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Stock Assessment of Pacific Hake (Whiting) in U.S. and Canadian Waters in 2006

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Executive Summary

Stock

This assessment reports the status of the coastal Pacific hake (*Merluccius productus*) resource off the west coast of the United States and Canada. The coastal stock of Pacific hake is currently the most abundant groundfish population in the California Current system. Smaller populations of hake occur in the major inlets of the north Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California. However, the coastal stock is distinguished from the inshore populations by larger body size, seasonal migratory behavior, and a pattern of low median recruitment punctuated by extremely large year classes. The population is modeled as a single stock, but the United States and Canadian fishing fleets are treated separately in order to capture some of the spatial variability in Pacific hake distribution.

Catches

Fishery landings from 1966 to 2005 have averaged 214 thousand mt, with a low of 90 thousand mt in 1980 and a peak harvest of 362 thousand mt in 1994. Recent landings have been above the long term average, at 335 thousand mt in 2004, and 360 thousand mt in 2005. Catches in both of these years were predominately comprised by the large 1999 year class. The United States has averaged 159 thousand mt, or 74.6% of the total landings over the time series, with Canadian catch averaging 54 thousand mt. The 2004 and 2005 landings had similar distributions, with 62.9 and 72.1%, respectively, harvested by the United States fishery. The current model assumes no discarding mortality of pacific hake.

Table a. Recent commercial fishery landings (1000s mt).

Year	US at-sea	US shore based	US tribal	US total	Canadian foreign and JV	Canadian shore based	Canadian total	Total
1996	113	85	15	213	67	26	93	306
1997	121	87	25	233	43	49	92	325
1998	120	88	25	233	40	48	88	321
1999	115	83	26	225	17	70	87	312
2000	116	86	7	208	16	6	22	231
2001	102	73	7	182	22	32	54	236
2002	63	46	23	132	0	51	51	183
2003	67	55	21	143	0	62	62	206
2004	90	96	24	210	59	65	124	335
2005	150	86	24	260	15	85	100	360

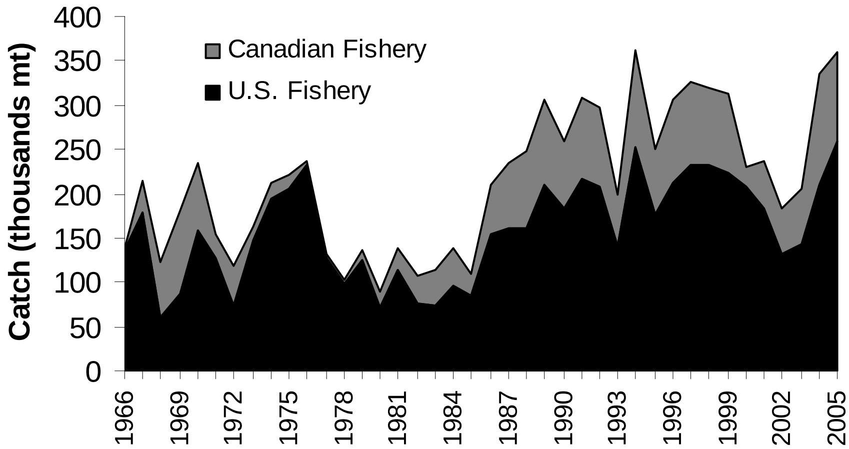


Figure a. Pacific whiting landings (1000s mt) by nation, 1966-2005.

Data and assessment

Age-structured assessment models of various forms have been used to assess Pacific hake since the early 1980's, using total fishery catches, fishery age compositions and abundance indices. In 1989, the hake population was modeled using a statistical catch-at-age model (Stock Synthesis) that utilizes fishery catch-at-age data and survey estimates of population biomass and age-composition data (Dorn and Methot, 1991). The model was then converted to AD Model Builder (ADMB) in 1999 by Dorn (1999), using the same basic population dynamics equations. This allowed the assessment to take advantage of ADMB's post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest. Since 2001, Helser et al. (2001, 2003, 2004) have used the same ADMB modeling platform to assess the hake stock and examine important assessment modifications and assumptions, including the time varying nature of the acoustic survey selectivity and catchability. The acoustic survey catchability coefficient (q) has been, and continues to be, one of the major sources of uncertainty in the model. Due to the lengthened acoustic survey biomass trends the assessment model was able to freely estimate the acoustic survey q. These estimates were substantially below the assumed value of q=1.0 from earlier assessments. The 2003 and 2004 assessment presented uncertainty in the final model result as a range of biomass. The lower end of the biomass range was based upon the conventional assumption that the acoustic survey q was equal to 1.0, while the higher end of the range represented a q=0.6 assumption.

This year's assessment used the Stock Synthesis modeling framework (SS2 Version 1.21, December, 2006) which was written by Dr. Richard Methot (Northwest Fisheries Science Center) in AD Model Builder. Conversion of the previous hake model into SS2 was guided by three principles: 1) the incorporation of less derived data, 2) explicitly model the underlying hake growth dynamics, and 3) achieve parsimony[1] in terms on model complexity. "Incorporating less derived data" entailed fitting observed data in their most elemental form. For instance, no pre-processing to convert length data to age compositional data was performed. Also, incorporating conditional age-at-length data, through age-length keys for each fishery and survey, allowed

[1] Parsimony is defined as a balance between the number of parameters needed to represent a complex state of nature and data quality/quantity to support accurate and precise estimation of those parameters.

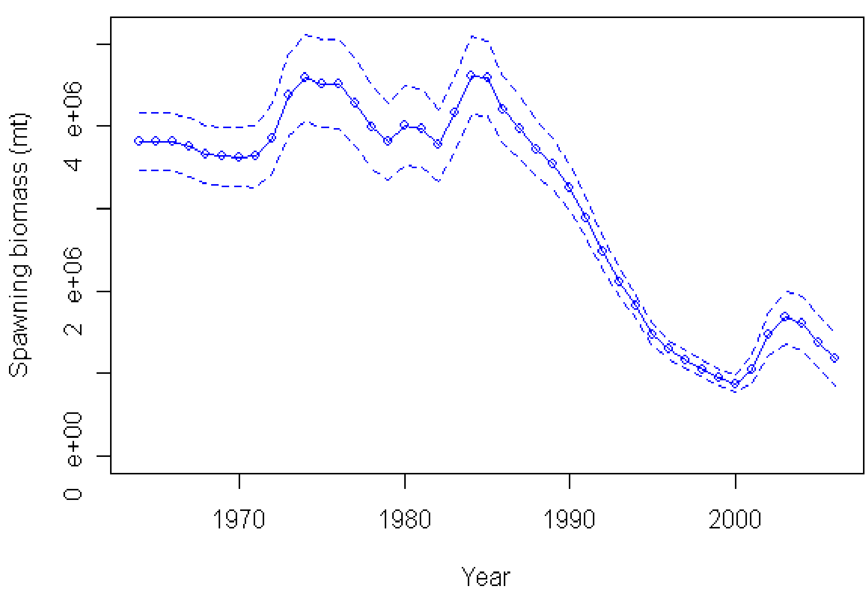
explicit estimation of expected growth, dispersion about that expectation, and its temporal variability, all conditioned on selectivity. As in the previous year's assessment, two models are presented to bracket the range of uncertainty in the acoustic survey catchability coefficient, *q*. The base model with steepness fixed at *h*=0.75 and *q*=1.0 represents the endpoint of the lower range while the alternative model which places a prior on *q* (effective *q*=0.7) represents the upper endpoint of the range. As such, model estimates presented below report a range of values representing these endpoints.

Stock biomass

Pacific hake spawning biomass declined rapidly after 1984 (4.6-5.1million mt) to the lowest point in the time series in 2000 (0.88-1.21 million mt). This long period of decline was followed by a brief increase to 1.68-2.13 million mt in 2003 as the 1999 year class matured. In 2006 (beginning of year), spawning biomass is estimated to be 1.18-1.60 million mt and approximately 30.9%-38.0% of the unfished level. Estimates of uncertainty in level of depletion range from 24.7%-36.9% and 29.7%-45.0% of unfished biomass for the base and alternative models, respectively, based on asymptotic confidence intervals.

Table b. Recent trend in Pacific hake spawning biomass and depletion level from the base and alternative SS2 models.

	Base Model				Alternative Model			
Year	Spawning biomass millions mt	~ 95% Interval	Relative Depletion	~ 95% Interval	Spawning biomass millions mt	~ 95% Interval	Relative Depletion	~ 95% Interval
1997	1.169	1.063 - 1.273	30.6%	-	1.314	1.146 - 1.482	30.66%	-
1998	1.056	0.954 - 1.157	27.7%	-	1.202	1.037 - 1.368	28.05%	-
1999	0.952	0.849 - 1.054	25.0%	-	1.102	0.934 - 1.271	25.72%	-
2000	0.880	0.767 - 0.990	23.1%	-	1.044	0.860 - 1.227	24.35%	-
2001	1.054	0.891 - 1.213	27.6%	-	1.288	1.025 - 1.551	30.04%	-
2002	1.485	1.217 - 1.746	38.9%	-	1.857	1.437 - 2.277	43.32%	-
2003	1.684	1.358 - 2.003	44.2%	-	2.132	1.624 - 2.641	49.74%	-
2004	1.617	1.280 - 1.945	42.4%	-	2.075	1.552 - 2.598	48.40%	-
2005	1.386	1.060 - 1.703	36.3%	30.4% - 42.1%	1.826	1.322 - 2.330	42.59%	35.2% - 50.1%
2006	1.178	0.857 - 1.491	30.9%	24.7% - 36.9%	1.601	1.109 - 2.093	38.00%	29.7% - 45.0%



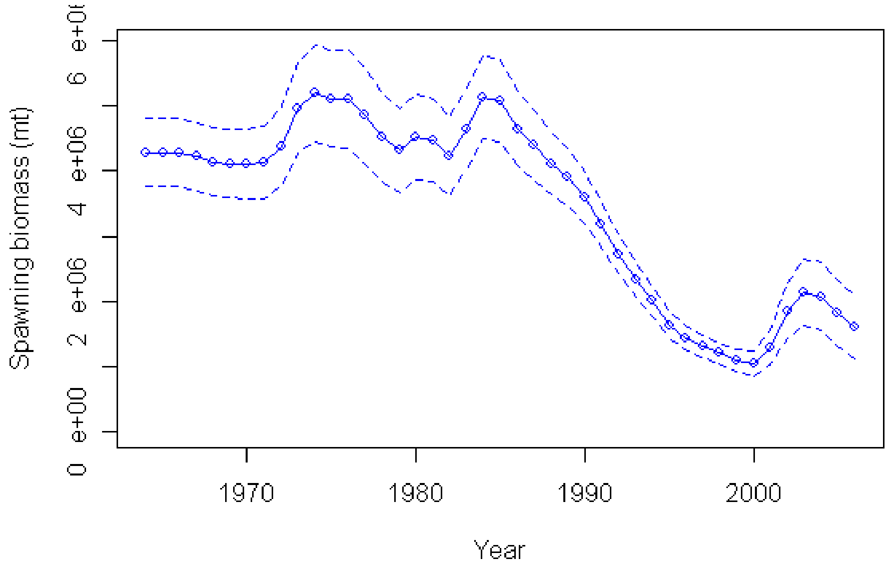


Figure b. Estimated spawning biomass time-series with approximate asymptotic 95% confidence intervals for the base (upper plot) and alternative (lower plot) models.

Recruitment

Estimates of Pacific hake recruitment indicate very large year classes in 1980 and 1984, with secondary recruitment events in 1970, 1973 and 1977, earlier in the time series. The recent 1999 year class was the single most dominate cohort since the late 1980s and has in large part support fishery catches during the last few years. Uncertainty in recruitment can be substantial as shown by asymptotic 95% confidence intervals. Recruitment to age 0 before 1967 is assumed to be equal to the long-term mean recruitment. Age-0 recruitment in 2003 is very uncertain, but predicted to be below the mean, despite some evidence to the contrary in the 2005 acoustic survey.

Table c. Recent estimated trend in Pacific hake recruitment.

	Base Model		Alternative Model	
Year	Recruitment (billions)	~ 95% Interval	Recruitment (billions)	~ 95% Interval
1997	1.933	1.671 - 2.227	2.275	1.893 - 2.735
1998	2.814	2.365 - 3.328	3.435	2.774 - 4.253
1999	13.789	11.337 - 16.692	17.323	13.667 - 21.956
2000	0.990	0.770 - 1.264	1.267	0.953 - 1.684
2001	1.372	1.048 - 1.783	1.787	1.322 - 2.416
2002	0.234	0.147 - 0.371	0.312	0.192 - 0.505
2003	2.338	1.502 - 3.618	3.137	1.978 - 4.976
2004	1.446	0.417 - 5.004	1.663	0.467 - 5.924
2005	0.279	0.069 - 1.131	0.323	0.079 - 1.315
2006	2.192	0.366 - 13.103	2.565	0.428 - 15.370

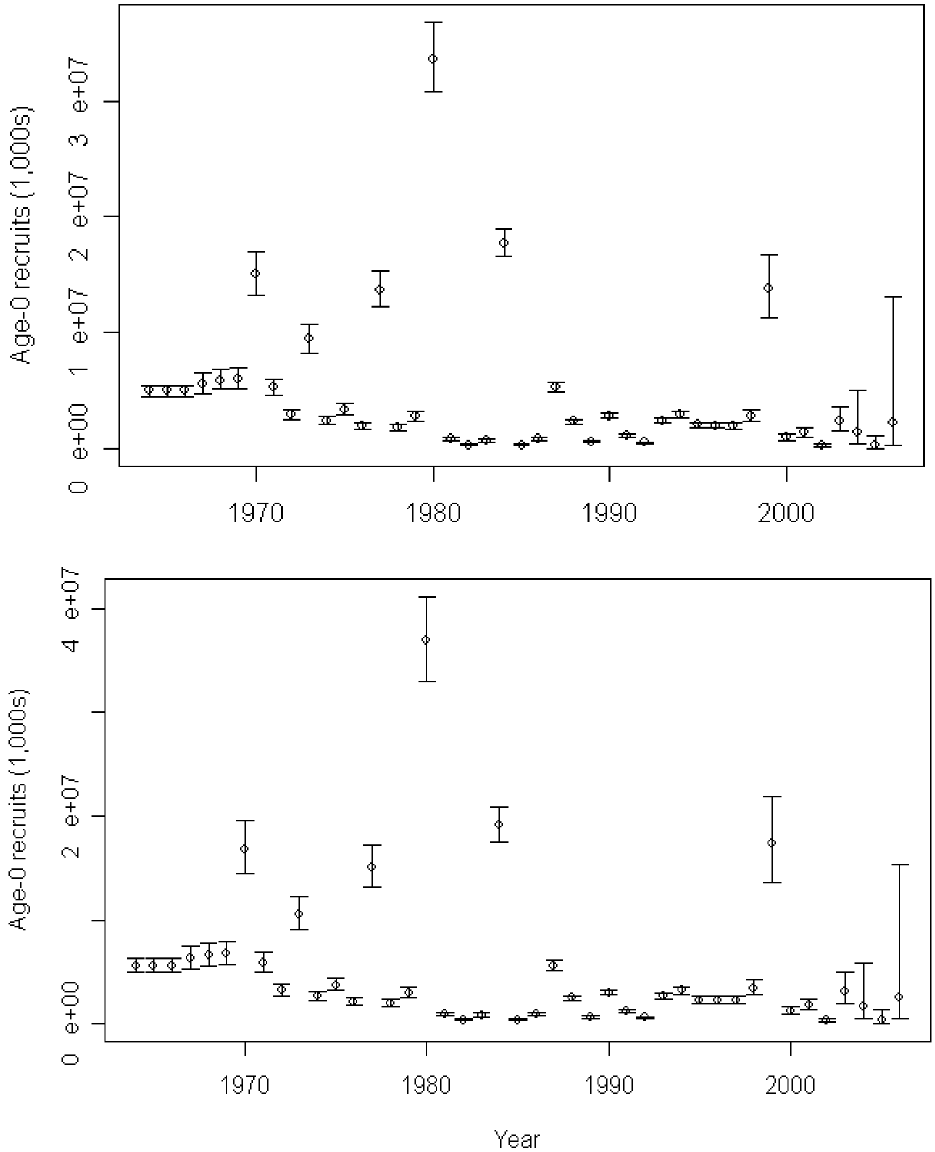


Figure c. Estimated recruitment time-series with approximate asymptotic 95% confidence intervals for the base (upper plot) and alternative (lower plot) models.

Reference points

Two types of reference points are reported in this assessment: those based on the assumed population parameters at the beginning of the modeled time period and those based on the most recent time period in a 'forward projection' mode of calculation. This distinction is important since temporal variability in growth and other parameters can result in different biological reference point calculations across alternative chronological periods. All strictly biological reference points (e.g., unexploited spawning biomass) are calculated based on the unexploited conditions at the start of the model, whereas management quantities (MSY, SB_{msy}, etc.) are based on the current growth and maturity schedules and are marked throughout this document with an asterisk (*).

Unexploited equilibrium Pacific hake spawning biomass (B_{zero}) from the base model was estimated to be 3.81 million mt (~ 95% confidence interval: 3.46 – 4.16 million mt), with a mean expected recruitment of 4.97 billion age-0 hake. Under the alternative model, spawning biomass (B_{zero}) from the base model was estimated to be 4.29 million mt (~ 95% confidence interval: 3.76 – 4.81 million mt), with a mean expected recruitment of 5.59 billion age-0 hake. Associated management reference points for target and critical biomass levels for the base model are 1.52 million mt (B40%) and 0.95 million mt (B25%), respectively. Under the alternative model, B40% and B25% are estimated to be 1.71 and 1.07 million mt, respectively. The MSY-proxy harvest amount (F40%) under the base model was estimated to be 573,945* mt (~ 95% confidence interval: 521,122-619,501), and 645,240* mt (~ 95% confidence interval: 566,830-712,848) under the alternative model. The spawning stock biomass that produces the MSY-proxy catch amount under the base model was estimated to be 1.06 million* mt (confidence interval is 0.96-1.14* million mt), and 1.19 million* mt (confidence interval is 1.04 -1.31* million mt) under the alternative model, given current life history parameters.

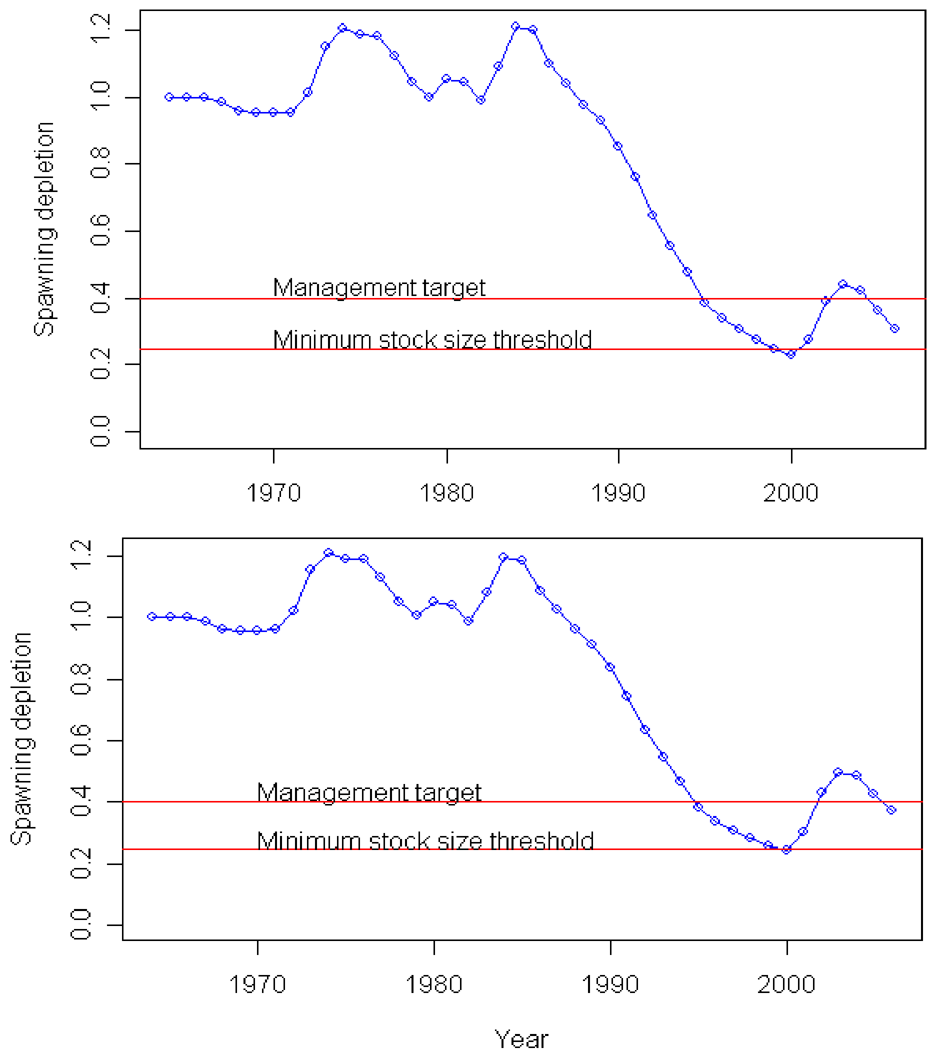


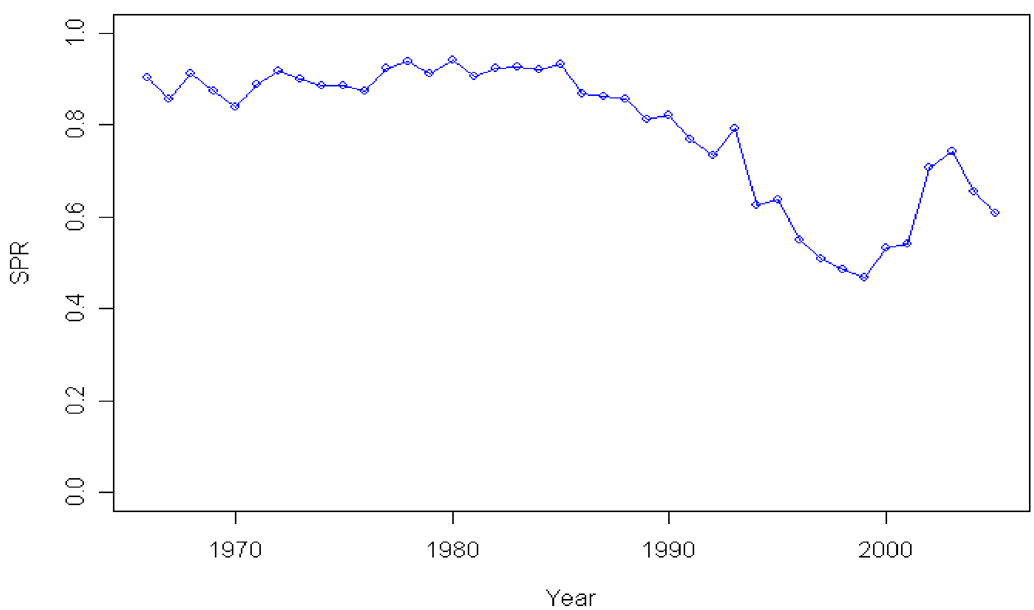
Figure d. Time series of estimated depletion, 1966-2006, for the base (upper plot) and alternative (lower plot) models.

Exploitation status

The estimated spawning potential ratio (SPR) for Pacific hake has been above the proxy target of 40% for the history of this fishery. In terms of its exploitation status, Pacific hake are presently above both the target biomass level (40% unfished biomass) and the target SPR rate (40%). The full exploitation history is portrayed graphically below which plots for each year the calculated SPR and spawning biomass level (B) relative to their corresponding targets, F40% and B40%, respectively.

Table d. Recent trend in spawning potential ratio (SPR).

	Base Model		alternative Model	
Year	Estimated SPR	~ 95% Interval	Estimated SPR	~ 95% Interval
1997	0.513	-	0.539	-
1998	0.491	-	0.521	-
1999	0.473	-	0.509	-
2000	0.540	-	0.584	-
2001	0.550	-	0.601	-
2002	0.716	-	0.762	-
2003	0.749	-	0.793	-
2004	0.664	-	0.721	-
2005	0.619	-	0.686	-



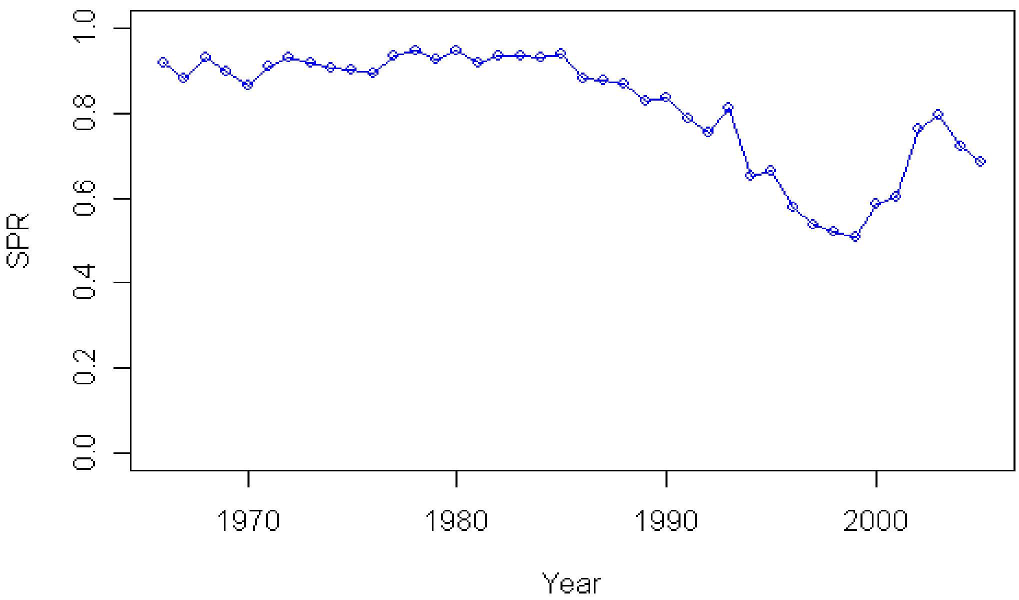
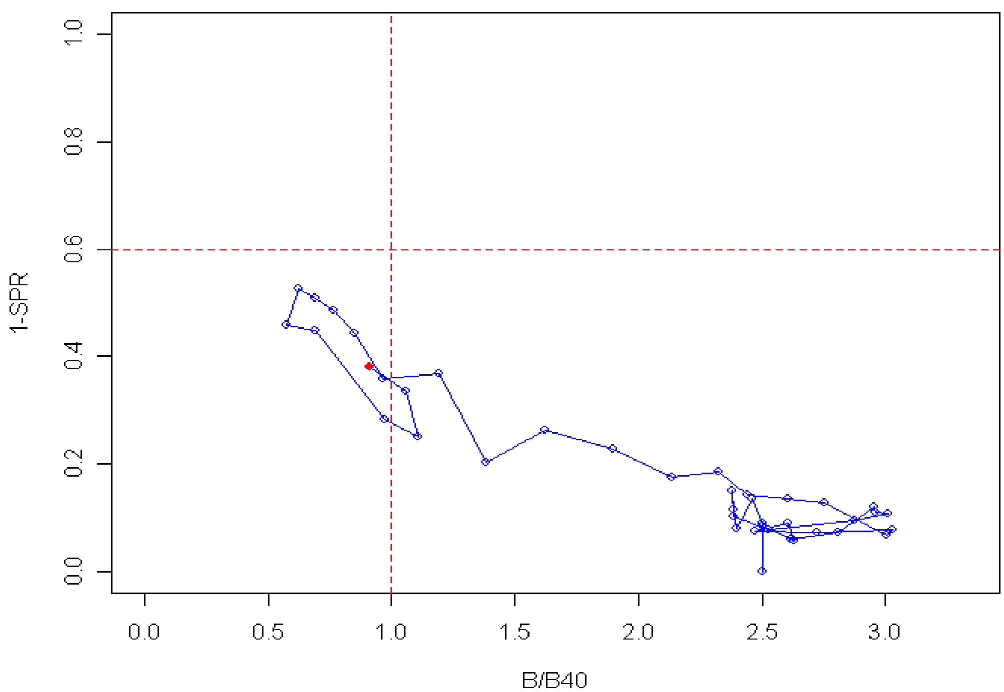


Figure e. Time series of estimated spawning potential ratio from base (upper plot) and alternative (lower plot) models.



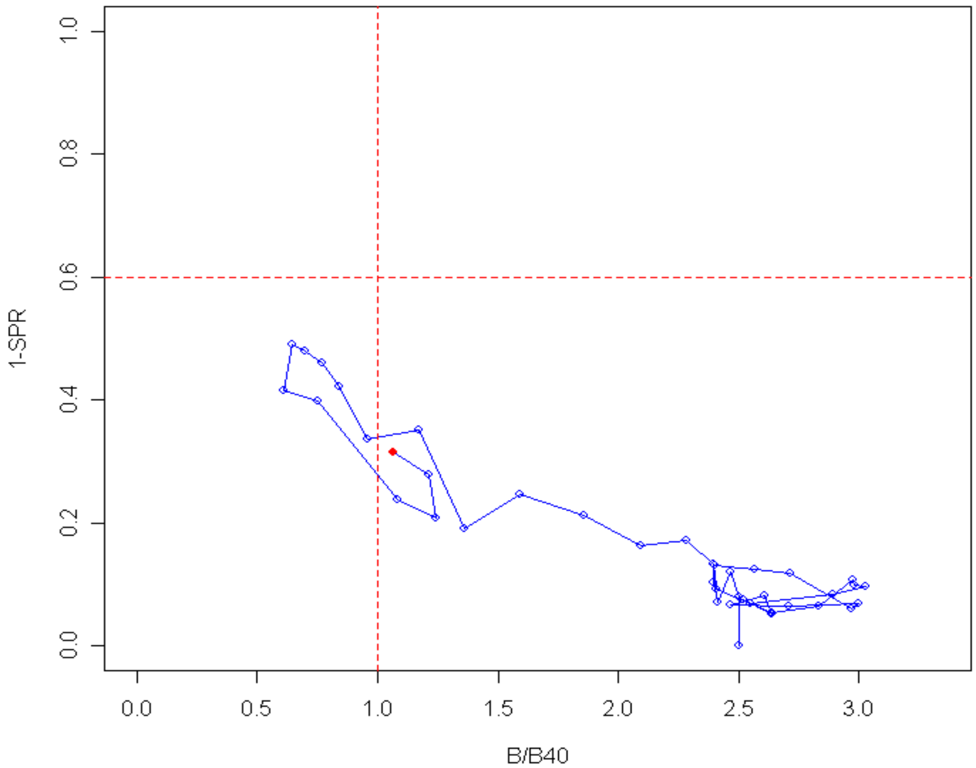


Figure f. Temporal pattern of estimated spawning potential ratio relative to the proxy target of 40% vs estimated spawning biomass relative to the proxy 40% level for base (upper plot) and alternative (lower plot) models.

Management performance

Since implementation of the Magnuson Fisheries Conservation and Management Act in the U.S. and the declaration of a 200 mile fishery conservation zone in Canada in the late 1970's, annual quotas have been the primary management tool used to limit the catch of Pacific hake in both zones by foreign and domestic fisheries. The scientists from both countries have collaborated through the Technical Subcommittee of the Canada-US Groundfish Committee (TSC), and there has been informal agreement on the adoption of an annual fishing policy. During the 1990s, however, disagreement between the U.S. and Canada on the division of the acceptable biological catch (ABC) between the two countries led to quota overruns; 1991-1992 quotas summed to 128% of the ABC and quota overruns have averaged 114% from 1991-1999. Since 2000, total catches have been below coastwide ABCs. A recent treaty between the United States and Canada (2003), which awaits final signature, establishes U.S. and Canadian shares of the coastwide allowable biological catch at 73.88% and 26.12%, respectively.

Table e. Recent trend in Pacific hake management performance.

Year	Total landings (mt)	ABC
1996	306,100	265,000
1997	325,215	290,000
1998	320,619	290,000
1999	311,855	290,000
2000	230,819	290,000
2001	235,962	238,000
2002	182,883	208,000
2003	205,582	235,000
2004	334,721	514,441
2005	360,306	

Unresolved problems and major uncertainties

The acoustic survey catchability, *q*, remains uncertain. This is largely driven by an inconsistency in the acoustic survey biomass time series and age compositions; age composition data suggest a large build up of stock biomass in the mid 1980s while the acoustic survey biomass time series is relatively flat since 1977.

Forecasts

Forecasts were generated assuming the maximum potential catch would be removed under 40:10 control rule for both the base and alternative models. Projections were based on the relative F contribution of 74.88% and 26.12% coast wide national allocation to the U.S. and Canada, respectively. For base case model, the 2006 coastwide ABC is estimated to be 661,681 mt with an OY of 593,750 mt. Under the alternative model, the 2006 coastwide ABC is estimated to be 904,944 mt with an OY of 883,490 mt. Spawning stock biomass is projected to decline with a corresponding relative depletion of 22.7% and 26.4% for the base and alternative models, respectively in 2007.

Table f. Three year projection of potential Pacific hake landings, spawning biomass and depletion for the base and alternative models under the 40:10 rule.

		Spawning biomass millions mt			Depletion percent unfished biomass		
Year	Expected coastwide catch (mt)	Mean	5%	95%	Mean	5%	95%
Base model, h=0.75, q=1.0							
2006	593,750	1.174	0.857	1.491	30.8%	24.7%	36.9%
2007	358,420	0.864	0.636	1.092	22.7%	18.1%	27.2%
2008	213,220	0.679	0.485	0.873	17.8%	13.5%	22.1%
2009	183,620	0.657	0.337	0.976	17.2%	9.2%	25.3%
Alt. model, h=0.75, q prior							
2006	883,490	1.601	1.109	2.093	38.0%	29.7%	45.0%
2007	522,510	1.130	0.795	1.464	26.4%	21.0%	31.7%
2008	302,300	0.851	0.588	1.113	19.8%	15.1%	24.5%
2009	240,700	0.792	0.404	1.179	18.5%	10.0%	26.9%

Decision table

A decision table was constructed to represent the uncertainty on the acoustic survey catchability coefficient, *q*. The base model with a *q*=1.0 represents the lower range while the alternative model which places a prior on *q* (effective *q*=0.7) represents the upper range. Below the decision table shows the consequences of management action given a state of nature. States of nature include the base model (*h*=0.75, *q*=1.0) and the alternative model (*h*=0.75, *q* prior). The management actions include the OY from each state of nature and two constant coastwide catch scenarios.

Table g. Decision table for two states of nature (base and alternative models) and four different harvest strategies given the state of nature.

			State of Nature	
Relative probability			**0.50**	**0.50**
Model			h = 0.75, q = 1.0	h = 0.75, q prior
Management action	Total coast-wide Catch (mt)	Year	Relative depletion (2.5%-97.5% interval)	
OY Model h=0.75, q=1.0	593,746	2006	0.308 (0.247-0.369)	0.380 (0.304-0.457)
	358,416	2007	0.227 (0.181-0.272)	0.310 (0.219-0.401)
	213,223	2008	0.178 (0.135-0.221)	0.263 (0.164-0.363)
	183,620	2009	0.172 (0.092-0.253)	0.254 (0.127-0.380)
OY Model h=0.75, q prior	883,490	2006	0.308 (0.247-0.369)	0.380 (0.304-0.457)
	522,511	2007	0.202 (0.125-0.279)	0.268 (0.215-0.322)
	302,298	2008	0.144 (0.056-0.232)	0.202 (0.155-0.249)
	240,702	2009	0.136 (0.020-0.252)	0.188 (0.104-0.273)
Total coast-wide	200,000	2006	0.308 (0.247-0.369)	0.380 (0.304-0.457)
catch = 200,000 mt	200,000	2007	0.282 (0.209-0.354)	0.351 (0.264-0.438)
	200,000	2008	0.250 (0.167-0.333)	0.315 (0.219-0.411)
	200,000	2009	0.239 (0.125-0.352)	0.299 (0.175-0.423)
Total coast-wide	400,000	2006	0.308 (0.247-0.369)	0.380 (0.304-0.457)
catch = 400,000 mt	400,000	2007	0.258 (0.184-0.332)	0.330 (0.241-0.419)
	400,000	2008	0.207 (0.122-0.292)	0.276 (0.177-0.375)
	400,000	2009	0.178 (0.063-0.294)	0.245 (0.118-0.372)

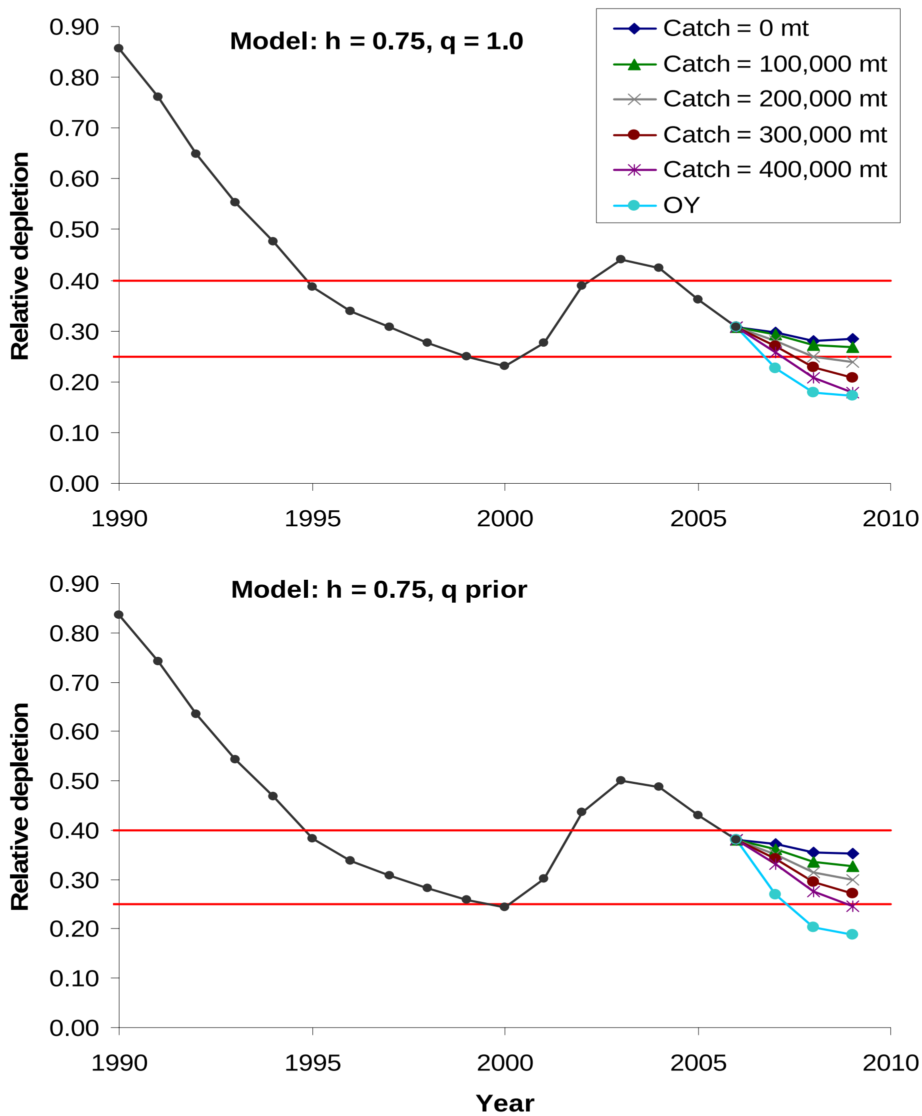


Figure g. Projections through 2009 for the base case (upper plot) and alternative (lower plot) models under various total coast-wide catch scenarios.

Research and data needs

1) The quantity and quality of biological data prior to 1988 from the Canadian fishery should be evaluated for use in developing length and conditional age at length compositions.
2) Evaluate whether modeling the distinct at-sea and shore based fisheries in the U.S. and Canada explain some lack of fit in the compositional data.
3) Compare spatial distributions of hake across all years and between bottom trawl and acoustic surveys to estimate changes in catchability/availability across years. The two primary issues are related to the changing spatial distribution of the survey as well as the environmental factors that may be responsible for changes in the spatial distribution of hake and their influences on survey catchability and selectivity.

4) Initiate analysis of the acoustic survey data to determine variance estimates for application in the assessment model. The analysis would provide a first cut to define the appropriate CV for the weighting of the acoustic data.
5) Develop an informed prior for the acoustic q. This could be done either with empirical experiments (particularly in off-years for the survey) or in a workshop format with technical experts. There is also the potential to explore putting the target strength estimation in the model directly. This prior should be used in the model when estimating the q parameter.
6) Review the acoustic data to assess whether there are spatial trends in the acoustic survey indices that are not being captured by the model. The analysis should include investigation of the migration (expansion/contraction) of the stock in relation to variation in environmental factors. This would account for potential lack of availability of older animals and how it affects the selectivity function.
7) Investigate aspects of the life history characteristics for Pacific hake and their possible effects on the interrelationship of growth rates and maturity at age. This should include additional data collection of maturity states and fecundity, as current information is limited.

Table h. Summary of recent trends in Pacific hake exploitation and stock levels; all values reported at the beginning of the year.

Base Model	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Landings (1000s mt)	306.1	325.2	320.6	311.9	230.8	236.0	182.9	205.6	334.7	360.3	NA
ABC (1000s mt)	265	290	290	290	290	238	208	235	514.441	265	
OY (1000s mt)											
SPR*	0.579	0.539	0.521	0.509	0.584	0.601	0.762	0.793	0.721	0.686	NA
Total biomass (millions mt)	2.601	2.437	2.184	1.958	1.761	1.813	3.657	3.534	3.274	2.640	2.328
Spawning biomass (millions mt)	1.293	1.169	1.056	0.952	0.880	1.054	1.485	1.684	1.617	1.386	1.178
~95% interval	1.180-1.405	1.063-1.273	0.954-1.157	0.849-1.054	0.767-0.990	0.891-1.213	1.217-1.746	1.358-2.003	1.280-1.945	1.060-1.703	0.857-1.491
Recruitment (billions)	1.988	1.933	2.814	13.789	0.990	1.372	0.234	2.338	1.446	0.279	2.192
~95% interval	1.711-2.167	1.617-2.152	2.271-3.199	10.770-15.912	0.722-1.199	0.972-1.681	0.124-0.343	1.238-3.233	4.165-4.988	4.165-4.988	4.165-4.988
Depletion	33.9%	30.6%	27.7%	25.0%	23.1%	27.6%	38.9%	44.2%	42.4%	36.3%	30.9%
~95% interval	NA	NA	NA	NA	NA	NA	NA	NA	NA	30.4%-42.1%	24.7%-36.9%

Alternative Model	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Landings (1000s mt)	306.1	325.2	320.6	311.9	230.8	236.0	182.9	205.6	334.7	360.3	NA
ABC (1000s mt)	265	290	290	290	290	238	208	235	514.441	265	
OY (1000s mt)											
SPR*	0.579	0.539	0.521	0.509	0.584	0.601	0.762	0.793	0.721	0.686	
Total biomass (millions mt)	2.979	2.812	2.556	2.340	2.166	2.295	4.801	4.699	4.427	3.680	3.389
Spawning biomass (millions mt)	1.443	1.314	1.202	1.102	1.044	1.288	1.857	2.132	2.075	1.826	1.601
~95% interval	1.266-1.620	1.146-1.482	1.037-1.368	0.934-1.271	0.860-1.227	1.025-1.551	1.437-2.277	1.624-2.641	1.552-2.598	1.322-2.330	1.109-2.093
Recruitment (billions)	2.275	2.275	3.435	17.323	1.267	1.787	0.312	3.137	1.663	0.323	2.565
~95% interval	1.945-2.661	1.893-2.735	2.774-4.253	13.677-21.956	0.953-1.684	1.322-2.416	0.192-0.505	1.978-4.976	0.467-5.924	0.079-1.315	0.428-15.370
Depletion	33.7%	30.7%	28.0%	25.7%	24.3%	30.0%	43.3%	49.7%	48.4%	42.6%	38.0%
~95% interval	NA	NA	NA	NA	NA	NA	NA	NA	NA	35.2%-50.1%	29.7%-45.1%

Table i. Summary of Pacific hake reference points.

Base Model

Quantity	Estimate	~95% Confidence interval
Unfished spawning stock biomass (SB_0, millions mt)	3.810	3.461 - 4.160
Unfished total biomass (B_0, millions mt)	9.200	NA
Unfished age 3+ biomass (millions mt)	7.832	NA
Unfished recruitment (R_0, billions)	4.974	4.536 – 5.447
Spawning stock biomass at MSY (SB_{msy})*	1.06	0.96 – 1.14
Basis for SB_{msy}	$F_{40\%}$ proxy	NA
SPR_{msy}*	40.0%	33.2%-46.7%
Basis for SPR_{msy}	$F_{40\%}$ proxy	NA
Exploitation rate corresponding to SPR_{msy}*	24.6%	NA
MSY* (mt)	573,945	521,122 – 619,501

Alternative Model

Quantity	Estimate	~95% Confidence interval
Unfished spawning stock biomass (SB_0, millions mt)	4.287	3.764 – 4.810
Unfished total biomass (B_0, millions mt)	10.333	NA
Unfished age 3+ biomass (millions mt)	8.804	NA
Unfished recruitment (R_0, billions)	5.593	4.955 - 6.313
Spawning stock biomass at MSY (SB_{msy})*	1.191	1.041 - 1.310
Basis for SB_{msy}	$F_{40\%}$ proxy	NA
SPR_{msy}*	40.0%	33.2%-46.7%
Basis for SPR_{msy}	$F_{40\%}$ proxy	NA
Exploitation rate corresponding to SPR_{msy}*	24.6%	NA
MSY* (mt)	645,240	566,830 - 712,848