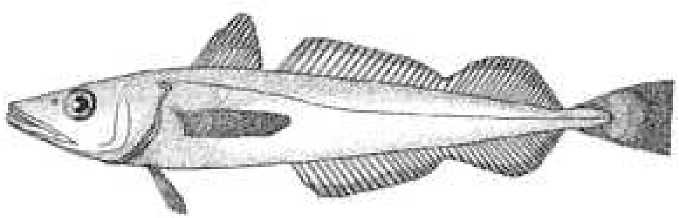
Agenda Item I.4
Supplemental Attachment 1
March 2017

Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2017



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

February 22, 2017

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

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APPENDICES

ONE-PAGE SUMMARY

- The stock assessment model for 2017 is similar in structure to the 2016 model. Updates to the data include the addition of fishery catch and age compositions from 2016, reanalyzed acoustic survey biomass and age compositions for 1995 (completing the reanalyzed acoustic survey time series initiated in the 2016 model), and other minor refinements such as catch estimates from earlier years.

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

- Coastwide catch in 2016 was 329,427 t, out of a TAC (adjusted for carryovers) of 497,500 t. Attainment in the U.S. was 70.7% of its quota; in Canada it was 53.7%. A variety of factors influenced the attainment of the quota.

- The stock is estimated to be at its highest biomass level since the 1980s as a result of estimated large 2010 and 2014 cohorts. The 2014 cohort has not yet been observed by the survey and only twice by the commercial fishery, thus its absolute size is highly uncertain.

- The median estimate of 2017 relative spawning biomass (spawning biomass at the start of 2017 divided by that at unfished equilibrium, B_0) is 89.2% but is highly uncertain (with 95% credible interval from 37.1% to 270.8%).

- The median estimate of 2017 female spawning biomass is 2.129 million t (with 95% credible interval from 0.763 to 7.445 million t).

- The spawning biomass in 2017 is estimated to have increased from 2016 due to the 2014 year-class likely being above average size.

- Based on the default harvest rule, the estimated median catch limit for 2017 is 969,840 t (with 95% credible interval from 293,697 to 3,710,305 t).

- As in the past, forecasts are highly uncertain due to uncertainty in estimates of recruitment for recent years. Forecasts were conducted across a range of catch levels.

- Projections setting the 2017 and 2018 catch equal to the 2016 TAC of 497,500 t show the estimated median relative spawning biomass decreasing from 89% in 2017 to 85% in 2018 and 79% in 2019. However, due to uncertainty there is an estimated 16% chance of the spawning biomass falling below 40% of B_0 in 2019. There is an estimated 63% chance of the spawning biomass declining from 2017 to 2018, and a 80% chance of it declining from 2018 to 2019 under this constant catch level.

EXECUTIVE SUMMARY

STOCK

This assessment reports the status of the coastal Pacific Hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the United States and Canada at the start of 2017. This stock exhibits seasonal migratory behavior, ranging from offshore and generally southern waters during the winter spawning season to coastal areas between northern California and northern British Columbia during the spring, summer and fall when the fishery is conducted. In years with warmer water the stock tends to move farther to the north during the summer. Older hake tend to migrate farther than younger fish in all years, with catches in the Canadian zone typically consisting of fish greater than four years old. Separate, and much smaller, populations of hake occurring in the major inlets of the northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California, are not included in this analysis.

CATCHES

Coast-wide fishery Pacific Hake landings averaged 226,439 t from 1966 to 2016, with a low of 89,930 t in 1980 and a peak of 363,135 t in 2005 (Figure a). Prior to 1966, total removals were negligible compared to the modern fishery. Over the early period, 1966–1990, most removals were from foreign or joint-venture fisheries. Over all years, the fishery in U.S. waters averaged 170,765 t, or 75.4% of the average total landings, while catch from Canadian waters averaged 55,824 t. Over the last 10 years, 2007–2016 (Table a), the average coastwide catch was 262,496 t

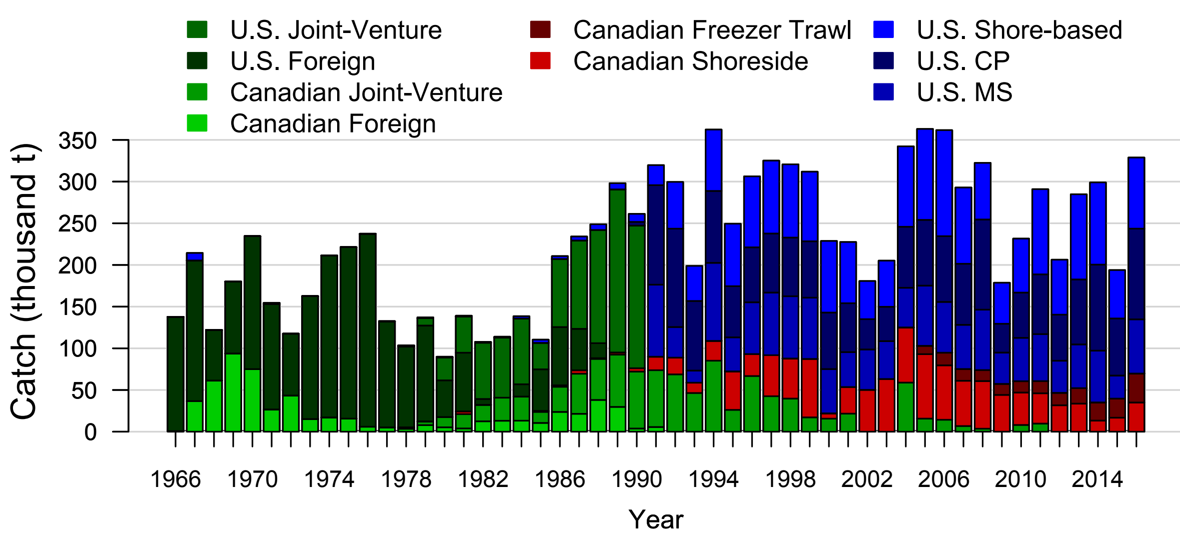

Figure a. Total Pacific Hake catch used in the assessment by sector, 1966–2016. U.S. tribal catches are included in the sectors where they are represented.

Table a. Recent commercial fishery catch (t). Tribal catches are included in the sector totals. Research catch includes landed catch associated with certain research-related activities. Catch associated with surveys and discarded bycatch in fisheries not targeting hake are not currently included in the model.

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	54,295	14,121	75,196	293,389
2008	72,440	108,195	67,861	0	248,496	3,592	57,117	13,214	73,924	321,802
2009	37,550	34,552	49,222	0	121,324	0	44,136	13,223	57,359	177,171
2010	52,022	54,284	64,736	0	171,043	8,081	38,907	13,573	60,562	230,755
2011	56,394	71,678	102,146	1,042	231,261	9,717	36,363	14,593	60,672	291,670
2012	38,512	55,264	65,919	448	160,144	0	31,699	14,909	46,608	205,787
2013	52,447	77,950	102,143	1,018	233,558	0	33,665	18,584	52,249	285,591
2014	62,102	103,203	98,640	197	264,141	0	13,326	21,787	35,113	298,705
2015	27,661	68,484	58,011	0	154,156	0	16,775	22,903	39,678	190,663
2016	65,035	108,786	85,293	572	259,687	0	35,012	34,729	69,741	329,427

with U.S. and Canadian catches averaging 206,149 t and 57,110 t, respectively. The coastwide catch in 2016 was 329,427 t, out of a total allowable catch (TAC, adjusted for carryovers) of 497,500 t. Attainment in the U.S. was 70.7% of its quota; in Canada it was 53.7%.

In this stock assessment, the terms catch and landings are used interchangeably. Estimates of discard within the target fishery are included, but discarding of Pacific Hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings in recent years. During the last five years, catches have been above the long-term average catch (226,439 t) in 2013, 2014 and 2016, and below it in 2012 and 2015. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal (through 2016) from that cohort estimated at approximately 1.28 million t. Through 2016, the total catch of the 2010 year class is estimated to be about 0.67 million t.

DATA AND ASSESSMENT

There was no survey in 2016. New data for this 2017 assessment, that were not in the 2016 assessment, are the 1995 survey biomass estimate (with associated age compositions) and the 2016 fishery catch and fishery age compositions. The mean weight at age for 2016 was added and minor refinements to historical catch estimates were also made. Finally, there was a minor revision to the 1998 survey biomass estimate (an increase of 2%). The 2016 assessment did not include the 1995 survey biomass estimate due to issues with the older survey data, but those issues have now been resolved. The revision to the 1998 point was due to discovery of a better set of variables used in the processing of the acoustic data for that year. Various other data types, including data on maturity, have been explored since the 2014 stock assessment, but are not included in the base model this year.

This Joint Technical Committee (JTC) assessment depends primarily on the fishery landings (1966–2016), acoustic survey biomass estimates (Figure b) and age-compositions (1995–2015), as well as fishery age-compositions (1975–2016). 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,

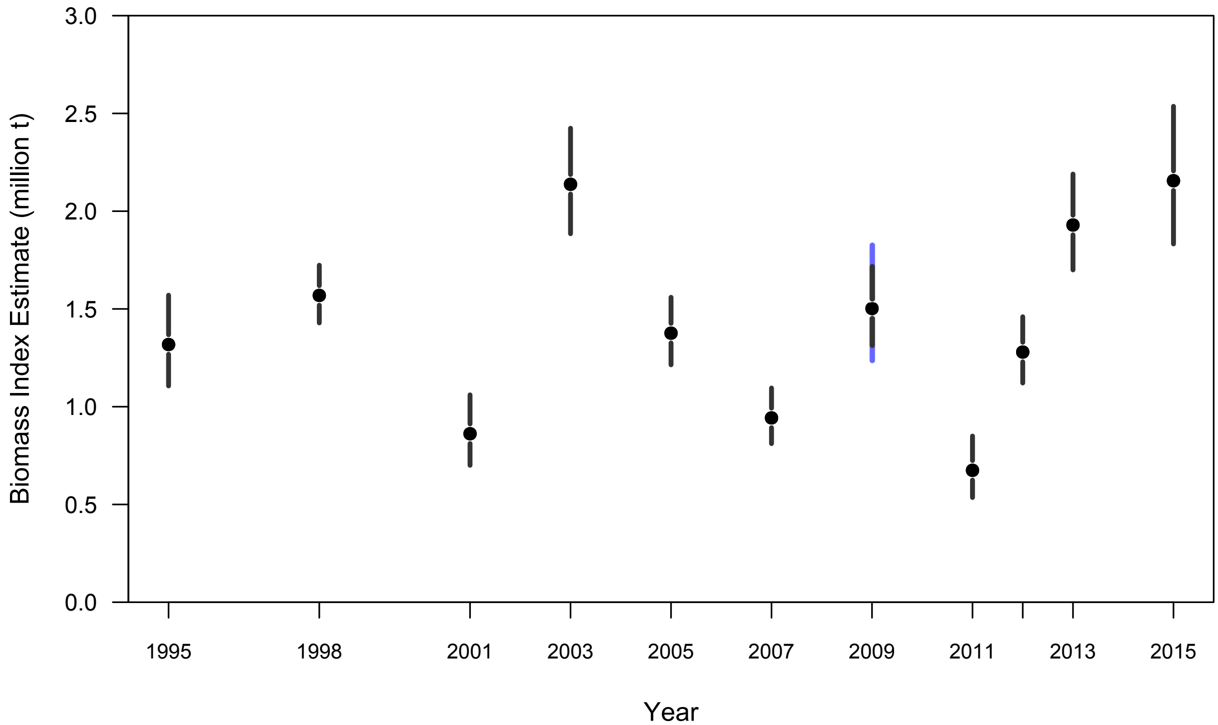

Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2015) in addition to squid/hake apportionment uncertainty (2009, in blue).

and 2015. Age-composition data from the aggregated fisheries and the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts.

The assessment uses a Bayesian estimation approach, sensitivity analyses, and retrospective investigations to evaluate the potential consequences of parameter uncertainty, alternative structural models, and historical performance of the assessment model, respectively. The Bayesian approach combines prior knowledge about natural mortality, stock-recruitment steepness (a parameter for stock productivity) and several other parameters, with likelihoods for acoustic survey biomass indices, acoustic survey age-composition data, and fishery age-composition data. Integrating the joint posterior distribution over model parameters (via the Markov Chain Monte Carlo algorithm) provides probabilistic inferences about uncertain model parameters and forecasts derived from those parameters. Sensitivity analyses are used to identify alternative structural models that may also be consistent with the data. Retrospective analyses identify possible poor performance of the assessment model with respect to future predictions. Past assessments have conducted closed-loop simulations which provide insights into how alternative combinations of survey frequency, assessment model selectivity assumptions, and harvest control rules affect expected management outcomes given repeated application of these procedures over the long-term. The results of past closed-loop simulations influence the decisions made for this assessment.

This 2017 assessment retains the structural form of the base assessment model from 2016 as well as

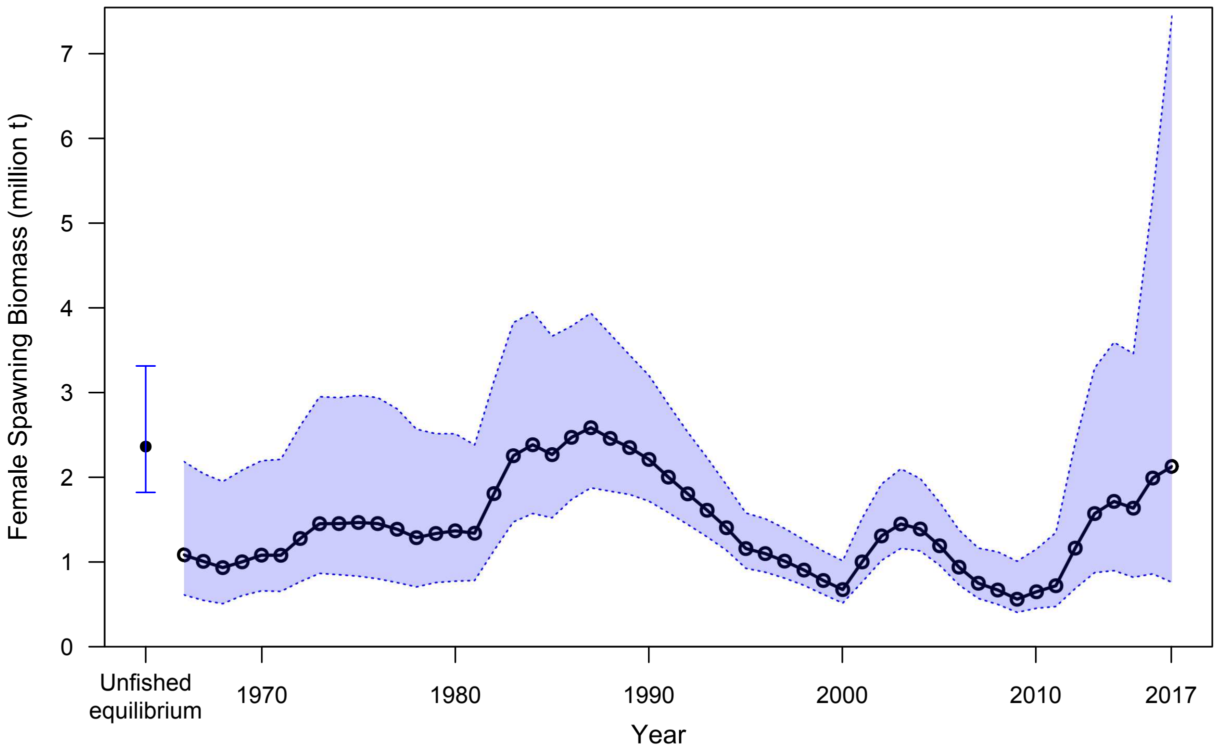

Figure c. Median of the posterior distribution for beginning of the year female spawning biomass through 2017 (solid line) with 95% posterior credibility intervals (shaded area). The solid circle with a 95% posterior credibility interval is the estimated unfished equilibrium biomass.

many of the previous elements as configured in Stock Synthesis (SS). Analyses conducted in 2014 showed that allowing for time-varying (rather than fixed) selectivity reduced the magnitude of extreme cohort strength estimates. In closed-loop simulations, management based upon assessment models allowing for 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 which force time-invariant fishery selectivity. Even a small degree of flexibility in the assessment model fishery selectivity could reduce the effects of errors caused by assuming selectivity is constant over time. Therefore, we retain time-varying selectivity in this assessment. The constraint on annual deviation in selectivity was loosened for this assessment, as the settings used in previous assessments resulted in an extremely large estimate of the 2014 year class without adequate basis (i.e., based upon quite limited data).

STOCK BIOMASS

The base stock assessment model indicates that since the 1960s, Pacific Hake female spawning biomass has ranged from well below to near unfished equilibrium (Figures c and d). The model estimates that it was below the unfished equilibrium in the 1960s, at the start of this assessment model, due to lower than average recruitment. The stock is estimated to have increased rapidly

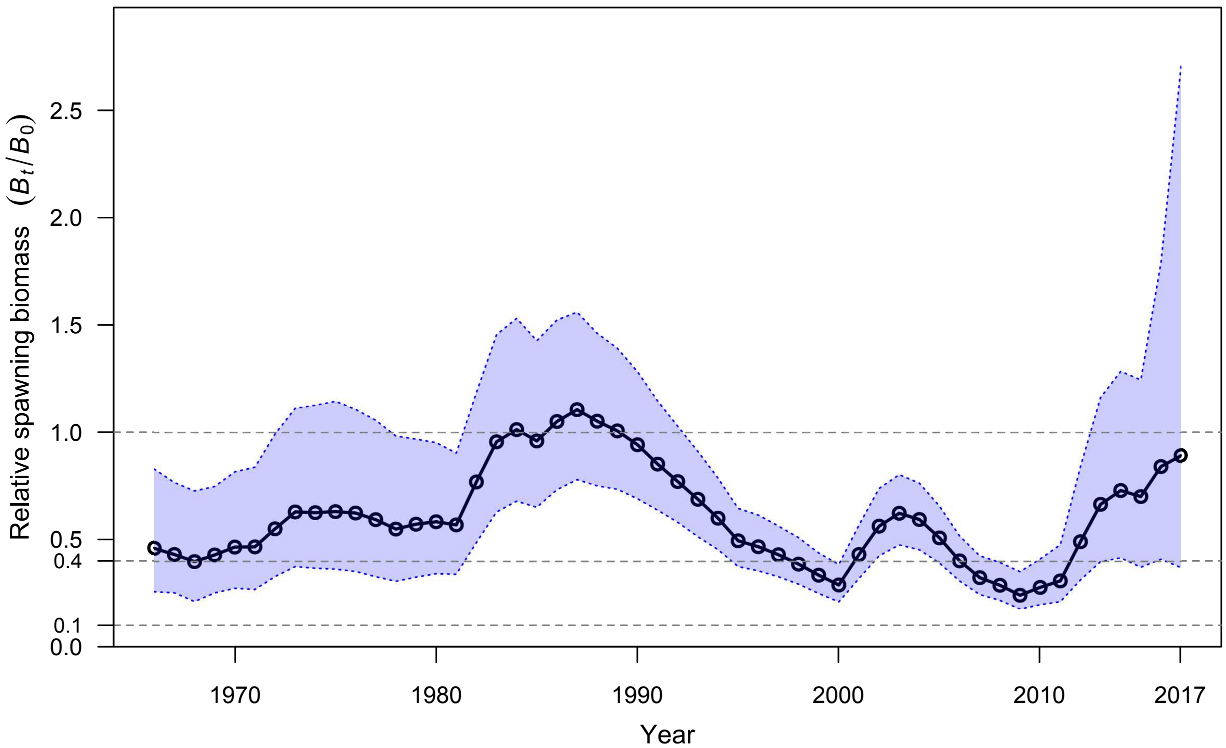

Figure d. Median (solid line) of the posterior distribution for relative spawning biomass (B_t/B_0) through 2017 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% levels.

to near unfished equilibrium after two or more large recruitments in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 as the large 1999 year class matured. The 1999 year class largely supported the fishery for several years due to relatively small recruitments between 2000 and 2007. With the aging 1999 year class, median female spawning biomass declined throughout the late 2000s, reaching a time-series low of 0.565 million t in 2009. The assessment model estimates that median spawning biomass declined from 2014 to 2015 after five years of increases from 2009 to 2014. These estimated increases were the result of a large 2010 cohort and an above-average 2008 cohort, and the recent decline is from the 2010 cohort surpassing the age at which gains in weight from growth are greater than the loss in weight from natural mortality. The model then estimates an increases from 2015 to 2017 due to the estimated large 2014 year class, which, on average, is similar to the average estimated size of the 2010 year class.

The median estimate of the 2017 relative spawning biomass (spawning biomass at the start of 2017 divided by that at unfished equilibrium, B_0) is 89.2% but is highly uncertain (with a 95% posterior credibility interval from 37.1% to 270.8%; Table b). The median estimate of the 2017 spawning biomass is 2.129 million t (with a 95% posterior credibility interval from 0.763 to 7.445 million t). The estimate of the 2016 female spawning biomass is 1.993 (0.864–5.307) million t. This is slightly higher than the 1.885 (0.791-4.781) million t estimated in the 2016 assessment.

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

Year	Spawning Biomass (thousand t)			Relative spawning biomass (B_t/B_0)		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2008	503.5	673.0	1,123.4	21.8%	28.9%	39.5%
2009	409.4	564.9	1,012.6	17.8%	24.2%	35.2%
2010	457.9	652.3	1,155.8	19.8%	27.9%	41.1%
2011	478.4	723.7	1,350.4	21.2%	30.9%	47.8%
2012	690.6	1,166.9	2,408.3	31.4%	49.2%	84.1%
2013	877.8	1,574.4	3,289.5	39.9%	66.6%	116.3%
2014	901.6	1,717.9	3,593.7	41.6%	73.0%	128.5%
2015	823.1	1,638.2	3,460.7	37.3%	70.2%	124.5%
2016	863.6	1,993.3	5,307.3	41.0%	84.2%	179.1%
2017	762.7	2,129.1	7,444.8	37.1%	89.2%	270.8%

Table c. Estimates of recent recruitment (millions of age-0) and recruitment deviations, where deviations below (above) zero indicate recruitment below (above) that estimated from the stock-recruit relationship.

Year	Absolute recruitment (millions)			Recruitment deviations		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2007	9.7	54.1	232.9	-4.547	-2.993	-1.684
2008	3,548.9	5,556.3	11,520.1	1.383	1.707	2.085
2009	517.0	1,212.8	3,272.3	-0.515	0.207	0.896
2010	8,397.7	15,807.7	36,920.2	2.273	2.755	3.230
2011	101.9	439.4	1,733.4	-2.223	-0.859	0.298
2012	594.7	1,722.0	5,692.2	-0.518	0.422	1.404
2013	53.4	402.3	2,114.8	-2.920	-1.098	0.451
2014	2,184.1	12,104.6	90,734.9	0.744	2.331	4.171
2015	51.4	733.4	11,789.4	-2.917	-0.442	2.196
2016	89.9	1,269.0	18,995.9	-2.563	0.047	2.812

RECRUITMENT

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

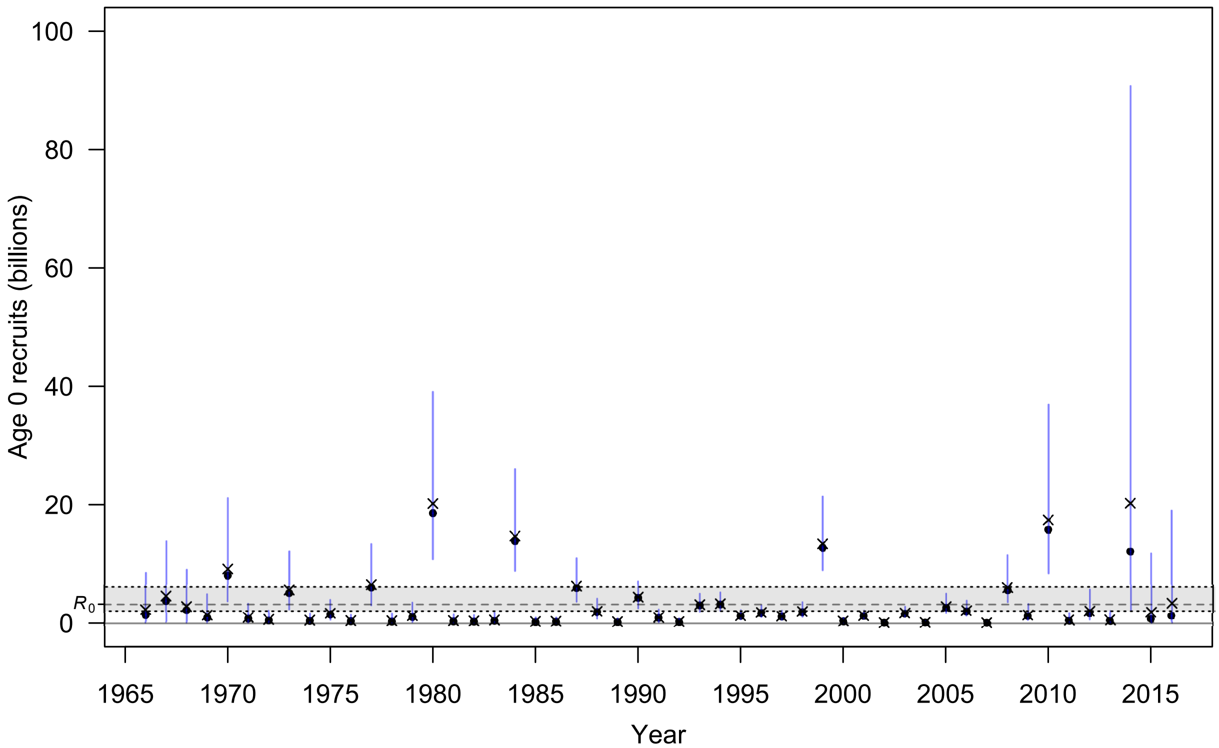

Figure e. Medians (solid circles) and means (×) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (blue lines). The median of the posterior distribution for mean unfished equilibrium recruitment (R_0) is shown as the horizontal dashed line with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

class comprising 70% of the coast-wide commercial catch in 2013, 64% of the 2014 catch, 71% of the 2015 catch and 37% of the 2016 catch. The smaller proportion of the 2010 year class in the 2016 catch is due to the large influx of the 2014 year class (47% of the 2016 catch was age-2 fish from the 2014 year class, which was similar to the proportion of age-2 fish, 41%, from the 2010 year class in 2012). The size of the 2010 year class is more uncertain than older cohorts but the median estimate is the second highest in the time series (after that for 1980). The model currently estimates smaller-than-average 2011, 2012 and 2013 year classes (median recruitment below the mean of all median recruitments). The 2014 year class is likely larger than average and potentially a similar magnitude as the 2010 year class, but is still highly uncertain. There is no information in the data to estimate the sizes of the 2016 and 2017 year classes. Retrospective analyses of year class strength for young fish have shown the estimates of recent recruitment to be unreliable prior to model age-3 (observed at age-2).

DEFAULT HARVEST POLICY

The default $F_{\text{SPR}=40\%}$–40:10 harvest policy prescribes the maximum rate of fishing mortality to equal $F_{\text{SPR}=40\%}$. This rate gives a spawning potential ratio (SPR) of 40%, meaning that the spawning biomass per recruit with $F_{\text{SPR}=40\%}$ is 40% of that without fishing. If spawning biomass is below

Table d. Recent estimates of relative fishing intensity, (1-SPR)/(1-SPR$_{40\%}$), and exploitation fraction (catch divided by age-3+ biomass).

Year	Relative fishing intensity			Exploitation fraction		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2007	0.649	0.952	1.338	0.138	0.222	0.284
2008	0.693	0.995	1.300	0.133	0.226	0.299
2009	0.518	0.811	1.113	0.078	0.140	0.191
2010	0.621	0.959	1.397	0.123	0.226	0.328
2011	0.526	0.883	1.298	0.092	0.183	0.270
2012	0.367	0.690	1.042	0.072	0.144	0.236
2013	0.350	0.666	0.941	0.034	0.072	0.129
2014	0.327	0.661	1.001	0.037	0.079	0.150
2015	0.197	0.450	0.810	0.029	0.061	0.123
2016	0.344	0.688	1.267	0.065	0.139	0.295

$B_{40\%}$ (40% of B_0), the policy reduces the TAC linearly until it equals zero at $B_{10\%}$ (10% of B_0). Relative fishing intensity for fishing rate F is $(1-\mathrm{SPR}(F))/(1-\mathrm{SPR}_{40\%})$, where SPR$_{40\%}$ is the target SPR of 40%.

EXPLOITATION STATUS

Median relative fishing intensity on the stock is estimated to have been below the target of 1.0 except for the year 1999 when spawning biomass was low (Table d (for recent years) and Figure f). Median exploitation fraction (catch divided by biomass of fish of age 3 and above) also peaked in 1999, and then reached even higher values in 2007, 2008 and 2010 (Table d and Figure g). Median relative fishing intensity is estimated to have declined from 95.9% in 2010 to 68.8% in 2016, while the exploitation fraction has decreased from 0.23 in 2010 to 0.14 in 2016. There is a considerable amount of uncertainty around estimates of relative fishing intensity, with the 95% posterior credibility interval reaching above the SPR management target for 2016 (Figure f).

MANAGEMENT PERFORMANCE

Over the last decade (2007–2016), the mean coast-wide utilization rate (i.e., landings/quota) has been 77.5% (Table e). Over the last five years (2012 to 2016), the mean utilization rates differed between the United States (74.9%) and Canada (49.1%). Total landings last exceeded the coast-wide quota in 2002 when utilization was 112%.

The median relative fishing intensity was below target in all years except 1999 (Figure f). The median female spawning biomass was above the $B_{40\%}$ reference point in all years except 1968, 1998-2000 and 2007-2011 (Figure d).

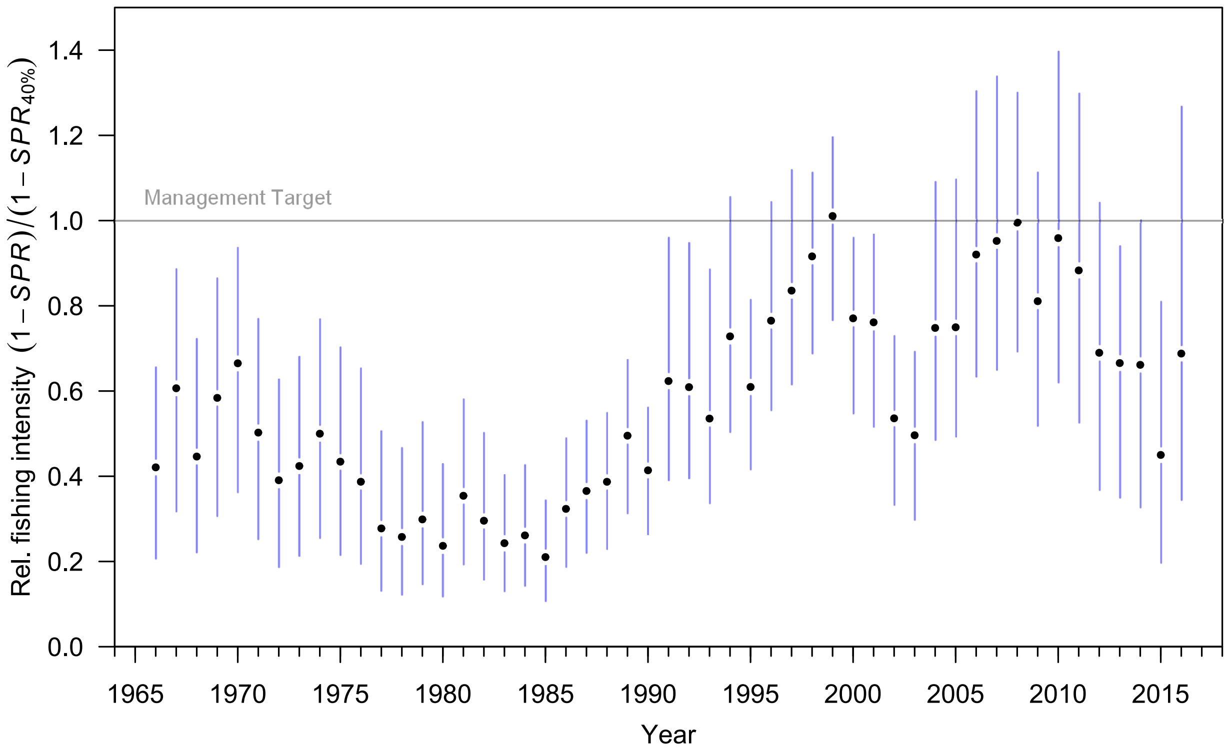

Figure f. Trend in median relative fishing intensity (relative to the SPR management target) through 2016 with 95% posterior credibility intervals. The management target defined in the Agreement is shown as a horizontal line at 1.0.

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

Year	US landings (t)	Canadian landings (t)	Total landings (t)	Coast-wide (US+Canada) catch target (t)	US catch target (t)	Canada catch target (t)	US proportion of catch target removed	Canada proportion of catch target removed	Total proportion of catch target removed
2007	217,682	75,196	293,389	328,358	242,591	85,767	89.7%	87.7%	89.4%
2008	248,496	73,924	321,802	364,842	269,545	95,297	92.2%	77.6%	88.2%
2009	121,324	57,359	177,171	184,000	135,939	48,061	89.2%	119.3%	96.3%
2010	171,043	60,562	230,755	262,500	193,935	68,565	88.2%	88.3%	87.9%
2011	231,261	60,672	291,670	393,751	290,903	102,848	79.5%	59.0%	74.1%
2012	160,144	46,608	205,787	251,809	186,036	65,773	86.1%	70.9%	81.7%
2013	233,558	52,249	285,591	365,112	269,745	95,367	86.6%	54.8%	78.2%
2014	264,141	35,113	298,705	428,000	316,206	111,794	83.5%	31.4%	69.8%
2015	154,156	39,678	190,663	440,000	325,072	114,928	47.4%	34.5%	43.3%
2016	259,687	69,741	329,427	497,500	367,553	129,947	70.7%	53.7%	66.2%

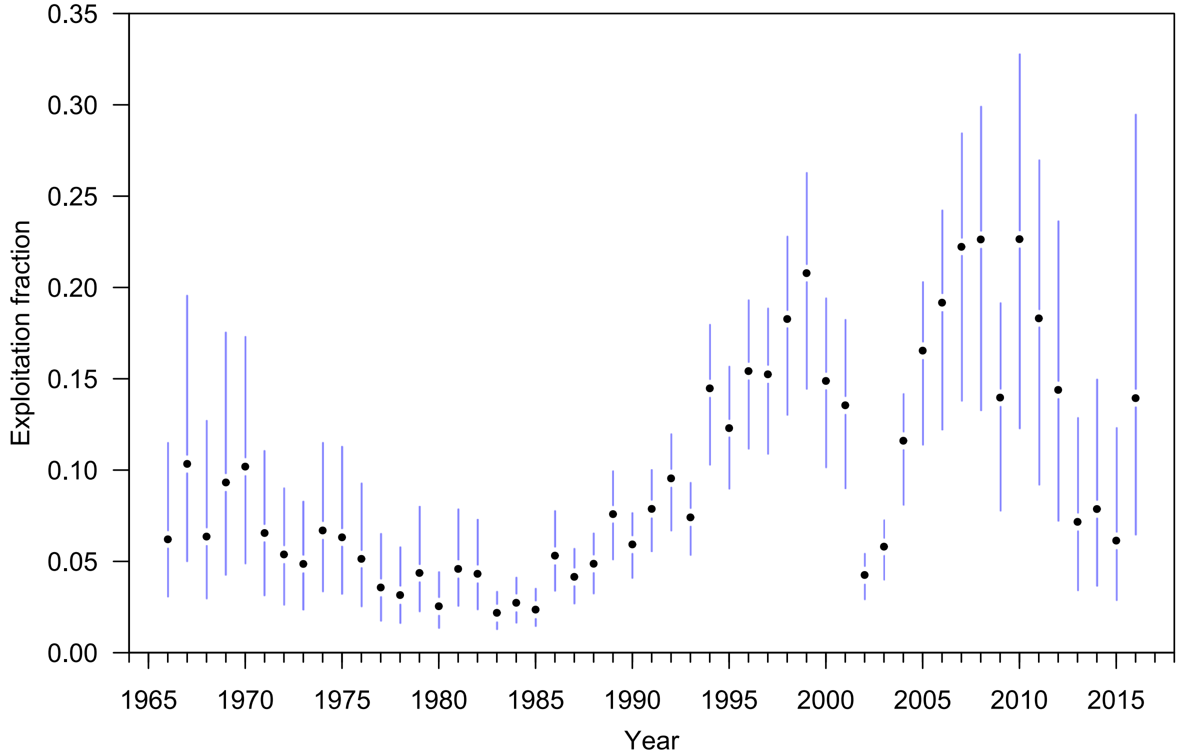

Figure g. Trend in median exploitation fraction (catch divided by age-3+ biomass) through 2016 with 95% posterior credibility intervals.

The joint history of the medians of relative spawning biomass and relative fishing intensity shows that only in 1999 was the median relative fishing intensity above the target of 1.0 and the female spawning biomass below the reference point of $B_{40\%}$ (Figure h). Between 2007 and 2011, however, median relative fishing intensity ranged from 81% to 100% and median relative spawning biomass between 0.24 and 0.32. Biomass has risen recently with the 2008, 2010 and 2014 recruitments, and median relative spawning biomass has been above the reference point of 40% since 2012.

While there is large uncertainty in the 2016 estimates of relative fishing intensity and relative spawning biomass, the model predicts a less than 4% joint probability of being both above the target relative fishing intensity in 2016 and below the $B_{40\%}$ relative spawning biomass level at the start of 2017.

REFERENCE POINTS

Estimates of the 2017 base model reference points with posterior credibility intervals are in Table f. The estimates are slightly different than those in the 2016 assessment, with slightly lower sustainable yields and reference biomasses estimated in this assessment.

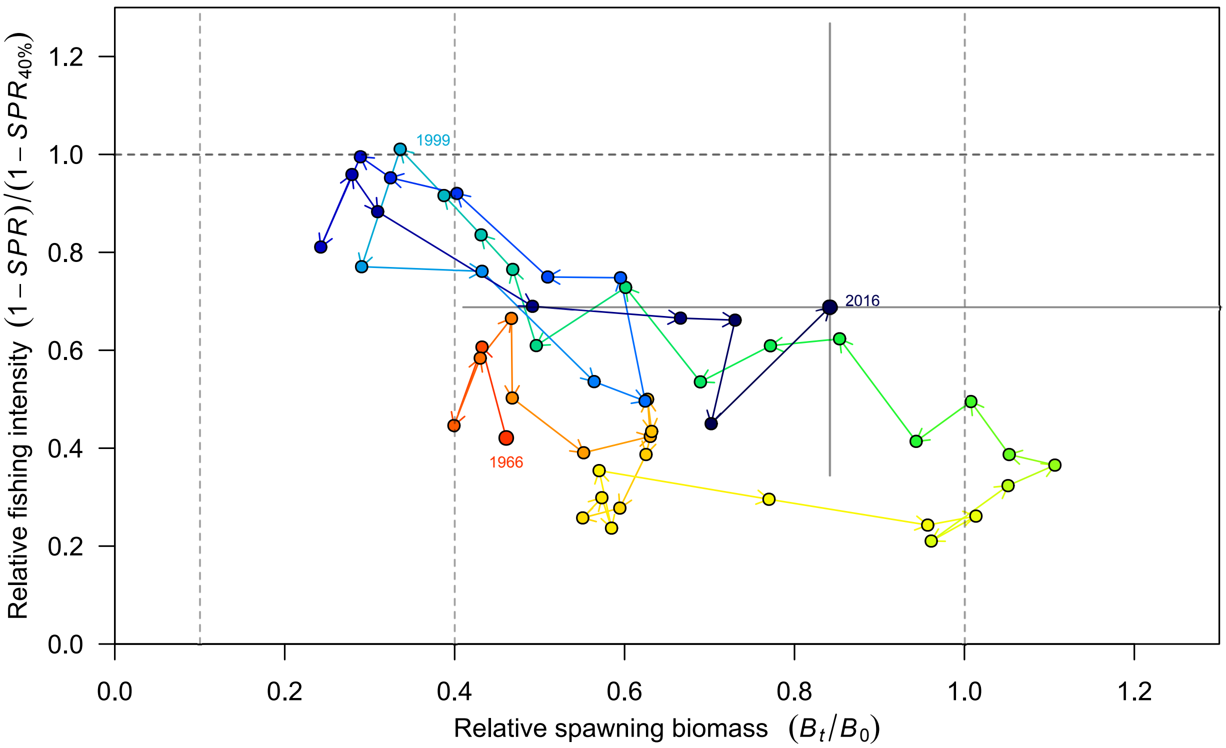

Figure h. Estimated historical path followed by medians of relative fishing intensity and relative spawning biomass for Pacific Hake with labels on the start and end years (and 1999). Gray bars span the 95% credibility intervals for 2016 relative fishing intensity (vertical) and relative spawning biomass (horizontal).

UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

Uncertainty measures in the base model underestimate the total uncertainty in the current stock status and projections because they do not account for possible alternative structural models for hake population dynamics and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distributions. To address structural uncertainties, the JTC investigated a range of alternative models, and we present a subset of key sensitivity analyses in the main document.

The Pacific Hake stock displays a very high recruitment variability relative to other west coast groundfish stocks, resulting in large and rapid biomass changes. This leads to a dynamic fishery that potentially targets strong cohorts resulting in time-varying fishery selectivity. This volatility results in a high level of uncertainty in estimates of current stock status and stock projections because, with limited data to estimate incoming recruitment, the cohorts are fished before the assessment can accurately determine how big the cohort is (i.e., cohort strength is not well known until it is at least age-3). This is particularly apparent for this assessment, because the 2014 cohort is potentially very large but is still highly uncertain (Figure e).

The JTC presented results from closed-loop simulations evaluating the effect of including potential age-1 indices on management outcomes at a 2015 Joint Management Committee (JMC) meeting

Table f. Summary of median and 95% credibility intervals of equilibrium reference points for the Pacific Hake base assessment model. Equilibrium reference points were computed using 1966–2016 averages for mean size-at-age and selectivity-at-age.

Quantity	**2.5th percentile**	**Median**	**97.5th percentile**
Unfished female spawning biomass (B_0, thousand t)	1,822	2,362	3,314
Unfished recruitment (R_0, millions)	2,054	3,170	6,121
Reference points (equilibrium) based on $F_{\text{SPR}=40\%}$			
Female spawning biomass at $F_{\text{SPR}=40\%}$ (thousand t)	624	836	1,152
SPR at $F_{\text{SPR}=40\%}$	–	40%	–
Exploitation fraction corresponding to $F_{\text{SPR}=40\%}$	18.9%	22.2%	27.0%
Yield associated with $F_{\text{SPR}=40\%}$ (thousand t)	260	380	590
Reference points (equilibrium) based on $B_{40\%}$ (40% of B_0)			
Female spawning biomass ($B_{40\%}$, thousand t)	729	945	1,326
SPR at $B_{40\%}$	40.9%	43.4%	50.9%
Exploitation fraction resulting in $B_{40\%}$	14.7%	19.4%	24.0%
Yield at $B_{40\%}$ (thousand t)	263	371	577
Reference points (equilibrium) based on estimated MSY			
Female spawning biomass (B_{MSY}, thousand t)	393	594	997
SPR at MSY	20.1%	29.5%	46.2%
Exploitation fraction corresponding to SPR at MSY	17.9%	33.1%	56.4%
MSY (thousand t)	275	400	645

in Victoria, B.C. We found that fitting to an unbiased age-1 survey results in lower catch, lower probability that spawning biomass falls below 10% of B_0, and a lower average annual variability in catch. However, comparable results in terms of catch could be achieved with a more precise age-2+ survey or alternative harvest control rules. The simulations assumed an age-1 survey design with consistent, effective, and numerous sampling, which may not be the case for the existing age-1 index. The age-1 index is not included in the base model but included in a sensitivity run.

FORECAST DECISION TABLES

The catch limit for 2017 based on the default $F_{\text{SPR}=40\%}$–40:10 harvest policy has a median of 969,840 t with a wide range of uncertainty, the 2.5% to 97.5% range being 293,697–3,710,305 t.

Decision tables give the projected population status (relative spawning biomass) and the relative fishing intensity under different catch alternatives for the base model (Tables g and h). The tables are organized such that the projected outcome for each potential catch level and year (each row) can be evaluated across the quantiles (columns) of the posterior distribution. Table g shows projected relative spawning biomass outcomes and Table h shows projected fishing intensity outcomes relative to the target fishing intensity (based on SPR; see table legend). Figure i shows the projected biomass for several catch alternatives.

Relative fishing intensity exceeding 100% indicates fishing in excess of the $F_{\text{SPR}=40\%}$ default har-

Table g. Forecast quantiles of Pacific Hake relative spawning biomass at the beginning of the year before fishing. Catch alternatives are based on: constant catch levels (rows a, b, c, d, e), including the TAC from 2016 (row d), the catch values that result in a median relative fishing intensity of 100% (row f), the median values estimated via the default harvest policy ($F_{\text{SPR}=40\%}$–40:10) for the base model (row g), and the fishing intensity that results in a 50% probability that the median projected catch will remain the same in 2017 and 2018 (row h). Row e uses 600,000 t rather than the 500,000 t from last year's assessment, because 500,000 t is essentially row d. Catch in 2019 does not impact the beginning of the year biomass in 2019.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year relative spawning biomass**				
	Year	Catch (t)					
a:	2017	0	41%	65%	89%	120%	224%
	2018	0	43%	70%	95%	135%	264%
	2019	0	46%	72%	99%	141%	276%
b:	2017	180,000	41%	65%	89%	120%	224%
	2018	180,000	39%	66%	91%	131%	261%
	2019	180,000	38%	65%	92%	134%	269%
c:	2017	350,000	41%	65%	89%	120%	224%
	2018	350,000	35%	62%	87%	127%	257%
	2019	350,000	30%	58%	85%	127%	261%
d:	2017	497,500	41%	65%	89%	120%	224%
2016	2018	497,500	32%	59%	85%	124%	254%
TAC	2019	497,500	24%	51%	79%	121%	256%
e:	2017	600,000	41%	65%	89%	120%	224%
	2018	600,000	30%	57%	82%	122%	252%
	2019	600,000	20%	47%	74%	117%	253%
f:	2017	934,000	41%	65%	89%	120%	224%
FI=	2018	848,000	23%	49%	76%	115%	246%
100%	2019	698,000	12%	35%	63%	105%	244%
g:	2017	969,840	41%	65%	89%	120%	224%
default	2018	843,566	22%	48%	75%	115%	245%
HR	2019	679,881	12%	34%	63%	104%	244%
h:	2017	866,263	41%	65%	89%	120%	224%
C2017=	2018	866,263	24%	51%	77%	117%	247%
C2018	2019	683,014	13%	36%	64%	106%	245%

Table h. Forecast quantiles of Pacific Hake relative fishing intensity (1-SPR)/(1-$SPR_{40\%}$) for the 2017–2019 catch alternatives presented in Table g. Values greater than 100% indicate relative fishing intensities greater than the $F_{SPR=40\%}$ harvest policy calculated using baseline selectivity.

Within model quantile			5%	25%	50%	75%	95%
Management Action			Relative fishing intensity				
	Year	Catch (t)					
a:	2017	0	0%	0%	0%	0%	0%
	2018	0	0%	0%	0%	0%	0%
	2019	0	0%	0%	0%	0%	0%
b:	2017	180,000	14%	25%	35%	47%	68%
	2018	180,000	11%	23%	33%	46%	68%
	2019	180,000	11%	23%	33%	47%	70%
c:	2017	350,000	26%	43%	58%	74%	97%
	2018	350,000	21%	40%	56%	75%	103%
	2019	350,000	21%	42%	58%	79%	110%
d:	2017	497,500	35%	55%	72%	89%	112%
2016	2018	497,500	29%	53%	72%	94%	122%
TAC	2019	497,500	29%	57%	76%	100%	131%
e:	2017	600,000	40%	63%	80%	98%	120%
	2018	600,000	34%	61%	81%	104%	131%
	2019	600,000	34%	65%	86%	112%	138%
f:	2017	934,000	56%	82%	100%	116%	135%
FI=	2018	848,000	45%	78%	100%	123%	141%
100%	2019	698,000	40%	76%	100%	127%	141%
g:	2017	969,840	57%	84%	102%	118%	136%
default	2018	843,566	45%	78%	100%	124%	141%
HR	2019	679,881	40%	75%	99%	127%	141%
h:	2017	866,263	53%	78%	97%	113%	133%
C2017=	2018	866,263	46%	79%	100%	123%	141%
C2018	2019	683,014	39%	75%	98%	126%	141%

vest rate catch limit. This can happen for the median relative fishing intensity in projected years because the $F_{SPR=40\%}$ default harvest-rate catch limit is calculated using baseline selectivity from all years, whereas the forecasted catches are removed using selectivity averaged over the last five years. Recent changes in selectivity will thus be reflected in the determination of fishing in excess of the default harvest policy. Alternative catch levels where median relative fishing intensity is 100% for three years of projections are provided for comparison (scenario f: FI=100%).

Management metrics that were identified as important to the JMC and the Advisory Panel (AP) in 2012 are presented for projections to 2018 and 2019 (Tables i and j and Figures j and k). These metrics summarize the probability of various outcomes from the base model given each potential management action. Although not linear, probabilities can be interpolated from these results for intermediate catch values. Figure i shows the predicted relative spawning biomass trajectory through 2019 for several of these management actions. With zero catch for the next two years, the biomass has a 17% probability of decreasing from 2017 to 2018, and a 39% probability

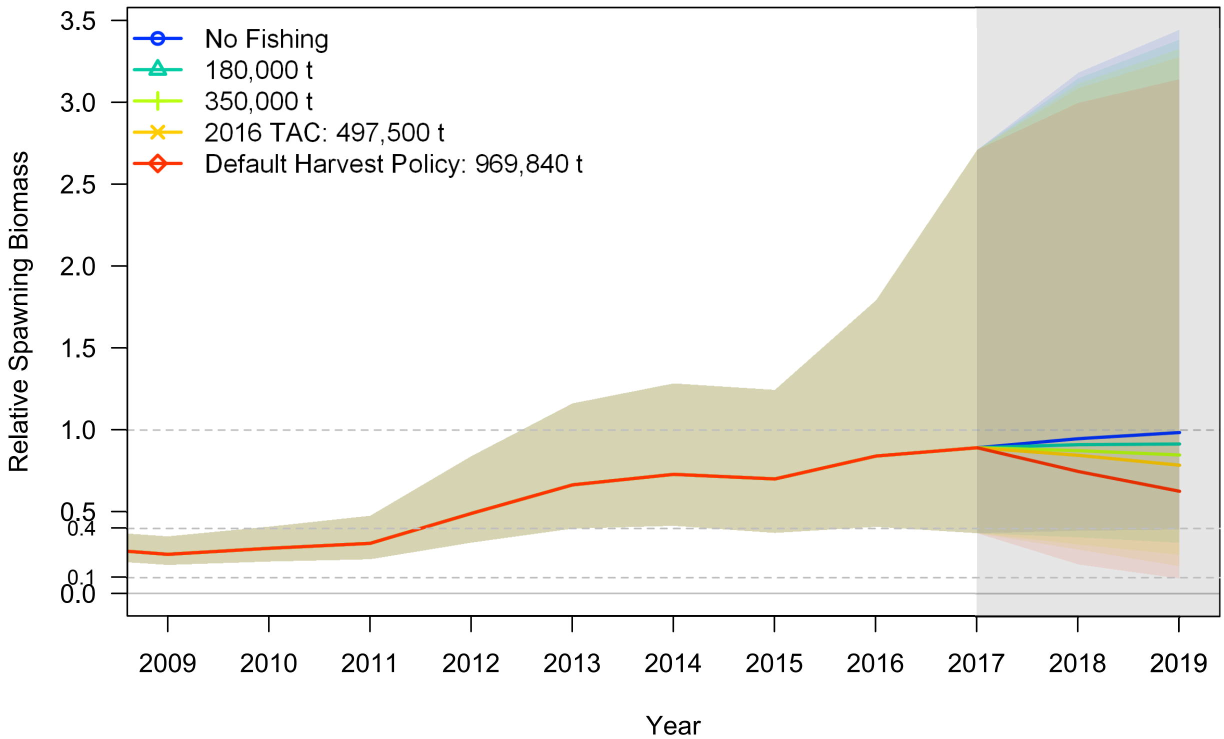

Figure i. Time series of estimated relative spawning biomass to 2017 from the base model, and forecast trajectories to 2019 for several management actions defined in Table g (grey region), with 95% posterior credibility intervals.

Table i. Probabilities related to spawning biomass, relative fishing intensity, and the 2018 default harvest policy catch for alternative 2017 catch options (catch options explained in Table g).

Catch in 2017	Probability $B_{2018}<B_{2017}$	Probability $B_{2018}<B_{40\%}$	Probability $B_{2018}<B_{25\%}$	Probability $B_{2018}<B_{10\%}$	Probability 2017 relative fishing intensity >100%	Probability 2018 default harvest policy catch <2017 catch
a: 0	17%	3%	0%	0%	0%	0%
b: 180,000	37%	6%	1%	0%	0%	1%
c: 350,000	51%	7%	1%	0%	4%	6%
d: 497,500	63%	9%	2%	0%	15%	18%
e: 600,000	67%	11%	3%	0%	23%	27%
f: 934,000	80%	18%	7%	0%	50%	55%
g: 969,840	82%	18%	7%	0%	52%	57%
h: 866,263	78%	17%	6%	0%	44%	50%

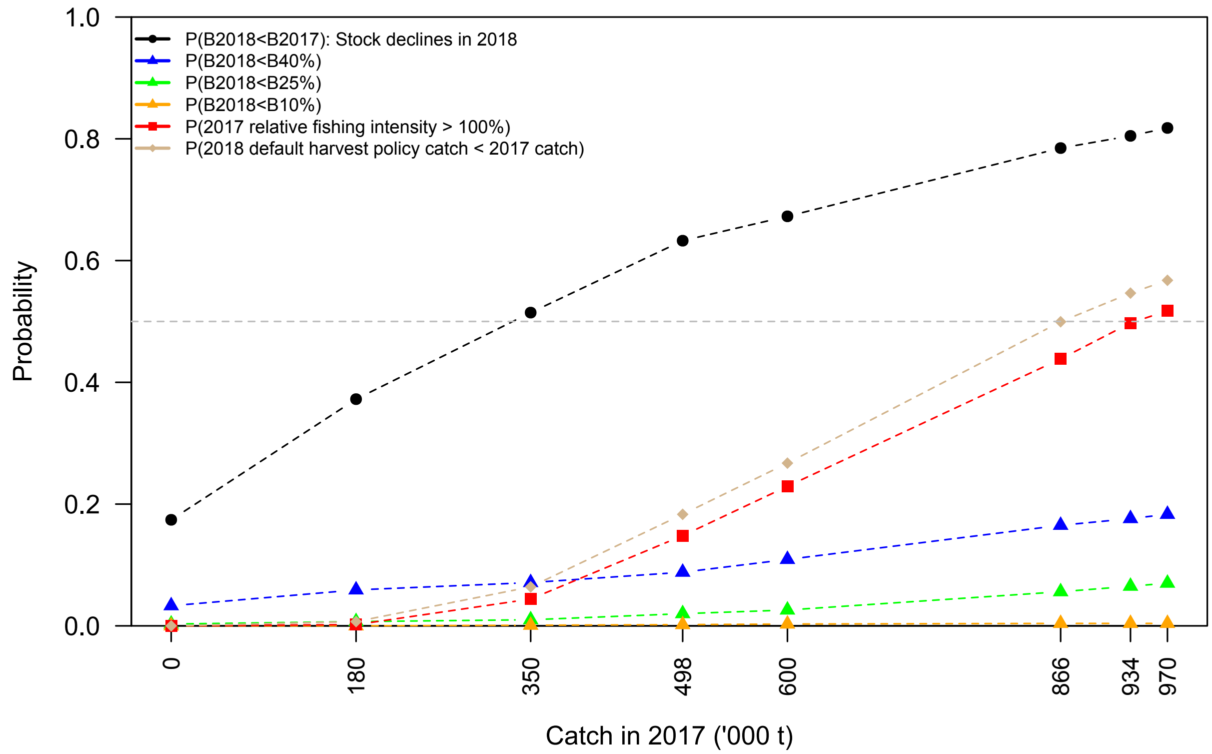

Figure j. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2018 default harvest policy catch for alternative 2017 catch options (catch options explained in Table g) as listed in Table i. The symbols indicate points that were computed directly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

of decreasing from 2018 to 2019

The probability of the spawning biomass decreasing from 2017 to 2018 is less than 50% for only the 0 t and 180,000 t catch levels (Table i and Figure j). The highest probability of decrease is 82%, which is for the default harvest policy. The predicted probability of the spawning biomass dropping below $B_{10\%}$ at the start of 2018 is less than 1% and the maximum probability of dropping below $B_{40\%}$ is 18% for all catches explored (Table i and Figure j). It should be noted that the natural mortality rate is larger than the current and future growth rate for the large 2010 year class. The model estimated below-average recruitment for the 2011, 2012 and 2013 cohorts, but a potentially large 2014 cohort that will result in increases to the spawning biomass as it continues to mature.

RESEARCH AND DATA NEEDS

There are many research projects that could improve the stock assessment for Pacific Hake and lead to improved biological understanding and decision-making. The top three are:

1. Investigate links between hake biomass, its spatial distribution and how these dynamics vary with ocean conditions and ecosystem variables such as temperature and prey availability.

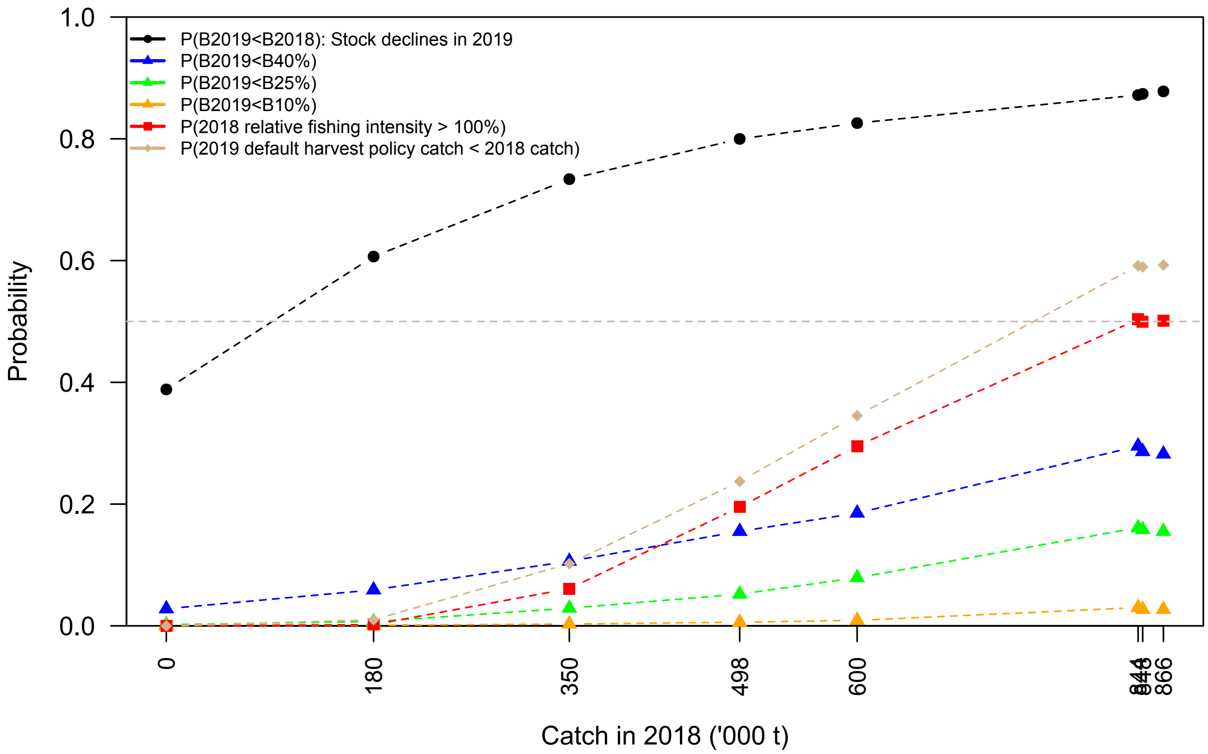

Figure k. Graphical representation of the probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options (including associated 2017 catch; catch options explained in Table g) as listed in Table j. The symbols indicate points that were computed directly from model output and lines interpolate between the points.

Table j. Probabilities related to spawning biomass, relative fishing intensity, and the 2019 default harvest policy catch for alternative 2018 catch options, given the 2017 catch level shown in Table i (catch options explained in Table g).

Catch in 2018	Probability $B_{2019}<B_{2018}$	Probability $B_{2019}<B_{40\%}$	Probability $B_{2019}<B_{25\%}$	Probability $B_{2019}<B_{10\%}$	Probability 2018 relative fishing intensity >100%	Probability 2019 default harvest policy catch <2018 catch
a: 0	39%	3%	0%	0%	0%	0%
b: 180,000	61%	6%	1%	0%	0%	1%
c: 350,000	73%	11%	3%	0%	6%	10%
d: 497,500	80%	16%	5%	1%	20%	24%
e: 600,000	83%	19%	8%	1%	30%	35%
f: 848,000	87%	29%	16%	3%	50%	59%
g: 843,566	87%	30%	16%	3%	50%	59%
h: 866,263	88%	28%	16%	3%	50%	59%

These investigations have the potential to improve the scenarios considered in future management strategy evaluation (MSE) work as well as providing a better basic understanding of drivers of hake population dynamics and availability to fisheries and surveys.

2. Continue development of the MSE tools to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them. Incorporate the feedback from JMC/AP/SRG/MSE Advisory Panels into operating model development. Specifically, make sure that the operating model is able to provide insight into the important questions defined by these groups. If a spatially, seasonally explicit operating model is needed, then research should focus on how best to model these dynamics in order to capture seasonal effects and potential climate forcing influences in the simulations (see item 1). Investigate the impact of making incorrect assumptions about the underlying recruitment process. Continue to coordinate our MSE research with other scientists in the region engaging in similar research.

3. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength, directionality of survey and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods. Apply bootstrapping methods to the acoustic survey time-series to incorporate more of the relevant uncertainties into the survey variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others. Continue to work with acousticians and survey personnel from the NWFSC, the SWFSC, and DFO to determine an optimal design for the Joint U.S./Canada acoustic survey. Develop automation and methods to allow for the availability of biomass and age composition estimates to the JTC in a timely manner after a survey is completed.