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

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

January 8, 2016

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

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

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

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

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

This document should be cited as follows: Taylor, I.G., C. Grandin, A.C. Hicks, N. Taylor, and S. Cox. 2015. Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2015. Prepared by the Joint Technical Committee of the U.S. and Canada Pacific Hake/Whiting Agreement; National Marine Fishery Service; Canada Department of Fisheries and Oceans. 159 p.

TABLE OF CONTENTS

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 fishery Pacific Hake landings averaged 224,364 t from 1966 to 2015, with a low of 89,930 t in 1980 and a peak of 363,135 t in 2005. Prior to 1966, total removals were negligible compared to the modern fishery. Over the early period, 1966–1990, most removals were from foreign or joint-venture fisheries. Over all years, the fishery in U.S. waters averaged 168,983 t, or 75.3% of the average total landings, while catch from Canadian waters averaged 55,381 t. Over the last 10 years, 2006–2015, the total average catch is 265,646 with U.S. and Canadian catches averaging 206,859 t and 58,786 t, respectively.

In this stock assessment, the terms catch and landings are used interchangeably. Estimates of discard within the target fishery are included, but discarding of Pacific Hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings in recent years. Recent coast-wide landings from 2010–2014 have been above the long term average of 224,364 t.

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 t.

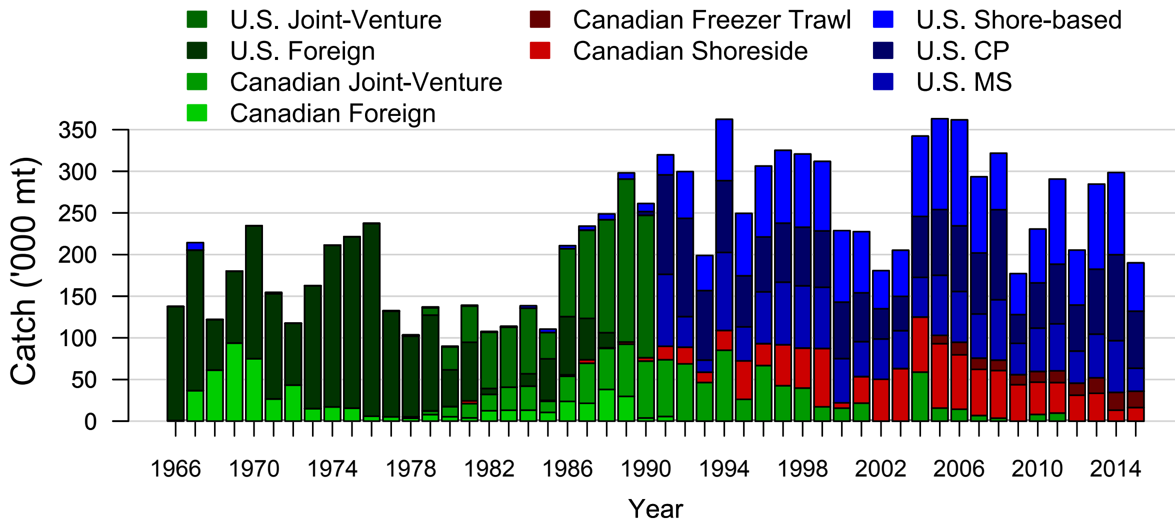

Figure 1. Total Pacific Hake catch used in the assessment by sector, 1966 – 2015. U.S. tribal catches are included in the sectors where they are represented.

Table 1. Recent commercial fishery catch (1,000's t). Tribal catches are included where applicable.

Year	US Mother-ship	US Catcher-Processor	US Shore-based	US Research	US Total	CAN Joint Venture	CAN Shore-side	CAN Freezer-Trawler	CAN Total	Total
2006	60,926	78,864	127,165	0	266,955	14,319	65,289	15,136	94,744	361,699
2007	52,977	73,263	91,441	0	217,682	6,780	55,390	13,537	75,707	293,389
2008	72,440	108,195	67,760	0	248,395	3,592	57,197	12,517	73,306	321,701
2009	37,550	34,552	49,223	0	121,325	0	43,774	12,073	55,847	177,172
2010	52,022	54,284	64,654	0	170,961	8,081	38,780	12,850	59,712	230,672
2011	56,394	71,678	102,147	1,042	231,262	9,717	36,632	14,060	60,409	291,671
2012	38,512	55,264	65,920	448	160,145	0	31,164	14,478	45,642	205,787
2013	52,470	77,950	102,143	1,018	233,581	0	33,451	18,583	52,033	285,614
2014	62,102	103,203	98,638	197	264,139	0	13,184	21,380	34,563	298,703
2015	27,658	68,484	58,009	0	154,152	0	16,364	19,532	35,896	190,047

DATA AND ASSESSMENT

The biomass estimate from the acoustic survey conducted in 2015 has been added to the model survey time series. The only other new data included in 2015 are the 2015 fishery age compositions and total catch. Various other data types, including data on maturity, have been explored since the 2014 stock assessment, but are not included in the base model for this year.

The Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966 – 2015), acoustic survey biomass estimates and age-composition (1995 – 2015; Figure 2), as well as fishery age-composition. While the 2011 survey index value was the lowest in the time-series, the index increased steadily over the four surveys conducted in 2011, 2012, 2013, and 2015. Age-composition data from the aggregated fisheries (1975–2014) and the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts.

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

This 2015 assessment retains the structural form of the base assessment model from 2014. The model retains many of the previous elements as configured in Stock Synthesis (SS). Analyses conducted in 2014 showed that the time-varying selectivity assessment model reduced the magnitude of extreme cohort strength estimates. In closed-loop simulations, management based upon assessment models with time-varying fishery selectivity led to higher median average catch, lower risk of falling below 10% of unfished biomass (B_0), smaller probability of fishery closures, and lower inter-annual variability in catch compared to assessment models with time-invariant fishery selectivity. It was found that even a small degree of flexibility in the assessment model fishery selectivity could reduce the effects of errors caused by assuming selectivity is constant over time.

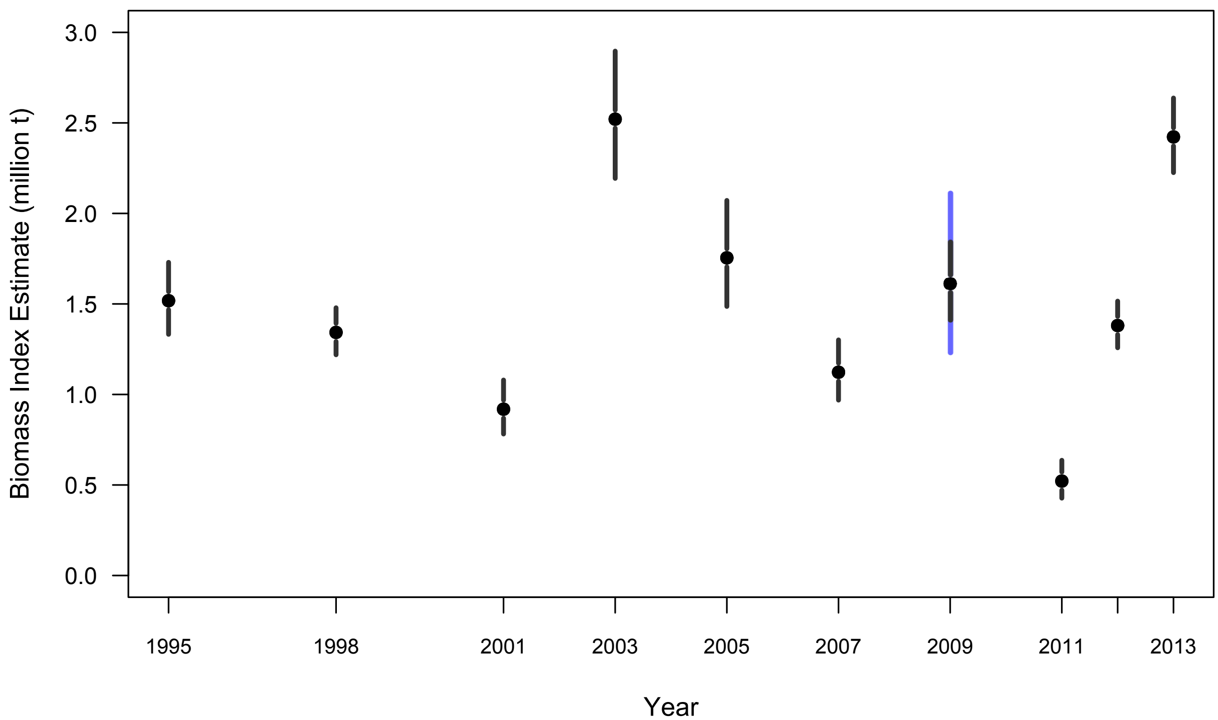

Figure 2. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2015) in addition to squid/hake apportionment uncertainty (2009, in blue).

STOCK BIOMASS

The base stock assessment model indicates that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium. The model estimates that it was below the unfished equilibrium in the 1960s and 1970s due to lower than average recruitment. The stock is estimated to have increased rapidly to near unfished equilibrium after two or more large recruitments in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007 entering the fishery to replace catches being removed during this period. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.497 million t in 2009. The assessment model estimates that spawning biomass declined from 2014 to 2015 after five years of increases from 2009 to 2014. The estimated increase was the result of a large 2010 and an above-average 2008 cohort. The 2015 median posterior spawning biomass is estimated to be 73.6% of the unfished equilibrium level (B_0) with 95% posterior credibility intervals ranging from 34.3% to 149.8%. The median estimates of 2014 and 2015 female spawning biomass values are 1.703 and 1.663 million t, respectively.

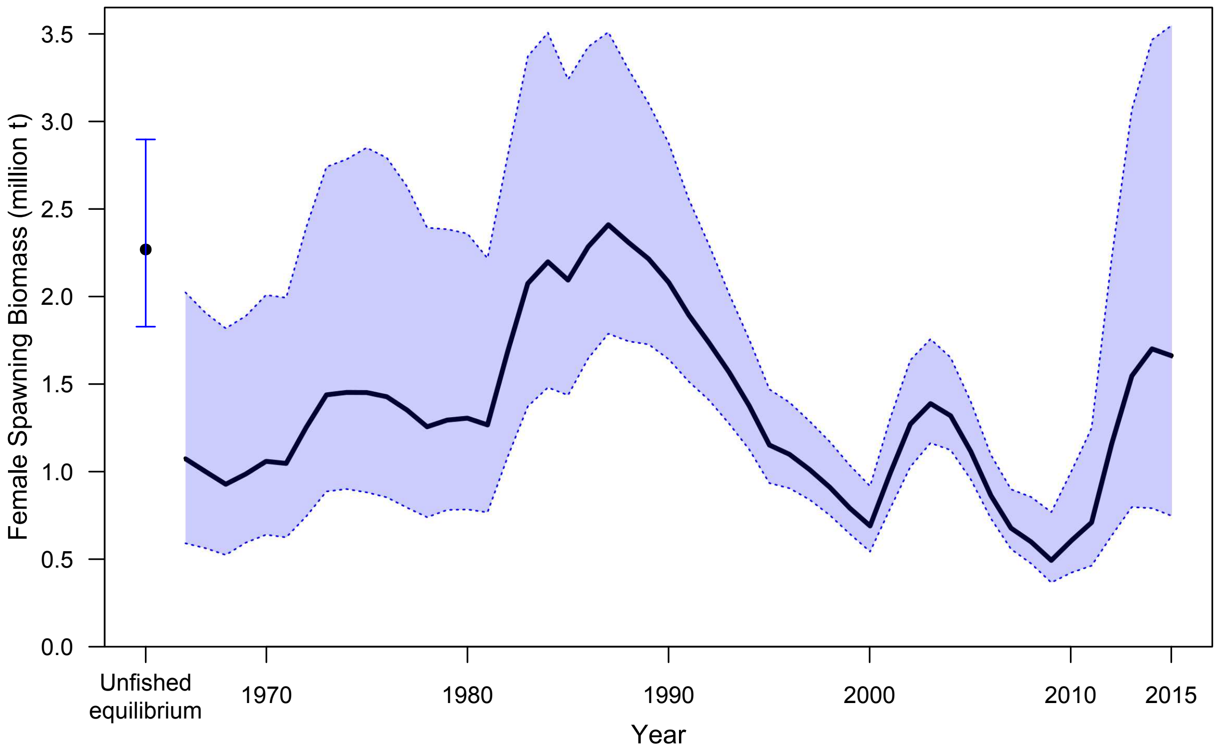

Figure 3. Median of the posterior distribution for female spawning biomass through 2015 (solid line) with 95% posterior credibility intervals (shaded area).

Table 2. Recent trends in estimated Pacific Hake female spawning biomass (thousand t) and relative spawning biomass level relative to estimated unfished equilibrium.

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

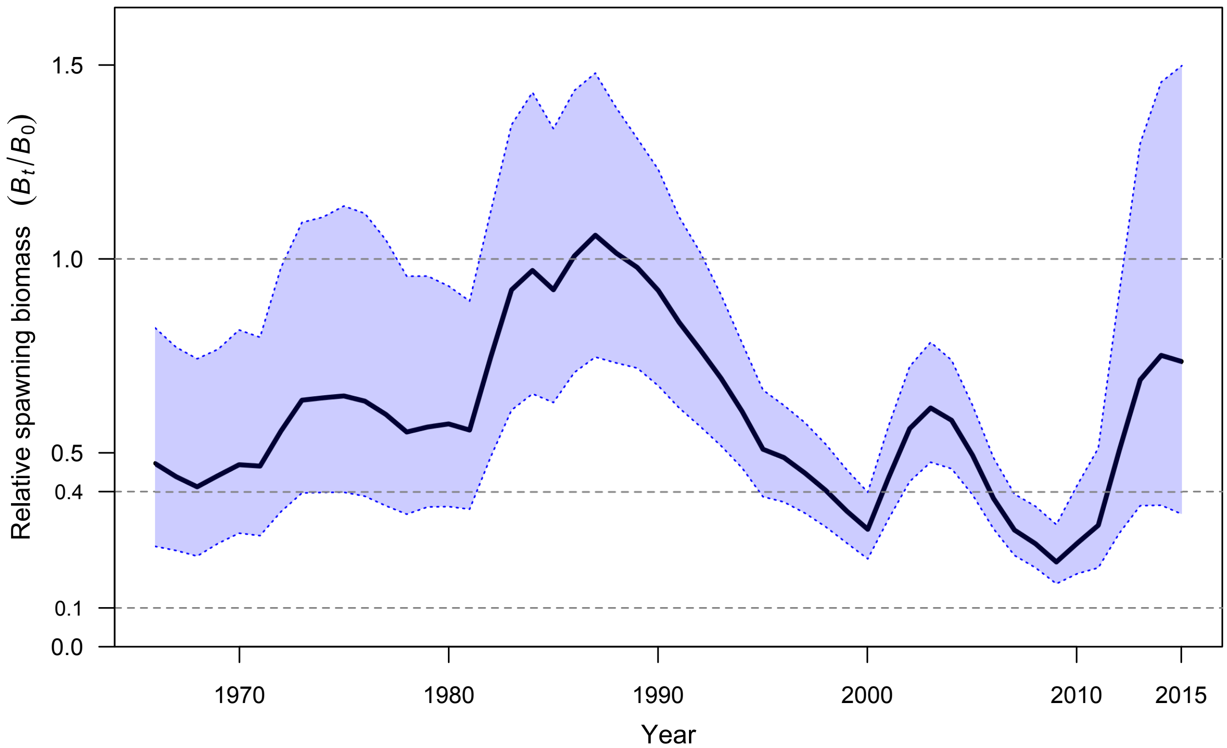

Figure 4. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2015 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

RECRUITMENT

The new data available for this assessment do not significantly change the estimated patterns of recruitment. Pacific Hake appear to have low average recruitment with occasional large year-classes. Very large year classes in 1980, 1984, and 1999 supported much of the commercial catch from the 1980s to the mid-2000s. From 2000 to 2007, estimated recruitment was at some of the lowest values in the time-series followed by a relatively large 2008 year class. The current assessment estimates a very strong 2010 year class comprising 70% of the coast-wide commercial catch in 2013 and 64% of the 2014 catch. Its size is still more uncertain than cohorts that have been observed for more years but the median estimate is the second highest in the time series (after the 1980 recruitment estimate). The model currently estimates a small 2011 year class, and smaller than average 2012 and 2013 year classes. There is little or no information in the data to estimate the sizes of the 2014 and 2015 year classes. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable prior to at least age 3.

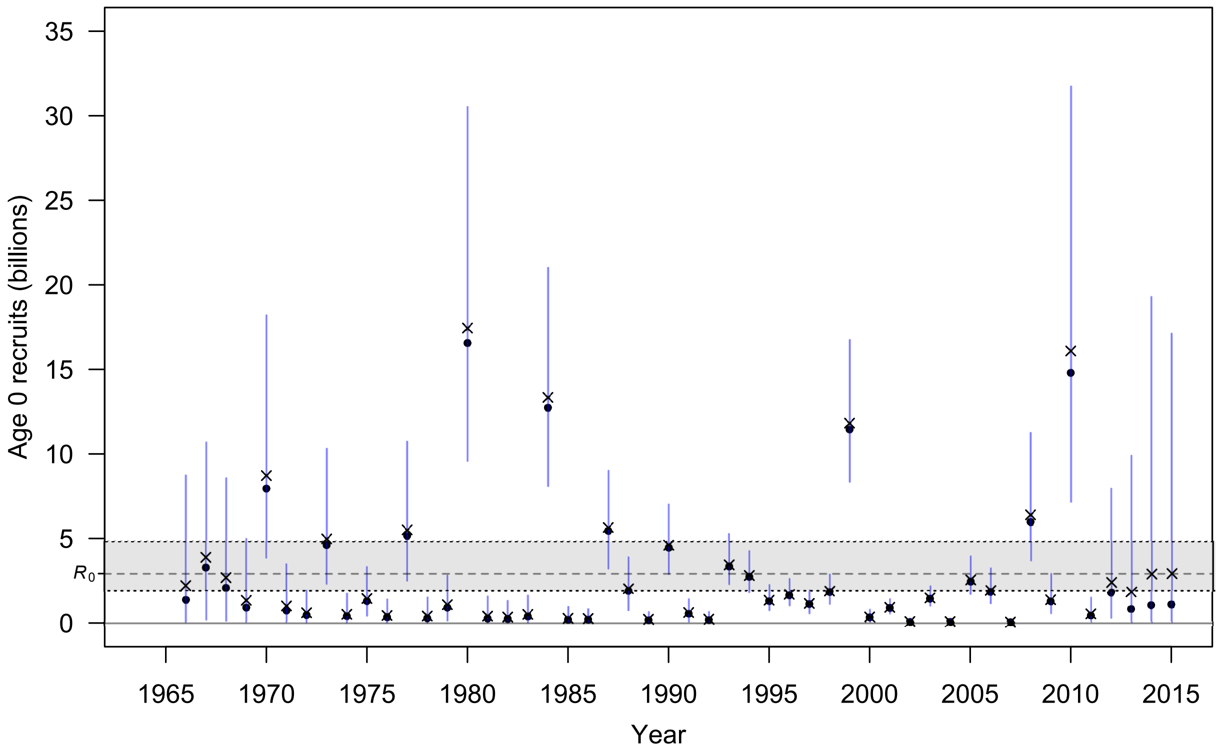

Figure 5. Medians (solid circles) and means (x) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with a 95% posterior credibility interval shaded between the dotted lines.

Table 3. Estimates of recent Pacific Hake recruitment (millions of age-0) and recruitment deviations (deviations below zero indicate less than median recruitment and deviations above zero indicate above median recruitment).

	Absolute recruitment (millions)			**Recruitment deviations**		
Year	**2.5th percentile**	**Median**	**97.5th percentile**	**2.5th percentile**	**Median**	**97.5th percentile**
2005	1,715.5	2,465.3	3,950.7	0.583	0.885	1.209
2006	1,173.4	1,852.6	3,249.5	0.277	0.631	1.018
2007	8.4	48.2	168.5	-4.652	-2.976	-1.800
2008	3,696.0	5,987.2	11,245.9	1.476	1.877	2.322
2009	575.5	1,289.5	2,926.6	-0.311	0.357	0.966
2010	7,181.6	14,799.4	31,733.8	2.192	2.767	3.355
2011	85.4	447.3	1,533.2	-2.337	-0.766	0.360
2012	311.4	1,818.1	7,954.9	-1.117	0.559	1.901
2013	52.5	833.3	9,911.5	-2.986	-0.225	2.185
2014	67.0	1,062.1	19,282.9	-2.743	0.041	2.769

EXPLOITATION STATUS

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

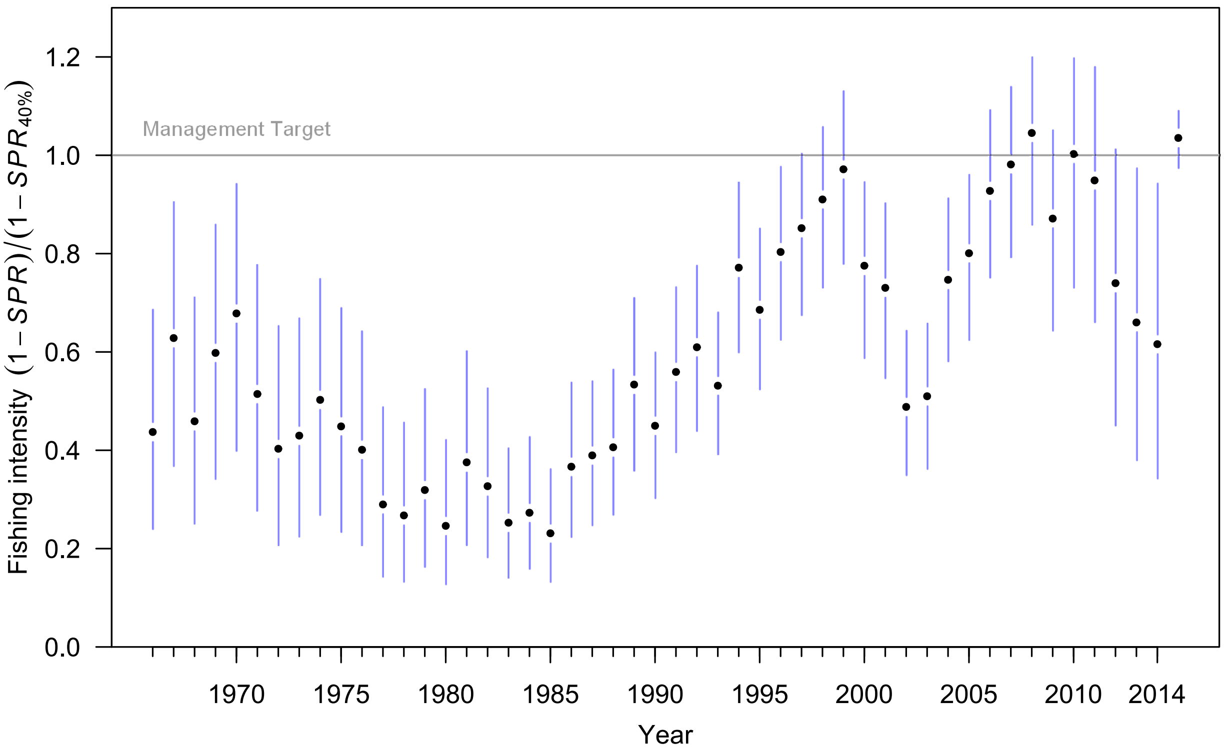

Figure 6. Trend in median fishing intensity (relative to the SPR management target) through 2014 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

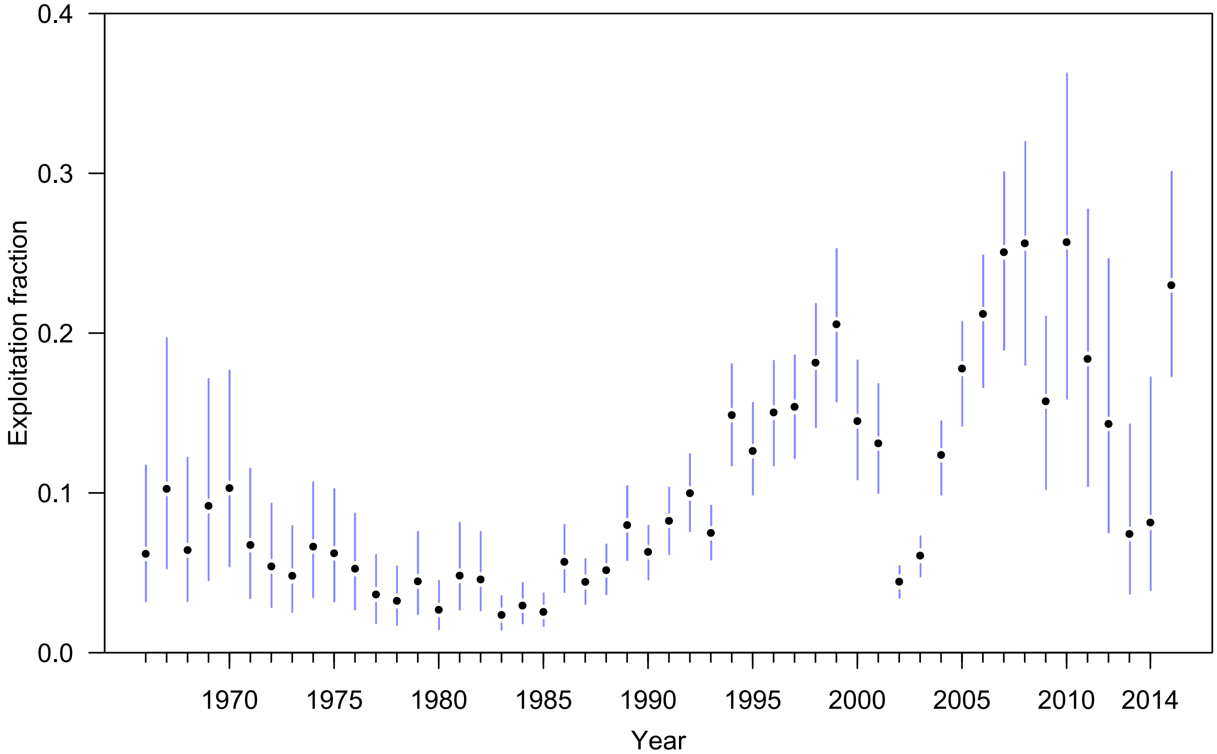

Figure 7. Trend in median exploitation fraction through 2014 with 95% posterior credibility intervals.

Table 4. Recent trend in fishing intensity. Relative spawning potential ratio; (1-SPR)/(1-$SPR_{40\%}$) and exploitation rate (catch divided by age 3+ biomass).

	Fishing intensity			**Exploitation fraction**		
Year	**2.5^{th} percentile**	**Median**	**97.5^{th} percentile**	**2.5^{th} percentile**	**Median**	**97.5^{th} percentile**
2005	0.624	0.801	0.960	0.142	0.178	0.207
2006	0.751	0.928	1.092	0.166	0.212	0.249
2007	0.792	0.981	1.139	0.190	0.251	0.301
2008	0.858	1.045	1.199	0.180	0.256	0.320
2009	0.643	0.871	1.051	0.102	0.157	0.211
2010	0.731	1.003	1.197	0.159	0.257	0.362
2011	0.661	0.949	1.179	0.104	0.184	0.277
2012	0.451	0.740	1.012	0.075	0.143	0.247
2013	0.380	0.660	0.974	0.037	0.074	0.143
2014	0.342	0.616	0.942	0.039	0.081	0.172

MANAGEMENT PERFORMANCE

Over the last decade, the average coast-wide utilization rate (i.e., utilization = landings/quota) has been 86.3%. From 2010 to 2014, the mean utilization rates differed between the United States (85%) and Canada (60%). Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%. Exploitation history in terms of joint biomass and F-target reference points shows that before 2007, median fishing intensity was below target and female spawning biomass was near or above target (Figure 5). Between 2007 and 2011, however, fishing intensity ranged from 87% to 105% and relative spawning biomass between 0.22 and 0.31. Biomass has risen recently with the 2008 and 2010 recruitments and correspondingly, fishing intensity has fallen below targets, and relative spawning biomass above targets for 2012 through 2014. While uncertainty in the 2014 fishing intensity estimates and relative spawning biomass is large, the model predicts a 1.4% joint probability of being both above the target fishing intensity in 2014 and below 40% relative spawning biomass at the start of 2015.

Table 5. Recent trends in Pacific Hake landings and management decisions.

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

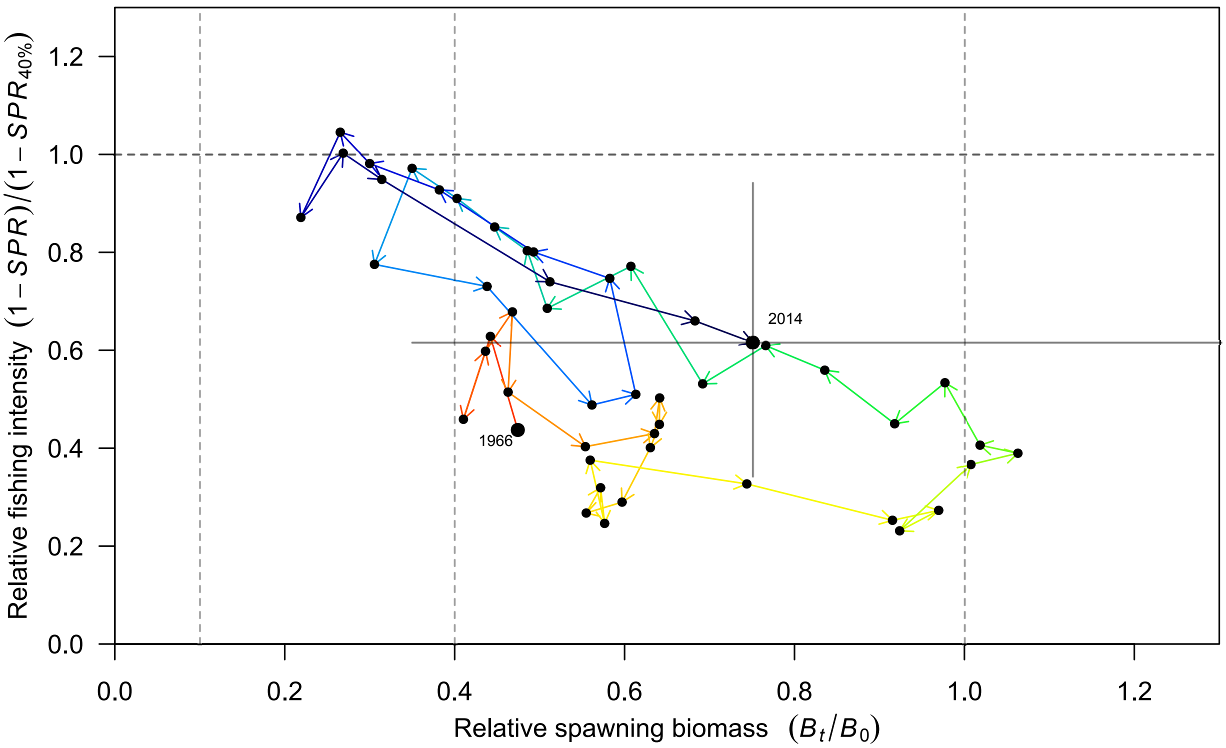

Figure 8. Estimated historical path followed by fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years. Gray bars span the 95% credibility intervals for 2014 fishing intensity (vertical) and relative spawning biomass (horizontal).

REFERENCE POINTS

We report estimates of the 2015 base model reference points with posterior credibility intervals in Table f. The estimates are slightly different than the estimates in the 2014 assessment with slightly greater yields and biomasses estimated in this assessment.

Table 6. Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2014 averages for mean size at age and selectivity at age.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female B (B_0, thousand t)	1,828	2,269	2,897
Unfished recruitment (R_0, millions)	1,932	2,923	4,812
Reference points (equilibrium) based on $F_{40\%}$			
Female spawning biomass ($B_{F40\%}$ thousand t)	613	814	1,025
$SPR_{MSY\text{-}proxy}$	–	40%	–
Exploitation fraction corresponding to SPR	18.5%	21.6%	25.6%
Yield at $B_{F40\%}$ (thousand t)	270	362	513
Reference points (equilibrium) based on $B_{40\%}$			
Female spawning biomass ($B_{40\%}$ thousand t)	731	907	1,159
$SPR_{B40\%}$	40.7%	43.4%	50.5%
Exploitation fraction resulting in $B_{40\%}$	14.4%	18.9%	23.2%
Yield at $B_{40\%}$ (thousand t)	264	352	503
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY} thousand t)	357	561	895
SPR_{MSY}	18.5%	29%	44.7%
Exploitation fraction corresponding to SPR_{MSY}	17.6%	33.3%	59.6%
MSY (thousand t)	277	384	563

UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

Uncertainty measures in the base model underestimate the total uncertainty in the current stock status and projections because they do not account for possible alternative structural models for hake population dynamics and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distributions. To address structural uncertainties, the JTC investigated a range of alternative models, and we present a subset of key sensitivity analyses in the main document. Uncertainty in the best method for calculating acoustic survey biomass is a particular focus and results from a model fit to an alternative set of survey biomass values are presented in the decision tables alongside the base model results.

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

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

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

FORECAST DECISION TABLE

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

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

Management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP) in 2012 are presented for projections to 2016 and 2017 (**FIX..Tables g.3 and g.4 and Figures j and k**). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values. Figure **FIX..i** shows the predicted relative spawning biomass trajectory through 2017 for several of these management actions. With zero catch for the next two years, the median biomass is predicted to remain stable from 2016 to 2017, with a **FIX..39**% probability of decreasing from 2015 to 2016 and a **FIX..51**% probability of decreasing from 2016 to 2017.

At all catch levels 180,000 t per year or greater, the spawning biomass is predicted to decline from 2015 to 2016 with greater than 68% probability (Table g.3 and Figure j). The model predicts high biomass levels and the predicted probability of dropping below 10% in 2016 is less than 1% and the maximum probability of dropping below $B_{40\%}$ is 21% for all catches explored. It should be noted that in addition to the natural mortality rate overtaking the growth rate for the 2010 year class, the model estimated below average recruitment for the 2011 and 2013 cohorts entering the 2016 spawning biomass, which also contributes to the relatively low catch that will result in a reduction in spawning biomass from 2015 to 2016. The probability that the 2017 spawning biomass will be less than the 2016 spawning biomass is greater than 50% for any catch level (including zero catch).

RESEARCH AND DATA NEEDS

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

1. Continue development of the management strategy evaluation (MSE) tools to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them. Incorporate the feedback from JMC/AP/SRG/MSE Advisory Panel into operating model development. Specifically, making sure that the operating model is able to provide insight into the important questions defined by these groups. If a spatially, seasonally explicit operating model is needed, then research should focus on how to best to model these dynamics to capture seasonal effects and potential climate forcing influences in the simulations.
2. Conduct further exploration of ageing imprecision and the effects of large cohorts via simulation and blind source age-reading of samples with differing underlying age distributions – with and without dominant year classes.
3. Continue to explore and develop statistical methods to parameterize time-varying fishery selectivity in assessment and forecasting.
4. Continue to investigate maturity observations of Pacific Hake and explore additional sampling sources to determine fecundity and when spawning occurs. Continue to explore ways to include new maturity estimates in the assessment. This would involve:
    (a) Having ages read for the 2014 trawl samples
    (b) Further investigation of the smaller maturity-at-length south of Point Conception
    (c) Determining the significance of batch spawning and viability of spawning events throughout the year
    (d) Studying fecundity as a function of size, age, weight, and batch spawning
5. Investigate links between hake spatial distribution and dynamics with ocean conditions and ecosystem variables such as temperature and prey availability. These investigations have the potential to improve the scenarios considered in future MSE work as well as

providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.

6. Continue to collect and analyze life-history data, including weight, maturity and fecundity for Pacific Hake. Explore possible relationships among these life history traits including time-varying changes as well as with body growth and population density. Currently available information is limited and outdated. Continue to explore the possibility of using additional data types (such as length data) within the stock assessment.
7. Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific Hake. This would include completing ongoing MSE analyses to investigate whether an age-1 index could reduce stock assessment and management uncertainty enough to improve overall management performance.
8. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength, directionality of survey and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods.
9. Maintain the flexibility to undertake annual acoustic surveys for Pacific Hake under pressing circumstances in which uncertainty in the hake stock assessment presents a potential risk to or underutilization of the stock.
10. Evaluate the quantity and quality of historical biological data (prior to 1989 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use as age-composition and weight-at-age data, and/or any historical indications of abundance fluctuations.
11. Consider alternative methods for treatment of recruitment variability (σ_r) including the use of prior distributions derived from meta-analytic methods, and for refining existing prior for natural mortality (M).
12. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others
13. Continue to coordinate our MSE research with other scientists in the region engaging in similar research.
14. Continue to investigate alternative ways to model and forecast recruitment. Use MSE simulations to investigate the impact of making incorrect assumptions about the underlying recruitment process.
15. Continue to work with acousticians and survey personnel from the NWFSC, the SWFSC, and DFO to determine an optimal design for the Joint U.S./Canada Hake/Sardine survey.
16. Explore the potential to use acoustic data collected from commercial fishing vessels to study hake distributions, schooling patterns, and other questions of interest. This could be similar to the "acoustic vessels of opportunity" program on fishing vessels targeting pollock in Alaska.

1 INTRODUCTION

** indicates something that needs to be checked (or cannot be automated). For now have concentrated on converting last year's text into LaTeX. Missing references are listed at the end.

The Joint US-Canada Agreement for Pacific Hake (called the Agreement) was signed in 2003 and went into force in 2008 but could not be implemented until 2010. This is the fifth annual stock assessment conducted under the treaty process. Under the Agreement, Pacific Hake or Pacific Whiting (*Merluccius Productus*) stock assessments are to be prepared by the Joint Technical Committee (JTC) comprised of both U.S. and Canadian scientists, and reviewed by the Scientific Review Group (SRG), consisting of representatives from both nations. Additionally, the Agreement calls for both of these bodies to include scientists nominated by an Advisory Panel (AP) of fishery stakeholders.

The data sources for this assessment are an acoustic survey as well as fishery and survey age-composition data. The assessment depends primarily upon the acoustic survey biomass index time-series for information on the scale of the current hake stock. Age-composition data from the aggregated fishery and the acoustic survey provide additional information allowing the model to resolve strong and weak cohorts. **Both sources show a very strong 2010 cohort dominating the age compositions in recent years. Annual fishery catch is not considered data in the sense that it does not contribute to the likelihood. However, the catch is an important source of information in contributing to changes in abundance and providing a lower bound on the available population biomass in each year.

This assessment is fully Bayesian, with the base model incorporating prior information on several key parameters (including natural mortality, M, and steepness of the stock-recruit relationship, h) and integrating over parameter uncertainty to provide results that can be probabilistically interpreted. From a range of alternate models investigated by the JTC, a subset of sensitivity analyses are also reported in order to provide a broad qualitative comparison of structural uncertainty with respect to the base case. These sensitivity analyses are thoroughly described in this assessment document. The structural assumptions of this 2015 base model are effectively the same as the 2014 base model. These models differ from the 2013 base model primarily through the addition of time-varying selectivity in the fishery.

1.1 STOCK STRUCTURE AND LIFE HISTORY

Pacific Hake, also referred to as Pacific whiting, is a semi-pelagic schooling species distributed along the west coast of North America generally ranging from 25° N. to 55° N. latitude (see Figure **1 for an overview map). It is among 18 species of hake from four genera (being the majority of the family *Merluccidae*), which are found in both hemispheres of the Atlantic and Pacific oceans (**Alheit and Pitcher 1995, **Lloris et al. 2005). The coastal stock of Pacific Hake is currently the most abundant groundfish population in the California Current system.

Smaller populations of this species occur in the major inlets of the Northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California. Genetic studies indicate that the Strait of Georgia and the Puget Sound populations are genetically distinct from the coastal population (Iwamoto et al., 2004; King et al., 2012). Genetic differences have also been found between the coastal population and hake off the west coast of Baja California (**Vrooman and Paloma 1977). The coastal stock is also distinguished from the inshore populations by larger body size and seasonal migratory behavior.

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

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

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

1.2 ECOSYSTEM CONSIDERATIONS

Pacific Hake are important to ecosystem dynamics in the Eastern Pacific due to their relatively large total biomass and potentially large role as both prey and predator in the Eastern Pacific Ocean. A more detailed description of ecosystem considerations is given in the 2013 Pacific Hake stock assessment (JTC, Joint Technical Committee, 2013). Recent research has developed an index of abundance for Humboldt Squid and suggested links between squid and hake abundance (Stewart et al., 2014).

**Last year's assessment: This document includes a sensitivity analysis where hake mortality was linked to the Humboldt Squid index (Section 3.5 below) although further research on this topic is needed.

1.3 MANAGEMENT OF PACIFIC HAKE

Since implementation of the Magnuson-Stevens Fishery Conservation and Management Act in the United States and the declaration of a 200 mile fishery conservation zone in both countries in the late 1970s, annual quotas (or catch targets) have been used to limit the catch of Pacific Hake in both zones. Scientists from both countries historically collaborated through the Technical 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 U.S. and Canada, establishes U.S. and Canadian shares of the coast-wide allowable biological catch at 73.88% and 26.12%, respectively, and this distribution has been adhered to since ratification of the Agreement.

Throughout the last decade, the total coast-wide catch has tracked harvest targets reasonably well (**Table 4). Since 1999, catch targets have been determined using an $F_{\mathrm{SPR}=40\%}$ default harvest rate with a 40:10 adjustment that decreases the catch linearly from the catch target at a relative spawning biomass of 40% and above, to zero catch at relative spawning biomass values of 10% or less (called the default harvest policy in the Agreement). Further considerations have often resulted in catch targets to be set lower than the recommended catch limit. In the last decade, total catch has never exceeded the quota, but harvest rates have approached the $F_{\mathrm{SPR}=40\%}$ target and, in retrospect, may have exceeded the target as estimated from this assessment [**true for this year??]. 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

**AME suggests putting U.S. then Canada, as elsewhere in the document. In 2015 assessment it was this way but tables had got mis-referenced.

Canadian groundfish managers distribute their portion (26.12%) of the Total Allowable Catch (TAC) as quota to individual license holders. In **2014, the Canadian Hake was allocated a TAC of **98,621 t plus **13,172 t of uncaught carryover fish from 2013. Canadian priority lies with the domestic fishery, but when there is determined to be an excess of fish for which there is not enough shoreside processing capacity, fisheries managers give consideration to a Joint-Venture fishery in which foreign processor vessels are allowed to accept codends from Canadian catcher vessels while at sea. The last joint venture program was conducted in **2011.

In 2015, all Canadian Pacific Hake trips remained subject to 100% observer coverage, by either electronic monitoring for the shoreside component of the domestic fishery or on-board observer for the freezer trawler component. All shoreside hake landings were also subject to 100% verification by the groundfish Dockside Monitoring Program (DMP). Retention of all catch, with the exception of prohibited species, was mandatory. The retention of groundfish other than Sablefish, Mackerel, Walleye Pollock, and Pacific Halibut on non-observed but electronically monitored, dedicated Pacific Hake trips, was not allowed to exceed 10% of the landed catch weight. The bycatch allowance for Walleye Pollock was 30% of the total landed weight.

1.3.2 Management of Pacific Hake in the United States

In the U.S. zone, participants in the directed fishery are required to use pelagic trawls with a codend mesh that is at least 7.5 cm (3 inches). Regulations also restrict the area and season of fishing to reduce the bycatch of Chinook salmon and several depleted rockfish stocks. The at-sea fisheries begin on May 15, but processing and night fishing (midnight to one hour after official sunrise) are prohibited south of 42° N. latitude (the Oregon-California border). Shore-based fishing is allowed after April 1 south of 42° N. latitude, but only 5% of the shore-based allocation is released prior to the opening of the main shore-based fishery (June 15). The current allocation agreement, effective since 1997, divides the U.S. non-tribal harvest among catcher-processors (34%), motherships (24%), and the shore-based fleet (42%). Since 2011, the non-tribal U.S. fishery has been fully rationalized with allocations in the form of IFQs to the shore-based sector and group shares to cooperatives in the at-sea mothership and catcher-processor sectors. Starting in 1996, the Makah Indian Tribe has also conducted a fishery with a specified allocation in its "usual and accustomed fishing area".

Shortly after the 1997 allocation agreement was approved by the Pacific Marine Fisheries Commission (PMFC; **2015 assessment says PFMC, okay?), fishing companies owning catcher-processor (CP) vessels with U.S. west coast groundfish permits established the Pacific Whiting Conservation Cooperative (PWCC). The primary role of the PWCC is to distribute the CP allocation among its members in order to achieve greater efficiency and product quality, as well as promoting reductions in waste and bycatch rates relative to the former "derby" fishery in which all vessels competed for a fleet-wide quota. The mothership fleet (MS) has also formed a co-operative where bycatch allocations are pooled and shared among the vessels. The individual cooperatives have internal systems of in-season monitoring and spatial closures to avoid and reduce bycatch of salmon and rockfish. The shore-based fishery is managed with Individual Fishing Quotas (IFQ).

1.4 FISHERIES

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

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

1.4.1 **Overview of the fisheries in 2014

**Will all need updating.

** The Joint Management Committee (JMC) determined an adjusted coast-wide catch target of **428,000 t for **2014, with a U.S. allocation of **316,206 t (**73.88%) and a Canadian allocation of **111,794 t (**26.12%). A review of the 2015 fishery is given below.

Canada

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

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

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

** The most abundant year classes in the Canadian catch were age 6 at 23.7%, age 4 at 15.3%, age 8 at 15.2%, age 5 at 12.6%, and age 7 at 9.0%. The large 1999 cohort, now age

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

For an overview of Canadian catch by year and fleet, see Table 8. For 2002, 2003, 2009, 2012, 2013, 2014 and 2015 there was no Joint-Venture fishery operating in Canada and this is reflected as zero catch in that sector for those years in Table 8.

United States

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

** Needs writing for 2015. The mothership sector started the season fishing in the north, but moved to waters off southern Oregon and Northern California after some high Pacific Ocean Perch bycatch events. Although the fleet encountered some older fish in the North, they fished predominantly on 4 year old fish in the South. Later in the season, high bycatch of darkblotched rockfish briefly halted fishing in the mothership sector. Coastwide catch of darkblotched rockfish was below target harvest levels, which provided industry and fishery managers the ability to transfer darkblotched rockfish quota to the mothership sector in order for them to continue utilizing their uncaught hake quota. Ultimately, the mothership fishery reopened, but with additional restrictions imposed on them intended to reduce salmon and rockfish bycatch. These restrictions also limited access for many of the harvesters to productive hake grounds. The 85.0% utilization of the mothership quota was a result of factors other than being able to catch fish (e.g. scheduled maintenance).

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

** Chinook salmon, protected under the Endangered Species Act (ESA), occurs as bycatch in the whiting [** shouldn't we stick with 'hake'?] fishery, which operates under an Incidental Take Statement. The amount of salmon bycatch allowed under this Incidental Take Statement was exceeded in October, and consequently, an Ocean Salmon Conservation Zone (where whiting fishing was prohibited) was implemented shoreward of 100 fathoms. The at-sea sectors fished in water deeper than 150 fathoms, and in October and November, some catches occurred far offshore in water deeper than 1,000 fathoms (**Figure 5).

MISSING REFERENCES

** References needed were in last year's assessment text but not in its bibliography or in the .bib file from Allan:

Alheit and Pitcher 1995

Lloris et al. 2005

Vrooman and Paloma 1977

Dorn 1991 - should this be Dorn and Methot 1991, as in the 2015 bibliography?

Dorn 1992

** References that were in last year's assessment but not its bibliography, but I'm taking from the .bib file:

Iwamoto et al. (2004)

King et al. (2012)

(Dorn, 1995) - there are two Dorn (1995) references in the .bib file, I assume the one referenced next to Agostini et al. is the CalCOFI report, not the stock assessment.

(Agostini et al., 2006)

Table 7. Annual catches of Pacific Hake (t) in U.S. waters by sector, 1966-2015. Tribal catches are included in the sector totals.

Year	Foreign	JV	Mothership	Catcher-Processor	Shore-based	Research	Total
1966	137,000	0	0	0	0	0	137,000
1967	168,700	0	0	0	8,960	0	177,660
1968	60,660	0	0	0	160	0	60,820
1969	86,190	0	0	0	90	0	86,280
1970	159,510	0	0	0	70	0	159,580
1971	126,490	0	0	0	1,430	0	127,920
1972	74,090	0	0	0	40	0	74,130
1973	147,440	0	0	0	70	0	147,510
1974	194,110	0	0	0	0	0	194,110
1975	205,650	0	0	0	0	0	205,650
1976	231,330	0	0	0	220	0	231,550
1977	127,010	0	0	0	490	0	127,500
1978	96,827	860	0	0	690	0	98,377
1979	114,910	8,830	0	0	940	0	124,680
1980	44,023	27,537	0	0	790	0	72,350
1981	70,365	43,557	0	0	838	0	114,760
1982	7,089	67,465	0	0	1,027	0	75,581
1983	0	72,100	0	0	1,051	0	73,151
1984	14,772	78,889	0	0	2,721	0	96,382
1985	49,853	31,692	0	0	3,894	0	85,439
1986	69,861	81,640	0	0	3,465	0	154,966
1987	49,656	105,997	0	0	4,795	0	160,448
1988	18,041	135,781	0	0	6,867	0	160,690
1989	0	195,636	0	0	7,414	0	203,050
1990	0	170,972	0	4,537	9,632	0	185,142
1991	0	0	86,408	119,411	23,970	0	229,789
1992	0	0	36,721	117,981	56,127	0	210,829
1993	0	0	14,558	83,466	42,108	0	140,132
1994	0	0	93,610	86,251	73,616	0	253,477
1995	0	0	40,805	61,357	74,962	0	177,124
1996	0	0	62,098	65,933	85,128	0	213,159
1997	0	0	75,128	70,832	87,416	0	233,376
1998	0	0	74,686	70,377	87,856	0	232,920
1999	0	0	73,440	67,655	83,470	0	224,565
2000	0	0	53,110	67,805	85,854	0	206,770
2001	0	0	41,901	58,628	73,412	0	173,940
2002	0	0	48,404	36,342	45,708	0	130,453
2003	0	0	45,396	41,214	55,335	0	141,945
2004	0	0	47,561	73,176	96,504	0	217,240
2005	0	0	72,178	78,890	109,052	0	260,120
2006	0	0	60,926	78,864	127,165	0	266,955
2007	0	0	52,977	73,263	91,441	0	217,682
2008	0	0	72,440	108,195	67,760	0	248,395
2009	0	0	37,550	34,552	49,223	0	121,325
2010	0	0	52,022	54,284	64,654	0	170,961
2011	0	0	56,394	71,678	102,147	1,042	231,262
2012	0	0	38,512	55,264	65,920	448	160,145
2013	0	0	52,470	77,950	102,143	1,018	233,581
2014	0	0	62,102	103,203	98,638	197	264,139
2015	0	0	27,658	68,484	58,009	0	154,152

Table 8. Annual catches of Pacific Hake (t) in Canadian waters by sector, 1966-2015.

Year	Foreign	JV	Shoreside	Freezer-trawl	Total
1966	700	0	0	0	700
1967	36,710	0	0	0	36,710
1968	61,360	0	0	0	61,360
1969	93,850	0	0	0	93,850
1970	75,010	0	0	0	75,010
1971	26,700	0	0	0	26,700
1972	43,410	0	0	0	43,410
1973	15,130	0	0	0	15,130
1974	17,150	0	0	0	17,150
1975	15,700	0	0	0	15,700
1976	5,970	0	0	0	5,970
1977	5,190	0	0	0	5,190
1978	3,450	1,810	0	0	5,260
1979	7,900	4,230	300	0	12,430
1980	5,270	12,210	100	0	17,580
1981	3,920	17,160	3,280	0	24,360
1982	12,480	19,680	0	0	32,160
1983	13,120	27,660	0	0	40,780
1984	13,200	28,910	0	0	42,110
1985	10,530	13,240	1,190	0	24,960
1986	23,740	30,140	1,770	0	55,650
1987	21,450	48,080	4,170	0	73,700
1988	38,080	49,240	830	0	88,150
1989	29,750	62,718	2,562	0	95,029
1990	3,810	68,314	4,021	0	76,144
1991	5,610	68,133	16,174	0	89,917
1992	0	68,779	20,043	0	88,822
1993	0	46,422	12,352	0	58,773
1994	0	85,154	23,776	0	108,930
1995	0	26,191	46,181	0	72,372
1996	0	66,779	26,360	0	93,139
1997	0	42,544	49,227	0	91,771
1998	0	39,728	48,074	0	87,802
1999	0	17,201	70,121	0	87,322
2000	0	15,625	6,382	0	22,007
2001	0	21,650	31,935	0	53,585
2002	0	0	50,244	0	50,244
2003	0	0	63,217	0	63,217
2004	0	58,892	66,175	0	125,067
2005	0	15,695	77,335	9,985	103,014
2006	0	14,319	65,289	15,136	94,744
2007	0	6,780	55,390	13,537	75,707
2008	0	3,592	57,197	12,517	73,306
2009	0	0	43,774	12,073	55,847
2010	0	8,081	38,780	12,850	59,712
2011	0	9,717	36,632	14,060	60,409
2012	0	0	31,164	14,478	45,642
2013	0	0	33,451	18,583	52,033
2014	0	0	13,184	21,380	34,563
2015	0	0	16,364	19,532	35,896

Table 9. Total U.S., Canadian and coastwide catches of Pacific Hake (t) from 1966-2015. The percentage of the total catch from each country's waters is also given.

Year	Total U.S.	Total Canada	Total coastwide	Percent U.S.	Percent Canada
1966	137,000	700	137,700	99.5	0.5
1967	177,660	36,710	214,370	82.9	17.1
1968	60,820	61,360	122,180	49.8	50.2
1969	86,280	93,850	180,130	47.9	52.1
1970	159,580	75,010	234,590	68.0	32.0
1971	127,920	26,700	154,620	82.7	17.3
1972	74,130	43,410	117,540	63.1	36.9
1973	147,510	15,130	162,640	90.7	9.3
1974	194,110	17,150	211,260	91.9	8.1
1975	205,650	15,700	221,350	92.9	7.1
1976	231,550	5,970	237,520	97.5	2.5
1977	127,500	5,190	132,690	96.1	3.9
1978	98,377	5,260	103,637	94.9	5.1
1979	124,680	12,430	137,110	90.9	9.1
1980	72,350	17,580	89,930	80.5	19.5
1981	114,760	24,360	139,120	82.5	17.5
1982	75,581	32,160	107,741	70.2	29.8
1983	73,151	40,780	113,931	64.2	35.8
1984	96,382	42,110	138,492	69.6	30.4
1985	85,439	24,960	110,399	77.4	22.6
1986	154,966	55,650	210,616	73.6	26.4
1987	160,448	73,700	234,148	68.5	31.5
1988	160,690	88,150	248,840	64.6	35.4
1989	203,050	95,029	298,079	68.1	31.9
1990	185,142	76,144	261,286	70.9	29.1
1991	229,789	89,917	319,705	71.9	28.1
1992	210,829	88,822	299,650	70.4	29.6
1993	140,132	58,773	198,905	70.5	29.5
1994	253,477	108,930	362,407	69.9	30.1
1995	177,124	72,372	249,496	71.0	29.0
1996	213,159	93,139	306,299	69.6	30.4
1997	233,376	91,771	325,147	71.8	28.2
1998	232,920	87,802	320,722	72.6	27.4
1999	224,565	87,322	311,887	72.0	28.0
2000	206,770	22,007	228,777	90.4	9.6
2001	173,940	53,585	227,525	76.4	23.6
2002	130,453	50,244	180,697	72.2	27.8
2003	141,945	63,217	205,162	69.2	30.8
2004	217,240	125,067	342,307	63.5	36.5
2005	260,120	103,014	363,135	71.6	28.4
2006	266,955	94,744	361,699	73.8	26.2
2007	217,682	75,707	293,389	74.2	25.8
2008	248,395	73,306	321,701	77.2	22.8
2009	121,325	55,847	177,172	68.5	31.5
2010	170,961	59,712	230,672	74.1	25.9
2011	231,262	60,409	291,671	79.3	20.7
2012	160,145	45,642	205,787	77.8	22.2
2013	233,581	52,033	285,614	81.8	18.2
2014	264,139	34,563	298,703	88.4	11.6
2015	154,152	35,896	190,047	81.1	18.9

REFERENCES

Agostini, V.N., Francis, R.C., Hollowed, A., Pierce, S.D., Wilson, C.D. and Hendrix, A.N. 2006. The relationship between Pacific hake (*Merluccius productus*) distribution and poleward subsurface flow in the California Current system. Canadian Journal of Fisheries and Aquatic Sciences **63**: 2648–2659.

Dorn, M.W. 1995. The effects of age composition and oceanographic conditions on the annual migration of Pacific whiting, *Merluccius productus.* CalCOFI Reports **36**: 97–105.

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

JTC, Joint Technical Committee. 2013. Status of the Pacific hake (whiting) stock in U.S. and Canadian Waters in 2013. Prepared for the Joint U.S.-Canada Pacific hake treaty process.

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

Stewart, J.S., Hazen, E., Bograd, S.J., Byrnes, J.E.K., Foley, D.G., Gilly, W.F., Robison, B.H. and Field, J.C. 2014. Combined climate- and prey-mediated range expansion of Humboldt squid (*Dosidicus gigas*), a large marine predator in the California Current System. Glob. Chang. Biol. **20**: 1832–1843.