (WCVI), which is the traditional area in which the Hake fishery operates.

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

#### 1.4.1.2 United States

The U.S. adjusted allocation of 269,745 mt is further divided to research, tribal, catcher-processor, mothership, and shore-based sectors. After the tribal allocation of 17.5% plus 16,000 mt, and a 2,500 mt allocation for research catch and bycatch in non-groundfish fisheries, the 2013 non-tribal U.S. catch limit of 204,040 mt was allocated to the catcher/processor (34%), mothership (24%), and shore-based (42%) commercial sectors. Therefore, the CP fleet was allocated 69,373 mt, the MS fleet was allocated 48,970 mt, and the shore-based fleet was allocated 85,697 mt. The at-sea fleet encountered larger fish in May and mainly smaller fish from the 2010 year class after May. The catches from the shore-based fleet were dominated by the 2010 year class. Tribal fisheries landed approximately 4,500 mt, but 30,000 mt were reapportioned from the tribal fisheries to the non-tribal fisheries on September 18, 2013. Both the at-sea and shore-based fleets nearly caught their respective total catch targets, leaving 40,332 mt, 15.0%, of the catch target uncaught.

A more detailed description of the 2013 fishery may be obtained from JTC meeting notes.

# 2 Data

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

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

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

- Mean observed weight-at-age from fishery and survey catches, 1975-2013.
- Aging-error matrices based on cross-read and double-blind-read otoliths.
- Proportion of female hake maturity by age (Dorn and Saunders 1997).

Some data sources were not included but have been explored, were used for sensitivity analyses, or were included in previous stock assessments, but not in this stock assessment (these data are discussed in more detail in the 2013 stock assessment document (JTC 2013)).

- Fishery and acoustic survey length composition information.
- Fishery and acoustic survey age-at-length composition information.
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1977, 1980, 1983, 1986, 1989, 1992).
- NWFSC/SWFSC/PWCC coast-wide juvenile hake and rockfish survey (2001–2009).
- Bycatch of Pacific Hake in the trawl fishery for pink shrimp off the coast of Oregon, 2004–2005, 2007–2008.
- Historical biological samples collected in Canada prior to 1990, but currently not available in electronic form.
- Historical biological samples collected in the U.S. prior to 1975, but currently not available in electronic form or too incomplete to allow analysis with methods consistent with more current sampling programs.
- CalCOFI larval hake production index, 1951–2006. The data source was previously explored and rejected as a potential index of hake spawning stock biomass, and has not been revisited since the 2008 stock assessment.
- Joint-U.S. and Canada acoustic survey index of age-1 Pacific Hake.
- Histological analysis of ovary samples collected during the 2010, 2012 and 2013 NWFSC bottom trawl surveys, the 2012 and 2013 acoustic surveys, and the at-sea fishery in 2013.

## 2.1 Fishery-dependent data

### 2.1.1 Total catch

The catch of Pacific Hake for 1966–2013 by nation and fishery sector is shown in Table 1 and Figure 4. Catches in U.S. waters prior to 1978 are available only by year from Bailey et al. (1982) and historical assessment documents. Canadian catches prior to 1989 are also unavailable in disaggregated form. For more recent catches, haul or trip-level information was available to partition the removals by month, during the hake fishing season, and estimate bycatch rates from observer information at this temporal resolution. This has allowed a more detailed investigation of shifts in fishery timing (see Figure 5 in 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 1991–2013 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 carry observers and are required 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 (Figure 5). During the 1990's, subsequent to the ascension of the domestic fleet in the U.S. and both the domestic and Joint-Venture fleets in Canada, most of the catch was taken in the spring. The 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 and similarly constraining.

### 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 1991–2013. 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, 1991–2013, were collected by port samplers located where there are substantial landings of Pacific Hake: primarily Eureka, Newport, Astoria, and Westport. Port samplers routinely take one sample per offload (or trip) consisting of 100 randomly selected fish for individual length and weight and from these, 20 for otolith extraction. The Canadian domestic fishery is subject to 100% observer coverage on the two processing vessels *Viking Enterprise* and *Osprey*, which together make up a fair portion of the Canadian 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 and 2013. On observed trips, otoliths (for aging) 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 electronically observed trips, port samplers obtain biological data from the landed catch. Observed domestic haul-level information is then aggregated to the trip level to be consistent with the unobserved trips that are sampled in ports. For the Canadian joint-venture fishery, an observer aboard the factory ship estimates the codend weight by measuring the diameter of the codend and doing a spherical volume calculation for each delivery from a companion catcher boat. Length samples are collected every second day of fishing operations, and otoliths are collected once a week. Length and age samples are taken randomly from a given codend. Since the weight of the sample from which biological information is taken is not recorded, sample weight must be inferred from a length-weight relationship applied to all lengths taken and summed over 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 for a specific year can be summarized as follows:

1. Count the number of fish at each age 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. Estimate total numbers-at-age ($\widehat{N}_{a,f}$) by expanding sampled numbers-at-age ($n_{a,f}$) by fishery sector landings ($C_f$) divided by the sampled weight for fleet $f$ ($b_f$). The raw frequency at age data ($p_{a,f}$), landings, and mean weight-at-age ($w_a$) can be used to estimate the total numbers at age in the catch for each sector.

$$\widehat{N}_{a,f} = \frac{C_f}{b_f} n_{a,f} = \frac{\sum_a w_a N_{a,f}}{\sum_a w_a n_{a,f}} n_{a,f} = \frac{n_{a,f} \sum_a w_a N_{a,f} \Big/ \sum_a n_{a,f}}{\sum_a w_a n_{a,f} \Big/ \sum_a n_{a,f}} = \frac{p_{a,f} C_f}{\sum_a w_a p_{a,f}}$$

4. Sum fleet specific total numbers-at-age across sectors to aggregate and normalize to proportions that sum to one.
5. Determine sample sizes (number of trips or hauls).

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.

The aggregate fishery age-composition data (1975–2013) confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999, with a small proportion from the 1999 year class (14 years old in 2013) 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 2013 fishery (Figure 6). The above average 2005 and 2006 year classes declined in proportion in the 2011 fishery samples, but remained persistent in the 2012 and 2013 fisheries, although were overwhelmed by the strong 2008 and 2010 cohorts. We caution that proportion-at-age data contains information about the relative numbers-at-age, and these can be affected by changing recruitment, selectivity or fishing mortality. The estimated absolute size of incoming cohorts becomes more precise after they have been observed several times (i.e., encountered by the fishery and survey over several years).

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

### 2.1.3 Catch per unit effort

Calculation of a reliable fishery CPUE metric is particularly problematic for Pacific Hake and it has never been used as a tuning index for assessment of this stock. There are many reasons that fishery CPUE would not index the abundance of Pacific Hake, which are discussed in the 2013 stock assessment (JTC 2013).

## 2.2 Fishery-independent data

An acoustic survey of age 2+ hake was included in this assessment, while bottom trawl, pre-recruit, and age 1 acoustic data sources were not used. See the 2013 stock assessment (JTC 2013) for a more thorough description and history of these fishery-independent data sources.

### 2.2.1 Acoustic survey

The joint U.S. and Canadian integrated acoustic and trawl survey has been the primary fishery-independent tool used to assess the distribution, abundance and biology of coastal Pacific Hake, along the west coasts of the United States and Canada. A detailed history of the acoustic survey is given in Stewart et al (2011). The acoustic surveys performed in 1995, 1998, 2001, 2003, 2005, 2007, 2009, 2011, 2012 and 2013 were used in this assessment (Table 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 age 2 and older. Age-0 and age-1 hake have been historically excluded from the survey efforts, due to largely different schooling behavior relative to older hake and concerns about different catchability by the trawl gear.

Distributions of hake backscatter plotted for each acoustic survey since 1995 illustrate the variable spatial patterns of age-2+ hake among years (Figure 2). The 1998 acoustic survey is notable because it shows an extremely northward occurrence that is thought to be related to the strong 1997-1998 El Niño. In contrast, the distribution of hake during the 2001 survey was compressed into the lower latitudes off the coast of Oregon and Northern California. In 2003, 2005 and 2007 the distribution of Pacific Hake did not show an unusual coast-wide pattern, but in 2009, 2011, and 2012 the majority of the hake distribution was again found in U.S. waters, which is more likely due to age-composition than the environment. The 2013 survey found and similar distribution of hake as in 2012, except that few aggregations of fish were found north of Vancouver Island. Older Pacific Hake tend to migrate farther north, but the distribution is variable among years.

Acoustic survey data from 1995 onward have been analyzed using geostatistical techniques (kriging), which accounts for spatial correlation to provide an estimate of total biomass as well as an estimate of the year-specific sampling variability due to patchiness of hake schools and irregular transects (Petitgas 1993; Rivoirard et al. 2000; Mello & Rose 2005; Simmonds and MacLenann, 2005). Advantages to the kriging approach are discussed in the 2013 stock assessment (JTC 2013).

During the acoustic surveys, mid-water trawls are made opportunistically to determine the species composition of observed acoustic sign and to obtain the length data necessary to scale the acoustic backscatter into biomass (see Table 4 for the number of trawls in each survey year). Biological samples collected from these trawls were post-stratified, based on similarity in size composition, and the composite length frequency was used to characterize the hake size distribution along each transect and to predict the expected backscattering cross section for Pacific Hake based on the fish size-target strength (TS) relationship. Biases, such as alternative TS relationships are partially accounted for in catchability, but variability in the estimated biomass due to uncertainty in target strength is not explicitly accounted for.

Results from research done in 2010 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 2013 survey was successful at providing a biomass estimate of Pacific Hake as well as an age composition of the surveyed population. The U.S. portion of the survey was operated jointly with a sardine survey, as in 2012, except that the NOAA Ship Bell Shimada performed all of the trawling for hake rather than a separate catcher vessel. Survey protocols were similar to past protocols, except that some previously collected environmental data was not collected.

Figure 7 shows the relative backscatter of age-2+ hake as observed in the 2013 survey. Many hake were observed off of Central California, Cape Mendocino, and Oregon. Backscatter was relatively low off of Vancouver Island and few aggregations of hake were observed around Haida Gwaii. Comparing the distribution of backscatter in 2012 and 2013 to the distribution of backscatter in previous surveys (Figure 2) shows that the stock was distributed more southerly in 2012 and 2013, which is partly due to the young age structure of the population. The distribution of hake in 2011–2013 was most similar to the distribution of hake in 2001, when the population was also dominated by young fish.

The 2013 survey biomass estimate is 2,422,661 metric tons, which is approximately 1.8 times the 2012 survey biomass estimate and 4.6 times the 2011 acoustic survey biomass estimate (Figure 9). 4.6% of this biomass was observed in Canadian waters in 2013. No Humboldt squid were observed in 2013, although considerable numbers were caught in both the survey and fishery in 2009. The estimated biomass was greatest off the coast of central California, northern California, and Oregon (Figure 8).

The estimated variability of the 2013 biomass estimate, measured as a coefficient of variance (CV), is 4.33% (Figure 9 and Table 4). This estimate of uncertainty accounts for sampling variability calculated using the geostatistical methods, but several additional sources of observation error are likely. 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 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 ten acoustic surveys are summarized in Figure 6 and show large proportions of the 1999, 2008, and 2010 year classes. The 2013 survey attributed 76.2% 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. This age-1 index has not been used in the stock assessment because more time is needed to develop the index, but preliminary estimates seem to track the estimated recruitment reasonably well (Figure 10). The JTC encourages a continuation of the effort to calculate an age-1 index from past surveys and to keep protocols in place such that a consistent age-1 index can be calculated in the future. The 2013 stock assessment provides a more detailed description of the age-1 index (JTC 2013).

### 2.2.2 Other fishery-independent data

Fishery-independent data from the Alaska Fisheries Science Center (AFSC) bottom trawl survey, the Northwest Fishery Science Center (NWFSC) bottom trawl survey, the NWFSC and Pacific Whiting Conservation Cooperative (PWCC) pre-recruit survey were not used in this assessment. More information on these data sources is given in the 2013 stock assessment (JTC 2013).

## 2.3 Externally analyzed data

### 2.3.1 Maturity

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

Histological samples have been collected during the 2009, 2012, and 2013 U.S. bottom trawl surveys, during the 2012 and 2013 joint U.S/Canada Hake/Sardine acoustic surveys, and from At-Sea hake Observer Program (ASHOP) observers aboard at-sea fishing vessels in 2013 (Table 5). Samples collected from the 2013 bottom trawl survey, the 2013 acoustic survey and during the autumn months in 2013 from ASHOP observers aboard at-sea fishing vessels were not available at the time of this assessment for analysis. It is expected that the maturity will be determined for these fish during 2014. In the course of the surveys, length bins were targeted for ovary collection to ensure an even coverage. The protocol for collection from at-sea fishery vessels was to randomly sample one ovary from the three fish randomly sampled for otoliths. Fish were randomly sampled for otoliths every third haul.

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

Oocytes exhibiting atresia were noted with a visual estimate of the percent atresia. If an ovary sample did not have yolk present in a healthy viable oocyte, then it was marked as immature. Specimens were classified as mature if they contained large oocytes with dark-stained vitellogenin yolk or characteristics associated with more advanced stages. Although not encountered, spent ovaries would also be defined as mature and would be characterized by the presence of large numbers of post ovulatory follicles (POFs), atresia, and typically small groups of immature oocytes. Fish that did not have yolk present but were large or older were not changed to a mature status because of these biological factors (Fig. 4). For this analysis, a fish was determined as spawning if it was marked mature and the percent atresia was less than 25%. Reader error in the determination of maturity for Pacific Hake was negligible (pers. comm., Melissa Head).

Maturity-at-age and length observations show differences across years (Figure 11), but it is difficult to determine if these difference are due to the source (bottom trawl, acoustic survey, or ASHOP) or the year. Some bottom trawl samples were available in 2012, but the majority of samples were from the acoustic survey. All age-2 fish were mature in 2009, while the majority of age-2 fish were immature in 2012. No age-2 fish were observed in the spring ASHOP samples.

Another interesting observation in Figure 11 is that there are large, old fish classified as immature. It is believed that these fish are “skip spawners” and will be spawning in the upcoming year. Figure 12 shows the proportion mature at length for each source and year, with a fitted logistic curve and the maturity-at-length from Dorn & Saunders (1997) shown for comparison. The logistic fits are forced to asymptote at one. With the few large fish classified as mature, the fitted line is less steep than expected, and the fits to the large number of observations of large fish affects the predictions of maturity-at-length for smaller fish due to the symmetry of the logistic curve.

Immature large and old fish indicate that 100% of these fish may not be mature. To account for this possibility, a logistic curve was fit to maturity at length from all years combined with and without an asymptote estimated (Figure 13). Estimating an asymptote improved the overall fit, especially for smaller fish.

The maturity-at-age was estimated using similar methods to those described by Dorn & Saunders (1997). Because length-stratified sampling design was used in the trawl and acoustic surveys, the small and large fish in a specific age group would be sampled disproportionally compared to their total abundance in the population, potentially causing bias in the estimated maturity-at-age if these fish showed different maturity characteristics than the more typical sizes of that age group. Using an age-length key reduces this bias when estimating maturity-at-age. An age-length key was calculated using acoustic survey data from 2009, and 2011–2013, overlapping with the collection of ovaries. All years were simply pooled before calculating the age-length key. Figure 14 shows the proportions of length-at-age, which sum to one across lengths for a specific age.

The proportion mature at length and age was estimated using a logistic regression of maturity against length and age with and without an estimated asymptote. The observations of mature and immature fish are shown in Figure 15 with contour lines showing the estimated proportion mature at length and age from the logistic model with an asymptote estimated. These predictions were passed through the age-length key to produce the estimates in Figure 16 and Table 7. The maturity-at-age with an asymptote of one does not actually asymptote to one because the prediction of maturity-at-length and age slowly approaches one, resulting in small fish of older ages having a small probability of being immature.

The estimated maturity-at-age using a logistic model with an estimated asymptote and data combined for all years is similar in trend to the predicted values for ages 1 through 4, but is slightly greater at ages 1 through 3. The most obvious difference is that less than 100% of old fish are predicted to be mature. We did not use this new maturity curve in the base assessment model because accurate year and source effects cannot be determined, and more data will be available soon. However, we do supply a sensitivity analysis to this new maturity-at-age ogive and show the effect it has on predictions of spawning biomass and management advice (see Section 3.5).

### 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 age data while neighboring year-classes are under-represented relative to what would be observed if ageing error were consistent at age across cohorts.

To account for these observation errors in the model, year-specific ageing-error matrices (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 standard deviation reduced by a factor of 0.55 for the 1980, 1984, 1999, 2008, and 2010 cohorts.

### 2.3.3 Weight-at-age

A matrix of empirically derived population weight at age by year is used in the current assessment model to translate numbers-at-age directly to biomass-at-age. Mean weight at age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2013 (Figure 17). Ages 15 and over for each year were pooled and assumed to have a constant weight at age. The combinations of age and year with no observations were assumed to change linearly over time between observations at any given age. For those years before and after all the observations at a given age, mean weights were assumed to remain constant prior to the first observation and after the last observation. The number of samples is generally proportional to the amount of catch, so the combinations of year and age with no samples should have relatively little importance in the overall estimates of the population dynamics. The use of empirical weight at age is a convenient method to capture the variability in both the weight-at-length relationship within and among years, as well as the variability in length-at-age, without requiring parametric models to represent these relationships. However, this method requires the assumption that observed values are not biased by strong selectivity at length or weight and that the spatial and temporal patterns of the data sources provide a representative view of the underlying population.

### 2.3.4 Length-at-age

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

## 2.4 Estimated parameters and prior probability distributions

The estimated parameters and prior probability distributions used in this stock assessment are reported in Table 8. Several important distributions are discussed in detail below.

### 2.4.1 Natural Mortality

Since the 2011 assessment, and again this year, a combination of the informative prior used in recent Canadian assessments and results from analyses using Hoenig’s method (Hoenig 1983) support the use of a log-normal distribution with a median of 0.2 and a log-standard deviation of 0.1. Historical treatment of natural mortality is discussed in the 2013 stock assessment (JTC 2013). Sensitivity to this prior has been evaluated extensively in many previous hake assessments (JTC 2013). Alternative prior distributions for $M$ typically have a significant impact on the model results, but in the absence of new information on $M$, there has been little option to update the prior and the sensitivities have not been repeated this year.

### 2.4.2 Steepness

The prior for steepness is based on the median (0.79), 20th (0.67) and 80th (0.87) percentiles from Myers et al. (1999) meta-analysis of the family Gadidae, and has been used in previous U.S. assessments since 2007. This prior is distributed $\beta(9.76, 2.80)$ which translates to a mean of 0.777 and a standard deviation of 0.113. Sensitivities to the variance on the prior on steepness were evaluated in the 2013 and 2012 assessments (JTC 2013, JTC 2012).

### 2.4.3 Variability on fishery selectivity deviations

Time-varying fishery selectivity was introduced in this assessment and was modelled with yearly deviations applied individually to the parameters for selectivity-at-age (more detail on the parameterization is provided in Appendix C). A penalty function in the form of a normal Gaussian distribution is applied to each deviation to keep the deviation from straying far from zero, unless the data are overwhelming. The amount of deviation from zero is controlled by a fixed standard deviation, $\phi$.

A standard deviation of 0.03 for this penalty function was used for each age and was estimated externally by treating the deviations as random effects and integrating over them using the Laplace method, as described by Thorson et al. (2014). The most likely estimate of the standard deviation (0.03 as seen in Figure 18) was then fixed in the base assessment model.

This parameterization allows for the estimation of time-varying selectivity without allowing large year-to-year changes. However, the current selectivity parameterization is limiting because each individual selectivity-at-age is correlated with the selectivity of other ages. In other words, it is difficult to disentangle the correlations. Therefore, we recommend that future research be expended on investigating alternative selectivity patterns that allow for easily interpretable annual variations.

# 3 Assessment

## 3.1 Modeling history

A large variety of age-structured stock assessment models have been used for Pacific Hake. Initially, a cohort analysis tuned to fishery CPUE was used (Francis et al. 1982). Later, the cohort analysis was tuned to NMFS triennial acoustic survey estimates of absolute abundance at age (Hollowed et al. 1988). Since 1989, stock synthesis models using fishery catch-at-age data and acoustic survey estimates of population biomass and age composition have been the primary assessment method (Dorn and Methot 1991).

While the age-structured assessment form has remained similar since 1991, management procedures have been modified in a variety of ways. There have been alternative data choices, post-data collection processing routines, different data weighting schemes, a huge number of structural assumptions for the stock assessment model, and alternative control rules.

Data processing, choices, and weighting have been modified several times in historical hake assessments. For example, acoustic data processing has been modified over the years through modifications to target strength calculations (Dorn and Saunders 1997) or the introduction of kriging(Stewart and Hamel 2010). While survey data have been the key index for abundance since 1988, which surveys have been used have varied considerably: the AFSC/NWFSC triennial bottom trawl survey was used from 1988 before being discarded from the 2009 assessment by (Hamel and Stewart 2009). While used for assessments in the early 1990s, (Stewart et al. 2011) reviewed pre-1995 acoustic survey data and deemed that their sampling had been insufficient to be comparable with more recent data; Various recruitment indices have been considered, but subsequently rejected (Helser et al. 2002, Helser et al. 2004, Stewart and Hamel 2010). Even where data have been consistently used, their weighting in the statistical likelihood has varied through various emphasis factors(e.g., Dorn 1994, Dorn et al. 1999); multinomial sample size on age-composition (Dorn et al. 1999, Helser et al. 2002, Helser et al. 2005, Stewart et al. 2011) and survey variance assumptions. The list of changes discussed above is for illustrative purposes only; it is only a small fraction of the different data choices analysts have made (and that reviewers/panels have required).

The structure of assessment models has perhaps had the largest number of changes. In terms of spatial models since 1994, analysts have considered explicitly spatial forms (Dorn 1994, Dorn and Saunders 1997), spatially implicit forms (Helser et al. 2006) and single-area models(JTC 2012). Predicted recruitment has been modeled by sampling historical recruitment (e.g., Dorn 1994, Helser et al. 2005), using a stock recruitment relationship parameterized using Fmsy/MSY (Martell 2010), and using several alternative steepness priors (JTC 2012, 2013). Selectivity has also been modeled in several ways: It has been both time varying with a random walk (Helser et al. 2002) and without (Dorn 1994, Dorn and Saunders 1997, JTC 2012, 2013) and invariant (JTC 2012, 2013); and it has been age-based (Dorn 1994, Dorn and Saunders 1997, JTC 2012, 2013) and length-based(Helser and Martell 2007).

Several harvest control rules have been explored as well. Pacific Hake stock assessments have presented decision makers with constant F, variable F and hybrid control rules: $F_{35\%}$, $F_{40\%}$, $F_{40\%}$-40:10, $F_{45\%}$, F45%-40:10, $F_{50\%}$ (e.g., Dorn 1996, JTC 2013) The above is only a small fraction of the number of management procedures that have actually been investigated. There have been many others combinations of data, assessment model and harvest control rule. In addition to the cases examined in the assessment documents, there have been many more requested at assorted review panel meetings.

While there have been many changes to Pacific Hake management procedures, they have not been capricious. Available data have changed over the years, and there have been many advances in the discipline of Fisheries Science. In some ways, the latter has evolved considerably over the course of the historical hake fishery: new statistical techniques and software have evolved (Bayesian vs. maximum likelihood methods for example); and the scientific literature has suggested potentially important biological dynamics to consider (explicit modelling of length at age for example). Policies requiring the application of specific control rules have also changed such as the United States' National Standards Guidelines in 2002 and the $F_{40\%}$-40:10 harvest control rule in The Agreement. Analysts making changes to Pacific Hake management procedures have been trying to improve the caliber and relevance of the assessments by responding to new scientific developments, policy requirements, and different reviewers. Until this year's MSE, none of these management procedure changes have been evaluated in simulation and quantitatively compared with performance measures.

## 3.2 Response to recent review recommendations

### 3.2.1 2014 Scientific Review Group (SRG) review

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

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

### 3.2.2 2013 SRG review

The 2013 SRG panel (19–22 February, 2013 in Vancouver, BC) conducted a thorough review of the data, analyses and modeling conducted by the JTC (a full summary can be found in the SRG panel report). The SRG endorsed the use of the base model for 2013. Other recommendations for this assessment made during the SRG review were: investigate time-varying selectivity, analyze the recent maturity data that has been collected, and collect ovaries for maturity determination from fishery catches. Specific responses to recommendations are given below.

### 3.2.3 2013 SRG recommendations and responses from the JTC

The 2013 SRG made several broad research recommendations. Unlike previous years, these included recommendation for both stock assessment and MSE development. Table 9 is a summary of the SRG 2013's broad research recommendations for acoustic research, life-history data, assessment model configuration, and MSE. In addition to these, the range of technical recommendations related to the MSE from SRG 2013 has been refined through subsequent May 2013 JMC, August 2013 MSE Steering Group, and January 2014 JTC meetings; Table 9 also summarizes the proposed and completed research activities specific to the MSE.

## 3.3 Model description

### 3.3.1 Base model

This year, the JTC changed the structural form of the base model. The model retains the 2013 base assessment configuration, except we have adopted a base model with time-varying fisheries selectivity. It was implemented using Stock Synthesis version 3.24s (Methot and Wetzel 2012) to estimate random deviations from the estimated base selectivity parameters. The flexibility of the time-varying selectivity is determined by the standard deviation ($\phi$) on a Gaussian penalty function. The value of this standard deviation is not estimable in SS directly, but we estimated this variance using the methods described by assuming that the deviations are random effects and using the methods described by Thorson et al. (2014), which we call "the Laplace approximation" since it uses a Laplace approximation to integrate over the random effects. The combination of the Laplace approximation and closed-loop simulations allowed us to justify the choice of the random effects variance, $\phi$=0.03 (as discussed above). Furthermore simulations showed that it may produce reasonable management performance even if the data come from a fishery that exhibits larger annual changes in year-to-year selectivity (see Table A.4 in Appendix A).

The structure of the base model, including parameter specifications, bounds and prior distributions (where applicable) is summarized in Table 8. The assessment model includes a single fishery representing the aggregate catch from all sectors in both nations. In response to the 2010 STAR panel recommendations, (Stewart et al. 2011) examined 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 and showed that a simpler model was able to mimic models parameterized with these more complex dynamics and concluded that increased model complexity could not be justified. We assume that acoustic survey selectivity does not change over time, but, as explained above, we treat commercial selectivity as time-varying. 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.

Growth is represented via the externally and empirically 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 (Stewart et al. 2011) but did not provide substantially different results. The inclusion of length data to model growth directly provides more complexity due to both the considerable growth of hake during the May through December fishing season and the variability in growth rates among cohorts and years, as investigated in Stewart et al. (2011).

Prior probability distributions and fixed values are used for several parameters. For the base model, the instantaneous rate of natural mortality ($M$) is estimated with a lognormal prior having a median of 0.2 and a standard deviation (in log-space) of 0.1 (described above). The stock-recruitment function is a Beverton-Holt parameterization, with the log of the mean unexploited recruitment freely estimated. This assessment uses the same Beta-distributed prior for stock-recruit steepness ($h$), based on Myers et al. (1999) that was applied in previous assessments (Stewart et al. 2011, JTC 2012, 2013). Year-specific recruitment deviations were estimated from 1946–2013. The standard deviation, $\sigma_r$, for recruitment variability, serving as both a recruitment deviation constraint and bias-correction, is fixed at a value of 1.4 in this assessment. This value is based on consistency with the observed variability in the time-series of recruitment deviation estimates, and is the same as assumed in 2013. Survey catchability was freely estimated with a uniform (noninformative) prior in log-space. Maturity and fecundity relationships are assumed to be time-invariant and fixed values remain unchanged from recent assessments.

Statistical likelihood functions used for data fitting are typical of many stock assessments. The acoustic survey index of abundance was fit via a log-normal likelihood function, using the observed (and extra 2009) sampling variability, estimated via kriging, as year-specific weighting. An additional constant and additive log(SD) component is included, which was freely estimated to accommodate unaccounted for sources of process and observation error. A multinomial likelihood was applied to age-composition data, weighted by the sum of the number of trips or hauls actually sampled across all fishing fleets, and the number of trawl sets in the research surveys. Input sample sizes were then iteratively down-weighted to allow for additional sources of process and observation error. This process resulted in tuned input sample sizes roughly equal to the harmonic mean of the effective sample sizes after model fitting, and tuning quantities have been unchanged since the 2012 assessment, even with the inclusion of time-varying selectivity.

## 3.4 Modeling results

### 3.4.1 Changes from 2013

A set of ‘bridging’ models in SS version 3.24s was constructed to clearly illustrate the component-specific effects of all changes to the base model from 2013 to 2014. Updating the 2012 catch, proportions at age and weight at age had no observable effects on spawning depletion. Likewise, updating from SS version 3.24j used in 2012 to 3.24s caused no change in the results.

The next bridging step was to include 2013 catches then separately fit fishery 2013 age-composition data and the 2013 survey data (Table 10). The former is similar to what the assessment (with time-invariant selectivity) would have been without a 2013 acoustic survey. Fit to fishery age-composition data alone, the current 2014 model predicts an increase in the 2012 stock size compared to the 2013 assessment. To explain the age-composition data, the model predicts a large 2010 year class but uncertainty in both depletion and 2010 year-class strength is large (Figure 19). Fits to 2013 survey data alone produced estimates of spawning depletion and 2010 recruitment levels that were smaller than when fitting fishery age-composition data alone (Figure 19).

The final bridging step was to add the 2013 acoustic survey biomass estimate and fishery age-compositions (all 2013 data, Figure 19). The main result of including all data sources was that uncertainty was reduced. In other words, without the 2013 acoustic survey data, the 2014 assessment would be much more uncertain.

### 3.4.2 Assessment model results

**Model Fit**

For the base model, the MCMC chain was run for 12,000,000 iterations with the first 2,010,000 discarded to eliminate 'burn-in' effects. Each 10,000$^{th}$ 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 20 and Figure 21). 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 22). Correlations among key parameters were generally low, with the exception of natural mortality ($M$) and the average unexploited equilibrium recruitment level ($R_0$), as well as recent recruitment, depletion in 2014, and predicted catch in 2014 (Figure 23).

We show the base model fit to the acoustic survey biomass index in Figure 24. The 2001 data point continues to be well below any model predictions that 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, along with El Niño conditions and age structure. The 2009 index is much higher than any predicted value observed during model evaluation. The uncertainty of this point is also higher than in other years, due to the presence of large numbers of Humboldt squid during the survey. The MLE slightly underfits the 2013 survey index.

Fits to the age-composition data show close correspondence to the dominant cohorts observed in the data and also identification of small cohorts, where the data give a consistent signal (Figure 25, Figure 26 and Figure 27). Because of the time-varying survey selectivity, the fit to commercial age-composition data is particularly good. Residual patterns to the fishery and survey age data do not show patterns that would indicate systematic bias in model predictions (Figure 28).

Posterior distributions for both steepness and natural mortality are strongly influenced by priors (Figure 29). The posterior for steepness was not updated much by the data, as expected given the low-sensitivity to steepness values found in previous hake assessments. The natural mortality parameter, on the other hand, is shifted to the right of the prior distribution and the prior may be constraining the posterior distribution. All other parameters showed substantial updating from non-informative priors to stationary posterior distributions.

Fishery selectivity varies mostly in recent years (Figure 30). Fishery selectivity in 2010 shows a high selectivity on age-4 fish, corresponding to the 2006 year class, and in 2011 age-3 selectivity is increased, corresponding to the 2008 year class. Even though the survey selectivity is time invariant, the posterior shows a broad band of uncertainty between ages 2 and 5 (Figure 32). The commercial selectivity is likewise very uncertain (Figure 31 and Figure 32), but in spite of this uncertainty, changes in year to year patterns are still evident, particularly for age 3 and 4 fish though these patterns might also reflect time-varying mortality processes.

**Stock biomass**

The base stock assessment model indicates that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium (Figure 33 and Figure 34). The model predicts that it was below the unfished equilibrium in the 1960s and 1970s (due to low recruitment). The stock is estimated to have increased rapidly after two or more large recruitments in the early 1980s to near unfished equilibrium, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007 entering the fishery to replace catches being removed during this period. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000's, reaching a time-series low of 0.479 million mt in 2009. The assessment model estimates that since 2009, spawning biomass has been increasing on the strength of a large 2010 cohort and above-average 2008 and 2009 year classes. The 2014 median posterior spawning biomass is estimated to be 81.79% of the unfished equilibrium level ($B_0$) with 95% posterior credibility intervals ranging from 41.55% to 168.79% (Table 11 and Table 12). The median estimate of 2014 female spawning biomass is 1.722 million mt (Table 11).

**Recruitment**

Pacific Hake appear to have low average recruitment with occasional large year-classes (Figure 35). Very large year classes in 1980, 1984, and 1999 supported much of the commercial catch from the 1980's to the mid 2000's. 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 35). The current assessment estimates a strong 2010 year class comprising 67% of the coast-wide 2013 commercial catch. Due to the small number of years it has been observed, its size is still more uncertain than older cohorts, although it is highly likely one of the five largest recruitments seen in the last three decades. The model currently estimates a lower-than average 2011 year class, and a slightly lower than average 2012 year class, although the only observations of the 2012 year class are the catch of age-1 fish in the fishery data. The sizes of the 2013 and 2014 year classes are unknown and are characterized by the underlying stock recruitment relationship assumptions (Figure 36) because they have not yet been observed in survey or commercial age-composition data. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable (JTC 2013)

The estimated recruitments with uncertainty for each predicted point and the overall stock recruit relationship are provided in Figure 36. Extremely large variability about the expectation and about the joint uncertainty of individual recruitment and spawning biomass pairs are clearly evident in this plot. High and low recruitment has been produced throughout the range of observed spawning biomass (Figure 36).

The standard deviation of the time series of median recruitment estimates for the years 1971–2010, which are well informed by the age compositions, is 1.50. The standard deviation of the MCMC samples of all recruitment deviations for the years 1946–2013, combining both the variability between years and the uncertainty within each year, is 1.51. These values are roughly consistent with the base model value of $\sigma_r$ = 1.4 and suggest that, if anything, $\sigma_r$ could be even higher.

**Exploitation status**

Median fishing intensity on the stock is estimated to have been consistently below the $F_{40\%}$ target until recently. The base model estimates of fishing intensity indicate that the SPR target was exceeded with a greater than 50% chance in 2008 and 2011 (Figure 38). It should be noted, however, that the harvest in those years did not exceed the catch limits that were specified, based on the best available science and harvest control rules in place at the time. The exploitation fraction does not necessarily correspond to fishing intensity because fishing intensity accounts for the age-structure. For example, fishing intensity remained nearly constant from 2010 to 2011 but the exploitation fraction declined in these years because of the large estimated proportion of 1-year-old fish in the latter year. Fishing intensity for 2013 appears to have a 98.4% probability of being below the management target.

**Management performance**
Recent catches have generally been below coast-wide targets. Total catches last exceeded the coast-wide catch target in 2002 when landings were 112% of the catch target. Over the last ten years, the average coast-wide utilization rate has been 86%. In the last five years (2009–2013), mean utilization rates between have differed between the United States and Canada at 85% and 76%, respectively. The underutilization in the United States is mostly a result of the unrealized catch in the tribal apportionment, while reports from stakeholders in Canada suggest that the Canadian fishery has changed in recent years and it is taking larger boats with greater horsepower to maintain catches.

Exploitation history in terms of joint biomass and *F*-target reference points shows that before 2007, median fishing intensity was below target and female spawning biomass was near or above target (Figure 33 and Figure 38 and Figure 40). Between 2007 and 2011, however, fishing intensity ranged from 89 to 106% and depletion between 0.23 and 0.32 (Table 11). Biomass has risen recently with the 2008 and 2010 recruitments (Figure 33) and correspondingly, fishing intensity has fallen below targets, and depletion above targets for 2012 and 2013 (Figure 40). While uncertainty in the 2013 fishing intensity estimates and depletion is large, the model predicts a 1% joint probability of being both above the target fishing intensity and below 40% depletion.

### 3.4.3 Model uncertainty
The base 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 ($M$), the selectivities, and recruitment deviations. The uncertainty portrayed by the posterior distribution is a better representation of the uncertainty when compared to maximum likelihood estimates (MLE) because it allows for asymmetry (see Stewart et al 2012 for further discussion and examples). Table 14 compares the median of the posterior to the MLE, showing that median biomass, recruitment, and depletion estimates from the posterior distribution are all larger in value. Figure 41 shows the MLE and Bayesian estimates as well as the skewed uncertainty in the posterior distributions for spawning biomass and recruitment

Uncertainty measures in the base model underestimate the total uncertainty in the current stock status and projections because they do not account for alternative structural models for hake population dynamics and fishery processes (e.g., recruitment, selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distributions. To address structural uncertainties, the JTC investigated a broad range of alternative models, and we present a subset of key sensitivity analyses in the main document. The posterior distribution of derived parameters from the base model encompasses the median estimates of most sensitivity models. We use the closed-loop simulation component of the Management Strategy Evaluation (MSE, see Appendix A) to illustrate the long-term average management performance of alternative assessment models.

The Pacific Hake stock displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid biomass changes. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts resulting in time-varying selectivity, and little data to inform incoming recruitment until the cohort is age 2 or greater, will, in most circumstances, continue to result in highly uncertain estimates of current stock status and even less-certain projections of the stock trajectory. Within-model uncertainty in this assessment's spawning stock biomass is largely a function of the potentially large 2010 year class now having been observed for the second year in the acoustic survey and for the third year in the fishery data.

At the JMC's direction, we continued to develop the Management Strategy Evaluation (MSE) approach to explore the expected performance of alternative harvest policies involving annual or biennial surveys using more challenging operating models (Appendix A). Of the wide range of recommendations made by the 2013 SRG, the MSE steering group and the 2014 JTC meeting, we focused on: the effects of operating models with time-varying selectivity; increasing the frequency of a survey to annual from biennial, management procedures (MPs) using assessment models with and without time-varying selectivity, and the default harvest control rule with floors and ceilings on TAC recommendations. Addressing last year's SRG recommendation of 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 the dynamics of the Pacific Hake fishery remains germane.

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

### 3.4.4 Reference points

We report estimates of the 2014 base reference points with posterior credibility intervals in Table 15. The estimates differ very little from the 2013 assessment: the maximum difference between the 2013 and 2014 median reference point estimates is 3.66%, for the $B_{\mathrm{MSY}}$ estimate.

### 3.4.5 Model projections

The median catch for 2014 based on the default harvest policy ($F_{40\%}$ – 40:10) is 872,424 mt, but has a wide range of uncertainty (Figure 42). The 95% posterior credibility interval ranges from 393,369 mt to 2,226,633 mt.

A decision table showing predicted population status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base model. The decision table (split into Table 16 and Table 17) is organized such that the projected outcomes for each potential catch level (rows) can be evaluated across the quantiles (columns) of the posterior distribution. The first table (Table 16) shows projected depletion outcomes, and the second (Table 17) 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.

Management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP) in 2012 are presented for projections to 2015 and 2016 (Table 18 and Table 19). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values. Figure 43 shows the predicted depletion trajectory through 2016 for several of these management actions.

At all catch levels above 190,000 mt, the spawning biomass is predicted to decline with greater than 50% probability (Figure 44). The model predicts high biomass levels and the predicted probability of dropping below 10% is effectively zero and the maximum probability of dropping below B40% is 13% for all catches explored. It should be noted that in addition to the natural morality rate overtaking the growth rate for the 2010 year class, the model estimated below average recruitment for the 2011 and 2012 cohorts entering the 2014 spawning biomass, which also contributes to the relatively low catch (190,000 mt) that will result in a reduction in spawning biomass from 2014 to 2015. Probabilities for these metrics given specific catches in 2015 are shown in Table 19 and Figure 45.

Until cohorts are five or six years old, the model's prediction of cohort strength is uncertain. The size of the 2010 year class is certainly above average, but is a major source of uncertainty in future projections of spawning biomass and catch. Therefore, following the 2013 assessment of Pacific Hake, additional forecast decision tables were created given three states of nature about the size of the 2010 year class: low 2010 recruitment, medium 2010 recruitment, and high 2010 recruitment. Each state of nature is defined to have a probability of 10%, 80%, and 10%, respectively.

Table 20 and Table 21 show 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 slightly above target with a 2014 catch of 375,000 mt, and a projected biomass of 40% in 2016. Median depletion is predicted to decline in 2016 across all states of nature for all catches above 190,000 mt.

Table 22 and Table 23 show the probability metrics in 2015 and in 2016 for each state of nature. Across all states of nature there are approximately equal probabilities that the spawning biomass in 2015 will be less than or greater than the spawning biomass in 2014 with a catch near 190,000 mt. For the low state of nature, there is a less than 50% probability that the 2015 spawning biomass will be below 40% of unfished equilibrium spawning biomass with a catch near 500,000 mt, but a constant catch of 375,000 mt in 2014 and 2015 results in a 50% probability that the spawning biomass in 2016 is less than 50% of unfished equilibrium spawning biomass.

An additional source of uncertainty was the 2013 estimate of biomass from the acoustic survey. Due to the presence of hake schools extending far offshore, the survey biomass estimate included an extrapolated area that contained at least 25% of the biomass. No observations occurred in this extrapolated area, thus there was a concern that the biomass was overestimated. A sensitivity run using a 2013 acoustic survey biomass estimate without the extrapolated area resulted in a lower 2014 spawning biomass and a 12% reduction in the predicted 2014 default harvest rate catch.

## 3.5 Sensitivity analyses

Sensitivity analyses were conducted to investigate structural uncertainty of the base model by investigating how changes to the model affected the estimated values and derived quantities. The sensitivities include the following:

1. Update the maturity ogive with recently collected data from 2009, 2012 and 2013.
2. Remove the 2012 survey data and index from the assessment to look at the effects of the annual surveys since 2011.
3. Increase the standard deviation on the time-varying selectivity parameters.
4. Estimate time-varying selectivity from 1975 to present.
5. Estimate fishery and survey selectivity to age 10.
6. Use a 2013 acoustic survey biomass estimate without extrapolation off of CA.

An update of the maturity ogive (Figure 16) results in very similar parameter estimates and derived quantities when compared to the base model (Figure 46 and Table 24). The base model in this assessment does not show large changes with the new maturity-at-age ogive, but because the new ogive estimates a larger proportion of young fish being mature, the model is most sensitive when large year classes are moving through the young ages (as seen in recent estimates of depletion in Figure 46).

Removal of the 2012 survey data and index from the assessment results in little difference in most parameter estimates from the model (Table 24). The depletion time series is slightly affected in the

1980's, but the largest changes are in the recruitment estimates for the 2008 and 2010 cohorts, especially with regard to uncertainty (Figure 46). This increase in uncertainty is expected because a critical year with observations of the 2008 and 2010 year classes when they were young has been removed. The estimates of the 2008 and 2010 year classes increased when removing the 2012 survey, which was a result of the fitting the 2013 index better. The closer fit to the 2013 index resulted in a larger increase in predicted biomass from the 2011 index to the2013 index which produced a higher value for depletion (Table 24).

Increasing the standard deviation on the time-varying selectivity parameters to 0.2 has a small effect on the depletion trajectory, with only a slight departure from the base in the early years and a more significant departure in recent years (Figure 47). This recent reduction in biomass is a result of a reduced estimate of the 2010 year class, due to the model interpreting the large proportion of the 2010 year class observed in the fishery data as changes in selectivity (Figure 47). With more observations of this year class, especially from the survey, the size of it should become more certain.

Estimating time-varying selectivity from 1975 to 2013 instead of 1991 to 2013 as in the base model, had little effect on the results. The estimates of selectivity were nearly identical to the base model for the 1991-2013 period, and from 1975-1990 the estimated selectivities showed little change from one year to the next (Figure 48.

Bayesian posterior distributions were estimated to compare additional sensitivities related to selectivity. These are 1) estimating non-parametric selectivity for both the fishery and acoustic survey to age-10 with selectivity deviations on each estimated age for the fishery, and 2) forcing fishery selectivity to be time-invariant and mimicking the base model from 2013 (JTC 2013). A comparison of the estimated selectivity at age and year is shown in Figure 49. When extending the estimates of selectivity-at-age to age 10, the acoustic survey begins to show large variability and unrealistic patterns past age 6 and the medians for fishery selectivity nearly linearly increase to age 11 (Figure 50). The stock is more depleted in the early years of the assessment, and then similar until recently when the stock is estimated to be less depleted, but wth greater uncertainty (Figure 51). This is mainly due to estimates of recruitment with larger estimates in recent years (Figure 51 and Table 25). Interestingly, the uncertainty in historical recruitment estimates is less prior to about 1980, and greater in recent years. This suggests that the historical age-structure is greatly influencing the estimates of selectivity-at-older ages.

Mimicking the base model from the 2013 assessment and not estimating time-varying selectivity resulted in little difference to the estimates of depletion except in recent years, which is a result of larger estimates for 2008 and 2010 recruitment (Table 25). Uncertainty was also slightly greater with time-invariant selectivity.

The 2013 acoustic survey biomass estimate of 2.42 million mt was comprised of at least 650,000 mt of extrapolated biomass in areas that were not surveyed, mostly off of northern California and southern Oregon. Therefore, a sensitivity run was done with a 2013 estimate of 1.8 million mt to investigate the effect of this value. The age compositions were not changed for this sensitivity, although it is likely that they would be affected. The model predicted a more depleted stock in 2015 with the lower 2013 survey estimate, resulting in a 12% reduction in the default harvest catch for 2014.

These sensitivities reflect current investigations into the Pacific Hake stock. The removal of the 2012 acoustic survey index and age composition data suggests that the estimation of recruitment of recent year-classes is more uncertain with a biennial survey than it would be with an annual survey. The relaxation of the standard deviation on the selectivity parameters has a pronounced effect on those parameters, but not on the overall results. Research into alternative parameterizations for time-varying selectivity would be useful to provide a more flexible framework, and investigating fisheries cohort targeting may lead to a better understanding of time-varying selectivity parameterization for future models.

## 3.6 Retrospective analyses

Retrospective analyses were performed by iteratively removing the terminal years' data and estimating the parameters under the assumptions of the base model. Overall, there is little retrospective change to the depletion trajectory up to the early 2000's, and most retrospective change occurs in the final years of the retrospective model (Figure 53). A consistent retrospective pattern is not apparent over the last 5 years. Over the last 3 years, the stock assessment has retrospectively underestimated the status, but removing 3 or more years of data resulted in the assessment over-estimating the status in the terminal year, which is likely related to the high 2009 acoustic survey estimate.

This pattern of high estimated uncertainty in the terminal year and variable retrospective estimates suggests that this model is unable to accurately estimate recruitment until the cohort has been observed for several years (Figure 53). For example, two cohorts that are currently estimated to be above average (2008 and 2010) show this pattern in Table 26. Without data informing the strength of these cohorts, the median value is near 1, and then the 'Retro -3 years' case in Table 26 shows a 2008 recruitment of 11.36 billion, which is subsequently reduced to 3.88, 4.75, and 5.15 billion with data from additional years. In contrast, the estimated size of the 2010 cohort consistently increases with the addition of new data and does not appear to be overestimated when it was age 2. The retrospective estimates of the 2008 year class are likely influenced by a unique situation of a high 2009 acoustic survey estimate and the presence of Humboldt Squid in 2009, which may have resulted in a high mortality on young hake.

Figure 54 shows the retrospective patterns of estimated recruitment deviations for various cohorts. The magnitude of the deviation is not well estimated until several years of catch-at-age data have been collected, incorporated into the model, and the cohort is older (Table 27). There is no particular pattern across cohorts, though. For example, the 1999, 2002, 2009 and 2010 cohorts monotonically increase in absolute magnitude for many years. Conversely, the 2000, 2001, 2003, 2005, 2006, and 2008 cohorts are estimated at a higher magnitude when they are young compared to when they are older, although there is no particular age at which there seems to be a bias. The standard deviation of the estimated deviations at a particular age across the cohorts (Table 27) suggests that the estimates begin to stabilize when the cohort is approximately 4 years old. This illustrates that multiple observations of each cohort are needed in order to more accurately determine their recruitment strength and/or that mean recruitment dynamics currently modelled in the stock assessment do not reflect realized recruitment very well.

Estimating time-varying selectivity for the fishery is new for the base model in this assessment, and that decision was partly based on the retrospective pattern of estimated recruitment deviations. Figure 55 and Table 27 show the retrospective estimates of recruitment deviations. The patterns are very similar for both time-varying and time-invariant models, but the introduction of time-varying selectivity reduced the occurrence of large absolute deviations at age 2 for many of the cohorts (Table 27). Adding more flexibility to time-varying selectivity by increasing $\phi$ to 0.20 reduced the magnitude of the deviations at age 2 even more. With few observations of the cohort when it is young, the model has little information to differentiate a change in selectivity that resulted in an unusual observation of proportions-at-age or if it is indeed a strong cohort. This may actually increase the bias of the model, both positively and negatively. It reduces the risk when incoming cohorts are strong, but may be overly optimistic when incoming cohorts are weak. The inclusion of time-varying selectivity was investigated further in the MSE (Appendix A) and showed favorable results.

A comparison of the actual assessment models used in each year since 1991 is shown in Figure 56. There has been a large difference in the models submitted each year, which can clearly be seen by looking at the spawning biomass trajectories. The variability between models, especially early on in the time series, is larger than the uncertainty (95% C.I.) reported in any single model in recent years. One important avenue which was investigated between 2004 and 2007 was the inclusion of several different, but fixed, survey catchability (q) values; and in the following years 2008 to present, it was allowed to be freely estimated by the model. In all the years prior to 2004, the survey catchability was fixed at 1.0. The fixing of survey catchability had the effect of driving the estimate of initial biomass upward, which in turn scaled the entire biomass trajectory up, leading to higher estimates of depletion than what we see today. The 2014 estimates of spawning biomass appear consistent with recent years, although the model structure has remained consistent, and the uncertainty intervals associated with them bracket the majority of the historical estimates.

# 4 Research and data needs

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

1. Examine statistical methods to parameterize time-varying fishery selectivity in assessment and forecasting.

2. 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.

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. Finalize the analysis of recently collected maturity samples and explore ways to include new maturity estimates 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 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.

7. Continue to explore process-based operating and assessment models that may be able to capture more realistic life-history variability (changes in size at age, M, fecundity at size etc.), as well as future fishery selectivity patterns.

8. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods.

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

10. Evaluate the quantity and quality of historical biological data (prior to 1988 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use as age-composition and weight-at-age data, and/or any historical indications of abundance fluctuations.

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

12. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others.

13. Coordinate our MSE research with other scientists in the region engaging in similar research.

14. Examine structured variation in key life-history quantities (i.e., length at age).

15. Examine alternative ways to model and forecast recruitment.

16. Investigate the utility of additional data sources (bottom trawl surveys, length data, etc.) for use in assessment and simulation models.

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# 7 Tables

**Table 1: Annual catches of Pacific Hake (1000s mt) in U.S. and Canadian waters by sector, 1966-2013. 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 | 137,000 | 0 | 0 | 0 | 137,000 | 700 | 0 | 0 | 700 | 137,700 |
| 1967 | 168,700 | 0 | 0 | 8,960 | 177,660 | 36,710 | 0 | 0 | 36,710 | 214,370 |
| 1968 | 60,660 | 0 | 0 | 160 | 60,820 | 61,360 | 0 | 0 | 61,360 | 122,180 |
| 1969 | 86,190 | 0 | 0 | 90 | 86,280 | 93,850 | 0 | 0 | 93,850 | 180,130 |
| 1970 | 159,510 | 0 | 0 | 70 | 159,580 | 75,010 | 0 | 0 | 75,010 | 234,590 |
| 1971 | 126,490 | 0 | 0 | 1,430 | 127,920 | 26,700 | 0 | 0 | 26,700 | 154,620 |
| 1972 | 74,090 | 0 | 0 | 40 | 74,130 | 43,410 | 0 | 0 | 43,410 | 117,540 |
| 1973 | 147,440 | 0 | 0 | 70 | 147,510 | 15,130 | 0 | 0 | 15,130 | 162,640 |
| 1974 | 194,110 | 0 | 0 | 0 | 194,110 | 17,150 | 0 | 0 | 17,150 | 211,260 |
| 1975 | 205,650 | 0 | 0 | 0 | 205,650 | 15,700 | 0 | 0 | 15,700 | 221,350 |
| 1976 | 231,330 | 0 | 0 | 220 | 231,550 | 5,970 | 0 | 0 | 5,970 | 237,520 |
| 1977 | 127,010 | 0 | 0 | 490 | 127,500 | 5,190 | 0 | 0 | 5,190 | 132,690 |
| 1978 | 96,827 | 860 | 0 | 690 | 98,377 | 3,450 | 1,810 | 0 | 5,260 | 103,637 |
| 1979 | 114,910 | 8,830 | 0 | 940 | 124,680 | 7,900 | 4,230 | 300 | 12,430 | 137,110 |
| 1980 | 44,023 | 27,537 | 0 | 790 | 72,350 | 5,270 | 12,210 | 100 | 17,580 | 89,930 |
| 1981 | 70,365 | 43,557 | 0 | 838 | 114,760 | 3,920 | 17,160 | 3,280 | 24,360 | 139,120 |
| 1982 | 7,089 | 67,465 | 0 | 1,027 | 75,581 | 12,480 | 19,680 | 0 | 32,160 | 107,741 |
| 1983 | 0 | 72,100 | 0 | 1,051 | 73,151 | 13,120 | 27,660 | 0 | 40,780 | 113,931 |
| 1984 | 14,772 | 78,889 | 0 | 2,721 | 96,382 | 13,200 | 28,910 | 0 | 42,110 | 138,492 |
| 1985 | 49,853 | 31,692 | 0 | 3,894 | 85,439 | 10,530 | 13,240 | 1,190 | 24,960 | 110,399 |
| 1986 | 69,861 | 81,640 | 0 | 3,465 | 154,966 | 23,740 | 30,140 | 1,770 | 55,650 | 210,616 |
| 1987 | 49,656 | 105,997 | 0 | 4,795 | 160,448 | 21,450 | 48,080 | 4,170 | 73,700 | 234,148 |
| 1988 | 18,041 | 135,781 | 0 | 6,867 | 160,689 | 38,080 | 49,240 | 830 | 88,150 | 248,839 |
| 1989 | 0 | 195,636 | 0 | 7,414 | 203,050 | 29,750 | 62,718 | 2,562 | 95,030 | 298,080 |
| 1990 | 0 | 170,972 | 4,537 | 9,632 | 185,141 | 3,810 | 68,314 | 4,021 | 76,145 | 261,286 |
| 1991 | 0 | 0 | 205,819 | 23,970 | 229,789 | 5,610 | 68,133 | 16,174 | 89,917 | 319,706 |
| 1992 | 0 | 0 | 154,702 | 56,127 | 210,829 | 0 | 68,779 | 20,043 | 88,822 | 299,651 |
| 1993 | 0 | 0 | 98,024 | 42,108 | 140,132 | 0 | 46,422 | 12,351 | 58,773 | 198,905 |
| 1994 | 0 | 0 | 179,861 | 73,616 | 253,477 | 0 | 85,162 | 23,775 | 108,937 | 362,414 |
| 1995 | 0 | 0 | 102,162 | 74,962 | 177,124 | 0 | 26,191 | 46,180 | 72,371 | 249,495 |
| 1996 | 0 | 0 | 128,031 | 85,128 | 213,159 | 0 | 66,779 | 26,363 | 93,142 | 306,301 |
| 1997 | 0 | 0 | 145,960 | 87,416 | 233,376 | 0 | 42,565 | 49,227 | 91,792 | 325,168 |
| 1998 | 0 | 0 | 145,063 | 87,856 | 232,919 | 0 | 39,728 | 48,074 | 87,802 | 320,721 |
| 1999 | 0 | 0 | 141,095 | 83,470 | 224,565 | 0 | 17,201 | 70,156 | 87,357 | 311,922 |
| 2000 | 0 | 0 | 120,915 | 85,854 | 206,769 | 0 | 15,059 | 6,382 | 21,441 | 228,210 |
| 2001 | 0 | 0 | 100,529 | 73,412 | 173,941 | 0 | 21,650 | 31,938 | 53,588 | 227,529 |
| 2002 | 0 | 0 | 84,746 | 45,708 | 130,454 | 0 | 0 | 50,239 | 50,239 | 180,693 |
| 2003 | 0 | 0 | 86,610 | 55,335 | 141,945 | 0 | 0 | 63,230 | 63,230 | 205,175 |
| 2004 | 0 | 0 | 120,737 | 96,504 | 217,241 | 0 | 58,892 | 66,191 | 125,083 | 342,324 |
| 2005 | 0 | 0 | 151,068 | 109,052 | 260,120 | 0 | 15,695 | 87,342 | 103,037 | 363,157 |
| 2006 | 0 | 0 | 139,790 | 127,165 | 266,955 | 0 | 14,319 | 80,486 | 94,805 | 361,760 |
| 2007 | 0 | 0 | 126,240 | 91,441 | 217,681 | 0 | 6,780 | 66,667 | 73,447 | 291,128 |
| 2008 | 0 | 0 | 180,635 | 67,760 | 248,395 | 0 | 3,592 | 70,157 | 73,749 | 322,144 |
| 2009 | 0 | 0 | 72,102 | 49,223 | 121,325 | 0 | 0 | 55,885 | 55,885 | 177,210 |
| 2010 | 0 | 0 | 106,306 | 63,795 | 170,101 | 0 | 8,081 | 48,012 | 56,093 | 226,194 |
| 2011 | 0 | 0 | 128,072 | 102,147 | 230,219 | 0 | 9,717 | 45,913 | 55,630 | 285,849 |
| 2012 | 0 | 0 | 93,776 | 65,797 | 159,573 | 0 | 0 | 46,776 | 46,776 | 206,349 |
| 2013 | 0 | 0 | 130,396 | 99,017 | 229,413 | 0 | 0 | 54,096 | 54,096 | 283,509 |
| Mean | | | | | 167,171 | | | | 56,067 | 223,238 |

**Table 2: Recent trend in Pacific Hake landings and management.**

| Year | Total Landings (mt) | Coast-wide (US+Canada) catch target (mt) | Proportion of catch target removed |
|---|---|---|---|
| 2004 | 342,323 | 501,073 | 68.3% |
| 2005 | 363,157 | 364,197 | 99.7% |
| 2006 | 361,760 | 364,842 | 99.2% |
| 2007 | 291,129 | 328,358 | 88.7% |
| 2008 | 322,144 | 364,842 | 88.3% |
| 2009 | 177,209 | 184,000 | 96.3% |
| 2010 | 226,195 | 262,500 | 86.2% |
| 2011 | 285,850 | 393,751 | 72.6% |
| 2012 | 206,350 | 251,809 | 82.0% |
| 2013 | 283,510 | 365,112 | 77.7% |

**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 (hauls) | Joint-venture (hauls) | At-sea (hauls) | Shore-based (trips) | Foreign | Joint-venture (hauls) | Domestic (hauls) |
| 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 | — | — | 631 | 76 | — | — | 144 |
| 2013 | — | — | 665 | 96 | — | — | 110 |

**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 |
| 2013 | 13 June | 11 Sept | Bell Shimada, Ricker | 2.423 | 0.0433 | 68 |

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

**Table 5: Number of Pacific Hake ovaries collected for histological analysis. The numbers in italics for the 2013 trawl survey, the 2013 acoustics survey, and the 2013 ASHOP Fall samples were not available for analysis in this assessment.**

| Length bin (cm) | Trawl Survey 2009 | Trawl Survey 2012 | *Trawl Survey 2013* | Acoustics Survey 2012 | *Acoustics Survey 2013* | ASHOP 2013 - Spring | *ASHOP 2013 - Fall* | Total |
|---|---|---|---|---|---|---|---|---|
| <20 | 12 | 0 | *0* | 0 | *0* | 0 | *0* | 12 |
| 20-21 | 6 | 0 | *0* | 0 | *0* | 0 | *0* | 6 |
| 22-23 | 17 | 0 | *2* | 0 | *0* | 0 | *0* | 19 |
| 24-25 | 16 | 2 | *1* | 3 | *4* | 0 | *0* | 26 |
| 26-27 | 8 | 2 | *1* | 7 | *8* | 0 | *0* | 26 |
| 28-29 | 4 | 2 | *3* | 11 | *10* | 0 | *0* | 30 |
| 30-31 | 5 | 2 | *1* | 21 | *1* | 0 | *0* | 30 |
| 32-33 | 13 | 4 | *3* | 12 | *5* | 0 | *0* | 37 |
| 34-35 | 4 | 1 | *3* | 24 | *15* | 5 | *0* | 52 |
| 36-37 | 9 | 4 | *4* | 14 | *36* | 15 | *5* | 87 |
| 38-39 | 19 | 3 | *4* | 8 | *15* | 16 | *34* | 99 |
| 40-41 | 17 | 3 | *5* | 14 | *51* | 16 | *41* | 147 |
| 42-43 | 17 | 1 | *3* | 9 | *14* | 12 | *8* | 64 |
| 44-45 | 13 | 3 | *1* | 11 | *14* | 14 | *2* | 58 |
| 46-47 | 18 | 5 | *8* | 8 | *23* | 7 | *1* | 70 |
| 48-49 | 20 | 5 | *2* | 6 | *10* | 6 | *2* | 51 |
| 50-51 | 15 | 4 | *4* | 9 | *17* | 7 | *0* | 56 |
| 52-53 | 5 | 7 | *5* | 10 | *13* | 3 | *0* | 43 |
| 54-55 | 9 | 2 | *3* | 9 | *6* | 4 | *0* | 33 |
| 56-57 | 5 | 7 | *3* | 6 | *7* | 1 | *0* | 29 |
| 58-59 | 5 | 2 | *2* | 7 | *2* | 0 | *0* | 18 |
| 60-61 | 7 | 3 | *1* | 4 | *0* | 0 | *0* | 15 |
| >61 | 19 | 9 | *11* | 6 | *3* | 0 | *0* | 48 |
| **Total** | **263** | **71** | ***70*** | **199** | ***254*** | **106** | ***93*** | **1056** |

**Table 6: Number of Pacific Hake ovary samples with maturity assigned.**

| Length (cm) | Trawl 2009 | Trawl 2012 | Acoustic 2012 | ASHOP Spring 2013 | Total |
|---|---|---|---|---|---|
| <20 | 12 | 0 | 0 | 0 | **12** |
| 20–21 | 6 | 0 | 0 | 0 | **6** |
| 21–23 | 17 | 0 | 0 | 0 | **17** |
| 23–25 | 16 | 2 | 3 | 0 | **21** |
| 25–27 | 8 | 2 | 7 | 0 | **17** |
| 27–29 | 4 | 2 | 11 | 0 | **17** |
| 29–31 | 5 | 2 | 21 | 0 | **28** |
| 31–33 | 11 | 4 | 12 | 0 | **27** |
| 33–35 | 4 | 1 | 24 | 5 | **34** |
| 35–37 | 7 | 4 | 14 | 15 | **40** |
| 37–39 | 19 | 3 | 8 | 16 | **46** |
| 39–41 | 16 | 3 | 14 | 15 | **48** |
| 41–43 | 17 | 1 | 9 | 12 | **39** |
| 43–45 | 13 | 3 | 11 | 14 | **41** |
| 45–47 | 18 | 5 | 8 | 7 | **38** |
| 47–49 | 20 | 5 | 6 | 6 | **37** |
| 49–51 | 15 | 4 | 9 | 7 | **35** |
| 51–53 | 5 | 7 | 10 | 3 | **25** |
| 53–55 | 9 | 2 | 9 | 3 | **23** |
| 55–57 | 5 | 7 | 6 | 1 | **19** |
| 57–59 | 5 | 2 | 7 | 0 | **14** |
| 59–61 | 7 | 3 | 4 | 0 | **14** |
| >61 | 19 | 9 | 6 | 0 | **34** |
| **Total** | **258** | **71** | **199** | **104** | **632** |

**Table 7: Estimated proportion mature-at-age from Dorn & Saunders (1997), a logistic model with an asymptote fixed at one, and a logistic model with an asymptote estimated (in the generalized linear model with length and age as covariates).**

| Age | Dorn1997 | Asymptote = 1 | Asymptote estimated |
|---|---|---|---|
| 1 | 0 | 0.1864 | 0.0553 |
| 2 | 0.18 | 0.3702 | 0.2752 |
| 3 | 0.66 | 0.7061 | 0.7245 |
| 4 | 0.89 | 0.7594 | 0.8730 |
| 5 | 0.97 | 0.7945 | 0.9130 |
| 6 | 0.99 | 0.9033 | 0.9230 |
| 7 | 1 | 0.8962 | 0.9244 |
| 8 | 1 | 0.9004 | 0.9247 |
| 9 | 1 | 0.9346 | 0.9248 |
| 10 | 1 | 0.9077 | 0.9248 |
| 11 | 1 | 0.9376 | 0.9248 |
| 12 | 1 | 0.9357 | 0.9248 |
| 13 | 1 | 0.9115 | 0.9248 |
| 14 | 1 | 0.9046 | 0.9248 |
| 15 | 1 | 0.8782 | 0.9248 |

**Table 8: Summary of estimated model parameters and priors in the base model. The Beta prior is parameterized with a mean and standard deviation. The lognormal distribution (LN) is parameterized with the median and standard deviation in log space.**

| Parameter | Number estimated | Bounds (low, high) | Prior (Mean, SD) (single value = fixed) |
|---|---|---|---|
| | Stock dynamics | | |
| Ln($R_0$) | 1 | (13,17) | uniform |
| Steepness ($h$) | 1 | (0.2,1.0) | ~Beta(0.777,0.113) |
| Recruitment variability ($\sigma_R$) | - | NA | 1.40 |
| Ln(Rec. deviations): 1946-2013 | 68 | (-6, 6) | ~LN(0, $\sigma_r$) |
| 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 |
| Selectivity deviations (1991-2013, ages 2-6) | 115 | NA | Normal(0,0.03) |
| Total: 14 + 67 recruitment deviations+115 selectivity deviations = 197 estimated parameters. | | | |
| See Appendix A for all parameter estimates. | | | |

**Table 9 Summary of SRG 2013 research recommendations and responses**

| Broad Recommendation | Response |
|---|---|
| **Acoustic Research**<br>- Record more information on the decision process used for assigning locations for trawl sites.<br>Age-1 index development<br>Inter-vessel calibrations<br>Investigate hake moving north as the survey is progressing from south to north, thus causing a Doppler effect | Deferred due to 2013 survey operations<br><br>Deferred due to 2013 survey operations<br>Deferred due to 2013 survey operations<br>Deferred due to 2013 survey operations |
| Life-history data improvements, especially maturity | Maturity data analyzed, new ogive used in assessment sensitivity case |
| Assessment model configuration:<br>More constant selectivity at age<br>Declining natural mortality at age<br>Consider alternatives to lognormal survey error<br>Investigate recruitment correlations<br>Time-varying selectivity | <br>Deferred<br>Deferred<br>Deferred<br>Deferred<br>Examined using MSE, comparative retrospective analyses, and presented as base model |
| Provide a summary of annual fishery operations | To be included in the future |
| Continue MSE development with input of JMC, JTC, AP and SRG for guidance | MSE workplan discussed at May 2013 JMC meeting<br>MSE steering group formed<br>MSE steering group teleconference September 2013<br>Questions to guide objective setting posed and discussed January 2013 JTC meeting |

**Table 10: Maximum likelihood estimates (MLE) of important quantities from the models bridging the 2013 base model to the 2014 model with the same assumptions as the 2013 base model, including time-invariant selectivity.**

| MLE results | 2013 base model | 2013 fishery data only | 2013 survey data only | All 2013 data |
|---|---|---|---|---|
| B0 (thousand mt) | 1,924 | 1,960 | 1,924 | 1,961 |
| Spawning biomass 2013 (thousand mt) | 932 | 1,156 | 1,056 | 1,176 |
| Spawning biomass 2014 (thousand mt) | 1,313 | 1,650 | 1,508 | 1,675 |
| | | | | |
| Depletion 2012 | 48.4% | 59.0% | 54.9% | 60.0% |
| Depletion 2013 | 68.2% | 84.2% | 78.4% | 85.4% |
| Depletion 2014 | 72.1% | 94.7% | 88.5% | 95.9% |
| | | | | |
| Age-0 recruits 2008 (billions) | 4.77 | 5.16 | 4.79 | 5.18 |
| Age-0 recruits 2010 (billions) | 11.62 | 16.06 | 14.87 | 16.41 |

**Table 11: Time-series of median posterior population estimates from the base model.**

| Year | Female spawning biomass (millions mt) | Depletion | Age-0 recruits (billions) | (1-SPR) / (1-$SPR_{40\%}$) | Exploitation fraction |
|---|---|---|---|---|---|
| 1966 | 1.046 | 0.489 | 1.426 | 0.449 | 0.064 |
| 1967 | 0.967 | 0.455 | 3.470 | 0.643 | 0.107 |
| 1968 | 0.899 | 0.423 | 2.003 | 0.475 | 0.067 |
| 1969 | 0.962 | 0.456 | 0.813 | 0.616 | 0.096 |
| 1970 | 1.031 | 0.485 | 7.529 | 0.697 | 0.105 |
| 1971 | 1.023 | 0.479 | 0.742 | 0.524 | 0.069 |
| 1972 | 1.218 | 0.570 | 0.448 | 0.412 | 0.056 |
| 1973 | 1.388 | 0.651 | 4.280 | 0.452 | 0.050 |
| 1974 | 1.405 | 0.659 | 0.375 | 0.512 | 0.069 |
| 1975 | 1.405 | 0.658 | 1.207 | 0.453 | 0.065 |
| 1976 | 1.376 | 0.647 | 0.332 | 0.420 | 0.054 |
| 1977 | 1.295 | 0.614 | 4.995 | 0.299 | 0.038 |
| 1978 | 1.203 | 0.567 | 0.270 | 0.277 | 0.034 |
| 1979 | 1.241 | 0.582 | 0.963 | 0.330 | 0.047 |
| 1980 | 1.242 | 0.584 | 16.282 | 0.263 | 0.028 |
| 1981 | 1.215 | 0.569 | 0.301 | 0.388 | 0.051 |
| 1982 | 1.618 | 0.761 | 0.239 | 0.335 | 0.048 |
| 1983 | 2.013 | 0.948 | 0.410 | 0.275 | 0.024 |
| 1984 | 2.122 | 1.008 | 12.880 | 0.279 | 0.031 |
| 1985 | 2.020 | 0.958 | 0.207 | 0.231 | 0.027 |
| 1986 | 2.248 | 1.061 | 0.198 | 0.375 | 0.059 |
| 1987 | 2.367 | 1.123 | 5.444 | 0.405 | 0.045 |
| 1988 | 2.277 | 1.079 | 1.897 | 0.414 | 0.052 |
| 1989 | 2.190 | 1.039 | 0.182 | 0.532 | 0.081 |
| 1990 | 2.063 | 0.975 | 4.395 | 0.457 | 0.064 |
| 1991 | 1.876 | 0.887 | 0.531 | 0.563 | 0.084 |
| 1992 | 1.723 | 0.810 | 0.181 | 0.609 | 0.101 |
| 1993 | 1.550 | 0.731 | 3.305 | 0.546 | 0.076 |
| 1994 | 1.354 | 0.642 | 2.475 | 0.779 | 0.151 |
| 1995 | 1.136 | 0.536 | 1.265 | 0.693 | 0.129 |
| 1996 | 1.077 | 0.505 | 1.607 | 0.824 | 0.153 |
| 1997 | 0.977 | 0.458 | 1.295 | 0.873 | 0.161 |
| 1998 | 0.869 | 0.409 | 1.836 | 0.926 | 0.192 |
| 1999 | 0.752 | 0.354 | 11.262 | 0.990 | 0.219 |
| 2000 | 0.660 | 0.311 | 0.348 | 0.797 | 0.150 |
| 2001 | 0.961 | 0.453 | 0.880 | 0.754 | 0.135 |
| 2002 | 1.242 | 0.587 | 0.073 | 0.513 | 0.045 |
| 2003 | 1.362 | 0.643 | 1.409 | 0.510 | 0.062 |
| 2004 | 1.294 | 0.611 | 0.071 | 0.750 | 0.126 |
| 2005 | 1.090 | 0.517 | 2.370 | 0.805 | 0.182 |
| 2006 | 0.843 | 0.400 | 1.843 | 0.953 | 0.217 |
| 2007 | 0.656 | 0.311 | 0.091 | 0.986 | 0.259 |
| 2008 | 0.579 | 0.274 | 5.148 | 1.064 | 0.262 |
| 2009 | 0.479 | 0.228 | 2.010 | 0.893 | 0.162 |
| 2010 | 0.568 | 0.269 | 15.364 | 1.000 | 0.261 |
| 2011 | 0.669 | 0.317 | 0.372 | 1.014 | 0.205 |
| 2012 | 1.139 | 0.540 | 0.841 | 0.769 | 0.146 |
| 2013 | 1.566 | 0.745 | 1.048 | 0.694 | 0.072 |
| 2014 | 1.722 | 0.818 | 0.983 | NA | NA |

**Table 12: 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 model**

| Year | Female spawning Biomass (millions mt) | Depletion | Age-0 recruits (billions) | (1-SPR) / (1-$SPR_{target}$) | Exploitation fraction |
|---|---|---|---|---|---|
| 1966 | 0.591-1.931 | 0.280-0.872 | 0.101-8.870 | 0.245-0.694 | 0.034-0.119 |
| 1967 | 0.545-1.808 | 0.260-0.792 | 0.139-12.970 | 0.379-0.920 | 0.056-0.205 |
| 1968 | 0.477-1.711 | 0.239-0.748 | 0.122-8.867 | 0.262-0.746 | 0.034-0.129 |
| 1969 | 0.587-1.759 | 0.284-0.760 | 0.062-4.586 | 0.364-0.892 | 0.048-0.185 |
| 1970 | 0.630-1.877 | 0.302-0.826 | 3.708-18.880 | 0.417-0.957 | 0.056-0.189 |
| 1971 | 0.614-1.912 | 0.301-0.845 | 0.067-3.376 | 0.292-0.790 | 0.036-0.113 |
| 1972 | 0.756-2.364 | 0.357-1.035 | 0.049-1.995 | 0.209-0.643 | 0.029-0.091 |
| 1973 | 0.869-2.703 | 0.414-1.209 | 2.170-9.881 | 0.233-0.687 | 0.026-0.080 |
| 1974 | 0.860-2.718 | 0.416-1.217 | 0.044-1.595 | 0.267-0.760 | 0.036-0.111 |
| 1975 | 0.850-2.738 | 0.408-1.223 | 0.479-3.347 | 0.234-0.697 | 0.034-0.108 |
| 1976 | 0.823-2.689 | 0.394-1.192 | 0.042-1.490 | 0.212-0.656 | 0.028-0.092 |
| 1977 | 0.769-2.550 | 0.372-1.117 | 2.548-10.579 | 0.145-0.499 | 0.020-0.064 |
| 1978 | 0.711-2.334 | 0.347-1.015 | 0.034-1.360 | 0.137-0.472 | 0.018-0.058 |
| 1979 | 0.747-2.324 | 0.360-1.004 | 0.135-3.111 | 0.169-0.546 | 0.025-0.080 |
| 1980 | 0.759-2.279 | 0.368-0.992 | 9.556-29.538 | 0.133-0.442 | 0.015-0.047 |
| 1981 | 0.746-2.161 | 0.364-0.956 | 0.035-1.590 | 0.210-0.614 | 0.029-0.083 |
| 1982 | 1.056-2.757 | 0.502-1.193 | 0.035-1.119 | 0.176-0.536 | 0.027-0.078 |
| 1983 | 1.364-3.308 | 0.643-1.469 | 0.046-1.561 | 0.149-0.427 | 0.015-0.036 |
| 1984 | 1.474-3.409 | 0.692-1.493 | 8.230-21.364 | 0.160-0.433 | 0.019-0.044 |
| 1985 | 1.417-3.153 | 0.664-1.381 | 0.024-0.917 | 0.130-0.362 | 0.017-0.038 |
| 1986 | 1.635-3.348 | 0.765-1.473 | 0.027-0.867 | 0.229-0.541 | 0.038-0.083 |
| 1987 | 1.761-3.434 | 0.812-1.520 | 3.264-9.059 | 0.260-0.565 | 0.031-0.060 |
| 1988 | 1.720-3.210 | 0.791-1.436 | 0.779-3.850 | 0.269-0.561 | 0.037-0.069 |
| 1989 | 1.698-3.006 | 0.778-1.370 | 0.022-0.698 | 0.362-0.705 | 0.059-0.106 |
| 1990 | 1.619-2.794 | 0.736-1.271 | 2.909-6.945 | 0.312-0.615 | 0.047-0.082 |
| 1991 | 1.503-2.478 | 0.677-1.154 | 0.071-1.330 | 0.408-0.736 | 0.063-0.105 |
| 1992 | 1.391-2.251 | 0.627-1.051 | 0.029-0.619 | 0.441-0.780 | 0.077-0.125 |
| 1993 | 1.264-2.014 | 0.563-0.939 | 2.260-4.993 | 0.392-0.697 | 0.059-0.093 |
| 1994 | 1.131-1.730 | 0.493-0.816 | 1.521-3.770 | 0.601-0.945 | 0.118-0.181 |
| 1995 | 0.944-1.453 | 0.411-0.684 | 0.713-2.166 | 0.518-0.858 | 0.101-0.157 |
| 1996 | 0.899-1.361 | 0.393-0.648 | 1.011-2.549 | 0.640-0.989 | 0.121-0.184 |
| 1997 | 0.816-1.253 | 0.360-0.588 | 0.713-2.300 | 0.692-1.018 | 0.127-0.194 |
| 1998 | 0.721-1.123 | 0.319-0.526 | 1.124-2.863 | 0.745-1.079 | 0.148-0.231 |
| 1999 | 0.614-0.989 | 0.275-0.462 | 8.324-16.381 | 0.800-1.147 | 0.168-0.267 |
| 2000 | 0.520-0.882 | 0.240-0.407 | 0.079-0.835 | 0.607-0.970 | 0.112-0.192 |
| 2001 | 0.771-1.258 | 0.353-0.584 | 0.548-1.384 | 0.572-0.929 | 0.102-0.173 |
| 2002 | 1.020-1.593 | 0.458-0.750 | 0.011-0.232 | 0.363-0.669 | 0.035-0.055 |
| 2003 | 1.148-1.711 | 0.512-0.814 | 0.988-2.165 | 0.367-0.671 | 0.049-0.074 |
| 2004 | 1.118-1.585 | 0.494-0.765 | 0.013-0.247 | 0.577-0.91 | 0.103-0.146 |
| 2005 | 0.951-1.343 | 0.418-0.647 | 1.677-3.858 | 0.635-0.965 | 0.149-0.210 |
| 2006 | 0.726-1.052 | 0.323-0.503 | 1.208-3.225 | 0.763-1.107 | 0.172-0.252 |
| 2007 | 0.553-0.867 | 0.247-0.401 | 0.015-0.303 | 0.804-1.134 | 0.197-0.308 |
| 2008 | 0.470-0.825 | 0.211-0.366 | 3.144-10.376 | 0.872-1.206 | 0.186-0.324 |
| 2009 | 0.365-0.746 | 0.169-0.327 | 1.059-4.371 | 0.67-1.059 | 0.105-0.215 |
| 2010 | 0.406-0.964 | 0.193-0.420 | 7.914-36.131 | 0.738-1.181 | 0.158-0.359 |
| 2011 | 0.443-1.271 | 0.215-0.543 | 0.039-1.639 | 0.695-1.225 | 0.109-0.312 |
| 2012 | 0.635-2.445 | 0.316-1.042 | 0.057-11.867 | 0.456-1.037 | 0.070-0.252 |
| 2013 | 0.813-3.499 | 0.410-1.526 | 0.063-15.498 | 0.379-0.989 | 0.032-0.140 |
| 2014 | 0.835-3.932 | 0.416-1.688 | 0.054-13.635 | 0.969-1.071 | 0.175-0.299 |

**Table 13: 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 | 1.60 | 1.17 | 0.77 | 0.56 | 0.44 | 0.36 | 0.30 | 0.26 | 0.22 | 0.19 | 0.17 | 0.14 | 0.12 | 0.11 | 0.09 | 0.39 |
| 1967 | 2.89 | 1.29 | 0.95 | 0.62 | 0.44 | 0.34 | 0.27 | 0.23 | 0.19 | 0.17 | 0.15 | 0.13 | 0.11 | 0.09 | 0.08 | 0.36 |
| 1968 | 2.12 | 2.33 | 1.04 | 0.76 | 0.47 | 0.33 | 0.25 | 0.19 | 0.16 | 0.14 | 0.12 | 0.10 | 0.09 | 0.08 | 0.07 | 0.31 |
| 1969 | 1.04 | 1.71 | 1.89 | 0.84 | 0.59 | 0.36 | 0.25 | 0.18 | 0.14 | 0.12 | 0.10 | 0.09 | 0.08 | 0.07 | 0.06 | 0.28 |
| 1970 | 6.39 | 0.84 | 1.38 | 1.50 | 0.64 | 0.44 | 0.26 | 0.18 | 0.13 | 0.10 | 0.08 | 0.07 | 0.06 | 0.05 | 0.05 | 0.24 |
| 1971 | 0.81 | 5.17 | 0.68 | 1.10 | 1.13 | 0.46 | 0.31 | 0.18 | 0.12 | 0.09 | 0.07 | 0.06 | 0.05 | 0.04 | 0.04 | 0.19 |
| 1972 | 0.47 | 0.65 | 4.17 | 0.54 | 0.85 | 0.85 | 0.35 | 0.23 | 0.13 | 0.09 | 0.06 | 0.05 | 0.04 | 0.04 | 0.03 | 0.17 |
| 1973 | 3.68 | 0.38 | 0.53 | 3.35 | 0.42 | 0.65 | 0.65 | 0.26 | 0.17 | 0.10 | 0.06 | 0.05 | 0.04 | 0.03 | 0.03 | 0.15 |
| 1974 | 0.40 | 2.97 | 0.31 | 0.42 | 2.60 | 0.32 | 0.49 | 0.48 | 0.19 | 0.12 | 0.07 | 0.05 | 0.04 | 0.03 | 0.02 | 0.13 |
| 1975 | 1.16 | 0.33 | 2.40 | 0.25 | 0.33 | 1.96 | 0.24 | 0.36 | 0.35 | 0.14 | 0.09 | 0.05 | 0.03 | 0.03 | 0.02 | 0.11 |
| 1976 | 0.33 | 0.93 | 0.26 | 1.92 | 0.19 | 0.25 | 1.47 | 0.18 | 0.26 | 0.26 | 0.10 | 0.07 | 0.04 | 0.03 | 0.02 | 0.10 |
| 1977 | 4.39 | 0.27 | 0.75 | 0.21 | 1.50 | 0.15 | 0.19 | 1.10 | 0.13 | 0.19 | 0.19 | 0.08 | 0.05 | 0.03 | 0.02 | 0.09 |
| 1978 | 0.27 | 3.55 | 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 | 0.92 | 0.22 | 2.87 | 0.17 | 0.48 | 0.13 | 0.91 | 0.09 | 0.11 | 0.65 | 0.08 | 0.11 | 0.11 | 0.04 | 0.03 | 0.08 |
| 1980 | 14.14 | 0.74 | 0.18 | 2.30 | 0.14 | 0.37 | 0.10 | 0.69 | 0.07 | 0.08 | 0.49 | 0.06 | 0.09 | 0.09 | 0.03 | 0.08 |
| 1981 | 0.32 | 11.43 | 0.60 | 0.14 | 1.83 | 0.11 | 0.29 | 0.08 | 0.53 | 0.05 | 0.06 | 0.38 | 0.05 | 0.07 | 0.07 | 0.09 |
| 1982 | 0.25 | 0.25 | 9.24 | 0.48 | 0.11 | 1.41 | 0.08 | 0.22 | 0.06 | 0.40 | 0.04 | 0.05 | 0.28 | 0.03 | 0.05 | 0.12 |
| 1983 | 0.43 | 0.20 | 0.21 | 7.42 | 0.38 | 0.09 | 1.08 | 0.06 | 0.17 | 0.04 | 0.30 | 0.03 | 0.04 | 0.22 | 0.03 | 0.13 |
| 1984 | 11.55 | 0.35 | 0.16 | 0.17 | 5.88 | 0.30 | 0.07 | 0.84 | 0.05 | 0.13 | 0.03 | 0.23 | 0.02 | 0.03 | 0.17 | 0.12 |
| 1985 | 0.20 | 9.33 | 0.28 | 0.13 | 0.13 | 4.60 | 0.23 | 0.05 | 0.64 | 0.04 | 0.10 | 0.03 | 0.18 | 0.02 | 0.02 | 0.22 |
| 1986 | 0.22 | 0.16 | 7.54 | 0.23 | 0.11 | 0.10 | 3.61 | 0.18 | 0.04 | 0.50 | 0.03 | 0.08 | 0.02 | 0.14 | 0.01 | 0.19 |
| 1987 | 4.82 | 0.18 | 0.13 | 6.05 | 0.18 | 0.08 | 0.08 | 2.72 | 0.14 | 0.03 | 0.38 | 0.02 | 0.06 | 0.02 | 0.11 | 0.15 |
| 1988 | 1.86 | 3.90 | 0.14 | 0.11 | 4.74 | 0.14 | 0.06 | 0.06 | 2.03 | 0.10 | 0.02 | 0.28 | 0.02 | 0.04 | 0.01 | 0.19 |
| 1989 | 0.18 | 1.50 | 3.15 | 0.11 | 0.08 | 3.63 | 0.10 | 0.05 | 0.04 | 1.52 | 0.08 | 0.02 | 0.21 | 0.01 | 0.03 | 0.15 |
| 1990 | 3.97 | 0.15 | 1.22 | 2.52 | 0.09 | 0.06 | 2.69 | 0.07 | 0.03 | 0.03 | 1.09 | 0.05 | 0.01 | 0.15 | 0.01 | 0.13 |
| 1991 | 0.56 | 3.21 | 0.12 | 0.97 | 1.96 | 0.07 | 0.05 | 1.98 | 0.06 | 0.02 | 0.02 | 0.81 | 0.04 | 0.01 | 0.11 | 0.10 |
| 1992 | 0.19 | 0.46 | 2.59 | 0.09 | 0.74 | 1.45 | 0.05 | 0.03 | 1.42 | 0.04 | 0.02 | 0.02 | 0.58 | 0.03 | 0.01 | 0.15 |
| 1993 | 3.05 | 0.15 | 0.37 | 2.07 | 0.07 | 0.55 | 1.06 | 0.03 | 0.02 | 1.00 | 0.03 | 0.01 | 0.01 | 0.41 | 0.02 | 0.11 |
| 1994 | 2.26 | 2.46 | 0.12 | 0.29 | 1.59 | 0.05 | 0.40 | 0.76 | 0.02 | 0.02 | 0.72 | 0.02 | 0.01 | 0.01 | 0.29 | 0.10 |
| 1995 | 1.19 | 1.83 | 1.99 | 0.10 | 0.22 | 1.13 | 0.04 | 0.26 | 0.48 | 0.02 | 0.01 | 0.46 | 0.01 | 0.01 | 0.01 | 0.25 |
| 1996 | 1.47 | 0.96 | 1.48 | 1.58 | 0.07 | 0.16 | 0.80 | 0.02 | 0.17 | 0.33 | 0.01 | 0.01 | 0.31 | 0.01 | 0.00 | 0.17 |
| 1997 | 1.20 | 1.19 | 0.78 | 1.16 | 1.16 | 0.05 | 0.11 | 0.50 | 0.02 | 0.11 | 0.21 | 0.01 | 0.00 | 0.19 | 0.01 | 0.11 |
| 1998 | 1.64 | 0.97 | 0.96 | 0.61 | 0.84 | 0.78 | 0.03 | 0.07 | 0.31 | 0.01 | 0.07 | 0.13 | 0.00 | 0.00 | 0.12 | 0.07 |
| 1999 | 10.34 | 1.33 | 0.78 | 0.75 | 0.43 | 0.54 | 0.49 | 0.02 | 0.04 | 0.18 | 0.01 | 0.04 | 0.07 | 0.00 | 0.00 | 0.11 |
| 2000 | 0.36 | 8.36 | 1.07 | 0.61 | 0.51 | 0.27 | 0.33 | 0.28 | 0.01 | 0.02 | 0.10 | 0.00 | 0.02 | 0.04 | 0.00 | 0.06 |
| 2001 | 0.80 | 0.29 | 6.75 | 0.85 | 0.45 | 0.36 | 0.18 | 0.20 | 0.17 | 0.01 | 0.01 | 0.06 | 0.00 | 0.01 | 0.03 | 0.04 |
| 2002 | 0.07 | 0.65 | 0.24 | 5.38 | 0.64 | 0.32 | 0.25 | 0.12 | 0.13 | 0.11 | 0.00 | 0.01 | 0.04 | 0.00 | 0.01 | 0.04 |
| 2003 | 1.29 | 0.06 | 0.52 | 0.19 | 4.20 | 0.48 | 0.24 | 0.18 | 0.08 | 0.10 | 0.08 | 0.00 | 0.01 | 0.03 | 0.00 | 0.04 |
| 2004 | 0.07 | 1.04 | 0.05 | 0.42 | 0.15 | 3.18 | 0.36 | 0.17 | 0.13 | 0.06 | 0.07 | 0.06 | 0.00 | 0.00 | 0.02 | 0.03 |
| 2005 | 2.13 | 0.06 | 0.84 | 0.04 | 0.31 | 0.10 | 2.20 | 0.24 | 0.11 | 0.08 | 0.04 | 0.05 | 0.04 | 0.00 | 0.00 | 0.03 |
| 2006 | 1.63 | 1.72 | 0.05 | 0.67 | 0.03 | 0.22 | 0.07 | 1.39 | 0.15 | 0.07 | 0.05 | 0.03 | 0.03 | 0.02 | 0.00 | 0.02 |
| 2007 | 0.10 | 1.32 | 1.39 | 0.04 | 0.47 | 0.02 | 0.13 | 0.04 | 0.80 | 0.09 | 0.04 | 0.03 | 0.01 | 0.02 | 0.01 | 0.01 |
| 2008 | 4.42 | 0.08 | 1.07 | 1.08 | 0.03 | 0.29 | 0.01 | 0.07 | 0.02 | 0.44 | 0.05 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 |
| 2009 | 1.71 | 3.58 | 0.06 | 0.83 | 0.72 | 0.01 | 0.16 | 0.01 | 0.04 | 0.01 | 0.21 | 0.02 | 0.01 | 0.01 | 0.00 | 0.01 |
| 2010 | 12.76 | 1.38 | 2.89 | 0.05 | 0.60 | 0.48 | 0.01 | 0.09 | 0.00 | 0.02 | 0.01 | 0.12 | 0.01 | 0.01 | 0.00 | 0.01 |
| 2011 | 0.44 | 10.32 | 1.11 | 2.24 | 0.03 | 0.34 | 0.28 | 0.01 | 0.05 | 0.00 | 0.01 | 0.00 | 0.07 | 0.01 | 0.00 | 0.01 |
| 2012 | 1.87 | 0.35 | 8.32 | 0.85 | 1.40 | 0.02 | 0.21 | 0.16 | 0.00 | 0.03 | 0.00 | 0.01 | 0.00 | 0.04 | 0.00 | 0.01 |
| 2013 | 2.30 | 1.51 | 0.28 | 6.55 | 0.62 | 0.97 | 0.01 | 0.13 | 0.11 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 |
| 2014 | 2.32 | 1.86 | 1.22 | 0.23 | 4.90 | 0.45 | 0.68 | 0.01 | 0.09 | 0.07 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.02 |

**Table 14: Select parameters, derived quantities, and reference point estimates for the base model MLE and posterior medians**

| | MLE | Posterior median |
|---|---|---|
| Parameters | | |
| $R_0$ (billions) | 2.35 | 2.72 |
| Steepness ($h$) | 0.863 | 0.826 |
| Natural mortality ($M$) | 0.213 | 0.222 |
| Acoustic catchability ($Q$) | 1.060 | |
| Additional acoustic survey SD | 0.294 | 0.360 |
| Derived Quantities | | |
| 2008 recruitment (billions) | 4.424 | 5.148 |
| 2010 recruitment (billions) | 12.764 | 15.364 |
| $B_0$ (thousand mt) | 1,993 | 2,132 |
| 2013 Depletion | 0.670 | 0.745 |
| 2012 Fishing intensity: (1-SPR)/(1-SPR40%) | 0.852 | 0.769 |
| Reference points based on $F_{40\%}$ | | |
| Female spawning biomass ($B_{F40\%}$ million mt) | 748 | 769 |
| $SPR_{MSY\text{-}proxy}$ | | |
| Exploitation fraction corresponding to SPR | 0.207 | 0.216 |
| Yield at $B_{F40\%}$ (million mt) | 322 | 342 |
| Reference points based on $B_{40\%}$ | | |
| Female spawning biomass ($B_{40\%}$ million mt) | 797 | 853 |
| $SPR_{B40\%}$ | 0.424 | 0.432 |
| Exploitation fraction resulting in $B_{40\%}$ | 0.190 | 0.191 |
| Yield at $B_{40\%}$ (million mt) | 315 | 334 |
| Reference points based on estimated MSY | | |
| Female spawning biomass ($B_{MSY}$ million mt) | 456 | 519 |
| $SPR_{MSY}$ | 0.259 | 0.284 |
| Exploitation fraction corresponding to $SPR_{MSY}$ | 0.363 | 0.342 |
| $MSY$ (million mt) | 346 | 363 |

**Table 15: Summary of median and 95% credibility base reference points for Pacific Hake. Mean size at age and selectivity at age were averaged from 1966-2013.**

| Quantity | $2.5^{th}$ percentile | Median | $97.5^{th}$ percentile |
|---|---|---|---|
| Unfished female *B* ($B_0$, thousand mt) | 1,690 | 2,132 | 2,748 |
| Unfished recruitment ($R_0$, billions) | 1,788 | 2,720 | 4,496 |
| **Reference points based on $F_{40\%}$** | | | |
| Female spawning biomass ($B_{F40\%}$ thousand mt) | 592 | 769 | 968 |
| $SPR_{MSY\text{-}proxy}$ | — | 40% | — |
| Exploitation fraction corresponding to SPR | 18.3% | 21.6% | 25.6% |
| Yield at $B_{F40\%}$ (thousand mt) | 252 | 342 | 489 |
| **Reference points based on $B_{40\%}$** | | | |
| Female spawning biomass ($B_{40\%}$ thousand mt) | 676 | 853 | 1,099 |
| $SPR_{B40\%}$ | 40.6% | 43.2% | 49.6% |
| Exploitation fraction resulting in $B_{40\%}$ | 14.9% | 19.1% | 23.2% |
| Yield at $B_{40\%}$ (thousand mt) | 248 | 334 | 479 |
| **Reference points based on estimated MSY** | | | |
| Female spawning biomass ($B_{MSY}$ thousand mt) | 347 | 519 | 844 |
| $SPR_{MSY}$ | 18.9% | 28.4% | 43.4% |
| Exploitation fraction corresponding to $SPR_{MSY}$ | 18.9% | 34.2% | 57.1% |
| *MSY* (thousand mt) | 263 | 363 | 524 |

**Table 16: Forecast quantiles of Pacific Hake spawning biomass depletion at the beginning of the year before fishing. Catch alternatives are based on: constant catch levels (rows a, e, g), the catch level that results in an equal probability of the population increasing or decreasing from 2014 to 2015 (row b), the approximate average catch over the last 5 years (row c), the catch level that results in the median spawning biomass to remain unchanged from 2014 to 2015 (row d), the approximate maximum historical catch (row f), the approximate maximum catch target (row h), the catch level that results in a 50% probability that the median projected catch will remain the same in 2015 (row i), the catch values that result in a median SPR ratio of 1.0 (row j), and the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base (row k).**

| Within model quantile | | | 5% | 25% | 50% | 75% | 95% |
|---|---|---|---|---|---|---|---|
| Management Action | | | **Beginning of year depletion** | | | | |
| | Year | Catch (mt) | | | | | |
| a: No catch | 2014 | 0 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 0 | 52% | 70% | 88% | 110% | 158% |
| | 2016 | 0 | 54% | 72% | 91% | 112% | 168% |
| b: B2014=B2015 | 2014 | 190000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 190000 | 47% | 65% | 84% | 105% | 154% |
| | 2016 | 190000 | 45% | 63% | 82% | 104% | 159% |
| c: average historical catch | 2014 | 235000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 235000 | 46% | 64% | 82% | 104% | 153% |
| | 2016 | 235000 | 43% | 61% | 80% | 102% | 157% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 275000 | 45% | 63% | 82% | 103% | 153% |
| | 2016 | 275000 | 41% | 59% | 78% | 100% | 156% |
| e | 2014 | 325000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 325000 | 44% | 62% | 80% | 102% | 151% |
| | 2016 | 325000 | 39% | 57% | 76% | 98% | 154% |
| f: near max historical catch | 2014 | 375000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 375000 | 43% | 61% | 79% | 101% | 150% |
| | 2016 | 375000 | 36% | 55% | 74% | 96% | 151% |
| g | 2014 | 425000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 425000 | 42% | 60% | 78% | 100% | 149% |
| | 2016 | 425000 | 33% | 52% | 71% | 94% | 149% |
| h: near max catch target | 2014 | 500000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 500000 | 40% | 58% | 76% | 98% | 147% |
| | 2016 | 500000 | 30% | 49% | 68% | 90% | 146% |
| i: highest C2014=C2015 | 2014 | 727000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 727000 | 35% | 53% | 71% | 94% | 141% |
| | 2016 | 727000 | 20% | 38% | 58% | 81% | 135% |
| j: fishing intensity = 100% | 2014 | 825000 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 660000 | 32% | 51% | 69% | 91% | 139% |
| | 2016 | 600000 | 19% | 38% | 57% | 80% | 135% |
| k: default harvest rule | 2014 | 872424 | 48% | 64% | 82% | 102% | 147% |
| | 2015 | 691686 | 31% | 50% | 68% | 90% | 139% |
| | 2016 | 604762 | 17% | 36% | 55% | 78% | 133% |

**Table 17: Forecast quantiles of Pacific Hake fishing intensity (1-SPR)/(1-SPR$_{40\%}$) for the 2014-2016 catch alternatives presented in Table 16 Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy.**

| Within model quantile | | | 5% | 25% | 50% | 75% | 95% |
|---|---|---|---|---|---|---|---|
| Management Action | | | Fishing Intensity | | | | |
| | Year | Catch (mt) | | | | | |
| a: No catch | 2014 | 0 | 0% | 0% | 0% | 0% | 0% |
| | 2015 | 0 | 0% | 0% | 0% | 0% | 0% |
| | 2016 | 0 | 0% | 0% | 0% | 0% | 0% |
| b: B2014=B2015 | 2014 | 190000 | 23% | 34% | 42% | 50% | 66% |
| | 2015 | 190000 | 23% | 34% | 42% | 52% | 68% |
| | 2016 | 190000 | 21% | 32% | 40% | 50% | 67% |
| c: average historical catch | 2014 | 235000 | 27% | 40% | 49% | 59% | 75% |
| | 2015 | 235000 | 28% | 40% | 50% | 61% | 78% |
| | 2016 | 235000 | 26% | 39% | 48% | 60% | 78% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 31% | 45% | 55% | 65% | 82% |
| | 2015 | 275000 | 32% | 46% | 56% | 68% | 86% |
| | 2016 | 275000 | 30% | 44% | 55% | 67% | 87% |
| e | 2014 | 325000 | 36% | 51% | 61% | 72% | 89% |
| | 2015 | 325000 | 37% | 52% | 64% | 76% | 94% |
| | 2016 | 325000 | 34% | 51% | 62% | 76% | 96% |
| f: near max historical catch | 2014 | 375000 | 40% | 56% | 67% | 78% | 95% |
| | 2015 | 375000 | 41% | 58% | 70% | 83% | 102% |
| | 2016 | 375000 | 39% | 57% | 69% | 84% | 105% |
| g | 2014 | 425000 | 44% | 61% | 72% | 83% | 101% |
| | 2015 | 425000 | 46% | 63% | 76% | 89% | 108% |
| | 2016 | 425000 | 43% | 63% | 76% | 91% | 113% |
| h: near max catch target | 2014 | 500000 | 49% | 67% | 79% | 90% | 107% |
| | 2015 | 500000 | 52% | 71% | 84% | 97% | 115% |
| | 2016 | 500000 | 50% | 71% | 85% | 101% | 122% |
| i: highest C2014=C2015 | 2014 | 727000 | 63% | 83% | 95% | 105% | 121% |
| | 2015 | 727000 | 68% | 89% | 102% | 116% | 132% |
| | 2016 | 727000 | 67% | 92% | 107% | 124% | 138% |
| j: fishing intensity = 100% | 2014 | 825000 | 68% | 88% | 100% | 110% | 125% |
| | 2015 | 660000 | 65% | 86% | 100% | 114% | 132% |
| | 2016 | 600000 | 59% | 84% | 100% | 118% | 136% |
| k: default harvest rule | 2014 | 872424 | 71% | 91% | 102% | 112% | 127% |
| | 2015 | 691686 | 67% | 88% | 103% | 116% | 134% |
| | 2016 | 604762 | 60% | 85% | 102% | 120% | 137% |

**Table 18: Probabilities of related to spawning biomass, fishing intensity, and 2015 catch limits for alternative 2014 catch options (catch options explained in Table 16).**

| Catch in 2014 | Probability SB2015<SB2014 | Probability SB2015<SB40% | Probability SB2015<SB25% | Probability SB2015<SB10% | Probability Fishing intensity in 2014 > 40% Target | Probability 2015 Catch Target < 2014 Catch |
|---|---|---|---|---|---|---|
| 0 | 8% | 1% | 0% | 0% | 0% | 0% |
| 190,000 | 50% | 2% | 0% | 0% | 0% | 0% |
| 235,000 | 58% | 3% | 0% | 0% | 0% | 0% |
| 275,000 | 64% | 3% | 0% | 0% | 0% | 1% |
| 325,000 | 70% | 3% | 0% | 0% | 1% | 3% |
| 375,000 | 75% | 4% | 0% | 0% | 2% | 5% |
| 425,000 | 79% | 4% | 0% | 0% | 5% | 9% |
| 500,000 | 83% | 5% | 0% | 0% | 11% | 18% |
| 727,000 | 91% | 9% | 2% | 0% | 37% | 50% |
| 825,000 | 92% | 12% | 2% | 0% | 50% | 62% |
| 872,424 | 92% | 13% | 3% | 0% | 55% | 68% |

**Table 19: Probabilities of related to spawning biomass, fishing intensity, and 2016 catch limits for alternative 2015 catch options (catch options explained in Table 16).**

| Catch in 2016 | Probability SB2016<SB2015 | Probability SB2016<SB40% | Probability SB2016<SB25% | Probability SB2016<SB10% | Probability Fishing intensity in 2015 > 40% Target | Probability 2016 Catch Target < 2015 Catch |
|---|---|---|---|---|---|---|
| 0 | 46% | 1% | 0% | 0% | 0% | 0% |
| 190,000 | 73% | 3% | 0% | 0% | 0% | 0% |
| 235,000 | 75% | 4% | 0% | 0% | 0% | 0% |
| 275,000 | 77% | 5% | 1% | 0% | 1% | 2% |
| 325,000 | 80% | 6% | 1% | 0% | 3% | 4% |
| 375,000 | 83% | 7% | 1% | 0% | 6% | 7% |
| 425,000 | 85% | 10% | 2% | 0% | 10% | 13% |
| 500,000 | 87% | 14% | 3% | 0% | 21% | 24% |
| 727,000 | 92% | 27% | 9% | 1% | 55% | 58% |
| 660,000 | 91% | 28% | 10% | 2% | 50% | 54% |
| 691,686 | 91% | 30% | 12% | 2% | 54% | 57% |

**Table 20: Forecast quantiles of Pacific Hake beginning of year depletion for the 2014-2016 catch alternatives presented in Table 16.**

| Probability of state of nature | | | 10% | 80% | 10% |
|---|---|---|---|---|---|
| Management Action | | | Beginning of year depletion | | |
| | Year | Catch (mt) | | | |
| a: No catch | 2014 | 0 | 49% | 82% | 141% |
| | 2015 | 0 | 55% | 88% | 149% |
| | 2016 | 0 | 59% | 90% | 145% |
| b: B2014=B2015 | 2014 | 190000 | 49% | 82% | 141% |
| | 2015 | 190000 | 50% | 83% | 144% |
| | 2016 | 190000 | 49% | 82% | 138% |
| c: average historical catch | 2014 | 235000 | 49% | 82% | 141% |
| | 2015 | 235000 | 49% | 82% | 143% |
| | 2016 | 235000 | 47% | 80% | 136% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 49% | 82% | 141% |
| | 2015 | 275000 | 48% | 82% | 142% |
| | 2016 | 275000 | 45% | 78% | 135% |
| e | 2014 | 325000 | 49% | 82% | 141% |
| | 2015 | 325000 | 47% | 80% | 141% |
| | 2016 | 325000 | 43% | 76% | 133% |
| f: near max historical catch | 2014 | 375000 | 49% | 82% | 141% |
| | 2015 | 375000 | 46% | 79% | 140% |
| | 2016 | 375000 | 40% | 73% | 131% |
| g | 2014 | 425000 | 49% | 82% | 141% |
| | 2015 | 425000 | 44% | 78% | 139% |
| | 2016 | 425000 | 37% | 71% | 129% |
| h: near max catch target | 2014 | 500000 | 49% | 82% | 141% |
| | 2015 | 500000 | 43% | 76% | 138% |
| | 2016 | 500000 | 34% | 68% | 126% |
| i: highest C2014=C2015 | 2014 | 727000 | 49% | 82% | 141% |
| | 2015 | 727000 | 37% | 71% | 133% |
| | 2016 | 727000 | 22% | 57% | 117% |
| j: fishing intensity = 100% | 2014 | 825000 | 49% | 82% | 141% |
| | 2015 | 660000 | 34% | 69% | 130% |
| | 2016 | 600000 | 21% | 57% | 116% |
| k: default harvest rule | 2014 | 872424 | 49% | 82% | 141% |
| | 2015 | 691686 | 33% | 68% | 129% |
| | 2016 | 604762 | 19% | 55% | 115% |

**Table 21: Forecast quantiles of Pacific Hake beginning of year depletion for the 2014-2016 catch alternatives presented in Table 16. Values greater than 100% indicate fishing intensities greater than the $F_{40\%}$ harvest policy.**

| Probability of state of nature | | | 10% | 80% | 10% |
|---|---|---|---|---|---|
| Management Action | | | **Fishing Intensity** | | |
| | Year | Catch (mt) | | | |
| a: No catch | 2014 | 0 | 0% | 0% | 0% |
| | 2015 | 0 | 0% | 0% | 0% |
| | 2016 | 0 | 0% | 0% | 0% |
| b: B2014=B2015 | 2014 | 190000 | 66% | 42% | 23% |
| | 2015 | 190000 | 68% | 42% | 24% |
| | 2016 | 190000 | 66% | 41% | 22% |
| c: average historical catch | 2014 | 235000 | 75% | 49% | 27% |
| | 2015 | 235000 | 78% | 50% | 29% |
| | 2016 | 235000 | 77% | 48% | 27% |
| d: med(B2014)=med(B2015) | 2014 | 275000 | 82% | 55% | 31% |
| | 2015 | 275000 | 86% | 56% | 33% |
| | 2016 | 275000 | 86% | 55% | 31% |
| e | 2014 | 325000 | 89% | 61% | 36% |
| | 2015 | 325000 | 94% | 64% | 38% |
| | 2016 | 325000 | 96% | 63% | 36% |
| f: near max historical catch | 2014 | 375000 | 96% | 67% | 40% |
| | 2015 | 375000 | 102% | 70% | 42% |
| | 2016 | 375000 | 104% | 70% | 40% |
| g | 2014 | 425000 | 101% | 72% | 44% |
| | 2015 | 425000 | 108% | 76% | 46% |
| | 2016 | 425000 | 112% | 76% | 45% |
| h: near max catch target | 2014 | 500000 | 107% | 79% | 49% |
| | 2015 | 500000 | 116% | 84% | 52% |
| | 2016 | 500000 | 121% | 85% | 51% |
| i: highest C2014=C2015 | 2014 | 727000 | 121% | 95% | 63% |
| | 2015 | 727000 | 132% | 102% | 68% |
| | 2016 | 727000 | 137% | 108% | 69% |
| j: fishing intensity = 100% | 2014 | 825000 | 125% | 100% | 68% |
| | 2015 | 660000 | 132% | 100% | 65% |
| | 2016 | 600000 | 135% | 101% | 62% |
| k: default harvest rule | 2014 | 872424 | 127% | 102% | 70% |
| | 2015 | 691686 | 134% | 103% | 67% |
| | 2016 | 604762 | 136% | 102% | 62% |

**Table 22: Probabilities related to spawning biomass, fishing intensity, and 2015 catch limits for alternative 2014 catch options (catch options explained in Table 16) and low, mid, and high state of nature. States of nature are defined on the lower 10%, middle 80%, and high 10% quantiles of 2010 recruitment.**

| | Catch in 2014 | Probability SB2015< SB2014 | Probability SB2015< SB40% | Probability SB2015< SB25% | Probability SB2015< SB10% | Probability Fishing intensity in 2014 > 40% Target | Probability 2015 Catch Target < 2014 Catch |
|---|---|---|---|---|---|---|---|
| **Lower 10% of 2010 recruitment** | 0 | 0% | 10% | 1% | 0% | 0% | 0% |
| | 190,000 | 53% | 22% | 1% | 0% | 1% | 1% |
| | 235,000 | 65% | 26% | 1% | 0% | 1% | 2% |
| | 275,000 | 71% | 26% | 1% | 0% | 1% | 9% |
| | 325,000 | 78% | 28% | 1% | 0% | 5% | 26% |
| | 375,000 | 83% | 32% | 2% | 1% | 24% | 50% |
| | 425,000 | 88% | 35% | 3% | 1% | 52% | 75% |
| | 500,000 | 90% | 43% | 4% | 1% | 92% | 94% |
| | 727,000 | 93% | 60% | 16% | 1% | 100% | 99% |
| | 825,000 | 96% | 71% | 21% | 1% | 100% | 99% |
| | 872,424 | 96% | 75% | 26% | 1% | 100% | 99% |
| | | | | | | | |
| **Middle 80% of 2010 recruitment** | 0 | 7% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 49% | 0% | 0% | 0% | 0% | 0% |
| | 235,000 | 58% | 0% | 0% | 0% | 0% | 0% |
| | 275,000 | 64% | 0% | 0% | 0% | 0% | 0% |
| | 325,000 | 69% | 1% | 0% | 0% | 0% | 0% |
| | 375,000 | 74% | 1% | 0% | 0% | 0% | 0% |
| | 425,000 | 78% | 1% | 0% | 0% | 0% | 2% |
| | 500,000 | 84% | 1% | 0% | 0% | 2% | 11% |
| | 727,000 | 91% | 3% | 0% | 0% | 33% | 50% |
| | 825,000 | 92% | 6% | 0% | 0% | 50% | 66% |
| | 872,424 | 93% | 7% | 0% | 0% | 57% | 73% |
| | | | | | | | |
| **Upper 10% of 2010 recruitment** | 0 | 26% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 54% | 0% | 0% | 0% | 0% | 0% |
| | 235,000 | 59% | 0% | 0% | 0% | 0% | 0% |
| | 275,000 | 63% | 0% | 0% | 0% | 0% | 0% |
| | 325,000 | 68% | 0% | 0% | 0% | 0% | 0% |
| | 375,000 | 70% | 0% | 0% | 0% | 0% | 0% |
| | 425,000 | 73% | 0% | 0% | 0% | 0% | 0% |
| | 500,000 | 74% | 0% | 0% | 0% | 0% | 0% |
| | 727,000 | 84% | 0% | 0% | 0% | 0% | 0% |
| | 825,000 | 88% | 0% | 0% | 0% | 0% | 0% |
| | 872,424 | 88% | 0% | 0% | 0% | 0% | 0% |

**Table 23: Probabilities related to spawning biomass, fishing intensity, and 2016 catch limits for alternative 2015 catch options (catch options explained in Table 16) and low, mid, and high state of nature. States of nature are defined on the lower 10%, middle 80%, and high 10% quantiles of 2010 recruitment.**

| | Catch in 2015 | Probability SB2016< SB2015 | Probability SB2016< SB40% | Probability SB2016< SB25% | Probability SB2016< SB10% | Probability Fishing intensity in 2015 > 40% Target | Probability 2016 Catch Target < 2015 Catch |
|---|---|---|---|---|---|---|---|
| **Lower 10% of 2010 recruitment** | 0 | 23% | 7% | 1% | 0% | 0% | 0% |
| | 190,000 | 67% | 24% | 2% | 0% | 1% | 1% |
| | 235,000 | 70% | 30% | 3% | 1% | 2% | 4% |
| | 275,000 | 72% | 38% | 6% | 1% | 6% | 17% |
| | 325,000 | 74% | 45% | 7% | 1% | 30% | 35% |
| | 375,000 | 77% | 50% | 10% | 1% | 56% | 62% |
| | 425,000 | 80% | 60% | 18% | 1% | 80% | 78% |
| | 500,000 | 85% | 69% | 24% | 1% | 97% | 93% |
| | 727,000 | 93% | 90% | 58% | 12% | 99% | 98% |
| | 660,000 | 91% | 90% | 61% | 16% | 99% | 98% |
| | 691,686 | 91% | 90% | 62% | 19% | 99% | 98% |
| | | | | | | | |
| **Middle 80% of 2010 recruitment** | 0 | 46% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 73% | 1% | 0% | 0% | 0% | 0% |
| | 235,000 | 75% | 1% | 0% | 0% | 0% | 0% |
| | 275,000 | 77% | 1% | 0% | 0% | 0% | 0% |
| | 325,000 | 80% | 2% | 0% | 0% | 0% | 0% |
| | 375,000 | 84% | 3% | 0% | 0% | 0% | 1% |
| | 425,000 | 85% | 5% | 0% | 0% | 3% | 6% |
| | 500,000 | 88% | 9% | 0% | 0% | 14% | 18% |
| | 727,000 | 92% | 23% | 4% | 0% | 56% | 60% |
| | 660,000 | 91% | 23% | 4% | 0% | 50% | 55% |
| | 691,686 | 92% | 26% | 7% | 0% | 55% | 59% |
| | | | | | | | |
| **Upper 10% of 2010 recruitment** | 0 | 69% | 0% | 0% | 0% | 0% | 0% |
| | 190,000 | 78% | 0% | 0% | 0% | 0% | 0% |
| | 235,000 | 81% | 0% | 0% | 0% | 0% | 0% |
| | 275,000 | 83% | 0% | 0% | 0% | 0% | 0% |
| | 325,000 | 84% | 0% | 0% | 0% | 0% | 0% |
| | 375,000 | 86% | 0% | 0% | 0% | 0% | 0% |
| | 425,000 | 87% | 0% | 0% | 0% | 0% | 0% |
| | 500,000 | 88% | 0% | 0% | 0% | 0% | 0% |
| | 727,000 | 92% | 0% | 0% | 0% | 0% | 0% |
| | 660,000 | 90% | 0% | 0% | 0% | 0% | 0% |
| | 691,686 | 91% | 0% | 0% | 0% | 0% | 0% |

**Table 24: Select parameters, derived quantities, and reference point estimates for the MLE base model and sensitivity runs. Likelihood components in grey are not directly comparable to the base model.**

| | Base model | New maturity | No 2012 survey | High TV sel | TV Sel from 1975 |
|---|---|---|---|---|---|
| Likelihoods | | | | | |
| Total | 181.61 | 181.61 | 180.30 | 157.86 | 180.03 |
| Survey Index | -4.59 | -4.59 | -3.48 | -4.53 | -4.59 |
| Survey age compositions | 45.81 | 45.81 | 43.35 | 45.50 | 45.79 |
| Fishery age compositions | 97.89 | 97.89 | 98.02 | 76.74 | 94.98 |
| Parameters | | | | | |
| $R_0$ (billions) | 2.35 | 2.35 | 2.37 | 2.36 | 2.34 |
| Steepness (*h*) | 0.863 | 0.863 | 0.864 | 0.863 | 0.863 |
| Natural mortality (*M*) | 0.213 | 0.213 | 0.213 | 0.213 | 0.213 |
| Acoustic catchability (*Q*) | 1.060 | 1.060 | 1.061 | 1.053 | 1.059 |
| Additional acoustic survey SD | 0.294 | 0.294 | 0.320 | 0.297 | 0.294 |
| Derived Quantities | | | | | |
| 2008 recruitment (billions) | 4.424 | 4.423 | 4.808 | 4.428 | 4.427 |
| 2010 recruitment (billions) | 12.764 | 12.764 | 15.776 | 11.517 | 12.790 |
| $B_0$ (thousand mt) | 1,993 | 1,901 | 1,997 | 1,995 | 1,982 |
| 2014 Depletion | 74.0% | 78.0% | 88.7% | 68.7% | 74.5% |
| 2013 Fishing intensity (1-SPR/1-SPR40%) | 77.8% | 78.1% | 73.1% | 83.4% | 77.6% |
| Reference points based on $F_{40\%}$ | | | | | |
| Female spawning biomass ($B_{F40\%}$ thousand mt) | 748 | 713 | 750 | 749 | 744 |
| Equilibrium exploitation fraction corresponding to SPR | 20.7% | 20.7% | 20.8% | 20.7% | 20.8% |
| Yield at $B_{F40\%}$ (thousand mt) | 322 | 322 | 324 | 322 | 321 |

**Table 25: Medians of the Bayesian posterior for select parameters, derived quantities, and reference points for the base model and sensitivity runs of 1) estimating non-parametric selectivity to age 10, or 2) not estimating time-varying fishery selectivity.**

| | Base model | Estimate selectivity to age 10 | Time invariant fishery selectivity | 2013 survey 1.8 mmt |
|---|---|---|---|---|
| Parameters | | | | |
| $R_0$ (billions) | 2.72 | 2.69 | 2.86 | 2.69 |
| Steepness ($h$) | 0.826 | 0.823 | 0.821 | 0.825 |
| Natural mortality ($M$) | 0.222 | 0.224 | 0.226 | 0.224 |
| Acoustic catchability ($Q$) | 0.962 | 1.518 | 0.934 | 0.970 |
| Additional acoustic survey SD | 0.360 | 0.374 | 0.394 | 0.359 |
| Derived Quantities | | | | |
| 2008 recruitment (billions) | 5.148 | 5.506 | 5.865 | 4.828 |
| 2010 recruitment (billions) | 15.364 | 17.107 | 19.073 | 13.607 |
| $B_0$ (thousand mt) | 2132 | 2083 | 2181 | 2102 |
| 2014 Depletion | 81.8% | 92.8% | 96.1% | 73.5% |
| 2013 Fishing intensity (1-SPR/1-SPR40%) | 69.4% | 66.8% | 60.3% | 73.2% |
| Reference points based on $F_{40\%}$ | | | | |
| Female spawning biomass ($B_{F40\%}$ thousand mt) | 769 | 754 | 780 | 758 |
| Equilibrium exploitation fraction corresponding to SPR | 21.6% | 21.9% | 22.0% | 21.8 |
| Yield at $B_{F40\%}$ (thousand mt) | 342 | 338 | 354 | 338 |

**Table 26: Select parameters, derived quantities, and reference point estimates for retrospective analyses using the base model. Values in italics are implied since they occur after the ending year of the respective retrospective analysis.**

| | Base model | -1 year | -2 years | -3 years | -4 years | -5 years |
|---|---|---|---|---|---|---|
| Parameters | | | | | | |
| $R_0$ (billions) | 2.72 | 2.65 | 2.41 | 2.99 | 2.82 | 2.77 |
| Steepness ($h$) | 0.826 | 0.829 | 0.817 | 0.812 | 0.813 | 0.814 |
| Natural mortality ($M$) | 0.222 | 0.223 | 0.219 | 0.225 | 0.222 | 0.223 |
| Acoustic catchability ($Q$) | NA | NA | NA | NA | NA | NA |
| Additional acoustic survey SD | 0.360 | 0.400 | 0.467 | 0.285 | 0.283 | 0.312 |
| Derived Quantities | | | | | | |
| 2008 recruitment (billions) | 5.15 | 4.75 | 3.88 | 11.36 | 1.11 | 0.80 |
| 2010 recruitment (billions) | 15.36 | 11.96 | 1.70 | 1.10 | 1.03 | 0.99 |
| $B_0$ (thousand mt) | 2,132 | 2,087 | 1,960 | 2,312 | 2,241 | 2,191 |
| 2009 Depletion | 22.8% | 19.8% | 16.4% | 43.0% | 49.7% | 35.1% |
| 2014 Depletion | 81.8% | *69.7%* | *26.3%* | *70.4%* | *42.6%* | *32.2%* |
| 2013 Fishing intensity (1-SPR/1-SPR40%) | 69% | *77%* | *112%* | *57%* | *77%* | *90%* |
| Reference points based on $F_{40\%}$ | | | | | | |
| Female spawning biomass ($B_{F40\%}$ thousand mt) | 769 | 752 | 705 | 821 | 792 | 785 |
| Equilibrium exploitation fraction corresponding to SPR | 21.6% | 21.7% | 21.3% | 22.0% | 21.7% | 21.8% |
| Yield at $B_{F40\%}$ (thousand mt) | 342 | 335 | 308 | 372 | 357 | 349 |

**Table 27: Retrospective estimates of recruitment devs at age for cohorts from 1999 to 2012 from the base model with time-varying selectivity (TV) and the model with time-invariant selectivity (noTV).**

| Cohort | Model | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 1999 | TV | NA | -0.169 | 1.125 | 1.437 | 2.211 | 2.292 |
| | noTV | NA | -0.155 | 1.102 | 1.399 | 2.184 | 2.254 |
| 2000 | TV | -0.234 | -0.576 | -1.406 | -1.470 | -1.006 | -0.827 |
| | noTV | -0.157 | -0.657 | -1.448 | -1.503 | -1.077 | -0.834 |
| 2001 | TV | 0.006 | -0.553 | -1.331 | -0.849 | -0.378 | -0.087 |
| | noTV | 0.161 | -0.467 | -1.275 | -0.877 | -0.394 | -0.097 |
| 2002 | TV | 0.053 | -0.312 | -1.060 | -1.844 | -2.059 | -2.265 |
| | noTV | 0.108 | -0.260 | -0.974 | -1.846 | -2.082 | -2.225 |
| 2003 | TV | -0.058 | -0.277 | 0.676 | 0.673 | 0.624 | 0.617 |
| | noTV | 0.014 | -0.206 | 0.642 | 0.584 | 0.584 | 0.634 |
| 2004 | TV | -0.009 | -0.331 | -0.507 | -1.597 | -2.105 | -2.202 |
| | noTV | 0.087 | -0.353 | -0.563 | -1.599 | -2.061 | -2.211 |
| 2005 | TV | -0.128 | -0.269 | 1.387 | 1.402 | 1.645 | 1.449 |
| | noTV | -0.027 | -0.196 | 1.408 | 1.428 | 1.630 | 1.391 |
| 2006 | TV | -0.024 | -0.301 | 0.479 | 1.447 | 1.499 | 0.453 |
| | noTV | -0.078 | -0.165 | 0.638 | 1.454 | 1.511 | 0.408 |
| 2007 | TV | -0.182 | -0.253 | -1.813 | -2.144 | -2.624 | -2.327 |
| | noTV | -0.056 | -0.126 | -1.787 | -2.091 | -2.619 | -2.292 |
| 2008 | TV | -0.158 | 0.129 | 2.391 | 1.657 | 1.740 | 1.782 |
| | noTV | -0.203 | 0.016 | 2.632 | 1.572 | 1.781 | 1.875 |
| 2009 | TV | -0.101 | -0.392 | 0.784 | 0.851 | 0.870 | NA |
| | noTV | -0.148 | -0.337 | 0.748 | 0.954 | 0.990 | NA |
| 2010 | TV | 0.057 | 0.927 | 2.664 | 2.883 | NA | NA |
| | noTV | 0.022 | 0.917 | 2.859 | 3.045 | NA | NA |
| 2011 | TV | -0.089 | -0.142 | -0.899 | NA | NA | NA |
| | noTV | -0.051 | -0.119 | -0.798 | NA | NA | NA |
| 2012 | TV | 0.038 | -0.114 | NA | NA | NA | NA |
| | noTV | -0.032 | -0.107 | NA | NA | NA | NA |
| **SD** | **TV** | **0.0940** | **0.3663** | **1.4735** | **1.6866** | **1.7525** | **1.7345** |
| | **noTV** | **0.1069** | **0.3530** | **1.5199** | **1.7040** | **1.7590** | **1.7249** |

# 8 Figures

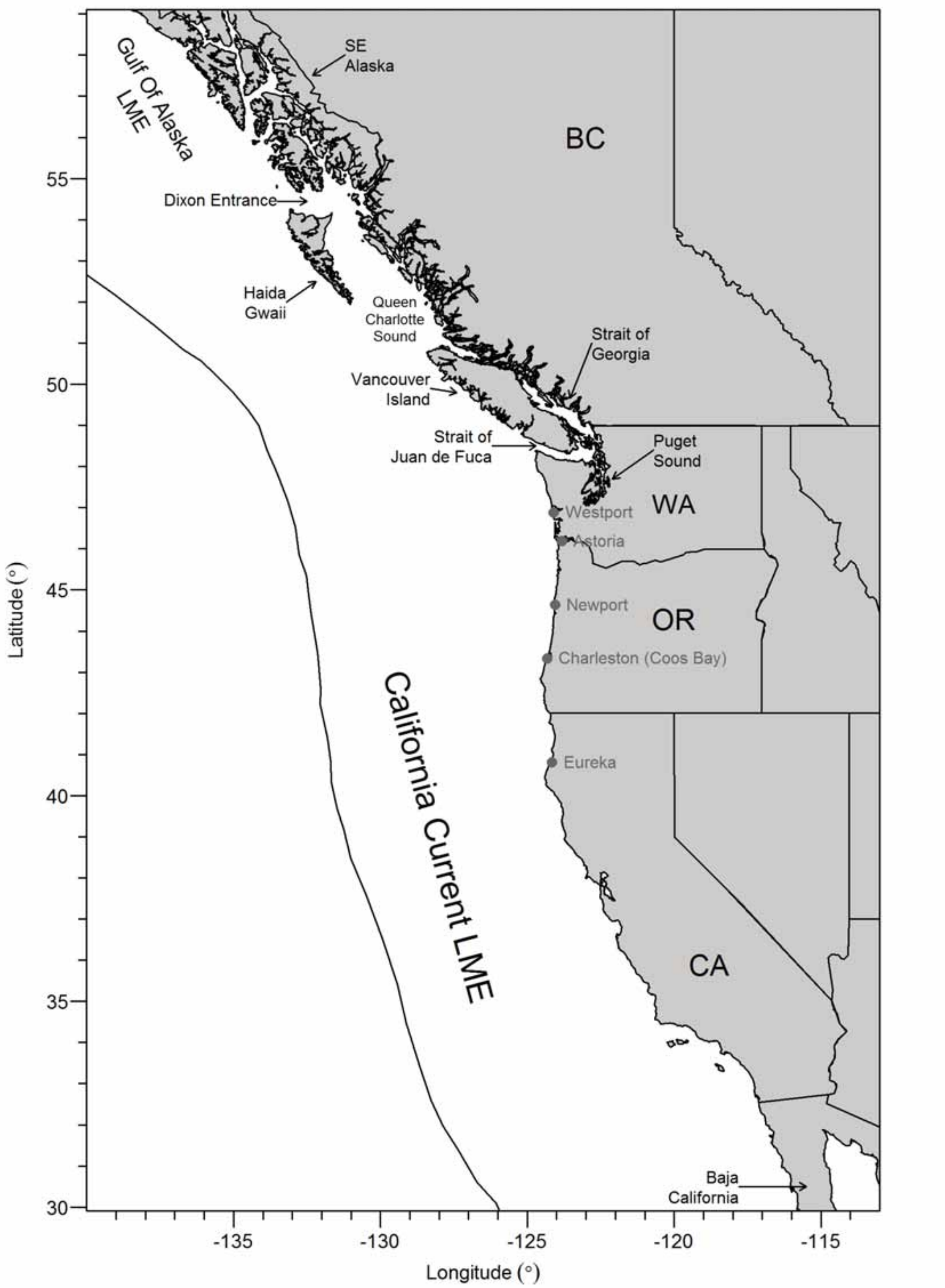



**Figure 1: Overview map of the area in the Northeast Pacific Ocean occupied by Pacific Hake. Common areas referred to in this document are shown.**

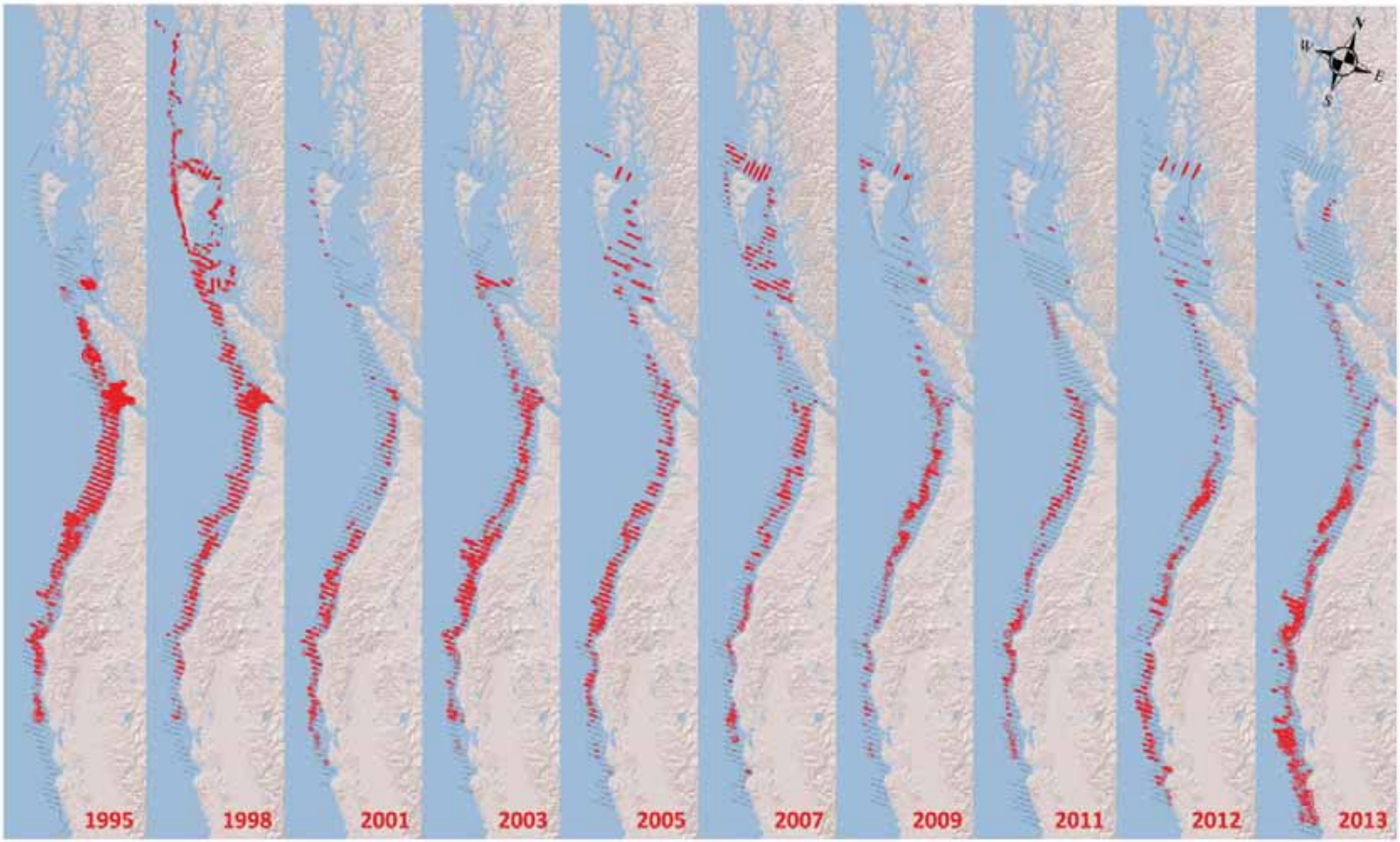



**Figure 2: Spatial distribution of acoustic backscatter attributable to Pacific Hake from joint US-Canada acoustic surveys 1995-2013. Area of the circle is roughly proportional to observed backscatter.**

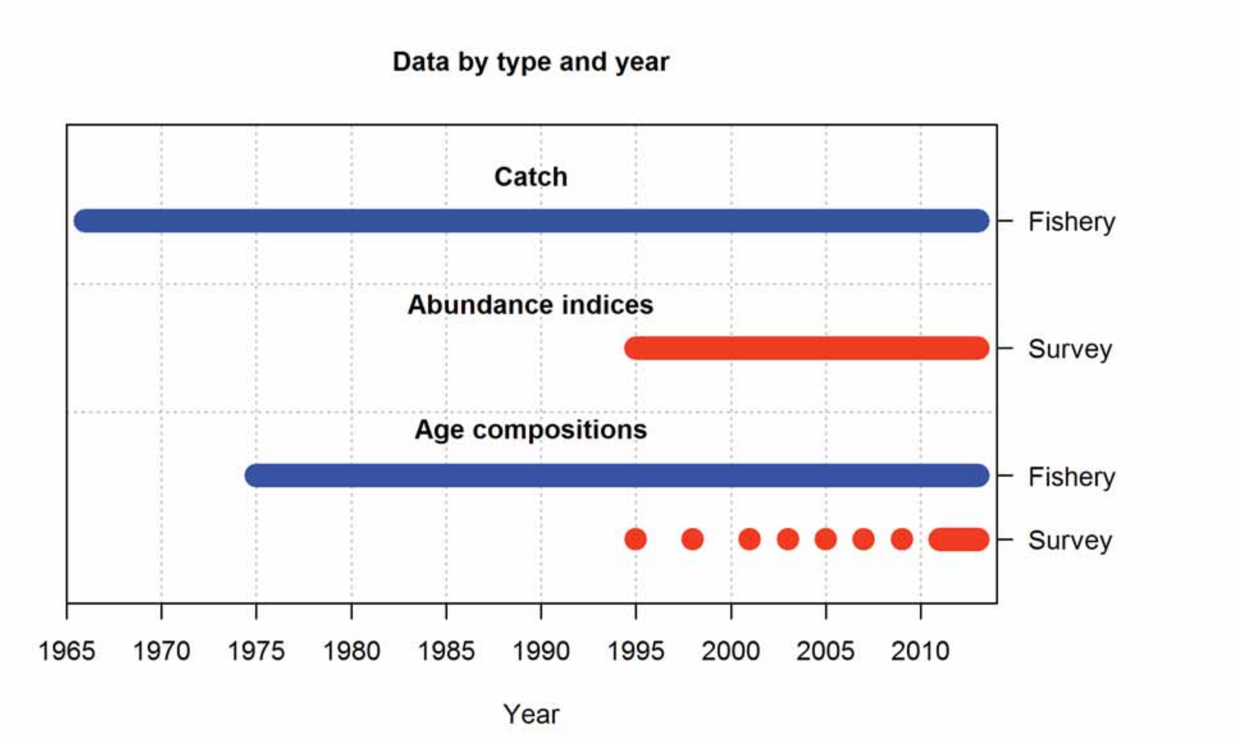



**Figure 3: Overview of data used in this assessment, 1966-2013.**

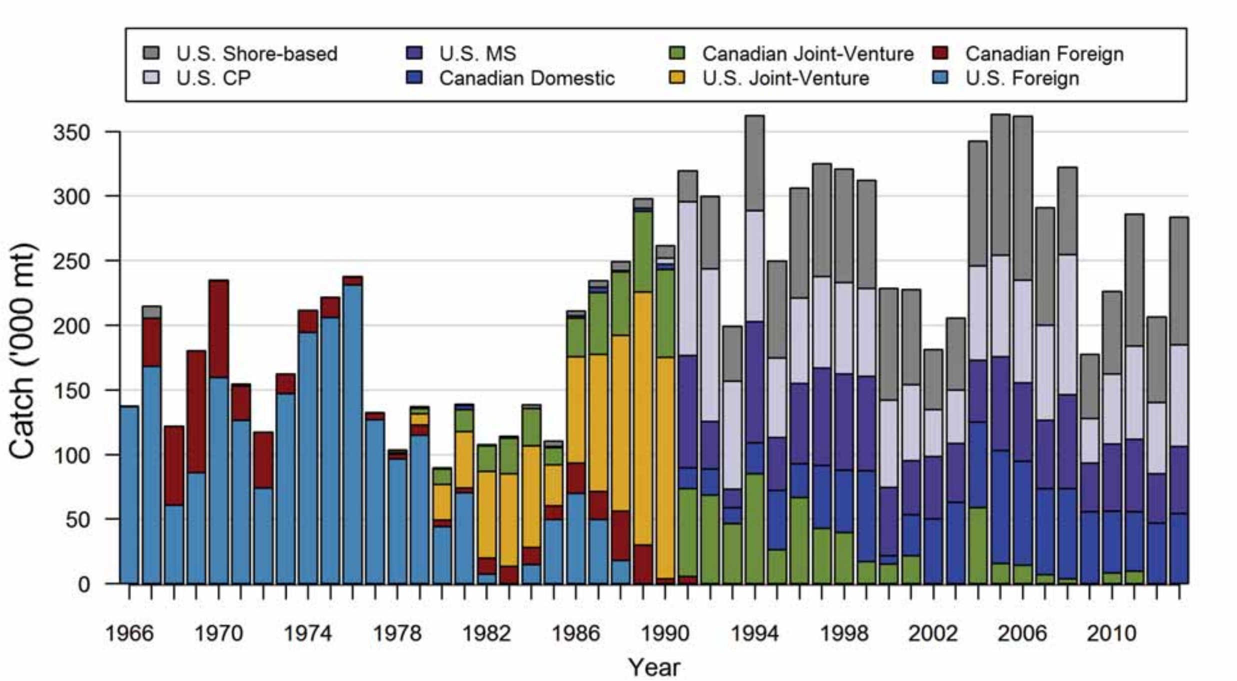



**Figure 4: Total Pacific Hake landings used in the assessment by sector, 1966-2013**

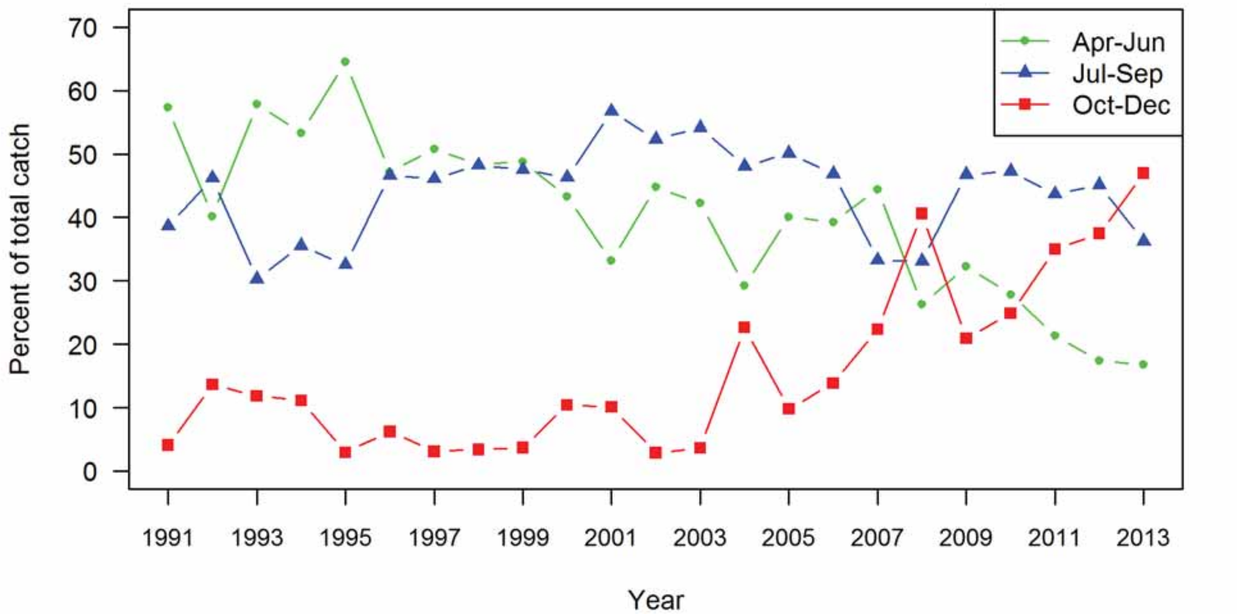



**Figure 5: Proportion of catch for the U.S. and Canada combined occurring in each season from April through December.**

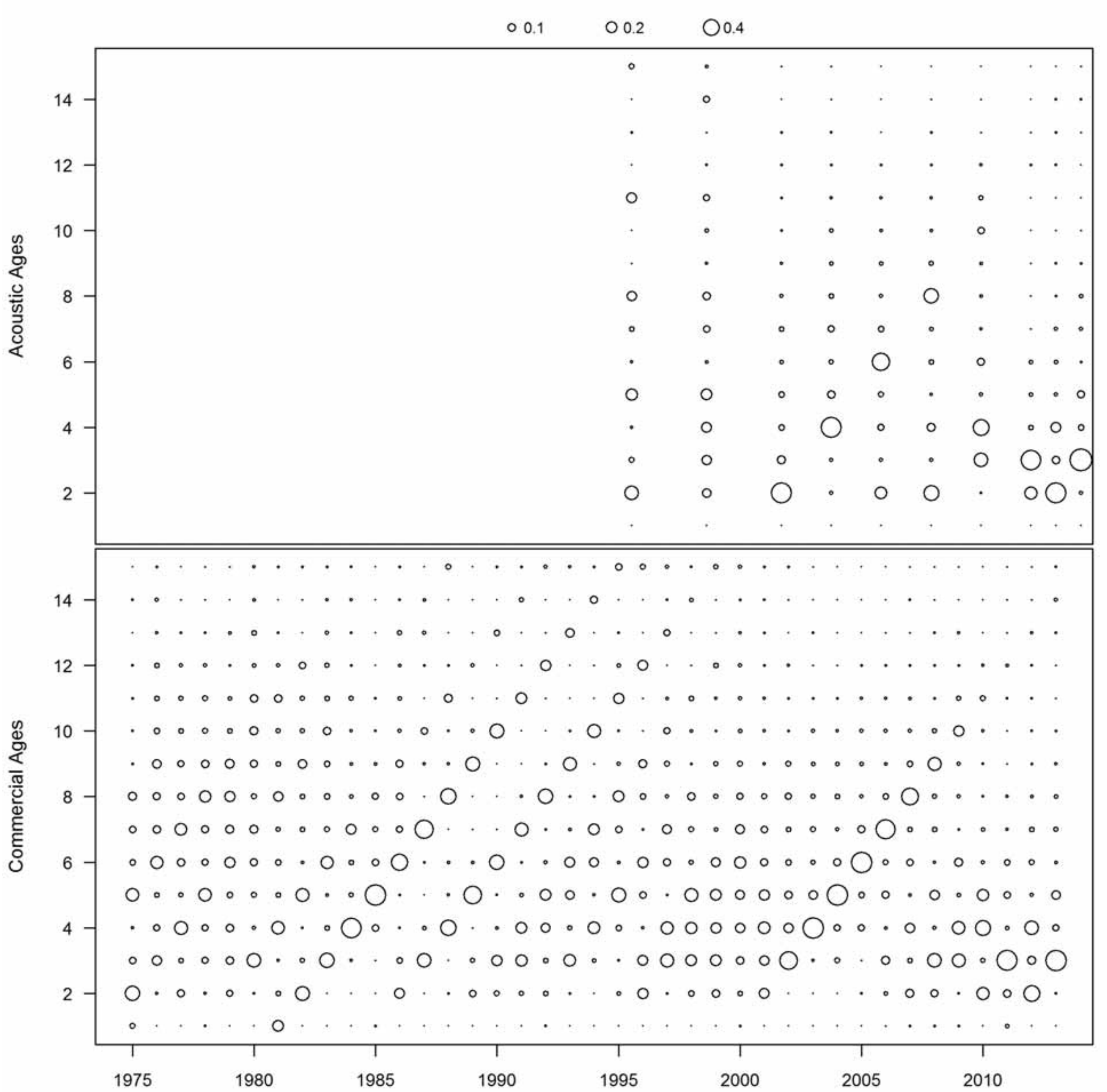



**Figure 6: Age compositions for the acoustic survey (top) and the aggregate fishery (bottom, all sectors combined) for the years 1975–2013. Proportions in each year sum to 1.0 and area of the bubbles are proportional to the proportion and consistent in both panels (see key at top).**

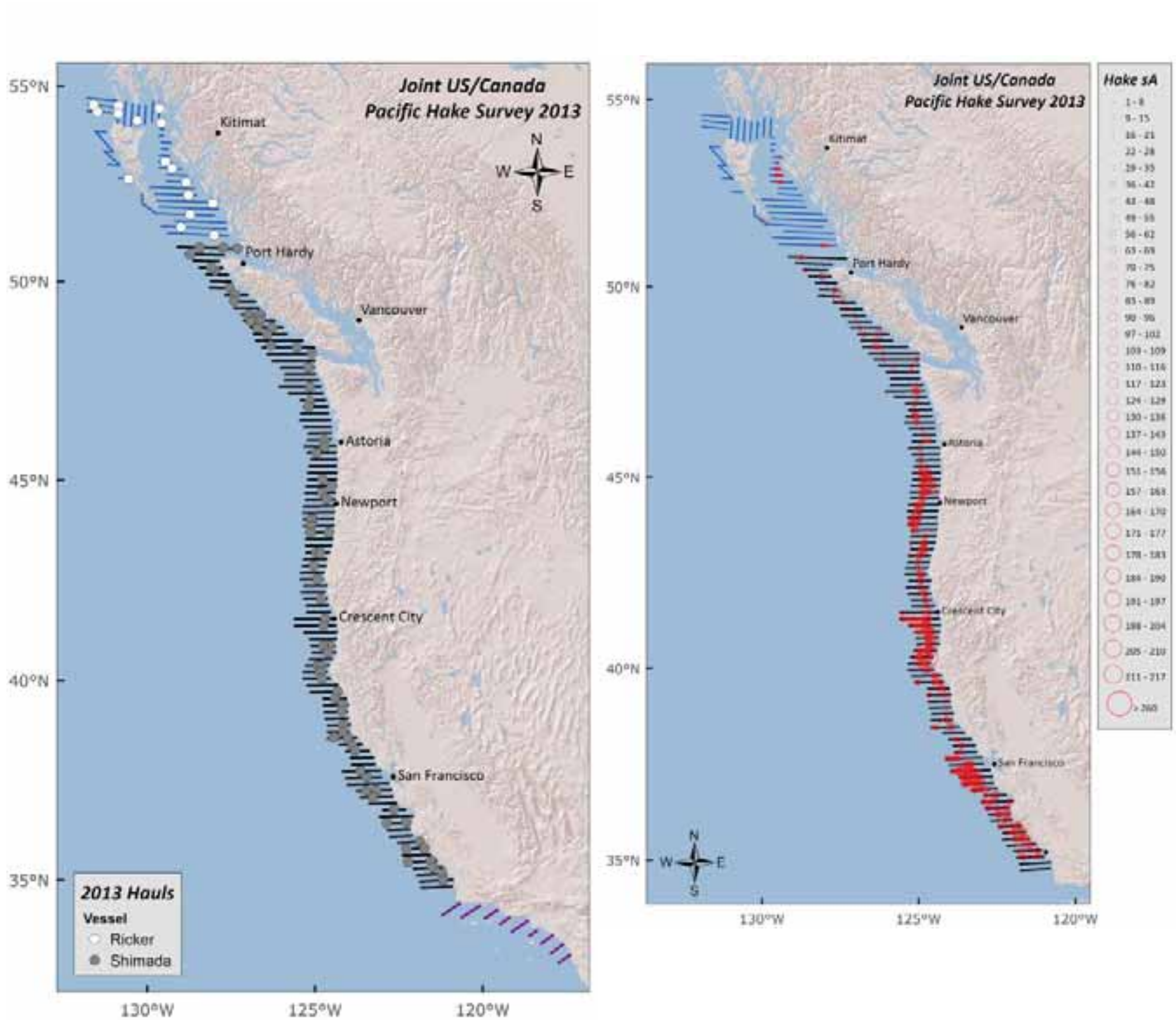



**Figure 7: Acoustic survey transects surveyed in 2012 with backscatter proportional to the area of the circle (left panel) and hauls that caught or did not catch Pacific Hake (right panel).**

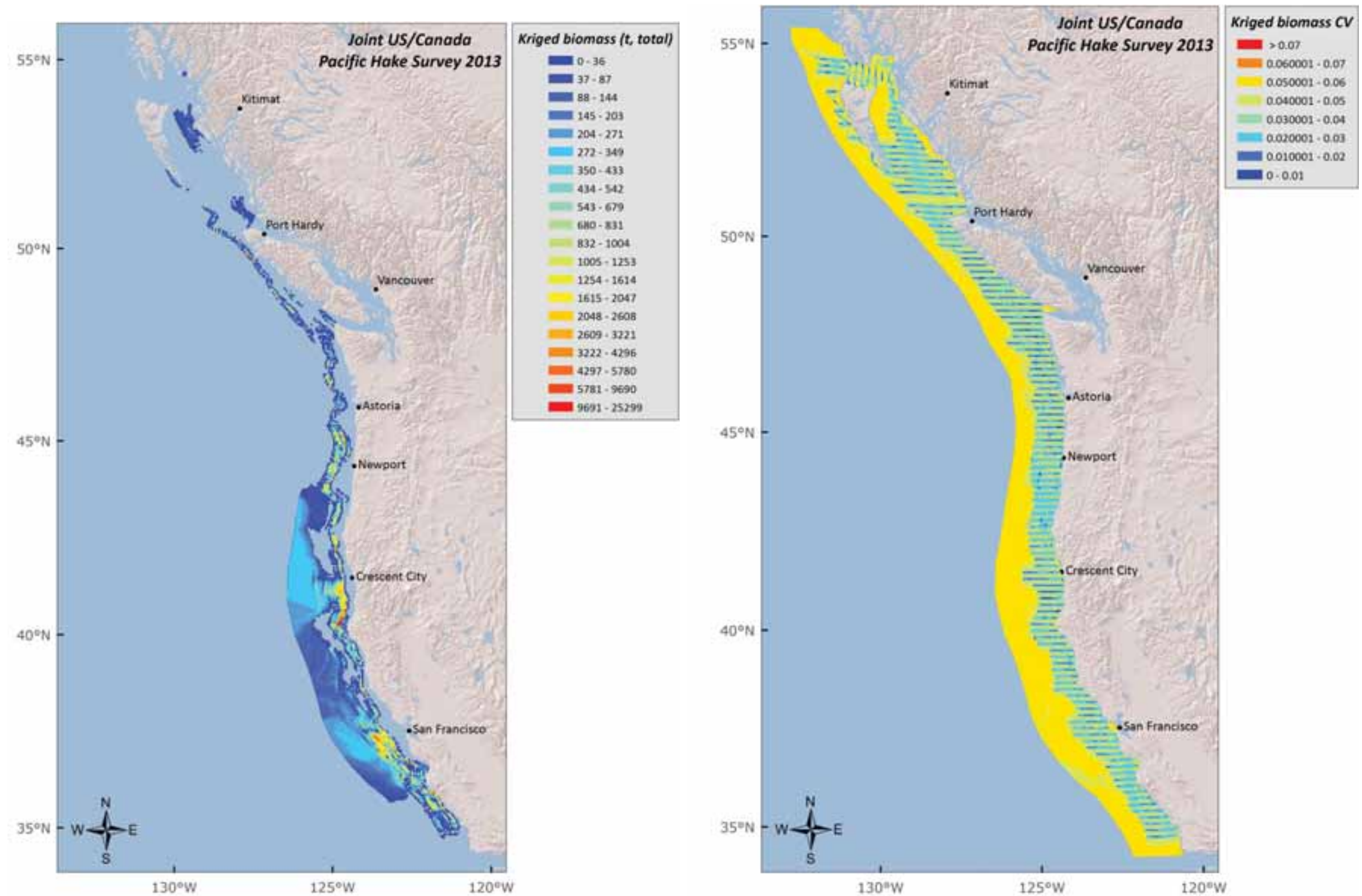



**Figure 8: Estimated biomass (left) and variance (right) from the kriging analysis of the 2013 acoustic survey data.**

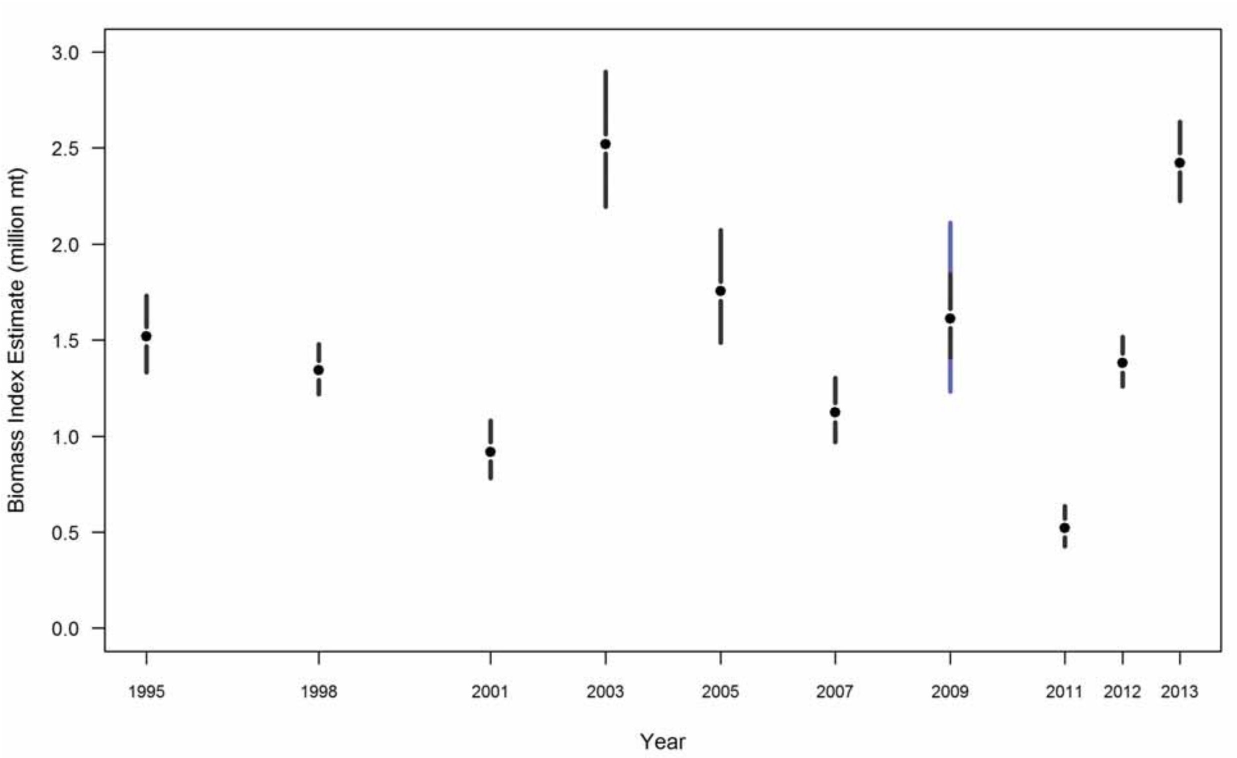



**Figure 9: Acoustic survey biomass indices (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995-2007, 2011–2013) and sampling variability as well as squid/hake apportionment uncertainty (blue bars, 2009).**

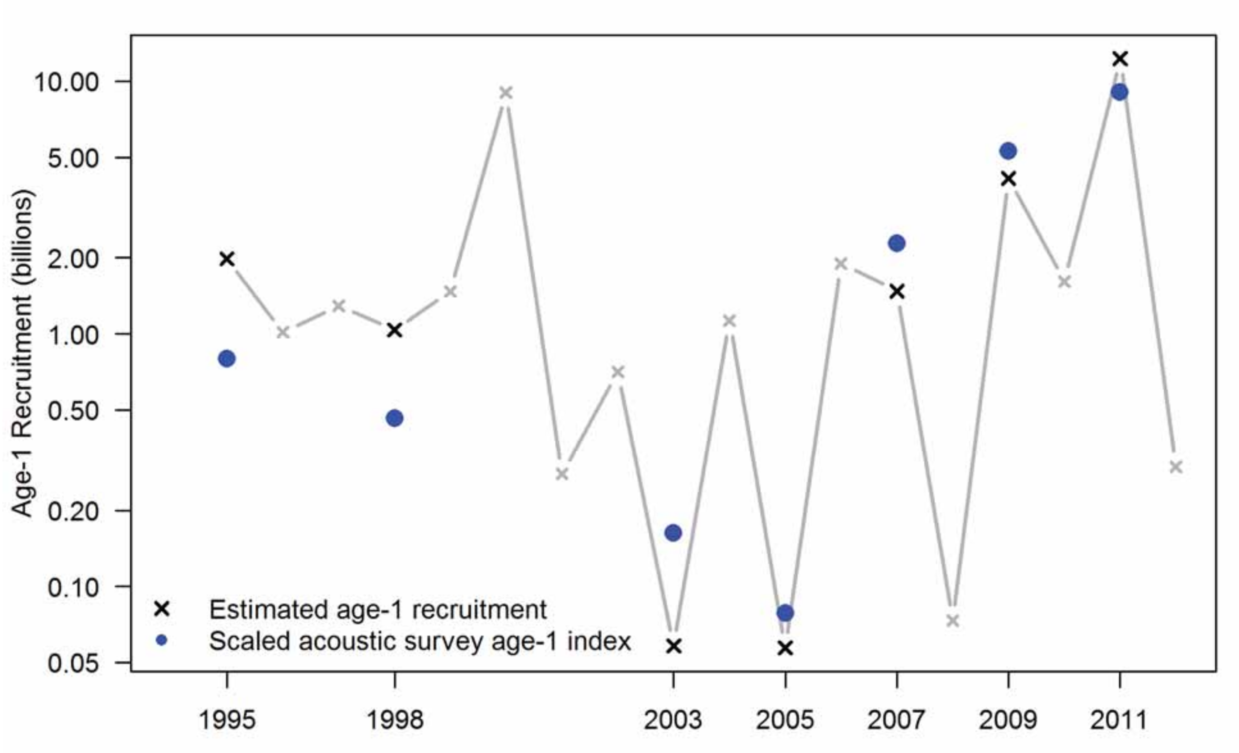



**Figure 10: Preliminary acoustic survey age-1 index overlaid on the base model predicted posterior median numbers at age-1. The y-axis is on a log scale with labels in real space. This figure represents a comparison with, not a fit to, the preliminary age-1 index data.**

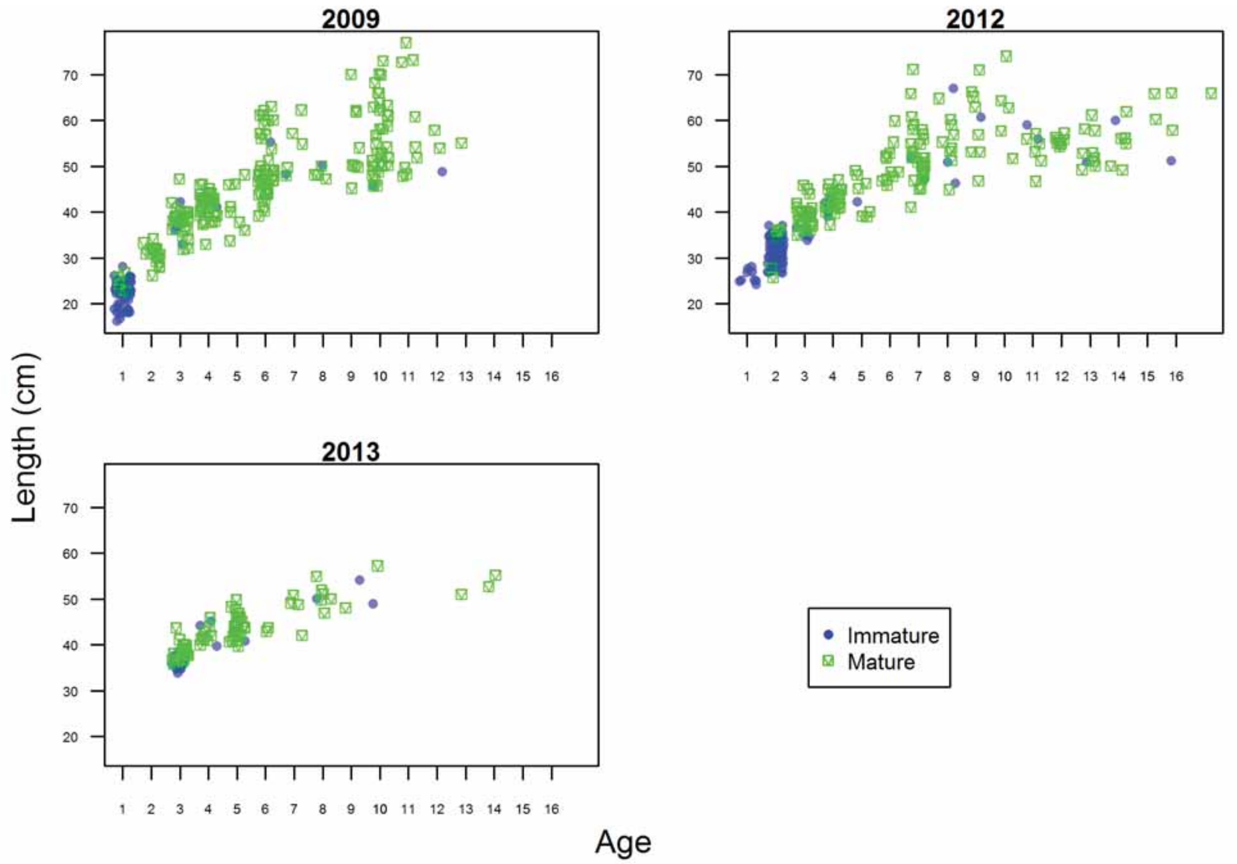



**Figure 11: Observations of mature (green boxes) and immature (blue circles) Pacific Hake determined from ovary samples collected from the bottom trawl survey (2009 & 2012), the acoustic survey (2012), and the at-sea hake observer program (2013). Observations are jittered along the x- and y- axes to show individual observations.**

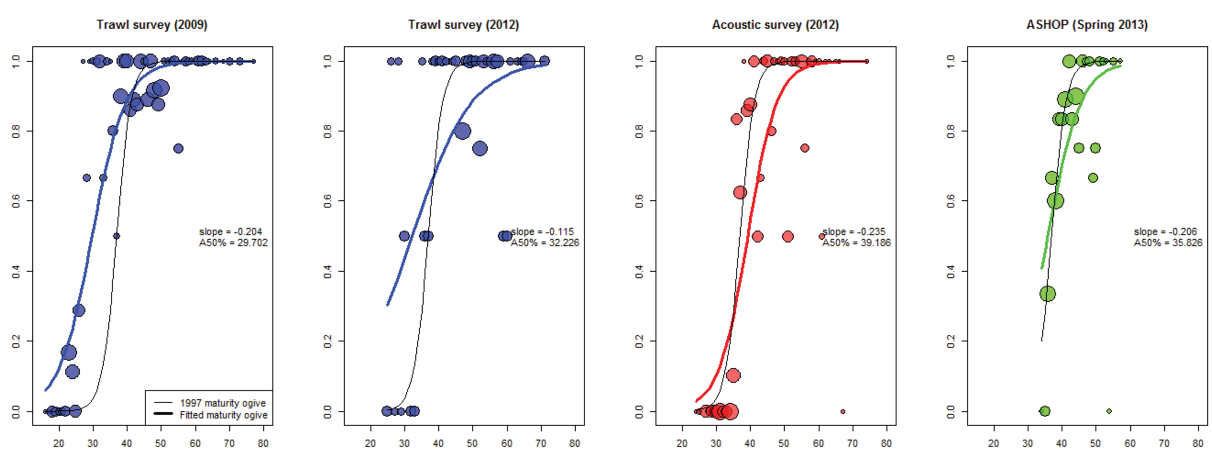



**Figure 12: Proportion mature at length for each combination of year and source. A fitted logistic model is shown by the thick colored line. The maturity-at-length from Dorn & Saunders (1997) is shown by the thin black line.**

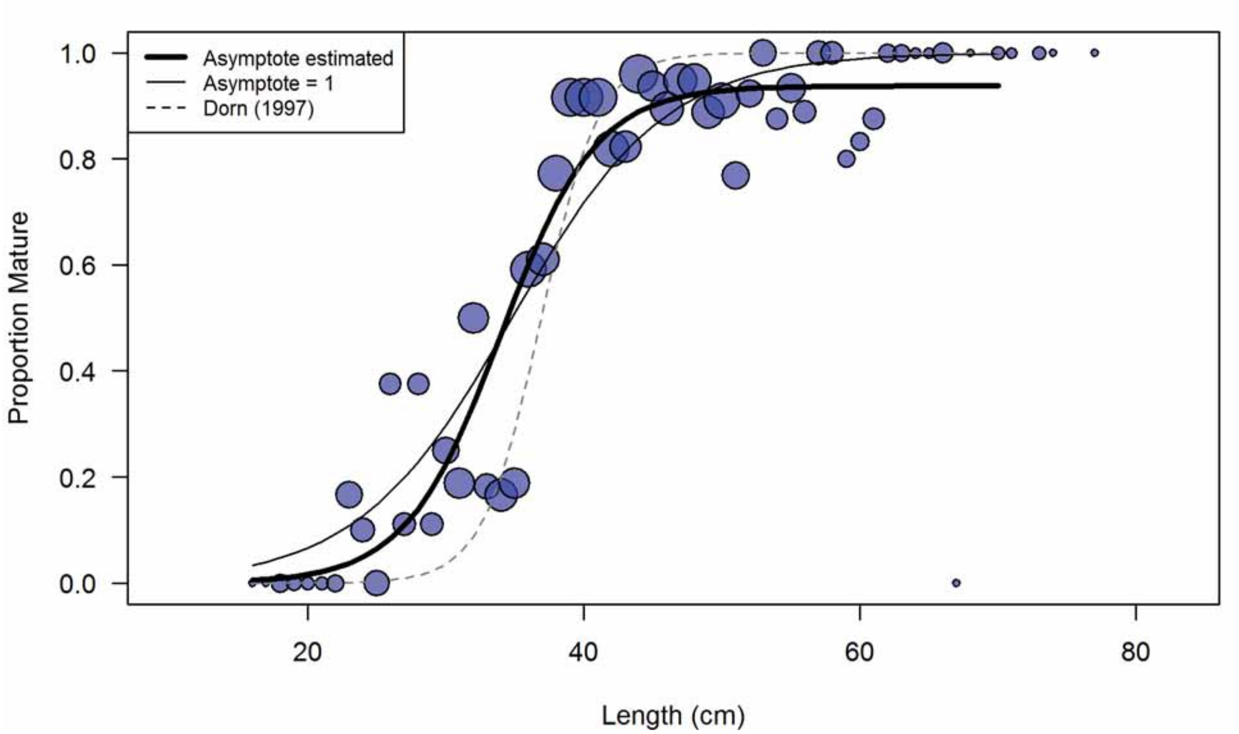



**Figure 13: Proportion mature-at-length shown as blue circles with the area of the circle proportional to the number of observations. A fitted logistic curve with an asymptote at one, a fitted logistic curve with an estimated asymptote, and the maturity-at-length from Dorn & Saunders (1997) are also shown.**

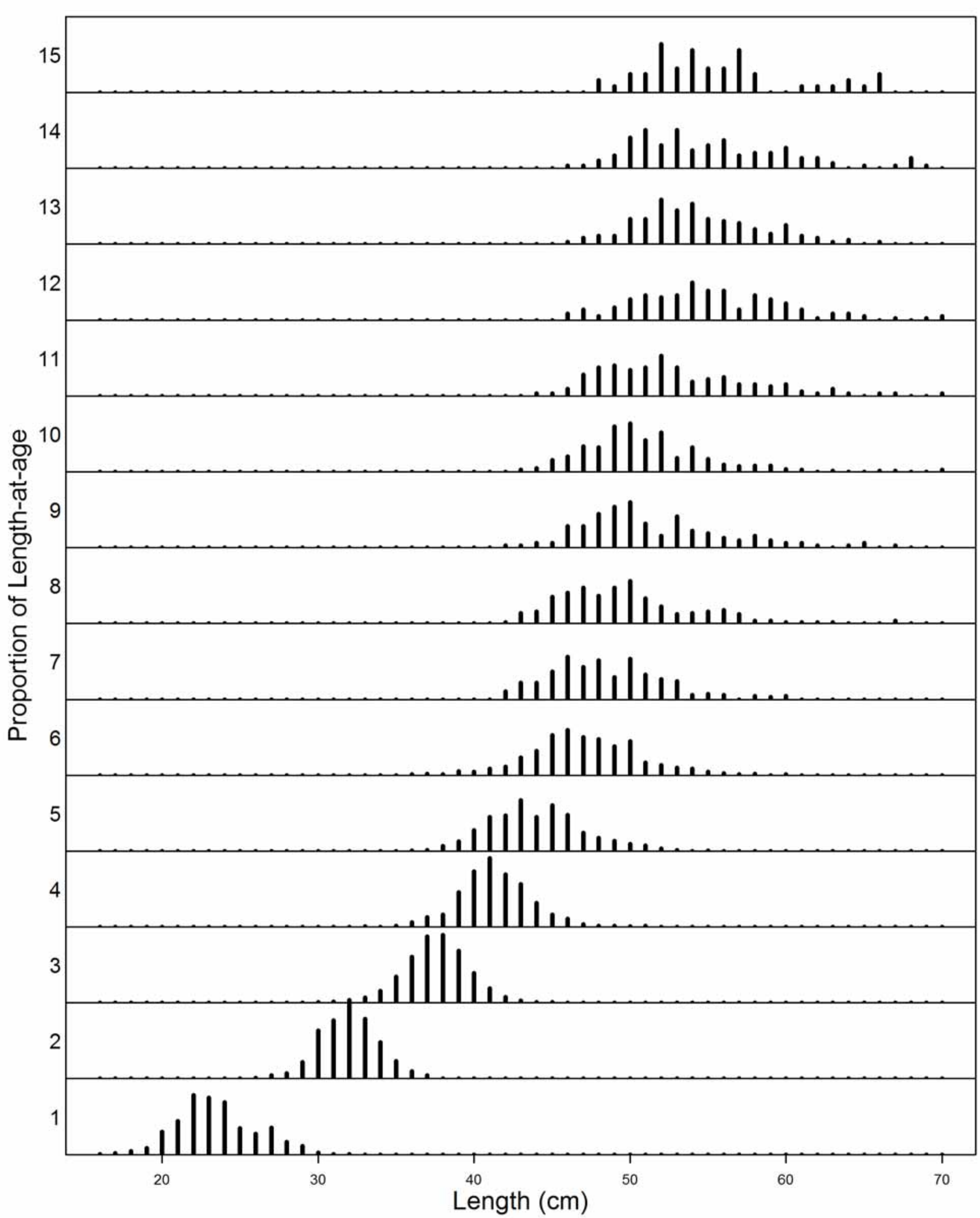



**Figure 14: Proportions of length-at-age (age-length key) used to determine maturity-at-age.**

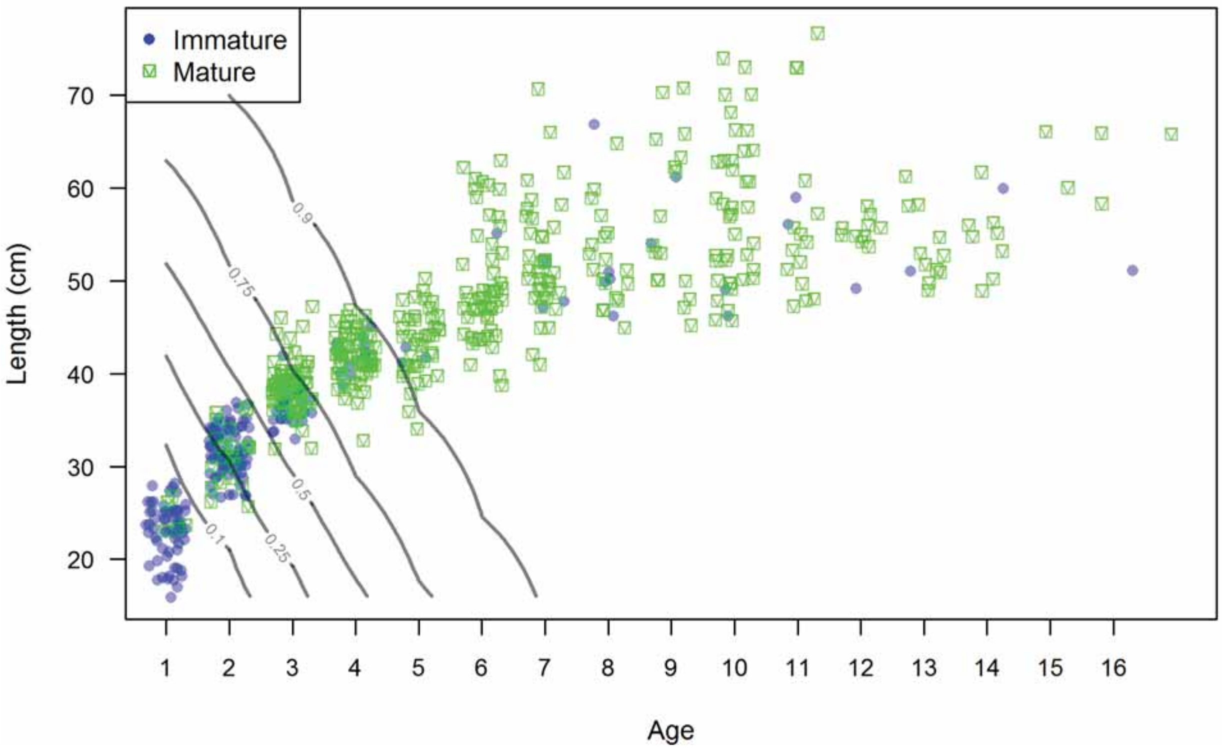



**Figure 15: Mature (green boxes) and immature (blue circles) observations at length (cm) and age. Predicted proportion mature from a fitted logistic regression of maturity against length and age, with an asymptote estimated, is shown by the contour lines. Observations are jittered along the x- and y- axes to show individual observations.**

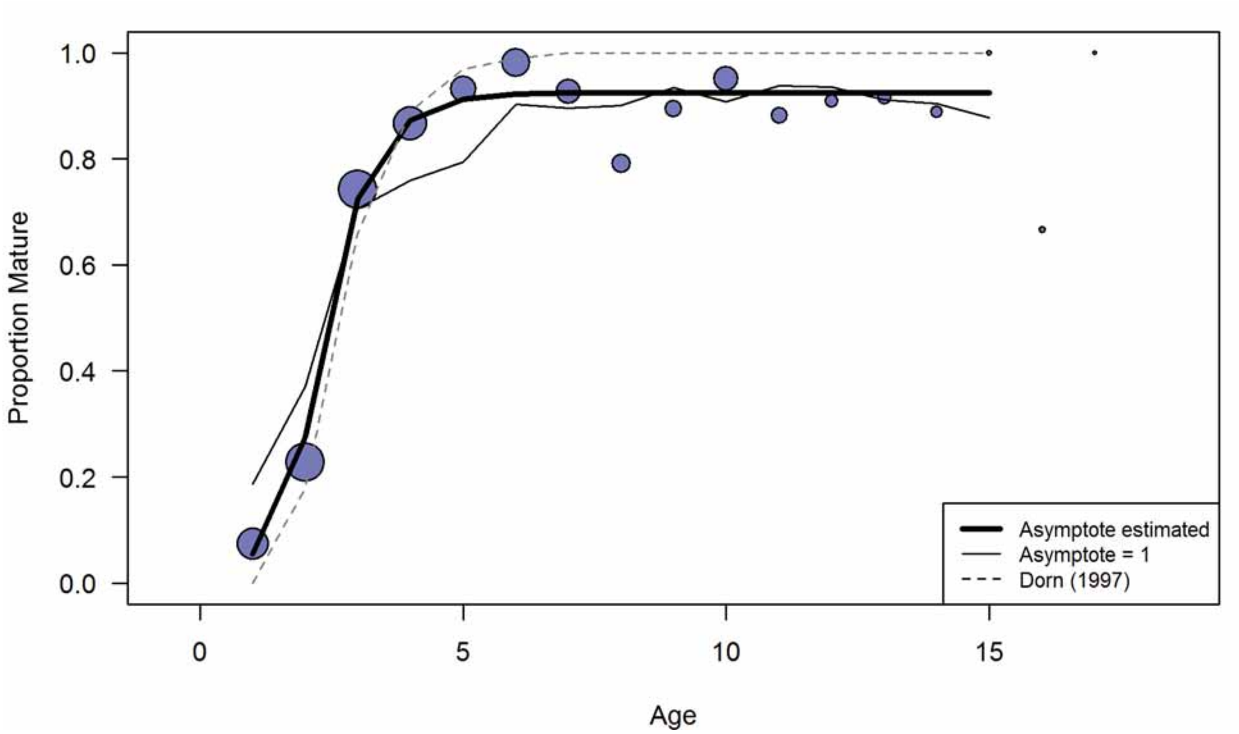



**Figure 16: Proportion mature at age shown by blue circles with the area of the circle proportional to the number of observations. Maturity-at-age is shown as a dashed line from Dorn & Saunders (1997), as a thin solid line from a logistic model with an asymptote at one, and as a thick solid line from a logistic model with the asymptote estimated.**

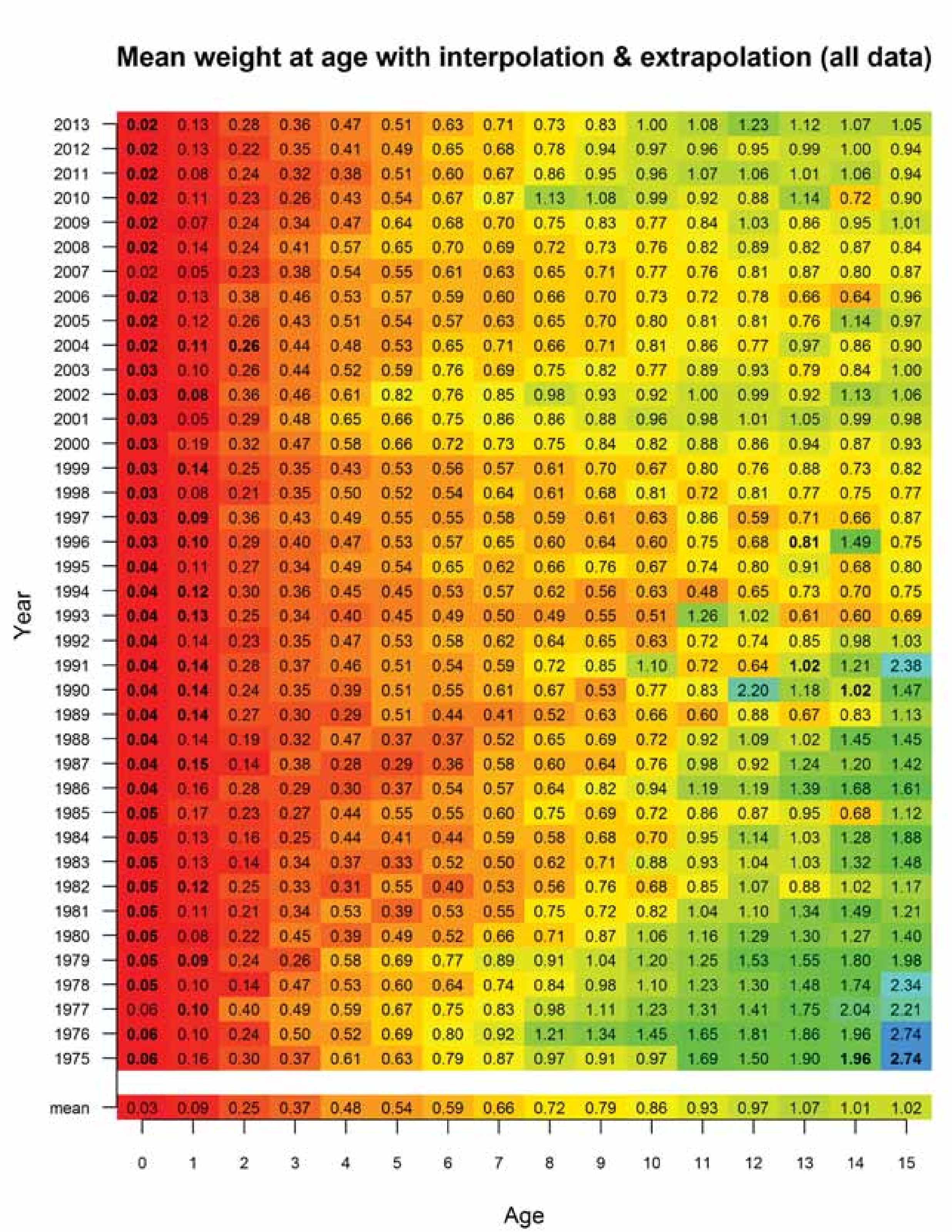



**Figure 17: Empirical weight-at-age (kg) used in the assessment. Numbers shown in bold were interpolated or extrapolated from adjacent years.**

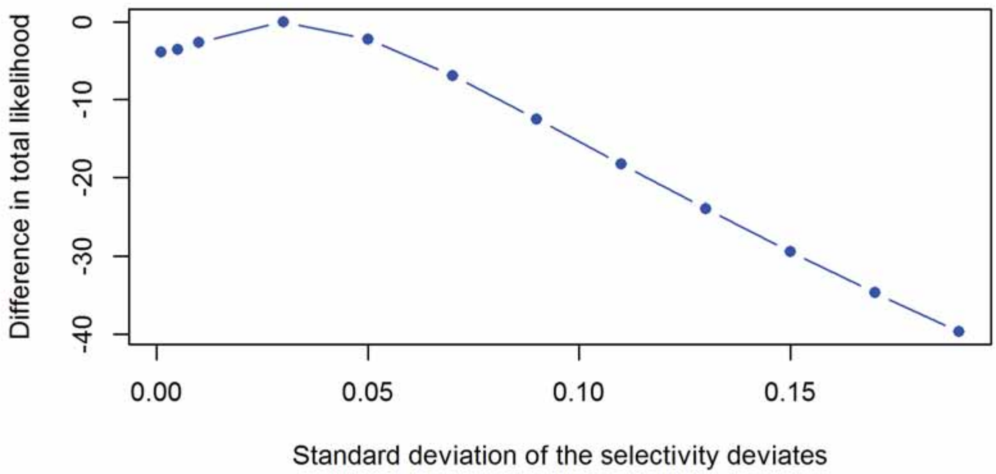



**Figure 18: Difference in the log likelihood from the maximum for the standard deviation for the penalty on the selectivity deviates determined from the random effects model using the Laplace approximation as described by Thorson et al. (2014).**

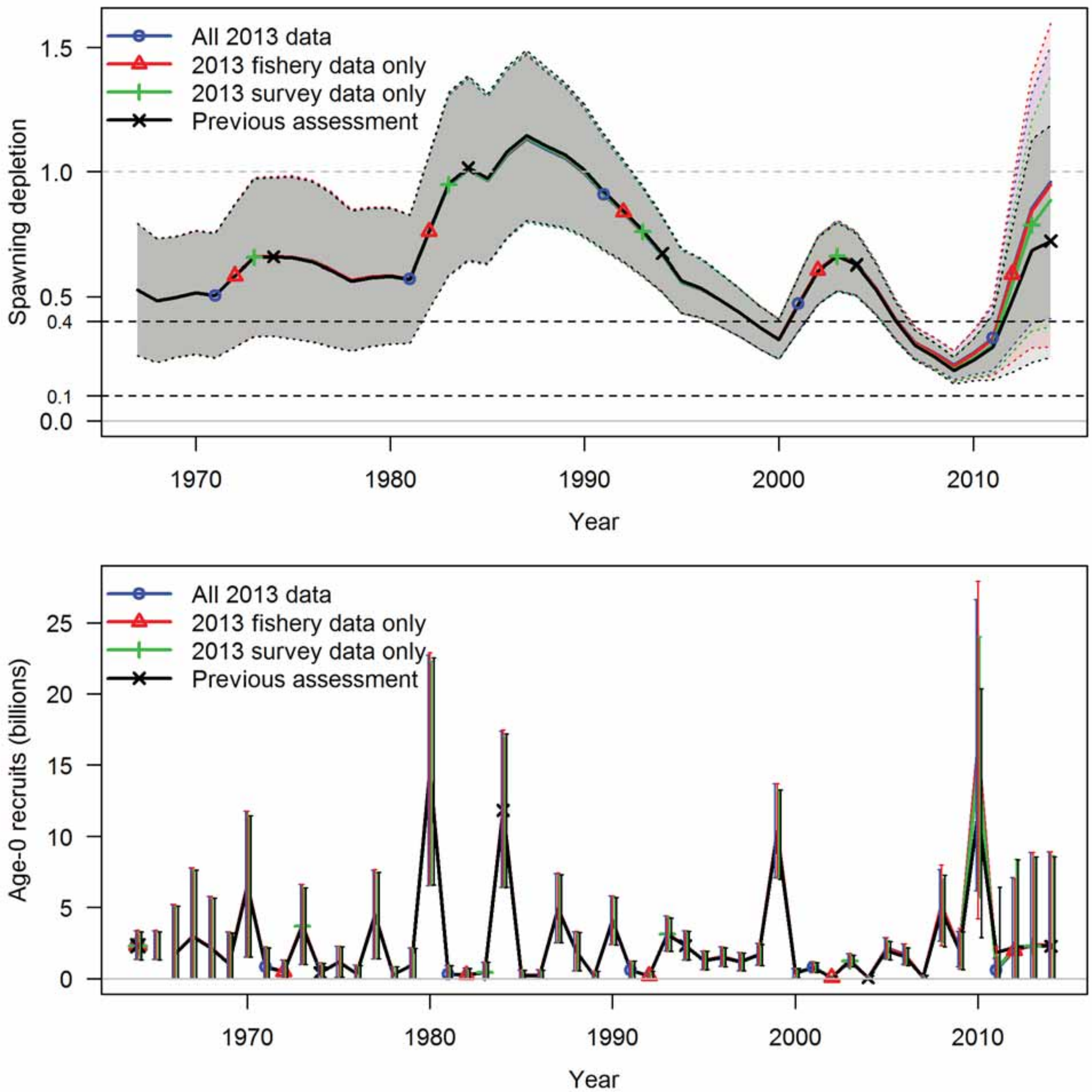



**Figure 19: Bridge models from the 2013 base model (previous assessment) to a similar model with all new 2013 data (All 2013 data).**

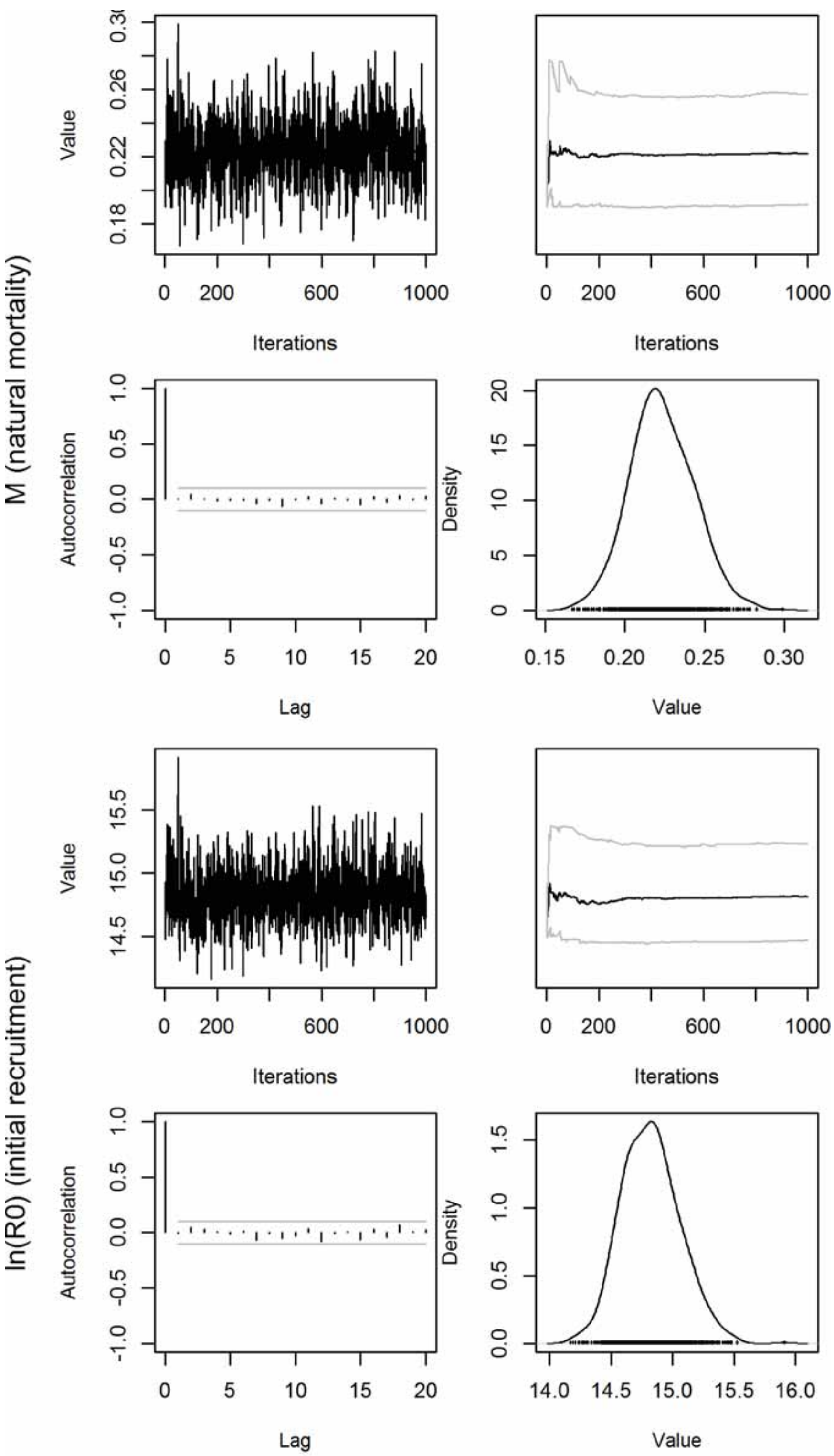



**Figure 20: Summary of MCMC diagnostics for natural mortality (upper panels) and log($R_0$) (lower panels) in the base model.**

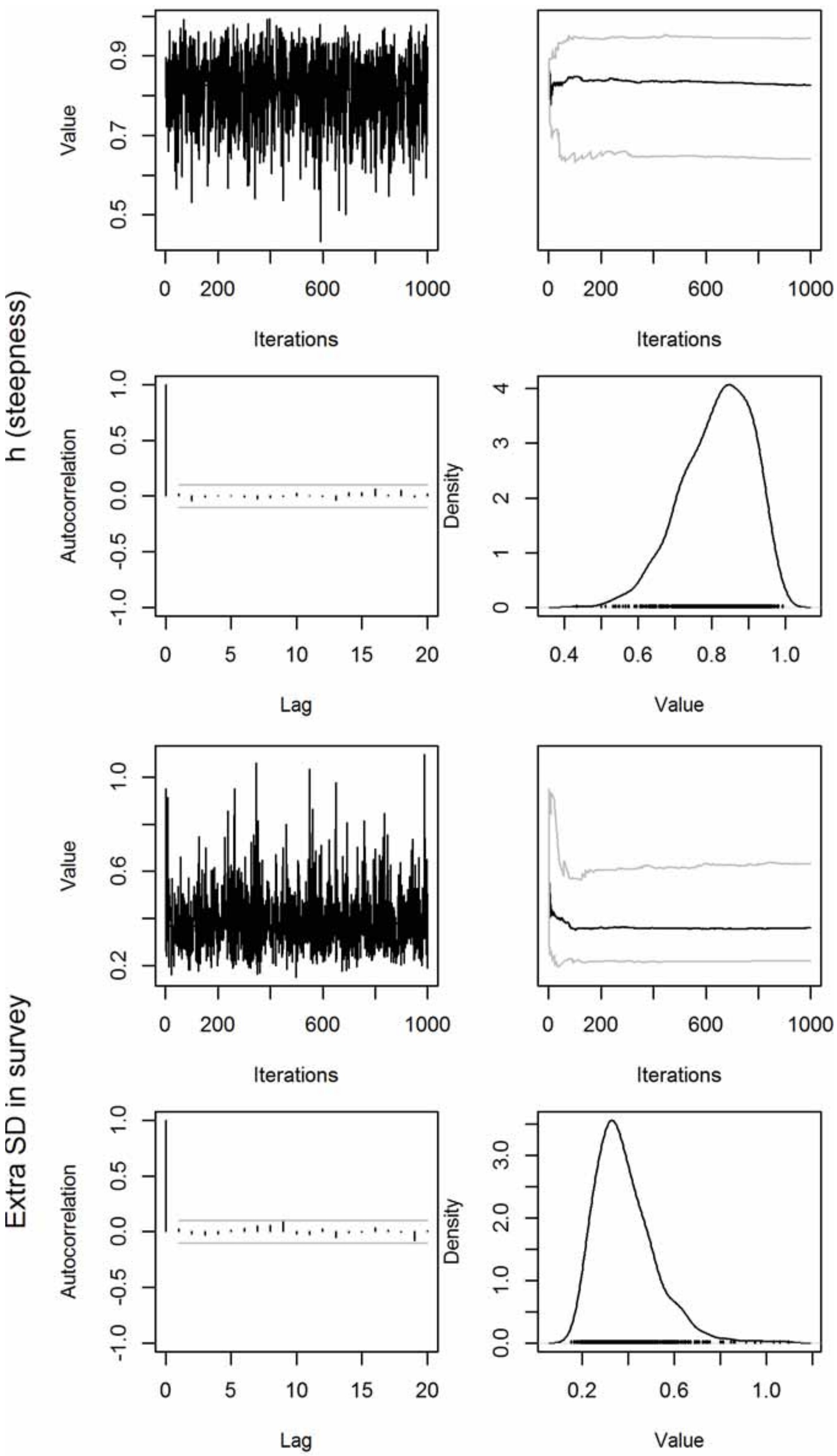



**Figure 21: Summary of MCMC diagnostics for steepness (upper panels) and the additional SD for the acoustic survey index (lower panels) in the base model.**

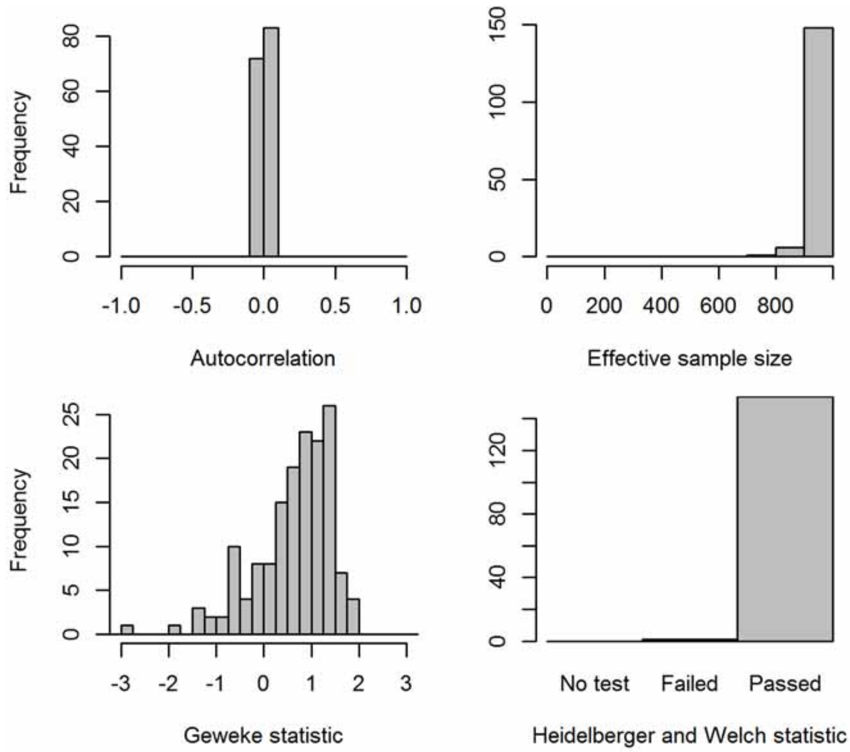



**Figure 22: Summary histograms of MCMC diagnostics for all base model parameters and derived quantities including the recruitment, spawning biomass, and depletion time-series.**

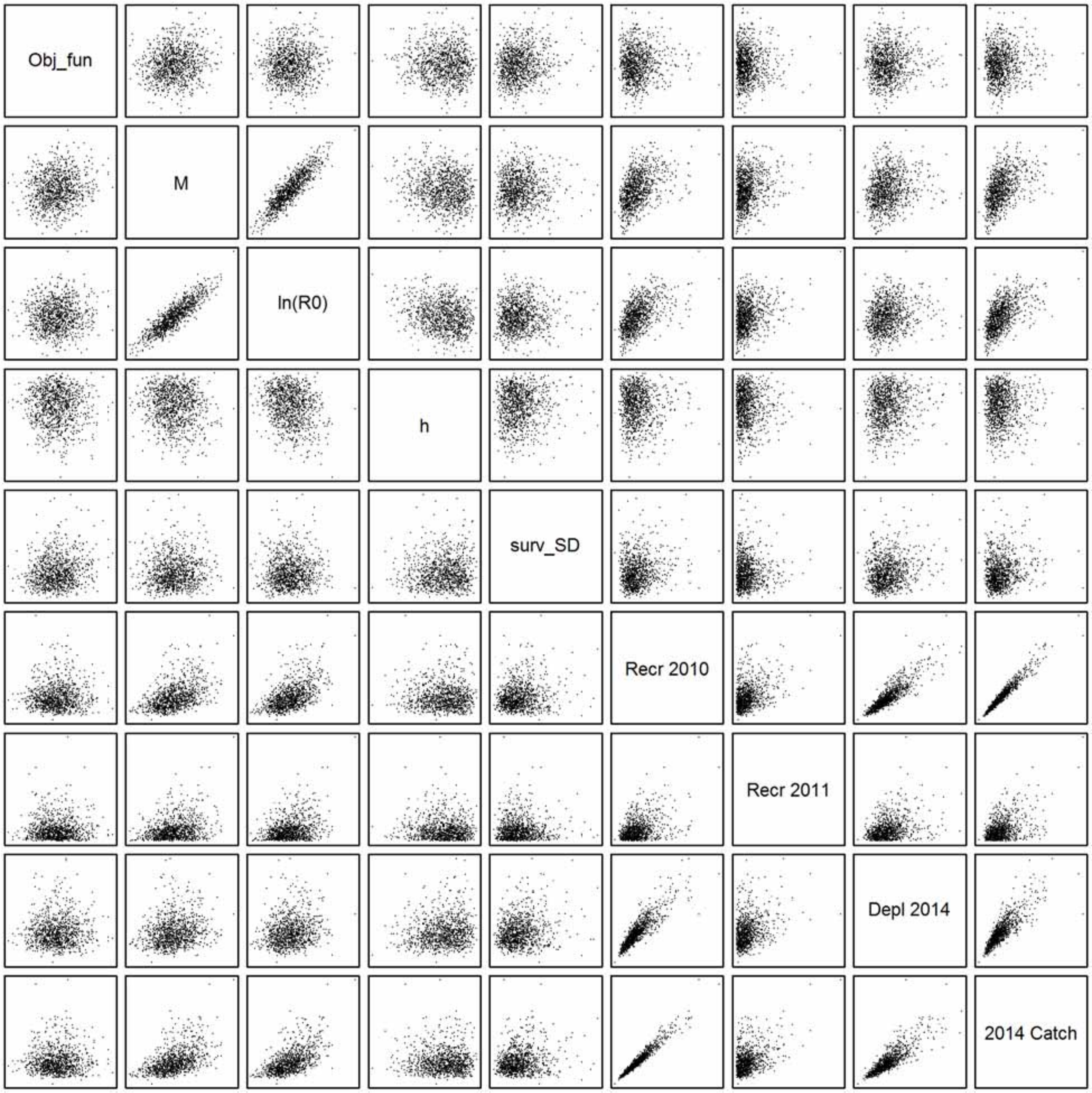



**Figure 23: Posterior correlations among key base-model parameters and derived quantities. From the top left the posteriors plotted are: objective function, natural mortality, $\ln(R_0)$, steepness, the process-error SD for the acoustic survey, the 2008 recruitment deviation, the 2010 recruitment deviation, the depletion level in 2012, and the default harvest rate yield for 2013.**

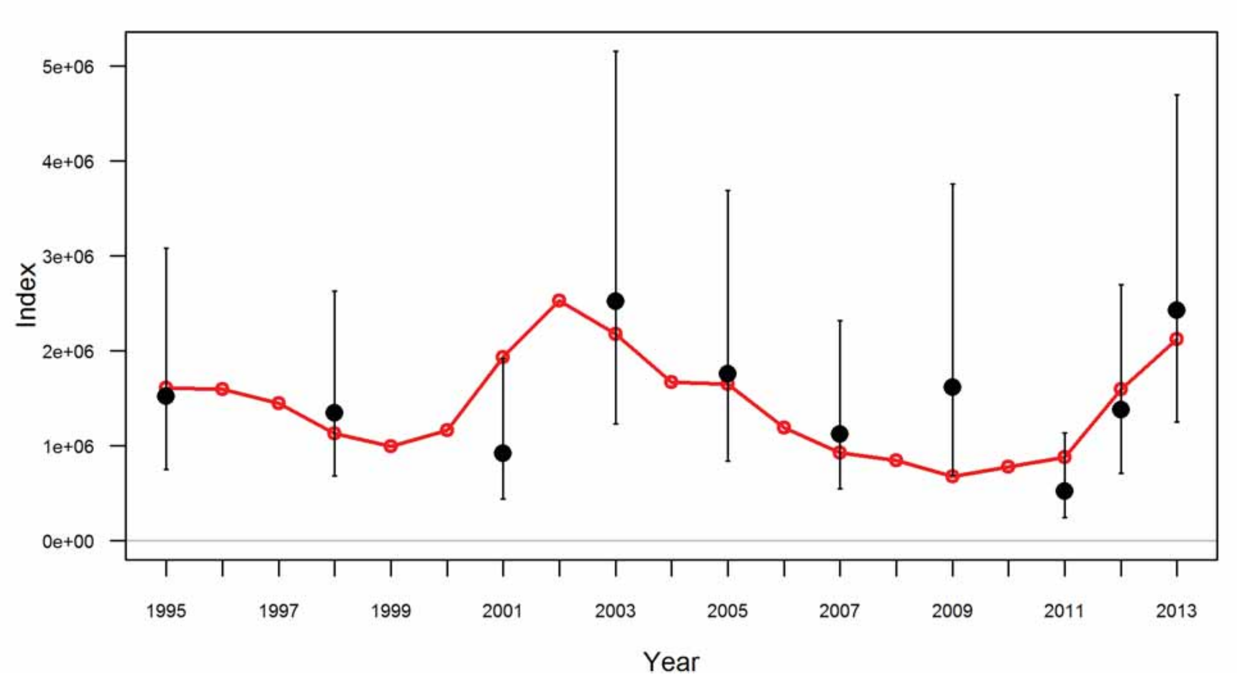



**Figure 24: Predicted MLE fits to the acoustic survey with 95% confidence intervals around the index points. Red circles connected by the line are predicted survey estimates in every year, including years without a survey.**

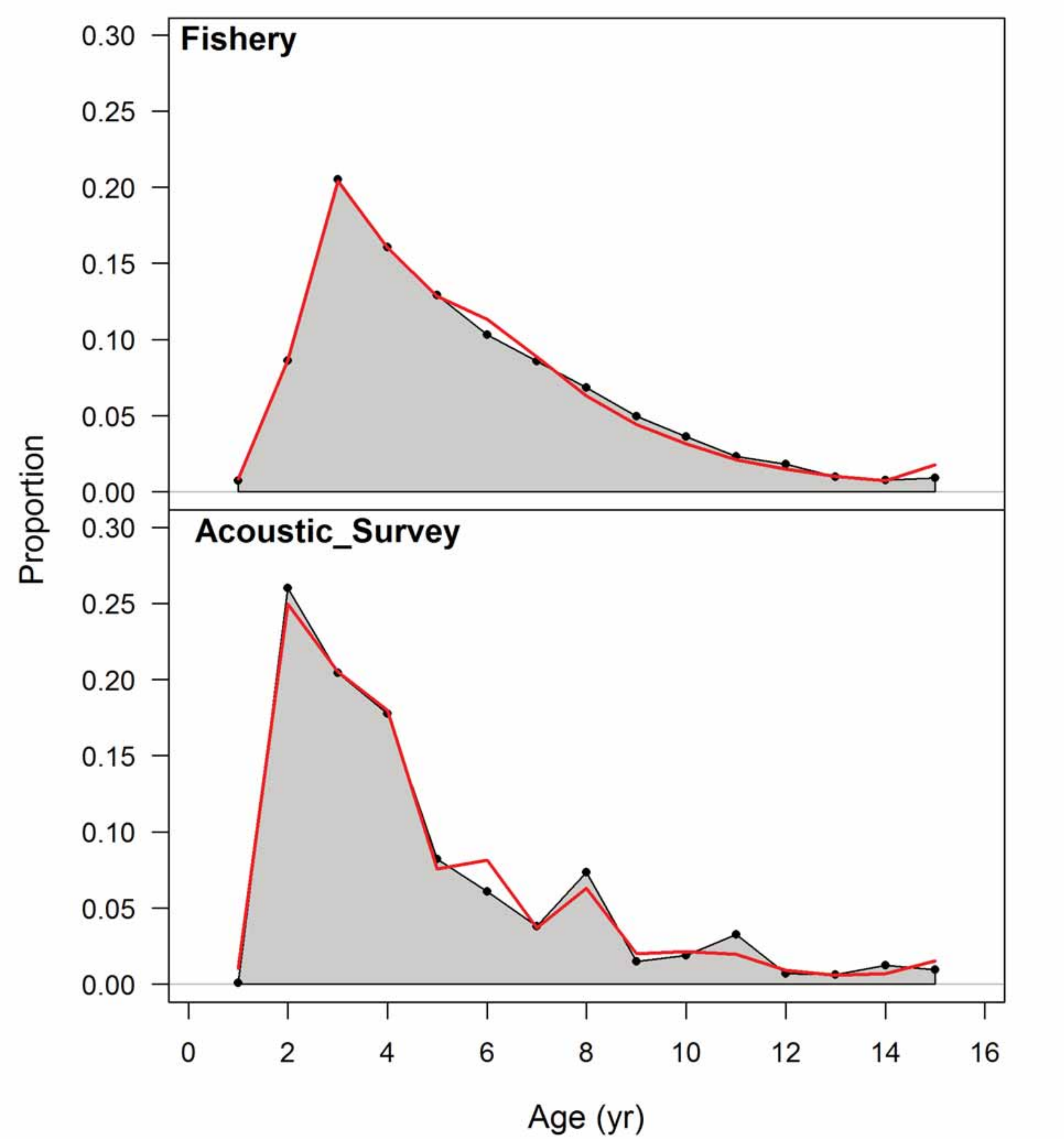



**Figure 25: Aggregate fit to fishery and survey age compositions.**

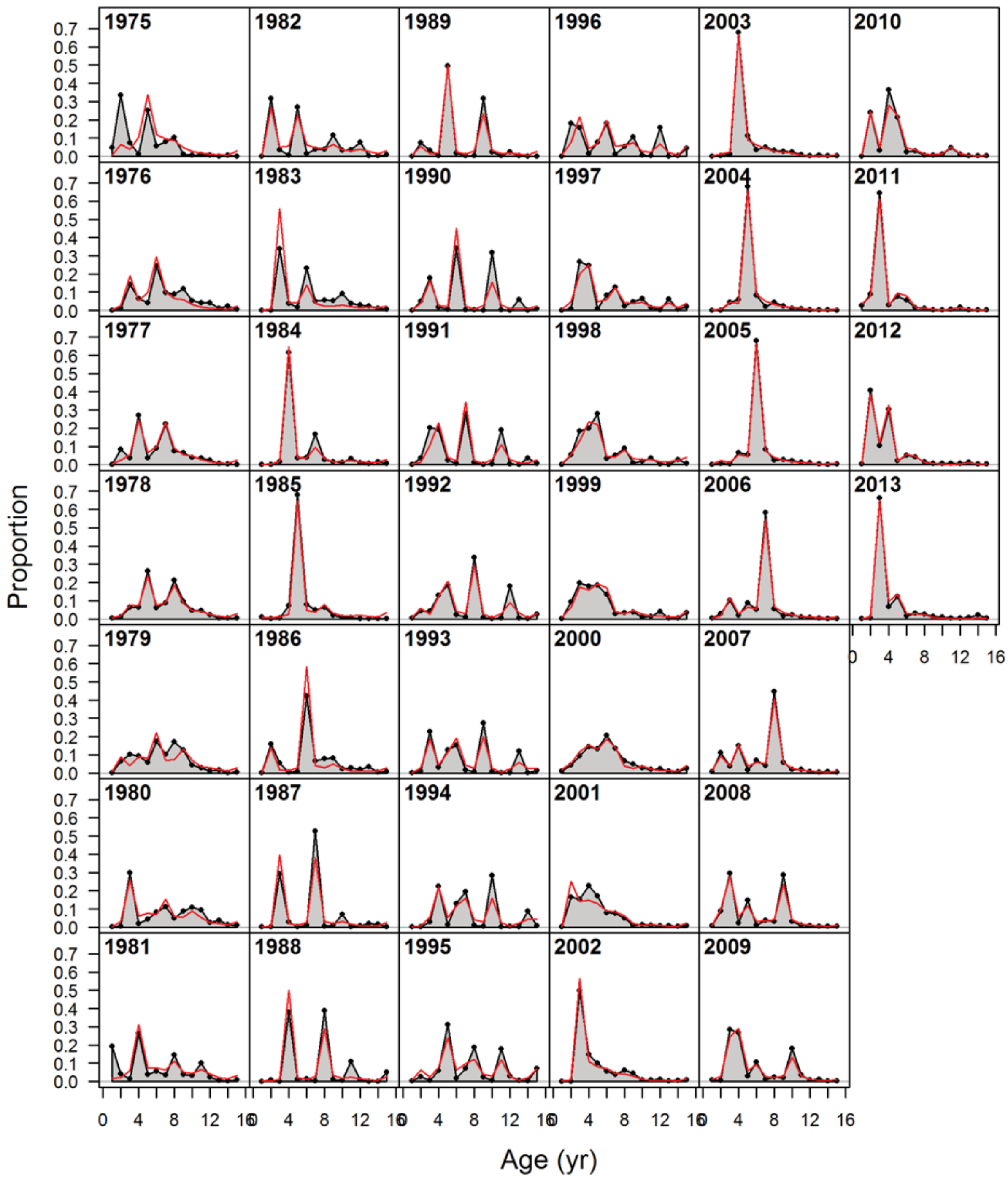



**Figure 26: Base model fit to the observed fishery age compositions.**

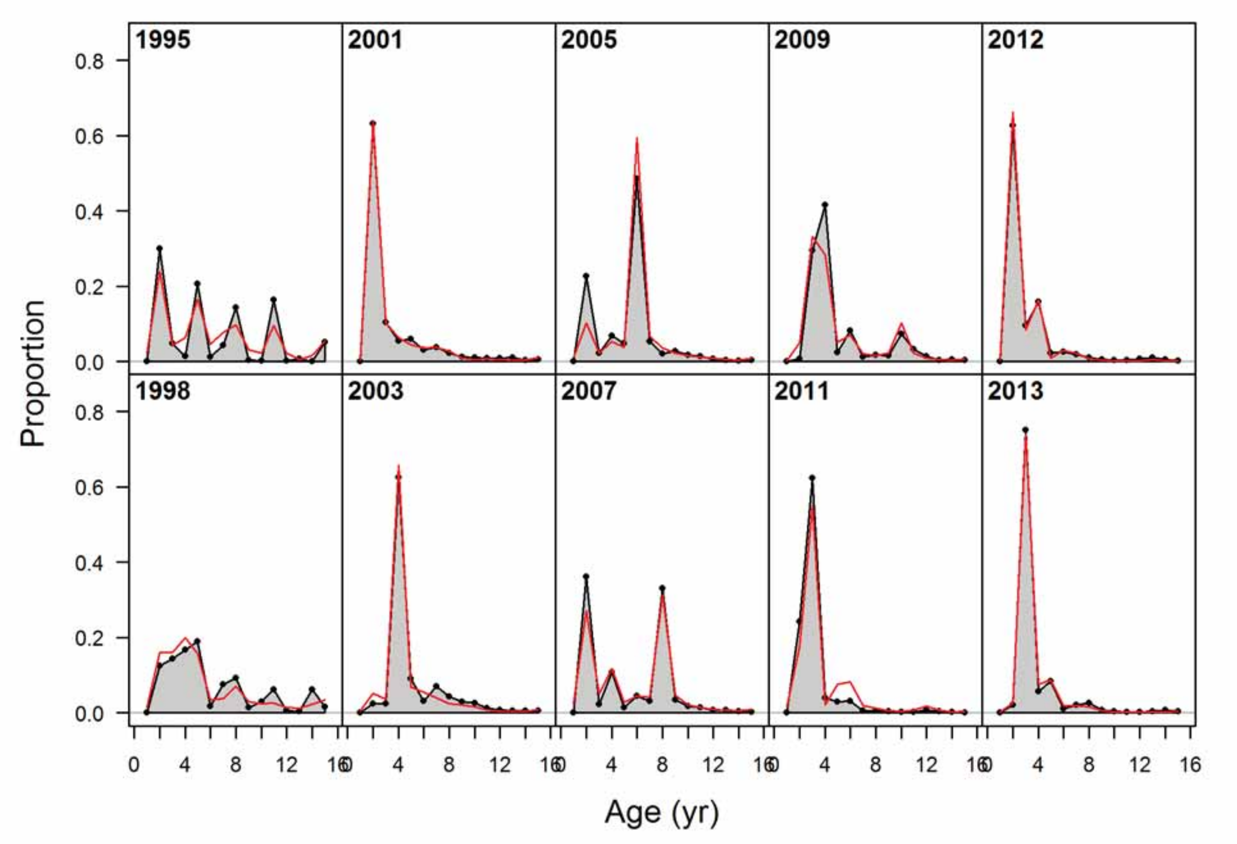



**Figure 27: Base model fit to the observed acoustic survey age composition data.**

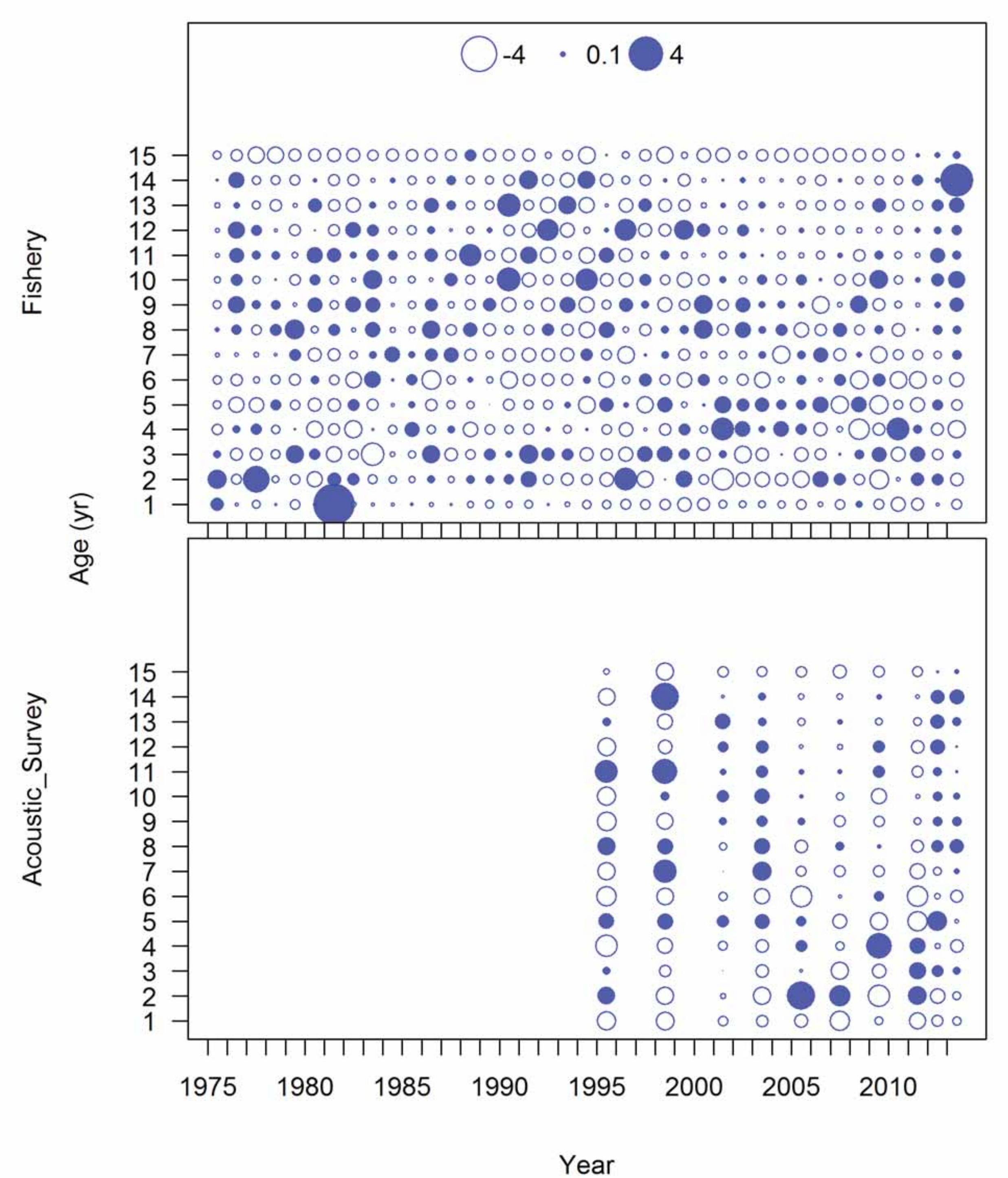



**Figure 28: Pearson residuals (observed - predicted) for base model fits to the fishery age composition data. Filled circles represent positive values.**

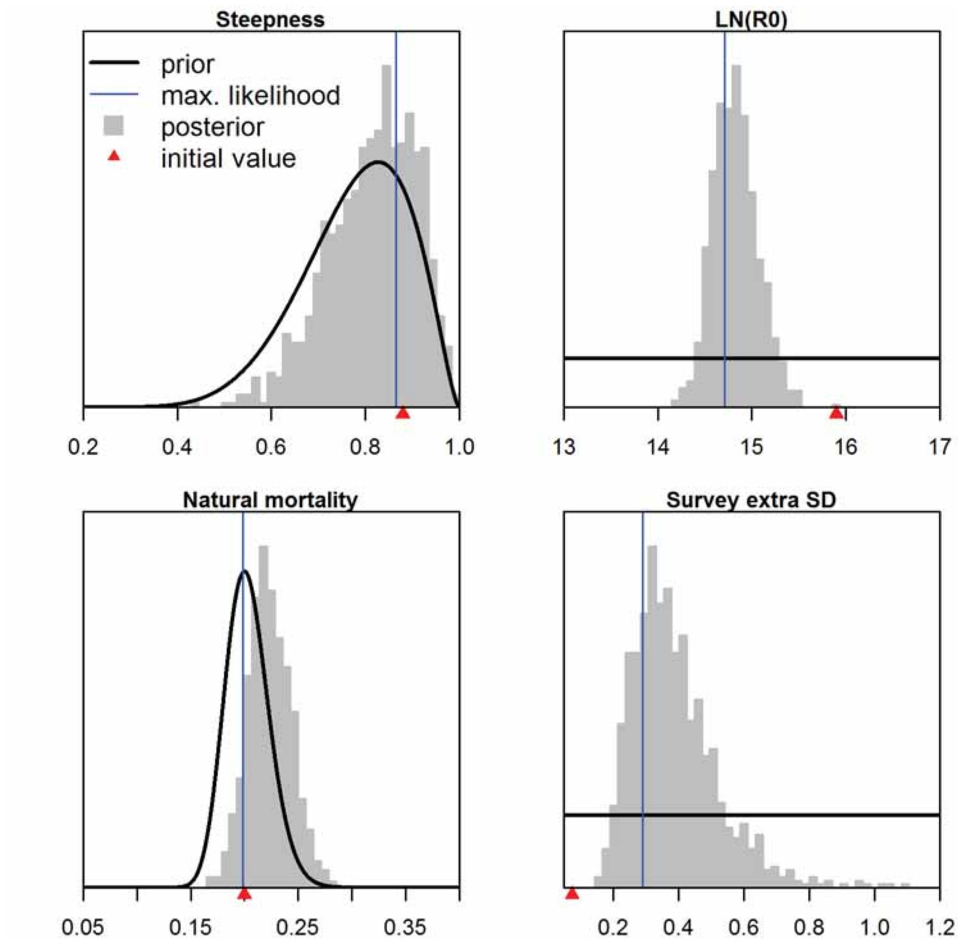



**Figure 29: Prior and posterior probability distributions for key parameters in the base model. From the top left, the parameters are: steepness (*h*), Natural mortality (*M*), equilibrium log recruitment ln($R_0$), and the additional process-error SD for the acoustic survey.**

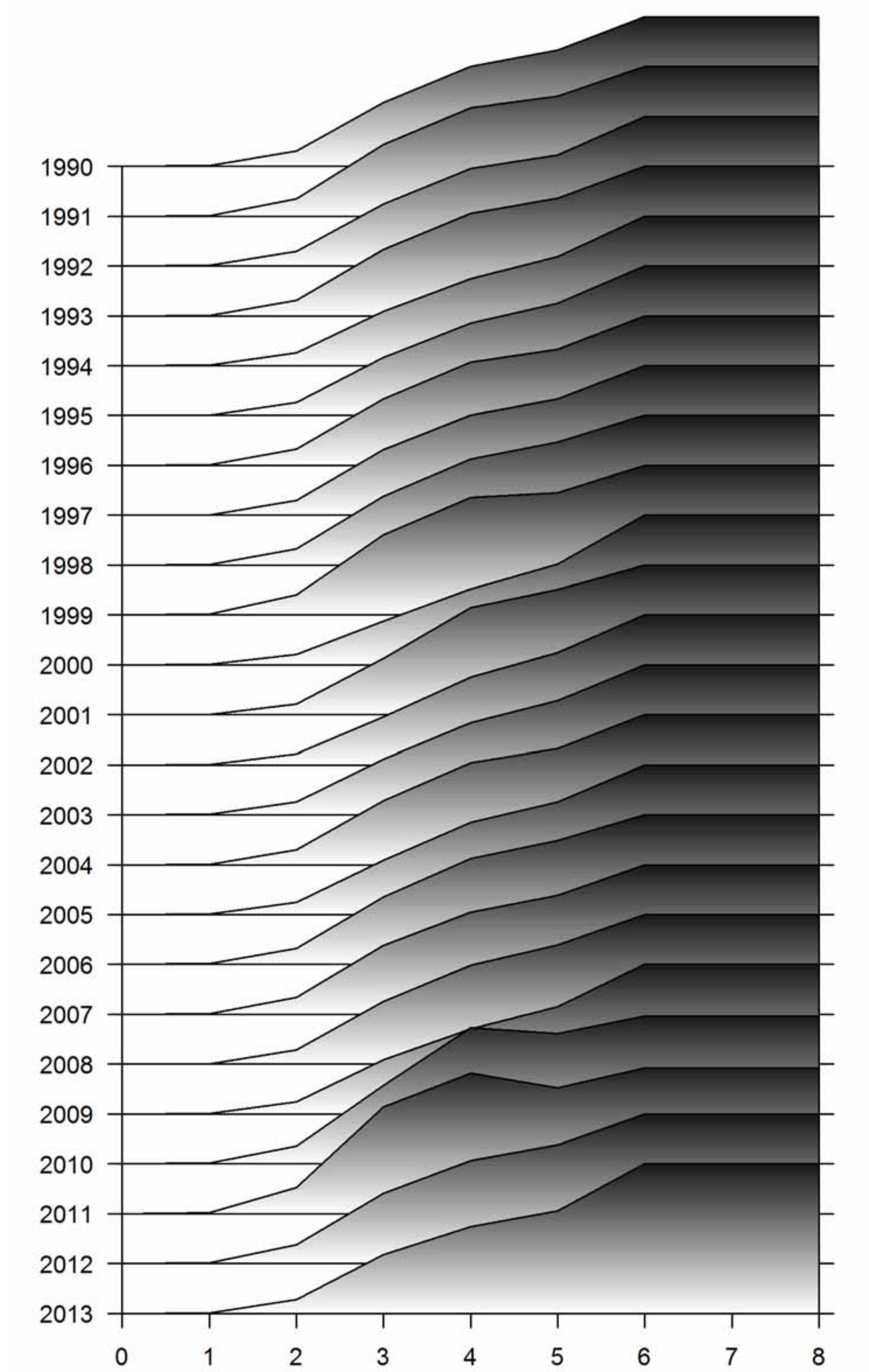



**Figure 30: Mountains plot of time varying fishery selectivity for the base model**

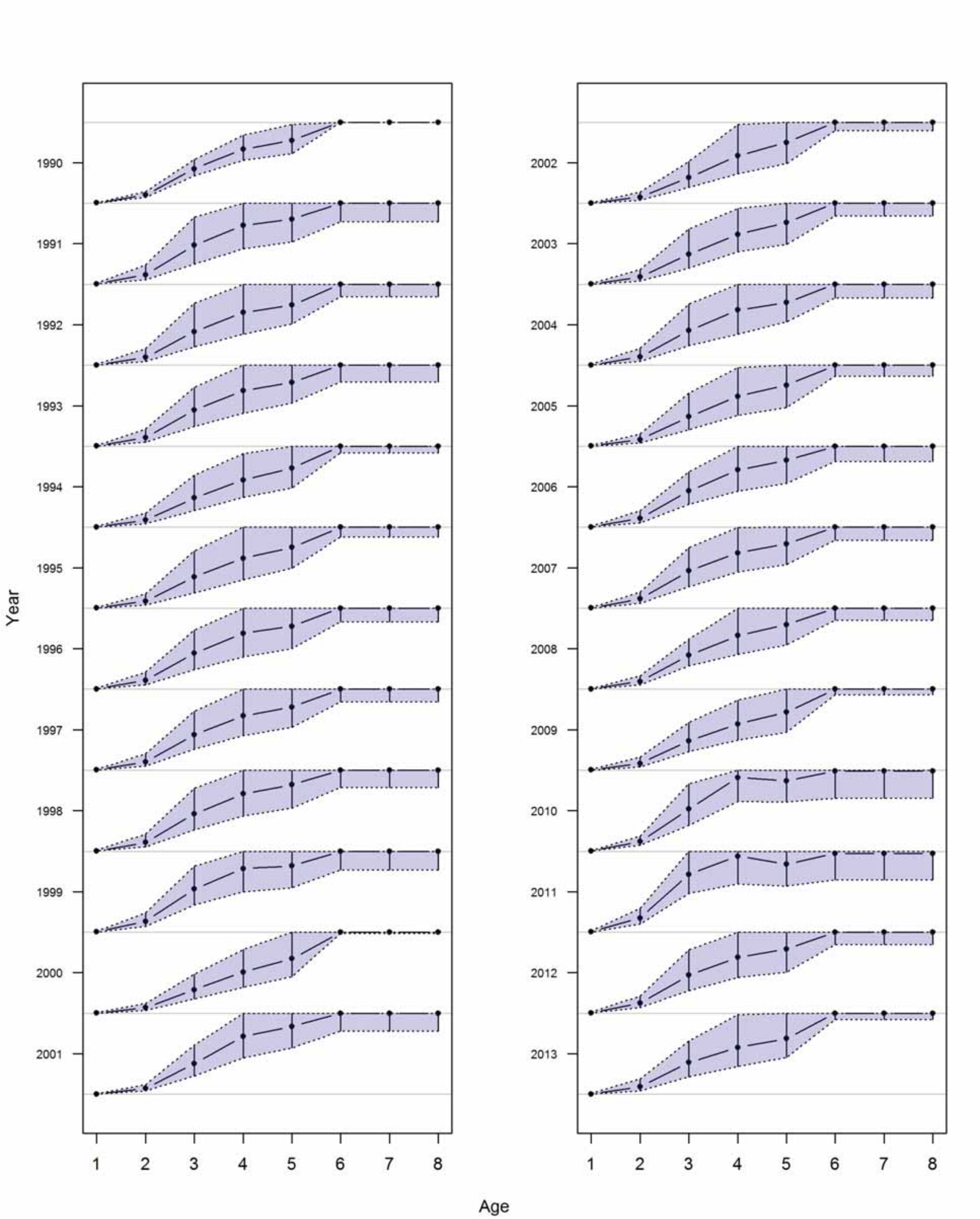



**Figure 31: Fishery selectivity sampled from posterior probability distribution by year. Black dots and bars indicate the median and 95% credibility interval, respectively. The shaded polygon also shows the 95% credibility interval.**

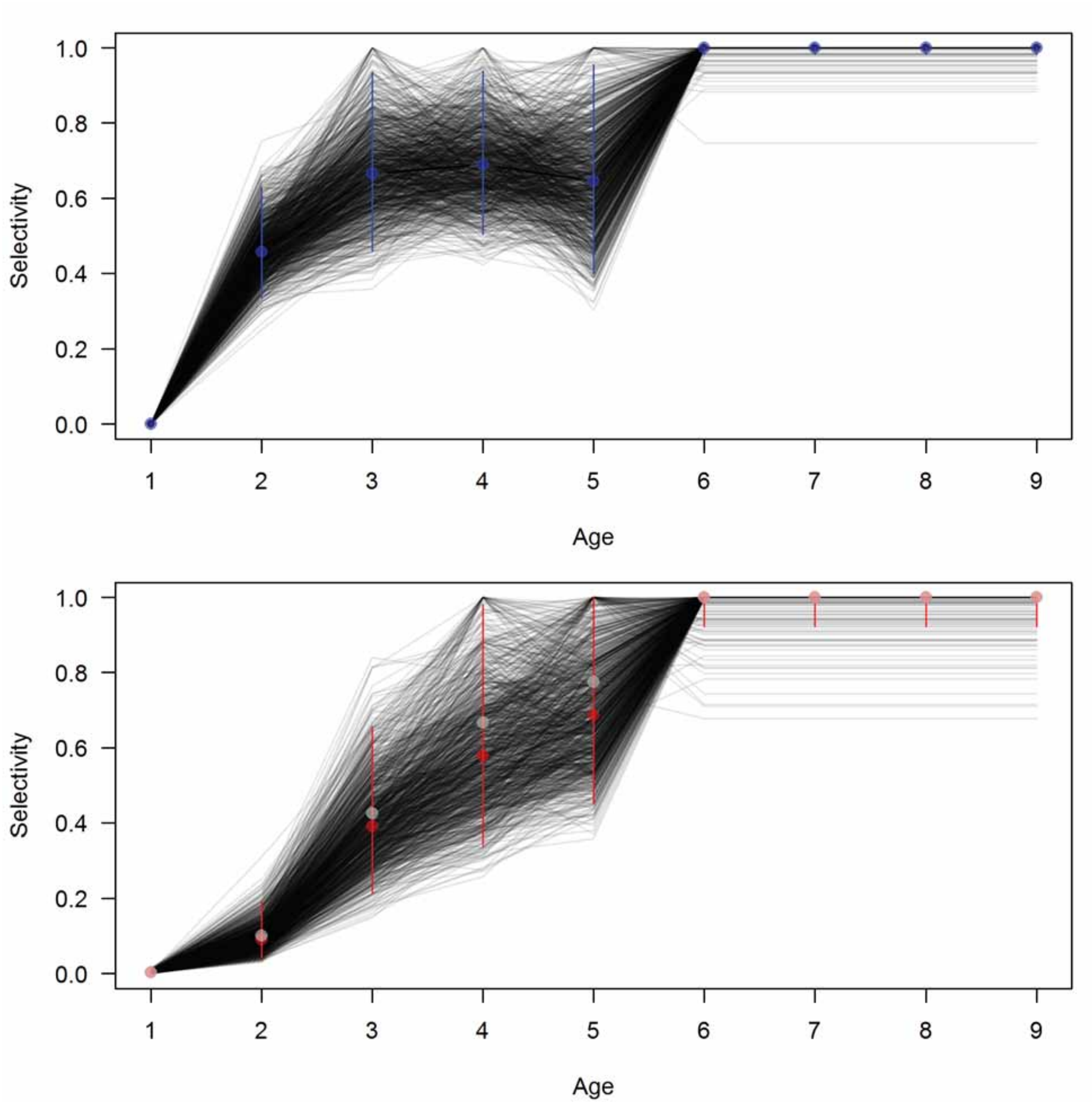



**Figure 32: Estimated acoustic (top) and fishery (bottom) selectivity (2013) ogives from the posterior distribution**

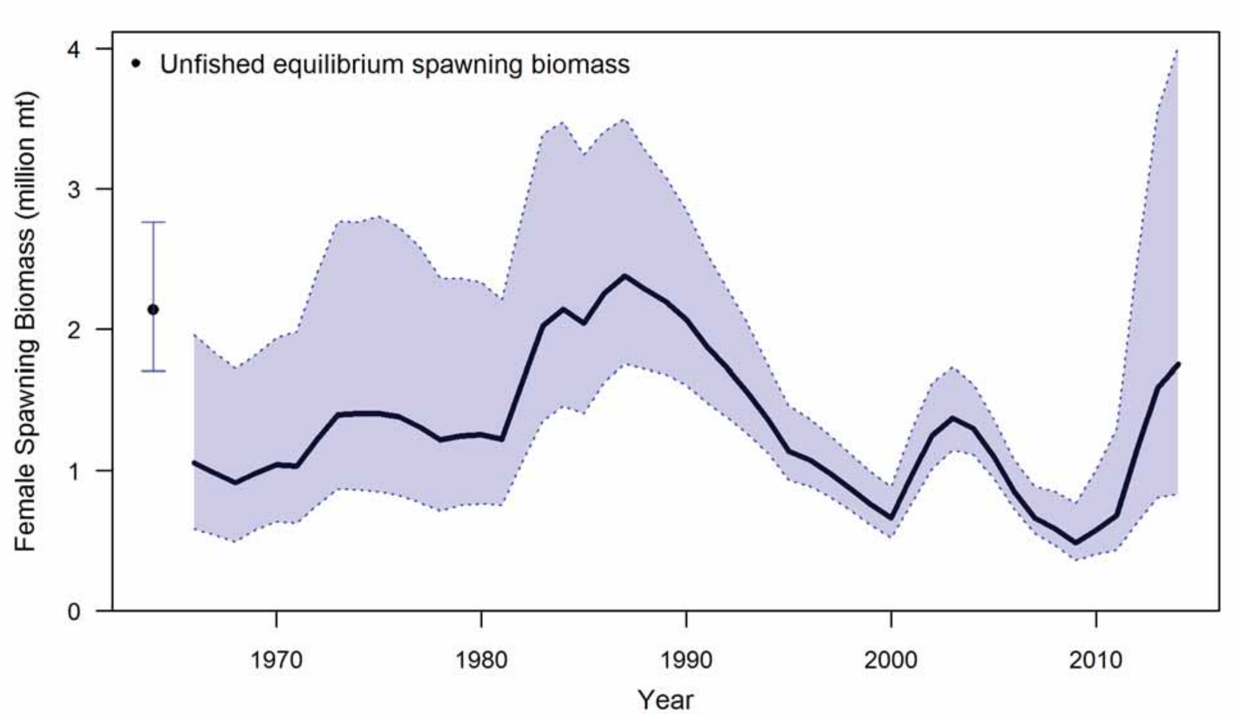


Figure 33: Median of the posterior distribution for female spawning biomass through 2013 (solid line) with 95% posterior credibility intervals (shaded area).

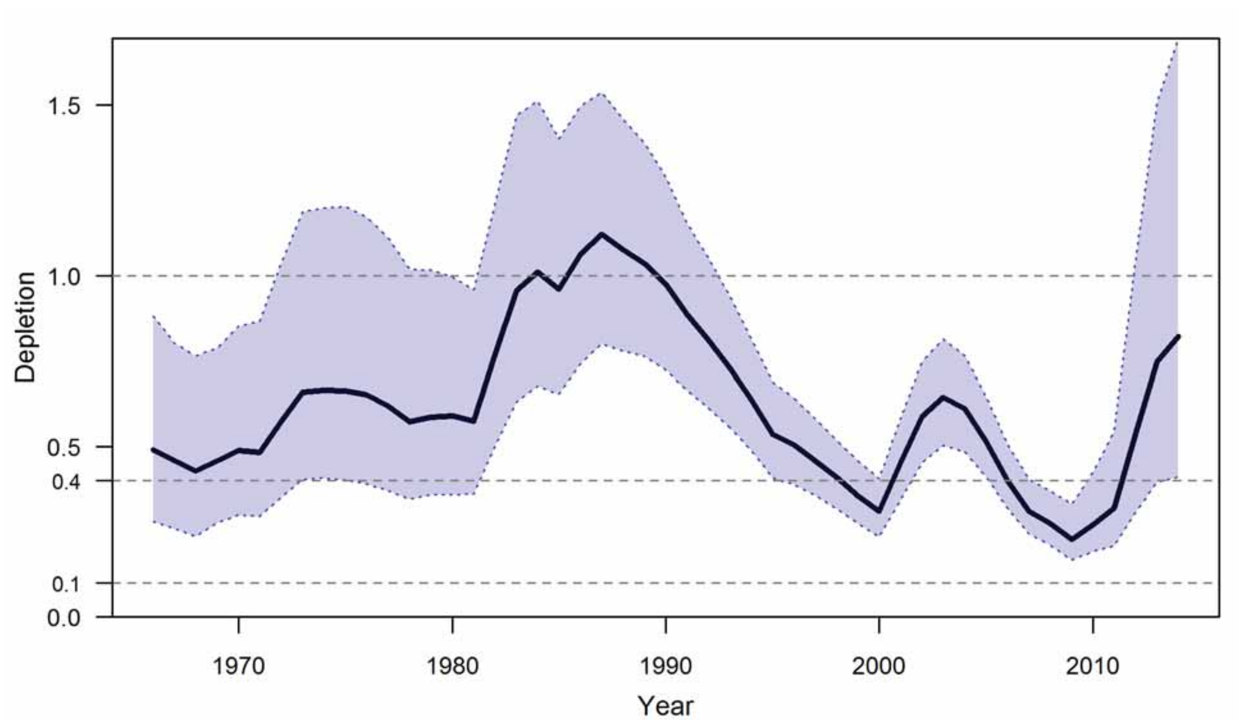


Figure 34: Median (solid line) of the posterior distribution for spawning depletion ($B_t$ /$B_0$) through 2013 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% depletion levels.

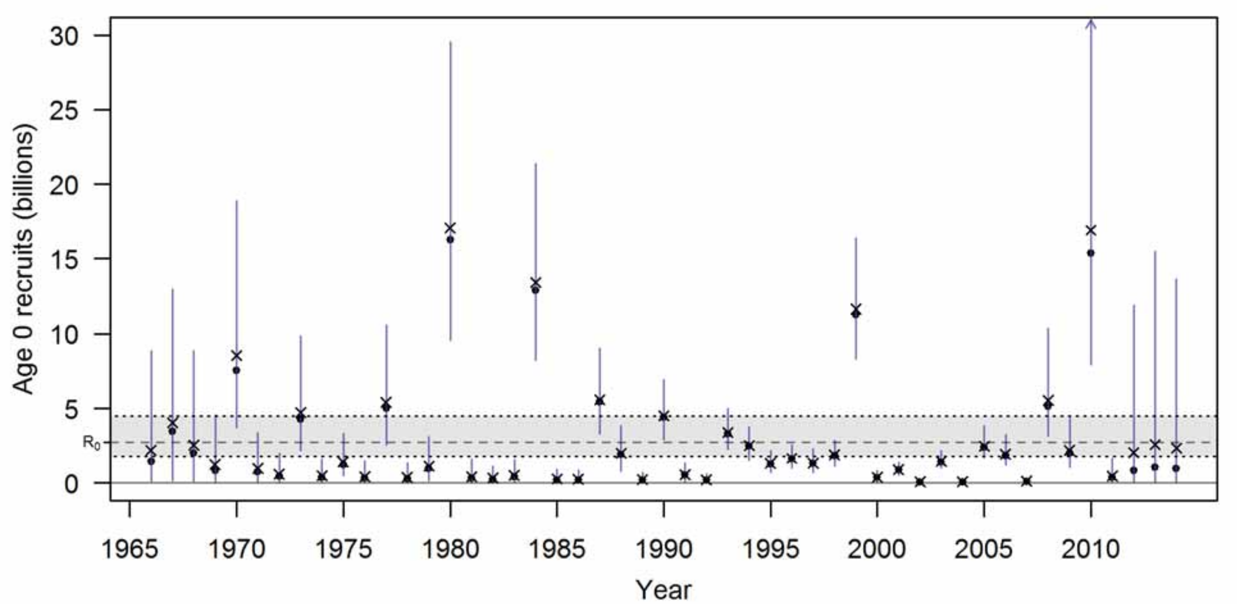



**Figure 35: Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment is shown as the horizontal dashed line with a 95% posterior credibility shaded on either side of the median.**

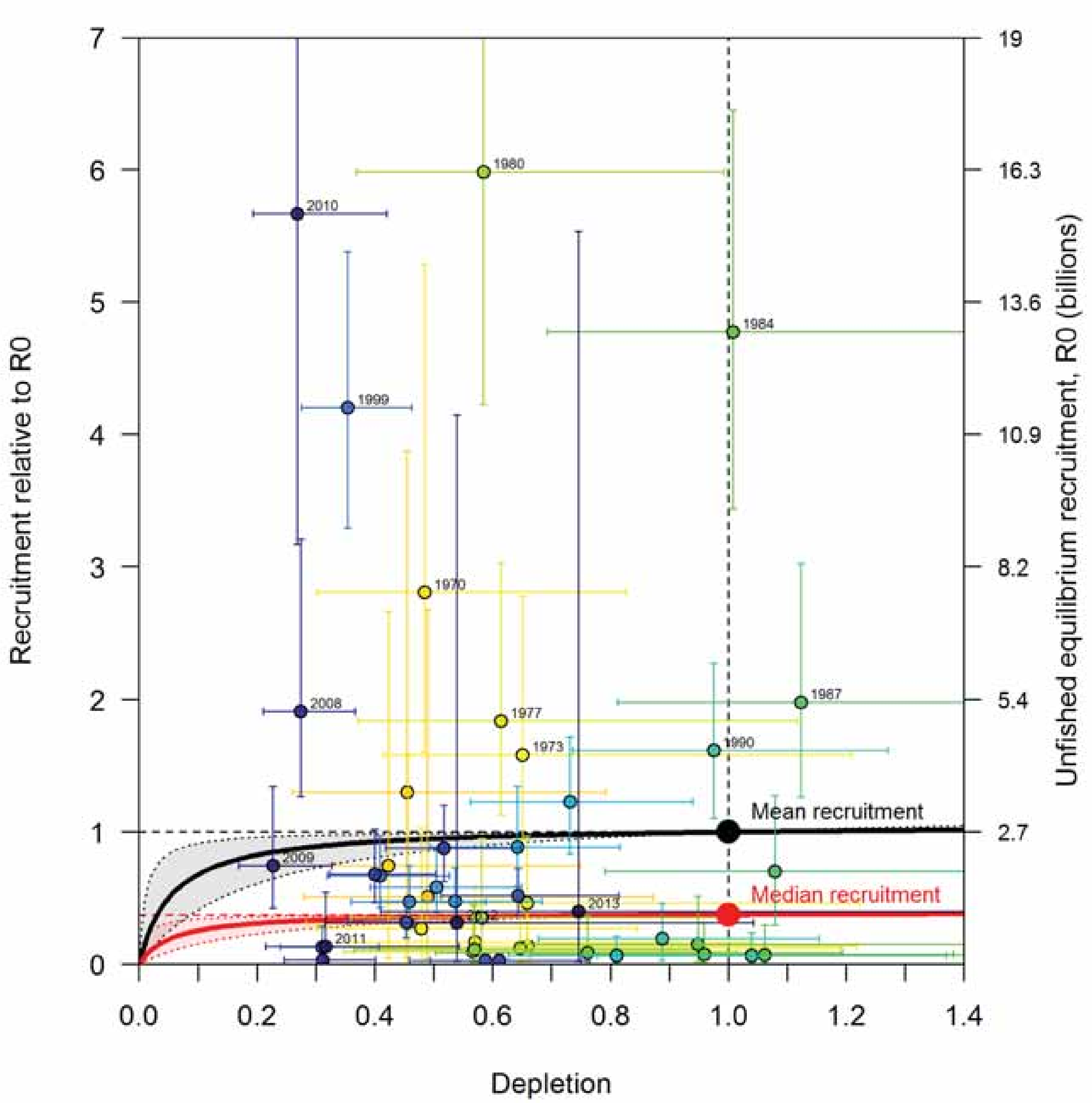



**Figure 36: Estimated stock-recruit relationship for the base model with median predicted recruitments and 95% posterior credibility intervals. The thick solid black line indicates the central tendency (mean) and the red line the central tendency after bias correcting for the log-normal distribution (median).**

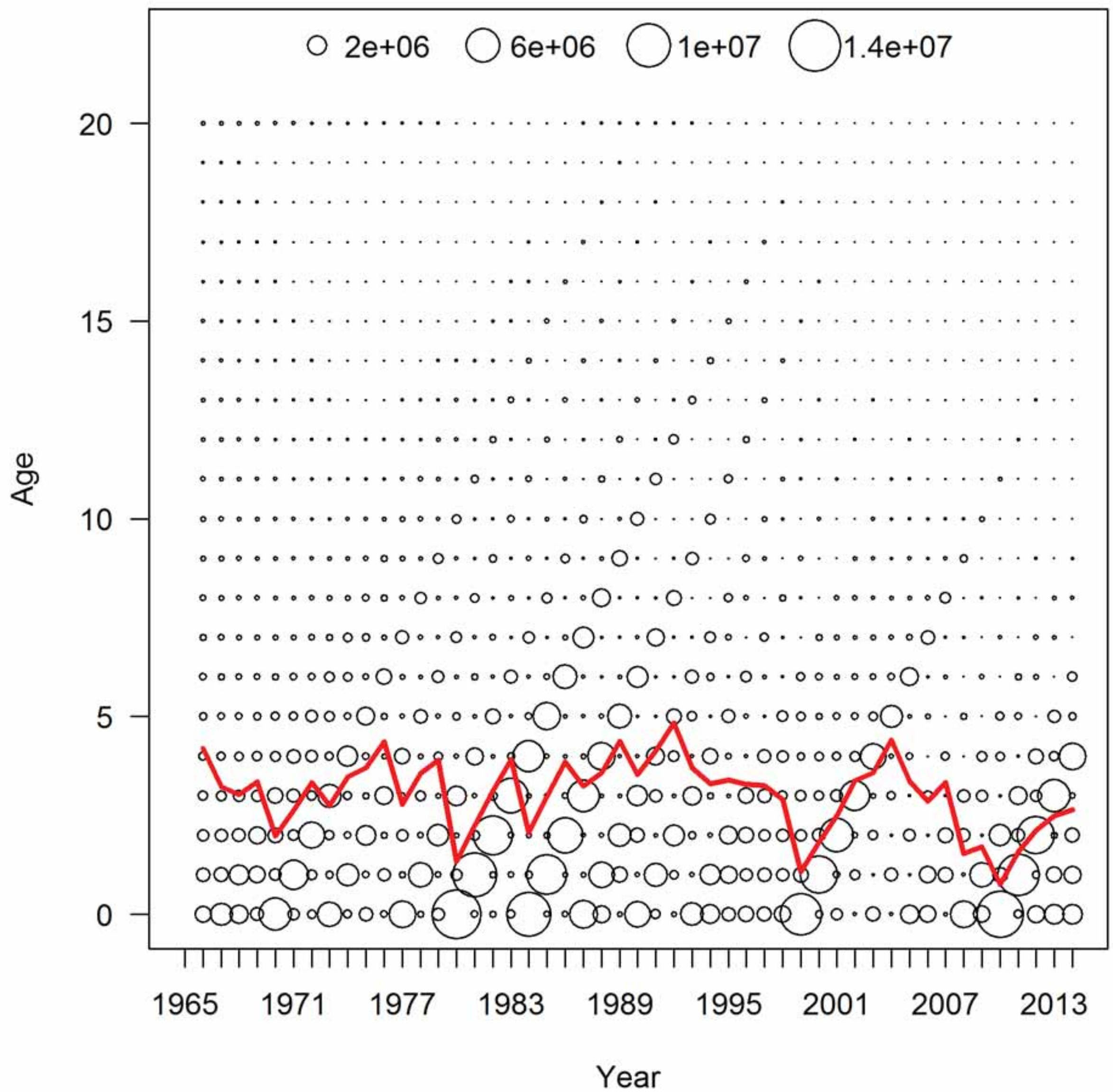



**Figure 37: Bubble plot of numbers at age by year from 1966 to 2014. The red line represents the mean age.**

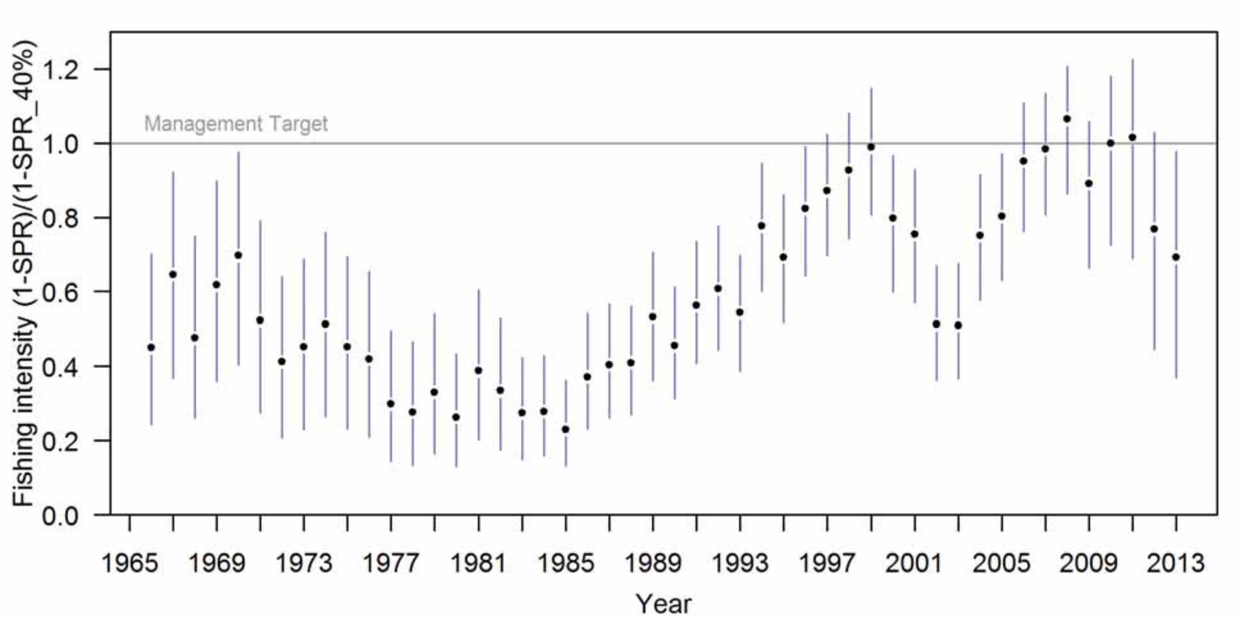



**Figure 38: Trend in median fishing intensity (relative to the SPR management target) through 2013 with 95% posterior credibility intervals. The management target define in the Agreement is shown as a horizontal line at 1.0.**

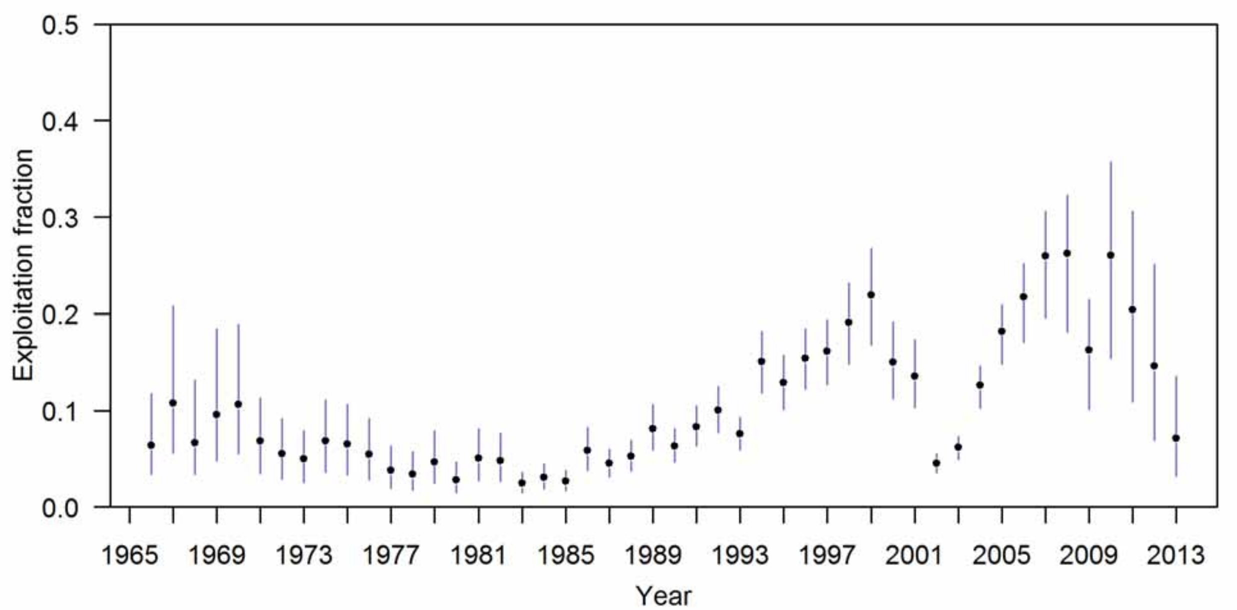



**Figure 39: Trend in median exploitation fraction through 2013 with 95% posterior credibility intervals.**

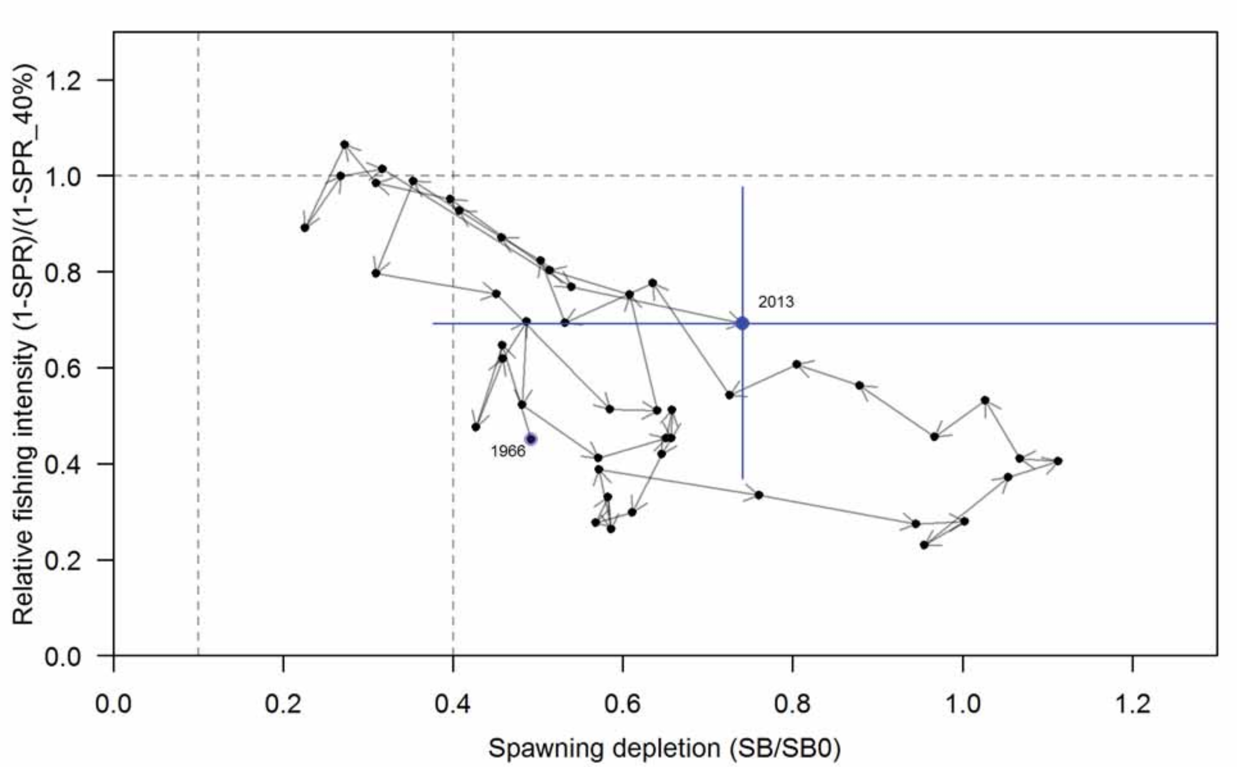



**Figure 40: Estimated historical path followed by fishing intensity and spawning biomass depletion for Pacific Hake over years 1966-2013, inclusive. indicateBlue2013. Blue bars span the 95% credibility intervals for 2013 fishing intensity (vertical) and spawning biomass depletion (horizontal). The dashed lines indicate the fishing intensity target (horizontal) and the F40:10 harvest control rule (vertical) 10% and 40% depletion points.**

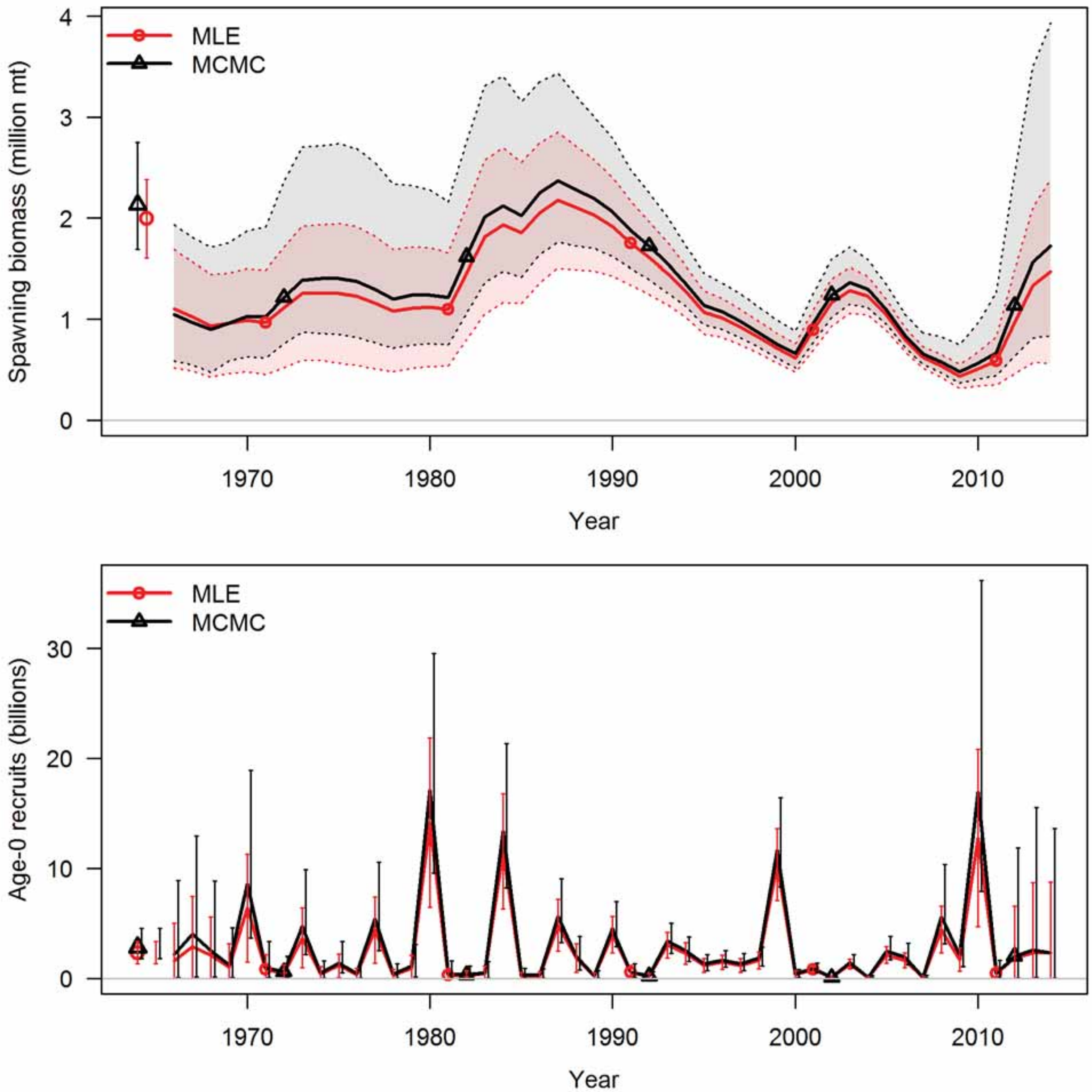



**Figure 41: A comparison of MLE estimates with 95% confidence intervals determined from asymptotic variance estimates (red) to the median of the posterior distribution with 95% credibility intervals (black).**

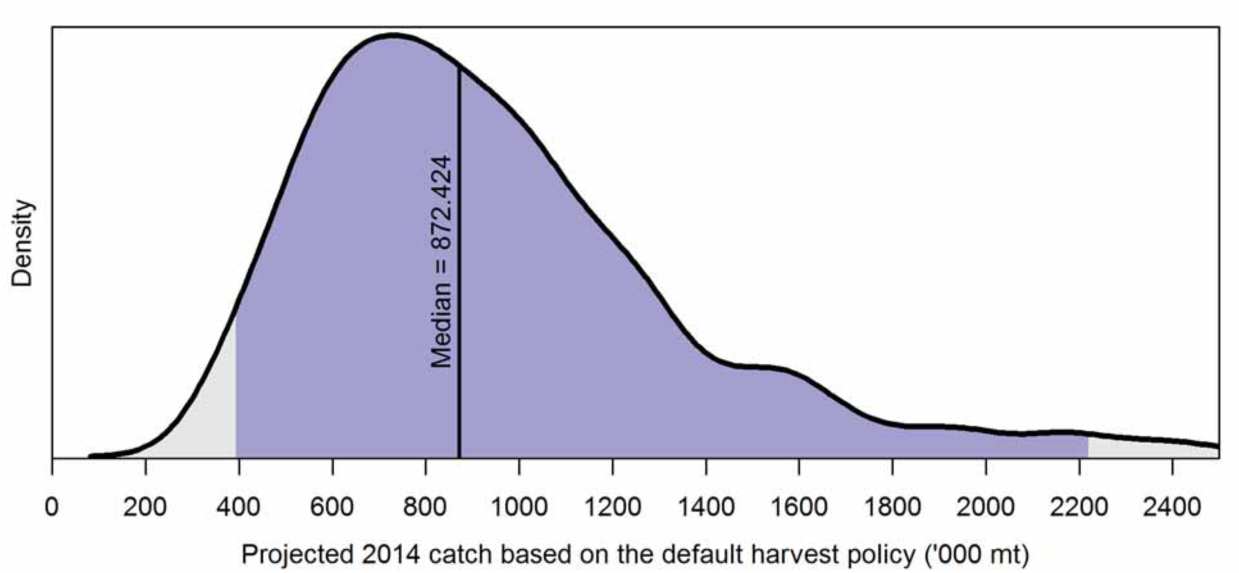


**Figure 42: The posterior distribution of 2014 catch calculated using the default harvest policy (F40%-40:10). The dark shaded area ranges from the 2.5% quantile to the 97.5% quantile.**

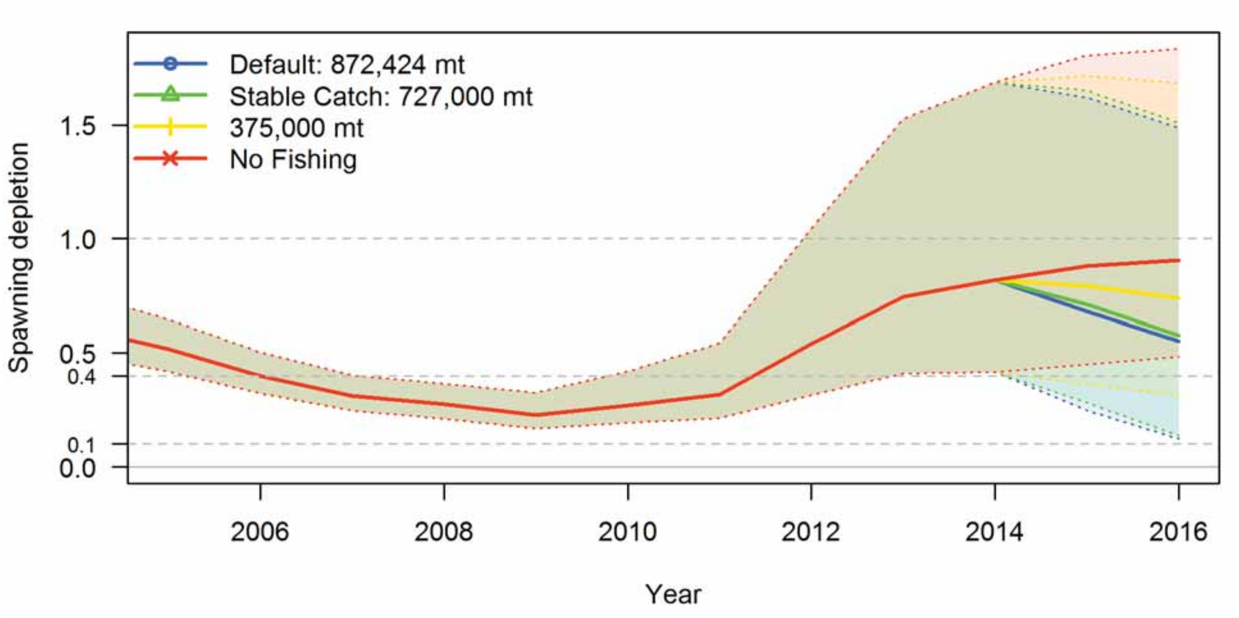


**Figure 43: Time-series of estimated spawning depletion to 2014 from the base model, and forecast trajectories to 2015 for several management options from the decision table, with 95% posterior credibility intervals. The 2014 catch of 872,424 mt was calculated using the default harvest policy, as defined in the Agreement.**

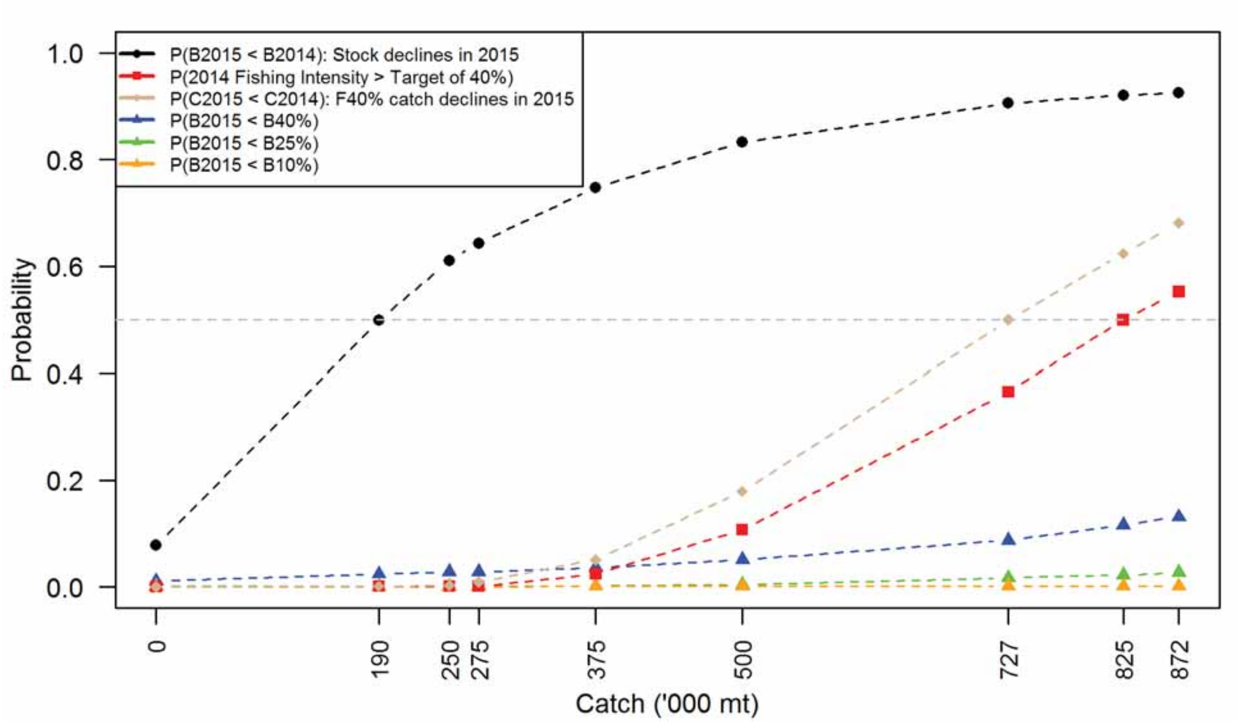



**Figure 44: Probabilities of various management metrics given different catch alternatives. Catch alternatives are described in Table 16. The points show these specific catch levels and lines interpolate between the points.**

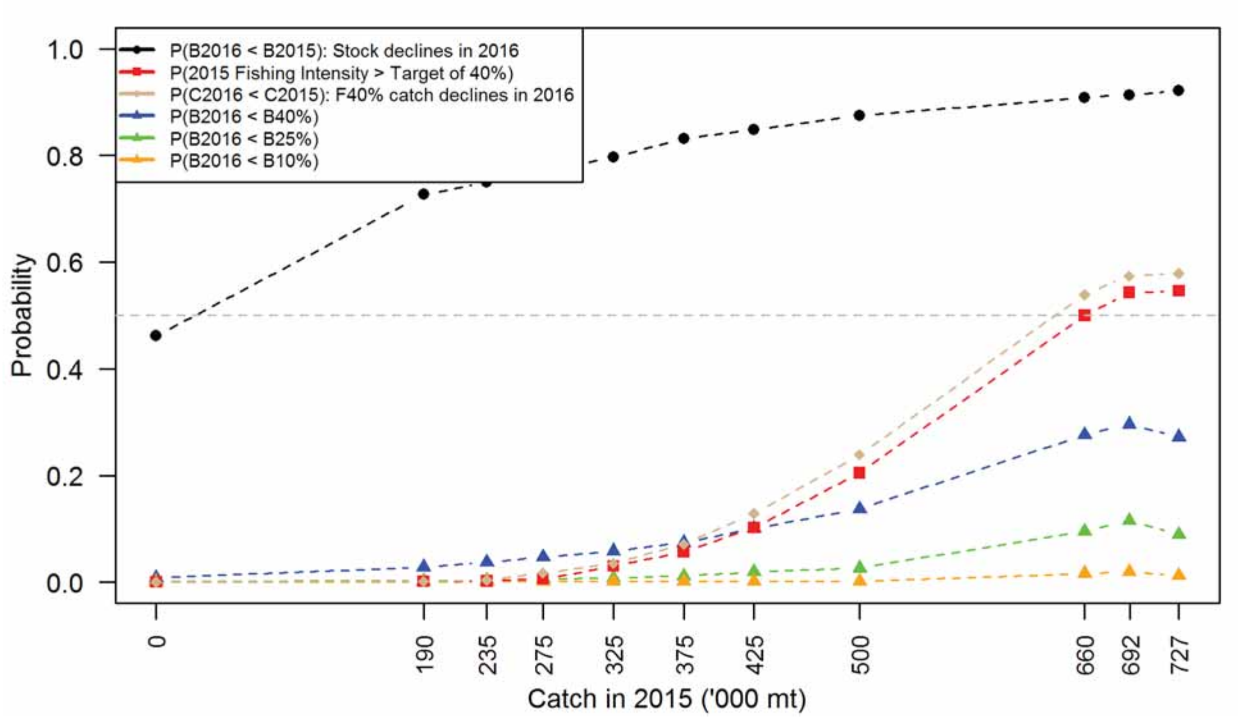



**Figure 45: Graphical representation of the results presented in Table 19 for catch in 2015. The symbols indicate points that were computed directly from model output and lines interpolate between the points. These catches are conditional on the catch in 2014, and 2014 catch levels corresponding to the 2015 catches of 660 and 692 were higher (see Table 16).**

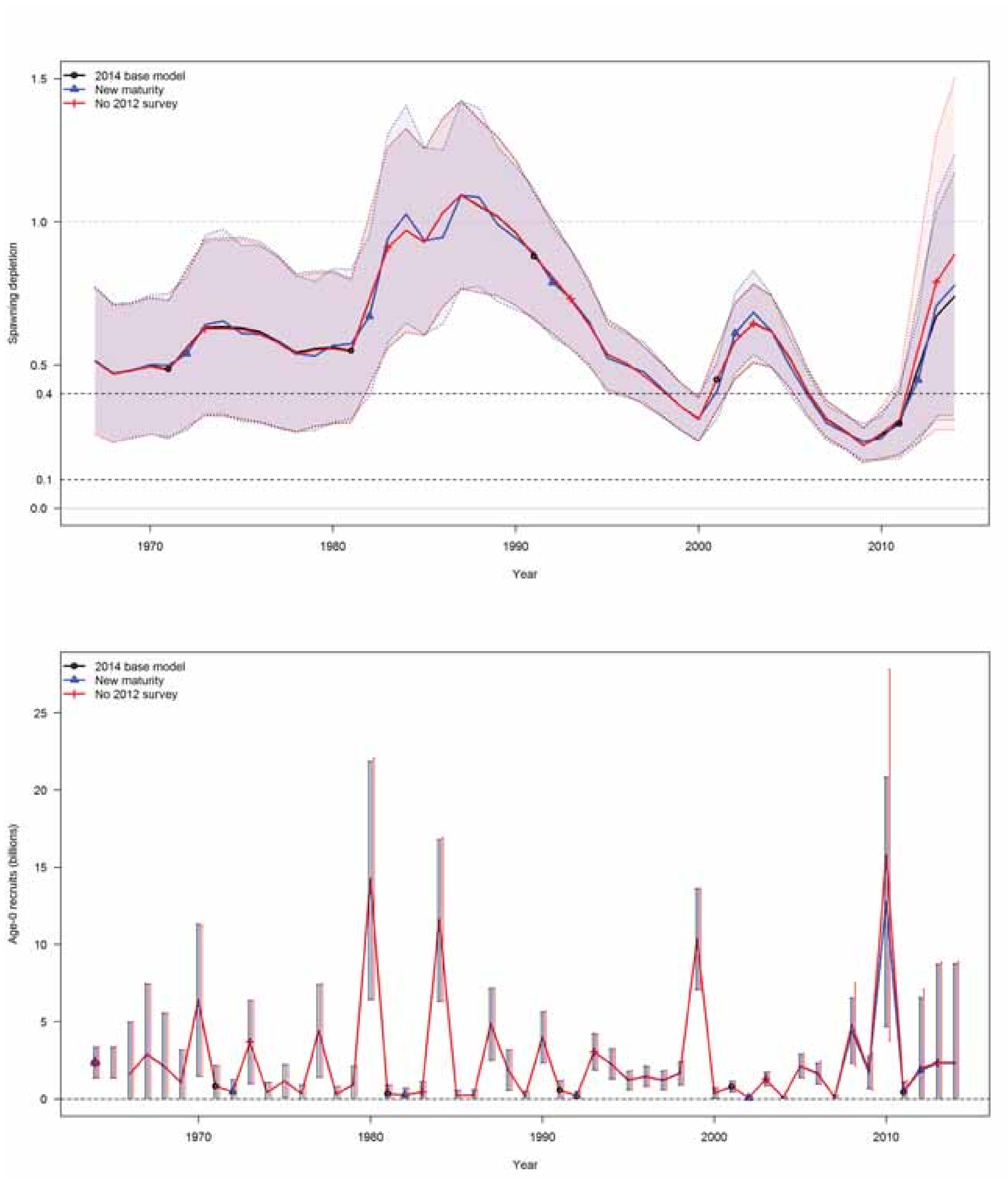



**Figure 46: Maximum likelihood (MLE) predictions of depletion (top) and recruitment (bottom) for sensitivity runs with 1) newly estimated maturity-at-age (blue, "New maturity", or 2) without a 2012 survey (red, "No 2012 survey").**

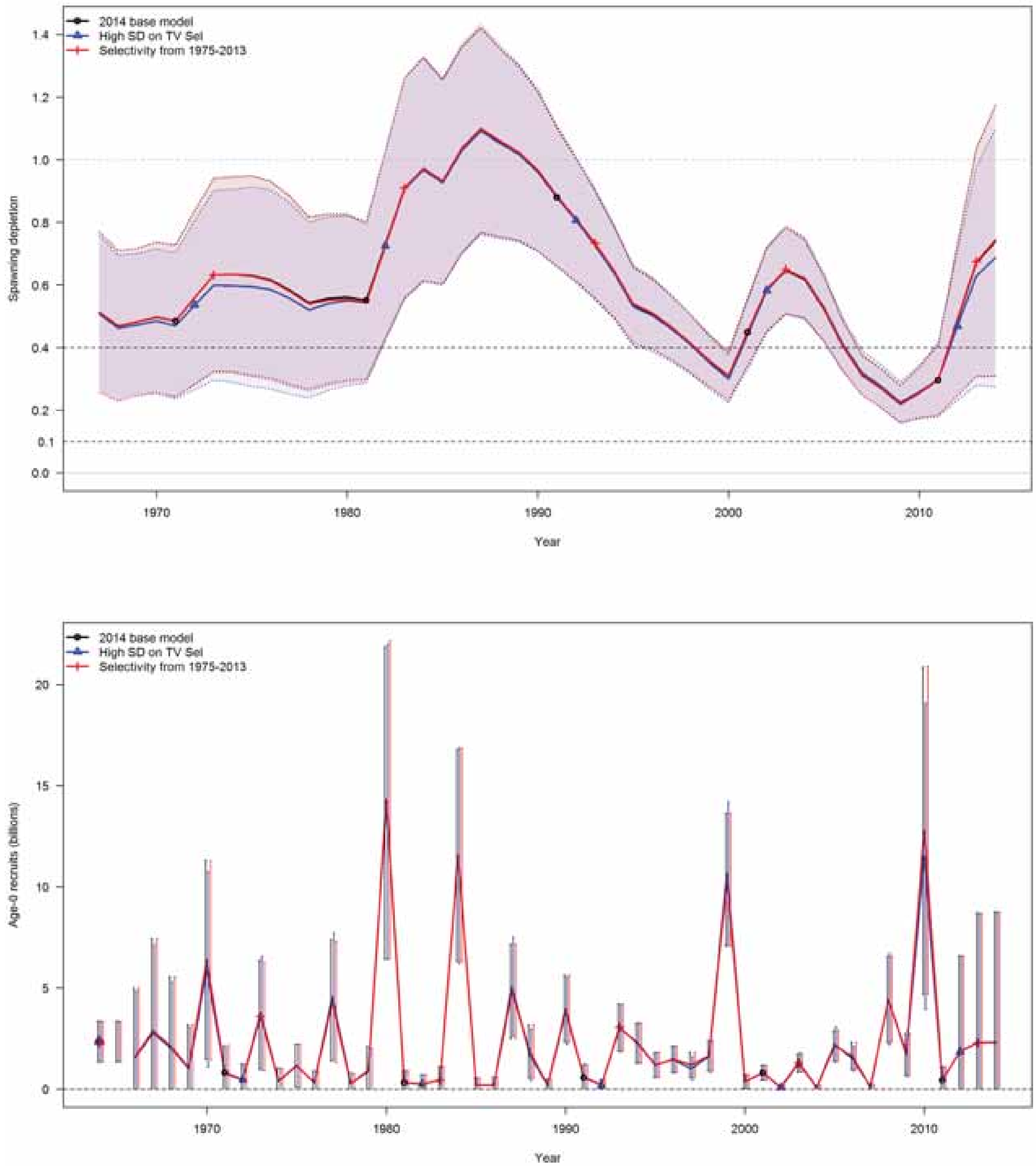



**Figure 47: Maximum likelihood (MLE) predictions of depletion (top) and recruitment (bottom) for sensitivity runs with 1) a value of 0.2 for the standard deviation of the selectivity deviation penalty (blue, "High SD of TV Sel", or 2) estimating selectivity deviations from 1975 to 2013 (red, "Selectivity from 1975-2013").**

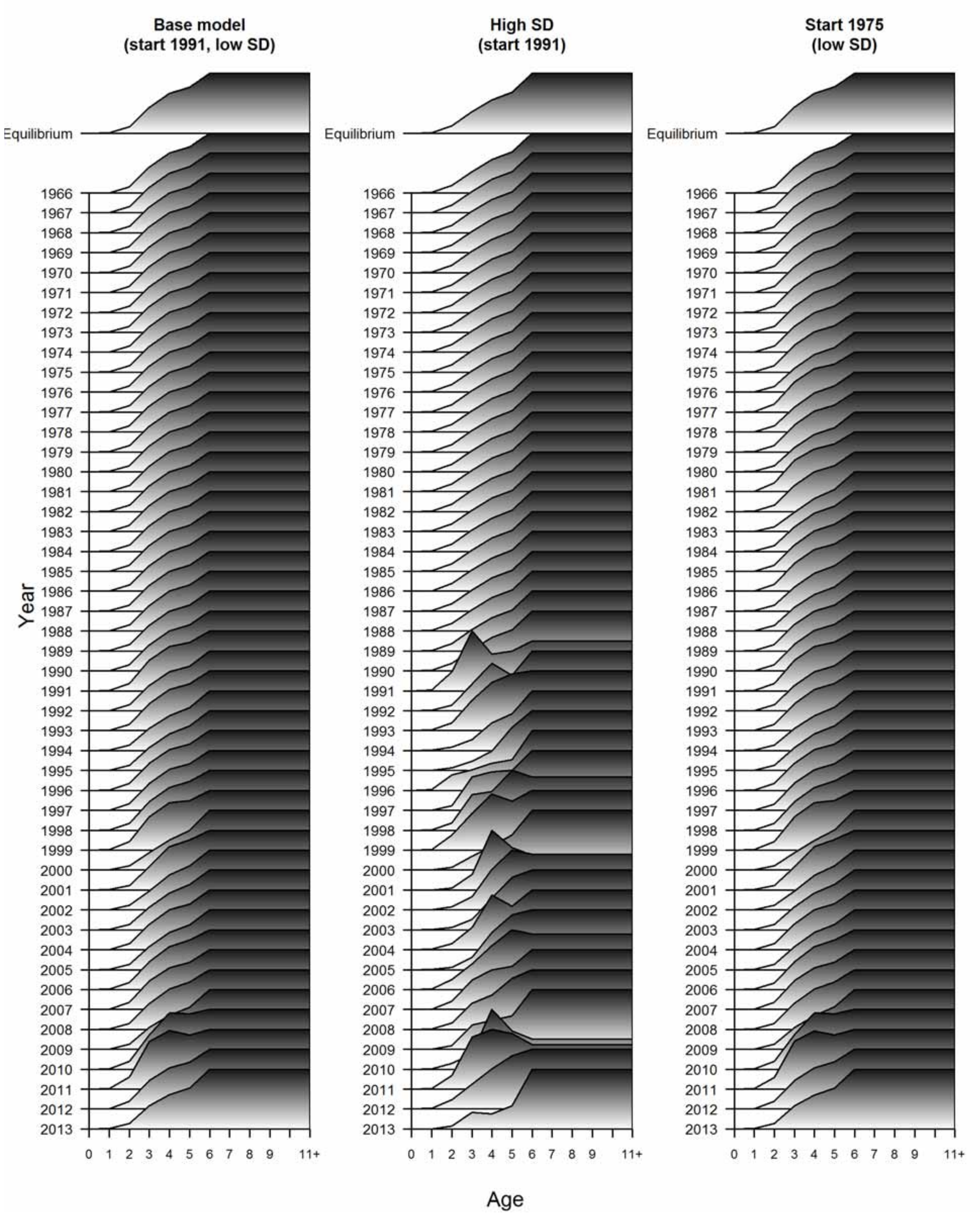



**Figure 48: Estimated selectivity for all years in the assessment model for the base model (left), the sensitivity with a high standard deviation on fishery selectivity (center), and the sensitivity estimating time-varying selectivitystarting in 1975 (right).**

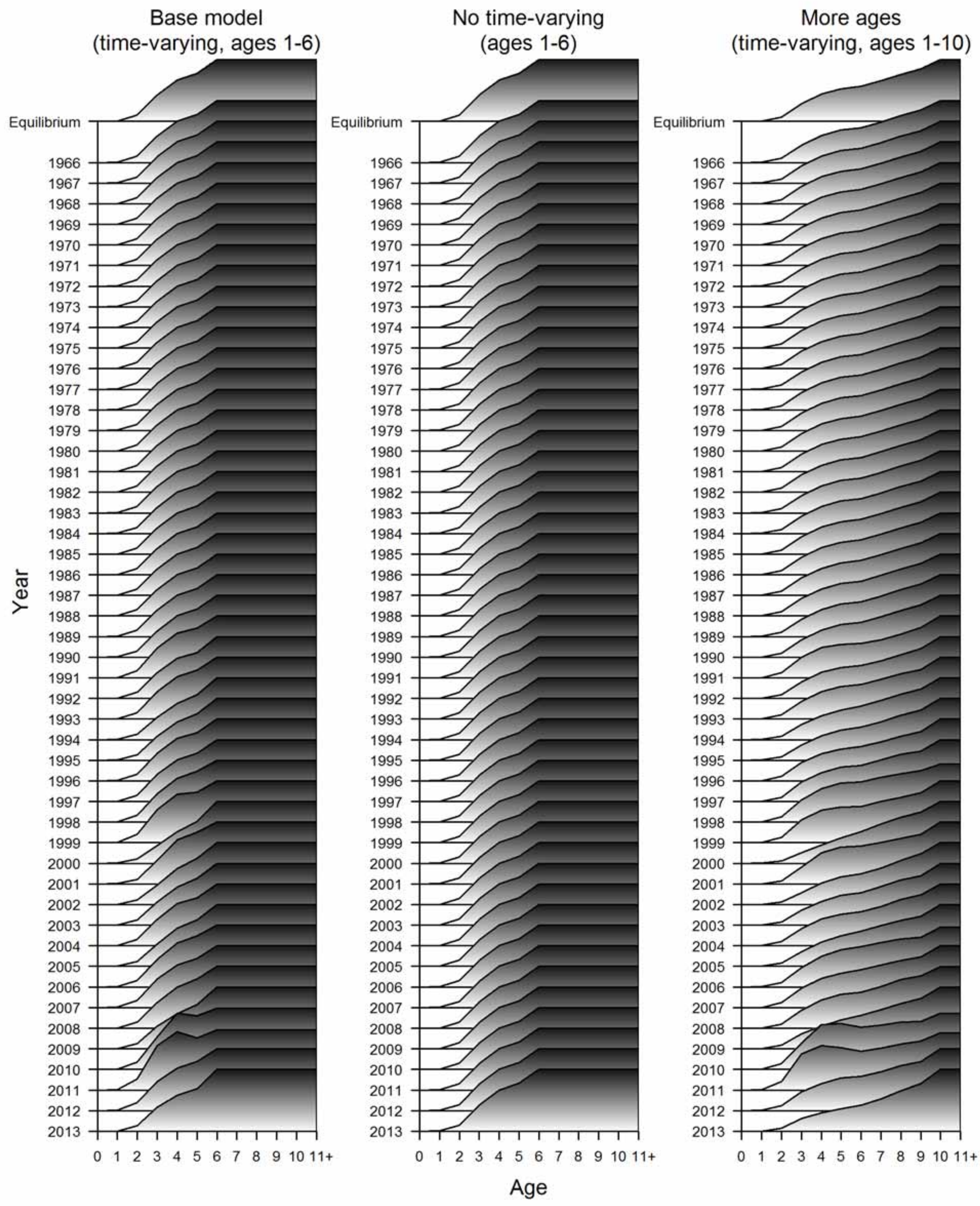
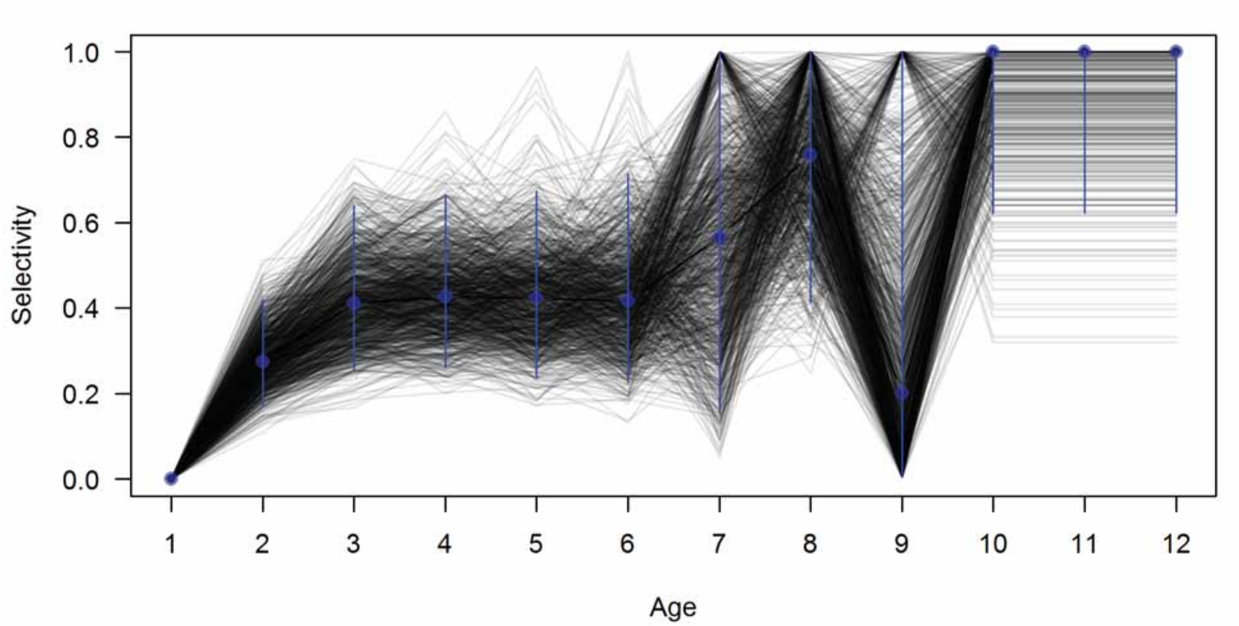



**Figure 49: Estimated selectivity for all years in the assessment model for the base model (left), the sensitivity with time-invariant fishery selectivity (center), and the sensitivity estimating selectivity to age 10 (right).**



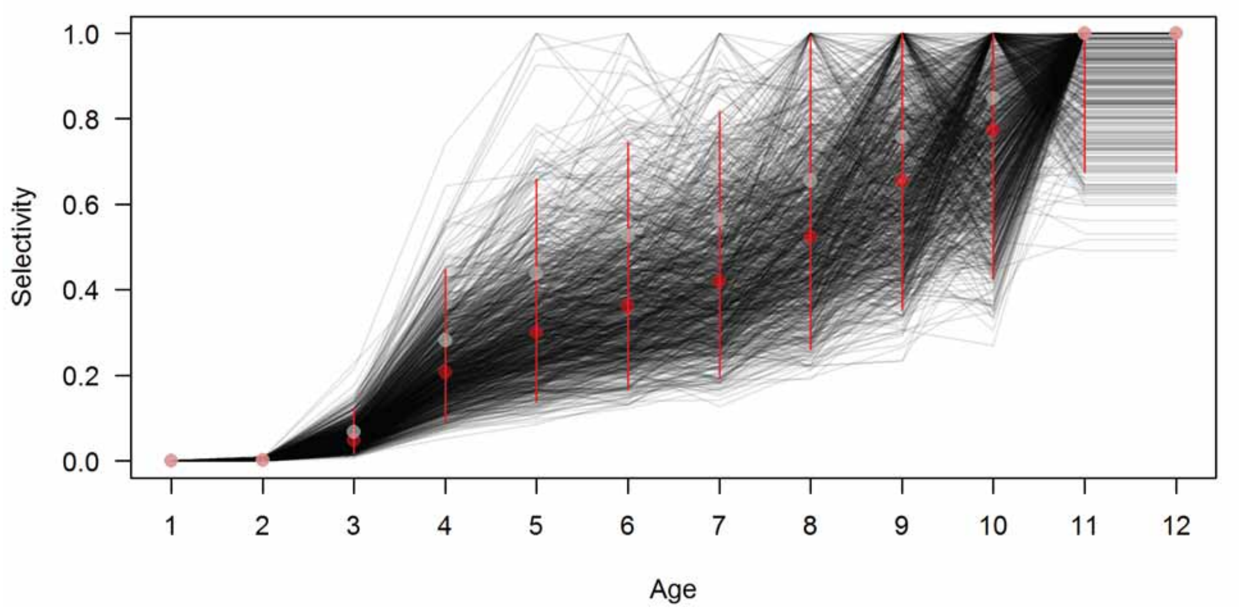
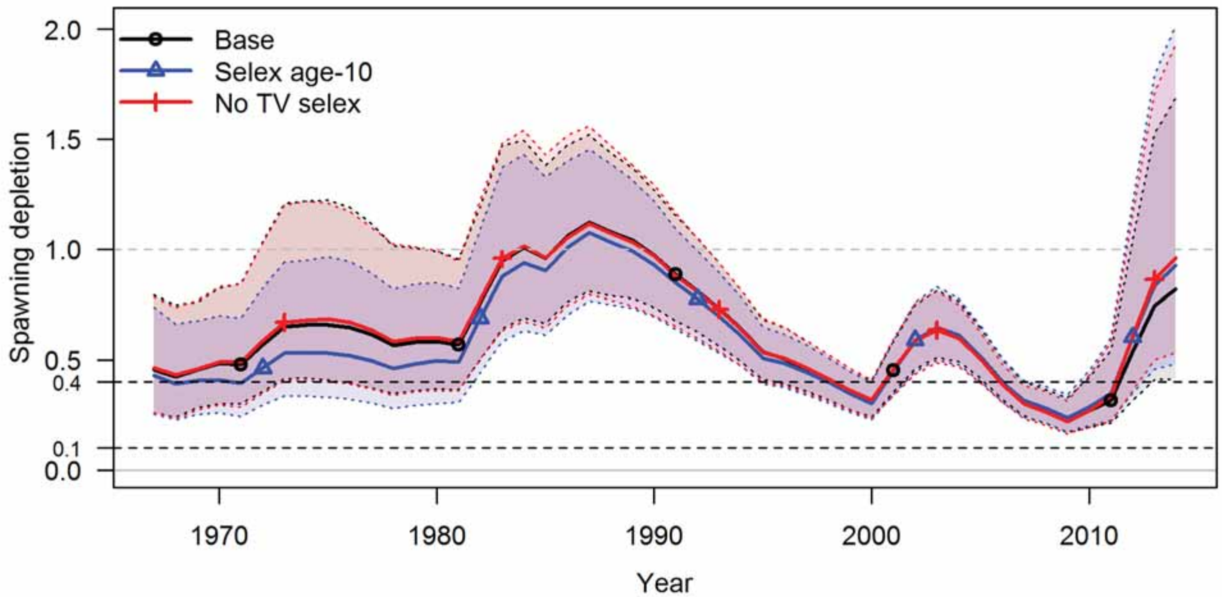




**Figure 50: Bayesian posterior predictions of acoustic (top) and fishery selectivity in 2013 (bottom) for the sensitivity run estimating non-parametric selectivity to age 10. Each grey line is the estimated selectivity from one sample of the posterior distribution. The blue or red dots are the median estimated selectivity-at-age with lines showing the 20.5% and 97.5% quantiles. The light colored dots in the fishery selectivity plot (bottom) are the median base selectivity estimate prior to 1990.**



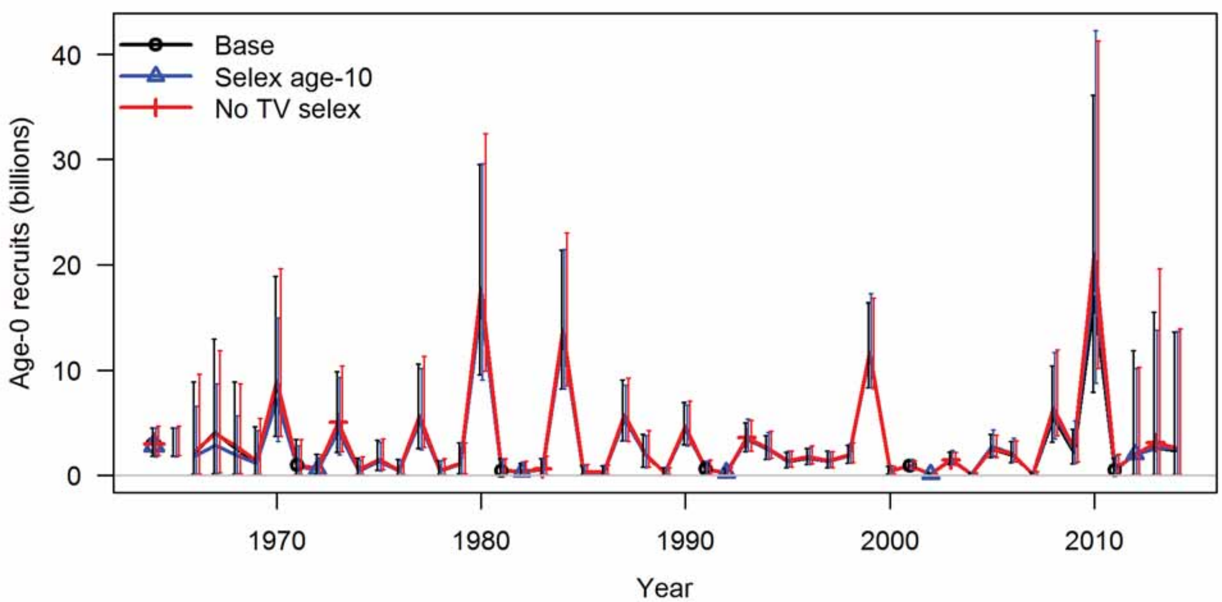




**Figure 51: Bayesian posterior predictions of depletion (top) and recruitment (bottom) for sensitivity runs with 1) estimating non-parametric selectivity to age 10 (blue, "Selex age-10"), or 2) not estimating time-varying fishery selectivity (red, "No TV selex").**

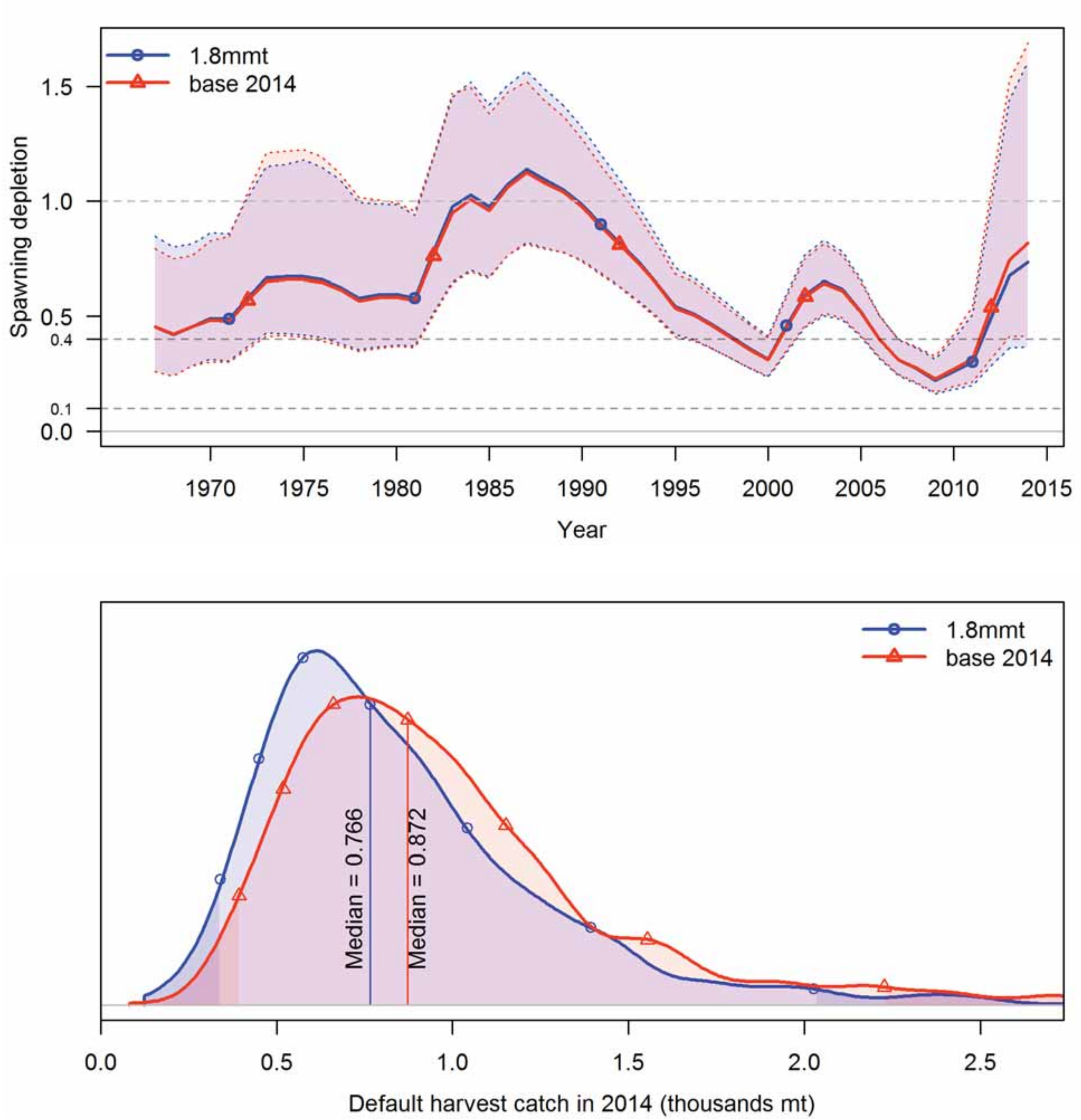



**Figure 52: Bayesian posterior predictions of depletion (top) and the default harvest rate catch in 2014 (bottom) for the sensitivity run using 1.8 million mt for the 2013 acoustic survey biomass estimate.**

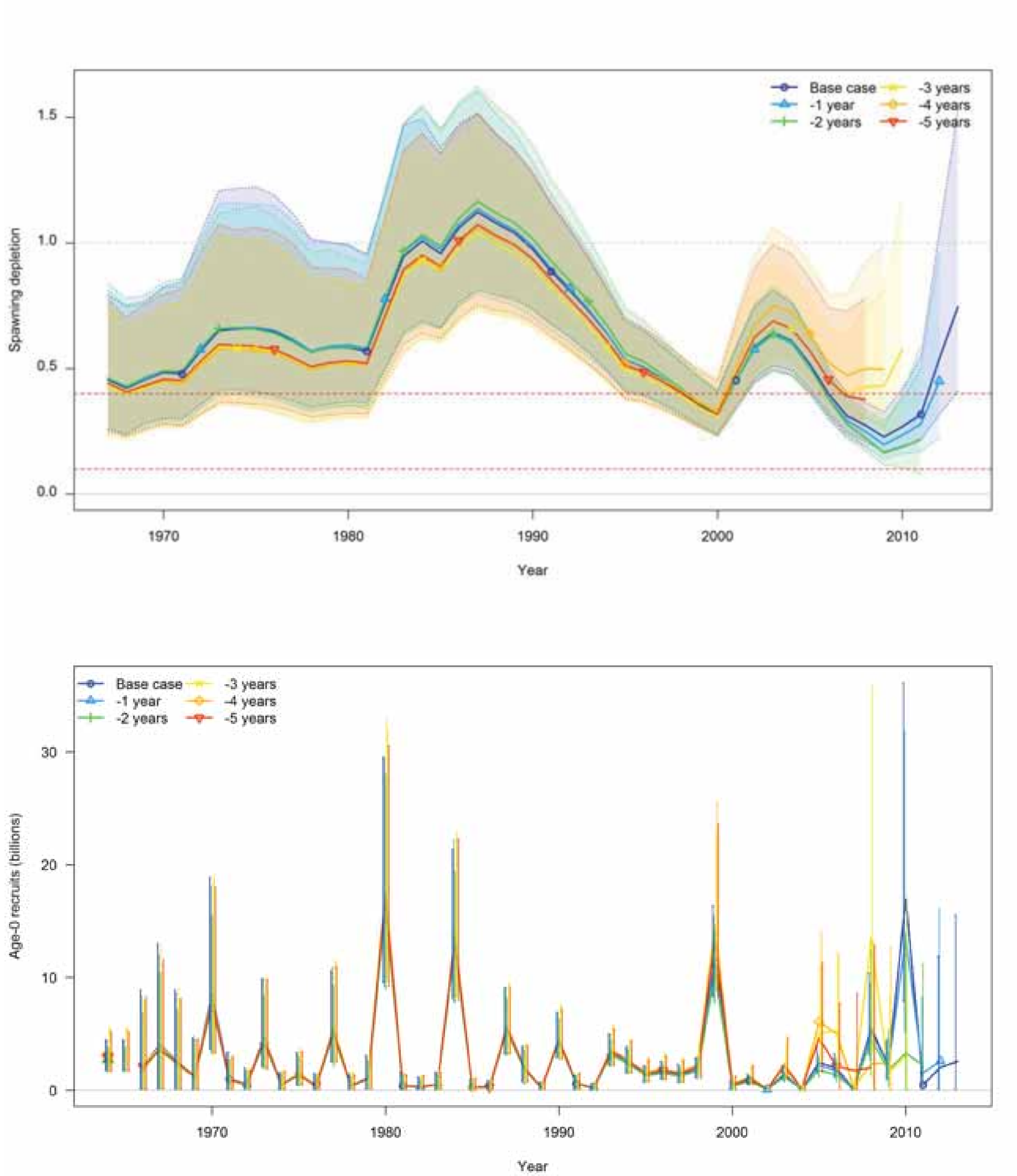



**Figure 53: Depletion estimates (top) and recruitment estimates (bottom) for the base model and retrospective runs.**

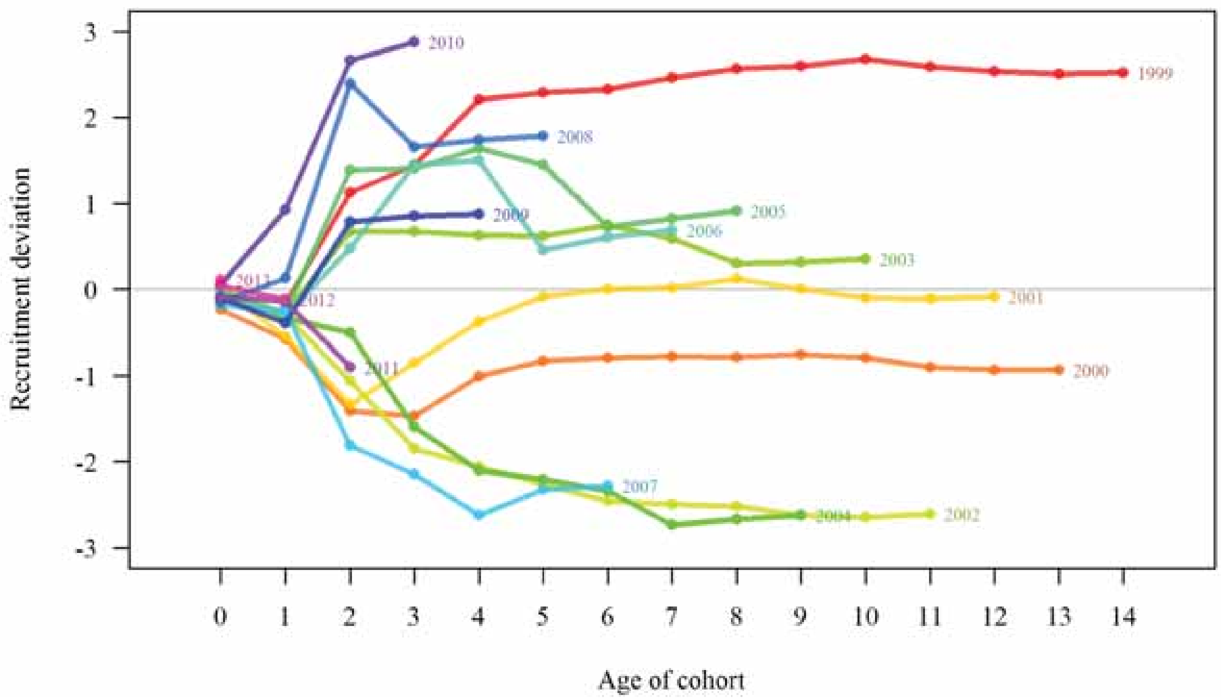



**Figure 54: Base model retrospective analysis of recruitment estimates over the last thirteen years. Lines represent estimated deviations in recruitment for cohorts starting in 1999 (with cohort birth year marked at the right of each line). Values are estimated in models with data available only up to the year in which each cohort was a given age. Recruitment deviations are log-scale difference between estimated recruitment and spawner-recruit expectation.**

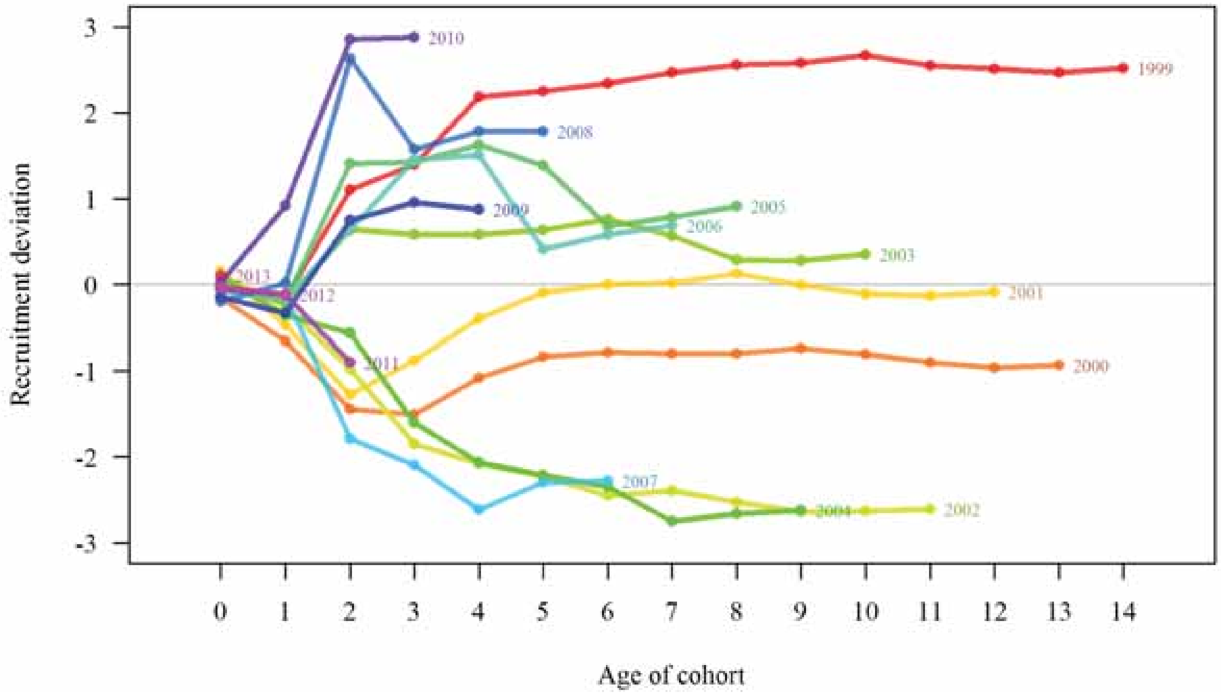


**Figure 55: Retrospective analysis of recruitment estimates over the last thirteen years for a model with time-invariant selectivity. See the caption from Figure 54 for more details about the plot.**

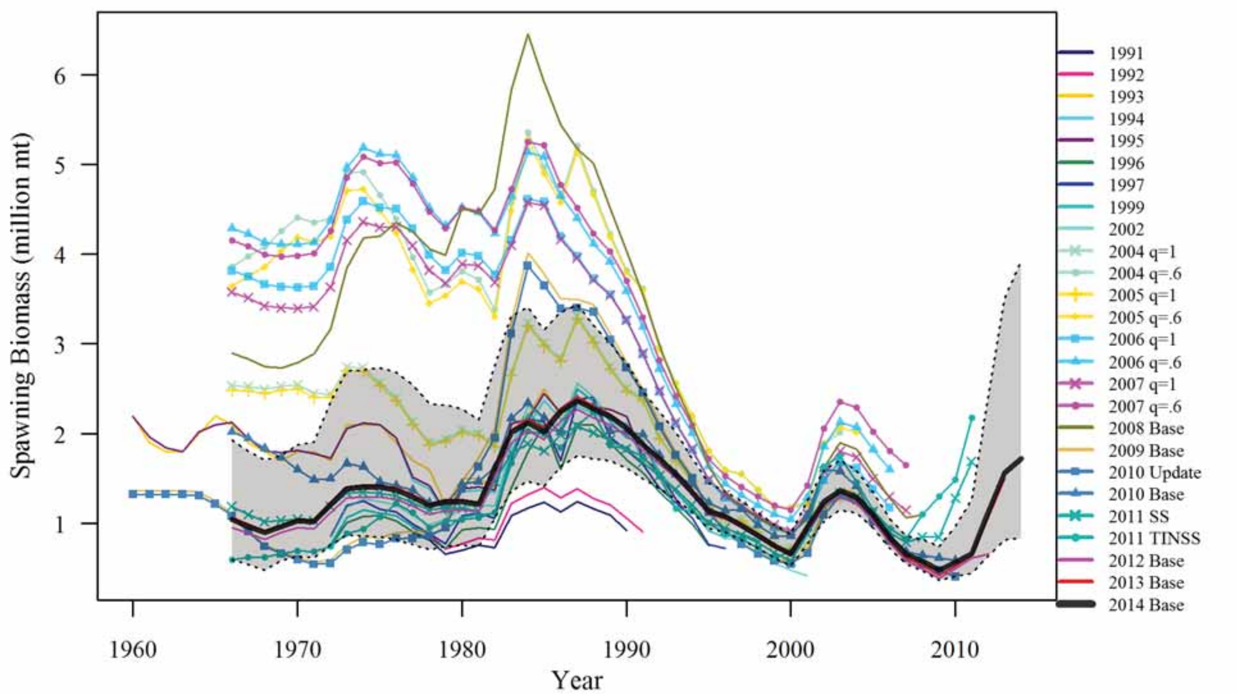



**Figure 56: Summary of historical Pacific Hake assessment estimates of spawning biomass. The 2013 assessment estimated trajectory (red line) are almost completely covered by the 2014 estimated trajectory.**

# Appendix A. Management Strategy Evaluation (MSE)

## Appendix A.1. Introduction

Fishing businesses succeed or fail based on their ability to be profitable despite unpredictable mechanical failures, changes in weather, fluctuating fish abundance, prices and costs, as well as increasingly precautionary fishing regulations. Developing a clear strategy for operating under these conditions may not be the absolute difference between success and failure, but it certainly increases the likelihood that uncontrollable events will be identified and handled in ways that are consistent with business goals and objectives.

Unpredictable fluctuations in fish stock abundances and productivity are the most significant challenges facing any fishing enterprise or management agency charged with promoting fishery sustainability. An inability to accurately forecast fish stock abundances limits fishery planning to only short time horizons (e.g., 1-2 years) during which stock assessment model predictions are reliable to an acceptable degree of certainty. On the other hand, promoting fishery sustainability requires a long-term view toward maintaining fish stocks and fisheries indefinitely. Highly precautionary and risk-averse decision-making is one way to ensure that short-term harvesting decisions do not interfere with long-term fishery sustainability. Consistently adopting conservative harvest options, which minimize the risks associated with stock assessment estimation and forecast errors, allow managers to err on the side of caution and limit risks to fish stocks. The main problem with conservative short-term decision-making is determining whether decisions are cautious enough or too cautious – without actually knowing the long-term consequences of each short-term decision, arguments can easily be made to favor any level of caution. Furthermore, the degree of caution used in short-term decisions is open to subjective interpretation both before decisions are made, and after the consequences are observed. Subjective interpretations of management performance are often based on who is either praising or criticizing the outcomes of decisions.

Like the fishing business, a fishery management system requires a strategy for decision-making that is consistent with short-term economic goals and long-term sustainability despite unpredictable changes in fish stock abundances and productivity, monitoring and stock assessment errors, and changing regulatory requirements. Consistency with sustainability goals needs to be determined objectively through a scientific process of testing the harvest strategy against the most important uncertainties about the fish stock and fishery. Such a scientific process of testing harvest strategies provides a mechanism for objectively criticizing the strategy and proposing alternatives that are consistent with a broad range of stakeholder interests and management goals.

A scientifically tested harvest strategy has several benefits for both fishing businesses and management agencies. For fishing businesses, a repeatable and predictable harvest strategy provides (*i*) assurance that short-term harvesting decisions are consistent with short- and long-term business objectives given existing fishing regulations and eco-certification constraints; (*ii*) a way to avoid using uncertainty in annual stock assessments to justify overly conservative or risky harvest decisions; and (*iii*) a mechanism to maintain or improve long-term asset (e.g., license) value. These benefits come from accurately predicting future management responses to whatever fish stock abundances might occur rather than counting on accurate stock assessment model predictions of future fish stock abundances. For management agencies, a strategic and predictable management response provides (*i*) assurance that long-term fishery sustainability is reasonably, or even highly, likely; (*ii*) reduced time and resource requirements for annual stock assessments and harvest decision-making; (*iii*) a mechanism for prioritizing requests for scientific research and advice; and (*iv*) concrete evidence that a harvest decision-making process complies with national and international fishery policies, agreements, and treaties.

Management strategy evaluation (MSE) is a structured decision-making process in which fishing businesses, management agencies, and other stakeholders collaborate to develop and test a harvest strategy (Figure A.1). A complete MSE approach involves four general harvest strategy components: (1) **Goals & Objectives** define the short- and long-term sustainability requirements of fishery stakeholders, government regulations, and eco-certifiers; (2) a **Management Procedure** represents the combination of monitoring data, stock assessment method, and harvest rule used to make short-term harvest decisions; (3) a **Simulation Test** (also called a closed-loop simulation) of the management procedure against operating models that reflect key stock assessment uncertainties (Figure A.2); and (4) **Application** of the management procedure to the real fishery. This MSE structure and process applies generally to most design-based engineering and operations problems in which uncertainty creates relatively high risks (e.g., airline travel, structural engineering, vehicle safety).

Developing the MSE components naturally flows in order from initial goals to application; however, short-term progress on individual components generates feedback and refinement of components that come earlier. For instance, the reverse arrows in Figure A.1 show that (a) clarifying the data, stock assessment, and harvest control rules that comprise a management procedure often leads to more specific goals and objectives, (b) simulation testing management procedures usually identifies unforeseen risks and the need to revise the procedures, or to find alternatives, and (c) applying a management procedure to the actual fishery provides real catch and stock abundance outcomes that can be compared to original simulated outcomes, as well as the initial goals and objectives. Completing each cycle of the MSE process provides stakeholders and managers with the experience needed to revise and improve each component of the process.

**The Pacific Hake harvest strategy**

At the present time, there is no formal harvest strategy containing all four elements of Figure A.1 for managing Pacific Hake fisheries, although some Management Procedure and Simulation Test elements of a strategy do exist. The Management Procedure contains Monitoring and Stock Assessment components that are both reviewed annually in collaborative processes involving stakeholders, managers, and technical experts. Although the Agreement provides a potential Harvest Rule – by defining the default harvest rate ($F_{40\%}$-40:10 adjustment) and catch limit allocation between countries – it does not specify how to consider uncertainty around the catch limit, and as a result, annual TACs often deviate substantially from the catch limits computed by applying the $F_{40\%}$-40:10 rule to stock assessment estimates of exploitable biomass (typically towards lower catch limits). Upper TAC limits seem to exist, but are not clearly quantified or rationalized based on stock assessment information. In a formal harvest strategy, TACs need to follow predictably from stock assessment information if the strategy aims to be repeatable. A harvest strategy with unpredictable annual TACs cannot be tested objectively in fishery system simulations, or any other means of establishing fishery sustainability.

The Goals & Objectives and Application components of a formal harvest strategy are missing for the Pacific Hake fishery. Although the default harvest rule in the Agreement aims to implement the $F_{SPR=40\%}$ fishing mortality rate, i.e., the fishing mortality rate that reduces spawning biomass-per-recruit to 40% of the unfished spawning biomass-per-recruit, there are no Objectives stating the acceptable risks to the hake stock or the fishery that should follow from applying this rule. It is well known that fishery stock assessment model errors (i.e., differences between estimated and true stock biomasses) can lead to higher or lower fishing mortality rates than target values such as $F_{40\%}$. Furthermore, stock assessment models are incomplete representations of actual fish populations and their interactions within marine ecosystems. These assessment realities make it highly unlikely that the future stock biomass will stabilize near $B_{40\%}$ with repeated application of the $F_{40\%}$-40:10 rule. On the contrary, it is likely that stocks will be frequently assessed below $B_{40\%}$ and, as well, below $B_{10\%}$, prompting large fluctuations in fishery catch and possible fishery closures of unknown duration.

For highly variable fish stocks such as Pacific Hake, simulation testing harvest strategies provides an indication of potential trade-offs among future stock size, catch variability, fishery closure frequency, and yield. Simulation results can also be used to help scope reasonable Goals & Objectives for the fishery harvest strategy.

**Pacific Hake Management Strategy Evaluation - 2013**

Since 2012, both the SRG and the JMC have recommended simulation testing Management Procedures for the Pacific Hake fishery. Two main objectives guiding this work were to determine:

(1) the expected long-term performance of applying the $F_{40\%}$-40:10 Harvest Rule as part of the Pacific Hake Management Procedure;
(2) the relative improvement in management performance of conducting Annual vs Biennial biomass surveys.

Simulation results obtained during 2012-13 suggested that Management Procedures based on the $F_{40\%}$-40:10 rule provided unrealistic ranges of biomass and catch compared to historically realized values. The wide range of outcomes also masked potential differences between Annual and Biennial surveys. Furthermore, it was noted by the 2013 SRG that the Operating Model was potentially optimistic in assuming that fishery selectivity was constant from year-to-year.

During 2013, the simulation testing objectives were revised to determine:

(1) the expected long-term performance of a revised Harvest Rule consisting of two parts:
    a. $F_{40\%}$-40:10 rule
    b. Floor (0 or 180,000 mt) and Ceiling (None, 375,000, or 500,000 mt) options that limit output TACs to pre-determined ranges
(2) the relative improvement in management performance of conducting Annual vs Biennial biomass surveys
(3) whether implementing time-varying selectivity in the Management Procedure stock assessment model improves or degrades management performance compared to fixed selectivity

The sections below describe Simulation Test outcomes against these objectives.

## Appendix A.2. Methods

The early-stage MSE process for the Pacific Hake fishery includes a closed loop Simulation Test of plausible hake population responses to Management Procedure outcomes (Figure A.2). The hake population dynamics component of the Operating Model is almost identical in structure to the Management Procedure stock assessment model, but the former represents basic parameter uncertainty as well as alternative hypotheses for fishery selectivity. The closed loop simulation proceeded as follows.

1. The Operating Model (OM) was conditioned on the 2013 stock assessment, with the addition of estimating time-varying fishery selectivity for all years. Simulations began in 2013 and a catch of 365,112 was removed in 2013 for all cases
2. From the OM, data were generated that were generally comparable to the real data collection system (Monitoring in Figure A.2), except that for the Annual Survey Case, the survey index and age composition were generated every year, and for the Biennial Survey Case every even numbered year.

3. The generated data were fit by an Assessment model run in Stock Synthesis version 3.24s, and was similar to the 2013 assessment model, unless otherwise noted.
4. The Harvest Rule was applied to determine a Total Allowable Catch (TAC).
5. The TAC specified by the Harvest Rule was input back into the OM to feedback into the annual stock dynamics represented by the OM. It was assumed that the entire TAC was taken by the fishery.
6. Steps 1-5 were projected forward for 30 years.
7. Steps 1-6 were repeated 1000 times with the stock dynamics determined from a sample from the posterior distribution of the conditioned OM, taking into account correlations between parameters.

**Operating model**

The operating model defines a scenario and was similar to the 2013 base assessment model for Pacific Hake reported by the JTC (2013), with the addition of time-varying selectivity in the fishery for all years (1966-2012). This was a Bayesian age-structured model stock assessment model built in Stock Synthesis version 3.24s (SS) (Methot and Wetzel 2012). The model was conditioned on (i.e., fitted to) data from 1975-2012, which resulted in marginal 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. An operating model with time-invariant selectivity was also considered, but most simulations used the operating model with time-varying fishery selectivity.

Time-varying selectivity was modelled using random deviates applied to each parameter for selectivity-at-age and year (see Appendix C for further details). These deviates were estimated for the years 1966–2012 with a standard deviation ($\phi$) of 0.2 in a normal distribution to penalize the deviate as it moved away from zero. For future simulated years, deviates were randomly generated by a multivariate normal distribution with the covariance matrix estimated from the deviates in the years 1966-2012. Figure A.3 shows the median estimated selectivity-at-age by year.

Markov Chain Monte Carlo (MCMC) was used to characterize the variability of the population by sampling every 10,000$^{th}$ point from a chain of 30,000,000, and discarding the first thinned sample as a burn-in, as was done in the 2012 assessment (JTC 2012). This left 2999 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 median spawning biomass trajectory with a 95% posterior credibility interval is shown in Figure A.4, with a few actual realizations to show the potential variability of a single simulation. The posterior distribution of parameters resulted in a median 2013 beginning of the year depletion of 71% with 2.5$^{th}$-% and 97.5$^{th}$-% percentiles of 30% and 184%, respectively.

**Management Procedures**

A Management Procedure is the combination of data collected (e.g., frequency and quality), the stock assessment, and the harvest control rule which assists in determining catch. Two general methods for determining catch targets were considered: an assessment or constant catch. Time-varying selectivity in the assessment and catch ranges were also considered (Table A.2).

Within data collection, the survey frequency was annual or biennial (in even years) and a survey index was always simulated for 2013 since the survey was underway when these simulations were being done. Fishery catch-at-age was available in every year, and survey catch-at-age data were available only when the survey was done. Weight-at-age, maturity-at-age, and other externally derived quantities were unchanged in the simulations. The methods for generating data are given below.

The stock assessment differed with regard to whether or not time-varying fishery selectivity was used and when used, the size of the standard deviation in the penalty on the deviates. Without time varying fishery selectivity, the assessment model was the same as the 2013 assessment model (JTC 2013) with the addition of new data as it was simulated in future years. When time-varying fishery selectivity was used in the assessment model, two values of the standard deviation for the penalties were considered: a value of 0.05 was considered "low" and a value of 0.2 was considered "high" (which matched the OM). More information on the assessment model is given below.

The default Harvest Rule, as defined in the Agreement, was used with and without a catch range. In consultation with stakeholders, ceilings of 375,000 and 500,000 mt were chosen as values to be considered. Furthermore, a floor of 180,000 mt was also considered. These ranges were included as options to mimic the behavior of management often setting quotas lower than the harvest control rule suggests, and the fishery not catching the entire quota. This is a simple way to introduce implementation error and the results are more likely to be closer to reality than the assumption of catching the entire quota in every year.

In addition to an assessment being used to supply the quantities necessary for the Harvest Rule, various levels of constant catch were implemented as a comparison. In these cases, the operating model was run into the future with a constant catch in every year, although in some years, when the biomass was unavailable, the entire constant catch was not taken.

Perfect information from the operating model was also used in the Harvest Rule as a benchmark against which to compare the cases using an Assessment. This case illustrates the fundamental properties of Management Procedures without assessment errors, which assist in disentangling the effects of assessment errors from the intrinsic properties of the Harvest Rule. Data and an assessment model were not needed in the constant catch and perfect information cases.

**Data generation**

Survey abundance index and age-composition data for the years 2013–2042 were generated with random error from the operating model to reflect the data typically available for stock recent assessments of Pacific Hake. 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 $s^{\mathrm{survey}}$ is taken from the posterior distribution and is different for each of the simulations. The beginning of year numbers-at-age, $N_{i,y,a}$, were from the operating model population, and , $\underline{w}_a$, , is the average of weight-at-age over the years from 1975 to 2012, as used in the 2013 stock assessment (JTC 2013). The plus-group 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 4 in JTC (2013) 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 2013 assessment (JTC 2013). A total standard error of 0.42, similar to that estimated from the 2013 assessment model, was used. With an intra-year standard error of 0.085, the inter-year standard error, from equation 3, was approximately 0.41.

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

$$n_{i.y,a} = N_{i,y,a} s_{i,a} \Omega \tag{4}$$

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 2013 assessment (JTC 2013)

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 as used in the 2013 stock assessment (JTC 2013), but without cohort ageing error. Ageing error was applied after the sampling process.

**Assessment model**

Simulated assessments were used to provide catch recommendations based on a Harvest Rule for each Management Procedure considered. These simulated assessment models estimated spawning stock and exploitable biomass by fitting each year's simulated index and age-composition data and were set up similarly to the 2013 SS base model (JTC 2013), with differences in how fishery selectivity was treated. Three assessment models were considered:

1. An assessment model with time-invariant selectivity, parameterized the same as the 2013 stock assessment model (JTC 2013).
2. An assessment model with a low amount of time-varying selectivity in the fishery. The standard deviation for the penalty on the random deviates ($\phi$) was set at 0.05.
3. An assessment model with a high amount of time-varying selectivity in the fishery. The standard deviation for the penalty on the random deviates ($\phi$) was set at 0.20, exactly the same as in the operating model.

Estimates were determined by maximizing the joint posterior density instead of the full posterior integration typically used in the stock assessment (i.e., JTC 2013). 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. In contrast to how recent stock assessments (JTC 2012, JTC 2013) have used Bayesian methods to presents a range of probabilistic options for the TAC, 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.

**Analysis and performance measures**

The performance of each case is measured using performance metrics defined for short- and long-term periods. Short-term, the next 10 years (2014–2023), performance statistics, which are dependent on the starting conditions in 2014, are helpful to stakeholders to ensure that the Management Procedures meet their immediate objectives. The long-term (2033–2042) performance statistics provide an insight into the equilibrium performance of each Management Procedure under different scenarios, and are useful to determine if a given management procedure could meet conservation and sustainability objectives.

Thirteen performance metrics in three general categories are presented based on the Harvest Rule defined in the Agreement and discussions with stakeholders. These three general categories are population status, catch, and age-structure of the population. For each of these categories, two types of statistics are reported. The median average of a value is calculated by finding the average over the 10 year time period for each of the 1000 simulations, and then determining the median of these averages from all of the simulations. Probabilities are defined as the number of times the condition is met out of the 10,000 realizations in that time period (10 years times 1,000 simulations).

The four metrics related to population status are median average depletion and percentages of simulations where depletion was below 10% of $B_0$, between 10% and 40% of $B_0$, and above 40% of $B_0$. Median average depletion provides a central tendency over all 1000 simulations, but does not provide an indication of the variability of depletion around that central tendency. The probabilities provide an idea of the variability as well as risk. Thresholds of 10% and 40% were chosen because they are the endpoints of the 40:10 control rule defined by the Agreement.

The six metrics based on catch are the median average catch, the average annual variability (AAV), the probability that the fishery is closed (catch=0), and the probability that catch is above and/or below thresholds of 180,000 and 375,000 mt. The average annual variability is a measure of the variability from year to year (Table A.1). The probability that catch is zero reflects how often the fishery is closed based on the assessment. The catch thresholds of 180,000 and 375,000 mt were determined from discussions with stakeholders (in particular, members of the Advisory Panel, AP). Industry members preferred to maintain a catch above 180,000, and a coast-wide catch of 375,000 mt is slightly above the maximum coast-wide catch ever realized in this fishery. These thresholds are only suggestive and were not necessarily agreed upon by all industry members in the U.S. and Canada. They are simply included here for illustrative purposes.

Three statistics determined from the age composition of the population are presented to represent the age diversity of the population, provide insight into the size of fish that may be encountered by the fishery, and to give an indication of the fishing opportunities in Canadian waters since fish younger than 4 years old tend to remain in U.S. waters during the fishing year. The effect of dominant year classes on the median average mean age is greatly diminished because the statistic is a conglomeration of random recruitments over years and simulations. The mean age over time estimated from the 2013 assessment is shown in Figure 26 of JTC (2013). This is an example of how the mean age may look in one particular simulation, and you can see how the averaging over years will smooth it. The median average age 4+ biomass represents the total biomass of age 4+ fish, and the median average ratio of biomass that is age 4+ is the age4+ biomass divided by the total biomass, then averaging across years and determining the median from the simulations.

## Appendix A.3. Results

**General patterns**

The Operating Model (OM) for this year's MSE is conditioned on the 2013 stock assessment. This means that the initial conditions include the very large 2010 year class. Accordingly, short-term (2014–2023) management procedure performance is characterized by higher average catch and lower risk of depletion than in the long term (2033–2042). The long-term period is chosen to be far enough in the future to dampen the effects of the initial conditions.

The long-term period includes numerous runs, some with large recruitments. About 2% of the simulated recruitments in this period are larger than the median estimate of 2010 recruitment. However, the distribution of recruitments for every future year includes both above- and below-average recruitments. The differences between short-term and long-term results are therefore an indication of the performance of the alternatives with or without the influence of a large recent recruitment event.

**Adding time-varying selectivity to Operating Model**

Including time-varying fishery selectivity in the OM changes both the initial conditions for the MSE and the interaction between the fishery and the population in the simulation years. Time-varying fishery selectivity reduces the influence of the fishery age-composition data relative to the survey data. Without time-varying selectivity, there is very little difference between the biennial and annual survey cases, but in the time-varying selectivity scenario, there is a distinct benefit to the larger quantity of data that comes from annual surveys when the Assessment has time-invariant selectivity (Table A.3). In the long term, the Average Annual Variation (AAV) in catch is reduced from 52% to 38% and the long-term probability of the fishery being closed due to the population being estimated below 10% of $B_0$ decreases from 13% to 5%. The probability that the OM population falls below 10% of $B_0$ is 6% with biennial surveys and 5% with annual surveys, indicating that the biennial survey case has a higher incidence of the assessment model falsely indicating that the population is below the threshold when in fact it remains above. This high rate of assessment error is due in part to the mismatch in assumptions about time-varying selectivity between the OM and the Assessment for these cases.

The extent of true variability in fishery selectivity is unknown, but the time-varying selectivity OM is likely to be a better representation of the true fishery than the OM with constant selectivity across all years. Therefore, all remaining MSE comparisons will focus on cases with time-varying fishery selectivity in the OM.

**Adding time-varying selectivity to the Assessment**

Estimating time-varying fishery selectivity in the Assessment increases the number of parameters in the model, but the better match in structure between OM and Assessment improves the performance. The addition of time-varying selectivity to the Assessment reduces the risk of the population falling below 10% of B0 from 6% and 5% with biennial or annual surveys, respectively, to 3% and 2% (Table A.4). The probability of closing the fishery due to the Assessment perceiving the biomass to be below 10% of the estimated B0 (whether or not this is true of the OM population) is reduced by a larger amount, 13% and 5% to 1% and 0%, respectively. Assessments with time-varying selectivity reduce short-term median average catch but increase the long-term catch by a greater amount. This change also reduces the variability in catch in both the short and long term (AAV declines from 52% to 31% in the biennial case for the long-term period).

When time-varying selectivity is added to the Assessment, under similar assumptions as in the OM, the benefit of the annual surveys is reduced. When the selectivity parameterization between the OM and the

Assessment do not match, the increase in data that comes from more frequent surveys reduces the risks associated with Assessment errors. With a better match in assumptions between the OM and the Assessment, these errors are less frequent and the marginal value of more frequent surveys is smaller.

The metrics related to age composition show little sensitivity to the choice of assumptions about time-varying selectivity. There are similar results for models with and without time-varying selectivity (long-term median average mean age 2.7 or 2.8, more than 1 million mt of age 4+ biomass, and 59-60% of the total biomass age 4 or greater). However, the perfect information case has a large impact on the age composition. In this case, the median average mean age is reduced to 2.4 and the fraction of biomass that is age 4 or greater falls to 54%. Under the default harvest policy (F40% with 40-10 adjustment), perfect information about spawning biomass allows the catch to increase immediately as soon as large recruitments contribute to spawning biomass, which leads to higher median average catch, lower stock status (28% instead of 37-39%), and fewer age 4+ fish remaining in the population (Table A.4). Without perfect information, the delay in estimating the strength of large recruitments leads to a lower than F40% harvest rate during periods of increasing abundance.

The effect of incorrect assessment model parameterization was larger than the relative differences in $\phi$. (Table A.5). The biennial survey cases with no time-varying selectivity in the assessment had a 13% probability of fishery closure in the long term but using assessment models with time-varying selectivity greatly reduced this risk at 3% and 1% probability for $\phi$=0.2 and $\phi$=0.05 cases, respectively. The probability of falling below 10% of B0 was actually lower in the low flexibility assessment case (2%) than in the high flexibility case where the Assessment matched the OM (3%). This is likely the result of a slightly lower median average catch.

**A range of catch values**

The cases where catch ranges were imposed, generally led to lower risk of spawning biomass being less than 10% of $B_0$, lower variability in catch, and higher long-term catch, but had lower catch in the short term (Table A.6). Due to time limitations, these cases were not considered in combination with time-varying selectivity in the Assessment, but could be expected to have resulted in changes in the same direction in those cases as well. With a biennial survey, going from unlimited catch to catch within a range of 0 - 500,000 mt or 0 - 375,000 mt increased the long-term median average catch from 199,000 mt to 203,000 or 216,000 mt (Table A.6 and Figure A.7). This is likely a result of both the buffering against assessment errors and banking of fish for future years. With no limit on the range of catch, assessment errors have the potential to set catch higher than the population can sustain. Also, by not setting the catch as high during periods when the biomass truly is very large, more fish are available in periods with lower recruitment. The median average depletion also increases from 39% of $B_0$ with unlimited catch to 45% of $B_0$ when a 375,000 mt catch cap is used. Thus, not only do fish live longer, but the 40-10 adjustment is used less often to reduce harvest rates, leading to a higher average catch with more stability. The proportion of the biomass that is age 4 or older increases slightly from 60% to 62% when catch doesn't go above 375,000 mt.

Maintaining catch within the range 180,000 - 375,000 mt involves setting catch at 180,000 when the default harvest rate determined by the $F_{40\%}$-40:10 adjustment goes below that value. Therefore, fishing will continue even when the population is estimated to have fallen below 10% of B0 as long as the available biomass is sufficient to allow the catch to be removed. This resulted in a considerable increase in the probability of the stock falling below 10% of unfished equilibrium biomass. This reduced the variability in catch compared to the case with a 0 - 375,000 mt catch range (long-term median AAV in catch falls from 34% to 19%), but the probability of $B < B_{10\%}$ increased from 5% to 19%. With this range in place, the probability of having catch below 180,000 due to lack of available biomass to be caught was 21%. This case also had lower mean age than the other catch range cases and the median average ratio of age 4+ biomass fell from 62% to 54% with the introduction of the 180,000 mt floor on catch.

The performance of the catch range management procedure was particularly sensitive to the starting conditions of the Operating Model. The introduction of a catch range generally results in lower short-term average catch (Table A.6) because the biomass estimated with a large simulated 2010 year class was high and applying an un-capped harvest control rule to these biomass estimates often results in large catches (5% of the simulations have a short-term average catch which is more than double the highest observed historical catch) (Table A.6).

**Constant catch**

In general, setting a constant catch did not perform well compared to cases with either the default harvest policy or the default harvest policy adjusted by some range (Table A.7). In the short term, constant catch values of 100,000 - 300,000 mt could be achieved in the majority of the simulations, but when a constant catch of 400,000 mt was attempted, the median average short-term catch was only 394,000 mt, indicating that a majority of the scenarios drove the population to a low enough level within 10 years that the constant catch could not be removed. In the long-term, only the 100,000 and 200,000 mt constant catches could be achieved by a majority of the simulations. Attempting a constant catch of 400,000 mt resulted in a long-term median average catch of 267,000 mt, which is actually lower than the 271,000 mt median average catch achieved when attempting a 300,000 mt constant catch. For any given year within the long-term period, a majority of the simulations had 300,000 mt available for the fishery (as indicated by the green line in Figure A.8), but only a minority of the simulations had that amount available in all 10 years of the long-term period so the median average catch is below 300,000 mt. The probability of having spawning biomass below 10% of B0 was only 1% in the 100,000 mt constant catch case, but increased to 10% at 200,000 mt, and 24% at 300,000. The only metrics by which the constant catch cases performed well were the probability of catch = 0, which was 0% in the constant catch scenarios because the 40-10 rule was overridden by the constant catch values and the fishery was never shut down entirely, and catches were very stable, with median AAV at 0% in the long term at 100,000 and 200,000 mt (but increased to 35% when a constant catch of 400,000 mt was attempted do to the higher frequency of catches being limited by unavailability of biomass to be removed). The catch and depletion for each individual year is depicted in Figure A.8 and Figure A.9, and shows that a constant catch of 400,000 mt continually declines into the future as does depletion for all constant catch scenarios. The declining biomass trend at the end of the simulation period with 300,000 mt constant catch suggests that a longer projection would also show the median annual catch to be declining in this case as well.

**Comparisons across management procedures**

The probabilities shown in the MSE results do not reveal the extent to which two metrics could be satisfies simultaneously. Figure A.10 shows the distribution of spawning depletion and catch for the 10,000 points associated with each of the 1000 simulations over the 10-year, short-term period (2014–2023) and the fraction of this distribution associated with different combinations related to the reference points 40% of $B_0$ and 180,000mt catch. For the four management procedures shown in Figure A.10, the maximum probability of having catch $\geq$ 180,000 mt and spawning biomass $\geq$ 40% of $B_0$ is 82%, and that is associated with the lowest median average short-term catch. Comparison of values associated with different metrics against each other reveal trade-offs that appear somewhat independent of the details of the management procedures. In the long-term, the probability of being below 40% of $B_0$ is greater than in the short-term (Figure A.11).

A graphical comparison of pairs of metrics from the tables of MSE results (Figures A.12 and A.13) shows that some trade-offs appear to be somewhat independent of management procedure. In particular, the median average depletion appears to decline almost linearly as a function of the median average catch (Figure A.12). The relationship between these quantities differs between the short-term and long-term time periods, but appears to be similar within a time period whether catch was removed by the default harvest control rule, limited to some catch range, or taken as a constant catch. Likewise, median average mean age increases almost linearly with depletion (Figure A.13). This relationship shows not only little difference between the methods for determining catch, but also little difference between short-term and long-term periods.

## Appendix A.4. Discussion

This year's MSE simulated a Pacific Hake management system that is highly volatile. Determining management procedures that produce sustainable fishing opportunities to all fishing sectors, while minimizing risk of depleting the population is a big challenge. In the MSE simulations, the default Harvest Rule leads to large year-to-year changes in catch (AAV), even in cases where perfect information about the population size is available. AAV is even higher when data are simulated with realistic errors; this leads to occasional inaccurate assessment results that can increase the risk of overfishing or foregone yield. The MSE analyses conducted this year focused on three dimensions of Management Procedures:

1. Testing the benefit of more frequent data (annual vs. biennial surveys)
2. Testing differences in assessment accuracy by modeling more underlying processes in the population dynamics (including time-varying fishery selectivity in the Assessment)
3. Investigating the management behavior that has been apparent in recent years by setting catches less than the default Harvest Rate suggests, and testing the trade-offs associated with dampening the variability in catch by attempting to maintain the catch within a given range (or at a single fixed value).

Using time-varying selectivity in both the OM and the assessment model has a large effect on management procedures performance. With time-varying selectivity in the OM, changes in the observed proportions at age in simulated catch data can be caused by recruitment and/or changes in selectivity-at-age. Without time-varying selectivity in the Assessment, these changes are more likely to be estimated as recruitment: this may bias estimates of biomass and recommended catch. Assessment models with time-varying selectivity have the flexibility to explain catch-at-age proportions as coming from a combination of recruitment and changes in selectivity. The more complex assessment model reduces the risk of overestimating high recruitment of recent cohorts and the potential for overfishing that may occur when these cohorts are smaller than expected. However, this may increase the risk of overestimating the size of a recent low recruitment event. This occurs because the penalty on recruitment deviations shrinks the estimates toward zero until enough data suggests otherwise. Time-varying selectivity allows an explanation other than low recruitment when few observations of a cohort have been made.

In the limited cases investigated in this MSE (and under the assumptions made), it is apparent that the introduction of time-varying selectivity to the assessment model has a greater benefit to stock status and catch in the long term than increased survey frequency. In the short term, an annual survey resulted in a higher average catch, but time-varying selectivity reduced the variability in the catch and lowered risk to the stock status. Combining both an annual survey and time-varying selectivity performed better than either option alone, but time-varying selectivity provided a large proportion of the improvement. These statistics are based on averages and medians over many realizations, and the benefits to specific situations were not specifically investigated. For example, from 2011 to 2013, an annual acoustic survey took place for Pacific Hake, and is believed to have resulted in a better assessment, mostly because of a reduction in uncertainty, which supported a belief that the stock was increasing. The survey predicted a high biomass in 2009 and a low biomass in 2011, causing concern for which estimate was more realistic. In this case, an annual survey in 2012 was very beneficial to increase the certainty that catch levels were being set appropriately. Future MSE analyses could evaluate the potential benefit of a system in which low biomass estimates would trigger occasional additional surveys within an otherwise biennial schedule, as occurred in 2011–2012.

Data and models are not the only tools that can be used to meet fishery and management objectives. Alternative Harvest Rules can improve performance, and also allow for consistent and understandable determination of the quota. For our simulations, we have modeled a strict $F_{40\%}$ 40:10 harvest strategy (except for the catch range scenarios), but in practice it is not clear how modifications to the TAC based on the current strategy are implemented, or how structural and parameter uncertainty is used in decision making. In the past decade, there have been multiple times when catch quotas have been set less than the median TAC predicted by the stock assessment model indicating that the decision making process is more complex than we have modeled in our simulations. The 2011 and 2013 stock assessments (JTC 2013, Stewart et al. 2011) are examples of uncertain assessments and precautionary management behavior. Both of these assessments predicted very large cohorts of age-3 fish based on high proportions at age 1 and 2 in the fishery age compositions, and age-2 fish in the 2012 survey age compositions. The uncertainty in year-class size was high and there was concern of the consequences of setting a quota at the level predicted by the median of the default Harvest Rule when actual recruitment may be lower than the predicted median recruitment. There was justification for setting the quotas lower than the assessment suggested, but our simulations have not defined or tested it, although they potentially could.

The catch ranges tested here attempted to mimic what would be precautionary behavior of managers, and/or allow for a minimum necessary catch to support the fishery. Not allowing catch to exceed a ceiling value resulted in higher long-term average catch because realized catches did not depend entirely on a potentially uncertain assessment model. There may also be a benefit associated with maintaining a higher average biomass, which could be quantified in future MSE analyses by combining catch ranges with perfect information about the stock status. And, as expected, catch variability is reduced because catches are not allowed to vary over wide ranges. However, given that the OM started with a likely increasing population size, the short-term catches are often curtailed. This is an example of the importance of defined objectives and performance metrics that can be used to balance the trade-offs between short- and long-term goals, as well as other objectives.

There is a dramatic difference between the results of the MSE and equilibrium reference points such as MSY. The median MSY estimate from the 2013 stock assessment is 357,000 mt and the equilibrium yield estimated associated with the F40% harvest rate is 337,000 mt. In contrast to this, the long-term median average catch that results from applying the harvest control rule with perfect information is only 251,000 mt when the OM has no time-varying selectivity, which is the case that best matches to the 2013 assessment. When the OM includes time-varying selectivity, the median MSY value is 337,000 mt and yet the majority of simulations with this OM can't sustain a constant catch of 300,000 mt in the long-term (the long-term median average catch is 271,000 mt in this case). The key difference in both these examples is that the equilibrium calculations are based on a stationary biomass level and the expected recruitment level associated with a particular point on the stock-recruit curve whereas the MSE simulations are characterized by highly variable recruitment. The variability in recruitment frequently causes the spawning biomass to fall below 40% of B0 at which point the catches in the perfect information case (but not the constant catch case) are reduced through the 40-10 adjustment to the default harvest rate. Perhaps more importantly, MSY is associated with a level of depletion that maximizes surplus production in equilibrium. Yet with highly variable recruitment, the spawning biomass is frequently driven to lower or higher levels associated with less productivity due to either a reduction in the spawning potential or a compensatory response to a high biomass. This result of Maximum Average Yield (MAY) often being less than MSY has been noted many times in fisheries literature (e.g., see Prager (1994)) In general, these differences suggest that for a population with recruitment as variable as Pacific Hake, the equilibrium reference points are less valuable for guiding expectations about future catch than more complex calculations such as those conducted within an MSE.

This MSE simulation tested a few Management Procedures and measured the performance against a small set of Goals & Objectives. However, this is only a small example of the utility of a MSE. Improvements can be made to the OM, such as modeling alternative recruitment dynamics (e.g., autocorrelation) or using patterns of historical recruitment, to provide a more realistic portrayal of the hake stock or alternative scenarios for simulation testing. Alternative assumptions about the sampling distribution used for simulated survey data could also be explored to model the effect of occasional extreme survey estimates. Status quo Management Procedures could be better defined by studying the past behavior of management and the fisheries at different stock sizes and including relationships between stock size and implementation error (the amount of catch relative to the TAC). New Management Procedures could be developed with the involvement of stakeholders, managers, and other interested parties, which are then Simulation Tested to determine if they meet Goals & Objectives. For example, specifically accounting for uncertainty and reducing the TAC in a repeatable manner, or limiting annual increases in catch can be easily investigated.

This is small number of potential additions and improvements to this MSE, but most importantly, consultation with stakeholders, managers, and other interested parties should occur to clearly define their Goals & Objectives. Once defined, Management Procedures can be Simulation Tested and the Application of a well performing and agreed upon strategy can be used to define future quotas.

## Appendix A.5. Tables

**Table A.1: Cases considered in the MSE as combinations of various procedures when using the Operating Model with time-varying selectivity.**

<table>
<tr><th></th><th>Catch determination</th><th>Survey Frequency</th><th>Time Vary Selex Assessment Model</th><th>Catch Ranges or Fixed Catch</th></tr>
<tr><td rowspan="19">Management Procedures</td><td rowspan="6">Assessment</td><td rowspan="3">Annual</td><td>None</td><td>None</td></tr>
<tr><td>Low (0.05)</td><td>None</td></tr>
<tr><td>High (0.20)</td><td>None</td></tr>
<tr><td rowspan="3">Biennial</td><td>None</td><td>None</td></tr>
<tr><td>Low (0.05)</td><td>None</td></tr>
<tr><td>High (0.20)</td><td>None</td></tr>
<tr><td rowspan="2">Assessment</td><td>Annual</td><td>None</td><td>375,000 (max)</td></tr>
<tr><td>Biennial</td><td>None</td><td>375,000 (max)</td></tr>
<tr><td rowspan="2">Assessment</td><td>Annual</td><td>None</td><td>500,000 (max)</td></tr>
<tr><td>Biennial</td><td>None</td><td>500,000 (max)</td></tr>
<tr><td rowspan="2">Assessment</td><td>Annual</td><td>None</td><td>180,000 (min); 375,000 (max)</td></tr>
<tr><td>Biennial</td><td>None</td><td>180,000 (min); 375,000 (max)</td></tr>
<tr><td rowspan="5">Constant Catch</td><td rowspan="6">NA</td><td rowspan="6">NA</td><td>100,000 (constant)</td></tr>
<tr><td>200,000 (constant)</td></tr>
<tr><td>300,000 (constant)</td></tr>
<tr><td>400,000 (constant)</td></tr>
<tr><td>500,000 (constant)</td></tr>
<tr><td>Benchmarks</td><td>Perfect Info</td><td>None</td></tr>
</table>

**Table A.2: Performance metrics used to evaluate performance with regard to stock status, catch, and age-structure of the population.**

| Metric | Description | Formula |
|---|---|---|
| *Stock status* | | |
| Median average depletion | The median of the average status of the stock (relative to $B_0$) over a defined period of time | $\text{Median}\left(\frac{1}{n+1}\sum_{i=t}^{t+n} SB_t \Big/ SB_0\right)$ |
| $P(B < B_{10\%})$<br>$P(B_{10\%} \leq B \leq B_{40\%})$<br>$P(B > B_{40\%})$ | The probability that spawning biomass is less than 10% unfished equilibrium spawning biomass ($B_{10\%}$), between $B_{10\%}$ and $B_{40\%}$, or greater than $B_{40\%}$ at any time in the period and in any simulation. | $\frac{N_{\text{within}}}{N_{\text{total}}}$<br>where $N_{within}$ is the total number of observations satisfying the criteria and $N_{total}$ is the total number of observations |
| *Catch* | | |
| Median average catch | The median of the average catch over the time period defined. | $\text{Median}\left(\frac{1}{n+1}\sum_{i=t}^{t+n} C_t\right)$ |
| Average annual variability (AAV) | The average absolute change in catch divided by the average total catch, and expressed as a percentage. | $\sum_{i=t+1}^{t+n} \lvert C_t - C_{t-1} \rvert \Big/ \sum_{i=t+1}^{t+n} C_t$ |
| Probability that catch = 0, is < 180,000 mt, between 180,000 and 375,000 mt, or > 375,000 mt | The probability that catch is zero, is less than 180,000 mt, between 180,000 mt and 375,000mt, or greater than 375,000 mt at any time in the period and in any simulation. | $\frac{N_{\text{within}}}{N_{\text{total}}}$<br>where $N_{within}$ is the total number of observations satisfying the criteria and $N_{total}$ is the total number of observations |
| *Age structure* | | |
| Median average mean age | The median of the average mean age over the time period defined. | $\text{Median}\left(\frac{1}{n+1}\sum_{i=t}^{t+n}\left(\sum_{a=0}^{20} aN_{a,t} \Big/ \sum_{a=0}^{20} N_{a,t}\right)\right)$ |
| Median average age 4+ biomass | The median of the average age 4 and older biomass over the time period defined. | $\text{Median}\left(\frac{1}{n+1}\sum_{i=t}^{t+n}\sum_{a=4}^{a=20} B_{a,t}\right)$ |
| Median average ratio of biomass that is age 4+ | The median of the average age 4 and older biomass divided by total biomass over the time period defined. | $\text{Median}\left(\frac{1}{n+1}\sum_{i=t}^{t+n}\left(\sum_{a=4}^{20} B_{a,t} \Big/ \sum_{a=0}^{20} B_{a,t}\right)\right)$ |

**Table A.3: Performance metrics for cases with and without time-varying selectivity in the Operating Model (OM).**

| | Short term (2014-2023) | | | | | | Long term (2033-2042) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | | | | | | | | | | | |
| Time-varying selectivity | None | None | None | OM | OM | OM | - | - | - | OM | OM | OM |
| Survey frequency | biennial | annual | perfect | biennial | annual | perfect | biennial | annual | perfect | biennial | annual | perfect |
| Metrics related to depletion | | | | | | | | | | | | |
| Median average depletion | 48% | 48% | 47% | 51% | 50% | 44% | 31% | 32% | 30% | 39% | 37% | 28% |
| Probability $B < B_{10\%}$ | 5% | 3% | 0% | 5% | 4% | 1% | 5% | 3% | 0% | 6% | 5% | 1% |
| Prob. $B \geq B_{10\%}$ & $B \leq B_{40\%}$ | 39% | 42% | 47% | 39% | 41% | 52% | 64% | 66% | 73% | 48% | 54% | 73% |
| Probability of $B > B_{40\%}$ | 56% | 55% | 53% | 57% | 56% | 47% | 31% | 31% | 26% | 45% | 41% | 25% |
| Metrics related to catch | | | | | | | | | | | | |
| Median of average catch (1000 mt) | 435 | 436 | 450 | 388 | 403 | 445 | 239 | 234 | 251 | 199 | 218 | 246 |
| Median of Average Annual Variability (AAV) in catch | 32% | 33% | 29% | 53% | 47% | 43% | 31% | 30% | 23% | 52% | 38% | 33% |
| Probability that catch = 0 | 2% | 1% | 0% | 10% | 7% | 1% | 2% | 1% | 0% | 13% | 5% | 1% |
| Prob. catch < 180,000 mt | 20% | 19% | 17% | 32% | 29% | 22% | 43% | 43% | 41% | 52% | 47% | 42% |
| Prob. catch ≥ 180,000 & catch ≤ 375,000 mt | 22% | 22% | 29% | 19% | 21% | 31% | 32% | 33% | 33% | 27% | 30% | 33% |
| Prob. catch > 375,000 mt | 58% | 58% | 54% | 49% | 50% | 47% | 25% | 25% | 26% | 21% | 22% | 25% |
| Metrics related to age composition | | | | | | | | | | | | |
| Median average mean age | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.7 | 2.5 | 2.6 | 2.5 | 2.7 | 2.7 | 2.4 |
| Median average age 4+ biomass (million mt) | 1.69 | 1.68 | 1.66 | 1.66 | 1.63 | 1.42 | 1.00 | 1.02 | 0.94 | 1.27 | 1.14 | 0.83 |
| Median average ratio of biomass that is age 4+ | 63% | 63% | 64% | 62% | 63% | 61% | 56% | 57% | 56% | 60% | 59% | 54% |

**Table A.4: Performance metrics for cases with and without time-varying selectivity in the Assessment. "OM" indicates time-varying selectivity in the Operating Model only. "OM & Assess" indicates time-varying selectivity in both the operating model and the assessment.**

| | Short term (2014-2023) | | | | | Long term (2033-2042) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | | | | | | | | | |
| Time-varying selectivity | OM | OM | OM & Assess | OM & Assess | OM | OM | OM | OM & Assess | OM & Assess | OM |
| Survey frequency | biennial | annual | biennial | annual | perfect | biennial | annual | biennial | annual | perfect |
| Metrics related to depletion | | | | | | | | | | |
| Median average depletion | 51% | 50% | 54% | 53% | 44% | 39% | 37% | 38% | 38% | 28% |
| Probability $B < B_{10\%}$ | 5% | 4% | 2% | 1% | 1% | 6% | 5% | 3% | 2% | 1% |
| Prob. $B \geq B_{10\%}$ & $B \leq B_{40\%}$ | 39% | 41% | 36% | 38% | 52% | 48% | 54% | 55% | 57% | 73% |
| Probability of $B > B_{40\%}$ | 57% | 56% | 62% | 61% | 47% | 45% | 41% | 42% | 42% | 25% |
| Metrics related to catch | | | | | | | | | | |
| Median of average catch (1000 mt) | 388 | 403 | 372 | 381 | 445 | 199 | 218 | 222 | 224 | 246 |
| Median of Average Annual Variability (AAV) in catch | 53% | 47% | 31% | 32% | 43% | 52% | 38% | 31% | 30% | 33% |
| Probability that catch = 0 | 10% | 7% | 1% | 0% | 1% | 13% | 5% | 1% | 0% | 1% |
| Prob. catch < 180,000 mt | 32% | 29% | 21% | 21% | 22% | 52% | 47% | 45% | 44% | 42% |
| Prob. catch ≥ 180,000 & catch ≤ 375,000 mt | 19% | 21% | 31% | 30% | 31% | 27% | 30% | 34% | 35% | 33% |
| Prob. catch > 375,000 mt | 49% | 50% | 48% | 49% | 47% | 21% | 22% | 21% | 21% | 25% |
| Metrics related to age composition | | | | | | | | | | |
| Median average mean age | 2.8 | 2.8 | 2.9 | 2.9 | 2.7 | 2.7 | 2.7 | 2.7 | 2.8 | 2.4 |
| Median average age 4+ biomass (million mt) | 1.66 | 1.63 | 1.80 | 1.74 | 1.42 | 1.27 | 1.14 | 1.19 | 1.16 | 0.83 |
| Median average ratio of biomass that is age 4+ | 62% | 63% | 65% | 65% | 61% | 60% | 59% | 59% | 60% | 54% |

**Table A.5: Performance metrics for cases with different levels of time-varying selectivity in the Assessment. "OM" indicates time-varying selectivity in the Operating Model only. "OM & Assess" indicates time-varying selectivity in both the operating model and the assessment. For more information on the values for time-varying selectivity flexibility (either 0, 0.05, or 0.20), see the Methods section.**

| | Short term (2014-2023) | | | Long term (2033-2042) | | |
|---|---|---|---|---|---|---|
| Specifications | | | | | | |
| Time-varying selectivity | OM | OM & Assess | OM & Assess | OM | OM & Assess | OM & Assess |
| Time-varying selectivity flexibility (OM, Assess) | (0.20, 0) | (0.20, 0.05) | (0.20, 0.20) | (0.20, 0) | (0.20, 0.05) | (0.20, 0.20) |
| Survey frequency | biennial | biennial | biennial | biennial | biennial | biennial |
| Metrics related to depletion | | | | | | |
| Median average depletion | 51% | 54% | 54% | 39% | 39% | 38% |
| Probability $B < B_{10\%}$ | 5% | 2% | 2% | 6% | 2% | 3% |
| Prob. $B \geq B_{10\%}$ & $B \leq B_{40\%}$ | 39% | 36% | 36% | 48% | 53% | 55% |
| Probability of $B > B_{40\%}$ | 57% | 62% | 62% | 45% | 45% | 42% |
| Metrics related to catch | | | | | | |
| Median of average catch (1000 mt) | 388 | 369 | 372 | 199 | 213 | 222 |
| Median of Average Annual Variability (AAV) in catch | 53% | 37% | 31% | 52% | 35% | 31% |
| Probability that catch = 0 | 10% | 3% | 1% | 13% | 3% | 1% |
| Prob. catch < 180,000 mt | 32% | 26% | 21% | 52% | 47% | 45% |
| Prob. catch ≥ 180,000 & catch ≤ 375,000 mt | 19% | 27% | 31% | 27% | 32% | 34% |
| Prob. catch > 375,000 mt | 49% | 48% | 48% | 21% | 21% | 21% |
| Metrics related to age composition | | | | | | |
| Median average mean age | 2.8 | 2.9 | 2.9 | 2.7 | 2.8 | 2.7 |
| Median average age 4+ biomass (million mt) | 1.66 | 1.77 | 1.80 | 1.27 | 1.24 | 1.19 |
| Median average ratio of biomass that is age 4+ | 62% | 65% | 65% | 60% | 61% | 59% |

**Table A.6: Performance metrics for cases with different catch ranges. These ranges are choices that the JMC could make, not a proposed alternative harvest control rule. In the case with a range of 180 - 375, the population may sometimes not have sufficient biomass for the catch to remain in that range. The frequency of these occurrences is indicated by the metric "Prob. catch ≥ 180,000 & catch ≤ 375,000 mt" having a value less than 100%.**

| | Short term (2014-2023) | | | | Long term (2033-2042) | | | |
|---|---|---|---|---|---|---|---|---|
| Specifications | | | | | | | | |
| Time-varying selectivity | OM | OM | OM | OM | OM | OM | OM | OM |
| Catch range (1000 mt) | - | < 500 | < 375 | 180 - 375 | - | < 500 | < 375 | 180 - 375 |
| Survey frequency | biennial | biennial | biennial | biennial | biennial | biennial | biennial | biennial |
| Metrics related to depletion | | | | | | | | |
| Median average depletion | 51% | 56% | 62% | 61% | 39% | 42% | 45% | 35% |
| Probability $B < B_{10\%}$ | 5% | 3% | 2% | 4% | 6% | 5% | 5% | 19% |
| Prob. $B \geq B_{10\%}$ & $B \leq B_{40\%}$ | 39% | 32% | 28% | 27% | 48% | 47% | 44% | 41% |
| Probability of $B > B_{40\%}$ | 57% | 64% | 70% | 69% | 45% | 49% | 51% | 41% |
| Metrics related to catch | | | | | | | | |
| Median of average catch (1000 mt) | 388 | 368 | 335 | 344 | 199 | 203 | 216 | 233 |
| Median of Average Annual Variability (AAV) in catch | 53% | 28% | 15% | 9% | 52% | 41% | 34% | 19% |
| Probability that catch = 0 | 10% | 8% | 6% | 0% | 13% | 12% | 10% | 0% |
| Prob. catch < 180,000 mt | 32% | 23% | 16% | 5% | 52% | 50% | 44% | 21% |
| Prob. catch ≥ 180,000 & catch ≤ 375,000 mt | 19% | 16% | 84% | 95% | 27% | 25% | 56% | 79% |
| Prob. catch > 375,000 mt | 49% | 61% | 0% | 0% | 21% | 26% | 0% | 0% |
| Metrics related to age composition | | | | | | | | |
| Median average mean age | 2.8 | 3.0 | 3.1 | 3.1 | 2.7 | 2.9 | 2.9 | 2.6 |
| Median average age 4+ biomass (million mt) | 1.66 | 1.87 | 2.10 | 2.07 | 1.27 | 1.32 | 1.39 | 1.06 |
| Median average ratio of biomass that is age 4+ | 62% | 66% | 67% | 67% | 60% | 61% | 62% | 54% |

**Table A.7: Performance metrics for cases with different constant catch values. In these cases, there is no assessment model or survey required to set the catch levels. In some cases, the population will fall to such a low level that the constant catch can't be removed, as indicated in the difference between the constant catch value and the median of average catch.**

| | Short term (2014-2023) | | | | Long term (2033-2042) | | | |
|---|---|---|---|---|---|---|---|---|
| Specifications | | | | | | | | |
| Time-varying selectivity | OM | OM | OM | OM | OM | OM | OM | OM |
| Constant catch (1000 mt) | 100 | 200 | 300 | 400 | 100 | 200 | 300 | 400 |
| Metrics related to depletion | | | | | | | | |
| Median average depletion | 82% | 74% | 66% | 58% | 72% | 51% | 32% | 21% |
| Probability $B < B_{10\%}$ | 0% | 1% | 3% | 6% | 1% | 10% | 24% | 35% |
| Prob. $B \geq B_{10\%}$ & $B \leq B_{40\%}$ | 9% | 17% | 23% | 28% | 20% | 33% | 36% | 37% |
| Probability of $B > B_{40\%}$ | 90% | 82% | 74% | 66% | 79% | 57% | 40% | 28% |
| Metrics related to catch | | | | | | | | |
| Median of average catch (1000 mt) | 100 | 200 | 300 | 394 | 100 | 200 | 271 | 267 |
| Median of Average Annual Variability (AAV) in catch | 27% | 8% | 2% | 3% | 0% | 0% | 14% | 38% |
| Probability that catch = 0 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Prob. catch < 180,000 mt | 100% | 1% | 4% | 8% | 100% | 12% | 27% | 39% |
| Prob. catch ≥ 180,000 & catch ≤ 375,000 mt | 0% | 99% | 96% | 10% | 0% | 88% | 73% | 17% |
| Prob. catch > 375,000 mt | 0% | 0% | 0% | 82% | 0% | 0% | 0% | 44% |
| Metrics related to age composition | | | | | | | | |
| Median average mean age | 3.6 | 3.4 | 3.2 | 3.0 | 3.8 | 3.1 | 2.4 | 2.1 |
| Median average age 4+ biomass (million mt) | 2.90 | 2.59 | 2.27 | 1.95 | 2.45 | 1.66 | 0.94 | 0.54 |
| Median average ratio of biomass that is age 4+ | 75% | 72% | 69% | 65% | 72% | 64% | 51% | 42% |

## Appendix A.6. Figures

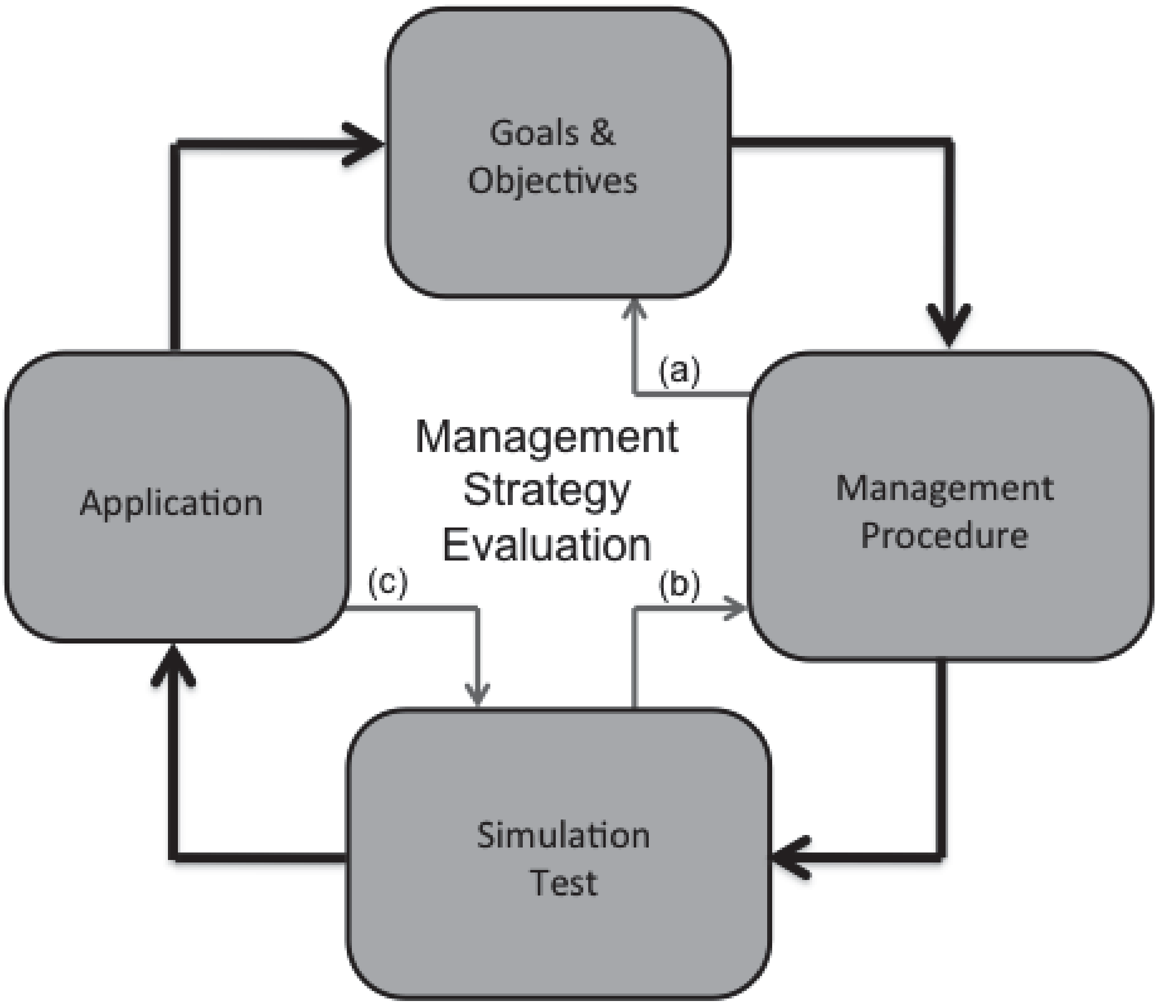



**Figure A.1: Four main elements of a fishery harvest strategy are developed through a Management Strategy Evaluation (MSE) process. The flows labelled (a-c) represent short-term response feedbacks that occur as part of each MSE sub-process. The Management Procedure and Simulation Test are linked via computer simulation of the fishery system as indicated in Figure 2.**

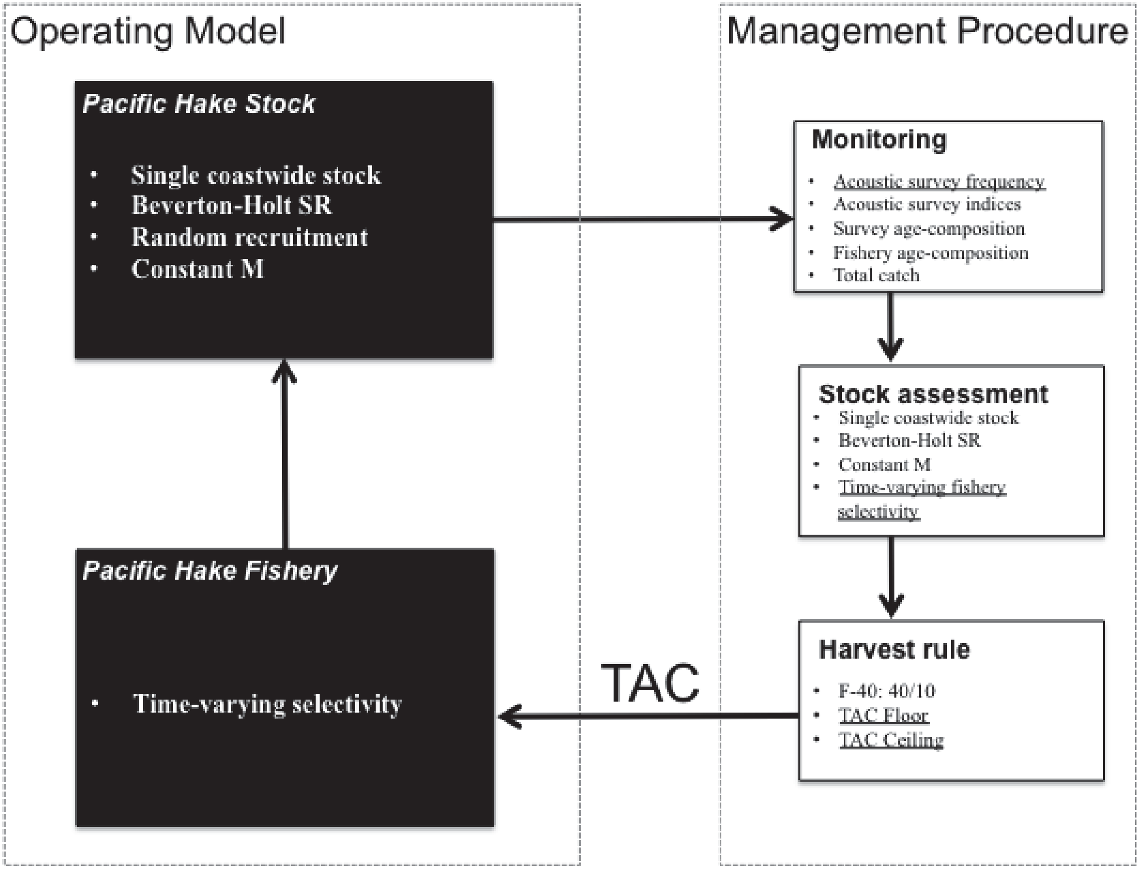



**Figure A.2: Structure of the Pacific Hake fishery system simulation test. The Operating model (left) represents the biological functioning of the Pacific Hake stock and the process driving temporal changes in fishery selectivity. The Management Procedure (right) specifies the flow of information from raw data collection through the Stock Assessment and Harvest Rule to determine the total allowable catch (TAC) by the fishery. Population dynamics models of Pacific Hake occur in both the Operating Model and in the Stock Assessment. Management Procedure options tested in the 2013 MSE simulations include (underlined elements within each box): (*i*) Acoustic survey frequency – Annual or Biennial; (*ii*) Time-varying fishery selectivity – Present (high or low variation $\phi$) or Absent; (*iii*) TAC Floor/Ceiling – various combinations TAC Floors (0 – 180,000 mt) and Ceilings (375,000 mt – 500,000 mt). Operating Model scenarios included high or no variability in fishery selectivity; otherwise, the Operating Model and Stock Assessment models were identical in structure.**

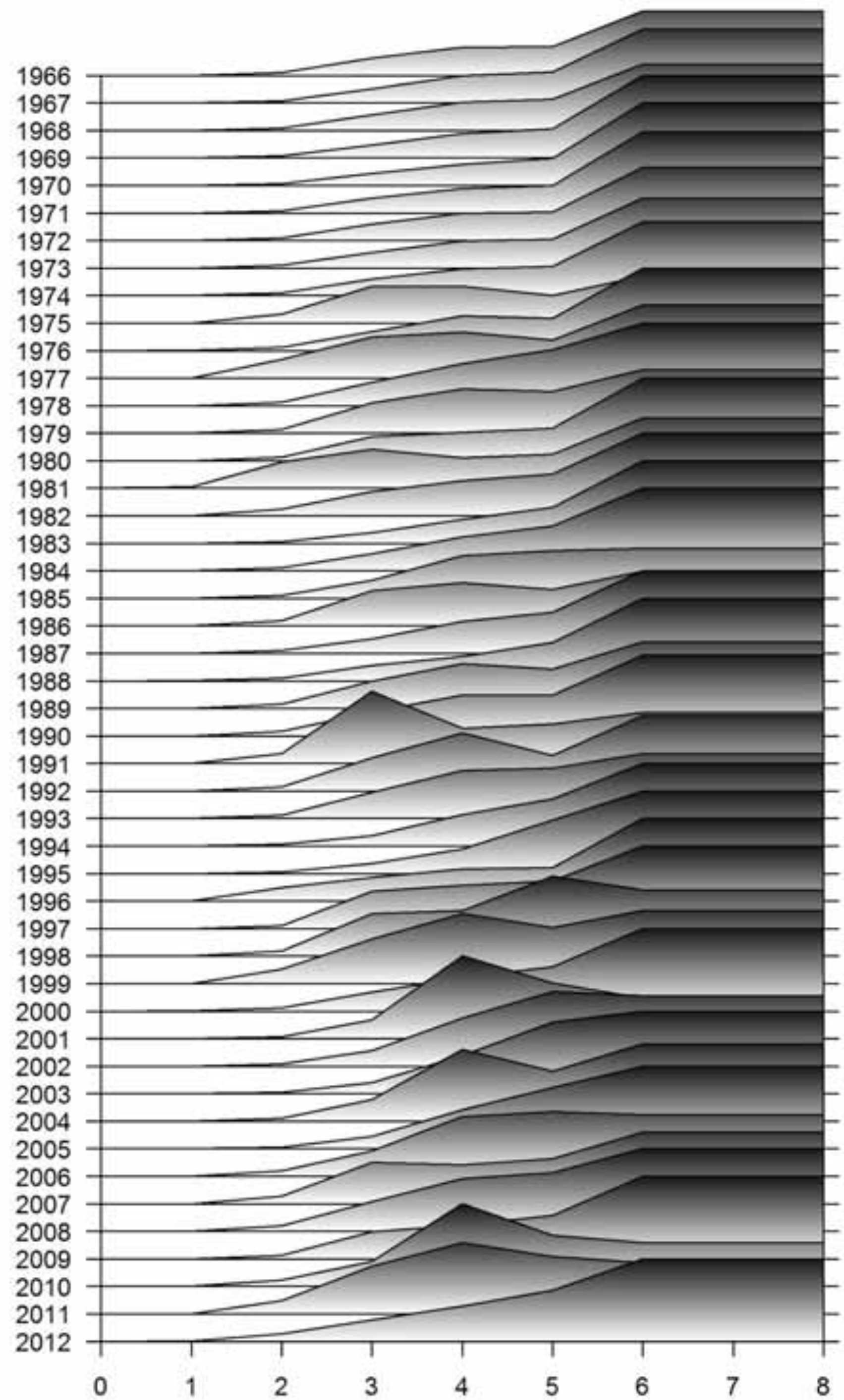



**Figure A.3: Median fishery selectivity-at-age by year in the operating model.**

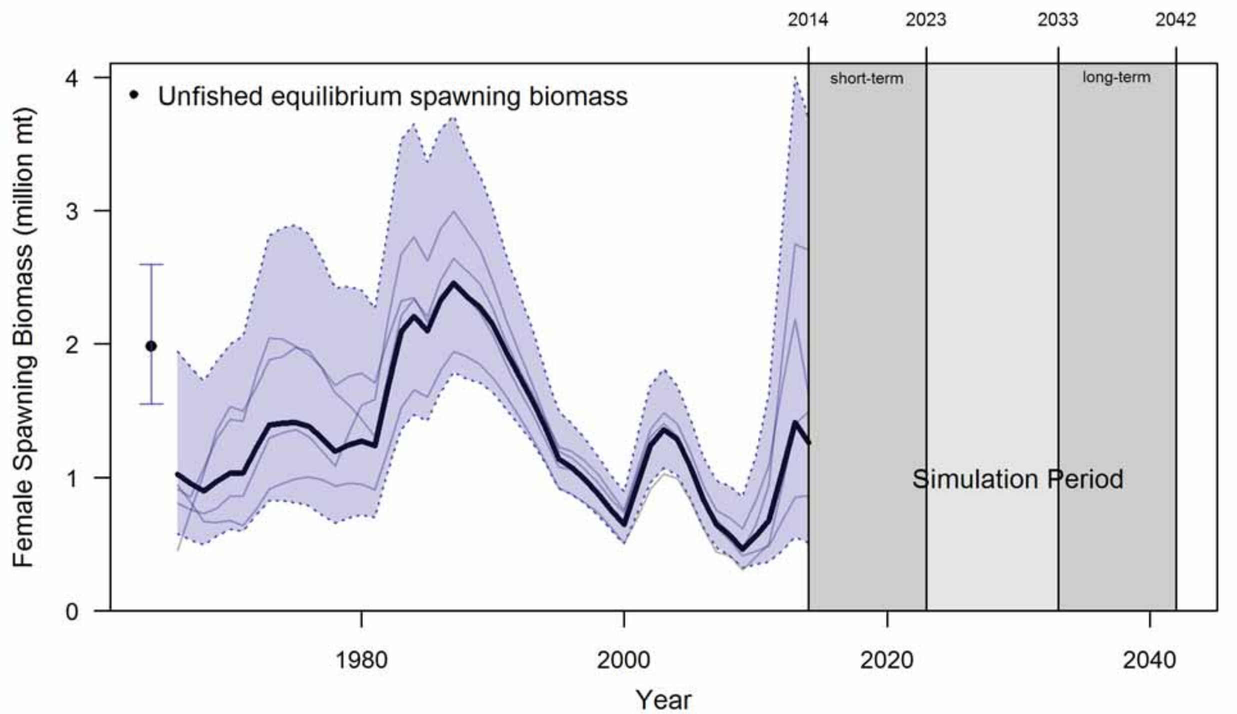


**Figure A.4: Median spawning biomass trajectory for the conditioned years of the operating model (solid black line) and a 95% probability interval (blue shaded area). A small number of randomly selected individual trajectories are shown as light grey lines.**

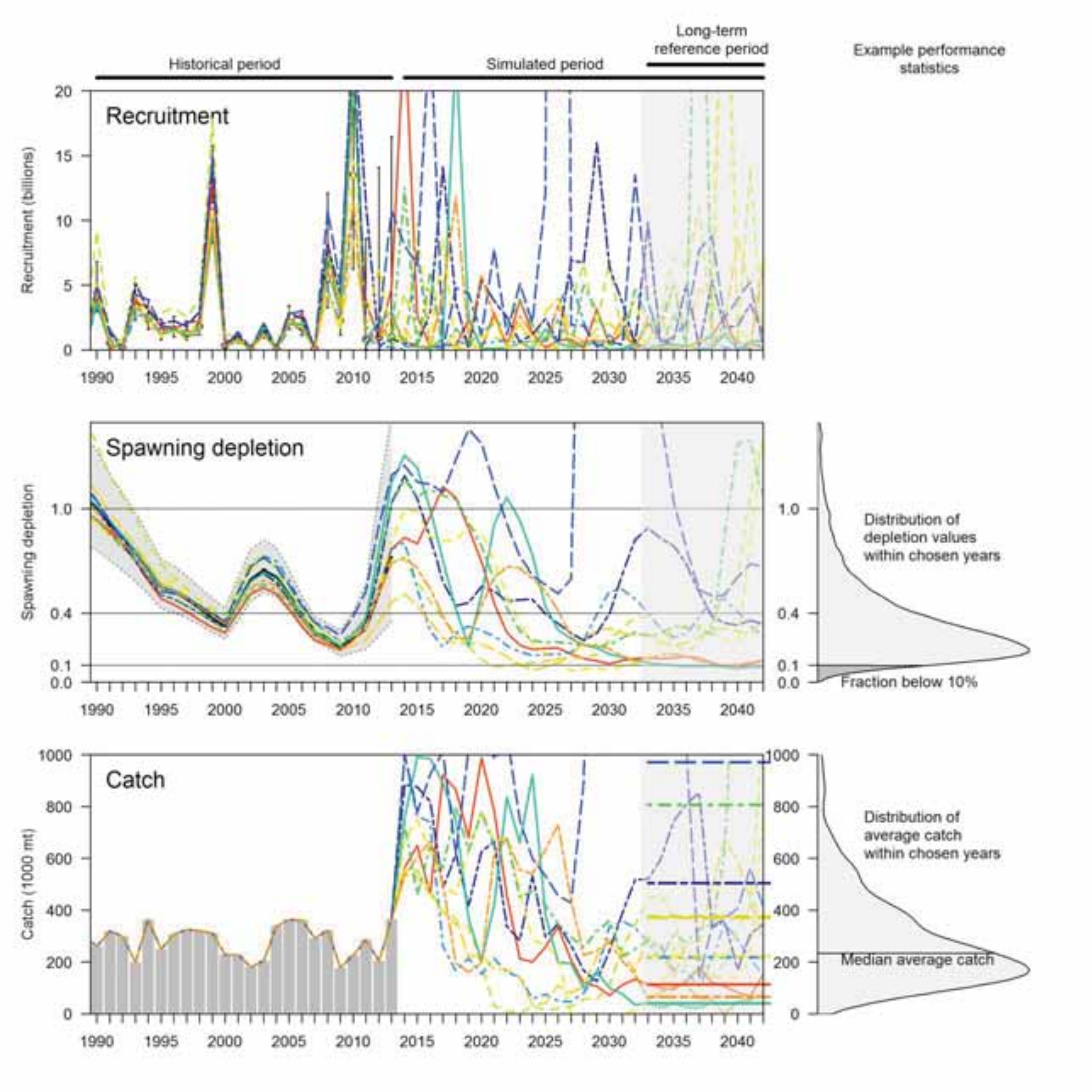



**Figure A.5: Illustration of time-series showing highly variable forecasts.**

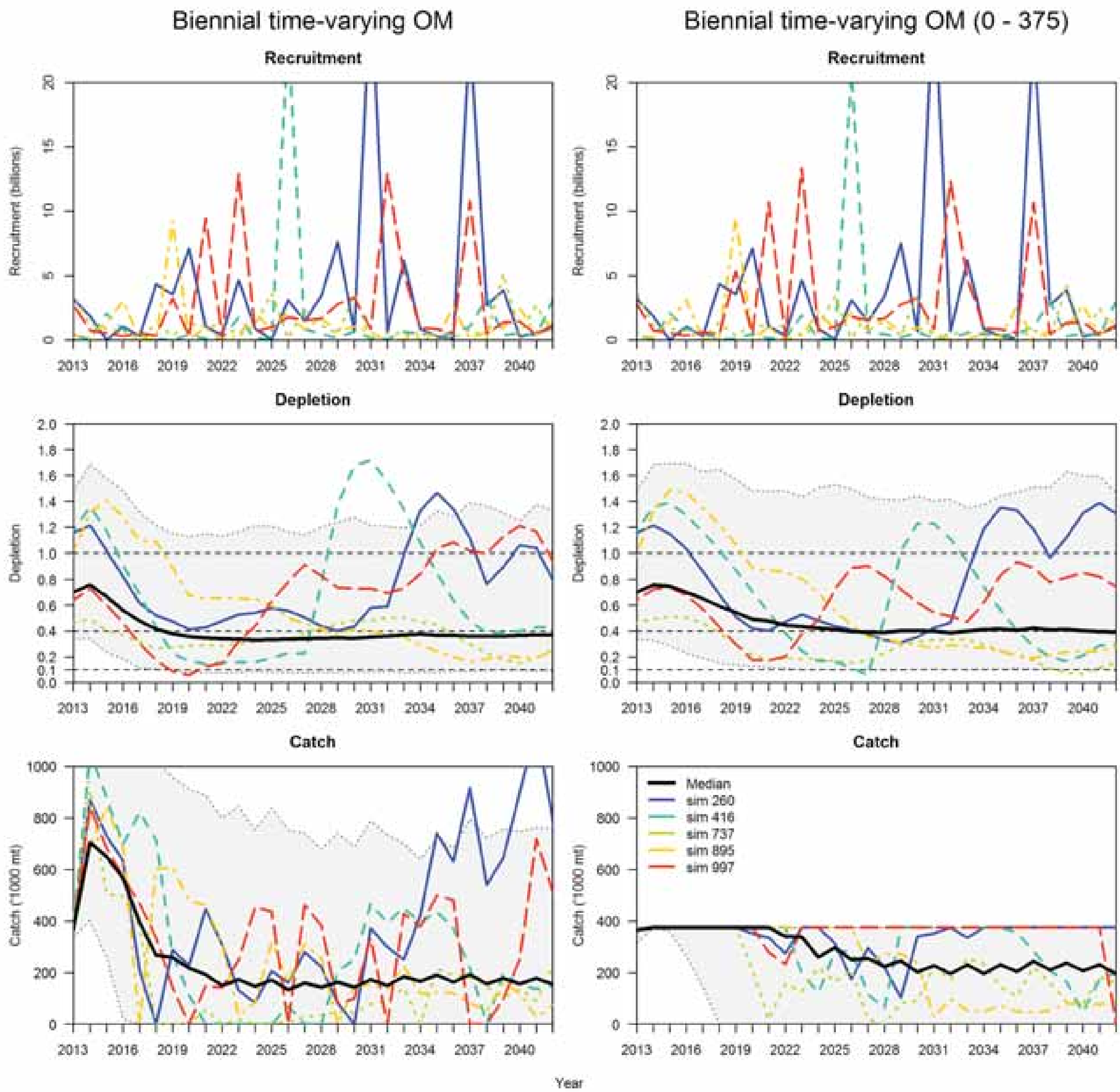



**Figure A.6: Illustration of catch, depletion, and recruitment for runs with biennial time-varying selectivity in the Operating Model (but not in the assessment), with no catch range (left column) or catch limited to the range 0 - 375,000 mt (right column). The colored lines show trajectories for a random set of 5 simulations. The black lines show the median of all 1000 simulations in each case.**

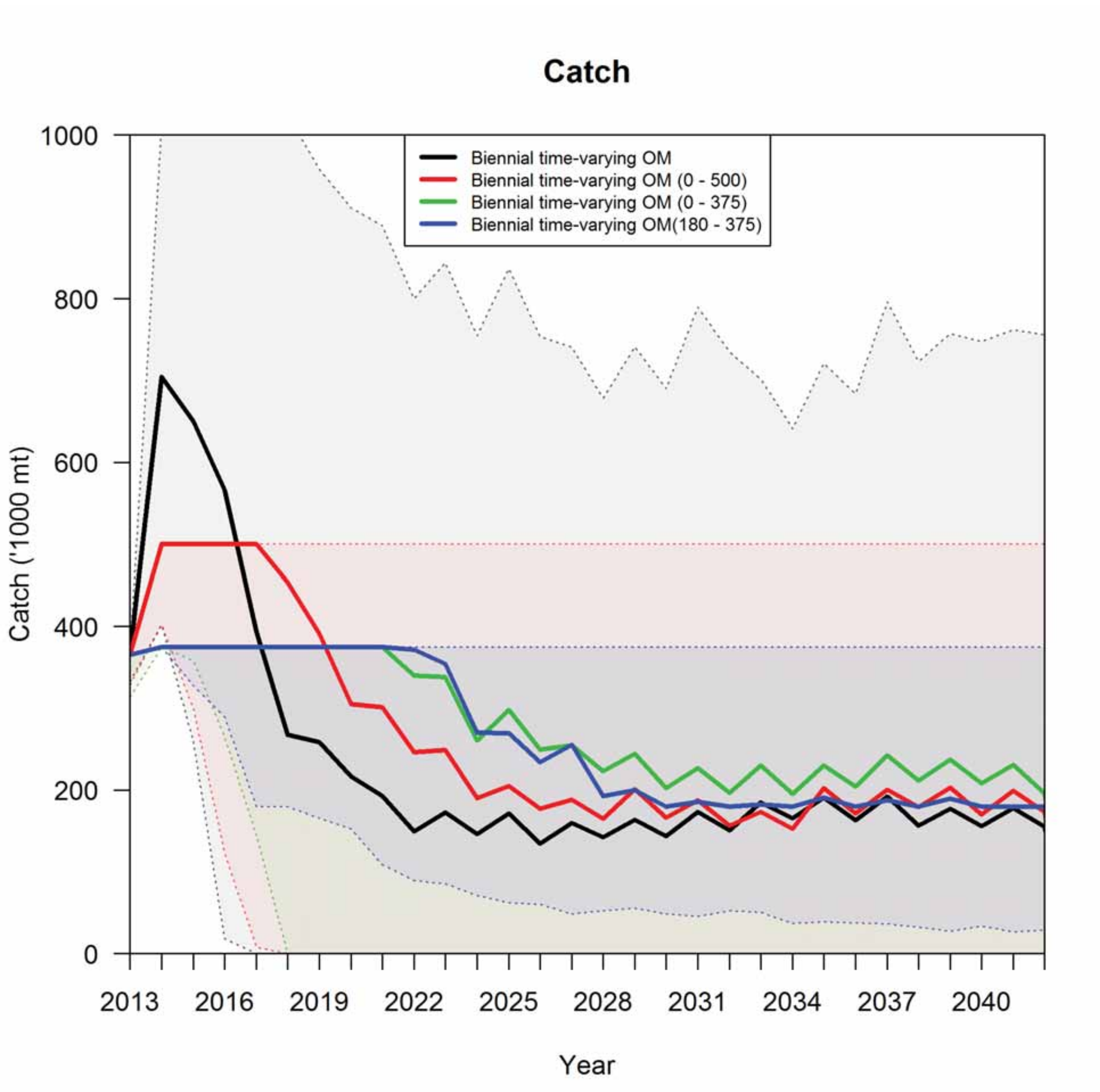



**Figure A.7: Time series of median catch (thick lines) with 95% intervals (shaded regions) showing the effect of different catch ranges for the cases shown in Table 4. The black and green lines are the same as the median lines shown in the lower panels of the previous figure (both black in that figure). Surveys are modeled as biennial in all cases and the Operating Model has time-varying fishery selectivity but the Assessment does not.**

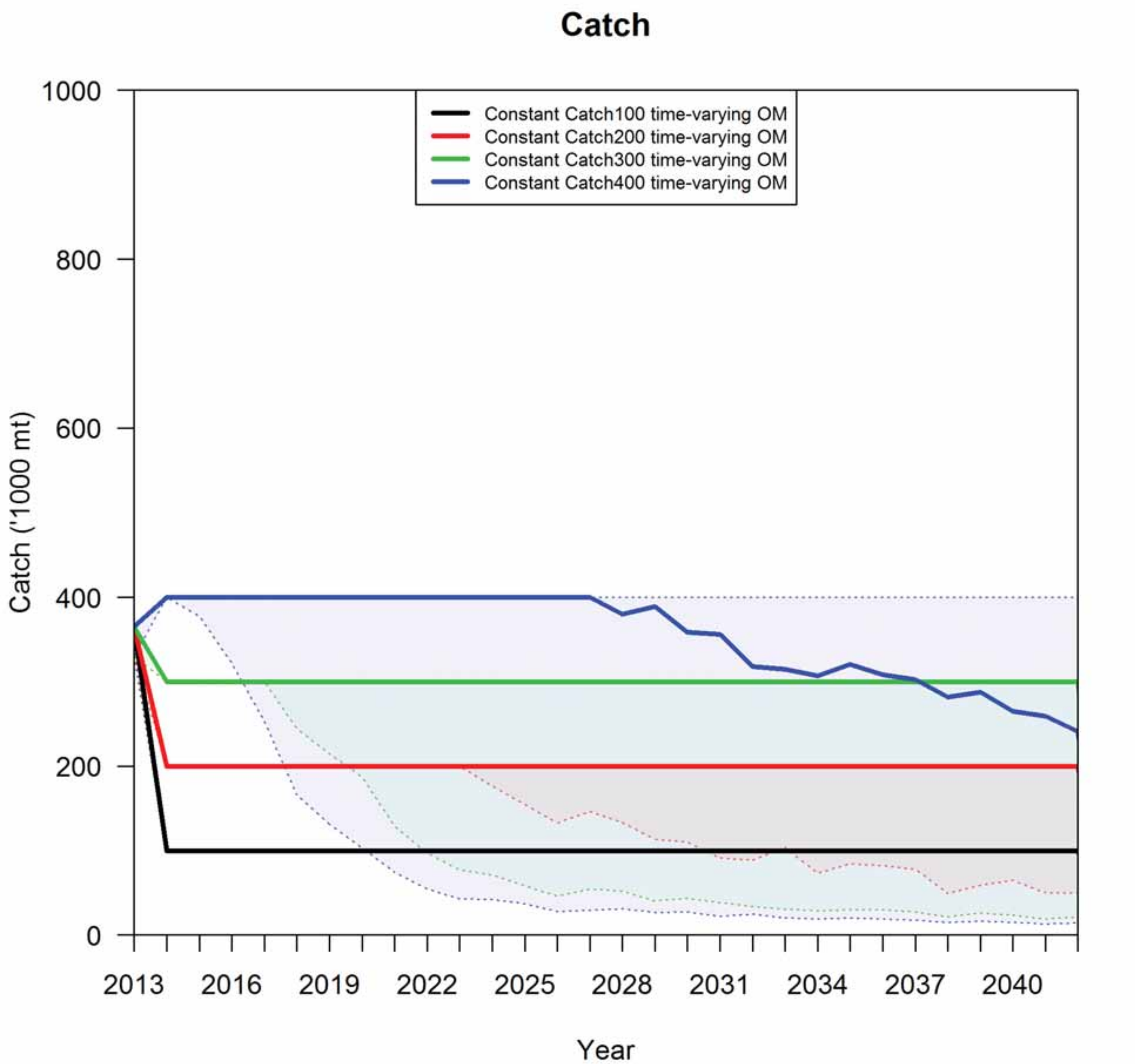



**Figure A.8: Time series of median catch (thick lines) with 95% intervals (shaded regions) showing the effect of different constant catch values shown in Table 5. Surveys are modeled as biennial in all cases and the Operating Model has time-varying fishery selectivity but the Assessment does not.**

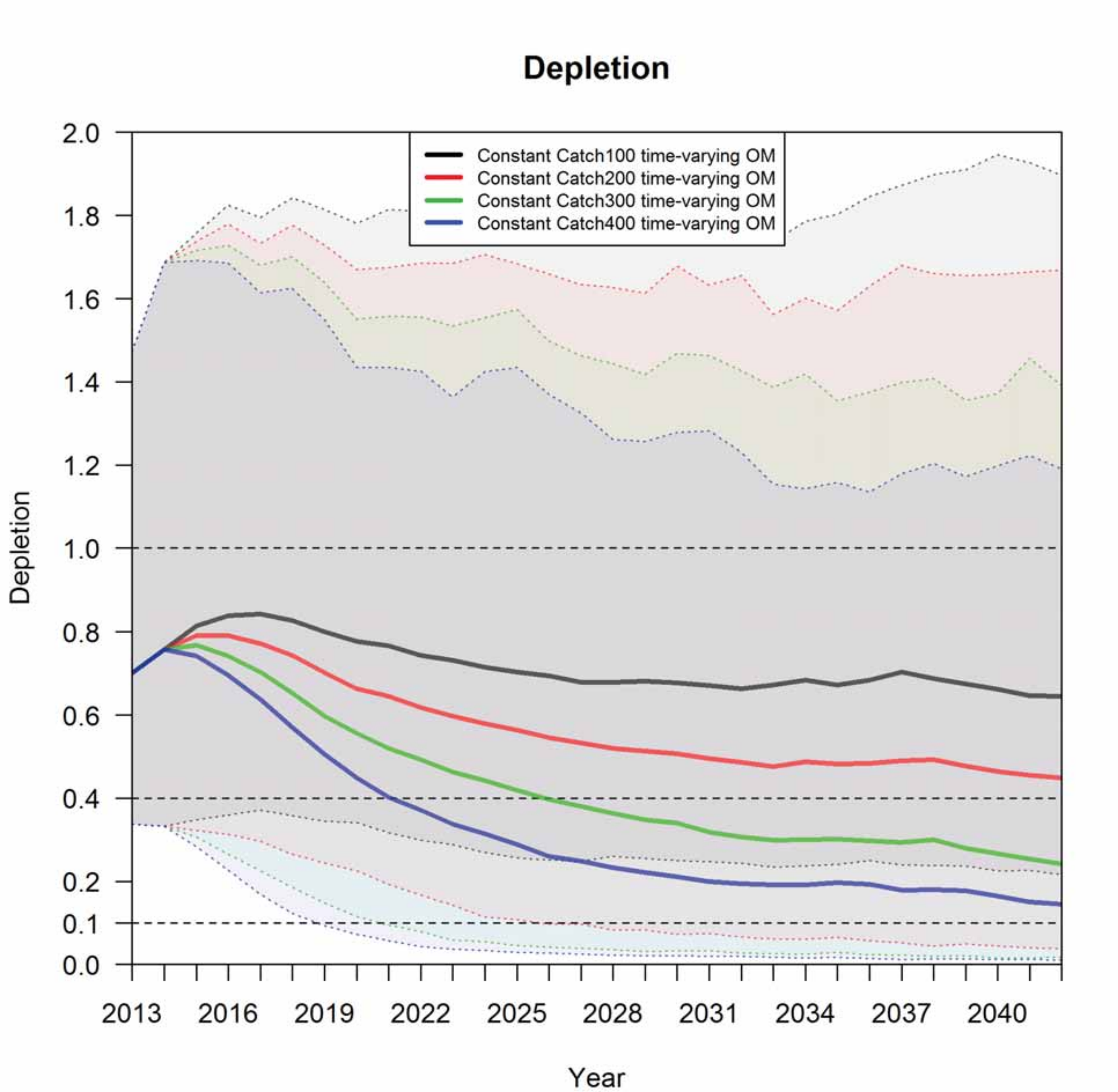



**Figure A.9: Time series of depletion (thick lines) with 95% intervals (shaded regions) showing the effect of different constant catch values shown in Table 5. The Operating Model has time-varying fishery selectivity but in these cases, there is no assessment model or survey required to set the catch levels.**

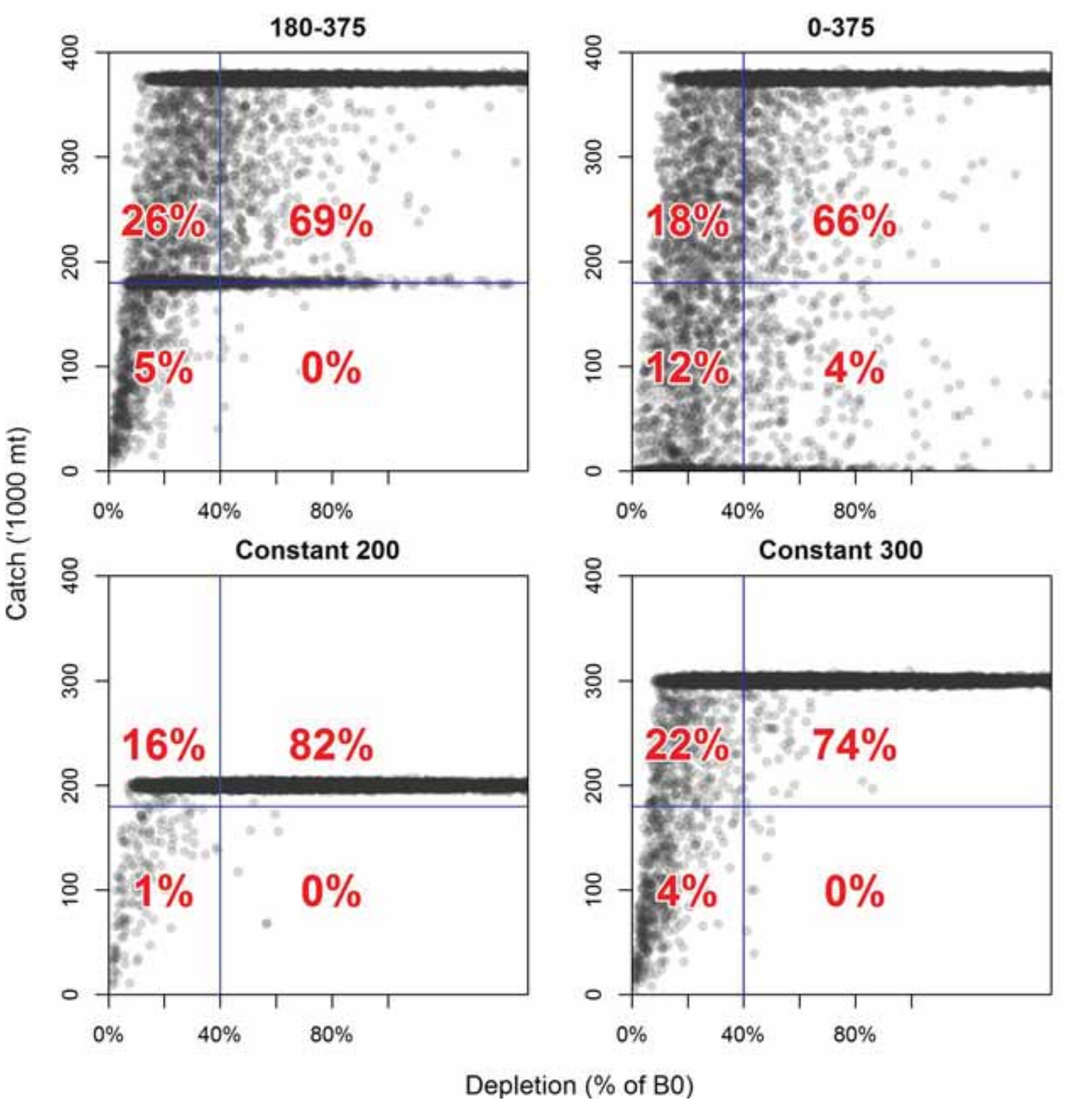



**Figure A.10: Distribution of depletion and catch values (gray points) for a subset of management procedures in the short-term (2014-2023), with percentages of the distribution associated with each quadrant related the reference points 40% of $B_0$ and 180,000 mt catch (red values). A sampling of only 4 management procedures is shown as indicated by the labels above each panel (with catch values represented in 1000s of mt). Gray points have been jittered to better visualize overlapping points associated with constant catch or limits of catch ranges.**

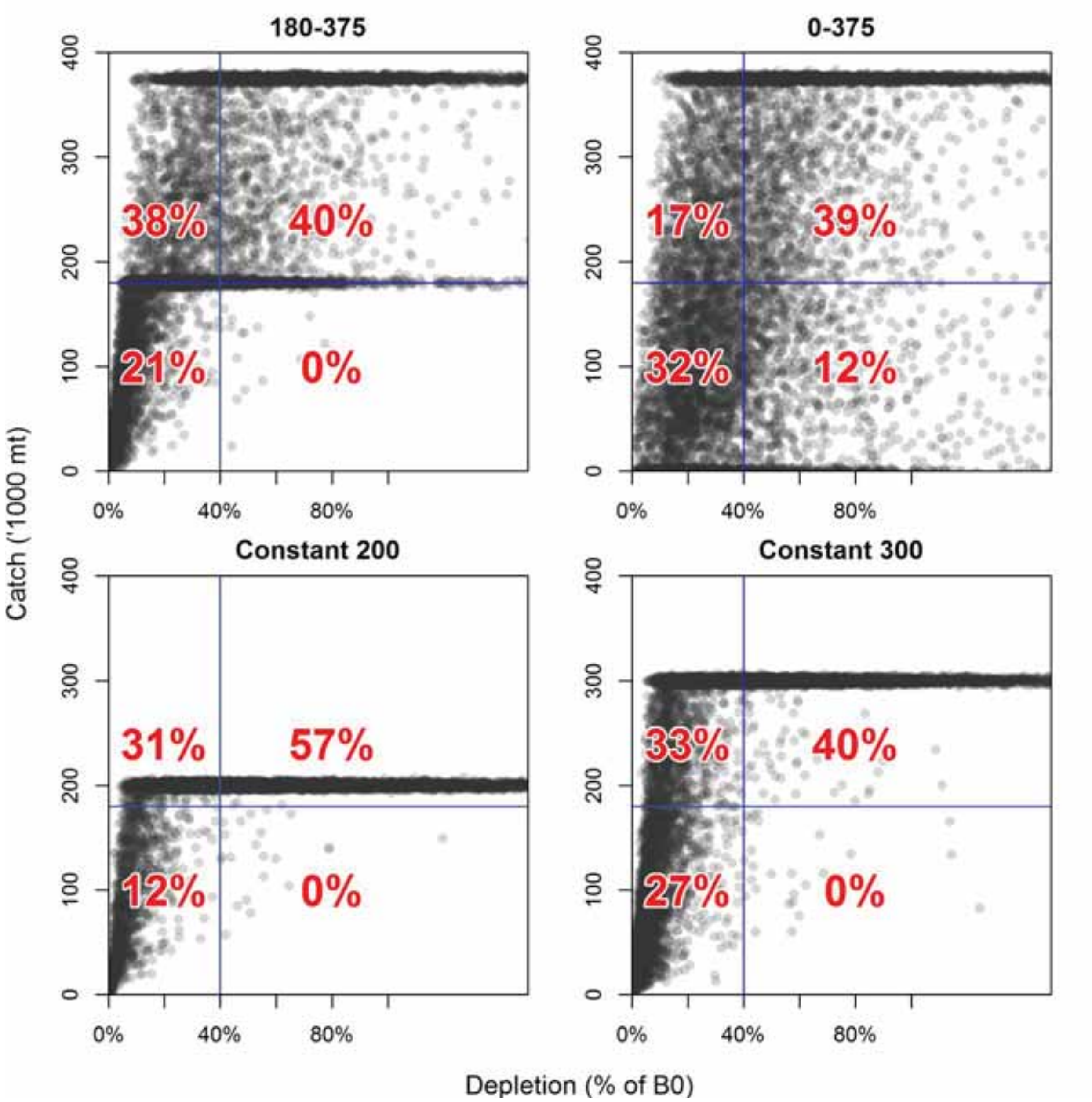



**Figure A.11: Distribution of depletion and catch values (gray points) for a subset of management procedures in the long-term (2033-2042), with percentages of the distribution associated with each quadrant related the reference points 40% of $B_0$ and 180,000 mt catch (red values). A sampling of only 4 management procedures is shown as indicated by the labels above each panel (with catch values represented in 1000s of mt). Gray points have been jittered to better visualize overlapping points associated with constant catch or limits of catch ranges.**

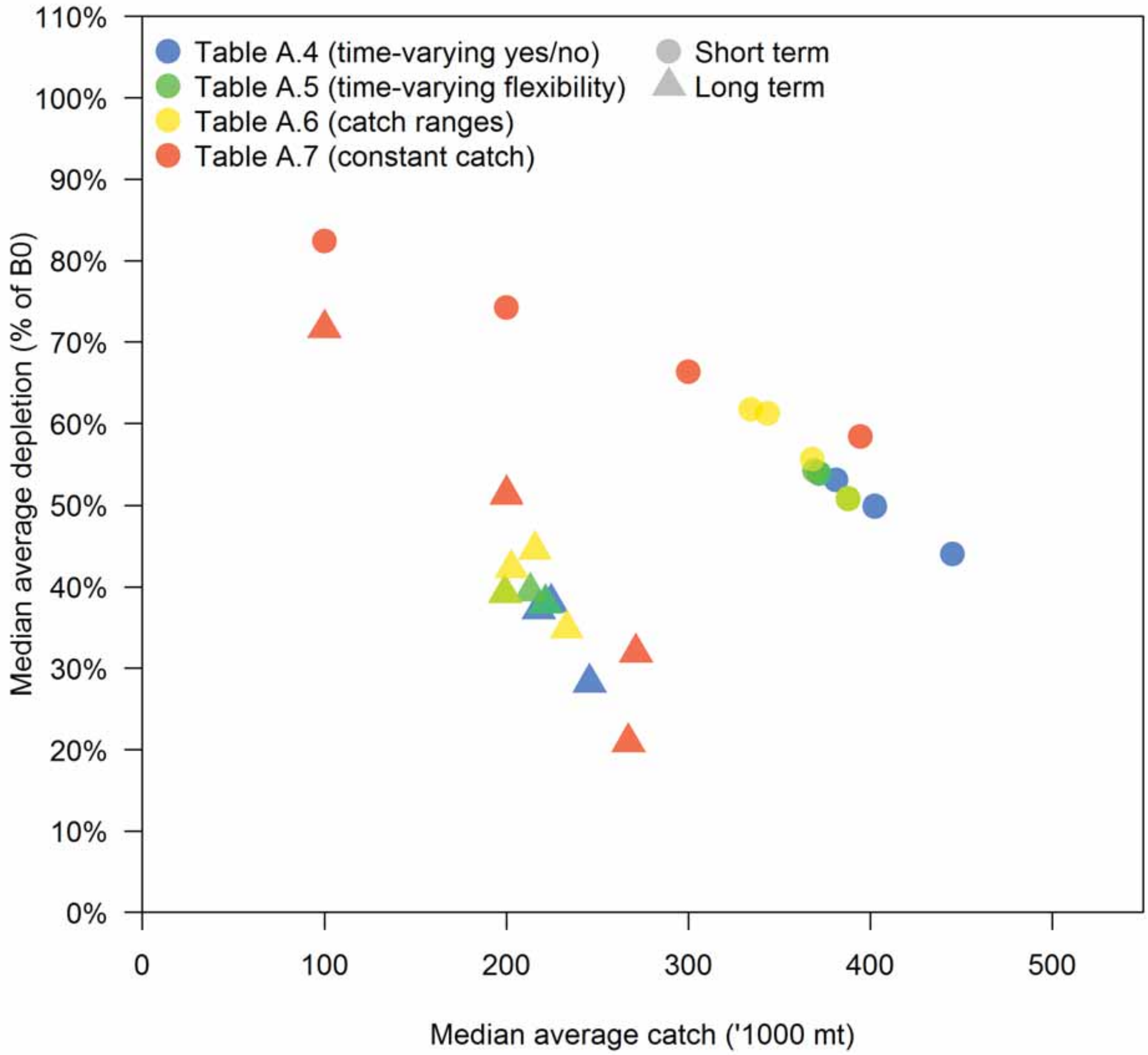



**Figure A.12: Relationship between median average catch and median average depletion shown in Tables A.4 – A.7 (Table A.3 is excluded because some of values without time-varying selectivity in the OM are not comparable).**

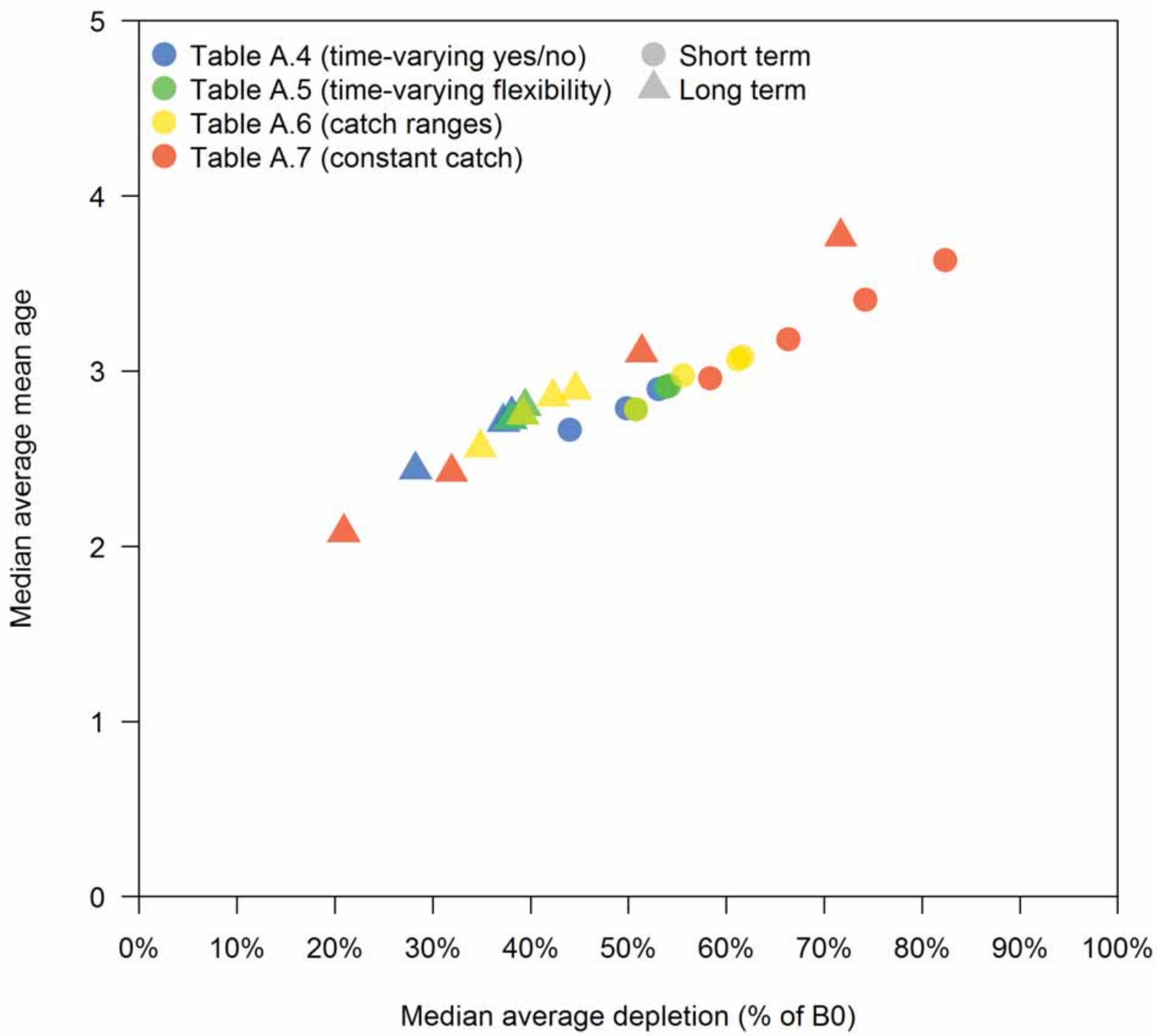



**Figure A.13: Relationship between median average depletion and median average mean age values shown in Tables A.4 – A.7 (Table A.3 is excluded because some of values without time-varying selectivity in the OM are not comparable).**

# Appendix B. List of terms and acronyms used in this document

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

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

40:10 adjustment: a reduction in the overall total allowable catch that is triggered when the biomass falls below 40% of its average equilibrium level in the absence of fishing. This adjustment reduces the total allowable catch on a straight-line basis from the 40% level such that the total allowable catch would equal zero when the stock is at 10% of its average equilibrium level in the absence of fishing.

ABC: Acceptable biological catch. See below.

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

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)

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

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

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

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

Backscatter: The scattering by a target back in the direction of an acoustic source. Specifically, the Nautical Area Scattering Coefficient (a measure of scattering per area denoted by $S_A$) is frequently referred to as backscatter.

California Current Ecosystem: The waters of the continental shelf and slope off the west coast of North America; commonly referring to the area from central California to southern British Columbia.

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

Catchability: The parameter defining the proportionality between a relative index of stock abundance (often a fishery independent survey) and the estimated stock abundance available to that survey (as modified by selectivity) in the assessment model.

Catch-per-unit-effort: A raw or (frequently) standardized and model-based metric of fishing success based on the catch and relative effort expended to generate that catch. Catch-per-unit-effort is often used as an index of stock abundance in the absence of fishery independent indices and/or where the two are believed to be proportional. See CPUE below.

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

Catch Target: A general term used to describe the catch value used for management. Depending on the context, this may be a limit rather than a target, and may be equal to a TAC, an ABC, the median result of applying the default harvest policy, or some other number. The JTC welcomes input from the JMC on the best terminology to use for these quantities.

Closed-Loop Simulation: A subset of an MSE that iteratively simulates a population using an operating model, generates data from that population and passes it to an estimation model, uses the estimation model and a management strategy to provide management advice, which then feeds back into the operating model to simulate an additional fixed set of time before repeating this process. This is illustrated in Figure A.2.

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

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

Catch Target: A general term used to describe the catch value used for management. Depending on the context, this may be a limit rather than a target, and may be equal to a TAC, an ABC, the median result of applying the default harvest policy, or some other number. The JTC welcomes input from the JMC on the best terminology to use for these quantities.

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

CPUE: Catch-per-unit-effort. See above.

CV: Coefficient of variation. A measure of uncertainty defined as the standard deviation (SD, see below) divided by the mean.

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

Depletion: 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.

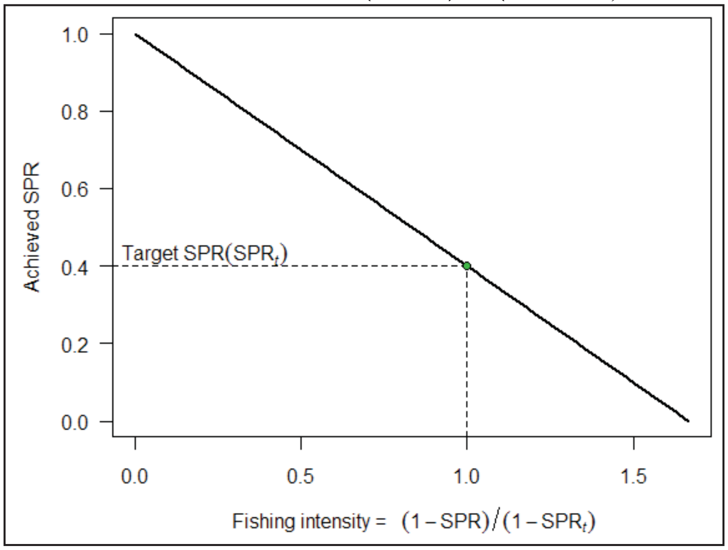
Exploitation fraction: A metric of fishing intensity that represents the total annual catch divided by the estimated population biomass over a range of ages assumed to be vulnerable to the fishery. This value is not equivalent to the instantaneous rate of fishing mortality (see below) or the Spawning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

Harvest Strategy: A formal system for managing a fishery that includes the elements shown in Figure A.1.

Harvest Control Rule: A process for determining an ABC from a stock assessment. (See "40:10 Harvest control rule" above)

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

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

Kt: Knots (nautical miles per hour).

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

MAP: maximum a posteriori probability. See below.

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

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

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

MCMC: Markov-Chain Monte-Carlo. A numerical method used to sample from the posterior distribution (see below) of parameters and derived quantities in a Bayesian analysis. It is more computationally intensive than the maximum likelihood estimate (MLE, see below), but provides a more accurate depiction of parameter uncertainty. See Stewart et al. (2012) for a discussion of issues related to differences between MCMC and MLE.

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

MPD: maximum posterior density. See above.

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

*MSY*: Maximum sustainable yield. See above.

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

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

OM: Operating Model. See above.

OY: Optimum yield. See above.

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

PBS: Pacific Biological Station of Fisheries and Oceans Canada (DFO, see above).

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

Pacific Hake/whiting ("Pacific Hake"): The stock of *Merluccius productus* located in the offshore waters of the United States and Canada (not including smaller stocks located in Puget Sound and the Strait of Georgia).

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

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

$Q$: Catchability. See above.

$R_0$: Estimated average level of annual recruitment occurring at $B_0$ (see below).

Recruits/recruitment: A group of fish born in the same year or the estimated production of new members to a fish population of the same age. Recruitment is reported at a specific life stage, often age 0 or 1, but sometimes corresponding to the age at which the fish first become vulnerable to the fishery. See also cohort and year-class.

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

Relative depletion: The ratio of the estimated beginning of the year female spawning biomass to estimated average unfished equilibrium female spawning biomass ($B_0$, 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. See $B_0$.

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

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

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

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

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

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

Simulation: State of nature, including combination of parameters controlling stock productivity, 2012 status, and time-series of recruitment deviations. There are 999 simulations for each case, numbered 2–1000. These simulation models are samples from the MCMC calculations associated with the 2011 assessment model.

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

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

Spawning potential ratio (SPR): A metric of fishing intensity. The ratio of the spawning output per recruit under a given level of fishing to the estimated spawning output per recruit in the absence of fishing. It achieves a value of 1.0 in the absence of fishing and declines toward 0.0 as fishing intensity increases.

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

SPR: Spawning potential ratio. See above.

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

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

SS: Stock Synthesis. See below.

SSC: Scientific and Statistical Committee (see above).

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

Steepness (*h*): A stock-recruit relationship parameter representing the proportion of $R_0$ expected (on average) when the female spawning biomass is reduced to 20% of $B_0$ (i.e., when relative 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. Details on non-parametric 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) 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 0.

Time-varying fishery selectivity is implemented through annual deviations in each of the estimated parameters for each age, $p_a$. This is formulated as

$$p_{a,y} = p_a + \varepsilon_{a,y}$$

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

$$-\log(L) \propto \frac{1}{2} \sum_{a=2}^{6} \sum_{y=1991}^{2013} \frac{{\varepsilon_{a,y}}^2}{\varphi^2}$$

The $\varphi$ value is set to 0.03 in the base model based on a selection process described in the Methods section.

# Appendix D. Estimated parameters in the base assessment model

| Parameter | Posterior median |
|---|---|
| NatM_p_1_Fem_GP_1 | 0.2218 |
| SR_LN.R0. | 14.8160 |
| SR_BH_steep | 0.8264 |
| Early_InitAge_20 | -0.2194 |
| Early_InitAge_19 | -0.0331 |
| Early_InitAge_18 | -0.0207 |
| Early_InitAge_17 | -0.0538 |
| Early_InitAge_16 | -0.0524 |
| Early_InitAge_15 | -0.1226 |
| Early_InitAge_14 | -0.0952 |
| Early_InitAge_13 | -0.1548 |
| Early_InitAge_12 | -0.2268 |
| Early_InitAge_11 | -0.2108 |
| Early_InitAge_10 | -0.2051 |
| Early_InitAge_9 | -0.2887 |
| Early_InitAge_8 | -0.4210 |
| Early_InitAge_7 | -0.3234 |
| Early_InitAge_6 | -0.3779 |
| Early_InitAge_5 | -0.4489 |
| Early_InitAge_4 | -0.3908 |
| Early_InitAge_3 | -0.3023 |
| Early_InitAge_2 | -0.2245 |
| Early_InitAge_1 | 0.0085 |
| Early_RecrDev_1966 | 0.3789 |
| Early_RecrDev_1967 | 1.3093 |
| Early_RecrDev_1968 | 0.7442 |
| Early_RecrDev_1969 | -0.1214 |
| Main_RecrDev_1970 | 2.0883 |
| Main_RecrDev_1971 | -0.2657 |
| Main_RecrDev_1972 | -0.7569 |
| Main_RecrDev_1973 | 1.4784 |
| Main_RecrDev_1974 | -0.9624 |
| Main_RecrDev_1975 | 0.2390 |
| Main_RecrDev_1976 | -1.0903 |
| Main_RecrDev_1977 | 1.6309 |
| Main_RecrDev_1978 | -1.2938 |
| Main_RecrDev_1979 | -0.0102 |
| Main_RecrDev_1980 | 2.8139 |
| Main_RecrDev_1981 | -1.1733 |
| Main_RecrDev_1982 | -1.4240 |
| Main_RecrDev_1983 | -0.9030 |
| Main_RecrDev_1984 | 2.5437 |

| Parameter | Posterior median |
|---|---|
| Main_RecrDev_1985 | -1.5907 |
| Main_RecrDev_1986 | -1.6652 |
| Main_RecrDev_1987 | 1.6569 |
| Main_RecrDev_1988 | 0.6224 |
| Main_RecrDev_1989 | -1.7088 |
| Main_RecrDev_1990 | 1.4653 |
| Main_RecrDev_1991 | -0.6553 |
| Main_RecrDev_1992 | -1.7323 |
| Main_RecrDev_1993 | 1.2079 |
| Main_RecrDev_1994 | 0.8936 |
| Main_RecrDev_1995 | 0.2905 |
| Main_RecrDev_1996 | 0.5047 |
| Main_RecrDev_1997 | 0.3057 |
| Main_RecrDev_1998 | 0.6686 |
| Main_RecrDev_1999 | 2.5193 |
| Main_RecrDev_2000 | -0.9330 |
| Main_RecrDev_2001 | -0.0902 |
| Main_RecrDev_2002 | -2.6048 |
| Main_RecrDev_2003 | 0.3556 |
| Main_RecrDev_2004 | -2.6231 |
| Main_RecrDev_2005 | 0.9120 |
| Main_RecrDev_2006 | 0.6893 |
| Main_RecrDev_2007 | -2.2801 |
| Main_RecrDev_2008 | 1.7819 |
| Main_RecrDev_2009 | 0.8704 |
| Late_RecrDev_2010 | 2.8826 |
| Late_RecrDev_2011 | -0.8993 |
| Late_RecrDev_2012 | -0.1142 |
| Late_RecrDev_2013 | 0.1051 |
| ForeRecr_2014 | -0.0708 |
| ForeRecr_2015 | -0.0200 |
| ForeRecr_2016 | -0.0131 |
| Q_extraSD_2_Acoustic_Survey | 0.3604 |
| AgeSel_1P_3_Fishery | 3.3848 |
| AgeSel_1P_4_Fishery | 1.4404 |
| AgeSel_1P_5_Fishery | 0.4506 |
| AgeSel_1P_6_Fishery | 0.1574 |
| AgeSel_1P_7_Fishery | 0.2542 |
| AgeSel_2P_4_Acoustic_Survey | 0.3641 |
| AgeSel_2P_5_Acoustic_Survey | 0.0379 |
| AgeSel_2P_6_Acoustic_Survey | -0.0642 |
| AgeSel_2P_7_Acoustic_Survey | 0.4381 |

| AgeSel Parameters | Posterior median |
|---|---|
| 3_Fishery_DEVadd_1991 | -0.0012 |
| 3_Fishery_DEVadd_1992 | -0.0004 |
| 3_Fishery_DEVadd_1993 | 0.0003 |
| 3_Fishery_DEVadd_1994 | -0.0023 |
| 3_Fishery_DEVadd_1995 | 0.0009 |
| 3_Fishery_DEVadd_1996 | 0.0006 |
| 3_Fishery_DEVadd_1997 | -0.0015 |
| 3_Fishery_DEVadd_1998 | -0.0004 |
| 3_Fishery_DEVadd_1999 | 0.0009 |
| 3_Fishery_DEVadd_2000 | 0.0042 |
| 3_Fishery_DEVadd_2001 | 0.0003 |
| 3_Fishery_DEVadd_2002 | 0.0012 |
| 3_Fishery_DEVadd_2003 | -0.0001 |
| 3_Fishery_DEVadd_2004 | 0.0006 |
| 3_Fishery_DEVadd_2005 | 0.0017 |
| 3_Fishery_DEVadd_2006 | 0.0001 |
| 3_Fishery_DEVadd_2007 | 0.0019 |
| 3_Fishery_DEVadd_2008 | 0.0015 |
| 3_Fishery_DEVadd_2009 | 0.0013 |
| 3_Fishery_DEVadd_2010 | 0.0034 |
| 3_Fishery_DEVadd_2011 | 0.0031 |
| 3_Fishery_DEVadd_2012 | -0.0018 |
| 3_Fishery_DEVadd_2013 | -0.0005 |
| 4_Fishery_DEVadd_1991 | 0.0000 |
| 4_Fishery_DEVadd_1992 | 0.0008 |
| 4_Fishery_DEVadd_1993 | 0.0007 |
| 4_Fishery_DEVadd_1994 | 0.0010 |
| 4_Fishery_DEVadd_1995 | 0.0043 |
| 4_Fishery_DEVadd_1996 | -0.0083 |
| 4_Fishery_DEVadd_1997 | 0.0038 |
| 4_Fishery_DEVadd_1998 | 0.0021 |
| 4_Fishery_DEVadd_1999 | -0.0072 |
| 4_Fishery_DEVadd_2000 | 0.0064 |
| 4_Fishery_DEVadd_2001 | 0.0330 |
| 4_Fishery_DEVadd_2002 | 0.0034 |
| 4_Fishery_DEVadd_2003 | 0.0018 |
| 4_Fishery_DEVadd_2004 | 0.0001 |
| 4_Fishery_DEVadd_2005 | 0.0079 |
| 4_Fishery_DEVadd_2006 | -0.0014 |
| 4_Fishery_DEVadd_2007 | -0.0047 |
| 4_Fishery_DEVadd_2008 | 0.0039 |
| 4_Fishery_DEVadd_2009 | 0.0029 |

| AgeSel Parameters | Posterior median |
|---|---|
| 4_Fishery_DEVadd_2010 | 0.0073 |
| 4_Fishery_DEVadd_2011 | -0.0055 |
| 4_Fishery_DEVadd_2012 | -0.0146 |
| 4_Fishery_DEVadd_2013 | 0.0025 |
| 5_Fishery_DEVadd_1991 | -0.0071 |
| 5_Fishery_DEVadd_1992 | -0.0003 |
| 5_Fishery_DEVadd_1993 | -0.0026 |
| 5_Fishery_DEVadd_1994 | 0.0033 |
| 5_Fishery_DEVadd_1995 | 0.0040 |
| 5_Fishery_DEVadd_1996 | -0.0021 |
| 5_Fishery_DEVadd_1997 | -0.0035 |
| 5_Fishery_DEVadd_1998 | -0.0039 |
| 5_Fishery_DEVadd_1999 | -0.0106 |
| 5_Fishery_DEVadd_2000 | 0.0148 |
| 5_Fishery_DEVadd_2001 | 0.0259 |
| 5_Fishery_DEVadd_2002 | 0.0224 |
| 5_Fishery_DEVadd_2003 | 0.0077 |
| 5_Fishery_DEVadd_2004 | -0.0010 |
| 5_Fishery_DEVadd_2005 | 0.0089 |
| 5_Fishery_DEVadd_2006 | 0.0008 |
| 5_Fishery_DEVadd_2007 | -0.0068 |
| 5_Fishery_DEVadd_2008 | 0.0019 |
| 5_Fishery_DEVadd_2009 | 0.0008 |
| 5_Fishery_DEVadd_2010 | 0.0097 |
| 5_Fishery_DEVadd_2011 | -0.0359 |
| 5_Fishery_DEVadd_2012 | -0.0127 |
| 5_Fishery_DEVadd_2013 | -0.0093 |
| 6_Fishery_DEVadd_1991 | -0.0066 |
| 6_Fishery_DEVadd_1992 | -0.0026 |
| 6_Fishery_DEVadd_1993 | -0.0021 |
| 6_Fishery_DEVadd_1994 | 0.0091 |
| 6_Fishery_DEVadd_1995 | 0.0082 |
| 6_Fishery_DEVadd_1996 | -0.0042 |
| 6_Fishery_DEVadd_1997 | -0.0024 |
| 6_Fishery_DEVadd_1998 | -0.0029 |
| 6_Fishery_DEVadd_1999 | -0.0168 |
| 6_Fishery_DEVadd_2000 | 0.0205 |
| 6_Fishery_DEVadd_2001 | 0.0002 |
| 6_Fishery_DEVadd_2002 | 0.0105 |
| 6_Fishery_DEVadd_2003 | 0.0092 |
| 6_Fishery_DEVadd_2004 | -0.0025 |
| 6_Fishery_DEVadd_2005 | 0.0070 |

| AgeSel Parameters | Posterior median |
|---|---|
| 6_Fishery_DEVadd_2006 | 0.0011 |
| 6_Fishery_DEVadd_2007 | -0.0021 |
| 6_Fishery_DEVadd_2008 | 0.0026 |
| 6_Fishery_DEVadd_2009 | 0.0117 |
| 6_Fishery_DEVadd_2010 | -0.0273 |
| 6_Fishery_DEVadd_2011 | -0.0336 |
| 6_Fishery_DEVadd_2012 | -0.0028 |
| 6_Fishery_DEVadd_2013 | 0.0051 |
| 7_Fishery_DEVadd_1991 | -0.0081 |
| 7_Fishery_DEVadd_1992 | 0.0058 |
| 7_Fishery_DEVadd_1993 | -0.0045 |
| 7_Fishery_DEVadd_1994 | 0.0103 |
| 7_Fishery_DEVadd_1995 | 0.0068 |
| 7_Fishery_DEVadd_1996 | -0.0006 |
| 7_Fishery_DEVadd_1997 | 0.0005 |
| 7_Fishery_DEVadd_1998 | -0.0102 |
| 7_Fishery_DEVadd_1999 | -0.0110 |
| 7_Fishery_DEVadd_2000 | 0.0209 |
| 7_Fishery_DEVadd_2001 | -0.0138 |
| 7_Fishery_DEVadd_2002 | 0.0062 |
| 7_Fishery_DEVadd_2003 | 0.0025 |
| 7_Fishery_DEVadd_2004 | -0.0009 |
| 7_Fishery_DEVadd_2005 | 0.0051 |
| 7_Fishery_DEVadd_2006 | -0.0093 |
| 7_Fishery_DEVadd_2007 | -0.0039 |
| 7_Fishery_DEVadd_2008 | -0.0037 |
| 7_Fishery_DEVadd_2009 | 0.0124 |
| 7_Fishery_DEVadd_2010 | -0.0273 |
| 7_Fishery_DEVadd_2011 | -0.0247 |
| 7_Fishery_DEVadd_2012 | -0.0035 |
| 7_Fishery_DEVadd_2013 | 0.0189 |

# Appendix E. SS data file

```
#C 2014 Hake control file - pre-SRG base model (run 21)
###################################################

### Global model specifications ###
1966    # Start year
2013    # 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

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

```
298079   1989    1
261286   1990    1
319705   1991    1  #updated 1/6/2014
299650   1992    1  #updated 1/6/2014
198905   1993    1  #updated 1/6/2014
362415   1994    1  #updated 1/6/2014
249495   1995    1  #updated 1/6/2014
306301   1996    1  #updated 1/6/2014
325168   1997    1  #updated 1/6/2014
320722   1998    1  #updated 1/6/2014
311922   1999    1  #updated 1/6/2014
228211   2000    1  #updated 1/6/2014
227529   2001    1  #updated 1/6/2014
180692   2002    1  #updated 1/6/2014
205175   2003    1  #updated 1/6/2014
342323   2004    1  #updated 1/6/2014
363157   2005    1
361761   2006    1  #updated 1/6/2014
291129   2007    1
322144   2008    1  #updated 1/6/2014
177209   2009    1  #updated 1/6/2014
226195   2010    1  #updated 1/6/2014
285850   2011    1
206350   2012    1
283510   2013    1  #updated 1/6/2014
# catches from 1991 to 2013 were updated because the US at-sea fleet was split
# by CP and MS and expansions were done for each instead of combined.

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

# Acoustic survey
# Year  seas    fleet   obs       se(log)
1995    1       2       1517948   0.0666
1996    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
1997    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
1998    1       2       1342740   0.0492
1999    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2000    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2001    1       2        918622   0.0823
2002    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2003    1       2       2520641   0.0709
2004    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2005    1       2       1754722   0.0847
2006    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2007    1       2       1122809   0.0752
2008    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2009    1       2       1612027   0.1375
```

```
2010    1       -2            1   1         #dummy observation to get expected value (negative fleet = no influence on results)
2011    1       2        521476   0.1015
2012    1       2       1380724   0.0475
2013    1       2       2422661   0.0433    #updated from 12/25/13 results on 1/7/2014

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

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

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

26 # Number of Data Length Bins
# Lower edge of bins
20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
0 #_N_Length_obs

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

41 # N_ageerror_definitions
# No ageing error
#0.5    1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5    11.5    12.5    13.5    14.5    15.5    16.5
17.5    18.5    19.5    20.5
#0.001  0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001   0.001
0.001   0.001   0.001   0.001
# Baseline ageing error
#0.5    1.5     2.5     3.5     4.5     5.5     6.5     7.5     8.5     9.5     10.5    11.5    12.5    13.5    14.5    15.5    16.5
17.5    18.5    19.5    20.5
#0.329  0.329   0.347   0.369   0.395   0.428   0.468   0.518   0.579   0.653   0.745   0.858   0.996   1.167   1.376   1.632   1.858
2.172   2.530   2.934   3.388
# Annual keys with cohort effect
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5      14.5       15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5      14.5       15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5      14.5       15.5      16.5    17.5    18.5    19.5    20.5
```

```
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 0.329242  0.1908044 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 0.329242  0.1908044 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5     14.5      15.5      16.5    17.5    18.5    19.5    20.5
0.329242 0.329242  0.346917  0.2027476 0.395312  0.42809   0.468362  0.2848125 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
```

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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
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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 0.329242 0.346917 0.368632 0.395312 0.42809 0.468362 0.2848125 0.57863 0.653316 0.745076 0.4717971 0.996322
1.1665   1.37557  1.63244  1.858    2.172    2.53     2.934    3.388
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 0.329242 0.346917 0.368632 0.395312 0.42809 0.468362 0.517841 0.57863 0.653316 0.745076 0.4717971 0.996322
1.1665   1.37557  0.897842 1.858    2.172    2.53     2.934    3.388
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
0.5      1.5      2.5      3.5      4.5      5.5      6.5      7.5      8.5      9.5      10.5     11.5     12.5
13.5     14.5     15.5     16.5     17.5     18.5     19.5     20.5
0.329242 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
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
```

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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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 0.329242  0.1908044 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 0.329242  0.346917  0.368632  0.395312  0.42809   0.468362  0.2848125 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 0.329242  0.1908044 0.368632  0.395312  0.42809   0.468362  0.517841  0.57863   0.653316  0.745076  0.4717971 0.996322
1.1665   1.37557   1.63244   1.858     2.172     2.53      2.934     3.388
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 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
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5      11.5      12.5
13.5     14.5      15.5      16.5      17.5      18.5      19.5      20.5
0.329242 0.329242  0.1908044 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
```

```
0.5      1.5       2.5       3.5       4.5       5.5       6.5       7.5       8.5       9.5       10.5       11.5       12.5
13.5      14.5       15.5      16.5      17.5    18.5    19.5    20.5
0.329242 0.329242  0.346917  0.202748  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

#Age comps updated 1/6/2014
49   # Number of age comp observations
1    # Length bin refers to: 1=population length bin indices; 2=data length bin indices
0    #_combine males into females at or below this bin number
# Acoustic survey ages (N=10)
#year   Season  Fleet   Sex     Partition       AgeErr  LbinLo  LbinHi  nTrips  a1      a2      a3      a4      a5      a6      a7
a8      a9      a10     a11     a12     a13     a14     a15
1995    1       2       0       0       23      -1      -1      68      0.000   0.304   0.048   0.014   0.209   0.012   0.042   0.144
0.003   0.001   0.165   0.001   0.007   0.000   0.051
1998    1       2       0       0       26      -1      -1      103     0.000   0.125   0.144   0.168   0.191   0.016   0.076   0.093
0.014   0.028   0.061   0.005   0.003   0.061   0.015
2001    1       2       0       0       29      -1      -1      57      0.000   0.641   0.104   0.054   0.060   0.030   0.037   0.022
0.011   0.010   0.008   0.008   0.010   0.002   0.004
2003    1       2       0       0       31      -1      -1      71      0.000   0.024   0.023   0.635   0.092   0.031   0.070   0.042
0.028   0.026   0.011   0.007   0.005   0.004   0.004
2005    1       2       0       0       33      -1      -1      47      0.000   0.229   0.021   0.069   0.048   0.492   0.053   0.020
0.027   0.016   0.013   0.007   0.002   0.001   0.002
2007    1       2       0       0       35      -1      -1      70      0.000   0.366   0.022   0.108   0.013   0.044   0.030   0.334
0.034   0.017   0.014   0.007   0.007   0.003   0.001
2009    1       2       0       0       37      -1      -1      66      0.000   0.006   0.299   0.421   0.023   0.082   0.012   0.016
0.015   0.073   0.032   0.013   0.003   0.004   0.002
2011    1       2       0       0       39      -1      -1      59      0.000   0.244   0.631   0.039   0.029   0.030   0.004   0.004
0.003   0.002   0.001   0.007   0.003   0.001   0.000
2012    1       2       0       0       40      -1      -1      96      0.000   0.637   0.097   0.161   0.022   0.026   0.019   0.01
0.005   0.003   0.002   0.006   0.009   0.005   0.001
2013    1       2       0       0       41      -1      -1      67      0.000   0.020   0.762   0.056   0.085   0.009   0.020   0.025
0.007   0.003   0.001   0.001   0.003   0.006   0.003

#Aggregate marginal fishery age comps (n=39)
#year   Season  Fleet   Sex     Partition       AgeErr  LbinLo  LbinHi  nTrips  a1      a2      a3      a4      a5      a6      a7
a8      a9      a10     a11     a12     a13     a14     a15
1975    1       1       0       0       3       -1      -1      13      0.046   0.338   0.074   0.012   0.254   0.055   0.080   0.105
0.010   0.006   0.009   0.005   0.000   0.005   0.000
1976    1       1       0       0       4       -1      -1      142     0.001   0.013   0.145   0.067   0.041   0.246   0.098   0.089
0.121   0.054   0.043   0.041   0.011   0.024   0.007
1977    1       1       0       0       5       -1      -1      320     0.000   0.084   0.037   0.275   0.036   0.091   0.227   0.076
0.065   0.040   0.036   0.023   0.006   0.003   0.001
1978    1       1       0       0       6       -1      -1      341     0.005   0.011   0.065   0.063   0.264   0.061   0.089   0.215
0.098   0.047   0.047   0.023   0.005   0.004   0.003
1979    1       1       0       0       7       -1      -1      116     0.000   0.065   0.102   0.094   0.057   0.177   0.103   0.174
0.128   0.042   0.029   0.010   0.016   0.000   0.004
1980    1       1       0       0       8       -1      -1      221     0.001   0.005   0.301   0.019   0.045   0.082   0.112   0.050
0.089   0.111   0.095   0.026   0.038   0.015   0.011
1981    1       1       0       0       9       -1      -1      154     0.195   0.040   0.014   0.267   0.039   0.055   0.034   0.147
0.038   0.032   0.102   0.023   0.005   0.002   0.007
```

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 1 | 1 | 0 | 0 | 10 | -1 | -1 | 170 | 0.000 | 0.321 | 0.035 | 0.005 | 0.273 | 0.015 | 0.037 | 0.039 |
| 0.118 | 0.033 | 0.036 | 0.076 | 0.002 | 0.003 | 0.007 | | | | | | | | | | |
| 1983 | 1 | 1 | 0 | 0 | 11 | -1 | -1 | 117 | 0.000 | 0.000 | 0.341 | 0.040 | 0.018 | 0.235 | 0.051 | 0.056 |
| 0.053 | 0.094 | 0.039 | 0.031 | 0.023 | 0.011 | 0.007 | | | | | | | | | | |
| 1984 | 1 | 1 | 0 | 0 | 12 | -1 | -1 | 123 | 0.000 | 0.000 | 0.014 | 0.621 | 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      851     0.002   0.413   0.106   0.305   0.022   0.052   0.041   0.015
0.007   0.006   0.005   0.005   0.012   0.004   0.003
2013    1       1       0       0       41      -1      -1      871     0.000   0.005   0.669   0.067   0.123   0.017   0.032   0.025
0.012   0.009   0.003   0.003   0.006   0.022   0.005

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 2014 Hake control file - pre-SRG base model (run 21)
###################################################

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

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

# Lo     Hi     Init    Prior   Prior   Prior   Param   Env     Use     Dev     Dev     Dev     Block   block
# bnd    bnd    value   mean    type    SD      phase   var     dev     minyr   maxyr   SD      design  switch
### Mortality
0.05     0.4    0.2     -1.609438 3     0.1     4       0       0       0       0       0       0       0       # M
### Growth parameters ignored in empirical input approach
2       15      5       32      -1      99      -5      0       0       0       0       0       0       0       # A0
45      60      53.2    50      -1      99      -3      0       0       0       0       0       0       0       # Linf
0.2     0.4     0.30    0.3     -1      99      -3      0       0       0       0       0       0       0       # VBK
0.03    0.16    0.066   0.1     -1      99      -5      0       0       0       0       0       0       0       # CV of len@age 0
0.03    0.16    0.062   0.1     -1      99      -5      0       0       0       0       0       0       0       # CV of len@age inf
# W-L, maturity and fecundity parameters
# Female placeholders (wtatage overrides these)
-3      3       7.0E-06 7.0E-06 -1      99      -50     0       0       0       0       0       0       0       # F W-L slope
-3      3       2.9624  2.9624  -1      99      -50     0       0       0       0       0       0       0       # F W-L exponent
# Maturity ok from 2010 assessment
-3      43      36.89   36.89   -1      99      -50     0       0       0       0       0       0       0       # L at 50% maturity
-3      3       -0.48   -0.48   -1      99      -50     0       0       0       0       0       0       0       # F Logistic maturity
slope
# No fecundity relationship
-3      3       1.0     1.0     -1      99      -50     0       0       0       0       0       0       0       # F Eggs/gm intercept
-3      3       0.0     0.0     -1      99      -50     0       0       0       0       0       0       0       # F Eggs/gm slope
# Unused recruitment interactions
0       2       1       1       -1      99      -50     0       0       0       0       0       0       0       # placeholder only
0       2       1       1       -1      99      -50     0       0       0       0       0       0       0       # placeholder only
0       2       1       1       -1      99      -50     0       0       0       0       0       0       0       # placeholder only
```

```
0       2       1       1       -1      99      -50     0       0       0       0       0       0       0       # placeholder only
0 0 0 0 0 0 0 0 0 0 # Unused MGparm_seas_effects

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

# Recruitment deviations
1970    # Start year standard recruitment devs
2009    # End year standard recruitment devs
1       # Rec Dev phase

1 # Read 11 advanced recruitment options: 0=no, 1=yes
1946    # Start year for early rec devs
3       # Phase for early rec devs
5       # Phase for forecast recruit deviations
1       # Lambda for forecast recr devs before endyr+1
1965    # Last recruit dev with no bias_adjustment
1971    # First year of full bias correction (linear ramp from year above)
2010    # Last year for full bias correction in_MPD
2012    # First_recent_yr_nobias_adj_in_MPD
0.87    # Maximum bias adjustment in MPD
0       # Period of cycles in recruitment (N parms read below)
-6      # Lower bound rec devs
6       # Upper bound rec devs
0       # Read init values for rec devs

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

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

```
# Catchability setup
# A=do power: 0=skip, survey is prop. to abundance, 1= add par for non-linearity
# B=env. link: 0=skip, 1= add par for env. effect on Q
# C=extra SD: 0=skip, 1= add par. for additive constant to input SE (in ln space)
# D=type: <0=mirror lower abs(#) fleet, 0=no par Q is median unbiased, 1=no par Q is mean unbiased, 2=estimate par for ln(Q)
#          3=ln(Q) + set of devs about ln(Q) for all years. 4=ln(Q) + set of devs about Q for indexyr-1
#A      B       C       D
0       0       0       0        # Fishery
0       0       1       0        # Survey
#LO     HI      INIT    PRIOR   PR_type SD      PHASE
0.05    1.2     0.0755  0.0755  -1      0.1     4 # additive value for acoustic survey

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

# Selectivity parameters
# Lo    Hi      Init    Prior   Prior   Prior   Param   Env     Use     Dev     Dev     Dev     Block   block
# bnd   bnd     value   mean    type    SD      phase   var     dev     minyr   maxyr   SD      design  switch
# Fishery age-based
  -1002 3       -1000   -1      -1      0.01    -2      0 0 0 0 0 0 0 # 0.0 at age 0
  -1    1        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Age 1 is Reference
  -5    9        2.8    -1      -1      0.01    2       0 2 1991 2013 0.03 0 0 # Change to age 2
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2013 0.03 0 0 # Change to age 3
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2013 0.03 0 0 # Change to age 4
  -5    9        0.1    -1      -1      0.01    2       0 2 1991 2013 0.03 0 0 # Change to age 5
  -5    9        0.0    -1      -1      0.01    2       0 2 1991 2013 0.03 0 0 # Change to age 6
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 7
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 8
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 9
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 10
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 11
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 12
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 13
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 14
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 15
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 16
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 17
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 18
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 19
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 20
```

```
# Acoustic survey - nonparametric age-based selectivity
  -1002 3       -1000   -1      -1      0.01    -2      0 0 0 0 0 0 0 # 0.0 at age 0
  -1002 3       -1000   -1      -1      0.01    -2      0 0 0 0 0 0 0 # 0.0 at age 1
  -1    1        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Age 2 is reference
  -5    9        0.1    -1      -1      0.01    2       0 0 0 0 0 0 0 # Change to age 3
  -5    9        0.1    -1      -1      0.01    2       0 0 0 0 0 0 0 # Change to age 4
  -5    9        0.0    -1      -1      0.01    2       0 0 0 0 0 0 0 # Change to age 5
  -5    9        0.0    -1      -1      0.01    2       0 0 0 0 0 0 0 # Change to age 6
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 7
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 8
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 9
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 10
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 11
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 12
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 13
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 14
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 15
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 16
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 17
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 18
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 19
  -5    9        0.0    -1      -1      0.01    -2      0 0 0 0 0 0 0 # Change to age 20

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

### Likelihood related quantities ###
1 # Do variance/sample size adjustments by fleet (1)
# # Component
 0    0   # Constant added to index CV
 0    0   # Constant added to discard SD
 0    0   # Constant added to body weight SD
 1    1   # multiplicative scalar for length comps
 0.12 0.94 # multiplicative scalar for agecomps
 1    1   # multiplicative scalar for length at age obs

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

999 # End control file
```

# Appendix G. SS starter file (starter.ss)

```
#C 2014 Hake starter file - pre-SRG base model (run 21)
###################################################

2014hake_data.SS        # Data file
2014hake_control.SS # Control file

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

999 # end of file marker
```

# Appendix H. SS forecast file (forecast.ss)

```
#C 2014 Hake starter file - pre-SRG base model (run 21)
###################################################

1       # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2       # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.4     # SPR target (e.g. 0.40)
0.4     # Biomass target (e.g. 0.40)
# Enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
-999 -999 -999 -999 -999 -999 # Bmark_years: beg_bio end_bio beg_selex end_selex beg_alloc
end_alloc
2       # Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
1       # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (use first-last alloc yrs);
5=input annual F
3       # N forecast years
1.0     # F scalar (only used for Do_Forecast==5)
# Enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
-4 0 -4 0 # Fcast_years:  beg_selex end_selex beg_alloc end_alloc
1       # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0.4     # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40)
0.1     # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
1.0     # Control rule target as fraction of Flimit (e.g. 0.75)
3       # N forecast loops (1-3) (fixed at 3 for now)
3       # First forecast loop with stochastic recruitment (fixed at 3 for now)
-1      # Forecast loop control #3 (reserved)
0       #_Forecast loop control #4 (reserved for future bells&whistles)
0       #_Forecast loop control #5 (reserved for future bells&whistles)
2017    # FirstYear for caps and allocations (should be after any fixed inputs)
0.0     # stddev of log(realized catch/target catch) in forecast
0       # Do West Coast gfish rebuilder output (0/1)
1999    # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
2002    # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
1       # fleet relative F:  1=use first-last alloc year; 2=read seas(row) x fleet(col) below
2       # basis for fcast catch tuning and for fcast catch caps and allocation  (2=deadbio;
3=retainbio; 5=deadnum; 6=retainnum)
-1      # max totalcatch by fleet (-1 to have no max)
-1      # max totalcatch by area (-1 to have no max)
1       # fleet assignment to allocation group (enter group ID# for each fleet, 0 for not
included in an alloc group)
# assign fleets to groups
1.0
# allocation fraction for each of: 2 allocation groups
0 # Number of forecast catch levels to input (else calc catch from forecast F)
2 # basis for input Fcast catch:  2=dead catch; 3=retained catch; 99=input Hrate(F) (units are
from fleetunits; note new codes in SSV3.20)

999 # verify end of input
```

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

```
# empirical weight-at-age Stock Synthesis input file for hake
# created by code in the R script: wtatage_calculations.R
# creation date: 2014-01-06 21:21:44
###################################################
161 # 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 0.0935 0.2474 0.3730 0.4823 0.5437 0.5933 0.6640 0.7226 0.7923 0.8634 0.9339 0.9735 1.0703
1.0069 1.0190 1.0190 1.0190 1.0190 1.0190 1.0190
  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 0.1380 0.2435 0.4123 0.5732 0.6488 0.6985 0.6914 0.7151 0.7280 0.7593 0.8241 0.8934 0.8227
0.8696 0.8425 0.8425 0.8425 0.8425 0.8425 0.8425
  2009    1      1  1     1    -1 0.0217 0.0667 0.2428 0.3430 0.4735 0.6410 0.6831 0.7047 0.7529 0.8263 0.7687 0.8363 1.0329 0.8561
0.9492 1.0124 1.0124 1.0124 1.0124 1.0124 1.0124
  2010    1      1  1     1    -1 0.0217 0.1089 0.2305 0.2621 0.4343 0.5361 0.6707 0.8666 1.1295 1.0818 0.9925 0.9214 0.8842 1.1424
0.7200 0.9031 0.9031 0.9031 0.9031 0.9031 0.9031
  2011    1      1  1     1    -1 0.0217 0.0845 0.2428 0.3194 0.3833 0.5103 0.5989 0.6727 0.8608 0.9476 0.9606 1.0749 1.0633 1.0148
1.0557 0.9368 0.9368 0.9368 0.9368 0.9368 0.9368
  2012    1      1  1     1    -1 0.0217 0.1290 0.2175 0.3531 0.4065 0.4884 0.6476 0.6841 0.7795 0.9363 0.9736 0.9639 0.9473 0.9949
1.0030 0.9373 0.9373 0.9373 0.9373 0.9373 0.9373
  2013    1      1  1     1    -1 0.0217 0.1297 0.2813 0.3552 0.4710 0.5090 0.6265 0.7149 0.7310 0.8338 0.9989 1.0752 1.2303 1.1187
1.0682 1.0545 1.0545 1.0545 1.0545 1.0545 1.0545
```

```
#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 0.0935 0.2474 0.3730 0.4823 0.5437 0.5933 0.6640 0.7226 0.7923 0.8634 0.9339 0.9735 1.0703
1.0069 1.0190 1.0190 1.0190 1.0190 1.0190 1.0190
  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 0.1380 0.2435 0.4123 0.5732 0.6488 0.6985 0.6914 0.7151 0.7280 0.7593 0.8241 0.8934 0.8227
0.8696 0.8425 0.8425 0.8425 0.8425 0.8425 0.8425
  2009    1      1  1     1     0 0.0217 0.0667 0.2428 0.3430 0.4735 0.6410 0.6831 0.7047 0.7529 0.8263 0.7687 0.8363 1.0329 0.8561
0.9492 1.0124 1.0124 1.0124 1.0124 1.0124 1.0124
  2010    1      1  1     1     0 0.0217 0.1089 0.2305 0.2621 0.4343 0.5361 0.6707 0.8666 1.1295 1.0818 0.9925 0.9214 0.8842 1.1424
0.7200 0.9031 0.9031 0.9031 0.9031 0.9031 0.9031
  2011    1      1  1     1     0 0.0217 0.0845 0.2428 0.3194 0.3833 0.5103 0.5989 0.6727 0.8608 0.9476 0.9606 1.0749 1.0633 1.0148
1.0557 0.9368 0.9368 0.9368 0.9368 0.9368 0.9368
  2012    1      1  1     1     0 0.0217 0.1290 0.2175 0.3531 0.4065 0.4884 0.6476 0.6841 0.7795 0.9363 0.9736 0.9639 0.9473 0.9949
1.0030 0.9373 0.9373 0.9373 0.9373 0.9373 0.9373
  2013    1      1  1     1     0 0.0217 0.1297 0.2813 0.3552 0.4710 0.5090 0.6265 0.7149 0.7310 0.8338 0.9989 1.0752 1.2303 1.1187
1.0682 1.0545 1.0545 1.0545 1.0545 1.0545 1.0545

#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 0.0935 0.2474 0.3730 0.4823 0.5437 0.5933 0.6640 0.7226 0.7923 0.8634 0.9339 0.9735 1.0703
1.0069 1.0190 1.0190 1.0190 1.0190 1.0190 1.0190
  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
```

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  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
```

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  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 0.1380 0.2435 0.4123 0.5732 0.6488 0.6985 0.6914 0.7151 0.7280 0.7593 0.8241 0.8934 0.8227
0.8696 0.8425 0.8425 0.8425 0.8425 0.8425 0.8425
  2009    1      1  1     1     1 0.0217 0.0667 0.2428 0.3430 0.4735 0.6410 0.6831 0.7047 0.7529 0.8263 0.7687 0.8363 1.0329 0.8561
0.9492 1.0124 1.0124 1.0124 1.0124 1.0124 1.0124
  2010    1      1  1     1     1 0.0217 0.1089 0.2305 0.2621 0.4343 0.5361 0.6707 0.8666 1.1295 1.0818 0.9925 0.9214 0.8842 1.1424
0.7200 0.9031 0.9031 0.9031 0.9031 0.9031 0.9031
  2011    1      1  1     1     1 0.0217 0.0845 0.2428 0.3194 0.3833 0.5103 0.5989 0.6727 0.8608 0.9476 0.9606 1.0749 1.0633 1.0148
1.0557 0.9368 0.9368 0.9368 0.9368 0.9368 0.9368
  2012    1      1  1     1     1 0.0217 0.1290 0.2175 0.3531 0.4065 0.4884 0.6476 0.6841 0.7795 0.9363 0.9736 0.9639 0.9473 0.9949
1.0030 0.9373 0.9373 0.9373 0.9373 0.9373 0.9373
  2013    1      1  1     1     1 0.0217 0.1297 0.2813 0.3552 0.4710 0.5090 0.6265 0.7149 0.7310 0.8338 0.9989 1.0752 1.2303 1.1187
1.0682 1.0545 1.0545 1.0545 1.0545 1.0545 1.0545

#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 0.0935 0.2474 0.3730 0.4823 0.5437 0.5933 0.6640 0.7226 0.7923 0.8634 0.9339 0.9735 1.0703
1.0069 1.0190 1.0190 1.0190 1.0190 1.0190 1.0190
  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
  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 0.1380 0.2435 0.4123 0.5732 0.6488 0.6985 0.6914 0.7151 0.7280 0.7593 0.8241 0.8934 0.8227
0.8696 0.8425 0.8425 0.8425 0.8425 0.8425 0.8425
  2009    1      1  1     1     2 0.0217 0.0667 0.2428 0.3430 0.4735 0.6410 0.6831 0.7047 0.7529 0.8263 0.7687 0.8363 1.0329 0.8561
0.9492 1.0124 1.0124 1.0124 1.0124 1.0124 1.0124
  2010    1      1  1     1     2 0.0217 0.1089 0.2305 0.2621 0.4343 0.5361 0.6707 0.8666 1.1295 1.0818 0.9925 0.9214 0.8842 1.1424
0.7200 0.9031 0.9031 0.9031 0.9031 0.9031 0.9031
  2011    1      1  1     1     2 0.0217 0.0845 0.2428 0.3194 0.3833 0.5103 0.5989 0.6727 0.8608 0.9476 0.9606 1.0749 1.0633 1.0148
1.0557 0.9368 0.9368 0.9368 0.9368 0.9368 0.9368
  2012    1      1  1     1     2 0.0217 0.1290 0.2175 0.3531 0.4065 0.4884 0.6476 0.6841 0.7795 0.9363 0.9736 0.9639 0.9473 0.9949
1.0030 0.9373 0.9373 0.9373 0.9373 0.9373 0.9373
  2013    1      1  1     1     2 0.0217 0.1297 0.2813 0.3552 0.4710 0.5090 0.6265 0.7149 0.7310 0.8338 0.9989 1.0752 1.2303 1.1187
1.0682 1.0545 1.0545 1.0545 1.0545 1.0545 1.0545
# End of wtatage.ss file
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