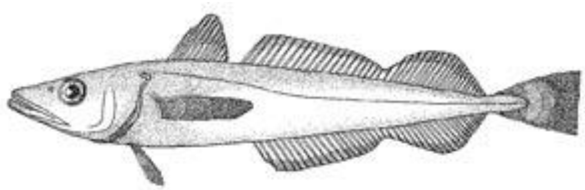
Status of the Pacific Hake (Whiting) stock in U.S. and Canadian Waters in 2011



Joint U.S. and Canadian Hake Technical Working Group

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Pending formal implementation of the Joint US-Canada treaty on Pacific Hake governing both scientific and management actions for Pacific hake, this document reports the collaborative efforts of a joint stock assessment team comprised of both U.S. and Canadian scientists operating in the spirit of the treaty agreement.

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Executive Summary

Stock

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

Catches

Coast-wide fishery landings of Pacific hake averaged 221 thousand mt from 1966 to 2010, with a low of 90 thousand mt in 1980 and a peak of 363 thousand mt in 2005. Prior to 1966 the total removals were negligible relative to the modern fishery. Recent coast-wide landings from 2006-2010 have been above the long term average, at 274 thousand mt. Landings between 2001 and 2008 were predominately comprised of fish from the very large 1999 year class, with the cumulative removal from that cohort exceeding 1.2 million mt. In 2008, the fishery began harvesting considerable numbers of the then emergent 2005 year class. Catches in 2009 were again dominated by the 2005 year class with some contribution from an emergent 2006 year class and relatively small numbers of the 1999 cohort. The 2010 fishery encountered very large numbers of two-year old hake from the 2008 year-class, while continuing to see substantial numbers from the 2005 and 2006 year-classes. The United States has averaged 164 thousand mt, or 74.5% of the average total landings over the time series, with Canadian catch averaging 56 thousand mt. In this stock assessment, the terms catch and landings are used interchangeably; estimates of discard within the target fishery are included, but discarding of Pacific hake in non-target fisheries is not. Total discard is estimated to be less than 1% of landings and therefore is likely to be negligible with regard to the population dynamics.

Table a. Recent commercial fishery landings (1000s mt). Tribal catches are included.

Year	US at-sea	US shore-based	US total	Canadian joint-venture	Canadian domestic	Canadian total	Total
2001	101	73	174	22	32	54	228
2002	85	46	130	0	50	50	181
2003	87	55	142	0	63	63	205
2004	117	97	214	59	66	125	339
2005	151	109	260	16	87	103	363
2006	140	127	267	14	80	95	362
2007	126	91	218	7	66	73	291
2008	181	68	248	4	70	74	322
2009	72	49	122	0	56	56	177
2010	106	55	161	8	48	56	217

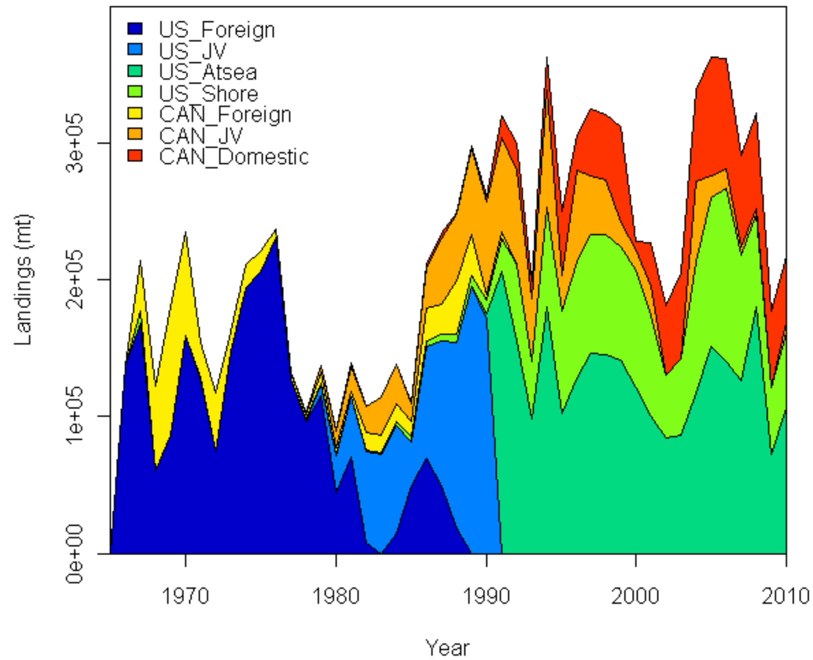

Figure a. Total Pacific hake landings used in the assessment by sector, 1966-2010. Tribal catches are included.

Data and assessment

Following the 2010 assessment, nearly all of the data sources available for Pacific hake have been reconstructed and thoroughly re-evaluated for 2011 from the original observations using consistent, and in some cases improved methods. In all cases small changes have occurred relative to data used for previous stock assessments; however the current results represent the best available information. Catches from all sectors and both nations were reconstructed from 1966 through 2010. Age-composition information is available from 1975-2010. The acoustic survey time-series was re-analyzed from the raw data, and kriging has been applied in order to provide a more robust estimate of total biomass as well as a measure of the annual sampling variability due to patchiness of hake schools and irregular transects. This has led to the conclusion that survey efforts prior to 1995 failed to sample a sufficient portion of the stock to be comparable with more recent surveys and that a reasonable estimate of the variance for those early years would render them uninformative for the stock assessment. The uncertainty in the 2009 acoustic survey biomass estimate attributable to the presence of large numbers of Humboldt squid has been quantified and explicitly included in the time-series. Age- and length-composition information from the acoustic survey has been re-processed to be consistent with the revised time-series, and the survey team's investigation into haul representativeness and survey stratification has supported their continued use in the stock assessment.

This assessment reports two models representing the collective work of the Joint Technical Working Group (JTWG). Extensive efforts to compare and revise both the Stock Synthesis and TINSS models from the 2010 assessment have been conducted. Both assessments depend upon the acoustic survey index of abundance, the aggregate fishery age-composition data and the age-composition data from the acoustic survey. Both models are fully Bayesian, incorporating prior information on key parameters and integrating over estimation and parameter uncertainty to provide results that can be probabilistically interpreted. The results from both models are presented in parallel throughout this document, and the likely causes of observed differences are discussed.

Stock biomass

Both stock assessment models indicate that the Pacific hake female spawning biomass was well below equilibrium at the start of the fishery and during the 1970s. The stock increased rapidly after two or more large recruitment events in the early 1980s and then declined rapidly after a peak in the mid- to late 1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 (1.44 million mt in the SS model and 1.75 million mt in the TINSS model) as the exceptionally large 1999 year class matured. In 2011 (beginning of year), spawning biomass is estimated to be rebounding rapidly based on the strength of recent year classes (2005, 2006 and particularly 2008, in both the SS and TINSS models), however this estimate is quite uncertain, with 95% posterior credibility intervals ranging from historical lows to well above equilibrium levels. Current median posterior spawning biomass equates to approximately 91% (SS model) or 175% (TINSS model) of the unfished level (SB_0). Estimates of uncertainty in current relative depletion are extremely broad, from 35%-203% of unfished biomass in the SS model and 75%-409% in the TINSS model. The estimate of spawning biomass for 2011 is 1.87 million mt in the SS model and 2.18 million mt in the TINSS model, both much larger than the 0.48 million mt estimated by the SS model in 2010 without information about the above-average 2008 recruitment. The 2010 TINSS median posterior estimate was 0.34 million mt. Model-averaged posterior median estimated 2011 spawning biomass (assuming equal weight for each model) was 2.03 million mt (0.72-5.14). This corresponds to a model-averaged posterior median 2011 depletion level of 126% (42%-350%).

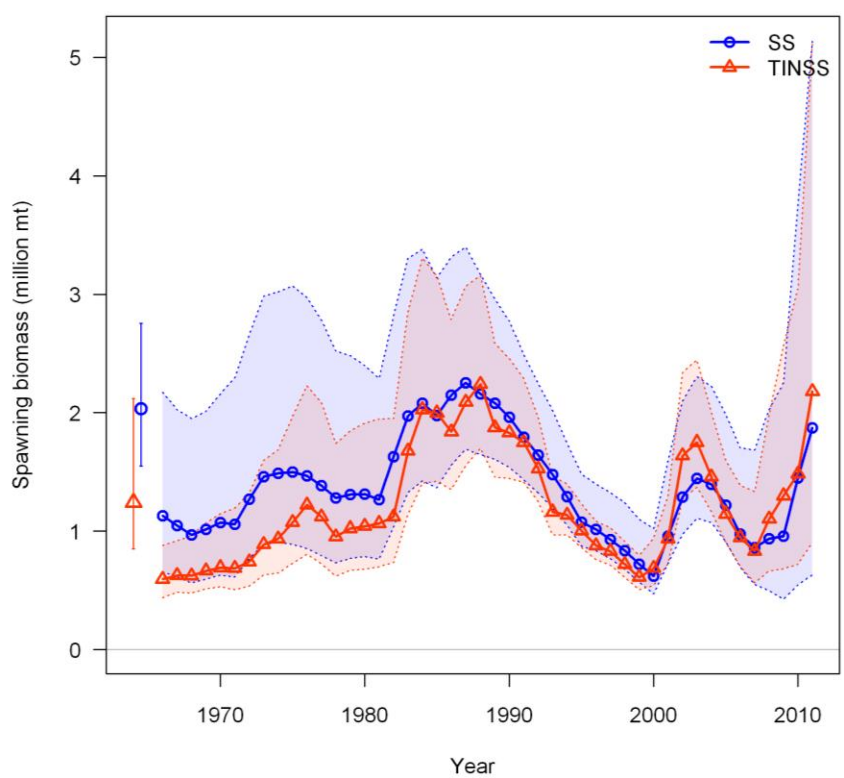

Figure b. Estimated female spawning biomass time-series from the two models with 95% posterior credibility intervals.

Table b. Recent trend in estimated Pacific hake female spawning biomass (million mt).

	SS			TINSS		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2002	0.972	1.289	2.099	1.269	1.638	2.338
2003	1.107	1.444	2.306	1.372	1.751	2.448
2004	1.075	1.397	2.223	1.164	1.460	2.004
2005	0.913	1.220	1.987	0.906	1.145	1.597
2006	0.695	0.976	1.704	0.702	0.945	1.387
2007	0.549	0.862	1.687	0.564	0.831	1.335
2008	0.501	0.937	2.026	0.664	1.103	1.978
2009	0.423	0.960	2.253	0.683	1.299	2.563
2010	0.544	1.451	3.767	0.720	1.485	3.047
2011	0.631	1.874	5.140	0.907	2.179	5.122

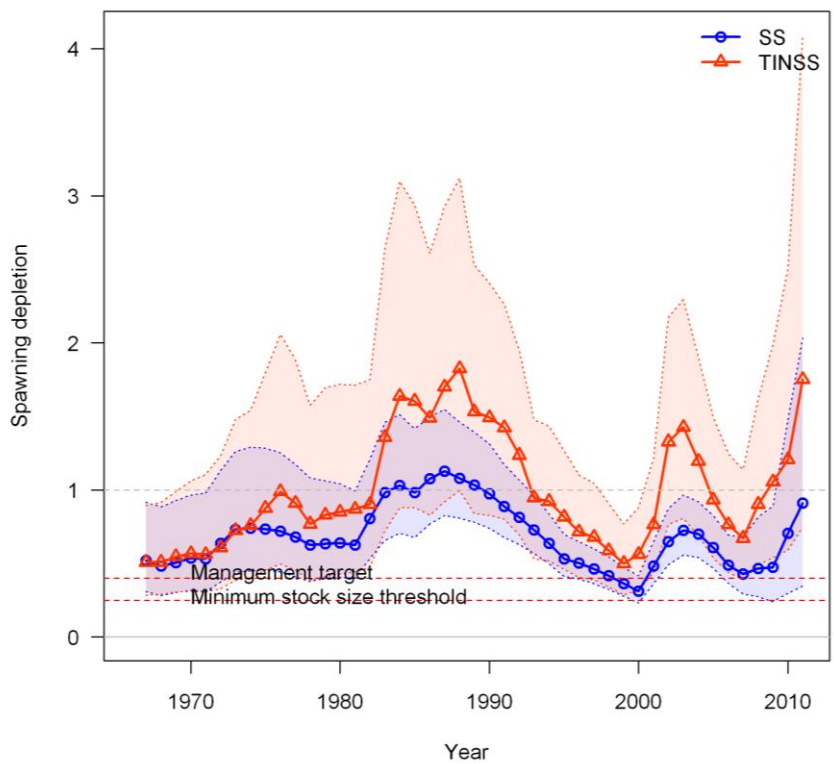

Figure c. Time-series of estimated relative spawning depletion through 2011 for both models with 95% posterior credibility intervals.

Table c. Recent trend in estimated relative spawning depletion from the two models.

	SS			TINSS		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2002	0.491	0.647	0.872	0.766	1.327	2.175
2003	0.557	0.726	0.965	0.808	1.426	2.294
2004	0.538	0.699	0.919	0.688	1.194	1.898
2005	0.467	0.608	0.824	0.537	0.932	1.494
2006	0.367	0.488	0.695	0.440	0.765	1.246
2007	0.293	0.428	0.676	0.388	0.672	1.139
2008	0.275	0.465	0.816	0.488	0.902	1.617
2009	0.239	0.474	0.890	0.540	1.054	1.985
2010	0.298	0.706	1.477	0.591	1.206	2.506
2011	0.347	0.911	2.031	0.749	1.751	4.089

Recruitment

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984 and 1999 in both assessment models. The strength of the 2008 cohort is estimated to be very large, and this is informed mainly by the 2010 fishery age compositions. Uncertainty in estimated recruitments is substantial, especially so for 2008, as indicated by the broad posterior intervals.

Table d. Recent trend in Pacific hake recruitment (billions age-0 for SS; billions of age-1 for TINSS).

	SS			TINSS		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2002	0.022	0.105	0.371	0.458	0.770	1.364
2003	1.107	1.874	3.656	0.144	0.250	0.455
2004	0.018	0.115	0.406	0.975	1.758	3.365
2005	2.309	4.579	10.515	0.280	0.515	1.107
2006	1.848	4.556	11.636	3.133	6.030	12.115
2007	0.021	0.129	0.619	2.426	5.426	12.569
2008	5.117	16.166	51.527	0.080	0.187	0.478
2009	0.059	0.874	10.239	3.308	12.304	38.549
2010	0.087	1.167	14.698	0.153	1.374	12.555
2011	0.081	1.090	18.852	0.012	0.855	56.714

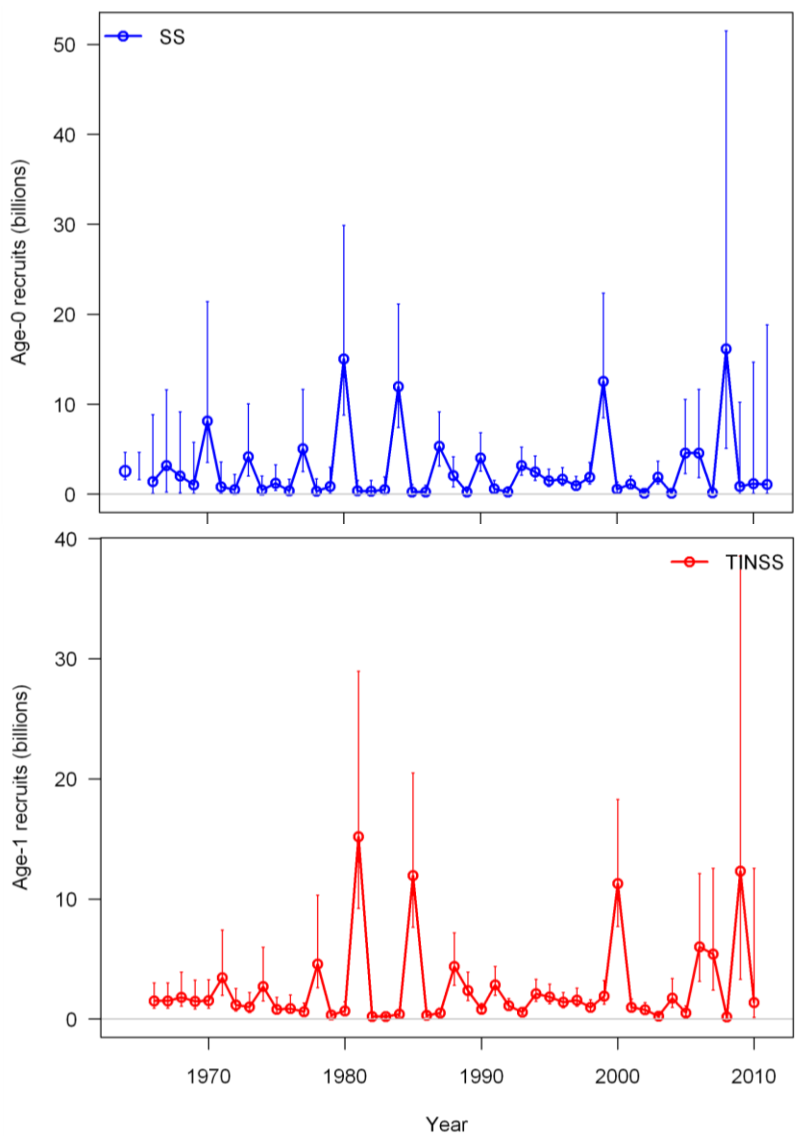

Figure d. Estimated Pacific hake recruitment time-series for both models with 95% posterior credibility intervals (billions age-0 for SS, upper panel; billions of age-1 for TINSS, lower panel).

Reference points

Unexploited equilibrium spawning biomass increased in the SS model to 2.03 million mt (from 1.33 million metric tons in the 2010 assessment), but the uncertainty is broad, with the 95% posterior credibility interval ranging from 1.55 to 2.76 million mt. In the TINSS model, the median of the posterior was 1.24 million metric tons (credibility interval: 0.85-2.12 million mt). The *MSY*-proxy target biomass ($SB_{40\%}$) is estimated to be 0.81 million mt in the SS model and 0.50 in the TINSS model. The minimum biomass thresholds ($SB_{25\%}$) are 0.51 and 0.31 million mt, respectively. *MSY* is estimated to be 355 thousand mt in the SS model and 160 thousand mt in the TINSS model. The equilibrium yield at the biomass target ($SB_{40\%}$) is estimated to be 323 thousand mt in the SS model and 158 thousand mt in the TINSS model. The full set of reference points are reported in table i below.

Exploitation status

The spawning potential ratio for Pacific hake is estimated to have been below the proxy target of 40% for both assessment models. Uncertainty in the value is large. Exploitation fraction (catch/age-3+ biomass) estimates are remarkably similar for the two models, as this calculation is not influenced by fishery selectivity. The full exploitation history in terms of both the biomass and *F* targets is portrayed graphically via a phase-plot.

Table e. Recent trend in relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.4}$) for both models.

	SS			TINSS		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2001	0.500	0.760	0.957	0.474	0.664	0.838
2002	0.269	0.459	0.630	0.322	0.481	0.638
2003	0.279	0.465	0.623	0.329	0.493	0.658
2004	0.440	0.679	0.856	0.466	0.653	0.832
2005	0.543	0.813	0.995	0.512	0.708	0.902
2006	0.614	0.908	1.096	0.508	0.721	0.924
2007	0.593	0.918	1.133	0.499	0.724	0.943
2008	0.559	0.918	1.184	0.486	0.725	0.976
2009	0.312	0.628	1.001	0.319	0.536	0.807
2010	0.303	0.637	1.047	0.301	0.530	0.824

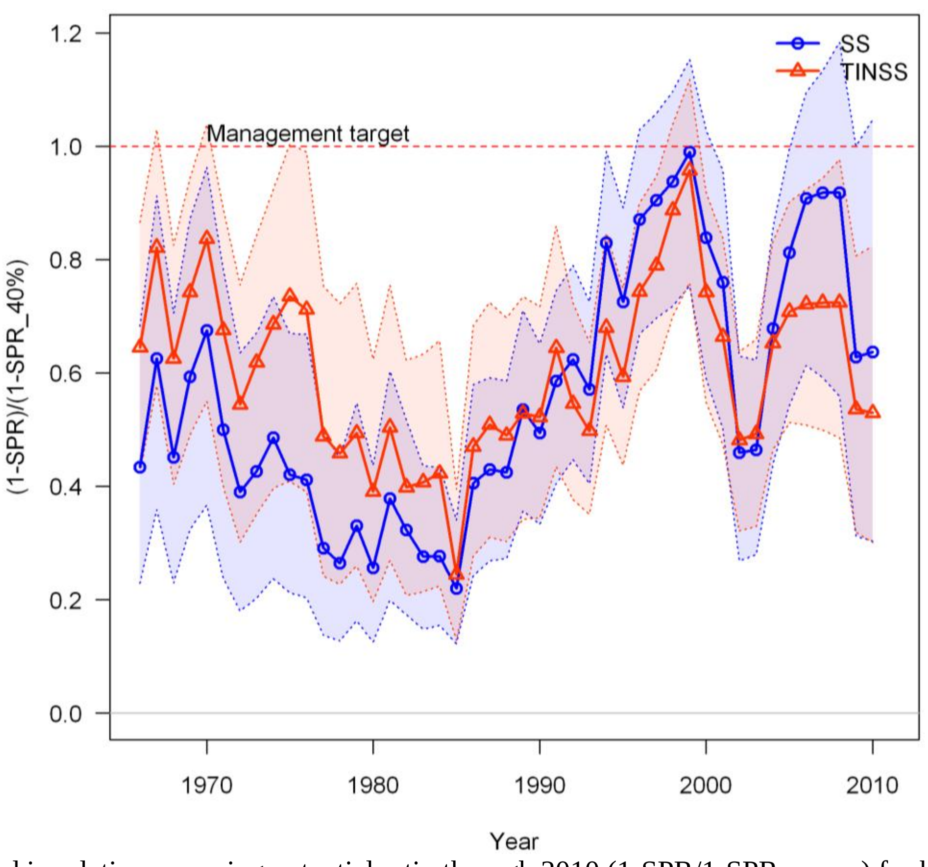

Figure e. Trend in relative spawning potential ratio through 2010 (1-SPR/1-$SPR_{Target=0.4}$) for both models.

Table f. Recent trend in exploitation fraction (catch/3+biomass) for both models (MLE values).

	SS			TINSS		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2001	0.087	0.144	0.199	0.092	0.159	0.266
2002	0.027	0.044	0.058	0.034	0.060	0.100
2003	0.036	0.058	0.076	0.041	0.069	0.113
2004	0.072	0.115	0.149	0.051	0.086	0.139
2005	0.100	0.164	0.216	0.068	0.114	0.187
2006	0.106	0.186	0.257	0.072	0.128	0.222
2007	0.109	0.210	0.319	0.092	0.173	0.313
2008	0.078	0.169	0.306	0.048	0.101	0.206
2009	0.034	0.080	0.182	0.038	0.086	0.183
2010	0.045	0.112	0.286	0.043	0.098	0.215

Management performance

Since implementation of the Magnuson-Stevens Fishery Conservation and Management Act in the U.S. and the declaration of a 200 mile fishery conservation zone in 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. 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 averaged 114% from 1991-1999. Since 2001, total catches have been below coast-wide ABCs. The current treaty between the United States and Canada, establishes U.S. and Canadian shares of the coast-wide allowable biological catch at 73.88% and 26.12%, respectively.

In many recent years, failure to extract the entire OY available to the fishery in U.S. waters has been a result of extremely restrictive bycatch limits on overfished rockfish species, particularly widow, darkblotched and canary rockfishes; in 2008, there was a voluntary ‘stand-down’ during the period of highest bycatch rates as the fleet approached the bycatch limit. Beginning in the 2009 fishery the U.S. mother-ship, catcher-processor and shore-based sectors were assigned sector specific, and much larger, bycatch limits. During 2009 and 2010 much of the U.S. tribal allocation remained uncaught and so the total catch remained below the OY.

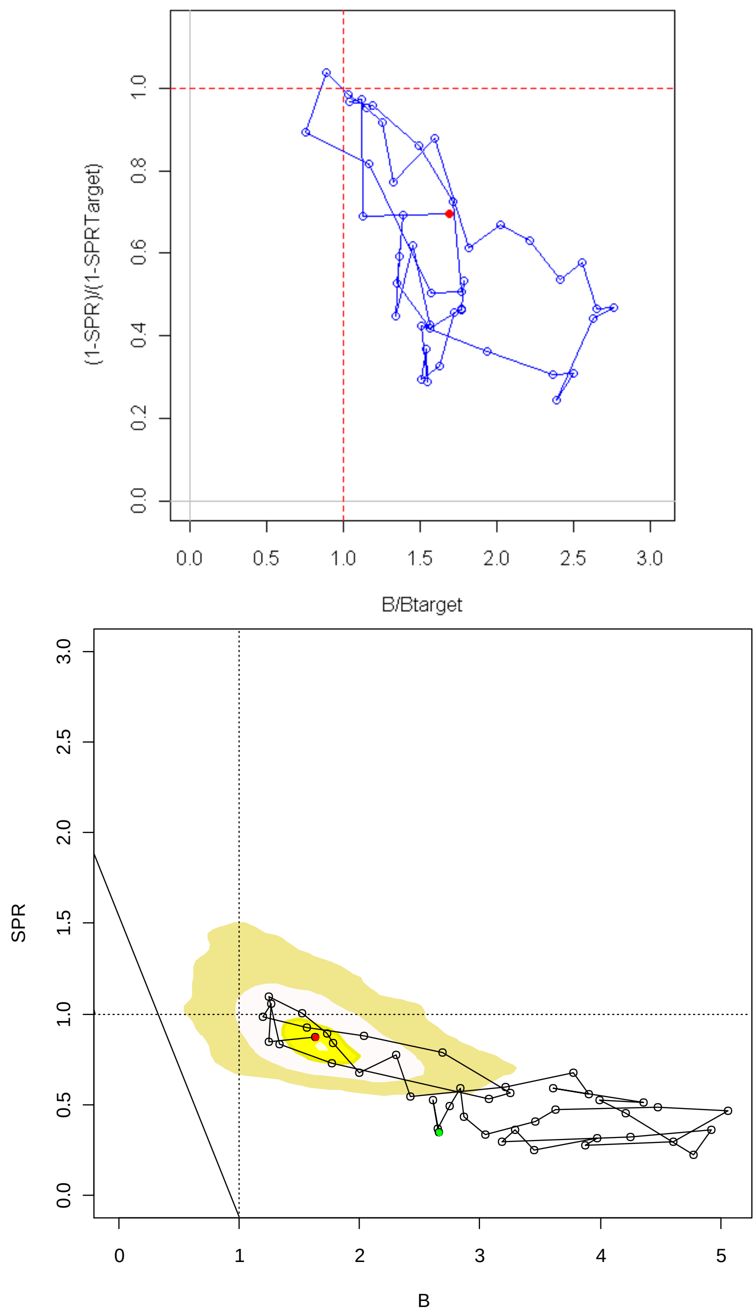

Figure f. Temporal pattern (phase plot) of relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.4}$) vs. estimated spawning biomass relative to the proxy 40% level through 2010 for the SS model (upper panel, note this calculation is based on the MLE). Lower panel shows relative spawning potential ratio (1-SPR/1-SPR_{MSY}) vs. estimated spawning biomass relative to the B_{MSY} level through 2010 for the TINSS model. The filled circle denotes 2010 and the line connects years through the time-series.

Table g. Recent trend in Pacific hake management performance.

Year	Total landings (mt)	Coast-wide (U.S. + Canada) OY (mt)	Coast-wide (U.S. + Canada) ABC (mt)
2001	227,531	238,000	238,000
2002	180,698	162,000	208,000
2003	205,177	228,000	235,000
2004	338,654	501,073	514,441
2005	363,157	364,197	531,124
2006	361,761	364,842	661,680
2007	290,545	328,358	612,068
2008	322,145	364,842	400,000
2009	177,459	184,000	253,582
2010	216,912	262,500	455,550

Unresolved problems and major uncertainties

Both assessment models integrate over the substantial uncertainty associated with several important model parameters including: acoustic survey catchability (q) and the productivity of the stock (SS via the steepness, h, of the stock-recruitment relationship; TINSS via F_{MSY}, and natural mortality, M). Although the Bayesian results presented include estimation uncertainty, this within-model uncertainty is likely a gross underestimate of the true uncertainty in current stock status and future projections, since it does not include all structural modeling choices, data-weighting uncertainty and scientific uncertainty in selection of prior probability distributions. In an effort to capture these additional sources of uncertainty, we report the results from the two models throughout this document.

Pacific hake displays the highest degree of recruitment variability of any west coast groundfish stock resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts, and a biennial rather than annual fishery-independent acoustic survey, will continue to result in highly uncertain estimates of current stock status and even less-certain projections of stock trajectory in future stock assessments. The primary source of uncertainty that is relevant to management decision-making for the 2011 fishing season is the strength of the 2008 year-class. The estimate for this cohort is very uncertain, and the stock trajectory is entirely dependent on its value. For this reason, the decision table explicitly includes columns representing alternate states of nature for low, middle and high estimated 2008 cohort strengths. The vast uncertainty in this year class will likely persist until the next acoustic survey has been conducted, providing a fishery independent estimate of its magnitude.

Forecasts and decision table

The model-averaged posterior median for the 2011 ABC (overfishing limit) from the SS and TINSS models (equally weighted) was 973,727 mt. This value was highly uncertain with lower and upper posterior values approximately one-half as likely (the 12.5th and 87.5th percentiles) ranging from 530,115 to 1,726,125 mt.

In order to reflect the considerable uncertainty in recent (especially 2008) and future year-class strengths, as well as current absolute biomass levels, three-year forecasts are reported in the decision table format. This allows for the evaluation of alternative management actions based on the full posterior distribution for both models. The decision table is organized such that the projected implications for each potential management action (the rows, containing a range of potential catch levels) can be evaluated for each of six states of nature (the columns). The six states of nature represent the lower 25%, middle 50% and upper 25% of the posterior distribution for the strength of the 2008 cohort for both the SS and TINSS models. Thus the middle value can be considered twice as likely as the first and last within each model. The choice of the 2008 cohort strength as the secondary axis of uncertainty (after including the two models) was based on the very large uncertainty associated with this recruitment as well as the fact that it is informed by only the 2010 fishery age composition data. For clarity, the decision table is divided into three sections: the first table projects the spawning biomass estimates, the second the relative depletion (for both of these the 2011 values will be identical for all management actions because they represent beginning of the year values) and the third the relative SPR rate. Relative SPR exceeding 1.0 indicates fishing in excess of the $SPR_{40\%}$ MSY-proxy (overfishing).

The stock is projected to increase in spawning biomass for all three states of nature in both models for catches up to an including 400,000 mt. At a catch level of 500,000 mt, the SS model predicts that the stock will not fall below 2011 levels at the mode of the posterior, but if the 2008 cohort is in the lower 25% of the posterior density, overfishing will occur and the stock will decline, while staying above the precautionary zone during the next three years. The TINSS model predicts that the stock will continue to increase at that harvest level under all three states of nature. The SS model 40:10 OY harvests are in excess of 800,000 mt at the mode of the posterior, while the TINSS model indicates that catches in excess of 700,000 and 1,100,000 mt would be consistent with the harvest control rule depending on whether the estimate of *MSY* or the $F_{40\%}$-proxy is applied. The differences between the two predictions are again likely due to the differences in estimated fishery selectivity and to the priors for the productivity parameters.

Table h.1. Decision table with three year projections of posterior distributions for Pacific hake female **spawning biomass** (millions mt, at the beginning of the year before fishing takes place). Catch alternatives are based on: 1) arbitrary constant catch levels of 50,000, 100,000, 150,000, 300,000, 400,000 and 500,000 mt (rows a-c, and e-g), 2) the status quo OY from 2010 (row d), and 3) the OY implied by the estimated F_{MSY} from the TINSS model (row h), and the values estimated via the 40:10 harvest control rule and the $F_{40\%}$ overfishing limit/target for the base case SS (row i) and TINSS models (row j).

			States of nature					
		Model	SS			TINSS		
		Within model probability	25%	50%	25%	25%	50%	25%
		Description	Low 2008 cohort	Modal density	High 2008 cohort	Low 2008 cohort	Modal density	High 2008 cohort
Management Action								
	Year	Catch (mt)						
a	2011	50,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	50,000	1.238	2.180	3.801	1.605	2.711	4.427
	2013	50,000	1.309	2.308	3.912	1.629	2.732	4.449
b	2011	100,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	100,000	1.215	2.157	3.777	1.581	2.686	4.403
	2013	100,000	1.262	2.261	3.866	1.584	2.685	4.403
c	2011	150,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	150,000	1.191	2.133	3.754	1.557	2.662	4.379
	2013	150,000	1.215	2.215	3.821	1.538	2.643	4.356
d	2011	262,500	1.053	1.873	3.232	1.358	2.174	3.534
	2012	262,500	1.138	2.081	3.701	1.503	2.608	4.325
	2013	262,500	1.110	2.110	3.718	1.439	2.539	4.252
e	2011	300,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	300,000	1.120	2.063	3.683	1.485	2.589	4.306
	2013	300,000	1.075	2.075	3.684	1.404	2.504	4.217
f	2011	400,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	400,000	1.073	2.016	3.636	1.437	2.541	4.258
	2013	400,000	0.982	1.982	3.593	1.313	2.409	4.124
g	2011	500,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	500,000	1.025	1.969	3.589	1.388	2.494	4.209
	2013	500,000	0.889	1.890	3.500	1.221	2.314	4.034
h	2011	704,600	1.053	1.873	3.232	1.358	2.174	3.534
	2012	781,000	0.928	1.879	3.493	1.292	2.398	4.107
	2013	784,200	0.662	1.671	3.280	0.998	2.083	3.820
i	2011	840,000	1.053	1.873	3.232	1.355	2.174	3.534
	2012	886,000	0.864	1.809	3.429	1.225	2.335	4.040
	2013	782,000	0.558	1.559	3.166	0.890	1.971	3.712
j	2011	1,120,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	1,107,000	0.734	1.683	3.297	1.080	2.201	3.900
	2013	1,007,000	0.369	1.333	2.943	0.450	1.742	3.485

Table h.2. Decision table with three year projections of posterior distributions for Pacific hake relative **depletion** (at the beginning of the year before fishing takes place). Catch alternatives are based on: 1) arbitrary constant catch levels of 50,000, 100,000, 150,000, 300,000, 400,000 and 500,000 mt (rows a-c, and e-g), 2) the status quo OY from 2010 (row d), and 3) the OY implied by the estimated F_{MSY} from the TINSS model (row h), and the values estimated via the 40:10 harvest control rule and the $F_{40\%}$ overfishing limit/target for the base case SS (row i) and TINSS models (row j).

			States of nature					
		Model	SS			TINSS		
		Within model probability	25%	50%	25%	25%	50%	25%
		Description	Low 2008 cohort	Modal density	High 2008 cohort	Low 2008 cohort	Modal density	High 2008 cohort
Management Action								
	Year	Catch (mt)						
a	2011	50,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	50,000	0.649	1.066	1.740	1.412	2.155	3.327
	2013	50,000	0.693	1.116	1.782	1.437	2.213	3.292
b	2011	100,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	100,000	0.633	1.055	1.729	1.389	2.142	3.307
	2013	100,000	0.669	1.095	1.760	1.397	2.173	3.252
c	2011	150,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	150,000	0.618	1.042	1.719	1.367	2.125	3.289
	2013	150,000	0.645	1.074	1.740	1.360	2.134	3.217
d	2011	262,500	0.549	0.909	1.493	1.144	1.749	2.704
	2012	262,500	0.589	1.014	1.698	1.320	2.087	3.260
	2013	262,500	0.591	1.023	1.693	1.269	2.049	3.138
e	2011	300,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	300,000	0.580	1.006	1.691	1.302	2.071	3.251
	2013	300,000	0.572	1.007	1.680	1.235	2.018	3.106
f	2011	400,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	400,000	0.556	0.984	1.670	1.264	2.022	3.214
	2013	400,000	0.519	0.963	1.642	1.147	1.939	3.019
g	2011	500,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	500,000	0.533	0.961	1.648	1.221	1.979	3.175
	2013	500,000	0.474	0.918	1.602	1.058	1.864	2.950
h	2011	704,600	0.549	0.909	1.493	1.144	1.749	2.704
	2012	781,000	0.484	0.913	1.604	1.145	1.900	3.114
	2013	784,200	0.357	0.809	1.496	0.852	1.677	2.763
i	2011	840,000	0.549	0.909	1.493	1.140	1.749	2.704
	2012	886,000	0.451	0.878	1.569	1.088	1.847	3.072
	2013	782,000	0.298	0.753	1.437	0.741	1.572	2.685
j	2011	1,120,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	1,107,000	0.387	0.816	1.505	0.916	1.733	2.930
	2013	1,007,000	0.202	0.643	1.329	0.359	1.383	2.510

Table h.3. Decision table with three year projections of posterior distributions for Pacific hake relative **spawning potential ratio** (1-SPR/1-SPRTarget=0.4; values greater than 1.0 denote overfishing). Catch alternatives are based on: 1) arbitrary constant catch levels of 50,000, 100,000, 150,000, 300,000, 400,000 and 500,000 mt (rows a-c, and e-g), 2) the status quo OY from 2010 (row d), and 3) the OY implied by the estimated F_{MSY} from the TINSS model (row h), and the values estimated via the 40:10 harvest control rule and the $F_{40\%}$ overfishing limit/target for the base case SS (row i) and TINSS models (row j).

			States of nature					
		Model	SS			TINSS		
		Within model probability	25%	50%	25%	25%	50%	25%
		Description	Low 2008 cohort	Modal density	High 2008 cohort	Low 2008 cohort	Modal density	High 2008 cohort
Management Action	Year	Catch (mt)						
a	2011	50,000	0.225	0.129	0.075	0.174	0.122	0.080
	2012	50,000	0.181	0.103	0.058	0.145	0.097	0.062
	2013	50,000	0.167	0.095	0.055	0.131	0.084	0.053
b	2011	100,000	0.399	0.241	0.145	0.311	0.225	0.152
	2012	100,000	0.334	0.197	0.113	0.266	0.184	0.120
	2013	100,000	0.316	0.184	0.107	0.247	0.162	0.103
c	2011	150,000	0.538	0.340	0.209	0.421	0.313	0.216
	2012	150,000	0.465	0.283	0.166	0.370	0.262	0.173
	2013	150,000	0.448	0.267	0.158	0.352	0.234	0.151
d	2011	262,500	0.766	0.519	0.337	0.608	0.470	0.338
	2012	262,500	0.699	0.451	0.274	0.560	0.411	0.282
	2013	262,500	0.699	0.437	0.266	0.551	0.379	0.250
e	2011	300,000	0.823	0.569	0.374	0.657	0.513	0.373
	2012	300,000	0.762	0.501	0.308	0.614	0.454	0.314
	2013	300,000	0.769	0.488	0.300	0.609	0.422	0.281
f	2011	400,000	0.946	0.685	0.466	0.764	0.613	0.457
	2012	400,000	0.905	0.620	0.392	0.740	0.557	0.395
	2013	400,000	0.933	0.615	0.387	0.748	0.529	0.359
g	2011	500,000	1.038	0.780	0.546	0.851	0.695	0.529
	2012	500,000	1.016	0.723	0.470	0.845	0.646	0.468
	2013	500,000	1.067	0.727	0.468	0.869	0.626	0.429
h	2011	704,600	1.166	0.926	0.682	0.986	0.824	0.648
	2012	781,000	1.214	0.932	0.650	1.055	0.835	0.631
	2013	784,200	1.307	0.973	0.664	1.139	0.843	0.599
i	2011	840,000	1.226	1.000	0.755	1.056	0.891	0.712
	2012	886,000	1.280	1.002	0.710	1.131	0.896	0.685
	2013	782,000	1.340	1.003	0.679	1.192	0.867	0.611
j	2011	1,120,000	1.308	1.110	0.878	1.166	1.004	0.820
	2012	1,107,000	1.359	1.118	0.822	1.325	1.014	0.786
	2013	1,007,000	1.378	1.116	0.815	1.664	1.027	0.733

Research and data needs

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

1) Conduct an annual acoustic survey.

2) Develop alternative indices for juvenile or young (0 and/or 1 year old) Pacific hake, perhaps based on existing acoustic survey observations or new sampling efforts.

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

4) Routinely collect life history information, including maturity and fecundity data for Pacific hake. Explore possible relationships among these observations as well as with growth and population density. Currently available information is limited and outdated.

5) Evaluate the quantity and quality of biological data prior to 1988 from the Canadian fishery for use in developing composition data.

6) Evaluate the quantity and quality of biological data prior to 1975 from the U.S. fishery for use in developing composition data.

7) 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.

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

9) Investigate meta-analytic methods for developing a prior on degree of recruitment variability (σ_r).

10) Develop management strategy evaluation tools to evaluate major sources of uncertainty relating to data, model structure and the harvest control rule for this fishery.

Table i.1. Summary of Pacific hake reference points from the SS model.

Quantity	2.5^{th} percentile	Median	97.5^{th} percentile
Unfished female spawning biomass (SB_0, million mt)	1.549	2.034	2.756
Unfished total biomass (million mt)	3.735	4.921	6.871
Unfished 3+ biomass (million mt)	3.239	4.252	5.760
Unfished recruitment (R_0, billions)	1.624	2.576	4.649
Reference points based on $SB_{40\%}$			
MSY Proxy female spawning biomass ($SB_{40\%}$ million mt)	0.620	0.814	1.102
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	0.406	0.435	0.512
Exploitation fraction resulting in $SB_{40\%}$	0.136	0.187	0.236
Yield at $SB_{40\%}$ (million mt)	0.217	0.323	0.521
Reference points based on SPR proxy for MSY			
Female spawning biomass at $SPR_{MSY\text{-}proxy}$ (SB_{SPR} million mt)	0.506	0.721	0.991
$SPR_{MSY\text{-}proxy}$	0.400	0.400	0.400
Exploitation fraction corresponding to SPR	0.182	0.217	0.258
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (million mt)	0.222	0.334	0.536
Reference points based on estimated MSY values			
Female spawning biomass at *MSY* (SB_{MSY} million mt)	0.315	0.491	0.790
SPR_{MSY}	0.189	0.286	0.451
Exploitation fraction corresponding to SPR_{MSY}	0.172	0.342	0.564
MSY (million mt)	0.228	0.355	0.581

Table i.2. Summary of Pacific hake reference points from the TINSS model.

Quantity	2.5^{th} percentile	Median	97.5^{th} percentile
Unfished female spawning biomass (SB_0, million mt)	0.851	1.242	2.121
Unfished total biomass (million mt)	2.046	3.008	5.258
Unfished 3+ biomass (million mt)	1.737	2.549	4.370
Unfished recruitment (R_0, billions)	0.891	1.491	2.903
Reference points based on $SB_{40\%}$			
MSY Proxy female spawning biomass ($SB_{40\%}$ million mt)	0.340	0.497	0.848
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	0.455	0.530	0.647
Exploitation fraction resulting in $SB_{40\%}$	0.101	0.151	0.194
Yield at $SB_{40\%}$ (million mt)	0.098	0.158	0.266
Reference points based on SPR proxy for MSY			
Female spawning biomass at $SPR_{MSY\text{-}proxy}$ (SB_{SPR} million mt)	0.000	0.283	0.497
$SPR_{MSY\text{-}proxy}$	0.400	0.400	0.400
Exploitation fraction corresponding to SPR	0.198	0.236	0.284
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (million mt)	0.000	0.145	0.253
Reference points based on estimated MSY values			
Female spawning biomass at *MSY* (SB_{MSY} million mt)	0.283	0.456	0.851
SPR_{MSY}	0.353	0.509	0.669
Exploitation fraction corresponding to SPR_{MSY}	0.093	0.165	0.268
MSY (million mt)	0.098	0.160	0.271

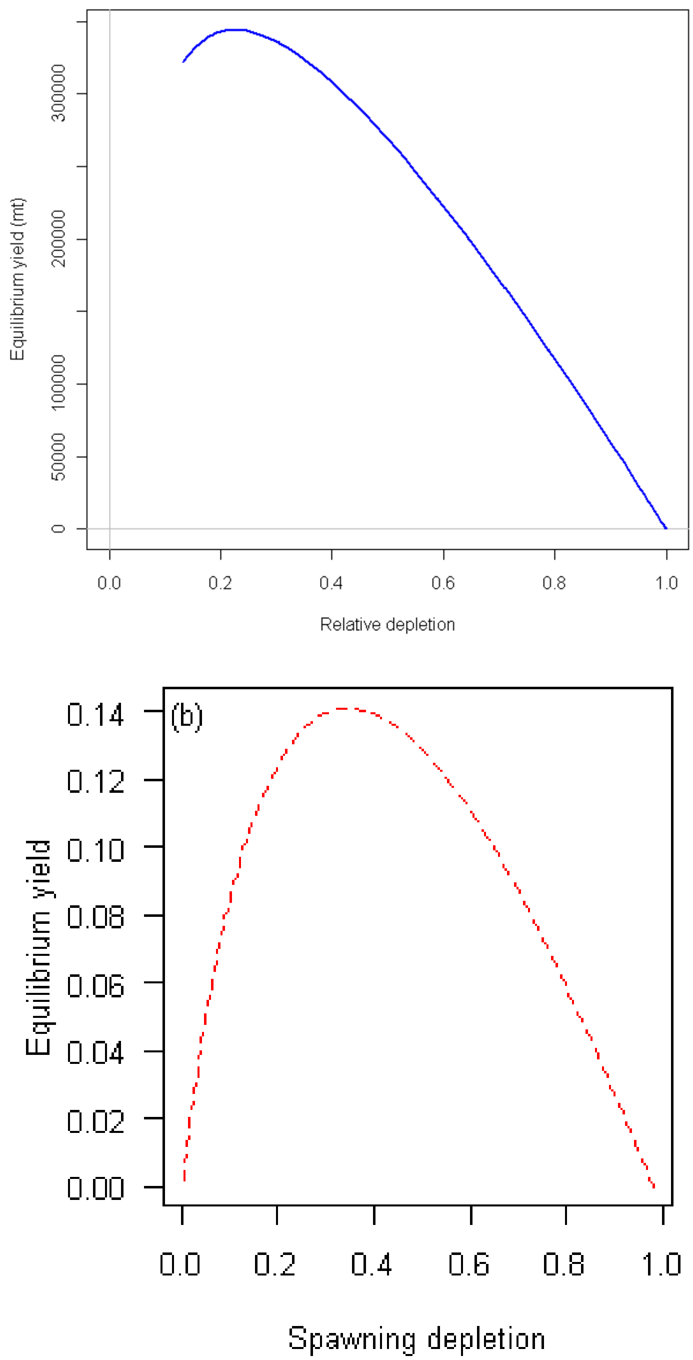

Figure h. Equilibrium yield curves for the SS (upper panel, mt) and TINSS (lower panel, million mt) assessment models. These results are based on MLE estimates.

1. Introduction

Prior to 1997, separate Canadian and U.S. assessments for Pacific hake were submitted to each nation's assessment review process. This practice resulted in differing yield options being forwarded to each country's managers for this shared trans-boundary fish stock. Multiple interpretations of Pacific hake status made it difficult to coordinate an overall management policy. Since 1997, the Stock Assessment and Review (STAR) process for the Pacific Fishery Management Council (PFMC) has evaluated assessment models and the PFMC council process, including NOAA Fisheries, has generated management advice that has been largely utilized by both nations. The Joint US-Canada treaty on Pacific Hake was formally ratified in 2006 (signed in 2007) by the United States as part of the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act. Although the treaty has been considered in force by Canada since June 25, 2008, an error in the original U.S. text required that the treaty be ratified again before it could be implanted. This second ratification occurred in 2010; however, as of this writing the treaty has not been fully implemented. Under the treaty, Pacific hake stock assessments are to be prepared by the Hake Technical Working Group comprised of U.S. and Canadian scientists and reviewed by a Scientific Review Group (SRG), with memberships as appointed by both parties to the agreement.

In keeping with the spirit of the treaty, this stock assessment document represents the work of a joint U.S. and Canadian stock assessment team. In addition, the stock assessment results reported here reflect nearly complete re-analysis of all available data for the Pacific hake stock during 2010. Many of these sources had not been investigated for decades and as a result the basic fishery and acoustic survey catch and age-frequency information differs somewhat from previous analyses after standardized methods were applied to raw data from both nations. The 2010 assessment and review process was marked by several rather difficult situations which included competing stock assessments from U.S. and Canadian analysts, as well as disagreement among analysts and reviewers on the use of certain data sources. Extensive modeling efforts conducted during 2010 as well as highly productive discussions among analysts have resulted in a unified document for 2011. It is our attempt to highlight progress made during 2010, residual areas of needed research, as well as ongoing scientific uncertainties in modeling choices, such that future technical working groups will enjoy a much easier working environment which fosters collaborative solutions to these difficult issues.

1.1 Stock structure and life history

Pacific hake (*Merluccius productus*), also referred to as Pacific whiting, is a semi-pelagic schooling species distributed along the west coast of North America generally ranging from 25^0 N. to 55^0 N. latitude. It is among 13 species of hake from the genus *Merluccius* (being the majority of the family *Merluccidae)*, which are distributed worldwide in both hemispheres of the Atlantic and Pacific oceans and collectively have constituted nearly two million mt of catch annually (Alheit and Pitcher 1995). 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 North Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California. Genetic studies indicate that Strait of Georgia and the Puget Sound populations are genetically distinct from the coastal population (Iwamoto et al.

2004). 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 Queen Charlotte Sound. Distributions of eggs, larvae, and infrequent observations of spawning aggregations indicate that Pacific hake spawning occurs off south-central California during January-March. Due to the difficulty of locating major offshore spawning concentrations, details of spawning behavior of hake remains poorly understood (Saunders and McFarlane 1997). In spring, adult Pacific hake migrate onshore and to the north to feed along the continental shelf and slope from northern California to Vancouver Island. In summer, Pacific hake form extensive mid-water aggregations in association with the continental shelf break, with highest densities located over bottom depths of 200-300 m (Dorn 1991, 1992). Pacific hake feed on euphausiids, pandalid shrimp, and pelagic schooling fish (such as eulachon and Pacific herring) (Livingston and Bailey 1985). Larger Pacific hake become increasingly piscivorous, and Pacific herring are commonly a large component of hake diet off Vancouver Island. Although Pacific hake are cannibalistic, the geographic separation of juveniles and adults usually prevents cannibalism from being an important factor in their population dynamics (Buckley and Livingston 1997).

Older Pacific hake exhibit the greatest northern migration each season, with two- and three-year old fish rarely observed in Canadian waters north of southern Vancouver Island. During El Niño events (warm ocean conditions, such as 1998), a larger proportion of the stock migrates into Canadian waters, apparently due to intensified northward transport during the period of active migration (Dorn 1995, Agostini et al. 2006). El Niño conditions also result in range extensions to the north, as evidenced by reports of hake off of southeast Alaska during these warm water years. Throughout the warm period experienced in 1990s, there were changes in typical patterns of hake distribution. Spawning activity was recorded north of California. Frequent reports of unusual numbers of juveniles off of Oregon to British Columbia suggest that juvenile settlement patterns also shifted northwards in the late 1990s (Benson et al. 2002, Phillips et al. 2007). Because of this shift, juveniles may have been subjected to increased cannibalistic predation and fishing mortality. However, the degree to which this was significant, and the proportion of the spawning and juvenile settlement that was further North than usual is unknown. Subsequently, La Nina conditions (colder water) in 2001 resulted in a southward shift in the stock’s distribution, with a much smaller proportion of the population found in Canadian waters in the 2001 survey. Hake were distributed across the entire range of the survey in 2003, 2005, 2007 (Figures 1 and 2) after displaying a very southerly distribution in 2001. Although a few adult hake (primarily from the 1999 cohort) were observed north of the Queen Charlotte Islands in 2009 most of the stock appears to have been distributed off Oregon and Washington.

1.2 Ecosystem considerations

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

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

1.3 Fisheries

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

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

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

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

1.4 Management of Pacific hake

Since implementation of the Magnuson-Stevens Fishery Conservation and Management Act in the U.S. and the declaration of a 200-mile fishery conservation zone in Canada in the late 1970's, annual harvest quotas have been the primary management tool used to limit the catch of Pacific hake. 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 acceptable biological catch (ABC) between U.S. and Canadian fisheries led to quota overruns; 1991-1992 quotas summed to

128% of the ABC, while the 1993-1999 combined quotas were 107% of the ABC on average. In the current Pacific hake agreement, the United States is allocated 73.88% of the total coast-wide harvest and Canada 26.12%.

In the last decade, the optimal yields (OYs, harvest targets) for Pacific hake have generally been set well below the Allowable Biological Catches (ABCs, harvest limits) and the total coast-wide catch has tracked the harvest targets reasonably closely (Table 2). In 2002, after Pacific hake was declared overfished by the U.S., the catch of 181 thousand metric tons exceeded the OY; however it was still below the ABC of 208 thousand mt. In 2004, after Pacific hake was declared rebuilt, and when the large 1999 cohort was at near-peak biomass, the catch fell well short of the OY of 501 thousand mt which is larger than the largest catch ever realized. Constraints imposed by bycatch of canary and widow rockfishes limited the commercial U.S. OY to 259 thousand mt. Neither the U.S. portion nor the total catch has substantially exceeded the harvest guidelines in any recent year, indicating that management procedures have been effective.

1.4.1 United States

In the U.S. zone, participants in the directed fishery are required to use pelagic trawls with a codend mesh that is at least 7.5 cm (3 inches). Regulations also restrict the area and season of fishing to reduce the bycatch of Chinook salmon and several depleted rockfish stocks. More recently, yields in the U.S. zone have been restricted to levels below optimum yields due to bycatch of overfished rockfish species, primarily widow and canary rockfishes, in the Pacific hake fishery. At-sea processing and night fishing (midnight to one hour after official sunrise) are prohibited south of 42° N. latitude. Fishing is prohibited in the Klamath and Columbia River Conservation zones, and a trip limit of 10,000 pounds is established for Pacific hake caught inside the 100-fathom contour in the Eureka INPFC area. During 1992-1995, the U.S. fishery opened on April 15; however in 1996 the opening date was changed to May 15. Shore-based fishing is allowed after April 1 south of 42° N. latitude, but is limited to 5% of the shore-based allocation being taken prior to the opening of the main shore-based fishery. The main shore-based fishery opens on June 15. Prior to 1997, at-sea processing was prohibited by regulation when 60 percent of the harvest guideline was reached. The current allocation agreement, effective since 1997, divides the U.S. non-tribal harvest guideline among factory trawlers (34%), vessels delivering to at-sea processors (24%), and vessels delivering to shore-based processing plants (42%). Since 1996, the Makah Indian Tribe has conducted a separate fishery with a specified allocation in its "usual and accustomed fishing area", and beginning in 2009 there has also been a Quileute tribal allocation.

1.4.2 Industry actions

Shortly after the 1997 allocation agreement was approved by the PFMC, fishing companies owning factory trawlers with U.S. west coast groundfish permits established the Pacific Whiting Conservation Cooperative (PWCC). The primary role of the PWCC is to allocate the factory trawler quota among its members to allow more efficient allocation of resources by fishing companies, improvements in processing efficiency and product quality, and a reduction in waste and bycatch rates relative to the former "derby" fishery in which all vessels competed for a fleet-wide quota. The PWCC also initiated recruitment research to support hake stock assessment. As part of this effort, PWCC sponsored a juvenile recruit survey in the summers of 1998 and 2001, which since 2002 has become an ongoing collaboration with NMFS. In 2009, the PWCC contracted a review of the 2009 stock assessment which was discussed in the 2010 stock assessment and was one of the contributing factors to the extensive re-analysis of historical data and modeling methods subsequent to that assessment.

1.5 Overview of Recent Fisheries

1.5.1 United States

In 2005 and 2006, the coast-wide ABCs were 531,124 and 661,680 mt respectively. The OYs for these years were set at 364,197 and 364,842 and were nearly fully utilized with abundant 1999 year-class comprising nearly all of the catch. For the 2007 fishing season the PFMC adopted a 612,068 mt ABC and a coast-wide OY of 328,358 mt. This coast-wide OY continued to be set considerably below the ABC in order to avoid exceeding bycatch limits for overfished rockfish. In 2008, the PFMC adopted an ABC of 400,000 mt and a coast-wide OY of 364,842 mt, based upon the 2008 stock assessment. This ABC was set below the overfishing level indicated by the stock assessment, and therefore the difference between the ABC and OY was substantially less than in prior years. However, the same bycatch constraints caused a mid-season closure in the U.S. in both 2007 and 2008 and resulted in final landings being below the OY in both years. Based on the 2009 whiting assessment, the Pacific council adopted a U.S.-Canada coast-wide ABC of 253,582 mt, and a U.S. ABC of 187,346 mt. The council adopted a U.S.-Canada coast-wide OY of 184,000 mt and a U.S. OY of 135,939 mt, reflecting the agreed-upon 73.88% of the OY apportioned to U.S. fisheries and 26.12% to Canadian fisheries. Bycatch limits were assigned to each sector of the fishery for the first time in 2009, preventing the loss of opportunity for all sectors if one sector exceeded the total bycatch limit and greatly reducing the 'race for fish' as bycatch accumulated during the season. In total, the 2009 U.S. fishery caught 121,110 mt, or 89.1% of the U.S. OY. Bycatch limits were not exceeded by any sector of the U.S. fishery and the fishery was able to harvest fish during the fall and early winter when bycatch rates were lower.

Faced with two stock assessments which yielded very different results, for 2010 the Pacific council adopted a U.S.-Canada coast-wide ABC of 455,550 mt, a U.S.-Canada coast-wide OY of 262,500 mt and a U.S. OY of 190,935 mt, reflecting the agreed-upon 73.88% of the OY apportioned to U.S. fisheries and 26.12% to Canadian fisheries. As in 2009, tribal fisheries did not harvest the full allocation granted them (49,939 mt in 2010), and two reapportionments were made to other sectors during the fishing season. In total, the 2009 U.S. fishery caught 160,818 mt, or 84.2% of the U.S. OY. Catcher-processor vessels fished from the May 15 start of the season through to December. Bycatch rates were generally not a problem, although known areas of high historical bycatch were still (anecdotally) being avoided. For periods during the fishing season and in certain areas of the coasts, many fishermen found it difficult to avoid the large schools of age-2 hake (200-300 grams) present off the U.S. coast. There were reports that increased search time resulted from efforts to avoid the schools of smaller fish. This was especially so for the shore-side fishery, which due to the presence of these small fish and to avoid bycatch of canary rockfish opted for a voluntary stand-down between June 30 to July 20. Some processors were able to make changes during the season in order process the smaller fish.

The U.S. tribal fishery reported a reduced amount of hake in their fishing areas and generally smaller sized fish.

1.5.2 Canada

The Canadian fishery has operated under an Individual Vessel Quota (IVQ) management system since 1997. Groundfish trawl vessels are allocated a set percentage of the Canadian TAC that is fully transferable within the trawl sector. Additionally the IVQ management regime allows an opportunity for vessel owner to exceed license holding by up to 15% and have these overages deducted from the quota for the subsequent year. Conversely, if less than the quota is taken, up to 15% can be carried over into the next year. For example, an apparent overage in 1998 was due to carry-over from 1997 when 9% of the quota was not taken; this policy has not resulted in catch exceeding the coast-wide OY in the past 7 years (Table 2).

Canadian Pacific hake catches were fully utilized in the 2005 fishing season with 85,284 mt and 15,178 mt taken by the shore-side and joint venture fisheries, respectively. In 2006, the joint-venture and shore-side fisheries harvested 13,700 mt and 80,000 mt, respectively. During the 2007 fishing season, Canadian fisheries harvested 85% of the 85,373 mt allocation. In 2008, Canadian fisheries harvested 78% of the 95,297 mt allocation with joint-venture and shore-side sectors catching 3,590 mt and 70,160 mt, respectively. During the 2009 season, no catches were made under joint-venture program. The Canadian shore-side fishery harvested 55,620 mt in 2009, or 115.7% of the Canadian OY.

Canada established the 2010 Canadian TAC at 68,565 mt, or 26.12% of the coast-wide OY taking into account the 2010 assessment, and in agreement with actions of the PFMC on setting the coast-wide OY. The carry forward from the 2009 season was 5,877 mt resulting in a total allowable harvest of 74,442 mt. This was allocated as 65,942 mt for delivery to shore-based facilities and 8,500 mt for delivery in to joint-venture fleet. The total catch for each fleet was 48,833 mt and 8,242 mt respectively, giving a total of 57,075 mt, or 77.0% of the 2010 quota. Since 23% of the quota was not captured in 2010, the Canadian fishery will carry over the maximum 15% into the 2011 season, as an overage allowance for 2011.

The fishery commenced in late April off the west coast of Vancouver Island. From mid-July to mid-August the fishing in the traditional area around La Perouse Bank limited due to presence of large quantities of small Hake in the area. The fishing fleet effort moved more westerly off the edge of the shelf where larger fish were found, however higher bycatch rates particularly of Yellowtail Rockfish were encountered. Vessels in the fleet are held individually accountable and responsible for the all catch and to many the increased bycatch proved to a major point of concern and affected fishing plans. The small fish presence resulted in many vessels to venture to more northerly waters into Queen Charlotte Sound. This resulted in deliveries into Port Hardy and the catch then shipped via trucks to Vancouver. This spatial shift of the fishery has been ongoing since 2008. The fleet moved back near the traditional grounds from August through October. Fishers continued to report the need to avoid large schools of small Hake (thought to be Age 2) in the area.

2. Available data sources

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

- Total catch from all U.S. and Canadian fisheries (1966-2010).
- Age compositions from the U.S. fishery (1975-2010) and Canadian fishery (1990-2010).
- Biomass indices and age compositions from the Joint U.S. and Canadian integrated acoustic and trawl survey (1995, 1998, 2001, 2003, 2005, 2007, and 2009).

Some sources were not included in the final base models, but have been explored and discarded in recent stock assessments or are included for 2011 via alternate models or sensitivity runs (these data are discussed in more detail below):

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

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

- Mean observed weight (at both size and age) from fishery and survey catches, 1975-2010.
- Mean observed length-at-age from fishery and survey catches, 1975-2010.
- Proportion of individual female hake mature by size and/or age from a sample collected in 1995.
- Aging error matrices based on cross-read and double-blind-read otoliths.

2.1 Fishery-dependent data

2.1.1 Total catch

The catch of Pacific hake for 1966-2009 by nation and fishery sector is shown in Table 1. Catches in U.S. waters for prior to 1978 are available only by year from Bailey et al. (1982) and historical assessment documents. Canadian catches prior to 1989 are also unavailable in disaggregated form. For more recent catches, haul or trip level information was available to partition the removals by month during the fishing season and estimate bycatch rates from observer information at this temporal resolution. This has allowed a more detailed investigation of shifts in fishery timing (Figure 5). Although the application of monthly bycatch rates differed from previous simpler analyses, it resulted in less than a 0.3% change in aggregate catch during the time-series. The U.S. shore-based landings are from the Pacific Fishery Information Network (PacFIN), foreign and joint-venture catches for 1981-1990 and domestic at-sea catches for 1991-2009 are estimated from the AFSC's and, subsequently, the NWFSC's at-sea hake observer programs stored in the NORPAC database. Canadian joint-venture catches from 1989 to April 2007 are from the Groundfish Biological (GFBio) database, the shore-based landings from 1989 to 1995 are from the Groundfish Catch (GFCatch) database, then from 1996 to April 2007 from the Pacific Harvest Trawl (PacHarvTrawl) database. From April 1, 2007 to the present the catch data for both fleets is found in the Fisheries Operations System (FOS). Discards are nominal relative to the total fishery catch. The majority of vessels in the U.S. shore-based fishery have operated under experimental fishing permits that required them to retain all catch and bycatch for sampling by plant observers. All U.S. at-sea vessels and Canadian joint-venture catches are monitored by at-sea observers. Observers use volume/density methods to estimate total catch. Domestic Canadian landings are recorded by dockside monitors using total catch weights provided by processing plants.

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

2.1.2 Fishery biological data

Biological information from the U.S. at-sea commercial Pacific hake fishery was extracted from the NORPAC database. This yielded length, weight and age information from the foreign and joint-venture fisheries from 1975-1990, and from the domestic at-sea fishery from 1991-2009. Specifically these data include sex-specific length and age data which observers collect by selecting fish randomly from each haul for biological data collection and otolith extraction. Biological samples from the U.S. shore-based fishery, 1991-2010, were collected by port samplers located where there are substantial landings of Pacific hake: primarily Crescent City, Newport, Astoria, and Westport. Port samplers routinely take one sample per offload (or trip) consisting of 100 randomly selected fish for individual length and weight and from these, 20 fish are randomly selected for otolith extraction. The Canadian domestic fishery is subject to 10% observer coverage. On observed trips, otoliths (for ageing) and lengths are sampled from Pacific hake caught in the first haul of the trip, with length samples taken on subsequent hauls. Sampled weight from which biological information is collected must be inferred from year-specific length-weight relationships. For unobserved trips, port samplers obtain biological data from the landed catch. Observed domestic haul-level information is then aggregated to the trip level to be consistent with the unobserved trips that are sampled in ports. For the Canadian joint-venture fishery, an observer aboard the factory ship records the codend weight for each delivery from a companion catcher boat. Length samples are collected every second day of fishing operations, and otoliths are collected once a week. Length and age samples are taken randomly from a given codend. Since the weight of the sample from which biological information is taken is not recorded, sample weight must be inferred from a weight-length relationship applied to all lengths taken and summed over haul.

The sampling unit for the shore-based fisheries is the trip, while the haul is the primary unit for the at-sea fisheries. Since detailed haul-level information is not recorded on trip landings documentation in the shore-based fishery, and hauls sampled in the at-sea fishery cannot be aggregated to a comparable trip level, there is no least common denominator for aggregating at-sea and shore-based fishery samples. As a result, samples sizes are simply the summed hauls and trips for fishery biological data. The magnitude of this sampling among sectors and over time is presented in Table 3.

Biological data were analyzed based on the sampling protocols used to collect them, and expanded to estimate the corresponding statistic from entire landed catch by fishery and year when sampling occurred. In general, the analytical steps can be summarized as follows:

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

To complete step (2), the expansion factor was calculated for each trip or haul based on the ratio of the total estimated catch weight divided by the total weight from which biological samples were taken. In cases where there was not an estimated sample weight, a predicted sample weight was computed by multiplying the count of fish in the sample by a mean individual weight, or by applying a year-specific length-weight relationship to the length of each fish in the sample, then summing these predicted weights. Anomalies can emerge when very small numbers of fish are sampled from very large landings; these were avoided by constraining expansion factors to not exceed the 95th percentile of all expansion factors calculated for each year and fishery. The total number of trips or hauls sampled is used as either the multinomial sample size input to the SS stock assessment model or as a relative weighting factor among years.

Aggregate fishery age compositions differed somewhat from those used in previous assessments, with smaller fish slightly more represented. This change is likely due to the calculation of age-composition data without including lengths extrapolated to ages via static age-length keys, as well as application of more accurate catch-weighting of the sector-specific compositions. These data confirm the well-known pattern of very large cohorts born in 1980, 1984 and 1999 (Figure 6). The most recent age-composition data from the 2009-2010 fishery indicate the presence of relatively strong 2005 and 2006 year classes. There was only a small number of fish from the 1999 year-class still present in the population, in 2010, at age 11. Most importantly for this assessment, is the presence of an extremely large relative proportion of one-year old hake in 2009 and 2-year old hake in 2010, indicating an unusually strong 2008 year-class.

Both the weight- and length-at-age information suggest that the growth of hake has changed markedly over time. This is particularly evident in the frequency of larger fish (> 55 cm) before 1990 and a shift to much smaller fish in more recent years (Figure 7). The treatment of length-at-age and weight-at-length are described in more detail in section 2.3.3 and 2.3.4 below. Although length composition data are not fit explicitly in the base case assessment models presented here, the presence of the 2008 year class is observed in both of the U.S. fishery sectors (Figure 8).

2.1.3 Bycatch in the pink shrimp fishery

Juvenile hake are frequently encountered by the trawl fishery for pink shrimp, which operates primarily in the waters off Oregon (NWFSC, 2009; Hannah and Jones, 2009). As part of the 2010 assessment, the estimated bycatch of juvenile hake in the pink shrimp fishery were examined in order to determine whether they might provide an alternate index of recent year-class strength prior to clear signal in the fishery. Many confounding factors resulted in an inability to create a proportional index of juvenile hake from the shrimp fishery. In the future, when and if the gear and behavior in the shrimp fishery becomes stable this potential index could be revisited, although spatial limitations may remain.

2.1.4 Catch per unit effort

Catch-per-unit-effort (CPUE) is a commonly utilized source of information about relative population trend in stock assessments world-wide. However, calculation of a reliable CPUE metric is particularly problematic for Pacific hake, and has therefore never been used as a tuning index for the stock assessment at any time during the 30-year assessment history. This is due to several important aspects of the fishery. The basic concept of “effort” is difficult to define for the hake fishery, as the use of acoustics, communication among vessels, extensive time spent searching and transit time between fishing ports and known areas of recurrent hake aggregations means that by the time a trawl net is put in the water, catch rates can be predicted by the fishing vessel reasonably well. Factory trawlers may continue to fish the same aggregation for days, while shore-based sectors may be balancing running time with hold capacity and therefore opt for differing catch rates. Further, during the last decade the hake fishery has been severely constrained due to bycatch avoidance. Periodic voluntary ‘stand-downs’, and temporary in-season closures have resulted from high bycatch rates, and in some years fishermen have changed their fishing behavior and fishing areas, in order to reduce bycatch of overfished rockfish species.

2.2 Fishery independent data

2.2.1 Acoustic survey

The joint U.S. and Canadian integrated acoustic and trawl survey has been the primary fishery independent tool used to assess the distribution, abundance and biology of coastal Pacific hake, *Merluccius productus*, along the west coasts of the United States and Canada. Coast-wide surveys were carried out jointly by the Alaska Fisheries Science Center (AFSC) and the Pacific

Biological Station (PBS) of the Canadian Department of Fisheries and Oceans (DFO) in 1995, 1998, and 2001. Following 2001, the responsibility for the U.S. portion of the survey was transferred to the Fishery Resource Analysis and Monitoring (FRAM) Division of NOAA's Northwest Fisheries Science Center (NWFSC). The survey was scheduled on a biennial basis, with joint acoustic surveys conducted by FRAM and PBS in 2003, 2005, 2007 and 2009. Between 1977 and 1992, acoustic surveys of Pacific hake were conducted every three years by the AFSC. However, these early surveys (1977–1992) covered only a reduced depth range and focused on U.S. waters (Table 4) and therefore are not used in the current assessment because of concerns over both bias and variability. Specific concerns are that Pacific hake abundance in the northern portion of the stock's range is highly variable and is not a simple fraction of the total population and that the survey did not extend offshore past a depth of 457 meters at most. A reasonable estimate of the variance for those early years would likely render them uninformative for the stock assessment, and raw data were not available from these surveys to re-analyze using current methods. Therefore, only acoustic surveys performed in 1995, 1998, 2001, 2003, 2005, 2007, and 2009 were used in this assessment (Table 5). The acoustic survey includes all waters off the coasts of the U.S. and Canada thought to contain portions of the coastal hake stock and all portions of the hake stock older than age-1. Age-0 and age-1 hake have been historically excluded from the survey efforts due to largely different schooling behavior relative to larger hake and concerns over drastically different catchability by the trawl gear.

The distribution of Pacific hake can vary greatly between years. It appears that northward migration patterns are related to the strength of subsurface flow of the California Current (Agostini et al. 2006) and upwelling conditions (Benson et al. 2002). Distributions of hake backscatter plotted for each acoustic survey since 1995 illustrate the variable spatial patterns (Figure 1). The 1998 acoustic survey stands out and shows an extremely northward occurrence that is thought to be tied to the strong 1997-1998 El Nino (Figure 2). In contrast, the distribution of hake during the 2001 survey was very compressed into the lower latitudes off the coast of Oregon and Northern California. In 2003, 2005 and 2007 the distributions generally followed the "normal" coast-wide pattern, but in 2009, the majority of the hake distribution was found in U.S. waters. Pacific hake also tend to migrate further north as they age. Figure 2 shows the mean location of Pacific hake observed in the acoustic survey by age and year. Age 2 hake are located in the southern portion of their distribution and the older ages are located more to the north within the same year. The mean locations of Pacific hake aged 6 and older tend to be more similar than the younger ages.

Historically, hake biomass (age 2+) was estimated from the survey data using a stratified transect design following Jolly & Hampton (1990). These design-based estimates did not account for spatial correlation of the data or patchiness of hake distributions and assumed that there was no hake biomass beyond the ends of each transect. In addition, estimates of variability were not routinely produced. For lack of a better methods, previous stock assessments assumed a constant variance for the acoustic survey index across all years, despite changes in the transect design and the distribution of the stock.

For the 2011 assessment of Pacific hake, acoustic survey data from 1995 onward were completely re-analyzed from the raw data using the conventional methods as well as geostatistical techniques (Petitgas 1993). Geostatistical methods account for spatial correlation and provide a more robust estimate of total biomass as well as an estimate of the year-specific sampling variability due to patchiness of hake schools and irregular transects. They have been endorsed by an ICES working group (Anon. 1993) as an appropriate method to analyze acoustic data, and have been used in many fisheries applications (Petitgas, 1993; Rivoirard et al. 2000; Mello & Rose 2005; Simmonds and MacLenann, 2005). More specifically, kriging was used to estimate both the biomass of Pacific hake and the uncertainty in that estimate from each year of the acoustic survey. There are several advantages to the kriging approach: 1) it provides the hake biomass and associated sample variance estimates simultaneously and properly accounts for spatial correlation along and between transects, 2) it provides biomass estimates in the area beyond transect lines but within correlation distance, 3) it provides maps of hake biomass and variance that take into account the heterogeneous and patchy hake distribution, and 4) it provides more flexibility in survey transect design such that transects do not need to be more or less perpendicular to the coast line, thus allowing for more efficient sampling designs.

During the acoustic surveys, mid-water trawls were made opportunistically to determine the species composition of observed acoustic marks and to obtain necessary length data to scale the acoustic backscatter into biomass (see Table 4 for the number of trawls). These biological samples have been post-stratified based on similarity in size composition and geographic proximity. There has been concern in past assessment reviews that the trawling conducted during the acoustic survey may not be representative of the acoustic backscatter due to stratification within schools as well as net avoidance behavior.

Field research done during the summer of 2010, and re-analysis of historical data was conducted in order to specifically address concerns in both the representativeness of trawling relative to observed backscatter and the sensitivity of the acoustic results to post-stratification. Both of these issues were made tractable due to the acquisition of all available historical data during 2010 and the development of new software to efficiently process these data. Multiple trawl sets were made on individual aggregations of hake during both U.S. and Canadian research cruises in 2010. In addition, a number of trawls were deployed with a camera mounted in the net to monitor fish behavior. These efforts revealed that hake were observed to be passively entering the net, without clear avoidance behavior. Further, the length composition of the trawl catch did vary substantially among hauls made in a relatively small area and short time period. In some cases, different modal structure was observed in the length-frequency distributions, indicating the presence of two or more cohorts. However, the only indication of systematic patterns occurred in a single bottom trawl deployed which captured somewhat larger fish than proximate mid-water trawls. Investigation of historical trawling effort revealed that trawl deployment was relatively proportional to observed backscatter as a function of distance off bottom, so such a pattern would be unlikely to produce a strong bias in the acoustic results. Because of the observed variability in the size structure of hake among hauls, it is quite reasonable to predict that there is a relatively large amount of observation error in survey estimates resulting from the fact that relatively few trawls are deployed each year (Table 4) and almost none repeated for a single aggregation. Utilizing software developed during 2010, sensitivity to post-survey stratification was evaluated for observations made in the most recent two acoustic surveys: 2007 and 2009. Alternate stratifications ranging from no stratification to schemes similar to historical methods were applied to each year’s biological samples. The results of this analysis indicated that biomass estimates varied by less than 9% over all stratification methods. This result suggests another source of variability in the acoustic results that could lead to variation in annual index observations relative to the true population, but also suggests that it is a relatively minor component among the sources of variability inherent to acoustic methods. These new analyses will be presented in more detail during the 2011 STAR panel, and were the primary basis for continued use of biological samples from the acoustic survey in the Pacific hake stock assessment models presented in this document.

The composite length frequency developed from the biological sampling was used to characterize the hake size distribution along each transect and to predict the expected backscattering cross section for Pacific hake based on the fish size-target strength (TS) relationship $TS_{db} = 20\log L - 68$ (Traynor 1996). Recent target strength work (Henderson and Horne 2007), based on in-situ and ex-situ measurements, estimated a regression intercept of 4-6 dB lower than that of Traynor (1996), suggesting that an individual hake reflects less acoustic energy, resulting in a larger estimated biomass than when using Traynor's (1996) equation. However, this difference would be accounted for directly in estimates of acoustic catchability within the assessment model. Estimates of biomass of hake at length (and age) within individual cells were summed for each transect to derive the conventional coast-wide estimate. Additionally, the cell-specific biomass estimates were used in the kriging analysis to provide kriged estimates. More details of the acoustic methods can be found in the background documents provided for the 2011 STAR panel.

The most recent acoustic survey (2009) spanned the continental slope and shelf areas along the west coast from south of Monterey California to the Dixon Entrance area. Biological sampling revealed the presence of four clear cohorts in the hake population (ages 3, 4, 6, and 10 corresponding to the 2006, 2005, 2003 and 1999 year classes), and also showed that Humboldt squid were present in very large numbers, representing the second most common species in the acoustic survey trawl catch by weight (47% after hake at 50%). Although the acoustic teams attempted to carefully and consistently delineate regions of backscatter to Pacific hake, the high abundance of Humboldt squid and the mixing of these two species resulted in an additional, and appreciable, source of uncertainty in the 2009 acoustic biomass estimate. This source of variability was relatively unexplored during the 2010 stock assessment and concerns over the potential magnitude of uncertainty in the hake biomass index that was attributable to mixing with squid led to the exclusion of that observation from one of the assessment models used by management. To address these concerns, a detailed re-analysis of the available data from 2009 was undertaken by the acoustics team and bootstrapping methods were employed to examine the variability in estimated hake abundance on a transect-by-transect basis. It was found that 61% of the estimated hake biomass occurred on transects that had no squid present. Two methods of bootstrapping the variability about the 39% of the hake biomass estimate that was potentially more variable due to the co-occurrence of Humboldt squid were: 1) resample from all the proportions of squid and hake observed during trawl sampling and assign them randomly to transects, and 2) create pdfs, based on the expert judgment of several acousticians, of the likely proportion of hake and squid below and above the depth threshold used for analysis and resample from these pdfs. Both methods yielded a similar level of variance in the resulting hake biomass estimates. Utilizing the larger of the two, the variance component attributable to Humboldt squid was roughly half as large as that attributable to sampling variability and school patchiness. To reflect these results in the stock assessment, the CV of the acoustic index based on the kriging analysis for 2009 (0.112) was inflated to a value of 0.138 (Table 5).

Comparisons of the acoustic survey biomass estimates (age 2+) are shown in Table 5 and Figure 9. The historical and reprocessed conventional estimates are not exactly the same, but are very similar. The kriged estimates are slightly greater than the conventional estimates, but follow the same pattern. This increase is expected because additional biomass beyond the end of each transect is predicted when kriging. In addition, year specific estimates of uncertainty are provided for the kriged estimates and the 2009 estimate of variability is inflated due to the presence of Humboldt squid (Table 5 and Figure 9). These estimates of uncertainty account for sampling variability and the variability due to squid in 2009, but several additional sources of observation error are also possible. For example, haul to haul variation in size and age, target strength uncertainty of hake as well as other species, and interannual differences in catchability likely lead to increased uncertainty in the acoustic estimates. In the future, it is possible that a thorough bootstrapping of many of these additional sources of variability can be conducted and the estimation of variance inflation constants in the assessment may be less important, but at present there is strong reason to believe that all survey variance estimates are underestimated relative to the true variability.

These uncertainties, as well as other factors, suggest that the survey estimates of biomass may not be an absolute estimate of biomass, but are more reasonably an index of abundance that describes the trend in Pacific hake biomass. The acoustic survey catchability coefficient, q, globally scales the population biomass predicted in the assessment model lower ($q<1$) or higher ($q>1$) to match the index of abundance, and uncertainty in q reflects the uncertainty in the absolute scale of the hake population. All stock assessments prior to 2004 that used the acoustic survey in age-structured assessments (e.g., Dorn et al. 1999) asserted $q=1.0$ and treated the parameter as a fixed quantity (In fact ABCs and OYs until 2003 were predicated upon that assumption). The 2004-2007 assessments presented two models with differing q's in order to bracket the range of uncertainty in the acoustic survey catchability coefficient. In 2008, an attempt was made to integrate out the uncertainty in q while incorporating uncertainty in the shape of the acoustic survey selectivity curve. In the 2009, 2010 and in current assessments q is estimated and the uncertainty is included in the estimates of population biomass from the assessment models.

As with the fishery data, acoustic survey age compositions were used to reconstruct the age structure of the hake observed by this survey. Proportions-at-age for the seven acoustic surveys are summarized in Figure 10 and clearly show the strong 1999 year class as well as the large 2005 and 2006 year classes. The acoustic survey does not include age-1 fish in their analysis. Therefore, with the most recent survey being conducted in 2009, the acoustic age data can only provide insight into the 2007 and earlier cohorts, but not the strength of the 2008 year-class.

2.2.2 Bottom trawl surveys

The Alaska Fisheries Science Center conducted a triennial bottom trawl survey along the west coast of North America from 1977 to 2001 (Wilkins et al. 1998). This survey was repeated for a final time by the Northwest Fisheries Science Center in 2004. In 1999, the Northwest Fisheries Science Center began to take responsibility for bottom trawl surveys off of the West Coast, and, in 2003, the Northwest Fisheries Science Center survey was extended shoreward to a depth of 30 fathoms to match the shallow limit of the triennial survey (Keller et al., 2008).

Despite similar seasonal timing of the two surveys, the 2003 and subsequent annual surveys differ from the triennial survey in size/horsepower of the chartered fishing vessels and bottom trawl gear used. As such, the two were determined (at a workshop on the matter in 2006) to be separate surveys which cannot be combined into one. In addition, the presence of significant densities of hake, both offshore and to the north of the area covered by the trawl survey, coupled with the questionable effectiveness of bottom trawls in catching mid-water schooling hake, limits the usefulness of this survey to assess the hake population. For these reasons neither the triennial, nor the Northwest Fisheries Science Center shelf trawl survey, have been used in recent assessments. With the growing time-series length of the NWFSC survey (now 8 years), future assessments should re-evaluate the use of the survey as an index of the adult and/or juvenile (age 0-1) hake population.

2.2.3 Pre-recruit survey

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

Trends in the coast-wide index have shown very poor correlations with estimated year-class strengths in recent assessment models, thus it has not been used in recent assessments. Because the survey was not conducted in 2010 it has not been revisited for this assessment.

2.3 Externally analyzed data

2.3.1 Maturity

The fraction mature by size and age is based on data reported in Dorn and Saunders (1997) and has remained unchanged since the 2006 stock assessment. These data consisted of 782 individual ovary collections based on visual maturity determinations by observers. The highest variability in the percentage of each length bin that was mature within an age group occurred at ages 3 and 4, with virtually all age-one fish immature and age 4+ hake mature. Within ages 3 and 4, the proportion of mature hake increased with larger sizes such that only 25% were mature at 31 cm while 100% were mature at 41 cm. Less than 10% of the fish smaller than 32 cm are predicted to be mature, while 100% maturity is predicted by 45 cm. Histological samples have been collected during recent bottom trawl surveys, but these samples have not yet been analyzed.

2.3.2 Aging error

With the transfer of Pacific hake ageing to the NWFSC in 2001, an effort was made to evaluate age reader agreement and calibrate readers at the Cooperative Aging Project (CAP, Newport, Oregon) with those at the Department of Fisheries and Oceans (DFO). As expected, agreement was greater for younger fish than for older fish. This exchange was used to estimate the ageing imprecision matrix applied in the 2008 assessment, using the maximum likelihood method of Punt et al. (2008). Subsequent to the 2008 assessment, 1,773 age estimates were compared between the CAP and AFSC for otoliths collected throughout the time-series but prior to 2001. These estimates allowed estimation of the degree of ageing imprecision for the AFSC ages. There were insufficient samples to estimate bias; however, precision was estimated and quantified as the standard deviation of observed age from true age. Values of imprecision at age estimated directly were found to be of similar magnitude to those from the CAP.

With this much larger available data set, the 2009 and 2010 assessments included an additional process influencing the ageing of hake: cohort-specific ageing error related to the relative strength of a year-class. This process reflects a tendency for uncertain age determinations to be assigned to predominant year classes. The result is a tendency towards reduced mis-ageing of strong year classes, and perhaps increased mis-ageing of neighbor year-classes. To account for this process in the model, we created year-specific ageing-error matrices (or vectors of standard deviations of observed age at true age), where the standard deviations of strong year classes were reduced by a constant proportion. In the 2009 and 2010 assessments, this proportion was determined empirically by comparing double read error rates for strong year classes with rates for other year classes. The result suggested that strong year classes only had 55% of the read-to-read disagreement in ageing as other year classes. In each year, that proportion (0.55) was applied for the strong year classes (for ages 2-15) as a multiplicative factor to the base ageing error vectors of standard deviations. For relatively strong but not dominant year classes, a proportion of 0.80 was applied. An alternative method of calculating the proportion by the age of the strong year class was explored in the 2010 assessment, with little change in overall results.

In 2010, a blind double-read study was conducted using otoliths collected across the years 2003-2009. One read was conducted by a reader who was aware of the year of collection, and therefore of the age of the strong year classes in each sample, while the other read was done by a reader without knowledge of the year of collection, and therefore with little or no information to indicate which ages would be more prevalent. The resulting data (a portion of which is shown in Figure 11) were analyzed via an optimization routine to estimate both ageing error and the cohort effect. The resultant ageing error was similar to the ageing error derived from the 2008 analysis, and the calculated strong cohort proportional ageing error was 0.41 (95% CI = 0.28 – 0.55), supporting the use of the 0.55 proportion.

In the current (2011) SS assessment, the ageing error matrix for all years is based on the analysis of CAP ageing error, since the AFSC and DFO ageing error data show similar results. In addition, we have applied the 0.55 proportion to the four strongest year classes (1980, 1984, 1999 and 2008). The use of the 0.8 proportion for moderately strong year classes was found to make negligible difference in results in previous assessments, and thus was not applied here. Sensitivity analyses to removing all ageing error and removing just the cohort effect are provided below.

2.3.3 Weight-at-length and age

In order to provide input values for the two models, a matrix of empirically derived population weight at age was required. Mean weight at age was calculated from samples pooled from all fisheries and the acoustic survey for the years 1975 to 2010 (Figure 12). Ages 15 and over were pooled and assumed to have the same weight at age. For ages 2 to 15+, 99% of the combinations of year and age had samples from which to calculate mean weight at age. At age 1, 58% of the years had samples available. Linear interpolation over both age and year dimensions was used to fill in the missing values. However, the samples are generally representative of the catch, so the combinations of year and age with no samples have very importance in the overall estimates of the population dynamics. The use of empirical weight at age is a convenient method to capture the variability in both the weight-at-length relationship within and among years (Figure 13) as well as the variability in length-at-age, without requiring parametric models to represent these relationships. However, this method requires the assumption that observed values are not biased by strong selectivity at length or weight and that the spatial and temporal patterns of the data sources provide a representative view of the underlying population

2.3.4 Length-at-age

In both 2011 assessment models and in models used for management prior to the 2006 stock assessment, variability in length-at-age was included in stock assessments via the calculation of empirical weight-at-age. In the 2006 and subsequent assessments that attempted to estimate the parameters describing a parametric growth curve, strong patterns have been identified in the observed data indicating sexually dimorphic and temporally variable growth. Synthesis models in recent years have not explicitly accounted for sex-specific patterns (although they have been documented repeatedly) but have allowed for the dramatic decline in maximum size and corresponding increase in growth rate observed in the data (Figure 7). Parametric growth models fit externally to data collected prior to 1990 and afterward show the same dramatically different rates of growth for both sexes that has been estimated inside the SS model in recent years (Figure 14). Hake show very rapid growth at younger ages, clearly evident in data partitioned into seasons within each year (Figures 15 and 16). The trajectories of individual cohorts also vary greatly, as has been documented in previous assessments.

In aggregate, these patterns result in a great amount of process error for length at age relative to commonly employed parametric growth models. This means that even complex approaches to modeling growth (and therefore fitting to length or age-at-length data explicitly) will have great difficulty in making predictions that mimic the observed data. This has been particularly evident in the residuals to the length-frequency data from recent SS models. We investigated models that allow for a high degree of complexity in the growth process and fit to length and age-at-length data in preparation for this assessment, but poor residual patterns persisted in all cases (Figure 17).

2.4 Prior probability distributions

The informative prior probability distributions used in this stock assessment are reported in Table 6. The two models used priors for different parameters, a summary for each model is provided in Table 7. Priors intended to be non-informative are listed in Tables 8 and 9. Several important distributions are discussed in detail below.

2.4.1 Natural Mortality

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

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

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

For the 2011 assessment, a combination of the informative prior used in recent Canadian assessments and the results from Hoenig's method described above were used to generate a log-normal distribution with a mean of 0.2 and a log-standard deviation of 0.1. Sensitivity to this prior is evaluated by examination of the posterior distribution as updated by the data, as well as the use of alternate priors, specifically a larger standard deviation about the point estimate.

2.4.2 Steepness

This assessment considered two priors for the steepness parameter (*h*) of the stock-recruit relationship: one directly informing the probability distribution via a Beta-distributed constraint, the second via informing the plausible distribution for F_{MSY}, which, given fixed life-history characteristics and selectivity, maps directly into an implied prior for steepness. The direct prior is based on the median (0.79), 20th (0.67) and 80th (0.87) percentiles from Myers et al. (1999) meta-analysis of the family Gadidae, and has been used in previous U.S. assessments since 2007. This prior is Beta-distributed with a mean of 0.777 and standard deviation of 0.113. The implied prior from F_{MSY} is explained below.

2.4.3 F_{MSY}

The underlying production function in TINSS is defined by three key population parameters (*MSY*, F_{MSY}, and *M*) and the parameters that define age-specific selectivity ($\hat{a}$ and $\hat{\lambda}$). Informative lognormal prior distributions were used for *MSY*, F_{MSY}, and *M* where the log means and log standard deviations are given in Table 6. These prior distributions for MSY and F_{MSY} were developed on an ad hoc basis and not necessarily derived from meta-analytic work that is the typical source of prior information.

In comparison to the SS model, a prior probability for F_{MSY} is nearly equivalent to a prior probability for steepness (*h*) A lognormal prior was assumed for F_{MSY}, with a mean corresponding to 0.35 and a standard deviation of 0.4 (corresponding to a 95% confidence interval for *h* of 0.16 to 0.77). This is broader than the prior used in 2010, which had a standard deviation of 0.263 (corresponding to a 95% confidence interval of 0.21 to 0.59). The prior was broadened to address concerns that the posterior predicted distribution for F_{MSY} (in this and previous assessments) tended to match the prior, indicating that the data contain little information about the productivity of the population. Broadening the prior for F_{MSY} therefore admits more uncertainty into the analysis.

Martell (2010) described the methodology to derive the 2010 prior for F_{MSY}, on which this prior is based. In his method, a steady-state, age-structured model was developed to calculate a Spawning Potential Ratio based on growth parameters from Francis et al. (1982), a natural mortality rate of 0.23, and a logistic selectivity curve. Arbitrarily, it was assumed that production is maximized somewhere between SPR=0.3 and SPR=0.45, and the corresponding values for $F_{30\%}$ and $F_{45\%}$ were then calculated. Based on the growth-maturity, natural mortality, and assumed selectivity, the values correspond to $F_{30\%} = 0.48$ and $F_{45\%} = 0.25$, which were then assumed to be the 10th and 90th percentiles for a lognormal distribution. Note that the SPR curve is insensitive to the assumed value of steepness and that $F_{40\%}$ is the assumed proxy for F_{MSY} that is used by the Pacific Fisheries Management Council. The analytical transformation from (*MSY*; F_{MSY}) to (SB_0; *h*) implies a prior density for the steepness parameter which is shown in Figure 18.

Note that in the Beverton-Holt stock recruitment model, values of *h* range between 0.2 and 1.0, where 0.2 implies that recruitment is nearly proportional to spawner/egg production, and 1.0 implies that recruitment is unrelated to spawner/egg production. The implied prior for *h* is sensitive to two key model components: the assumed prior distribution for F_{MSY}, and the ratio of the age at which fish recruit to the fishery and the age at which fish mature. Larger values of F_{MSY} imply a more productive stock and higher values of *h* for given selectivity and maturity schedules. Similarly, if fish recruit to the fishery prior to maturing then the levels of recruitment compensation (or *h*) must increase for a given value of F_{MSY}. This relationship is highly non-linear (Forrest et al. 2008). Therefore, critical pieces of information are the maturity-at-age and weight-at-age schedules used to develop the age-specific fecundity relationship, as well as the age at which fish recruit to the fishery.

2.4.4 MSY

The global scaling parameter in this model is *MSY*, the maximum long-term sustainable yield. The prior for this parameter was the same as that used in the 2010 assessment (Martell 2010). Since 1966, the average annual catch has been 221 thousand mt, and in the last decade 268 thousand mt. The TINSS model assumes a rather diffuse lognormal prior for *MSY*, with median value corresponding to 200,000 mt and a standard deviation of 500 thousand mt. This represents a 95% confidence interval of roughly 75 thousand mt to 532 thousand mt. Assigning a prior density for *MSY* is nearly equivalent to assigning a prior density for the global scaling parameter *q*.

2.4.5 Acoustic survey catchability (q)

A lognormal prior was placed on the survey catchability parameter *q*, in the TINSS model, with mean corresponding to 1 and log-standard deviation 0.1 (95% confidence interval of 0.82 and 1.22). The prior was used to help achieve model convergence. It might be considered overly precise, although it is worth noting that the maximum likelihood estimate was 0.73, outside the confidence limits of the prior. Sensitivity tests were done to evaluate the influence of the standard deviation of this prior.

3. Stock assessment

3.1 Modeling history

Age-structured assessment models of various forms have been used to assess Pacific hake since the early 1980s, using total fishery landings, fishery length and age compositions, and abundance indices. Modeling approaches have evolved as new analytical techniques have been developed. Initially, a cohort analysis tuned to fishery CPUE was used (Francis et al. 1982). Later, the cohort analysis was tuned to NMFS triennial acoustic survey estimates of absolute abundance at age (Francis and Hollowed 1985, Hollowed et al. 1988a). In 1989, the hake population was modeled using a statistical catch-at-age model (Stock Synthesis) that utilized fishery catch-at-age data and survey estimates of population biomass and age-composition data (Dorn and Methot, 1991). The model was then converted to AD Model Builder (ADMB) in 1999 by Dorn et al. (1999), using the same basic population dynamics equations. This allowed the assessment to take advantage of ADMB's post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest. Beginning in 2001, Helser et al. (2001, 2003, and 2004) used the same ADMB model to assess the hake stock and examine important assessment modifications and assumptions, including the time varying nature of the acoustic survey selectivity and catchability. The acoustic survey catchability coefficient (*q*) was one of the major sources of uncertainty in the model. The 2004 and 2005 assessments presented uncertainty in the final model result as a range of biomass. The lower end of the biomass range was based upon the conventional assumption that the acoustic survey *q* was equal to 1.0, while the higher end of the range represented a *q*=0.6 assumption.

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

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

In 2010 two competing models (one built in TINSS and one in SS) were presented to the STAR panel. Estimates of absolute stock size and yields differed greatly between the two models, and the causes of these differences went largely unidentified. The SSC recommended that the Pacific council base management advice on both models.

For 2011 we have focused on collaborative modeling, considerably refining both the historical U.S. and Canadian models to better understand the reasons for previous differences among models and to better present the uncertainty in current stock status in the spirit of the Pacific hake treaty.

3.2 Response to recent review recommendations

3.2.1 2011 STAR Panel and SSC review

The 2011 STAR panel (7-11 February, 2011) conducted a thorough review of the data, analyses and modeling conducted by the joint technical team (a full summary can be found in the STAR panel report). During the course of the review, several aspects of the TINSS model were improved, leading to results that were more similar to those from the SS model. Further, several errors and inconsistencies were identified in the underlying code that could be rectified during the review. Subsequent to the STAR review, several additional inconsistencies in the treatment of weight-at-age for various calculations were discovered. These issues were corrected, and the revised results presented to the SSC during the PFMC meeting (5 March, 2011). At the request of the SSC, the posterior distributions for management-related quantities from the SS and TINSS models were combined with equal weight in order to provide model-averaged estimates. All results reported in this document represent the final values on which the SSC and PFMC decisions were based.

3.2.2 2010 STAR Panel recommendations

1. *A detailed analysis of catch, effort, length, and age data by sex, going as far back as possible, and split by fleet, and vessel type, is needed to help understand the commercial data which go into the stock assessment models. In particular, this would enable, (i) defensible length and age frequencies to be constructed by fleet (not just shore-based and at-sea within country), which in turn may enable the modeling of the fisheries data with constant selectivities over time within fleet (or, at least, lead to a reduction in the need for time-varying selectivities); and (ii) abundance indices (i.e. one or more fleet-based CPUE indices) to be explored to provide an alternative (or an addition) to the acoustic survey biomass (should the squid remain in the region and continue to make survey-based hake biomass unreliable; also, having alternative or additional indices would strengthen the ability of the modelers to adequately assess the hake stock). This should also include additional spatial data describing the tribal and shore-based fisheries.*

Response: Catch, length, weight and age data were broken out by sex, fleet and season for the 2011 assessment. Models were constructed that utilized each of these data sources (the efforts described below); however, these models did not prove sufficiently different from the simpler Empirical Age model to justify their use. By conducting this exercise, we have been able to show that the model we are using mimics the model which includes the added complexity, and future assessments can continue to consider and revise the range of possible models which have been explored using the data processing tools that have been developed.

2. *Analysis from all data sources (commercial and acoustic survey) aimed at understanding the spatial, vertical, and temporal patterns of hake distribution (by length, age, and sex).*

Response: Much progress was made on this topic during 2010. The re-analysis of acoustic biological samples to investigate haul representativeness and sensitivity to stratification is described in section 2.2.1 above.

3. *Fund research into the appropriateness of attempting to produce biomass estimates at length, age, and sex, from acoustic surveys of semi-demersal species such as hake and pollock, including in the presence of possible confounding species such as Humboldt squid and lingcod. Once the work has been done (by statistician(s) with practical fisheries experience, in conjunction with acousticians) convene a workshop to discuss and review the findings. Ideally this should also address the issue of adequately sampling to groundtruth the acoustic estimates, including, for example, duration of trawl sampling, using a commercial trawler to sample, using another (additional) gear type to sample.*

Response: A workshop to evaluate acoustic survey design and methods is planned for 2012.

4. Place a very high priority on obtaining a defensible length to target strength relationship for hake.

Response: It is a high priority. Although alternate values for target strength will scale pure biomass estimates proportionally (and thus be absorbed by a freely estimated catchability coefficient), delineation of mixed-species backscatter may be sensitive to the relative target strengths for each component species. Aggregations of hake with sufficient individual targets were not present during the cruises conducted in 2010, but this research will be continued as is possible. Ongoing research by the U.S. and Canadian acoustics teams includes the use of a 'drop-transducer' for resolving single targets at depth as well as tethered animal observations.

5. Construct informed priors for the acoustic qs associated with the existing time series (this will ensure that future model runs stay in sensible space, or alternatively, that the estimates will be a revealing diagnostic).

Response: This is an area for future research, but not one that is likely to be easily resolved. Such a prior was unnecessary for the current SS model. A description of the prior for q used in the TINSS model is provided in section 2.4.5 above.

5. Provide an option in SS3 to disable or severely limit the penalty on recruitment deviations while maintaining internal consistency in the definition of B0.

Response: This is a general topic of research for age-structured models and likely requires simulation testing under varying data quality and quantity scenarios to determine its performance. A way to limit the penalty on recruitment in SS is to fix a very large σ_r parameter. However, this would cause the highly variable estimates in recruitment under the current modeling approach to only become more variable. Without including the assumption that recruitment has a distribution, nothing would prevent wild fluctuations in recruitments during early years with no data or the most recent recruitment years that have not yet been observed in the age composition data. Fundamentally, the connection between an internally consistent B0 and assumptions about a central tendency in recruitment are difficult if not impossible to separate.

3.2.3 2009 STAR Panel recommendations

1. *The Panel recommends the investigation of how the biological sampling in the acoustic survey occurs to determine whether these data are representative of the backscatter in the survey.*

Response: Mid-water and bottom trawls are made during survey operations in order to classify the observed acoustic quantity and to gather the length and age data needed to scale the acoustic data into units of biomass. The locations of these trawl deployments are not systematic, but rather opportunistic, depending on the local acoustic observations, recent trawl effort, and other logistical constraints (time available for trawling, time required to process the catch, weather and sea conditions, etc.). Due primarily to logistic and time constraints, not all scattering aggregations can be sampled. Typically, one to three trawl sets are made per day during the survey. While the biological sampling is not random, a comparative analysis of the occurrence of backscatter versus the deployment of trawl over both depth and latitude did not indicate a source of bias from the trawl sampling. Variability in the size and age structure of the trawl samples due to sparse sampling is therefore likely to contribute an additional source of process error in the acoustic index of abundance. The estimation of an additional variance component in the SS model accounts for this and other sources of process error.

2. *The panel recommends and investigation of how the biological samples are processed and applied to the acoustic estimates, including the post-stratification of length samples.*

Response: Documentation of the analysis methods has been completed and provided as part of the background materials for this assessment. Analysis of post-stratification methods and results during 2010 indicated that the time-series of abundance was remarkably robust to the stratification method (all stratification analyses produced < 10% change in the resulting biomass estimate). Pending re-analysis of all years from 1995-2009, a simpler *a priori* stratification approach may be employed in future surveys and historical estimates reanalyzed to be consistent with that choice of strata.

3. *The panel recommends that the raw data in the acoustic survey, including the length samples, be appropriately assembled to allow statistical analysis of these data as well as appropriate stratification*.

Response: All extant raw acoustic data has been assembled during 2010 and reanalyzed for this assessment. Data prior to 1995 was found to be inadequate to reconstruct abundance estimates and spatial coverage was such that reasonable variance estimates would be prohibitively large. Automated software tools for processing and kriging the acoustic data and for processing biological samples will allow bootstrapping of additional variance components for future stock assessments.

4. *The Panel recommends that a Management Strategy Evaluation approach be used to evaluate whether the current 40-10 harvest control rule is sufficient to produce the management advice necessary to ensure the sustainable use of the Pacific hake stock with its dramatically episodic recruitment. The 40-10 rule assumes that simply reducing catches in a linear fashion as stock biomass declines will be sufficient to guide the fishery back towards the target spawning biomass level. However, with the fishery being dependent upon a single declining cohort just reducing the catch may achieve the status quo but it rebuilding will not occur without new recruitment.*

Response: The STAT agrees strongly with this recommendation; however the extensive work on data processing and modeling methods during 2010 was a necessary first step before an MSE could be undertaken by the joint technical working group. Canadian scientists have begun research into this area, and it is likely that this issue will be addressed by the committees formed to fulfill the now ratified but currently not implemented hake treaty.

4.1 *Related to Recommendation 4, the operating model developed for the Management Strategy Evaluation should evaluate how well the different assessment models recapture true population dynamics. At issue is whether a simpler model such as ADAPT / VPA performs better or worse than a more complex model such as SS2.*

Response: One of the top research priorities provided in this assessment is to develop management strategy evaluation tools to evaluate major sources of uncertainty relating to data, model structure and the harvest control rule for this fishery.

5. *Future assessment models should explore gender- and length-based selection processes, in recognition that the gender differ in growth and that many of the more influential dynamic processes that operate in the fishery and length-based but are currently considered from and age-based perspective (for example selectivity).*

Response: A range of models was explored in preparation for the 2011 assessment with some including length-based selectivity, explicitly fitting to sex-specific data sources and estimating the degree of dimorphic growth. The conclusion for this effort, was that the processes driving growth of hake (both weight at length and length at age) are extremely dynamic, far more so than for most west coast groundfish. Hake get markedly heavier for their length during the growing season and this growth varies significantly from year to year. Prior to 1990 the patterns of length at age differed dramatically from growth observed in more recent years, and this variability is far more pronounced than the modest but significant difference between males and females. In aggregate, we were unable to create parsimonious models which could mimic the temporal variability in growth sufficiently to provide statistically acceptable fits to the length and age-at-length observations. While this may be possible in the future, it must be recognized that hake are atypical in the degree of growth variability relative to other groundfish. Even if such models could be constructed, it would not be a foregone conclusion that they could provide more reliable management advice than the somewhat simpler empirical approaches here, given that several models reported in this document, which included parametric growth, provided very consistent results.

6. When the raw acoustic survey data become available there should be a re-evaluation of the treatment of pre-1995 acoustic survey data and index values. For example, the biomass index implied by the area covered by the pre-1995 surveys should be compared with the total biomass from the full area covered by the post-1995 surveys. The difference between these two indices has implications for the magnitude of the survey catchability coefficient prior to 1995.

Response: All available historical acoustic survey data have been reanalyzed for this stock assessment. Data prior to 1995 were found to be inadequate to reconstruct abundance estimates for the entire stock and spatial coverage was such that reasonable variance estimates would be prohibitively large.

7. *There should be further exploration of geographical variations in fish densities and relationships with average age and the different fisheries, possibly by including spatial-structure into future assessment models.*

Response: The addition of spatial structure into the assessment model was beyond the scope of available resources for the 2011 assessment, but could be considered for future analyses.

8. *There should be exploration of possible environmental effects on recruitment and the acoustic survey.*

Response: A Fisheries And The Environment (FATE) proposal was funded and the research to investigate environmental effects on hake distribution, using acoustic survey data and an array of environmental variables is ongoing (see figure 2).

3.2.4 2009 Industry contracted review

A review of the 2009 Pacific hake stock assessment was conducted in 2009 by Quantitative Resource Assessment LLC (Dr. Mark Maunder, 2009). The review was thorough and suggested a number of improvements to the model; in particular, Dr. Maunder suggested two main changes to the assessment: 1) Explicit modeling of sex structure (i.e. treating males and females separately in the model and the data), and 2) Splitting the data into more fisheries, in part to improve the modeling of selectivity and changes in selectivity over time. Of additional concern was the treatment of the acoustic survey data for years when geographic coverage was incomplete as well as the assumption that trawl sampling (the biological data) and acoustic backscatter (the acoustic index) necessarily arise from the same selectivity process. Dr. Maunder emphasized that, due to actual differences in growth between the sexes, most of the other suggested improvements would be far less helpful without a split-sex model.

Response: Several assessment models including split-sex and fleet-disaggregated dynamics were constructed for this assessment and are reported as sensitivity analyses. These assumptions did not produce markedly different results for age-based selectivity and data constructs. As described above, models fully utilizing all available length observations, and length-based selectivity contained residual patterns that precluded their use for management advice. The data processing tools and re-analysis of historical observations will make it far easier for future stock assessments to revisit this topic and perhaps make additional progress. The potential benefit to full utilization of all length data could be a reduction in the considerable uncertainty in the assessment models, however the reliability of such models may need to be simulation-tested given the extremely dynamic growth processes observed in the historical time-series.

The acoustic survey data prior to 1995 have been removed from the stock assessment due to the raw observations being unusable. This is due to the incomplete spatial and depth coverage of the sampling and the prohibitively large variance that would result from analysis consistent with the recent time-series (kriging).

3.3 2011 Model descriptions

3.3.1 Stock Synthesis

This assessment uses the Stock Synthesis (SS) modeling framework developed by Dr. Richard Methot at the NWFSC. The Stock Synthesis application provides a general framework for modeling fish stocks that permits the complexity of population dynamics to vary in response to the quantity and quality of available data. In the current base assessment model, both the complexity of the data and the dynamics of the model are intended to be quite simple, and efforts have been made to be as consistent with the TINSS model as possible. Additional complexity is explored via sensitivity analysis, and sources of difference between the two models are highlighted where they have been identified.

In the SS model, the Pacific hake population is assumed to be a single coast-wide stock along the Pacific coast of the United States and Canada. Sexes are combined within all data sources, including fishery and survey age compositions, as well as in the model dynamics. The accumulator age for the internal dynamics of the population is set at 20 years, well beyond the expectation of asymptotic growth. The modeled period includes the years 1966-2010 (last year of available data), with forecasts extending to 2013. The population was assumed to be in equilibrium 20 years prior to the first year of the model, allowing a ‘burn-in’ of recruitment estimates such that the age structure in the first year of the model was free of all equilibrium assumptions. Since there were no large-scale commercial fisheries for hake until the arrival of foreign fleets in the mid- to late 1960s, no fishing mortality is assumed prior to 1966.

The model structure, including parameter specifications, bounds and prior distributions (where applicable) is summarized Table 8. The assessment model includes a single fishery representing the aggregate catch from all sectors in both nations (in comparison to recent SS assessments that have separated U.S. and Canadian fisheries into separate fleets). The effect of modeling the U.S. foreign, joint-venture, at-sea and shore-based fisheries, as well as the Canadian foreign, joint-venture and domestic fisheries as separate fleets is explored in a sensitivity analysis. Estimated selectivity for both the acoustic survey and commercial fishery does not change over time, unlike recent SS models. The selectivity curves were modeled as non-parametric functions estimating age-specific values for each age beginning at age 2 for the acoustic survey, since age-1 fish are not included in the design, and age-1 for the fishery, as small numbers are observed in some years. Selectivity is forced to be constant after age 5, but this restriction is evaluated via sensitivity analysis, as are alternate parameterizations. There was no evidence of dome-shaped selectivity in this assessment; this is a change from previous models which may be related to the removal of inconsistent acoustic survey observations prior to 1995.

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

For the base model, the instantaneous rate of natural mortality (*M*) is estimated with a lognormal prior having a mean of 0.2 and σ (in log-space) of 0.1 (described above). The stock-recruitment function was a Beverton-Holt parameterization, with the log of the mean unexploited recruitment freely estimated. This assessment used a beta prior for stock-recruit steepness (*h*) applied to previous assessments and described above. Year-specific recruitment deviations were estimated from 1946-2010. The constraint and bias-correction standard deviation, σ_R, for recruitment variability is fixed at a value of 1.3 in this assessment based on consistency with the observed variability in the time-series. Maturity and fecundity relationships are assumed to be time-invariant and fixed values remain unchanged from recent assessments.

The acoustic survey index of abundance was fit via a log-normal likelihood function, using the observed sampling variability, estimated via kriging as year-specific weighting, with an additional constant and additive log(SD) component, which was freely estimated to accommodate unaccounted for sources of process and observation error. Survey catchability was freely estimated with a uniform (noninformative) prior in log-space. A Multinomial likelihood was applied to age-composition data, weighted by the sum of the number of trips or hauls actually sampled across all fishing fleets, and the number of trawl sets in the research surveys. Input sample sizes were then iteratively down-weighted to allow for additional sources of process and observation error. This process resulted in tuned input sample sizes roughly equal to the harmonic mean of the effective sample sizes after model fitting.

3.3.2 TINSS

TINSS is an age-structured model that is conditioned on historical catch and parameterized from a management-oriented perspective, where leading estimated parameters are *MSY* and F_{MSY}. These were referred to as *C** and *F** in previous assessments (Martell 2008; 2009; 2010) after Schnute and Kronlund (1996), the original proponents of management-oriented models. For internal consistency within the present document, these parameters will now be referred to as *MSY* and F_{MSY} throughout. In management-oriented models, *MSY* and F_{MSY} are directly estimated as parameters and analytically transformed to their biological equivalents SB_0 and steepness, through the survivorship, growth, maturity and selectivity schedules (see Appendix F and Martell et al., 2008 for a detailed description of the transformation). In other respects, the model is structurally very similar to SS. The main differences are: the treatment of selectivity; the negative log-likelihood function for catch-at-age residuals; partitioning of observation and process error; and priors on the leading estimated parameters *MSY* and F_{MSY}. Where possible, sensitivity to these factors is reported below.

The TINSS model presented here differs from the 2010 assessment (Martell, 2010). The model is no longer initialized at equilibrium. Instead, annual recruitment is estimated as the product of an estimated mean recruitment (estimated in log space) and log-normally distributed annual recruitment deviations. Residuals are constrained to conform to a Beverton-Holt stock recruitment relationship, as in SS, with the stock-recruit parameters derived from the leading parameters *MSY* and F_{MSY}. The validity of the assumption of equilibrium starting conditions has been questioned in previous assessments, particularly because the stock displays a high degree of recruitment variability. The decision to remove this assumption was made jointly by the two stock assessment teams.

A total of 69 model parameters are conditionally estimated (Table 9). A summary of the input data is provided in Appendix D. The technical description of the model is provided in Appendix F; see also Martell et al. (2008) for further description of the model. The approach of TINSS is to fit an age-structured population dynamics model to time-series information on relative abundance, and age-composition data from the commercial fishery and acoustic survey using a Bayesian estimation framework. First, TINSS is conditioned on the total landings where the fishing mortality rate each year is determined by solving the instantaneous Baranov catch equation using the observed total landings and the estimated vulnerable biomass. The Baranov catch equation is solved using a derivative based root finding method. The model is fit to the acoustic survey biomass (Table 5), assuming that these data are proportional to the vulnerable biomass seen by the survey and also that observation errors are lognormal. Survey data were weighted multiplicatively in the objective function by the relative CVs from the kriging estimates. The model estimates the inverse of the total variance φ^{-2} as well as the variance ratio ρ, which partitions the total variance into the variances used for observation and process error (i.e., ρ represents the proportion of the total variance due to observation error).

The objective function contains five major components: 1) the negative log-likelihood of the relative abundance data; 2) the negative log-likelihood of the catch-at-age proportions in the commercial fishery; 3) the negative log-likelihood of the catch-at-age proportions in the acoustic survey; 4) the prior distributions for model parameters, and 5) two penalty functions that constrain the estimates of steepness to lie between 0.2 and 1, and prevent annual exploitation rates from exceeding 1. Note that the value of the penalty functions was 0 for all samples from the posterior distribution. The joint posterior distribution was numerically approximated using the Markov Chain Monte Carlo routines built into AD Model Builder (Otter Research 2008). Posterior samples were drawn systematically every 1,000 iterations from a chain of length 2 million (the first 2,000 samples were dropped to allow for sufficient burn-in). Convergence was diagnosed using visual inspection of the trace plots and examination of autocorrelation in posterior chains.

Catch advice is based on the samples from the joint posterior distribution. Empirical weight-at-age data, aggregated and weighted from both US and Canadian data, were used to convert numbers-at-age to weight-at-age (Figure 12, and described in section 2.3.3 above).

The biomass index was treated as a relative abundance index that is directly proportional to the survey vulnerable biomass as the beginning of the year. It is assumed that the observation errors in the relative abundance index are log-normally distributed. The survey catchability parameter q is treated as an uncertain parameter, but the maximum likelihood estimate of q is used in the calculation of the objective function (see Walters and Ludwig 1994). A normal prior,

~N(0.0, 0.1), was placed on log q. Sensitivity to the standard deviation of this prior was tested. Fishing mortality in the assessment model was conditioned on the observed total catch weight (combined US and Canada catch), and it was assumed that total catch is known and reported without error.

Age-composition information was assumed to come from a multivariate logistic distribution where the predicted proportion-at-age is a function of the predicted population age-structure and the age specific vulnerability to the fishing gear (Richards and Schnute 1998). The likelihood for the age-composition data was evaluated at the conditional maximum likelihood estimate of the variance (i.e., no subjective weighting scheme was used to scale likelihood for the age-composition information).

No aging errors were assumed in this assessment. Historical observations on mean weight-at-age show systematic changes where the average weights-at-age have declined from the mid-1970s and increased again slightly late 1990s (Figure 12). A number of the historical cohorts have growth trajectories that initially increase from age2 to age-8 then decline or stay relatively flat (e.g., 1977 cohort). Given these data, there are at least three alternative explanations for the observed decreases in mean weight-at-age: 1) changes in condition factor associated with food availability; 2) intensive size selective fishing mortality with differential fishing mortality rates on faster growing individuals; and 3) apparent changes in selectivity over time. All three of these variables are confounded, and it is not possible to capture decreasing weight-at-age using the von Bertalanffy growth model and a fixed allometric relationship between length and weight. As such, TINSS uses the observed mean weight-at-age data from the commercial fishery to scale population numbers to biomass.

It was assumed that recruitment follows a Beverton-Holt type stock-recruitment relationship and the process error terms are represented by a vector of deviation parameters (ωj) that are assumed to be log-normally distributed. Both fishing mortality and natural mortality were assumed to occur simultaneously. Instantaneous fishing mortality was based on the Baranov catch equation where the analytical solution for F_t is found using an iterative Newton-Raphson method with a fixed number of iterations to ensure the proper derivative information is carried forward in the autodiff libraries. Selectivity, or vulnerability-at-age, to the fishing gear was assumed to be age-specific, time-invariant, and is represented by an asymptotic logistic function. Selectivity in the acoustic survey was also assumed to be asymptotic, following a logistic curve, and time-invariant. Age-specific fecundity is assumed to be proportional to the product of body-weight and the proportion-at-age that are sexually mature.

As in the SS base model, the commercial catch and age-composition information from Canada and the U.S. was combined to represent a single fishery. The aggregation of the commercial catch data has the potential to create a bias in the predicted-age composition because it assumes that the age-specific fishing mortality rates between the two countries has been relatively consistent over time. Furthermore, the combining of the age-composition data is done using a weighted average, where the weights are based on the proportion of U.S. or Canadian landings by weight rather than by numbers.

3.4 Modeling results

3.4.1 Changes from 2010

Virtually all data sources and modeling approaches have been re-evaluated for 2011 and both the TINSS and SS models represent quite different model formulations than previously applied. The details and results are described fully below.

3.4.2 Model selection and evaluation

The SS modeling framework allows the fitting of a wide range of model complexities with only relatively small changes to input files and data organization. With the data-processing tools developed during 2010, the efficiency with which the technical team could explore alternate model formulations increased dramatically, no longer being hampered by an excessive period of time for data processing and formatting for each model. For this assessment, a multitude of models were constructed, ranging from simple production models to seasonal, sex-specific, fleet-disaggregated models with fully specified growth sub-models. An overview of these efforts is provided in Table 7, and the range of models is included in the sensitivity analyses.

The base SS generally provides similar results to those with more complex dynamics and a complex treatment of the data. However, as noted above and in the sensitivity section below, we were unable to find a parameterization that provided acceptable fits to the observed length and age-at-length data. This is likely due to temporal changes in growth among years and cohorts, as well as possibly mortality and fishery selectivity. A simple four-parameter production model, fitting to only the survey index, provided results that were so uncertain as to be of little value for management purposes (Figure 19).

Iterative reweighting of the composition data in the base case SS model did not produce large changes in the results, and resulted in a down-weighting of the fishery sample sizes to 10%, and the acoustic data to 89%, of the observed number of trips/hauls. This is consistent with the high degree of correlation among fishery tows for the at-sea fleet and the much greater temporal and spatial spread of the acoustic hauls. The additional variance component for the acoustic survey was estimated to be 0.26 at the median of the posterior distribution, indicating that additional process error, beyond simple sampling variability was present (as expected), but that it was not overwhelmingly large (although it did substantially exceed the sampling variance) and therefore the fit to the survey still informed the assessment.

The TINSS model is provided as an alternative to the SS models and to maintain consistency with recent assessment years. The SS base model is much more similar to TINSS compared to previous years: both models contain aggregated fishery information, empirical weights at age and similar prior assumptions where possible. A fundamental difference is the multivariate logistic likelihood functions used to calculate residuals in the commercial and survey age compositions. The multivariate logistic likelihood function (Richards et al. 1997) uses the conditional maximum likelihood estimate of the variance to weight the age composition data. This likelihood function was originally introduced into TINSS in response to problems encountered in previous assessments, where the age composition data had to be subjectively down-weighted to reduce retrospective bias (Martell 2010). In general, the multivariate logistic likelihood is more robust to weighting problems, although it does assume a single variance across all years, which may produce overly large residuals in some years.

A summary of the fit to the age-composition data and survey index for both models can be found in the model results section 3.4.3.

3.4.3 Assessment model results

Bayesian results are presented here for both assessment models. For the SS model, the MCMC chain was run for 5,000,000 iterations with the first 9,999 discarded to eliminate 'burn-in' effects. The 10,000th value and every 5,000th subsequent value were retained, resulting in 999 samples from the posterior distributions for model parameters and derived quantities. Stationarity of the posterior distribution for model parameters was assessed via a suite of standard diagnostic tests. The objective function, as well as all estimated parameters and derived quantities, showed good mixing during the chain and no evidence for lack of convergence. Autocorrelation was low (Figures 21 and 22) and correlation-corrected effective sample sizes were sufficient to summarize the posterior distributions. Neither the Geweke nor the Hiedelberger and Welch statistics for these parameters exceeded critical values more frequently than expected via random chance (Figure 23). Correlations among key parameters and derived quantities were generally low (Figure 24).

The fit of the modeled time series to the acoustic survey biomass index is shown in Figure 25. The fit to the acoustic survey biomass time series is quite reasonable, given the sum of the input and estimated variance components. The 2001 data point was well below the predictions made by any model we evaluated, and no direct cause for this is known, however it was conducted about one month earlier than all other surveys between 1995 and 2009 (Table 4), which may explain some portion of the anomaly. The 2009 index is higher than any predicted value observed in model evaluation. The uncertainty of this point is also higher than in other years, due to the presence of large numbers of Humboldt squid during the survey. This has been accounted for in both the data and the models.

Selectivity at age for both the fishery and survey is relatively uncertain (an important property of the non-parametric selectivity option) but generally consistent with the observation that fish are fully selected by the time they reach their full size (Figure 26). Fits to the age-composition data in the SS model are also reasonably good, with close correspondence to the dominant cohorts observed in the data and also identification of small cohorts, where the data give a consistent signal (Figures 27-29). These fits are improved over simpler models that do not include ageing error and the cohort effect on ageing error. Residual patterns to the fishery and survey age data do not show particularly evident trends that would indicate systematic bias in model predictions (Figures 30 and 31).

Posterior distributions for SS model parameters showed that for both steepness and natural mortality the prior distributions were likely strongly influencing the posterior (Figure 32).

In the TINSS model, the MCMC chain was run for 5,000,000 iterations. Every 5,000th subsequent value was retained, resulting in 1,000 samples from the posterior distributions for model parameters and derived quantities. Stationarity of the posterior distribution for model parameters was assessed by visualization of trace plots (Figure 33) and analysis of lagged autocorrelation. Autocorrelation plots (Figures 34 and 35) indicate minor autocorrelation for all parameters. There was some unresolved confounding among the parameters describing the scale of recruitment, the variability in recruitment and natural mortality in this population. Further evidence for confounding among these parameters is the negative correlation between the posterior estimates of $\ln\bar{R}$ and φ^{-2}, and between $\ln\bar{R}$ and M in the cross-correlation plot of posterior estimates (Figure 36 and 37). The plots of posterior density compared with prior density (Figure 38) provide further evidence that there is little information in the data about the productivity of the population (the posterior distribution for F_{MSY} is almost identical to the prior).

The fit of the modeled time series to the acoustic survey biomass index is shown in Figure 25. The assessment model fit to the acoustic survey biomass time series is similar to that for SS, although the TINSS model fit to the 2009 data point, despite down-weighting of this point.

The estimate of selectivity at age for the fishery is higher than in recent years (Figure 39; MLE of age at 50% first harvest estimated to be 4.83, compared to 3.51 from the 2010 TINSS assessment (Martell 2010).

Fits to the age-composition data in TINSS are reasonably good, with close correspondence of the dominant cohorts (Figures 40 and 41). Residual patterns to the fishery and survey age data do not show strong trends that would indicate systematic bias in model predictions (Figures 42 and 43), although the model did tend to overestimate proportion of age six fish, suggesting that age at 50% first harvest was overestimated, or natural mortality underestimated.

Both stock assessment models indicate that the Pacific hake female spawning biomass was well below equilibrium at the start of the fishery and during the 1970s (Figure 44 and Tables 10-14). The stock increased rapidly after two or more large recruitment events in the early 1980s (Figure 45 and Tables 15-16) and then declined rapidly 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 (1.44 million mt in the SS model and 1.75 million mt in the TINSS model) as the exceptionally large 1999 year class matured. In 2011 (beginning of year), spawning biomass is estimated to be rebounding rapidly based on the strength of recent year classes (2005, 2006 and particularly 2008, in both the SS and TINSS models), however this estimate is quite uncertain, with 95% posterior credibility intervals ranging from historical lows to well above equilibrium levels. Current median posterior spawning biomass equates to approximately 91% (SS model) or 175% (TINSS model) of the unfished level (SB_0; Figure 46). Estimates of uncertainty in current relative depletion are extremely broad, from 35%-203% of unfished biomass in the SS model and 75%-409% in the TINSS model (Figure 47). The estimate of spawning biomass for 2011 is 1.87 million mt in the SS model and 2.18 million mt in the TINSS model, both much larger than the 0.48 million mt estimated by the SS model in 2010 without information about the above-average 2008 recruitment. The 2010 TINSS median posterior estimate was 0.34 million mt. Model-averaged posterior median estimated 2011 spawning biomass (assuming equal weight for each model) was 2.03 million mt (0.72-5.14; Table 14). This corresponds to a model-averaged posterior median 2011 depletion level of 126% (42%-350%).

Estimates of historical Pacific hake recruitment indicate very large year classes in 1980, 1984 and 1999 in both assessment models. The strength of the 2008 cohort is estimated to be very large, and this is informed mainly by the 2010 fishery age compositions. Uncertainty in estimated recruitments is substantial, especially so for 2008, as indicated by the broad posterior intervals (Figure 45). A comparison of the stock-recruit relationships and recruitment deviations from the two models is provided in figures 48-50.

3.4.4 Model uncertainty

Both assessment models integrate over the substantial uncertainty associated with several important model parameters including: acoustic survey catchability (*q*) and the productivity of the stock (SS via the steepness, *h*, of the stock-recruitment relationship; TINSS via F_{MSY}, and natural mortality, *M*). Although the Bayesian results presented include estimation uncertainty, this within-model uncertainty is likely a gross underestimate of the true uncertainty in current stock status and future projections, since it does not include all structural modeling choices, data-weighting uncertainty and scientific uncertainty in selection of prior probability distributions. In an effort to capture these additional sources of uncertainty, we report the results from the two models throughout this document.

The Pacific hake stock displays the highest degree of recruitment variability of any west coast groundfish resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts and a biennial rather than annual fishery independent acoustic survey, will continue to result in highly uncertain estimates of current stock status and even less certain projections of stock trajectory in future stock assessments. The primary source of uncertainty that is relevant to management decision-making for the 2011 fishing season is the strength of the 2008 year-class. The estimate for this cohort is very uncertain, and the stock trajectory is entirely dependent on its value. For this reason, the decision table explicitly included columns representing alternate states of nature for low, mid and high estimated 2008 cohort strength. The vast uncertainty in this year class will likely persist until an acoustic survey has been conducted that provides an independent estimate of the magnitude.

3.4.5 Reference points

Unexploited equilibrium spawning biomass increased in the SS model to 2.03 million mt (from 1.33 million metric tons in the 2010 assessment), but the uncertainty is broad, with the 95% posterior credibility interval ranging from 1.55 to 2.76 million mt (Table 17). In the TINSS model, the median of the posterior was 1.24 million metric tons (Table 17; credibility interval: 0.85-2.12 million mt). The *MSY*-proxy target biomass ($SB_{40\%}$) is estimated to be 0.81 million mt in the SS model and 0.50 in the TINSS model. The minimum biomass thresholds ($SB_{25\%}$) are 0.51 and 0.31 million mt, respectively. *MSY* is estimated to be 355 thousand mt in the SS model and 160 thousand mt in the TINSS model (Figure 51). The equilibrium yield at the biomass target ($SB_{40\%}$) is estimated to be 323 thousand mt in the SS model and 158 thousand mt in the TINSS model. The full set of reference points are reported in Table 17.

The spawning potential ratio for Pacific hake is estimated to have been below the proxy target of 40% for both assessment models (Figure 52). Uncertainty in the value is large, and the TINSS model estimates that the SPR target has been exceeded in 1997 and 1998, while the SS model estimates that the value has remained below target. This difference is likely due to the very different selectivity curves estimated for the fishery in the two models and to the priors for the productivity parameters (see sensitivity analyses in section 3.4.7 below). Exploitation fraction (catch/age-3+ biomass estimates are remarkably similar for the two models, as this calculation is not influenced by fishery selectivity. The full exploitation history in terms of both the biomass and *F* targets is portrayed graphically via a phase-plot (Figure 53).

3.4.6 Model projections

The model-averaged posterior median for the 2011 ABC (overfishing limit) from the SS and TINSS models (equally weighted) was 973,727 mt. This value was highly uncertain with lower and upper posterior values approximately one-half as likely (the 12.5th and 87.5th percentiles) ranging from 530,115 to 1,726,125 mt.

In order to reflect the considerable uncertainty in recent (especially 2008) and future year-class strengths, as well as current absolute biomass levels, all forecasts are reported in the decision table format (Table 18). This allows for the evaluation of alternative management actions based on the full posterior distribution for both models. The decision table is organized such that the projected implications for each potential management action (the rows, containing a range of potential catch levels) can be evaluated for each of six states of nature (the columns). The six states of nature represent the lower 25%, middle 50% and upper 25% of the posterior distribution for the strength of the 2008 cohort for both the SS and TINSS models. Thus the middle value can be considered twice as likely as the first and last within each model. The choice of the 2008 cohort strength as the secondary axis of uncertainty (after including the two models) was based on the very large uncertainty associated with this recruitment as well as the fact that it is informed by only the 2010 fishery age composition data. For clarity, the decision table is divided into three sections: the first table projects the spawning biomass estimates, the second the relative depletion (for both of these the 2011 values will be identical for all management actions because they represent beginning of the year values) and the third the relative SPR rate. Relative SPR exceeding 1.0 indicates fishing in excess of the $SPR_{40\%}$ MSY-proxy (overfishing).

The stock is projected to increase in spawning biomass for all three states of nature in both models for catches up to an including 400,000 mt. At a catch level of 500,000 mt, the SS model predicts that the stock will not fall below 2011 levels at the mode of the posterior, but if the 2008 cohort is in the lower 25% of the posterior density, overfishing will occur and the stock will decline, while staying above the precautionary zone during the next three years. The TINSS model predicts that the stock will continue to increase at that harvest level under all three states of nature. The SS model 40:10 OY harvests are in excess of 800,000 mt at the mode of the posterior, while the TINSS model indicates that catches in excess of 700,000 and 1,100,000 mt would be consistent with the harvest control rule depending on whether the estimate of *MSY* or the $F_{40\%}$-proxy is applied. The differences between the two predictions are again likely due to the differences in estimated fishery selectivity and to the priors for the productivity parameters.

3.4.7 Sensitivity and retrospective analyses

A number of sensitivity analyses were conducted to test the effect of structural choices on the SS model results. These results, as well as retrospective analyses, (both within and among assessments) are presented below. Since both models are fully Bayesian, posterior parameter distributions for the base cases are provided instead of the frequently reported likelihood profiles, which are an imperfect proxy for the actual posteriors.

To expedite the comparison of sensitivities, MLE estimates are used instead of attempting to create full, converged posteriors for all sensitivity runs. In other words, the base model (Empirical Age or EA) MLE estimates are compared to the MLE estimates from each alternate sensitivity model via both. Because MLE estimates are used, the similarity between MCMC and MLE estimates were evaluated. Figures 54-57 show the MLE estimates and the medians of the posterior distributions of spawning biomass and depletion in 2011 for the SS and TINSS base-case models. The median of the posterior distribution for spawning biomass and 2011 depletion is slightly greater than the MLE estimate, which is expected due to the skewness of the posterior distribution. Additional comparisons are shown in Tables 19-20, and show a similar pattern. Overall, the MLE estimates and the medians of the posterior distributions are very similar for both the SS and TINSS models, and the MLE is likely to show similar patterns in sensitivity and retrospective analyses.

The first set of sensitivities for SS evaluated model structures that were more complex than the base-case model. Three models were tested.

1. **Age with Growth:** Similar to the Empirical Age model but used a growth curve that was externally estimated from length and age data. Composition data was fit for each of seven fishery sectors (instead of being aggregated into a single fishery as in the base model).
2. **Age by Sex with Growth:** Similar to the Age with Growth model, but modeled females and males separately. Age compositions and growth curves were sex-specific. Composition data were fit for each of seven fishery sectors (instead of being aggregated into a single fishery as in the base model).
3. **Age with Catch by Season:** Similar to Age with Growth, but fishery catches were further disaggregated into nine seasons within each year to account for both fishery timing and growth within the year. Changes in weight-at-length were explicitly modeled for each year and each season within the year based on externally estimated parameters. Composition data was fit for each of seven fishery sectors (instead of being aggregated into a single fishery as in the base model).

Results of these three models compared to the Empirical Age model are shown in Table 21 and Figure 58. The four models were remarkably similar in terms of spawning biomass trajectories, although the Empirical Age model tended to have the lowest spawning biomass. Historic large year classes tended to be larger for the Empirical Age model, but the 2008 cohort was smaller. The estimated parameters were generally similar, and it is interesting to note that the estimated male and female natural mortalities were almost identical. The biggest difference was in estimates of long-term average unexploited biomass, which resulted in differences in depletion. The Age with Sex and Growth model estimated the largest long-term average unexploited biomass, thus showed the most depleted stock in 2011. The long-term average unexploited biomass for the Age with Growth model was slightly higher than the Empirical Age and Age with Catch by Season models, which both used empirical weight-at-age instead of growth. Overall, more complex models did not result in appreciable differences in the basic results and the more parsimonious Empirical Age model appears to predict the abundance of Pacific hake consistently.

The next sensitivity analysis addresses the uncertainty of the 2008 year-class and the sensitivity of the forecasts to removing the 2010 age data. Spawning biomass in 2010 and 2011 is projected to increase dramatically due to the large estimated 2008 year class, although its estimate includes a great deal of uncertainty. Removing the 2010 age data makes very little difference to the historic spawning biomass and recruitment time-series, but greatly reduces the 2010 and 2011 spawning biomass estimates due to the prediction of much lower recruitment in 2008, which was close to equilibrium recruitment (Figure 59). The recent large year-classes from 2005 and 2006 were also slightly affected, but parameters not associated with recent recruitments remained nearly unchanged (Table 22). This sensitivity shows that the majority of information for the 2008 year class is in the 2010 age data. The 2009 fishery catch-at-age data showed a slight hint of a strong 2008 year class (Figure 6), but due to low selectivity at age-1 and no other data to support this observation, it was not very informative. The acoustic survey specifically excludes age-1 fish, thus there was no indication of this cohort in the 2009 acoustic survey data. A 2010 acoustic survey would have been extremely informative to the prediction of recent and future spawning biomass because it would have been an additional observation either corroborating or invalidating the observation from the fishery.

The influence of prior distributions developed for steepness (*h*) and natural mortality (*M*) were investigated through additional sensitivity testing. To provide a rough comparison of the aggregate effects of the priors for *M*, *MSY*, and F_{MSY} used in the 2010 TINSS model, the implied prior for steepness from that model was implemented in SS. This steepness prior had a mean of 0.48 and a SD of 0.10 (this differs from the somewhat updated value resulting from the 2011 assessment, but is still illustrative with regard to the effects of a prior on steepness with a mode at a much lower value). This alternate prior resulted in very little change to recent estimates of spawning biomass, but increased the estimate of equilibrium biomass, resulting in predictions of a more depleted stock (Table 23 and Figure 60). Next, the standard deviation on the prior for M was increased to 0.5 from 0.10, resulting in an increased estimate of natural mortality as well as larger estimates of spawning biomass and a less depleted stock. Estimates of equilibrium biomass were similar, but showed increased uncertainty. Finally, fixing *M* at 0.23 (the value used in recent assessments), produced intuitive results falling between the base run and the widened M prior run (Table 23 and Figure 61). Overall, lower values of steepness and natural mortality independently resulted in a slightly more depleted stock and smaller virgin equilibrium recruitment.

The effect of using ageing error was addressed for the SS model. The base model assumes that cohort ageing error occurs, and a sensitivity test to using ageing error without the additional cohort ageing error showed minor differences. As expected, the large estimated recruitments were slightly stronger than with cohort ageing error and equilibrium spawning biomass was slightly less, but there was virtually no change to 2011 depletion (Table 24 and Figure 62). Spawning biomass at the beginning of the time-series was slightly less than the base case. Removing ageing error altogether resulted in a slightly larger change to predictions. The equilibrium spawning biomass was further reduced, and large recruitments were smaller than those estimated in the base model, resulting in a smaller increase in the spawning biomass in recent years. Therefore, 2011 depletion was lower and the SPR ratio was slightly higher.

Estimated selectivity was different for the SS and TINSS models, and was investigated through additional sensitivity tests. The SS model compared three runs to its base-case: 1) non-parametric, age-specific parameters estimated up to age 8, 2) estimating parameters for a parametric double-normal selectivity curve, and 3) introducing time-varying selectivity. The results indicated that the SS model was quite insensitive to the shape and complexity of the selectivity curves (Table 25 and Figure 63) and that the support for dome-shaped selectivity observed in recent stock assessments has disappeared, likely due to the removal of inconsistent and incomplete acoustic surveys prior to 1995. There was some discussion of time-varying selectivity during the 2011 STAR panel and the general result that the first sensitivity run listed above produced a somewhat lower estimate of the 2008 year-class was of interest to the panel. At the informal request of the GMT, the 2011 ABC catch implied by the 40:10 harvest control rule was calculated for the sensitivity run with time-varying selectivity in all years. The value was 757,738 mt, somewhat lower than the base case model, but still relatively larger compared to recent actual catches.

The key sensitivities in the TINSS analysis were assumed priors for the leading parameters F_{MSY} and *MSY* and to the prior for *M*. Sensitivity to these assumptions was tested using MLE results.

A full list of sensitivity analyses is provided in Table 26. Maximum likelihood estimates of predicted model quantities were relatively insensitive to priors for F_{MSY} and *MSY* (Figures 64 and 65; Tables 27 and 28); and quite sensitive to priors for *M* and *q* (Figures 66 and 67, Tables 29 and 30). F_{MSY} and *MSY* tended to be positively correlated (Figure 37). Therefore, higher estimated F_{MSY} occurred with higher estimated *MSY*. These values translated (through the selectivity function) to estimates of higher steepness and lower R_0, respectively (Tables 27 and 28). This represents unresolved confounding between a larger, less productive population versus a smaller, more productive population, with both able to explain the observations equally well. This type of confounding is typical of many stock assessments.

The effect of varying the mean of *M* in the prior had an expected effect. Increasing the mean resulted in estimates of a larger population with smaller unfished biomass and correspondingly slightly larger predicted depletion in 2011 (Figure 66 and Table 29). The opposite was true when mean *M* was decreased. Increasing the SD for survey catchability (*q*) resulted in higher estimates of *q* compared to the base (Table 30). Corresponding estimates of spawning biomass predictably decreased slightly as the catchability increased, as did estimates of depletion.

Retrospective analyses were conducted by systematically removing the terminal years' data sequentially for five years. For the SS model, no retrospective pattern was observed for spawning biomass and recruitment estimates prior to the year 2000 (Figure 68). Parameter estimates also showed no patterns except that the additional variability on the acoustic survey index increased each time an observation was removed (Table 31). A retrospective pattern may seem to be present in recent estimates of spawning biomass, but this can be explained by the recent large year-classes supporting the spawning biomass. As data are removed, less information is available to accurately estimate these recruitments, thus they move towards equilibrium recruitment, and the estimated spawning biomass becomes lower. The effect of additional data can also be seen in the 1999 year class, which increases as data are added since observations of this cohort are persistent through time. This further shows that recent data are critical to accurately estimate current and future biomass.

An analogous retrospective analysis was performed for the maximum likelihood estimates from the TINSS model. There was a slight downward retrospective bias in spawning stock biomass in runs when data was excluded (Figure 69, Table 32). For example, as data are removed, estimates of spawning stock biomass in 2006 generally become smaller. This is due to a modest decrease in the estimate of the strength of the 1999 cohort - as indicated by the estimates of age-1 recruits in the year 2000 (Figure 34). Retrospective estimates of unfished spawning stock biomass SB_0 and the parameters that defined the underlying production (F_{MSY} and M) also showed very little trend as data were sequentially removed. Estimates of SB_0 were relatively stable as data from 2005, and onward, were included in the assessment. Estimates of M and F_{MSY} were also relatively stable. Overall, the retrospective analysis suggest that the underlying production function is relatively stable, and change in estimates of spawning stock biomass is due to retrospective changes in age-1 recruits.

A comparison of the models put forward for management since 1991 (a retrospective among assessment models) shows that there has been considerable uncertainty in the Pacific hake stock biomass and status (Figure 70). Model-to-model variability (especially in the early portion of the time-series) is larger than the uncertainty reported in any single model, and this pattern does not appear to dampen as subsequent assessments are developed. Perhaps the most important feature of this historical perspective is the inclusion of alternate values for survey catchability during 2004-2007, and then freely estimated values from 2008-the present; prior to that period catchability was ubiquitously assumed to be equal to 1.0.

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6. Tables

Table 1. Annual catches of Pacific hake (1000s mt) in U.S. and Canadian waters by sector, 1966-2010. Tribal catches are included in the sector totals.

	U.S					Canada				
Year	Foreign	JV	At-sea	Shore -based	Total U.S.	Foreign	JV	Domestic	Total Canada	Total
1966	137.00	0.00	0.00	0.00	137.00	0.70	0.00	0.00	0.70	137.70
1967	168.70	0.00	0.00	8.96	177.66	36.71	0.00	0.00	36.71	214.37
1968	60.66	0.00	0.00	0.16	60.82	61.36	0.00	0.00	61.36	122.18
1969	86.19	0.00	0.00	0.09	86.28	93.85	0.00	0.00	93.85	180.13
1970	159.51	0.00	0.00	0.07	159.58	75.01	0.00	0.00	75.01	234.59
1971	126.49	0.00	0.00	1.43	127.92	26.70	0.00	0.00	26.70	154.62
1972	74.09	0.00	0.00	0.04	74.13	43.41	0.00	0.00	43.41	117.54
1973	147.44	0.00	0.00	0.07	147.51	15.13	0.00	0.00	15.13	162.64
1974	194.11	0.00	0.00	0.00	194.11	17.15	0.00	0.00	17.15	211.26
1975	205.65	0.00	0.00	0.00	205.65	15.70	0.00	0.00	15.70	221.35
1976	231.33	0.00	0.00	0.22	231.55	5.97	0.00	0.00	5.97	237.52
1977	127.01	0.00	0.00	0.49	127.50	5.19	0.00	0.00	5.19	132.69
1978	96.83	0.86	0.00	0.69	98.38	3.45	1.81	0.00	5.26	103.64
1979	114.91	8.83	0.00	0.94	124.68	7.90	4.23	0.30	12.43	137.11
1980	44.02	27.54	0.00	0.79	72.35	5.27	12.21	0.10	17.58	89.93
1981	70.36	43.56	0.00	0.88	114.80	3.92	17.16	3.28	24.36	139.16
1982	7.09	67.46	0.00	1.03	75.58	12.48	19.68	0.00	32.16	107.74
1983	0.00	72.10	0.00	1.05	73.15	13.12	27.66	0.00	40.78	113.93
1984	14.77	78.89	0.00	2.72	96.38	13.20	28.91	0.00	42.11	138.49
1985	49.85	31.69	0.00	3.89	85.44	10.53	13.24	1.19	24.96	110.40
1986	69.86	81.64	0.00	3.47	154.97	23.74	30.14	1.77	55.65	210.62
1987	49.66	106.00	0.00	4.80	160.45	21.45	48.08	4.17	73.70	234.15
1988	18.04	135.78	0.00	6.87	160.69	38.08	49.24	0.83	88.15	248.84
1989	0.00	195.64	0.00	7.41	203.05	29.75	62.72	2.56	95.03	298.08
1990	0.00	170.97	4.54	9.63	185.14	3.81	68.31	4.02	76.14	261.29
1991	0.00	0.00	205.82	23.97	229.79	5.61	68.13	16.17	89.92	319.71
1992	0.00	0.00	154.74	56.13	210.87	0.00	68.78	20.04	88.82	299.69
1993	0.00	0.00	98.04	42.11	140.15	0.00	46.42	12.35	58.77	198.92
1994	0.00	0.00	179.87	73.62	253.48	0.00	85.16	23.78	108.94	362.42
1995	0.00	0.00	102.31	74.96	177.27	0.00	26.19	46.18	72.37	249.64
1996	0.00	0.00	128.11	85.13	213.24	0.00	66.78	26.36	93.14	306.38
1997	0.00	0.00	146.05	87.42	233.47	0.00	42.57	49.23	91.79	325.26
1998	0.00	0.00	145.16	87.86	233.01	0.00	39.73	48.07	87.80	320.81
1999	0.00	0.00	141.02	83.47	224.49	0.00	17.20	70.16	87.36	311.84
2000	0.00	0.00	120.92	85.85	206.77	0.00	15.06	6.38	21.44	228.21
2001	0.00	0.00	100.53	73.41	173.94	0.00	21.65	31.94	53.59	227.53
2002	0.00	0.00	84.75	45.71	130.46	0.00	0.00	50.24	50.24	180.70
2003	0.00	0.00	86.61	55.34	141.95	0.00	0.00	63.23	63.23	205.18
2004	0.00	0.00	117.07	96.50	213.57	0.00	58.89	66.19	125.08	338.65
2005	0.00	0.00	151.07	109.05	260.12	0.00	15.69	87.34	103.04	363.16
2006	0.00	0.00	139.79	127.17	266.96	0.00	14.32	80.49	94.80	361.76
2007	0.00	0.00	126.24	91.44	217.68	0.00	6.78	66.08	72.86	290.55
2008	0.00	0.00	180.64	67.76	248.40	0.00	3.59	70.16	73.75	322.14
2009	0.00	0.00	72.35	49.22	121.57	0.00	0.00	55.88	55.88	177.46
2010	0.00	0.00	106.31	54.50	160.82	0.00	8.08	48.01	56.09	216.91
Average:					164.28				56.31	220.60

Table 2. Recent trend in Pacific hake management performance.

Year	Total landings (mt)	Coast-wide (U.S. + Canada) OY (mt)	Coast-wide (U.S. + Canada) ABC (mt)
2001	227,531	238,000	238,000
2002	180,698	162,000	208,000
2003	205,177	228,000	235,000
2004	338,654	501,073	514,441
2005	363,157	364,197	531,124
2006	361,761	364,842	661,680
2007	290,545	328,358	612,068
2008	322,145	364,842	400,000
2009	177,459	184,000	253,582
2010	216,912	262,500	455,550

Table 3. U.S. and Canadian fishery sampling summary by year for data included in this stock assessment. Foreign, joint-venture and at-sea sectors are in number of hauls sampled for age-composition, the shore-based sector is in number of trips.

	U.S.				Canada		
Year	Foreign	Joint-venture	At-sea	Shore-based	Foreign	Joint-venture	Domestic
1975	13	0	0	0	0	0	0
1976	142	0	0	0	0	0	0
1977	320	0	0	0	0	0	0
1978	336	5	0	0	0	0	0
1979	99	17	0	0	0	0	0
1980	191	30	0	0	0	0	0
1981	113	41	0	0	0	0	0
1982	52	118	0	0	0	0	0
1983	0	117	0	0	0	0	0
1984	49	74	0	0	0	0	0
1985	37	19	0	0	0	0	0
1986	88	32	0	0	0	0	0
1987	22	34	0	0	0	0	0
1988	39	42	0	0	0	0	0
1989	0	77	0	0	0	0	0
1990	0	143	0	15	0	5	0
1991	0	0	116	26	0	18	0
1992	0	0	164	46	0	33	0
1993	0	0	108	36	0	25	6
1994	0	0	143	50	0	41	0
1995	0	0	61	51	0	35	0
1996	0	0	123	35	0	28	0
1997	0	0	127	65	0	27	3
1998	0	0	149	64	0	21	9
1999	0	0	389	80	0	14	31
2000	0	0	413	91	0	25	0
2001	0	0	429	82	0	28	2
2002	0	0	342	71	0	0	37
2003	0	0	358	78	0	0	21
2004	0	0	381	72	0	20	28
2005	0	0	499	58	0	11	45
2006	0	0	549	83	0	21	67
2007	0	0	524	68	0	1	36
2008	0	0	680	52	0	0	51
2009	0	0	594	57	0	0	26
2010	0	0	729	47	0	0	24

Table 4. Acoustic survey summary, 1977-2009.

Year	Start date	End date	Vessels[1]	Inshore limit (m)	Offshore limit (depth, m)	Northern limit (°N)	Number of hauls with bio. samples
1977	12 July	29 Sept.	Miller Freeman	91	457	50.0	85
1980	1 July	11 Sept.	Miller Freeman	55	457	50.0	49
1983	27 July	29 Sept.	Miller Freeman	55	366	49.5	35
1986[2]	30 June	31 July	Miller Freeman	55	366	49.5	43
1989	22 July	25 Aug.	Miller Freeman	55	366	50.0	22
1992	7 July	19 Aug.	Miller Freeman	55	366	51.7	43
1995	1 July	1 Sept.	Miller Freeman, Ricker	50	1,500	55.0	69
1998	6 July	27 Aug.	Miller Freeman, Ricker	50	1,500	55.0	84
2001	15 June	29 July	Miller Freeman, Ricker	50	1,500	55.0	49
2003	29 June	1 Sept.	Ricker	50	1,500	55.0	71
2005	20 June	19 Aug.	Miller Freeman	50	1,500	55.0	49
2007	20 June	21 Aug.	Miller Freeman	50	1,500	55.0	130
2009	30 June	7 Sept.	Miller Freeman, Ricker	50	1,500	55.0	61

[1]Multi-vessel coverage always included some transects sampled by only one vessel.
[2]Unexplained differences in pre- and post-survey calibration lead to a 1.5x difference in estimated stock biomass.

Table 5. Historical and updated acoustic survey biomass estimates (millions of metric tons) and SEs of the log-index representing only sampling variability (1995-2007) and sampling variability as well as squid/hake apportionment uncertainty (2009).

Year	Historical	Reprocessed	Kriged	SE ln(value)
1995	1.385	1.360	1.518	0.067
1998	1.185	1.103	1.343	0.049
2001	0.737	0.694	0.919	0.082
2003	1.840	1.608	2.521	0.071
2005	1.265	1.228	1.755	0.085
2007	0.879	0.824	1.123	0.075
2009	1.462	1.419	1.612	0.137

Table 6. Informative prior probability distributions used in this stock assessment.

Parameter	prior	Justification
Steepness (*h*)	~Beta(mean=0.777, SD=0.113)	Myers et al. 1999 meta-analysis results for Gadids.
Steepness (*h*)	~Beta(mean=0.478, SD=0.096)	Implied from F_{MSY}, *MSY* and selectivity in the 2010 TINSS model.
Natural mortality (*M*)	~log(N)(mean=0.2, SD=0.1)	Hoenig's method and maximum age = 22.
Maximum sustainable harvest rate (F_{MSY})	~log(N)(mean=0.35, SD=0.4)	See section 2.4 in text.
Maximum sustainable harvest (*MSY*)	~log(N)(mean=200,000, SD=500,000)	See section 2.4 in text.
Acoustic survey catchability (*q*)	~log(N)(mean=1.0, SD=0.1)	See section 2.4 in text.

Table 7. Structural overview of alternate models evaluated for 2011.

Model	TINSS	Production	SS base (Empirical age)	Age with growth	Age sex and growth	Age catch season	Age sex length	Age sex length season
Data use								
Aggregate fishery catch	X	X	X					
Catch by sector				X	X	X	X	X
Catch by sector and season						X		X
Aggregate fishery age data	X		X					
Fishery age data by sector				X	X	X	X	X
Fishery age data by sector and sex					X		X	X
Fishery length data by sex							X	X
Fishery age-at-length data								X
Survey index	X	X	X	X		X	X	X
Survey index and timing						X		X
Survey age data	X		X	X	X	X	X	X
Survey age by sex					X		X	X
Survey length data							X	X
Survey age at length data								X
Aggregate weight at age	X		X					
Aggregate length at age				X	X	X		
Informative priors								
Natural mortality (*M*)	X	X	X	X	X	X	X	X
Steepness (*h*)		X	X	X	X	X	X	X
F_{MSY}	X							
MSY	X							
Acoustic catchability (*q*)	X							
Dynamics								
Stochastic recruitment	X		X	X	X	X	X	X
Empirical weight at age	X		X					
Fixed parametric growth		X		X	X	X		
Estimated growth							X	X
Includes dimorphic growth					X		X	X
Weight length variation among years	X		X			X		X
Variably timing of fishery removals						X		X
Ageing error			X	X	X	X	X	X
Age-based selectivity	X	X	X	X	X	X		
Size-based selectivity							X	X

Table 8. Summary of estimated model parameters in the base case SS model.

Parameter	Number estimated	Bounds (low, high)	Prior (Mean, SD) (single value = fixed)
Stock dynamics			
Ln(R_0)	1	(13,18)	uniform
Steepness (*h*)	1	(0.2,1.0)	~Beta(0.777,0.113)
Recruitment variability (σ_R)	-	NA	1.30
Ln(Rec. deviations): 1946-2011	66	(-6, 6)	~Ln(N(0, σ_r))
Natural mortality (*M*)	1	(0.05,0.4)	~Ln(N(0.2,0.1))
Catchability and selectivity (double normal)			
Acoustic survey:			
Catchability (*q*)	1	NA	Analytic solution
Additional value for acoustic survey log(SE)	1	(0.0, 1.0)	uniform
Non parametric age-based selectivity: ages 3-5	3	(-5,9)	Uniform in scaled logistic space
Fishery:			
Non parametric age-based selectivity: ages 2-5	4	(-5,9)	Uniform in scaled logistic space

Total: 12 + 66 recruitment deviations = 88 estimated parameters. See Appendix A for all parameter estimates.

Table 9. Summary of estimated model parameters in the base case TINSS model.

Parameter	Number estimated	Bounds (low,high)	Prior (Mean, SD) (single value=fixed)
Maximum Sustainable Yield (*MSY*)	1	(0.01,3)	~lognormal(0.2,0.5)
Fishing mortality at *MSY* (F_{MSY})	1	(0.01,3)	~lognormal(0.35,0.4)
Natural mortality (*M*)	1	(0.05,0.9)	~lognormal(0.2,0.1)
Commercial fishery: age at 50% vulnerability (a)	1	(0,14)	Uniform
Commercial fishery: SD of logistic selectivity (γ)	1	(0.05,5)	Uniform
Survey: age at 50% vulnerability ($\bar{a}$)	1	(0,14)	Uniform
Survey: SD of logistic selectivity ($\bar{\gamma}$)	1	(0.05,5)	~gamma(4.0,2.25)
Variance ratio (ρ)	1	(0.01,0.999)	~beta(3,12)
Inverse total variance (φ^{-2})	1	(0.01,150)	~gamma(7.5,5.8)
Log of the mean recruitment ($\ln \bar{R}$)	1	None	Uniform
log of survey catchability (*q*)	Implicitly estimated	None	~Normal(0,0.1)
Log recruitment deviations	59	(-5,5)	~Normal(0,τ[1])

1. τ = standard deviation of recruitment residuals

Table 10. Time-series of median posterior population estimates from the SS model. The first two quantities are not available from the MCMC in SS, so MLE values are reported; spawning biomass is reported for both MLE and MCMC for comparison.

Year	Total biomass (millions mt) from MLE	Age 3+ biomass (millions mt) from MLE	Female spawning biomass (millions mt) from MLE	Female spawning biomass (millions mt)	Depletion	Age-0 recruits (billions)	1-SPR / 1-SPR40%	Exploitation fraction (catch/3+ biomass)
1966	2.85	2.47	1.19	1.13	55%	1.39	0.43	0.06
1967	2.76	2.30	1.10	1.05	52%	3.18	0.63	0.10
1968	2.68	2.12	1.02	0.97	48%	2.01	0.45	0.06
1969	2.77	2.11	1.03	1.02	51%	1.04	0.59	0.09
1970	2.92	2.27	1.05	1.07	54%	8.12	0.68	0.10
1971	2.99	2.26	1.03	1.06	53%	0.80	0.50	0.07
1972	3.35	2.12	1.19	1.27	64%	0.52	0.39	0.05
1973	3.48	3.18	1.34	1.46	73%	4.16	0.43	0.05
1974	3.37	3.00	1.35	1.49	74%	0.47	0.49	0.06
1975	4.21	3.37	1.34	1.50	73%	1.23	0.42	0.06
1976	4.34	4.15	1.31	1.47	72%	0.38	0.41	0.05
1977	3.95	3.37	1.23	1.39	68%	5.07	0.29	0.04
1978	3.36	2.93	1.15	1.28	63%	0.34	0.26	0.03
1979	3.58	2.81	1.17	1.31	64%	0.84	0.33	0.04
1980	3.80	3.01	1.17	1.31	64%	15.02	0.26	0.03
1981	3.89	2.59	1.14	1.27	62%	0.39	0.38	0.05
1982	4.32	2.11	1.47	1.63	80%	0.30	0.32	0.05
1983	4.22	4.13	1.79	1.97	98%	0.50	0.28	0.03
1984	4.63	4.03	1.89	2.08	103%	11.94	0.28	0.03
1985	5.32	3.71	1.81	1.98	98%	0.25	0.22	0.03
1986	5.24	3.25	1.99	2.15	108%	0.25	0.41	0.06
1987	4.84	4.58	2.09	2.25	113%	5.32	0.43	0.05
1988	4.84	4.19	2.01	2.16	108%	2.06	0.42	0.06
1989	4.32	3.24	1.93	2.08	103%	0.23	0.54	0.09
1990	4.13	3.64	1.83	1.96	97%	4.04	0.49	0.07
1991	3.93	3.46	1.68	1.79	89%	0.60	0.59	0.09
1992	3.31	2.68	1.53	1.64	81%	0.23	0.62	0.10
1993	2.56	2.32	1.38	1.48	73%	3.17	0.57	0.08
1994	2.56	2.14	1.21	1.29	64%	2.45	0.83	0.16
1995	2.48	1.72	1.01	1.08	53%	1.50	0.73	0.14
1996	2.37	1.78	0.95	1.01	50%	1.65	0.87	0.16
1997	2.26	1.80	0.87	0.93	46%	0.96	0.91	0.17
1998	1.85	1.53	0.79	0.84	42%	1.89	0.94	0.20
1999	1.98	1.30	0.67	0.72	36%	12.53	0.99	0.22
2000	3.41	1.31	0.58	0.62	31%	0.55	0.84	0.16
2001	3.61	1.45	0.88	0.96	48%	1.11	0.76	0.14
2002	4.03	3.84	1.19	1.29	65%	0.11	0.46	0.04
2003	3.50	3.28	1.34	1.44	73%	1.87	0.46	0.06
2004	2.92	2.75	1.30	1.40	70%	0.11	0.68	0.12
2005	2.46	2.06	1.13	1.22	61%	4.58	0.81	0.16
2006	2.38	1.82	0.90	0.98	49%	4.56	0.91	0.19
2007	2.05	1.28	0.79	0.86	43%	0.13	0.92	0.21
2008	2.72	1.76	0.85	0.94	46%	16.17	0.92	0.17
2009	2.81	1.98	0.85	0.96	47%	0.87	0.63	0.08
2010	3.94	1.73	1.28	1.45	71%	1.17	0.64	0.11
2011	4.85	4.33	1.69	1.87	91%	1.09	NA	NA

Table 11. Time-series of median posterior population estimates from the TINSS model.

Year	Total biomass (millions mt)	Age 3+ biomass (millions mt)	Female spawning biomass (millions mt)	Depletion	Age-1 recruits (billions)	1-SPR / 1-SPR40%	Exploitation fraction
1966	0.76	1.26	0.60	0.49	1.50	0.64	0.17
1967	0.74	1.35	0.63	0.51	1.50	0.82	0.16
1968	0.70	1.33	0.62	0.51	1.80	0.63	0.16
1969	0.76	1.41	0.67	0.55	1.47	0.74	0.15
1970	0.78	1.50	0.69	0.57	1.56	0.84	0.14
1971	0.78	1.45	0.69	0.56	3.43	0.68	0.14
1972	0.85	1.51	0.74	0.61	1.17	0.54	0.14
1973	0.96	2.04	0.89	0.72	1.02	0.62	0.10
1974	1.04	1.98	0.93	0.76	2.70	0.69	0.10
1975	1.35	2.14	1.07	0.87	0.82	0.74	0.10
1976	1.54	2.72	1.22	0.99	0.89	0.71	0.08
1977	1.42	2.33	1.12	0.91	0.62	0.49	0.09
1978	1.31	1.99	0.95	0.77	4.58	0.46	0.10
1979	1.48	1.94	1.02	0.83	0.35	0.49	0.11
1980	1.28	2.53	1.04	0.85	0.66	0.39	0.08
1981	1.33	2.17	1.07	0.87	15.19	0.50	0.10
1982	1.42	1.75	1.12	0.90	0.21	0.40	0.12
1983	1.65	4.49	1.68	1.36	0.20	0.41	0.05
1984	2.03	4.27	2.03	1.64	0.40	0.42	0.05
1985	2.49	3.99	2.00	1.60	11.97	0.24	0.05
1986	2.69	3.24	1.84	1.49	0.31	0.47	0.07
1987	2.59	5.16	2.09	1.70	0.52	0.51	0.04
1988	2.73	4.65	2.24	1.83	4.39	0.49	0.05
1989	2.52	3.63	1.87	1.53	2.37	0.53	0.06
1990	2.59	3.91	1.83	1.49	0.82	0.52	0.05
1991	2.41	3.72	1.75	1.42	2.83	0.64	0.06
1992	2.13	3.06	1.53	1.24	1.11	0.55	0.07
1993	1.59	2.50	1.16	0.95	0.59	0.50	0.09
1994	1.57	2.37	1.14	0.92	2.11	0.68	0.09
1995	1.43	1.99	1.01	0.82	1.86	0.59	0.11
1996	1.19	1.86	0.88	0.72	1.41	0.74	0.12
1997	1.02	1.79	0.83	0.68	1.57	0.79	0.12
1998	0.86	1.53	0.72	0.59	0.98	0.89	0.14
1999	0.72	1.32	0.61	0.50	1.91	0.96	0.16
2000	0.82	1.38	0.69	0.56	11.28	0.74	0.16
2001	1.04	1.62	0.94	0.76	0.98	0.66	0.13
2002	1.38	4.35	1.64	1.33	0.77	0.48	0.05
2003	1.55	3.74	1.75	1.43	0.25	0.49	0.06
2004	1.64	3.02	1.46	1.19	1.76	0.65	0.07
2005	1.55	2.26	1.15	0.93	0.51	0.71	0.10
2006	1.34	2.03	0.94	0.76	6.03	0.72	0.11
2007	1.15	1.52	0.83	0.67	5.43	0.72	0.14
2008	1.20	2.54	1.10	0.90	0.19	0.72	0.08
2009	1.28	3.03	1.30	1.05	12.30	0.54	0.07
2010	1.64	2.65	1.49	1.21	1.37	0.53	0.08
2011	2.18	5.27	2.18	1.75	0.86	NA	NA

Table 12. Time-series of ~95% posterior credibility intervals for female spawning biomass, relative depletion estimates, age-0 recruits, relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.4}$) and exploitation fraction (catch/3+biomass) from the SS model.

Year	Female spawning Biomass (millions mt)	Depletion	Age-0 recruits (billions)	(1-SPR) / (1-SPR_{target})	Exploitation fraction
1966	0.66-2.17	33%-100%	0.09-8.84	0.23-0.68	0.03-0.10
1967	0.61-2.03	31%-92%	0.23-11.59	0.36-0.91	0.05-0.18
1968	0.56-1.95	28%-88%	0.15-9.14	0.23-0.71	0.03-0.11
1969	0.60-2.01	30%-93%	0.09-5.78	0.32-0.87	0.04-0.16
1970	0.63-2.16	32%-96%	3.54-21.43	0.37-0.96	0.05-0.18
1971	0.61-2.30	31%-98%	0.08-3.59	0.24-0.78	0.03-0.12
1972	0.77-2.66	38%-113%	0.06-2.18	0.18-0.64	0.02-0.09
1973	0.89-2.99	44%-126%	2.00-10.06	0.20-0.67	0.02-0.08
1974	0.90-3.02	45%-129%	0.06-2.00	0.24-0.73	0.03-0.11
1975	0.89-3.07	46%-128%	0.41-3.28	0.21-0.67	0.03-0.10
1976	0.86-2.97	44%-125%	0.06-1.67	0.20-0.67	0.03-0.09
1977	0.79-2.78	41%-117%	2.50-11.65	0.14-0.49	0.02-0.06
1978	0.73-2.52	38%-108%	0.04-1.72	0.13-0.45	0.02-0.06
1979	0.77-2.48	40%-106%	0.12-3.00	0.16-0.55	0.02-0.08
1980	0.79-2.40	41%-104%	8.82-29.89	0.13-0.44	0.01-0.04
1981	0.76-2.29	40%-99%	0.05-1.54	0.20-0.60	0.03-0.08
1982	1.03-2.81	53%-121%	0.04-1.53	0.17-0.52	0.03-0.08
1983	1.33-3.30	66%-146%	0.07-1.93	0.15-0.44	0.02-0.04
1984	1.42-3.38	70%-151%	7.40-21.16	0.15-0.43	0.02-0.05
1985	1.37-3.14	68%-142%	0.03-1.10	0.12-0.34	0.02-0.04
1986	1.56-3.32	77%-150%	0.04-1.01	0.24-0.58	0.04-0.09
1987	1.69-3.40	83%-155%	3.13-9.16	0.27-0.59	0.03-0.06
1988	1.65-3.17	81%-146%	0.81-4.16	0.27-0.59	0.04-0.07
1989	1.61-2.96	78%-139%	0.03-0.83	0.36-0.71	0.06-0.11
1990	1.54-2.77	74%-131%	2.57-6.84	0.33-0.65	0.05-0.08
1991	1.43-2.49	68%-117%	0.10-1.51	0.41-0.74	0.06-0.11
1992	1.32-2.25	63%-107%	0.04-0.80	0.45-0.79	0.08-0.13
1993	1.20-2.02	57%-96%	2.10-5.25	0.40-0.73	0.06-0.10
1994	1.05-1.74	50%-84%	1.55-4.23	0.63-0.99	0.12-0.19
1995	0.88-1.48	41%-70%	0.87-2.77	0.54-0.89	0.10-0.17
1996	0.84-1.40	39%-65%	1.01-2.98	0.67-1.03	0.12-0.20
1997	0.77-1.32	36%-60%	0.41-1.97	0.70-1.06	0.12-0.21
1998	0.68-1.24	32%-54%	1.11-3.55	0.72-1.10	0.13-0.24
1999	0.57-1.10	28%-47%	8.50-22.37	0.75-1.15	0.15-0.28
2000	0.47-1.02	23%-42%	0.17-1.34	0.59-1.03	0.10-0.21
2001	0.73-1.60	36%-65%	0.63-2.04	0.50-0.96	0.09-0.20
2002	0.97-2.10	49%-87%	0.02-0.37	0.27-0.63	0.03-0.06
2003	1.11-2.31	56%-97%	1.11-3.66	0.28-0.62	0.04-0.08
2004	1.07-2.22	54%-92%	0.02-0.41	0.44-0.86	0.07-0.15
2005	0.91-1.99	47%-82%	2.31-10.51	0.54-0.99	0.10-0.22
2006	0.69-1.70	37%-69%	1.85-11.64	0.61-1.10	0.11-0.26
2007	0.55-1.69	29%-68%	0.02-0.62	0.59-1.13	0.11-0.32
2008	0.50-2.03	28%-82%	5.12-51.53	0.56-1.18	0.08-0.31
2009	0.42-2.25	24%-89%	0.06-10.24	0.31-1.00	0.03-0.18
2010	0.54-3.77	30%-148%	0.09-14.70	0.30-1.05	0.05-0.29
2011	0.63-5.14	35%-203%	0.08-18.85	NA	NA

Table 13. Time-series of ~95% posterior credibility intervals for female spawning biomass, relative depletion estimates, age-1 recruits, relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.4}$) and exploitation fraction (catch/3+biomass) from the TINSS model.

Year	Female spawning Biomass (millions mt)	Depletion	Age-1 recruits (billions)	(1-SPR) / (1-SPR_{target})	Exploitation fraction
1966	0.44-0.88	27%- 84%	0.91-3.02	0.42-0.87	0.07-0.33
1967	0.48-0.92	28%- 89%	0.91-3.02	0.58-1.03	0.06-0.29
1968	0.48-0.97	29%- 92%	1.07-3.91	0.40-0.83	0.07-0.30
1969	0.51-1.07	31%- 99%	0.86-3.25	0.49-0.94	0.06-0.29
1970	0.53-1.15	31%-106%	0.91-3.29	0.55-1.04	0.06-0.27
1971	0.51-1.19	30%-111%	1.98-7.42	0.40-0.89	0.06-0.28
1972	0.53-1.32	33%-123%	0.68-2.54	0.30-0.76	0.05-0.27
1973	0.63-1.60	38%-148%	0.56-2.21	0.35-0.84	0.04-0.21
1974	0.65-1.68	40%-154%	1.49-5.96	0.40-0.92	0.04-0.21
1975	0.73-1.97	45%-179%	0.45-1.81	0.41-1.00	0.04-0.20
1976	0.81-2.23	50%-206%	0.48-2.00	0.39-0.99	0.03-0.16
1977	0.73-2.09	45%-189%	0.34-1.34	0.24-0.75	0.03-0.19
1978	0.62-1.74	38%-158%	2.61-10.31	0.23-0.72	0.04-0.23
1979	0.67-1.85	41%-169%	0.20-0.76	0.26-0.76	0.04-0.22
1980	0.68-1.91	43%-172%	0.37-1.44	0.20-0.62	0.03-0.18
1981	0.70-1.95	44%-171%	9.23-28.98	0.27-0.75	0.04-0.21
1982	0.74-1.95	47%-175%	0.11-0.43	0.21-0.62	0.05-0.27
1983	1.14-2.85	72%-264%	0.12-0.37	0.21-0.63	0.02-0.10
1984	1.41-3.31	88%-310%	0.24-0.76	0.22-0.66	0.02-0.10
1985	1.42-3.16	88%-294%	7.65-20.49	0.13-0.39	0.02-0.11
1986	1.35-2.79	83%-261%	0.19-0.56	0.28-0.68	0.03-0.13
1987	1.55-3.07	92%-293%	0.33-0.90	0.31-0.72	0.02-0.08
1988	1.70-3.16	100%-312%	2.81-7.18	0.30-0.70	0.02-0.09
1989	1.46-2.59	84%-253%	1.55-3.90	0.34-0.73	0.03-0.11
1990	1.45-2.46	83%-241%	0.55-1.29	0.34-0.72	0.02-0.10
1991	1.41-2.29	80%-226%	1.99-4.39	0.43-0.86	0.02-0.11
1992	1.25-1.96	69%-195%	0.76-1.71	0.38-0.72	0.03-0.13
1993	0.97-1.47	53%-148%	0.41-0.92	0.35-0.65	0.04-0.15
1994	0.97-1.40	52%-143%	1.48-3.30	0.51-0.85	0.04-0.16
1995	0.86-1.23	46%-126%	1.27-2.90	0.44-0.75	0.05-0.19
1996	0.76-1.09	41%-110%	0.95-2.21	0.57-0.90	0.05-0.20
1997	0.71-1.03	39%-105%	1.08-2.56	0.61-0.95	0.05-0.21
1998	0.61-0.92	34%- 91%	0.63-1.63	0.70-1.04	0.06-0.25
1999	0.51-0.80	29%- 77%	1.24-3.20	0.76-1.12	0.07-0.29
2000	0.54-0.94	32%- 88%	7.73-18.29	0.55-0.92	0.07-0.29
2001	0.73-1.30	44%-121%	0.59-1.69	0.47-0.84	0.06-0.25
2002	1.27-2.34	77%-218%	0.46-1.36	0.32-0.64	0.02-0.09
2003	1.37-2.45	81%-229%	0.14-0.45	0.33-0.66	0.02-0.11
2004	1.16-2.00	69%-190%	0.98-3.36	0.47-0.83	0.03-0.13
2005	0.91-1.60	54%-149%	0.28-1.11	0.51-0.90	0.04-0.18
2006	0.70-1.39	44%-125%	3.13-12.11	0.51-0.92	0.04-0.20
2007	0.56-1.33	39%-114%	2.43-12.57	0.50-0.94	0.06-0.28
2008	0.66-1.98	49%-162%	0.08-0.48	0.49-0.98	0.03-0.19
2009	0.68-2.56	54%-198%	3.31-38.55	0.32-0.81	0.02-0.17
2010	0.72-3.05	59%-251%	0.15-12.56	0.30-0.82	0.03-0.22
2011	0.91-5.12	75%-409%	0.01-56.74	NA	NA

Table 14. Model-averaged (equal weight) time-series of female spawning biomass and relative depletion estimates from both models.

	Female spawning biomass (millions mt)			Depletion		
Year	2.5th Percentile	Median	97.5th Percentile	2.5th Percentile	Median	97.5th Percentile
1966	0.45	0.77	1.94	0.29	0.53	1.05
1967	0.49	0.76	1.80	0.30	0.51	0.91
1968	0.49	0.74	1.69	0.28	0.49	0.90
1969	0.53	0.80	1.77	0.30	0.53	0.96
1970	0.55	0.83	1.89	0.31	0.55	1.01
1971	0.53	0.84	1.92	0.31	0.54	1.03
1972	0.56	0.96	2.25	0.35	0.62	1.18
1973	0.66	1.13	2.59	0.41	0.73	1.37
1974	0.68	1.16	2.61	0.43	0.75	1.41
1975	0.76	1.25	2.68	0.45	0.80	1.58
1976	0.82	1.31	2.71	0.46	0.84	1.77
1977	0.75	1.22	2.53	0.43	0.78	1.66
1978	0.65	1.08	2.26	0.38	0.69	1.39
1979	0.69	1.13	2.29	0.40	0.72	1.49
1980	0.70	1.16	2.27	0.41	0.73	1.51
1981	0.71	1.16	2.16	0.41	0.72	1.53
1982	0.79	1.35	2.59	0.50	0.85	1.57
1983	1.17	1.82	3.12	0.68	1.11	2.31
1984	1.42	2.05	3.38	0.73	1.22	2.73
1985	1.39	1.99	3.15	0.71	1.18	2.63
1986	1.41	2.00	3.14	0.78	1.21	2.40
1987	1.61	2.18	3.26	0.85	1.30	2.66
1988	1.67	2.20	3.17	0.83	1.29	2.81
1989	1.49	1.98	2.84	0.79	1.18	2.33
1990	1.48	1.90	2.64	0.76	1.12	2.26
1991	1.42	1.77	2.39	0.70	1.04	2.13
1992	1.28	1.58	2.14	0.65	0.94	1.85
1993	1.00	1.31	1.86	0.56	0.80	1.39
1994	0.99	1.20	1.62	0.50	0.73	1.35
1995	0.87	1.03	1.38	0.43	0.62	1.19
1996	0.77	0.94	1.30	0.40	0.57	1.04
1997	0.73	0.88	1.21	0.37	0.53	0.98
1998	0.62	0.77	1.11	0.33	0.47	0.85
1999	0.52	0.66	0.98	0.28	0.41	0.73
2000	0.49	0.66	0.97	0.24	0.38	0.84
2001	0.73	0.95	1.45	0.37	0.57	1.15
2002	1.01	1.49	2.24	0.51	0.84	1.98
2003	1.15	1.62	2.39	0.58	0.92	2.12
2004	1.10	1.43	2.15	0.56	0.84	1.72
2005	0.91	1.17	1.84	0.48	0.71	1.35
2006	0.70	0.96	1.60	0.38	0.58	1.14
2007	0.56	0.84	1.53	0.31	0.52	1.05
2008	0.55	1.03	2.00	0.30	0.62	1.48
2009	0.48	1.14	2.41	0.26	0.69	1.82
2010	0.62	1.47	3.36	0.35	0.93	2.23
2011	0.72	2.03	5.14	0.42	1.26	3.50

Table 15. Estimated numbers at age at the beginning of the year from the SS model (MLE; millions).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1966	1.71	1.24	0.84	0.62	0.49	0.40	0.34	0.29	0.25	0.21	0.18	0.15	0.13	0.11	0.09	0.40
1967	2.79	1.38	1.00	0.67	0.49	0.38	0.30	0.25	0.22	0.19	0.16	0.14	0.12	0.10	0.08	0.37
1968	2.18	2.25	1.11	0.80	0.51	0.36	0.27	0.22	0.18	0.16	0.13	0.11	0.10	0.08	0.07	0.33
1969	1.18	1.76	1.82	0.89	0.62	0.39	0.27	0.20	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.30
1970	6.81	0.95	1.42	1.45	0.68	0.46	0.28	0.19	0.15	0.12	0.10	0.08	0.07	0.06	0.05	0.26
1971	0.92	5.50	0.77	1.13	1.09	0.49	0.32	0.20	0.14	0.10	0.08	0.07	0.06	0.05	0.04	0.22
1972	0.53	0.74	4.44	0.62	0.87	0.82	0.36	0.24	0.15	0.10	0.08	0.06	0.05	0.04	0.04	0.19
1973	3.62	0.43	0.60	3.56	0.48	0.67	0.62	0.27	0.18	0.11	0.08	0.06	0.05	0.04	0.03	0.18
1974	0.50	2.92	0.35	0.48	2.77	0.37	0.50	0.46	0.21	0.13	0.08	0.06	0.04	0.03	0.03	0.16
1975	1.17	0.41	2.36	0.28	0.37	2.08	0.27	0.37	0.34	0.15	0.10	0.06	0.04	0.03	0.03	0.14
1976	0.41	0.94	0.33	1.89	0.22	0.28	1.55	0.20	0.28	0.26	0.11	0.07	0.05	0.03	0.02	0.12
1977	4.45	0.33	0.76	0.26	1.47	0.16	0.21	1.16	0.15	0.21	0.19	0.08	0.06	0.03	0.02	0.11
1978	0.34	3.59	0.26	0.61	0.21	1.14	0.13	0.16	0.90	0.12	0.16	0.15	0.07	0.04	0.03	0.10
1979	0.83	0.27	2.90	0.21	0.48	0.16	0.88	0.10	0.13	0.69	0.09	0.12	0.11	0.05	0.03	0.10
1980	13.41	0.67	0.22	2.33	0.17	0.37	0.12	0.68	0.08	0.10	0.53	0.07	0.09	0.09	0.04	0.10
1981	0.38	10.82	0.54	0.18	1.84	0.13	0.29	0.10	0.52	0.06	0.07	0.41	0.05	0.07	0.07	0.11
1982	0.31	0.31	8.74	0.44	0.14	1.41	0.10	0.22	0.07	0.40	0.04	0.06	0.31	0.04	0.06	0.13
1983	0.53	0.25	0.25	7.02	0.34	0.11	1.08	0.08	0.17	0.06	0.30	0.03	0.04	0.24	0.03	0.14
1984	10.81	0.43	0.20	0.20	5.54	0.27	0.08	0.83	0.06	0.13	0.04	0.23	0.03	0.03	0.18	0.14
1985	0.26	8.73	0.34	0.16	0.16	4.32	0.21	0.06	0.64	0.05	0.10	0.03	0.18	0.02	0.03	0.25
1986	0.26	0.21	7.05	0.28	0.13	0.13	3.37	0.16	0.05	0.50	0.04	0.08	0.03	0.14	0.02	0.21
1987	4.75	0.21	0.17	5.65	0.22	0.10	0.09	2.53	0.12	0.04	0.38	0.03	0.06	0.02	0.11	0.17
1988	1.96	3.84	0.17	0.14	4.39	0.16	0.07	0.07	1.89	0.09	0.03	0.28	0.02	0.04	0.01	0.21
1989	0.23	1.58	3.10	0.13	0.11	3.34	0.12	0.06	0.05	1.42	0.07	0.02	0.21	0.02	0.03	0.17
1990	3.65	0.19	1.28	2.48	0.10	0.08	2.42	0.09	0.04	0.04	1.03	0.05	0.02	0.15	0.01	0.15
1991	0.63	2.95	0.15	1.02	1.91	0.08	0.06	1.78	0.07	0.03	0.03	0.76	0.04	0.01	0.11	0.12
1992	0.24	0.51	2.38	0.12	0.78	1.40	0.06	0.04	1.27	0.05	0.02	0.02	0.54	0.03	0.01	0.16
1993	2.96	0.20	0.41	1.90	0.09	0.57	0.99	0.04	0.03	0.90	0.03	0.02	0.01	0.38	0.02	0.12
1994	2.25	2.39	0.16	0.33	1.45	0.07	0.41	0.71	0.03	0.02	0.65	0.02	0.01	0.01	0.27	0.10
1995	1.39	1.82	1.93	0.12	0.24	0.98	0.04	0.26	0.46	0.02	0.01	0.41	0.02	0.01	0.01	0.24
1996	1.49	1.12	1.46	1.53	0.09	0.17	0.66	0.03	0.18	0.31	0.01	0.01	0.28	0.01	0.01	0.17
1997	0.88	1.21	0.91	1.16	1.10	0.06	0.10	0.41	0.02	0.11	0.19	0.01	0.01	0.18	0.01	0.11
1998	1.70	0.71	0.97	0.71	0.82	0.71	0.04	0.06	0.25	0.01	0.07	0.12	0.01	0.00	0.11	0.07
1999	11.27	1.37	0.57	0.76	0.50	0.52	0.42	0.02	0.04	0.15	0.01	0.04	0.07	0.00	0.00	0.11
2000	0.55	9.10	1.11	0.45	0.52	0.31	0.29	0.24	0.01	0.02	0.08	0.00	0.02	0.04	0.00	0.06
2001	1.01	0.44	7.34	0.87	0.32	0.35	0.19	0.19	0.15	0.01	0.01	0.05	0.00	0.01	0.03	0.04
2002	0.10	0.81	0.36	5.82	0.64	0.22	0.23	0.13	0.12	0.10	0.01	0.01	0.04	0.00	0.01	0.04
2003	1.71	0.08	0.66	0.29	4.50	0.48	0.17	0.17	0.10	0.09	0.07	0.00	0.01	0.03	0.00	0.04
2004	0.11	1.38	0.07	0.53	0.22	3.40	0.36	0.12	0.13	0.07	0.07	0.06	0.00	0.01	0.02	0.03
2005	4.13	0.09	1.12	0.05	0.39	0.16	2.35	0.25	0.09	0.09	0.05	0.05	0.04	0.00	0.00	0.04
2006	4.02	3.34	0.07	0.88	0.04	0.27	0.10	1.52	0.16	0.06	0.06	0.03	0.03	0.03	0.00	0.03
2007	0.14	3.25	2.69	0.06	0.62	0.03	0.16	0.06	0.92	0.10	0.03	0.04	0.02	0.02	0.02	0.02
2008	14.28	0.11	2.62	2.12	0.04	0.40	0.02	0.10	0.04	0.55	0.06	0.02	0.02	0.01	0.01	0.02
2009	1.74	11.53	0.09	2.06	1.49	0.03	0.24	0.01	0.06	0.02	0.33	0.04	0.01	0.01	0.01	0.02
2010	2.21	1.41	9.30	0.07	1.55	1.08	0.02	0.17	0.01	0.04	0.02	0.23	0.02	0.01	0.01	0.02
2011	2.24	1.78	1.13	7.41	0.05	1.12	0.75	0.01	0.12	0.00	0.03	0.01	0.16	0.02	0.01	0.02

Table 16. Estimated numbers at age from the TINSS model (millions).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1966	NA	1.30	1.10	0.66	0.71	0.09	0.08	0.07	0.06	0.06	0.05	0.04	0.04	0.03	0.03	0.06
1967	NA	1.30	1.02	0.86	0.50	0.51	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.06
1968	NA	1.53	1.01	0.78	0.63	0.34	0.33	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.04
1969	NA	1.22	1.20	0.79	0.59	0.46	0.24	0.22	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03
1970	NA	1.30	0.95	0.92	0.59	0.42	0.31	0.15	0.13	0.01	0.01	0.01	0.01	0.01	0.01	0.02
1971	NA	2.80	1.01	0.73	0.68	0.40	0.27	0.18	0.09	0.07	0.01	0.01	0.01	0.00	0.00	0.02
1972	NA	0.94	2.20	0.79	0.55	0.49	0.28	0.18	0.12	0.05	0.04	0.01	0.00	0.00	0.00	0.01
1973	NA	0.83	0.74	1.72	0.60	0.41	0.36	0.20	0.12	0.08	0.04	0.03	0.00	0.00	0.00	0.01
1974	NA	2.18	0.65	0.58	1.31	0.44	0.29	0.24	0.13	0.08	0.05	0.02	0.02	0.00	0.00	0.01
1975	NA	0.66	1.71	0.50	0.43	0.95	0.30	0.19	0.15	0.08	0.05	0.03	0.01	0.01	0.00	0.01
1976	NA	0.71	0.52	1.33	0.38	0.32	0.67	0.21	0.12	0.10	0.05	0.03	0.02	0.01	0.01	0.00
1977	NA	0.50	0.56	0.40	1.02	0.28	0.23	0.46	0.14	0.08	0.06	0.03	0.02	0.01	0.01	0.01
1978	NA	3.70	0.39	0.44	0.31	0.78	0.21	0.17	0.33	0.10	0.06	0.05	0.02	0.01	0.01	0.01
1979	NA	0.29	2.93	0.31	0.34	0.24	0.58	0.16	0.12	0.24	0.07	0.04	0.03	0.02	0.01	0.01
1980	NA	0.55	0.23	2.30	0.24	0.26	0.18	0.43	0.11	0.09	0.17	0.05	0.03	0.02	0.01	0.02
1981	NA	12.52	0.44	0.18	1.80	0.19	0.20	0.13	0.31	0.08	0.06	0.12	0.04	0.02	0.02	0.02
1982	NA	0.17	9.90	0.34	0.14	1.37	0.14	0.14	0.09	0.22	0.06	0.04	0.08	0.03	0.01	0.03
1983	NA	0.17	0.14	7.81	0.27	0.11	1.03	0.10	0.11	0.07	0.16	0.04	0.03	0.06	0.02	0.03
1984	NA	0.34	0.13	0.11	6.11	0.21	0.08	0.77	0.08	0.08	0.05	0.12	0.03	0.02	0.04	0.03
1985	NA	10.21	0.27	0.10	0.08	4.72	0.16	0.06	0.57	0.06	0.06	0.04	0.08	0.02	0.02	0.06
1986	NA	0.26	8.11	0.21	0.08	0.07	3.65	0.12	0.05	0.43	0.04	0.04	0.03	0.06	0.02	0.06
1987	NA	0.44	0.21	6.39	0.17	0.06	0.05	2.71	0.09	0.03	0.31	0.03	0.03	0.02	0.05	0.05
1988	NA	3.77	0.35	0.16	4.98	0.13	0.05	0.04	1.96	0.06	0.02	0.22	0.02	0.02	0.01	0.07
1989	NA	2.05	2.98	0.28	0.13	3.81	0.09	0.04	0.03	1.40	0.05	0.02	0.16	0.02	0.02	0.06
1990	NA	0.72	1.62	2.34	0.21	0.10	2.80	0.07	0.02	0.02	0.97	0.03	0.01	0.11	0.01	0.05
1991	NA	2.51	0.57	1.27	1.82	0.16	0.07	2.04	0.05	0.02	0.01	0.68	0.02	0.01	0.08	0.04
1992	NA	0.99	1.98	0.45	0.98	1.36	0.12	0.05	1.41	0.03	0.01	0.01	0.46	0.02	0.01	0.08
1993	NA	0.52	0.78	1.55	0.34	0.73	0.99	0.08	0.04	0.95	0.02	0.01	0.01	0.30	0.01	0.06
1994	NA	1.87	0.41	0.61	1.20	0.26	0.54	0.70	0.06	0.02	0.65	0.02	0.01	0.00	0.21	0.05
1995	NA	1.64	1.47	0.32	0.46	0.86	0.18	0.35	0.44	0.04	0.01	0.39	0.01	0.00	0.00	0.15
1996	NA	1.23	1.29	1.14	0.24	0.34	0.61	0.12	0.23	0.28	0.02	0.01	0.25	0.01	0.00	0.10
1997	NA	1.37	0.96	1.00	0.85	0.17	0.22	0.38	0.07	0.13	0.16	0.01	0.01	0.14	0.00	0.06
1998	NA	0.83	1.06	0.73	0.73	0.58	0.11	0.13	0.21	0.04	0.07	0.09	0.01	0.00	0.07	0.03
1999	NA	1.64	0.65	0.80	0.53	0.49	0.35	0.06	0.07	0.11	0.02	0.03	0.04	0.00	0.00	0.05
2000	NA	9.70	1.26	0.48	0.57	0.34	0.28	0.18	0.03	0.03	0.05	0.01	0.02	0.02	0.00	0.02
2001	NA	0.84	7.58	0.97	0.36	0.40	0.22	0.17	0.11	0.02	0.02	0.03	0.00	0.01	0.01	0.01
2002	NA	0.66	0.66	5.86	0.73	0.26	0.27	0.14	0.11	0.07	0.01	0.01	0.02	0.00	0.01	0.01
2003	NA	0.21	0.52	0.52	4.52	0.55	0.19	0.19	0.10	0.07	0.04	0.01	0.01	0.01	0.00	0.01
2004	NA	1.52	0.17	0.41	0.40	3.40	0.40	0.13	0.13	0.07	0.05	0.03	0.01	0.01	0.01	0.01
2005	NA	0.45	1.19	0.13	0.31	0.29	2.35	0.26	0.09	0.08	0.04	0.03	0.02	0.00	0.00	0.01
2006	NA	5.21	0.35	0.92	0.10	0.22	0.20	1.51	0.16	0.05	0.05	0.03	0.02	0.01	0.00	0.01
2007	NA	4.74	4.07	0.27	0.68	0.07	0.14	0.12	0.88	0.09	0.03	0.03	0.01	0.01	0.01	0.01
2008	NA	0.17	3.71	3.13	0.20	0.48	0.05	0.09	0.07	0.51	0.05	0.02	0.02	0.01	0.01	0.01
2009	NA	10.44	0.13	2.84	2.32	0.14	0.32	0.03	0.05	0.04	0.29	0.03	0.01	0.01	0.00	0.01
2010	NA	1.21	8.24	0.10	2.19	1.74	0.10	0.22	0.02	0.04	0.03	0.19	0.02	0.01	0.01	0.01
2011	NA	0.93	0.96	6.45	0.08	1.64	1.26	0.07	0.15	0.01	0.02	0.02	0.13	0.01	0.00	0.01

Table 17.1. Summary of Pacific hake reference points from the SS model.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (SB_0, millions mt)	1.549	2.034	2.756
Unfished total biomass (millions mt)	3.735	4.921	6.871
Unfished 3+ biomass (millions mt)	3.239	4.252	5.760
Unfished recruitment (R_0, billions)	1.624	2.576	4.649
Reference points based on $SB_{40\%}$			
MSY Proxy female spawning biomass ($SB_{40\%}$ mt)	0.620	0.814	1.102
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	0.406	0.435	0.512
Exploitation fraction resulting in $SB_{40\%}$	0.136	0.187	0.236
Yield at $SB_{40\%}$ (million mt)	0.217	0.323	0.521
Reference points based on SPR proxy for MSY			
Female spawning biomass at $SPR_{MSY\text{-}proxy}$ (SB_{SPR} mt)	0.506	0.721	0.991
$SPR_{MSY\text{-}proxy}$	0.400	0.400	0.400
Exploitation fraction corresponding to SPR	0.182	0.217	0.258
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (million mt)	0.222	0.334	0.536
Reference points based on estimated MSY values			
Female spawning biomass at *MSY* (SB_{MSY} mt)	0.315	0.491	0.790
SPR_{MSY}	0.189	0.286	0.451
Exploitation fraction corresponding to SPR_{MSY}	0.172	0.342	0.564
MSY (million mt)	0.228	0.355	0.581

Table 17.2. Summary of Pacific hake reference points from the TINSS model.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female spawning biomass (SB_0, millions mt)	0.851	1.242	2.121
Unfished total biomass (millions mt)	2.046	3.008	5.258
Unfished 3+ biomass (millions mt)	1.737	2.549	4.370
Unfished recruitment (R_0, billions)	0.891	1.491	2.903
Reference points based on $SB_{40\%}$			
MSY Proxy female spawning biomass ($SB_{40\%}$ mt)	0.340	0.497	0.848
SPR resulting in $SB_{40\%}$ ($SPR_{SB40\%}$)	0.455	0.530	0.647
Exploitation fraction resulting in $SB_{40\%}$	0.101	0.151	0.194
Yield at $SB_{40\%}$ (million mt)	0.098	0.158	0.266
Reference points based on SPR proxy for MSY			
Female spawning biomass at $SPR_{MSY\text{-}proxy}$ (SB_{SPR} mt)	0.000	0.283	0.497
$SPR_{MSY\text{-}proxy}$	0.400	0.400	0.400
Exploitation fraction corresponding to SPR	0.198	0.236	0.284
Yield with $SPR_{MSY\text{-}proxy}$ at SB_{SPR} (million mt)	0.000	0.145	0.253
Reference points based on estimated MSY values			
Female spawning biomass at *MSY* (SB_{MSY} mt)	0.283	0.456	0.851
SPR_{MSY}	0.353	0.509	0.669
Exploitation fraction corresponding to SPR_{MSY}	0.093	0.165	0.268
MSY (million mt)	0.098	0.160	0.271

Table 18.1. Decision table with three year projections of posterior distributions for Pacific hake female **spawning biomass** (millions mt, at the beginning of the year before fishing takes place). Catch alternatives are based on: 1) arbitrary constant catch levels of 50,000, 100,000, 150,000, 300,000, 400,000 and 500,000 mt (rows a-c, and e-g), 2) the status quo OY from 2010 (row d), and 3) the OY implied by the estimated F_{MSY} from the TINSS model (row h), and the values estimated via the 40:10 harvest control rule and the F40% overfishing limit/target for the base case SS (row i) and TINSS models (row j).

			States of nature					
		Model	SS			TINSS		
		Within model probability	25%	50%	25%	25%	50%	25%
		Description	Low 2008 cohort	Modal density	High 2008 cohort	Low 2008 cohort	Modal density	High 2008 cohort
Management Action								
	Year	Catch (mt)						
a	2011	50,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	50,000	1.238	2.180	3.801	1.605	2.711	4.427
	2013	50,000	1.309	2.308	3.912	1.629	2.732	4.449
b	2011	100,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	100,000	1.215	2.157	3.777	1.581	2.686	4.403
	2013	100,000	1.262	2.261	3.866	1.584	2.685	4.403
c	2011	150,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	150,000	1.191	2.133	3.754	1.557	2.662	4.379
	2013	150,000	1.215	2.215	3.821	1.538	2.643	4.356
d	2011	262,500	1.053	1.873	3.232	1.358	2.174	3.534
	2012	262,500	1.138	2.081	3.701	1.503	2.608	4.325
	2013	262,500	1.110	2.110	3.718	1.439	2.539	4.252
e	2011	300,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	300,000	1.120	2.063	3.683	1.485	2.589	4.306
	2013	300,000	1.075	2.075	3.684	1.404	2.504	4.217
f	2011	400,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	400,000	1.073	2.016	3.636	1.437	2.541	4.258
	2013	400,000	0.982	1.982	3.593	1.313	2.409	4.124
g	2011	500,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	500,000	1.025	1.969	3.589	1.388	2.494	4.209
	2013	500,000	0.889	1.890	3.500	1.221	2.314	4.034
h	2011	704,600	1.053	1.873	3.232	1.358	2.174	3.534
	2012	781,000	0.928	1.879	3.493	1.292	2.398	4.107
	2013	784,200	0.662	1.671	3.280	0.998	2.083	3.820
i	2011	840,000	1.053	1.873	3.232	1.355	2.174	3.534
	2012	886,000	0.864	1.809	3.429	1.225	2.335	4.040
	2013	782,000	0.558	1.559	3.166	0.890	1.971	3.712
j	2011	1,120,000	1.053	1.873	3.232	1.358	2.174	3.534
	2012	1,107,000	0.734	1.683	3.297	1.080	2.201	3.900
	2013	1,007,000	0.369	1.333	2.943	0.450	1.742	3.485

Table 18.2. Decision table with three year projections of posterior distributions for Pacific hake relative **depletion** (at the beginning of the year before fishing takes place). Catch alternatives are based on: 1) arbitrary constant catch levels of 50,000, 100,000, 150,000, 300,000, 400,000 and 500,000 mt (rows a-c, and e-g), 2) the status quo OY from 2010 (row d), and 3) the OY implied by the estimated F_{MSY} from the TINSS model (row h), and the values estimated via the 40:10 harvest control rule and the F40% overfishing limit/target for the base case SS (row i) and TINSS models (row j).

			States of nature					
		Model	SS			TINSS		
		Within model probability	25%	50%	25%	25%	50%	25%
		Description	Low 2008 cohort	Modal density	High 2008 cohort	Low 2008 cohort	Modal density	High 2008 cohort
Management Action								
	Year	Catch (mt)						
a	2011	50,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	50,000	0.649	1.066	1.740	1.412	2.155	3.327
	2013	50,000	0.693	1.116	1.782	1.437	2.213	3.292
b	2011	100,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	100,000	0.633	1.055	1.729	1.389	2.142	3.307
	2013	100,000	0.669	1.095	1.760	1.397	2.173	3.252
c	2011	150,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	150,000	0.618	1.042	1.719	1.367	2.125	3.289
	2013	150,000	0.645	1.074	1.740	1.360	2.134	3.217
d	2011	262,500	0.549	0.909	1.493	1.144	1.749	2.704
	2012	262,500	0.589	1.014	1.698	1.320	2.087	3.260
	2013	262,500	0.591	1.023	1.693	1.269	2.049	3.138
e	2011	300,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	300,000	0.580	1.006	1.691	1.302	2.071	3.251
	2013	300,000	0.572	1.007	1.680	1.235	2.018	3.106
f	2011	400,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	400,000	0.556	0.984	1.670	1.264	2.022	3.214
	2013	400,000	0.519	0.963	1.642	1.147	1.939	3.019
g	2011	500,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	500,000	0.533	0.961	1.648	1.221	1.979	3.175
	2013	500,000	0.474	0.918	1.602	1.058	1.864	2.950
h	2011	704,600	0.549	0.909	1.493	1.144	1.749	2.704
	2012	781,000	0.484	0.913	1.604	1.145	1.900	3.114
	2013	784,200	0.357	0.809	1.496	0.852	1.677	2.763
i	2011	840,000	0.549	0.909	1.493	1.140	1.749	2.704
	2012	886,000	0.451	0.878	1.569	1.088	1.847	3.072
	2013	782,000	0.298	0.753	1.437	0.741	1.572	2.685
j	2011	1,120,000	0.549	0.909	1.493	1.144	1.749	2.704
	2012	1,107,000	0.387	0.816	1.505	0.916	1.733	2.930
	2013	1,007,000	0.202	0.643	1.329	0.359	1.383	2.510

Table 18.3. Decision table with three year projections of posterior distributions for Pacific hake relative **spawning potential ratio** (1-SPR/1-SPRTarget=0.4; values greater than 1.0 denote overfishing). Catch alternatives are based on: 1) arbitrary constant catch levels of 50,000, 100,000, 150,000, 300,000, 400,000 and 500,000 mt (rows a-c, and e-g), 2) the status quo OY from 2010 (row d), and 3) the OY implied by the estimated F_{MSY} from the TINSS model (row h), and the values estimated via the 40:10 harvest control rule and the F40% overfishing limit/target for the base case SS (row i) and TINSS models (row j).

			States of nature					
		Model	SS			TINSS		
		Within model probability	25%	50%	25%	25%	50%	25%
		Description	Low 2008 cohort	Modal density	High 2008 cohort	Low 2008 cohort	Modal density	High 2008 cohort
Management Action								
	Year	Catch (mt)						
a	2011	50,000	0.225	0.129	0.075	0.174	0.122	0.080
	2012	50,000	0.181	0.103	0.058	0.145	0.097	0.062
	2013	50,000	0.167	0.095	0.055	0.131	0.084	0.053
b	2011	100,000	0.399	0.241	0.145	0.311	0.225	0.152
	2012	100,000	0.334	0.197	0.113	0.266	0.184	0.120
	2013	100,000	0.316	0.184	0.107	0.247	0.162	0.103
c	2011	150,000	0.538	0.340	0.209	0.421	0.313	0.216
	2012	150,000	0.465	0.283	0.166	0.370	0.262	0.173
	2013	150,000	0.448	0.267	0.158	0.352	0.234	0.151
d	2011	262,500	0.766	0.519	0.337	0.608	0.470	0.338
	2012	262,500	0.699	0.451	0.274	0.560	0.411	0.282
	2013	262,500	0.699	0.437	0.266	0.551	0.379	0.250
e	2011	300,000	0.823	0.569	0.374	0.657	0.513	0.373
	2012	300,000	0.762	0.501	0.308	0.614	0.454	0.314
	2013	300,000	0.769	0.488	0.300	0.609	0.422	0.281
f	2011	400,000	0.946	0.685	0.466	0.764	0.613	0.457
	2012	400,000	0.905	0.620	0.392	0.740	0.557	0.395
	2013	400,000	0.933	0.615	0.387	0.748	0.529	0.359
g	2011	500,000	1.038	0.780	0.546	0.851	0.695	0.529
	2012	500,000	1.016	0.723	0.470	0.845	0.646	0.468
	2013	500,000	1.067	0.727	0.468	0.869	0.626	0.429
h	2011	704,600	1.166	0.926	0.682	0.986	0.824	0.648
	2012	781,000	1.214	0.932	0.650	1.055	0.835	0.631
	2013	784,200	1.307	0.973	0.664	1.139	0.843	0.599
i	2011	840,000	1.226	1.000	0.755	1.056	0.891	0.712
	2012	886,000	1.280	1.002	0.710	1.131	0.896	0.685
	2013	782,000	1.340	1.003	0.679	1.192	0.867	0.611
j	2011	1,120,000	1.308	1.110	0.878	1.166	1.004	0.820
	2012	1,107,000	1.359	1.118	0.822	1.325	1.014	0.786
	2013	1,007,000	1.378	1.116	0.815	1.664	1.027	0.733

Table 19. Select likelihoods, parameters and estimated quantities for SS MLE and posterior medians. Likelihood comparisons are not meaningful between MLE and posterior results.

	MLE	Posterior median
Negative log-likelihood		
Total	155.460	NA
Survey index	-5.478	NA
Age data	129.445	NA
Parameter priors	0.174	NA
Parameters		
R_0 (billions)	2.253	2.576
Steepness (*h*)	0.851	0.810
Natural mortality (*M; m/f*)	0.214	0.223
Acoustic catchability (*Q*)	1.019	NA
Additional acoustic survey SD	0.195	0.265
Reference points		
2008 recruitment deviation	2.617	2.729
SB_0 (million mt)	1.893	2.034
2011 Depletion	0.890	0.910
2010 SPR ratio	0.695	0.637

Table 20. Select likelihoods, parameters and estimated quantities for TINSS MLE and posterior medians. Likelihood comparisons are not meaningful between MLE and posterior results.

	MLE	Posterior median
Negative log-likelihood		
Total	-276.23	NA
Survey index	1.44	NA
Commercial age data	-288.67	NA
Survey age data	-53.92	NA
Parameter priors	64.92	NA
Parameters		
MSY	0.13	0.15
F_{MSY}	0.34	0.41
R_0 (billions)	1.23	1.49
Steepness (*h*)	0.55	0.54
Natural mortality (*M; m/f*)	0.23	0.24
Acoustic catchability (*Q*)	1.25	1.22
Reference points		
2009 age-1 recruitment deviation	2.42	2.63
SB_0 (million mt)	1.16	1.24
2011 Depletion	1.62	1.75
2010 SPR ratio	0.6	0.53

Table 21. Select likelihoods, parameters and estimated quantities for SS sensitivity analyses to basic model structure. Likelihood values in italics are not comparable.

	Empirical age	Age with growth	Age by sex with growth	Age with catch by season
Negative log-likelihood				
Total	155.460	*390.107*	*650.547*	*407.663*
Survey index	-5.478	-6.171	-5.706	-5.137
Age data	129.445	*355.405*	*610.428*	*369.765*
Parameter priors	0.174	0.201	0.096	0.144
Parameters				
R_0 (billions)	2.253	2.347	2.371	2.139
Steepness (*h*)	0.851	0.863	0.873	0.863
Natural mortality (*M; m/f*)	0.214	0.214	0.206/0.206	0.212
Acoustic catchability (*Q*)	1.019	0.942	0.997	1.011
Additional acoustic survey SD	0.195	0.167	0.183	0.207
Reference points				
2008 recruitment deviation	2.617	3.177	3.297	3.121
SB_0 (million mt)	1.893	2.157	2.567	1.942
2011 Depletion	0.890	0.936	0.720	0.872
2010 SPR ratio	0.695	0.626	0.710	0.681

Table 22. Select likelihoods, parameters and estimated quantities for SS sensitivity analyses to the exclusion of the 2010 fishery age data. Likelihood values in italics are not comparable.

	Base SS	No 2010 fishery data
Negative log-likelihood		
Total	155.460	146.378
Survey index	-5.478	-5.555
Age data	129.445	*122.642*
Parameter priors	0.174	0.146
Parameters		
R_0 (billions)	2.253	2.271
Steepness (*h*)	0.851	0.850
Natural mortality (*M; m/f*)	0.214	0.213
Acoustic catchability (*Q*)	1.019	0.960
Additional acoustic survey SD	0.195	0.194
Reference points		
2008 recruitment deviation	2.617	0.773
SB_0 (million mt)	1.893	1.923
2011 Depletion	0.890	0.485
2010 SPR ratio	0.695	0.719

Table 23. Select likelihoods, parameters and estimated quantities for SS sensitivity analyses to the priors on steepness and natural mortality. Likelihood values in italics are not comparable.

	Base SS	Low *h* prior	M prior SD = 0.5	M fixed at 0.23
Negative log-likelihood				
Total	155.460	*156.742*	*154.618*	*154.814*
Survey index	-5.478	-5.364	-5.308	-5.414
Age data	129.445	129.351	129.270	129.369
Parameter priors	0.174	*0.653*	*0.055*	*-0.059*
Parameters				
R_0 (billions)	2.253	2.662	3.614	2.685
Steepness (*h*)	0.851	0.529	0.841	0.847
Natural mortality (*M; m/f*)	0.214	0.220	0.256	0.230
Acoustic catchability (*Q*)	1.019	0.995	0.813	0.940
Additional acoustic survey SD	0.195	0.199	0.203	0.198
Reference points				
2008 recruitment deviation	2.617	2.691	2.564	2.595
SB_0 (million mt)	1.893	2.122	2.171	1.973
2011 Depletion	0.890	0.787	1.042	0.949
2010 SPR ratio	0.695	0.682	0.509	0.622

Table 24. Select likelihoods, parameters and estimated quantities for SS sensitivity analyses to the structure of ageing error. Likelihood values in italics are not comparable.

	Base SS	No cohort ageing error	No ageing error
Negative log-likelihood			
Total	*155.460*	*222.264*	*109.160*
Survey index	-5.478	-5.413	-5.200
Age data	*129.445*	*193.481*	*91.795*
Parameter priors	*0.174*	*0.100*	*0.238*
Parameters			
R_0 (billions)	2.253	2.172	2.149
Steepness (*h*)	0.851	0.843	0.852
Natural mortality (*M; m/f*)	0.214	0.212	0.216
Acoustic catchability (*Q*)	1.019	1.026	1.032
Additional acoustic survey SD	0.195	0.198	0.205
Reference points			
2008 recruitment deviation	2.617	2.745	2.116
SB_0 (million mt)	1.893	1.858	1.776
2011 Depletion	0.890	0.890	0.797
2010 SPR ratio	0.695	0.706	0.726

Table 25. Select likelihoods, parameters and estimated quantities for SS sensitivity analyses to fishery and survey selectivity parameterization. Likelihood values in italics are not comparable.

	SS base	Non-parametric selectivity to age 8	Double-normal selectivity (dome-shaped)	Time-varying non-parametric selectivity
Negative log-likelihood				
Total	155.460	145.893	170.529	123.635
Survey index	-5.478	-5.574	-6.298	-5.775
Age data	129.445	119.918	145.474	91.257
Parameter priors	0.174	0.184	0.062	0.064
Parameters				
R_0 (billions)	2.253	2.103	2.183	1.978
Steepness (*h*)	0.851	0.854	0.848	0.856
Natural mortality (*M; m/f*)	0.214	0.214	0.210	0.209
Acoustic catchability (*Q*)	1.019	1.702	0.838	1.305
Additional acoustic survey SD	0.195	0.191	0.166	0.187
Reference points				
2008 recruitment deviation	2.617	2.581	2.316	1.935
SB_0 (million mt)	1.893	1.765	1.897	1.727
2011 Depletion	0.890	0.845	0.714	0.653
2010 SPR ratio	0.695	0.766	0.740	0.754

Table 26. Sensitivity to priors and model assumptions tested in TINSS. Note sensitivity runs shown in the table were done individually, with all other priors set to the values in the base case (Table 9).

Parameter	Distribution	μ, σ	μ, σ	μ, σ	μ, σ	
F_{MSY}	lognormal	0.35, 0.262[1]	0.3, 0.4	0.4, 0.4	0.35,0.5	Prior mapped from SS steepness prior
MSY	lognormal	0.15, 0.5	0.3, 0.5	0.2, 0.75		
M	lognormal	0.15, 0.1	0.25, 0.1	0.2,0.5		
q	lognormal	0, 0.2	0, 0.3			

1. 2010 assessment prior (Martell 2010)

Table 27. Select parameters and estimated quantities for TINSS sensitivity analyses to the prior for F_{MSY} to the acoustic survey. Note that recruits are age 1 and not directly comparable with SS.

	TINSS Base	***μ, σ***	***μ, σ***	***μ, σ***	***μ, σ***	***μ, σ***
Parameters		**0.35, 0.262**	**0.3, 0.4**	**0.4, 0.4**	**0.35,0.5**	**Mapped from SS prior on steepness**
MSY	0.134	0.134	0.128	0.140	0.133	0.186
F_{MSY}	0.343	0.346	0.302	0.383	0.340	0.959
R_0 (billions)	1.225	1.224	1.241	1.213	1.226	1.152
Steepness (*h*)	0.546	0.549	0.515	0.574	0.544	0.829
Natural mortality (*M; m/f*)	0.227	0.227	0.227	0.228	0.227	0.230
Acoustic catchability (*Q*)	1.255	1.255	1.254	1.255	1.255	1.257
Reference points						
2009 log recruitment deviation	2.422	2.421	2.432	2.413	2.422	2.371
SB_0 (million mt)	1.165	1.163	1.186	1.149	1.166	1.077
2011 Depletion	1.623	1.625	1.606	1.636	1.623	1.689
2010 SPR ratio	0.638	0.638	0.639	0.638	0.638	0.633

Table 28. Select parameters and estimated quantities for TINSS sensitivity analyses to the prior for *MSY*. Note that recruits are age 1 and not directly comparable with SS.

	TINSS Base	μ, σ	μ, σ	μ, σ
Parameters		**0.3,0.5**	**0.15,0.5**	**0.2,0.75**
MSY	0.134	0.148	0.124	0.125
F_{MSY}	0.343	0.369	0.323	0.325
R_0 (billions)	1.225	1.308	1.171	1.176
Steepness (*h*)	0.546	0.565	0.531	0.532
Natural mortality (*M; m/f*)	0.227	0.228	0.227	0.227
Acoustic catchability (*Q*)	1.255	1.250	1.258	1.257
Reference points				
2009 log recruitment deviation	2.422	2.450	2.402	2.404
SB_0 (million mt)	1.165	1.238	1.115	1.119
2011 Depletion	1.623	1.575	1.663	1.659
2010 SPR ratio	0.638	0.645	0.634	0.635

Table 29. Select parameters and estimated quantities for TINSS sensitivity analyses to the prior for M. Note that recruits are age 1 and not directly comparable with SS.

	TINSS Base	***μ, σ***	***μ, σ***	***μ, σ***
Parameters		**0.15, 0.1**	**0.25, 0.1**	**0.2, 0.5**
MSY	0.134	0.133	0.139	0.150
F_{MSY}	0.343	0.313	0.357	0.338
R_0 (billions)	1.225	0.800	1.827	3.523
Steepness (*h*)	0.546	0.673	0.460	0.356
Natural mortality (*M; m/f*)	0.227	0.166	0.283	0.365
Acoustic catchability (*Q*)	1.255	1.335	1.185	1.095
Reference points				
2009 log recruitment deviation	2.422	2.558	2.235	1.814
SB_0 (million mt)	1.165	1.267	1.194	1.443
2011 Depletion	1.623	1.207	1.911	2.126
2010 SPR ratio	0.638	0.510	0.726	0.823

Table 30. Select parameters and estimated quantities for TINSS sensitivity analyses to the standard deviation of the prior for survey selectivity Q. Note that recruits are age 1 and not directly comparable with SS.

	TINSS Base	SD fixed 0.2	SD fixed 0.3
Parameters			
MSY	0.134	0.126	0.122
F_{MSY}	0.343	0.342	0.341
R_0 (billions)	1.225	1.026	0.962
Steepness (h)	0.546	0.578	0.588
Natural mortality ($M; m/f$)	0.227	0.210	0.204
Acoustic catchability (Q)	1.255	1.720	2.054
Reference points			
2009 log recruitment deviation	2.422	2.121	1.982
SB_0 (million mt)	1.165	1.112	1.095
2011 Depletion	1.623	1.089	0.912
2010 SPR ratio	0.638	0.519	0.467

Table 31. Select likelihoods, parameters and estimated quantities for SS retrospective analyses. Likelihood values in italics are not comparable to the SS base model.

	Base SS	-1 year	-2 years	-3 years	-4 years	-5 years
Negative log-likelihood						
Total	155.460	*146.378*	*138.073*	*134.258*	*128.301*	*124.731*
Survey index	-5.478	-5.555	*-4.470*	*-4.496*	*-3.230*	*-3.136*
Age data	129.445	*122.642*	*115.022*	*111.783*	*106.085*	*102.900*
Parameter priors	0.174	0.146	0.164	0.154	0.126	0.144
Parameters						
R_0 (billions)	2.253	2.271	2.275	2.263	2.183	2.252
Steepness (*h*)	0.851	0.850	0.850	0.849	0.846	0.846
Natural mortality (*M; m/f*)	0.214	0.213	0.214	0.213	0.213	0.213
Acoustic catchability (*Q*)	1.019	0.960	1.030	1.038	1.071	1.113
Additional acoustic survey SD	0.195	0.194	0.214	0.213	0.244	0.250
Reference points						
2008 recruitment deviation	2.617	0.773	NA	NA	NA	NA
SB_0 (million mt)	1.893	1.923	1.916	1.910	1.855	1.904
2006 Depletion	0.478	0.506	0.449	0.445	0.402	0.356
2005 SPR ratio	0.860	0.835	0.877	0.884	0.937	0.987

Table 32. Retrospective tables for TINSS model runs. *Results based on pre-SSC model code*.

	Base TINSS	-1 year	-2 years	-3 years	-4 years	-5 years
Negative log-likelihood						
Total	-276.27	-274.68	-260.69	-245.5	-212.6	-199.79
Survey index	1.44	2.63	1.13	1.54	1.28	1.54
Commercial age data	-288.7	*-278.2*	*-261.52*	*-243.41*	*-229.11*	*-217.0*
Survey age data	-53.92	*-61.6*	*-58.97*	*-60.88*	*-39.63*	*-39.07*
Parameter priors	64.91	62.49	58.67	57.25	54.86	54.74
Parameters						
MSY (million mt)	0.134	0.128	0.129	0.131	0.126	0.127
FMSY	0.343	0.343	0.350	0.346	0.345	0.341
Natural mortality (*M*)	0.227	0.220	0.218	0.215	0.208	0.203
Acoustic catchability (*q*)	1.25	1.20	1.21	1.15	1.12	1.08
Reference points						
2009 log recruitment deviation	2.42	0.31	NA	NA	NA	NA
SB_0 (million mt)	1.14	1.12	1.10	1.11	1.08	1.10
2006 SSB	1.05	1.01	0.81	0.93	0.85	0.90
2006 Depletion	0.92	0.91	0.74	0.84	0.78	0.816
2005 SPR ratio	0.79	0.76	0.83	0.93	0.85	0.83

7. Figures

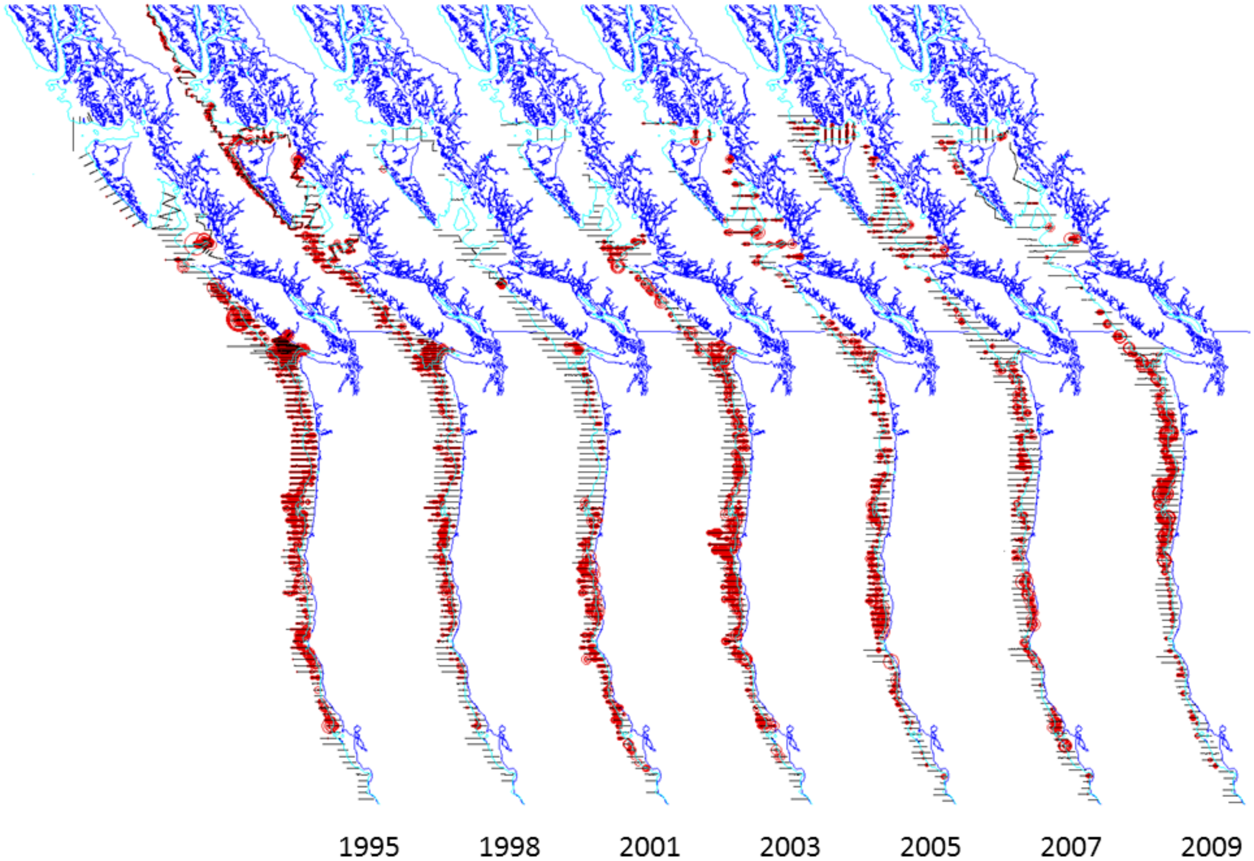


Figure 1. Spatial distribution of acoustic backscatter attributable to Pacific hake from joint US-Canada acoustic surveys 1995-2009. Area of the circles is proportional to observed backscatter.

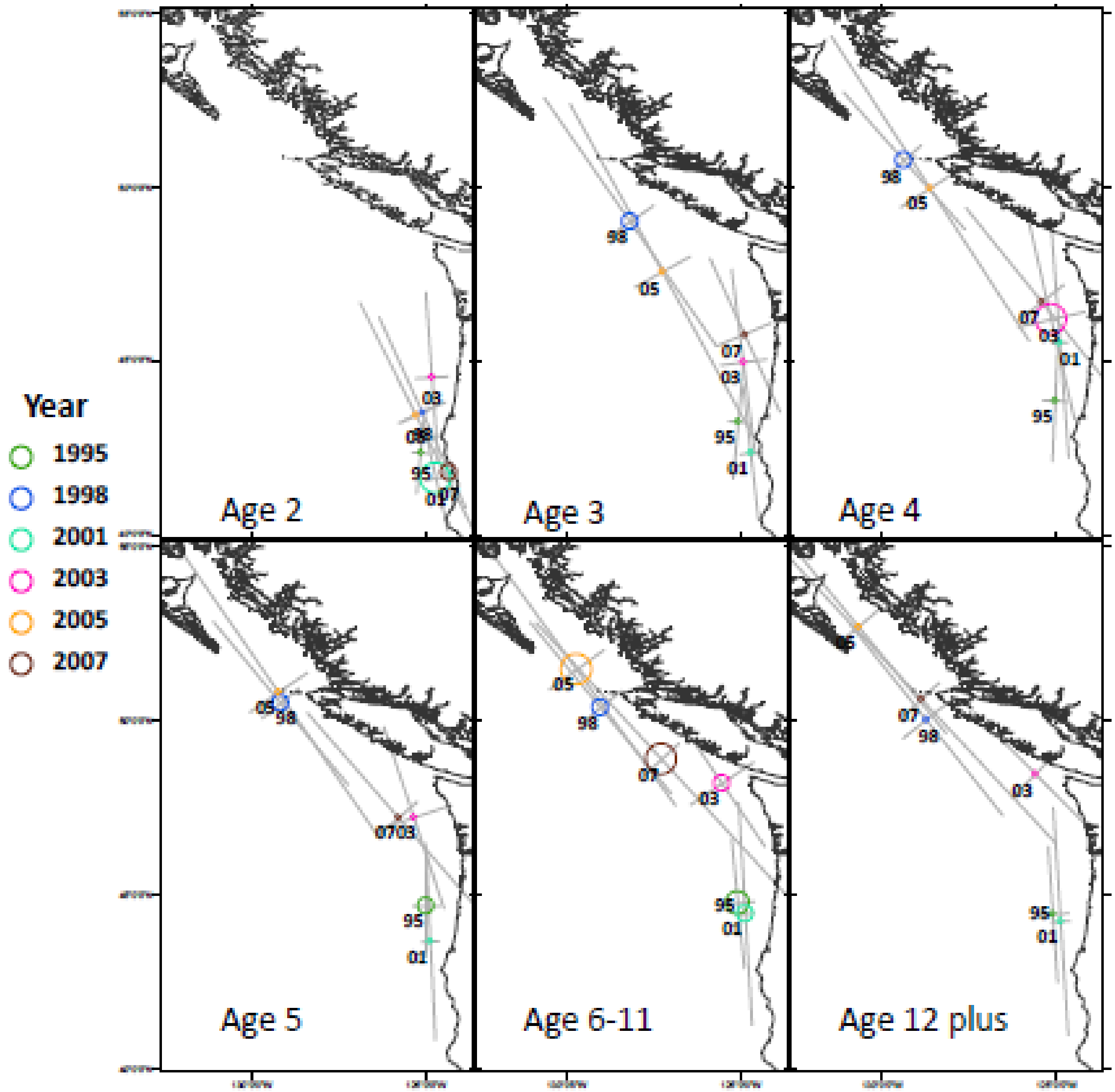


Figure 2. The mean spatial location of the hake stock (circles are proportional to biomass) and variance (grey lines) by age group and year based on acoustic survey observations 1995-2007 (Figure courtesy of O'Conner and Haltuch's ongoing Fisheries And The Environment project investigating the links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

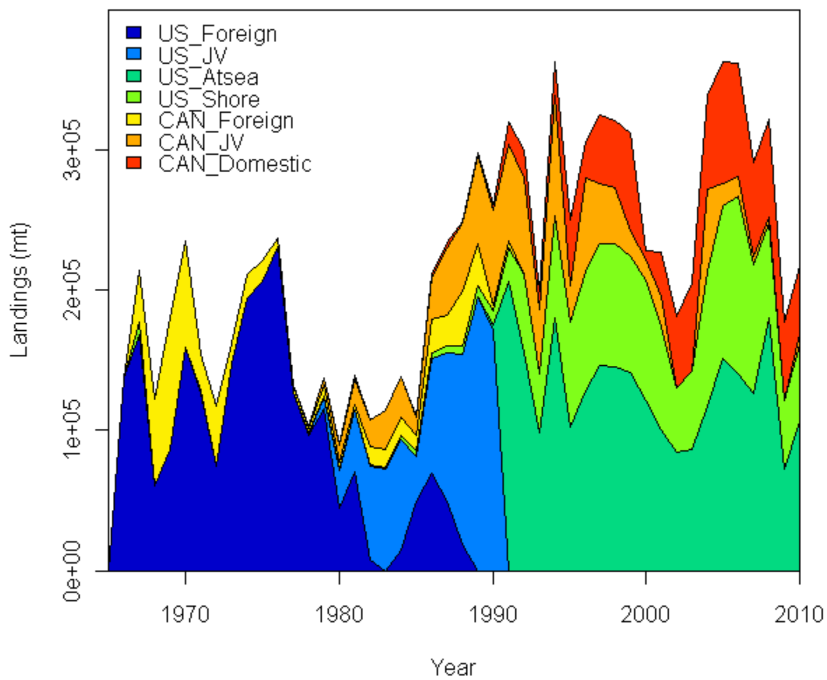


Figure 3. Total Pacific hake landings used in the assessment by sector, 1966-2010.

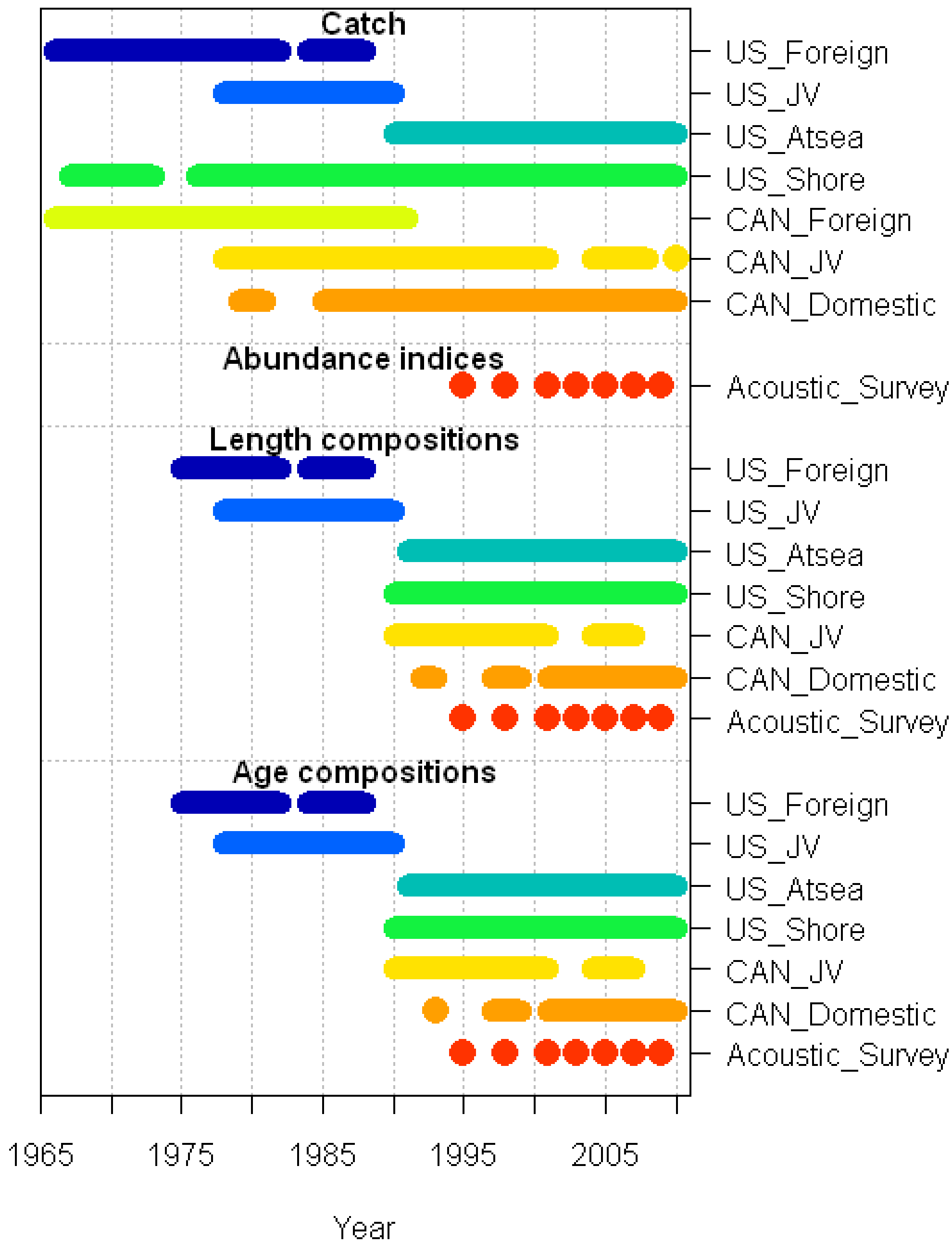


Figure 4. Overview of data sources available for Pacific hake, 1966-2010.

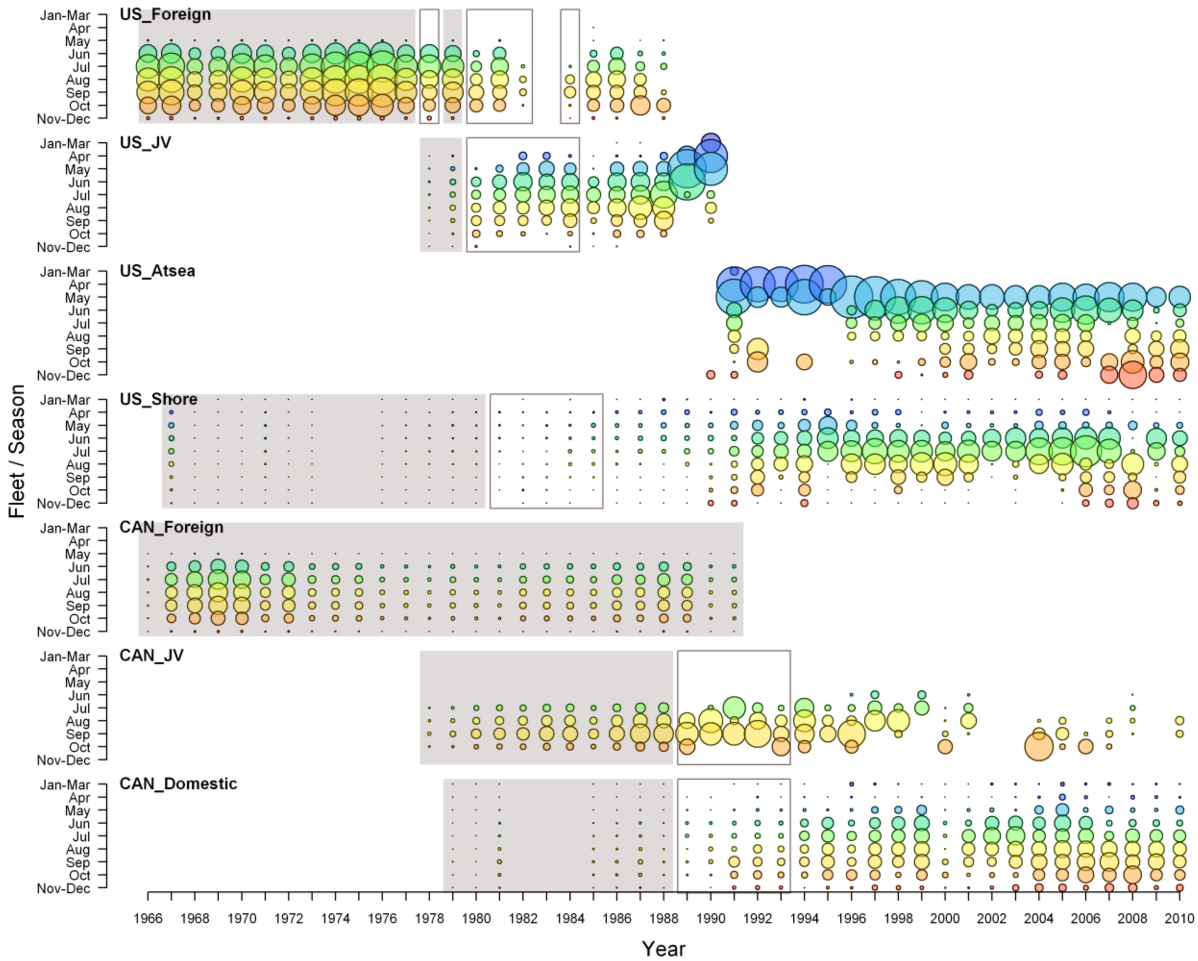


Figure 5. Within and among year temporal patterns in reconstructed Pacific hake landings by sector, 1966-2010. The area of each circle is proportional to catch for that period. Shaded rectangles indicate years in which only annual catch was available, open rectangles indicate 5-year reference period used to calculate average seasonal distribution to distribute annual catch values. The Canadian foreign fleet had no seasonal data available, so the seasonal distribution was assumed to be the same as the U.S. foreign fleet.

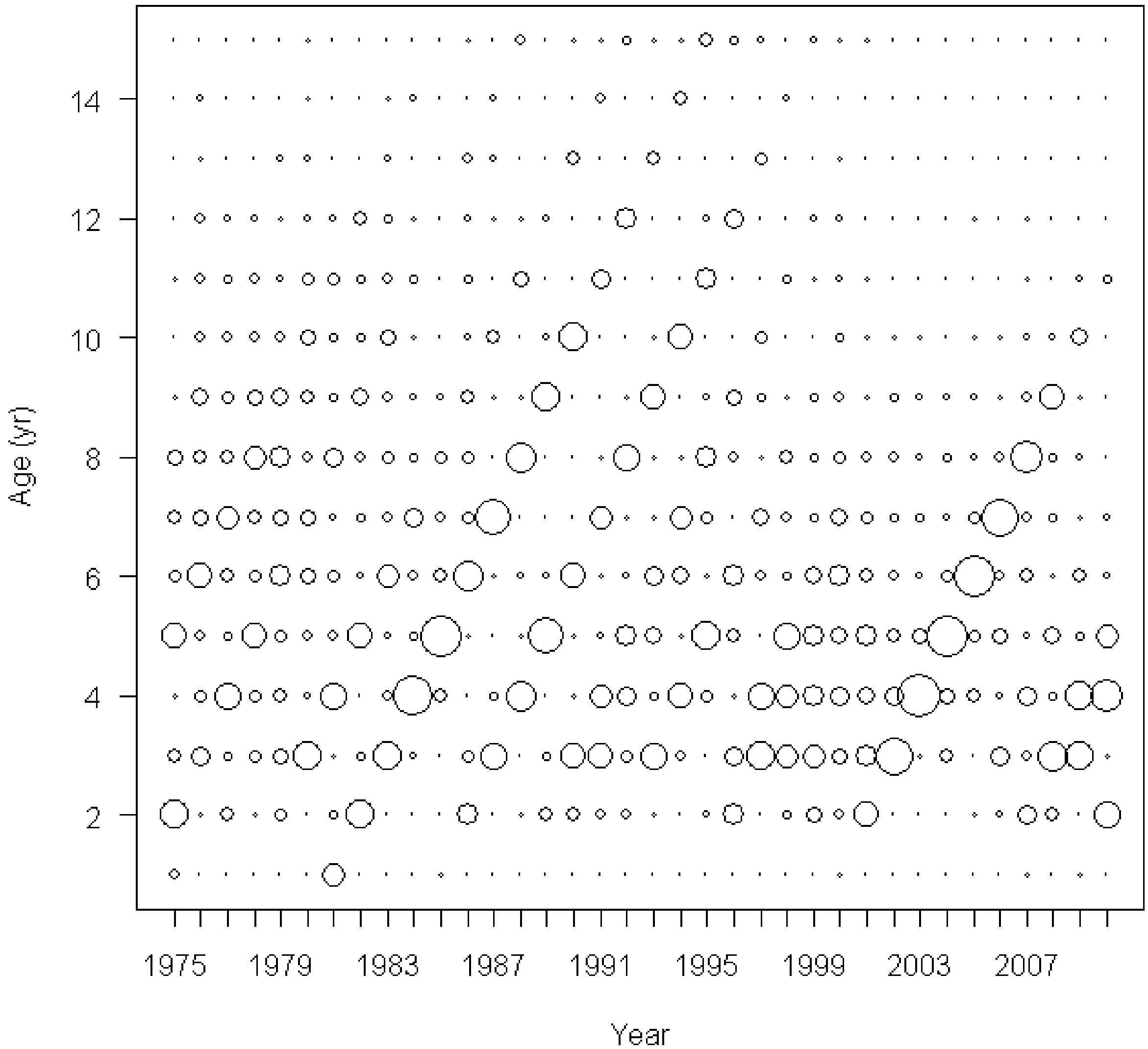


Figure 6. Aggregate fishery (all sectors combined) age compositions, 1975-2010. Proportions in each year sum to 1.0, maximum bubble size represents a value of 0.77.

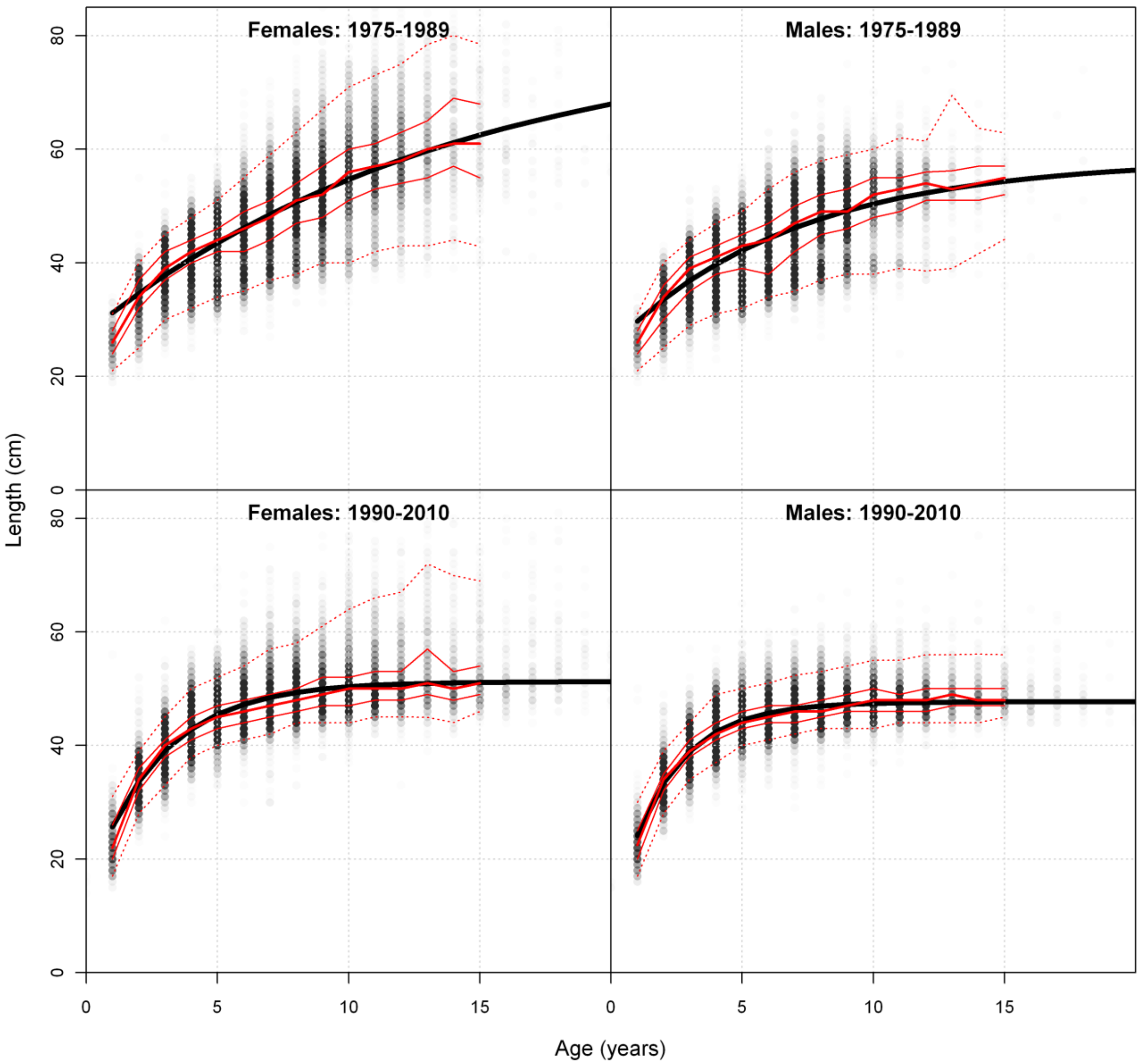


Figure 7. Estimated growth curves for females and males fit to length and age data for the time periods 1975-1989 and 1990-2010. Darkness of grey points indicates the number of samples at each value. Red lines indicate median, as well as 50% and 95% intervals of the observed lengths at each age from 1 to 15.

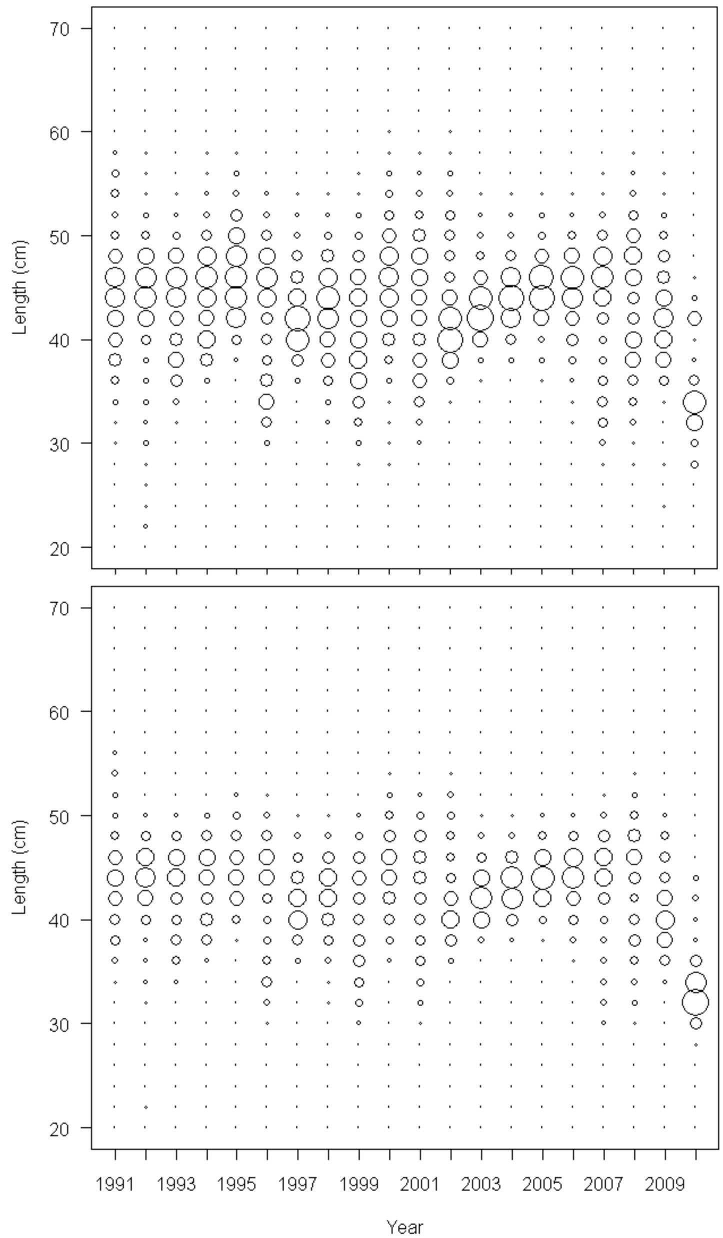


Figure 8. U.S. at-sea fishery length compositions, 1991-2010. Proportions in each year sum to 1.0 across both sexes in each year, maximum bubble size represents a value of 0.17 for females (upper panel) and 0.31 for males (lower panel).

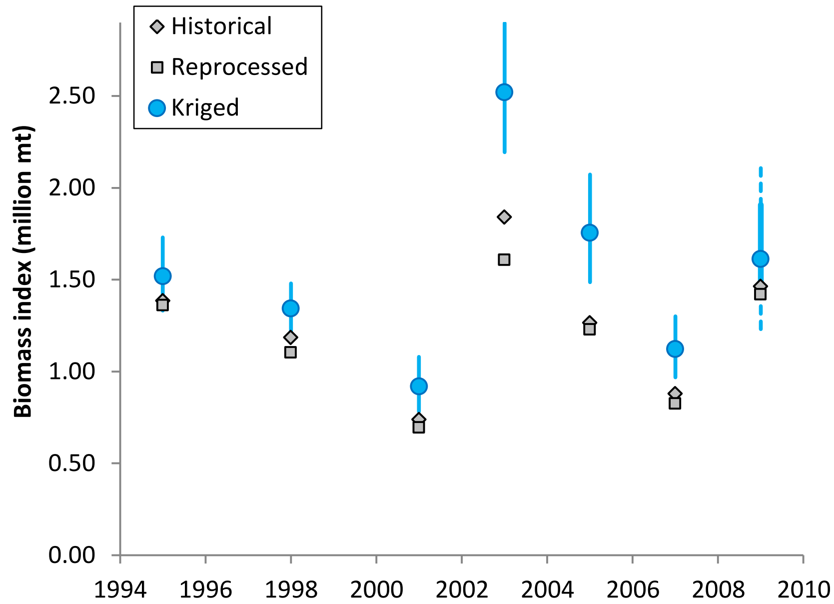


Figure 9. Historical and updated acoustic survey biomass estimates (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995-2007) and sampling variability as well as squid/hake apportionment uncertainty (2009).

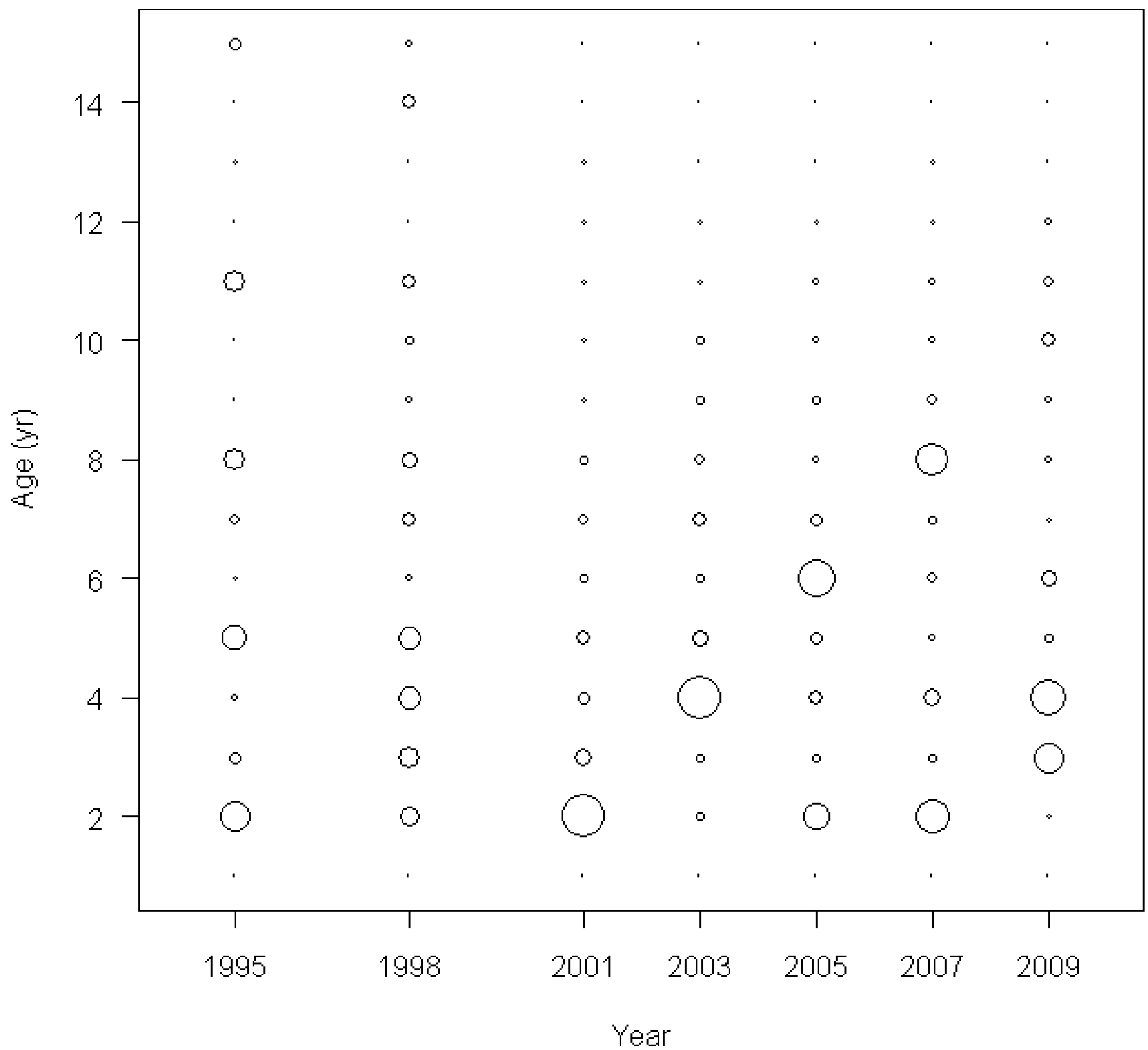


Figure 10. Acoustic survey age compositions, 1995-2009. Proportions in each year sum to 1.0, maximum bubble size represents a value of 0.63.

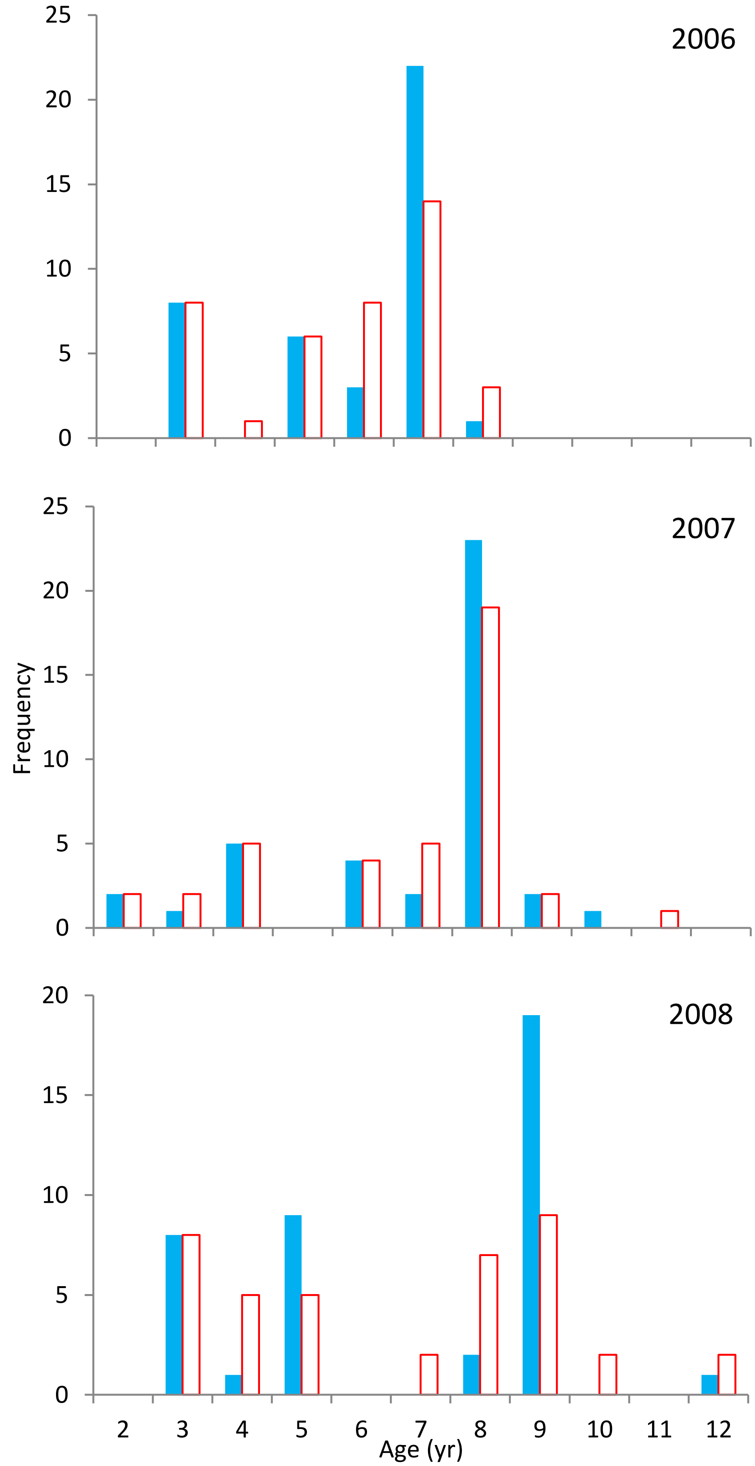


Figure 11. Comparison of age-frequency distributions from three recent years when otoliths were read under normal conditions (filled bars) and when the same set of otoliths was read, but were analyzed in a mixed sample where the reader was unaware of the collection year (open bars).

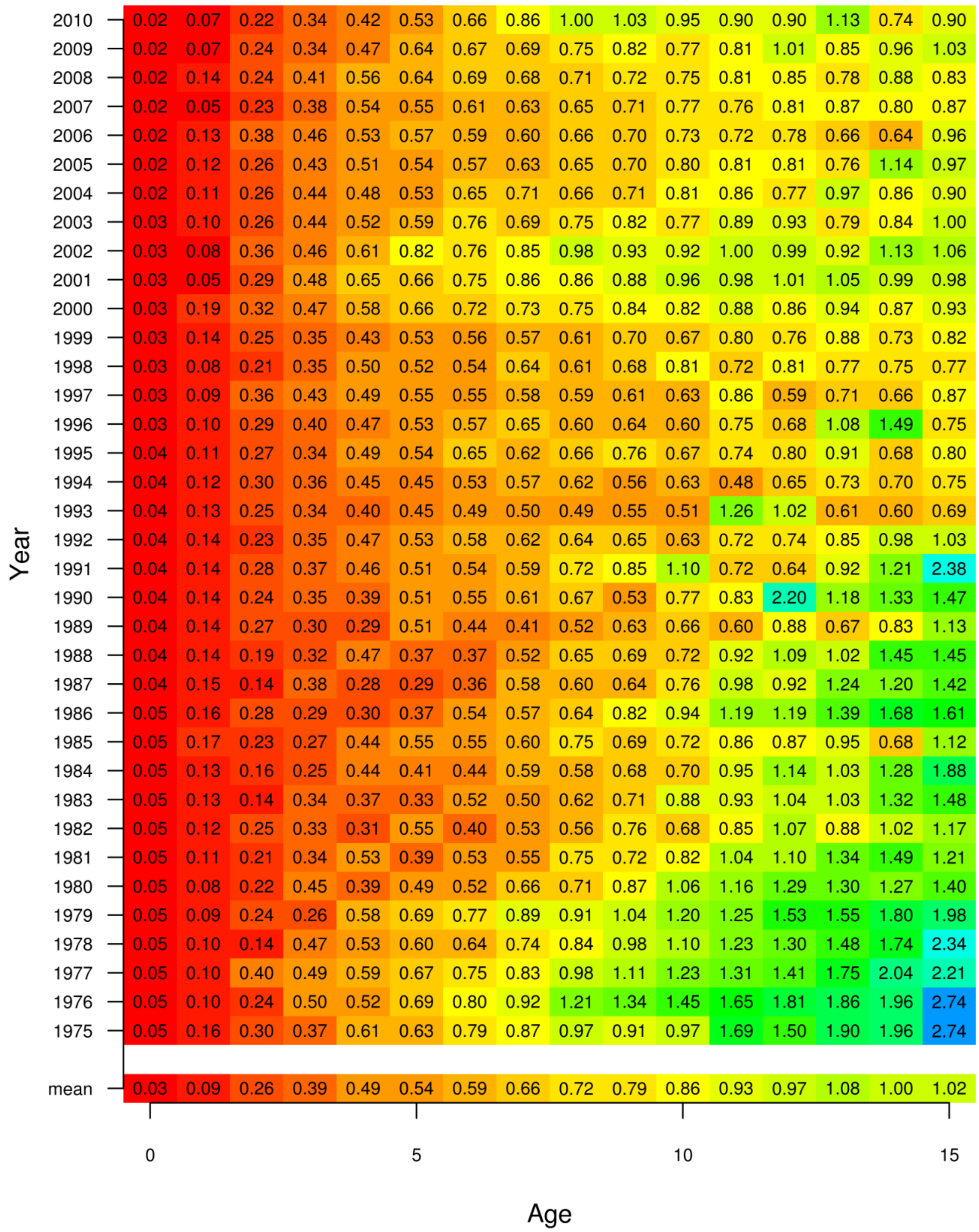


Figure 12. Interpolated matrix of weight at age (kg) used in both models.

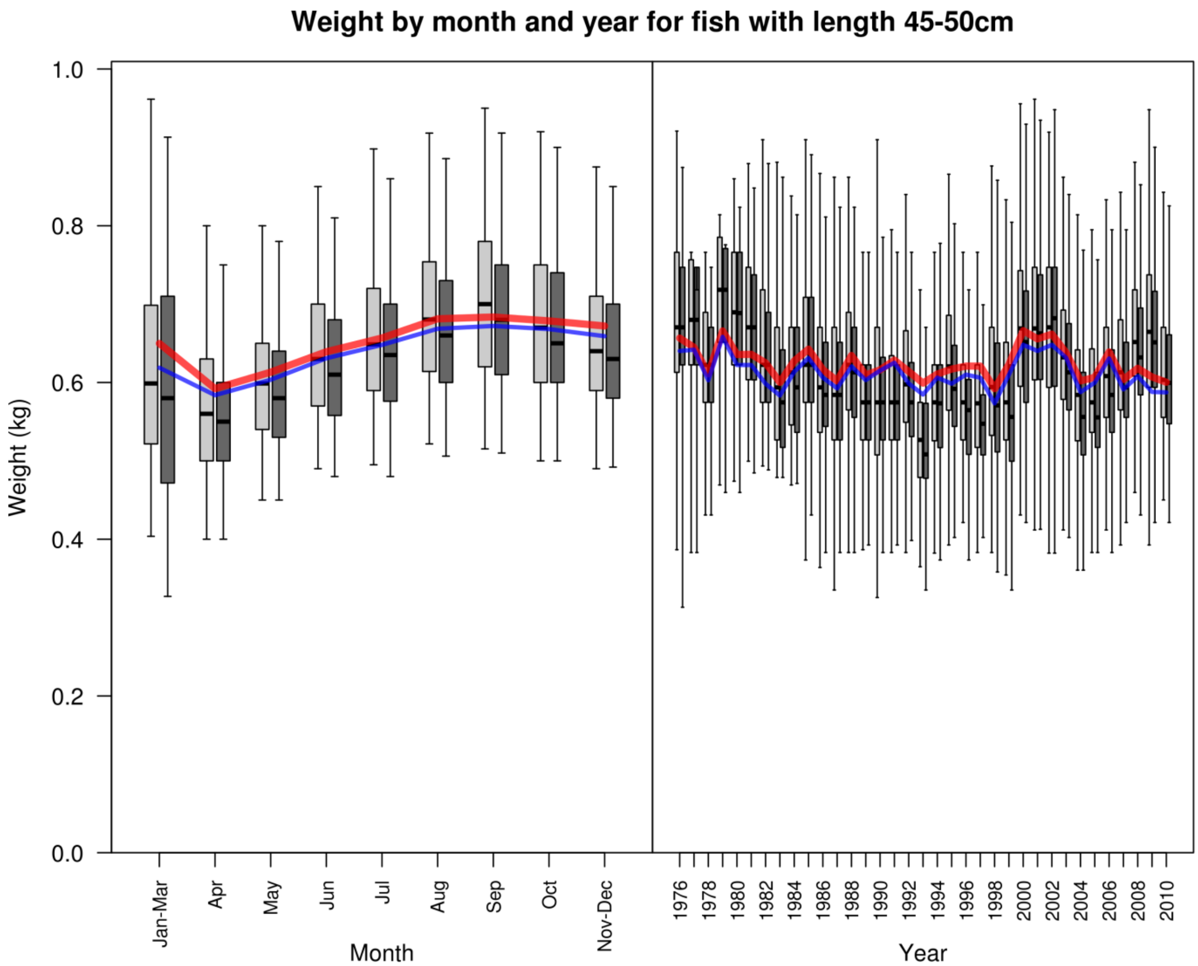


Figure 13. Variability in weight at length (45-50 cm long fish) for females (light boxes) and males (dark boxes) by month and year. The median value (dark line), central 50% of samples (grey box) and 95% intervals (whiskers) are shown for the raw data, and the lines spanning the boxes indicate the average predicted weight by month and year of a 47cm fish calculated from a linear model that relates log(weight) to log(length) (upper line represents females; lower line males.

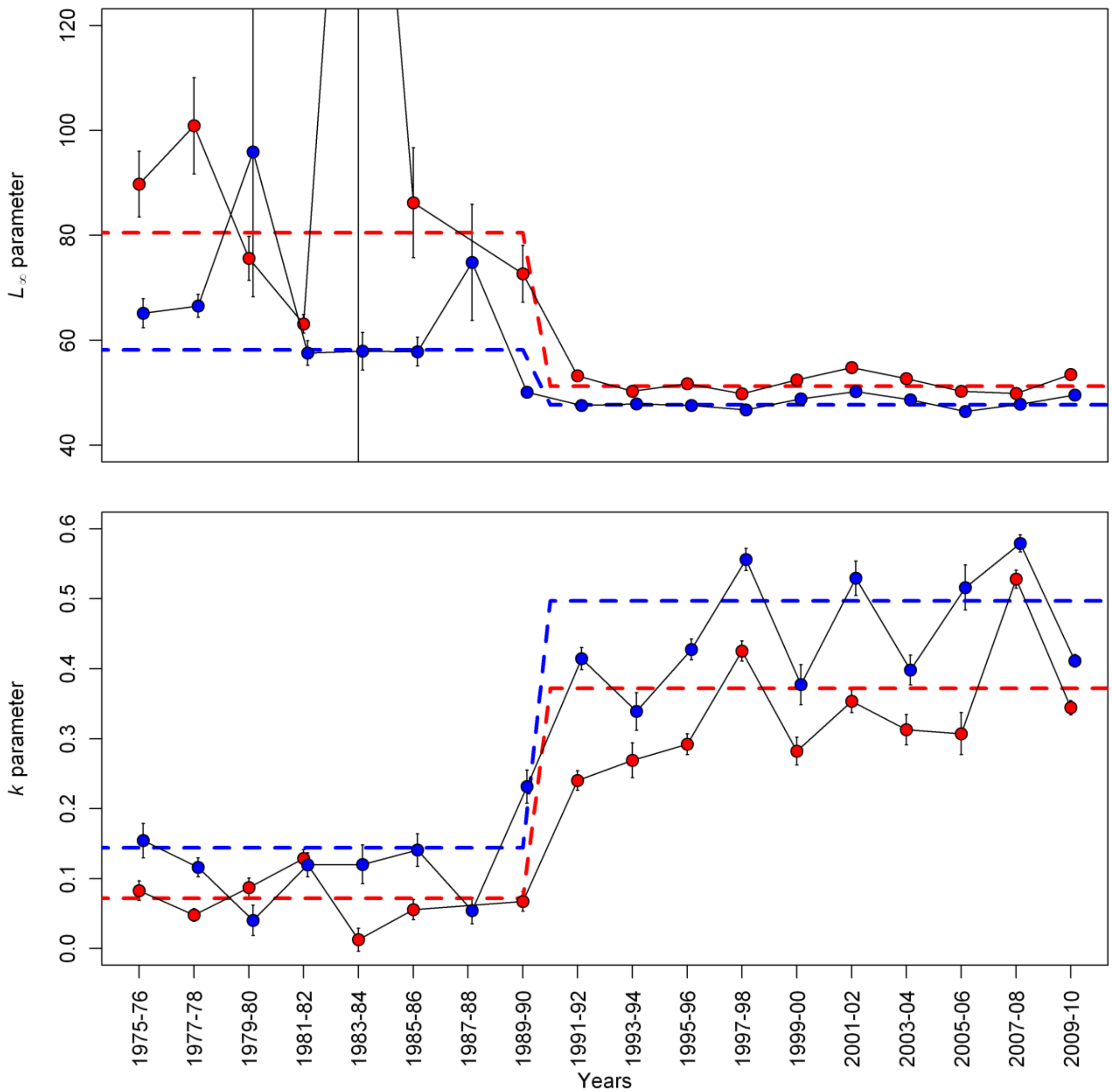


Figure 14. Estimated parameters from von Bertalanffy growth estimates for males (blue) and females (red). Circular points are estimates for each pair of adjacent years with 95% intervals shown around estimates. Thicker dashed lines show estimates of growth curves fit to data that has been divided into the time periods 1975-1989 and 1990-2010.

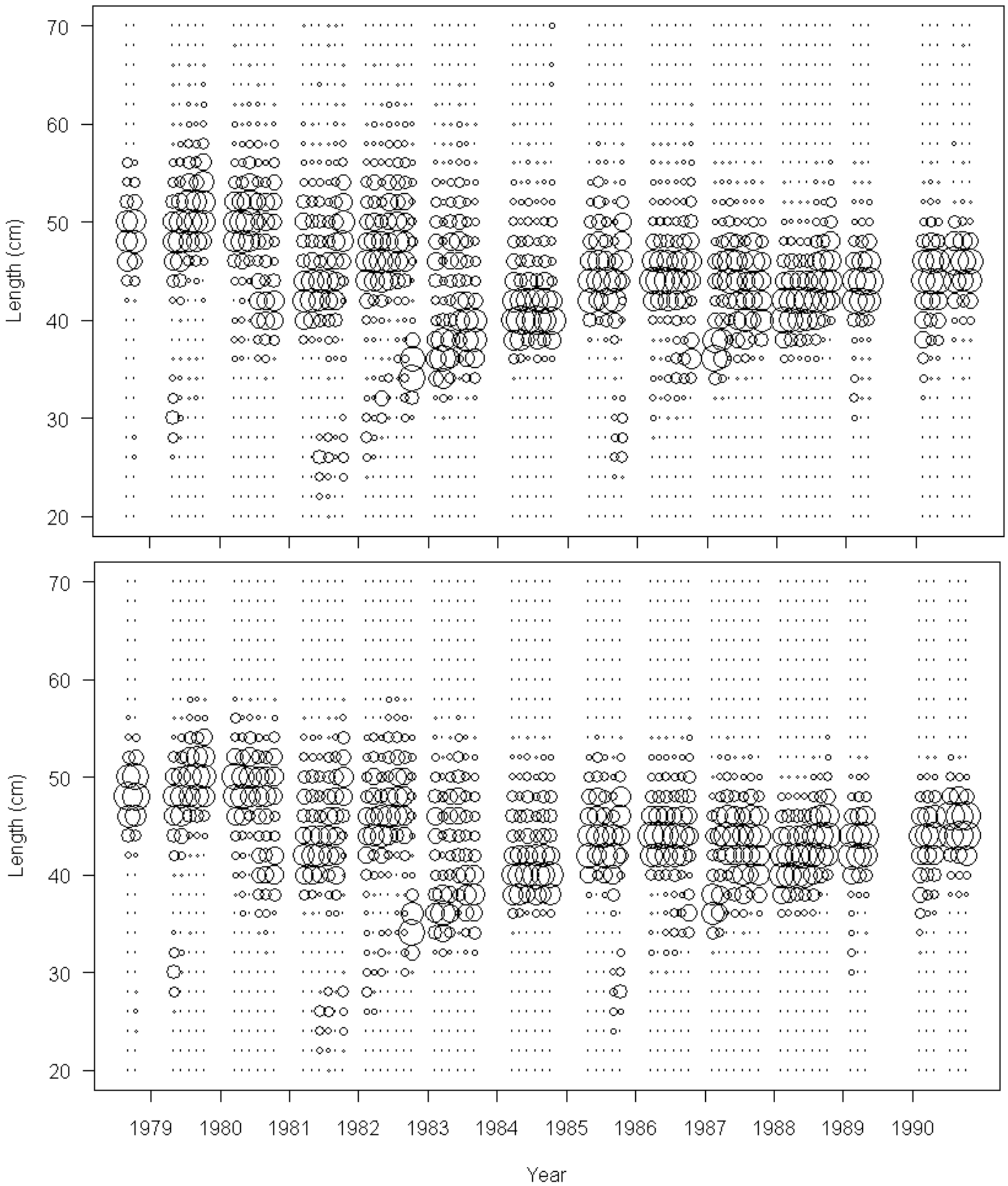


Figure 15. U.S. joint-venture fishery length compositions, 1991-2010 by season. Proportions in each season sum to 1.0 across both sexes in each year, maximum bubble size represents a value of 0.18 for females (upper panel) and 0.20 for males (lower panel).

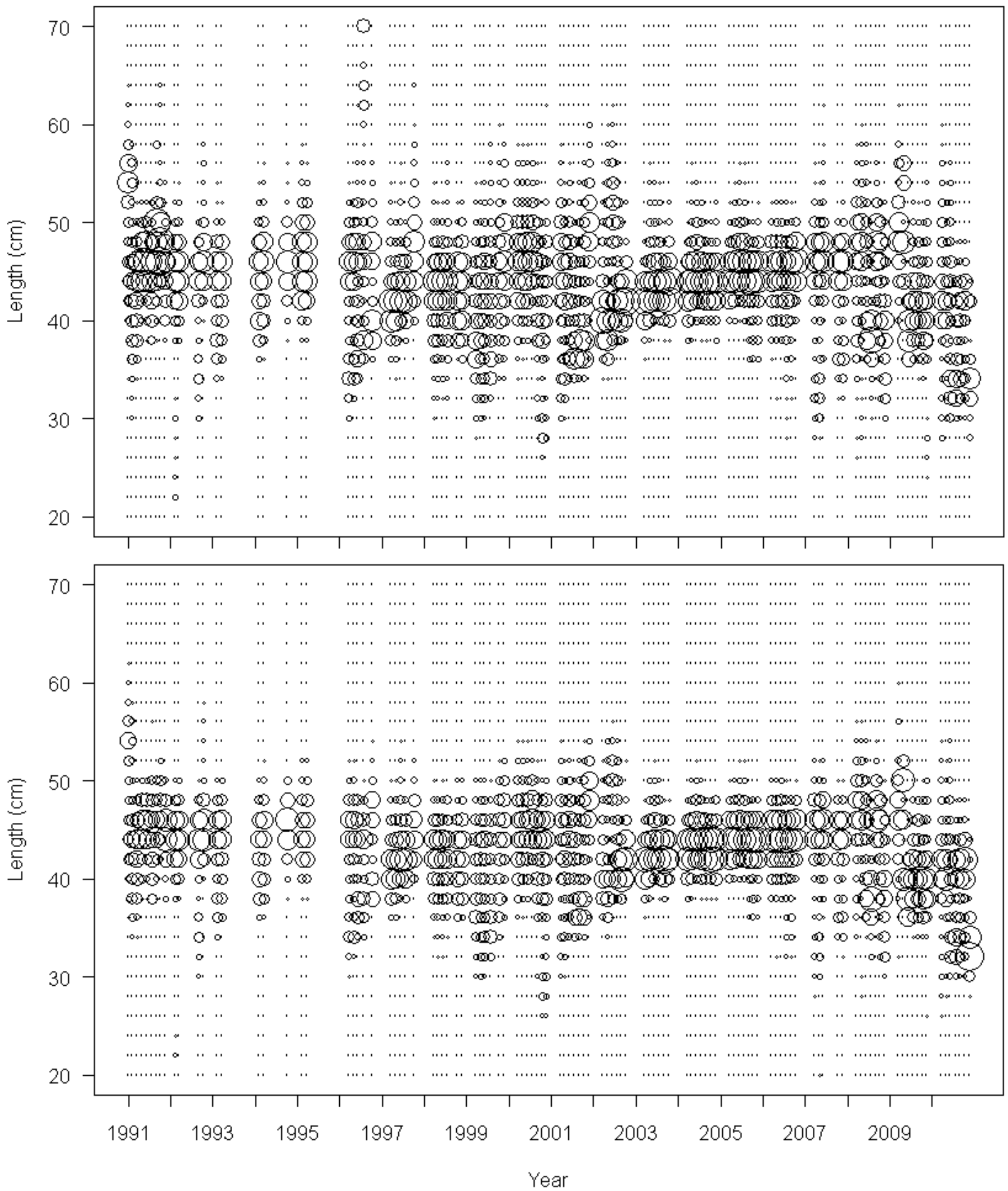


Figure 16. U.S. at-sea fishery length compositions, 1991-2010 by season. Proportions in each season sum to 1.0 across both sexes in each year, maximum bubble size represents a value of 0.24 for females (upper panel) and 0.32 for males (lower panel).

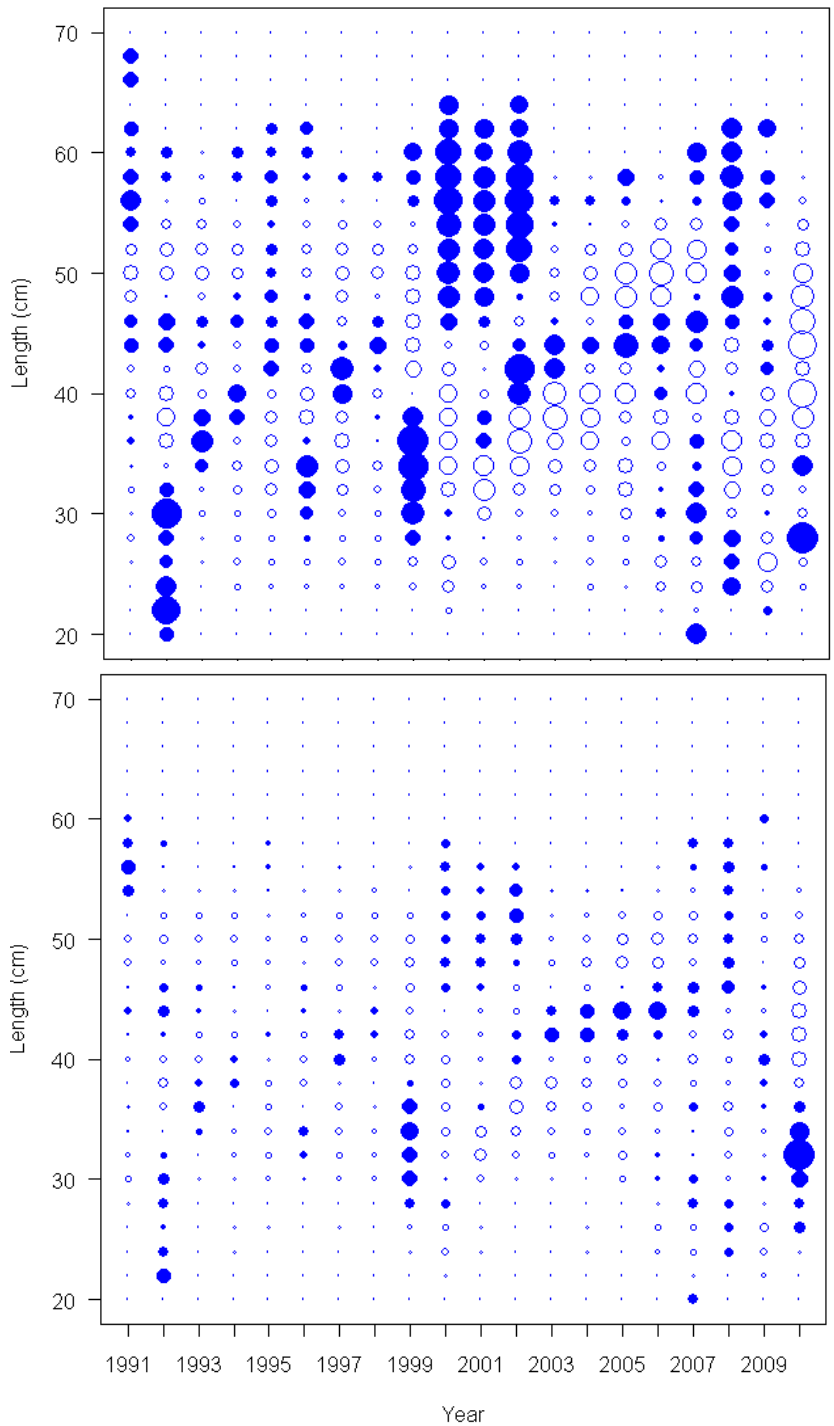


Figure 17. Fits to the observed U.S. at-sea fishery length composition data for females (upper panel) and males (lower panel) from the alternate model estimating growth parameters internally, but still failing to account for the complexity in the growth process.

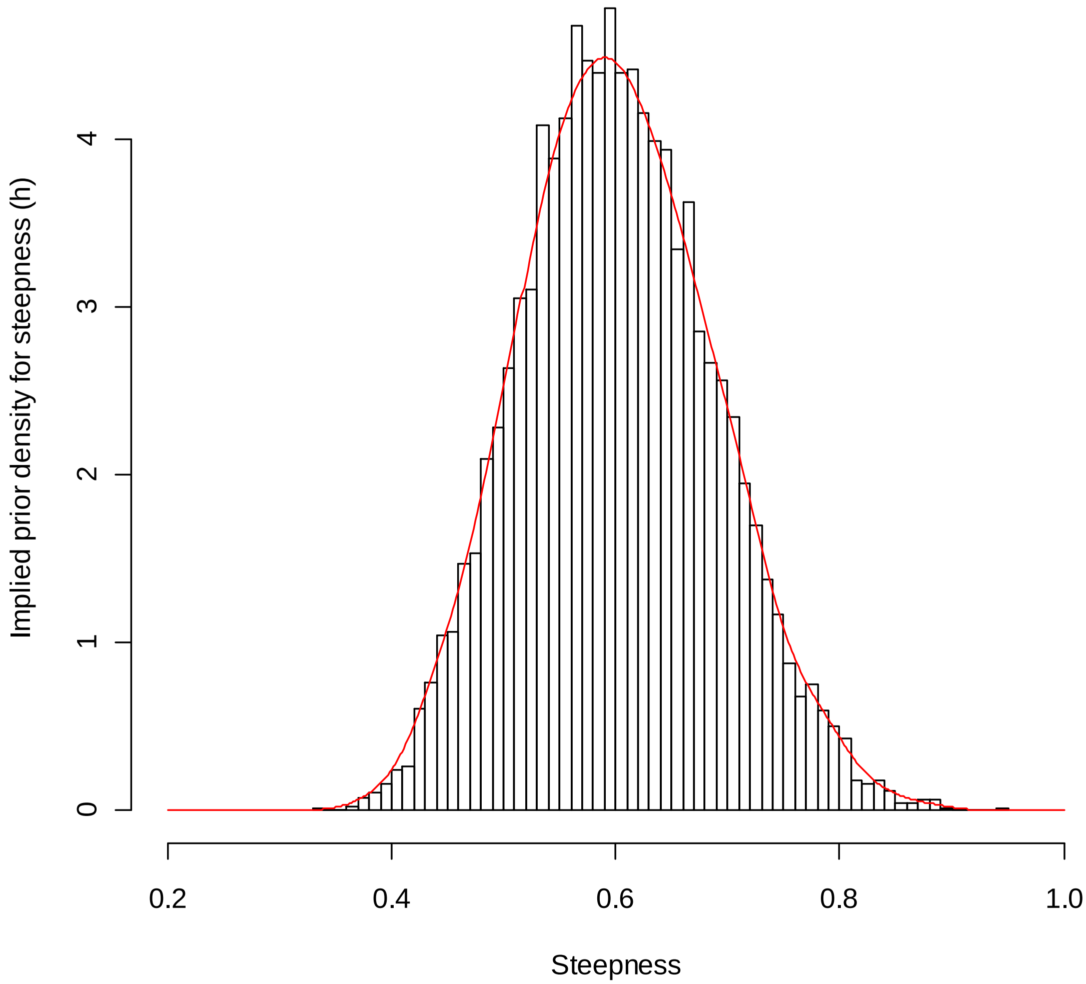


Figure 18. Prior for steepness implied by the transformation of TINSS priors.

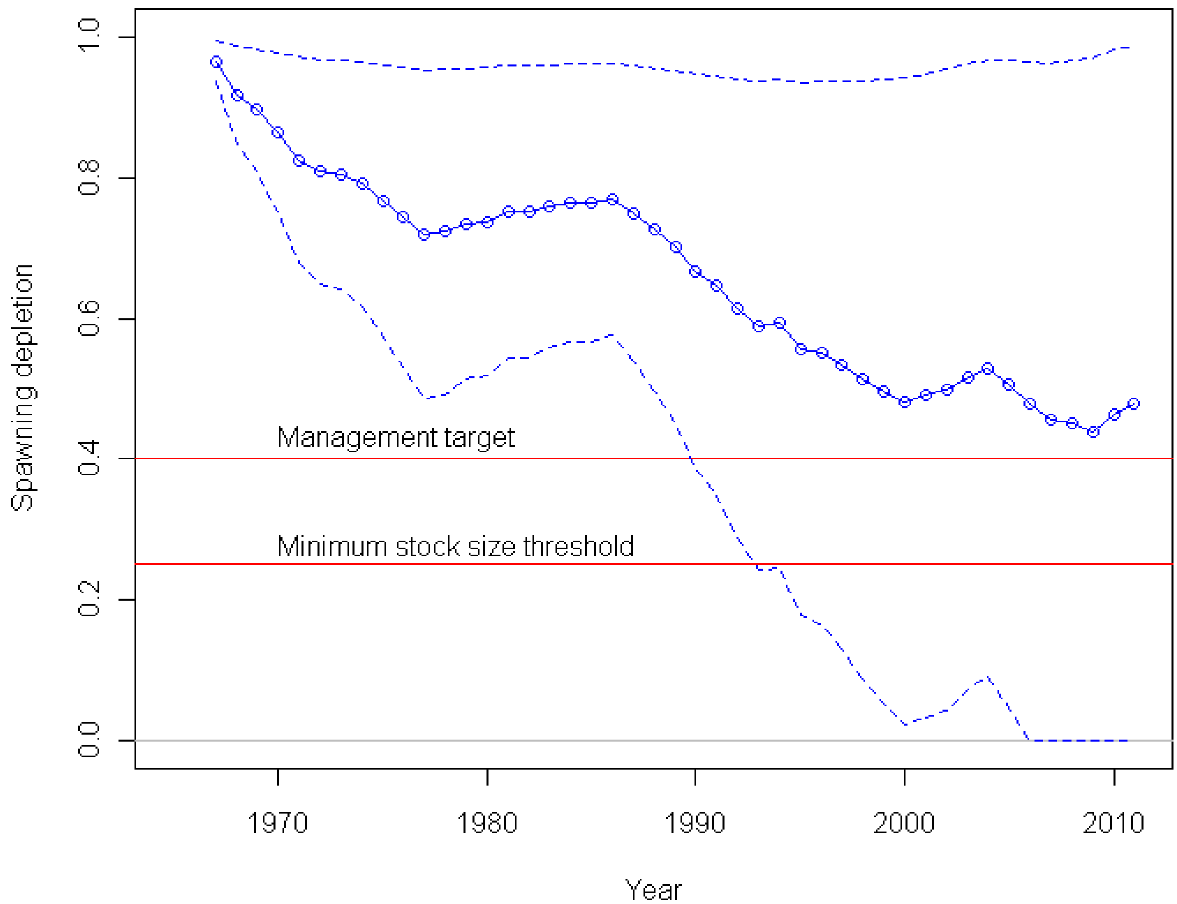


Figure 19. Time-series of relative depletion for a simple 4 parameter production model illustrating the low information content in the acoustic index and the need for fully utilizing the available age data.

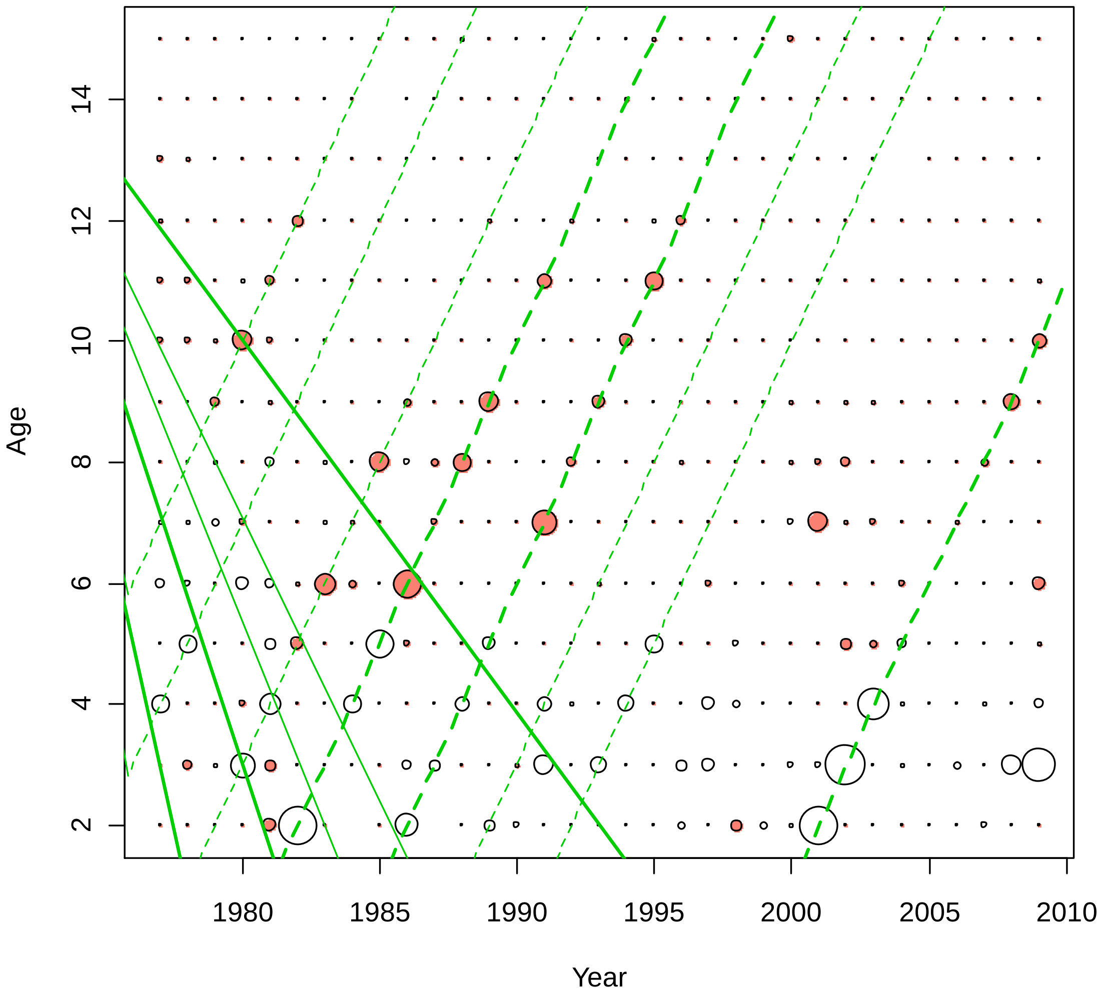


Figure 20. Change in the proportions at age from those used by the TINSS model in 2010 to those used by both models in 2011. Filled circles denote 2011 < 2010.

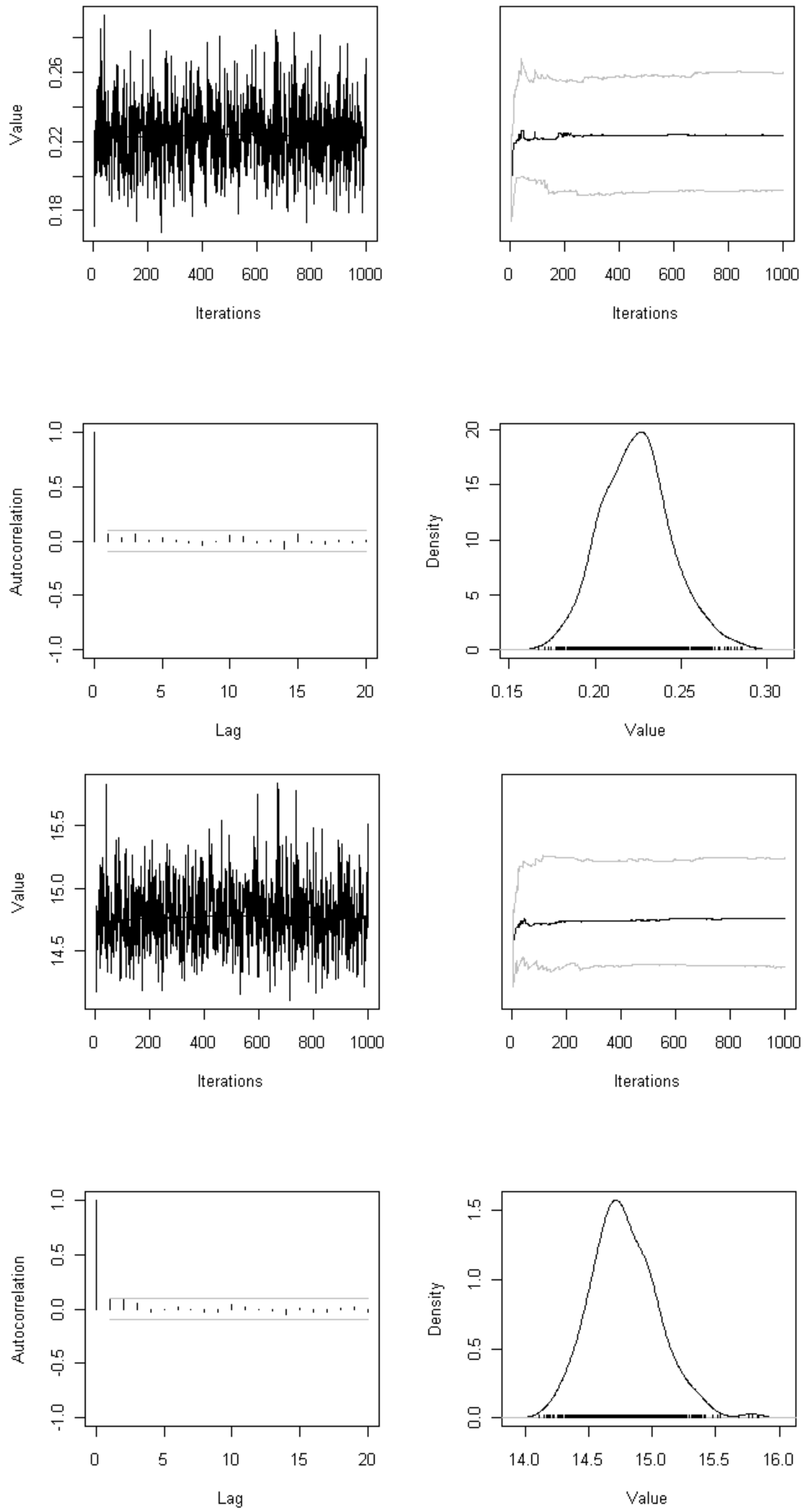


Figure 21. Summary of MCMC diagnostics for natural mortality (upper panels) and log(R_0) (lower panels) in the SS model.

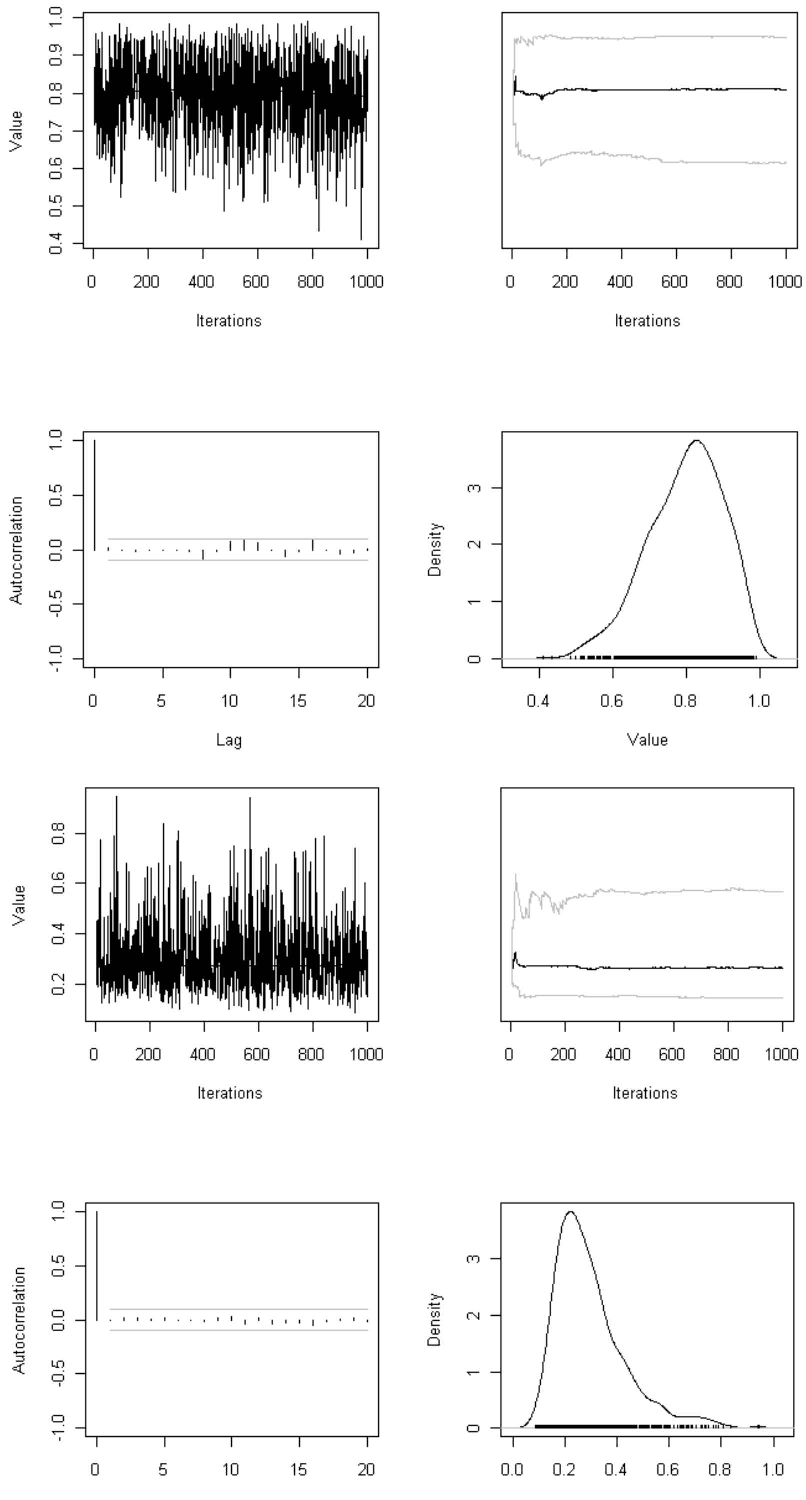


Figure 22. Summary of MCMC diagnostics for steepness (upper panels) and the additional SD for the acoustic survey index (lower panels) in the SS model.

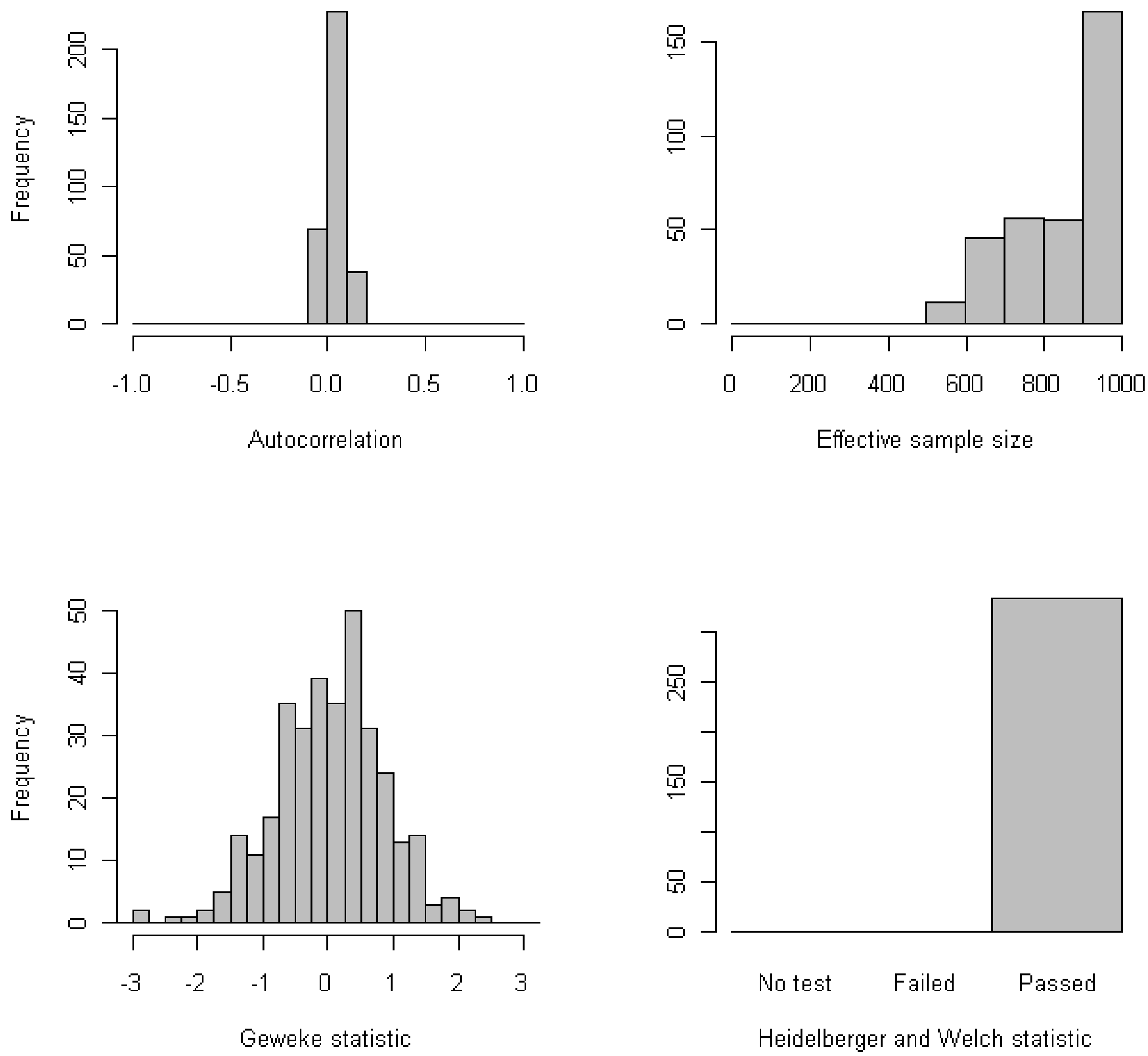


Figure 23. Summary histograms of MCMC diagnostics for all estimated SS parameters and derived quantities including the recruitment, spawning biomass, relative SPR and depletion time-series'.

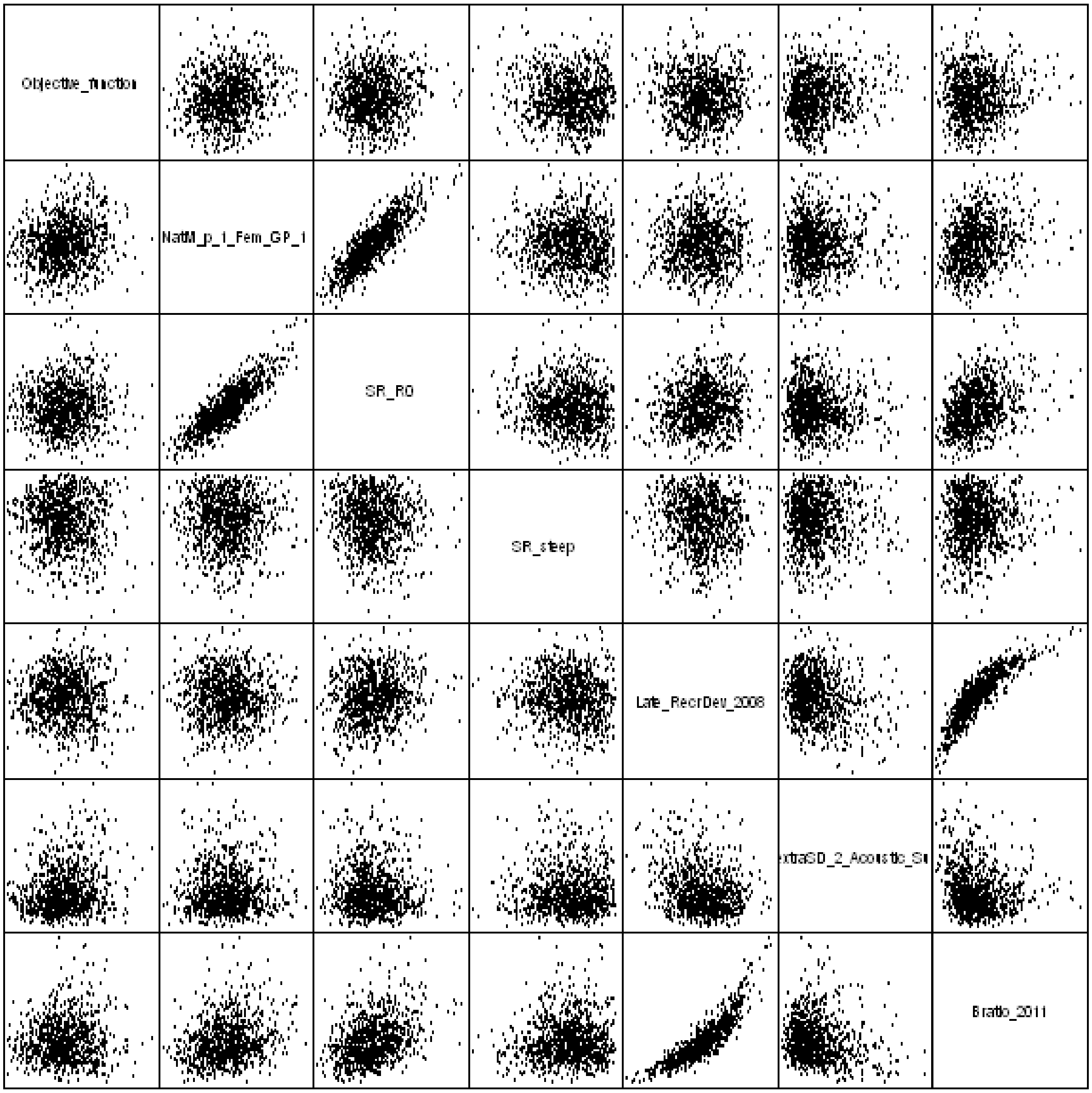


Figure 24. Posterior correlations among key SS model parameters and derived quantities. From the top left the posteriors plotted are: objective function, natural mortality, ln(R_0), Steepness, the 2008 recruitment deviation, the additional SD for the acoustic survey and the depletion level in 2011.

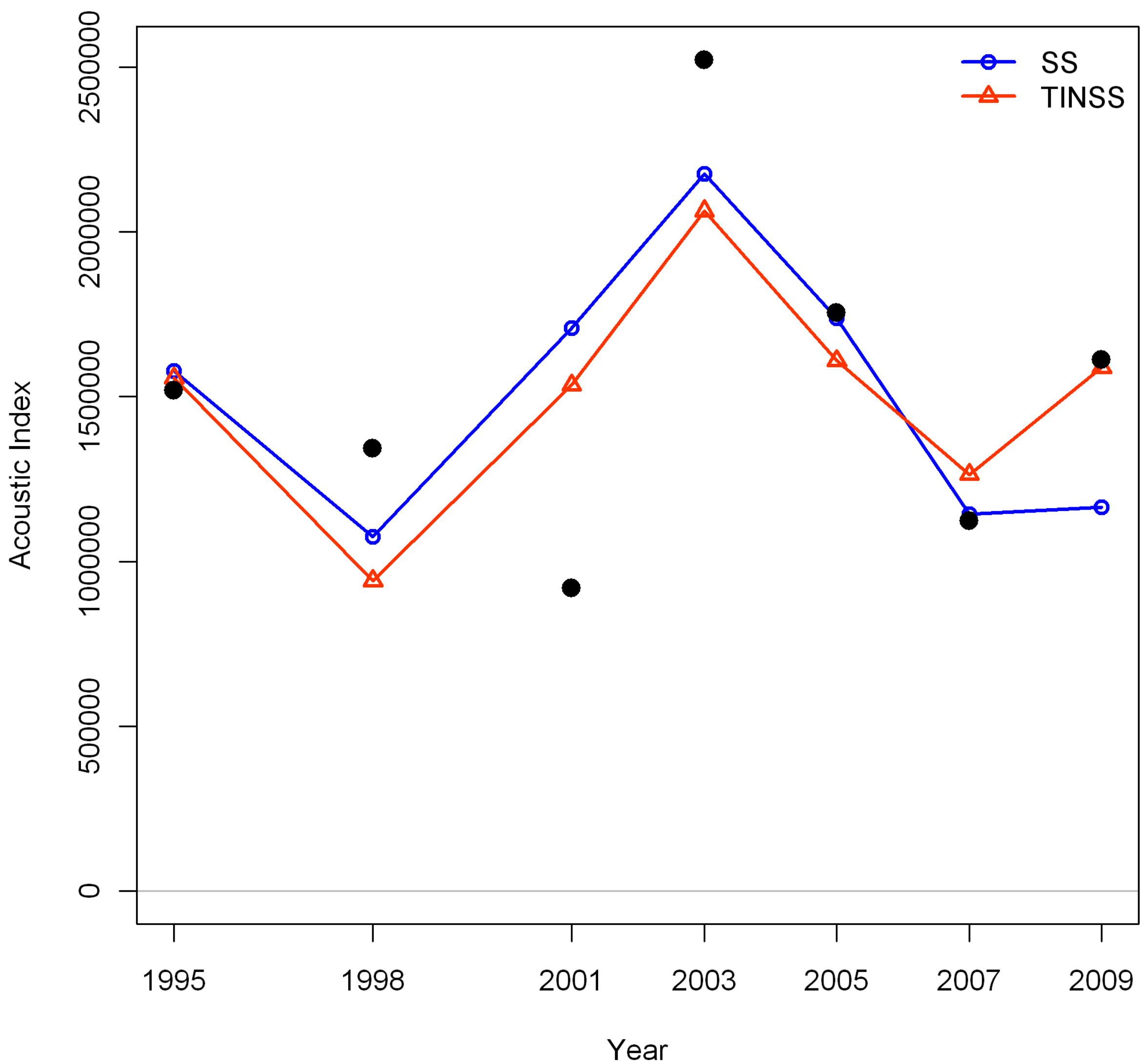


Figure 25. Predicted MLE fit to the acoustic survey biomass index for both models.

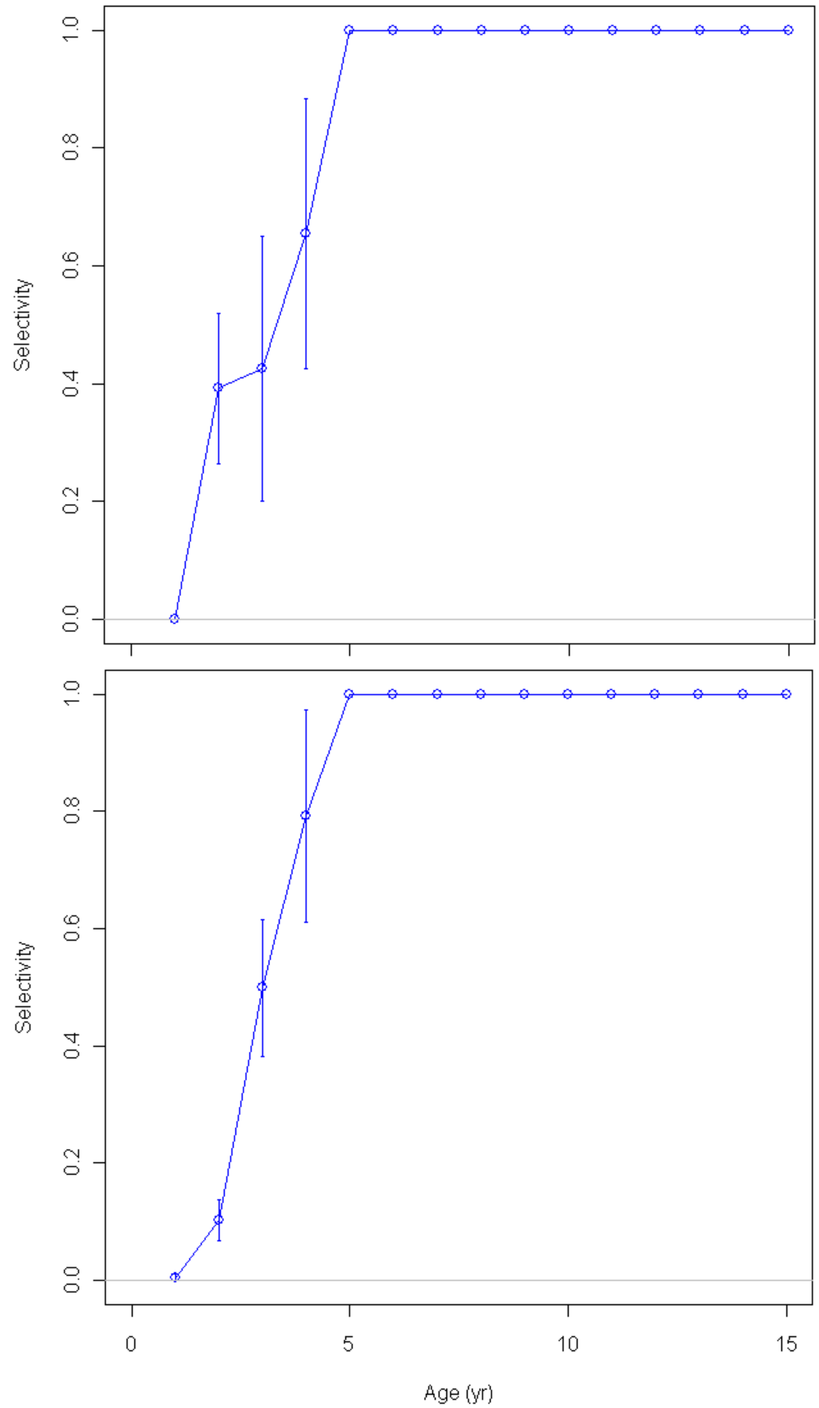


Figure 26. Estimated selectivity curves for the acoustic survey (upper panel) and fishery (lower panel) from the SS model. Vertical bars represent 95% confidence intervals about the MLE.

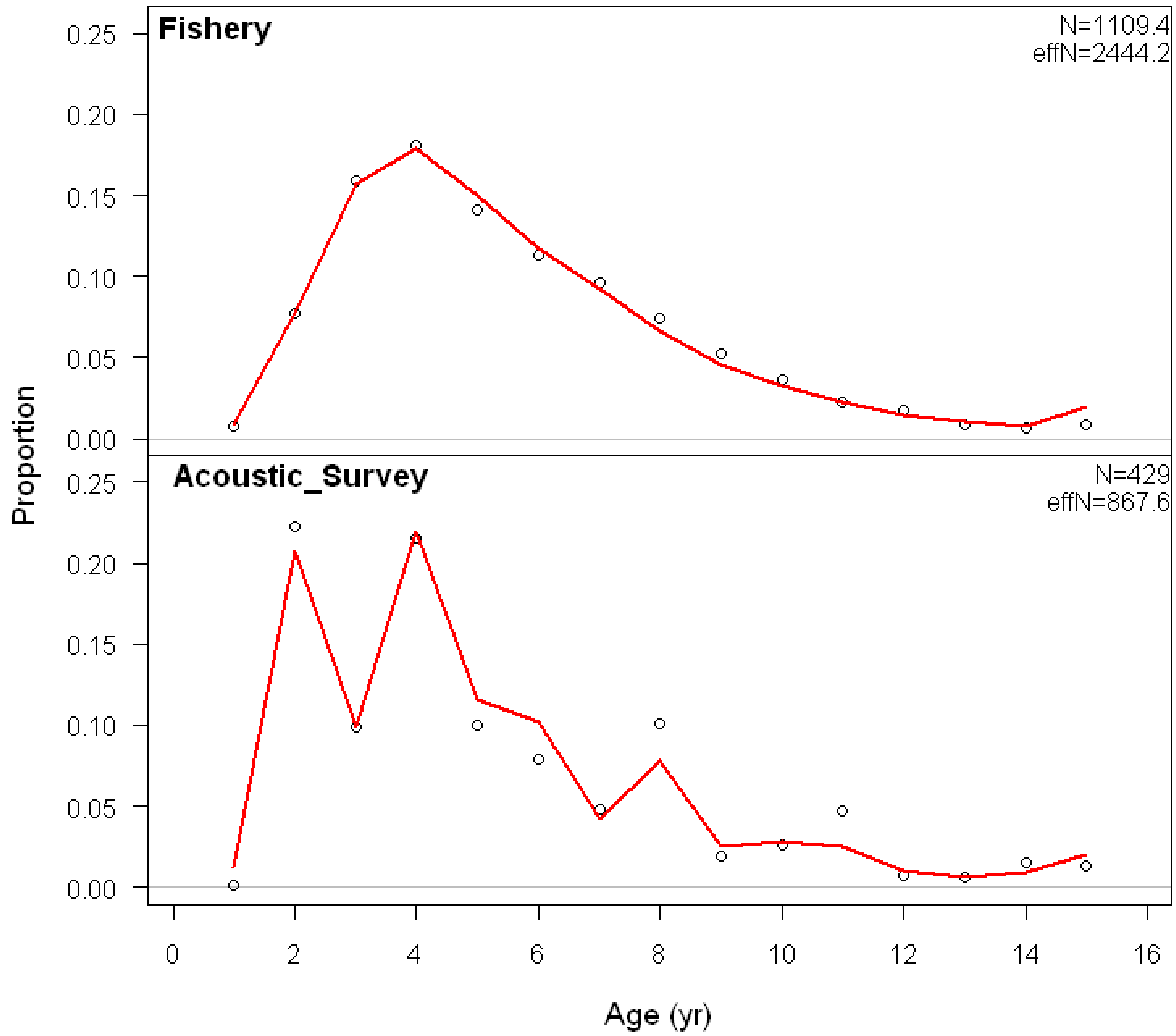


Figure 27. SS model fit to the aggregate fishery and acoustic age composition data.

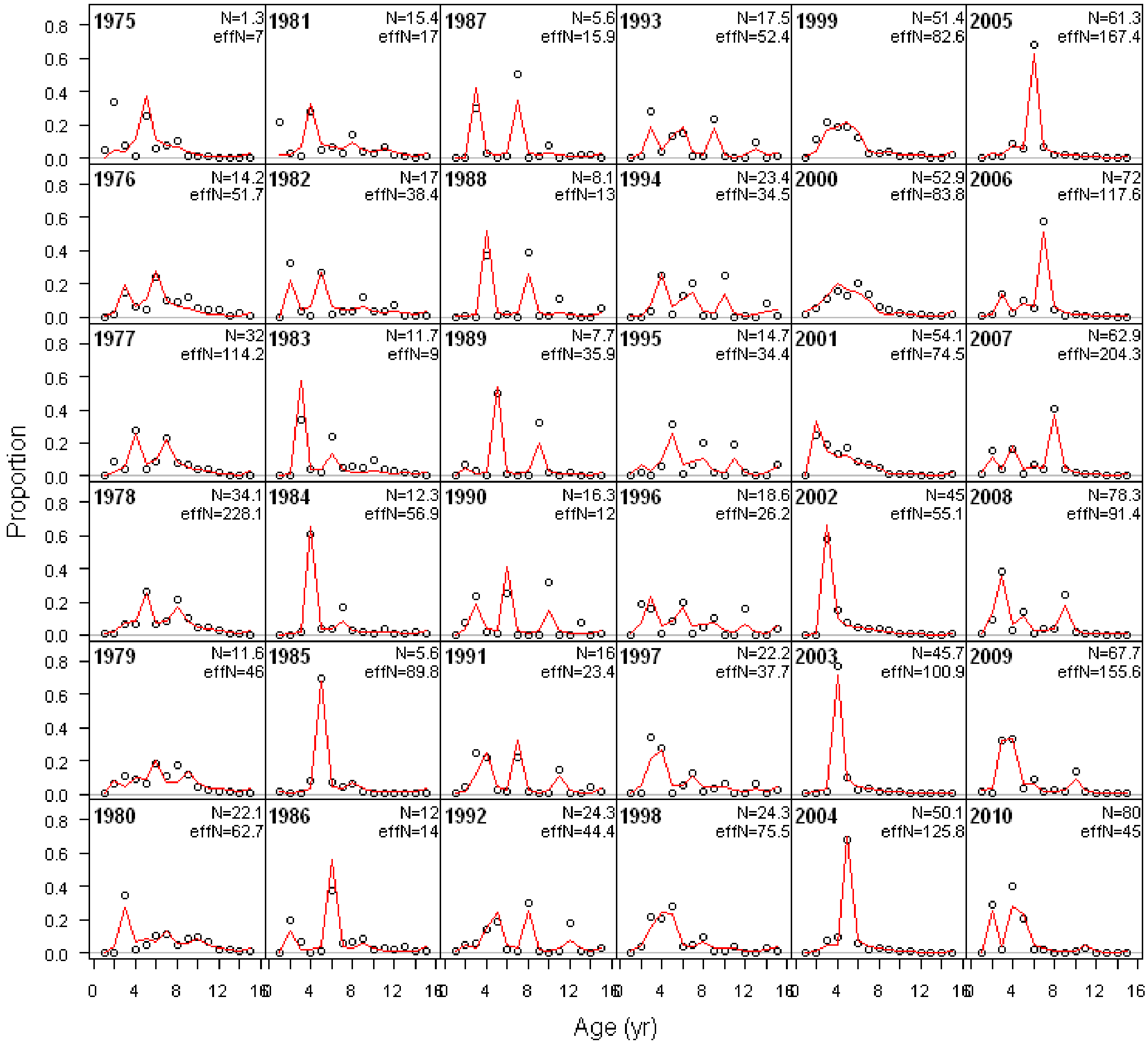


Figure 28. SS model fit to the observed fishery age composition data.

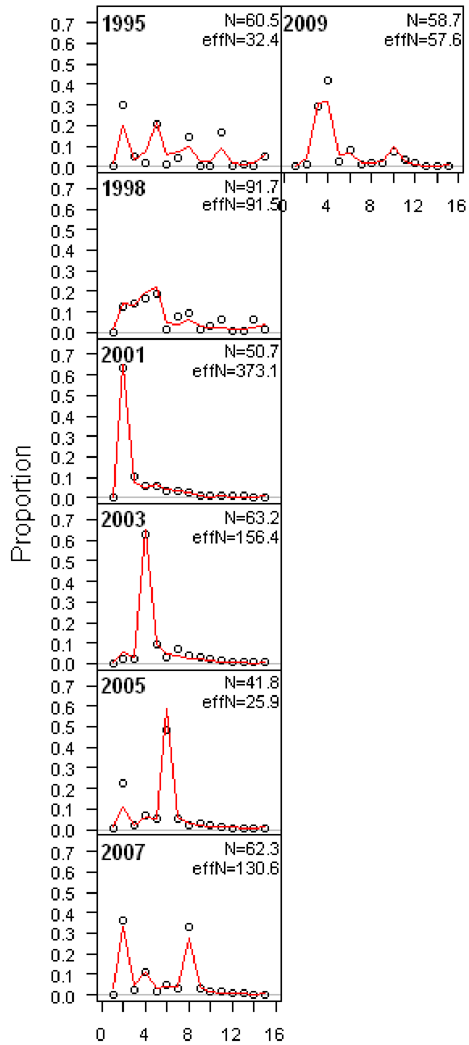


Figure 29. SS model fit to the observed acoustic survey age composition data.

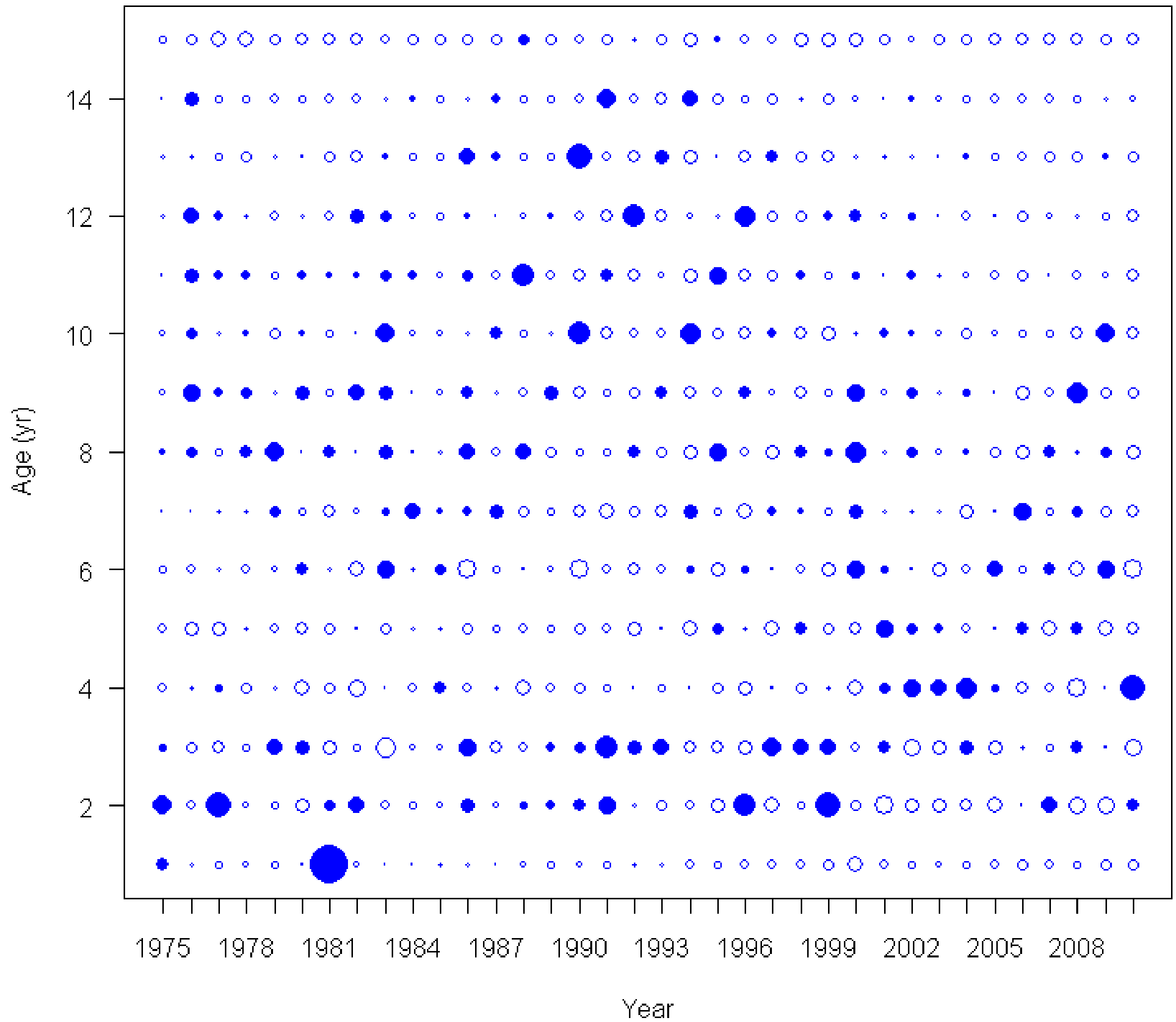


Figure 30. Pearson standardized residuals (observed - predicted) for SS model fits to the fishery age composition data. Maximum bubble size = 5.53; filled circles represent positive values.

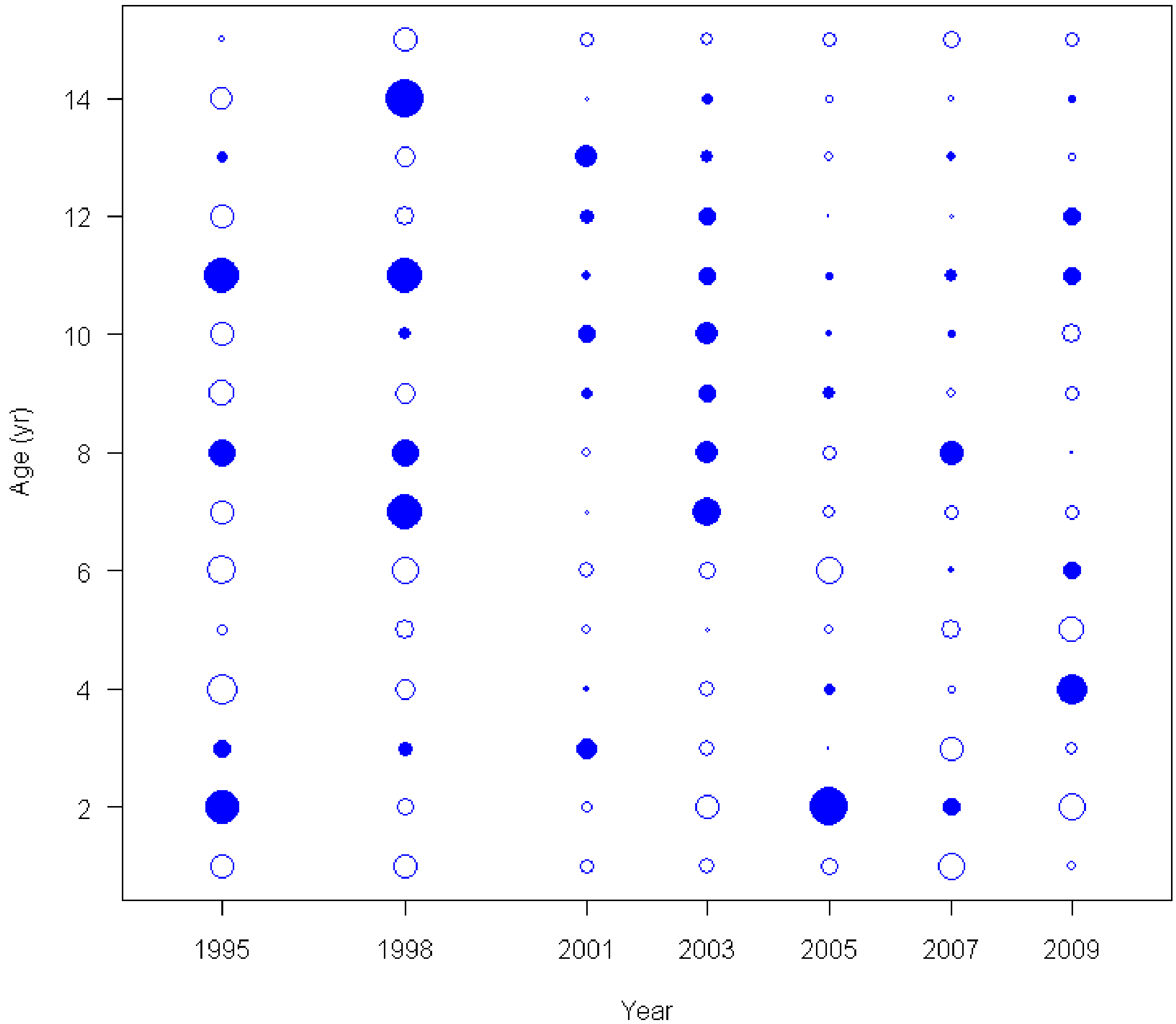


Figure 31. Pearson standardized residuals (observed - predicted) for SS model fits to the acoustic survey age composition data. Maximum bubble size = 2.7; filled circles represent positive values.

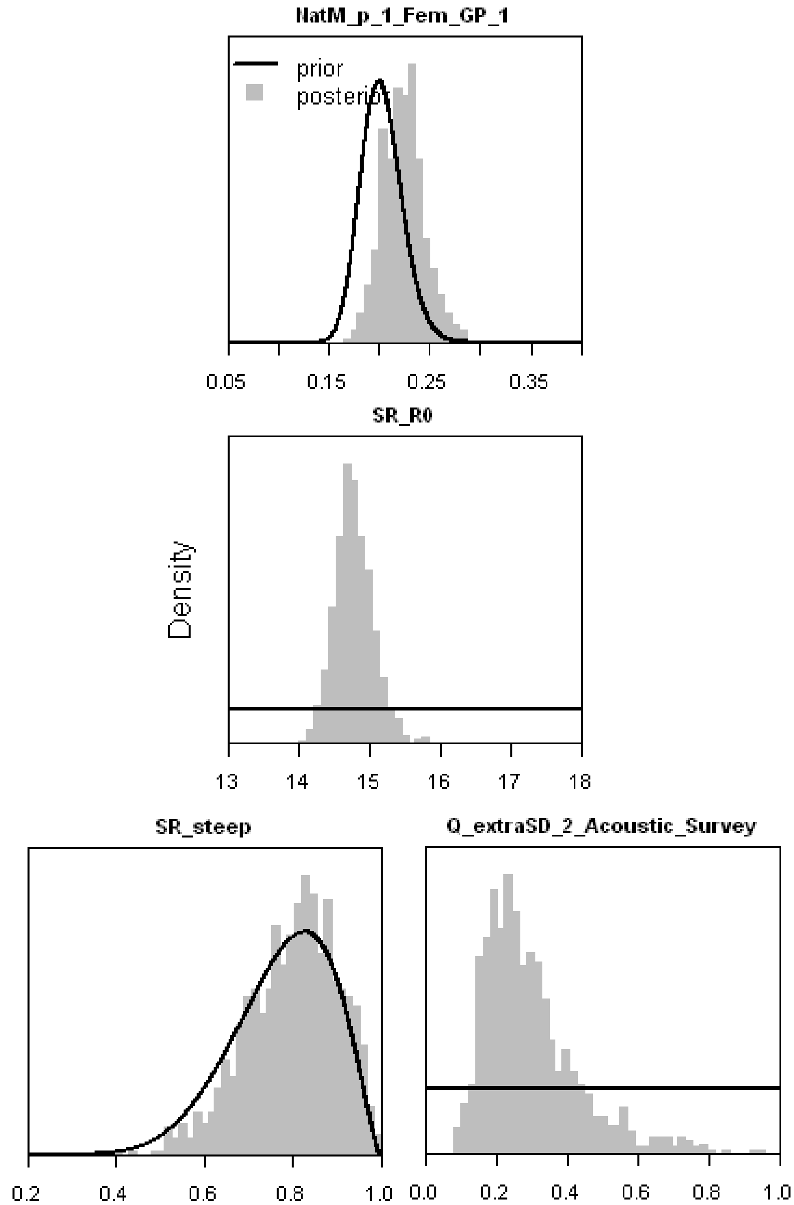


Figure 32. Prior and posterior probability distributions for key parameters in the SS model. From the top, the parameters are: Natural mortality, ln(R_0), steepness and the additional SD for the acoustic survey.

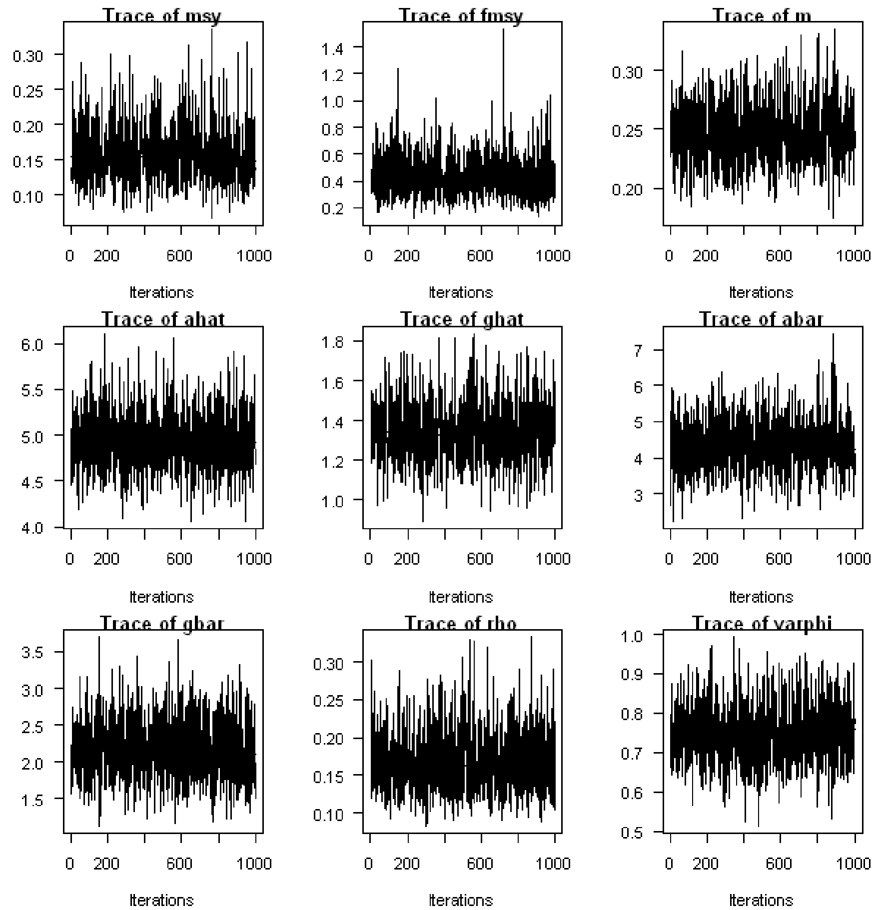


Figure 33. MCMC trace plots for key TINSS model parameters.

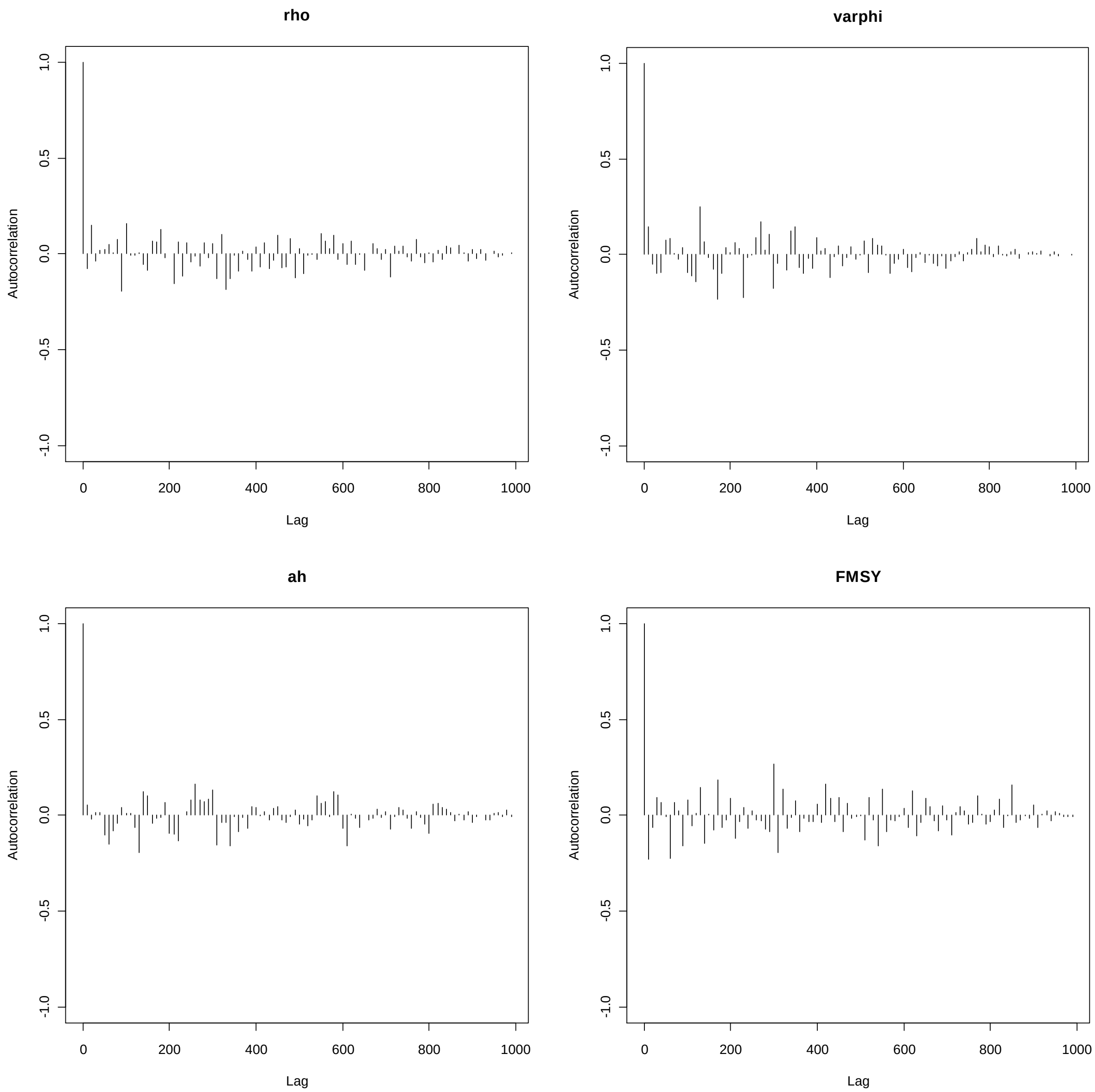


Figure 34. Autocorrelation plots for key TINSS model parameters (left to right): ρ, φ^{-2}, $\hat{a}$ and F_{MSY}.

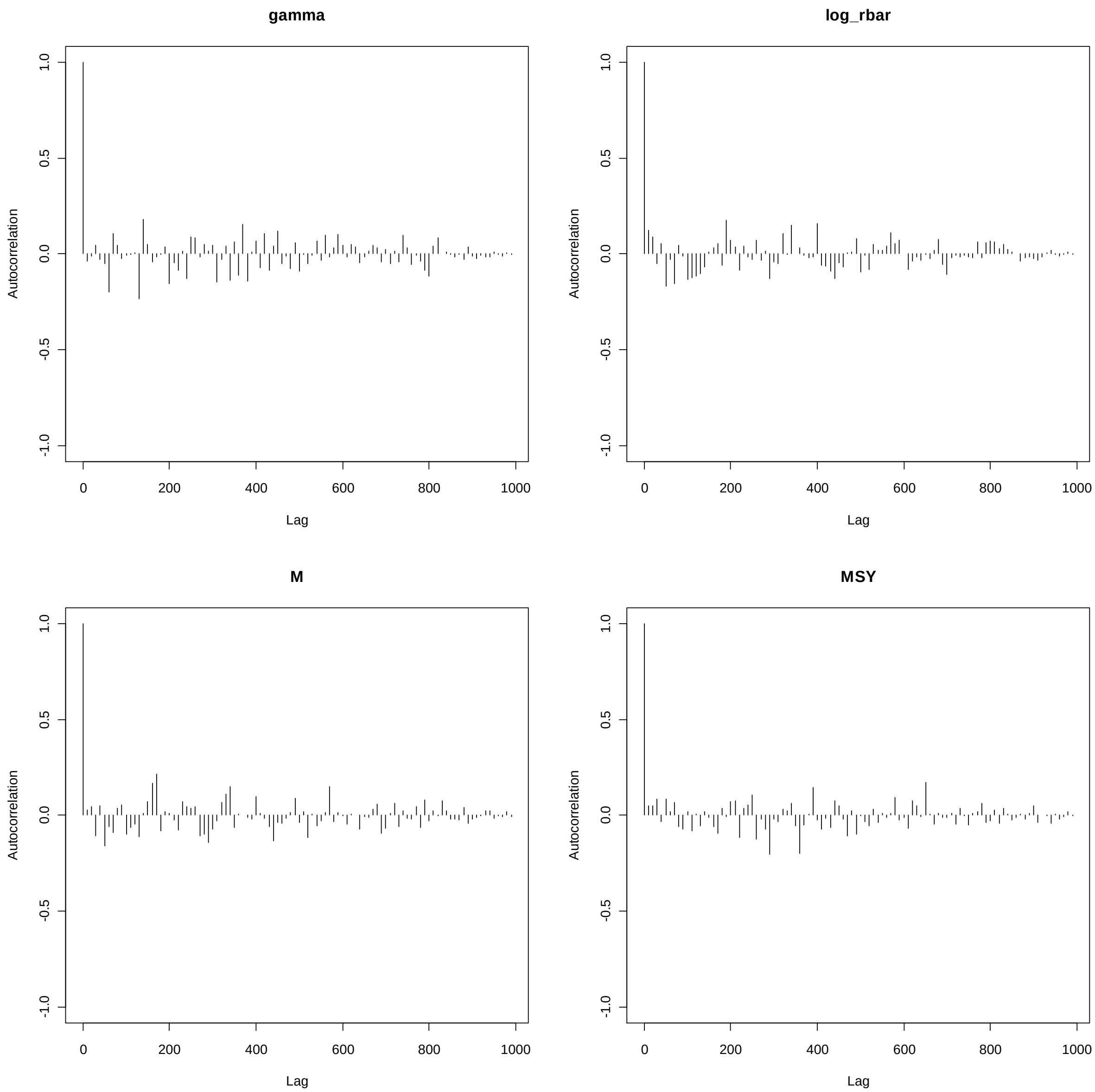


Figure 35. Autocorrelation plots for key TINSS model parameters (left to right): $\hat{\lambda}$, $\ln \bar{R}$, *M*, and *MSY*.

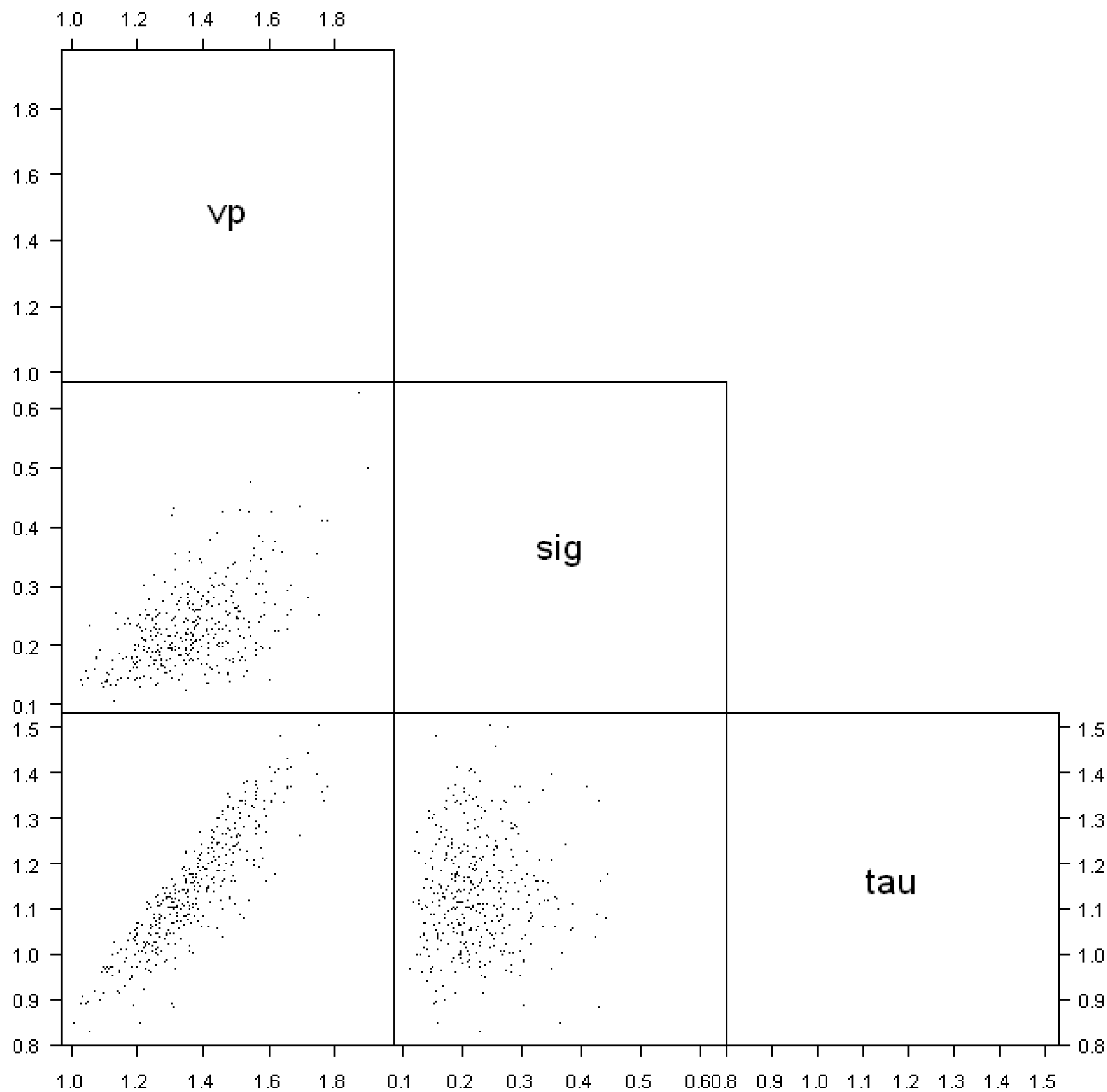


Figure 36. Posterior correlations among key TINSS variance parameters.

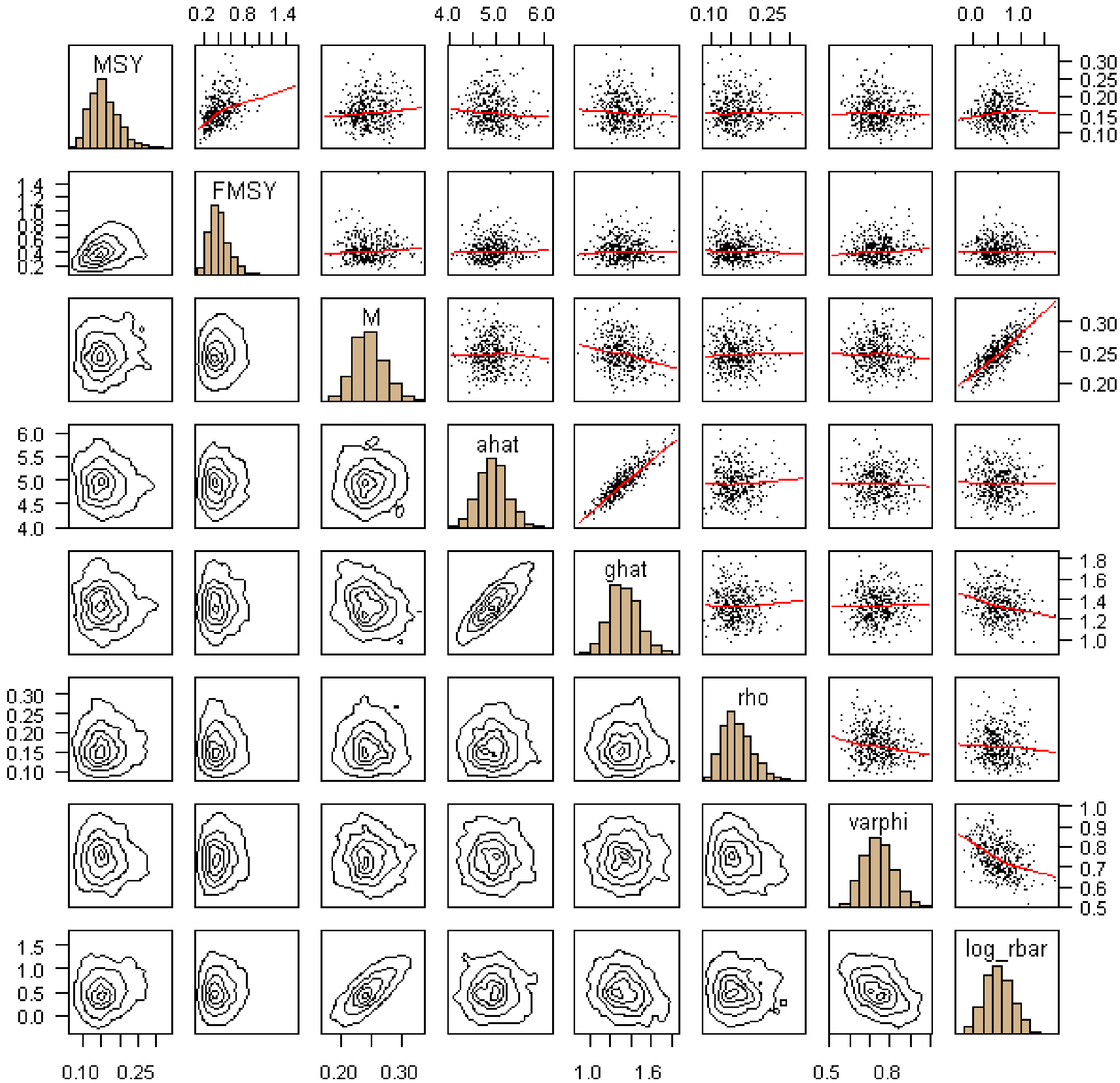


Figure 37. Additional posterior correlations among key TINSS parameters.

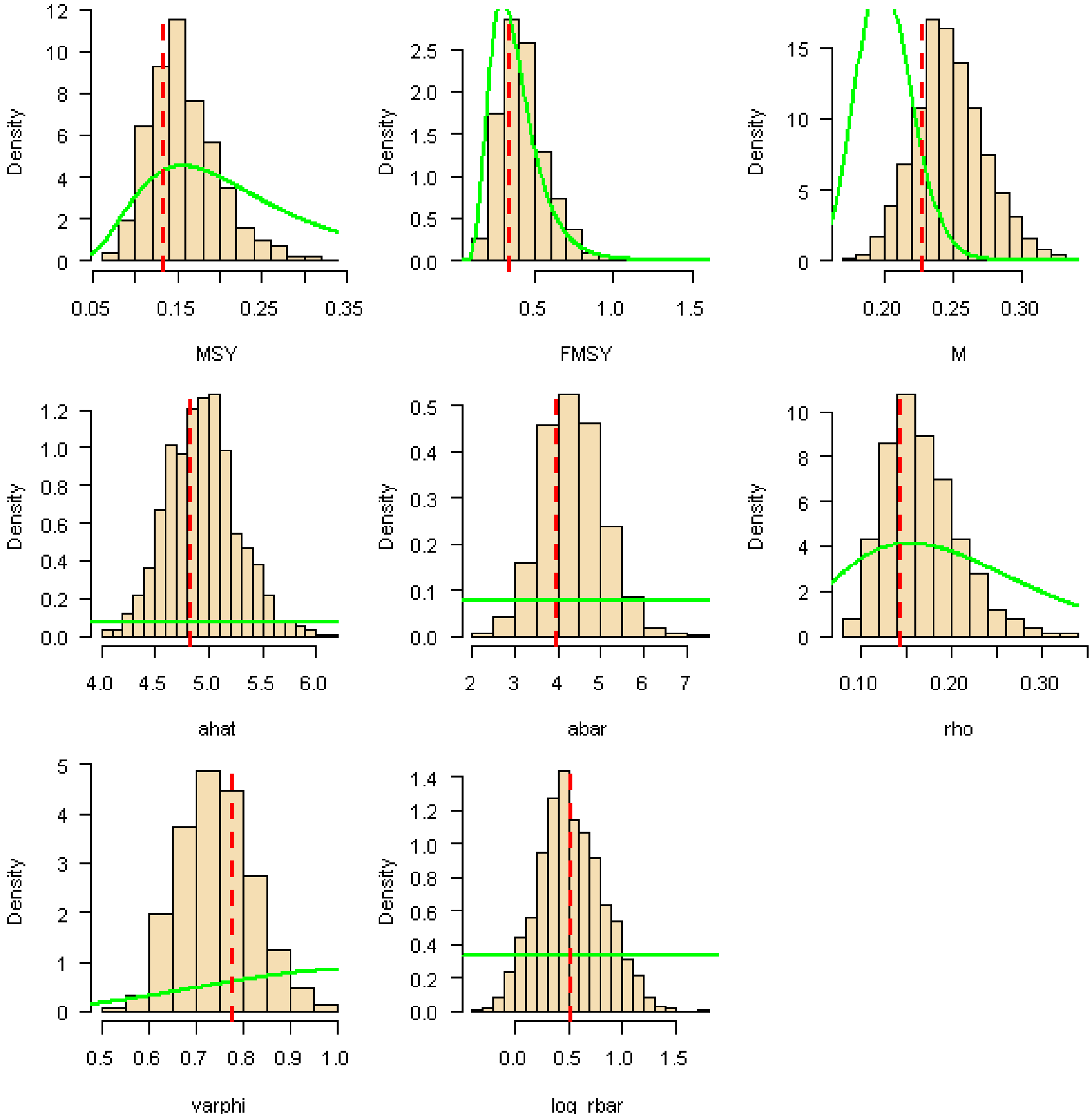


Figure 38. Prior and posterior probability distributions for key parameters in the TINSS model. Lines indicate the prior distribution, bars the posterior density. Vertical dashed lines the MLE estimates.

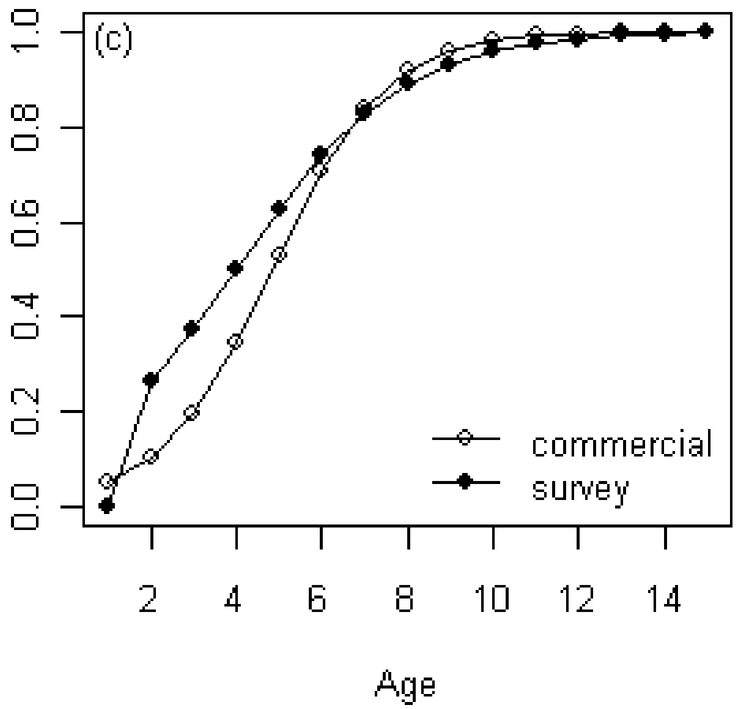


Figure 39. Estimated selectivity curve for the fishery and for the acoustic survey from the TINSS model.

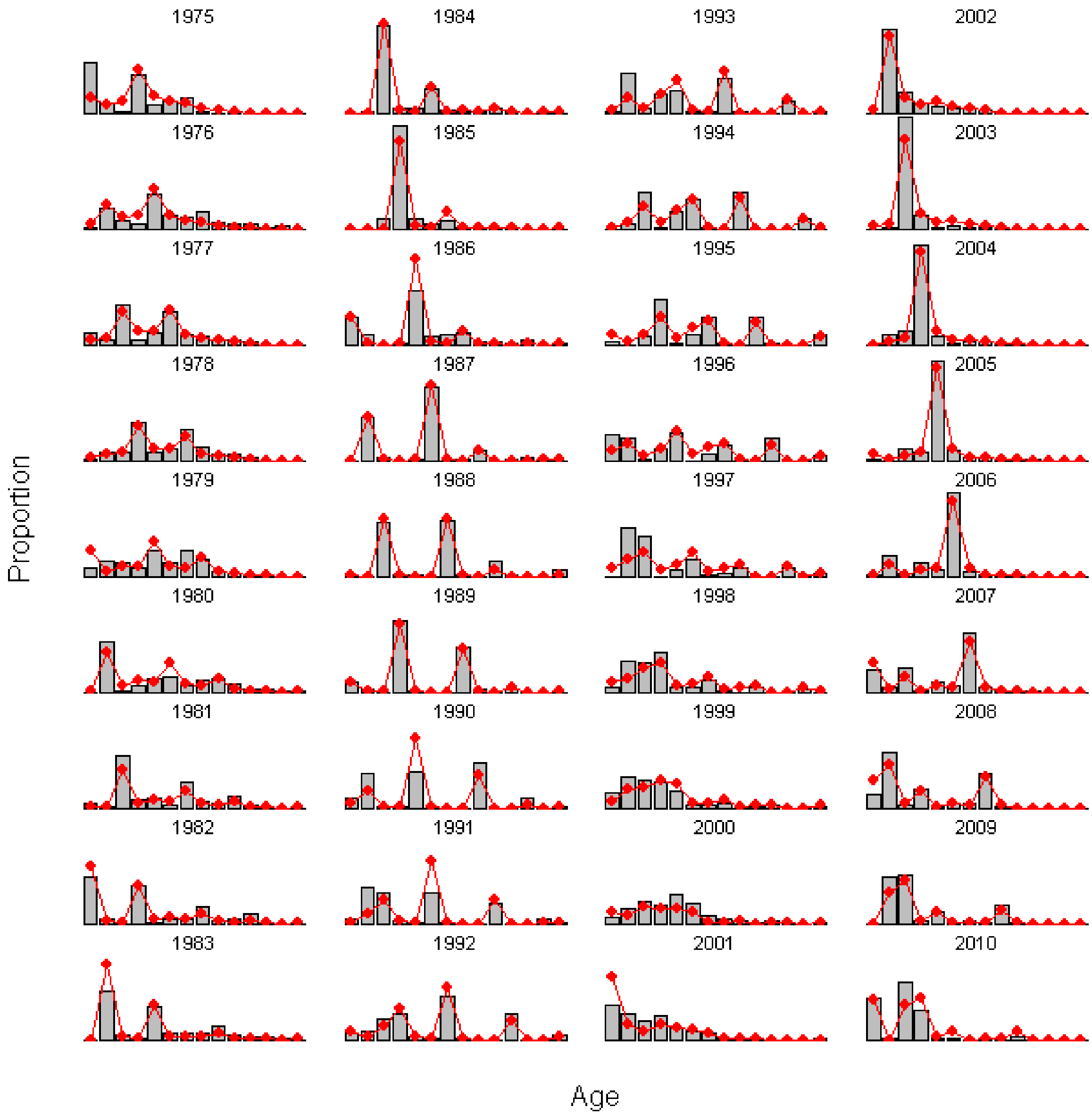


Figure 40. TINSS model fit to the observed fishery age composition data.

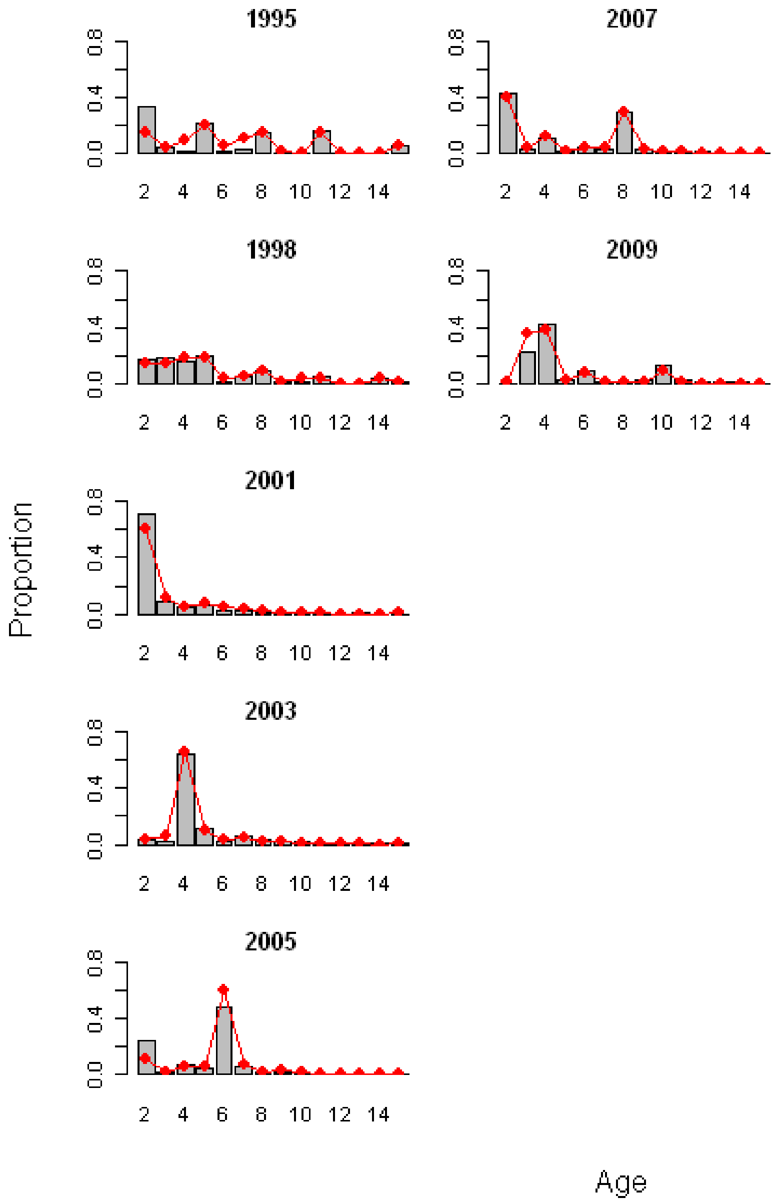


Figure 41. TINSS model fit to the observed acoustic survey age composition data.

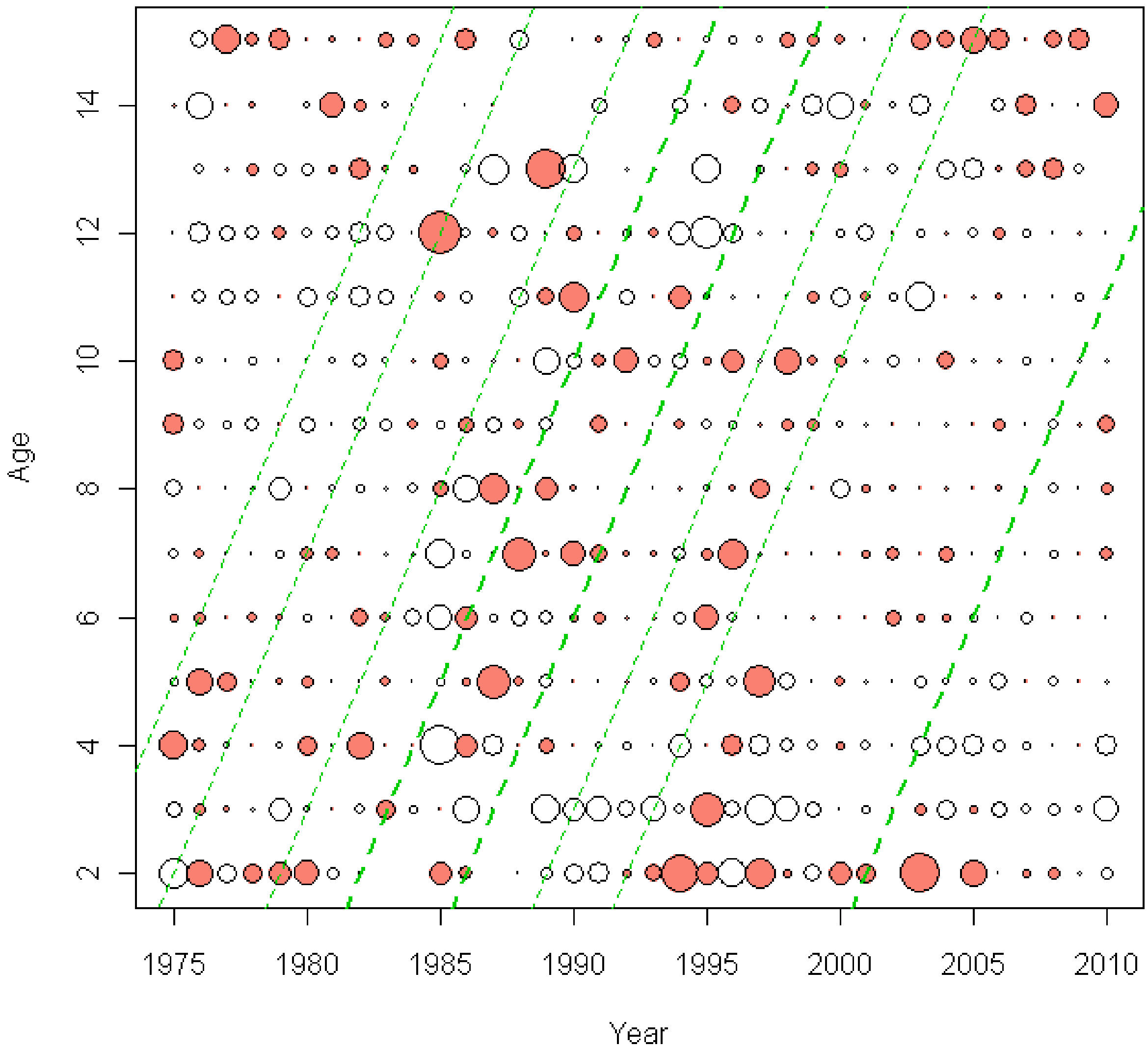


Figure 42. Residuals (filled bubbles denote negative values) for TINSS model fits to the fishery age composition data.

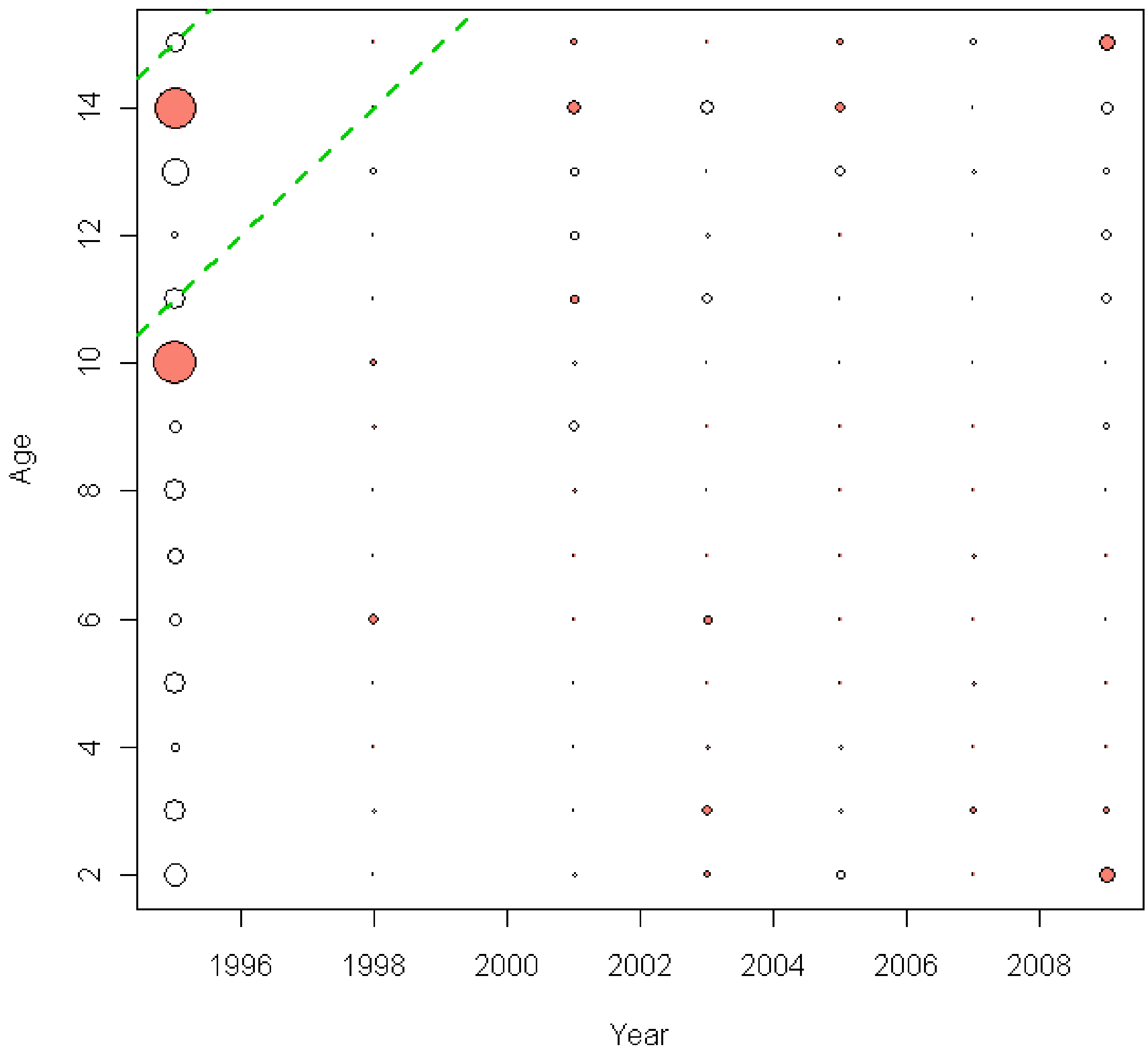


Figure 43. Residuals (filled bubbles denote negative values) for TINSS model fits to the acoustic survey age composition data.

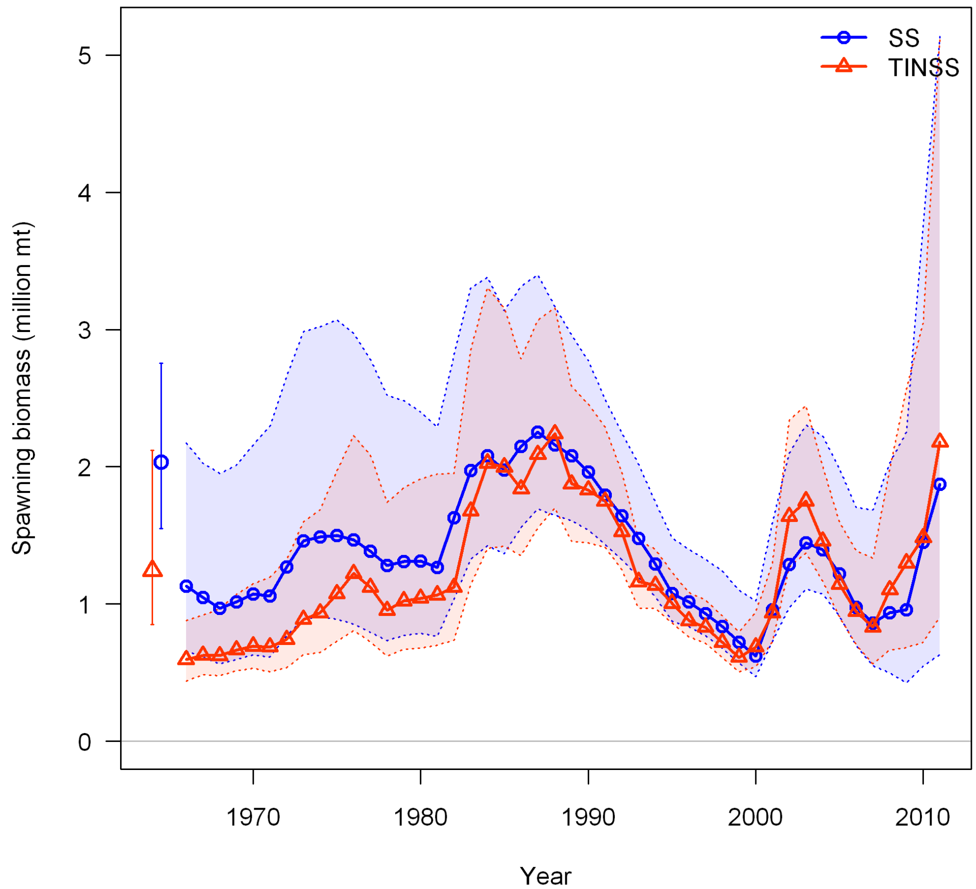


Figure 44. Posterior female spawning biomass time-series for both models with 95% posterior credibility intervals.

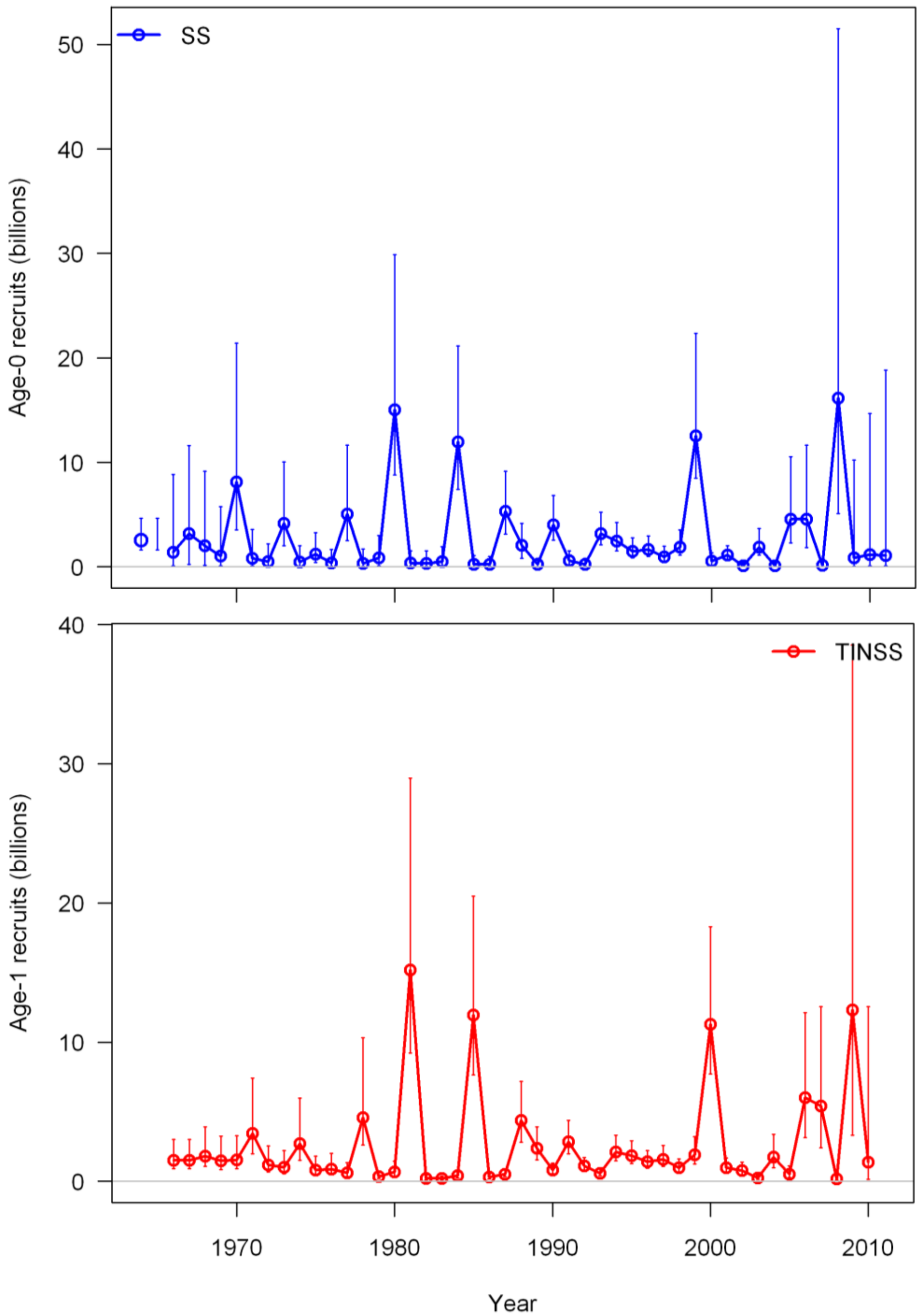


Figure 45. Posterior recruitment time-series for both models (age-0 for SS, upper panel; age-1 for TINSS, lower panel) with 95% posterior credibility intervals.

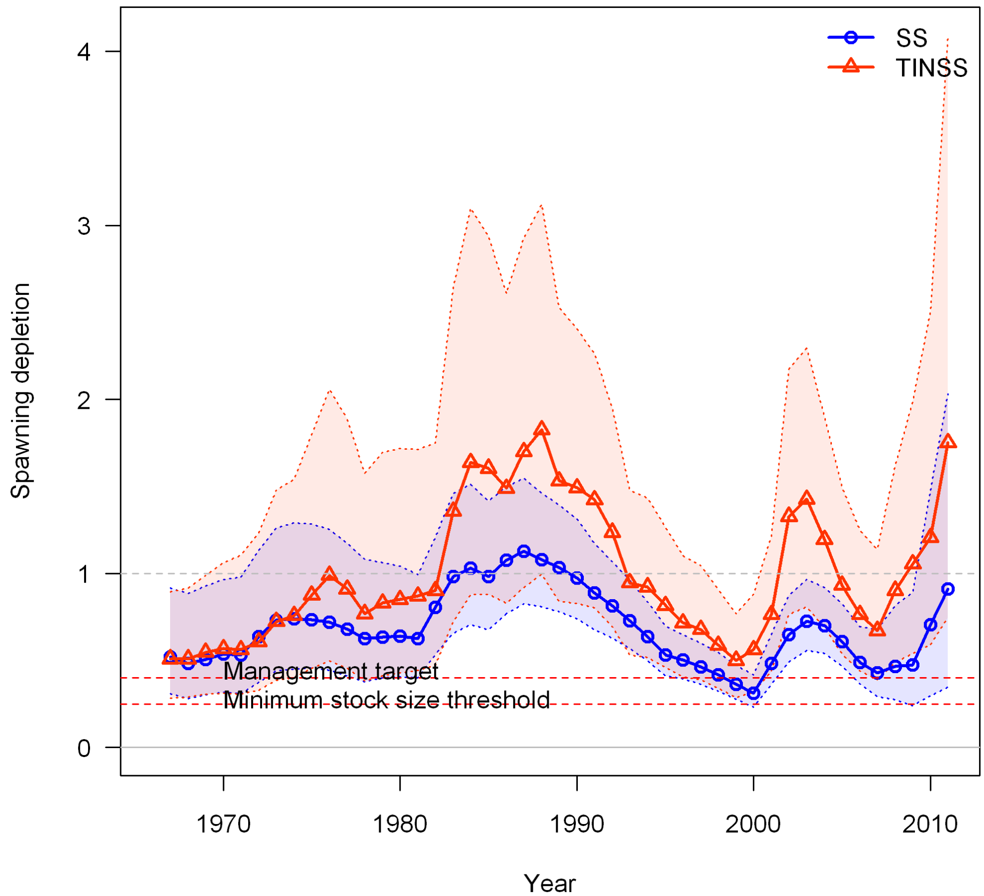


Figure 46. Time-series of posterior relative depletion for both models.

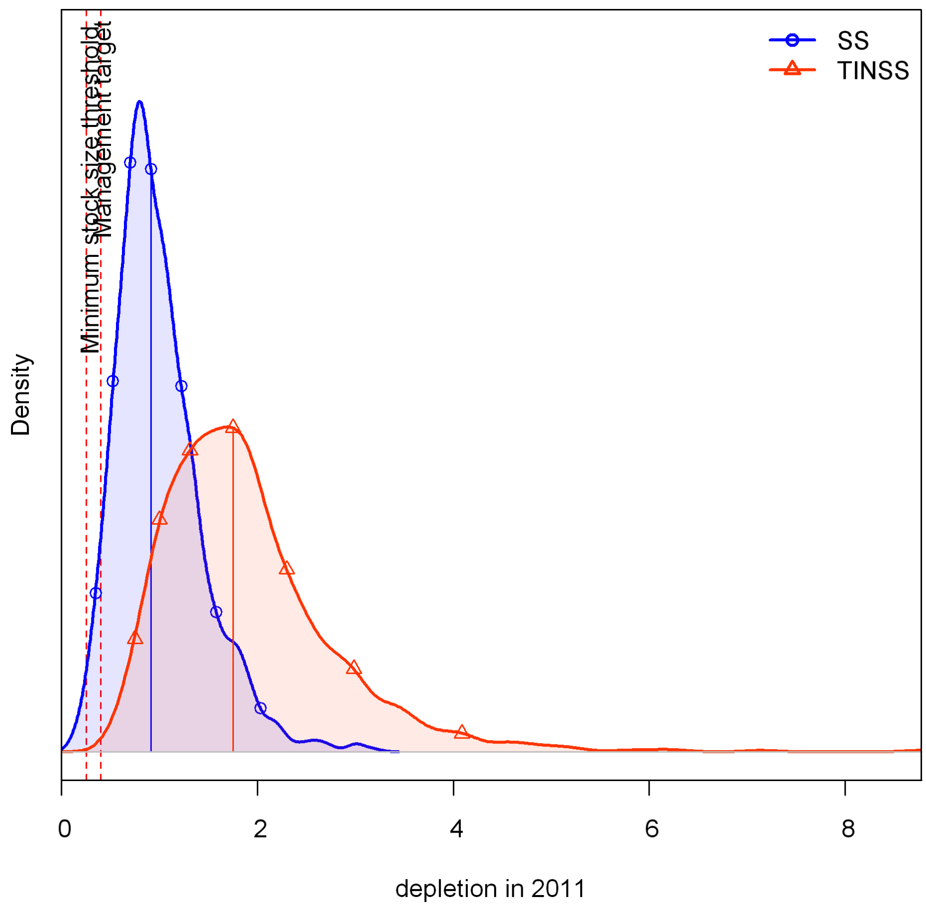


Figure 47. Comparison of posterior probability distributions for 2011 relative depletion for both models.

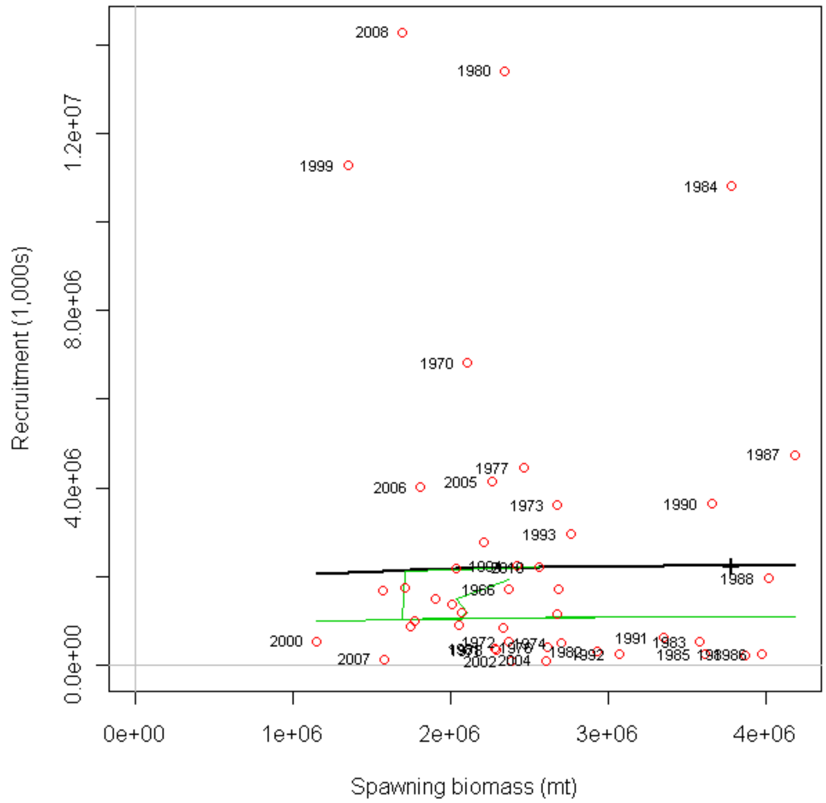


Figure 48. Estimated (MLE) stock-recruit relationship for the SS model.

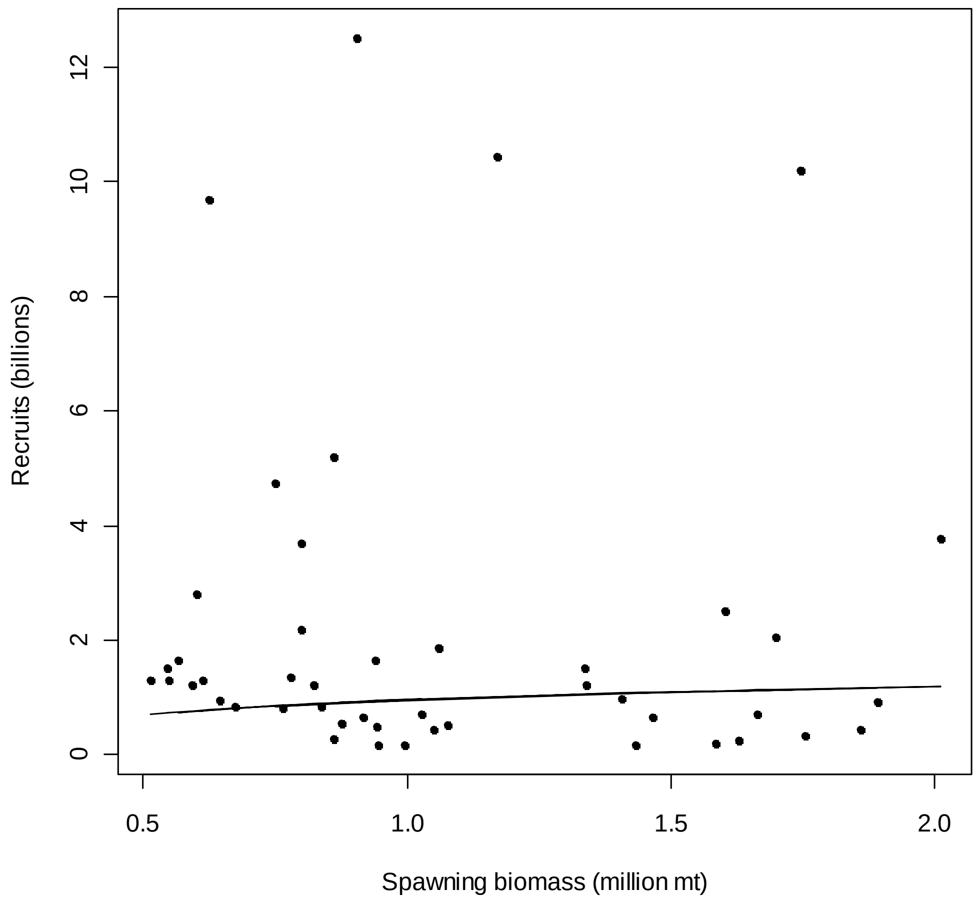


Figure 49. Estimated stock-recruit relationship for the TINSS model.

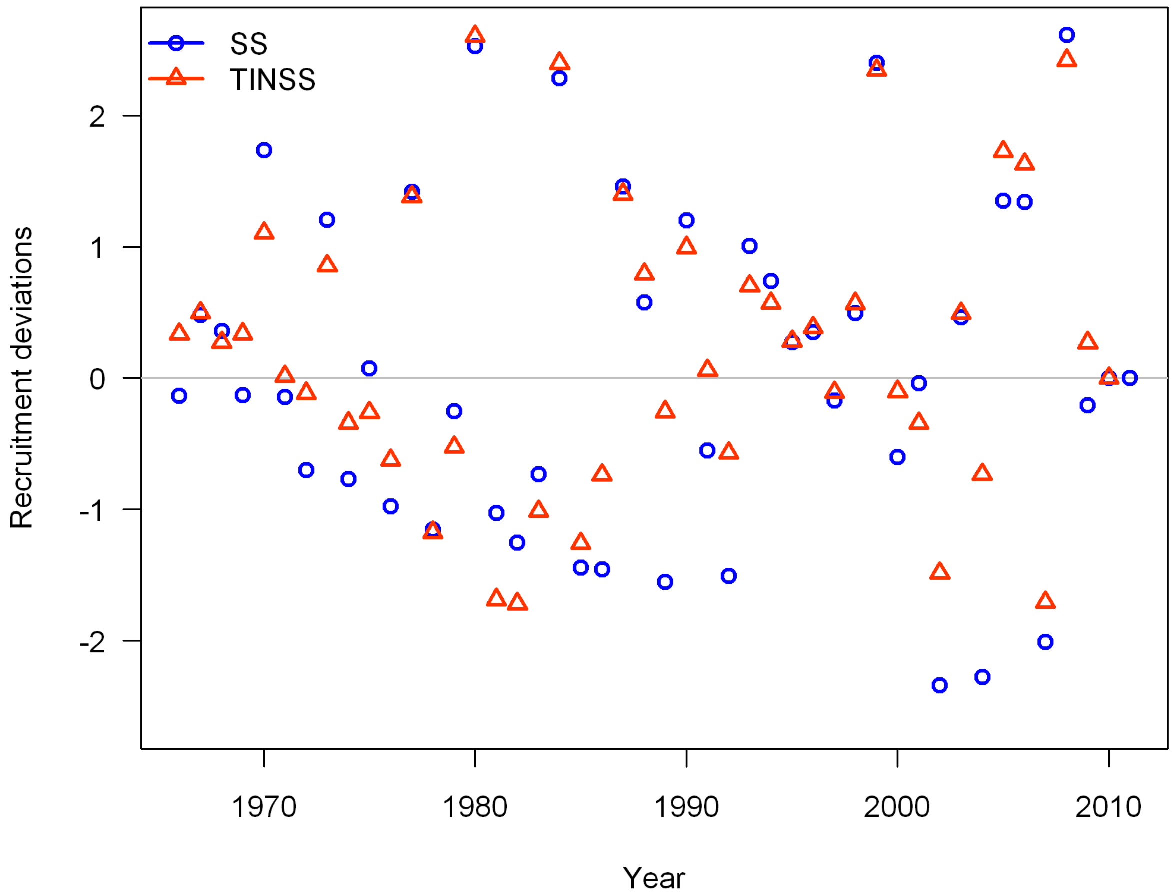


Figure 50. Comparison of the recruitment deviations in both models.

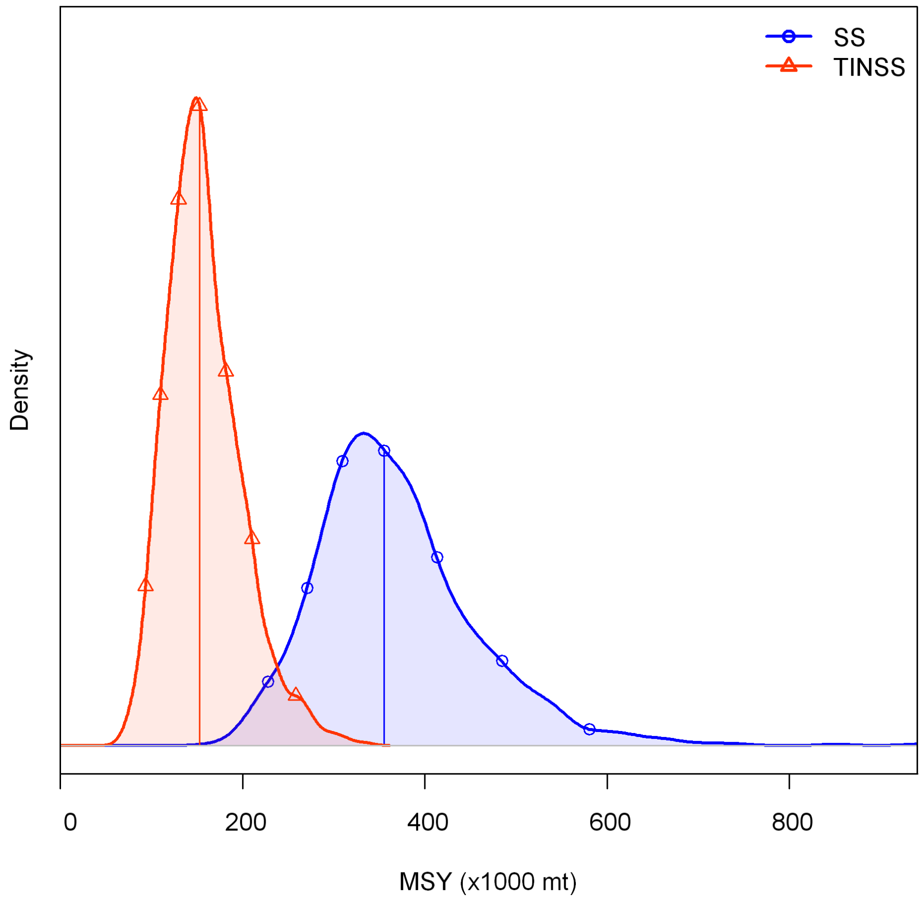


Figure 51. Comparison of posterior probability distributions for MSY for both models.

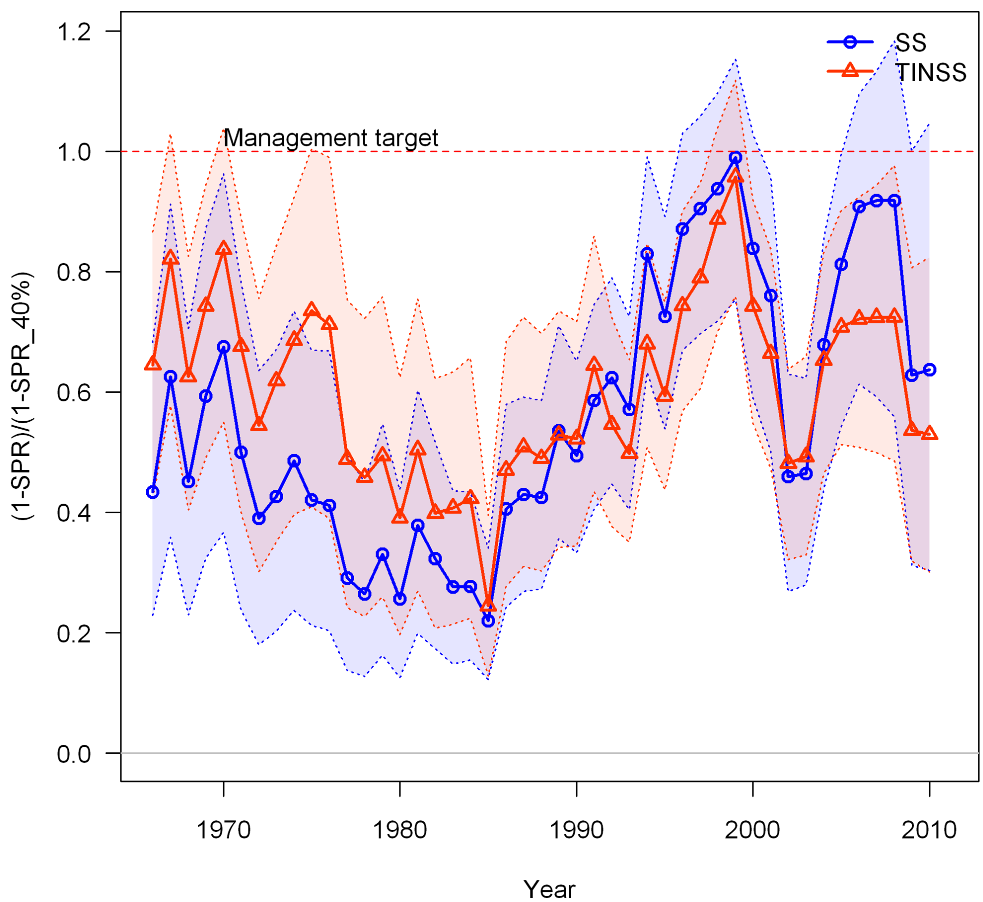


Figure 52. Time-series of relative spawning potential ratio (1-SPR/1-SPR$_{Target=0.4}$) for both models.

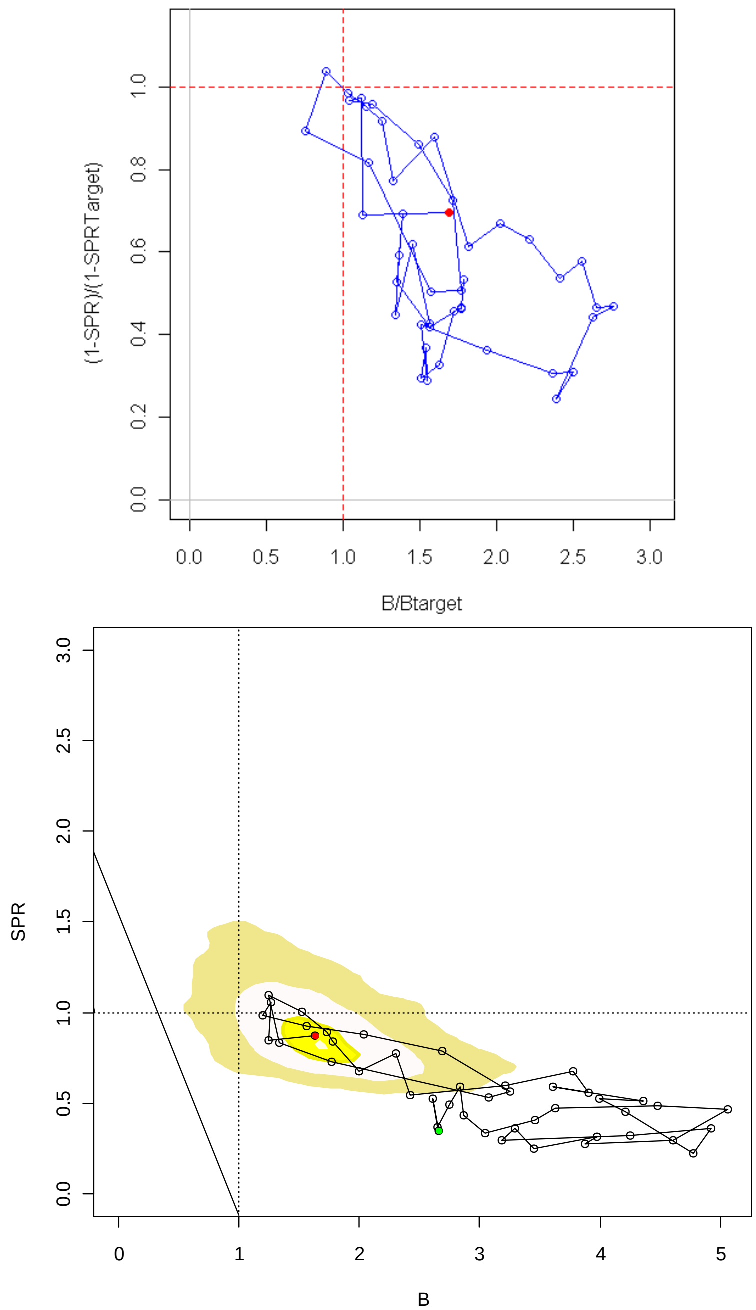


Figure 53. Temporal pattern (phase plot) of relative spawning potential ratio (1-SPR/1-$SPR_{Target=0.4}$) vs. estimated spawning biomass relative to the proxy 40% level through 2010 for the SS model (upper panel, note this calculation is based on the MLE). Lower panel shows relative spawning potential ratio (1-SPR/1-SPR_{MSY}) vs. estimated spawning biomass relative to the SB_{MSY} level through 2010 for the TINSS model. The filled circle denotes 2010 and the line connects years through the time-series.

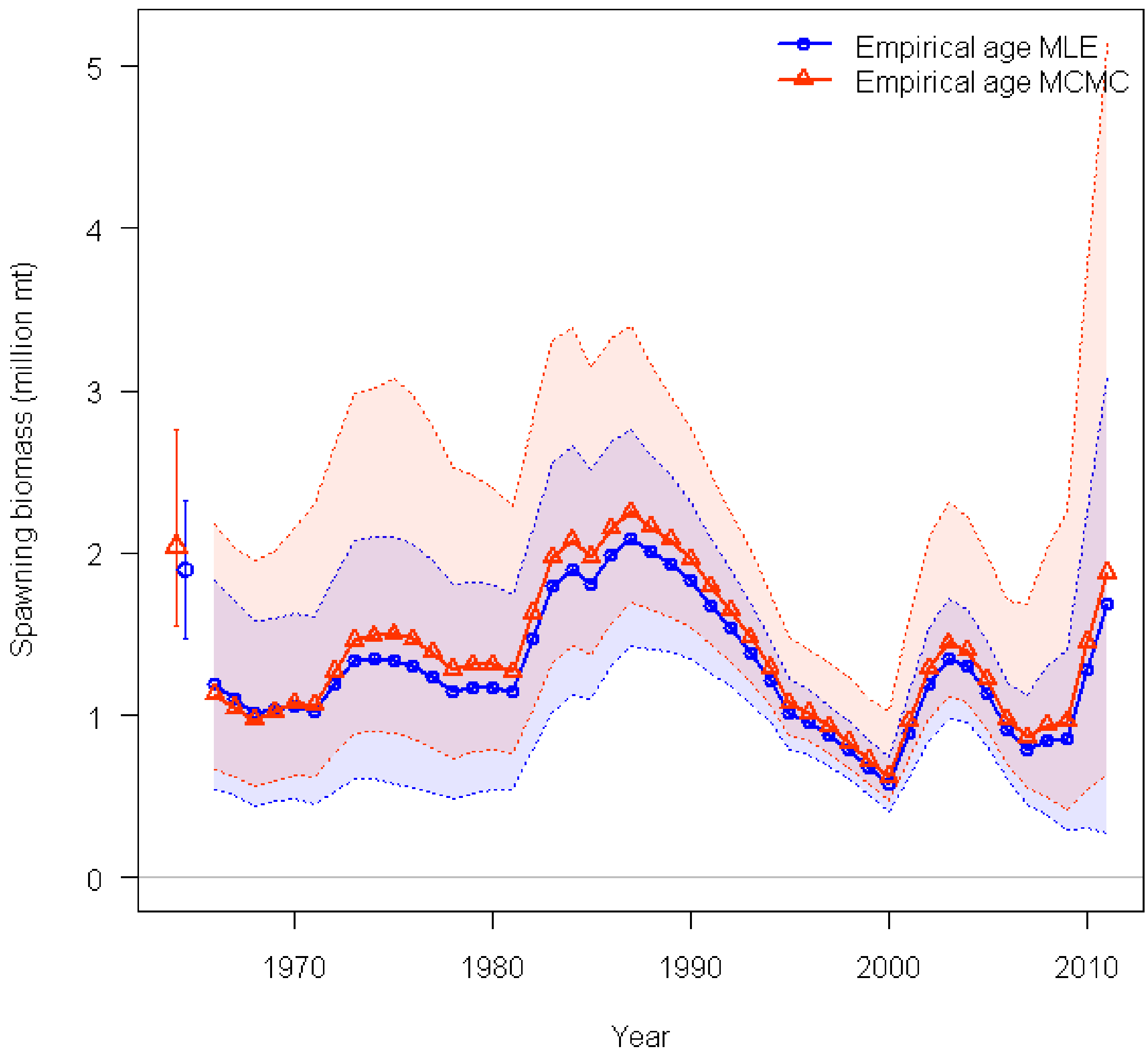


Figure 54. Comparison of maximum likelihood estimates and Bayesian posterior median results for spawning biomass from the SS model.

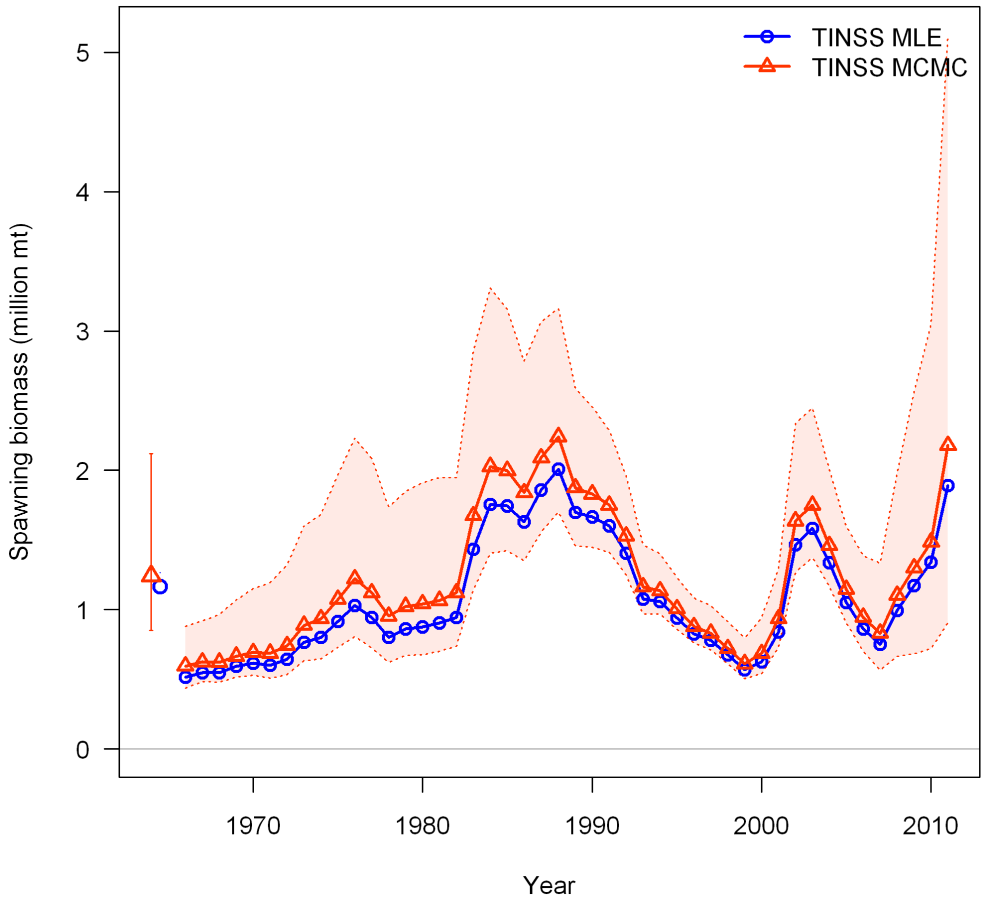


Figure 55. Comparison of maximum likelihood estimates and Bayesian posterior median results for spawning biomass from the TINSS model.

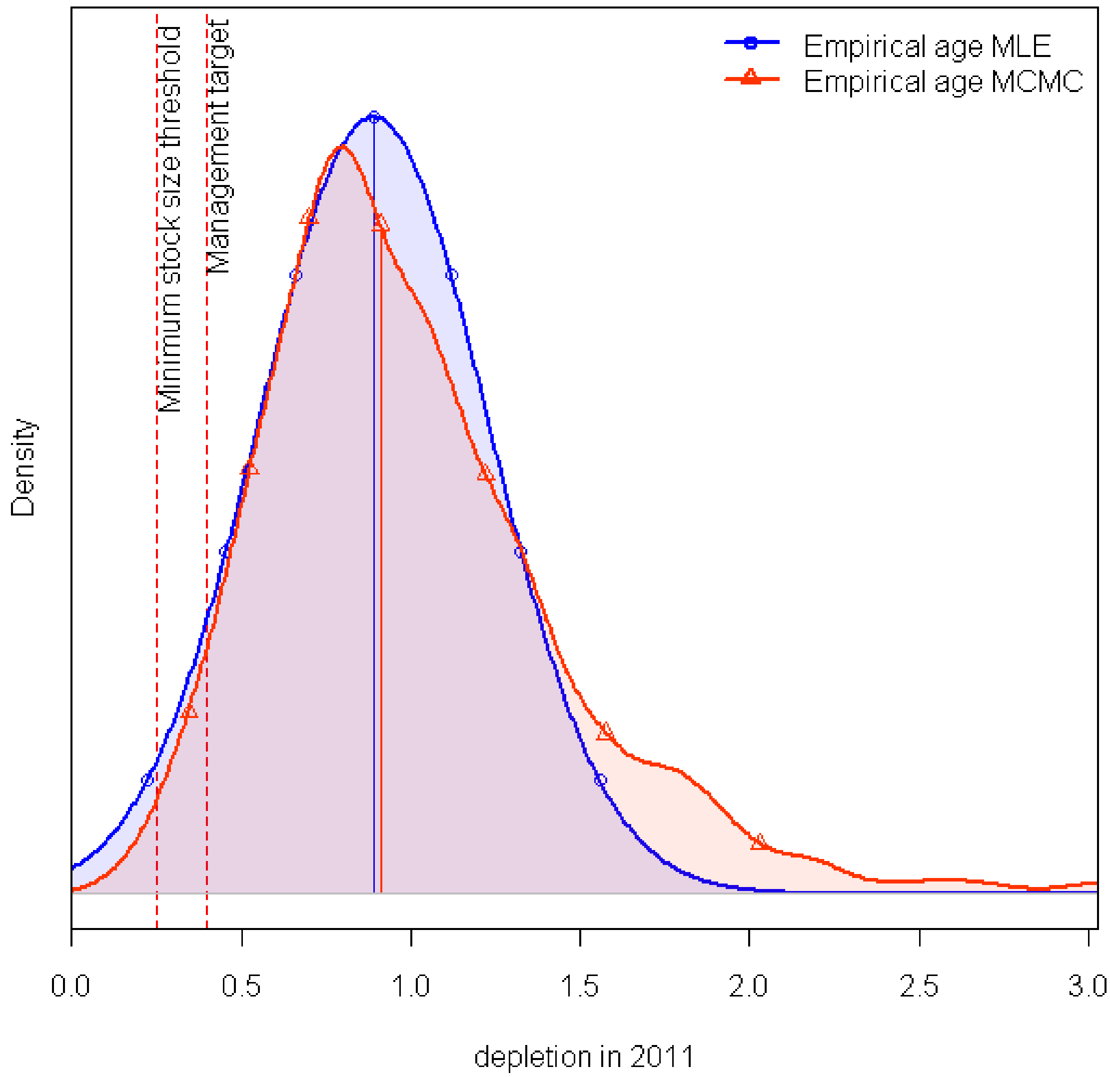


Figure 56. Comparison of maximum likelihood estimates and Bayesian posterior median results for current relative depletion from the SS model.

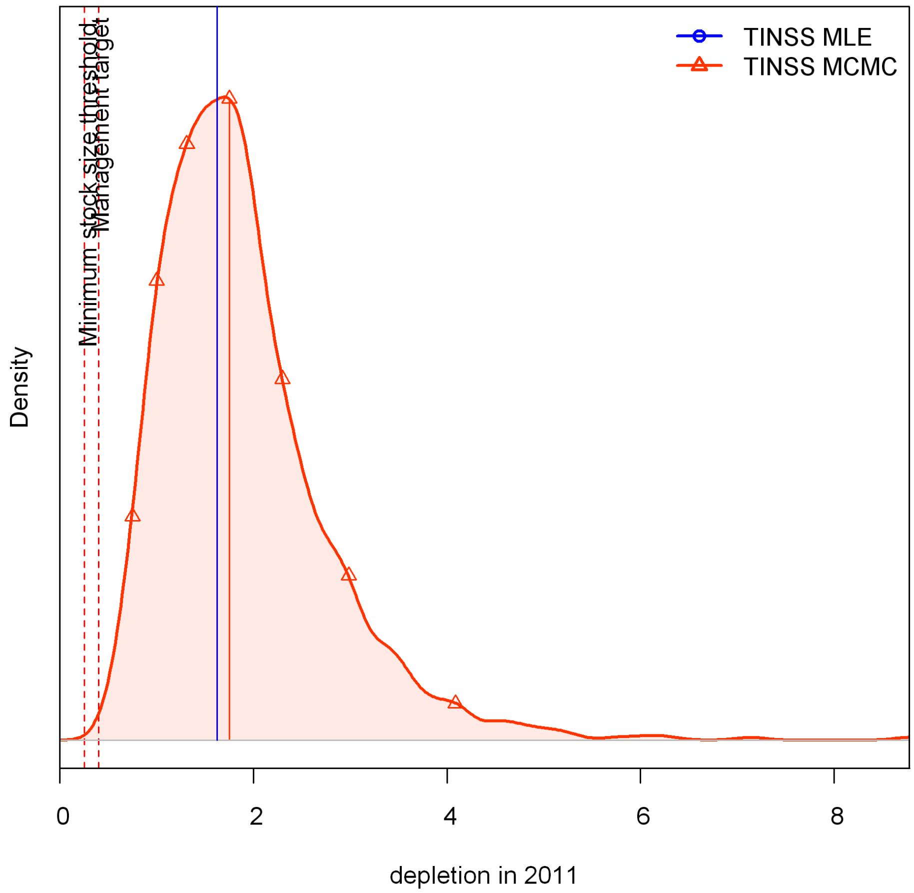


Figure 57. Comparison of maximum likelihood estimates and Bayesian posterior median results for current relative depletion from the TINSS model.

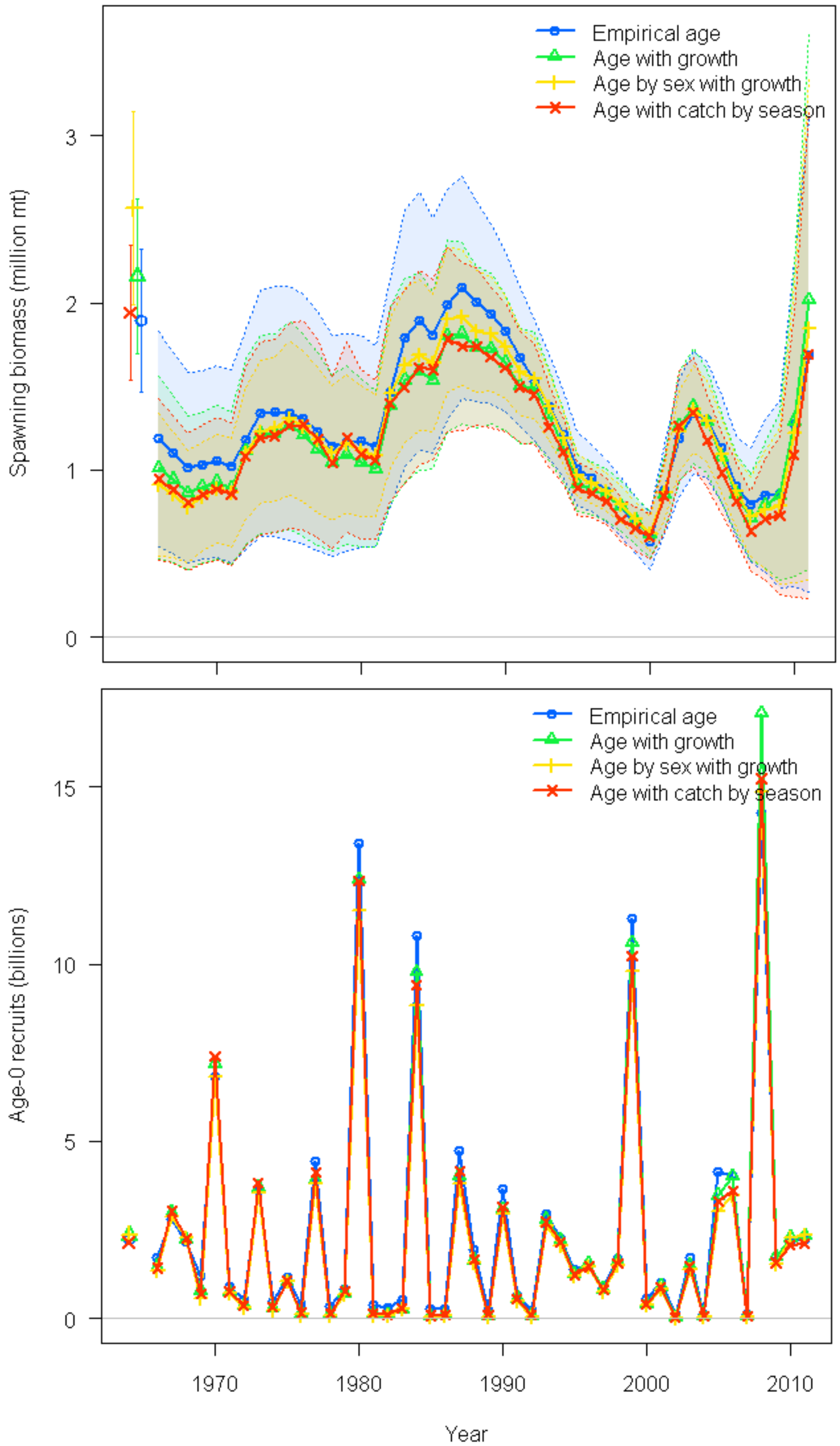


Figure 58. Results of sensitivity analysis among four candidate SS models.

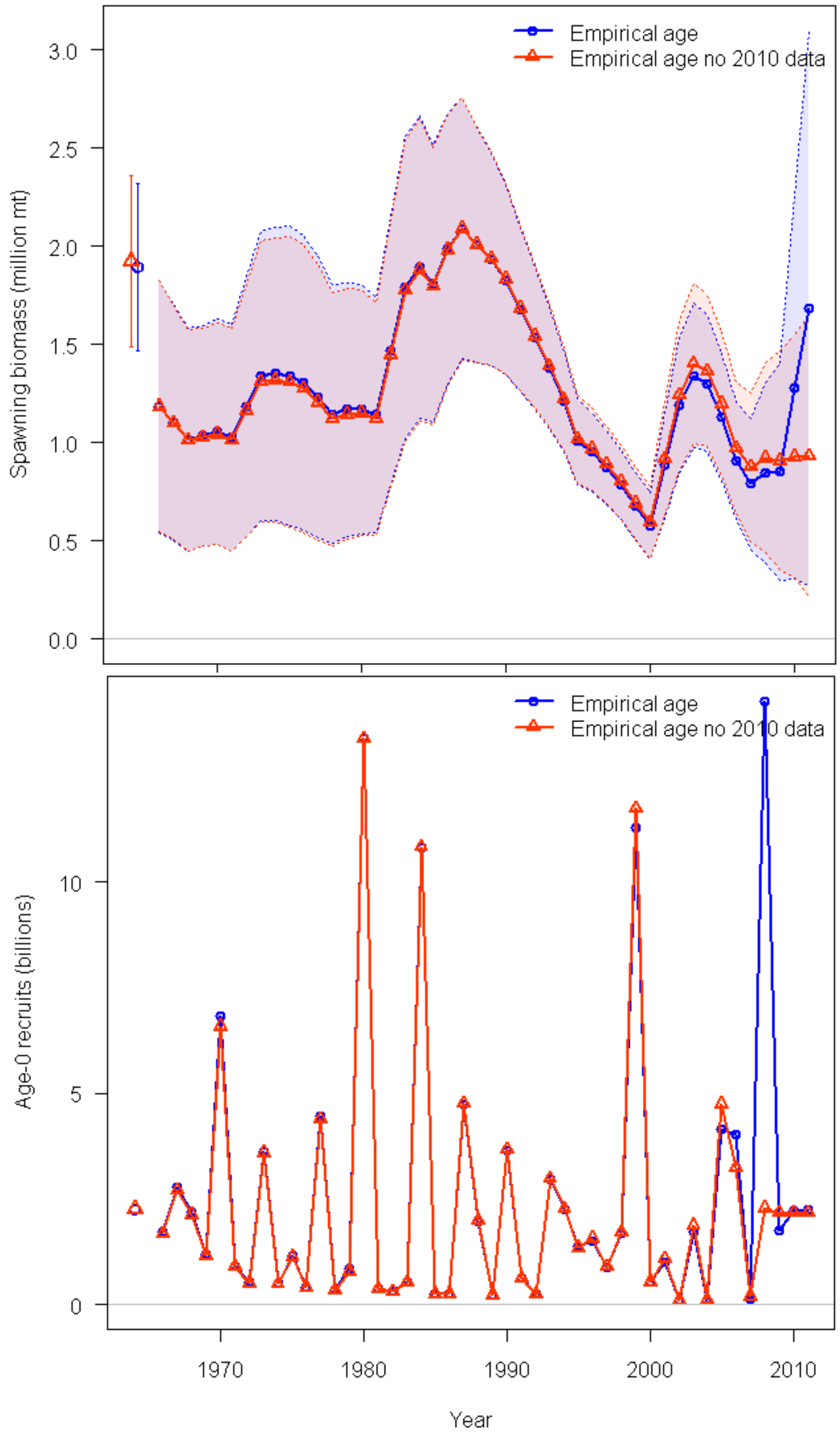


Figure 59. Results of sensitivity analysis for the SS model to exclusion of the 2010 fishery age data.

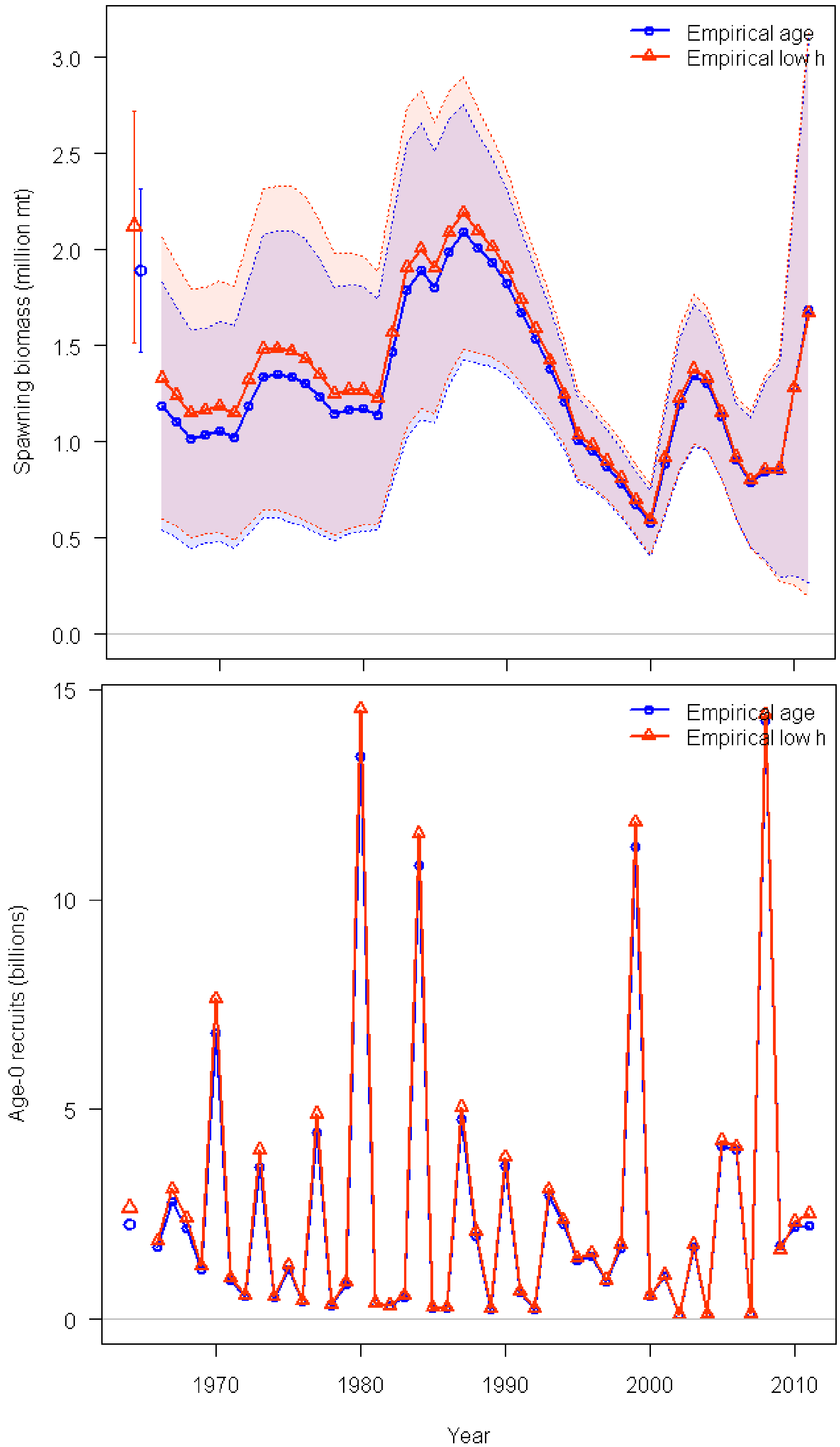


Figure 60. Results of sensitivity analysis for the SS model to the prior for steepness.

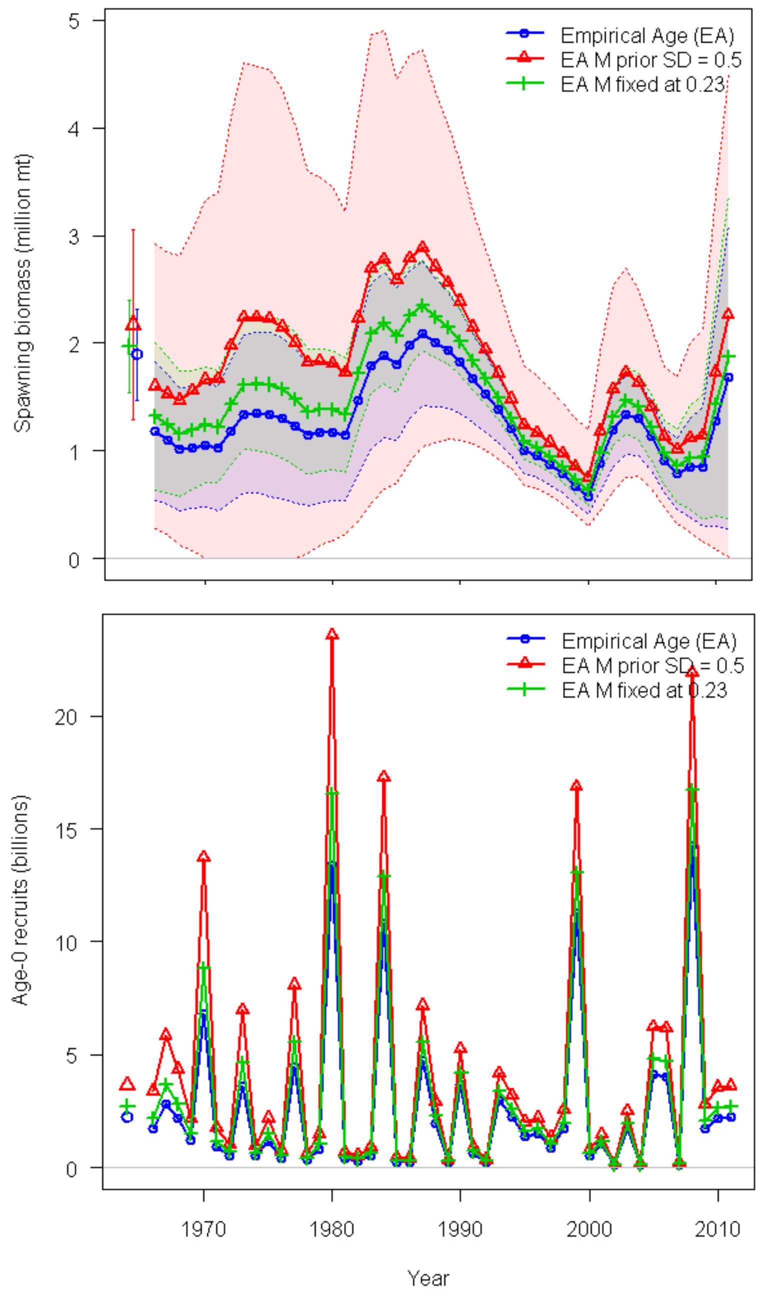


Figure 61. Results of sensitivity analysis for the SS model to the treatment of natural mortality rate.

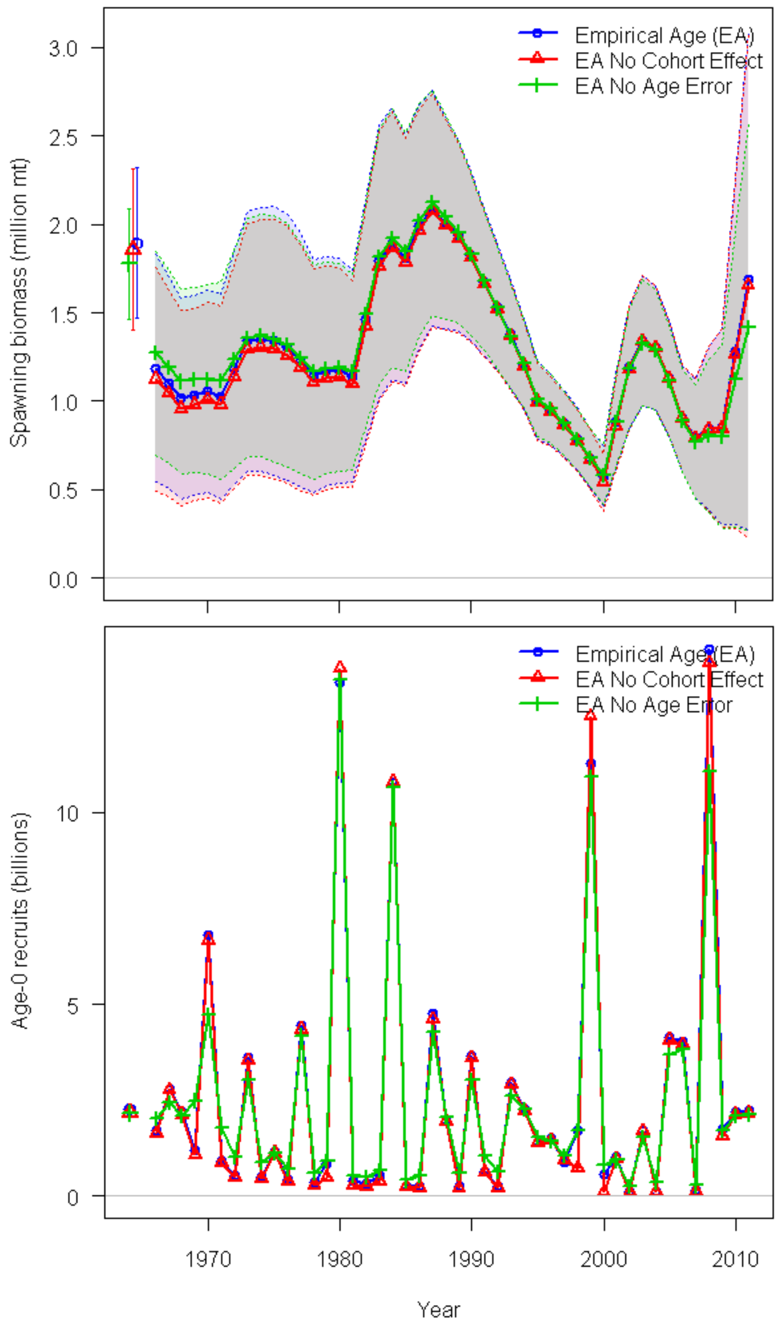


Figure 62. Results of sensitivity analysis for the SS model to the application of alternate ageing error approaches.

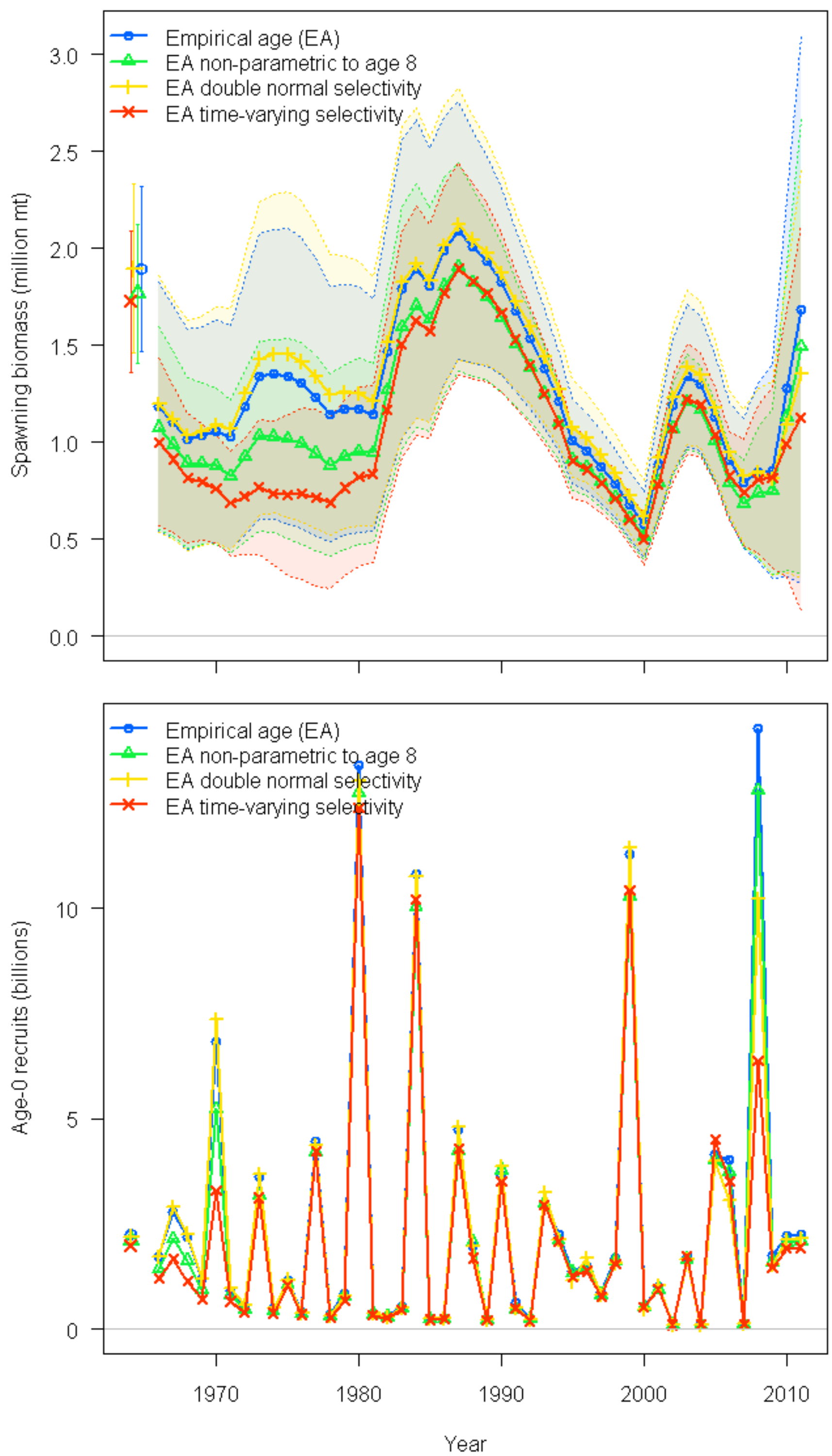


Figure 63. Results of sensitivity analysis for the SS model to fishery and survey selectivity parameterization.

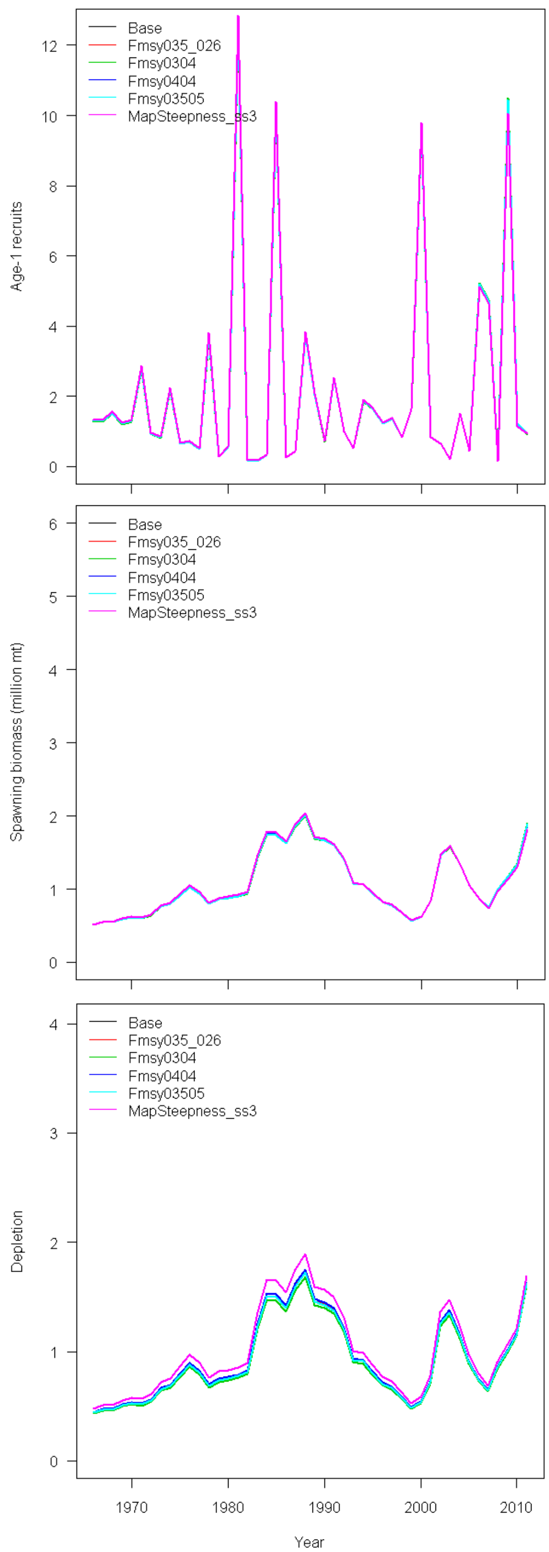


Figure 64. Results of sensitivity analysis for the TINSS model to the prior on F_{MSY}.

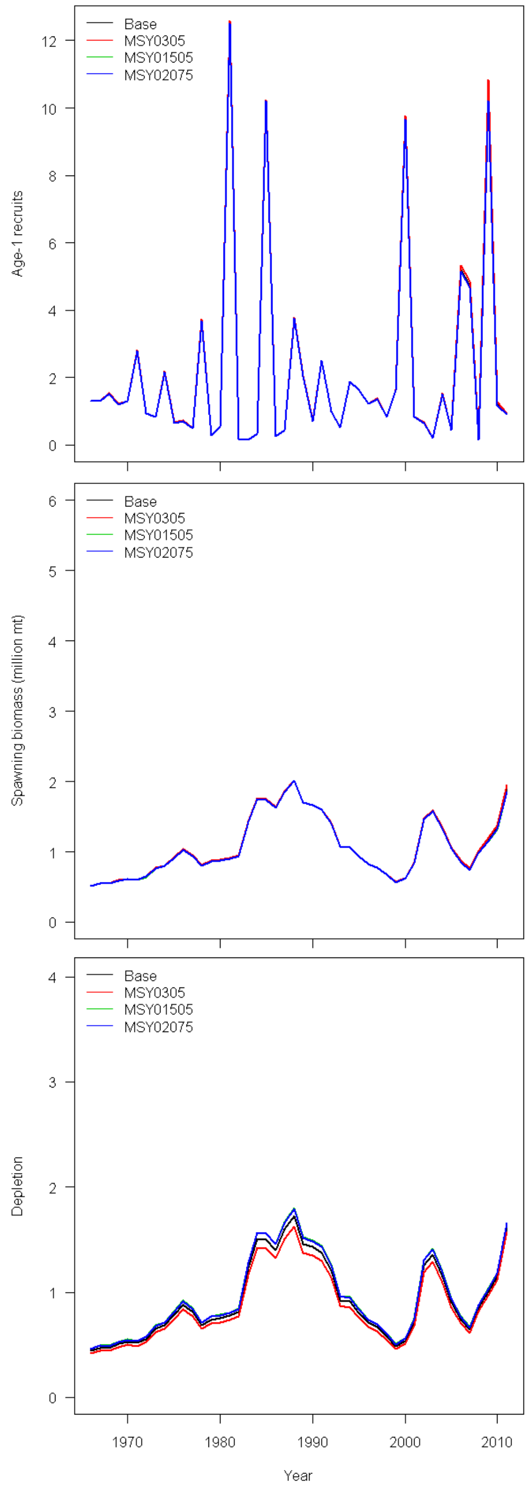


Figure 65. Results of sensitivity analysis for the TINSS model to the prior on *MSY*.

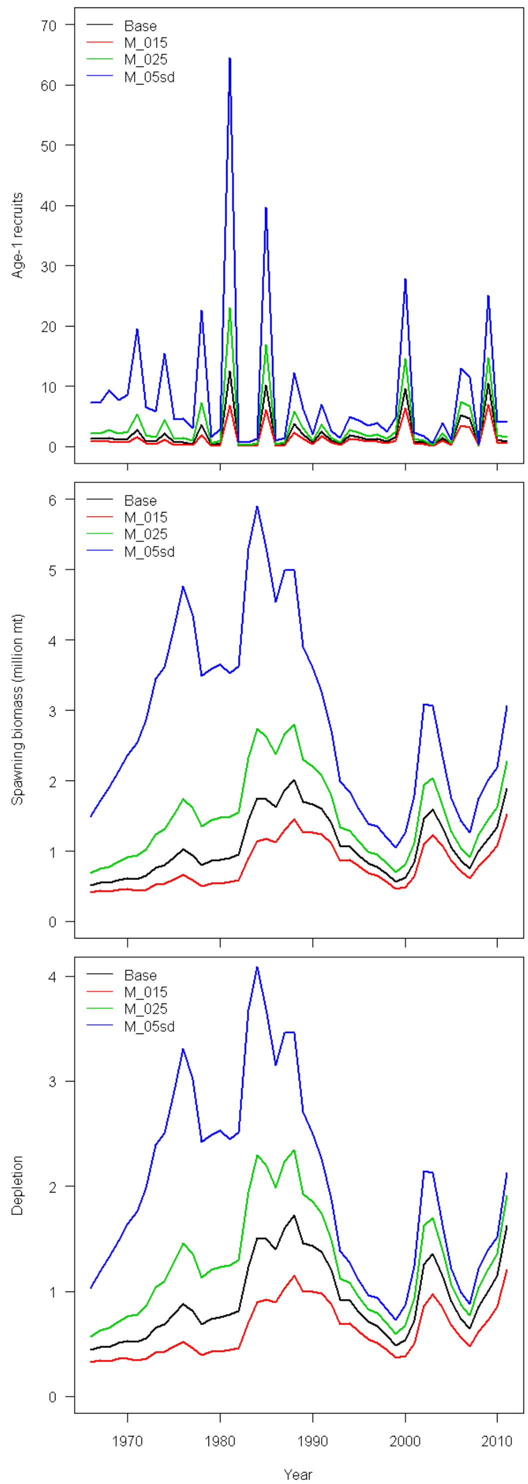


Figure 66. Results of sensitivity analysis for the TINSS model to the prior on *M*.

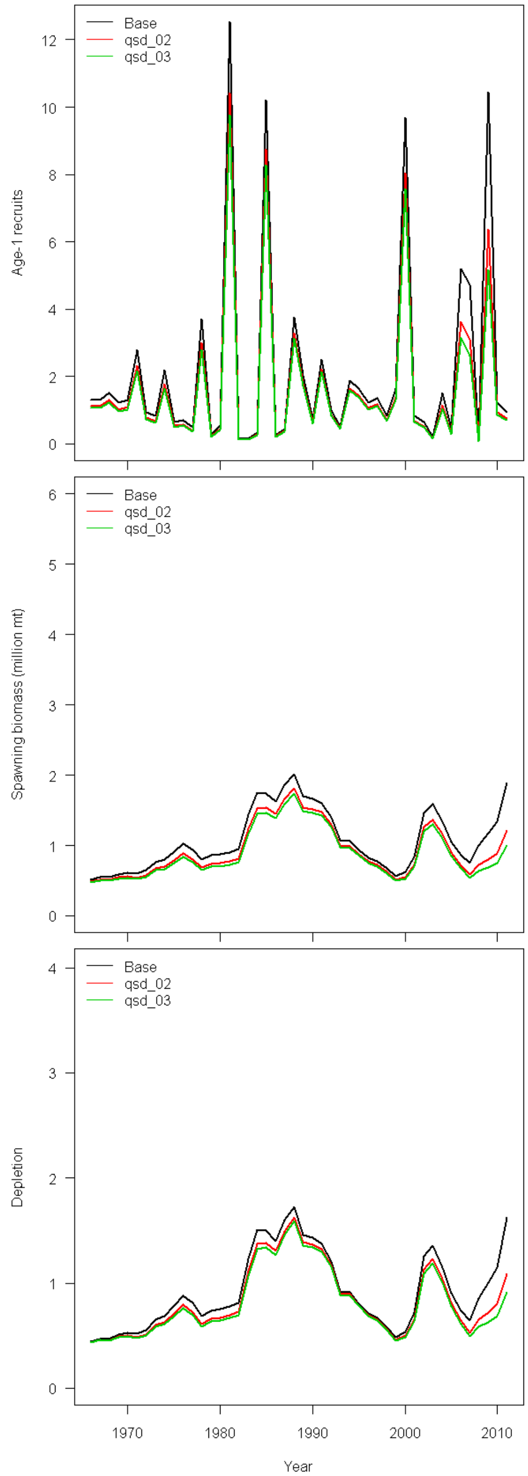


Figure 67. Results of sensitivity analysis for the TINSS model to the prior on *q*.

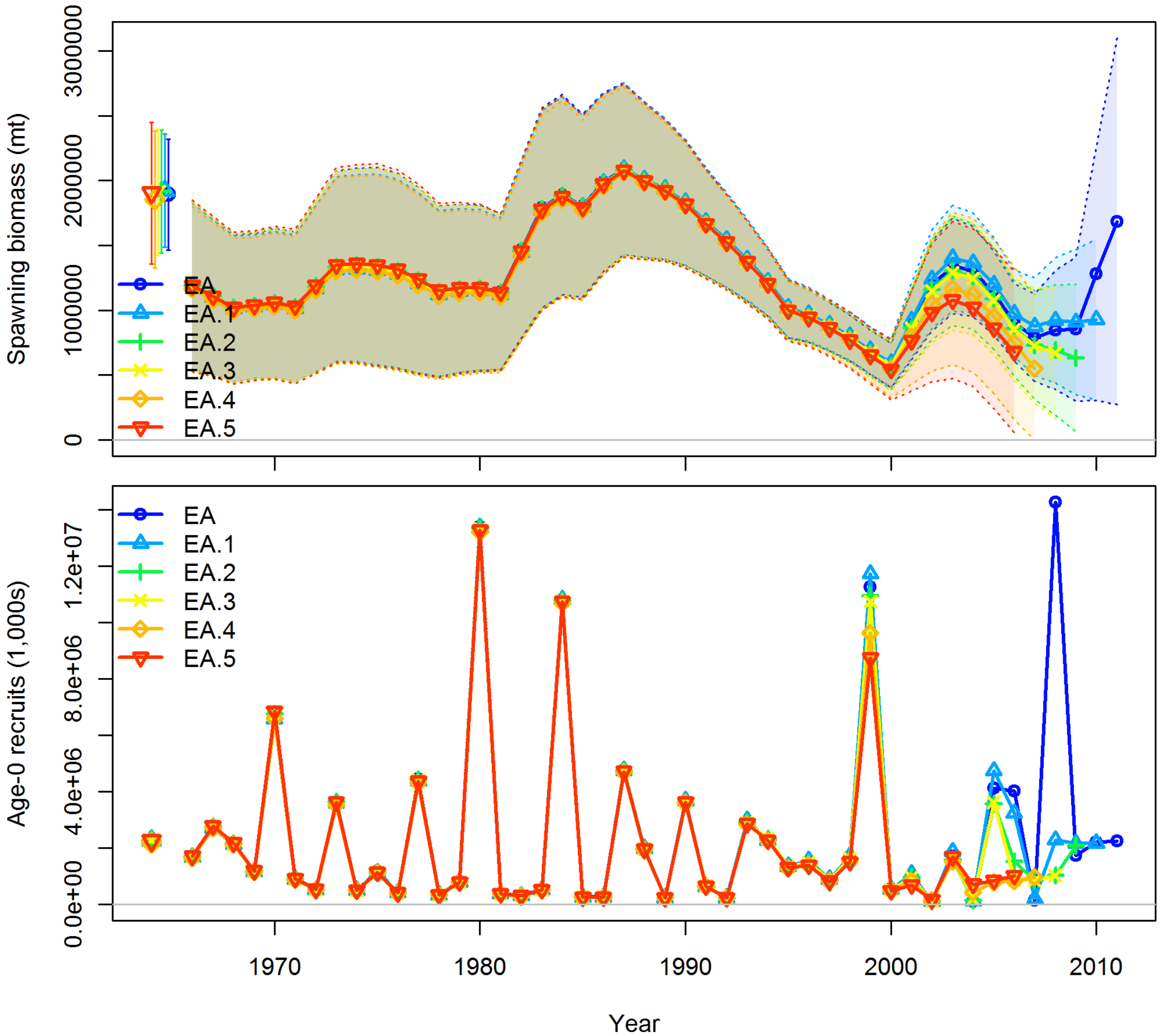
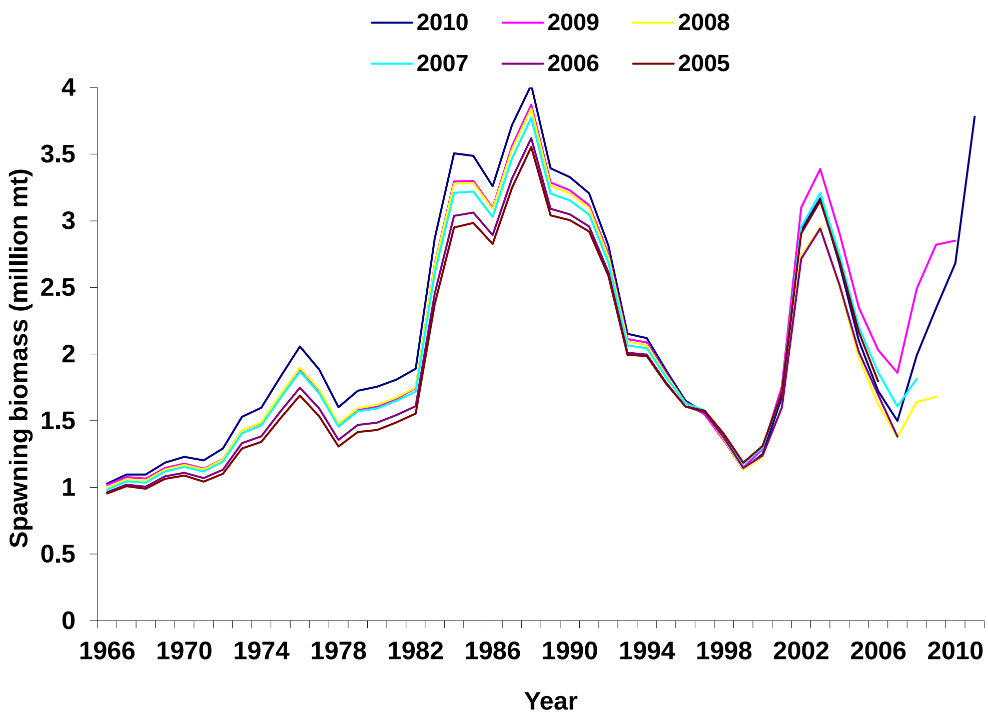


Figure 68. Retrospective pattern for the SS model over the terminal years 2011 to 2006 as data from each terminal year are sequentially removed from the model.



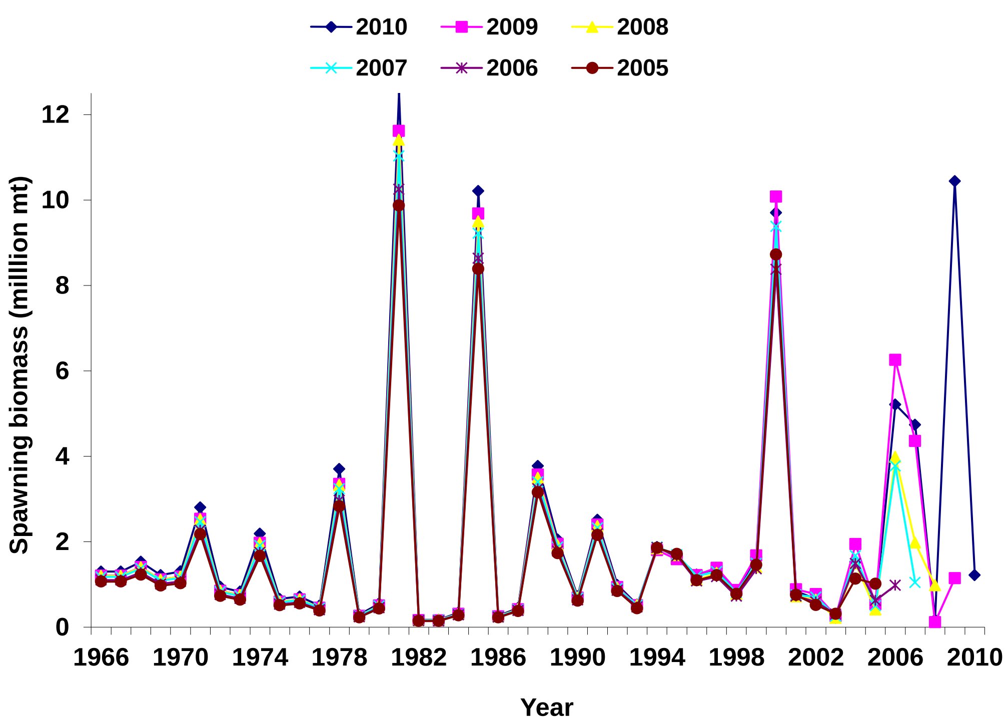


Figure 69. Retrospective pattern for the TINSS model over the terminal years 2011 to 2006 as data from each terminal year are sequentially removed from the model. Note that these results are based on the pre-SSC model.

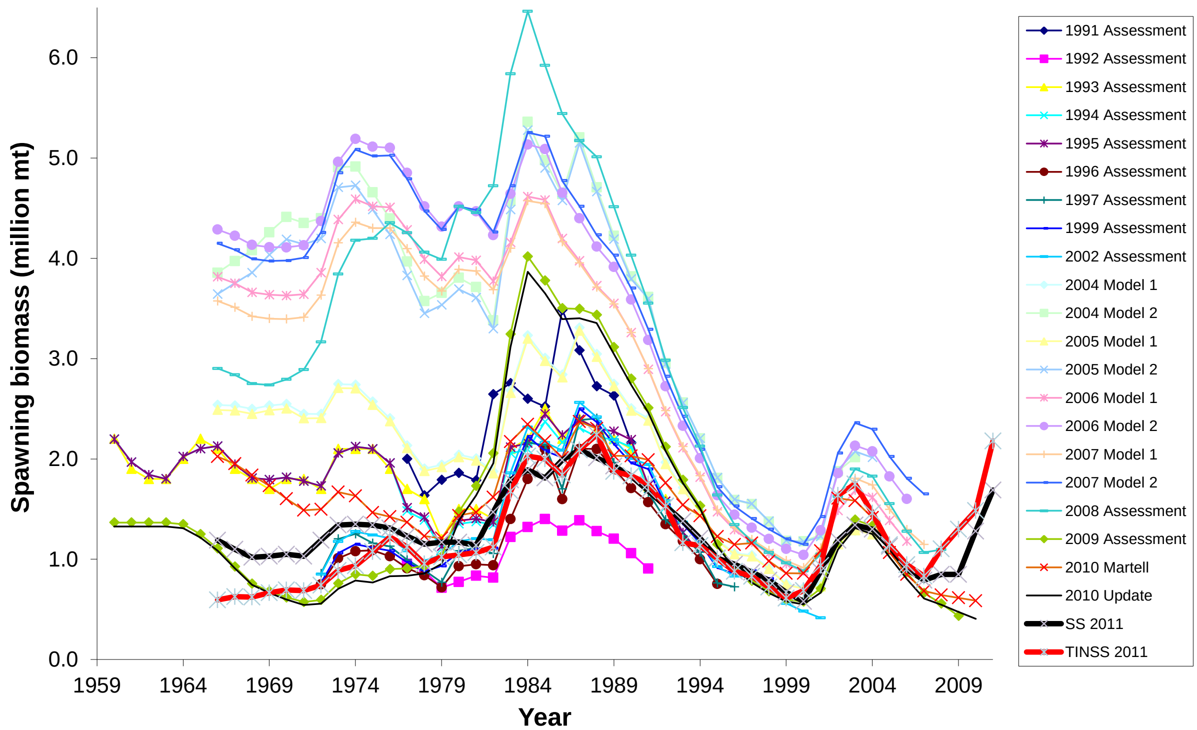


Figure 70. Posterior medians for both the SS (thick black line) and TINSS (thick red line) models in a retrospective comparing 2011 model results with previous stock assessments since 1991 (updates in 1998, 2000, 2001, 2003 are not included).

8. Appendix A. List of terms and acronyms used in this document

Note: Many of these definitions are drawn from the Pacific Fishery Management Council's list (http://www.pcouncil.org/wp-content/uploads/Acronyms-7-14-10.pdf)

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

ABC: Acceptable biological catch. See below.

Acceptable biological catch: The ABC is a scientific calculation of the sustainable harvest level of a fishery and is used to set the upper limit of the optimum yield (see below). It is calculated by applying the estimated (or proxy) harvest rate that produces maximum sustainable yield (*MSY*, see below) to the estimated exploitable stock biomass (the portion of the fish population that can be harvested).

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

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

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

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

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

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

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

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

Depletion: Abbreviated term for relative depletion (see below).

DFO: Fisheries and Oceans Canada. Federal organization which delivers programs and services that support sustainable use and development of Canada's waterways and aquatic resources.

DOC: United States Department of Commerce. Parent organization of the National Marine Fisheries Service (NMFS).

El Niño: Abnormally warm ocean climate conditions in the California Current Ecosystem (see above) as a result of broad changes in the Eastern Pacific Ocean across the eastern coast of Latin America (centered on Peru) often around the end of the calendar year.

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

F: Instantaneous rate of fishing mortality (or fishing mortality rate, see below).

$F_{40\%}$: The rate of fishing mortality estimated to reduce the spawning potential ratio (SPR, see below) to 40%.

Female spawning biomass: The biomass of mature female fish at the beginning of the year. Occasionally, especially in reference points, this term is used to mean spawning output (expected egg production, see below) when this is not proportional to spawning biomass. See also spawning biomass.

Fishing mortality rate, or instantaneous rate of fishing mortality (F): A metric of fishing intensity that is usually reported in reletion to the most highly selected ages(s) or length(s), or occasionally as an average over an age range that is vulnerable to the fishery. Because it is an instantaneous rate operating simultaneously with natural mortality, it is *not* equivalent to exploitation fraction (or percent annual removal; see above) or the Spawning Potential Ratio (*SPR*, see below).

F_{MSY}: The rate of fishing mortality estimated to produce the maximum sustainable yield from the stock.

Kt: Knots (nautical miles per hour).

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

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

MCMC: Markov-Chain Monte-Carlo. A numerical method used to sample from the posterior distribution (see below) of parameters and derived quantities in a Bayesian analysis.

MSY: Maximum sustainable yield. See above.

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

NA: Not available.

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

NMFS: National Marine Fisheries Service. See above.

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

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

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

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

OY: Optimum yield. See above.

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

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

PFMC: Pacific Fishery Management Council.

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

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

q: Catchability. See above.

R_0: Estimated average level of annual recruitment occurring at SB_0 (see below).

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

Recruitment deviation: The offset of the recruitment in a given year relative to the stock-recruit function; values occur on a log scale.

Relative depletion: The ratio of the estimated beginning of the year female spawning biomass to estimated average unfished equilibrium female spawning biomass (SB_0, see below).

Relative SPR: A measure of fishing intensity transformed to have an interpretation more like F: as fishing increases the metric increases. Relative SPR is the ratio of (1-SPR) to (1-$SPR_{xx\%}$), where "*xx*" is the proxy or estimated SPR rate that produces MSY.

SB_0: The estimated average unfished equilibrium female spawning biomass or spawning output if not directly proportional to spawning biomass.

$SB_{10\%}$: The level of female spawning biomass (output) corresponding to 10% of average unfished equilibrium female spawning biomass (SB_0, size of fish stock without fishing; see below). For many groundfish (including hake), this is the level at which the calculated catch based on the 40:10 harvest control rule (see above) is equal to 0.

$SB_{25\%}$: The level of female spawning biomass (output) corresponding to 25% of average unfished equilibrium female spawning biomass (SB_0, size of fish stock without fishing; see below). For many groundfish (including hake), this is the threshold below which the stock is designated as overfished.

$SB_{40\%}$: The level of female spawning biomass (output) corresponding to 40% of average unfished equilibrium female spawning biomass (SB_0, size of fish stock without fishing; see below). For many groundfish (including hake) this is the management target stock size and the proxy for SB_{MSY} (see below). This is also the Pacific Fishery Management Council's threshold for declaring a stock rebuilt if it has previously been designated as overfished.

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

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

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

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

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

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

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

SPR: Spawning potential ratio. See above.

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

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

SS: One of two age-structured stock assessment models applied in this stock assessment analysis (Stock Synthesis; see also TINSS).

SSC: Scientific and Statistical Committee (see above).

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

STAT: Stock Assessment Team. The individuals preparing the scientific analysis leading to, and including, stock assessments submitted to the Pacific Fishery Management Council's review process.

Steepness (*h*): A stock-recruit relationship parameter representing the proportion of R_0 expected (on average) when the female spawning biomass is reduced to 20% of SB_0 (i.e., when relative depletion is equal to 20%). This parameter can be thought of one important component to the productivity of the stock.

Target strength: The amount of backscatter from an individual acoustic target.

TINSS: One of two age-structured stock assessment models applied in this stock assessment analysis (This Is Not Stock Synthesis; see also SS).

Total Biomass: Aggregate biomass of all individual fish in the stock regardless of age or sex.

Vulnerable biomass: The demographic portion of the stock available for harvest by the fishery.

Year-class: A group of fish born in the same year. See also cohort and recruitment.

9. Appendix B. List of all estimated parameters in the SS model

Parameter	MLE	MCMC median
NatM_p_1_Fem_GP_1	0.21	0.22
SR_R0	14.63	14.76
SR_steep	0.85	0.81
Early_InitAge_20	-0.27	-0.18
Early_InitAge_19	-0.08	0.04
Early_InitAge_18	-0.10	-0.06
Early_InitAge_17	-0.12	-0.03
Early_InitAge_16	-0.14	-0.16
Early_InitAge_15	-0.17	-0.18
Early_InitAge_14	-0.20	-0.05
Early_InitAge_13	-0.24	-0.18
Early_InitAge_12	-0.29	-0.09
Early_InitAge_11	-0.34	-0.18
Early_InitAge_10	-0.39	-0.30
Early_InitAge_9	-0.45	-0.31
Early_InitAge_8	-0.50	-0.32
Early_InitAge_7	-0.56	-0.30
Early_InitAge_6	-0.62	-0.30
Early_InitAge_5	-0.66	-0.48
Early_InitAge_4	-0.67	-0.43
Early_InitAge_3	-0.64	-0.32
Early_InitAge_2	-0.57	-0.11
Early_InitAge_1	-0.39	0.03
Early_RecrDev_1966	-0.13	0.24
Early_RecrDev_1967	0.48	1.14
Early_RecrDev_1968	0.36	0.69
Early_RecrDev_1969	-0.13	0.04
Main_RecrDev_1970	1.74	2.07
Main_RecrDev_1971	-0.14	-0.26
Main_RecrDev_1972	-0.70	-0.73
Main_RecrDev_1973	1.21	1.36
Main_RecrDev_1974	-0.77	-0.84
Main_RecrDev_1975	0.08	0.16
Main_RecrDev_1976	-0.98	-1.08
Main_RecrDev_1977	1.42	1.55
Main_RecrDev_1978	-1.15	-1.13
Main_RecrDev_1979	-0.25	-0.27
Main_RecrDev_1980	2.53	2.65
Main_RecrDev_1981	-1.03	-1.03
Main_RecrDev_1982	-1.25	-1.28

Parameter	MLE	MCMC median
Main_RecrDev_1983	-0.73	-0.81
Main_RecrDev_1984	2.29	2.38
Main_RecrDev_1985	-1.44	-1.51
Main_RecrDev_1986	-1.45	-1.50
Main_RecrDev_1987	1.46	1.55
Main_RecrDev_1988	0.58	0.59
Main_RecrDev_1989	-1.55	-1.61
Main_RecrDev_1990	1.20	1.28
Main_RecrDev_1991	-0.55	-0.62
Main_RecrDev_1992	-1.51	-1.57
Main_RecrDev_1993	1.01	1.08
Main_RecrDev_1994	0.74	0.82
Main_RecrDev_1995	0.27	0.36
Main_RecrDev_1996	0.35	0.46
Main_RecrDev_1997	-0.17	-0.06
Main_RecrDev_1998	0.50	0.61
Main_RecrDev_1999	2.40	2.55
Main_RecrDev_2000	-0.60	-0.57
Main_RecrDev_2001	-0.04	0.07
Main_RecrDev_2002	-2.34	-2.31
Main_RecrDev_2003	0.46	0.56
Main_RecrDev_2004	-2.28	-2.26
Main_RecrDev_2005	1.35	1.47
Main_RecrDev_2006	1.34	1.48
Main_RecrDev_2007	-2.01	-2.07
Late_RecrDev_2008	2.62	2.73
Late_RecrDev_2009	-0.21	-0.20
Late_RecrDev_2010	0.00	0.09
ForeRecr_2011	0.00	-0.01
ForeRecr_2012	0.00	-0.01
ForeRecr_2013	0.00	0.08
Q_extraSD_2_Acoustic_Survey	0.20	0.26
AgeSel_1P_3_Fishery	2.90	2.98
AgeSel_1P_4_Fishery	1.57	1.58
AgeSel_1P_5_Fishery	0.46	0.47
AgeSel_1P_6_Fishery	0.23	0.22
AgeSel_2P_4_Acoustic_Survey	0.08	0.06
AgeSel_2P_5_Acoustic_Survey	0.43	0.45
AgeSel_2P_6_Acoustic_Survey	0.42	0.40

10. Appendix C. List of all estimated parameters in the TINSS model

Parameter	MLE	MCMC median
MSY	0.13	0.15
F_{MSY}	0.34	0.41
M	0.23	0.25
Age at 50% first harvest (comm)	4.83	4.92
SD fishery selectivity (comm)	1.32	1.33
Age at 50% first harvest (survey)	3.98	4.30
SD fishery selectivity (survey)	1.94	2.14
Variance ratio (rho)	0.14	0.16
Inverse total variance	0.78	0.74
Mean recruitment #1 - 1952	-1.13	-2.04
Mean recruitment #2 - 1953	-0.53	-1.59
Mean recruitment #3 - 1954	-0.61	-1.37
Mean recruitment #4 - 1955	-0.70	-1.71
Mean recruitment #5 - 1956	-0.79	-1.86
Mean recruitment #6 - 1957	-0.89	-1.94
Mean recruitment #7 - 1958	-0.98	-2.03
Mean recruitment #8 - 1959	-1.08	-2.00
Mean recruitment #9 - 1960	-1.18	-2.16
Mean recruitment #10 - 1961	-1.29	-2.22
Mean recruitment #11 - 1962	-1.44	-2.50
Mean recruitment #12 - 1963	0.41	0.55
Mean recruitment #13 - 1964	0.12	0.28
Mean recruitment #14 - 1965	0.40	0.61
Mean recruitment #15 - 1966	0.34	0.55
Mean recruitment #16 - 1967	0.50	0.74
Mean recruitment #17 - 1968	0.27	0.53
Mean recruitment #18 - 1969	0.34	0.59
Mean recruitment #19 - 1970	1.11	1.38
Mean recruitment #20 - 1971	0.01	0.31
Mean recruitment #21 - 1972	-0.12	0.18
Mean recruitment #22 - 1973	0.86	1.14
Mean recruitment #23 - 1974	-0.34	-0.05
Mean recruitment #24 - 1975	-0.26	0.02
Mean recruitment #25 - 1976	-0.62	-0.34
Mean recruitment #26 - 1977	1.38	1.67
Mean recruitment #27 - 1978	-1.17	-0.90
Mean recruitment #28 - 1979	-0.52	-0.26
Mean recruitment #29 - 1980	2.60	2.87
Mean recruitment #30 - 1981	-1.69	-1.42
Mean recruitment #31 - 1982	-1.72	-1.46

Parameter	MLE	MCMC median
Mean recruitment #32 - 1983	-1.01	-0.77
Mean recruitment #33 - 1984	2.40	2.62
Mean recruitment #34 - 1985	-1.26	-1.04
Mean recruitment #35 - 1986	-0.74	-0.53
Mean recruitment #36 - 1987	1.40	1.60
Mean recruitment #37 - 1988	0.79	1.00
Mean recruitment #38 - 1989	-0.25	-0.07
Mean recruitment #39 - 1990	1.00	1.18
Mean recruitment #40 - 1991	0.06	0.23
Mean recruitment #41 - 1992	-0.57	-0.39
Mean recruitment #42 - 1993	0.70	0.87
Mean recruitment #43 - 1994	0.57	0.75
Mean recruitment #44 - 1995	0.28	0.46
Mean recruitment #45 - 1996	0.39	0.59
Mean recruitment #46 - 1997	-0.11	0.10
Mean recruitment #47 - 1998	0.57	0.78
Mean recruitment #48 - 1999	2.35	2.56
Mean recruitment #49 - 2000	-0.10	0.10
Mean recruitment #50 - 2001	-0.34	-0.14
Mean recruitment #51 - 2002	-1.48	-1.26
Mean recruitment #52 - 2003	0.49	0.70
Mean recruitment #53 - 2004	-0.73	-0.53
Mean recruitment #54 - 2005	1.73	1.92
Mean recruitment #55 - 2006	1.63	1.82
Mean recruitment #56 - 2007	-1.71	-1.55
Mean recruitment #57 - 2008	2.42	2.63
Mean recruitment #58 - 2009	0.27	0.44
Mean recruitment #59 - 2010	0.00	-0.35

11. Appendix D. SS model input files

```
# 2011 hake Empirical age model starter file

2011_hake_EA_data.SS        # Data file
2011_hake_EA_control.SS # Control file

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

999 # end of file marker

# 2011 hake Empirical Age model forecast file

1       # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2       # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.4     # SPR target (e.g. 0.40)
0.4     # Biomass target (e.g. 0.40)
# Enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
2005 2010 2005 2010 2005 2010 # Bmark_years: beg_bio end_bio beg_selex end_selex beg_alloc end_alloc
2       # Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
1       # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (use first-last alloc yrs); 5=input annual F
3       # N forecast years
1.0     # F scalar (only used for Do_Forecast==5)
# Enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
2005 2010 2005 2010 # Fcast_years:  beg_selex end_selex beg_alloc end_alloc
1       # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0.4     # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40)
0.1     # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
1.0     # Control rule target as fraction of Flimit (e.g. 0.75)
3       # N forecast loops (1-3) (fixed at 3 for now)
3       # First forecast loop with stochastic recruitment (fixed at 3 for now)
-1      # Forecast loop control #3 (reserved)
0       #_Forecast loop control #4 (reserved for future bells&whistles)
0       #_Forecast loop control #5 (reserved for future bells&whistles)
2011    # FirstYear for caps and allocations (should be after any fixed inputs)
0.0     # stddev of log(realized catch/target catch) in forecast
0       # Do West Coast gfish rebuilder output (0/1)
```

```
1999        # Rebuilder:  first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
2002        # Rebuilder:  year for current age structure (Yinit) (-1 to set to endyear+1)
1           # fleet relative F:  1=use first-last alloc year; 2=read seas(row) x fleet(col) below
2           # basis for fcast catch tuning and for fcast catch caps and allocation  (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
-1          # max totalcatch by fleet (-1 to have no max)
-1          # max totalcatch by area (-1 to have no max)
1           # fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an alloc group)
# assign fleets to groups
1.0
# allocation fraction for each of: 2 allocation groups
0 # Number of forecast catch levels to input (else calc catch from forecast F)
2 # basis for input Fcast catch:  2=dead catch; 3=retained catch; 99=input Hrate(F) (units are from fleetunits; note new codes in SSV3.20)

999 # verify end of input

# 2011 hake Empirical age data file

########################################

### Global model specifications ###
1966        # Start year
2010        # End year
1           # Number of seasons/year
12          # Number of months/season
1           # Spawning occurs at beginning of season
1           # Number of fishing fleets
1           # Number of surveys
1           # Number of areas
Fishery%Acoustic_Survey
0.5 0.5 # fleet timing_in_season
1 1         # Area of each fleet
1           # Units for catch by fishing fleet: 1=Biomass(mt),2=Numbers(1000s)
0.01        # SE of log(catch) by fleet for equilibrium and continuous options
1           # Number of sexes
20          # Number of ages in population dynamics

### Catch section ###
0  # Initial equilibrium catch (landings + discard) by fishing fleet

45 # Number of lines of catch
# Catch Year Season
137700      1966        1
214370      1967        1
122180      1968        1
180130      1969        1
234590      1970        1
154620      1971        1
117540      1972        1
162640      1973        1
211260      1974        1
221350      1975        1
237520      1976        1
132690      1977        1
103640      1978        1
137110      1979        1
89930       1980        1
139158      1981        1
107741      1982        1
113931      1983        1
138492      1984        1
110399      1985        1
210616      1986        1
234148      1987        1
248840      1988        1
298079      1989        1
261286      1990        1
319710      1991        1
```

299687	1992	1
198924	1993	1
362422	1994	1
249644	1995	1
306383	1996	1
325257	1997	1
320815	1998	1
311844	1999	1
228214	2000	1
227531	2001	1
180698	2002	1
205177	2003	1
338654	2004	1
363157	2005	1
361761	2006	1
290545	2007	1
322145	2008	1
177459	2009	1
216912	2010	1

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

Year seas index obs se(log)
Acoustic survey

1995	1	2	1517948	0.0666
1998	1	2	1342740	0.0492
2001	1	2	918622	0.0823
2003	1	2	2520641	0.0709
2005	1	2	1754722	0.0847
2007	1	2	1122809	0.0752
2009	1	2	1612027	0.1375

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

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

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

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

7 #_N_Length_obs
Marginal acoustic lengths to show implied fit

1995	1	2	0	0	-106	0.000	0.000	0.000	0.000	0.000	0.005	0.060
	0.186	0.108	0.023	0.021	0.086	0.166	0.173	0.109	0.041	0.013	0.004	0.002
	0.001	0.001	0.000	0.000	0.000	0.000	0.000					
1998	1	2	0	0	-127	0.000	0.000	0.002	0.006	0.027	0.047	0.061
	0.049	0.047	0.075	0.087	0.140	0.170	0.139	0.082	0.037	0.017	0.007	0.004
	0.001	0.001	0.001	0.000	0.000	0.000	0.000					
2001	1	2	0	0	-77	0.000	0.000	0.000	0.001	0.006	0.063	0.233
	0.309	0.121	0.033	0.035	0.037	0.039	0.040	0.037	0.019	0.011	0.005	0.003
	0.002	0.002	0.001	0.001	0.001	0.001	0.001					

2003	1	2	0	0	-81	0.000	0.000	0.000	0.000	0.000	0.003	0.009
	0.015	0.026	0.046	0.148	0.344	0.244	0.102	0.038	0.015	0.005	0.002	0.001
	0.001	0.000	0.000	0.000	0.000	0.000	0.001					
2005	1	2	0	0	-53	0.000	0.000	0.000	0.000	0.002	0.011	0.059
	0.100	0.057	0.022	0.037	0.139	0.273	0.182	0.078	0.024	0.009	0.003	0.002
	0.001	0.001	0.000	0.000	0.000	0.000	0.001					
2007	1	2	0	0	-70	0.000	0.000	0.004	0.013	0.065	0.145	0.127
	0.061	0.029	0.011	0.016	0.046	0.103	0.164	0.133	0.049	0.019	0.006	0.002
	0.001	0.001	0.001	0.001	0.000	0.000	0.000					
2009	1	2	0	0	-80	0.000	0.000	0.000	0.000	0.000	0.001	0.003
	0.020	0.084	0.200	0.210	0.160	0.089	0.065	0.059	0.037	0.014	0.006	0.003
	0.001	0.001	0.000	0.000	0.000	0.000	0.000					

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

38 # N_ageerror_definitions

0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.1810831	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.19080435		0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813
	0.996322	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388			
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.2027476	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.2174216	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				

0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.1810831	0.346917	0.368632	0.395312	0.2354495	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.19080435		0.368632	0.395312	0.42809	0.2575991	0.517841	0.57863	0.653316	0.745076	0.857813
	0.996322	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388			
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.2027476	0.395312	0.42809	0.468362	0.28481255		0.57863	0.653316	0.745076	0.857813
	0.996322	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388			
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.2174216	0.42809	0.468362	0.517841	0.3182465	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.2354495	0.468362	0.517841	0.57863	0.3593238	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.2575991	0.517841	0.57863	0.653316	0.4097918	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.28481255		0.57863	0.653316	0.745076	
	0.47179715		0.996322	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388	
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.3182465	0.653316	0.745076	0.857813	0.5479771
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.3593238	0.745076	0.857813	0.996322
	0.641575	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.4097918	0.857813	0.996322
	1.1665	0.7565635	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.47179715	
	0.996322	1.1665	1.37557	0.897842	1.858	2.172	2.53	2.934	3.388			
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.5479771
	1.1665	1.37557	1.63244	1.0219	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	0.641575	1.37557	1.63244	1.858	1.1946	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	0.7565635	1.63244	1.858	2.172	1.3915	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	0.897842	1.858	2.172	2.53	1.6137	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.1810831	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.0219	2.172	2.53	2.934	1.8634				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				

0.329242	0.329242	0.19080435		0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813
	0.996322	1.1665	1.37557	1.63244	1.858	1.1946	2.53	2.934	3.388			
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.2027476	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	1.3915	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.2174216	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	1.6137	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.2354495	0.468362	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	1.8634				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.2575991	0.517841	0.57863	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.28481255		0.57863	0.653316	0.745076	0.857813
	0.996322	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388			
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.3182465	0.653316	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.3593238	0.745076	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.1810831	0.346917	0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.4097918	0.857813	0.996322
	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388				
0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5				
0.329242	0.329242	0.19080435		0.368632	0.395312	0.42809	0.468362	0.517841	0.57863	0.653316	0.745076	
	0.47179715		0.996322	1.1665	1.37557	1.63244	1.858	2.172	2.53	2.934	3.388	

43 # Number of age comp observations
1 # Length bin refers to: 1=population length bin indices; 2=data length bin indices
0 #_combine males into females at or below this bin number

Acoustic survey ages (N=7)

1995	1	2	0	0	23	-1	-1	68	0	0.304	0.048	0.014
	0.209	0.012	0.042	0.144	0.003	0.001	0.165	0.001	0.007	0.000	0.051	
1998	1	2	0	0	26	-1	-1	103	0	0.125	0.144	0.168
	0.191	0.016	0.076	0.093	0.014	0.028	0.061	0.005	0.003	0.061	0.015	
2001	1	2	0	0	29	-1	-1	57	0	0.641	0.104	0.054
	0.060	0.030	0.037	0.022	0.011	0.010	0.008	0.008	0.010	0.002	0.004	
2003	1	2	0	0	31	-1	-1	71	0	0.024	0.023	0.635
	0.092	0.031	0.070	0.042	0.028	0.026	0.011	0.007	0.005	0.004	0.004	
2005	1	2	0	0	33	-1	-1	47	0	0.229	0.021	0.069
	0.048	0.492	0.053	0.020	0.027	0.016	0.013	0.007	0.002	0.001	0.002	
2007	1	2	0	0	35	-1	-1	70	0	0.366	0.022	0.108
	0.013	0.044	0.030	0.334	0.034	0.017	0.014	0.007	0.007	0.003	0.001	
2009	1	2	0	0	37	-1	-1	66	0	0.006	0.299	0.421
	0.023	0.082	0.012	0.016	0.015	0.073	0.032	0.013	0.003	0.004	0.002	

Aggregate catch-weighted marginal fishery ages (N=36)

1975	1	1	0	0	3	-1	-1	13	0.046	0.338	0.074	0.012
	0.254	0.055	0.08	0.105	0.01	0.006	0.009	0.005	0	0.005	0	
1976	1	1	0	0	4	-1	-1	142	0.001	0.013	0.145	0.067
	0.041	0.246	0.098	0.089	0.121	0.054	0.043	0.041	0.011	0.024	0.007	
1977	1	1	0	0	5	-1	-1	320	0	0.084	0.037	0.275
	0.036	0.091	0.227	0.076	0.065	0.04	0.036	0.023	0.006	0.003	0.001	
1978	1	1	0	0	6	-1	-1	341	0.004	0.011	0.066	0.063
	0.265	0.061	0.088	0.215	0.098	0.047	0.045	0.024	0.005	0.004	0.003	

1979	1	1	0	0	7	-1	-1	116	0	0.062	0.106	0.093
	0.059	0.182	0.104	0.179	0.122	0.04	0.023	0.01	0.015	0	0.005	
1980	1	1	0	0	8	-1	-1	221	0.002	0.004	0.35	0.019
	0.048	0.1	0.116	0.051	0.089	0.096	0.065	0.023	0.02	0.008	0.008	
1981	1	1	0	0	9	-1	-1	154	0.218	0.03	0.014	0.282
	0.046	0.063	0.025	0.147	0.035	0.032	0.071	0.024	0.006	0.002	0.006	
1982	1	1	0	0	10	-1	-1	170	0	0.326	0.035	0.004
	0.269	0.015	0.035	0.039	0.119	0.032	0.036	0.076	0.003	0.003	0.007	
1983	1	1	0	0	11	-1	-1	117	0	0	0.341	0.04
	0.018	0.235	0.051	0.056	0.053	0.094	0.039	0.031	0.023	0.011	0.007	
1984	1	1	0	0	12	-1	-1	123	0	0	0.015	0.613
	0.036	0.039	0.169	0.031	0.015	0.012	0.035	0.009	0.005	0.015	0.006	
1985	1	1	0	0	13	-1	-1	56	0.011	0.002	0.004	0.077
	0.705	0.074	0.043	0.056	0.015	0.006	0.005	0.002	0	0	0	
1986	1	1	0	0	14	-1	-1	120	0	0.199	0.07	0.004
	0.011	0.377	0.058	0.07	0.088	0.022	0.028	0.017	0.04	0.007	0.009	
1987	1	1	0	0	15	-1	-1	56	0	0	0.306	0.03
	0.001	0.01	0.516	0.003	0.013	0.073	0	0.008	0.021	0.019	0	
1988	1	1	0	0	16	-1	-1	81	0	0.009	0	0.379
	0.01	0.015	0.001	0.395	0.009	0.005	0.113	0.009	0	0	0.054	
1989	1	1	0	0	17	-1	-1	77	0	0.073	0.032	0.003
	0.502	0.016	0.003	0.001	0.322	0.023	0.001	0.023	0.001	0	0	
1990	1	1	0	0	18	-1	-1	163	0	0.073	0.24	0.013
	0.008	0.254	0.003	0.003	0	0.317	0.001	0.001	0.076	0	0.012	
1991	1	1	0	0	19	-1	-1	160	0	0.044	0.253	0.224
	0.025	0.009	0.222	0.013	0.002	0.002	0.149	0.005	0	0.043	0.009	
1992	1	1	0	0	20	-1	-1	243	0.006	0.045	0.056	0.145
	0.185	0.02	0.01	0.305	0.008	0.001	0.005	0.178	0.005	0	0.032	
1993	1	1	0	0	21	-1	-1	175	0	0.011	0.285	0.036
	0.138	0.154	0.014	0.009	0.24	0.009	0.002	0.001	0.093	0	0.009	
1994	1	1	0	0	22	-1	-1	234	0	0.001	0.039	0.257
	0.012	0.129	0.204	0.009	0.003	0.256	0.001	0.003	0	0.079	0.008	
1995	1	1	0	0	23	-1	-1	147	0.002	0.021	0.004	0.06
	0.318	0.014	0.071	0.197	0.019	0.004	0.191	0.02	0.005	0.001	0.073	
1996	1	1	0	0	24	-1	-1	186	0	0.186	0.163	0.01
	0.085	0.196	0.006	0.046	0.107	0.002	0.003	0.157	0	0.001	0.037	
1997	1	1	0	0	25	-1	-1	222	0	0.007	0.342	0.275
	0.005	0.054	0.126	0.009	0.032	0.06	0.004	0.002	0.06	0.002	0.023	
1998	1	1	0	0	26	-1	-1	243	0	0.038	0.217	0.206
	0.282	0.035	0.043	0.092	0.009	0.007	0.037	0.003	0.001	0.024	0.006	
1999	1	1	0	0	27	-1	-1	514	0	0.111	0.223	0.192
	0.188	0.126	0.031	0.032	0.035	0.007	0.012	0.022	0.001	0.002	0.017	
2000	1	1	0	0	28	-1	-1	529	0.013	0.052	0.113	0.154
	0.131	0.201	0.14	0.062	0.04	0.027	0.019	0.02	0.009	0.005	0.015	
2001	1	1	0	0	29	-1	-1	541	0	0.245	0.188	0.132
	0.172	0.091	0.066	0.046	0.012	0.013	0.011	0.006	0.006	0.004	0.009	
2002	1	1	0	0	30	-1	-1	450	0	0	0.588	0.152
	0.073	0.05	0.035	0.039	0.028	0.008	0.007	0.007	0.002	0.003	0.007	
2003	1	1	0	0	31	-1	-1	457	0	0.001	0.013	0.782
	0.102	0.019	0.029	0.018	0.016	0.009	0.006	0.002	0.002	0.001	0.001	
2004	1	1	0	0	32	-1	-1	501	0	0	0.073	0.097
	0.688	0.058	0.015	0.028	0.021	0.006	0.007	0.001	0.003	0	0.002	
2005	1	1	0	0	33	-1	-1	613	0	0.011	0.006	0.085
	0.061	0.693	0.07	0.022	0.021	0.014	0.007	0.008	0.002	0	0.001	
2006	1	1	0	0	34	-1	-1	720	0.003	0.017	0.143	0.021
	0.098	0.052	0.582	0.041	0.011	0.014	0.007	0.004	0.003	0.001	0.001	
2007	1	1	0	0	35	-1	-1	629	0.014	0.156	0.039	0.164
	0.016	0.073	0.045	0.406	0.043	0.017	0.013	0.008	0.002	0.001	0.002	
2008	1	1	0	0	36	-1	-1	783	0.006	0.092	0.383	0.026
	0.137	0.01	0.036	0.033	0.241	0.018	0.006	0.006	0.001	0.002	0.001	
2009	1	1	0	0	37	-1	-1	677	0.014	0.007	0.323	0.334
	0.028	0.09	0.009	0.021	0.013	0.135	0.016	0.003	0.005	0.002	0.001	
2010	1	1	0	0	38	-1	-1	800	0	0.289	0.014	0.404
	0.211	0.015	0.019	0.002	0.003	0.006	0.03	0.004	0	0.001	0	

0 # No Mean size-at-age data
0 # Total number of environmental variables

0 # Total number of environmental observations
0 # No Weight frequency data
0 # No tagging data
0 # No morph composition data

999 # End data file
2011 hake Empirical age model weight-at-age file

##

120 # Number of lines of weight-at-age input to be read

20 # Maximum age
if yr=-yr, then fill remaining years for that seas, growpattern, sex, fleet
fleet 0 contains begin season pop WT
fleet -1 contains mid season pop WT
fleet -2 contains maturity*fecundity

Maturity x fecundity vector from fixed externally estimated growth and maturity at length

#Yr	seas	sex	GP	bseas	fleet	a0	a1	a2	a3	a4	a5	a6
	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16	a17	a18
	a19	a20	Note									
-1940	1	1	1	1	-2	0.0000	0.0000	0.1003	0.2535	0.3992	0.5180	0.6131
	0.6895	0.7511	0.8007	0.8406	0.8724	0.8979	0.9181	0.9342	0.9469	0.9569	0.9649	0.9711
	0.9761	0.9830										

#Yr	seas	sex	GP	bseas	fleet	a0	a1	a2	a3	a4	a5	a6
	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16	a17	a18
	a19	a20	Note									
# Mid-season (N=37)												
-1940	1	1	1	1	-1	0.0300	0.0912	0.2575	0.3940	0.4928	0.5445	0.5906
	0.6620	0.7210	0.7907	0.8625	0.9312	0.9680	1.0779	1.0022	1.0213	1.0213	1.0213	1.0213
	1.0213	1.0213										
1975	1	1	1	1	-1	0.0550	0.1575	0.2987	0.3658	0.6143	0.6306	0.7873
	0.8738	0.9678	0.9075	0.9700	1.6933	1.5000	1.9000	1.9555	2.7445	2.7445	2.7445	2.7445
	2.7445	2.7445										
1976	1	1	1	1	-1	0.0550	0.0986	0.2359	0.4973	0.5188	0.6936	0.8041
	0.9166	1.2097	1.3375	1.4498	1.6532	1.8066	1.8588	1.9555	2.7445	2.7445	2.7445	2.7445
	2.7445	2.7445										
1977	1	1	1	1	-1	0.0550	0.1006	0.4021	0.4870	0.5902	0.6650	0.7493
	0.8267	0.9781	1.1052	1.2349	1.3148	1.4058	1.7511	2.0367	2.2094	2.2094	2.2094	2.2094
	2.2094	2.2094										
1978	1	1	1	1	-1	0.0539	0.1026	0.1360	0.4699	0.5300	0.6027	0.6392
	0.7395	0.8391	0.9775	1.0971	1.2349	1.3028	1.4814	1.7419	2.3379	2.3379	2.3379	2.3379
	2.3379	2.3379										
1979	1	1	1	1	-1	0.0528	0.0913	0.2410	0.2587	0.5821	0.6868	0.7677
	0.8909	0.9128	1.0369	1.1987	1.2482	1.5326	1.5520	1.7950	1.9817	1.9817	1.9817	1.9817
	1.9817	1.9817										
1980	1	1	1	1	-1	0.0517	0.0800	0.2236	0.4529	0.3922	0.4904	0.5166
	0.6554	0.7125	0.8740	1.0616	1.1623	1.2898	1.3001	1.2699	1.3961	1.3961	1.3961	1.3961
	1.3961	1.3961										
1981	1	1	1	1	-1	0.0506	0.1079	0.2137	0.3422	0.5264	0.3933	0.5254
	0.5462	0.7464	0.7204	0.8231	1.0413	1.0989	1.3449	1.4926	1.2128	1.2128	1.2128	1.2128
	1.2128	1.2128										
1982	1	1	1	1	-1	0.0494	0.1183	0.2465	0.3336	0.3097	0.5496	0.3956
	0.5275	0.5629	0.7606	0.6837	0.8539	1.0670	0.8793	1.0186	1.1693	1.1693	1.1693	1.1693
	1.1693	1.1693										
1983	1	1	1	1	-1	0.0483	0.1287	0.1357	0.3410	0.3694	0.3277	0.5200
	0.5028	0.6179	0.7060	0.8800	0.9299	1.0356	1.0310	1.3217	1.4823	1.4823	1.4823	1.4823
	1.4823	1.4823										
1984	1	1	1	1	-1	0.0472	0.1315	0.1642	0.2493	0.4385	0.4113	0.4352
	0.5872	0.5802	0.6758	0.7010	0.9513	1.1364	1.0258	1.2807	1.8800	1.8800	1.8800	1.8800
	1.8800	1.8800										
1985	1	1	1	1	-1	0.0461	0.1740	0.2297	0.2679	0.4414	0.5497	0.5474
	0.6014	0.7452	0.6933	0.7231	0.8584	0.8698	0.9458	0.6759	1.1217	1.1217	1.1217	1.1217
	1.1217	1.1217										

1986	1	1	1	1	-1	0.0450	0.1555	0.2771	0.2909	0.3024	0.3735	0.5425
	0.5717	0.6421	0.8209	0.9403	1.1860	1.1900	1.3864	1.6800	1.6142	1.6142	1.6142	1.6142
	1.6142	1.6142										
1987	1	1	1	1	-1	0.0439	0.1478	0.1388	0.3790	0.2786	0.2870	0.3621
	0.5775	0.5975	0.6369	0.7638	0.9820	0.9250	1.2407	1.2031	1.4157	1.4157	1.4157	1.4157
	1.4157	1.4157										
1988	1	1	1	1	-1	0.0428	0.1400	0.1870	0.3189	0.4711	0.3689	0.3731
	0.5163	0.6474	0.6851	0.7183	0.9167	1.0924	1.0225	1.4500	1.4537	1.4537	1.4537	1.4537
	1.4537	1.4537										
1989	1	1	1	1	-1	0.0417	0.1389	0.2737	0.3047	0.2931	0.5134	0.4386
	0.4064	0.5167	0.6263	0.6611	0.6027	0.8758	0.6686	0.8282	1.1264	1.1264	1.1264	1.1264
	1.1264	1.1264										
1990	1	1	1	1	-1	0.0406	0.1378	0.2435	0.3506	0.3906	0.5111	0.5462
	0.6076	0.6678	0.5300	0.7691	0.8313	2.2000	1.1847	1.3258	1.4668	1.4668	1.4668	1.4668
	1.4668	1.4668										
1991	1	1	1	1	-1	0.0394	0.1367	0.2754	0.3697	0.4598	0.5138	0.5437
	0.5907	0.7210	0.8497	1.0997	0.7185	0.6403	0.9227	1.2051	2.3828	2.3828	2.3828	2.3828
	2.3828	2.3828										
1992	1	1	1	1	-1	0.0383	0.1356	0.2316	0.3473	0.4743	0.5334	0.5817
	0.6210	0.6406	0.6530	0.6330	0.7217	0.7354	0.8501	0.9750	1.0272	1.0272	1.0272	1.0272
	1.0272	1.0272										
1993	1	1	1	1	-1	0.0372	0.1274	0.2486	0.3384	0.3960	0.4539	0.4935
	0.5017	0.4880	0.5491	0.5100	1.2630	1.0250	0.6135	0.5995	0.6850	0.6850	0.6850	0.6850
	0.6850	0.6850										
1994	1	1	1	1	-1	0.0361	0.1191	0.3000	0.3626	0.4469	0.4473	0.5262
	0.5700	0.6218	0.5598	0.6341	0.4850	0.6491	0.7300	0.7013	0.7455	0.7455	0.7455	0.7455
	0.7455	0.7455										
1995	1	1	1	1	-1	0.0350	0.1108	0.2682	0.3418	0.4876	0.5367	0.6506
	0.6249	0.6597	0.7560	0.6670	0.7442	0.7998	0.9101	0.6804	0.8008	0.8008	0.8008	0.8008
	0.8008	0.8008										
1996	1	1	1	1	-1	0.0339	0.1007	0.2876	0.3982	0.4674	0.5317	0.5651
	0.6509	0.5957	0.6362	0.6049	0.7500	0.6756	1.0804	1.4853	0.7509	0.7509	0.7509	0.7509
	0.7509	0.7509										
1997	1	1	1	1	-1	0.0328	0.0906	0.3555	0.4322	0.4931	0.5476	0.5453
	0.5833	0.5855	0.6071	0.6315	0.8633	0.5946	0.7118	0.6618	0.8693	0.8693	0.8693	0.8693
	0.8693	0.8693										
1998	1	1	1	1	-1	0.0317	0.0805	0.2091	0.3539	0.5041	0.5172	0.5420
	0.6412	0.6099	0.6769	0.8078	0.7174	0.8100	0.7733	0.7510	0.7714	0.7714	0.7714	0.7714
	0.7714	0.7714										
1999	1	1	1	1	-1	0.0306	0.1352	0.2502	0.3455	0.4251	0.5265	0.5569
	0.5727	0.6117	0.7030	0.6650	0.7989	0.7554	0.8787	0.7348	0.8187	0.8187	0.8187	0.8187
	0.8187	0.8187										
2000	1	1	1	1	-1	0.0294	0.1899	0.3216	0.4729	0.5766	0.6598	0.7176
	0.7279	0.7539	0.8378	0.8159	0.8814	0.8554	0.9391	0.8744	0.9336	0.9336	0.9336	0.9336
	0.9336	0.9336										
2001	1	1	1	1	-1	0.0283	0.0512	0.2867	0.4843	0.6527	0.6645	0.7469
	0.8629	0.8555	0.8802	0.9630	0.9790	1.0054	1.0494	0.9927	0.9768	0.9768	0.9768	0.9768
	0.9768	0.9768										
2002	1	1	1	1	-1	0.0272	0.0756	0.3583	0.4575	0.6058	0.8160	0.7581
	0.8488	0.9771	0.9322	0.9176	0.9974	0.9890	0.9236	1.1250	1.0573	1.0573	1.0573	1.0573
	1.0573	1.0573										
2003	1	1	1	1	-1	0.0261	0.1000	0.2551	0.4355	0.5225	0.5879	0.7569
	0.6915	0.7469	0.8246	0.7692	0.8887	0.9266	0.7894	0.8414	0.9965	0.9965	0.9965	0.9965
	0.9965	0.9965										
2004	1	1	1	1	-1	0.0250	0.1081	0.2577	0.4360	0.4807	0.5319	0.6478
	0.7068	0.6579	0.7094	0.8050	0.8581	0.7715	0.9704	0.8631	0.8959	0.8959	0.8959	0.8959
	0.8959	0.8959										
2005	1	1	1	1	-1	0.0239	0.1162	0.2603	0.4311	0.5086	0.5393	0.5682
	0.6336	0.6550	0.7027	0.7962	0.8104	0.8109	0.7602	1.1449	0.9678	0.9678	0.9678	0.9678
	0.9678	0.9678										
2006	1	1	1	1	-1	0.0228	0.1324	0.3831	0.4575	0.5341	0.5740	0.5910
	0.5979	0.6560	0.6997	0.7259	0.7220	0.7753	0.6580	0.6399	0.9550	0.9550	0.9550	0.9550
	0.9550	0.9550										
2007	1	1	1	1	-1	0.0217	0.0461	0.2272	0.3776	0.5352	0.5530	0.6073
	0.6328	0.6475	0.7055	0.7723	0.7627	0.8137	0.8702	0.8008	0.8698	0.8698	0.8698	0.8698
	0.8698	0.8698										

2008 1 1 1 1 -1 0.0217 0.1403 0.2445 0.4081 0.5630 0.6371 0.6865
0.6818 0.7084 0.7210 0.7488 0.8073 0.8483 0.7755 0.8834 0.8332 0.8332 0.8332 0.8332
0.8332 0.8332
2009 1 1 1 1 -1 0.0217 0.0667 0.2448 0.3431 0.4712 0.6371 0.6702
0.6942 0.7463 0.8226 0.7672 0.8115 1.0147 0.8503 0.9582 1.0334 1.0334 1.0334 1.0334
1.0334 1.0334
2010 1 1 1 1 -1 0.0217 0.0667 0.2231 0.3365 0.4205 0.5297 0.6615
0.8603 0.9986 1.0276 0.9480 0.8981 0.9024 1.1253 0.7350 0.9045 0.9045 0.9045 0.9045
0.9045 0.9045
Begin season (N=37)
-1940 1 1 1 1 0 0.0300 0.0912 0.2575 0.3940 0.4928 0.5445 0.5906
0.6620 0.7210 0.7907 0.8625 0.9312 0.9680 1.0779 1.0022 1.0213 1.0213 1.0213 1.0213
1.0213 1.0213
1975 1 1 1 1 0 0.0550 0.1575 0.2987 0.3658 0.6143 0.6306 0.7873
0.8738 0.9678 0.9075 0.9700 1.6933 1.5000 1.9000 1.9555 2.7445 2.7445 2.7445 2.7445
2.7445 2.7445
1976 1 1 1 1 0 0.0550 0.0986 0.2359 0.4973 0.5188 0.6936 0.8041
0.9166 1.2097 1.3375 1.4498 1.6532 1.8066 1.8588 1.9555 2.7445 2.7445 2.7445 2.7445
2.7445 2.7445
1977 1 1 1 1 0 0.0550 0.1006 0.4021 0.4870 0.5902 0.6650 0.7493
0.8267 0.9781 1.1052 1.2349 1.3148 1.4058 1.7511 2.0367 2.2094 2.2094 2.2094 2.2094
2.2094 2.2094
1978 1 1 1 1 0 0.0539 0.1026 0.1360 0.4699 0.5300 0.6027 0.6392
0.7395 0.8391 0.9775 1.0971 1.2349 1.3028 1.4814 1.7419 2.3379 2.3379 2.3379 2.3379
2.3379 2.3379
1979 1 1 1 1 0 0.0528 0.0913 0.2410 0.2587 0.5821 0.6868 0.7677
0.8909 0.9128 1.0369 1.1987 1.2482 1.5326 1.5520 1.7950 1.9817 1.9817 1.9817 1.9817
1.9817 1.9817
1980 1 1 1 1 0 0.0517 0.0800 0.2236 0.4529 0.3922 0.4904 0.5166
0.6554 0.7125 0.8740 1.0616 1.1623 1.2898 1.3001 1.2699 1.3961 1.3961 1.3961 1.3961
1.3961 1.3961
1981 1 1 1 1 0 0.0506 0.1079 0.2137 0.3422 0.5264 0.3933 0.5254
0.5462 0.7464 0.7204 0.8231 1.0413 1.0989 1.3449 1.4926 1.2128 1.2128 1.2128 1.2128
1.2128 1.2128
1982 1 1 1 1 0 0.0494 0.1183 0.2465 0.3336 0.3097 0.5496 0.3956
0.5275 0.5629 0.7606 0.6837 0.8539 1.0670 0.8793 1.0186 1.1693 1.1693 1.1693 1.1693
1.1693 1.1693
1983 1 1 1 1 0 0.0483 0.1287 0.1357 0.3410 0.3694 0.3277 0.5200
0.5028 0.6179 0.7060 0.8800 0.9299 1.0356 1.0310 1.3217 1.4823 1.4823 1.4823 1.4823
1.4823 1.4823
1984 1 1 1 1 0 0.0472 0.1315 0.1642 0.2493 0.4385 0.4113 0.4352
0.5872 0.5802 0.6758 0.7010 0.9513 1.1364 1.0258 1.2807 1.8800 1.8800 1.8800 1.8800
1.8800 1.8800
1985 1 1 1 1 0 0.0461 0.1740 0.2297 0.2679 0.4414 0.5497 0.5474
0.6014 0.7452 0.6933 0.7231 0.8584 0.8698 0.9458 0.6759 1.1217 1.1217 1.1217 1.1217
1.1217 1.1217
1986 1 1 1 1 0 0.0450 0.1555 0.2771 0.2909 0.3024 0.3735 0.5425
0.5717 0.6421 0.8209 0.9403 1.1860 1.1900 1.3864 1.6800 1.6142 1.6142 1.6142 1.6142
1.6142 1.6142
1987 1 1 1 1 0 0.0439 0.1478 0.1388 0.3790 0.2786 0.2870 0.3621
0.5775 0.5975 0.6369 0.7638 0.9820 0.9250 1.2407 1.2031 1.4157 1.4157 1.4157 1.4157
1.4157 1.4157
1988 1 1 1 1 0 0.0428 0.1400 0.1870 0.3189 0.4711 0.3689 0.3731
0.5163 0.6474 0.6851 0.7183 0.9167 1.0924 1.0225 1.4500 1.4537 1.4537 1.4537 1.4537
1.4537 1.4537
1989 1 1 1 1 0 0.0417 0.1389 0.2737 0.3047 0.2931 0.5134 0.4386
0.4064 0.5167 0.6263 0.6611 0.6027 0.8758 0.6686 0.8282 1.1264 1.1264 1.1264 1.1264
1.1264 1.1264
1990 1 1 1 1 0 0.0406 0.1378 0.2435 0.3506 0.3906 0.5111 0.5462
0.6076 0.6678 0.5300 0.7691 0.8313 2.2000 1.1847 1.3258 1.4668 1.4668 1.4668 1.4668
1.4668 1.4668
1991 1 1 1 1 0 0.0394 0.1367 0.2754 0.3697 0.4598 0.5138 0.5437
0.5907 0.7210 0.8497 1.0997 0.7185 0.6403 0.9227 1.2051 2.3828 2.3828 2.3828 2.3828
2.3828 2.3828
1992 1 1 1 1 0 0.0383 0.1356 0.2316 0.3473 0.4743 0.5334 0.5817
0.6210 0.6406 0.6530 0.6330 0.7217 0.7354 0.8501 0.9750 1.0272 1.0272 1.0272 1.0272
1.0272 1.0272

1993	1	1	1	1	0	0.0372	0.1274	0.2486	0.3384	0.3960	0.4539	0.4935
	0.5017	0.4880	0.5491	0.5100	1.2630	1.0250	0.6135	0.5995	0.6850	0.6850	0.6850	0.6850
	0.6850	0.6850										
1994	1	1	1	1	0	0.0361	0.1191	0.3000	0.3626	0.4469	0.4473	0.5262
	0.5700	0.6218	0.5598	0.6341	0.4850	0.6491	0.7300	0.7013	0.7455	0.7455	0.7455	0.7455
	0.7455	0.7455										
1995	1	1	1	1	0	0.0350	0.1108	0.2682	0.3418	0.4876	0.5367	0.6506
	0.6249	0.6597	0.7560	0.6670	0.7442	0.7998	0.9101	0.6804	0.8008	0.8008	0.8008	0.8008
	0.8008	0.8008										
1996	1	1	1	1	0	0.0339	0.1007	0.2876	0.3982	0.4674	0.5317	0.5651
	0.6509	0.5957	0.6362	0.6049	0.7500	0.6756	1.0804	1.4853	0.7509	0.7509	0.7509	0.7509
	0.7509	0.7509										
1997	1	1	1	1	0	0.0328	0.0906	0.3555	0.4322	0.4931	0.5476	0.5453
	0.5833	0.5855	0.6071	0.6315	0.8633	0.5946	0.7118	0.6618	0.8693	0.8693	0.8693	0.8693
	0.8693	0.8693										
1998	1	1	1	1	0	0.0317	0.0805	0.2091	0.3539	0.5041	0.5172	0.5420
	0.6412	0.6099	0.6769	0.8078	0.7174	0.8100	0.7733	0.7510	0.7714	0.7714	0.7714	0.7714
	0.7714	0.7714										
1999	1	1	1	1	0	0.0306	0.1352	0.2502	0.3455	0.4251	0.5265	0.5569
	0.5727	0.6117	0.7030	0.6650	0.7989	0.7554	0.8787	0.7348	0.8187	0.8187	0.8187	0.8187
	0.8187	0.8187										
2000	1	1	1	1	0	0.0294	0.1899	0.3216	0.4729	0.5766	0.6598	0.7176
	0.7279	0.7539	0.8378	0.8159	0.8814	0.8554	0.9391	0.8744	0.9336	0.9336	0.9336	0.9336
	0.9336	0.9336										
2001	1	1	1	1	0	0.0283	0.0512	0.2867	0.4843	0.6527	0.6645	0.7469
	0.8629	0.8555	0.8802	0.9630	0.9790	1.0054	1.0494	0.9927	0.9768	0.9768	0.9768	0.9768
	0.9768	0.9768										
2002	1	1	1	1	0	0.0272	0.0756	0.3583	0.4575	0.6058	0.8160	0.7581
	0.8488	0.9771	0.9322	0.9176	0.9974	0.9890	0.9236	1.1250	1.0573	1.0573	1.0573	1.0573
	1.0573	1.0573										
2003	1	1	1	1	0	0.0261	0.1000	0.2551	0.4355	0.5225	0.5879	0.7569
	0.6915	0.7469	0.8246	0.7692	0.8887	0.9266	0.7894	0.8414	0.9965	0.9965	0.9965	0.9965
	0.9965	0.9965										
2004	1	1	1	1	0	0.0250	0.1081	0.2577	0.4360	0.4807	0.5319	0.6478
	0.7068	0.6579	0.7094	0.8050	0.8581	0.7715	0.9704	0.8631	0.8959	0.8959	0.8959	0.8959
	0.8959	0.8959										
2005	1	1	1	1	0	0.0239	0.1162	0.2603	0.4311	0.5086	0.5393	0.5682
	0.6336	0.6550	0.7027	0.7962	0.8104	0.8109	0.7602	1.1449	0.9678	0.9678	0.9678	0.9678
	0.9678	0.9678										
2006	1	1	1	1	0	0.0228	0.1324	0.3831	0.4575	0.5341	0.5740	0.5910
	0.5979	0.6560	0.6997	0.7259	0.7220	0.7753	0.6580	0.6399	0.9550	0.9550	0.9550	0.9550
	0.9550	0.9550										
2007	1	1	1	1	0	0.0217	0.0461	0.2272	0.3776	0.5352	0.5530	0.6073
	0.6328	0.6475	0.7055	0.7723	0.7627	0.8137	0.8702	0.8008	0.8698	0.8698	0.8698	0.8698
	0.8698	0.8698										
2008	1	1	1	1	0	0.0217	0.1403	0.2445	0.4081	0.5630	0.6371	0.6865
	0.6818	0.7084	0.7210	0.7488	0.8073	0.8483	0.7755	0.8834	0.8332	0.8332	0.8332	0.8332
	0.8332	0.8332										
2009	1	1	1	1	0	0.0217	0.0667	0.2448	0.3431	0.4712	0.6371	0.6702
	0.6942	0.7463	0.8226	0.7672	0.8115	1.0147	0.8503	0.9582	1.0334	1.0334	1.0334	1.0334
	1.0334	1.0334										
2010	1	1	1	1	0	0.0217	0.0667	0.2231	0.3365	0.4205	0.5297	0.6615
	0.8603	0.9986	1.0276	0.9480	0.8981	0.9024	1.1253	0.7350	0.9045	0.9045	0.9045	0.9045
	0.9045	0.9045										
# Fishery (N=37)												
-1940	1	1	1	1	1	0.0300	0.0912	0.2575	0.3940	0.4928	0.5445	0.5906
	0.6620	0.7210	0.7907	0.8625	0.9312	0.9680	1.0779	1.0022	1.0213	1.0213	1.0213	1.0213
	1.0213	1.0213										
1975	1	1	1	1	1	0.0550	0.1575	0.2987	0.3658	0.6143	0.6306	0.7873
	0.8738	0.9678	0.9075	0.9700	1.6933	1.5000	1.9000	1.9555	2.7445	2.7445	2.7445	2.7445
	2.7445	2.7445										
1976	1	1	1	1	1	0.0550	0.0986	0.2359	0.4973	0.5188	0.6936	0.8041
	0.9166	1.2097	1.3375	1.4498	1.6532	1.8066	1.8588	1.9555	2.7445	2.7445	2.7445	2.7445
	2.7445	2.7445										
1977	1	1	1	1	1	0.0550	0.1006	0.4021	0.4870	0.5902	0.6650	0.7493
	0.8267	0.9781	1.1052	1.2349	1.3148	1.4058	1.7511	2.0367	2.2094	2.2094	2.2094	2.2094
	2.2094	2.2094										

1978	1	1	1	1	1	0.0539	0.1026	0.1360	0.4699	0.5300	0.6027	0.6392
	0.7395	0.8391	0.9775	1.0971	1.2349	1.3028	1.4814	1.7419	2.3379	2.3379	2.3379	2.3379
	2.3379	2.3379										
1979	1	1	1	1	1	0.0528	0.0913	0.2410	0.2587	0.5821	0.6868	0.7677
	0.8909	0.9128	1.0369	1.1987	1.2482	1.5326	1.5520	1.7950	1.9817	1.9817	1.9817	1.9817
	1.9817	1.9817										
1980	1	1	1	1	1	0.0517	0.0800	0.2236	0.4529	0.3922	0.4904	0.5166
	0.6554	0.7125	0.8740	1.0616	1.1623	1.2898	1.3001	1.2699	1.3961	1.3961	1.3961	1.3961
	1.3961	1.3961										
1981	1	1	1	1	1	0.0506	0.1079	0.2137	0.3422	0.5264	0.3933	0.5254
	0.5462	0.7464	0.7204	0.8231	1.0413	1.0989	1.3449	1.4926	1.2128	1.2128	1.2128	1.2128
	1.2128	1.2128										
1982	1	1	1	1	1	0.0494	0.1183	0.2465	0.3336	0.3097	0.5496	0.3956
	0.5275	0.5629	0.7606	0.6837	0.8539	1.0670	0.8793	1.0186	1.1693	1.1693	1.1693	1.1693
	1.1693	1.1693										
1983	1	1	1	1	1	0.0483	0.1287	0.1357	0.3410	0.3694	0.3277	0.5200
	0.5028	0.6179	0.7060	0.8800	0.9299	1.0356	1.0310	1.3217	1.4823	1.4823	1.4823	1.4823
	1.4823	1.4823										
1984	1	1	1	1	1	0.0472	0.1315	0.1642	0.2493	0.4385	0.4113	0.4352
	0.5872	0.5802	0.6758	0.7010	0.9513	1.1364	1.0258	1.2807	1.8800	1.8800	1.8800	1.8800
	1.8800	1.8800										
1985	1	1	1	1	1	0.0461	0.1740	0.2297	0.2679	0.4414	0.5497	0.5474
	0.6014	0.7452	0.6933	0.7231	0.8584	0.8698	0.9458	0.6759	1.1217	1.1217	1.1217	1.1217
	1.1217	1.1217										
1986	1	1	1	1	1	0.0450	0.1555	0.2771	0.2909	0.3024	0.3735	0.5425
	0.5717	0.6421	0.8209	0.9403	1.1860	1.1900	1.3864	1.6800	1.6142	1.6142	1.6142	1.6142
	1.6142	1.6142										
1987	1	1	1	1	1	0.0439	0.1478	0.1388	0.3790	0.2786	0.2870	0.3621
	0.5775	0.5975	0.6369	0.7638	0.9820	0.9250	1.2407	1.2031	1.4157	1.4157	1.4157	1.4157
	1.4157	1.4157										
1988	1	1	1	1	1	0.0428	0.1400	0.1870	0.3189	0.4711	0.3689	0.3731
	0.5163	0.6474	0.6851	0.7183	0.9167	1.0924	1.0225	1.4500	1.4537	1.4537	1.4537	1.4537
	1.4537	1.4537										
1989	1	1	1	1	1	0.0417	0.1389	0.2737	0.3047	0.2931	0.5134	0.4386
	0.4064	0.5167	0.6263	0.6611	0.6027	0.8758	0.6686	0.8282	1.1264	1.1264	1.1264	1.1264
	1.1264	1.1264										
1990	1	1	1	1	1	0.0406	0.1378	0.2435	0.3506	0.3906	0.5111	0.5462
	0.6076	0.6678	0.5300	0.7691	0.8313	2.2000	1.1847	1.3258	1.4668	1.4668	1.4668	1.4668
	1.4668	1.4668										
1991	1	1	1	1	1	0.0394	0.1367	0.2754	0.3697	0.4598	0.5138	0.5437
	0.5907	0.7210	0.8497	1.0997	0.7185	0.6403	0.9227	1.2051	2.3828	2.3828	2.3828	2.3828
	2.3828	2.3828										
1992	1	1	1	1	1	0.0383	0.1356	0.2316	0.3473	0.4743	0.5334	0.5817
	0.6210	0.6406	0.6530	0.6330	0.7217	0.7354	0.8501	0.9750	1.0272	1.0272	1.0272	1.0272
	1.0272	1.0272										
1993	1	1	1	1	1	0.0372	0.1274	0.2486	0.3384	0.3960	0.4539	0.4935
	0.5017	0.4880	0.5491	0.5100	1.2630	1.0250	0.6135	0.5995	0.6850	0.6850	0.6850	0.6850
	0.6850	0.6850										
1994	1	1	1	1	1	0.0361	0.1191	0.3000	0.3626	0.4469	0.4473	0.5262
	0.5700	0.6218	0.5598	0.6341	0.4850	0.6491	0.7300	0.7013	0.7455	0.7455	0.7455	0.7455
	0.7455	0.7455										
1995	1	1	1	1	1	0.0350	0.1108	0.2682	0.3418	0.4876	0.5367	0.6506
	0.6249	0.6597	0.7560	0.6670	0.7442	0.7998	0.9101	0.6804	0.8008	0.8008	0.8008	0.8008
	0.8008	0.8008										
1996	1	1	1	1	1	0.0339	0.1007	0.2876	0.3982	0.4674	0.5317	0.5651
	0.6509	0.5957	0.6362	0.6049	0.7500	0.6756	1.0804	1.4853	0.7509	0.7509	0.7509	0.7509
	0.7509	0.7509										
1997	1	1	1	1	1	0.0328	0.0906	0.3555	0.4322	0.4931	0.5476	0.5453
	0.5833	0.5855	0.6071	0.6315	0.8633	0.5946	0.7118	0.6618	0.8693	0.8693	0.8693	0.8693
	0.8693	0.8693										
1998	1	1	1	1	1	0.0317	0.0805	0.2091	0.3539	0.5041	0.5172	0.5420
	0.6412	0.6099	0.6769	0.8078	0.7174	0.8100	0.7733	0.7510	0.7714	0.7714	0.7714	0.7714
	0.7714	0.7714										
1999	1	1	1	1	1	0.0306	0.1352	0.2502	0.3455	0.4251	0.5265	0.5569
	0.5727	0.6117	0.7030	0.6650	0.7989	0.7554	0.8787	0.7348	0.8187	0.8187	0.8187	0.8187
	0.8187	0.8187										

2000	1	1	1	1	1	0.0294	0.1899	0.3216	0.4729	0.5766	0.6598	0.7176
	0.7279	0.7539	0.8378	0.8159	0.8814	0.8554	0.9391	0.8744	0.9336	0.9336	0.9336	0.9336
	0.9336	0.9336										
2001	1	1	1	1	1	0.0283	0.0512	0.2867	0.4843	0.6527	0.6645	0.7469
	0.8629	0.8555	0.8802	0.9630	0.9790	1.0054	1.0494	0.9927	0.9768	0.9768	0.9768	0.9768
	0.9768	0.9768										
2002	1	1	1	1	1	0.0272	0.0756	0.3583	0.4575	0.6058	0.8160	0.7581
	0.8488	0.9771	0.9322	0.9176	0.9974	0.9890	0.9236	1.1250	1.0573	1.0573	1.0573	1.0573
	1.0573	1.0573										
2003	1	1	1	1	1	0.0261	0.1000	0.2551	0.4355	0.5225	0.5879	0.7569
	0.6915	0.7469	0.8246	0.7692	0.8887	0.9266	0.7894	0.8414	0.9965	0.9965	0.9965	0.9965
	0.9965	0.9965										
2004	1	1	1	1	1	0.0250	0.1081	0.2577	0.4360	0.4807	0.5319	0.6478
	0.7068	0.6579	0.7094	0.8050	0.8581	0.7715	0.9704	0.8631	0.8959	0.8959	0.8959	0.8959
	0.8959	0.8959										
2005	1	1	1	1	1	0.0239	0.1162	0.2603	0.4311	0.5086	0.5393	0.5682
	0.6336	0.6550	0.7027	0.7962	0.8104	0.8109	0.7602	1.1449	0.9678	0.9678	0.9678	0.9678
	0.9678	0.9678										
2006	1	1	1	1	1	0.0228	0.1324	0.3831	0.4575	0.5341	0.5740	0.5910
	0.5979	0.6560	0.6997	0.7259	0.7220	0.7753	0.6580	0.6399	0.9550	0.9550	0.9550	0.9550
	0.9550	0.9550										
2007	1	1	1	1	1	0.0217	0.0461	0.2272	0.3776	0.5352	0.5530	0.6073
	0.6328	0.6475	0.7055	0.7723	0.7627	0.8137	0.8702	0.8008	0.8698	0.8698	0.8698	0.8698
	0.8698	0.8698										
2008	1	1	1	1	1	0.0217	0.1403	0.2445	0.4081	0.5630	0.6371	0.6865
	0.6818	0.7084	0.7210	0.7488	0.8073	0.8483	0.7755	0.8834	0.8332	0.8332	0.8332	0.8332
	0.8332	0.8332										
2009	1	1	1	1	1	0.0217	0.0667	0.2448	0.3431	0.4712	0.6371	0.6702
	0.6942	0.7463	0.8226	0.7672	0.8115	1.0147	0.8503	0.9582	1.0334	1.0334	1.0334	1.0334
	1.0334	1.0334										
2010	1	1	1	1	1	0.0217	0.0667	0.2231	0.3365	0.4205	0.5297	0.6615
	0.8603	0.9986	1.0276	0.9480	0.8981	0.9024	1.1253	0.7350	0.9045	0.9045	0.9045	0.9045
	0.9045	0.9045										

Survey (N=8)

-1940	1	1	1	1	2	0.030	0.091	0.257	0.394	0.493	0.544	0.591
	0.662	0.721	0.791	0.863	0.931	0.968	1.078	1.002	1.021	1.021	1.021	1.021
	1.021	1.021										
-1995	1	1	1	1	2	0.035	0.111	0.268	0.342	0.488	0.537	0.651
	0.625	0.660	0.756	0.667	0.744	0.800	0.910	0.680	0.801	0.801	0.801	0.801
	0.801	0.801										
-1998	1	1	1	1	2	0.032	0.081	0.209	0.354	0.504	0.517	0.542
	0.641	0.610	0.677	0.808	0.717	0.810	0.773	0.751	0.771	0.771	0.771	0.771
	0.771	0.771										
-2001	1	1	1	1	2	0.028	0.051	0.287	0.484	0.653	0.665	0.747
	0.863	0.855	0.880	0.963	0.979	1.005	1.049	0.993	0.977	0.977	0.977	0.977
	0.977	0.977										
-2003	1	1	1	1	2	0.026	0.100	0.255	0.436	0.522	0.588	0.757
	0.691	0.747	0.825	0.769	0.889	0.927	0.789	0.841	0.996	0.996	0.996	0.996
	0.996	0.996										
-2005	1	1	1	1	2	0.024	0.116	0.260	0.431	0.509	0.539	0.568
	0.634	0.655	0.703	0.796	0.810	0.811	0.760	1.145	0.968	0.968	0.968	0.968
	0.968	0.968										
-2007	1	1	1	1	2	0.022	0.046	0.227	0.378	0.535	0.553	0.607
	0.633	0.647	0.705	0.772	0.763	0.814	0.870	0.801	0.870	0.870	0.870	0.870
	0.870	0.870										
-2009	1	1	1	1	2	0.022	0.067	0.245	0.343	0.471	0.637	0.670
	0.694	0.746	0.823	0.767	0.812	1.015	0.850	0.958	1.033	1.033	1.033	1.033
	1.033	1.033										

End of file

2011 hake Empirical Age model control file

##

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

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

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

0 0 0 0 0 0 0 0 0 0 # Unused MGparm_seas_effects

Spawner-recruit parameters
3 # S-R function: 1=B-H w/flat top, 2=Ricker, 3=standard B-H, 4=no steepness or bias adjustment

# Lo	Hi	Init	Prior	Prior	Prior	Param	
# bnd	bnd	value	mean	type	SD	phase	
13	18	15.9	15	-1	99	1	# Ln(R0)

```
0.2     1     0.88    0.777   2        0.113   4      # Steepness with Myers' prior
1.0     1.6   1.3     1.1     -1       99      -6     # Sigma-R
-5      5     0       0       -1       99      -50    # Env link coefficient
-5      5     0       0       -1       99      -50    # Initial equilibrium recruitment offset
 0      2     0       1       -1       99      -50  # Autocorrelation in rec devs
0 # index of environmental variable to be used
0 # SR environmental target: 0=none;1=devs;_2=R0;_3=steepness
1 # Recruitment deviation type: 0=none; 1=devvector; 2=simple deviations

# Recruitment deviations
1970    # Start year standard recruitment devs
2007    # End year standard recruitment devs
1       # Rec Dev phase

1 # Read 11 advanced recruitment options: 0=no, 1=yes
1946    # Start year for early rec devs
3       # Phase for early rec devs
5       # Phase for forecast recruit deviations
1       # Lambda for forecast recr devs before endyr+1
1965    # Last recruit dev with no bias_adjustment
1971    # First year of full bias correction (linear ramp from year above)
2008    # Last year for full bias correction in_MPD
2009    # First_recent_yr_nobias_adj_in_MPD
0.85    # Maximum bias adjustment in MPD
0       # Period of cycles in recruitment (N parms read below)
-6      # Lower bound rec devs
6       # Upper bound rec devs
0       # Read init values for rec devs

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

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

# Catchability setup
# A=do power: 0=skip, survey is prop. to abundance, 1= add par for non-linearity
# B=env. link: 0=skip, 1= add par for env. effect on Q
# C=extra SD: 0=skip, 1= add par. for additive constant to input SE (in ln space)
# D=type: <0=mirror lower abs(#) fleet, 0=no par Q is median unbiased, 1=no par Q is mean unbiased, 2=estimate par for ln(Q)
#         3=ln(Q) + set of devs about ln(Q) for all years. 4=ln(Q) + set of devs about Q for indexyr-1
# A B C D
# Create one par for each entry > 0 by row in cols A-D
0       0     0       0        # US_Foreign
0       0     1       0        # Acoustic_Survey

#LO     HI    INIT    PRIOR   PR_type  SD      PHASE
0       1     0.0755  0.0755  -1       0.1      4 # additive value for acoustic survey

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

Selectivity parameters

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

0 # Tagging flag: 0=no tagging parameters,1=read tagging parameters

Likelihood related quantities
1 # Do variance/sample size adjustments by fleet (1)
Component
0 0 # Constant added to index CV
0 0 # Constant added to discard SD
0 0 # Constant added to body weight SD
1 1 # multiplicative scalar for length comps
0.10 0.89 # multiplicative scalar for agecomps
1 1 # multiplicative scalar for length at age obs

1 # Lambda phasing: 1=none, 2+=change beginning in phase 1
1 # Growth offset likelihood constant for Log(s): 1=include, 2=not
0 # N changes to default Lambdas = 1.0

Component codes:
1=Survey, 2=discard, 3=mean body weight
4=length frequency, 5=age frequency, 6=Weight frequency
7=size at age, 8=catch, 9=initial equilibrium catch
10=rec devs, 11=parameter priors, 12=parameter devs
13=Crash penalty
Component fleet/survey phase value wtfreq_method

1   # Extra SD reporting switch
2 2 -1 15 # selex type (fleet), len=1/age=2, year, N selex bins (4 values)
1 1   # Growth pattern, N growth ages (2 values)
1 -1 1   # NatAge_area(-1 for all), NatAge_yr, N Natages (3 values)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 # placeholder for vector of selex bins to be reported
-1 # growth ages
-1 # NatAges

999 # End control file

12. Appendix E. TINSS model input files

```
#Data file for 2010 Assessment of Pacific Hake - TINSS
#Model Dimensions
1966	2010	15

#Observed catch megatons (1e6Kg) 1966-2009
#Entire series updated January 7 2011 - aggregate data supplied by Ian Stewart  #
137700	214370	122180	180130	234590	154620	117540	162640	211260	221350	237520	132690	103637
	137110	89930	139158	107741	113931	138492	110399	210616	234148	248840	298079	261365
	320985	302309	199337	363134	250462	307529	326275	322583	314150	229707	229113	182345
	206717	340793	365072	363174	291865	326155	182181	217850

#n_yt - number of acoustic survey yearws
7
#Acoustic survey data year, yt, relwt,suvey_index
#THESE ARE NEW ESTIMATES GENERATED BY CHU (KRIGING) -- Jan 2011
#Relative weights are based on Chu's CVs, where all are scaled to the lowest CV (1998)
 1995	1.518	1.356	1
 1998	1.343	1.000	1
 2001	0.919	1.675	1
 2003	2.521	1.443	1
 2005	1.755	1.726	1
 2007	1.123	1.530	1
 2009	1.612	2.808	1

## Number of ages, and a list of those ages
# numages
14
# ages
2 3 4 5 6 7 8 9 10 11 12 13 14 15
#Extracted from the SS base input file marginals
0.324964	0.043475	0.012039	0.212541	0.009810	0.032765	0.148871	0.002177	0.000000	0.158452	0.000354	0.006429	0.000000
	0.048122
0.168351	0.187074	0.157169	0.195749	0.014026	0.055093	0.087607	0.010731	0.015903	0.048868	0.003121	0.001999	0.042448
	0.011861
0.709921	0.089531	0.052761	0.056572	0.026180	0.026069	0.014190	0.008255	0.005804	0.002446	0.002162	0.004212	0.000400
	0.001496
0.029781	0.025334	0.640666	0.109500	0.027623	0.060058	0.039723	0.021949	0.022287	0.007181	0.004232	0.004367	0.003083
	0.004214
0.239916	0.024324	0.072095	0.051813	0.482518	0.052666	0.017966	0.024352	0.013884	0.011229	0.004744	0.002436	0.000323
	0.001734
0.428146	0.024375	0.101876	0.011527	0.041221	0.026044	0.289941	0.030229	0.013473	0.013191	0.007185	0.006086	0.002778
	0.003928
0.001881	0.229516	0.423131	0.024861	0.091878	0.007856	0.018074	0.024434	0.128613	0.029027	0.009417	0.005566	0.005402
	0.000343

#Age proportions (from number at age calcs_revised)
1975
2010
#Obtained from Ian Stewart, NMFS, January 10 2011
0.3546695 0.0776495 0.0125918 0.2665268 0.0577125 0.0839454 0.1101784 0.0104932 0.0062959 0.0094439 0.0052466 0.0000000 0.0052466
	0.0000000
0.0130000 0.1450000 0.0670000 0.0410000 0.2460000 0.0980000 0.0890000 0.1210000 0.0540000 0.0430000 0.0410000 0.0110000 0.0240000
	0.0070000
0.0840000 0.0370000 0.2750000 0.0360000 0.0910000 0.2270000 0.0760000 0.0650000 0.0400000 0.0360000 0.0230000 0.0060000 0.0030000
	0.0010000
0.0110553 0.0663317 0.0633166 0.2663317 0.0613065 0.0884422 0.2160804 0.0984925 0.0472362 0.0452261 0.0241206 0.0050251 0.0040201
	0.0030151
0.0620000 0.1060000 0.0930000 0.0590000 0.1820000 0.1040000 0.1790000 0.1220000 0.0400000 0.0230000 0.0100000 0.0150000 0.0000000
	0.0050000
0.0040120 0.3510532 0.0190572 0.0481444 0.1003009 0.1163490 0.0511535 0.0892678 0.0962889 0.0651956 0.0230692 0.0200602 0.0080241
	0.0080241
0.0383142 0.0178799 0.3601533 0.0587484 0.0804598 0.0319285 0.1877395 0.0446999 0.0408685 0.0906769 0.0306513 0.0076628 0.0025543
	0.0076628
```

0.3263263 0.0350350 0.0040040 0.2692693 0.0150150 0.0350350 0.0390390 0.1191191 0.0320320 0.0360360 0.0760761 0.0030030 0.0030030 0.0070070
0.0000000 0.3413413 0.0400400 0.0180180 0.2352352 0.0510511 0.0560561 0.0530531 0.0940941 0.0390390 0.0310310 0.0230230 0.0110110 0.0070070
0.0000000 0.0150000 0.6130000 0.0360000 0.0390000 0.1690000 0.0310000 0.0150000 0.0120000 0.0350000 0.0090000 0.0050000 0.0150000 0.0060000
0.0020222 0.0040445 0.0778564 0.7128413 0.0748231 0.0434783 0.0566229 0.0151668 0.0060667 0.0050556 0.0020222 0.0000000 0.0000000 0.0000000
0.1990000 0.0700000 0.0040000 0.0110000 0.3770000 0.0580000 0.0700000 0.0880000 0.0220000 0.0280000 0.0170000 0.0400000 0.0070000 0.0090000
0.0000000 0.3060000 0.0300000 0.0010000 0.0100000 0.5160000 0.0030000 0.0130000 0.0730000 0.0000000 0.0080000 0.0210000 0.0190000 0.0000000
0.0090090 0.0000000 0.3793794 0.0100100 0.0150150 0.0010010 0.3953954 0.0090090 0.0050050 0.1131131 0.0090090 0.0000000 0.0000000 0.0540541
0.0730000 0.0320000 0.0030000 0.5020000 0.0160000 0.0030000 0.0010000 0.3220000 0.0230000 0.0010000 0.0230000 0.0010000 0.0000000 0.0000000
0.0729271 0.2397602 0.0129870 0.0079920 0.2537463 0.0029970 0.0029970 0.0000000 0.3166833 0.0009990 0.0009990 0.0759241 0.0000000 0.0119880
0.0440000 0.2530000 0.2240000 0.0250000 0.0090000 0.2220000 0.0130000 0.0020000 0.0020000 0.1490000 0.0050000 0.0000000 0.0430000 0.0090000
0.0452261 0.0562814 0.1457286 0.1859296 0.0201005 0.0100503 0.3065327 0.0080402 0.0010050 0.0050251 0.1788945 0.0050251 0.0000000 0.0321608
0.0109890 0.2847153 0.0359640 0.1378621 0.1538462 0.0139860 0.0089910 0.2397602 0.0089910 0.0019980 0.0009990 0.0929071 0.0000000 0.0089910
0.0009990 0.0389610 0.2567433 0.0119880 0.1288711 0.2037962 0.0089910 0.0029970 0.2557443 0.0009990 0.0029970 0.0000000 0.0789211 0.0079920
0.0210421 0.0040080 0.0601202 0.3186373 0.0140281 0.0711423 0.1973948 0.0190381 0.0040080 0.1913828 0.0200401 0.0050100 0.0010020 0.0731463
0.1861862 0.1631632 0.0100100 0.0850851 0.1961962 0.0060060 0.0460460 0.1071071 0.0020020 0.0030030 0.1571572 0.0000000 0.0010010 0.0370370
0.0069930 0.3416583 0.2747253 0.0049950 0.0539461 0.1258741 0.0089910 0.0319680 0.0599401 0.0039960 0.0019980 0.0599401 0.0019980 0.0229770
0.0380000 0.2170000 0.2060000 0.2820000 0.0350000 0.0430000 0.0920000 0.0090000 0.0070000 0.0370000 0.0030000 0.0010000 0.0240000 0.0060000
0.1111111 0.2232232 0.1921922 0.1881882 0.1261261 0.0310310 0.0320320 0.0350350 0.0070070 0.0120120 0.0220220 0.0010010 0.0020020 0.0170170
0.0526316 0.1143725 0.1558704 0.1325911 0.2034413 0.1417004 0.0627530 0.0404858 0.0273279 0.0192308 0.0202429 0.0091093 0.0050607 0.0151822
0.2447552 0.1878122 0.1318681 0.1718282 0.0909091 0.0659341 0.0459540 0.0119880 0.0129870 0.0109890 0.0059940 0.0059940 0.0039960 0.0089910
0.0000000 0.5885886 0.1521522 0.0730731 0.0500501 0.0350350 0.0390390 0.0280280 0.0080080 0.0070070 0.0070070 0.0020020 0.0030030 0.0070070
0.0009990 0.0129870 0.7812188 0.1018981 0.0189810 0.0289710 0.0179820 0.0159840 0.0089910 0.0059940 0.0019980 0.0019980 0.0009990 0.0009990
0.0000000 0.0730731 0.0970971 0.6886887 0.0580581 0.0150150 0.0280280 0.0210210 0.0060060 0.0070070 0.0010010 0.0030030 0.0000000 0.0020020
0.0109890 0.0059940 0.0849151 0.0609391 0.6923077 0.0699301 0.0219780 0.0209790 0.0139860 0.0069930 0.0079920 0.0019980 0.0000000 0.0009990
0.0170854 0.1437186 0.0211055 0.0984925 0.0522613 0.5849246 0.0412060 0.0110553 0.0140704 0.0070352 0.0040201 0.0030151 0.0010050 0.0010050
0.1583756 0.0395939 0.1664975 0.0162437 0.0741117 0.0456853 0.4121827 0.0436548 0.0172589 0.0131980 0.0081218 0.0020305 0.0010152 0.0020305
0.0927419 0.3860887 0.0262097 0.1381048 0.0100806 0.0362903 0.0332661 0.2429435 0.0181452 0.0060484 0.0060484 0.0010081 0.0020161 0.0010081
0.0070922 0.3272543 0.3383992 0.0283688 0.0911854 0.0091185 0.0212766 0.0131712 0.1367781 0.0162107 0.0030395 0.0050659 0.0020263 0.0010132
0.2895792 0.0140281 0.4048096 0.2114228 0.0150301 0.0190381 0.0020040 0.0030060 0.0060120 0.0300601 0.0040080 0.0000000 0.0010020 0.0000000

###Entire series revised January 2011
#Catch Weight at age (1966-2010) #2 3 4 5 6 7 8 9 10 11 12 13 14 15
#NB 1966-1974 average of new series. NEW SERIES FROM 1975-2010
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441 0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895 1.002178301 1.021286413

0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.257481216 0.39400288 0.492793898 0.544458326 0.590642252 0.661987441
0.720983453 0.79070932 0.862534484 0.931223433 0.968035893 1.077946895
1.002178301 1.021286413
0.29870000 0.36583333 0.61428571 0.63059322 0.78733333 0.87384615
0.96782609 0.90750000 0.97000000 1.69333333 1.50000000 1.90000000
1.95548387 2.74454545
0.23588889 0.49731523 0.51880342 0.69356436 0.80412664 0.91658683
1.20970944 1.33748756 1.44977419 1.65323077 1.80664286 1.85882353
1.95548387 2.74454545
0.40213918 0.48697761 0.59020032 0.66503049 0.74929883 0.82669643
0.97808418 1.10521739 1.23491667 1.31484375 1.40583893 1.75114286
2.03666667 2.20941176
0.13600000 0.46988067 0.53004975 0.60265116 0.63924603 0.73948998
0.83905125 0.97746606 1.09707641 1.23493333 1.30279279 1.48142857
1.74185185 2.33785714
0.24099415 0.25866906 0.58212219 0.68675000 0.76767988 0.89092827
0.91282353 1.03686316 1.19870504 1.24818182 1.53263158 1.55200000
1.79500000 1.98166667
0.22363610 0.45294532 0.39223388 0.49043111 0.51659017 0.65542640
0.71254258 0.87403290 1.06156239 1.16230511 1.28982398 1.30013998
1.26990338 1.39611787
0.21369204 0.34218451 0.52643683 0.39328076 0.52537284 0.54624801
0.74643154 0.72040710 0.82312746 1.04129930 1.09886254 1.34494905
1.49264179 1.21278224
0.24653481 0.33362180 0.30971104 0.54961219 0.39556275 0.52747468
0.56285031 0.76057432 0.68371073 0.85390604 1.06698709 0.87927747
1.01864626 1.16933755
0.13566524 0.34096417 0.36941340 0.32767627 0.51997252 0.50275519
0.61789214 0.70601496 0.88001394 0.92990138 1.03557547 1.03102479
1.32166478 1.48232826
0.16424805 0.24928139 0.43851121 0.41132567 0.43515119 0.58722506
0.58020098 0.67577693 0.70095627 0.95125625 1.13644080 1.02578701
1.28072686 1.88000000
0.22966052 0.26787099 0.44142516 0.54966722 0.54740107 0.60141968
0.74523402 0.69334233 0.72311980 0.85840481 0.86975845 0.94581146
0.67585208 1.12169523
0.27707890 0.29092716 0.30241291 0.37345020 0.54245831 0.57173262
0.64206578 0.82090752 0.94031880 1.18604258 1.18996338 1.38637838
1.68002863 1.61417195
0.13877080 0.37904309 0.27861241 0.28701524 0.36205024 0.57750167
0.59746377 0.63692487 0.76375750 0.98200000 0.92500000 1.24065847
1.20305556 1.41571429
0.18702917 0.31886271 0.47112526 0.36894266 0.37305932 0.51633089
0.64737340 0.68510514 0.71830474 0.91669355 1.09239800 1.02250000
1.45000000 1.45368421

0.27366376 0.30472737 0.29306066 0.51337112 0.43863520 0.40636682
0.51666161 0.62633661 0.66114451 0.60267921 0.87576137 0.66862495
0.82817339 1.12644152
0.24351955 0.35059305 0.39063291 0.51111111 0.54621590 0.60764706
0.66777778 0.53000000 0.76908504 0.83125000 2.20000000 1.18473958
1.32576979 1.46680000
0.27538646 0.36969094 0.45981049 0.51378883 0.54372501 0.59067830
0.72099231 0.84972731 1.09974500 0.71847703 0.64032616 0.92271811
1.20511007 2.38284268
0.23163526 0.34726390 0.47433367 0.53340285 0.58166290 0.62102838
0.64059633 0.65301308 0.63295238 0.72168750 0.73543574 0.85010388
0.97500000 1.02718798
0.24863477 0.33838638 0.39601559 0.45391162 0.49348435 0.50167127
0.48802061 0.54908173 0.50996778 1.26297848 1.02500000 0.61348267
0.59947560 0.68500683
0.30000000 0.36256819 0.44694443 0.44731209 0.52615739 0.57003303
0.62183271 0.55976868 0.63408591 0.48500000 0.64907053 0.73000000
0.70129383 0.74551903
0.26821941 0.34178356 0.48761090 0.53672651 0.65060574 0.62494533
0.65973460 0.75598834 0.66704600 0.74419008 0.79982070 0.91005329
0.68038800 0.80081935
0.28760477 0.39815937 0.46742091 0.53166497 0.56512213 0.65089275
0.59572554 0.63617054 0.60485893 0.75000000 0.67557066 1.08043189
1.48529312 0.75087280
0.35546668 0.43216342 0.49307190 0.54763825 0.54526919 0.58332152
0.58545411 0.60707999 0.63153126 0.86333333 0.59459533 0.71183323
0.66184450 0.86930057
0.20908259 0.35390632 0.50414352 0.51720322 0.54201367 0.64121672
0.60988953 0.67689398 0.80784095 0.71742604 0.80997222 0.77333679
0.75102382 0.77137444
0.25017474 0.34549509 0.42508452 0.52652152 0.55687307 0.57268168
0.61174441 0.70304254 0.66503020 0.79886551 0.75544156 0.87871807
0.73484377 0.81867906
0.32163706 0.47293400 0.57656707 0.65978248 0.71760699 0.72792653
0.75387583 0.83776017 0.81593982 0.88135650 0.85538032 0.93913350
0.87444513 0.93364097
0.28667013 0.48433345 0.65267299 0.66450168 0.74692172 0.86287378
0.85545556 0.88015276 0.96298011 0.97903170 1.00540360 1.04944391
0.99269319 0.97676624
0.35833768 0.45750803 0.60578654 0.81598945 0.75814483 0.84878395
0.97707839 0.93223037 0.91759764 0.99743645 0.98895030 0.92363636
1.12500786 1.05731574
0.25506658 0.43552760 0.52245840 0.58790967 0.75685516 0.69148433
0.74693619 0.82461197 0.76915859 0.88871563 0.92659886 0.78943743
0.84142105 0.99645447
0.25767880 0.43602338 0.48066852 0.53192394 0.64778325 0.70683173
0.65792953 0.70943498 0.80501139 0.85807677 0.77148793 0.97044112
0.86305714 0.89590979
0.26029102 0.43114615 0.50856231 0.53934367 0.56823418 0.63362898
0.65497943 0.70273466 0.79622012 0.81040001 0.81086008 0.76020813
1.14485228 0.96784213
0.38310324 0.45748259 0.53407862 0.57398092 0.59098940 0.59786461
0.65600380 0.69965612 0.72589389 0.72199927 0.77530848 0.65800684
0.63991740 0.95502880
0.22721310 0.37755780 0.53521799 0.55297335 0.60730849 0.63275570
0.64746281 0.70549432 0.77226548 0.76269225 0.81368488 0.87023922
0.80084133 0.86975166
0.24446516 0.40805706 0.56301528 0.63705509 0.68653507 0.68177596
0.70842585 0.72103335 0.74883032 0.80726107 0.84833938 0.77547025
0.88341564 0.83322320
0.24484950 0.34309938 0.47116844 0.63707054 0.67019360 0.69422922
0.74626057 0.82258945 0.76719860 0.81152735 1.01474456 0.85034884
0.95815532 1.03337456
0.22310125 0.33650576 0.42050916 0.52965997 0.66149447 0.86025314
0.99855978 1.02761276 0.94798173 0.89814715 0.90243485 1.12533293
0.73500000 0.90446245

#Aging error std for constructing a classification matrix.
0.329242 0.329242 0.346917 0.368632 0.395312 0.42809 0.468362 0.517841 0.57863 0.653316 0.745076 0.857813 0.996322 1.1665 1.37557 1.63244

#eof
999

#Control file for Tinss.exe with modifications by Robyn Forrest
#logmsy - switch for estimating log of msy 1=log(msy) 0=msy CHANGE FIRST LINE OF THETA BELOW (FIRST LINE IF LOGS)
0
#verbose (0=false, 1=true)
0
#Retro years
0
#steepmap
0
#meanbet -- mean of SS3 beta distribution for steepness
0.777
#meansd -- sd of SS3 beta distribution for steepness
0.113

eqm Switch to determine whether model is initialised at equilibrium
0

Priors

Fmsy mean
#0.35
0.35
Fmsy sd
0.4

Msy mean
0.2
Msy sd
0.5

M mean
0.2
M sd
0.1

rhoAlpha
3
rhoBeta
12

____
POPULATION PARAMETERS (theta)
____
#np
9

# ival	lb	ub	phz	#parameter
0.2	0.01	3.0	1	#msy
0.35	0.01	3.0	1	#fmsy
0.2	0.05	0.9	1	#m
3.5	0.00	14.0	1	#ahat - age at 50% first harvest FISHERY
0.45	0.05	5.0	1	#ghat - standard eviation in selectivity FISHERY
2.5	2.00	14.0	1	#abar - logistic survey selectivity (base =2.0)
0.45	0.05	5.0	1	#gbar - logistic survey selectivity (base =0.45)
0.15	0.01	0.999	3	#rho
1.25	0.01	150.0	2	#varphi

____
#

```
#
#_____________________________________________________________________________#
#          LIFE-HISTORY_PARAMETERS                                                        #
#_____________________________________________________________________________#
#nphi
9
#ival             lb               ub               phz                        #parameter
#_____________________________________________________________________________#
25.15            20.00            40.0             -2        #l1
52.948   41.00        80.0         -2        #l2
0.334             0.01             0.9              -2        #rho_vbk
6.5359e-6  0.00        1.0          -1        #a
2.98684          0.00             4.0              -1        #b
2.7                                0.10             15.0           -1        #lam1
0.37                      0.00          2.5            -1        #lam2
2.721                     0.00          5.0            -1        #adot  maturity (Dorn 1997): age at 50% maturity
0.488                     0.00          1.0            -1        #gdot  maturity: sd maturity
#_____________________________________________________________________________#
999
```

13. Appendix F. TINSS model description and documentation