Stock Assessment of Pacific Hake (Whiting) in U.S. and Canadian Waters in 2003

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Summary of Stock Status

The coastal population of Pacific hake (*Merluccius productus*, also called Pacific hake) was assessed using an age-structured assessment model. The U.S. and Canadian fisheries were treated as distinct fisheries. The primary indicator of stock abundance is the acoustic survey, and a midwater trawl juvenile survey provides an indicator of recruitment. New data in this assessment included updated catch at age through 2003, recruitment indices from the juvenile survey in 2003, and results from the U.S./Canadian acoustic survey conducted in summer of 2003. Based on the new acoustic survey and updated data, the strength of the 1999 year class, and consequently mature female spawning biomass was greater than previously estimated in the 2002 assessment.

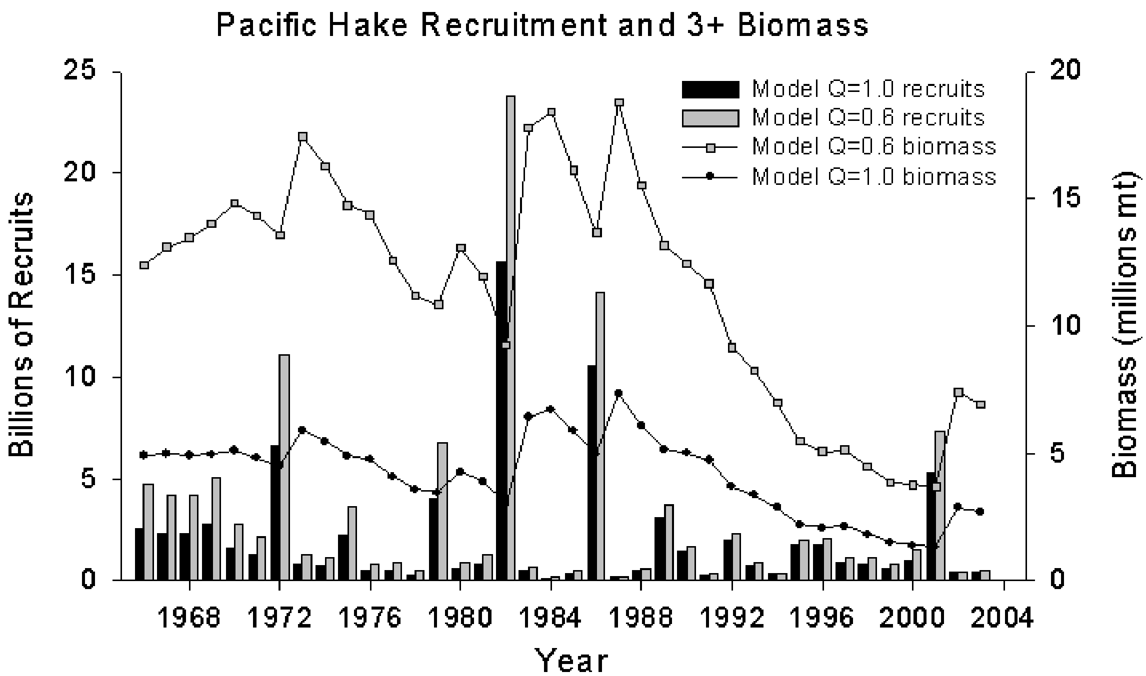
Status of Stock: The hake stock in 2003 was estimated to range from 2.6 to 4.0 million mt (age 3+ biomass) for the Q=1.0 and Q=0.6 model scenarios, respectively. Stock biomass increased to a historical high in 1987 due to exceptionally large 1980 and 1984 year classes, then declined as these year classes passed through the population and were replaced by more moderate year classes. Stock size stabilized briefly between 1995-1997, but then declined continuously to its lowest point in 2001. Since 2001, stock biomass has increased substantially as the strong 1999 year class has entered the population. The mature female biomass in 2003 was estimated to range from 47% to 49% (Q=1.0 and Q=0.6) of an unfished stock. Thus the stock can be considered to be rebuilt to the target level of abundance only 3 years after reaching a low level that resulted in the depleted (overfished) determination. The hindcast estimation of biomass in 2001 remains near, but slightly above, the depleted level (25% of the unfished level).

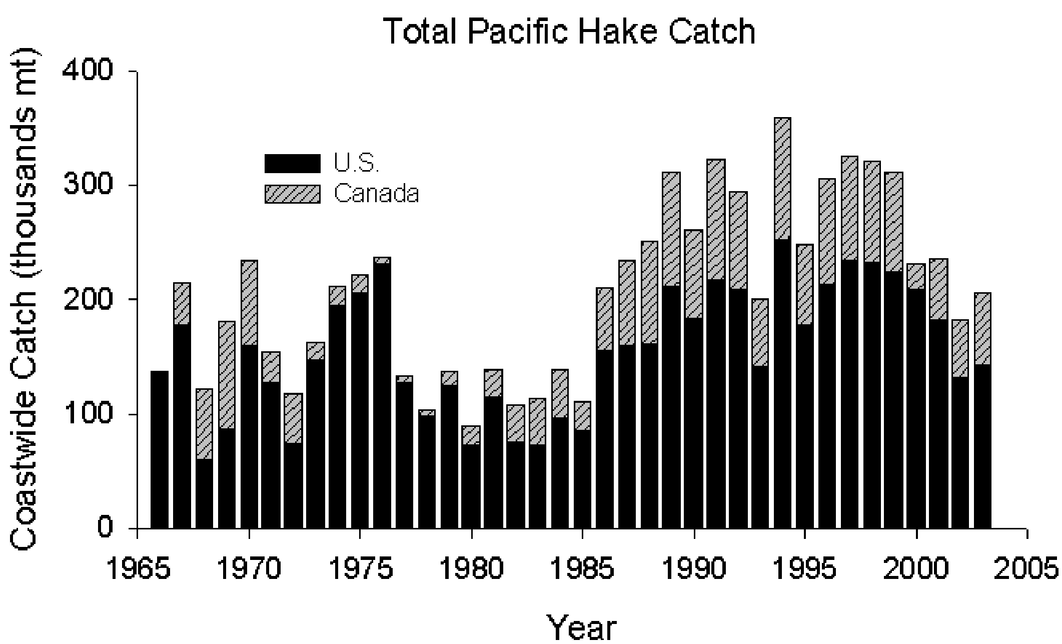
The coastwide ABC and OY for 2004 are estimated to be 501,000 mt and 740,000 mt (Q=1.0 and Q=0.6) based upon a F40% harvest rate and 416,000 mt and 630,000 mt mt (Q=1.0 and Q=0.6) based upon the F45% harvest rate. With biomass above 40% unfished biomass level, the 40:10 OY adjustment would not be applied. Projections beyond 2004 are for a decline in stock biomass and ABC-OY as the 1999 year class passes through its age of peak abundance. At this time there is no evidence of sufficiently large recruitments after 1999 to maintain the stock at a high abundance level. By 2006, the spawning stock biomass is projected to again decline to near the depleted threshold (25% unfished). Such a rapid increase and subsequent decrease in stock abundance and potential yield is to be expected for a stock with such extreme fluctuations in recruitment. A new examination of the harvest policy that takes into account this variability is recommended for this highly fluctuating stock.

Pacific hake (hake) catch and stock status table (catches in thousands of metric tons and biomass in millions of metric tons):

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
U.S. landings	141	253	178	213	233	233	225	208	182	132	144
Canadian landings	59	106	70	93	92	89	87	22	54	51	62
Total	200	359	248	306	325	321	312	230	236	183	206
ABC	178	325	223	265	290	290	290	290	238	208	235
Model 1b (Q=1.0)											
Age 3+ stock biomass	3.4	2.9	2.2	2.1	2.1	1.8	1.5	1.4	1.3	2.9	2.7
Female mature biomass	1.7	1.5	1.2	1.1	1.0	0.9	0.8	0.7	0.7	1.2	1.3
Exploitation rate	6%	12.5%	11.2%	14.7%	15.3%	17.5%	20.7%	16.6%	17.9%	6.4%	7.6%
Model 1c (Q=0.6)											
Age 3+ stock biomass	4.9	4.2	3.3	3.0	3.1	2.7	2.3	2.3	2.2	4.4	4.2
Female mature biomass	2.6	2.2	1.8	1.6	1.5	1.4	1.2	1.2	1.2	1.9	2.0
Exploitation rate	4.0%	8.6%	7.5%	10.1%	10.6%	11.9%	13.5%	10.2%	10.7%	4.1%	5.9%

Data and Assessment: An age-structured assessment model was developed by Dorn et al. (1998) using AD model builder , a modeling environment for developing and fitting multi-parameter non-linear models. The most recent assessment presented here for 2003 used revised 1977-1992 acoustic survey biomass estimates based on new deep-water and northern expansion factors and a slightly different model configuration than used in 2002 assessment. However, the results of the assessment were robust among numerous model configurations explored.





Major Uncertainties: The hake assessment is highly dependent on acoustic survey estimates of abundance. Since 1993, the assessment has relied primarily on an absolute biomass estimate from the joint US-Canadian acoustic survey. The acoustic target strength of Pacific hake, used to scale acoustic data to biomass, is based on a small number of *in situ* observations. While the fit to the acoustic survey time series has improved with revision of the survey biomass estimates (1977-1992) these are still uncertain with poor fits in some years. Large fluctuations in the most recent estimates of recruitment and biomass (2001) are not entirely unexpected given the high uncertainty in terminal year estimates. This is because the information content regarding the 1999 year class, in particular, was only present as age 2 fish in the 2001 fishery and acoustic survey age compositions, and coupled with the relatively low acoustic survey biomass in 2001 produced lower estimates. The addition of new information regarding fishery and survey age compositions, along with the 2003 survey biomass estimate, decreases the level of uncertainty about this year class.

Uncertainty in the assessment result is characterized in terms of variability in model parameters and in terms of the assumption regarding the acoustic survey catchability coefficient, Q. All past assessment results and recommendations have been based upon fixing the acoustic survey Q=1.0; thus asserting that the acoustic survey estimate of biomass is an absolute measure of biomass and not just a relative measure. The past several assessments have explored relaxation of this assumption, but final results have been based upon the Q=1.0 scenario. The ability to relax the Q=1.0 assumption in this year's assessment is based upon: 1) continued lengthening of the acoustic survey time series, thus allowing the survey to be treated as an index of relative abundance in the model; 2) relatively better model fits to the data when Q is less than 1.0; and 3) high quality of expertise in the STAR Panel to allow critical examination of the Q=1.0 assertion. Uncertainty in the final model result is therefore represented by a range of biomass. The lower biomass end of the range is based upon the conventional assumption that the acoustic survey catchability coefficient, Q=1.0, while the higher end of the range represents the Q=0.6 assumption. Even lower Q values are indicated by some model runs, but these are considered by the STAT team and STAR panel to be implausibly low. Future assessments may be able to explore alternative model configurations that could provide more insight on which aspect of the data lead to the low Q estimates.

The relative probability of the range of plausible Q levels was discussed extensively. The two endpoints are considered as less likely than intermediate points and an equal blending of results from the two endpoints is not unreasonable.

Target Fishing Mortality Rates: Target fishing mortality rates used in projections were based on F40% and F45% the fishing mortality rate corresponding to the corresponding F %B0 of unfished spawning stock biomass-per-recruit, with the 40-10 policy implemented when biomass falls below 40% unfished. Bayesian credibility intervals generated from 1,000,000 Markov Chain Monte Carlo samples were used to evaluate uncertainty in biomass, spawning biomass, depletion rates and coastwide yield. An estimate of stock productivity (e.g. ABC) that equally blends the two model endpoints is reasonable as a risk-neutral best estimate. An OY that is closer to the Q=1.0 result would be risk-averse, would not constrain the expected short-term fishery demands and would reduce the magnitude of the projected short-term stock decline.

Projection table of coastwide yield (thousands of tons), spawning biomass (millions of tons), and depletion rates under different harvest rate policies and model alternatives. Percentiles shown (10%, 50% and 90%) are based on 2,500,000 Markov chain Monte Carlo simulations:

Final Model 1b (Q=1.0)

Harvest Policy	Year	3+ Bioimass (million mt) 10%	50%	90%	SpawningBioimass (million mt) 10%	50%	90%	Depletion Rate 10%	50%	90%	Coastwide yield (t) 10%	50%	90%
	2004	2.007	2.307	2.673	1.011	1.160	1.337	0.385	0.434	0.495	428372	501073	580313
	2005	1.573	1.839	2.190	0.801	0.927	1.084	0.304	0.346	0.401	288914	355372	438254
F40% (40-10)	2006	1.061	1.251	1.523	0.573	0.675	0.831	0.215	0.253	0.310	181377	241722	331852
Harvest Policy	2007	0.954	1.284	2.395	0.509	0.655	1.052	0.192	0.245	0.396	137269	220477	436093
	2008	0.956	1.494	3.072	0.507	0.737	1.361	0.189	0.276	0.510	137269	220477	436093
	2004	1.999	2.298	2.691	1.011	1.157	1.339	0.381	0.432	0.494	351816	412814	482618
	2005	1.661	1.933	2.288	0.840	0.974	1.138	0.317	0.362	0.421	255813	316302	383068
F45% (40-10)	2006	1.158	1.355	1.655	0.624	0.732	0.894	0.233	0.272	0.331	176448	227319	304560
Harvest Policy	2007	1.042	1.387	2.437	0.559	0.716	1.085	0.209	0.266	0.412	137933	210085	379724
	2008	1.040	1.600	3.178	0.550	0.790	1.425	0.204	0.294	0.530	137933	210085	379724

Final Model 1c (Q=0.6)

Harvest Policy	Year	3+ Bioimass 10%	50%	90%	SpawningBioimass 10%	50%	90%	Depletion Rate 10%	50%	90%	Coastwide yield (t) 10%	50%	90%
	2004	2.753	3.530	4.513	1.417	1.806	2.302	0.369	0.452	0.549	560224	740368	955991
	2005	2.159	2.727	3.485	1.110	1.398	1.776	0.289	0.350	0.426	363334	503666	682808
F40% (40-10)	2006	1.486	1.832	2.325	0.809	1.011	1.293	0.210	0.250	0.313	225035	325649	482064
Harvest Policy	2007	1.361	1.903	3.534	0.735	0.976	1.561	0.188	0.244	0.391	175928	299935	630135
	2008	1.406	2.190	4.477	0.740	1.089	1.988	0.186	0.271	0.497	175928	299935	630135
	2004	2.773	3.581	4.588	1.431	1.834	2.336	0.373	0.454	0.552	471371	629709	812876
	2005	2.265	2.895	3.719	1.170	1.484	1.889	0.304	0.367	0.448	331550	457371	613371
F45% (40-10)	2006	1.612	2.001	2.582	0.879	1.095	1.418	0.227	0.270	0.335	221059	308924	453286
Harvest Policy	2007	1.482	2.020	3.361	0.800	1.057	1.551	0.205	0.261	0.383	174915	283252	519288
	2008	1.475	2.315	4.629	0.793	1.160	2.095	0.198	0.287	0.520	174915	283252	519288

INTRODUCTION

This assessment has been developed in the spirit of a recent agreement between the U.S. and Canada for the sharing of this trans-boundary resource. Under this agreement, not yet ratified by Congress, the stock assessment is to be reviewed by a Scientific Review Group (SRG), appointed by both parties. Prior to 1997, separate Canadian and U.S. assessments were submitted to each nation's assessment review process. In the past, this has resulted in differing yield options being forwarded to managers. Multiple interpretations of stock status made it difficult to coordinate overall management policy for this trans-boundary stock. To address this problem, the working group agreed in 1997 to present scientific advice in a single assessment, while that agreement was officially formalized in 2003. To further coordinate scientific advice, this report was submitted to a joint Canada-U.S. SRG for technical review in fulfillment of the agreement and to satisfy management responsibilities of both the U.S. Pacific Fisheries Management Council (PFMC) and the Canadian Pacific Stock Assessment Review Committee (PSARC). The Review Group meeting was held in Seattle, WA at the Northwest Fisheries Science Center, during Feb 2-4, 2003. While this report forms the basis for scientific advice to managers, final advice on appropriate yield is deferred to Canadian DFO managers by the PSARC Groundfish Sub-committee and the PSARC Steering Committee, and to the U.S. Pacific Fisheries Management Council by the Groundfish Management Team.

Stock Structure and Life History

Pacific hake (*Merluccius productus*), also called Pacific whiting, is a codlike species distributed off the west coast of North America from 25° N. to 51° N. lat. It is among 11 other species of hakes from the genus, *Merluccidae*, which are distributed in both hemispheres of the Atlantic and Pacific Oceans and constitute nearly two millions t of catches 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 hake occur in the major inlets of the north Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California. Electrophoretic studies indicate that Strait of Georgia and the Puget Sound populations are genetically distinct from the coastal population (Utter 1971). 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 distinguished from the inshore populations by larger body size, seasonal migratory behavior, and a pattern of low median recruitment punctuated by extremely large year classes.

The coastal stock typically ranges from southern California to Queen Charlotte Sound. Spawning occurs off south-central California during January-March. Due to the difficulty of locating major spawning concentrations, 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, hake form extensive midwater aggregations near the continental shelf break, with highest densities located over bottom depths of 200-300 m (Dorn et al. 1994). The prey of hake include euphausiids, pandalid shrimp, and pelagic schooling fish (such as eulachon and herring) (Livingston and Bailey, 1985). Larger hake become increasingly piscivorous, and herring are large component of hake diet off Vancouver Island.

Although 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 (age 5+), larger, and predominantly female hake migrate into the Canadian zone. During El Niños, a larger proportion of the stock migrates into Canadian waters, apparently due to intensified northward transport during the period of active migration (Dorn 1995). Range extensions to the north also occur during El Niños, as evidenced by reports of hake from S.E. Alaska during warm water years. During the warm period experienced in 1990s, there have been changes in typical patterns of distribution. Spawning activity has been recorded north of California, and frequent reports of unusual numbers of juveniles from Oregon to British Columbia suggest that juvenile settlement patterns have also shifted northwards in the late 1990s. Because of this, juveniles may be subjected to increased predation from cannibalism and to increased vulnerability to fishing mortality. Subsequently, La Niña conditions apparently caused a southward shift in the center of the stock's distribution and a smaller portion was found in Canadian water in the 2001 survey.

Fisheries

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

Large-scale harvesting of Pacific hake in the U.S. zone began in 1966 when factory trawlers from the former Soviet Union began targeting on Pacific hake. During the mid 1970's, the factory trawlers from Poland, Federal Republic of Germany, the former German Democratic Republic and Bulgaria also participated in the fishery. During 1966-1979, the catch in U.S. waters averaged 137,000 t per year (Table 1). A joint-venture fishery was initiated in 1978 between two U.S. trawlers and Soviet factory trawlers acting as motherships. By 1982, the joint-venture catch surpassed the foreign catch. 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. In 1989, the U.S. fleet capacity had grown to a level sufficient to harvest entire quota, and no foreign fishing was allowed.

Historically, the foreign and joint-venture fisheries produced fillets and headed and gutted products. In 1989, Japanese motherships began producing surimi from Pacific hake, using a newly developed process to inhibit myxozoan-induced proteolysis. In 1990, domestic catcher-processors and motherships entered the Pacific hake fishery in the U.S. zone. Previously, these vessels had engaged primarily in Alaskan pollock fisheries. The development of surimi production techniques made Pacific hake a viable alternative. In 1991, joint-venture fishery for Pacific hake ended because of the high level of participation by domestic catcher-processors and motherships, and the growth of shore-based processing capacity. Shore-based processors of Pacific hake had been constrained historically by a limited domestic market for Pacific hake fillets and headed and gutted products. The construction of surimi plants in Newport and Astoria led to a rapid expansion of shore-based landings in the early 1990's.

The Pacific hake fishery in Canada exhibits a similar pattern, although phasing out of the foreign and joint-venture fisheries has lagged a few years relative to the U.S. experience. Since 1968, more Pacific hake have been landed than any other species in the groundfish fishery on Canada's west coast (Table 1). Prior to 1977, the former Soviet Union caught the majority of hake in the Canadian zone, with Poland and Japan harvesting much smaller amounts. Since declaration of the 200-mile extended fishing zone in 1977, the Canadian fishery has been divided into shore-based, joint-venture, and foreign fisheries. In 1990, the foreign fishery was phased out. Since the demand of Canadian shore-based processors remains below the available yield, the joint-venture fishery will continue through 2002. Poland is the only country that participated in the 1998 joint-venture fishery. The majority of the shore-based landings of the coastal hake stock are processed into surimi, fillets, or mince by processing plants at Ucluelet, Port Alberni, and Delta. Small deliveries were made in 1998 to plants in Washington and Oregon. 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 lat. off the south coast of Vancouver Island, where there are sufficient quantities of fish in proximity to processing plants.

Management of Pacific hake

Since implementation of the Fisheries Conservation and Management Act in the U.S. and the declaration of a 200 mile fishery conservation zone in Canada in the late 1970's, annual quotas have been the primary management tool used to limit the catch of Pacific hake in both zones by foreign and domestic fisheries. The scientists from both countries have collaborated through the TSC, and there has been informal agreement on the adoption of an annual fishing policy. However, overall management performance has been hampered by a long-standing disagreement between the U.S. and Canada on the division of the acceptable biological catch (ABC) between U.S. and Canadian fisheries. In 1991-1992, U.S. and Canadian managers set quotas that summed to 128% of the ABC, while in 1993-2001, the combined quotas were 107% of the ABC on average. The 2002 and 2003 fishing year were somewhat different from years past in that the ABC of Pacific hake was utilized at an average of 87%. In a recent preliminary agreement between the United States and Canada (2003) 74% and 26%, respectively, of the coastwide allowable biological catch is to be allocated to the two countries. Furthermore, the agreement, yet to be ratified, states that a Joint Technical Committee will exchange data and conduct stock assessments which will be reviewed by a Scientific Review Group.

United States

Prior to 1989, catches in the U.S. zone were substantially below the harvest guideline, but since 1989 the entire harvest guideline has been caught with the exception of 2000, 2001 and 2003 which were 90%, 96% and 96% of the quota, respectively. The total U.S. catch has not significantly exceeded the harvest guideline for the U.S. zone (Table 2), indicating that in-season management procedures have been very effective.

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. At-sea processing and night fishing (midnight to one hour after official sunrise) are prohibited south of 42° N lat. Fishing is prohibited in the Klamath and Columbia River Conservation zones, and a trip limit of 10,000 pounds is established for hake caught inside the 100-fathom contour in the Eureka INPFC area. During 1992-95, the U.S. fishery opened on April 15, however in 1996 the opening date was moved to May 15. Shore-based fishing is allowed after April 1 south of 42° N. lat. 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. A new allocation agreement, effective in 1997, divided the U.S. non-tribal harvest guideline between factory trawlers (34%) , vessels delivering to at-sea processors (24%), and vessels delivering to shore-based processing plants (42%).

Shortly after this allocation agreement was approved by the PFMC, fishing companies with factory trawler permits established the Pacific Whiting Conservation Cooperative (PWCC). The primary role of the PWCC is to allocate the factor trawler quota between its members. Anticipated benefits of the PWCC include 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 conducts research to support hake stock assessment. As part of this effort, PWCC sponsored a juvenile recruit survey in summer of 1998 and 2001, which continued in 2002 and 2003 in collaboration with NMFS scientists.

Canada

The Canadian Department of Fisheries and Oceans (DFO) is responsible for managing the Canadian hake fishery. Prior to 1987, the quota was not reached due to low demand for hake. In subsequent years the quota has been fully subscribed, and total catch has been successfully restricted to ±5% of the quota (Table 2).

Domestic requirements are given priority in allocating yield between domestic and joint-venture fisheries. During the season, progress towards the domestic allocation is monitored and any anticipated surplus is re-allocated to the joint-venture fishery. The Hake Consortium of British Columbia coordinates the day-to-day fleet operations within the joint-venture fishery. Through 1996, the Consortium split the available yield equally among participants or pools of participants. In 1997, Individual Vessel Quotas (IVQ) were implemented for the British Columbia trawl fleet. IVQs of Pacific hake were allotted to licence holders based on a combination of vessel size and landing history. Vessels are allocated proportions of the domestic or joint-venture hake quota. There is no direct allocation to individual shoreside processors. Licence holders declare the proportion of their hake quota that will be landed in the domestic market, and shoreside processors must secure catch from vessel licence holders.

Overview of Recent Fishery and Management

United States

In 1998, the GMT recommended a status quo ABC of 290,000 mt for 1998 (i.e. the same as 1997). The ABC recommendation was based on a decision table with alternative recruitment scenarios for the 1994 year class, which was again considered a major source of uncertainty in current stock status. Recommendations were based on the moderate risk harvest strategy. The PFMC adopted the recommended ABC and allocated 80 percent of the ABC (232,000 mt) to U.S. fisheries.

The GMT recommended a status quo ABC of 290,000 mt for 1999 and 2000. This coastwide ABC was roughly the average coastwide yield of 301,000 mt and 275,000 mt projected for 1999 and 2000, respectively based on F40% (40-10 option) harvest policy.

In 2000, a Pacific hake assessment update was performed by Helser et al. (2001). While additional catch and age composition data were available at the time of the assessment, the 2001 coastwide acoustic survey which serves as the primary index of hake abundance was not. Using the same configuration with the updated fishery composition data and recruitment indices the assessment model showed consistent projections with the 1998 assessment. Based on this, the GMT recommended that the ABC in 2001 be set to the projected yield of 238,000 mt based on the F40% (40-10 option) harvest policy. Allowable biological catches in 2002 and 2003 were based the 2001 Pacific hake stock assessment (Helser et al. 2001) with updated fishery data and a new acoustic survey biomass estimated for 2001. Due to declining biomass and an estimated depletion level of 20% unfished biomass in the 2001 assessment the ABC in 2002 was 208,000 mt and based the F45% (40-10) harvest policy. However, the ABC in 2003 was adjusted upward to 235,000 mt under the same harvest policy to reflect projected increases in biomass from the relatively strong 1999 year class.

Landings of the at-sea fishery constituted roughly 54% of the total U.S. fishery catches since 1999. Significant distributional shifts in the Pacific hake population, presumably due to oceanographic conditions, has caused major fluctuations in the center of the at-sea harvesting sector. Most notable in recent years was the northward shift in 1999 at-sea fleet activity in which most catches were distributed North of the Columbia River (roughly 91% of the at-sea catches) and coincided with a strong El Nino the preceding year. At sea catches returned to more normal spatial distribution patterns in the 2000 fishing season with roughly 60% occurring north and 40% occurring south of the Columbia River. In 2001, the pattern of the at-sea catches were opposite of those seen in 1999 with only roughly 22% north of the Columbia River (Fig. 2). This coincided with a relatively strong La Nina. The at sea catch distributions for 2002 and 2003 were representative of more normal patterns with roughly 60% and 40% of the catches south and north of Newport, OR., respectively. In 2003, the at-sea catch of hake was 67,473 mt, with Motherships harvesting 39% (26,021m t) while the catcher/processor sector harvesting 61% (55,389 mt) of the hake allocation.

The total shore-based U.S. landings in 2002 and 2003 were 46,000 mt and 45,000 mt, respectively. The primary ports harvesting Pacific hake in 2002 were Newport, Oregon (18,553m t), Astoria, Oregon (12,171 mt), Coos Bay, Oregon (1,580 mt), Washington coastal ports (primarily Westport) (10,610 mt) , and Eureka, California (2,773 mt). In 2003, landings from Eureka were down roughly 50% from 2002, but up by over 2,000 mt in the Washington coastal port of Ilwaco. In aggregate, these ports accounted for more than 99% of all shore-based hake landings. The shore-based fishery began in mid June and ended on July 14 when the harvest guideline was attained.

Since 1996, the Makah Indian Tribe has conducted a separate fishing in its" Usual and Accustomed Fishing Area." The tribal fishery was allocated 15,000 mt of hake in 1996 with an increase to 25,000 mt in 1997- 1999, 32,500 mt in 1999-2000, and 20,000 mt in 2001-2003. The tribal harvest essentially all of its allocated catch between 1996-1999, however, in 2000 and 2001 the Makah Tribe only harvested 6,500 mt and 6,774 mt, respectively. In 2003, the Makah fishery began in June 13 and harvested roughly 90% of its allocated 25,000 mt.

Canada

DFO managers allow a 15% discrepancy between the quota and total catch. The quota may be exceeded by up to 15%, which is then taken off the quota for the subsequent year. If less than the quota is taken, up to 15% can be carried over into the next year. For instance, the overage in 1998 (Table 2) is due to carry-over from 1997 when 9% of the quota was not taken. Between 1999-2001 the PSARC groundfish subcommittee recommended to DFO managers yields based on F40% (40-10) option and Canadian managers adopted allowable catches prescribed at 30% of the coastwide ABC (Table 14; Dorn et al. 1999).

The all-nation catch in the Canadian zone was 53,585 mt in 2001, up from only 22,401 mt in 2000 (Table 1). In 2000, the shore-based landings in the Canadian zone hit a record low since 1990 due to a decrease in availability. Catches in 2001 increased substantially over those of 2000 for both the Joint Venture and shore-based sectors over catches in 2000, but were still below recommended TAC. Total Canadian catches in 2002 and 2003 were 50,769 mt and 62,090 mt, respectively, and constituted nearly 87% of the total allocation of that country.

ASSESSMENT

Modeling Approaches

Age-structured assessment models have been used to assess Pacific hake since the early 1980's. 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 survey estimates of absolute abundance at age (Hollowed et al. 1988a). Since 1989, a stock synthesis model that utilizes fishery catch-at-age data and survey estimates of population biomass and age composition has been the primary assessment method (Dorn and Methot, 1991). Dorn et al. (1999) converted the age-structured stock synthesis Pacific hake model to an age-structured model using AD model builder (Fournier 1996). The conversion from stock synthesis to AD model builder consisted of programming the population dynamics and likelihood equations in the model implementation language (a superset of C++). In that assessment, Dorn et al. (1999) provided model validation using a side-by-side comparison of model results between stock synthesis and ADMB, and then extended the approach to take advantage of AD model builder's post-convergence routines to calculate standard errors (or likelihood profiles) for any quantity of interest, allowing for a unified approach to the treatment of uncertainty in estimation and forward projection. Helser et al. (2001), using the same AD model builder modeling framework, conducted the Pacific hake stock assessment for 2001. That assessment included updated fishery and new survey biomass estimates, with exploration of numerous alternative model structures and assumptions. While the same modeling framework is employed in this assessment, several important modifications have been made, most notable of which are: 1) revision of acoustic survey biomass estimates from 1977-1992 to reflect new deep-water and northern expansion factors; 2) initialization of the population age composition in 1966 (vs. 1972) including estimates of recruitment at age 2 from 1966-2003; and 3) discrete temporal changes in the acoustic survey selectivity.

Data Sources

The data used in the stock assessment model included:

- Total catch from the U.S. and Canadian fisheries (1966-2003).

- Catch at age and average weights at age from the U.S. (1973-2003) and Canadian fisheries (1977-2003).

- Biomass and age composition from the Joint US-Canadian acoustic/midwater trawl surveys (1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998, 2001, and 2003).

- Indices of young-of-the-year abundance from the Santa Cruz Laboratory larval rockfish surveys (1986-2003). In this assessment and in the previous assessment (Helser et al. 2001), Santa Cruz Laboratory indices of young -of-the-year were used as an age-2 tuning index for s stock reconstruction and for future projections (two years out from the terminal year in the assessment).

The model also uses biological parameters to characterize the life history of hake. These parameters are used in the model to estimate spawning and population biomass, and obtain predictions of fishery and survey biomass from the parameters estimated by the model:

- Proportion mature at age.

- Weight at age and year by fishery and by survey

- Natural mortality (*M*)

Total catch

Table 1 gives the catch of Pacific hake for 1966-2003 by nation and fishery. Catches in U.S. waters for 1966-1980 are from Bailey et al. (1982). Prior to 1977, the at-sea catch was reported by foreign nationals without independent verification by observers. Bailey et al. (1982) suggest that the catch from 1968 to 1976 may have been under-reported because the apparent catch per vessel-day for the foreign feet increased after observers were placed on foreign vessels in the late 1970's. For 1981-2003, the shore-based landings are from Pacific Fishery Information Network (PacFIN). Foreign and joint-venture catches for 1981-1990, and domestic at-sea catches for 1991-2003 are estimated by the North Pacific Groundfish Observer Program (NPGOP).

At-sea discards are included in the foreign, joint-venture, at-sea domestic catches in the U.S. zone. Discards have not been estimated for the shore-based fishery. The majority of vessels in the U.S. shore-based fishery operate under experimental fishing permits that require them to retain all catch and bycatch for sampling by plant observers. Canadian joint-venture catches are monitored by at-sea observers, which are placed on all processing vessels. 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.

Fishery age composition

Catch at age for the foreign fishery in the U.S. zone during 1973-1975 is given in Francis and Hollowed (1985), and was reported by Polish and Soviet scientists at bilateral meetings. Estimates of catch at age for the U.S. zone foreign and joint-venture fisheries in 1976-1990, and the at-sea domestic fishery in 1991-2003, were derived from length-frequency samples and length-stratified otolith samples collected by observers. Sample size information is provided in Table 3. In general, strata were defined by the combination of three seasonal time periods and three geographic areas. Methods and sample sizes by strata are given in Dorn (1991, 1992). During 1992-2003, at-sea catch was generally restricted to between May and August in the early part of the year (April-June) north of 42° N. lat., so only two spatial strata were used (roughly north and south of Cape Falcon, 45° 46′ N. lat.), and no seasonal strata were defined. The Makah fishery (1996-2003) was defined as a separate strata because of its restricted geographic limits and different seasons.

Biological samples from the shore-based fishery were collected by port samplers at Newport, Astoria, Crescent City, and Westport from 1997-2003. A stratified random sampling design is used to estimate the age composition of the landed catch (sample size information provided in Table 3). Shore-based strata are defined on the basis of port of landing. In 1997- 2003, four strata defined 1) northern California (Eureka and Crescent City), 2) southern Oregon (Newport and Coos Bay), and 3) northern Oregon (Astoria and Warrenton), and 4) Washington coastal ports (Illwaco and Westport). No seasonal strata have been used for the shore-based fishery due to the general brevity of the fishery; however, port samplers are instructed to distribute their otolith samples evenly throughout the fishing season.

Biological samples from the Canadian joint-venture fishery were collected by fisheries observers, placed on all foreign processing vessels in 1997-2003. Shore-based Canadian landings are sampled by port samplers. The Canadian catch at age is estimated from random otoliths samples.

Figure 3 shows the estimated age composition for the shore-based fishery by port in the

U.S. zone from 2001-2003. The shore-based age compositions show both temporal and spatial variation. In general, the age compositions are composed of older fish in the more northerly fishing ports, particularly Washington coastal ports. The 1999 year class is prominent in all ports as age 3 fish in 2002 and age 4 fish in 2003.

Figure 4 shows the estimated age composition for the at sea fishery by stratum (including Makah tribal fishing area) in the U.S. zone from 2001-2003. As in the shore-based fishery age compositions comprise older fish in the northern stratum and the Makah area. The 1999 year class is also a dominate age in the at sea fishery catches seen as age 3 fish in 2002 and age 4 fish in 2003.

Table 4 (Figs. 5-6) give the estimated U.S. fishery (1973-2003) and Canadian fishery catch at age (1977-2003). The U.S. fishery catch at age was compiled from the NORPAC database maintained by the North Pacific Groundfish Observer Program, and from an additional database of shore-based biological sampling maintained by the Resource Assessment and Resource Ecology Program at AFSC. The Canadian catch at age for 1997-2003 was compiled from a database at the Pacific Biological Station. The 1980 and 1984 year classes appear as the dominant year classes in both the U.S. fishery and Canadian fishery age compositions (Figs. 5-6). The 1970 and 1977 year classes, and more recently the 1999 year class, are also evident.

Since aging Pacific hake was transferred to the Northwest Fisheries Science Center in 2001 an effort was made to cross-calibrate age reader agreement. Cross-calibration was performed on a total of 197 otoliths from the 2003 acoustic survey between the Northwest Fisheries Science Center (NWFSC) and Department of Fisheries and Oceans (DFO). Overall agreement between NWFSC/DFO was 50%, and for ages assigned that were aged within one and two years, the agreement was 86% and 96%, respectively. As would be expected, agreement between the three labs was better for younger fish than for older fish. These cross-calibration results were somewhat better than 2001 comparisons between NWFSC/DFO, but poorer than 1998 comparisons between AFSC (Alaska Fishery Science Center) and DFO. It should be noted, however, that agreement between two age readers at NWFSC was closer to 87%, with 98% agreement within one year of age. Agreement for ages 3-4 and ages 5-7 was 82% and 40%, respectively, for NWFSC between reader comparisons, with similar results for NWFSC/DFO comparisons. Also, when ages did not agree between the three labs agers at the NWFSC tended to assign older ages than DFO. Additional comparisons are needed to further calibrate ageing criteria between agencies.

Triennial Acoustic Survey (Biomass and Age Composition)

The integrated acoustic and trawl surveys, used to assess the distribution, abundance and biology of coastal Pacific hake, *Merluccius productus*, along the west coasts of the United States and Canada have been historically conducted triennially by Alaska Fisheries Science Center (AFSC) since 1977 and annually along the Canadian west coast since 1990 by Pacific Biological Station (PBS) scientists. The triennial surveys in 1995, 1998, and 2001 were carried out jointly by AFSC and DFO. Following 2001, the responsibility of the US portion of the survey was transferred to Fishery Resource Analysis and Monitoring (FRAM) Division scientists at the Northwest Fisheries Science Center (NWFSC). The joint

2003 survey was conducted by FRAM and PBS scientists, marking not only the change in the US participants but also shortens the frequency between surveys.

The 2003 survey was conducted by joint US and Canadian science teams aboard the vessel CCGS *W.E. Ricker* from 29 June to 1 September 2003, covering the length of the west coast from south of Monterey California (36.1° N) to the Dixon Entrance area (51.4° N). A total of 119 line transects, generally oriented east-west and spaced at 10 nm intervals, were completed (Fig. 7). During the 2003 acoustic survey, aggregations of hake were found along the continental shelf break from just north of San Francisco Bay (38° N) to Queen Charlotte Sound (52° N). Peak concentrations of hake were observed north of Cape Mendocino, California (ca. 43° N), in the area spanning the US-Canadian border off Cape Flattery and La Perouse Bank (ca. 48.5° N), and in Queen Charlotte Sound (ca. 51° N). Along transect 44 (42.9° N), hake were found in a continuous aggregation that extended to over 2500 meters of water and 20 nm further offshore than seen previously in this area. By contrast, no hake were found north of transect 98 in Queen Charlotte Sound (52° N). As revealed by the associated midwater and bottom trawl samples, the majority of the coastal stock is currently dominated by the 1999 year-class (age 4), with most fish at an average size of 43-44 cm in tows south of 48° N, are larger hake found further north.

Hake distribution during the 2003 acoustic survey appeared to be more representative of normal years. Aggregations of Pacific hake showed a marked contrast in 1998 and 2001 relative to the 2003 acoustic survey (Fig. 7 continued). In 1998, major aggregations were observed off Oregon between Cape Blanco and Coos Bay; near the US-Canada border, between northern Vancouver Island and southern Queen Charlotte Sound, and to lesser extent along the west side of the Queen Charlotte Islands, northern Hecate Strait, and Dixon Entrance. Hake were found as far north as 58° N. lat. in the Gulf of Alaska. There was also a large northward shift in the distribution of biomass compared to previous surveys. In contrast, most of the biomass of hake in the 2001 acoustic survey was distributed south of Newport, Oregon (Fig 7). Aggregations of hake in the 2001 acoustic survey were observed off northern California between Cape Mendocino and San Francisco Bay and off southern Oregon near Cape Blanco. The most notable differences between the 1998 and 2001 survey was the presence of hake aggregations south of Cape Blanco and the absence of hake off the Washington coast in the 2001 survey.

The 2001 and 2003 acoustic survey were similar in that 80% and 86%, respectively, of the total hake biomass occurred south of 47°30'N (i.e., Monterey, Eureka, and Columbia INPFC areas). In contrast, only 35% of the total biomass in 1998 was observed south of 47°30'N. The biomass in Canadian waters in 1998 was nearly triple the level reported in 1995. In 2001 and 2003, age 3+ hake biomass was split 80/20 between the U.S. and Canadian zone.

The 1998 survey results indicate a moderate decline of about 15% in hake biomass relative to the previous coastwide survey in 1995, however the 2001 acoustic survey dropped 62% relative to the 1998 survey. In contrast, the 2003 biomass estimate (1843 million mt) increased 120% over the 737,000 mt of the 2001 survey. The strong 1999 year class shown entering the population as age 4 fish in 2003 is principally responsible for the increase.

Revision of the Acoustic Survey Biomass and Age Composition

In 1996, research on hake acoustic target strength (Traynor 1996) resulted in a new target strength model of TS = 20 log L - 68. Target strength (TS) is a measure of the acoustic reflectivity of the fish and is necessary to scale relative acoustic estimates of fish abundance to absolute estimates of abundance. Biomass estimates for the 1977-89 acoustic surveys were re-estimated using the new target strength.

Relative to the more recent surveys (1992-2003) in which hake aggregations were found further offshore and in more northerly latitudes, the 1977-1989 surveys were corrected for the limited geographic coverage by calculating deep water and northern expansion factors used to adjust the total acoustic backscatter (Dorn 1996). Dorn's (1996) revised acoustic time series, which averaged 31% higher than the original time series for 1977-89, had been used in subsequent stock assessments until 2001.

In this assessment, we revisited the deep water and northern expansion factor calculations with additional acoustic survey data, 1992-2001 inclusive. Appendix 1 shows the steps in the calculation of the new biomass estimates for 1977-1989. Tables A-F show the calculations used for deep-water expansion factors while Tables G-H show northern expansions. Table A gives the biomass (at -35dB/kg) by stratum and the offshore and northern limits of each survey from 1977-1989. Deep-water expansion factors were estimated by latitudinal strata (INPFC area) as the total biomass in an area divided by the biomass within the depth limits of the earlier surveys. These expansion factors are shown by stratum in Table B and are based on the 1992-2001 surveys, with 1992-2001 average in Table C. The biomass at -35dB/kg by stratum was converted back into total acoustic backscatter for the stratum based on the equation, $\sigma_{bs} = 4\pi 10^{(TS/10)}$, and the deep-water expansion factors multiplied to each year on a per stratum basis (Appendix A, Table D). The mean acoustic backscattering cross section per fish in a stratum was obtained as a weighted average from the raw length frequency distribution with that stratum and the length-specific acoustic backscattering cross section, σ, for a length-TS relationship of TS=20 log L-68. The mean acoustic backscattering cross section per fish by strata are shown in Table E. Dividing total area acoustic backscatter by the mean acoustic backscatter cross section per fish give an estimate of the total number of fish by stratum based on the new target strength relationship (Table F).

The next step was to adjust the total numbers of fish due to the limited northern latitudinal coverage of the 1977-1992 surveys. We include 1992 in these calculations since that survey ended at 51.7 ^{o} N latitude and subsequent surveys (1998) showed hake aggregations further north. Thus, only the survey years 1995-2001 were used to generate northern expansion factors. Northern expansion factors were estimated on the basis of age since older hake are known to migrate further north (Dorn et al. 1993). Northern expansion factors were estimated as the total biomass divided by the biomass within the northern latitudinal limits of the earlier surveys. Table G shows the northern expansion factors by survey year 1995-2001, along with the average for all three years. Due to the variability in expansion factors from one age to the next we used the predicted value from a smoothing function for application. Before the northern expansions could be applied, the total adjusted numbers (after applying deep-water expansions) by stratum (Table F) had to be converted to biomass at age. To do this, the adjusted numbers at age were partitioned into proportions at age for each stratum, after which the total numbers summed by age across stratum were multiplied by the mean weight at age to derive biomass at age. Table H shows an example of this calculation using the smoothed average northern expansion factors at age are applied to biomass at age generated from adjusted numbers in 1983(based on smoothed average deep-water expansion factors).

Finally, two sets of calculations of the expansions were performed. The first was based on the average deep-water (1992-2001) and average (1995-2001) northern expansion factors. The second set of calculations was based on applying more recent survey years to the earlier survey years which were more representative of the oceanographic conditions observed. For instance, expansion factors calculated from the 1998 survey year with the strong El Nino event was applied to the 1992 and 1983 survey years, while the 2001 survey year during which a La Nina was observed was applied to the 1989 survey year. Calculations based on the 1995 survey years, which are more typical of transition years between El Nino and La Nina, were applied similarly to the 1977, 1980, and 1986 survey years. The revised 1977-1989 acoustic survey biomass estimates based on the new expansion factors are shown in Figure 8. Only nominal differences between Dorn's (1996) and the revised acoustic biomass estimates were observed for all years except 1992 for calculations based on average expansion factors. The 29% increase in revised biomass estimates for 1992 is mostly due to the increase in the age-based northern expansion factor which was applied to substantial biomass of the 1980 and 1984 year class still present as age 8 and age 12 fish in the 1992 age compositions. Revised biomass estimates based on year-specific expansion factor calculations, shown in the bottom panel, also show an increase in 1992 biomass estimates (35%) in addition to increases in biomass for 1977-1986 (16%-20%). Again, these increases are principally due to the application of age-based expansion factors.

In general, we feel the year-specific expansion factor calculations are superior to those based on averages since these take advantage on our knowledge of the migratory response of the hake population to varying oceanographic conditions and the northern distributional extent of the different age classes in the population. In either case, uncertainty regarding the actual acoustic survey biomass between 1977-1989 remains and because of their dependence on the deep water and northern expansion factors, the 1977-89 biomass estimates were assumed to be more uncertain than the 1992-2001 biomass estimates. For this reason, we applied a CV = 0.2 for the 1977-1989 acoustic survey biomass estimates, whereas a CV=0.1 was applied to the 1992-2003 biomass. We feel that a lower CV (0.2) than compared to previous assessments (CV=0.5) for 1997-1989 biomass estimates is warranted because additional survey data (1992-2001) and age-based northern expansion factors were used in the revised calculations. As a measure of consistency, we also revised the numbers at age and therefore the age compositions for 1977-1992 used in the ADMB model based on the new expansion factors. The previous and revised age compositions and biomass for the AFSC acoustic survey are given in Table 5 and Figure 9 shows the acoustic survey age compositions. To reflect this we halved the effected multinomial sample sizes for the 1977-1989 age compositions (N=40) relative to the effective samples sizes from 1992-2003 (N=80). Finally, as a sensitivity analysis model runs were preformed using revised biomass estimates based on both the year-specific and time averaged expansion factors.

Triennial Shelf Trawl Survey (Hake distribution)

The Alaska Fisheries Science Center has conducted a triennial bottom trawl survey along the west coast of North America between 1977-2001 (Wilkins et al. 1998). In 2003, the Northwest Fisheries Science Center took responsibility for the triennial bottom trawl survey. Despite similar seasonal timing of the two surveys, the 2003 survey differed in size/horsepower of the chartered fishing vessels and bottom trawl gear used. For this reason, the continuity of the shelf survey remains to be evaluated. In addition, the presence of significant densities of hake both offshore and to the north of the area covered by the trawl survey limits the usefulness of this survey to assess the hake population. More over, bottom trawl used in the survey is limited in its effectiveness at catching mid-water schooling hake. In the context of this assessment we examine the spatial distribution of hake in this survey relative to that found in the acoustic survey.

The most recent survey conducted by the NWFSC was carried out from June 30 to September, 2003, from south of Point Conception (33° N. lat.) to the U.S./Canadian border (approx. 48°30′ N. lat.) aboard four chartered commercial trawlers (See Turk et al. 2001 for details). The vessels were equipped with the FRAM Division's standardized Aberdeen bottom trawls and net mensuration equipment. Pacific hake were caught at 436 of the 511 successfully sampled stations. Catch rates of age 2+ hake were highest in the Columbia and Vancouver INPFC areas followed by Eureka (Figure 10). Catch rates over the entire survey area increased with depth. By in large, the spatial distribution of hake in the acoustic survey is consistent with the distribution of hake seen in the triennial bottom trawl survey in 2003.

Santa Cruz Laboratory Midwater Trawl Recruit Survey

The Santa Cruz Laboratory of the Southwest Fisheries Science Center has conducted annual surveys since 1983 to estimate the relative abundance of pelagic juvenile rockfish off central California. Although not specifically designed to sample juvenile hake, young-of-the-year juvenile hake occur frequently in the midwater trawl catches. In this assessment as in the previous 2001 assessment the index is used to project the relative strength of recruitment (Table 8, fig 11). This index was obtained using from a generalized linear model (GLM) fit to the log-transformed CPUEs (Ralston et al. 1998; Sakuma and Ralston 1996). Specifically, the year effect from the GLM was back-transformed to obtain an index of abundance. Only the Monterey outside stratum was used because of its higher correlation with hake recruitment. Also, Dorn et al. (1999) showed that the juvenile index was significantly correlated to the predicted recruitment two years later in the stock assessment model. The index in 1999 suggested that recruitment in 2001 may be above average, which has largely been confirmed by other data sources such as numbers at age in the fishery catches and acoustic survey. Except for the 2001 larval index (representing age 2 recruitment in 2003) which appears to be average, the most recent 2002 and 2003 indexes are among the lowest observed since 1986. As will be discussed below, the PWCC recruit survey shows a marked contrast to the 2003 survey index. The series average CV, estimated from the GLM, was calculated to be approximately 0.50 and was therefore used in the assessment model.

PWCC-NMFS midwater trawl survey

The Pacific Whiting Conservation Cooperative (PWCC) and the National Marine Fisheries Service, Northwest Science Center (NWFSC) and Santa Cruz Laboratory (SCL), Southwest Fisheries Science Center has been conducting a cooperative survey of juvenile hake and rockfish relative abundance and distribution off Oregon and California since 1999. This survey is an expansion of the Santa Cruz Laboratory's juvenile survey conducted in between Monterrey Bay and Pt. Reyes, California. Prior to 2001 results between the PWCC survey and the SCL survey were not comparable because of trawl gear differences. Since 2001, the gear has been comparable and side-by-side comparisons were made between the PWCC vessel *Excalibur* and the SCL vessel *David Starr Jordan.*

The PWCC Pacific whiting prerecruit survey is conducted in May at stations across the continental shelf between Newport Oregon (44º30'N) and Point Arguello California (34º 30' N). Several stations were sampled on transects located at 30 nm intervals. Transect stations were located over waters between 50 m. and approximately 1200 m. depth. A total of 113 trawl samples were taken during the survey.

A modified anchovy midwater trawl with an 86' headrope and ½" codend with a 1/4" liner was used to obtain samples of juvenile hake and rockfish. Trawling was done at night with the head rope at 30 m at a speed of 2.7 kt. Some trawls were made prior to dusk to compare day/night differences in catch. Trawls sets of 15 minutes duration at target depth were conducted along transects located at 30 nm intervals along the coast (Figure 1). Stations were located along each transect from 50m bottom depth seaward to 700 m. with hauls taken over bottom depths of 50, 100, 200, 300, and 500 meters at each transect.

The hake YOY were primarily distributed between 40 and 41 N. Lesser amounts of YOY hake were encountered in the Monterey Bay area relative to earlier years, and fewer hake YOY were captured at the southern extreme of the survey area. The total number of YOY hake captured in the 2003 PWCC/NMFS survey was much greater than in prior years. In 2001 5,610 hake YOY were captured, and in 2002 a total of 6,359 were captured, while in 2003 the number increased to 42,541. The absolute variance was higher in 2003 with a high proportion of YOY hake in a few hauls; however the coefficient of variation was nearly similar between years, indicating that 2003 results were not anomalous.

The Santa Cruz survey results indicate that 2001 hake year class is near the long-term mean of the index, but that 2002 is a relatively weak year class, and 2003 estimated abundance is the lowest observed. The PWCC index, on the other hand, indicates that the 2001 and 2002 are both near average year-classes and 2003 a strong year class. The conclusion of two near average year classes is based on a comparison of 2001 and 2002 results. In 2001, the Santa Cruz index was average and the PWCC coast wide distribution of hake YOY showed Monterrey Canyon as the center of abundance. However, in 2002, the center of abundance in the PWCC survey was further north, and proportionally less hake YOY occurred in the Monterrey Bay area.

In 2003 the difference in number of hake YOY between the PWCC and Santa Cruz surveys was more pronounced. The PWCC survey had a nearly seven fold increase in estimated abundance over the previous two years, while the Santa Cruz survey found the lowest number in the time series.
The PWCC hake prerecruit survey results are interesting that they show an entirely different time series than the Santa Cruz survey over the same time period. The PWCC survey indicates 2001 and 2002 abundance to be about the same magnitude and 2003 to be significantly higher. The Santa Cruz Survey, on the other hand indicates a totally opposite trend, with 2003 indicated to be the least abundant year class of the series. However, until a longer time series is established, or a calibration can be achieved with the Santa Cruz juvenile rockfish survey it is difficult to determine what the results mean in terms of future abundance levels of the measured year class. As the year classes in question accrue to the catch the question of relative year class size will be established. The expansion of the hake recruitment index beyond the traditional NMFS Santa Cruz Lab survey area raises questions of consistency in hake larval distribution. The results of the 2002 and 2003 PWCC survey suggest that transport of larval may spatially varying with larvae reaching the outer shelf north of the Monterey index area in some years. However, it is possible that the larvae follow a set transport pattern but varying temporally. If there is a temporal component there may be some evidence in larval daily growth or an environmental signal. With additional data, it may be possible to model and predict the distribution of YOY and better deploy survey effort.

Weight at age

Year-specific weights at age are used in all years for each fishery and survey and for the population because significant variation in Pacific hake weight at age has been observed (Table 9) (Dorn 1995). In particular, weight at age declined substantially during the 1980's, then remained fairly constant to 1998. Interestingly, average weights at age increased substantially in 2000 and 2001 in both the fishery and surveys, suggesting more favorable growth in recent years. Weights at age, however, have declined in both the fishery and survey in 2003. Weight at age is inversely correlated with sea-surface temperature and (to a lesser extent) adult biomass (Dorn 1992). Weight at age estimates for 1977-87 are given in Hollowed et al. (1988b). Weight-at-age vectors since 1987 were derived from the length-weight relationship for that year and unbiased length at age calculated using age length keys (Dorn 1992). In some cases, a linear interpolation of the weight at age of the strong year classes was used for the weaker year classes whose weight at age was poorly estimated or not available due to small sample sizes. This was necessary only for the older or less abundant age groups. Population weight at age, used to calculate spawning biomass, was assumed to be equal to the nearest AFSC acoustic survey weight-at-age.

Age at Maturity

Dorn and Saunders (1997) estimate female maturity at age with a logistic regression using ovary collections and visual maturity determinations by observers as

Age														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.000	0.176	0.661	0.890	0.969	0.986	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Natural mortality

The natural mortality currently used for Pacific hake stock assessment and population modeling is 0.23. This estimate was obtained by tracking the decline in abundance of a year class from one triennial acoustic survey to the next (Dorn et. al 1994). Pacific hake longevity data, natural mortality rates for Merluciids worldwide, and previously published estimates of 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).

Model Development

Population dynamics

The age-structured model for hake describes the relationships between population numbers by age and year. The modeled population includes individuals from age 2 to age 15, with age 15 defined as a "plus" group, i.e., all individuals age 15 and older. The model extends from 1966 to 2003. The Baranov (1918) catch equations are assumed, so that

$$c_{ijk} = N_{ij} \frac{F_{ijk}}{Z_{ij}} [1 - \exp(-Z_{ij})]$$

$$N_{i+1\,j+1} = N_{ij} \exp(-Z_{ij})$$

$$Z_{ij} = \sum_k F_{ijk} + M$$

except for the plus group, where

$$N_{i+1,15} = N_{i,14} \exp(-Z_{i,14}) + N_{i,15} \exp(-Z_{i,15})$$

where N_{ij}= population abundance at the start of year *I* for age *j* fish, F_{ijk} = fishing mortality rate in year *I* for age *j* fish in fishery *k*, and c_{ijk} = catch in year *I* for age *j* fish in fishery *k*. A constant natural mortality rate, *M*, irrespective of year and age, is assumed.

The U.S. and Canadian fisheries are modeled as distinct fisheries. Fishing mortality is modeled as a product of year-specific and age-specific factors (Doubleday 1976)

$$F_{ijk} = s_{jk} f_{ik}$$

where s_{jk} = age-specific selectivity in fishery k, and f_{ik} = the annual fishing mortality rate for fishery k. To ensure that the selectivities are well determined, we require that $\max(s_{jk}) = 1$ for each fishery. Following previous assessments, a scaled double-logistic function (Dorn and Methot 1990) was used to model age-specific selectivity

$$s_j^{/} = \left(\frac{1}{1 + \exp[-\beta_1(j - \alpha_1)]} \right) \left(1 - \frac{1}{1 + \exp[-\beta_2(j - \alpha_2)]} \right)$$

$$s_j = s_j^{/} \;/\; \max_j \; (s_j^{/})$$

where α_1 = inflection age, β_1 = slope at the inflection age for the ascending logistic part of the equation, and α_2 , β_2= the inflection age and slope for the descending logistic part. The subscript k , used to index a fishery or survey, has been suppressed in the above and subsequent equations in the interest of clarity.

Measurement error

Model parameters were estimated by maximum likelihood (Fournier and Archibald 1982, Kimura 1989, 1990, 1991). Fishery observations consist of the total annual catch in tons, C_i, and the proportions at age in the catch, p_{ij}. Predicted values from the model are obtained from

$$\hat{C}_i = \sum_j w_{ij} \; c_{ij}$$

$$\hat{p}_{ij} = c_{ij} \;/\; \sum_j c_{ij}$$

where w_{ij} is the weight at age j in year I . Year- and fishery-specific weights at age are used because of the changes in weight at age during the modeled time period.

Log-normal measurement error in total catch and multinomial sampling error in the proportions at age give a log-likelihood of

$$\log L_k = -\sum_i [\log(C_i) - \log(\hat{C}_i)]^2 / 2\sigma_i^2 + \sum_i m_i \sum_j p_{ij} \log(\hat{p}_{ij} / p_{ij})$$

where σ_i is standard deviation of the logarithm of total catch (~ CV of total catch) and m_i is the size of the age sample. In the multinomial part of the likelihood, the expected proportions at age have been divided by the observed proportion at age, so that a perfect fit to the data for a year gives a log likelihood value of zero (Fournier and Archibald 1982). This formulation of the likelihood allows considerable flexibility to give different weights (i.e. emphasis) to each estimate of annual catch and age composition. Expressing these weights explicitly as CVs (for the total catch estimates), and sample sizes (for the proportions at age) assists in making reasonable assumptions about appropriate weights for estimates whose variances are not routinely calculated.

Survey observations from age-structured survey (acoustic survey) consist of a total biomass estimate, B_i, and survey proportions at age π_{ij}. Predicted values from the model are obtained from

$$\hat{B}_i = q \sum_j w_{ij}\, s_j\, N_{ij} \exp[-\phi_i Z_{ij}]$$

where q = survey catchability, s_j = selectivity at age for the survey, and ϕ_i = fraction of the year to the mid-point of the survey. Survey selectivity was modeled using a double-logistic function of the same form used for fishery selectivity. The expected proportions at age in the survey in the ith year are given by

$$\hat{\pi}_{ij} = s_j\, N_{ij} \exp[-\phi_i Z_{ij}] / \sum_j s_j\, N_{ij} \exp[-\phi_i Z_{ij}]$$

Log-normal errors in total biomass and multinomial sampling error in the proportions at age give a log-likelihood for survey k of

$$\log L_k = -\sum_i [\log(B_i) - \log(\hat{B}_i)]^2 / 2\sigma_i^2 + \sum_i m_i \sum_j \pi_{ij} \log(\hat{\pi}_{ij} / \pi_{ij})$$

where σ_i is the standard deviation of the logarithm of total biomass (~ CV of the total biomass) and m_i is the size of the age sample from the survey.

For surveys that produce only an index of recruitment at age 2, R_i , predicted values from the model are

$$\hat{R}_i = q \, N_{i2}$$

Log-normal measurement error in the survey index gives a log-likelihood of

$$\log L_k = -\sum_i [\log(R_i) - \log(\hat{R}_i)]^2 \,/\, 2\sigma_i^2$$

where σ_i is the standard deviation of the logarithm of recruitment index. Since the recruitment surveys occur several years before recruitment at age 2, the indices need to be shifted forward the appropriate number of years.

Process error and Bayes priors

Process error refers to random changes in parameter values from one year to the next. Annual variation in recruitment and fishing mortality can be considered types of process error (Schnute and Richards 1995). In the hake model, these are estimated as free parameters, with no additional error constraints. We use a process error to describe changes in fisheries selectivity over time using a random walk (Gudmundsson 1996).

To model temporal variation in a parameter γ , the year-specific value of the parameter is given by

$$\gamma_i = \bar{\gamma} + \delta_i$$

where $\bar{\gamma}$ is the mean value (on either a log scale or linear scale), and δ_i is an annual deviation subject to the constraint $\Sigma \, \delta_i = 0$. For a random walk process error where annual *changes* are normally distributed, the log-likelihood becomes

$$\log L_{Proc.\ Err.} = -\sum \frac{(\delta_i - \delta_{i+1})^2}{2\sigma_i^2}$$

where σ_i is the standard deviation of the annual change in the parameter. We use a process error model for all four parameters of the U.S. fishery double-logistic curve. For the Canadian fishery double-logistic curve, a process error model was used only for the two parameters of the ascending part of the curves. Since the descending portion is almost asymptotic, little improvement in fit can be obtained by including process error for those parameters.

Bayesian methods offer a number of conceptual and methodological advantages in stock assessment (Punt and Hilborn 1997). We adopt an incremental approach of adding Bayes priors to what is essentially a maximum likelihood model. In non-linear optimization, the usual practice is to place upper and lower bounds on estimated parameters (a feature of both stock synthesis and AD model builder). From a Bayesian perspective, placing bounds on the possible values of a parameter corresponds to using a uniform prior for that parameter. Additional constraints are imposed on a parameter γ by adding the log likelihood for a log-normal prior,

$$\log L_{Prior} = \frac{-[\log(\gamma) - \log(\tilde{\gamma})]^2}{2\sigma^2}$$

where $\tilde{\gamma}$ is the prior mean, and σ is the standard deviation of the logarithm of the prior. In this assessment, we continue to use a prior for the slope of the ascending part of the acoustic survey double-logistic function.

The total log likelihood is the sum of the likelihood components for each fishery and survey, plus terms for process error and priors,

$$Log\ L = \sum_k Log\ L_k + \sum_p Log\ L_{Proc.\ Err.} + Log\ L_{Prior}\ .$$

Likelihood components and variance assumptions for the base-run assessment model are given in the following table:

Likelihood component	Error model	Variance assumption
U.S. fishery total catch	Log-normal	CV = 0.05
U.S. age composition	Multinomial	Sample size = 80
Canadian fishery total catch	Log-normal	CV = 0.05
Canadian fishery age composition	Multinomial	Sample size = 80
Acoustic survey biomass	Log-normal	CV = 0.10, CV = 0.50 for 1977-89
Acoustic survey age composition	Multinomial	Sample size = 80 (92-03)
Santa Cruz Laboratory larval rockfish survey	Log-normal	CV = 0.5
Fishery selectivity random walk process error	Slope: Log-normal Inflection age: Normal	CV = 0.25 SE = 1.0
Prior on acoustic survey slope	Log-normal	Prior mean = 0.9, Prior CV = 0.2

Ageing error

The model was configured to accumulate the marginal age groups at different ages to prevent obvious instances of aging error from affecting the model fit. This approach was used most frequently when a portion of an incoming strong year classes was misaged into an adjacent year class. We also used this approach to obtain reliable estimates of initial age composition. Marginal age groups were combined in the following situations:

- Accumulate the older fish at age 13 in 1973 at age 14 in 1974. Rationale: an age 12+ group is estimated for the initial age composition in 1972 (or 1966 with the 2003 basemodel).

- Accumulate the older fish in the fishery and survey data at age 7 in 1978, age 8 in 1979, age 9 in 1980, etc.. The Canadian age data was only accumulated in 1978 and 1979, but not in subsequent years. Rationale: large numbers of the strong 1970 year class were misaged into the 1971 year class starting in 1978.

- Accumulate the younger fish at age-3 fish in 1979. Rationale: The strong 1977 year class appeared as 3-year-old fish in 1979 due to a small sample size in the age-length key for that year.

- Accumulate the younger fish to age 4 in 1984 and age 5 in 1985 in the Canadian fishery age composition. Rationale: The strong 1980 year class was misaged into the 1981 year class.

- Accumulate the younger fish to age 3 in the 1986 U.S. fishery age composition. Rationale: The strong 1984 year class (2-year-old fish) was misaged into the 1983 year class (3-year-old fish).

- Accumulate the younger fish to age 5 in 1995 and age 6 in 1996 in the Canadian fishery age composition. Rationale: In the 1995 Canadian age composition, the number of 4-year-old fish was greater than the number of 5-year-old fish. In 1996, the age 5-fish were 75% as abundant as the age-6 fish in the Canadian fishery age composition, but only 35% as abundant in the U.S. fishery age composition. The 1991 year class (4-year-old fish in 1995) has been much less common in U.S. fishery samples than the 1990 year class (5-year-old fish in 1995) in each year during 1992-95. It is likely that the 4-year-old fish in the Canadian age composition data are misaged fish from the 1990 year class.

Optimization algorithm and convergence criteria

The optimizer in AD model builder is a quasi-Newton routine that uses auto-differentiation to obtain the gradient (Press et al. 1972). The model is determined to have converged when the maximum gradient component is less than a small constant (set to 1 x 10^{-4} for the hake model). Optimization occurs over a number of phases, in which progressively more parameters are estimated. Typically the initial phase consists of a catch curve analysis (Ricker 1973) to obtain rough estimates of mean recruitment and fishing mortality. The intermediary stages correspond to separable age-structured models (Deriso et al 1987), while the final stages also include the parameters for time varying selectivity. Thus the model mimics the entire historical development of quantitative stock assessment during a single estimation run. Identical parameter estimates (to 5 decimal places) were obtained when the initial values for mean recruitment and mean fishing mortality were halved and doubled (R = 0.5, 1.0, 2.0 billion, F = 0.1, 0.2, 0.4), suggesting that final parameter estimates were independent of initial values. After the model converges, the Hessian is estimated using finite differences. Standard errors are obtained using the inverse Hessian method. We also assess uncertainty using AD model builder routines for obtaining likelihood profiles and Markov chain Monte Carlo samples from the likelihood function.

Model parameters as in the previous assessment model as well as the 2003 update, can be classified as follows:

Population process modeled	Number of parameters estimated	Estimation details
Initial age structure	Ages 3-12 (age 12 is the plus group in 1972) = 10	Estimated as log deviances from the log mean
Recruitment	Years 1972-2003 = 32	Estimated as log deviances from the log mean
Average selectivity to fisheries and age-structured surveys	4 * (No. of fisheries + No. of surveys) = 4 * (2 + 3) = 20	Slope parameters estimated on a log scale, a prior is used for the acoustic survey ascending slope parameter.
Annual changes in fishery selectivity	4 * (No. of fisheries) * (No. of yrs -1) = 4 * 1.5 * 32 = 192	Estimated as deviations from mean selectivity and constrained by random walk process error
Year and age-specific selectivity for the 1994 & 1997 year class	U.S fishery: 1996 & 1997 = 2 Canadian fishery: 1999- 2002 = 4	Bounded by (0,1)
Survey catchability	No. of surveys = 1	Acoustic survey catchability not estimated, SWFSC catchabilities estimated on a log scale
Natural mortality	Age- and year-invariant = 1	Not estimated
Fishing mortality	No. of fisheries * (No. of yrs) = 2 * 32 = 64	Estimated as log deviances from the log mean
Total	130 conventional parameters + 192 process error parameters + 4 fixed parameters = 326	

Model selection and evaluation

This assessment used the AD model builder software with initially the same model structure and assumptions as in the 2001 assessment. Since Dorn et al. (1999) confirmed consistency with the previous assessment using the stock synthesis program and confirmed model estimates of recruitment and biomass with simulated data, there was little need for further testing and confirmation. The steps toward model selection and evaluation taken in this assessment were to first compare model results between the 2001 assessment and the present assessment using updated catch at age information and survey biomass data without changes to the model structure or assumptions. This model was hence forth referred to as the 2003 updated model and does not yet include the revised expansion factors. The basic model structure included 1) acoustic survey biomass CVs = 0.1 during 1992-2003 and CVs = 0.5 during 1977-1989 to better reflect uncertainty in the earlier years, 2) an index of recruitment to age 2 based on the SWFSC larval rockfish survey, 1986-2003 with a CV=0.5, 3) use of time varying fishery selectivity functions modeled as a random walk process error, and 4) use of a prior on the ascending limb slope parameter of the acoustic survey selectivity. For the most part, the addition of the random walk process error was to account for changes in fishery selectivity which was strongly influenced by El Niño (1983, 1992, 1997-98) driven distribution changes in the hake population. In addition, it was clear that the 1997 year class was unusually abundant as age-2 and age-3 fish in the 1999 and 2000 Canadian catch at age data, respectively (fig. 6). This pattern in the age composition data was unlike any other year and apparently due to the extreme northward extension of juvenile hake in 1997. Since age-specific selectivity is estimated as smooth functions over time the model was unable to accommodate this rapid shift in catch at age. Thus, we estimated year- and age-specific selectivity patterns for the 1997 year class in the 1999 - 2002 Canadian fishery. Dorn et al. (1999)

provided similar model accommodation by estimating year- and age-specific selectivity parameters for the 1994 year class in the 1996 and 1997 U.S. fishery.

Comparison of preliminary model results of the 2003 updated model with the 2001 assessment using only updated data show similar trends in biomass and recruitment over time. In particular, the increase in biomass during 1980-1987, due to the large 1980 and 1984 year classes, and subsequent decline in biomass between 1987-1995 were nearly identical between the two model runs (Fig. 12). Biomass between 1995 and 2001, however, was higher in the 2003 updated model than previously predicted by the 2001 stock assessment. Recruitment shows a similar pattern between assessments, except that in recent years (1995-2001) recruitment was estimated to be more optimistic than previously estimated in the 2001 assessment. As such, higher recruitment would be expected to generate higher recent biomass. Of particular note is the contrast in the relative strength of the 1999 year class (age 2 fish in 2001), which is estimated to be 64% higher in the present assessment. Large fluctuations in the most recent estimates of recruitment and biomass are not entirely unexpected given the high uncertainty in terminal year estimates. This is because the information content regarding the 1999 year class, in particular, was only present as age 2 fish in the 2001 fishery and acoustic survey age compositions, and coupled with the relatively low acoustic survey biomass in 2001 produced lower estimates. The addition of new information regarding fishery and survey age compositions, along with the 2003 survey biomass estimate, reduces the level of uncertainty about this year class.

Model fits to the observed acoustic and trawl survey biomass estimates also show similar patterns between 2003 updated model and the 2001 assessment (Fig. 13). While both assessment results show relatively poor fits to the acoustic survey (between 1983-1992), the 2003 update predicts slightly less biomass between 1983-1989, and more biomass in 2001. Finally, estimated selectivity, averaged for the most recent three years, were compared between the two assessments (Fig. 14). Both the U.S. and Canadian fishery selectivity showed changes between assessments. U.S. fishery selectivity at age 2 and 3 in 2003 updated model declined relative to the previous assessment, but in both cases fish were fully selected by age 4. Hake of younger ages were slightly less selected in the Canadian fishery than compared to the U.S., and selectivity again declined relative to the previous assessment. Differences in the acoustic survey selectivity were less pronounced between this and the previous assessments, but this assessment did show a slight decline in fish less than five years of age.

The next step was then to examine the 2003 updated model (updated data through 2003 with same model structure as used in the 2001 assessment) results relative to changes in revision of the acoustic survey biomass estimates, initializing the population age structure in 1966 to take advantage of the information content of the age compositions in the early years of the fishery (1973-1979), and explore alternative possible model structures. Specifically our intent was to incorporated the new revised acoustic survey biomass estimates 1977-1992 into the assessment model with updated data through 2003 and then build upon this foundation incrementally by initializing the population age structure back to 1966 (estimating recruitment from 1966-2003) and allowing for a time discrete acoustic survey selectivity. To facilitate results and discussion these model variants are defined as follows:

Option 1: 2003 updated model with an acoustic survey biomass CV of 0.5 in 1977-89 and a CV = 0.1 in 1992-2003. Santa Cruz Laboratory juvenile index survey CV=0.5.

Option 2: 2003 updated model as in Option 1 but incorporate revised acoustic survey biomass based on time averaged deep-water and northern expansion factors. Acoustic survey biomass CV=0.2 in 1977-1989 and CV=0.1 in 1992-2003. Santa Cruz Laboratory juvenile index survey CV=0.5.

Option 3: 2003 updated model as in Option 1 but incorporate revised acoustic survey biomass based on year-specific deep-water and northern expansion factors. Acoustic survey biomass CV=0.2 in 1977-1989 and CV=0.1 in 1992-2003. Santa Cruz Laboratory juvenile index survey CV=0.5.

Option 4: Model as in Option 3 with year-specific expansion factors, but initialize the population age structure back to 1966 and estimate recruitment from 1966-2003.

Option 5: same as Option 4 but allow acoustic survey selectivity to be estimated separately for discrete time periods. Initial examination of time varying acoustic survey selectivity showed a marked shift to older ages in 1983 and again in 1992. Thus, we estimated a separate acoustic survey selectivity for 1983 and 1992 and another for the other years.

Comparison of the model results based on the above revised survey data and model variants are shown in Figs. 15-17 and in the table below. In particular, results of Options 2-3 are compared specifically to Option 1 to systematically track changes based on revised acoustic biomass series. Model results of Options 4-5 and specifically compared to those of Option 3 as alternative model configurations. Only very nominal differences were observed in model output between the 2003 updated model (Option 1) and results based on revised acoustic survey biomass (both Option 2 and Option 3). Acoustic survey selectivity changed slightly for both Options 2 and 3 compared to Option 1; selectivity declined on younger aged fish but increased on older fish. However, there was little if any difference between survey selectivity for Options 2 and 3. The actual fit of the acoustic survey to the revised data series for Options 2 and 3 also appeared to show very nominal differences except that the expected survey biomass was closer to that observed in 1983 and 1992 for Option 3 (year-specific expansion factors) (Fig. 15).

			Depletion		
Model configuration	**AVE. R**	**B0**	**2001**	**2002**	**2003**
2001 basemodel	1.71	2.10	0.20	-	-
2001 basemodel - data revision	1.72	2.12	0.20		
Option 1	1.73	2.13	0.29	0.44	0.49
Option 2	1.75	2.16	0.31	0.50	0.56
Option 3	1.76	2.17	0.30	0.47	0.52
Option 4	1.75	2.09	0.31	0.46	0.50
Option 5	1.74	2.18	0.28	0.43	0.46

* See text for description of model options.

These results translate into very little differences in the estimated time series of spawning biomass and recruitment to age 2 among Options 1 - 3 (Fig. 16). In fact, the table above which gives the average recruitment, unfished biomass and estimated depletion rates in 2001-2003, illustrates that among Options 1 - 3 the depletion rate in 2001 varied only between 29% and 31%. The difference was slightly greater by 2003 in which the depletion rate varied from a low of 49% for Option 1 vs. 56% for Option 2. Because of these very slight differences and our endorsement of using the new acoustic survey biomass based on year-specific expansion factors (Option 3), we compared subsequent model configurations (Options 4-5) relative to Option 3. For Option 4 there was very little difference in the acoustic survey selectivity or the relative fit of the expected biomass to the revised year-specific biomass time series (Fig. 15). Estimates of spawning biomass were, however, higher prior to1983 from Option 4 vs. Option 3, largely due to higher estimated recruitments (Fig. 17). An intermediate run consisting of the 2003 updated model (Option 1) and initializing the population age composition back in 1966 revealed that re-configuring the model to reach an equilibrium biomass and age composition in 1996 had a greater impact on early biomass estimates than incorporating revised acoustic survey biomass estimates alone (see "initialize 1966" on Fig. 17). This effect, however, had little impact on the declining trend in biomass during 1987-2001 or on the current estimated depletion level (Fig. 17 and table above).

For Option 5, employing a discrete time-varying acoustic survey selectivity appeared to produce better fits between the expected and revised acoustic survey biomass compared to all other options, particularly in the 1983 and 1992 survey year (Fig. 15). Acoustic survey selectivity for Option 5 shows a much lower selectivity at younger ages (2-8) in 1983 and 1992, while for all other years the selectivity pattern remains largely unchanged from the2003 updated model (Option 1). Again these differences translate into relatively high spawning biomass and recruitment prior to the time series peak in 1987 (Fig. 17). Despite the differences in biomass and recruitment during the earlier years among the different options, the decline in spawning biomass during the last decade has been very consistent. Again, the above table shows relatively small differences in the estimated depletion rates in 2001 ranging from 27% to 31%, and ranging from 45% to 50% in 2003.

The STAT team, upon consultation with the STAR convened on February 2-4 in Seattle, WA, examined a wide range of different model configurations and model assumptions, other than the 5 options described above. In general, this evaluation focused on values other than Q=1.0 for the acoustic survey catchability as well as model error structure assumptions. Resultant analyses revealed that the assumed model error structures (i.e. log-normal for survey biomass and multinomial for age compositions) were reasonably supported by examination of Q-Q plots of standardized residuals for each of the data components in the assessment model (Figures 18-20), but that modifications in acoustic and recruitment

Standard deviation of the Pearson residuals for the five data sets used in the hake assessment model by model run designation.

Run	Acoustic Survey Biomass Indices	Tiburon recruitment Indices	US fishery age proportions	Canada fishery age proportions	AFSC acoustic survey age proportions
Option 4	2.46	2.30	0.70	0.81	0.94
1.A	0.98	1.09	1.20	1.02	0.91
1.B	2.42	1.10	1.21	1.04	1.06
1.C	1.04	1.13	1.20	1.01	0.87
2.A	1.11	1.16	1.20	1.00	0.82
2.B	1.07	1.15	1.21	0.99	1.10

survey CVs and age composition effective sample sizes were warranted. The table above illustrates these results showing the standard deviation of the Pearson residuals for the five data sources used by the various assessment model configurations. Values substantially higher and lower than unity indicates that the data are over- or under-dispersed, respectively, relative to the error assumed for the individual data component in the model. In general, the results suggested that the assumed CVs for the acoustic and the Santa Cruz Laboratory (Tiburon) recruitment surveys (based on the original model options as shown in Option 4 above) were too low relative to the actual deviations predicted by the model. Through a process of tuning, the CVs specified for subsequent modeling were increased to CV=0.5 (1977-1989) and CV=0.3 (1992-2003) for the acoustic survey and CV=1.1 for the Santa Cruz Laboratory recruitment survey. Standard deviations of Pearson residuals shown above for model runs 1a, 1c, 2a, and 2b reflect the increased CVs. Model run 1b was specified at original lower CVs as a means for comparison of results. Similarly, the results in the above table show that a decrease in effective samples sizes for acoustic survey age compositions and increases in effective sample sizes for fishery age compositions are warranted as shown by comparison of Option 4 and other model runs (1a, 1c, 2a, and 2b). The above models representing changes in assumed CVs and weights on age compositions produced internally consistent mean squared errors.

In addition, various model configurations that included different data component weights were explored in which acoustic survey Q was freely estimated. In nearly all cases, the models tended to fit the data better when survey Q was less than 1.0; in some case Q was estimated as low as 0.26.

Based on these considerations, and after extensive review of alternative models and discussion, the STAT and STAR settled on two alternative models that encompassed the range in model uncertainty and represented equally plausible alternatives (model 1b and model 1c). The final two models are given below with two others that assisted in an orthogonal evaluation of the chosen alternatives. Each of these are in essence progeny from Option 4 above. These model configuration s were:

Final Model 1a: Model as in Option 4 (above) with year-specific expansion factors; initialization of the population age structure back to 1966 and estimate recruitment from 1966-2003; time invariant acoustic survey selectivity; acoustic survey fixed at Q=1.0; acoustic survey CV=0.5 (1977-1989) and CV=0.3 (1992-2003); Santa Cruz recruitment survey CV=1.1; 1986 acoustic survey biomass and age composition data removed (removed due to transducer calibration issues).

Final Model 2a: Model as in Final Model (1a) above but freely estimate acoustic survey Q.

Final Model 1b: Model as in Final Model (1a) above, but acoustic survey CV=0.2 (1977-1989) and CV=0.1 (1992-2003).

Final Model 1c: Model as in Final Model (1a) above, except acoustic survey fixed at Q=0.6.

Final Model 2b: Model as in Final Model (2a) but acoustic survey age compositions removed. Model results were evaluated at the STAR but not report here.

Results of the above model runs are given in Table 10 and Figures 21-22. Model 1a, 1c, and 2a are directly comparable in terms of the change in likelihoods because each assumes identical data component weights. Based on the relative difference in total negative log likelihoods model 2a (-502.36) fits better than model 1a (-515.82) or model 1c (506.67). Model 2a freely estimates acoustic survey catchability (Q=0.26) compared to model 1a in which it is fixed at Q=1.0, and a decrease in 13 likelihood units for one additional parameter to estimate Q provides some justification of the former model. Model 1a fits better compared to the model 1b (Q=1.0) because it assumes a lower fixed value of Q=0.6. Improvement in model fits appears to occur in the acoustic survey biomass and age composition data with Qs less than one (Table 10). These results are shown graphically in Figure 21 which shows the expected acoustic survey biomass closer to the observed biomass for model 2a. As in previous model runs, the alternative models fit poorly to the early acoustic biomass due to the large CVs on the earlier surveys (1977-1989) and also because the age composition data predict greater biomass during the mid 1980s (due to the strong 1980 and 1984 year class) than would be predicted by the trend in survey biomass. Model 2a attempts to better reconcile the difference in expected biomass between the age composition data and the trend in acoustic biomass better because a Q less than 1.0 would allow for biomass to be scaled higher than the observed trend. Thus, the acoustic survey biomass would be considered a relative index.

Acoustic survey selectivity is highly "domed" as in the early model Options. Each model show roughly the same pattern in acoustic survey selectivity on the descending limb, but models in which either survey Q is freely estimated or less than 1.0 have slighly higher selectivity for the younger ages of fish (Figure 21).

As might be expected, trends in spawning stock biomass are higher for models 2a and 1c in which acoustic survey Q is either estimated or assumed less than 1.0 (Figure 22). Correspondingly, spawning biomass is lowest for models 1b and 1a in which survey Q is assumed to be 1.0. Results among the models are similar in estimates of recruitment to age 2; higher recruitment for model with Q less than 1.0 to essentially account for the higher biomass (Figure 22). These results illustrate the nature of treating the primary abundance index (i.e., the acoustic survey) as an absolute measure compared to a relative measure of biomass by either estimating Q (<<1.0 in the present case) or assuming it to be less than 1.0. As such, the implications can be profound in terms of determining the allowable harvest levels based on estimated exploitable biomass and thus determining the most plausible Q is by no means trival.

All past assessment results and recommendations have been based upon fixing the acoustic survey Q=1.0; thus asserting that the acoustic survey estimate of biomass is an absolute measure of biomass and not just a relative measure. This was in large part based upon the best expert opinions and inability to quantitatively estimate it. This assessment, as well as the past several, have explored relaxation of this assumption. The ability to relax the Q=1.0 assumption in this year's assessment is based upon: 1) continued lengthening of the acoustic survey time series, thus allowing the survey to be treated as an index of relative abundance in the model; 2) relatively better model fits to the data when Q is less than 1.0; and 3) high quality of expertise in the STAR Panel to allow critical examination of the Q=1.0 assertion.

Because of the importance of Q in scaling biomass, a Bayesian prior would be the best means to quantitatively blend expert belief and simultaneously allow the model to best fit the data. Presently, the best model fit to the data and expert opinion are incongruous. Accordingly, two models (Q=0.6 and Q=1.0 as specified in Final Models 1c and 1b, respectively) are asserted as representing plausible extremes in the state of nature and therefore uncertainty in the final model result is represented by a range of biomass. The lower biomass end of the range is based upon the conventional assumption that the acoustic survey catchability coefficient, Q=1.0 (Model 1b), while the higher end of the range represents the Q=0.6 assumption (Model 1c). Even lower Q values are indicated by some model runs, but these are considered by the STAT team and STAR panel to be implausibly low (as in Model 2a). Future assessments may be able to explore alternative model configurations that could provide more insight on which aspect of the data lead to the low Q estimates. It was agreed by both the STAT team and STAR panel that model 2a unlikely because a Q < 0.3 would be implausible for an acoustic echo integration survey with the level of coverage provided by the joint US-Canadian survey. Model 1b was chosen over Model 1a (intermediate to Model 1b and Model 1c) to represent the lower bound on expected biomass over the assessment time series.

Model Evaluation

Residual plots were prepared to examine the goodness of fit of the base-run model to the age composition data. The Pearson residuals for a multinomial distribution are

$$r_i = \frac{p_i - \hat{p}_i}{\sqrt{(\hat{p}_i(1 - \hat{p}_i)/m)}} ,$$

where p_i is the observed proportion at age, and m is the nominal sample size (McCullagh and Nelder 1983). Figures 23-25 show Pearson residuals of the fit to the U.S. fishery, Canadian fishery, and acoustic survey age compositions. Although there are large residuals for some ages and years, no severe pattern of residuals is evident in the fishery age composition. There is a moderate residual pattern of positive residuals for the strong year classes and negative residuals for the weak year classes, particularly for the older fish. This pattern is strongest in the Canadian fishery age composition, but is also present to some degree in the U.S. fishery age composition. A tendency for age readers to prefer the strong year classes as fish become older and more difficult to age could account for this pattern (Kimura et al. 1992).

In general, the revised acoustic survey biomass based on the new deep-water and northern expansion factors reconciles the model to the data better than previous assessments, except with regard to the 1989 acoustic survey biomass which now lies well below the expected survey biomass (Fig. 26). The model fits the most recent surveys estimates, 1992-2001, reasonably well, but seems to essentially split the difference between the 2001-2003 survey biomass. As in previous assessments, the age composition data favors an increased biomass to 1986 followed by a decline to at least 1995. The acoustic biomass time series is highest in 1986, but otherwise is relatively flat. The 1986 acoustic survey, the second largest disparity between the expected and observed survey biomass, may have underestimated the biomass present in those years. In 1986, there was a 1.7 dB drop in the acoustic source level between pre- and post-survey calibrations. Due to uncertainty in the 1986 acoustic survey calibration the biomass from that year was omitted from the data series as specified in all final models.

Comparison of the expected survey age composition from both final models 1b and 1c to the observed revised acoustic survey age composition also shows reasonable model fits to the data (Fig. 27). Some major differences are represented in the relative strength of year classes predicted between the two alternative models (i.e., the 1980 yearclass).

Final Model Results

Parameter estimates and model output for models 1b and 1c are presented in a series of tables and figures. Results of both models 1b and 1c are presented to bracket the uncertainty in model configurations, specifically related to different assumptions of acoustic survey Q. Estimated selectivity for the U.S. and Canadian fisheries is shown in Figure 27. U.S. fishery selectivity was strongly dome-shaped in the early years (<1980) with ages 6-12 being fully selected by the fishery. Over time the age-specific selectivity in the U.S. fishery increased on both younger and older fish. Average selectivity in recent years (1998-2003) is 20% on age-2, 70% on age-3 and 90% on age-4 fish. Changes in Canadian fishery selectivity is equally pronounced over time and generally shows the same pattern with increasing selectivity toward younger fish. The descending limb of the Canadian fishery selectivity was time-invariant and thus selectivity on the oldest age groups remained constant through time. Both models 1b and 1c show qualitatively the same fishery selectivity and hence only those patterns associated with model 1b are shown.

Selectivity of acoustic survey is given in Table 11 and previously shown in Figure 26. Selectivity in the acoustic survey was high on age-2 through age-4 fish relative to the fishery selectivity, but both reached maximum selectivity on ages 5-9. Acoustic survey selectivity from model 1c was higher on younger ages relative to model 1b and due to the lower value of survey Q assumed for model 1c.

Table 12 provides estimated time series of population biomass, age-2 recruitment, and percent utilization of the total age 3+ biomass by the U.S. and Canadian fisheries for 1966-2003 for models 1b and 1c (see also Fig. 28). Both models show largely the same biomass and recruitment trajectories through time with the exception that model 1c (Q=0.6) has absolute estimates elevated above those of model 1b. In the early 1970s to early 1980s biomass was relatively stable with low levels of recruitment punctuated infrequently by more moderate year classes (Fig. 28) Biomass increased substantially during the middle 1980s as the 1980 (1982 recruitment) and 1984 (1986 recruitment) year classes recruited to the population. The time series peak 1987 biomass ranges between 7 and 11 million mt for model 1b and 1c, respectively. Population biomass then declined after 1987 as the 1980 and 1984 year class were replaced by more moderate year classes and the 1980 and 1984 year classes were exploited. In more recent years (1997 - 2001), biomass declined to its lowest level in the time series of 1.3 and 2.7 million mt in 2001 for models 1b and 1c, respectively. However, as the 1999 year class, estimated to be the fourth largest, recruited into the population biomass increase substantially in 2002 and 2003. As a consequence, spawning biomass in 2003 was estimated to be between 2.7 million mt (Model 1b) and 4.2 million mt (Model 1c), and at roughly 48% of unfished biomass. The harvest rate of age-3+ Pacific hake was generally below 10% during 1972-93, then increased to above 20% in 1999-2001.

Uncertainty and Sensitivity Analyses

Uncertainty in current stock size and other state variables were explored using a Markov Chain Monte Carlo simulation in AD model builder. Although MCMC has been used mostly in Bayesian applications, it can also be used to obtain likelihood-based confidence regions. It has the advantage of producing the true marginal likelihood (ore marginal distributions) of the parameter, rather than the conditional mode, as with the likelihood profile. We ran the MCMC routine in ADMB drawing 2,500,000 samples in which the first 25% of the samples were discarded (as the burn-in) and every 1000^{th} sample saved to reduce autocorrelation in the chain sequence. Initial MCMC runs revealed significant autocorrelation among sequential draws of the chain even after a lag of 100. Results of the MCMC simulation were evaluated for nonconvergence to the target posterior distribution. The final samples from the MCMC were used to develop the probability distributions of the target marginal posterior. MCMC diagnostic results are only shown for model 1b since results were qualitatively similar for both final models 1b and 1c.

Convergence diagnostics of selected parameters from the MCMC simulation suggests that no severe problems of non-convergence is present for the 2003 basemodel (Fig. 29 and 30). Trace plots (panels A) of two selected model state variables, Bzero or unfished biomass and 2003 spawning biomass, illustrate that these variables are quite stable over the thinned chain sequence and that the percentiles (panels C) shown suggest reasonable stationarity. In addition, autocorrelations between 1000^{th} draws of the chain sequence drop below +/- 0.10 after the first lag indicating that thinning the chain at a rate of every 1000^{th} draw should substantially reduce between draw correlation. Kernel density plots for these variables are also shown in Figure 29 (panel D). Figure 30 provides a more thorough summary of 46 parameters (and state variables) from the MCMC simulation. Except for a few parameters with autocorrelation above 0.15, most of the 46 parameters examined achieve autocorrelations of less than 0.10 after chain sequence thinning rate of every 1000^{th} draw. Furthermore, most of the 46 parameters examined have a Geweke statistic of less than +/- 1.96 indicating stationarity of the mean of the parameter. Finally, all 46 parameters passed the Heidelberger-Welch statistic test. If passed the retained sample is deemed to estimate the posterior mean with acceptable precision, while if failed, it implies that a longer MCMC run is needed to increase the accuracy of the posterior estimates for the given variable. Based on the above diagnostic tests the retained MCMC sample appears acceptable for use in characterizing the uncertainty (distribution) of state variables.

Sensitivity to survey catchability assumptions

A decision analysis was conducted to evaluate the consequences of assuming a harvest rate policy associated with lower or higher acoustic survey Q (assumed state on nature) when in fact the converse was true (true state on nature). This analysis defines a 2x2 matrix with two assumed states of nature (Q=1.0 and Q=0.6) and two true states of nature (Q=1.0 and Q=0.6) under both the F40%(40-10) and F45%(40-10) harvest rate policies. It should be noted that Q=1.0 and Q=0.6 correspond to Final Models 1b and 1c, respectively, which have slightly different specifications. Projected spawning biomass, depletion level (% unfished biomass), and exploitation rates in 2004-2005 were examined (Table 13). Results of this analysis suggest that more dire consequences occur when assuming harvest rate policies consistent with the Q=0.6 model assumption when in fact the Q=1.0 model assumption turns out to be the true state of nature (lower left diagonal of Table13), than when the converse is the case. As such, the female spawning biomass drops to 490 million mt in 2006 with a depletion level of only 18% compared to spawning biomass of 655 million mt and a depletion level of 24% when the harvest policy is assume correctly for the Q=1.0 model assumption. Under the more conservative scenario when harvest rates are consistent with the Q=1.0 model assumption and the Q=0.6 model assumption turns out to be the true state of nature (upper right diagonal of Table 15) the depletion level reaches 29% compared to 24% when the harvest policy assumed is consistent with the true state of nature. In general, these results suggest rather significant differences between which model is assumed for setting harvest rates and the resulting risks involved because survey acoustic Q determines directly the assumed absolute level of harvest from the exploitable stock biomass.

To further evaluate uncertainty both final models 1b and 1c were run in which acoustic survey Q was freely estimated. As specified, the final model acoustic survey catchabilities were fixed and Q=1.0 (Final Model 1b) and Q=0.6 (Final Model 1c) in the model runs, which represent fixed point estimates. To explore the uncertainty in these values based upon the model configurations for models 1b and 1c, acoustic survey Q was freely estimated and then uncertainty was characterized using the samples drawn from a Markov Chain Monte Carlo simulation of the posterior distribution. Marginal posteriors of acoustic survey catchability from Final Models 1b and 1c were also compared to acoustic survey Q freely estimated from model option 4. Acoustic survey q was estimated to be approximately 0.58 (posterior model of MCMC sample) with 95% credibility intervals ranging from 0.38 to 0.76 (Fig. 31) for model option 4. Acoustic survey Q was estimated to be much lower for Final Models 1b and 1c; Q=0.38 and Q=0.26, respectively. In the case of Final Model 1c, a lower emphasis on the acoustic survey biomass for all years caused survey Q to be lower in order to scale biomass up to a level of magnitude consistent with that predicted by the age compositions. Correspondingly when higher emphasis was placed on survey biomass (i.e. Final Model 1b) survey Q was estimated to be higher because greater weight was given to the model to fit the survey biomass relative to the age compositions. It should be noted that estimated biomass and recruitment translate into substantially higher biomass for models when q is assumed to be less than 1.0. Both the STAT and STAR conceded that acoustic survey catchability substantially less than 0.6 seems unplausible.

Uncertainty in 2003 stock size and female spawning biomass

The results of the MCMC based on 2,500,000 simulations was then plotted to evaluate the uncertainty of the state variables of interest. Results show that 2003 female spawning biomass was estimated to be 1.25 million mt and 2.0 million mt for final models 1b and 1c, respectively (Fig. 32). Based on the marginal posterior distributions 2003 female spawning biomass has greater than a 70% probability of exceeding the 40% unfished biomass level for both model alternatives (Fig. 32). Uncertainty in the 2003 depletion level was also examined. The posterior mode of the depletion level (B_{2003}/B_{zero}) was estimated to be approximately 48% of unfished biomass for both models 1b and 1c, with less than a 5% chance of being below 40%B0 (Fig. 32).

TARGET FISHING MORTALITY RATES

To evaluate harvesting strategies and target fishing mortality rates for projections, we employed the 40-10 option that provides a more gradual response to declining stock sizes by reducing *catches* linearly, rather than fishing mortality. The 40-10 option can be expressed approximately in fishing mortality as

$$F_{ABC} = F_{40\%} \frac{B_{40\%}}{B} \left[\frac{B - B_{10\%}}{B_{40\%} - B_{10\%}} \right],$$

Dorn et al. (1999) evaluated the 40-10 option relative to the hybrid F strategy (Shuter and Koonce, 1985) that was formerly used to manage the hake stocks and found approximately the same overall reduction in harvest rates. In general, they concluded that as a control law the general form of 40-10 policy was an improvement over the hybrid F strategy. Moreover, using a Bayesian meta-analysis of Merluciid stock recruit relationships, Dorn et al. (1999) showed that F40-F45% may be appropriate proxies for F_{MSY} depending of the level of risk aversion.

The following estimates of F40%, F45%, and F50% under the 40-10 option were obtained using the life history vectors in Table 14. The Canadian F multiplier is used to scale the Canadian fishing mortality so that the mean yield per recruit for the U.S. and Canadian fisheries corresponds to the historical distribution of catches (~25%). Previous work has demonstrated that overall yield per recruit is relatively insensitive to the allocation of yield within the range in dispute. Unfished spawning biomass was based on mean 1966-2003 recruitment (2.1 and 3.1 billion for models 1b and 1c, respectively) and SPR at F=0 (1.233 kg/recruit).

Final Model 1b

SPR rate	U.S. Fishing mortality	Canadian F multiplier	Equilibrium harvest rate
F40%	0.243	0.546	20.1%
F45%	0.187	0.627	16.8%
F50%	0.153	0.659	14.0%
Unfished female spawning biomass	2.73 million t		
B40%	1.092 million t		

Final Model 1c

SPR rate	U.S. Fishing mortality	Canadian F multiplier	Equilibrium harvest rate
F40%	0.227	0.630	20.2%
F45%	0.168	0.595	16.8%
F50%	0.153	0.568	13.9%
Unfished female spawning biomass	4.10 million t		
B40%	1.64 million t		

HARVEST PROJECTIONS

For harvest projections, model estimates of population numbers at age in 2001 and their variance were projected forward for the years 2004-2008. Estimates of future recruitment, N_{i2}, are also needed for the projections. Survey indices of age-0 abundance in 2002 and 2003 available from the Santa Cruz Laboratory larval rockfish survey are used to represent projected recruitment in 2004 and 2005. Recruitment estimates projected in future years were modeled to account for two sources of variability: random variation in recruitment (process error), and sampling variability of the index (measurement error). For example, if recruitment itself is not highly variable, an index that shows an extremely low or high value should be shrunk towards the mean, particularly if it is known that sampling variability for that index is large. The appropriate tradeoff between these different sources of uncertainty is obtained by adding a log likelihood term for future recruitments in the final estimation phase. Assuming that both recruitment variability and sampling variability are log normal,

$$\log L_{Fut.\ Recr.} = -\frac{1}{2\sigma_r^2}\sum_i[\log(N_{i2}) - \overline{\log(N_2)}\,]^2 - \sum_k \frac{1}{2\sigma_k^2}\sum_i[\log(q_k N_{i2}) - \log(R_i)]^2$$

where $\overline{\log(N_2)}$ is the mean log recruitment as estimated by the base-run model, σ_r is the standard deviation of log recruitment, and σ_k is the standard deviation of the log index from survey k, which can be estimated using the prediction error of the index in the assessment model. These parameters were fixed at the values estimated by the two final model alternatives. The standard deviations for log recruitment ($Model 1b{:}\sigma_r = 1.17 Model 1c{:}\sigma_r = 1.27$) and the log index ($Model 1b{:}\sigma_k = 1.28 Model 1c{:}\sigma_k = 1.36$) of the Santa Cruz Laboratory recruitment survey were similar implying that estimates of future recruitment should be roughly an average of the log mean recruitment from the assessment model run and the Santa Cruz Laboratory survey prediction. In years when no indices are available, as in 2006-2008, the estimated log recruitment will be drawn toward the mean log recruitment from the assessment model and thus uncertainty will be equal to the process error in recruitment. As with other state variables, the uncertainty in short-term projections were evaluated using MCMC simulation. Use of MCMC for projections would be particularly appropriate since the MCMC draws from a log-normal distribution and, as such, produces biomass levels more like that generated from the arithmetic mean recruitment.

Results of short-term projections are given in Table 15 and state variables are summarized in terms of 10%, 50% and 90% of 2,500,000 MCMC samples for each of the harvest rates policies (Also see Fig. 33-34). Under both final model alternatives 1b and 1c and under all harvest rates policies, female spawning biomass is projected to decline to near 25% unfished biomass between 2004 and 2006, due to lower than average recruitment expected from the Santa Cruz Laboratory recruit index. Both final model alternatives 1b and 1c show essentially the same levels of projected depletion, although their actual biomass levels differ. However, the decline in spawning biomass is somewhat dependent upon the harvest policy chosen; under the F45% (40-10) option the 2006 depletion rate falls to 27%B0 as compared to 25%B0 under the F40% option (Table 15). Despite the short- term decline, spawning biomass is projected to increase only slightly to between 27% and 30%B0 by 2008 depending upon the model and harvest rate policy, as the assumed low 2002 and 2003 year classes are replaced by long-term average recruitment. Information on recruitment from the NMFS-PWCC survey is not yet of sufficient duration to include in this assessment, but it suggests that the 2003 year class may not be as low as indicated by the Tiburon index.

Projected 2004 Coastwide yield varies substantially between the two final model alternatives 1b and 1c. Under final model 1b with assumed survey Q=1.0, 2004 coastwide yield ranges from a low of 412,800 mt to 501,000 mt under the F45% (40-10) and F40% (40-10) harvest rate policy, respectively (Table 15, Fig. 34). Contrastingly, higher 2004 coastwide yields are estimated from final model 1c ranging from 629,700 mt to 740,400 mt under the F45% (40-10) and F40% (40-10) harvest rate policy, respectively (Table 15, Fig. 34). As with spawning biomass, coastwide yield is projected to decline, but without a subsequent increase after 2006.

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Table 1. Annual catches of Pacific whiting (1,000 t) in U.S. and Canadian management zones by foreign, joint venture (JV), domestic at-sea, domestic shore-based, and tribal fisheries, 1966-2003.

	U.S.						Canada				U.S. and Canada total
			Domestic								
Year	Foreign	JV	At-sea	Shore	Tribal	Total	Foreign	JV	Shore	Total [1]	
1966	137.000	0.000	0.000	0.000	0.000	137.000	0.700	0.000	0.000	0.700	137.700
1967	168.699	0.000	0.000	8.963	0.000	177.662	36.713	0.000	0.000	36.713	214.375
1968	60.660	0.000	0.000	0.159	0.000	60.819	61.361	0.000	0.000	61.361	122.180
1969	86.187	0.000	0.000	0.093	0.000	86.280	93.851	0.000	0.000	93.851	180.131
1970	159.509	0.000	0.000	0.066	0.000	159.575	75.009	0.000	0.000	75.009	234.584
1971	126.485	0.000	0.000	1.428	0.000	127.913	26.699	0.000	0.000	26.699	154.612
1972	74.093	0.000	0.000	0.040	0.000	74.133	43.413	0.000	0.000	43.413	117.546
1973	147.441	0.000	0.000	0.072	0.000	147.513	15.125	0.000	0.001	15.126	162.639
1974	194.108	0.000	0.000	0.001	0.000	194.109	17.146	0.000	0.004	17.150	211.259
1975	205.654	0.000	0.000	0.002	0.000	205.656	15.704	0.000	0.000	15.704	221.360
1976	231.331	0.000	0.000	0.218	0.000	231.549	5.972	0.000	0.000	5.972	237.521
1977	127.013	0.000	0.000	0.489	0.000	127.502	5.191	0.000	0.000	5.191	132.693
1978	96.827	0.856	0.000	0.689	0.000	98.372	3.453	1.814	0.000	5.267	103.639
1979	114.909	8.834	0.000	0.937	0.000	124.680	7.900	4.233	0.302	12.435	137.115
1980	44.023	27.537	0.000	0.792	0.000	72.352	5.273	12.214	0.097	17.584	89.936
1981	70.365	43.556	0.000	0.839	0.000	114.760	3.919	17.159	3.283	24.361	139.121
1982	7.089	67.464	0.000	1.024	0.000	75.577	12.479	19.676	0.002	32.157	107.734
1983	0.000	72.100	0.000	1.050	0.000	73.150	13.117	27.657	0.000	40.774	113.924
1984	14.722	78.889	0.000	2.721	0.000	96.332	13.203	28.906	0.000	42.109	138.441
1985	49.853	31.692	0.000	3.894	0.000	85.439	10.533	13.237	1.192	24.962	110.401
1986	69.861	81.640	0.000	3.463	0.000	154.964	23.743	30.136	1.774	55.653	210.617
1987	49.656	105.997	0.000	4.795	0.000	160.448	21.453	48.076	4.170	73.699	234.147
1988	18.041	135.781	0.000	6.876	0.000	160.698	38.084	49.243	0.830	90.490	251.188
1989	0.000	203.578	0.000	7.418	0.000	210.996	29.753	62.618	2.563	99.532	310.528
1990	0.000	170.972	4.713	8.115	0.000	183.800	3.814	68.313	4.022	76.680	260.480
1991	0.000	0.000	196.905	20.600	0.000	217.505	5.605	68.133	16.178	104.522	322.027
1992	0.000	0.000	152.449	56.127	0.000	208.576	0.000	68.779	20.048	86.370	294.946
1993	0.000	0.000	99.103	42.119	0.000	141.222	0.000	476.422	12.355	58.783	200.005
1994	0.000	0.000	179.073	73.656	0.000	252.729	0.000	85.162	23.782	106.172	358.901
1995	0.000	0.000	102.624	74.965	0.000	177.589	0.000	26.191	46.193	70.418	248.007
1996	0.000	0.000	112.776	85.127	14.999	212.902	0.000	66.779	26.395	93.174	306.076
1997	0.000	0.000	121.173	87.410	24.840	233.423	0.000	42.565	49.227	91.792	325.215
1998	0.000	0.000	120.452	87.856	24.509	232.817	0.000	39.728	48.074	87.802	320.619
1999	0.000	0.000	115.259	83.419	25.844	224.522	0.000	17.201	70.132	87.333	311.855
2000	0.000	0.000	116.090	85.828	6.500	208.418	0.960	15.059	6.382	22.401	230.819
2001	0.000	0.000	102.129	73.474	6.774	182.377	0.000	21.650	31.935	53.585	235.962
2002	0.000	0.000	63.258	45.708	23.148	132.114	0.000	0.000	50.769	50.769	182.883
2003	0.000	0.000	67.473	55.335	20.684	143.492	0.000	0.000	62.090	62.090	205.582
Average 1966-2003						156.482				51.506	207.988

[1] Canadian fishery total catch revised 1996-2001.

Table 2. Harvest strategies, coastwide ABCs, quotas or havest guidelines for U.S. and Canadian zones, and Pacific whiting catches (t) in the U.S. and Canadian zone (1978-98).

Year	Harvest strategy	Acceptable Biological Catch (t) (coastwide)	U.S. harvest guideline or quota (t)	U.S. catch (t)	% of U.S. harvest guideline utilized	Canadian scientific recommendations, low to high risk (t), (CAN) = Canadian zone only	Canadian quota (t)	Canadian catch (t)	% of Canadian quota utilized	Total Catch (t)	% of ABC harvested
1978	N/A	---	130,000	98,372	75.7	NA	NA	5,267	NA	103,639	---
1979	N/A	---	198,900	124,681	62.7	35,000 (CAN)	35,000	12,435	35.5	137,116	---
1980	N/A	---	175,000	72,353	41.3	35,000 (CAN)	35,000	17,584	50.2	89,937	---
1981	N/A	---	175,000	114,762	65.6	35,000 (CAN)	35,000	24,361	69.6	139,123	---
1982	N/A	---	175,500	75,578	43.1	35,000 (CAN)	35,000	32,157	91.9	107,735	---
1983	N/A	---	175,500	73,151	41.7	35-40,000 (CAN)	45,000	40,774	90.6	113,925	---
1984	N/A	270,000	175,500	96,381	54.9	35-40,000 (CAN)	45,000	42,109	93.6	138,490	51.3
1985	N/A	212,000	175,000	85,440	48.8	45-67,000 (CAN)	50,000	24,962	49.9	110,402	52.1
1986	N/A	405,000	295,800	154,963	52.4	75-150,000 (CAN)	75,000	55,653	74.2	210,616	52.0
1987	N/A	264,000	195,000	160,449	82.3	75-150,000 (CAN)	75,000	73,699	98.3	234,148	88.7
1988	Variable effort	327,000	232,000	160,690	69.3	98-176,000 (CAN)	98,000	90,490	92.3	251,180	76.8
1989	Variable effort	323,000	225,000	210,992	93.8	87-98,000 (CAN)	98,000	99,532	101.6	310,524	96.1
1990	Variable effort - high risk	245,000	196,000	183,800	93.8	32-70,000 (CAN)	73,500	76,680	104.3	260,480	106.3
1991	Hybrid -mod. risk	253,000	228,000	217,505	95.4	175-311,000	98,000	104,522	106.7	322,027	127.3
1992	Hybrid -mod. risk	232,000	208,800	208,576	99.9	160-288,000	90,000	86,370	96.0	294,946	127.1
1993	Hybrid -mod. risk	178,000	142,000	141,222	99.5	122-220,000	61,000	58,783	96.4	200,005	112.4
1994	Hybrid-low risk	325,000	260,000	252,729	97.2	325-555,000	110,000	106,172	96.5	358,901	110.4
1995	Hybrid-low risk	223,000	178,400	176,107	98.7	223-382,000	76,500	70,418	92.0	246,525	110.5
1996	Hybrid-low risk	265,000	212,000	212,900	100.4	161-321,000	91,000	88,240	97.0	301,140	113.6
1997	Hybrid-moderate risk	290,000	232,000	233,423	100.6	161-321,000	99,400	90,630	91.2	324,053	111.7
1998	Hybrid-moderate risk	290,000	232,000	232,509	100.2	116-233,000	80,000	86,738	108.4	319,247	110.1
1999	40-10 option-moderate risk	290,000	232,000	242,522	104.5	90,300	90,300	86,637	95.9	329,159	113.5
2000	40-10 option-moderate risk	290,000	232,000	208,418	89.8	90,300	90,300	22,257	24.6	230,675	79.5
2001	40-10 option-moderate risk	238,000	190,400	182,377	95.8	81,600	81,600	53,257	65.3	235,634	99.0
2002		208,000	129,600	129,993	100.3			50,796		180,789	86.9
2003		235,000	148,200	141,506	95.5			62,090		203,596	86.6

Table 3. Length and age sample sizes for estimates of Pacific whiting age composition for U.S. surveys and fisheries. A. AFSC acoustic survey, B. U.S. shore-based fishery, C. U.S. at-sea fishery.

A. AFSC acoustic survey

Year	No. hauls	No. lengths	No. aged
1977	116	11,695	4,262
1980	72	8,296	2,952
1983	38	8,614	1,327
1986	48	12,702	2,074
1989	25	5,606	1,730
1992	62	15,852	2,184
1995	95	22,896	2,118
1998	108	33,347	2,417
2001	90	16,442	2,536
2003	182	3,007	3,007

B. U.S. shore-based fishery

Year	No. samples	No. aged
1990	15	660
1991	26	934
1992	47	1,062
1993	36	845
1994	50	1,457
1995	51	1,441
1996	34	1,123
1997	58	1,759
1998	66	2,021
1999	61	1,452
2000	75	1,314
2001	39	1,983
2002	71	1,582
2003	79	1,561

Estimation methods:
A. Acoustic survey. Age-length keys by geographic strata (Wilson and Guttormsen 1997)
B. U.S. shore-based fishery. Stratified random design with strata based on port groups.
C. U.S. at-sea fishery. Age-length keys by geographic strata (Dorn 1991). Number of hauls are those where length samples were taken.

C. U.S. at-sea fishery

Year	No. hauls	No. lengths	No. aged
1973		NA	
1974		NA	
1975		NA	
1976	279	53,429	4,077
1977	1,103	142,971	7,698
1978	832	124,771	5,839
1979	1,156	173,356	3,124
1980	682	102,248	5,336
1981	905	135,740	4,268
1982	1,145	171,816	4,258
1983	1,112	166,858	3,232
1984	1,625	243,684	3,310
1986	3,161	474,107	3,070
1987	2,876	431,454	3,175
1988	2,801	420,144	3,043
1989	2,666	368,807	3,041
1990	2,101	268,083	3,112
1991	1,022	112,477	1,335
1992	848	78,626	2,175
1993	423	33,100	1,196
1994	645	47,917	1,775
1995	434	30,285	690
1996	530	33,209	1,333
1997	632	49,592	1,147
1998	744	47,789	998
1999	284	49,246	1,047
2000	237	48,143	1,257
2001	287	48,426	1,104
2002	258	23,433	1,970
2003	264	24,420	1,770

Table 4. Catch at age (millions of fish) for the Pacific whiting fisheries, 1973-2003. Separate tables are given for U.S. and Canadian fisheries. The aggregate catch from all foreign, joint venture, domestic fisheries is included in these estimates.

	Age															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
U.S. fisheries																
1973	0.00	0.00	55.92	9.67	21.72	40.22	25.16	23.01	21.51	10.33	4.51	1.94	1.08	0.00	0.00	215.07
1974	29.31	1.30	0.98	150.14	20.52	35.50	44.29	25.73	11.40	3.58	1.63	0.98	0.33	0.00	0.00	325.69
1975	0.00	88.43	2.69	3.70	128.11	21.86	23.54	38.00	17.15	7.40	3.70	1.35	0.34	0.00	0.00	336.27
1976	0.00	0.33	36.85	29.29	29.62	185.27	27.65	13.82	4.93	0.99	0.33	0.00	0.00	0.00	0.00	329.09
1977	0.00	1.81	3.80	54.35	11.23	19.93	68.11	11.05	5.80	2.72	1.45	0.73	0.18	0.00	0.00	181.16
1978	0.01	0.02	4.56	8.58	51.87	9.48	20.32	38.57	5.74	2.48	1.28	0.52	0.20	0.05	0.01	143.69
1979	0.00	4.34	8.74	17.41	10.15	48.01	15.47	29.48	20.82	4.25	1.70	0.50	0.22	0.05	0.03	161.17
1980	0.00	0.13	24.67	2.16	6.90	7.16	20.11	9.57	11.99	9.92	1.74	1.35	1.01	0.59	0.14	97.44
1981	13.38	1.25	2.30	97.62	6.89	9.64	6.77	23.33	6.26	7.24	7.05	0.95	0.48	0.12	0.13	183.41
1982	0.00	27.51	1.93	1.57	57.88	5.02	5.78	5.02	11.96	2.43	2.53	4.64	0.34	0.13	0.03	126.77
1983	0.00	0.00	86.60	7.22	3.63	36.79	4.68	3.72	3.32	5.24	1.62	1.00	1.00	0.16	0.14	155.12
1984	0.00	0.00	2.59	164.97	7.18	5.18	17.54	2.17	1.24	0.82	1.34	0.21	0.20	0.31	0.03	203.78
1985	2.27	0.55	1.32	12.36	113.50	9.74	4.30	6.75	0.61	0.34	0.24	0.36	0.00	0.00	0.00	152.34
1986	0.00	62.92	12.88	1.85	9.34	171.79	21.55	10.76	12.45	1.53	1.05	0.38	0.79	0.15	0.05	307.49
1987	0.00	0.00	124.20	6.58	1.68	2.72	151.56	7.89	3.09	14.87	0.57	0.15	0.15	1.25	0.00	314.71
1988	0.00	1.22	1.31	172.76	8.02	1.40	2.60	96.93	5.16	0.72	8.32	0.15	0.24	0.00	0.65	299.48
1989	0.00	8.65	9.57	3.88	257.20	7.80	2.46	2.74	106.63	6.62	0.87	5.37	0.03	0.12	0.57	412.51
1990	0.00	5.69	85.34	10.97	1.92	152.02	2.56	1.14	0.71	95.97	0.47	0.00	6.07	0.00	0.41	363.27
1991	0.00	0.95	43.96	98.32	19.35	6.00	151.49	6.63	1.31	0.93	60.10	2.11	0.00	9.74	0.65	401.54
1992	0.97	18.53	9.94	51.95	109.58	10.27	5.09	131.94	4.84	2.38	0.79	42.06	0.63	0.20	1.88	391.05
1993	0.00	1.90	70.49	9.07	42.90	59.65	3.75	3.06	81.86	1.81	0.43	0.20	20.95	0.12	2.47	298.66
1994	0.00	0.23	16.48	121.89	4.82	76.93	104.64	3.29	2.04	115.38	0.46	2.06	0.22	29.13	3.65	476.31
1995	0.20	1.02	0.41	19.96	114.38	3.32	27.40	66.22	3.09	0.53	58.19	1.09	0.91	0.10	18.55	315.36
1996	0.00	102.26	71.90	6.75	34.60	97.87	1.81	17.17	46.84	0.90	0.17	50.38	0.00	0.49	14.81	445.94
1997	0.00	2.00	173.73	163.98	3.01	27.17	48.41	3.05	10.71	18.59	0.39	0.77	17.33	0.47	8.38	477.97
1998	0.00	26.97	117.63	103.21	133.25	16.56	20.27	41.66	4.83	2.35	17.29	1.52	0.48	11.85	3.32	501.20
1999	0.00	47.58	112.329	100.72	91.74	54.50	16.20	19.69	19.86	3.94	6.16	9.99	1.34	1.68	9.92	495.66
2000	2.13	15.24	34.58	50.95	46.19	62.31	40.85	21.48	13.48	7.83	6.52	6.74	2.83	2.72	7.44	321.30
2001	0.00	52.82	59.10	40.31	59.74	29.69	25.99	15.21	3.99	4.54	3.64	2.31	1.80	1.55	2.86	303.57
2002	0.00	0.00	156.354	36.31	15.63	12.58	8.08	6.75	5.32	1.26	1.16	1.36	0.50	0.32	1.04	246.68
2003	0.03	1.40	9.57	198.18	30.70	6.74	8.30	7.00	4.18	2.86	1.42	0.59	0.88	0.31	0.62	272.78

Table 4. Continued. Canadian catch at age.

	Age															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
								Canadian fisheries								
1977	0.00	0.01	0.01	0.25	0.09	0.30	1.83	0.53	0.50	0.42	0.40	0.35	0.16	0.00	0.00	4.85
1978	0.00	0.00	0.00	0.20	0.35	0.28	1.06	1.31	1.12	0.62	0.48	0.21	0.18	0.09	0.00	5.90
1979	0.00	0.00	0.00	0.21	0.62	1.30	1.14	2.10	3.02	1.10	0.79	0.37	0.25	0.17	0.12	11.19
1980	0.00	0.00	0.00	0.00	0.47	0.62	2.46	0.92	1.18	6.74	1.27	0.62	0.62	0.20	0.00	15.10
1981	0.00	0.00	0.00	1.01	0.27	1.41	1.38	4.28	0.85	2.36	6.18	1.49	0.60	0.85	0.00	20.68
1982	0.00	0.00	0.00	0.69	13.35	1.10	1.44	1.41	4.41	1.00	0.78	6.04	0.59	0.47	0.00	31.28
1983	0.00	0.06	14.02	1.03	1.80	32.15	1.29	1.87	1.67	5.59	0.77	0.26	3.41	0.26	0.13	64.31
1984	0.00	0.00	1.11	13.27	1.73	9.26	20.86	2.04	2.35	1.54	4.81	0.93	0.80	2.65	0.37	61.72
1985	0.00	0.06	0.06	2.45	8.03	1.65	3.25	9.62	0.49	0.55	0.55	1.65	0.37	0.00	1.59	30.32
1986	0.00	0.14	0.14	0.28	3.97	38.41	2.41	2.41	11.48	1.28	0.57	0.99	1.42	0.43	1.42	65.35
1987	0.00	0.00	0.90	0.60	0.15	2.56	70.71	2.86	2.86	10.38	0.60	0.45	1.20	0.90	1.20	95.37
1988	0.00	0.00	0.31	15.28	0.62	1.13	2.36	66.66	2.26	1.44	7.90	0.51	0.21	0.21	0.62	99.51
1989	0.00	0.00	0.20	0.59	35.55	0.20	0.39	0.59	69.34	1.76	1.37	8.59	0.39	0.20	1.17	120.34
1990	0.00	0.00	2.80	2.08	0.21	48.67	0.73	0.21	0.00	27.50	0.42	0.00	1.25	1.04	2.08	86.99
1991	0.00	0.00	0.11	6.11	2.46	0.43	70.60	0.54	0.00	0.21	47.47	0.21	0.11	2.25	0.11	130.61
1992	0.00	0.00	0.67	7.63	17.81	3.55	0.40	56.83	0.27	0.00	0.13	30.79	0.07	0.13	1.21	119.49
1993	0.00	0.07	0.77	2.52	12.91	17.54	1.89	0.21	40.62	0.21	0.14	0.14	12.49	0.21	0.21	89.93
1994	0.00	0.00	0.70	2.87	3.07	15.20	26.86	4.20	0.80	67.45	0.87	0.27	0.13	22.73	1.33	146.48
1995	4.88	0.04	0.53	6.31	5.03	3.21	10.72	15.96	3.25	0.67	33.81	0.68	0.04	0.15	9.41	94.70
1996	0.00	12.46	2.89	1.44	12.03	16.06	4.31	14.28	17.05	2.84	1.10	34.27	0.06	0.00	10.01	128.80
1997	0.00	0.81	22.17	19.19	2.52	17.21	16.22	2.25	11.08	14.42	3.24	0.54	18.65	1.35	4.06	133.73
1998	0.14	0.14	9.15	39.39	38.25	3.56	13.74	14.27	1.64	7.74	7.17	0.99	0.67	5.50	1.91	144.26
1999	1.45	26.28	9.65	18.35	40.74	25.71	1.94	8.39	8.47	2.65	3.66	4.26	0.56	0.19	4.05	156.36
2000	0.00	0.11	9.45	1.96	2.38	7.03	4.16	0.53	1.94	1.07	0.34	0.79	0.49	0.25	0.79	31.28
2001	0.00	0.04	0.86	12.32	3.24	5.06	14.31	7.54	1.70	2.37	2.72	0.95	1.69	1.41	1.61	55.81
2002	0.00	0.00	0.55	4.24	14.59	4.85	5.37	10.57	5.81	0.85	1.15	1.53	0.20	0.59	1.68	51.98
2003	0.00	0.00	0.54	28.66	16.21	6.24	10.16	5.88	6.52	4.63	1.60	0.65	0.96	0.24	0.53	82.81

Table 5. AFSC acoustic survey estimates of Pacific whiting biomass and age composition. Surveys in 1995 and 1998 were cooperative surveys between AFSC and DFO. Biomass and age composition for 1977-89 were adjusted as described in Dorn (1996) to account for changes in target strength, depth and geographic coverage. Biomass estimates at 20 log l - 68 in 1992 and 1995 are from Wilson and Guttormson (1997). The biomass in 1995 includes 27,251 t of Pacific whiting found by the DFO survey vessel W.E. Ricker in Queen Charlotte Sound. (This estimate was obtained from 43,200 t, the biomass at -35 dB/kg multiplied by 0.631, a conversion factor from -35 dB/kg to 20 log l - 68 for the U.S. survey north of 50^{o}30' N lat.). In 1992, 1995, and 1998, 20,702 t, 30,032 t, and 8,034 t of age-1 fish respectively is not included in the total survey biomass. In 2001 no age one fish were captured in survey trawls.

	Total biomass at 20 log l - 68 (1,000 t)	Number at age (million)														
Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	1596.422	0.22	135.48	121.24	718.01	63.29	87.41	745.78	106.23	78.20	40.90	39.47	21.80	8.49	2.18	2.25
1980	1701.482	0.00	14.45	1641.32	151.15	91.20	70.79	326.83	110.38	248.08	97.65	60.94	9.71	16.66	3.71	2.89
1983	1364.656	0.00	1.23	2918.17	50.86	20.64	304.29	31.84	34.78	26.00	51.01	12.46	13.39	14.84	2.69	0.00
1986	2397.386	0.00	3610.65	91.38	17.56	112.09	1701.85	179.58	131.65	181.21	21.62	21.03	1.47	10.37	2.35	0.00
1989	1805.603	0.00	571.25	200.82	39.29	1864.35	38.91	15.27	24.54	626.89	30.64	2.77	53.71	0.00	0.00	2.00
1992	1417.327	190.54	227.03	45.97	235.77	502.09	57.21	19.85	994.22	28.52	16.85	6.93	323.37	17.19	0.00	14.81
1995	1385.205	316.41	880.52	117.80	32.62	575.90	26.58	88.78	403.38	5.90	0.00	429.34	0.96	17.42	0.00	130.39
1998	1185.932	98.31	414.33	460.41	386.81	481.76	34.52	135.59	215.61	26.41	39.14	120.27	7.68	4.92	104.47	29.19
2001	737.743	0.00	1471.36	185.56	109.35	117.25	54.26	54.03	29.41	17.11	12.03	5.07	4.48	8.73	0.83	3.10
2003	1842.627	5.19	99.78	84.88	2146.50	366.87	92.55	201.22	133.09	73.54	74.67	24.06	14.18	14.63	10.33	14.12

Estimates of numbers at age based on year-specific deep-water and northern expansion factors applied to 1977-1992.

	Total biomass at 20 log l - 68 (1,000 t)	Number at age (million)														
Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	1915.01	0.24	151.94	144.57	902.04	82.60	115.79	1001.86	138.13	102.08	58.53	54.82	28.54	10.61	2.79	3.46
1980	2115.09	0.00	16.18	1971.21	190.90	115.65	94.42	417.83	154.83	333.21	133.62	78.76	13.26	22.81	4.75	3.49
1983	1646.68	0.00	1.10	3254.35	107.83	32.62	428.59	68.59	47.27	33.71	92.68	21.86	25.80	26.90	4.32	0.00
1986	2857.06	0.00	4555.66	119.65	21.04	148.80	2004.57	215.71	171.63	225.45	27.33	28.72	2.08	10.85	3.49	0.00
1989	1237.69	0.00	411.82	141.76	31.19	1276.32	28.43	10.08	18.30	435.18	22.95	1.75	43.08	0.00	0.00	1.76
1992	2169.20	230.71	318.37	42.50	246.38	630.74	77.96	31.61	1541.82	46.68	28.08	14.14	533.23	27.13	0.00	28.42
1995	1385.00	316.41	880.52	117.80	32.62	575.90	26.58	88.78	403.38	5.90	0.00	429.34	0.96	17.42	0.00	130.39
1998	1185.00	98.31	414.33	460.41	386.81	481.76	34.52	135.59	215.61	26.41	39.14	120.27	7.68	4.92	104.47	29.19
2001	737.00	0.00	1471.36	185.56	109.35	117.25	54.26	54.03	29.41	17.11	12.03	5.07	4.48	8.73	0.83	3.10
2003	1840.00	5.19	99.78	84.88	2146.50	366.87	92.55	201.22	133.09	73.54	74.67	24.06	14.18	14.63	10.33	14.12

Table 6. AFSC trawl survey estimates of Pacific whiting biomass (1,000 t) and age composition (million). The biomass estimates for 1977 and 1986, when the trawl survey did not extend into the Canadian zone, were adjusted as described in Dorn et al. (1991). In 1995, 53,730 t of age-1 fish is not included in the biomass estimate. In 1998, 20,658 t of age-1 fish is not included in the biomass estimate. Age composition data for 2001 should be considered preliminary. AFSC acoustic survey age-length key was applied to trawl survey length compositions to derive numbers and biomass at age.

	Area-swept biomass estimate (1,000 t)	Number at age (million)														
Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	76.307	0.57	7.96	4.05	16.87	3.28	7.46	33.45	7.70	6.11	3.96	2.21	1.14	0.41	0.02	0.08
1980	188.299	0.30	1.80	234.42	6.91	12.53	11.37	22.31	14.32	16.93	11.96	4.63	2.28	1.20	0.99	1.43
1983	128.808	0.11	0.27	201.77	7.40	1.43	34.06	8.53	6.63	8.57	10.71	4.36	3.16	2.20	0.24	0.43
1986	254.566	0.00	203.50	8.95	2.81	1.33	202.20	10.37	5.21	59.96	2.23	2.20	0.55	8.88	0.20	0.69
1989	379.810	114.10	44.57	14.09	11.93	172.32	10.24	15.84	4.97	270.64	9.69	1.43	36.48	0.14	0.33	2.65
1992	352.538	56.14	47.95	5.72	28.12	78.63	9.10	3.32	202.78	3.60	3.25	2.61	74.35	3.43	0.00	4.85
1995	529.527	592.70	171.38	22.12	20.88	97.14	6.48	49.25	233.89	0.00	0.00	181.53	0.00	4.61	0.00	142.41
1998	476.459	212.14	442.40	285.14	132.36	151.01	12.48	34.31	72.23	12.36	7.24	46.03	0.68	4.55	33.74	14.03
2001	379.276	36.74	398.62	93.26	50.07	78.97	45.24	55.03	27.47	11.10	12.92	6.52	4.31	4.46	1.30	0.86
2003	Not Available															

Table 7. DFO acoustic survey estimates of Pacific whiting biomass (1,000 t) and age composition (proportion in numbers) in the Canadian zone. The biomass and age composition in 1995 are from the U.S.-Canadian joint survey of the Canadian zone, and is reported in Wilson and Guttormsen (1997).

	Total biomass at -35 dB/kg (1,000 t)	Number at age (million)														
Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1990	317.338	0.00	0.00	37.40	10.33	0.98	287.37	2.95	0.00	0.00	145.16	1.97	0.00	3.94	0.00	0.98
1991	563.308	0.00	0.00	2.96	54.46	10.69	1.48	448.06	1.48	0.00	1.48	346.79	3.49	1.48	23.97	0.00
1992	1101.328	0.00	0.00	8.58	88.95	214.54	54.69	1.04	840.57	3.24	0.00	0.00	351.39	0.52	4.29	7.77
1993	638.906	0.00	0.35	12.34	14.79	97.23	154.49	24.32	9.55	421.22	4.03	1.86	2.49	173.32	1.44	7.66
1994	224.907	0.00	1.44	5.96	7.87	8.34	36.86	53.37	10.35	2.33	138.50	1.08	0.00	0.00	37.16	0.74
1995	374.400	112.05	0.00	0.00	1.49	71.19	7.40	29.33	144.78	2.84	0.00	181.00	0.00	10.15	0.00	38.41
1996	447.410	1.18	77.89	21.83	7.08	79.07	61.96	29.51	57.83	92.06	18.88	8.26	175.26	17.11	3.54	41.31
1997	649.793	0.00	1.30	179.48	143.06	15.61	120.95	115.75	13.01	72.83	94.94	10.40	5.20	146.97	1.30	24.71

Table 8. Tiburon Midwater trawl laval rockfish survey estimates of log whiting abundance (Sakuma and Ralston 1997).

		All Strata		Monterey outside stratum only	
Year class	Year of recruitment	log(numbers)	SE	log(numbers)	SE
1986	1988	1.679	0.192	3.131	0.494
1987	1989	3.129	0.172	6.258	0.475
1988	1990	3.058	0.161	4.921	0.461
1989	1991	0.979	0.170	2.008	0.475
1990	1992	1.323	0.173	3.553	0.475
1991	1993	2.134	0.167	3.769	0.475
1992	1994	0.583	0.166	2.507	0.494
1993	1995	3.095	0.173	7.048	0.475
1994	1996	2.152	0.177	3.470	0.475
1995	1997	0.768	0.173	1.940	0.475
1996	1998	1.968	0.174	4.594	0.494
1997	1999	1.487	0.197	3.034	0.525
1998	2000	0.602	0.177	1.557	0.494
1999	2001	-	-	4.589	0.475
2000	2002	-	-	2.584	0.494
2001	2003	-	-	3.415	0.475
2002	2004	-	-	2.089	0.513
2003	2005	-	-	0.508	0.475

Table 9. Weight at age (kg) used in the stock assessment model.

	U.S. fishery weight at age [1]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1966-78	0.119	0.264	0.407	0.514	0.610	0.656	0.696	0.743	0.812	0.880	0.956	0.993	1.065	1.093	1.125
1979	0.143	0.264	0.456	0.570	0.667	0.734	0.793	0.831	0.905	0.944	1.016	1.088	1.156	1.071	1.208
1980	0.141	0.298	0.470	0.559	0.646	0.722	0.790	0.825	0.867	0.899	0.995	1.046	1.050	1.040	1.159
1981	0.137	0.286	0.429	0.547	0.632	0.697	0.760	0.809	0.858	0.888	0.934	1.000	1.055	1.075	1.176
1982	0.143	0.253	0.396	0.509	0.605	0.669	0.730	0.788	0.856	0.877	0.901	0.976	1.053	1.061	1.016
1983	0.150	0.253	0.328	0.447	0.525	0.589	0.637	0.680	0.721	0.791	0.806	0.850	0.878	1.005	0.999
1984	0.187	0.293	0.387	0.434	0.550	0.607	0.658	0.712	0.753	0.798	0.863	0.906	0.934	0.952	1.113
1985	0.213	0.321	0.412	0.491	0.545	0.619	0.679	0.796	0.777	0.831	0.920	0.961	1.023	1.004	1.111
1986	0.192	0.294	0.386	0.464	0.518	0.538	0.617	0.663	0.735	0.755	0.816	0.877	0.919	0.928	1.094
1987	0.187	0.297	0.394	0.460	0.517	0.546	0.563	0.627	0.681	0.720	0.748	0.834	0.856	0.893	0.975
1988	0.197	0.303	0.395	0.466	0.520	0.570	0.572	0.596	0.641	0.702	0.733	0.803	0.874	0.886	0.955
1989	0.192	0.232	0.320	0.402	0.454	0.502	0.538	0.565	0.577	0.584	0.668	0.752	0.826	0.900	0.854
1990	0.195	0.248	0.364	0.418	0.515	0.522	0.553	0.559	0.542	0.589	0.616	0.759	0.707	0.779	0.851
1991	0.195	0.291	0.374	0.461	0.505	0.527	0.576	0.629	0.604	0.566	0.641	0.601	0.802	0.866	0.887
1992	0.216	0.275	0.367	0.472	0.513	0.554	0.579	0.581	0.600	0.581	0.600	0.617	0.763	0.521	0.797
1993	0.196	0.283	0.348	0.402	0.468	0.511	0.509	0.524	0.557	0.556	0.569	0.603	0.587	0.636	0.615
1994	0.196	0.236	0.357	0.428	0.458	0.518	0.562	0.613	0.563	0.612	0.566	0.638	0.765	0.656	0.645
1995	0.120	0.277	0.468	0.488	0.493	0.514	0.591	0.590	0.601	0.619	0.636	0.617	0.651	0.655	0.669
1996	0.120	0.278	0.378	0.451	0.519	0.547	0.568	0.574	0.599	0.583	0.760	0.629	0.625	0.647	0.630
1997	0.097	0.340	0.421	0.471	0.536	0.532	0.572	0.584	0.603	0.625	0.746	0.657	0.684	0.623	0.716
1998	0.204	0.238	0.364	0.452	0.490	0.506	0.535	0.549	0.560	0.780	0.620	0.719	0.630	0.689	0.687
1999	-	0.244	0.338	0.414	0.505	0.527	0.548	0.572	0.638	0.582	0.722	0.698	0.846	0.750	0.780
2000	0.184	0.401	0.478	0.556	0.630	0.687	0.707	0.730	0.810	0.782	0.825	0.770	0.883	0.818	0.906
2001	-	0.319	0.485	0.591	0.632	0.681	0.740	0.749	0.767	0.826	0.780	0.823	0.838	0.801	0.825
2002	-	0.435	0.443	0.547	0.679	0.684	0.743	0.847	0.810	0.756	0.876	0.813	0.821	0.929	0.925
2003	0.429	0.420	0.472	0.500	0.539	0.585	0.609	0.620	0.641	0.664	0.669	0.697	0.674	0.685	0.760

[1] U.S. Fishery mean weights age age revised 1998-2001.

	Canadian fishery weight at age [2]														
1972-76	0.135	0.370	0.606	0.742	0.827	0.861	0.905	0.987	1.221	1.111	1.163	1.206	1.222	1.213	1.247
1977	0.143	0.355	0.570	0.744	0.824	0.871	0.875	0.957	1.020	1.104	1.164	1.222	1.240	1.207	1.273
1978	0.133	0.313	0.502	0.658	0.783	0.818	0.825	0.858	0.922	0.992	1.072	1.153	1.171	1.132	1.205
1979	0.141	0.332	0.532	0.701	0.830	0.916	0.935	0.969	0.989	1.046	1.137	1.175	1.266	1.237	1.299
1980	0.140	0.319	0.496	0.655	0.780	0.869	0.979	0.955	0.970	1.037	1.073	1.180	1.229	1.225	1.301
1981	0.136	0.309	0.479	0.660	0.741	0.829	0.891	0.985	0.961	0.977	1.137	1.096	1.172	1.204	1.272
1982	0.126	0.288	0.449	0.584	0.674	0.779	0.842	0.902	0.904	0.959	0.987	1.028	1.097	1.127	1.269
1983	0.120	0.264	0.399	0.515	0.607	0.630	0.730	0.785	0.824	0.789	0.890	0.926	0.883	0.960	1.091
1984	0.137	0.296	0.439	0.557	0.643	0.710	0.723	0.816	0.856	0.896	0.911	0.975	0.987	0.957	1.076
1985	0.142	0.311	0.465	0.584	0.712	0.740	0.792	0.871	0.889	0.931	0.978	1.048	1.037	1.012	1.067
1986	0.125	0.281	0.431	0.548	0.633	0.659	0.742	0.795	0.888	0.880	0.932	0.986	1.143	0.988	1.048
1987	0.149	0.314	0.457	0.566	0.643	0.692	0.706	0.768	0.801	0.827	0.877	0.919	0.943	0.940	0.978
1988	0.120	0.315	0.655	0.608	0.754	0.652	0.767	0.801	0.909	1.066	1.054	0.766	1.159	1.111	1.305
1989	0.192	0.315	0.521	0.666	0.657	0.690	0.924	0.807	0.806	1.071	0.950	1.049	0.779	0.852	1.515
1990	0.195	0.315	0.567	0.603	0.598	0.659	0.709	0.660	0.753	0.745	0.738	0.805	0.938	0.852	1.225
1991	0.195	0.315	0.521	0.629	0.751	0.777	0.712	0.891	0.753	0.782	0.758	0.794	0.779	0.957	0.923
1992	0.216	0.315	0.550	0.561	0.633	0.684	0.689	0.713	0.710	0.782	0.722	0.754	0.779	0.890	0.958
1993	0.196	0.315	0.440	0.515	0.530	0.558	0.588	0.567	0.600	0.589	0.834	0.805	0.619	0.852	0.923
1994	0.196	0.315	0.557	0.594	0.648	0.692	0.714	0.745	0.719	0.772	0.720	0.788	0.779	0.792	0.921
1995	0.120	0.315	0.668	0.652	0.663	0.728	0.741	0.766	0.800	0.909	0.805	0.757	0.779	0.852	0.847
1996	0.120	0.329	0.481	0.568	0.628	0.632	0.671	0.676	0.693	0.762	0.676	0.739	0.779	0.852	0.786
1997	0.120	0.496	0.536	0.574	0.658	0.700	0.687	0.717	0.739	0.746	0.754	0.811	0.782	0.836	0.819
1998	-	0.351	0.448	0.570	0.580	0.607	0.676	0.667	0.669	0.699	0.717	0.756	0.809	0.794	0.775
1999	-	0.284	0.413	0.494	0.620	0.616	0.645	0.715	0.713	0.729	0.778	0.810	0.779	0.850	0.802
2000	-	0.528	0.524	0.604	0.695	0.782	0.764	0.831	0.851	0.837	0.811	0.931	0.882	0.892	0.951
2001	-	0.315	0.766	0.812	0.842	0.909	1.020	1.016	1.047	1.099	1.102	1.120	1.053	1.045	1.150
2002	-	0.315	0.697	0.897	0.980	0.953	1.058	1.113	1.091	1.119	1.124	1.104	1.367	1.149	1.192
2003	-	0.400	0.606	0.656	0.709	0.848	0.785	0.813	0.898	0.84	0.9	0.982	0.845	0.899	1.134

[2] Canadian fishery mean weights at age (1988-2002) revised. See Appendix 1.

Table 9. Weight at age (kg) used in the stock assessment model (cont).

AFSC acoustic survey weight at age [1]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	0.123	0.256	0.388	0.492	0.589	0.662	0.724	0.796	0.860	0.892	0.949	1.008	1.057	1.093	1.119
1980	0.107	0.261	0.455	0.561	0.672	0.759	0.861	0.894	0.948	1.003	1.081	1.122	1.170	1.176	1.205
1983	0.122	0.228	0.308	0.457	0.570	0.667	0.723	0.776	0.826	0.891	0.917	0.935	0.985	1.034	1.032
1986	0.165	0.262	0.367	0.465	0.532	0.558	0.658	0.715	0.815	0.823	0.865	0.908	1.006	0.995	1.069
1989	0.143	0.321	0.387	0.461	0.521	0.561	0.599	0.621	0.634	0.638	0.682	0.729	0.870	0.984	1.069
1992	0.119	0.205	0.357	0.508	0.554	0.578	0.654	0.642	0.688	0.655	0.758	0.705	0.697	0.734	0.800
1995	0.097	0.220	0.344	0.438	0.548	0.605	0.639	0.624	0.630	0.682	0.717	0.701	0.727	0.752	0.728
1998	0.081	0.189	0.343	0.527	0.534	0.587	0.658	0.631	0.645	0.766	0.709	0.830	0.735	0.744	0.790
2001	-	0.250	0.419	0.505	0.617	0.708	0.795	0.845	0.894	1.211	1.038	1.101	0.941	0.875	1.056
2003	0.139	0.264	0.411	0.515	0.544	0.716	0.687	0.728	0.788	0.754	0.769	0.820	0.780	0.815	0.841

[1] Mean weights at age from 2001 acoustic survey revised.

AFSC bottom trawl survey weight at age

1977	0.123	0.256	0.388	0.492	0.589	0.662	0.724	0.796	0.860	0.892	0.949	1.008	1.057	1.093	1.119
1980	0.107	0.261	0.455	0.561	0.672	0.759	0.861	0.894	0.948	1.003	1.081	1.122	1.170	1.176	1.205
1983	0.122	0.228	0.308	0.457	0.570	0.667	0.723	0.776	0.826	0.891	0.917	0.935	0.985	1.034	1.032
1986	0.165	0.262	0.367	0.465	0.532	0.558	0.658	0.715	0.815	0.823	0.865	0.908	1.006	0.995	1.069
1989	0.143	0.321	0.387	0.461	0.521	0.561	0.599	0.621	0.634	0.638	0.682	0.729	0.870	0.984	1.069
1992	0.119	0.205	0.357	0.508	0.554	0.578	0.654	0.642	0.688	0.655	0.758	0.705	0.697	0.734	0.800
1995	0.091	0.204	0.279	0.408	0.476	0.530	0.609	0.659	0.682	0.704	0.727	0.730	0.733	0.706	0.679
1998	0.097	0.189	0.339	0.480	0.502	0.532	0.534	0.575	0.583	0.655	0.669	0.639	0.762	0.670	0.710
2001	-	0.189	0.339	0.480	0.502	0.532	0.534	0.575	0.583	0.655	0.669	0.639	0.762	0.670	0.710

DFO acoustic survey weight at age

1990	0.119	0.205	0.533	0.575	0.592	0.647	0.623	0.646	0.646	0.669	0.656	0.957	0.957	0.957	0.957
1991	0.119	0.205	0.533	0.560	0.592	0.641	0.615	0.633	0.633	0.650	0.656	0.657	0.657	0.657	0.657
1992	0.119	0.205	0.629	0.600	0.653	0.685	0.686	0.705	0.657	0.698	0.698	0.739	0.744	0.744	0.810
1993	0.196	0.283	0.541	0.595	0.624	0.641	0.688	0.718	0.704	0.827	0.847	0.624	0.741	0.685	0.995
1994	0.196	0.567	0.585	0.614	0.654	0.694	0.720	0.782	0.775	0.761	1.083	0.935	0.935	0.787	0.810
1995	0.098	0.235	0.371	0.508	0.642	0.778	0.739	0.740	0.691	0.739	0.787	0.769	0.752	0.771	0.790
1996	0.330	0.403	0.482	0.582	0.655	0.650	0.665	0.693	0.686	0.688	0.684	0.705	0.779	0.798	0.671
1997	0.330	0.488	0.572	0.598	0.673	0.710	0.722	0.731	0.746	0.785	0.749	0.713	0.761	0.689	0.742

Population weight at age

1972-78	0.123	0.256	0.388	0.492	0.589	0.662	0.724	0.796	0.860	0.892	0.949	1.008	1.057	1.093	1.119
1979-81	0.107	0.261	0.455	0.561	0.672	0.759	0.861	0.894	0.948	1.003	1.081	1.122	1.170	1.176	1.205
1982-84	0.122	0.228	0.308	0.457	0.570	0.667	0.723	0.776	0.826	0.891	0.917	0.935	0.985	1.034	1.032
1985-87	0.165	0.262	0.367	0.465	0.532	0.558	0.658	0.715	0.815	0.823	0.865	0.908	1.006	0.995	1.069
1988-90	0.143	0.321	0.387	0.461	0.521	0.561	0.599	0.621	0.634	0.638	0.682	0.729	0.870	0.984	1.069
1991-93	0.119	0.205	0.357	0.508	0.554	0.578	0.654	0.642	0.688	0.655	0.758	0.705	0.697	0.734	0.800
1994-96	0.097	0.220	0.344	0.438	0.548	0.605	0.639	0.624	0.630	0.682	0.717	0.701	0.727	0.752	0.728
1997-99	0.081	0.189	0.343	0.527	0.534	0.587	0.658	0.631	0.645	0.766	0.709	0.830	0.735	0.744	0.790
1999-01	-	0.250	0.419	0.505	0.617	0.708	0.795	0.845	0.894	1.211	1.038	1.101	0.941	0.875	1.056
2002-03	0.139	0.264	0.411	0.515	0.544	0.716	0.687	0.728	0.788	0.754	0.769	0.820	0.780	0.815	0.841

Female multiplier for spawning biomass

All yrs.	0.511	0.510	0.511	0.510	0.512	0.522	0.525	0.535	0.543	0.547	0.569	0.568	0.572	0.581	0.589

Table 10. Configuration, error assumptions and output (likelihoods and derived parameters) from various final model alternatives explored in the 2004 Pacific hake assessment. See text for description of model configurations.

	Model Configuration					
Parameters	4.0	1.A	1.B	1.C	2.A	2.B
q	0.563	1.000	1.000	0.600	0.276	0.208
Sigmas						
Acoustic: 77-89	0.50	0.50	0.20	0.50	0.50	0.50
Acoustic: 92-03	0.10	0.30	0.10	0.30	0.30	0.30
Tiburon	0.50	1.10	1.10	1.10	1.10	1.10
US Fishery effective sample	80	300	300	300	300	300
Canada Fishery effective sample	80	130	130	130	130	130
Acoustic survey effective sample	80	60	60	60	60	60
Rdevs	1.15	1.26	1.17	1.27	1.26	1.25
Likelihoods						
US Fishery: catch	-0.03	-0.02	-0.10	-0.01	0.00	0.00
US Fishery:age	-79.19	-245.40	-248.67	-244.39	-243.53	-244.54
Canadian Fishery: catch	0.00	-0.01	-0.02	0.00	0.00	0.00
Canadian Fishery: age	-96.20	-160.26	-167.85	-157.98	-157.00	-155.04
Acoustic survey biomass	-21.32	-10.84	-33.52	-6.68	-5.86	-5.42
Acoustic survey age	-43.90	-31.57	-37.97	-29.59	-28.08	0.00
Tiburon survey index	-40.17	-8.98	-9.01	-9.56	-10.08	-9.84
Acoustic survey slope	-0.12	-0.12	-0.48	-0.02	0.00	0.00
Recruits	-19.85	-21.83	-20.20	-21.93	-21.80	-21.51
Random walk	-16.61	-32.65	-32.00	-32.38	-31.88	-31.93
Forecast	-4.13	-4.13	-4.13	-4.13	-4.13	-4.13
Total likelihood	-321.53	-515.82	-553.96	-506.67	-502.36	-472.41
Derived Parameters						
B0	3.64	3.33	2.72	4.03	6.34	6.24
B2003	1.80	1.31	1.28	2.03	4.28	3.87
Ratio	49.6%	39.4%	47.1%	50.5%	67.5%	62.0%
US Fishery 2004 catch (X1000 t)	510.7	350.1	381.9	585.8	1238.2	1143.1
US Fishery 2004 F	0.25	0.23	0.24	0.25	0.26	0.26
Canada Fishery 2004 catch (X 1000 t)	180.6	123.8	135.0	207.1	437.8	404.1
Canada Fishery 2004 F	0.08	0.10	0.11	0.09	0.08	0.08
Total Catch (X 1000 t)	691.2	473.9	517.0	792.9	1675.9	1547.2

Table 11. Selectivity at age for Pacific whiting fisheries and surveys for final models 1b and 1c (See text for description). The fisheries and surveys were modeled using double logistic selectivity functions, with random walk process error for the U.S. and Canadian fisheries. The fishery selectivity coefficients reported below are the average of the annual selectivity coefficients for all years (1966-2003), and for the last ten years (1994-2003).

Age	U.S. fishery, all years		U.S. fishery, 1994-03		Canadian fishery, all years		Canadian fishery, 1994-03		Acoustic survey (all years)	
Model	1b	1c	1b	1c	1b	1c	1b	1c	1b	1c
2	0.104	0.108	0.131	0.136	0.016	0.017	0.040	0.040	0.323	0.536
3	0.411	0.458	0.495	0.539	0.062	0.070	0.155	0.173	0.518	0.752
4	0.768	0.827	0.854	0.886	0.138	0.172	0.238	0.289	0.725	0.901
5	0.945	0.977	0.987	1.000	0.354	0.435	0.504	0.610	0.889	0.977
6	0.997	1.000	1.000	1.000	0.625	0.712	0.694	0.812	0.980	1.000
7	1.000	0.980	0.998	0.981	0.854	0.906	0.894	0.959	1.000	0.988
8	0.972	0.926	0.991	0.949	0.957	0.979	0.973	0.995	0.962	0.946
9	0.907	0.830	0.977	0.897	0.991	1.000	0.995	1.000	0.877	0.872
10	0.795	0.690	0.950	0.815	1.000	1.000	1.000	0.994	0.754	0.763
11	0.626	0.510	0.893	0.693	0.996	0.976	0.995	0.969	0.609	0.624
12	0.434	0.322	0.782	0.527	0.963	0.887	0.961	0.881	0.460	0.471
13	0.268	0.178	0.585	0.342	0.815	0.655	0.813	0.650	0.327	0.329
14	0.143	0.092	0.339	0.193	0.449	0.324	0.448	0.322	0.221	0.214
15	0.067	0.047	0.161	0.102	0.133	0.109	0.133	0.108	0.144	0.132

Table 12. Time series of estimated biomass, recruitment, and utilization for 1966-2003 for final models 1b and 1c (See text for description). U.S. and Canadian exploitation rate is the catch in biomass divided by the total biomass of age 3+ fish at the start of the year. Population biomass is in millions of tons of age-3 and older fish at the start of the year. Recruitment is given in billions of age-2 fish.

Year	Population biomass (million t)		Female spawning biomass		Recruits (billion)		U.S. exploitation rate		Canada exploitation rate		Total exploitation rate	
Model	1b	1c	1b	1c	1b	1c	1b	1c	1b	1c	1b	1c
1966	4.912	7.425	2.538	3.857	2.536	4.704	2.8%	1.8%	0.0%	0.0%	2.8%	1.9%
1967	4.974	7.856	2.532	3.971	2.303	4.211	3.6%	2.3%	0.7%	0.5%	4.3%	2.7%
1968	4.913	8.086	2.498	4.080	2.290	4.174	1.2%	0.8%	1.2%	0.8%	2.5%	1.5%
1969	4.961	8.397	2.532	4.258	2.764	5.041	1.7%	1.0%	1.9%	1.1%	3.6%	2.1%
1970	5.099	8.886	2.548	4.411	1.581	2.800	3.1%	1.8%	1.5%	0.8%	4.6%	2.6%
1971	4.818	8.597	2.449	4.353	1.248	2.116	2.7%	1.5%	0.6%	0.3%	3.2%	1.8%
1972	4.503	8.132	2.447	4.398	6.638	11.097	1.6%	0.9%	1.0%	0.5%	2.6%	1.4%
1973	5.892	10.456	2.746	4.908	0.787	1.326	2.5%	1.4%	0.3%	0.1%	2.8%	1.6%
1974	5.455	9.751	2.739	4.915	0.717	1.163	3.6%	2.0%	0.3%	0.2%	3.9%	2.2%
1975	4.891	8.846	2.571	4.658	2.251	3.653	4.2%	2.3%	0.3%	0.2%	4.5%	2.5%
1976	4.744	8.614	2.405	4.396	0.492	0.816	4.9%	2.7%	0.1%	0.1%	5.0%	2.8%
1977	4.080	7.551	2.135	3.968	0.521	0.872	3.1%	1.7%	0.1%	0.1%	3.3%	1.8%
1978	3.588	6.706	1.904	3.573	0.304	0.514	2.7%	1.5%	0.1%	0.1%	2.9%	1.5%
1979	3.449	6.506	1.941	3.655	4.059	6.786	3.6%	1.9%	0.4%	0.2%	4.0%	2.1%
1980	4.273	7.851	2.041	3.806	0.559	0.914	1.7%	0.9%	0.4%	0.2%	2.1%	1.1%
1981	3.904	7.169	2.005	3.713	0.830	1.314	2.9%	1.6%	0.6%	0.3%	3.6%	1.9%
1982	3.006	5.539	1.875	3.381	15.620	23.809	2.5%	1.4%	1.1%	0.6%	3.6%	1.9%
1983	6.419	10.656	2.684	4.572	0.464	0.686	1.1%	0.7%	0.6%	0.4%	1.8%	1.1%
1984	6.719	11.030	3.230	5.361	0.146	0.210	1.4%	0.9%	0.6%	0.4%	2.1%	1.3%
1985	5.876	9.661	3.006	4.976	0.331	0.462	1.5%	0.9%	0.4%	0.3%	1.9%	1.1%
1986	4.962	8.195	2.840	4.640	10.559	14.178	3.1%	1.9%	1.1%	0.7%	4.2%	2.6%
1987	7.337	11.256	3.309	5.205	0.173	0.224	2.2%	1.4%	1.0%	0.7%	3.2%	2.1%
1988	6.096	9.305	3.046	4.707	0.466	0.582	2.6%	1.7%	1.5%	1.0%	4.1%	2.7%
1989	5.153	7.897	2.749	4.225	3.067	3.725	4.1%	2.7%	1.9%	1.3%	6.0%	3.9%
1990	4.984	7.475	2.503	3.818	1.425	1.666	3.7%	2.5%	1.5%	1.0%	5.2%	3.5%
1991	4.731	6.989	2.403	3.614	0.283	0.324	4.6%	3.1%	2.2%	1.5%	6.8%	4.6%
1992	3.688	5.493	1.966	2.955	2.025	2.322	5.7%	3.8%	2.3%	1.6%	8.0%	5.4%
1993	3.376	4.941	1.714	2.563	0.773	0.908	4.2%	2.9%	1.7%	1.2%	5.9%	4.0%
1994	2.870	4.193	1.480	2.204	0.325	0.380	8.8%	6.0%	3.7%	2.5%	12.5%	8.6%
1995	2.198	3.293	1.193	1.810	1.722	2.022	8.1%	5.4%	3.2%	2.1%	11.3%	7.5%
1996	2.080	3.044	1.061	1.591	1.735	2.055	10.2%	7.0%	4.5%	3.1%	14.7%	10.1%
1997	2.131	3.076	1.040	1.549	0.903	1.129	11.0%	7.6%	4.3%	3.0%	15.3%	10.6%
1998	1.833	2.688	0.915	1.376	0.838	1.103	12.7%	8.7%	4.8%	3.3%	17.5%	11.9%
1999	1.509	2.309	0.755	1.183	0.572	0.794	14.9%	9.7%	5.8%	3.8%	20.7%	13.5%
2000	1.391	2.254	0.716	1.180	1.013	1.511	15.0%	9.2%	1.6%	1.0%	16.6%	10.2%
2001	1.317	2.214	0.746	1.242	5.308	7.317	13.8%	8.2%	4.1%	2.4%	17.9%	10.7%
2002	2.855	4.441	1.164	1.878	0.398	0.433	4.6%	3.0%	1.8%	1.1%	6.4%	4.1%
2003	2.696	4.161	1.283	2.016	0.457	0.493	5.3%	3.4%	2.3%	1.5%	7.6%	4.9%
Avg. 1966-03	4.150	6.867	2.098	3.499	2.065	3.101	4.9%	3.1%	1.6%	1.0%	6.6%	4.2%

Table 13. Decision table evaluating the consequences of assuming a harvest rate policy associated with lower or higher acoustic survey Q (assumed state on nature) when in fact the converse was true (true state on nature). This analysis defines a 2x2 matrix with two assumed states of nature (Q=1.0 and Q=0.6 as specified in final models 1b and 1c, respectively) and two true states of nature (Q=1.0 and Q=0.6) under both the F40%(40-10) and F45%(40-10) harvest rate policies. Projected spawning biomass (millions mt), depletion level (% unfished biomass), and exploitation rates in 2004-2005 are given. Bottom of table also includes consequences of a constant harvest in which US fisheries take 250,000 mt annually while Canada takes allocated percentage (26.12% OY) of optimum yield.

			True State of Nature					
Assumed State of Nature			***Q = 1.0***			***Q = 0.6***		
	Year	**OY Assumed**	**Spawning Biomass**	**Percent Unfished**	**Exploitation Rate**	**Spawning Biomass**	**Percent Unfished**	**Exploitation Rate**
Q = 1.0								
	2004	514,441	1.193	0.437	0.215	1.866	0.455	0.136
F40% (40-10)	**2005**	362,573	0.940	0.344	0.195	1.574	0.384	0.116
	2006	228,593	0.655	0.240	0.185	1.183	0.288	0.110
	2004	442,698	1.193	0.437	0.178	1.866	0.455	0.112
F45% (40-10)	**2005**	322,020	0.988	0.361	0.165	1.621	0.395	0.100
	2006	219,329	0.714	0.261	0.163	1.241	0.302	0.098
Q = 0.6								
	2004	780758	1.193	0.437	0.310	1.866	0.455	0.212
F40% (40-10)	**2005**	528,428	0.820	0.300	0.309	1.424	0.347	0.190
	2006	313,132	0.490	0.179	0.356	0.976	0.238	0.173
	2004	649,304	1.193	0.437	0.264	1.866	0.455	0.177
F45% (40-10)	**2005**	472,590	0.879	0.321	0.262	1.494	0.364	0.162
	2006	302,340	0.559	0.205	0.294	1.061	0.258	0.154
Constant Catch	**2004**	384,372	1.193	0.437	0.162	-	-	-
250,000 mt US +	**2005**	344,704	1.007	0.369	0.174	-	-	-
.2612*F40%OY Can.	**2006**	309,708	0.717	0.262	0.230	-	-	-
Constant Catch	**2004**	453,934	-	-	-	1.866	0.455	0.125
250,000 mt US +	**2005**	388,025	-	-	-	1.597	0.389	0.126
.2612*F40%OY Can.	**2006**	331,790	-	-	-	1.183	0.288	0.152

Table 14. Life history and fishery vectors used to estimate spawning biomass per recruit (SPR) fishing mortalities.

Age	Natural mortality	U.S. fishery selectivity (Avg. 1994-2003)		Canadian fishery selectivity (Avg 1994-2003)		U.S. fishery weight at age (kg) (Avg. 1978-2003)	Canadian fishery weight at age (kg) (Avg. 1976-2003)	Population weight at age (kg) (Avg. 1977-2003)	Proportion of mature females	Multiplier for female weight at age
		1b	1c	1b	1c					
2	0.23	0.1311	0.1361	0.040	0.040	0.294	0.332	0.246	0.176	0.510
3	0.23	0.4950	0.5389	0.155	0.173	0.401	0.528	0.378	0.661	0.511
4	0.23	0.8541	0.8858	0.238	0.289	0.481	0.626	0.493	0.890	0.510
5	0.23	0.9873	0.9998	0.504	0.610	0.549	0.702	0.568	0.969	0.512
6	0.23	1.0000	1.0000	0.694	0.812	0.590	0.745	0.640	0.986	0.522
7	0.23	0.9977	0.9810	0.894	0.959	0.632	0.789	0.700	0.996	0.525
8	0.23	0.9910	0.9486	0.973	0.995	0.668	0.827	0.727	1.000	0.535
9	0.23	0.9774	0.8965	0.995	1.000	0.695	0.857	0.773	1.000	0.543
10	0.23	0.9496	0.8151	1.000	0.994	0.723	0.896	0.832	1.000	0.547
11	0.23	0.8931	0.6933	0.995	0.969	0.769	0.920	0.849	1.000	0.569
12	0.23	0.7818	0.5269	0.961	0.881	0.797	0.953	0.886	1.000	0.568
13	0.23	0.5848	0.3424	0.813	0.650	0.845	0.975	0.897	1.000	0.572
14	0.23	0.3393	0.1933	0.448	0.322	0.845	0.989	0.920	1.000	0.581
15+	0.23	0.1615	0.1020	0.133	0.108	0.903	1.084	0.971	1.000	0.589

Table 15. Projections of Pacific hake biomass, yield and depletion rates for 2004-2008 under different harvest rate policies from final models 1b and 1c. Shown are Bayesian credibility intervals (10%, 50%, and 90%) generated from 2,500,000 MCMC samples.

Final Model 1b

		3+ Bioimass (million mt)			SpawningBioimass (million mt)			Age-2 Recruits (billion)			Depletion Rate			Coastwide yield (t)		
Harvest Policy	Year	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
	2004	2.007	2.307	2.673	1.011	1.160	1.337	0.177	0.459	1.255	0.385	0.434	0.495	428372	501073	580313
	2005	1.573	1.839	2.190	0.801	0.927	1.084	0.080	0.228	0.583	0.304	0.346	0.401	288914	355372	438254
F40% (40-10)	2006	1.061	1.251	1.523	0.573	0.675	0.831	0.259	1.079	4.384	0.215	0.253	0.310	181377	241722	331852
Harvest Policy	2007	0.954	1.284	2.395	0.509	0.655	1.052	0.257	1.034	4.193	0.192	0.245	0.396	137269	220477	436093
	2008	0.956	1.494	3.072	0.507	0.737	1.361	0.273	1.104	4.472	0.189	0.276	0.510	137269	220477	436093
	2004	1.999	2.298	2.691	1.011	1.157	1.339	0.171	0.480	1.274	0.381	0.432	0.494	351816	412814	482618
	2005	1.661	1.933	2.288	0.840	0.974	1.138	0.078	0.212	0.587	0.317	0.362	0.421	255813	316302	383068
F45% (40-10)	2006	1.158	1.355	1.655	0.624	0.732	0.894	0.267	1.076	4.242	0.233	0.272	0.331	176448	227319	304560
Harvest Policy	2007	1.042	1.387	2.437	0.559	0.716	1.085	0.269	1.060	4.246	0.209	0.266	0.412	137933	210085	379724
	2008	1.040	1.600	3.178	0.550	0.790	1.425	0.257	1.106	4.457	0.204	0.294	0.530	137933	210085	379724

Final Model 1c

		3+ Bioimass			SpawningBioimass			Age-2 Recruits (billion)			Depletion Rate			Coastwide yield (t)		
Harvest Policy	Year	10%	50%	90%	10%	50%	90%	0.100	0.500	0.900	10%	50%	90%	10%	50%	90%
	2004	2.753	3.530	4.513	1.417	1.806	2.302	0.198	0.551	1.497	0.369	0.452	0.549	560224	740368	955991
	2005	2.159	2.727	3.485	1.110	1.398	1.776	0.092	0.262	0.722	0.289	0.350	0.426	363334	503666	682808
F40% (40-10)	2006	1.486	1.832	2.325	0.809	1.011	1.293	0.366	1.560	6.617	0.210	0.250	0.313	225035	325649	482064
Harvest Policy	2007	1.361	1.903	3.534	0.735	0.976	1.561	0.348	1.517	6.065	0.188	0.244	0.391	175928	299935	630135
	2008	1.406	2.190	4.477	0.740	1.089	1.988	0.381	1.514	6.470	0.186	0.271	0.497	175928	299935	630135
	2004	2.773	3.581	4.588	1.431	1.834	2.336	0.204	0.575	1.542	0.373	0.454	0.552	471371	629709	812876
	2005	2.265	2.895	3.719	1.170	1.484	1.889	0.091	0.252	0.677	0.304	0.367	0.448	331550	457371	613371
F45% (40-10)	2006	1.612	2.001	2.582	0.879	1.095	1.418	0.331	1.472	5.488	0.227	0.270	0.335	221059	308924	453286
Harvest Policy	2007	1.482	2.020	3.361	0.800	1.057	1.551	0.343	1.507	6.476	0.205	0.261	0.383	174915	283252	519288
	2008	1.475	2.315	4.629	0.793	1.160	2.095	0.375	1.610	6.674	0.198	0.287	0.520	174915	283252	519288

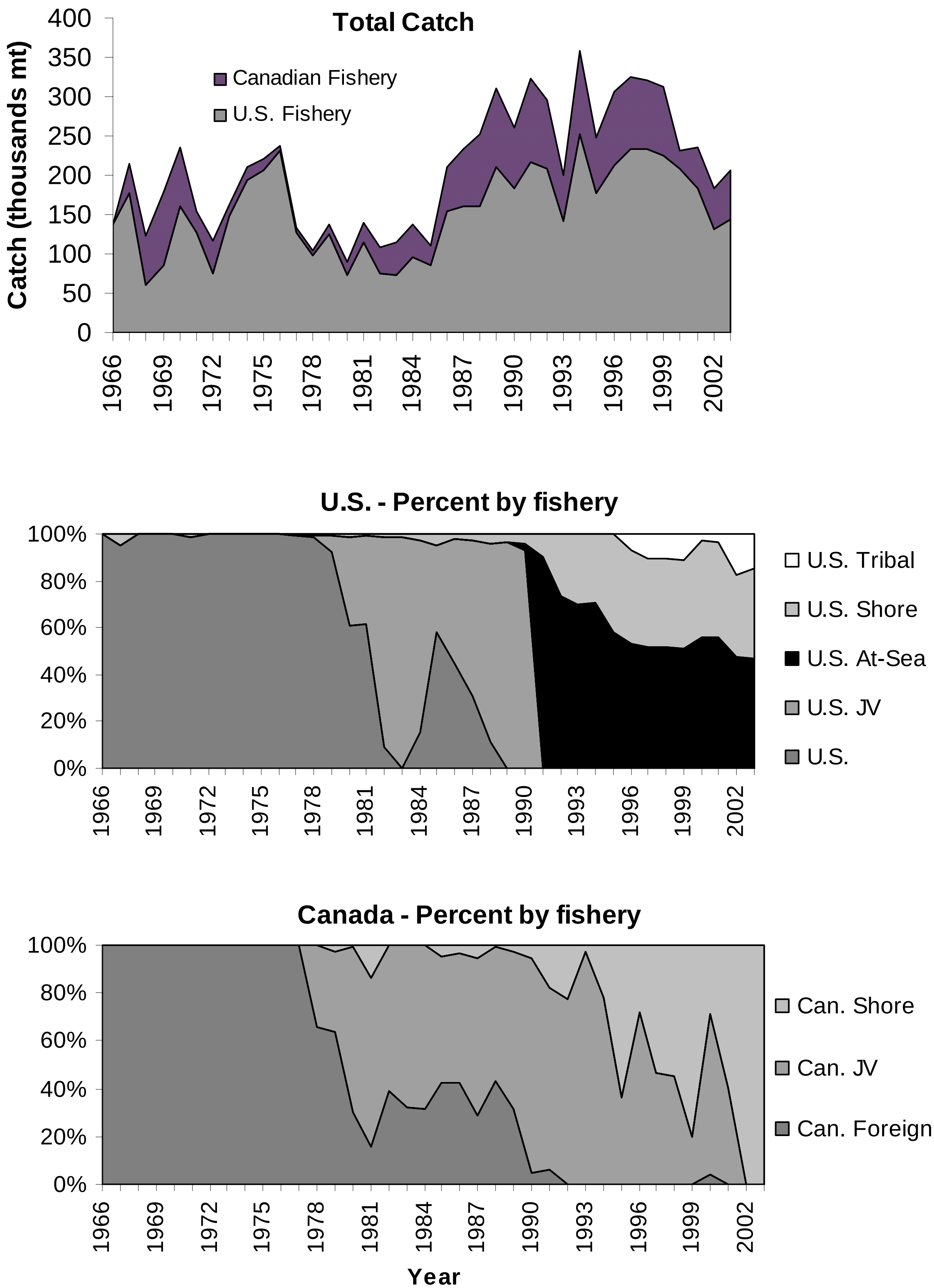


Figure 1. Total catch of Pacific hake in the U.S. and Canadian zones (1966-2003) (upper panel). Percent catch by fishery within each zone (lower panels).

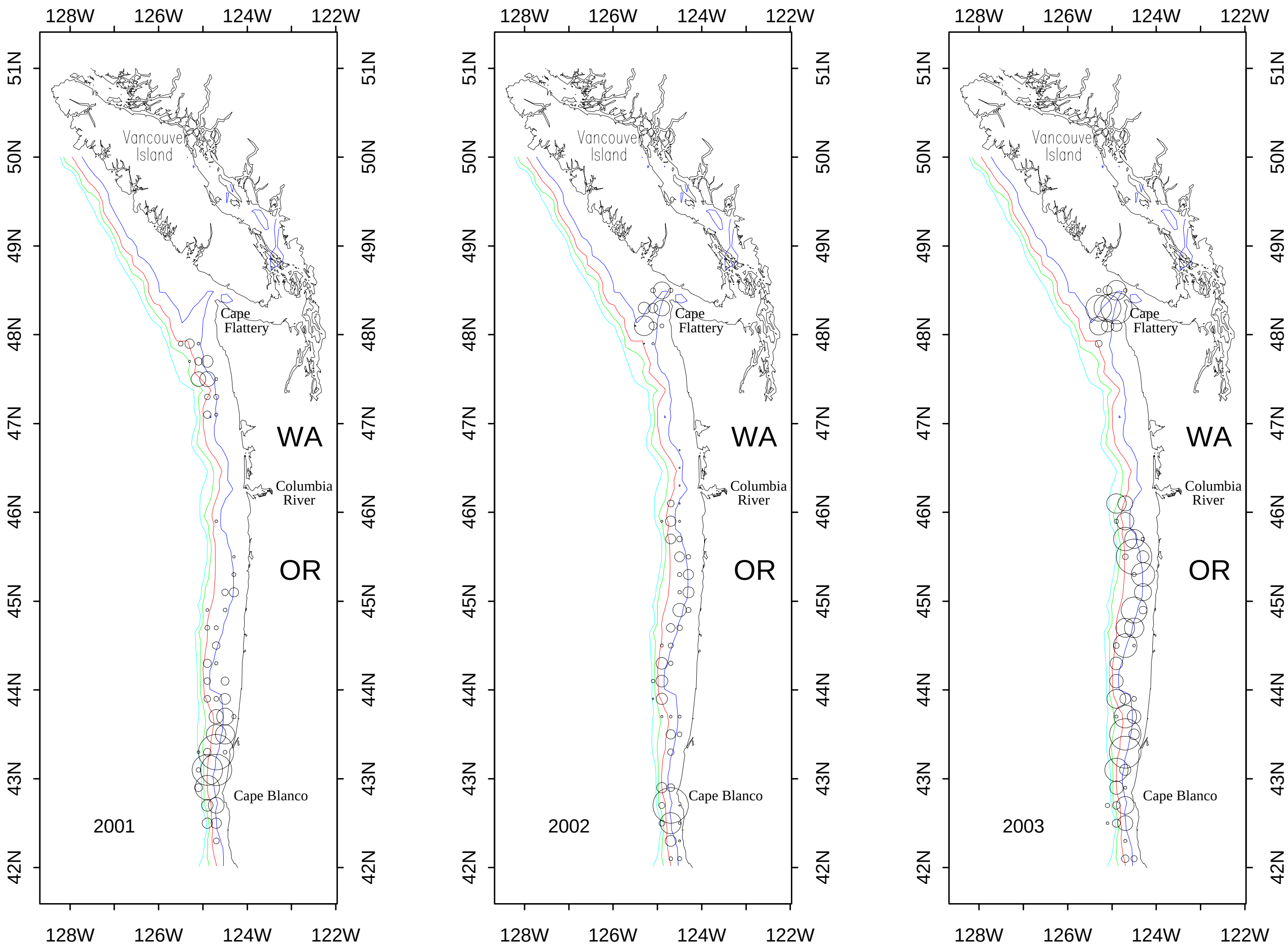


Figure 2. Catch by 20 km^2 block for factory and catcher boats in the 2001-2003 at-sea fishery for Pacific hake. Area of circle is proportional to the total catch within the block.

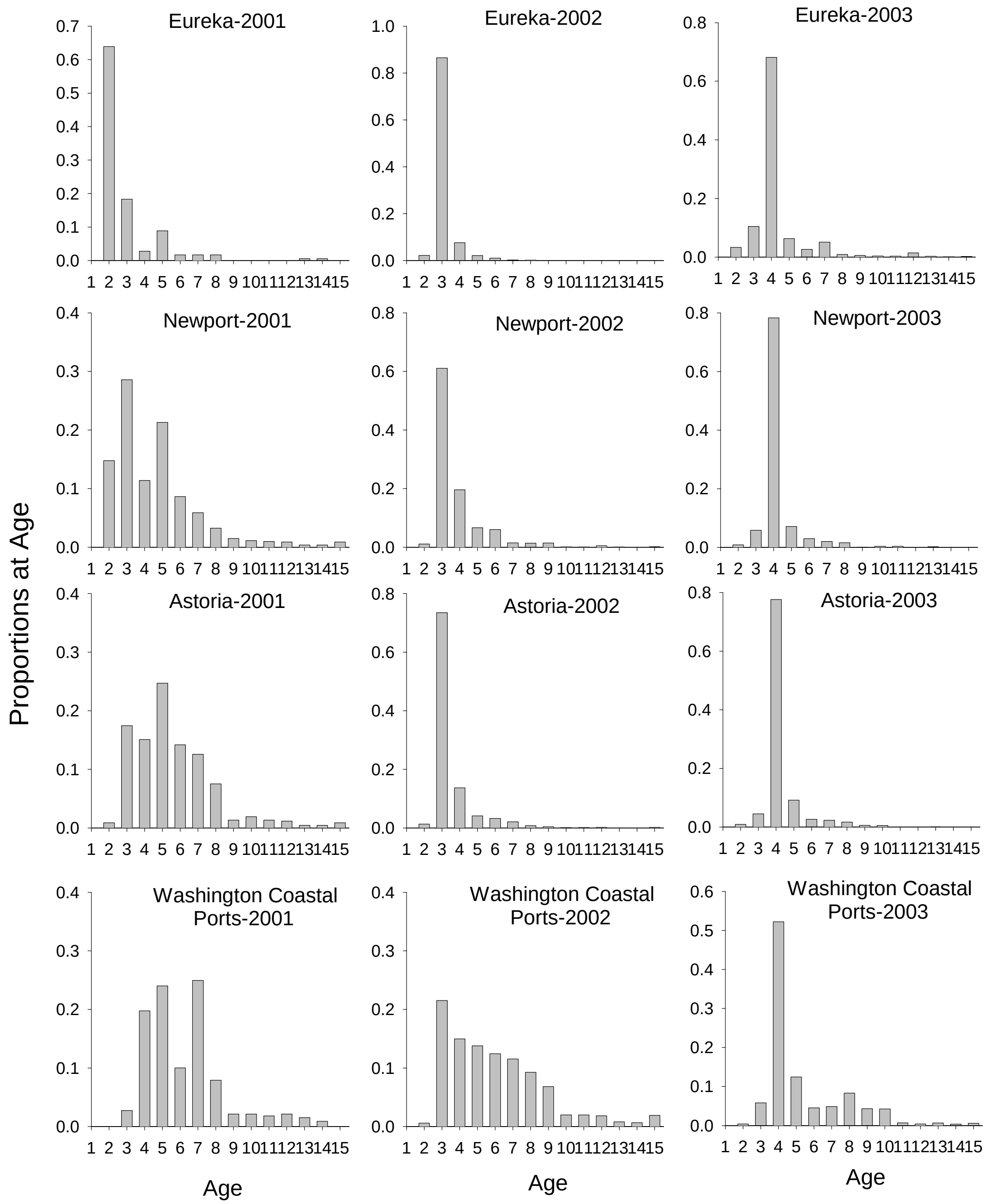


Figure 3. Pacific hake proportion by age from shore-based landings in the U.S. zone, 2001-2003.

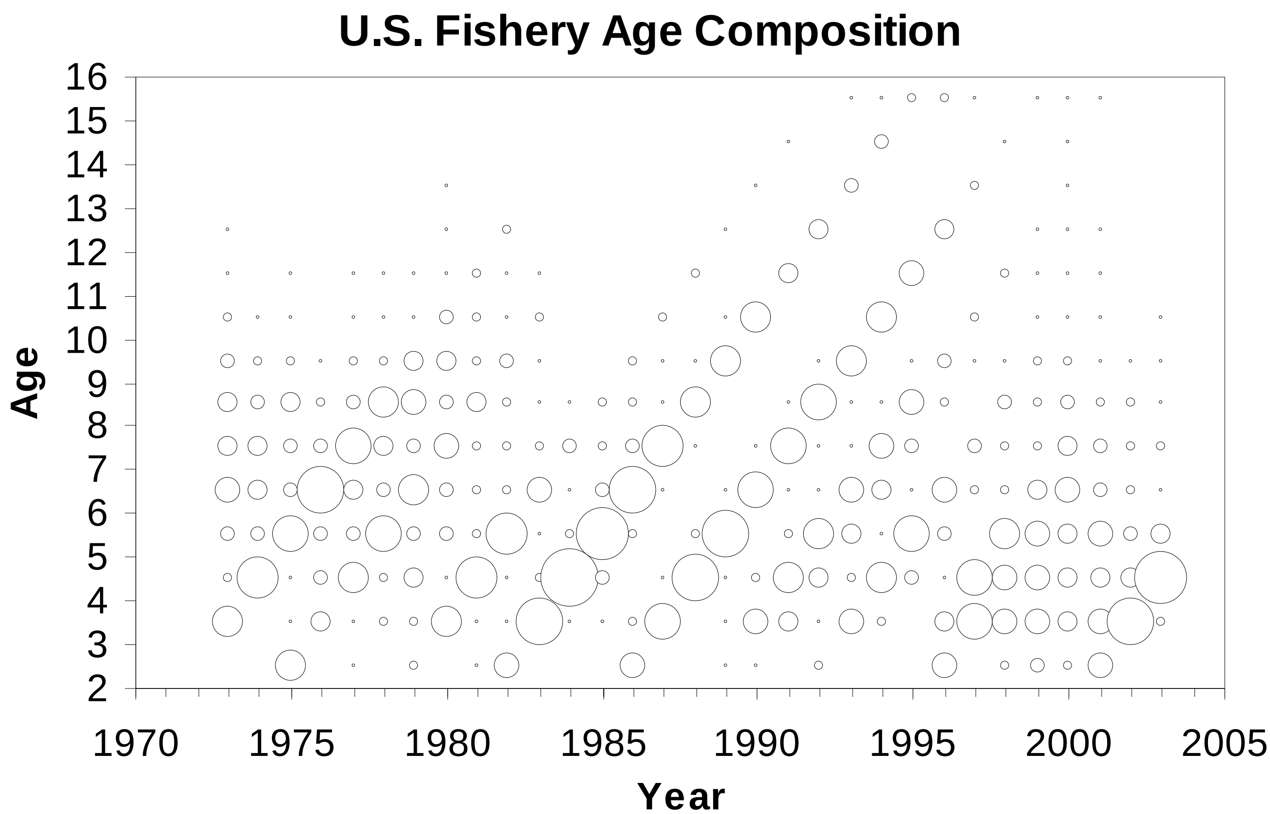


Figure.5. Catch at age of Pacific hake in the U.S. fisheries during 1973-2003. The diameter of the circle is proportional to the catch at age

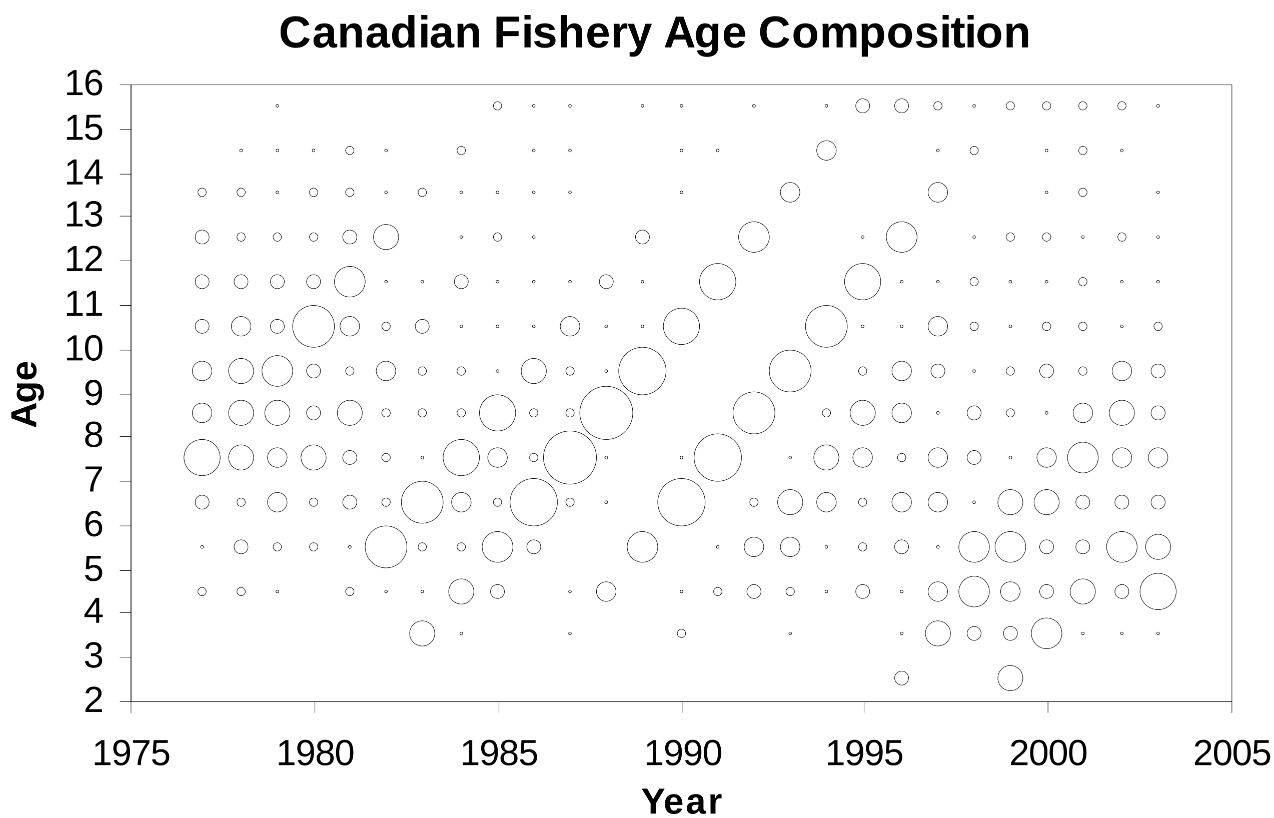


Figure 6. Catch at age of Pacific hake in the Canadian fisheries during 1977-2003. The diameter of the circle is proportional to the catch at age

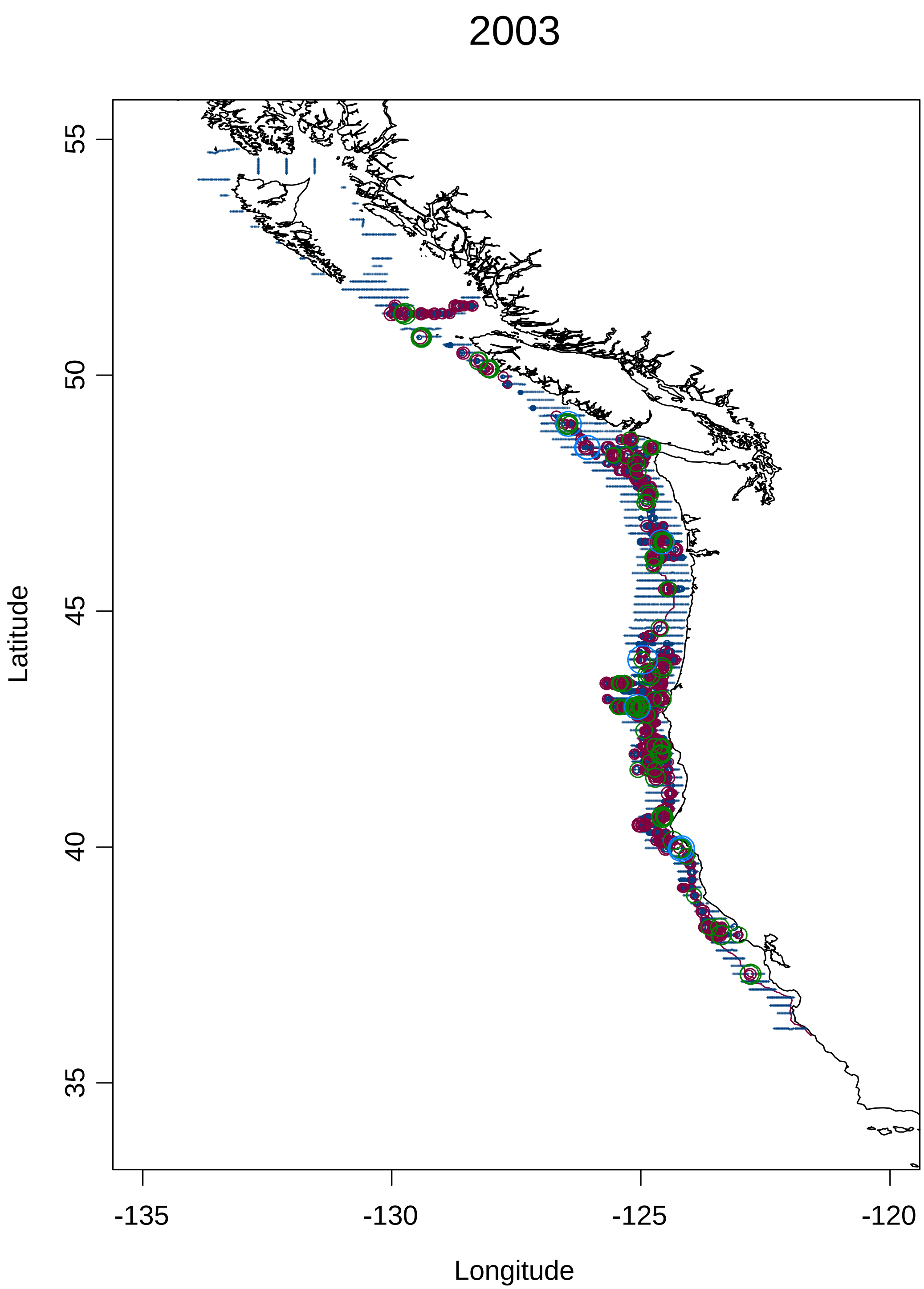


Figure 7. Acoustic backscattering (SA) attributed to Pacific hake along transects off the U.S. and Canada west coast shelf and slope between Monterey, CA, and Newport, OR, during the 2003 acoustic echo integration-trawl survey.

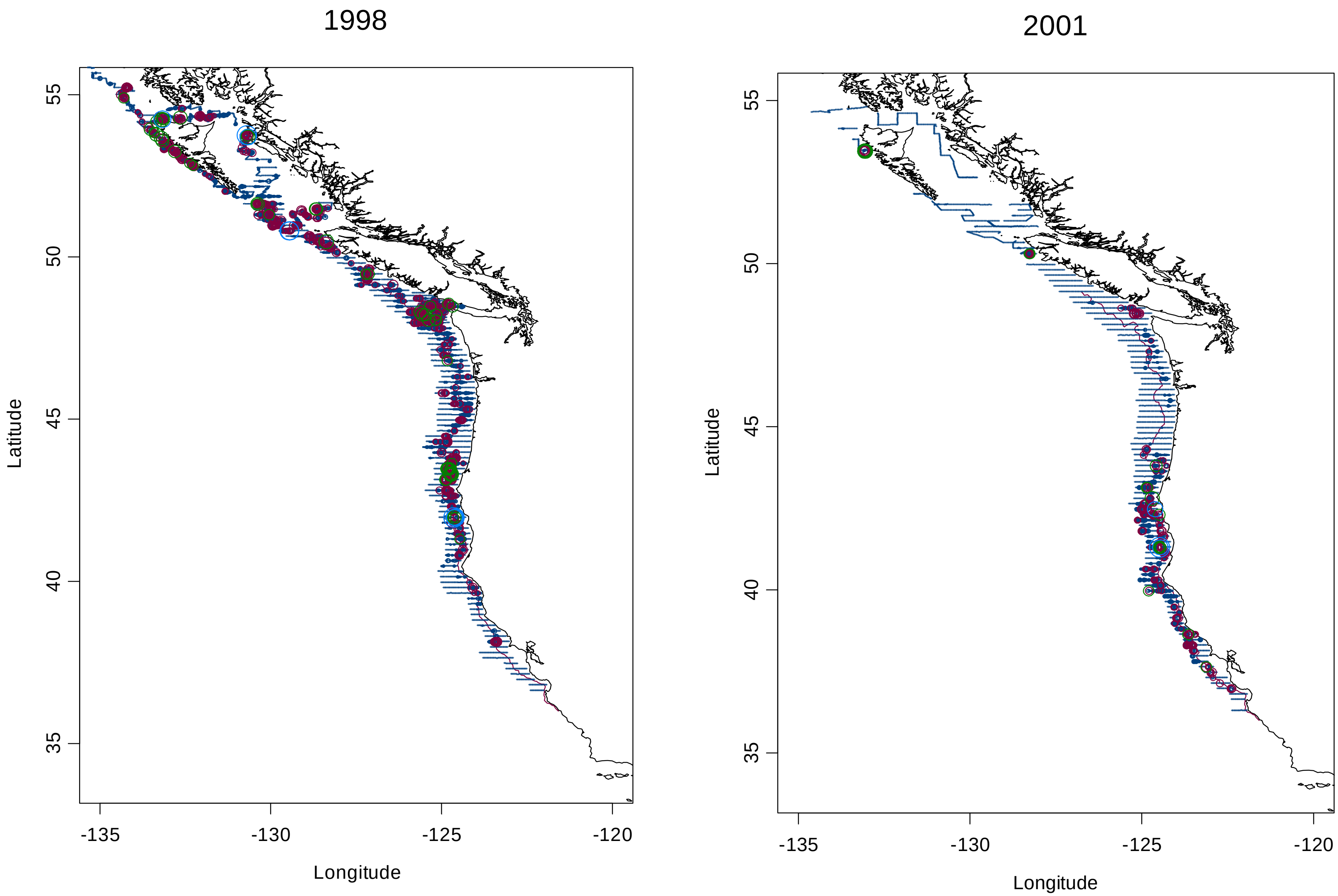
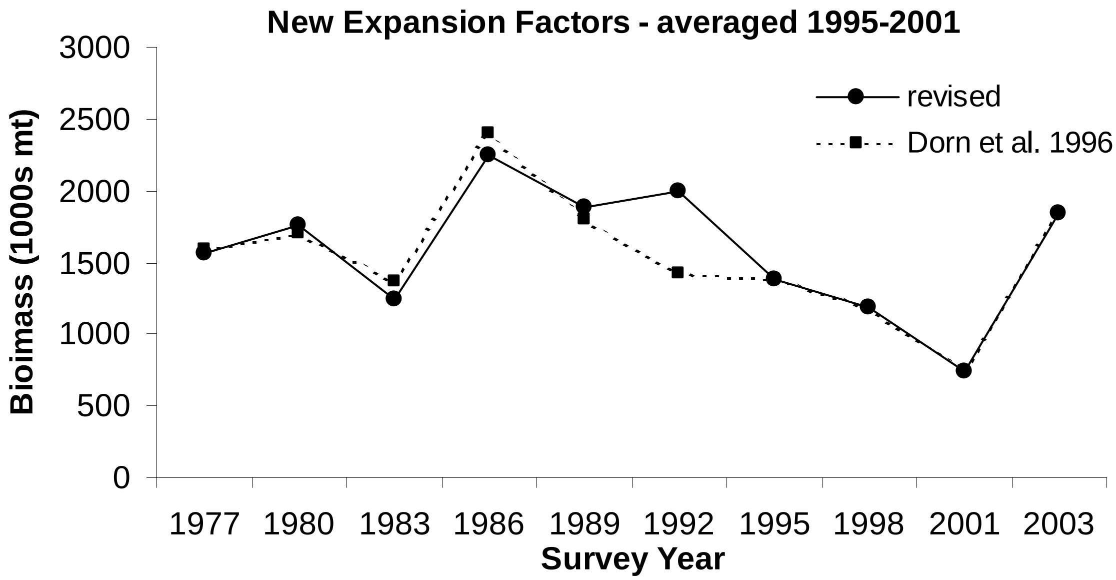


Figure 7 continued. Acoustic backscattering (SA) attributed to Pacific hake along transects off the U.S. and Canada west coast shelf and slope between Monterey, CA, and Newport, OR, during the 1998 and 2001 acoustic echo integration-trawl survey.



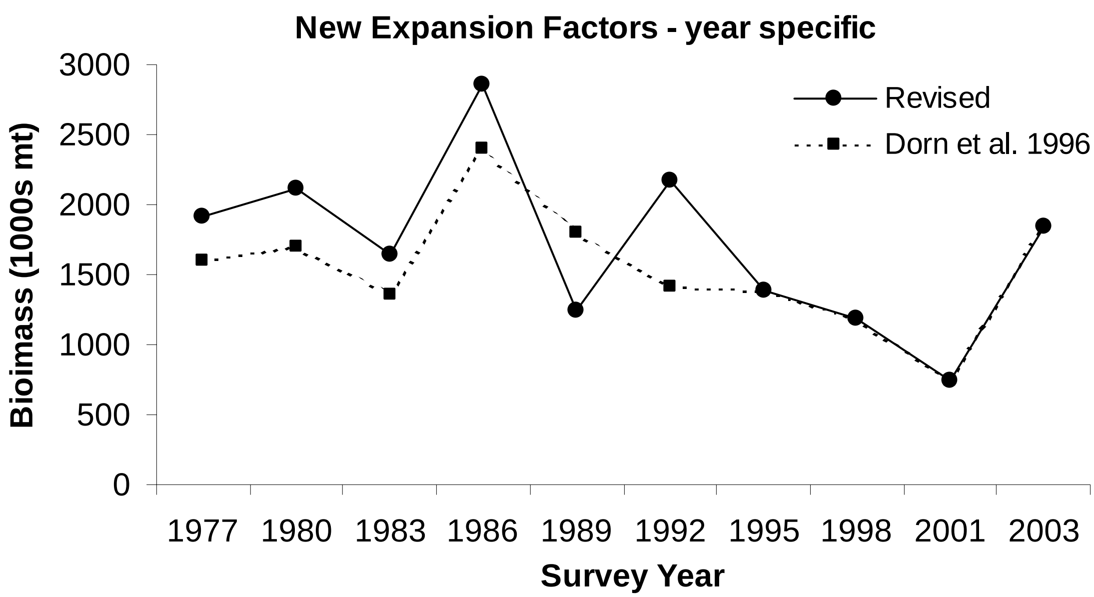


Figure 8. Trends in Pacific hake biomass in the acoustic survey based of revised deep water and northern expansion factors. Estimates in top panel were based on average deep water expansion factors from the 1992-2001 acoustic survey and average northern expansion factors from the 1995-2001 acoustic survey. Estimates in bottom panel were based on year-specific deep water and northern expansions factors corresponding to similar oceanographic conditions, i.e. 1998 survey was used to calculate expansion factors which were applied to the 1983 survey (See text for details).

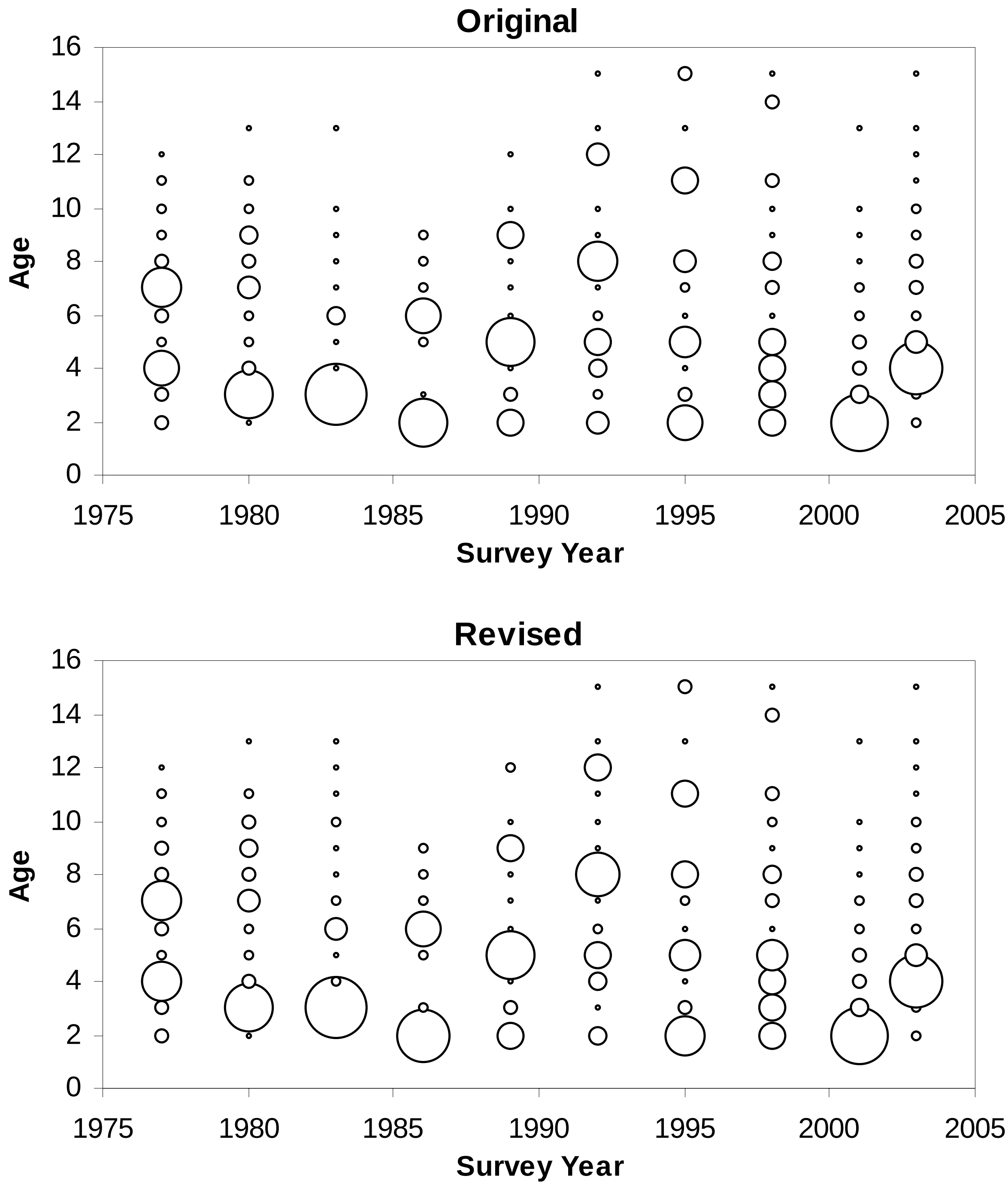


Figure 9. Catch at age of Pacific hake from the acoustic survey, 1977-2003. Top panel shows original catch at age while bottom panel give revised catch at age based on the new year-specific deep-water and northern expansion factors. The diameter of the circle is proportional to the catch at age

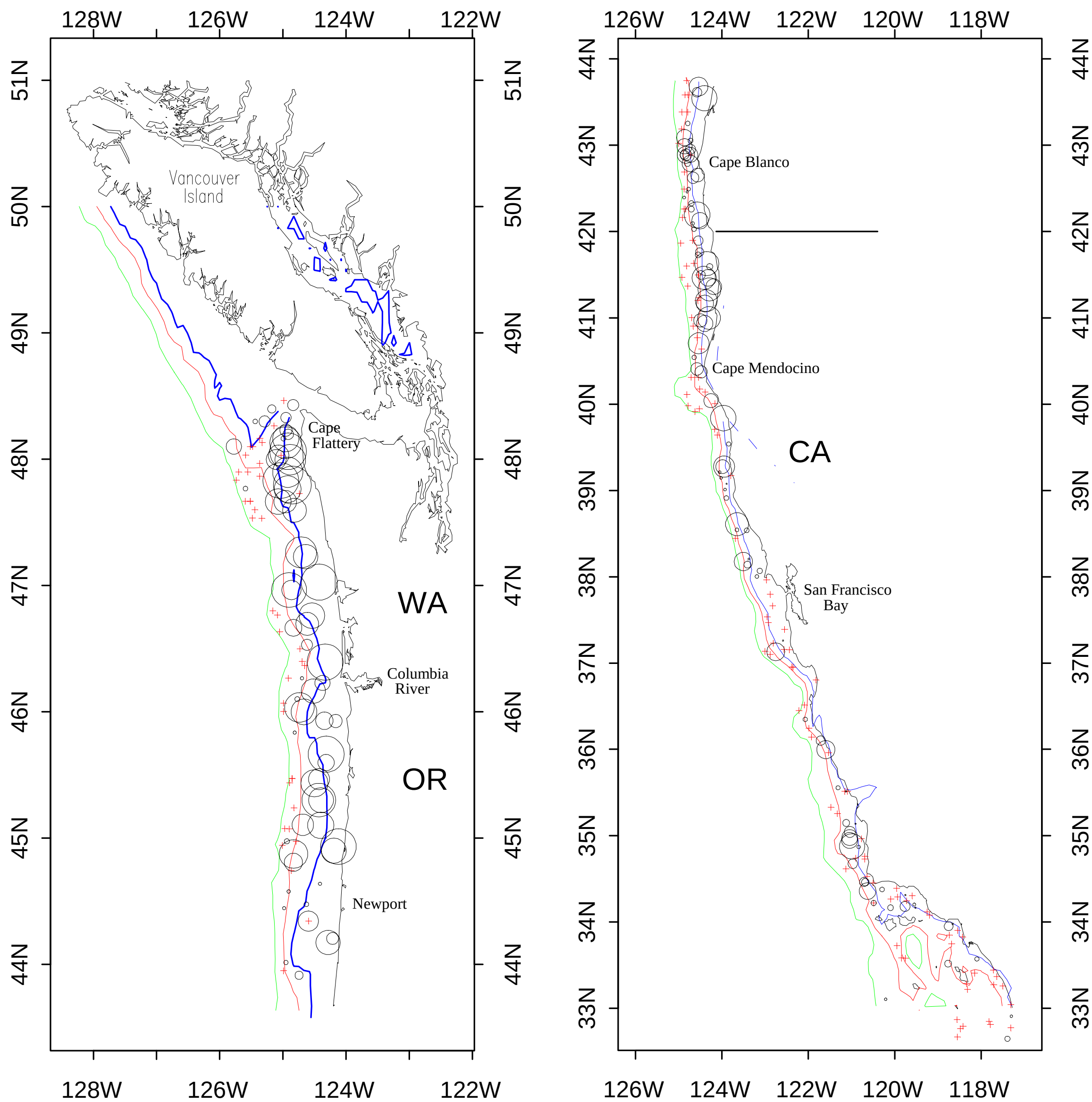


Figure 10. Spatial distribution of age 2+ (> 30 cm) Pacific hake in the NWFSC 2003 bottom trawl (Triennial) survey.

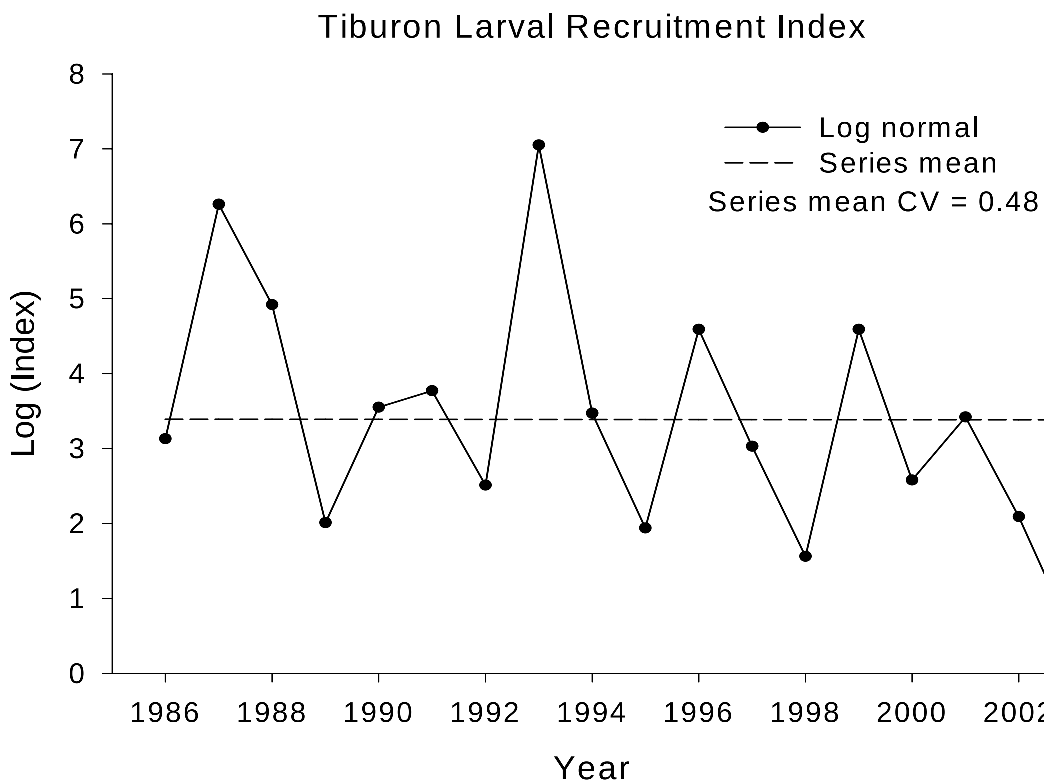


Figure 11. Santa Cruz Laboratory juvenile recruitment index (Monterey inside stratum only), 1986-2003. Index is obtained from a generalized linear model fit to the log-transformed CPUEs (Ralston et al. 1998). The juvenile index is projected two years in advance and is used as an index of age 2 hake recruitment, i.e., 1986 juvenile index represents age 2 hake recruitment in 1988.

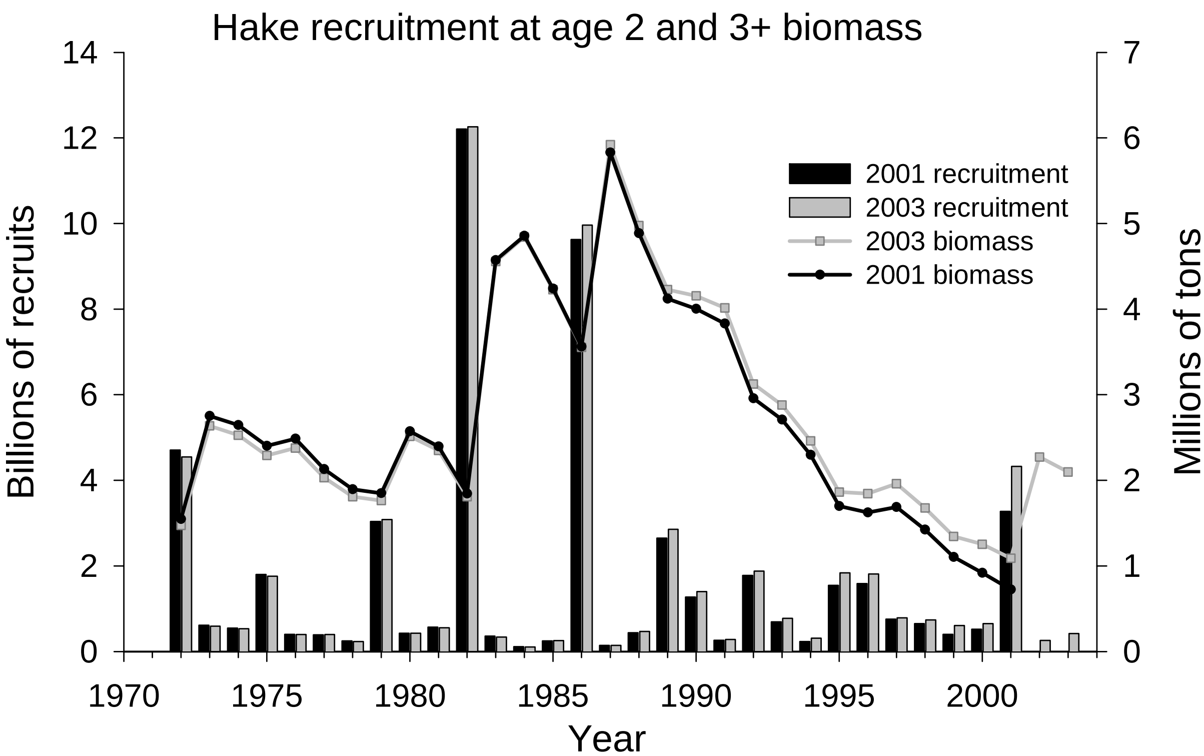


Figure 12. Comparison of trends in age 2+ biomass and recruitment between the most recent assessment 2003 model update presented in this document and the 2001 Pacific hake assessment (Helser et al. 2001). Both models employed the same model structure and assumptions, but the 2003 updated reflects only updated fishery catch and the new 2003 acoustic survey biomass estimate.

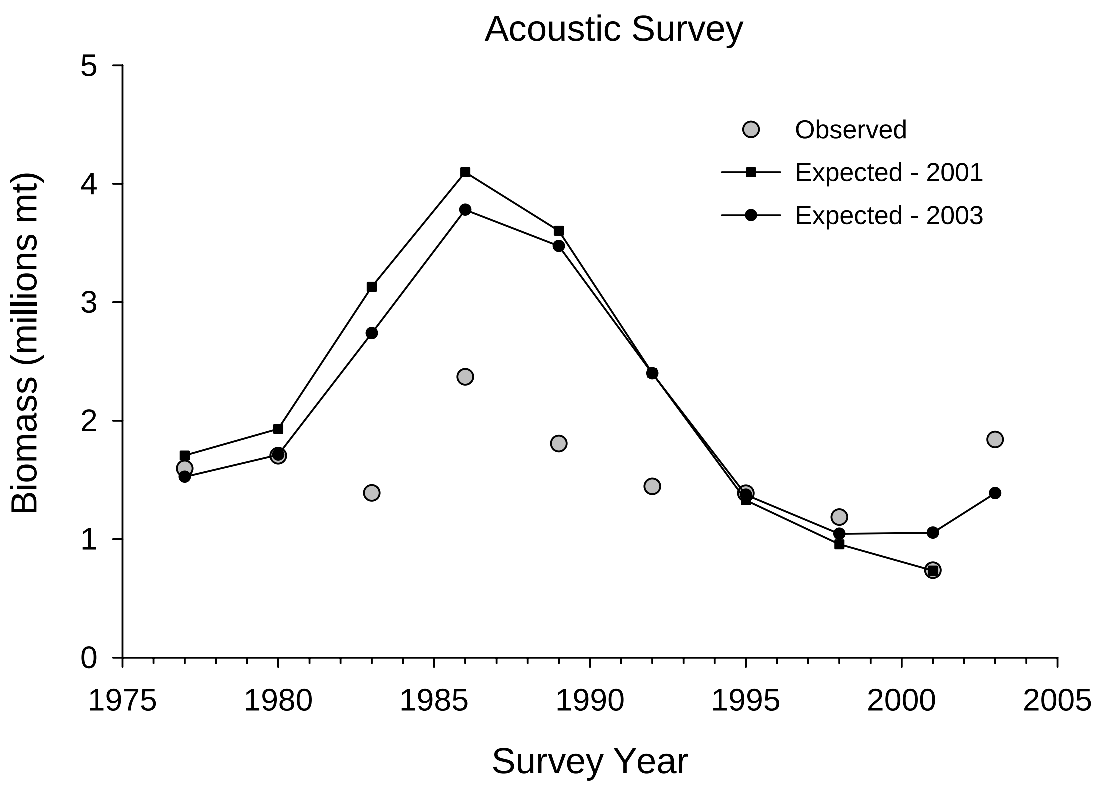
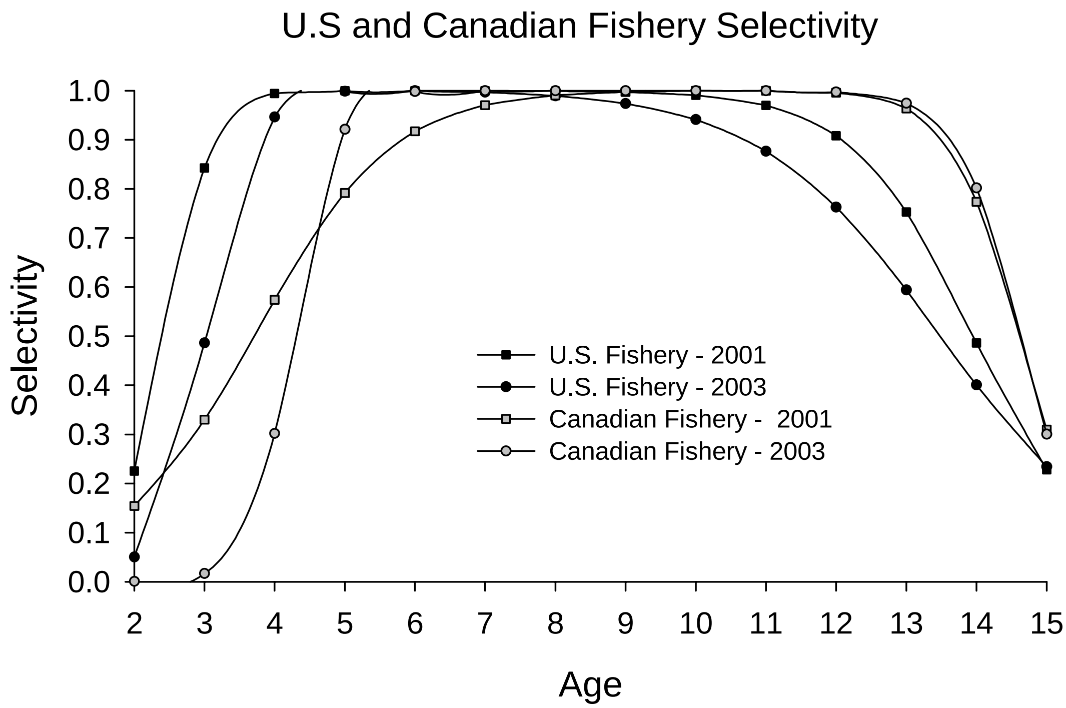


Figure 13. Comparison of observed and predicted acoustic survey biomass indices estimated from the 2003 model update presented in this document and the 2001 Pacific hake assessment (Helser et al. 2001). Both models employed the same model structure and assumptions.



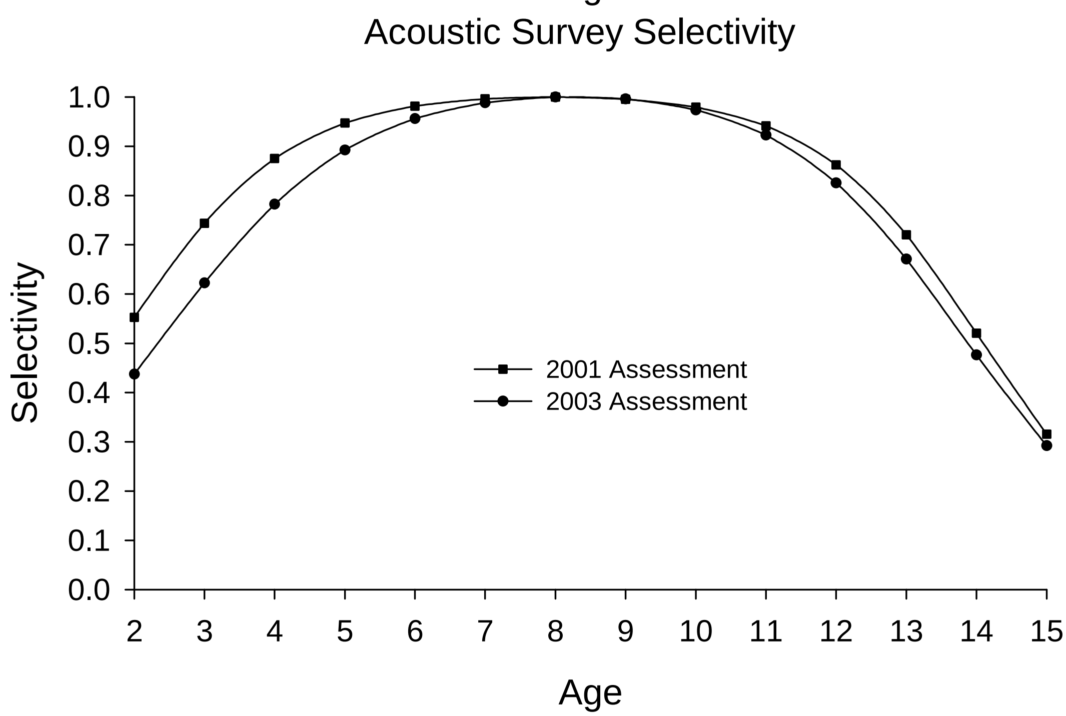


Figure 14. Comparison of average fishery and acoustic survey selectivity (most recent three years) estimated from the 2003 model update presented in this document (2003) and the 2001 Pacific hake assessment (Helser et al. 2001). Both models employed the same model structure and assumptions.

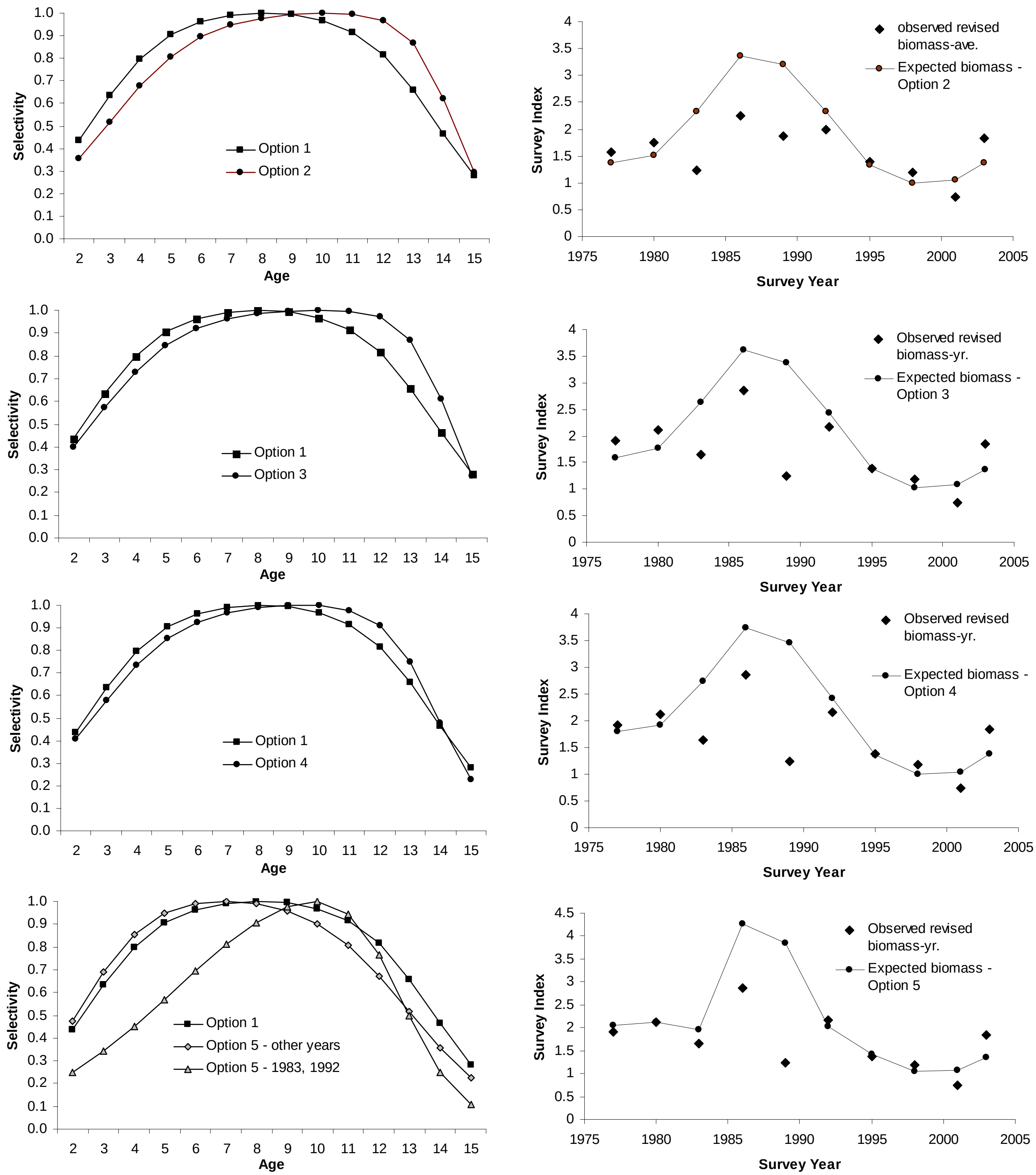


Figure 15. Comparison of acoustic survey selectivity and the fit of expected to observed acoustic survey biomass estimates, 1977-2003, among five different model options. See text for explanation of model options.

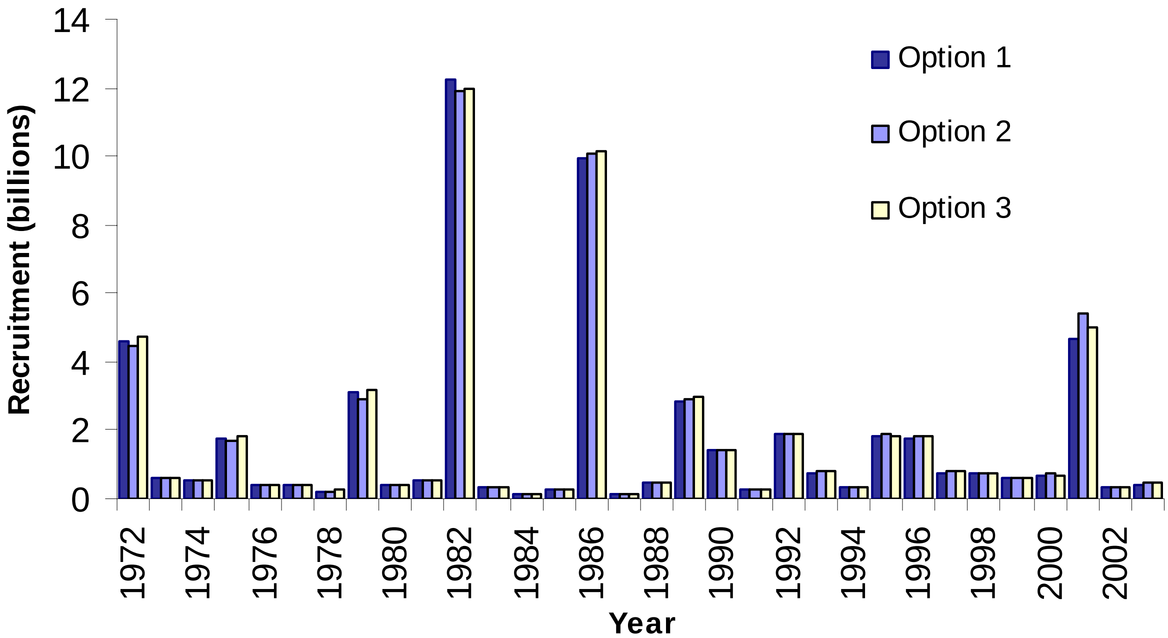
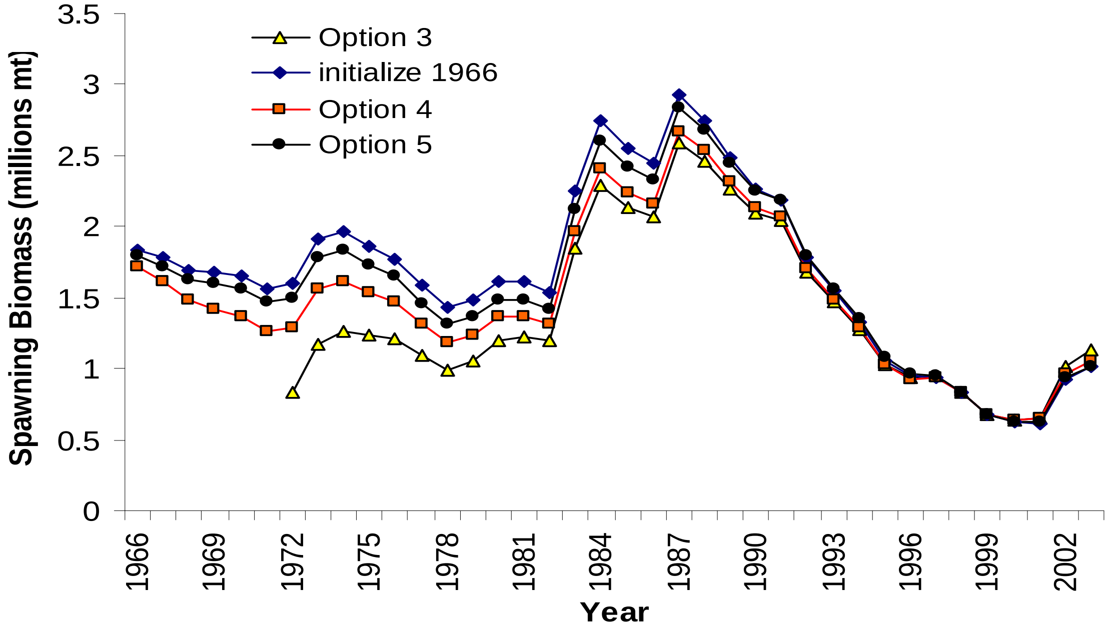


Figure 16. Estimates of Pacific hake spawning biomass and recruitment to age 2 among three different model options. See text for explanation of different model options.



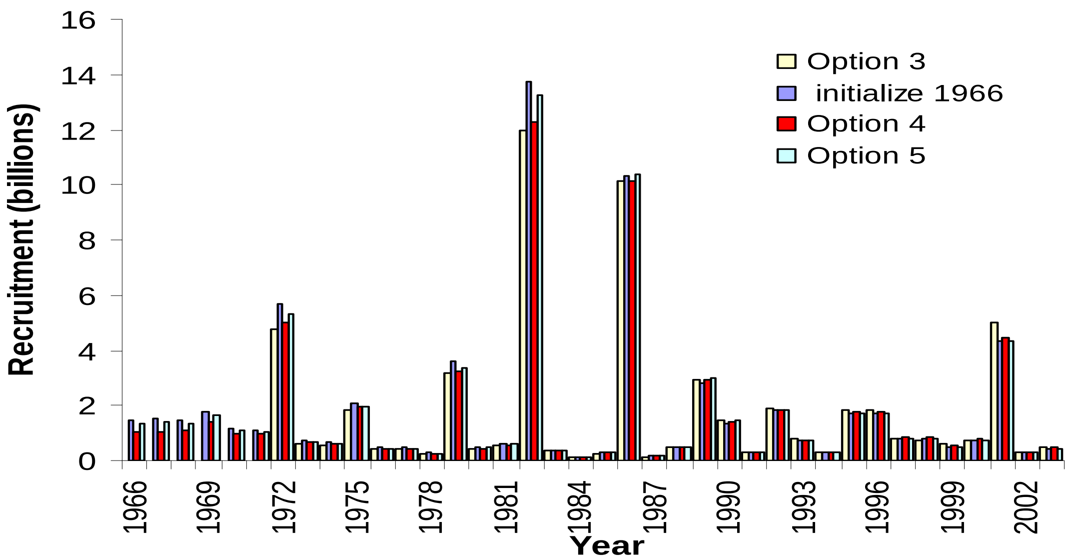


Figure 17. Estimates of Pacific hake spawning biomass and recruitment to age 2 among different model options. See text for explanation of different model options.

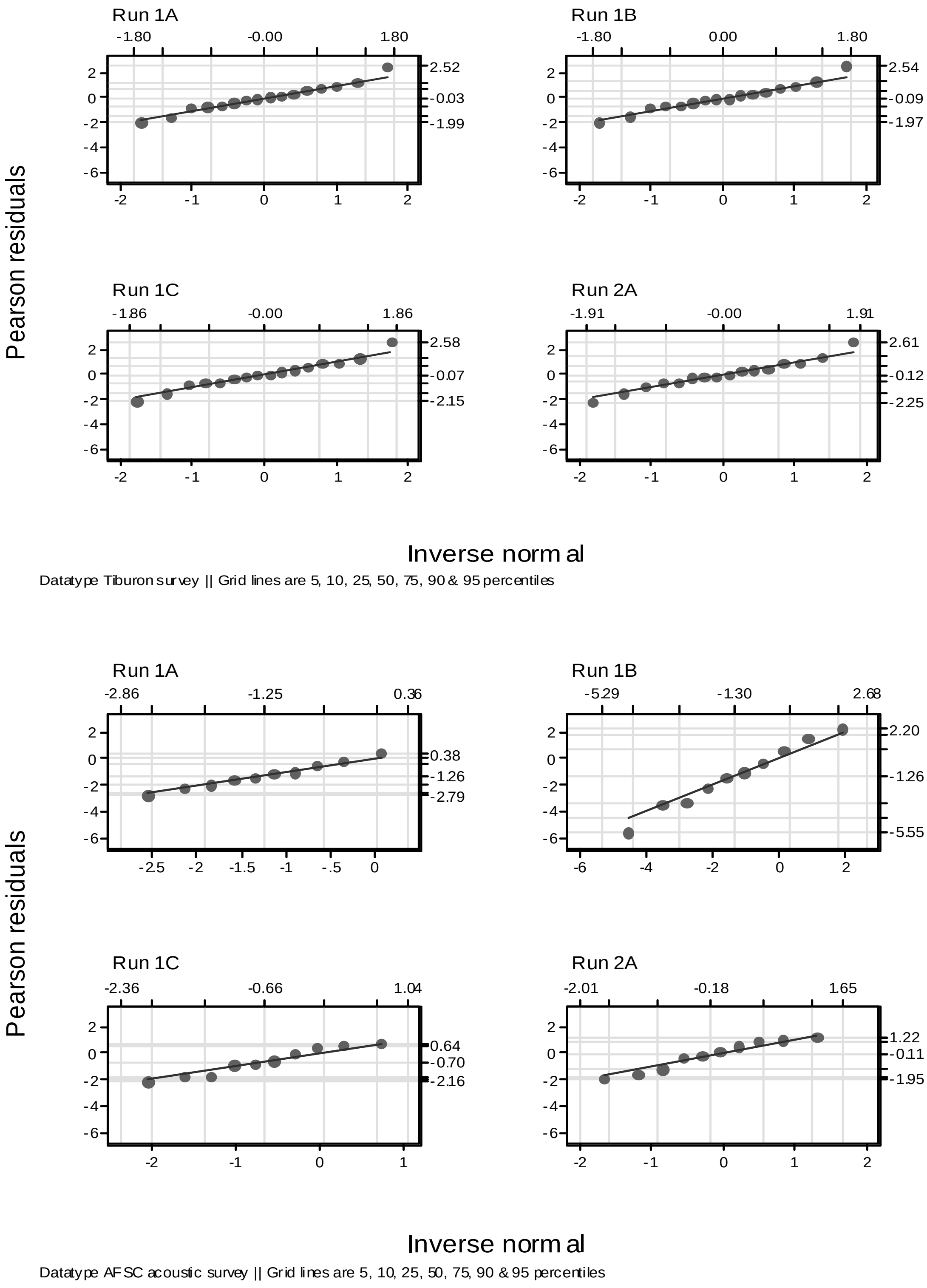


Figure 18. Q-Q plots of the Pearson residuals for the fit to the acoustic survey biomass (top) and Tiburon recruitment survey (bottom) data for Runs 1A, 1B, 1C and 2A.

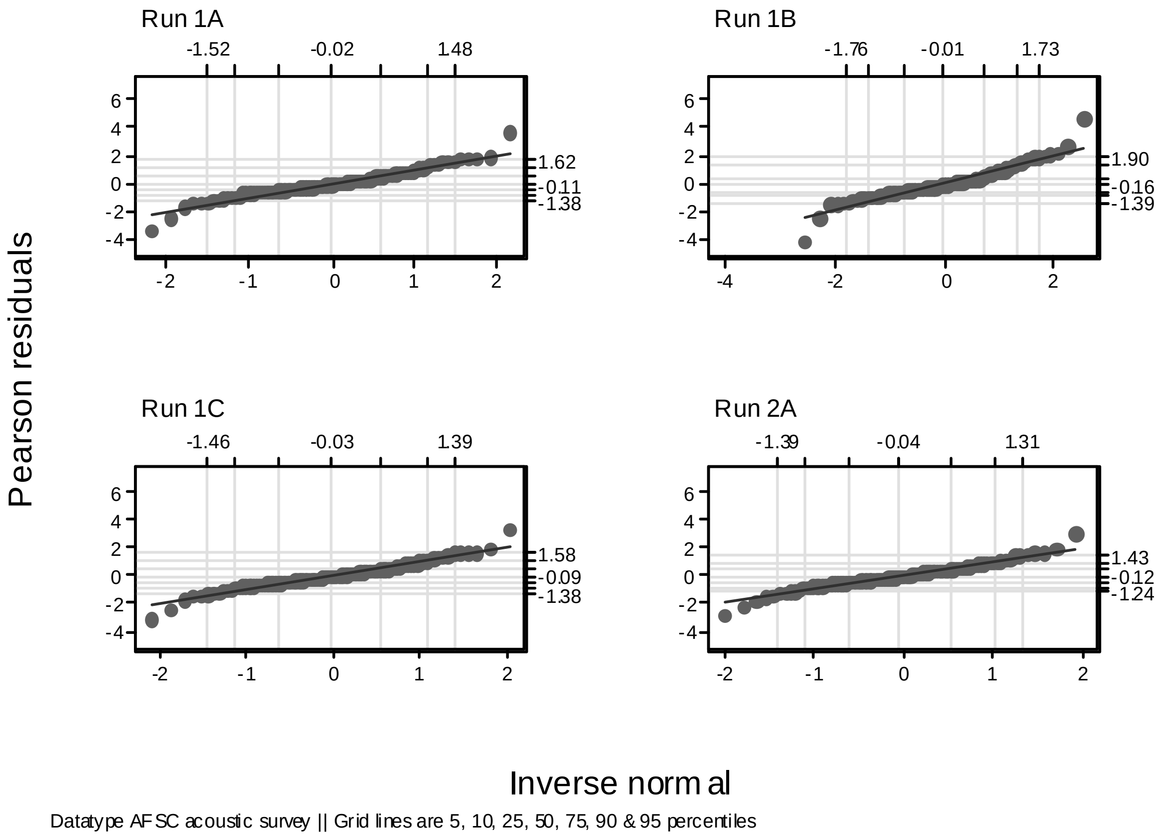
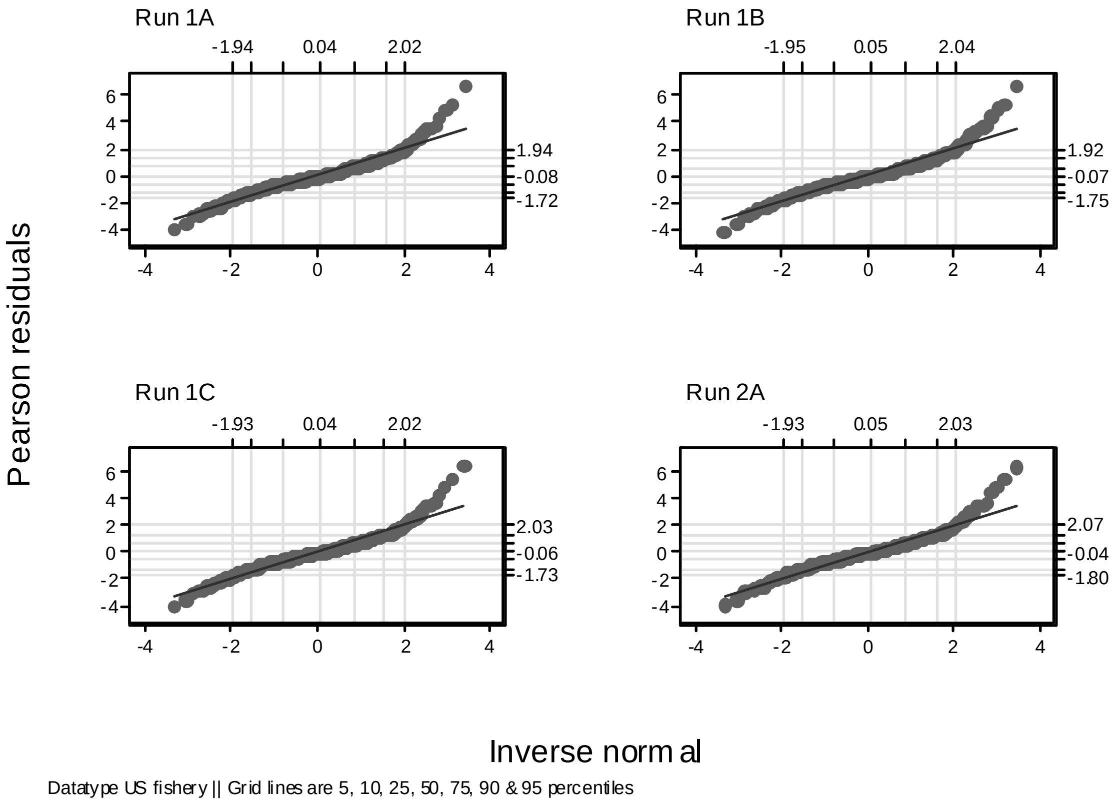


Figure 19. Q-Q plots of the Pearson residuals for the fit to the acoustic survey age composition data for Runs 1A, 1B, 1C and 2A.



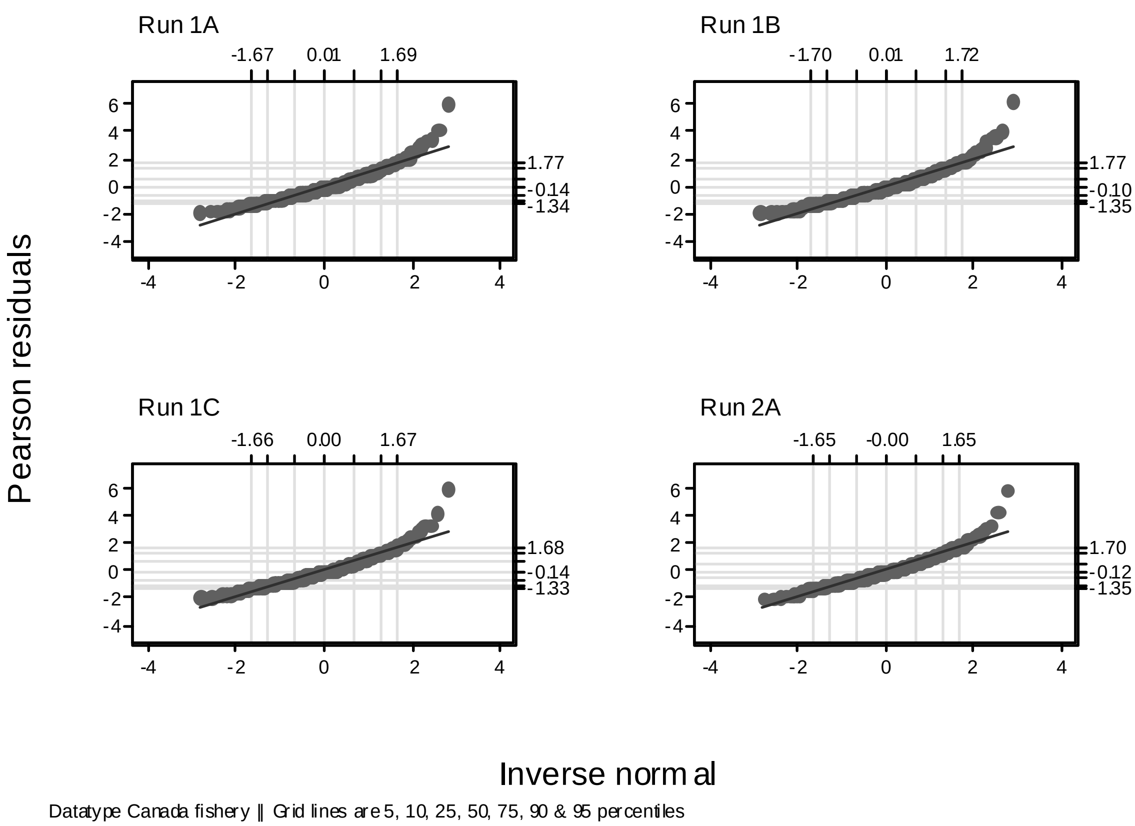
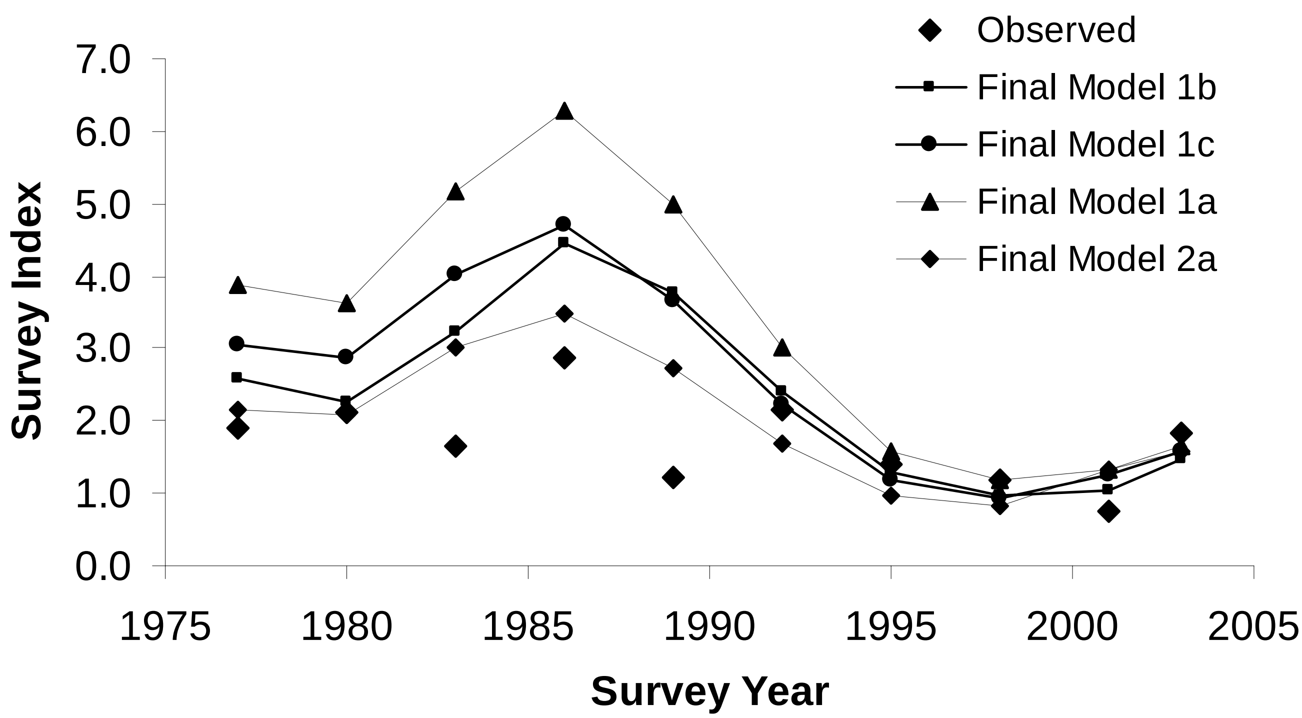


Figure 20. Q-Q plots of the Pearson residuals for the fit to the U.S (top) and Canadian (bottom) fishery age composition data for Runs 1A, 1B, 1C and 2A.



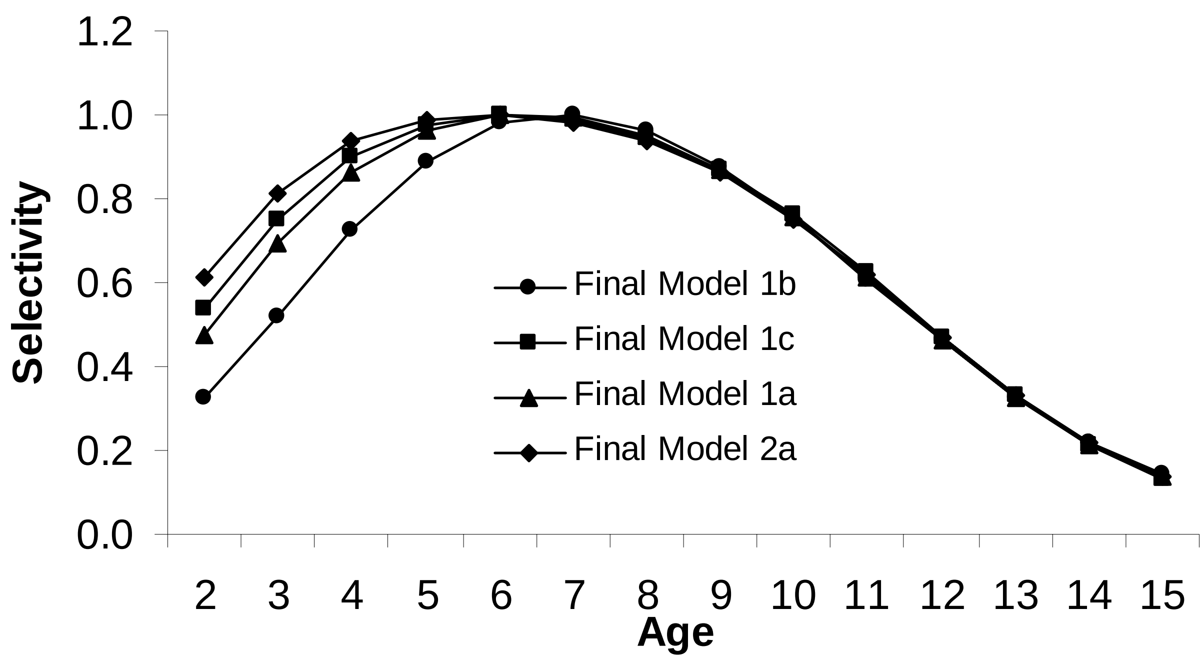
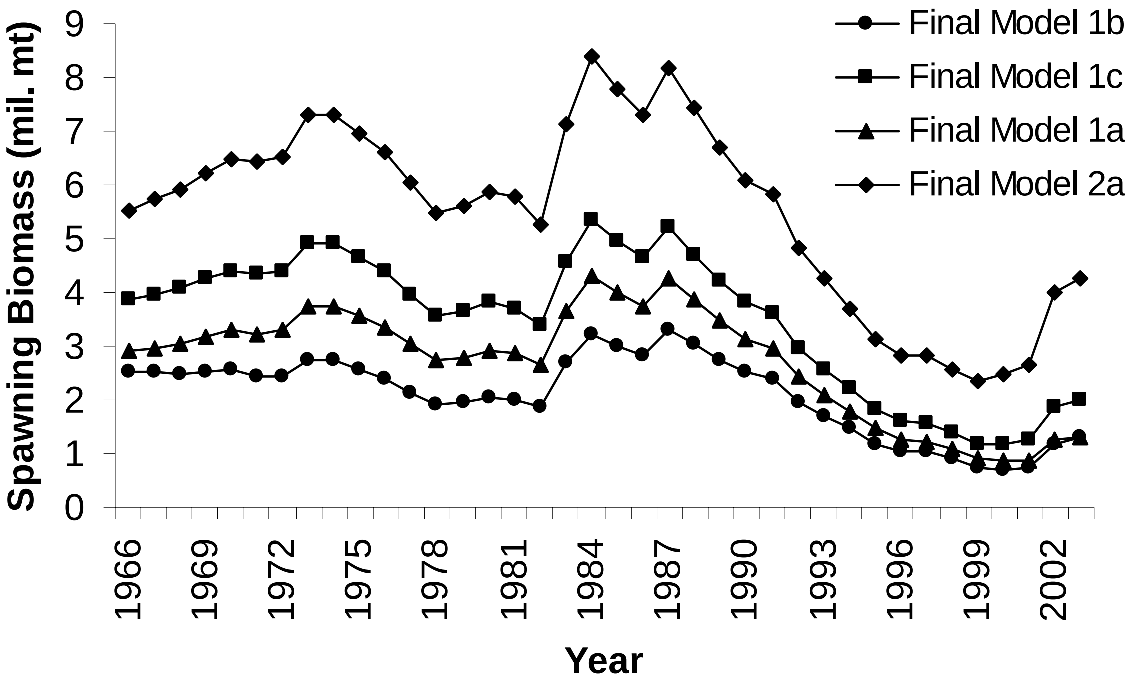


Figure 21. Comparison of acoustic survey selectivity and the fit of expected to observed acoustic survey biomass estimates, 1977-2003, among 4 final model options. See text for explanation of model options.



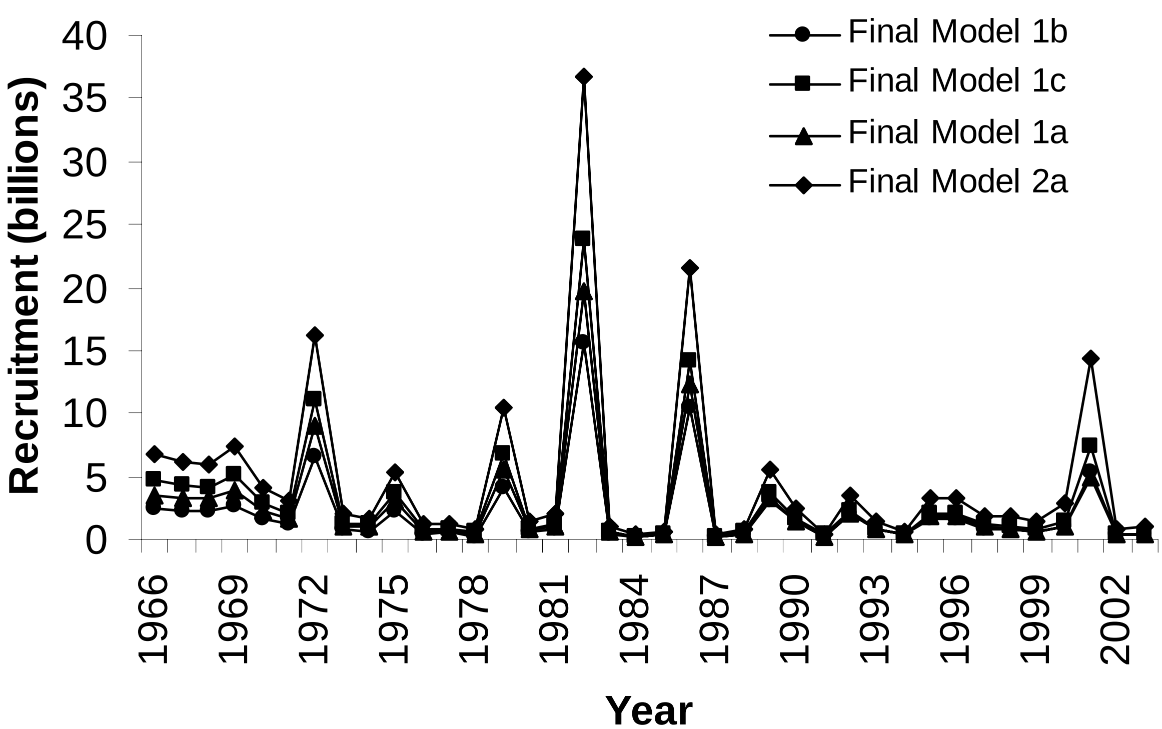
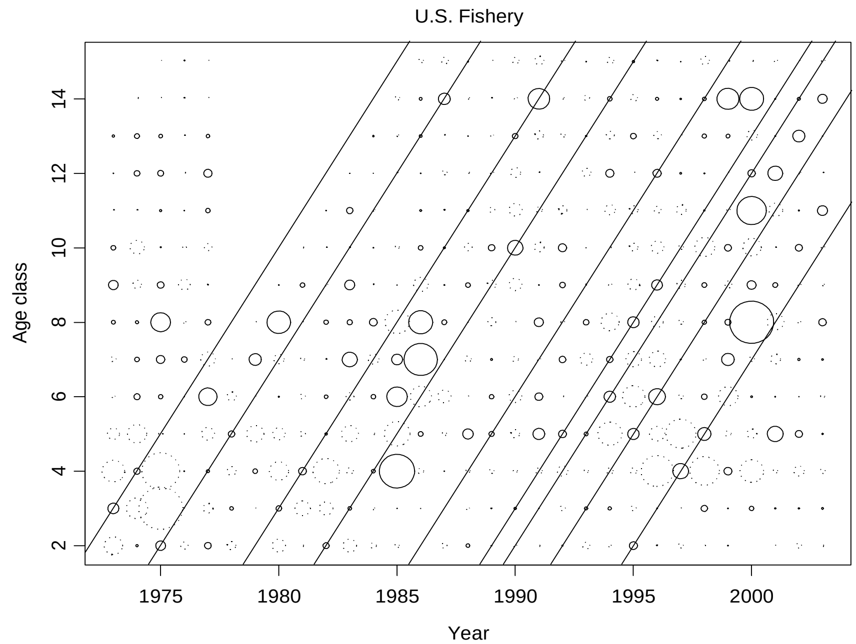


Figure 22. Estimates of Pacific hake spawning biomass and recruitment to age 2 among four different final model options. See text for explanation of different model options.



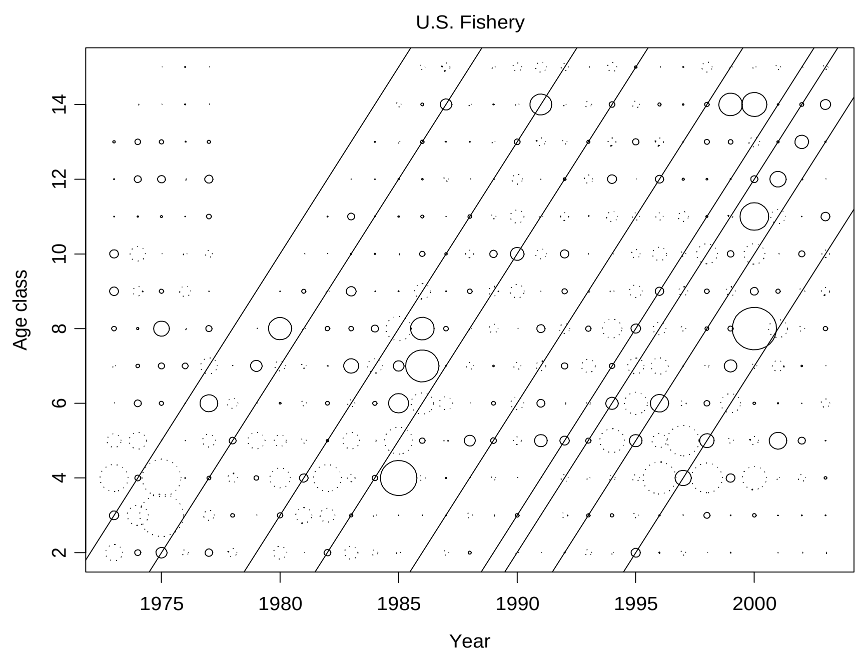
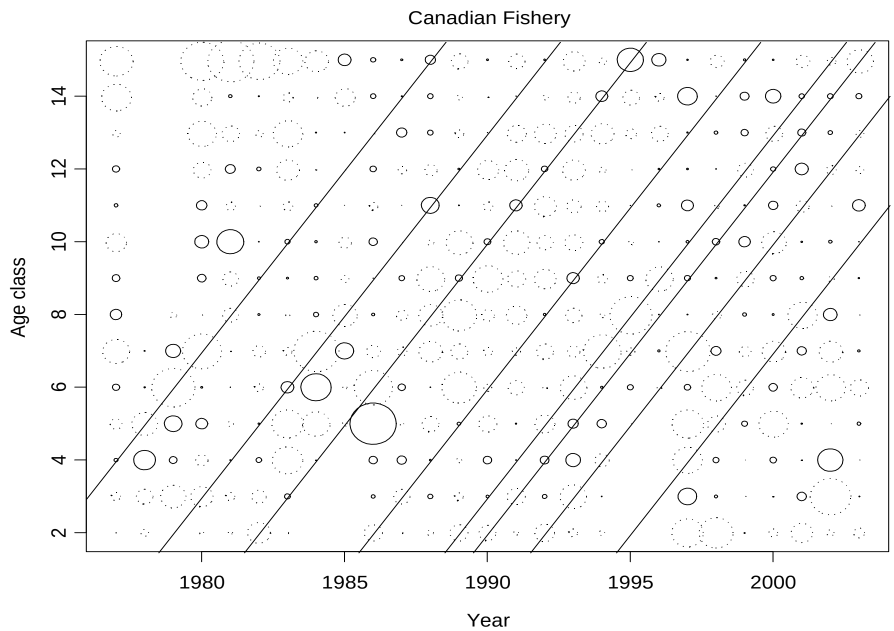


Figure 23. Pearson residuals from Final Models 1b (top panel) and 1c (bottom panel) for the U.S. fishery age composition. Circle areas are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. The largest residual in absolute value is 3.7 for the age-2 fish in 1975. Diagonal lines show strong year classes (1970, 1973, 1977, 1980, 1984, 1988, 1990, and 1993).



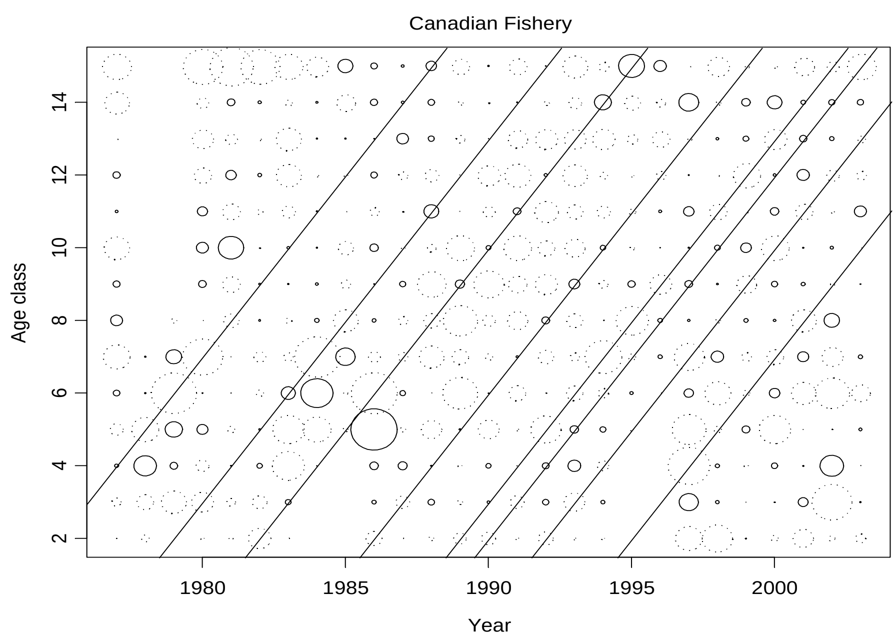
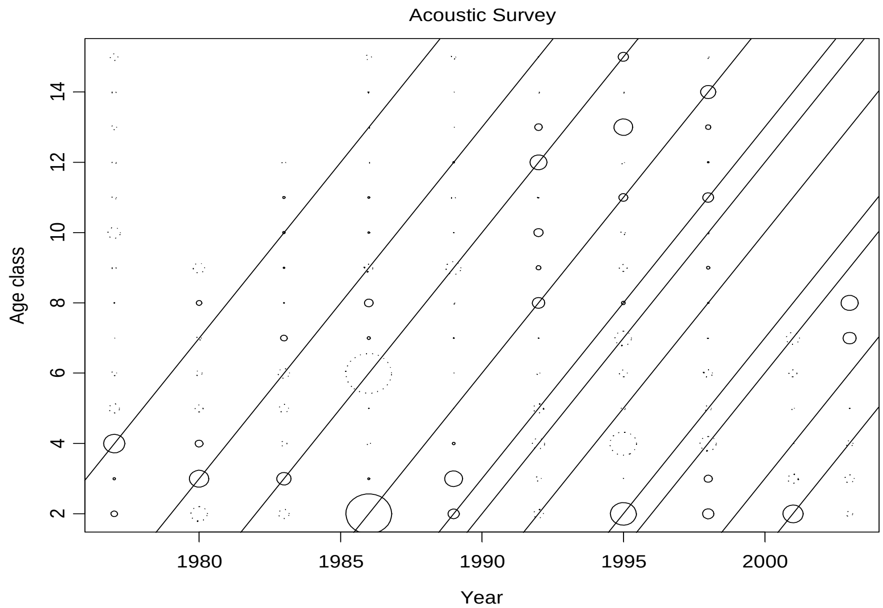


Figure 24. Pearson residuals from Final Models 1b (top panel) and 1c (bottom panel) for the Canadian fishery age composition. Circle areas are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. The largest residual in absolute value is 5.1 for the age-5 fish in 1986. Diagonal lines show strong year classes (1973, 1977, 1980, 1984, 1987, 1988, 1990, and 1993).



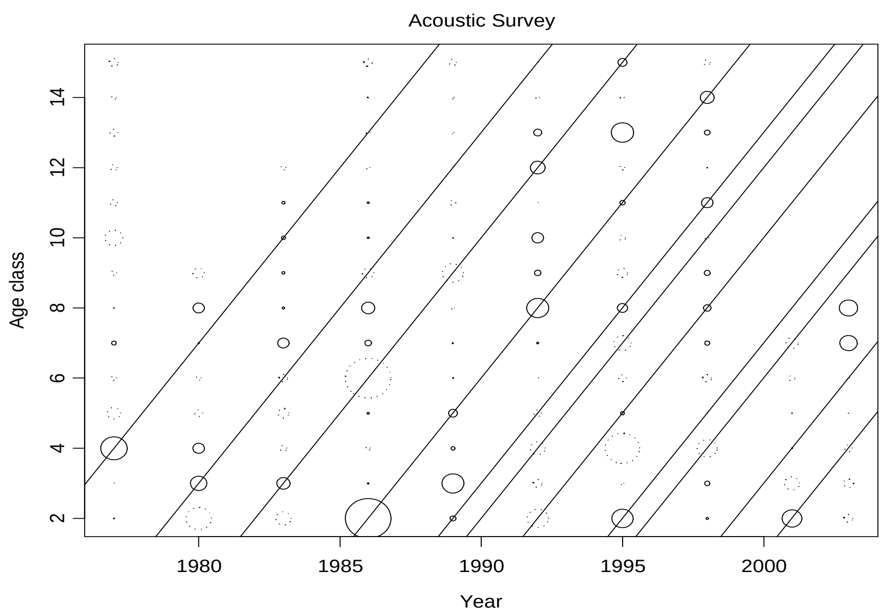


Figure 25. Pearson residuals from Final Models 1b (top panel) and 1c (bottom panel) for the acoustic survey age composition. Circle areas are proportional to the magnitude of the residual. Circles drawn with dotted lines indicate negative residuals. The largest residual in absolute value is -2.9 for the age-6 fish in 1986. Diagonal lines show strong year classes (1973, 1977, 1980, 1984, 1988, 1990, and 1993).

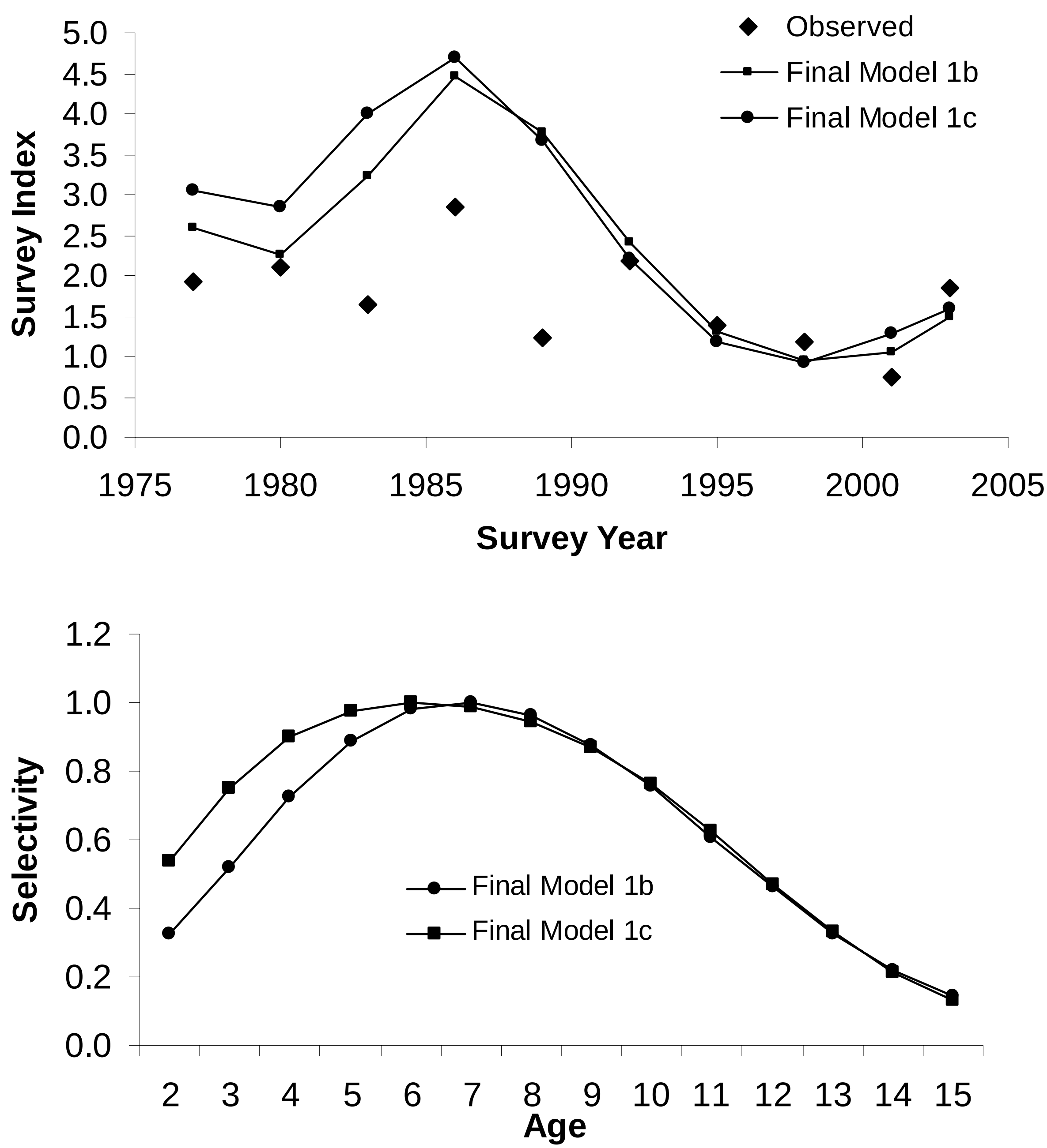


Figure 26. Fit of the expected to observed (revised 1977-1992 year-specific expansion factors) acoustic survey biomass and acoustic survey selectivity from final models 1b and 1c. See text for description of model configurations.

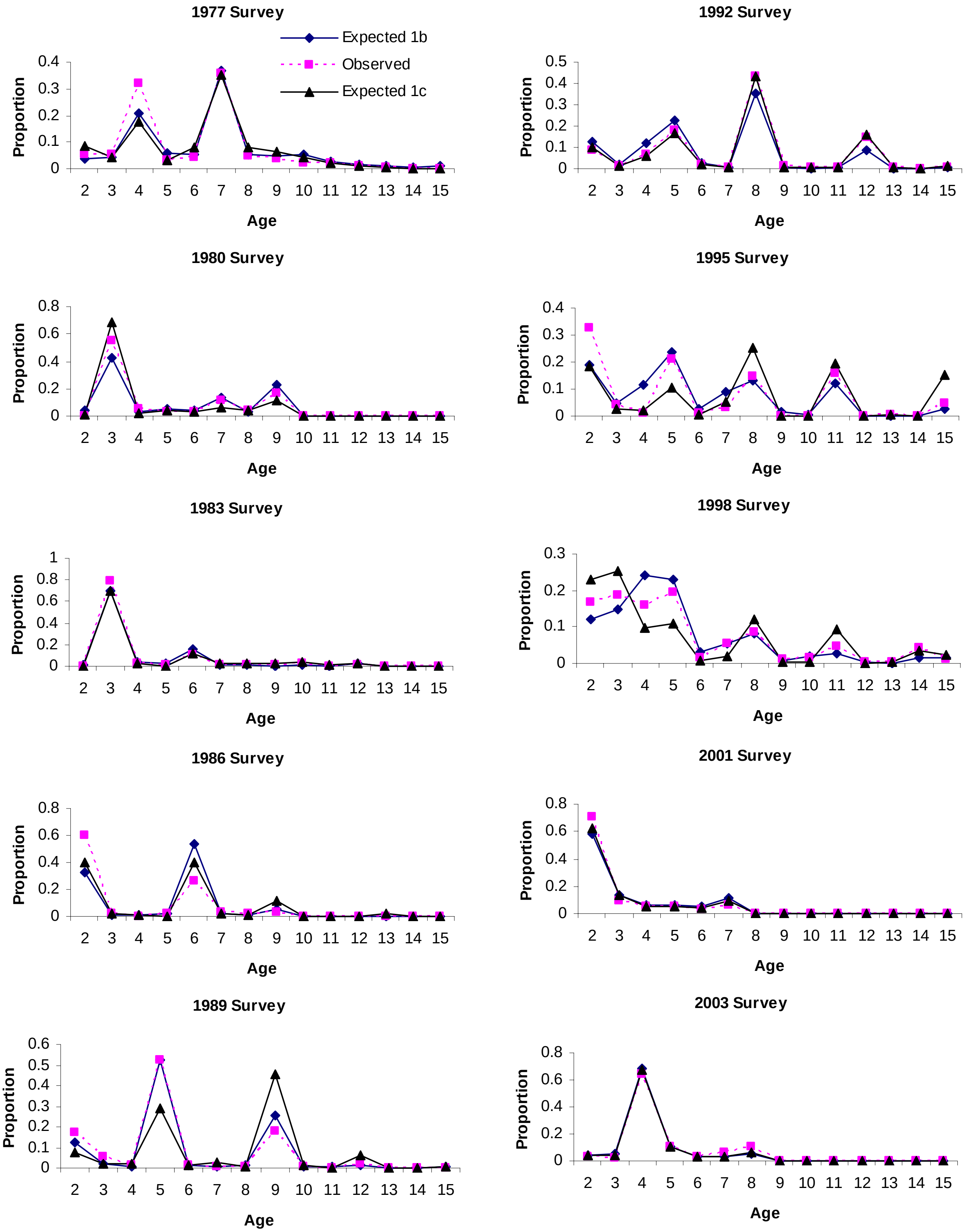


Figure 22. Fit of the expected to the observed acoustic survey age compositions, 1977-2003, for Final Models 1b and 1c (See text for description of model configuration).

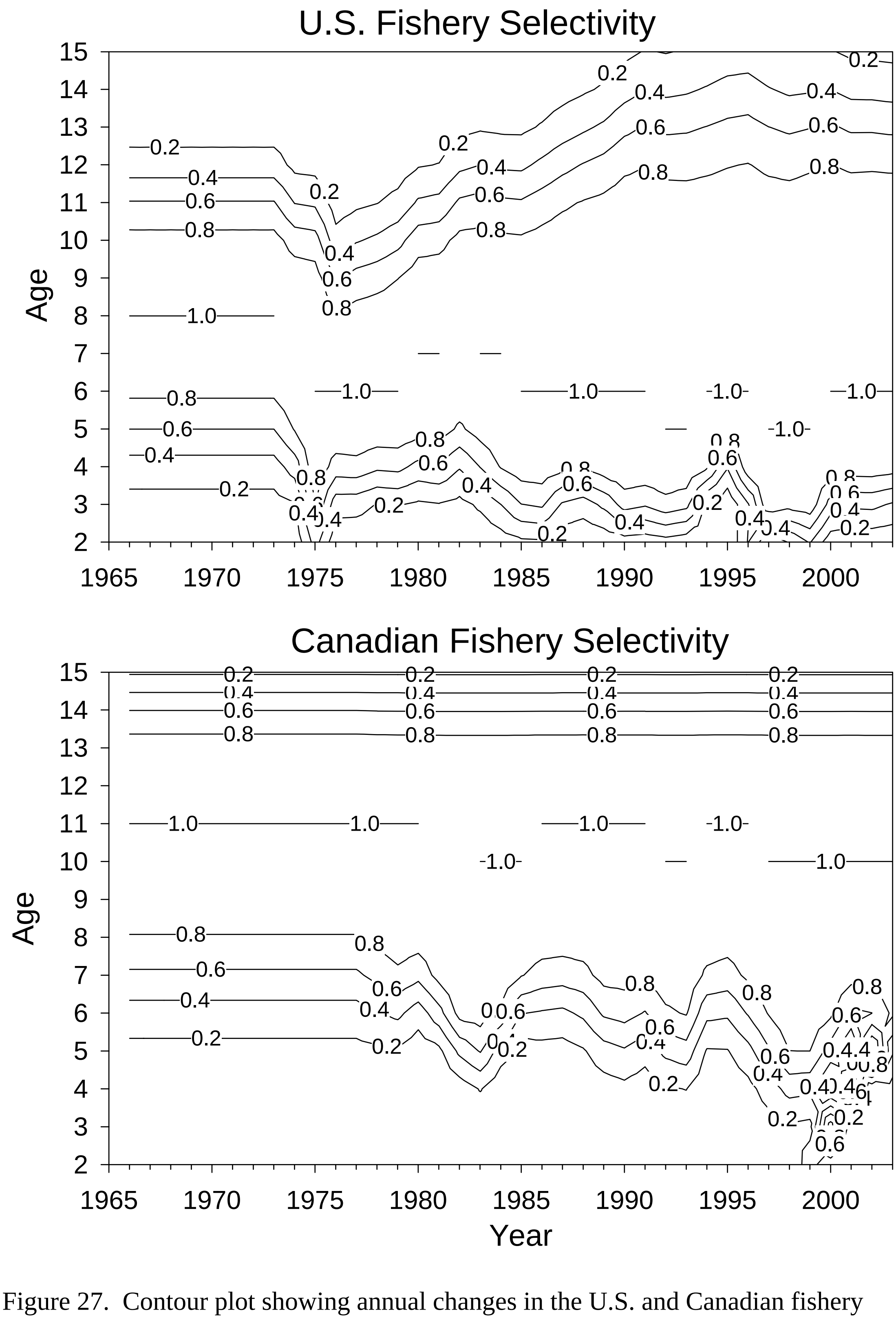


Figure 27. Contour plot showing annual changes in the U.S. and Canadian fishery selectivity at age estimated by Final Model 1b (Fishery selectivity from Final model 1c is qualitatively similar and not shown). Time varying selectivity was estimated using a random walk process error for parameters associated with both the ascending and descending limb of the selectivity function in the U.S. fishery. In the Canadian fishery annual variation was assumed for only the ascending portion of the double logistic function.

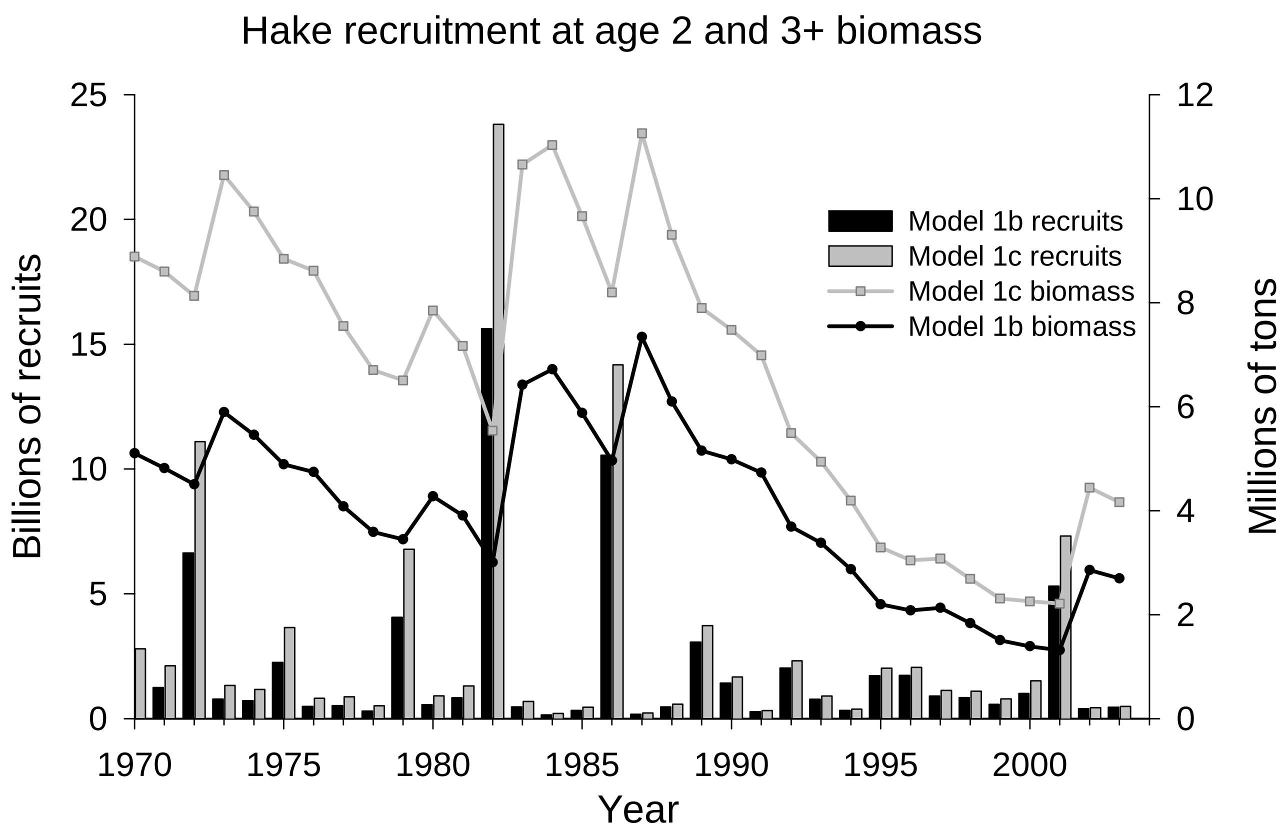


Figure 28. Estimated time series of Pacific hake age 3+ biomass (million mt) and age-2 recruitment (billions of fish) during 1966-2003 from Final Models 1b and 1c (See text for description of model configurations).

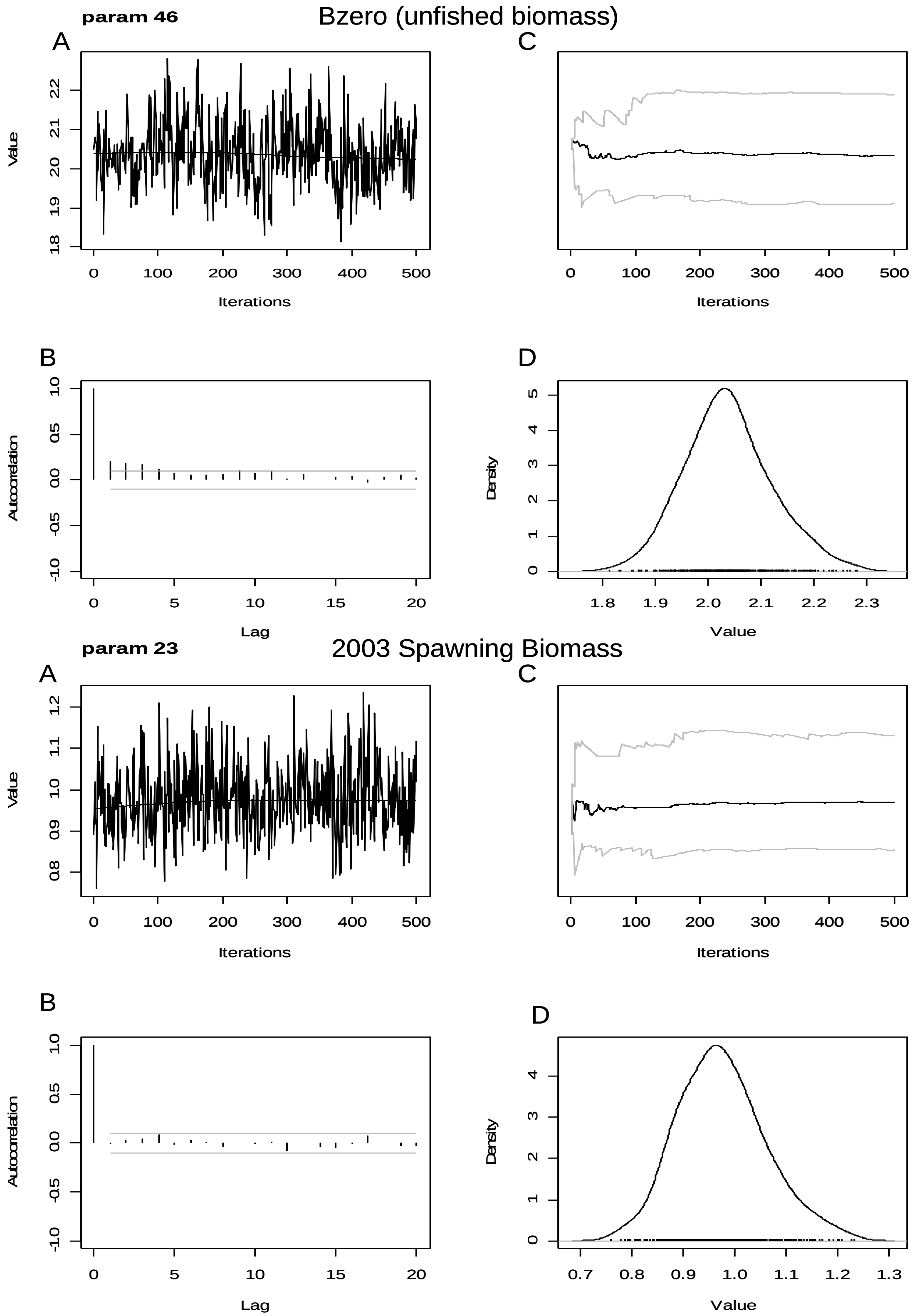


Figure 29. Results of Markov Chain Monte Carlo simulation diagnostics for selected parameters, Bzero (top) and spawning biomass (bottom), from Final Model 1b showing: A) trace plots (with running average), B) chain sequence autocorrelation, C) 5%, 50% and 95% of the chain sequence, and D) kernel density. MCMC diagnostics were qualitatively similar for Final Model 1c and are not shown.

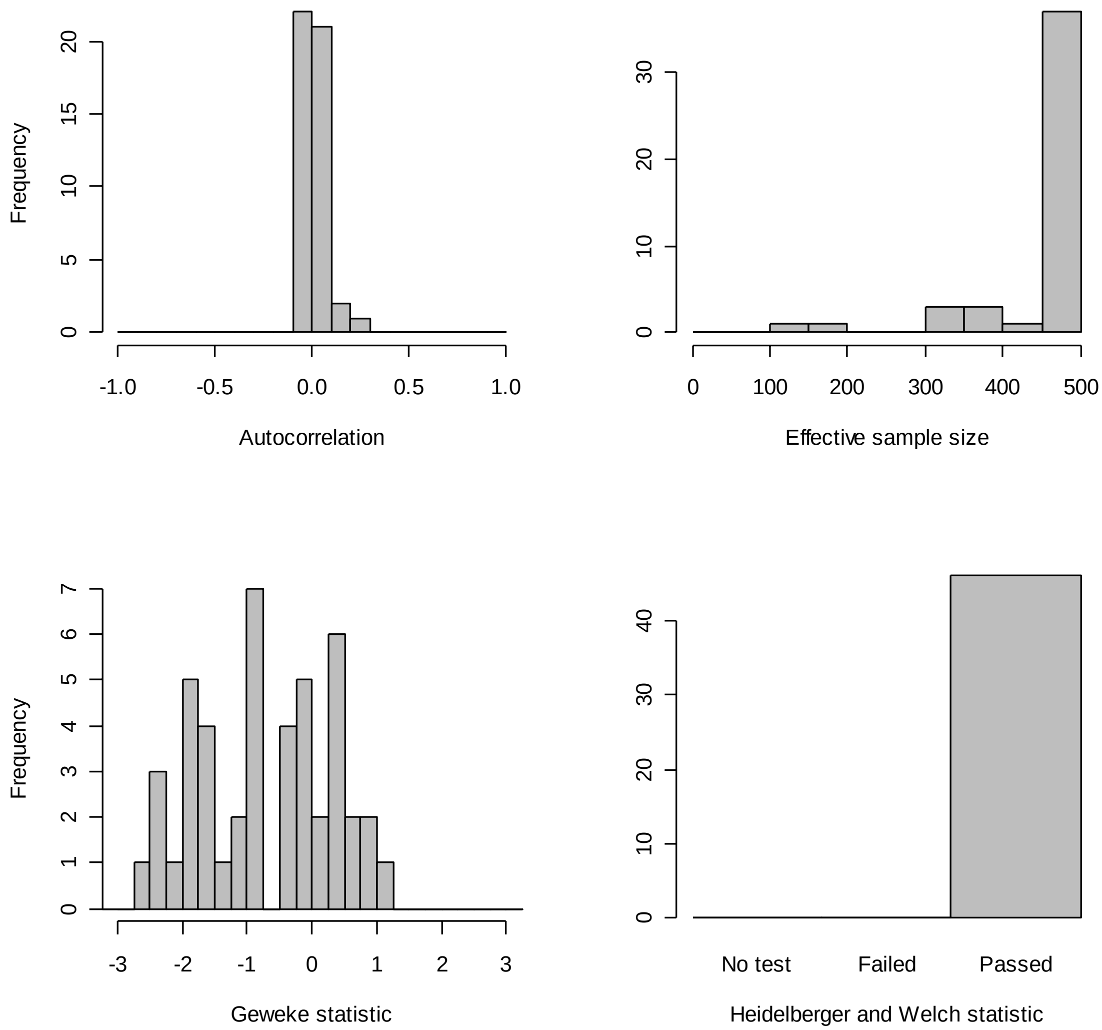


Figure 30. Summary diagnostics for 46 parameters from Final Model 1b based on 1,000 draws (after discarding first 20% of samples and thinned at every 1000th sample) from the Markov Chain Monte Carlo simulation of the posterior distribution. Plots shown are autocorrelation, effective sample size (x10), Geweke statistics of convergence of the mean (should be < |2|), and Heidelberger and Welch statistic. MCMC diagnostics were qualitatively similar for Final Model 1c and are not shown.

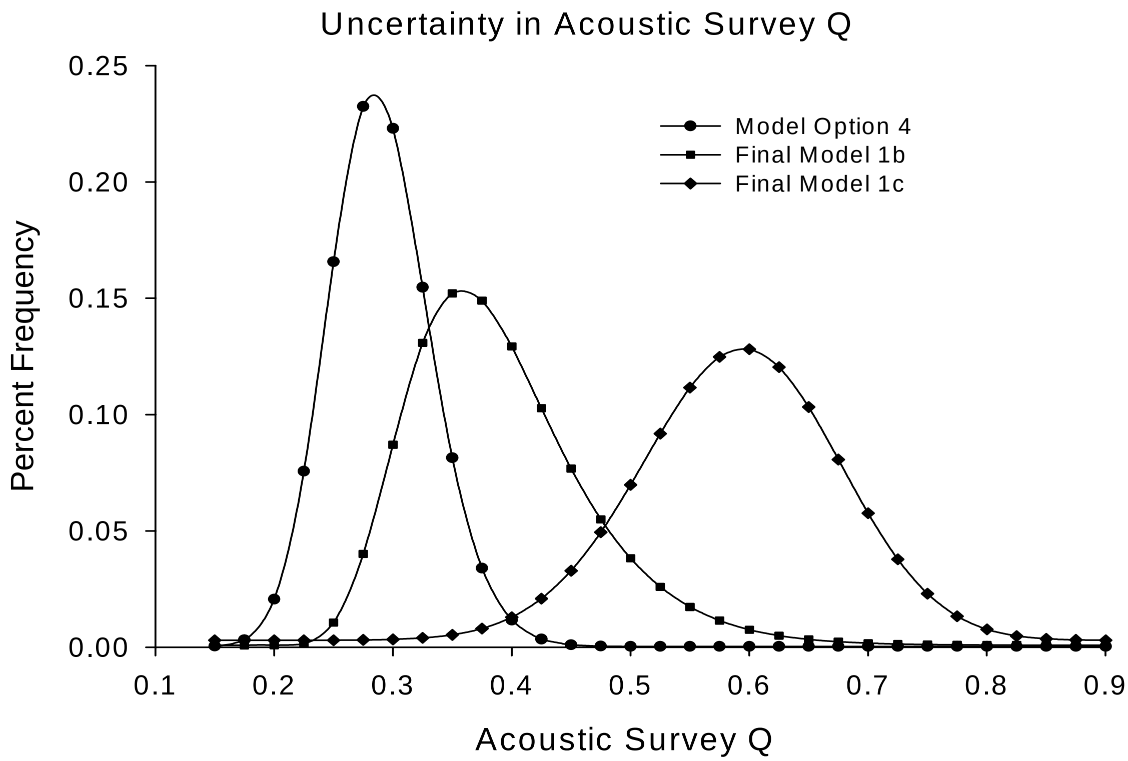


Figure 31. Uncertainty in acoustic survey catchability (q) for Model Option 4 and Final Models 1b and 1c from 2,500,000 MCMC samples.

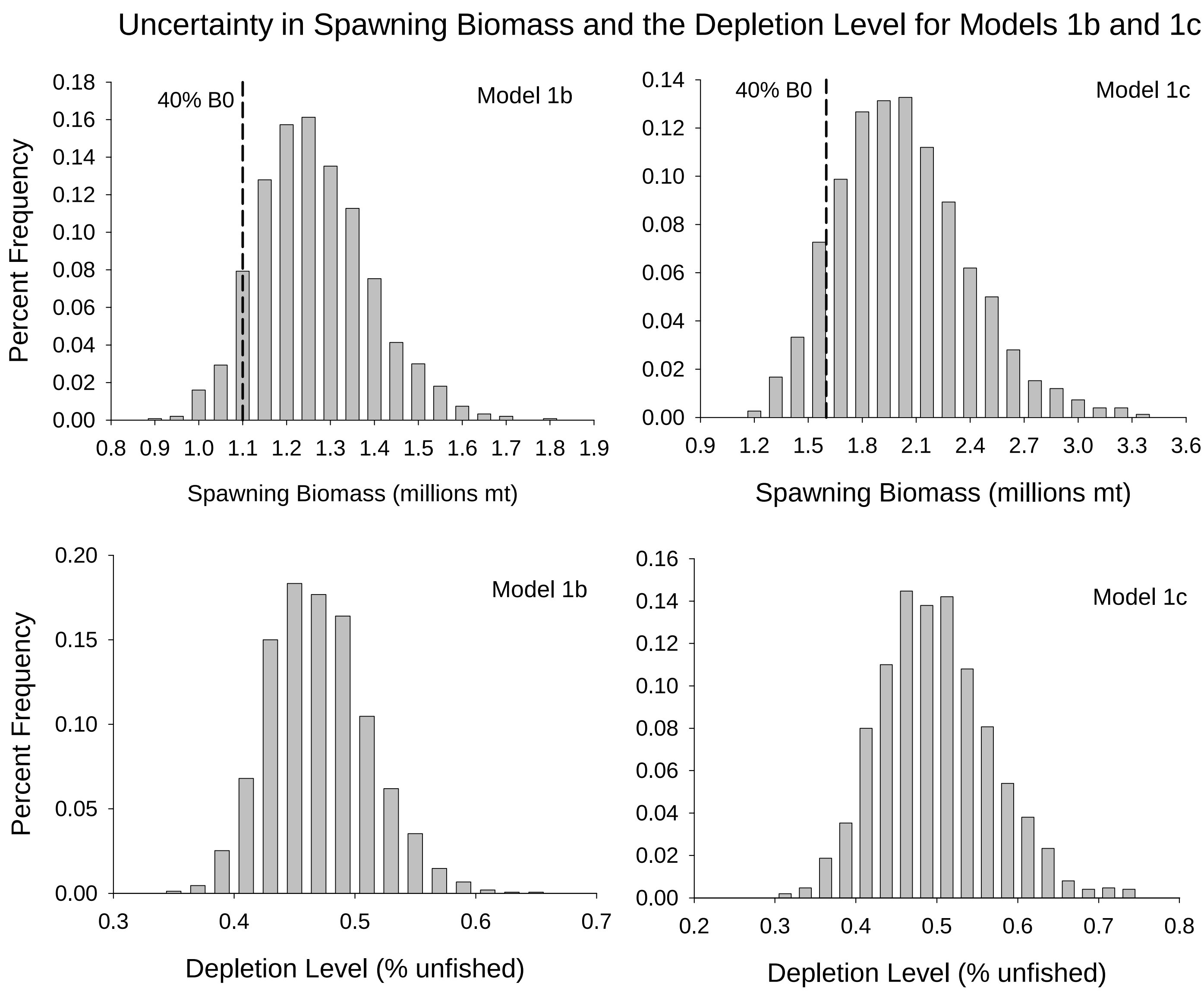


Figure 32. Uncertainty in the 2003 female spawning biomass and the corresponding depletion rate (% unfished biomass) for the Final Models 1b and 1c as shown by marginal posterior distributions based on 2,500,000 Markov Chain Monte Carlo samples.

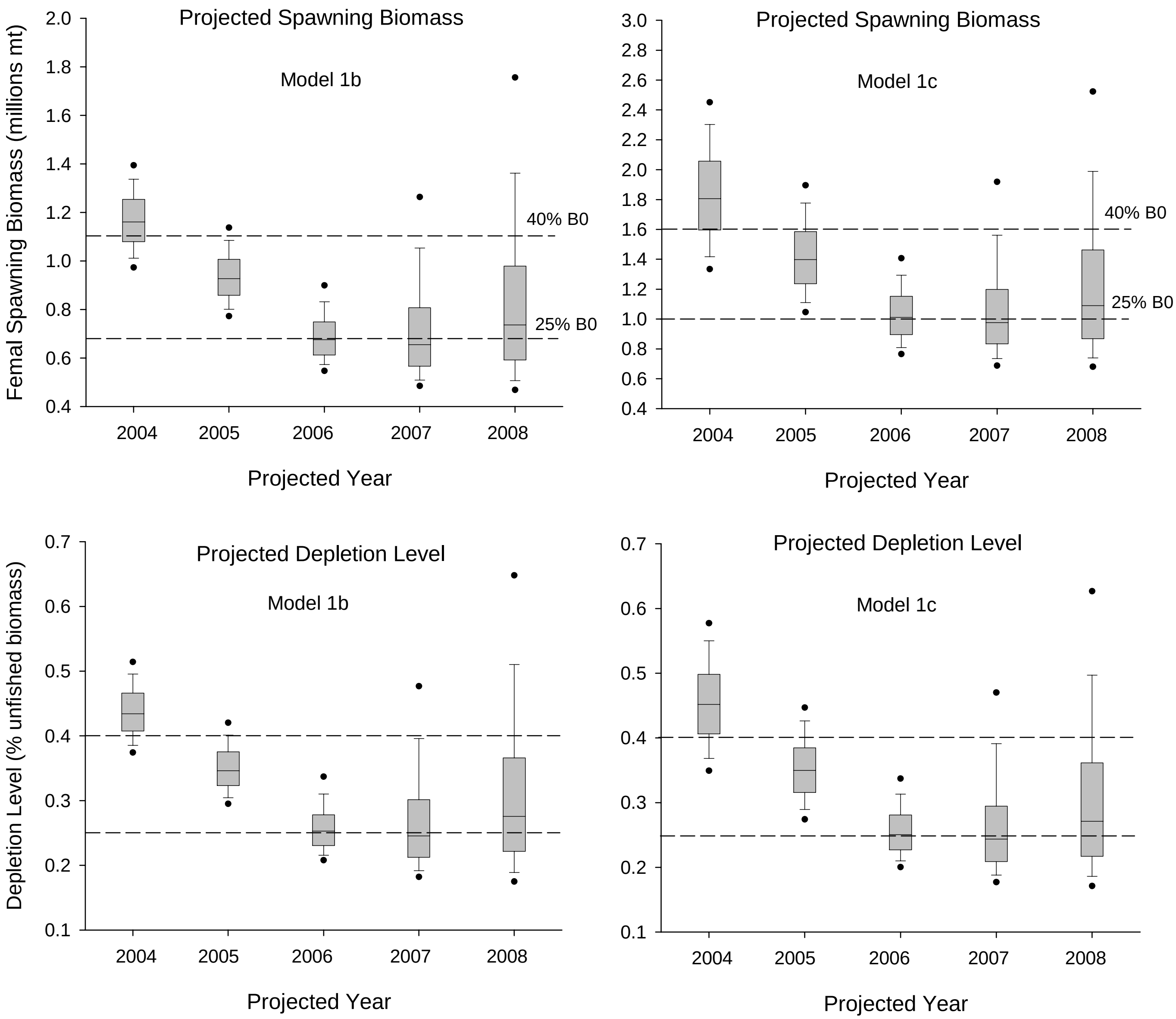


Figure 33. Uncertainty in projected 2004-2008 female spawning biomass and the depletion level (% unfished biomass) under the F40% (40-10) harvest rate policy from Final models 1b and 1c. Boxplots shown are based on 2,500,000 Markov Chain Monte Carlo samples. Table 14 provides projection results from F45% (40-10) and F50% (40-10) harvest rate policies.

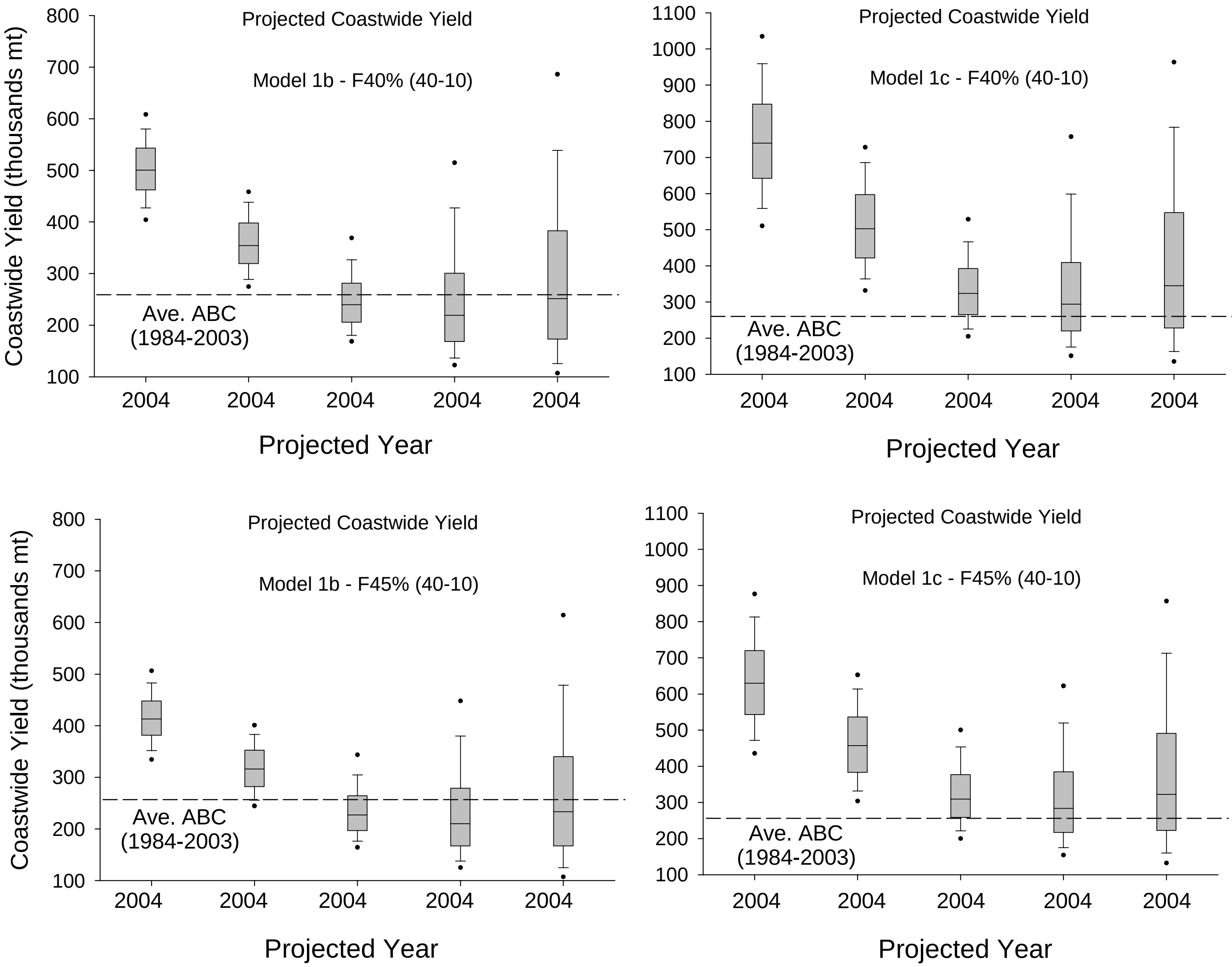


Figure 34. Uncertainty in projected 2004-2008 coastwide yield under the F40% (40-10) and F45% (40-10) harvest rate policies for Final Models 1b and 1c. Boxplots shown are based on based on 2,500,000 Markov Chain Monte Carlo samples.

APPENDIX 1: REVISED EXPANSION FACTOR CALCULATION AND APPLICATION

A. Biomass by region (from Dorn) -35db/kg

Strata	Strata No.	1977	1980	1983	1986	1989	1992
		Survey Year					
Mont.	1	108.087	579.841	56.203	770.292	209.437	
Eureka	2	360.944	182.783	252.265	192.205	360.454	
S. Col.	3	274.138	82.113	303.477	273.846	303.690	
N.C / Van.	4	194.741	338.295	330.198	367.099	254.378	
Canada	5	191.382	162.402	258.725	284.316	104.603	
	Total	1129.292	1345.434	1200.868	1887.758	1232.562	2577.615
	Inshore limit	91 m	55 m	55 m	55 m	55 m	
	Offshore limit	457 m	457 m	366 m	366 m	366 m	
	Northern limit	50 N	50 N	49.5 N	49.5 N	50 N	51.7 N
	Survey used	1995	1995	1998	1995	2001	1998

B. 1992 deep water expansion factors by region

Strata	Strata No.	1977	1980	1983	1986	1989
		Survey Year				
Mont.	1	1.82	1.82	2.02	2.02	2.02
Eureka	2	3.32	3.32	4.71	4.71	4.71
S. Col.	3	1.45	1.45	1.77	1.77	1.77
N. C/Van.	4	1.35	1.35	1.41	1.41	1.41
Canada	5	1.55	1.55	1.26	1.26	1.68

1995 deep water expansion factors by region

Strata	Strata No.	1977	1980	1983	1986	1989
		Survey Year				
Mont.	1	2.40	2.40	3.53	3.53	3.53
Eureka	2	3.39	3.39	3.87	3.87	3.87
S. Col.	3	1.86	1.86	2.05	2.05	2.05
N. C/Van.	4	1.20	1.20	1.24	1.24	1.24
Canada	5	1.59	1.59	1.33	1.33	1.92

1998 deep water expansion factors by region

Strata	Strata No.	1977	1980	1983	1986	1989
		Survey Year				
Mont.	1	1.16	1.16	1.28	1.28	1.28
Eureka	2	1.57	1.57	2.10	2.10	2.10
S. Col.	3	1.55	1.55	1.95	1.95	1.95
N. C/Van.	4	1.23	1.23	1.26	1.26	1.26
Canada	5	1.24	1.24	1.29	1.29	1.95

2001 deep water expansion factors by region

Strata	Strata No.	1977	1980	1983	1986	1989
		Survey Year				
Mont.	1	2.10	2.10	2.54	2.54	2.54
Eureka	2	2.04	2.04	2.29	2.29	2.29
S. Col.	3	1.11	1.11	1.14	1.14	1.14
N. C/Van.	4	1.00	1.00	1.00	1.00	1.00
Canada	5	1.00	1.00	1.00	1.00	1.00

C. Average deep water expansion factors by region

Strata	Strata No.	1977	1980	1983	1986	1989
		Survey Year				
Mont.	1	1.87	1.87	2.34	2.34	2.34
Eureka	2	2.58	2.58	3.24	3.24	3.24
S. Col.	3	1.49	1.49	1.73	1.73	1.73
N. C/Van.	4	1.20	1.20	1.23	1.23	1.23
Canada	5	1.35	1.35	1.22	1.22	1.64

D. Total acoustic backscattering cross section

Strata	Strata No.	Survey Year 1977	1980	1983	1986	1989
Mont.	1	804125	4313790	523778	7178661	1951828
Eureka	2	3704827	1876134	3254209	2479437	4649843
S. Col.	3	1627766	487567	2085702	1882058	2087166
N.C / Van.	4	925835	1608318	1612517	1792723	1242251
Canada	5	1024075	869005	1255760	1379970	681450

E. Mean acoustic backscatter per fish at 20 log L - 68

Strata	Strata No.	Survey Year 1977	1980	1983	1986	1989
Mont.	1	0.003756	0.003242	0.002673	0.002418	0.003405
Eureka	2	0.004146	0.003675	0.002662	0.003914	0.003520
S. Col.	3	0.004780	0.004824	0.002939	0.003238	0.003940
N. C/Van.	4	0.005318	0.005450	0.003469	0.003923	0.004108
Canada	5	0.006021	0.006011	0.004686	0.004560	0.004306

F. Total numbers of fish at 20 log L - 68

Strata	Strata No.	Survey Year 1977	1980	1983	1986	1989
Mont.	1	214083499	1330518547	195967560	2968869791	573140560
Eureka	2	893591551	510514894	1222263772	633404855	1321119034
S. Col.	3	340553090	101070657	709724996	581202708	529792311
N. C/Van.	4	174106292	295090548	464839305	456936452	302364752
Canada	5	170082952	144558788	268005234	302597273	158242442

G. Northern expansion factors by survey year.

	1995 Survey Year				1998 Survey Year			
Age	Total	>49.5 deg N	ratio	smoothed	Total	>49.5 deg N	ratio	smoothed
2	152.77	0.00	1.00	1.04	78.47	0.28	1.00	1.00
3	34.79	2.56	1.08	1.10	159.74	7.47	1.05	1.12
4	207.18	37.90	1.22	1.17	205.54	52.74	1.35	1.25
5	482.16	73.50	1.18	1.23	257.17	47.28	1.23	1.33
6	57.50	7.31	1.15	1.27	20.24	5.50	1.37	1.43
7	21.87	12.85	2.42	1.32	87.88	43.96	2.00	1.52
8	1108.29	264.65	1.31	1.36	135.43	33.04	1.32	1.55
9	33.26	18.79	2.30	1.43	16.85	4.43	1.36	1.60
10+	448.06	146.50	1.49	1.49	226.47	92.69	1.69	1.64

	2001 Survey Year				Years
Age	Total	>49.5 deg N	ratio	smoothed	Averaged
2	367.73	0.00	1.00	1.02	1.03
3	77.82	0.13	1.00	1.05	1.10
4	60.96	19.41	1.47	1.08	1.18
5	72.83	3.83	1.06	1.10	1.24
6	38.59	1.29	1.03	1.10	1.29
7	43.42	2.46	1.06	1.09	1.35
8	24.72	3.09	1.14	1.09	1.39
9	15.31	0.87	1.06	1.09	1.45
10+	33.17	2.68	1.09	1.09	1.51

H. Example worksheet for northern biomass expansions based on average ratios.

			Stratum No.				Mean		Average	Expanded
AGE	1	2	3	4	5	Total	Weight	Biomass	Ratio	Biomass
2	0	0	0	816736	192687	1009423	0.271	273345	1.026	280430.935
3	188583025	1192297408	670366901	362324677	53610890	2467182901	0.325	802722741	1.103	885730104
4	1621952	20995523	6102971	5960324	5728096	40408865	0.394	15909804	1.181	18787734
5	547115	690990	2221568	5879468	6050080	15389219	0.472	7259236	1.244	9027992.87
6	3755544	4304632	20335634	57409094	123745065	209549968	0.641	134358596	1.292	173617662
7	286414	374654	1831111	6093108	13209532	21794819	0.674	14689196	1.347	19791909.7
8	351480	1128301	1603756	6286885	14369096	23739519	0.775	18391170	1.387	25512742
9	241900	209373	1144396	5833438	10507331	17936438	0.798	14313051	1.450	20750145.1
10	215313	1176283	4030564	6919787	22096365	34438311	0.840	28926546	1.512	43744001.7
11	126197	85785	506683	1579119	5866690	8164474	0.894	7299668	1.512	11038880.7
12	184049	1000824	1200394	2638819	4567339	9591426	0.784	7516705	1.512	11367093.6
13	54572	0	381019	3024160	6517139	9976889	0.862	8596829	1.512	13000505.5
14	0	0	0	73690	1544924	1618614	1.011	1636370	1.512	2474590.69
15	0	0	0	0	0	0	1.011	0	1.512	0
Total	195967560	1222263772	709724996	464839305	268005234	2860800867		1.062E+09		1235123792