Chapter 3: Assessment of the Sablefish stock in Alaska

by

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Executive Summary

Summary of major changes

Relative to last year's assessment, we made the following substantive changes in the current assessment.

Input data: We added relative abundance and length data from the 2010 longline survey, relative abundance and length data from the 2009 longline and trawl fisheries, age data from the 2009 longline survey and 2009 longline fishery, updated 2009 catch and estimated 2010 catch to the assessment model. As recommended in the 2009 CIE review and 2010 sablefish modeling workshop, we are eliminating the longline surveys' relative population weight (RPW) indices from the model to avoid double use of the information from those surveys. We now only fit relative population numbers (RPN) from the longline surveys.

Model changes: We are recommending minor adjustments to the variance assumptions in the model. By eliminating an index, it was appropriate to rebalance data weightings. We used the standard deviation of the normalized residuals (SDNR) as a criterion to reweight the compositional likelihoods. This resulted in a model with better balance between likelihood components and less weight on length information when ages were available. Key results for the recommended model compared to last year's recommendations are shown below.

	Last year		**This year**	
Quantity/Status	2010	2011	2011	2012
M (natural mortality)	0.10	0.10	0.10	0.10
Specified/recommended Tier	3b	3b	3b	3b
Projected biomass (ages 2+)	233,107	236,110	251,141	256,761
Female spawning biomass (t)				
Projected	99,897	95,594	102,139	97,307
$B_{100\%}$	281,816	281,816	275,270	275,270
$B_{40\%}$	112,726	112,726	110,108	110,108
$B_{35\%}$	98,636	98,636	96,345	96,345
F_{OFL}	0.100	0.100	0.106	0.106
$maxF_{ABC}$ (maximum allowable = F40%)	0.084	0.084	0.089	0.089
Specified/recommended F_{ABC}	0.084	0.084	0.089	0.089
Specified/recommended OFL (t)	18,030	16,175	18,950	17,377
Specified/recommended ABC (t)	15,230	13,658	16,040	14,697
Is the stock being subjected to overfishing?	No	No	No	No
Is the stock currently overfished?	No	No	No	No
Is the stock approaching a condition of being overfished?	No	No	No	No

Assessment results: The fishery abundance index was down 17% from 2008 to 2009 (the 2010 data are not available yet). The survey abundance index increased 13% from 2009 to 2010 following a 16%

decrease from 2006 to 2009. Spawning biomass is projected to be lower from 2011 to 2014, and then stabilize.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1979-2008. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 110,108 t (combined across the EBS, AI, and GOA), 0.097, and 0.115, respectively. Projected female spawning biomass (combined areas) for 2011 is 102,139 t (93% of $B_{40\%}$), placing sablefish in sub-tier “b” of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.089, which translates into a 2011 ABC (combined areas) of 16,040 t. The OFL fishing mortality rate is 0.106 which translates into a 2011 OFL (combined areas) of 18,950 t. Model projections indicate that this stock is neither overfished nor approaching an overfished condition.

We recommend a 2011 ABC of 16,040 **t.** The maximum permissible yield for 2011 from an adjusted $F_{40\%}$ strategy is 16,040 t. The maximum permissible yield for 2011 is a 5% increase from the 2010 ABC of 15,230 t. This increase is supported by a substantial increase in the domestic longline survey index that offset the prior year’s decrease in the fishery abundance index. There was also a slight increase in estimates of incoming recruitment year classes. Spawning biomass is projected to decline through 2013, and then is expected to increase assuming average recruitment is achieved. Because of the lack of recent strong year classes, the maximum permissible ABC is projected to be 14,697 t in 2012 and 13,978 in 2013 (using estimated catches, instead of maximum permissible, see Table 3.10).

Projected 2011 spawning biomass is 37% of unfished spawning biomass. Spawning biomass has increased from a low of 30% of unfished biomass in 2002 to 37% projected for 2011. The 1997 year class has been an important contributor to the population but has been reduced and should comprise 10% of the 2011 spawning biomass. The 2000 year class appears to be larger than the 1997 year class, and is now 95% mature and should comprise 24% of the spawning biomass in 2011. The 2002 year class is beginning to show signs of strength and will comprise 9% of spawning biomass in 2011 and is 86% mature.

In December 1999, the Council apportioned the 2000 ABC and OFL based on a 5-year exponential weighting of the survey and fishery abundance indices. We used the same algorithm to apportion the 2011 ABC and OFL.

Apportionments are based on survey and fishery information	2010 ABC Percent	2010 Survey RPW	2009 Fishery RPW	2011 ABC Percent	2010 ABC	2011 ABC	Change
Total					15,230	16,040	5%
Bering Sea	18%	20%	11%	18%	2,790	**2,850**	2%
Aleutians	14%	9%	12%	12%	2,070	**1,900**	-8%
Gulf of Alaska	68%	71%	77%	70%	10,370	**11,290**	9%
Western	16%	13%	12%	14%	1,660	**1,620**	-2%
Central	43%	41%	39%	42%	4,510	**4,740**	5%
W. Yakutat	14%	19%	19%	16%	1,480	**1,830**	24%
E. Yakutat / Southeast	26%	28%	30%	27%	2,720	**3,100**	14%

After the adjustment for the 95:5 hook-and-line:trawl split in the Eastern Gulf of Alaska, the 2011 ABC for West Yakutat is 1,990 t and for East Yakutat/Southeast is 2,940 t. This adjustment projected to 2012 is 1,820 t for W. Yakutat and 2,700 t for E. Yakutat.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2011	1,990 t	2,940 t
	2012	1,818 t	2,700 t

Responses to the joint BSAI/GOA Plan team comments

The November 2009 joint plan team minutes included the following requests:

"*The author should contact the IPHC about getting them to collect length and weight data for sablefish on their survey, and to evaluate the data to see if the distribution of those data are similar to surveys.*"

We have not contacted the IPHC with this request yet. We need to do some analysis to determine what types of collections would be useful before asking the IPHC to conduct additional work.

"*Evaluate additional statistical methods for consideration of whale depredation issue*."

We have made substantial progress on a survey CPUE index that specifically addresses whale depredation (Appendix 3C).

"*Evaluate recalculating the RPW in the BS due to potential for inflation of biomass in that region from the extrapolation from a limited number of stations.*"

As shown in our survey index analysis (Appendix 3C), using a modeling approach should remove the need for *ad hoc* corrections that have been used in the past for the Bering Sea.

"*Include additional information in assessment on prohibited species bycatch, particularly of golden king crab in the pot fishery*."

We have included additional information in the *Pot fishery* section that describes bycatch in the pot fisheries of the Bering Sea and Aleutian Islands with a table of top species.

Responses to SSC comments specific to the sablefish assessment

The December 2009 SSC minutes included the following comments:

"In 2009, evidence of killer whale depredation was recorded for 10 out of 16 Bering Sea stations of the NMFS longline survey. The author explored several methods to correct for this high level of depredation and none worked to his satisfaction. Therefore, he treated 2009 as if no survey had occurred in the region and estimated the Bering Sea portion of the stock by multiplying the survey estimate from the last year the Bering Sea was sampled (2007) by the ratio of change from the Gulf of Alaska survey (2007-2009). The SSC agrees with this approach for this year's assessment however, they note that this is not a long-term solution to the problem of depredation in the Bering Sea. The SSC encourages the author to continue to explore statistical and modeling approaches that will take advantage of the full data set to interpolate depredated stations. The SSC recommends that the author explore alternative survey methods and evaluate if these methods may be less susceptible to whale depredation. The SSC realizes that developing a reliable index of sperm whale depredation may be difficult, but this remains an important concern for this assessment because it could influence the reliability of longline survey catch rates as an index of abundance trends."

We have initiated a substantial reanalysis of the longline survey index, specifically to address the depredation issues with both killer whales and sperm whales. While substantial progress has been made, we were not ready to utilize the new index (documented in Appendix 3C) until several issues are fully explored. We hope to incorporate the new index in the 2011 assessment.

"*While gully stations are sampled during the survey, the catch rates used in the model do not include gully stations. Gully stations may provide information on juvenile sablefish. The author examined the trends in gully stations and the slope stations to see if the gully stations portrayed a different pattern than the RPNs used in the assessment. The trends were similar in both datasets however, the correlation was not high. The author found some evidence that the gully stations may provide information on incoming year classes of sablefish. The SSC encourages the author to continue to explore the information content of the gully stations especially with respect to estimating incoming year classes. The author also compared sablefish catch rates from the IPHC longline survey to the catch rates from the sablefish longline survey. The two time series were comparable although the IPHC survey was more variable. The SSC encourages the author to continue to explore whether sablefish catch rates from the IPHC survey could be used to provide additional information to the assessment. In particular, the SSC recommends that the author work with the IPHC to determine whether the IPHC survey data could be used to fill in CPUE in areas missed by the NMFS sablefish survey.*"

We continue to monitor trends in these alternate surveys and stations in the 2010 assessment. The current work on the survey CPUE index aims to explore the use of the gully stations.

"*The time trend in the domestic longline fishery CPUE continues to be different from the surveys. The SSC continues to be concerned that inclusion of the longline fishery CPUE as an index of population status may not be appropriate. It is possible that this index does not reflect population trends because the fleet targets high density regions that would exhibit relatively constant CPUE rates across time. The author indicated that he will examine the implications of dropping this index and the SSC supports that analysis.*"

The CIE panel suggested that we continue to use the fishery index in the model. We believe that in its current form, it may not be informative about relative abundance. However, we agree with the panel that if the data are modeled more appropriately (considering spatial dynamics, vessel effects, and targeting), we may find that the data can be more informative for future assessments. We plan to address this issue by following a similar approach to the modeling being conducted for the survey CPUE index. The 2010 modeling workshop recommended examining a core fleet, modeling only the IFQ fishery (1995-present), and working with industry to determine the appropriate variables to best capture fishery catch rates.

"*Results of the assessment show that there have been no strong year classes of sablefish since 2000. This is the longest period without a strong year class in the time series. The 2000 year class will represent a large portion of the spawning biomass in the near future. The retrospective pattern that previously showed the assessment was overestimating sablefish abundance appears to have been improved in recent years. The SSC recommends that this retrospective pattern continue to be examined in the future.*"

Although the intention of reweighting compositional indices was to compensate for the removal of an abundance index, it appears to have substantially improved retrospective trends from the model (e.g. Figure 3.23a and 3.23b)

"*The Authors noted that several model changes that were recommended by the CIE will be considered at a workshop in the spring of 2010. The SSC supports this approach to addressing model changes and recommends that a SSC member attend this meeting (Franz Mueter has volunteered to represent the SSC). The SSC reviewed the CIE comments and the author's responses that were contained in an Appendix to the SAFE. The SSC encourages work on each of the issues identified. In particular, the SSC highlights the need to address the following issues:*

The authors should justify why both RPNs and RPWs are necessary in the model and why this does not constitute double weighting."

In the recommended model in this assessment, the RPWs are removed and the model is reweighted to compensate for the change in relative likelihood caused by removing an abundance index.

The SSC continues to encourage the development of a sablefish migration model. This model would provide improved estimates of exploitation by cohort and would provide a useful tool for area apportionments. They support the authors' plan to review the available tagging data to assess sablefish movement and to model apportionment.

We consider this to be a high priority and hope to make substantial progress on analysis of tagging data and movement model scenarios in the near future.

The SSC noted that the report submitted by the public included a recommendation to consider shortening the time series. The SSC does not recommend dropping the early part of the time series but they do recommend exploring the use of temporal partitions to adjust for changes in the survey, exploitation, or biology of the stock.

We do not agree with the recommendation of shortening the time series. There is substantial historical data for sablefish that contribute to the contrast necessary to estimate key parameters in the model. We currently partition the data into different stanzas based on changes in the fishery and biological parameters.

Plan team summaries

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2009	149,000	13,190	11,160	11,160	10,910
	2010	140,000	12,270	10,370	10,370	9,638
	2011	149,000	13,340	11,290		
	2012	138,000	12,232	10,345		
BS	2009	39,000	3,210	2,720	2,720	891
	2010	38,000	3,310	2,790	2,790	631
	2011	37,000	3,360	2,850		
	2012	35,000	3,081	2,611		
AI	2009	28,000	2,600	2,200	2,200	1,096
	2010	27,000	2,450	2,070	2,070	999
	2011	25,000	2,250	1,900		
	2012	23,000	2,063	1,741		

Year	2010				**2011**		2012	
Region	OFL	ABC	TAC	Catch*	OFL	ABC	OFL	ABC
BS	3,310	2,790	2,790	631	3,360	2,850	3,081	2,611
AI	2,450	2,070	2,070	999	2,250	1,900	2,063	1,741
GOA	12,270	10,370	10,370	9,638	13,340	11,290	12,232	10,345
W	--	1,660	1,660	1,261	--	1,620	--	1,484
C	--	4,510	4,510	4,259	--	4,740	--	4,343
WYAK	--	1,480	1,480	1,544	--	1,830	--	1,678
SEO	--	2,720	2,720	2,574	--	3,100	--	2,840
Total	18,030	15,230	15,230	11,268	18,950	16,040	17,377	14,697

*Current as of October 10, 2010 (http://www.fakr.noaa.gov).

Introduction

Distribution: Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the Gulf of Alaska, westward to the Aleutian Islands, and into the Bering Sea (Wolotira et al. 1993). Adult sablefish occur along the continental slope, shelf gullies, and in deep fjords, generally at depths greater than 200 m. Sablefish observed from a manned submersible were found on or within 1 m of the bottom (Krieger 1997). In contrast to the adult distribution, juvenile sablefish (less than 40 cm) spend their first two to three years on the continental shelf of the Gulf of Alaska, and occasionally on the shelf of the southeast Bering Sea. The Bering Sea shelf is utilized significantly in some years and little used during other years (Shotwell 2007).

Stock structure and management units: Sablefish form two populations based on differences in growth rate, size at maturity, and tagging studies (McDevitt 1990, Saunders et al. 1996, Kimura et al. 1998). A northern population inhabits Alaska and northern British Columbia waters and a southern population inhabits southern British Columbia, Washington, Oregon, and California waters, with mixing of the two populations occurring off southwest Vancouver Island and northwest Washington.

Sablefish are assessed as a single population in Federal waters off Alaska because northern sablefish are highly migratory for at least part of their life (Heifetz and Fujioka 1991, Maloney and Heifetz 1997, Kimura et al. 1998). Sablefish are managed by discrete regions to distribute exploitation throughout their wide geographical range. There are four management areas in the Gulf of Alaska: Western, Central, West Yakutat, and East Yakutat/Southeast Outside (SEO); and two management areas in the Bering Sea/Aleutian Islands (BSAI): the eastern Bering Sea (EBS) and the Aleutian Islands (AI) region.

Early life history: Spawning is pelagic at depths of 300-500 m near the edges of the continental slope (Mason et al. 1983, McFarlane and Nagata 1988), with eggs developing at depth and larvae developing near the surface as far offshore as 180 miles (Wing 1997). Average spawning date in Alaska based on otolith analysis is March 30 (Sigler et al. 2001). Along the Canadian coast (Mason et al. 1983) and off Southeast Alaska (Jennifer Stahl, ADF&G, personal communication) sablefish spawn from January-April with a peak in February. Farther down the coast off of central California sablefish spawn earlier, from October-February (Hunter et al. 1989). Sablefish in spawning condition were also noted as far west as Kamchatka in November and December (Orlov and Biryukov 2005). The size of sablefish at 50% maturity off California and Canada is 58-60 cm for females, corresponding to an age of approximately 5 years (Mason et al. 1983, Hunter et al. 1989). In Alaska, most young-of-the-year sablefish are caught in the central and eastern Gulf of Alaska (Sigler et al. 2001). Near the end of the first summer, pelagic juveniles less than 20 cm drift inshore and spend the winter and following summer in inshore waters, reaching 30-40 cm by the end of their second summer (Rutecki and Varosi 1997). After their second summer, they begin moving offshore to deeper water, typically reaching their adult habitat, the upper continental slope at 4 to 5 years. This corresponds to the age range when sablefish start becoming reproductively viable (Mason et al. 1983). Younger fish (age 3-4) inhabit shallower waters on the shelf, while older fish migrate down to the slope. Fish also tend to move counterclockwise through the Gulf of Alaska with age (e.g., Maloney and Sigler 2008, Heifetz and Fujioka 1991).

Fishery

Early U.S. fishery, 1957 and earlier

Sablefish have been exploited since the end of the 19th century by U.S. and Canadian fishermen. The North American fishery on sablefish developed as a secondary activity of the halibut fishery of the United States and Canada. Initial fishing grounds were off Washington and British Columbia and then spread to Oregon, California, and Alaska during the 1920's. Until 1957, the sablefish fishery was exclusively a U.S. and Canadian fishery, ranging from off northern California northward to Kodiak Island in the Gulf of Alaska; catches were relatively small, averaging 1,666 t from 1930 to 1957, and generally limited to areas near fishing ports (Low et al. 1976).

Foreign fisheries, 1958 to 1987

Japanese longliners began operations in the eastern Bering Sea in 1958. The fishery expanded rapidly in this area and catches peaked at 25,989 t in 1962 (Table 3.1a, Figure 3.1). As the fishing grounds in the eastern Bering were preempted by expanding Japanese trawl fisheries, the Japanese longline fleet expanded to the Aleutian Islands region and the Gulf of Alaska. In the Gulf of Alaska, sablefish catches increased rapidly as the Japanese longline fishery expanded, peaking at 36,776 t overall in 1972. Catches in the Aleutian Islands region remained at low levels with Japan harvesting the largest portion of the sablefish catch. Most sablefish harvests were taken from the eastern Being Sea until 1968, and then from the Gulf of Alaska until 1977. Heavy fishing by foreign vessels during the 1970's led to a substantial population decline and fishery regulations in Alaska, which sharply reduced catches. Catch in the late 1970's was restricted to about one-fifth of the peak catch in 1972, due to the passage of the Magnuson-Stevens Act (MSFCMA).

Sasaki (1985) described the gear used in the directed Japanese longline fishery. He found only minor differences in the structure of fishing gear and the fishing technique used by Japanese commercial longline vessels. There were small differences in the length of hachis (Japanese term for a longline skate) and in the number of hooks among vessels, but hook spacing remained about 1.6 m. The use of squid as bait also remained unchanged, except some vessels used Pacific saury as bait when squid was expensive. The standard number of hachis fished per day was 376 (Sasaki 1978) and the number of hooks per hachi was 43 until 1979, when the number was reduced to 40 (T. Sasaki, Japan Fisheries Agency, 4 January 1999).

Japanese trawlers caught sablefish mostly as bycatch in fisheries targeting other species. Two trawl fisheries caught sablefish in the Bering Sea through 1972: the North Pacific trawl fishery which caught sablefish as bycatch in the directed pollock fishery, and the land-based dragnet fishery that sometimes targeted sablefish (Sasaki 1973). The latter fishery mainly targeted rockfishes, Greenland turbot, and Pacific cod, and only a few vessels targeted sablefish (Sasaki 1985). The land-based fishery caught more sablefish, averaging 7,300 t from 1964 to 1972, compared to the North Pacific trawl fishery, which averaged 4,600 t. In the Gulf of Alaska, sablefish were caught as bycatch in the directed Pacific Ocean perch fishery until 1972, but some vessels started targeting sablefish in 1972 (Sasaki 1973). Most net-caught sablefish were caught by stern trawls, but significant amounts also were caught by side trawls and Danish seines the first few years of the Japanese trawl fishery.

Other foreign nations besides Japan also caught sablefish. Substantial U.S.S.R. catches were reported from 1967-73 in the Bering Sea (McDevitt 1986). Substantial R.O.K. catches were reported from 1974-1983 scattered throughout Alaska. Other countries reporting minor sablefish catches were Republic of Poland, Taiwan, Mexico, Bulgaria, Federal Republic of Germany, and Portugal. The U.S.S.R. gear was factory-type stern trawl and the R.O.K. gear was longlines and pots (Low et al. 1976).

Recent U.S. fishery, 1977 to present

The U.S. longline fishery began expanding in 1982 in the Gulf of Alaska and in 1988, harvested all sablefish taken in Alaska except minor joint venture catches. Following domestication of the fishery, the previously year-round season in the Gulf of Alaska began to shorten in 1984. By the late 1980's, the average season length decreased to 1-2 months. In some areas, this open-access fishery was as short as 10 days, warranting the label "derby" fishery.

Year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Season length (months)	12	7.6	3.0	1.5	1.2	1.8	1.5	1.3	0.9	0.7	0.5	0.3

Season length continued to decrease until Individual Fishery Quotas (IFQ) were implemented for hook-and-line vessels in 1995 along with an 8-month season. From 1995 to 2002 the season ran from approximately March 15-November 15. Starting in 2003 the season was extended by moving the start date to approximately March 1. The sablefish IFQ fishery is concurrent with the halibut IFQ fishery.

The expansion of the U.S. fishery was helped by exceptional recruitment during the late 1970's. This exceptional recruitment fueled an increase in abundance for the population during the 1980's. Increased abundance led to increased quotas and catches peaked again in 1988 at about 70% of the 1972 peak. Abundance has since fallen as the exceptional late 1970's year classes have dissipated. Catches fell again in 2000 to approximately 42% of the 1988 peak. Catches since 2000 have increased modestly, largely due to a strong 1997 year class.

IFQ management has increased fishery catch rates and decreased the harvest of immature fish (Sigler and Lunsford 2001). Catching efficiency (the average catch rate per hook for sablefish) increased 1.8 times with the change from an open-access to an IFQ fishery. The improved catching efficiency of the IFQ fishery reduced the variable costs incurred in attaining the quota from eight to five percent of landed value, a savings averaging US$3.1 million annually. Decreased harvest of immature fish improved the chance that individual fish will reproduce at least once. Spawning potential of sablefish, expressed as spawning biomass per recruit, increased nine percent for the IFQ fishery.

The directed fishery is primarily a hook-and-line fishery. Sablefish also are caught as bycatch during directed trawl fisheries for other species groups such as rockfish and deepwater flatfish. Five State of Alaska fisheries land sablefish outside the IFQ program; the major State fisheries occur in the Prince William Sound, Chatham Strait, and Clarence Strait and the minor fisheries in the northern Gulf of Alaska and Aleutian Islands. The minor state fisheries were established by the State of Alaska in 1995, the same time as the Federal Government established the IFQ fishery, primarily to provide open-access fisheries to fishermen who could not participate in the IFQ fishery. For Federal and State sablefish fisheries combined, the number of longline vessels targeting sablefish (Hiatt 2009) was:

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Vessels	700	646	504	544	528	511	503	491	438	438	399	409	395	388	389

Longline gear in Alaska is fished on-bottom. In the 1996 directed fishery for sablefish, average set length was 9 km and average hook spacing was 1.2 m. The gear is baited by hand or by machine, with smaller boats generally baiting by hand and larger boats generally baiting by machine. Circle hooks usually are used, except for modified J-hooks on some boats with machine baiters. The gear usually is deployed from the vessel stern with the vessel traveling at 5-7 knots. Some vessels attach weights to the longline, especially on rough or steep bottom, so that the longline stays in place and lays on-bottom.

Depredation by killer whales and sperm whales is not uncommon in the Alaska sablefish IFQ fishery (Sigler et al. 2007). Killer whale depredation occurs in the Bering Sea, Aleutian Islands, and Western Gulf of Alaska. Sperm whale depredation occurs in the Central and Eastern Gulf of Alaska.

Pot fishing for sablefish has increased in the Bering Sea and Aleutian Islands as a response to depredation of longline catches by killer whales. In 2000 the pot fishery accounted for less than ten percent of the fixed gear sablefish catch in the Bering Sea and Aleutian Islands. Since 2004, pot gear has accounted for over half of the Bering Sea fixed gear IFQ catch and up to 34% of the catch in the Aleutians. In 2009, pot fishing remained a high portion of the fixed gear catch in the BS (70%), whereas in the Aleutian Islands pot fishing decreased from 22% to 7.6% of the fixed gear catch. A small amount of pot fishery data is available from observer and logbook data and is now included in the fishery catch rate section.

Catch

Annual catches in Alaska averaged about 1,700 t from 1930 to 1957 and exploitation rates remained low until Japanese vessels began fishing for sablefish in the Bering Sea in 1958 and the Gulf of Alaska in 1963. Catches rapidly escalated during the mid-1960's. Annual catches in Alaska reached peaks in 1962, 1972, and 1988 (Table 3.1a). The 1972 catch was the all-time high, at 53,080 t, and the 1962 and 1988 catches were 50% and 72% of the 1972 catch. Evidence of declining stock abundance and passage of the MSFCMA led to significant fishery restrictions from 1978 to 1985, and total catches were reduced substantially. Catches averaged about 12,200 t during this time. Exceptional recruitment fueled increased abundance and increased catches during the late 1980's. The domestic fishery also expanded during the 1980's, harvesting 100% of the catch in the Gulf of Alaska by 1985 and in the Bering Sea and Aleutians by 1988. Catches declined during the 1990's. Catches peaked at 38,406 t in 1988, fell to about 13,000 t in the late 1990's, and have been near 13,000 t recently. The proportion of catch due to pot fisheries in the Bering Sea and the Aleutian Islands increased starting in 2000 (Table 3.1b) and is discussed further below.

Bycatch and discards

Sablefish discards have decreased in recent years. From 1994 to 2003 discards averaged 1,357 t for the GOA and BSAI combined (Table 3.2 Hanselman et al. 2008). The highest amount was 800 t in 2004, of which 667 t occurred in the GOA and 133 t occurred in the BSAI. Discards decreased after 2003, down to an average in 2004-09 of 697 mt, 89% of which occurred in the GOA. The discards from trawl fisheries decreased from a 1994-2003 average of 825 t to an average of 262 mt for 2004-2009, while hook and line fisheries decreased slightly from 525 t down to 462 t (Table 3.2).

Table of the average catch (t) of the most abundant species caught in the 2005-2009 sablefish fishery are shown below. Grenadiers are by far the most abundant bycatch in the sablefish fishery. Commercially valuable species taken in the sablefish fishery include thornyhead rockfish, shortraker rockfish, rougheye rockfish, and Pacific cod.

	Hook and Line			Other Gear			All Gear		
Species	Discard	Retained	Total	Discard	Retained	Total	Discard	Retained	Total[1]
Grenadiers[2]	-	-	8,834	-	-	104	-	-	8,938
Thornyhead rockfish	46	377	423	2	14	16	49	391	440
Arrowtooth flounder	321	87	408	110	18	128	431	105	536
Other skates	202	8	209	1	1	2	203	8	211
Shortraker rockfish	79	119	199	4	3	6	83	122	205
Longnose skate	167	6	173	1	1	2	168	7	175
Spiny dogfish	170	0	170	0	0	0	170	0	170
Rougheye rockfish	40	89	128	3	1	4	42	89	132
Pacific cod	32	74	106	1	6	8	33	81	114
Greenland turbot	40	53	93	20	5	25	60	58	118
Other	92	32	124	24	22	46	117	53	170
Total All Species	1,189	845	10,867	166	71	341	1,356	914	11,209

[1] Data from Terry Hiatt (AKFIN database), only includes catch where sablefish were defined as the target. [2]Grenadiers are only listed as Total because they are not defined in the discard tables.

Previous management actions

Quota allocation: Amendment 14 to the Gulf of Alaska Fishery Management Plan allocated the sablefish quota by gear type: 80% to fixed gear (including pots) and 20% to trawl in the Western and Central Gulf of Alaska, and 95% to fixed gear and 5% to trawl in the Eastern Gulf of Alaska, effective 1985. Amendment 13 to the Bering Sea/Aleutian Islands Fishery Management Plan, allocated the sablefish quota by gear type, 50% to fixed gear and 50% to trawl in the eastern Bering Sea, and 75% to fixed gear and 25% to trawl gear in the Aleutians, effective 1990.

IFQ management: Amendment 20 to the Gulf of Alaska Fishery Management Plan and 15 to the Bering Sea/Aleutian Islands Fishery Management Plan established IFQ management for sablefish beginning in 1995. These amendments also allocated 20% of the fixed gear allocation of sablefish to a CDQ reserve for the Bering Sea and Aleutian Islands.

Maximum retainable allowances: Maximum retainable allowances for sablefish were revised in the Gulf of Alaska by a regulatory amendment, effective 10 April 1997. The percentage depends on the basis species: 1% for pollock, Pacific cod, Atka mackerel, “other species”, and aggregated amount of non-groundfish species. Fisheries targeting deep flatfish, rex sole, flathead sole, shallow flatfish, Pacific ocean perch, shortraker and rougheye rockfish, other rockfish, northern rockfish, pelagic rockfish, demersal shelf rockfish in the Southeast Outside district, and thornyheads are allowed 7%. Arrowtooth flounder fisheries are not allowed to retain any sablefish.

Allowable gear: Amendment 14 to the Gulf of Alaska Fishery Management Plan banned the use of pots for fishing for sablefish in the Gulf of Alaska, effective 18 November 1985, starting in the Eastern area in 1986, in the Central area in 1987, and in the Western area in 1989. An earlier regulatory amendment was approved in 1985 for 3 months (27 March - 25 June 1985) until Amendment 14 was effective. A later regulatory amendment in 1992 prohibited longline pot gear in the Bering Sea (57 FR 37906). The prohibition on sablefish longline pot gear use was removed for the Bering Sea, except from 1 to 30 June to prevent gear conflicts with trawlers during that month, effective 12 September 1996. Sablefish longline pot gear is allowed in the Aleutian Islands.

Management areas: Amendment 8 to the Gulf of Alaska Fishery Management Plan established the West and East Yakutat management areas for sablefish, effective 1980.

A summary of these management measures and a time series of catch, ABC and TAC is shown below.

Year	Catch(t)	ABC	TAC	Management measure
1980	10,444		18,000	Amendment 8 to the Gulf of Alaska Fishery Management Plan established the West and East Yakutat management areas for sablefish.
1981	12,604		19,349	
1982	12,048		17,300	
1983	11,715		14,480	
1984	14,109		14,820	
1985	14,465		13,480	Amendment 14 of the GOA FMP allocated sablefish quota by gear type: 80% to fixed gear and 20% to trawl gear in WGOA and CGOA and 95% fixed to 5% trawl in the EGOA.
1986	28,892		21,450	Pot fishing banned in Eastern GOA.
1987	35,163		27,700	Pot fishing banned in Central GOA.
1988	38,406		36,400	
1989	34,829		32,200	Pot fishing banned in Western GOA.
1990	32,115		33,200	Amendment 15 of the BSAI FMP allocated sablefish quota by gear type: 50% to fixed gear in and 50% to trawl in the EBS, and 75% fixed to 25% trawl in the Aleutian Islands.
1991	27,073		28,800	
1992	24,932		25,200	Pot fishing banned in Bering Sea (57 FR 37906).
1993	25,433		25,000	
1994	23,760		28,840	
1995	20,954		25,300	Amendment 20 to the Gulf of Alaska Fishery Management Plan and 15 to the Bering Sea/Aleutian Islands Fishery Management Plan established IFQ management for sablefish beginning in 1995. These amendments also allocated 20% of the fixed gear allocation of sablefish to a CDQ reserve for the Bering Sea and Aleutian Islands. In 1997, maximum retainable allowances for sablefish were revised in the Gulf of Alaska.
1996	17,577		19,380	Pot fishing ban repealed in Bering Sea except from June 1-30.
1997	14,922	19,600	17,200	Maximum retainable allowances for sablefish were revised in the Gulf of Alaska. The percentage depends on the basis species.
1998	14,108	16,800	16,800	
1999	13,575	15,900	15,900	
2000	15,919	17,300	17,300	
2001	14,097	16,900	16,900	
2002	14,789	17,300	17,300	
2003	16,371	18,400	20,900	
2004	17,720	23,000	23,000	
2005	16,619	21,000	21,000	
2006	15,417	21,000	21,000	
2007	15,011	20,100	20,100	
2008	14,335	18,030	18,030	Pot fishing ban repealed in Bering Sea for June 1-30 (74 FR 28733).
2009	13,206	16,080	16,080	
2010	11,268	15,230	15,230	

Data

The following table summarizes the data used for this assessment:

Source	Data	Years
Fisheries	Catch	1960-2010
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. longline fishery	CPUE, length	1990-2009
	Age	1999-2009
U.S. trawl fisheries	Length	1990,1991,1999, 2005-2009
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-2010
	Age	1996-2009
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009

Fishery

Length, catch, and effort data were historically collected from the Japanese and U.S. longline and trawl fisheries, and are now collected from U.S. longline, trawl, and pot fisheries (Table 3.3). The Japanese data were collected by fishermen trained by Japanese scientists (L. L. Low, Alaska Fisheries Science Center, pers. commun., 25 August 1999). The U.S. fishery length and age data were collected by at-sea and plant observers. No age data were systematically collected from the fisheries until 1999 because of the difficulty of obtaining representative samples from the fishery and because only a small number of sablefish can be aged each year. The equations used to compile the fishery and survey data used in the assessment are shown in Appendix A of the 2002 SAFE (Sigler et al. 2002).

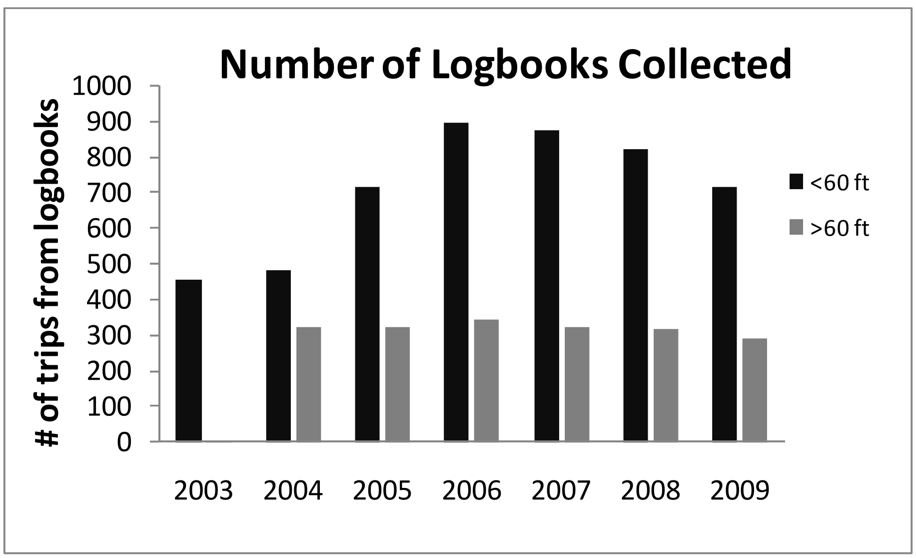
The catches used in this assessment (Table 3.1) include catches from minor State-managed fisheries in the northern Gulf of Alaska and in the Aleutian Islands region because fish caught in these State waters are reported using the area code of the adjacent Federal waters in Alaska Regional Office catch reporting system (G. Tromble, Alaska Regional Office, pers. comm., 12 July 1999), the source of the catch data used in this assessment. Minor State fisheries catches averaged 180 t from 1995-1998 (ADFG), about 1% of the average total catch. Most of the catch (80%) is from the Aleutian Islands region. The effect of including these State waters catches in the assessment is to overestimate biomass by about 1%, a negligible error considering statistical variation in other data used in this assessment.

Some catches probably were not reported during the late 1980's (Kinoshita et al. 1995). Unreported catches could account for the Japan-U.S. cooperative longline survey index's sharp drop from 1989-90 (Table 3.4, Figures 3.2 and 3.3). We tried to estimate the amount of unreported catches by comparing reported catch to another measure of sablefish catch, sablefish imports to Japan, the primary buyer of sablefish. However the trends of reported catch and imports were similar, so we decided to change our approach for catch reporting in the 1999 assessment. We assumed that non-reporting is due to at-sea discards, and apply discard estimates from 1994 to 1997 to inflate U.S. reported catches before 1994 (2.9% for hook-and-line and 26.6% for trawl).

One problem with the fishery data has been low length sample sizes for the trawl fishery (Table 3.3). From 1992 to 1998, few lengths were collected each year and the resultant length frequencies were inadequate and could not be used in the assessment model. The problem was that sablefish often are caught with other species like rockfish and deepwater flatfish, but are not the predominant species. The observer sampling protocol called for sampling the predominant species, so sablefish were poorly sampled. We communicated this problem to the observer program and together worked out revised sampling protocols. The revision greatly improved the sample size, so that the 1999 length data for the trawl fishery can be used for the assessment. The sample sizes for the years 2000-2004 were low and length compositions for these years were not used for the assessment. However since 2005, at least several hundred lengths have been collected each year and the data has been incorporated into the assessment.

Longline fishery catch rate analysis

Fishery information is available from longline and pot vessels which target sablefish in the IFQ fishery. Records of catch and effort for these vessels are collected by observers and by vessel captains in voluntary and required logbooks. Fishery data from the Observer Program are available since 1990. Vessels between 60 and 125 feet carry an observer 30% of the time and vessels >125 feet carry an observer 100% of the time. Since 1999, logbooks have been required for vessels >60 feet. Vessels <60 feet are not required to carry observers or submit logbooks but many do participate in a voluntary logbook program formed in 1997. Logbook participation by vessels <60 feet has increased greatly in recent years. Since 2003 vessels <60 feet have accounted for approximately 69% of all logbooks submitted. Both voluntary and required logbooks are used in catch rate analyses. For the logbook program, the International Pacific Halibut Commission (IPHC) is contracted to collect both voluntary and required logs through dockside sampling and to enter the data into an electronic format. Information from the log is edited by IPHC samplers and is considered confidential between the vessel and the IPHC. To ensure confidentiality, the IPHC masks the identity of the vessel when the data are provided to assessment scientists. A strong working relationship between the IPHC and fishermen has improved logbook participation by volunteer vessels in recent years.



Only sets targeting sablefish are included in catch rate analyses. For observer data, a sablefish targeted set is defined as a set where sablefish weight was greater than any other species (see 2005 SAFE, "Target Species Determination", page 254). For logbook data, the target is declared by the captain. The weights reported in logbooks are usually approximate because the captain typically estimates the catch for each set while at sea without an accurate scale measurement. An accurate weight for the entire trip is measured at landing and recorded as the IFQ landing report. We estimate the actual set weight by multiplying the IFQ landing report weight by the proportion of the trip weight that was caught in the set, from logbook reported weights. Hook spacing for both data sets was standardized to a 39 inch (1m) spacing following the method used for standardizing halibut catch rates (Skud and Hamley 1978, Sigler and Lunsford 2001).

Each set's catch rate was calculated by dividing the catch in weight by the standardized number of hooks. These catch rates are used to compute average catch rates by vessel and NPFMC region.

Extensive filtering of the logbook and observer data occurs before the catch information for a set is included in analyses. All sets that experienced killer whale depredation are excluded from the observer fishery catch rate analysis since any depredation would bias CPUE downward. From 1990-2009 an average of 22% of observed sets in the Bering Sea were affected by killer whale depredation (avg. number of non-depredated sets = 23; range 6-56, avg. number of depredated sets = 7; range 1-37). In other areas killer whales depredate only 0-2% of observed sets.

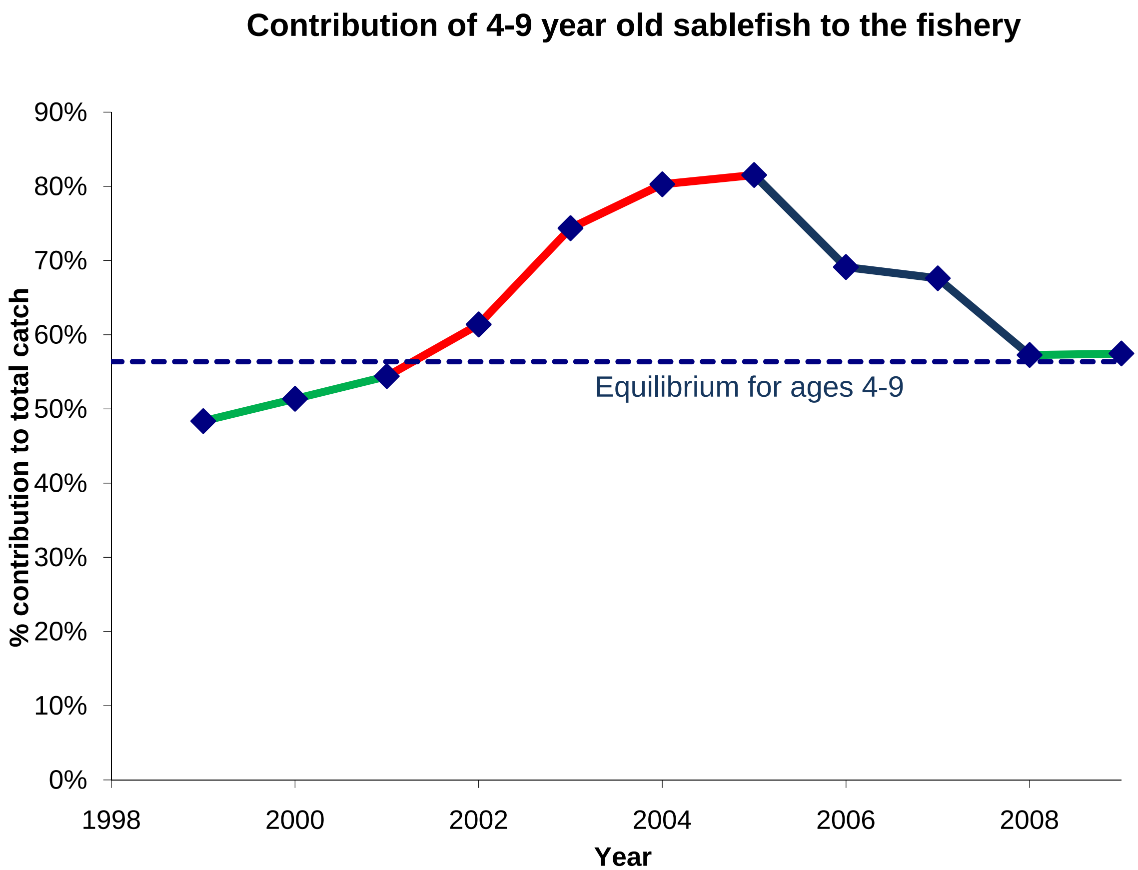
Additionally, some logs are excluded because of other issues. Sets were excluded whenever data were missing for a set and a catch rate could not be calculated or assigned to a season, area, or a year. Some sets use multiple gear configurations with more than one hook spacing. A standardized catch rate cannot be calculated because the number of sablefish caught on each configuration is unknown; logbook sets with multiple configurations were excluded. In logbooks, if catch is reported in number instead of weight, the trip is excluded. A small number of sets were eliminated from the logbook data because skipper estimated trip weight was very different than the IFQ reported trip weight.

Longline sample sizes: Observer data used in this analysis represent on average 14% of the annual IFQ hook and line catch. The percent of the IFQ catch observed was lowest in the East Yakutat/SE (5%), highest in West Yakutat and Aleutian Islands (~22%), and moderate in the Bering Sea, Central Gulf, and Western Gulf (10-14%). Although the percent of catch observed is not highest in the Central Gulf, the number of sets and vessels observed is greatest in this area and lowest in the Bering Sea (Table 3.5). In the Bering Sea fewer than 10 sets were observed from 2002-2005; however, since 2006 more sets have been observed. Observer coverage in the Aleutian Islands was consistent in all years except 2005 when only 23 sets from six vessels were observed. Since then observed sets increased and in 2009, there were 335. Low sample sizes for longline fishing in the Bering Sea are likely a result of poor observer coverage for sablefish directed trips and because pot fishing accounts for such a large proportion of the catch in these areas. Additionally, killer whales impact sablefish catch rates in these areas. For example, in 2009, 14% of observed sets in the Bering Sea were affected by killer whale depredation; these sets were eliminated from the analysis.

Logbook sample sizes are substantially higher than observer samples sizes, especially since 2004. Logbook samples increased sharply in 2004 in all areas primarily because the IPHC was used to edit and enter logbooks electronically. This increasing trend is likely due to the strong working relationship the IPHC has with fishermen, their diligence in collecting logbooks dockside, and because many vessels <60 feet are now participating in the program voluntarily. Similar to the observer data, logbook data had fewer sets in the Bering Sea and the Aleutian Islands, but had high samples sizes throughout the Gulf of Alaska.

Longline catch rates: In all years, catch rates are generally highest in the East Yakutat/Southeast and West Yakutat areas and are lowest in the Bering Sea and Aleutian Islands (Table 3.5, Figures 3.4, 3.5). Catch rate trends are generally similar for both the observer and logbook data, except in the Aleutian Islands and the Bering Sea where sample sizes are relatively small, but they have been more similar in recent years. The general trends are very similar between the two data sources, but in 2009, they were slightly divergent in the Central Gulf. Since 2004, though, the logbook data is more substantial than the observer data and has lower CV's and SE's due to the large number of vessels, especially in west and east Yakutat (Table 3.5).

The age structure of the population may help explain why catch rates have remained stable while survey abundance has generally decreased. Year classes typically show up in the fishery beginning at age 4. The influence of the 1997 and 2000 year classes to the fishery is evident as catch rates generally increased during the years 2001-2004 for both the observer and logbook data in all areas of the GOA (Figures 3.4 and 3.5). These years correspond to when the 1997 and 2000 year classes were major contributors to the fishery. The percent of catch attributed to 4-9 year old fish increased from 48% in 1999 to nearly 82% of the catch in 2005. As these year classes were targeted, the survey estimates declined. By 2009, the catch of this age group had decreased to about what we would expect at equilibrium levels with the current fishing mortality. These large pulses of recruits targeted by the fishery might explain some of the mismatch between the survey and fishery catch rates because the fishery can sustain catch rates by targeting year classes.



Longline spatial and temporal patterns: Changes in spatial or temporal patterns of the fishery may cause fishery catch rates to be unrepresentative of abundance. For example, fishers sometimes target concentrations of fish, even as geographic distribution shrinks when abundance declines (Crecco and Overholtz 1990). Overfishing of northern (Newfoundland) cod likely was made worse by an incorrect interpretation of fishery catch rates; assessment scientists did not realize that the area occupied by the stock was diminishing while the fishery catch rates remained level (Rose and Kulka 1999). We examined fishery longline data for seasonal and annual differences in effort and catch rate. Such changes may cause fishery catch rates to be unrepresentative of abundance. In the longline data, seasonal changes in effort were minimal across years. The majority of effort occurs in the spring and less in the summer and fall. The highest catch rates are also in the spring, moderate in the summer, and lowest in the fall. The majority of the longline effort is located along the continental slope and in deep cross-gullies. Likewise, areas of high catch rates occur throughout the fishing area and do not appear to change over time. Overall, no substantial changes in the fishery were detected over time or on a seasonal basis.

Pot fishery catch rate analysis

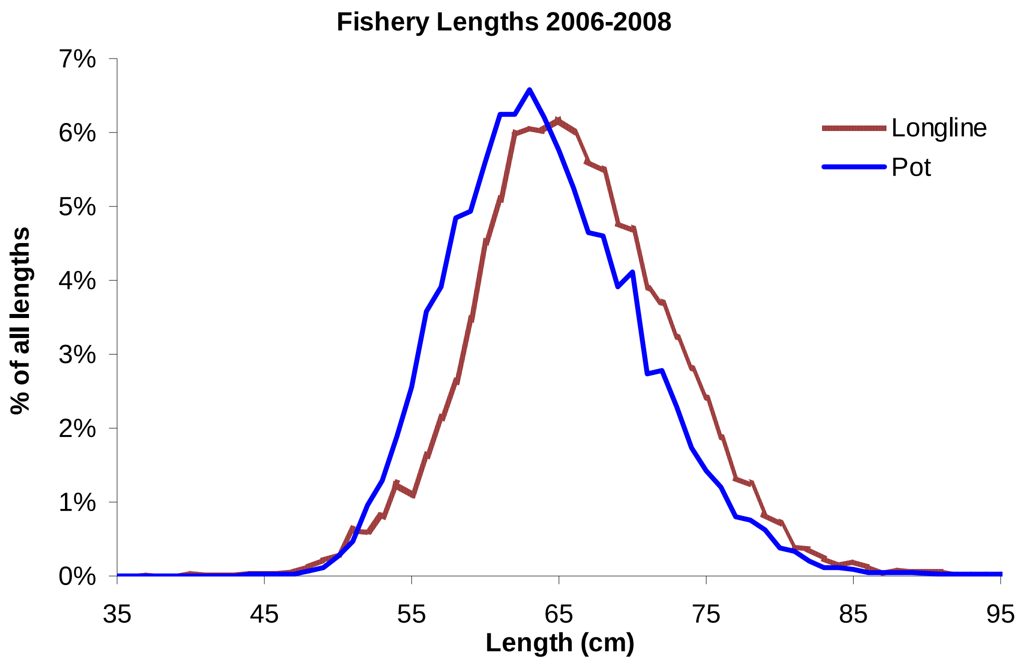
Pot catch rates: There is more uncertainty in pot catch rates from 1999-2004 because there were few observed vessels during this period. From 2005-2009 the average catch rate was 13 lbs/pot in the Aleutian

Islands and 25 lbs/pot the Bering Sea. In logbooks, the average catch rate in the Aleutian Islands from 2005-2009 was 31 lbs/pot and in the Bering Sea it was 26lbs/pot . In logbooks, more sets are recorded than in observer data. This may help explain the discrepancy between catch rates from the two data sources. The number of vessels has increased in the Bering Sea since 2005 and the number of sets in the Bering Sea also continues to increase. Because of the high variability and low sample sizes it is difficult to discern any trends in catch rates in logbooks or observer data.

The composition of bycatch species caught in observed pots that retained sablefish in the Bering Sea and Aleutian Islands is comprised mostly of arrowtooth/Kamchatka flounder, brown king crab, Greenland turbot, Pacific halibut, and giant grenadier. Almost all of the brown king crab are caught in the AI. The average catch (kg) from 2005-2009 is presented because catch and observed coverage in pots increased starting in 2005. The ten most common species caught in both the BS and the AI is summarized in the table below. Because pot data is limited, annual fluctuations in catch of bycatch species may not be dependable. For this reason, the average catch (2005-2009, in kg) is presented instead of a time series. The most recent data is presented independently, but is not complete since the IFQ fishery runs through mid-November.

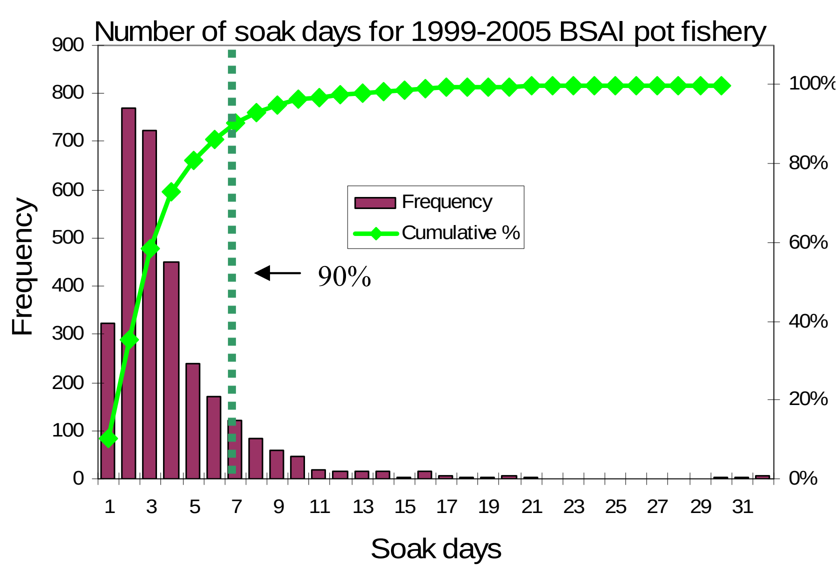
Area	Species	2005-2009	2010
		Average catch (kg)	
BS	Sablefish	166,680	73,052
	Arrowtooth/Kamchatka	14,313	10,742
	Greenland turbot	4,999	1,920
	Pacific halibut	3,972	3,612
	Giant grenadier	3,326	2,437
	Snail	1,660	739
	Pacific cod	1,173	737
	Angulatus tanner	1,128	308
	Fish waste	590	20
	Brown king crab	235	505
AI	Sablefish	90,589	6,576
	Brown king crab	8,450	867
	Arrowtooth/Kamchatka	6,451	66
	Giant grenadier	3,570	0
	Greenland turbot	1,703	721
	Pacific halibut	544	546
	Fish waste	541	0
	Couesi king crab	420	0
	Shortspine thoryhead	264	15
	Shortraker rockfish	158	0

Pot length frequencies: We compared the length frequencies recorded by observers from the 2006-2008 longline and pot fisheries. The average length of sablefish in the Aleutian Islands and in the Bering Sea was smaller for sablefish caught by pot gear (63.8 cm) than longline gear (66.0 cm), but the distributions indicate that both fisheries focus primarily on adults. Pot and longline gear is set at similar depths in the Aleutians and Bering Sea and catch males and females at the same rates (average % females in BS/AI was 58% for both gear types). We do not believe that the difference in lengths is significant enough to affect population recruitment and did not see any indication that undersized fish were being selected by pots.



Sablefish diets in pots: The North Pacific Fishery Management Council requested that the AFSC Auke Bay Laboratory scientists investigate a number of issues related to management of the sablefish pot fishery in the Bering Sea and the Aleutian Islands. One concern was the possibility of cannibalism by larger sablefish while in pots. Because few small sablefish are found in pots, there was concern that small sablefish were entering the pots and being cannibalized by larger sablefish. No sablefish were found in the stomachs of large pot-caught sablefish. Most stomachs were empty (72%); the most common item found was squid (13%) (see the 2008 SAFE).

Pot soak times: In 2006, some questions were raised about storing pots at sea, escape rings, and biodegradable panels. While we have not analyzed the consequences of these potential regulatory issues, in 2006 we examined the soak times of the observed pot sets. These are plotted below:



In an experiment examining escape mechanisms for Canadian sablefish, Scarsbrook et al. (1988) showed that in their control traps fish had only 5% mortality up to 10 days; in the current fishing environment, 90% of the pot sets were soaked for 7 days or fewer.

Longline surveys

AFSC Longline Surveys

Overview: Catch, effort, age, length, weight, and maturity data are collected during sablefish longline surveys. These longline surveys likely provide an accurate index of sablefish abundance (Sigler 2000). Japan and the United States conducted a cooperative longline survey for sablefish in the Gulf of Alaska annually from 1978 to 1994, adding the Aleutians Islands region in 1980 and the eastern Bering Sea in 1982 (Sasaki 1985, Sigler and Fujioka 1988). Since 1987, the Alaska Fisheries Science Center has conducted annual longline surveys of the upper continental slope, referred to as domestic longline surveys, designed to continue the time series of the Japan-U.S. cooperative survey (Sigler and Zenger 1989). The domestic longline survey began annual sampling of the Gulf of Alaska in 1987, biennial sampling of the Aleutian Islands in 1996, and biennial sampling of the eastern Bering Sea in 1997 (Rutecki et al. 1997). The domestic survey also samples major gullies of the Gulf of Alaska in addition to sampling the upper continental slope. The order in which areas are surveyed was changed in 1998 to reduce interactions between survey sampling and short, intense fisheries. Before 1998, the order was Aleutians and/or Bering Sea, Western Gulf, Central Gulf, Eastern Gulf. Starting in 1998, the Eastern Gulf area was surveyed before the Central Gulf area. Longline survey catches are tabled in appendix 3B.

Length data were collected for all survey years, and sablefish otoliths were collected for most survey years. Not all otolith collections were aged until 1996, when we began aging samples in the year they were collected. Otolith collections were length-stratified from 1979-94 and random thereafter.

Standardization: Kimura and Zenger (1997) compared the performance of the two surveys from 1988 to 1994 in detail, including experiments comparing hook and gangion types used in the two surveys. The abundance index for both longline surveys decreased from 1988 to 1989, the cooperative survey decreased from 1989 to 1990, while the domestic survey increased (Table 3.4). Kimura and Zenger (1997) attributed the difference to the domestic longline survey not being standardized until 1990.

Whale Depredation: Killer whale depredation of the survey's sablefish catches has been a problem in the Bering Sea since the beginning of the survey (Sasaki 1987). The problem occurred mainly east of 170^{o} W in the eastern Bering Sea and to a lesser extent in the northeast Aleutians between 170^{o} W and 175^{o} W. The 1983 (Sasaki 1984), 1986, 1987 (T. Sasaki, pers. commun., Far Seas Fisheries Research Laboratory), and 1988 Bering Sea abundance indices likely were underestimated, although sablefish catches were lower at all stations in 1987 compared to 1986, regardless of whether killer whales were present. Killer whale depredation has been fairly consistent since 1990 (Table 3.6). Since 1990, portions of the gear affected by killer whale depredation during domestic longline surveys have been excluded from the analysis of the survey data. In 2009, however, killer whales depredated ten of sixteen Bering Sea stations which significantly impacted catch and biased the abundance index. Several adjustment methods were explored and the one chosen was the same methodology that we use when the Bering Sea is not sampled; multiplying the last year the Bering Sea was sampled (2007) by the ratio of change from the Gulf of Alaska (2007 to 2009) (Hanselman et al. 2009). Therefore, 2009 abundance indices (RPN, RPW) for the Bering Sea presented in this assessment are computed estimates rather than sampled estimates typical of odd years in the Bering Sea.

Continued analysis regarding killer whale depredation and its effects on abundance indices is warranted and we hope to explore modeling approaches that will take advantage of the full data set to interpolate abundance indices for depredated stations.

Sperm whale depredation may affect longline catches in the Gulf of Alaska. Data on sperm whale depredation have been collected since the 1998 longline survey (Table 3.6). Apparent sperm whale depredation is defined as sperm whales being present with the occurrence of damaged sablefish. Sperm whales are most commonly observed in the Central and Eastern Gulf of Alaska (98% of sightings); the majority of interactions occur in the West Yakutat and East Yakutat/Southeast areas. Sperm whale presence and evidence of depredation has been variable since 1998. Occurrence of depredation has ranged from 10% of sampling days that sperm whales were present in 2001 to 90% in 2008. Sperm whales have often been present but not depredating on the gear, except in 2003 and 2008 when depredation occurred every time sperm whales were observed. Presence and depredation of sperm whales were lower in 2010 than in 2009 and closer to the 1998-2009 average.

Multiple studies have attempted to quantify sperm whale depredation rates. An early study using data collected by fisheries observers in Alaskan waters found no significant effect on the commercial fishery catch (Hill et al. 1999). Another study using data collected from commercial vessels in southeast Alaska, found a small, significant effect comparing longline fishery catches between sets with sperm whales present and sets with sperm whales absent (3% reduction, 95% CI of (0.4 – 5.5%), t-test, $p = 0.02$, Straley et al. 2005).

A general linear model fit to longline survey data from 1998-2004 found neither sperm whale presence ($p = 0.71$) nor depredation rate ($p = 0.78$) increased significantly from 1998 to 2004. Catch rates were about 2% less at locations where depredation occurred, but the effect was not significant ($p = 0.34$). This analysis has been updated through 2009 and now shows a significant effect of approximately four kilograms per hundred hooks in the Central and Eastern Gulf regions, which translates into approximately a 2% decrease in overall catch in those areas (J. Liddle pers. comm.). A retrospective analysis of this data indicates the effect is not significant until the 2009 data is added, indicating the increasing depredation effect has combined with accumulating survey data to give increased power to detect the moderate reduction in CPUE.

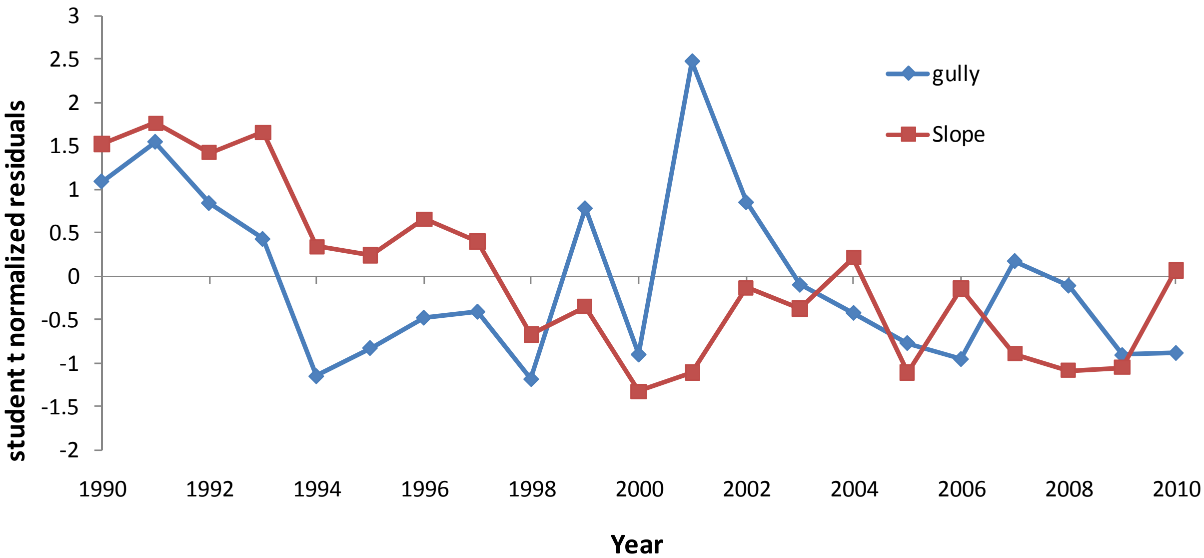
Longline survey catch rates are not adjusted for sperm whale depredation because we do not know when measureable depredation began during the survey time series, because past studies of depredation on the longline survey showed no significant effect, and because sperm whale depredation is difficult to detect (Sigler et al. 2007). Because of recent increases in presence and depredation at survey stations as indicated by whale observations and significant results of recent studies, we are currently evaluating a statistical adjustment to survey catch rates using a general linear modeling approach (Appendix 3C). This approach has the power to model both sperm whale and killer whale impacts on the survey catch rates and correct depredation-related decreases in catch rates.

Gully Stations: In addition to the continental slope stations sampled during the survey, twenty-seven stations are sampled in gullies at the rate of one to two stations per day. The sampled gullies are Shelikof Trough, Amatuli Gully, W-grounds, Yakutat Valley, Spencer Gully, Ommaney Trench, Dixon Entrance, and one station on the continental shelf off Baranof Island. The majority of these stations are located in deep gully entrances to the continental shelf in depths from 150-300 m in areas where the commercial fishery targets sablefish. No gullies are currently sampled in the Western Gulf of Alaska, Aleutian Islands, or Bering Sea.

Previous analyses have shown that on average gully stations catch fewer larger fish than adjacent slope stations and length distributions are generally different (Rutecki et al. 1997, Zenger et al. 1994). Compared with the adjacent regions of the slope, sablefish catch rates for gully stations have been mixed with no significant trend (Zenger et al. 1994). Important characteristics of gully catches are that they may indicate recruitment signals before slope areas because of their shallow depth which younger sablefish typically inhabit. Catch rates from these stations have not been included in the historical abundance index calculations because of their locations relative to the more preferred slope habitat of adult sablefish and in particular because of their shallow depths.

These areas do support significant numbers of sablefish, however, and are important areas sampled by the survey. We compared the RPNs of gully stations to the RPNs of slope stations in the GOA to see if catches were comparable, or more importantly, if they portrayed different trends than the RPNs used in this assessment.

Gully RPNs were highly correlated ($r = 0.817$) with slope RPNs in the East Yakutat/Southeast Outside area but poorly correlated in the West Yakutat ($r = 0.458$) and Central Gulf regions ($r = 0.155$). To compare trends, we computed Student's-*t* normalized residuals for all GOA gullies and slope stations and plotted them for the time series. If the indices were correlated, then the residuals would track one another over time.



Overall, gully catches in the GOA were poorly correlated with slope catches ($r = 0.302$). There also is no evidence of major differences in trends. In regards to gully catches being a recruitment indicator, the increase in the gully RPNs in 1999 and 2001-2002 may be in response to the above average 1997 and 2000 year classes. Both the 2001 and 2002 RPNs for the gully stations are higher than the peak in 1999, which supports the current model estimate that the 2000 year class was larger than 1997. Therefore, gully stations may show large year classes earlier and be a better gauge of their strength than slope survey stations. In the future, we will continue to explore sablefish catch rates in gullies and explore their usefulness for indicating recruitment; they may also be useful for quantifying depredation, since sperm whales have rarely depredated on catches from gully stations.

Interactions between the fishery and survey are described in Appendix 3A.

IPHC Longline Surveys

The International Pacific Halibut Commission (IPHC) conducts a longline survey each year to assess Pacific halibut. This survey differs from the AFSC longline survey in gear configuration and sampling design, but catches substantial numbers of sablefish. More information on this survey can be found in Soderlund et al. (2009). A major difference between the two surveys is that the IPHC survey samples the shelf consistently from ~ 10-500 meters, whereas the AFSC survey samples the slope and select gullies from 200-1000 meters. Because the majority of effort occurs on the shelf in shallower depths, the IPHC survey may catch smaller and younger sablefish than the AFSC survey; however, lengths of sablefish are not taken on the IPHC survey.

For comparison to the AFSC survey, IPHC relative population number's (RPN) were calculated using the same methods as the AFSC survey values, the only difference being the depth stratum increments. First an average CPUE was calculated by depth stratum for each region. The CPUE was then multiplied by the area size of that stratum. A region RPN was calculated by summing the RPNs for all strata in the region. Area sizes used to calculate biomass in the RACE trawl surveys were utilized for IPHC RPN calculations. Area sizes differ between the IPHC and AFSC longline surveys because the IPHC surveys the shelf while the AFSC survey samples the slope.

The first figure below compares the RPNs for the two time series for all areas combined. The two series track well, but the IPHC survey RPN has more variability. This makes sense because it surveys shallower water on the shelf where younger sablefish reside. Since the abundance of younger sablefish will be more variable as year classes pass through, the survey should more closely resemble the NMFS GOA trawl survey index described below (Figure 3.3). Differences in scale can be attributed to CPUE calculation methods (i.e., the AFSC CPUE is fish/skate (45 hooks), and the IPHC CPUE is fish/hook).

Because of their differences in variability we computed Student's t normalized residuals and plotted them for the time series (2^{nd} figure below). The trends compared this way tracked very closely (Pearson's *r* = 0.63, p-value=0.028) and suggested a similar recent decreasing trend and terminus. Trends by region were also similar but more variable for most areas. We will continue to examine trends in each region and at each depth interval for evidence of recruiting year classes and for comparison to the AFSC longline survey. There is some effort in depths shallower than 200 meters on the AFSC survey, and we will compute RPNs for these depths for future comparisons with the IPHC RPNs.

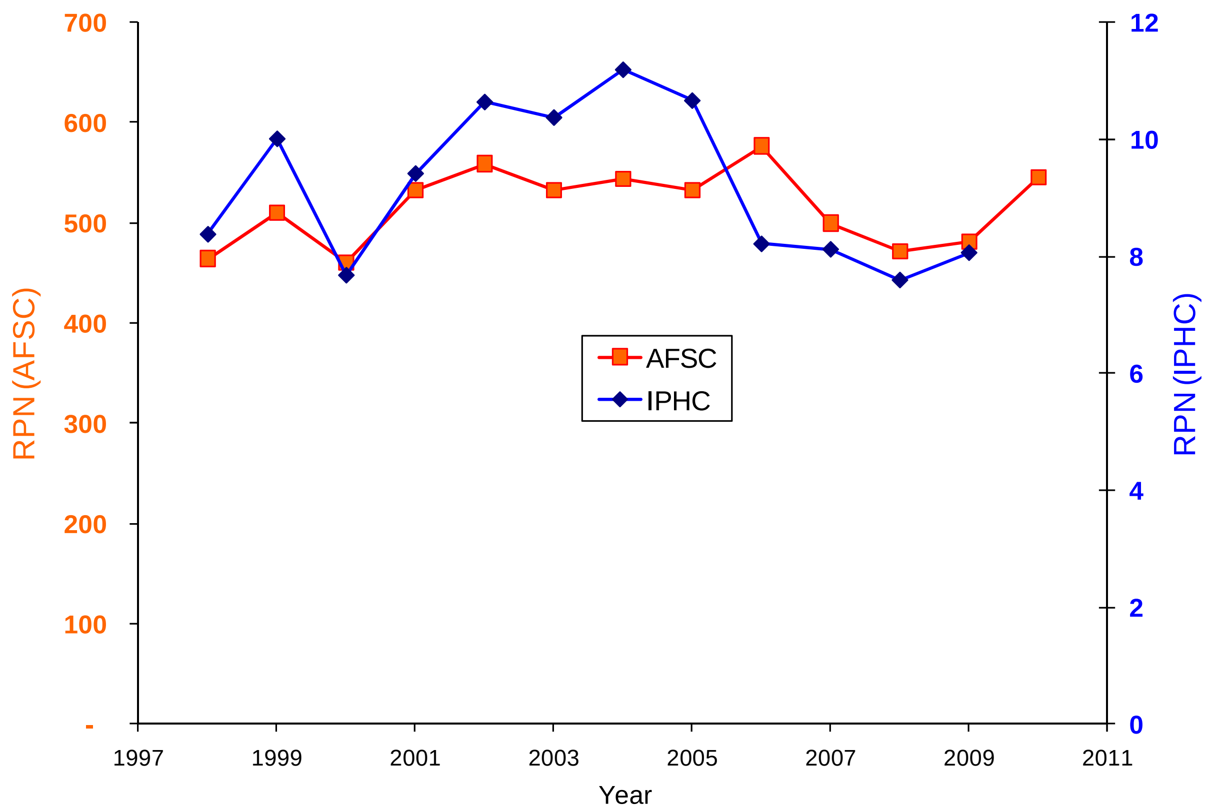


Figure. Comparison of RPNs computed for the IPHC and AFSC longline surveys.

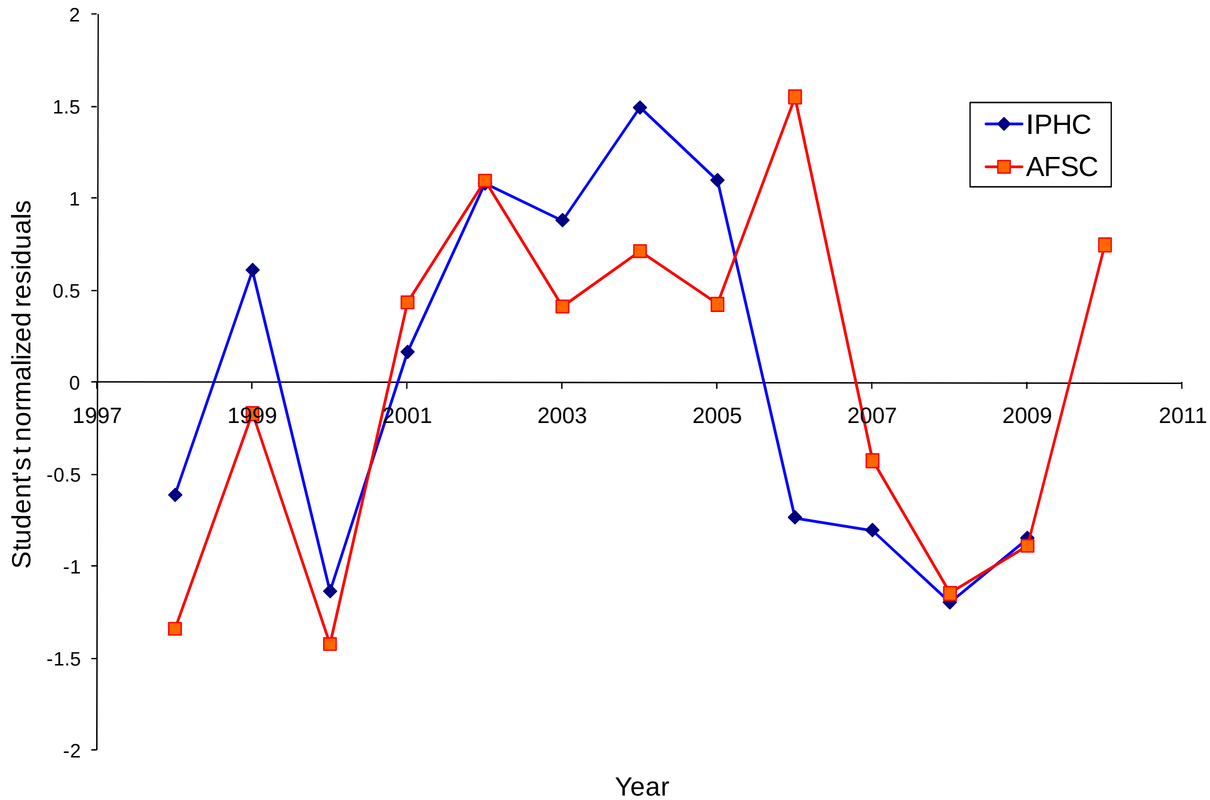


Figure. Student's t normalized residuals of the IPHC and AFSC RPN indices for sablefish.

Trawl surveys

Trawl surveys of the upper continental slope that adult sablefish inhabit have been conducted biennially or triennially since 1980 in the Aleutian Islands, and 1984 in the Gulf of Alaska. Trawl surveys of the Eastern Bering Sea slope were conducted biennially from 1979-1991 and standardized for 2002, 2004, and 2008. Trawl surveys of the Eastern Bering Sea shelf are conducted annually. Trawl survey abundance indices were not previously used in the sablefish assessment because they were not considered good indicators of the sablefish relative abundance. However, there is a long time series of data available and given the trawl survey's ability to sample smaller fish, it may be a better indicator of recruitment than the longline survey. There is some difficulty with combining estimates from the Bering Sea and Aleutian Islands with the Gulf of Alaska estimates since they occur on alternating years. A method could be developed to combine these indices, but it leaves the problem of how to use the length data to predict recruitment since the data could give mixed signals on year class strength. At this time we are using only the Gulf of Alaska trawl survey biomass estimates (<500 m depth, Figure 3.3) and length data (<500 m depth, Figures 3.14, 3.15) as an index for the whole population. The largest proportion of sablefish biomass is in the Gulf of Alaska so it should be indicative of the overall population. Biomass estimates used in the assessment for 1984-2009 are shown in Table 3.4. The GOA trawl survey index is at a low level in 2009, similar to 2007 and 1999.

Aleutian Islands and Bering Sea Slope survey biomass estimates are not used in the assessment model but are tracked in the following figure:

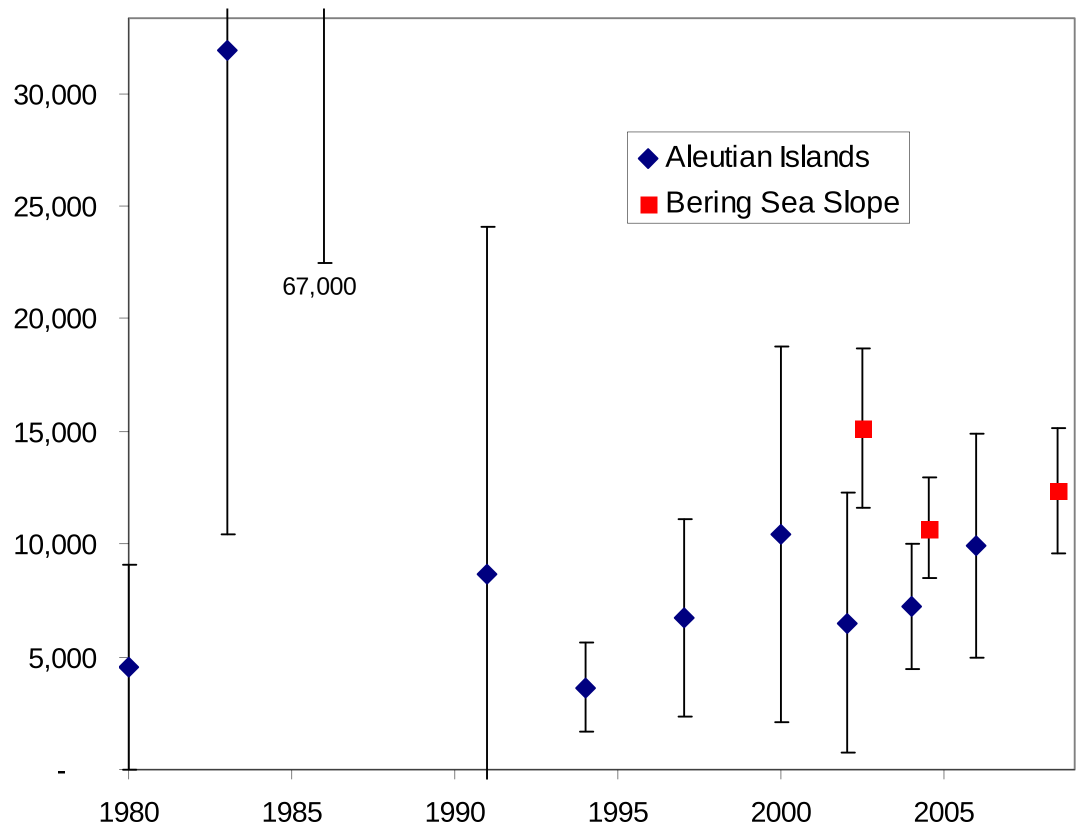


Figure. Aleutian Islands and Bering Sea Slope biomass estimates from NMFS trawl surveys. Bering Sea Slope years are jittered forward 6 months so they do not overlap with Aleutian Islands estimates and y-axis is restricted from showing highest biomass (67,000 t) so recent data is more visible.

Trawl survey catches are tabled in Appendix 3B.

Other surveys

The Alaska Department of Fish and Game conducts mark-recapture and a longline survey in Northern Southeast Alaska Inside (NSEI) waters. This population treated as a separate population, but some migration into and out of Inside waters has been confirmed with tagging studies. This population has been low to moderate recently, with their longline survey confirming the lows in 1999/2000 (see figure below), but showing a mild increase through 2008 (Dressel 2009). However, their most recent abundance estimates from a mark-recapture program, shows a sizeable decline from 2007 to 2008 after increases from 2005-2007 (Dressel per. comm. 2009).

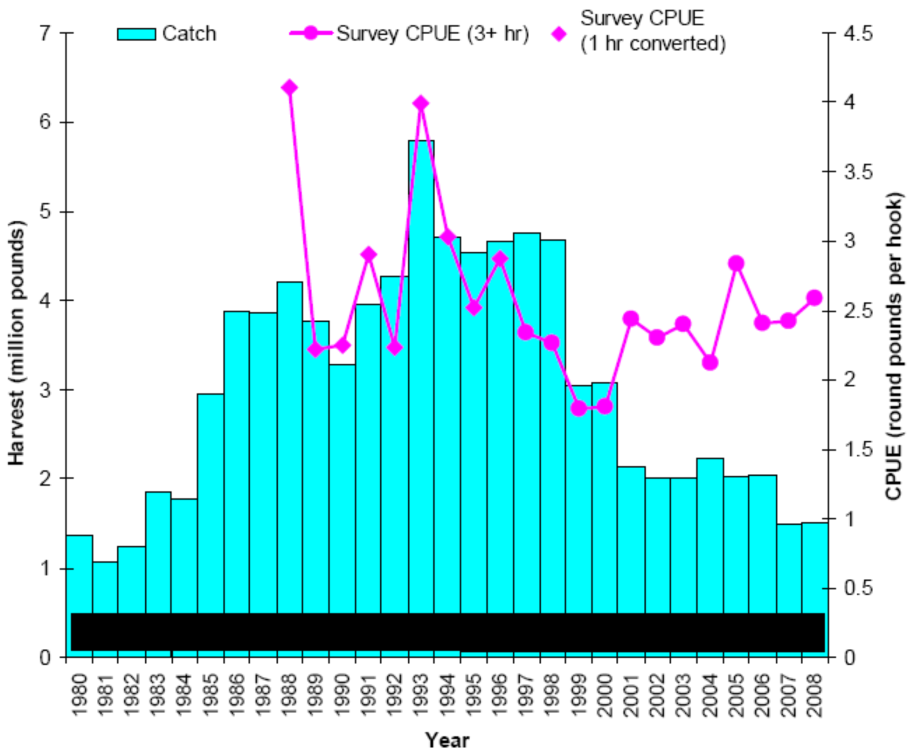


Figure. Northern Southeast Inside sablefish long line survey catch per unit effort in round pounds per hook and harvest over time (from Dressel per. comm. 2009).

The Department of Fish and Oceans of Canada (DFO) conducts a trap survey, conducts tagging studies, and tracks fishery catch rates in British Columbia, Canada. In a recent report (TSC 2008) they summarized the following:

"Catch rates from the fall standardized survey have declined by about 62% since a recent high in 2003. The 2007 stratified random survey declined about 30% from 2006 to 2007. Trap fishery catch rates in 2006 and 2007 are at about the level observed during the mid-2000 to mid-2002 period and much lower than those observed in the early 1990s. Catch rates from a survey in mainland B.C. inlets, where there is no directed sablefish fishing, have declined about 50% since a recent high in 2002."
These large reported declines in abundance south of Alaska concern us, and point to the need to attempt to better understand the contribution to Alaska sablefish productivity from B.C. sablefish. Some ideas we have proposed are to conduct an area-wide study of sablefish tag recoveries, and to attempt to model the population to include B.C. sablefish.

Relative abundance trends – long-term

Relative abundance has cycled through three valleys and two peaks with peaks in about 1970 and 1985 (Table 3.4, Figures 3.2 and 3.3). The post-1970 decrease likely is due to heavy fishing. The 1985 peak likely is due to the exceptionally large late 1970's year classes. Since 1988, relative abundance has decreased substantially. Regionally, abundance decreased faster in the Eastern Bering Sea, Aleutian Islands, and western Gulf of Alaska and more slowly in the central and eastern Gulf of Alaska (Figure 3.6). These regional abundance changes likely are due to size-dependent migration. Small sablefish typically migrate westward, while large sablefish typically migrate eastward (Heifetz and Fujioka 1991). The recruitment of the strong late 1970's year classes accounted for the sharp increase in overall abundance during the early 1980's. During the late 1980's as sablefish moved eastward, abundance fell quickly in the western areas, fell slowly in the Central area, and remained stable in the Eastern area. The size-dependent migration and pattern of regional abundance changes indicate that the western areas are the outer edges of sablefish distribution and less favored habitat than the central and eastern Gulf of Alaska.

Above average year classes typically are first abundant in the western areas, another consequence of size-dependent migration. For example, an above average 1997 year class first became important in the survey in the western areas at age 4 (2001 plot), and shows up in the Central Gulf throughout 2002-3 and then the Eastern Gulf in 2004 (Figure 3.7). Overall, above average year classes became abundant in the western areas at ages 4-5, in the central area at ages 4-9, and in the eastern area at ages 4-7 (Table 3.7). The strongest year classes (1977 and 2000) appear in the central and eastern areas at the earliest age (4), whereas the remaining above average year classes appear in these areas at later ages (6-9).

In the East Yakutat/Southeast area, sablefish abundance decreased for many years until 2002, when the fishery index, but not the survey index, increased (Figure 3.4). The survey index continued to generally decrease through 2003, but stabilized in the 2004 and 2005 surveys, and increased in 2006. The recent stabilization and increase in the survey index was likely caused by the 1997 and 2000 year classes entering the fishery. However, surveys in 2008 and 2009 have shown this area to be at its lowest levels during the domestic survey. In 2010, there was a substantial increase in the abundance index in the entire Eastern Gulf of Alaska. While this is positive, there has been an overall long-term decline in abundance for this area, which is considered a part of the main spawning area (central and eastern Gulf of Alaska). We will continue to monitor this trend closely.

Relative abundance trends – short-term

Assessment results: The fishery abundance index was down 17% from 2008 to 2009 (the 2010 data are not available yet). The survey abundance index increased 13% from 2009 to 2010 following a 16% decrease from 2006 to 2009.

Analytic approach

Model Structure

The sablefish population is represented with an age-structured model. The analysis presented here extends earlier age structured models developed by Kimura (1990) and Sigler (1999), which all stem from the work by Fournier and Archibald (1982). The current model configuration follows a more complex version of the Gulf of Alaska Pacific ocean perch model (Hanselman et al. 2005a) with split sexes to attempt to more realistically represent the underlying population dynamics of sablefish. The current configuration was accepted by the Groundfish Plan Team and NPFMC in 2008 (Hanselman et al. 2008). The population dynamics and likelihood equations are described in Box 1. The analysis was completed using AD Model Builder software, a C++ based software for development and fitting of general nonlinear statistical models (Otter Research 2000).

Parameters Estimated Independently

The following table lists the parameters estimated independently:

Parameter name	Value	Value	Source
Time period	1981-1993	1996-2004	
Natural mortality	0.1	0.1	Johnson and Quinn (1988)
Female maturity-at-age	$m_a = 1/(1+e^{-0.84(a-6.60)})$		Sasaki (1985)
Length-at-age - females	$\bar{L}_a = 75.6(1-e^{-0.208(a+3.63)})$	$\bar{L}_a = 80.2(1-e^{-0.222(a+1.95)})$	Hanselman et al. (2007)
Length-at-age - males	$\bar{L}_a = 65.3(1-e^{-0.227(a+4.09)})$	$\bar{L}_a = 67.8(1-e^{-0.290(a+2.27)})$	Hanselman et al. (2007)
Weight-at-age - females	$\ln \hat{W}_a = \ln(5.47) + 3.02 \ln(1-e^{-0.238(a+1.39)})$		Hanselman et al. (2007)
Weight-at-age - males	$\ln \hat{W}_a = \ln(3.16) + 2.96 \ln(1-e^{-0.356(a+1.13)})$		Hanselman et al. (2007)
Age-age conversion	Known	Known	Heifetz et al. (1999)
Recruitment variability (σ_r)	1.2	1.2	Sigler et al. (2002)

Age and Size of Recruitment: Juvenile sablefish rear in nearshore and continental shelf waters, moving to the upper continental slope as adults. Fish first appear on the upper continental slope, where the longline survey and longline fishery primarily occur, at age 2 and a length of about 45 cm fork length. Fish are susceptible to trawl gear at an earlier age than to longline gear because trawl fisheries usually occur on the continental shelf and shelf break inhabited by younger fish, and catching small sablefish is hindered by the large bait and hooks on longline gear.

Growth and maturity: Sablefish grow rapidly in early life, growing 1.2 mm d^{-1} during their first spring and summer (Sigler et al. 2001). Within 100 days after first increment formation, they average 120 mm. Sablefish are currently estimated to reach average maximum lengths and weights of 68 cm and 3.4 kg for males and 80 cm and 6.2 kg for females.

New growth relationships recently were estimated because many more age data were available (Hanselman et al. 2007); this analysis was accepted by the Plan Team in November 2007. We divided the data into two time periods based on the change in sampling design that occurred in 1995. It appears that sablefish maximum length and weight has increased slightly over time. New age-length conversion matrices were constructed using these curves with normal error fit to the standard deviations of the collected lengths at age (Figure 3.8). These new matrices provided for a superior fit to the data. Therefore, we use a bias-corrected and updated growth curve for the older data (1981-1993) and a new growth curve describing recent randomly collected data (1996-2004).

Sablefish are difficult to age, especially those older than eight years (Kimura and Lyons 1991). To compensate, we use an ageing error matrix based on known-age otoliths (Heifetz et al. 1999).

Fifty percent of females are mature at 65 cm, while 50 percent of males are mature at 57 cm (Sasaki 1985), corresponding to ages 6.5 for females and 5 for males (Table 3.8). Maturity parameters were estimated independently of the assessment model and then incorporated into the assessment model as fixed values. The maturity - length function is $m_l = 1 / (1 + e^{-0.40 (L - 57)})$ for males and $m_l = 1 / (1 + e^{-0.40 (L}$

$^{-65)}$) for females. Maturity at age was computed using logistic equations fit to the length-maturity relationships shown in Sasaki (1985, Figure 23, Gulf of Alaska). Prior to the 2006 assessment, average male and female maturity was used to compute spawning biomass. Beginning with the 2006 assessment, female-only maturity has been used to compute spawning biomass. Female maturity-at-age from Sasaki (1985) is described by the logistic fit of $m_a = 1/(1+e^{-0.84(a-6.60)})$.

Maximum age and natural mortality: Sablefish are long-lived; ages over 40 years are regularly recorded (Kimura et al. 1993). Reported maximum age for Alaska is 94 years (Kimura et al. 1998); the previous reported maximum was 62 (Sigler et al. 1997). Canadian researchers report age determinations up to 55 years (McFarlane and Beamish 1983). A natural mortality rate of M=0.10 has been assumed for previous sablefish assessments, compared to M=0.112 assumed by Funk and Bracken (1984). Johnson and Quinn (1988) used values of 0.10 and 0.20 in a catch-at-age analysis and found that estimated abundance trends agreed better with survey results when M=0.10 was used.

Natural mortality has been modeled in a variety of ways in previous assessments. For sablefish assessments before 1999, natural mortality was assumed to equal 0.10. For assessments from 1999 to 2003, natural mortality was estimated rather than assumed to equal 0.10; the estimated value was about 0.10. For the 2004 assessment, a more detailed analysis of the posterior probability showed that natural mortality was not well-estimated by the available data. The posterior distribution of natural mortality was very wide, ranging to near zero. The acceptance rate during Markov Chain Monte Carlo (MCMC) runs was low, 0.10-1.15. Parameter estimates even for MCMC chains thinned to every 1000th value showed some serial correlation. For the 2005 assessment we assumed that we knew the approximate value of natural mortality very precisely (c.v. = 0.001 for prior probability distribution) and that the approximate value was 0.10. At this level of prior precision, it was essentially a fixed parameter. Using such a precise prior on a relatively unknown parameter to fix it is of no use except to acknowledge that we do not know the parameter value exactly. However, it creates confusion and is an improper use of Bayesian priors, so in 2006 we returned to fixing the parameter at 0.10.

Variance and effective sample sizes: Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The standardized deviation of normalized residuals (SDNR) is closely related to the root mean squared error (RMSE) or effective sample size; values of SDNR of approximately 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year i of the abundance index was computed as

$$\delta_i = \frac{\ln(I_i) - \ln(\hat{I}_i)}{\sigma_i}$$

where σ_i is the input sampling standard deviation of the estimated abundance index. For age or length composition data assumed to follow a multinomial distribution, the normalized residuals for age/length group a in year i were computed as

$$\delta_{i,a} = \frac{(y_{i,a} - \hat{y}_{i,a})}{\sqrt{\hat{y}_{i,a}(1-\hat{y}_{i,a})/n_i}}$$

where y and $\hat{y}$ are the observed and estimated proportion, respectively, and n is the input assumed sample size for the multinomial distribution. The effective sample size was also computed for the age and length compositions modeled with a multinomial distribution, and for a given year i was computed as

$$E_i = \frac{\sum_a \hat{y}_a * (1 - \hat{y}_a)}{\sum_a (\hat{y}_a - y_a)^2}.$$

An effective sample size that is nearly equal to the input sample size can be interpreted as having a model fit that is consistent with the input sample size.

For the 2010 recommended assessment model, we used average SDNR as a criterion to help reweight the age and length compositions. SDNR is a common metric used for goodness of fit in other fisheries, particularly in New Zealand (e.g. Langley and Maunder 2009) and has been recommended for use in fisheries models in Alaska during multiple CIE reviews such as Atka mackerel (R.I.C.C. Francis) and rockfish (P. Cordue). We iteratively reweighted the model by setting an objective function penalty to reduce the deviations of average SDNR of a data component from one. Initially, we tried to fit all multinomial components this way, but due to tradeoffs in fit, it was found that the input sample sizes became too large and masked the influence of important data such as abundance indices. Given that we have age and length samples from nearly all years of the longline surveys, we chose to eliminate the attempt to fit the length data well enough to achieve an average SDNR of one, and reweighted all age components and only length components where no age data exists (e.g. domestic trawl fishery). The abundance index SDNRs were calculated, but no attempt was made to adjust their input variance because we have *a priori* knowledge about their sampling variances. This process was completed before the 2010 data were added into the assessment. The table below shows the input CVs/sample sizes for the data sources and their associated output SDNR for the recommended model. This reweighting is intended to be done once and then fixed for at least several years.

	Input N/CV	SDNR	Effective N
Multinomial Compositions			
Domestic LL Fishery Ages	200	0.99	176
Domestic LL Fishery Lengths	120	0.86	321
Trawl Fishery Sizes	50	0.94	101
LL Survey Ages	160	0.96	175
NMFS Trawl Survey Lengths	140	0.96	188
Domestic LL Survey Lengths	20	0.30	196
Japanese/Coop LL Survey Lengths	20	0.32	199
Lognormal abundance indices			
Domestic RPN	5%	1.93	
Japanese/Coop RPN	5%	1.47	
Domestic Fishery RPW	10%	0.81	
Foreign Fishery RPW	10%	1.17	
NMFS Trawl Survey	8-14%	2.41	

Parameters Estimated Conditionally

Below is a summary of the parameter totals estimated conditionally in the recommended model:

Parameter name	Symbol	Number
Catchability	q	6
Log-mean-recruitment	μ_r	1
Spawners-per-recruit levels	F_{35}, F_{40}, F_{50}	3
Recruitment deviations	τ_y	78
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	102
Fishery selectivity	fs_a	8
Survey selectivity	ss_a	7
Total		207

Catchability is separately estimated for the Japanese longline fishery, the cooperative longline survey, the domestic longline survey, U.S. longline derby fishery, U.S. longline IFQ fishery, and the NMFS GOA trawl survey. Information is available to link these estimates of catchability. Kimura and Zenger (1997) analyzed the relationship between the cooperative and domestic longline surveys. For assessments through 2006, we used their results to create a prior distribution which linked catchability estimates for the two surveys. For 2007, we estimated new catchability prior distributions based on the ratio of the various abundance indices to a combined Alaskan trawl index. This resulted in similar mean estimates of catchability to those previously used, but allowed us to estimate a prior variance to be used in the model. This also facilitates linking the relative catchabilities between indices. These priors were used in the recommended model for 2008. This analysis was presented at the September 2007 Plan Team and is presented in its entirety in Hanselman et al. (2007). Lognormal prior distributions were used with the parameters shown below and in Figure 3.9:

Index	U.S. LL Survey	Jap. LL Survey	Fisheries	GOA Trawl
Mean	7.857	4.693	4.967	0.692
CV	33%	24%	33%	30%

Recruitment is not estimated with a stock-recruit relationship, but is estimated with a level of average recruitment with deviations from average recruitment for the years 1933-2010.

Fishing mortality is estimated with two average fishing mortality parameters for the two fisheries (fixed gear and trawl) and deviations from the average for years 1960-2010 for each fishery.

Selectivity is represented using a function and is separately estimated by sex for the longline survey, fixed-gear fishery, and the trawl survey. Selectivity for the longline surveys and fixed-gear fishery is restricted to be asymptotic by using the logistic function. Selectivity for the trawl fishery and trawl survey are dome-shaped (right descending limb) and estimated with a two-parameter gamma-function and a power function respectively (see Box 1 for equations). This right-descending limb is allowed because we do not expect that the trawl survey and fishery will catch older aged fish as frequently because they fish shallower than the fixed-gear fishery. Selectivity for the fixed-gear fishery is estimated separately for the "derby" fishery prior to 1995 and the IFQ fishery from 1995 thereafter. Fishers may choose where they fish in the IFQ fishery, compared to the crowded fishing grounds during the 1985-1994 "derby" fishery, when fishers reportedly often fished in less productive depths due to crowding (Sigler and Lunsford 2001). In choosing their ground, they presumably target bigger, older fish, and depths that produce the most abundant catches.

Bayesian analysis

Since the 1999 assessment, we developed a limited Bayesian analysis that considered uncertainty in the value of natural mortality as well as survey catchability. The Bayesian analysis has been modified in various ways since the 1999 assessment. In this assessment, the Bayesian analysis considers additional uncertainty in the remaining model parameters, but not natural mortality. The multidimensional posterior distribution is mapped by Bayesian integration methods. The posterior distribution was computed based on 10 million MCMC simulations drawn from the posterior distribution and thinned to 5,000 parameter draws to remove serial correlation between successive draws and a burn-in of 1 million draws was removed from the beginning of the chain. This was determined to be sufficient through simple chain plots, and comparing the means and standard deviations of the first half of the chain with the second half.

We estimated the posterior probability that projected abundance will fall below thresholds of 17.5% (minimum stock size threshold or MSST) and 35% (maximum sustainable yield or MSY) of the unfished spawning biomass based on the posterior probability estimates. Abundance was projected for 14 years. In the projections, future recruitments varied as random draws from a lognormal distribution with the mean and standard deviation of the 1979-2008 recruitment, in addition to the uncertainty propagated during the MCMC simulations.

In previous assessments, the decision analysis thresholds were based on Mace and Sissenwine (1993). However, in the North Pacific Fishery Management Council setting we have thresholds that are defined in the Council harvest rules. These are when the spawning biomass falls below MSY or $B_{35\%}$ and when the spawning biomass falls below ½ MSY or $B_{17.5\%}$ which calls for a rebuilding plan under the Magnuson-Stevens Act. For the previous analysis based on Mace and Sissenwine (1993), see Hanselman et al. 2005b.

Box 1	**Model Description**
Y	Year, $y=1, 2,\ldots T$
T	Terminal year of the model
A	Model age class, $a = a_0, a_0+1, \ldots, a_+$
a_0	Age at recruitment to the model
a_+	Plus-group age class (oldest age considered plus all older ages)
L	Length class
Ω	Number of length bins (for length composition data)
G	Gear-type (g = longline surveys, longline fisheries, or trawl fisheries)
X	Index for likelihood component
$w_{a,s}$	Average weight at age a and sex s
φ_a	Proportion of females mature at age a
μ_r	Average log-recruitment
μ_f	Average log-fishing mortality
$\phi_{y,g}$	Annual fishing mortality deviation
τ_y	Annual recruitment deviation ~ $(0, \sigma_r)$
σ_r	Recruitment standard deviation
$N_{y,a,s}$	Numbers of fish at age a in year y of sex s
M	Natural mortality
$F_{y,a,g}$	Fishing mortality for year y, age class a and gear g ($= s_a^g \mu_f e^{\phi_{y,g}}$)
$Z_{y,a}$	Total mortality for year y and age class a ($=\sum_g F_{y,a,g} + M$)
R_y	Recruitment in year y
B_y	Spawning biomass in year y
$s_{a,s}^g$	Selectivity at age a for gear type g and sex s
$A_{50\%}, d_{50\%}$	Age at 50% selection for ascending limb, age at 50% deselection for descending limb
δ	Slope/shape parameters for different logistic curves
$\mathbf{A}$	Ageing-error matrix dimensioned $a_+ \times a_+$
$\mathbf{A}^l$	Age to length conversion matrix dimensioned $a_+ \times \Omega$
q_g	Abundance index catchability coefficient by gear
λ_x	Statistical weight (penalty) for component x
$I_y, \hat{I}_y$	Observed and predicted survey index in year y
$P_{y,l,s}^g, \hat{P}_{y,l,s}^g$	Observed and predicted proportion at length l for gear g in year y and sex s
$P_{y,a,s}^g, \hat{P}_{y,a,s}^g$	Observed and predicted proportion at observed age a for gear g in year y and sex s
ψ_y^g	Sample size assumed for gear g in year y (for multinomial likelihood)
n_g	Number of years that age (or length) composition is available for gear g
$q_{\mu,g}, \sigma_{q,g}$	Prior mean, standard deviation for catchability coefficient for gear g
M_μ, σ_M	Prior mean, standard deviation for natural mortality
$\sigma_{r_\mu}, \sigma_{\sigma_r}$	Prior mean, standard deviation for recruitment variability

Equations describing state dynamics	**Model Description** (continued)
$N_{1,a} = \begin{cases} R_1, & a = a_0 \\ e^{\left(\mu_r + \tau_{a_0 - a + 1}\right)} e^{-(a-a_0)M}, & a_0 < a < a_+ \\ e^{(\mu_r)} e^{-(a-a_0)M} \left(1 - e^{-M}\right)^{-1}, & a = a_+ \end{cases}$	Initial year recruitment and numbers at ages.
$N_{y,a} = \begin{cases} R_y, & a = a_0 \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}}, & a_0 < a < a_+ \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}} + N_{y-1,a} e^{-Z_{y-1,a}}, & a = a_+ \end{cases}$	Subsequent years recruitment and numbers at ages
$R_y = e^{\left(\mu_r + \tau_y\right)}$	Recruitment
Selectivity equations	
$s_{a,s}^g = \left(1 + e^{(-\delta_{g,s}(a - a_{50\%,g,s}))}\right)^{-1}$	Logistic selectivity
$s_{a,s}^g = \dfrac{a^{\delta_{g,s}}}{\max\left(s_{a,s}^g\right)}$	Inverse power family
$s_{a,s}^g = \left(\dfrac{a}{a_{\max}}\right)^{a_{\max,g,s}/p} e^{(a_{\max,g,s} - a)/p}$ $p = 0.5\left[\sqrt{a_{\max,g,s}{}^2 + 4\delta_{g,s}{}^2} - a_{\max,g,s}\right]$	Reparameterized gamma distribution
$s_{a,s}^g = \left(1 - \varphi_s^g\right)^{-1} \left(\dfrac{\left(1 - \varphi_s^g\right)}{\varphi_s^g}\right)^{\varphi_s^g} \dfrac{\left(e^{(\delta_{g,s}\varphi_s^g(a_{50\%,g,s} - a))}\right)}{\left(1 + e^{(\delta_{g,s}(a_{50\%,g,s} - a))}\right)}$	Exponential-logistic selectivity
Observation equations	
$\hat{C}_{y,g} = \sum_1^g \sum_1^s w_{a,s} N_{y,a,g,s} F_{y,a,g,s} \left(1 - e^{-Z_{y,a,g,s}}\right) Z_{y,a,g,s}^{-1}$	Catch biomass in year *y*
$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} N_{y,a,s} \dfrac{s_{a,s}^g}{\max\left(s_{a,s}^g\right)} w_{a,s}$	Survey biomass index (RPW)
$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} N_{y,a,s} \dfrac{s_{a,s}^g}{\max\left(s_{a,s}^g\right)}$	Survey biomass index (RPN)
$\hat{P}_{y,\cdot,s}^g = N_{y,a,s} s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s_{a,s}^g\right)^{-1} \mathbf{A}_s$	Vector of fishery or survey predicted proportions at age
$\hat{P}_{y,\cdot,s}^g = N_{y,\cdot,s} s_s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s_{a,s}^g\right)^{-1} \mathbf{A}_s^l$	Vector of fishery or survey predicted proportions at length

Posterior distribution components	**Model Description** (continued)
$L_C = \lambda_c \sum_1^g \sum_y \left(\ln C_{g,y} - \ln \hat{C}_{g,y}\right)^2 / \left(2\sigma_C^2\right)$	Catch likelihood
$L_I = \lambda_I \sum_1^g \sum_y \left(\ln I_{g,y} - \ln \hat{I}_{g,y}\right)^2 / \left(2\sigma_I^2\right)$	Survey biomass index likelihood
$L_{age} = \lambda_{age} \sum_{i=1}^{n_g} -\psi_y^g \sum_{a_0}^{a_+} \left(P_{i,a}^g + v\right) \ln\left(\hat{P}_{i,a}^g + v\right)$	Age composition likelihood
$L_{length} = \lambda_{length} \sum_{i=1}^{n_g} -\psi_y^g \sum_{l=1}^{\Omega} \left(P_{i,l}^g + v\right) \ln\left(\hat{P}_{i,l}^g + v\right)$	Length composition likelihood (ψ_y^g=sample size, n_g = number of years of data for gear *g*, *i* = year of data availability, *v* is a constant set at 0.001)
$L_q = \left(\ln \hat{q}^g - \ln q_\mu^g\right)^2 / 2\sigma_q^2$	Prior on survey catchability coefficient for gear *g*
$L_M = \left(\ln \hat{M} - \ln M_\mu\right)^2 / 2\sigma_M^2$	Prior for natural mortality
$L_{\sigma_r} = \left(\ln \hat{\sigma}_r - \ln \sigma_{r_\mu}\right)^2 / 2\sigma_{\sigma_r}^2$	Prior distribution for σ_r
$L_\tau = 0.1 \sum_{y=1}^{T} \frac{\tau_y^2}{2\hat{\sigma}_r^2} + n \ln \hat{\sigma}_r$	Prior on recruitment deviations
$L_f = \lambda_f \sum_1^g \sum_{y=1}^{T} \phi_{y,g}^2$	Regularity penalty on fishing mortality
$L_{Total} = \sum_x L_x$	Total objective function value

Model Evaluation

For this assessment, we present last year's model updated for 2010 with no model changes. In addition, we present a model with the RPW index removed and a third model with newly tuned data weightings that we are recommending. A comparison of the model likelihood components and key parameter estimates from 2009 are compared with three 2010 configurations in Box 2.

Box 2: Model comparison of the 2009 and 2010 models by contribution to the objective function (negative log-likelihood values) and key parameters.

Model Likelihood Components (Data)	**2009** **Model 1**	**-** **Model 1**	**2010** **Model 2**	- **Model 3**
Catch	4	4	3	8
Domestic LL survey RPW	46	49	0	0
Domestic LL survey RPN	24	29	40	40
Japanese LL survey RPW	31	31	0	0
Japanese LL survey RPN	26	27	20	18
Domestic LL fishery RPW	17	17	21	7
Japanese LL fishery RPW	21	21	23	11
NMFS GOA trawl survey	53	58	56	14
Domestic LL survey ages	224	238	221	141
Domestic LL fishery ages	41	44	40	148
Domestic LL survey lengths	123	128	123	53
Japanese LL survey ages	216	216	214	143
Japanese LL survey lengths	106	106	106	46
NMFS trawl survey lengths	83	88	88	216
Domestic LL fishery lengths	80	85	81	195
Domestic trawl fishery lengths	23	28	28	126
Data likelihood	1118	1168	1064	1165
Total objective function value	1141	1190	1086	1184
Key parameters				
Number of parameters	204	207	207	207
B_{2011} *(Female spawning biomass)*	100	99	94	102
$B_{40\%}$ *(Female spawning biomass)*	113	110	107	110
B_{1960} *(Female spawning biomass)*	151	147	161	177
$B_{0\%}$ *(Female spawning biomass)*	282	276	268	275
SPR% current	35%	36%	35%	37%
$F_{40\%}$	0.095	0.095	0.096	0.097
$F_{40\%}$ *(adjusted)*	0.084	0.085	0.083	0.089
ABC	**15.2**	**16.2**	**14.9**	**16.0**
$q_{Domestic\ LL\ survey}$	7.8	7.8	8.1	7.7
$q_{Japanese\ LL\ survey}$	6.0	5.9	6.1	6.3
$q_{DomesticLL\ fishery}$	4.2	4.1	4.3	4.2
$q_{Trawl\ Survey}$	1.0	1.0	1.0	1.0
$a_{50\%}$ *(domestic LL survey slectivity)*	3.8	3.8	3.9	3.9
$a_{50\%}$ (LL fishery selectivity)	4.1	4.1	4.1	4.1
μ_r *(average recruitment)*	18.0	18.5	18.0	18.5
σ_r *(recruitment variability)*	1.20	1.20	1.20	1.20

This model is the same model used since 2006 with additional data. For the 2010 assessment, we present several alternative models based on changes to the input data described in the **Model parameters estimated independently** section. The three models are identical in all aspects except for inclusion/exclusion of the longline survey RPW indices and some input variance tuning. Our usual criteria for choosing a superior model are: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, catchabilities, and selectivities, (3) a good visual fit to length and age compositions, and (4) parsimony. The basic features of the model runs presented in this document are described in the following table:

Model Number	**Model Description**
Model 1 (Base case)	• Model from Hanselman et al. 2009, the base model appended with new data since the 2009 assessment.
Model 2	• Remove the longline survey RPW indices
Model 3	• Remove the longline survey RPW indices • Iteratively reweight compositional data, with the exception of lengths when there are ages

Because the models presented have different amounts of data and different data weightings, it is not reasonable to compare their negative log likelihoods so we cannot compare them by the first criterion above. We removed the longline survey RPW indices because of the “double use” of this abundance source when using both RPNs and RPWs. Both the 2009 CIE review and the 2010 sablefish modeling workshop recommended this change. Since removing an index from the model inherently changes the relative weight of all other data components (Model 2), we chose to reweight data components for Model 3. We iteratively reweighted the 2009 model prior to adding the 2010 data to yield SDNR values on compositional data close to 1. Model 3 yields SDNR values close to one for the compositional data we were reweighting (see following figure). Model 3 generally produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. In terms of parsimony, the three models are equivalent in terms of parameters, but Model 3 has the simplest assumptions about input variances and data inputs. While we were not reweighting the data to force input and output effective sample sizes to be equivalent, fitting to get an SDNR value of one improved the ratio of input sample size to effective sample size as well. The reweighting was done to rebalance the weighting various data components, but also had an unintended benefit of improving the retrospective patterns revealed in previous assessments (Figures 3.22 and 3.23). For these reasons, for 2011 ABC and OFL, we recommend Model 3. The remainder of the results will be from Model 3.

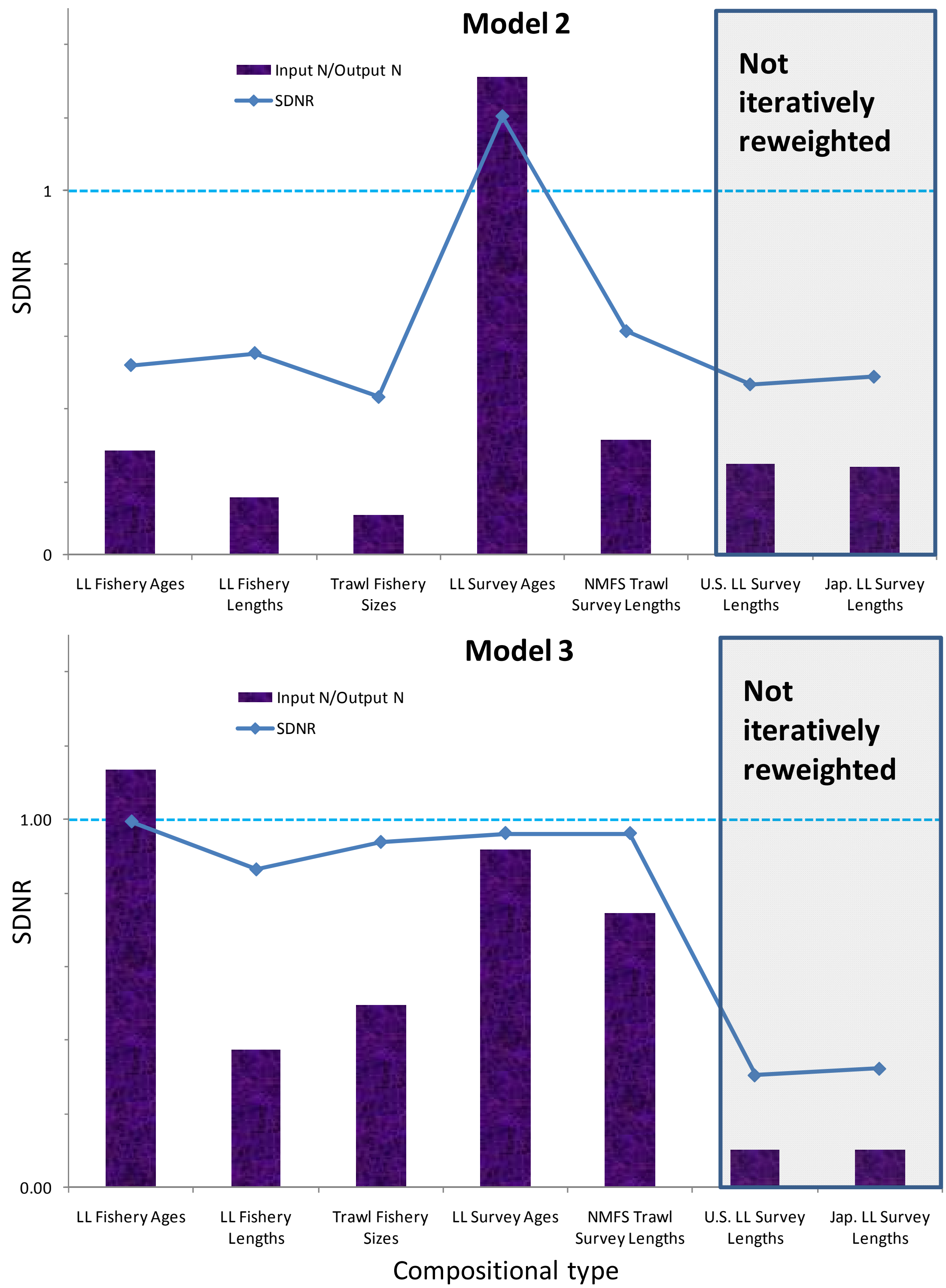


Figure. Comparison of the standard deviation of normalized residuals (SDNR) and ratio of input sample size and output effective sample size data for compositional data for Models 2 and 3. Values closer to one indicate input variances and output variances are similar.

Model Results

Definitions

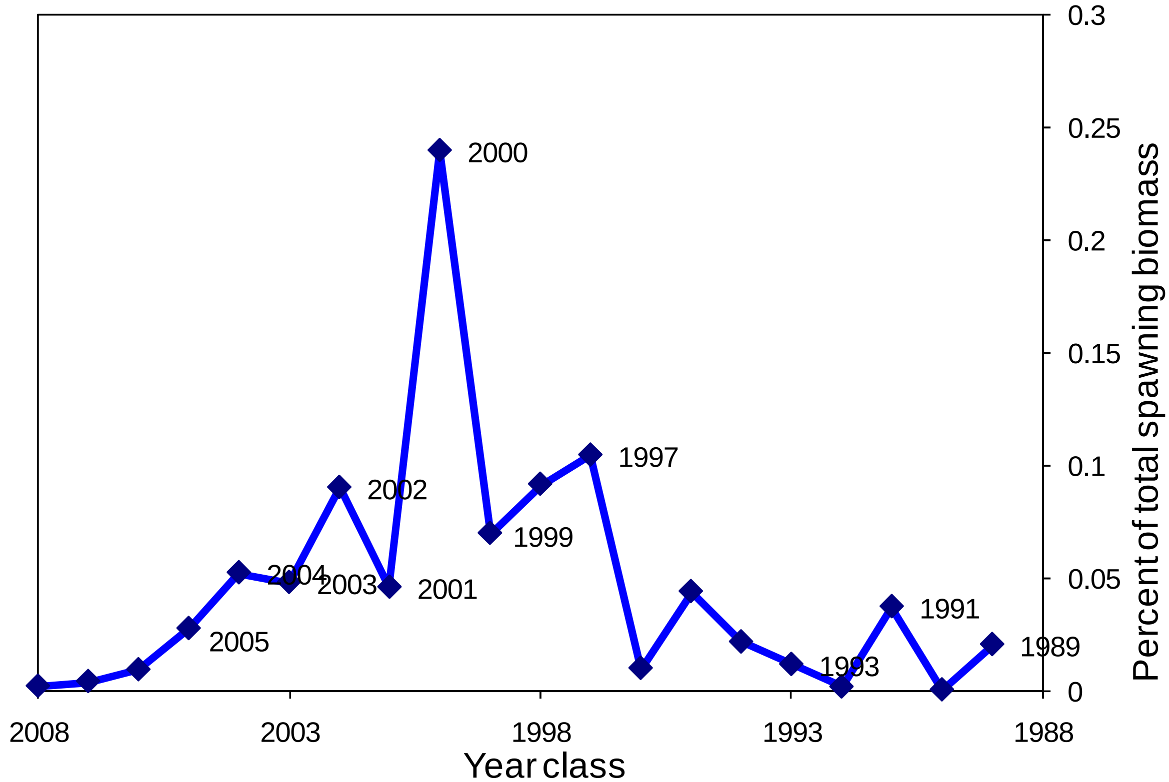
Spawning biomass is the biomass estimate of mature females. Total biomass is the estimate of all sablefish age two and greater. Recruitment is measured as number of age two sablefish. Fishing mortality is fully-selected F, meaning the mortality at the age the fishery has fully selected the fish.

Abundance trends

Sablefish abundance increased during the mid-1960's (Table 3.9, Figure 3.10) due to strong year classes in the early 1960's. Abundance subsequently dropped during the 1970's due to heavy fishing; catches peaked at 53,080 t in 1972. The population recovered due to a series of strong year classes from the late 1970's (Figure 3.18, Table 3.11); spawning abundance peaked again in 1987. The population then decreased because these strong year classes expired. The model suggested an increasing trend in spawning biomass since the all-time low in 2002, but is exhibiting a steady decrease in total biomass since 2003 (Figure 3.10).

Projected 2011 spawning biomass is 37% of unfished spawning biomass. Spawning biomass has increased from a low of 30% of unfished biomass in 2002 to 37% projected for 2011. The 1997 year class has been an important contributor to the population but has been reduced and should comprise 10% of the 2011 spawning biomass. The 2000 year class appears to be larger than the 1997 year class, and is now 95% mature and should comprise 24% of the spawning biomass in 2011. The 2002 year class is beginning to show signs of strength and will comprise 9% of spawning biomass in 2011 and is 86% mature.

The following figure shows the age composition of spawning biomass projected for 2011 for the last 20 year-classes.



Recruitment trends

Annual estimated recruitment varies widely (Figure 3.18b). The two recent strong year classes in 1997 and 2000 were evident in all data sources. After 2000, few strong year classes are apparent. Few small fish were caught in the 2005 through 2009 trawl surveys (Figures 3.12-13). The 2001 year class appeared to be an above-average year class in the Aleutian Islands/Western Gulf in the 2005-2007 longline survey age compositions. However, the 2001 year class appeared moderate in the Central Gulf in the 2006-2007 survey age composition (Figure 3.7) and is still low in the overall age compositions (Figure 3.18). The 2002 year class appears weak in the 2005 and 2006 longline survey age composition, but showed up somewhat in the Central Gulf in the 2007 age compositions and again in the 2008 Eastern Gulf age compositions. The RPN by age class is quite low in the 2008 age composition (Figure 3.7), but shows an interesting flattening of the middle age distribution. In the Central Gulf, the 1998-2003 year classes all have almost identical RPNs. One possible explanation is the targeting discussed earlier is removing the peaks caused by large year classes like 2000. The 2009 survey age composition class shows some different year classes looking stronger such as the 2003 year class in the Bering Sea and Western GOA.

Year classes are classified as weak if they were in the bottom 25% of recruitment values, strong if they were in the top 25% of recruitment values, and average if they were in the middle 50% of recruitment values. The following table using values estimated recruitment values shows that 12 out of the last 14 year classes (1993-2006) were average or below average except for the 1997 and 2000 year classes.

Strong	1960	1963	1964	1970	1971	1977	1978	1980	1982	1991	1997	2000	
Average	1959	1961	1962	1965	1966	1967	1974	1979	1981	1984	1985	1988	
	1989	1993	1994	1995	1998	1999	2001	2002	2003	2004	2005	2006	2007
Weak	1958	1968	1969	1972	1973	1975	1976	1983	1986	1987	1990	1992	1996

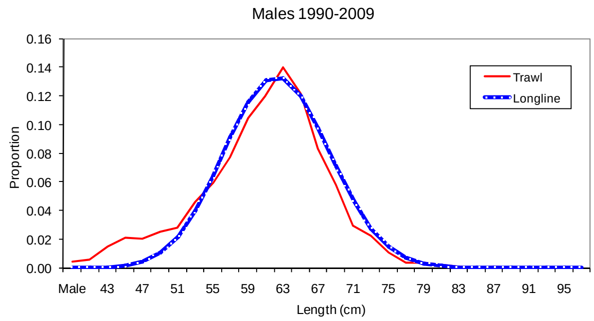
Average recruitment during 1979-2008 is 18.5 million 2-year-old sablefish per year, which is similar to the average recruitment for the 1958-2008 year classes. Estimates of recruitment strength during the 1960's are less certain because they depend on length data but not age data and because the abundance index is based only on the fishery catch rate, which may be a biased measure of abundance.

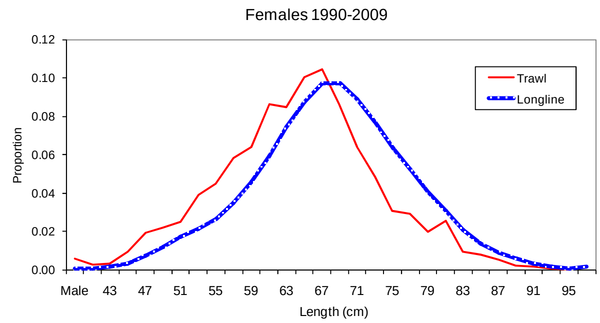
Juvenile sablefish are pelagic and at least part of the population inhabits shallow near-shore areas for their first one to two years of life (Rutecki and Varosi 1997). In most years, juveniles are found only in a few places such as Saint John Baptist Bay near Sitka, Alaska. Widespread, abundant age-1 juveniles likely indicate a strong year class. Abundant age-1 juveniles were reported for the 1960 (J. Fujioka & H. Zenger, NMFS, pers. commun.), 1977 (Bracken 1983), 1980, 1984, and 1998 year classes in southeast Alaska, the 1997 and 1998 year classes in Prince William Sound (W. Bechtol, ADFG, pers. commun.), and the 1998 year class near Kodiak Island (D. Jackson, ADFG, pers. commun.).

Sablefish recruitment varies greatly from year to year (Figure 3.18), but shows some relationship to environmental conditions. Sablefish recruitment success is related to winter current direction and water temperature; above average recruitment is more common for years with northerly drift or above average sea surface temperature (Sigler et al. 2001). Sablefish recruitment success also is related to recruitment success of other groundfish species. Strong year classes were synchronous for many northeast Pacific groundfish stocks for the 1961, 1970, 1977, and 1984 year classes (Hollowed and Wooster 1992). For sablefish in Alaska, the 1960-1961 and 1977 year classes also were strong. Some of the largest year classes of sablefish occurred when abundance was near the historic low, the 1977-1978 and 1980-1981 year classes. These strong year classes followed the 1976/1977 North Pacific regime shift. The 1977 year class was associated with the Pacific Decadal Oscillation (PDO) phase change and the 1977 and 1981 year classes were associated with warm water and unusually strong northeast Pacific pressure index (NEPI, Hollowed and Wooster 1992). Larger than average year classes were produced again in 1997-2000, when the population was at a recent low point. Some species such as walleye pollock and sablefish may exhibit increased production at the beginning of a new environmental regime, when bottom up forcing prevails and high turnover species compete for dominance, which later shifts to top down forcing once dominance is established (Bailey 2000, Hunt et al. 2002). The large year classes of sablefish indicate that the population, though low, still was able to take advantage of favorable environmental conditions and produce large year classes.

Selectivities

Selectivity is asymptotic for the longline survey and fisheries and dome-shaped (or descending right limb) for the trawl survey and trawl fishery (Figure 3.19). The age-of-50% selection is 3.9 years for females in the longline survey and 4.1 years for the females in the IFQ longline fishery. Males were selected at an older age than females in both the derby and IFQ fisheries. Females are selected at an older age in the IFQ fishery than in the derby fishery (Figure 3.19a). Selection of younger fish during short open-access seasons likely was due to crowding of the fishing grounds, so that some fishers were pushed to fish shallower water that young fish inhabit (Sigler and Lunsford 2001). Relative to the longline survey, small fish are more vulnerable and older fish are less vulnerable to the trawl fishery (see following figure) because trawling often occurs on the continental shelf in shallower waters (< 300 m) where young sablefish reside. The trawl fishery selectivity is the same for males and females (Figure 3.19a). The simpler selectivity curves for the trawl survey are nearly identical to previous estimates, but the curves for the trawl fishery differ and appear more biologically reasonable (Figure 3.19). These patterns are consistent with the idea that sablefish recruit to the fishery at 3-5 years of age and then gradually become less available to the trawl fishery as they move offshore into deeper waters. The trawl survey selectivity has a reasonably smooth descending shape that probably describes trawl selectivity to 500 m in the Gulf of Alaska (Figure 3.19b).





Fishing mortality and management path

Fishing mortality was estimated to be high in the 1970s, relatively low in the early 1980s and then increased and held relatively steady in the 1990s and 2000s (Figure 3.20). Goodman et al. (2002) suggested that stock assessment authors use a “management path” graph as a way to evaluate management and assessment performance over time. Previously we used the management path as suggested by Goodman et al. (2002), but several reviews have suggested a similar phase-plane plot that shows our harvest control rules. In this “management path” we plot estimated fishing mortality relative to the (current) limit value and the estimated spawning biomass relative to target spawning biomass ($B_{40\%}$). Figure 3.21 shows that recent management has generally constrained fishing mortality below the limit rate, but has not been able to keep the stock above the $B_{40\%}$ target.

Uncertainty

We compared a selection of parameter estimates from the Markov-Chain Monte Carlo (MCMC) simulations with the maximum-likelihood estimates, and compared each method’s associated level of uncertainty (see following table). Mean and median catchability estimates were similar. The estimate of $F_{40\%}$ was lower by maximum likelihood and shows some skewness as indicated by the difference between the MCMC mean and median values. Under both methods the variances are similar except for estimation of a large year class (2000) where the uncertainty is higher for MCMC methods. Ending female spawning biomass and the last large recruitment (2000) are estimated precisely by both methods.

Table of key parameter estimates and their uncertainty.

Parameter	μ	μ (MCMC)	Median (MCMC)	σ	σ(MCMC)	BCI-Lower	BCI-Upper
$q_{domesticLL}$	7.72	7.73	7.73	0.03	0.23	7.30	8.20
q_{coopLL}	6.31	6.33	6.33	0.03	0.21	5.93	6.73
q_{trawl}	0.99	0.92	0.92	0.07	0.08	0.78	1.10
$F_{40\%}$	0.097	0.107	0.102	0.024	0.032	0.063	0.177
2010 SSB (kt)	105.6	106.2	101.5	4.1	3.8	94.5	109.1
2000 Year Class	42.7	47.4	47.4	2.8	6.3	35.7	58.1

Retrospective analysis

Retrospective analysis is the examination of the consistency among successive estimates of the same parameters obtained as new data are added to a model. Retrospective analysis has been applied most commonly to age-structured assessments. Retrospective biases can arise for many reasons, ranging from bias in the data (e.g., catch misreporting, non-random sampling) to different types of model misspecification such as wrong values of natural mortality, or temporal trends in values set to be invariant. Classical retrospective analysis involves starting from some time period earlier in the model and successively adding data and testing if there is a consistent bias in the outputs (NRC 1998).

For this assessment, we show the retrospective trend in spawning biomass and total biomass for six years (2005-2010). This analysis is simply removing all new data that have been added for each consecutive year for the preferred model. Each year of the assessment generally adds one year of longline fishery lengths, trawl fishery lengths, longline survey lengths, longline and fishery ages (from one year prior), fishery abundance index, and longline survey index. Every other year, a trawl survey estimate and corresponding length composition are added.

In last year's assessment model retrospective analysis, spawning biomass estimates for the current time period were generally patterned in one direction (Figure 3.22a). The historic part of the spawning biomass time series remains relatively constant with the addition of new data, which is reassuring. This drift in spawning biomass estimates in general retains the same trend, but moves downward. In addition to reflecting incoming data that suggests lower biomass and recruitment, there may be some model bias affecting the estimates. In the recommended Model 3 for 2011, this retrospective pattern all but disappears and patterns are more a reflection of new data (Figure 3.22b).

Total biomass showed a slightly different pattern in the 2009 assessment where not only do the estimates become lower, but the recent trend exhibited by the three most recent "assessments" shows a reversal and now is descending (Figure 3.22a). Model 3 in this assessment shows less of a pattern (Figure 3.23b).

Revealing retrospective trends can show potential biases in the model, but may not prove what their source is. Other times a retrospective trend is merely a matter of the model having too much inertia in the age-structure and other historic data to respond to the most recent data. We will monitor and explore these patterns in the future.

Projections and Harvest Alternatives

The following table summarizes key reference points from the assessment of sablefish in Alaska:

Natural mortality (M)	0.10
Tier	3b
Equilibrium unfished spawning biomass	275,270
Reference point spawning biomass, $B_{40\%}$	110,108
Reference point spawning biomass, $B_{35\%}$	96,345
Spawning biomass	102,139
2010 total (age 4+) biomass	221,000
Maximum permissible fishing level	
$F_{40\%}$	0.097
$F_{40\%}$ adjusted	0.089
$F_{40\%}$ adjusted Yield	**16,040**
Overfishing level	
$F_{35\%}$	0.115
$F_{35\%}$ adjusted	0.106
$F_{35\%}$ adjusted Yield	18,950
Authors' recommendation	
F	0.089
ABC	**16,040**

We recommend a 2011 ABC of 16,040 t. The maximum permissible yield for 2011 from an adjusted $F40_{\%}$ strategy is 16,040 t. The maximum permissible yield for 2011 is a 5% increase from the 2010 ABC of 15,230 t. This increase is supported by a substantial increase in the domestic longline survey index that offset the prior year's decrease in the fishery abundance index. There was also a slight increase in estimates of incoming recruitment year classes. Spawning biomass is projected to decline through 2013, and then is expected to increase assuming average recruitment is achieved. Because of the lack of recent strong year classes, the maximum permissible ABC is projected to be 14,697 t in 2012 and 13,978 in 2013 (using estimated catches, instead of maximum permissible, see Table 3.10).

Reference fishing mortality rate

Sablefish are managed under Tier 3 of NPFMC harvest rules which specify that the fishing rate be adjusted downward when biomass is below the target reference biomass. Compared to a constant fishing rate strategy, the adjustable rate strategy was shown in simulations by Sigler and Fujioka (1993) to significantly reduce the risk of overfishing of sablefish, while attaining nearly the same yield with lower fishing effort. Fujioka et al (1997) showed analytically the same advantages of an adjustable fishing rate compared to a constant fishing rate strategy. Reference points are calculated using recruitments from 1979-2008. The updated point estimates of $B40_{\%}$, $F40_{\%}$, and $F35_{\%}$ from this assessment are 110,108 t (combined across the EBS, AI, and GOA), 0.097, and 0.115, respectively. Projected female spawning biomass (combined areas) for 2011 is 102,139 t (93% of B40%), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of FABC under Tier 3b is 0.089, which translates into a 2011 ABC (combined areas) of 16,040 t. The OFL fishing mortality rate is 0.106 which translates into a 2011 OFL (combined areas) of 18,950 t. Model projections indicate that this stock is neither overfished nor approaching an overfished condition.

Population projections

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2010 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2011 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2010. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch after 2010 is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1,000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2011, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the catch in 2010 to the ABC recommended in the assessment for

2010. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.) In this scenario we use the ratio of most recent catch to ABC, and apply it to estimated ABCs for 2011 and 2011 to determine the catch for 2011 and 2012, then maximum permissible thereafter. Projections incorporating estimated catches help produce more accurate projections for fisheries that do not utilize all of the TAC.

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2006-2010 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above 1) above its MSY level in 2010 or 2) above ½ of its MSY level in 2010 and above its MSY level in 2020 under this scenario, then the stock is not overfished.)

Scenario 7: In 2011 and 2012, F is set equal to *max* F_{ABC}, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2023 under this scenario, then the stock is not approaching an overfished condition.)

Spawning biomass, fishing mortality, and yield are tabulated for the seven standard projection scenarios (Table 3.10). The difference for this assessment for projections is in Scenario 2 (Author's F); we use pre-specified catches to increase accuracy of short-term projections in fisheries (such as sablefish) where the catch is usually less than the ABC. This was suggested to help management with setting preliminary ABCs and OFLs for 2011 and 2012. In this scenario we use the ratio of most recent catch to ABC, and apply it to estimated ABCs for 2011 and 2012 to determine the catch for 2011 and 2012, then set catch at maximum permissible thereafter.

Status determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2011, it does not provide the best estimate of OFL for 2012, because the mean 2011 catch under Scenario 6 is predicated on the 2011 catch being equal to the 2011 OFL, whereas the actual 2011 catch will likely be less than the 2010 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2009) is 14,335 t. This is less than the 2009 OFL of 19,000 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2010:
a. If spawning biomass for 2010 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2010 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2010 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 3.10). If the mean spawning biomass for 2020 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:
a. If the mean spawning biomass for 2013 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2013 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2013 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2023. If the mean spawning biomass for 2023 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Table 3.10, the stock is not overfished and is not approaching an overfished condition.

Bayesian analysis

The estimates of ending spawning biomass are well-defined by the available data. Most of the probability lies between 95,000 and 105,000 t (Figure 3.24). The probability changes smoothly and exhibits a relatively normal distribution.

Scatter plots of selected pairs of model parameters were produced to evaluate the shape of the posterior distribution (Figure 3.25). The plots indicate that the parameters are reasonably well defined by the data. As expected, catchabilities and ending spawning biomass are confounded. The catchability of the longline survey is most confounded with ending spawning biomass because it has the most influence in the model in recent abundance predictions.

We estimated the posterior probability that projected abundance will fall, or stay below thresholds of 17.5% (MSST), and 35% (MSY), and 40% (B_{target}) of the unfished spawning biomass based on the posterior probability estimates. Abundance was projected for 14 years. For management, it is important to know the risk of falling under these thresholds. The probability that spawning biomass falls below key biological reference points was estimated based on the posterior probability distribution for spawning biomass. The probability that next year's spawning biomass was below $B_{35\%}$ was 0.33. During the next three years, the probability of falling below $B_{17.5\%}$ is near zero, the probability of falling below $B_{35\%}$ is 0.99, and the probability of staying below $B_{40\%}$ is near 100% (Figure 3.26).

Alternate Projection

During the 2007 rockfish CIE review, it was suggested that projections should account for uncertainty in the entire assessment, not just recruitment from the endpoint of the assessment. For this assessment we show a projection that considers uncertainty from the whole model by running projections within the model. This projection propagates uncertainty throughout the entire assessment procedure and is based on 10,000,000 MCMC (burnt-in and thinned) using the standard Tier 3 harvest rules. The projection shows wide credible intervals on future spawning biomass (Figure 3.27). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1979-2007 recruitments, and this projection predicts that the median spawning biomass will dip below $B_{35\%}$ by 2011, and then return to $B_{40\%}$ if average recruitment is attained.

Acceptable biological catch

We recommend a 2011 ABC of 16,040 t. The maximum permissible yield for 2011 from an adjusted $F40_{\%}$ strategy is 16,040 t. The maximum permissible yield for 2011 is a 5% increase from the 2010 ABC of 15,230 t. This increase is supported by a substantial increase in the domestic longline survey index that offset the prior year's decrease in the fishery abundance index. There was also a slight increase in estimates of incoming recruitment year classes. Spawning biomass is projected to decline through 2013, and then is expected to increase assuming average recruitment is achieved. Because of the lack of recent strong year classes, the maximum permissible ABC is projected to be 14,697 t in 2012 and 13,978 in 2013 (using estimated catches, instead of maximum permissible, see Table 3.10).

Projected 2011 spawning biomass is 37% of unfished spawning biomass. Spawning biomass has increased from a low of 30% of unfished biomass in 2002 to 37% projected for 2011. The 1997 year class has been an important contributor to the population but has been reduced and should comprise 10% of the 2011 spawning biomass. The 2000 year class appears to be larger than the 1997 year class, and is now 95% mature and should comprise 24% of the spawning biomass in 2011. The 2002 year class is beginning to show signs of strength and will comprise 9% of spawning biomass in 2011 and is 86% mature.

The following table shows the maximum permissible ABC, and ABCs recommended by the stock assessment authors, Plan Teams, SSC, and NPFMC, by fishing year 1997-2009.

Year	Maximum permissible	Authors	Plan Teams	SSC	NPFMC
1997	23,200	17,200	19,600	17,200	17,200
1998	19,000	16,800	16,800	16,800	16,800
1999	15,900	15,900	15,900	15,900	15,900
2000	17,300	17,000	17,300	17,300	17,300
2001	16,900	16,900	16,900	16,900	16,900
2002	21,300	17,300	17,300	17,300	17,300
2003	25,400	18,400	18,400	20,900	20,900
2004	25,400	23,000 or 20,700	23,000	23,000	23,000
2005	21,000	21,000	21,000	21,000	21,000
2006	21,000	21,000	21,000	21,000	21,000
2007	20,100	20,100	20,100	20,100	20,100
2008	18,030	18,030	18,030	18,030	18,030
2009	16,080	16,080	16,080	16,080	16,080
2010	15,230	15,230	15,230	15,230	15,230

Area apportionment of harvests

The combined ABC has been apportioned to regions using weighted moving average methods since 1993; these methods reduce the magnitude of inter-annual changes in the apportionment. Weighted moving average methods are robust to uncertainties about movement rates and measurement error of biomass distribution, while adapting to current information about biomass distribution. The 1993 TAC was apportioned using a 5 year running average with emphasis doubled for the current year survey abundance index in weight (relative population weight or RPW). Since 1995, the ABC was apportioned using an exponential weighting of regional RPWs. Exponential weighting is implied under certain conditions by the Kalman filter. The exponential factor is the measurement error variance divided by the prediction error variance (Meinhold and Singpurwalla 1983). Prediction error variance depends on the variances of the previous year's estimate, the process error, and the measurement error. When the ratio of measurement error variance to process error variance is r, the exponential factor is equal to $1-2/(\sqrt{4r+1}+1)$ (Thompson 2004). For sablefish we do not estimate these values, but instead set the exponential factor at ½, so that, except for the first year, the weight of each year's value is ½ the weight of the following year. The weights are year index 5: 0.0625; 4: 0.0625; 3: 0.1250; 2: 0.2500; 1: 0.5000. A $(1/2)^x$ weighting scheme reduced annual fluctuations in regional ABC, while keeping regional fishing rates from exceeding overfishing levels in a stochastic migratory model, where *x* is the year index (J. Heifetz, Auke Bay Lab, pers. comm.). Because mixing rates for sablefish are sufficiently high and fishing rates sufficiently low, moderate variations of biomass-based apportionment would not significantly change overall sablefish yield unless there are strong differences in recruitment, growth, and survival by area (Heifetz et al. 1997).

Previously, the Council approved apportionments of the ABC based on survey data alone. Starting with the 2000 ABC, the Council approved an apportionment based on survey and fishery data. We continue to use survey and fishery data to apportion the 2011 ABC. The fishery and survey information were combined to apportion ABC using the following method. The RPWs based on the fishery data were weighted with the same exponential weights used to weight the survey data (year index 5: 0.0625; 4: 0.0625; 3: 0.1250; 2: 0.2500; 1: 0.5000). The fishery and survey data were combined by computing a weighted average of the survey and fishery estimates, with the weight inversely proportional to the variability of each data source. The variance for the fishery data has typically been twice that of the survey data, so the survey data was weighted twice as much as the fishery data. Recent improvements in sample size of observer and logbook collections have reduced the variance on the fishery sources.

Apportionments are based on survey and fishery information	2010 ABC Percent	2010 Survey RPW	2009 Fishery RPW	2011 ABC Percent	2010 ABC	2011 ABC	Change
Total					15,230	**16,040**	5%
Bering Sea	18%	20%	11%	18%	2,790	**2,850**	2%
Aleutians	14%	9%	12%	12%	2,070	**1,900**	-8%
Gulf of Alaska	68%	71%	77%	70%	10,370	**11,290**	9%
Western	16%	13%	12%	14%	1,660	**1,620**	-2%
Central	43%	41%	39%	42%	4,510	**4,740**	5%
W. Yakutat	14%	19%	19%	16%	1,480	**1,830**	24%
E. Yakutat / Southeast	26%	28%	30%	27%	2,720	**3,100**	14%

After the adjustment for the 95:5 hook-and-line:trawl split in the Eastern Gulf of Alaska, the 2011 ABC for West Yakutat is 1,990 t and for East Yakutat/Southeast is 2,940 t. This adjustment projected to 2012 is 1,820 t for W. Yakutat and 2,700 t for E. Yakutat.

	Year	W. Yakutat	E. Yakutat/Southeast
Adjusted for 95:5 hook-and-line: trawl split in EGOA	2011	1,990 t	2,940 t
	2012	1,818 t	2,700 t

This year's apportionment reflects a substantial increase in the longline survey index in the Central and Eastern Gulf area, while the survey index declined in the Western Gulf and the Aleutian Islands. The Bering Sea and Aleutian Islands has substantial declines in Fishery RPW, while fishery RPWs improved substantially only in West Yakutat (Figure 3.28a). The only area to have sizeable increases in both fishery and survey RPWs was West Yakutat which showed the largest change in apportionment this year. The standard weighted average approach described above, which includes values from 2006-2010 for survey RPWs and 2005-2009 for fishery RPWs, greatly alleviates the effect of an individual year's change in RPW (Figure 3.28b). The Gulf of Alaska overall is now capturing a larger share of the apportionment. However, the current apportionment is characteristic of most prior years except for 2005 (Figure 3.28c).

Overfishing level (OFL)

Applying an adjusted $F_{35\%}$ as prescribed for OFL in Tier 3b results in a value of 18,950 t for the combined stock. The OFL is apportioned by region, Bering Sea (3,360 t), Aleutian Islands (2,250 t), and Gulf of Alaska (13,340 t), by the same method as the ABC apportionment.

Ecosystem considerations

Preliminary results of first-order trophic interactions for sablefish have recently been provided from the ECOPATH model, an ecosystem modeling software package. While prominence of some interactions may be the result of insufficient data, estimation of prey interactions of adult sablefish in the Gulf of Alaska appear reasonable. However, most diet information is from the trawl survey, which does not fully sample the sablefish population. Sampling coverage appeared the broadest geographically in 2005 in the Gulf so we show that data as an example (Figure 3.29). In 2005, more than half of adult sablefish diet consisted of offal, squid, pandalid shrimp, and walleye pollock. Further analysis of prey data may help form hypotheses to explain increases and decreases in sablefish abundance.

Significant predator interactions on sablefish may be more difficult to predict accurately. Sablefish may not be sufficiently abundant to be prominent or consistent enough in predator diets to discern their major predators, given the current level of sampling of potential predators. Sufficient sampling of potential predators of adult sablefish, such as sharks and whales, may not be feasible. We will closely monitor developments in these models and their corresponding data for interesting trends and hypotheses.

Ecosystem considerations for the Alaska sablefish fishery are summarized in Table 3.12.

Ecosystem effects on the stock

Prey population trends: Young-of-the-year sablefish prey mostly on euphausiids (Sigler et al. 2001) and copepods (Grover and Olla 1990), while juvenile and adult sablefish are opportunistic feeders. Larval sablefish abundance has been linked to copepod abundance and young-of-the-year abundance may be similarly affected by euphausiid abundance because of their apparent dependence on a single species (McFarlane and Beamish 1992). The dependence of larval and young-of-the-year sablefish on a single prey species may be the cause of the observed wide variation in annual sablefish recruitment. No time series is available for copepod and euphausiid abundance, so predictions of sablefish abundance based on this predator-prey relationship are not possible.

Juvenile and adult sablefish feed opportunistically, so diets differ throughout their range. In general, sablefish < 60 cm FL consume more euphausiids, shrimp, and cephalopods, while sablefish > 60 cm FL consume more fish (Yang and Nelson 2000). In the Gulf of Alaska, fish constituted 3/4 of the stomach content weight of adult sablefish with the remainder being invertebrates (Yang and Nelson 2000). Of the fish found in the diets of adult sablefish, pollock were the most abundant item while eulachon, capelin, Pacific herring, Pacific cod, Pacific sand lance, and flatfish also were found. Squid were the most important invertebrate and euphausiids and jellyfish were also present. In southeast Alaska, juvenile sablefish also consume juvenile salmon at least during the summer months (Sturdevant et al. 2009). Off the coast of Oregon and California, fish made up 76 percent of the diet (Laidig et al. 1997), while euphausiids dominated the diet off the southwest coast of Vancouver Island (Tanasichuk 1997). Off Vancouver Island, herring and other fish were increasingly important as sablefish size increased; however, the most important prey item was euphausiids. It is unlikely that juvenile and adult sablefish are affected by availability and abundance of individual prey species because they are opportunistic feeders. The only likely way prey could affect growth or survival of juvenile and adult sablefish is by overall changes in ecosystem productivity.

Predators/Competitors: The main juvenile sablefish predators are adult coho and chinook salmon, which prey on young-of-the-year sablefish during their pelagic stage. Sablefish were the fourth most commonly reported prey species in the salmon troll logbook program from 1977 to 1984 (Wing 1985), however the effect of salmon predation on sablefish survival is unknown. The only other fish species reported to prey on sablefish in the Gulf of Alaska is Pacific halibut; however, sablefish comprised less than 1% of their stomach contents (M-S. Yang, Alaska Fisheries Science Center, 14 October 1999). Although juvenile sablefish may not be a prominent prey item because of their relatively low and sporadic abundance compared to other prey items, they share residence on the continental shelf with arrowtooth flounder, halibut, Pacific cod, bigmouth sculpin, big skate, and Bering skate, which are the main piscivorous groundfishes in the Gulf of Alaska (Yang et al. 2006). It seems possible that predation of sablefish by other fish is significant to the success of sablefish recruitment even though they are not a common prey item.

Sperm whales are likely a major predator of adult sablefish. Fish are an important part of sperm whale diet in some parts of the world, including the northeastern Pacific Ocean (Kawakami 1980). Fish have appeared in the diets of sperm whales in the eastern Aleutians and Gulf of Alaska. Although fish species were not identified in sperm whale diets in Alaska, sablefish were found in 8.3% of sperm whale stomachs off of California (Kawakami 1980).

Sablefish distribution is typically thought to be on the upper continental slope in deeper waters than most groundfish. However, during the first two to three years of their life sablefish inhabit the continental shelf. Length samples from the NMFS bottom trawl survey suggest that the range of juvenile sablefish on the shelf varies dramatically from year to year. In particular, juveniles utilize the Bering Sea shelf extensively in some years, while not at all in others (Shotwell 2007). Juvenile sablefish (< 60 cm FL) prey items overlap with the diet of small arrowtooth flounder. On the continental shelf of the Gulf of Alaska, both species consumed euphausiids and shrimp predominantly; these prey are prominent in the diet of many other groundfish species as well. This diet overlap may cause competition for resources between small sablefish and other groundfish species.

Changes in the physical environment: Mass water movements and temperature changes appear related to recruitment success. Above-average recruitment was somewhat more likely with northerly winter currents and much less likely for years when the drift was southerly. Recruitment was above average in 61% of the years when temperature was above average, but was above average in only 25% of the years when temperature was below average. Growth rate of young-of-the-year sablefish is higher in years when recruitment is above average (Sigler et al. 2001).

Anthropogenic changes in the physical environment: The Essential Fish Habitat Environmental Impact Statement (EFH EIS) (NMFS 2005) concluded that the effects of commercial fishing on the habitat of sablefish is minimal or temporary in the current fishery management regime primarily based on the criterion that sablefish are currently above Minimum Stock Size Threshold (MSST).

Juvenile sablefish are substantially dependent on benthic prey (18% of diet by weight) and the availability of benthic prey may be adversely affected by fishing. Little is known about effects of fishing on benthic habitat or the habitat requirements for growth to maturity. Although sablefish do not appear to be directly dependent on physical structure, reduction of living structure is predicted in much of the area where juvenile sablefish reside and this may indirectly reduce juvenile survivorship by reducing prey availability or by altering the abilities of competing species to feed and avoid predation.

Effects of the sablefish fishery on the ecosystem

Fishery-specific contribution to bycatch of prohibited species, forage species, HAPC biota, marine mammals and birds, and other sensitive non-target species: The sablefish fishery catches significant portions of the spiny dogfish and unidentified shark total catch, but there is no distinct trend through time (see table at the end of this section). The sablefish fishery catches the majority of grenadier total catch (average 66%) and the trend is stable. The catch of seabirds in the sablefish fishery averages 17% of the total catch. The trend in seabird catch is variable but appears to be decreasing, presumably due to widespread use of measures to reduce seabird catch. Sablefish fishery catches of other species is minor.

Table. Catch of prohibited species, forage species, HAPC biota, marine mammals and birds, and other non-target species, such as sharks, in sablefish directed fisheries. Percent of catch refers to that attributable to directed sablefish fisheries in all areas of Alaska.

Biota	2003-2005 average	2006	2007	2008	2009	Average	Average catch (t)
Birds	12.0%	19.0%	25.5%	22.7%	16.8%	17.3%	1.81
Brittle stars	0.5%	0.2%	0.7%	0.2%	5.2%	0.5%	0.15
Corals Bryozoans	1.2%	3.0%	0.4%	3.0%	6.1%	2.0%	0.96
Eelpouts	1.0%	2.1%	1.3%	9.7%	2.5%	2.2%	2.4
Grenadier	64.0%	80.6%	18.8%	46.0%	68.8%	65.6%	4,484.16
Large Sculpins	0.1%	0.1%	0.1%	0.0%	0.3%	0.1%	7.76
Octopus	0.6%	0.1%	0.5%	0.2%	0.2%	0.4%	2.19
Sea anemone	0.1%	0.3%	2.4%	0.6%	1.2%	0.7%	0.99
Sea star	0.0%	0.2%	1.1%	0.1%	0.2%	0.2%	6.81
Shark, Other	7.2%	1.2%	3.5%	15.3%	0.0%	3.8%	4.64
Shark, pacific sleeper	3.1%	4.4%	0.9%	2.0%	1.6%	2.9%	14.39
Shark, salmon	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.17
Shark, spiny dogfish	18.7%	12.4%	19.6%	16.8%	23.5%	17.6%	145
Skate, Big	0.2%	0.7%	0.1%	0.2%	0.1%	0.3%	3.15
Skate, Longnose	3.9%	3.8%	1.5%	3.0%	2.3%	3.1%	16.11
Skate, Other	0.5%	0.9%	0.7%	0.4%	0.6%	0.6%	123.72
Snails	1.6%	4.4%	4.8%	3.3%	8.8%	3.2%	6.06
Sponge	0.3%	0.4%	0.1%	9.3%	0.8%	1.3%	2.75

The shift from an open-access to an IFQ fishery has nearly doubled catching efficiency which has reduced the number of hooks deployed (Sigler and Lunsford 2001). Although the effects of longline gear on bottom habitat are poorly known, the reduced number of hooks deployed during the IFQ fishery must reduce the effects on benthic habitat. The IFQ fishery likely has also reduced discards of other species because of the slower pace of the fishery and the incentive to maximize value from the catch.

Fishery-specific concentration of target catch in space and time relative to predator needs in space and time (if known) and relative to spawning components: The sablefish fishery largely is dispersed in space and time. The longline fishery lasts 8-1/2 months. The quota is apportioned among six regions of Alaska.

Fishery-specific effects on amount of large size target fish: The longline fishery catches mostly medium and large-size fish which are typically mature. The trawl fishery, which on average accounts for about 13% of the total catch, often catches small and medium fish. The trawl fishery typically occurs on the continental shelf where juvenile sablefish occur. Catching these fish as juveniles reduces the yield available from each recruit.

Fishery-specific contribution to discards and offal production: Discards of sablefish in the longline fishery are small, typically less than 5% of total catch (Table 3.2). The catch of sablefish in the longline fishery typically consists of a high proportion of sablefish, 90% or more. However at times grenadiers may be a significant catch and they are almost always discarded.

Fishery-specific effects on age-at-maturity and fecundity of the target species: The shift from an open-access to an IFQ fishery has decreased harvest of immature fish and improved the chance that individual fish will reproduce at least once. Spawning potential of sablefish, expressed as spawning biomass per recruit, increased 9% from the derby fishery (1990-1994) to the IFQ fishery (1995-1998) (Sigler and Lunsford 2001).

Fishery-specific effects on EFH non-living substrate:

The primary fishery for sablefish is with longline gear. While it is possible that longlines could move small boulders it is unlikely fishing would persist where this would often occur. Relative to the effect on living structures and relative to the effect by bottom tending mobile gear, a significant effect of longlines on bedrock, cobbles, or sand is not easily envisioned.

Data gaps and research priorities

There is little information on early life history of sablefish and recruitment processes. A better understanding of juvenile distribution, habitat utilization, and species interactions would improve understanding of the processes that determine the productivity of the stock. Better estimation of recruitment and year class strength would improve assessment and management of the sablefish population. Improved fishery observer coverage in the Bering Sea and Aleutian Islands would provide additional data to monitor the emerging pot fishery in these areas and would improve the fishery catch rate analyses.

Future sablefish research is going to focus on several directions:

1) A sablefish data/modeling workshop was held in February 2010. Research prioritized during this workshop which we hope to pursue include:.
    a. Explore GLMs for analyzing fishery catch rates and survey data
    b. Evaluate the use of length and age data from the same survey and year
    c. Investigate the inclusion of trawl survey age data
    d. Investigate the inclusion of longline survey gully ages and abundance data
    e. Explore the use of unsexed Japanese longline and trawl length data
    f. Explore the use of environmental data to aid in determining recruitment
    g. Explore the inclusion of different sources of sex-ratio data
    h. Implement the use of migration rate data in the assessment

2) Improve knowledge of sperm whale and killer whale depredation and continue to quantify depredation effects on survey catch rates and fishery catch rates.
3) Account for all sablefish removals in order to be compliant with Annual Catch Limit (ACL) requirements. This includes accounting for all catch and removals due to whale depredation. Additionally, methods to incorporate these removals in the model and stock assessment will be explored.
4) An integrated Gulf of Alaska Ecosystem project funded by the North Pacific Research Board is underway and is looking at recruitment processes of major groundfish including sablefish. We hope to work closely with this project to help understand sablefish recruitment dynamics.
5) We hope to develop a sablefish migration model which will help in examining spatially explicit characteristics of the Alaska-wide sablefish model.

Literature Cited

Bailey, K. M. 2000. Shifting control of recruitment of walleye pollock Theragra chalcogramma after a major climatic and ecosystem change. Marine Ecology Progress Series, 198, 215–224.

Bracken, B. 1983. Sablefish migration in the Gulf of Alaska based on tag recoveries. Proceedings of the International Sablefish Symposium. Alaska Sea Grant Report 83-8.

Crecco, V. and W. J. Overholtz. 1990. Causes of density-dependent catchability for Georges Bank haddock *Melanogrammus aeglefinus*. Can. J. Fish. Aquat. Sci. 47: 385-394.

Dressel, S. C. 2009. 2006 Northern Southeast Inside sablefish stock assessment and 2007 forecast and quota. Alaska Department of Fish and Game, Fishery Data Series No. 09-50, Anchorage.

Fournier, D. and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aq. Sci. 39: 1195-1207.

Fujioka, J. T., J. Heifetz, and M. F. Sigler. 1997. Choosing a harvest strategy for sablefish, *Anoplopoma fimbria*, based on uncertain lif-history strategies. *In* M. Saunders and J. Wilkins (eds.). Proceeding fo the International Symposium on the Biology and Management of Sablefish. pp. 247-251. NOAA Tech. Rep. 130.

Funk, F. and B. E. Bracken. 1984. Status of the Gulf of Alaska sablefish (*Anoplopoma fimbria*) resource in 1983. Alaska Dept. Fish Game., Info. Leafl. 235, 55 p.

Goodman, D., M. Mangel, G. Parkes, T.J. Quinn II, V. Restrepo, T. Smith, and K. Stokes. 2002. Scientific Review of the Harvest Strategy Currently Used in the BSAI and GOA Groundfish Fishery Management Plans. Draft report. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Grover, J. J. and B. L. Olla. 1990. Food habits of larval sablefish Anoplopoma fimbria from the Bering Sea. Fish. Bull. 88: 811-814.

Hanselman, D. H., J. Fujioka, C. Lunsford, and C. Rodgveller. 2009. Alaskan Sablefish. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2010. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D. H., C. Lunsford, J. Fujioka, and C. Rodgveller. 2007. Alaskan Sablefish. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2008. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D.H., J. Heifetz, J.T. Fujioka, and J.N. Ianelli. 2005a. Gulf of Alaska Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska. pp. 525-578. North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, AK 99510.

Hanselman, D.H., C.R. Lunsford, M.F. Sigler, and J.T. Fujioka. 2005b. Alaska sablefish assessment for 2006. *In* Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, AK 99510.

Heifetz, J., D. Anderl, N.E. Maloney, and T.L. Rutecki. 1999. Age validation and analysis of ageing error from marked and recaptured sablefish, *Anoplopoma fimbria*. Fish. Bull. 97: 256-263

Heifetz, J. and J. T. Fujioka. 1991. Movement dynamics of tagged sablefish in the northeastern Pacific Ocean. Fish. Res., 11: 355-374.

Heifetz, J., J. T. Fujioka, and T. J. Quinn II. 1997. Geographic apportionment of sablefish, *Anoplopoma fimbria*, harvest in the northeastern Pacific Ocean. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 229-238. NOAA Tech. Rep. 130.

Hiatt, T. 2009. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Island area: Economic status of the groundfish fisheries off Alaska, 2009. Available North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, Alaska 99510.

Hill, P. S., J. L. Laake, and E. Mitchell. 1999. Results of a pilot program to document interactions between sperm whales and longline vessels in Alaska waters. NOAA Tech. Memo. NMFS-AFSC-108. 42 p.

Hollowed, A.B. and W.S. Wooster. 1992. Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. ICES Mar. Sci. Symp. 195, 433-444.

Hunt, G. L., P. Stabeno, G. Walters, E. Sinclair, R.D. Brodeur, J.M. Napp and N. Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Res. 49: 5821-5853.

Hunter, J. R., B. J. Macewicz, and C. A. Kimbrell. 1989. Fecundity and other aspects of reproduction in sablefish, Anoplopoma fimbria, in central California waters. CalCOFI Rep. 30: 61-72.

Johnson, Scott L. and Terrance J. Quinn II. 1988. Catch-Age Analysis with Auxiliary Information of sablefish in the Gulf of Alaska. Contract report to National Marine Fisheries Service, Auke Bay, Alaska. 79 pp. Center for Fisheries and Ocean Sciences, University of Alaska, Juneau, Alaska.

Kawakami, T. 1980. A review of sperm whale food. Sci. Rep. Whales Res. Inst. 32: 199-218.

Kimura, D. K. 1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47: 2364-2374.

Kimura, D. K. and J. J. Lyons. 1991. Between-reader bias and variability in the age-determination process. Fish. Bull. 89: 53-60.

Kimura, D. K., A. M. Shimada, and S. A. Lowe. 1993. Estimating von Bertalanffy growth parameters of sablefish, *Anoplopoma fimbria*, and Pacific cod Gadus macrocephalus using tag-recapture data. Fish. Bull. 91: 271-280.

Kimura, D. K., A. M. Shimada, and F. R. Shaw. 1998. Stock structure and movement of tagged sablefish, *Anoplopoma fimbria*, in offshore northeast Pacific waters and the effects of El Niño-Southern Oscillation on migration and growth. Fish. Bull. 96: 462-481.

Kimura, D. K., and H. H. Zenger. 1997. Standardizing sablefish (*Anoplopoma fimbria*) longline survey abundance indices by modeling the log-ratio of paired comparative fishing cpues. ICES J. Mar. Sci. 54:48-59.

Kinoshita, R. K., A. Greig, and J. M. Terry. 1995. Economic status of the groundfish fisheries off Alaska, 1995. Available North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, Alaska 99510.

Krieger, K. J. 1997. Sablefish, *Anoplopoma fimbria*, observed from a manned submersible. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 115-121. NOAA Tech. Rep. 130.

Laidig, T. E., P. B. Adams, and W. M. Samiere. 1997. Feeding habits of sablefish, *Anoplopoma fimbria*, off the coast of Oregon and California. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 65-80. NOAA Tech.

Rep. 130.

Langley, A.D. and M. Maunder. 2009. Stock assessment of TRE 7. New Zealand Fisheries Assessment Report 2009/49. 42p.

Low, L. L., G. K. Tanonaka, and H. H. Shippen. 1976. Sablefish of the Northeastern Pacific Ocean and Bering Sea. Northwest Fisheries Science Center Processed Report. 115 p.

Mace, P. M. and M. P. Sissenwine. 1993. How much spawning per recruit is enough? In S. J. Smith, J. J. Hunt, and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120: 101-118.

Maloney, N. E. and J. Heifetz. 1997. Movements of tagged sablefish, *Anoplopoma fimbria*, released in the eastern Gulf of Alaska. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 115-121. NOAA Tech. Rep. 130.

Maloney, N. E., and M. F. Sigler. 2008. Age-specific movement patterns of sablefish (Anoplopoma fimbria) in Alaska. Fish. Bull. 106: 305-316.

Mason, J. C. R. J. Beamish, and G. A. McFarlane. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (Anoplopoma fimbria) off the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 40: 2126-2134.

McDevitt, S. A. 1986. A summary of sablefish catches in the Northeast Pacific Ocean, 1956-84. NOAA Tech. Memo. NMFS F/NWC-101. 34 p.

McDevitt, S. A. 1990. Growth analysis of sablefish from mark-recapture data from the northeast Pacific. M.S. University of Washington. 87 p.

McFarlane, G.A. and R.J. Beamish. 1983. Preliminary observations on the juvenile biology of sablefish (Anoplopoma fimbria) in waters off the west-coast of Canada, p. 119-136. *In* Proceedings of the International Sablefish Symposium. Alaska Sea Grant Rep. 83-8.

McFarlane, G.A. and R.J. Beamish. 1992. Climatic influence linking copepod production with strong year-class in sablefish, Anoplopoma fimbria. Can. J. Fish. Aquat. Sci. 49: 743– 753.

McFarlane, G. A. and W. D. Nagata. 1988. Overview of sablefish mariculture and its potential for industry. Alaska Sea Grant Report 88-4. PP. 105-120. University of Alaska Fairbanks, Fairbanks, Alaska 99775.

Meinhold, R. J. and N. D. Singpurwalla, 1983. Understanding the Kalman Filter. The American Statistician, May 1983, Vol 37, No. 2, pp. 123-127.

National Marine Fisheries Service. 2005. Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska. http://www.fakr.noaa.gov/habitat/seis/efheis.htm.

National Research Council. 1998. Improving fish stock assessments. National Academy Press, Washington, DC, 177 pp

Orlov, A. M., and I. A. Biryukov. 2005. First report of sablefish in spawning condition off the coast of Kamchatka and the Kuril Islands. ICES J. Mar. Sci. 62: 1016-1020.

Otter Research. 2000. An introduction to AD model builder 4. Available Box 265, Station A, Nanaimo, BC V9R 5K9 Canada. http://otter-rsch.ca/adm.zip

Rose, G. A. and D. W. Kulka. 1999. Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (*Gadus morhua*) declined. Can. J. Fish. Aquat. Sci. 56 (Suppl. 1): 118-127.

Rutecki, T. L., M. F. Sigler and H. H. Zenger Jr. 1997. Data report: National Marine Fisheries Service longline surveys, 1991-97.

Rutecki, T.L. and E.R. Varosi. 1997. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in Southeast Alaska. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 45-54. NOAA Tech. Rep. 130.

Sasaki, T. 1973. Data on the Japanese blackcod fisheries in the North Pacific--I. Development and history of the Japanese blackcod fisheries through 1972. Unpubl. Rep., 22 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Sasaki, T. 1978. Recalculation of longline effort and stock assessment of blackcod in the North Pacific. Unpubl. Rep., 23 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Sasaki, T. 1984. Condition of sablefish stock in the eastern Bering Sea, Aleutian Islands region, and the Gulf of Alaska in 1983. Unpubl. Rep., 18 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Sasaki, T. 1985. Studies on the sablefish resources in the North Pacific Ocean. Bulletin 22, (1-108), Far Seas Fishery Laboratory. Shimizu, 424, Japan.

Sasaki, T. 1987. Stock assessment of sablefish in the eastern Bering Sea, Aleutian Islands region, and the Gulf of Alaska in 1987. Unpubl. Rep., 33 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Saunders, M. W., B. M. Leaman, V. Haist, R. Hilborn, and G. A. McFarlane. 1996. Sablefish stock assessment for 1996 and recommended yield options for 1997. Unpublished report available Department of Fisheries and Oceans, Biological Sciences Branch, Pacific Biological Station, Nanaimo, British Columbia, V9R 5K6.

Scarsbrook, J. R., G. A. McFarlane, and W. Shaw. 1988. Effectiveness of experimental escape mechanisms in sablefish traps. North Amer. J. Fish. Manage. 8: 158-161.

Shotwell, K. 2007. Distribution of juvenile sablefish in the Gulf of Alaska and Bering Sea/Aleutian Islands as shown by integrating NMFS surveys. Unpubl. Report. Auke Bay Laboratory, Juneau, Alaska.

Sigler, M.F., C.R. Lunsford, J.T. Fujioka, and S.A. Lowe. 2002. Alaska sablefish assessment for 2003. *In* Stock assessment and fishery evaluation report for the groundfish fisheries of the Bering Sea and Aleutian Islands. pp. 449-514. North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, AK 99510.

Sigler, M. F. 2000. Abundance estimation and capture of sablefish, *Anoplopoma fimbria*, by longline gear. Can. J. Fish. Aquat. Sci. 57: 1270-1283.

Sigler, M. F. 1999. Abundance estimation of Alaskan sablefish with an age-structured population model. Fish. Bull. 97: 591-603.

Sigler, M. F. and J. T. Fujioka. 1988. Evaluation of variability in sablefish, *Anoplopoma fimbria*, abundance indices in the Gulf of Alaska using the bootstrap method. Fish. Bull. 86: 445-452.

Sigler, M. F., and J. T. Fujioka. 1993. A comparion of policies for harvesting sablefish (*Anoplopma fimbria*) in the Gulf of Alaska. *In* G. Kruse, D. M. Eggers, R. J. Marasco, C. Pautzke, and T. J. Quinn II (eds.), Proceedings of the International Symposium on Management Strategies of Exploited Fish Populations. Univ. Alaska, Fairbanks, Alaska Sea Grant Rep. 93 102.

Sigler, M. F., S. A. Lowe, and C. Kastelle. 1997. Area and depth differences in the age-length relationship of sablefish *Anoplopoma fimbria* in the Gulf of Alaska. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 55-63. NOAA Tech. Rep. 130.

Sigler, M. F. and C. R. Lunsford. 2001. Effects of individual quotas on catching efficiency and spawning potential in the Alaska sablefish fishery. Can. J. Fish. Aquat. Sci. 58: 1300-1312.

Sigler, M.F., C.R. Lunsford, J.M. Straley, and J.B. Liddle. 2007. Sperm whale depredation of sablefish longline gear in the northeast Pacific Ocean. Mar. Mammal Sci. doi:10.1111/j.1748-7692.2007.00149.

Sigler, M. F., T. L. Rutecki, D. L. Courtney, J. F. Karinen, and M.-S.Yang. 2001. Young-of-the-year sablefish abundance, growth, and diet. Alaska Fish. Res. Bull. 8(1): 57-70.

Sigler, M. F. and H. H. Zenger. 1989. Assessment of Gulf of Alaska sablefish and other groundfish based on the domestic longline survey, 1987. NOAA Tech. Memo. NMFS F/NWC-169. 54 p.

Skud, B. E., and J. M. Hamley. 1978. Factors affecting longline catch and effort: I. General review. II. Hook-spacing. III. Bait loss and competition. Intnl. Pac. Halibut Comm. Sci. Rep. No. 64.

Soderlund, E., E. Anderson, C. L. Dykstra, T. Geernaert, and A. M. Ranta. 2009. 2008 standardized stock assessment survey. Int. Pac. Comm. Report of Assessment and Research Activities 2008 469-496.

Straley, J., T. O'Connell, S. Mesnick, L. Behnken, and J. Liddle. 2005. Sperm Whale and Longline Fisheries Interactions in the Gulf of Alaska. North Pacific Research Board R0309 Final Report, 15 p.

Sturdevant, M. V., M. F. Sigler, and J. A. Orsi. 2009. Sablefish predation on juvenile Pacific salmon in the coastal marine waters off southeast Alaska in 1999. Trans. Amer. Fish. Soc. 138: 675-691.

Tanasichuk, R. W. 1997. Diet of sablefish, *Anoplopoma fimbria*, from the southwest coast of Vancouver Island. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 93-98. NOAA Tech. Rep. 130.

Thompson, G. G. 2004. Estimation of Pacific Cod Biomass Distributions Based on Alternative Weightings of Trawl Survey Estimates. Appendix to Nov. 2004 Pacific Cod Stock Assessment and Fishery Evaluation report.

TSC 2008. Report of the Technical Subcommittee of the Canada-United States Groundfish Committee. Forty-Ninth Annual Meeting of the TSC. May 6-7, 2008. Seattle, Washington.

Wing, B. L. 1985. Salmon stomach contents from the Alaska Troll Logbook Program, 1977-84. NOAA Tech. Memo. NMFS F/NWC-91. 41 p.

Wing, B. L. 1997. Distribution of sablefish, *Anoplopoma fimbria*, larvae in the Eastern Gulf of Alaska. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 13-26. NOAA Tech. Rep. 130.

Wolotira, R. J. J., T. M. Sample, S. F. Noel, and C. R. Iten. 1993. Geographic and bathymetric distributions for many commercially important fishes and shellfishes off the west coast of North America, based on research survey and commercial catch data, 1912-1984. NOAA Tech. Memo. NMFS-AFSC-6. 184 pp.

Yang, M-S. and M. W. Nelson. 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. NOAA Tech. Memo. NMFS-AFSC-112. 174 p.

Yang, M-S. K. Dodd, R. Hibpshman, and A. Whitehouse. 2006. Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001. NOAA Tech. Memo. NMFS-AFSC-164. 199 p.

Zenger, H. H., Jr., M. F. Sigler, and E. R. Varosi. 1994. Assessment of Gulf of Alaska sablefish and other groundfish species based on the 1988 National Marine Fisheries Service longline survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-39, 55 p.

Tables

Table 3.1a. Alaska sablefish catch (t). The values include landed catch and discard estimates. Discards were estimated for U.S. fisheries before 1993 by multiplying reported catch by 2.9% for fixed gear and 26.9% for trawl gear (1994-1997 averages) because discard estimates were unavailable. Eastern includes both West Yakutat and East Yakutat / Southeast.

		BY AREA								BY GEAR	
Year	Grand total	Bering Sea	Aleu-tians	Western	Central	Eastern	West Yakutat	East Yakutat/ SEO.	Un-known	Fixed	Trawl
1956	773	0	0	0	0	773			0	773	0
1957	2,059	0	0	0	0	2,059			0	2,059	0
1958	477	6	0	0	0	471			0	477	0
1959	910	289	0	0	0	621			0	910	0
1960	3,054	1,861	0	0	0	1,193			0	3,054	0
1961	16,078	15,627	0	0	0	451			0	16,078	0
1962	26,379	25,989	0	0	0	390			0	26,379	0
1963	16,901	13,706	664	266	1,324	941			0	10,557	6,344
1964	7,273	3,545	1,541	92	955	1,140			0	3,316	3,957
1965	8,733	4,838	1,249	764	1,449	433			0	925	7,808
1966	15,583	9,505	1,341	1,093	2,632	1,012			0	3,760	11,823
1967	19,196	11,698	1,652	523	1,955	3,368			0	3,852	15,344
1968	30,940	14,374	1,673	297	1,658	12,938			0	11,182	19,758
1969	36,831	16,009	1,673	836	4,214	14,099			0	15,439	21,392
1970	37,858	11,737	1,248	1,566	6,703	16,604			0	22,729	15,129
1971	43,468	15,106	2,936	2,047	6,996	16,382			0	22,905	20,563
1972	53,080	12,758	3,531	3,857	11,599	21,320			15	28,538	24,542
1973	36,926	5,957	2,902	3,962	9,629	14,439			37	23,211	13,715
1974	34,545	4,258	2,477	4,207	7,590	16,006			7	25,466	9,079
1975	29,979	2,766	1,747	4,240	6,566	14,659			1	23,333	6,646
1976	31,684	2,923	1,659	4,837	6,479	15,782			4	25,397	6,287
1977	21,404	2,718	1,897	2,968	4,270	9,543			8	18,859	2,545
1978	10,394	1,193	821	1,419	3,090	3,870			1	9,158	1,236
1979	11,814	1,376	782	999	3,189	5,391			76	10,350	1,463
1980	10,444	2,205	275	1,450	3,027	3,461			26	8,396	2,048
1981	12,604	2,605	533	1,595	3,425	4,425			22	10,994	1,610
1982	12,048	3,238	964	1,489	2,885	3,457			15	10,204	1,844
1983	11,715	2,712	684	1,496	2,970	3,818			35	10,155	1,560
1984	14,109	3,336	1,061	1,326	3,463	4,618			305	10,292	3,817
1985	14,465	2,454	1,551	2,152	4,209	4,098			0	13,007	1,457
1986	28,892	4,184	3,285	4,067	9,105	8,175			75	21,576	7,316
1987	35,163	4,904	4,112	4,141	11,505	10,500			2	27,595	7,568
1988	38,406	4,006	3,616	3,789	14,505	12,473			18	29,282	9,124

Table 3.1a. Alaska sablefish catch (t). The values include landed catch and discard estimates. Discards were estimated for U.S. fisheries before 1993 by multiplying reported catch by 2.9% for fixed gear and 26.9% for trawl gear (1994-1997 averages) because discard estimates were unavailable. Eastern includes both West Yakutat and East Yakutat / Southeast.

		BY AREA								BY GEAR	
Year	Grand total	Bering Sea	Aleu-tians	Western	Central	Eastern	West Yakutat	East Yakutat/ SEO.	Un-known	Fixed	Trawl
1989	34,829	1,516	3,704	4,533	13,224	11,852			0	27,509	7,320
1990	32,115	2,606	2,412	2,251	13,786	11,030			30	26,598	5,518
1991	27,073	1,318	2,168	1,821	11,662	10,014			89	23,124	3,950
1992	24,932	586	1,497	2,401	11,135	9,171			142	21,614	3,318
1993	25,433	668	2,080	739	11,971	9,975	4,619	5,356	0	22,912	2,521
1994	23,760	694	1,726	555	9,495	11,290	4,497	6,793	0	20,797	2,963
1995	20,954	990	1,333	1,747	7,673	9,211	3,866	5,345	0	18,342	2,612
1996	17,577	697	905	1,648	6,772	7,555	2,899	4,656	0	15,390	2,187
1997	14,922	728	929	1,374	6,237	5,653	1,928	3,725	0	13,287	1,635
1998	14,108	614	734	1,435	5,877	5,448	1,969	3,479	0	12,644	1,464
1999	13,575	677	671	1,487	5,873	4,867	1,709	3,158	0	11,590	1,985
2000	15,919	828	1,314	1,587	6,172	6,018	2,066	3,952	0	13,906	2,013
2001	14,097	878	1,092	1,589	5,518	5,020	1,737	3,283	0	10,863	1,783
2002	14,789	1,166	1,139	1,863	6,180	4,441	1,550	2,891	0	10,852	2,261
2003	16,371	927	1,009	2,118	7,088	5,228	1,880	3,347	0	14,286	2,085
2004	17,720	1,038	955	2,170	7,457	6,099	2,299	3,800	0	16,063	1,656
2005	16,574	1,064	1,481	1,929	6,701	5,399	1,824	3,575	0	15,018	1,556
2006	15,339	1,037	1,132	2,140	5,870	5,161	1,865	3,296	0	14,097	1,242
2007	15,011	1,173	1,149	2,064	5,610	5,015	1,772	3,243	0	13,776	1,235
2008	14,609	1,125	893.528	1,670	5,547	5,373	2,055	3,318	0	13,486	1,122
2009	13,206	891	1,096	1,445	5,022	4,752	1,804	2,948	0	12,150	1,057

Table 3.1b. Retained Alaska sablefish catch (t) in the Aleutian Islands and the Bering Sea by gear type. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages.

Aleutian Islands				
Year	Pot	Trawl	Longline	Total
1991-1999	6	73	1,210	1,289
2000	111	39	925	1,074
2001	105	39	975	1,119
2002	316	42	761	1,120
2003	384	32	539	955
2004	688	115	679	1,481
2005	458	60	614	1,132
2006	632	40	476	1,149
2007	177	76	641	894
2008	78	75	943	1,096
2009	111	39	925	1,074
Bering Sea				
1991-1999	5	189	539	733
2000	40	284	418	742
2001	106	353	405	864
2002	382	295	467	1,144
2003	355	231	413	999
2004	432	293	312	1,038
2005	590	273	202	1,064
2006	584	84	368	1,037
2007	879	92	203	1,173
2008	751	183	191	1,125
2009	557	93	240	891

Table 3.2. Discarded catches of sablefish (amount [t], percent of total catch, total catch [t]) by gear (H&L=hook & line, Pot, Trwl=trawl), FMP area for 1994-2009. Average values are shown for 1994-2003. Annual values for 1994-2003 are shown in previous sablefish SAFE chapters.

		BSAI			GOA			Combined		
YEAR	Gear	Discard	% Discard	Catch	Discard	% Discard	Catch	Discard	% Discard	Catch
1994 -	H&L	122	10%	1,281	403	3%	13,358	525	4%	14,639
2003	Pot	7	2%	508				7	2%	508
Average	Trwl	52	17%	314	773	35%	2,232	825	32%	2,546
	Total	181	9%	2,103	1,177	8%	15,590	1,357	8%	17,693
2004	H&L	29	3.4%	852	461	3.2%	14,346	489	3.2%	15,197
	Pot	18	2.2%	817	-	0.0%	-	18	2.2%	817
	Trwl	86	26.5%	325	206	15.5%	1,332	292	17.7%	1,656
	Total	133	6.7%	1,993	667	4.3%	15,677	800	4.5%	17,670
2005	H&L	28	3.2%	880	255	2.0%	12,860	283	2.1%	13,741
	Pot	33	2.6%	1,277	-	0.0%	-	33	2.6%	1,277
	Trwl	32	8.2%	388	181	15.5%	1,169	213	13.7%	1,556
	Total	93	3.7%	2,545	436	3.1%	14,029	529	3.2%	16,574
2006	H&L	46	4.7%	982	286	2.4%	12,073	332	2.5%	13,055
	Pot	6	0.6%	1,042	-	0.0%	-	6	0.6%	1,042
	Trwl	10	7.2%	144	269	24.5%	1,098	280	22.5%	1,242
	Total	62	2.9%	2,168	556	4.2%	13,171	618	4.0%	15,339
2007	H&L	16	2.3%	679	242	2.1%	11,586	258	2.1%	12,265
	Pot	46	3.0%	1,511	-	0.0%	-	46	3.0%	1,511
	Trwl	9	6.5%	132	175	15.9%	1,103	184	14.9%	1,235
	Total	70	3.0%	2,322	417	3.3%	12,689	488	3.2%	15,011
2008	H&L	90	10.9%	832	737	6.3%	11,727	827	6.6%	12,558
	Pot	5	0.6%	928	-	0.0%	-	5	0.6%	928
	Trwl	1	0.4%	259	72	8.4%	864	73	6.5%	1,122
	Total	97	4.8%	2,018	809	6.4%	12,590	906	6.2%	14,609
2009	H&L	18	1.5%	1,183	739	7.2%	10,331	756	6.6%	11,515
	Pot	2	0.2%	635	-	0.0%	-	2	0.2%	635
	Trwl	6	3.7%	168	81	9.1%	889	87	8.3%	1,057
	Total	26	1.3%	1,986	820	7.3%	11,220	845	6.4%	13,206
2004 -	H&L	38	4.2%	901	453	3.7%	12,154	491	3.8%	13,055
2009	Pot	18	1.8%	1,035	-	0.0%	-	18	1.8%	1,035
Average	Trwl	24	10.2%	236	164	15.3%	1,076	188	14.4%	1,312
	Total	80	3.7%	2,172	617	4.7%	13,229	697	4.5%	15,402

Table 3.3. Sample sizes for age and length data collected from Alaska sablefish. Japanese fishery data from Sasaki (1985), U.S. fishery data from the observer databases, and longline survey data from longline survey databases. All fish were sexed before measurement, except for the Japanese fishery data.

	LENGTH							AGE		
	U.S. NMFS trawl survey (GOA)	Japanese fishery		U.S. fishery		Cooperative longline survey	Domestic longline survey	Cooperative longline survey	Domestic longline survey	U.S. longline fishery
Year		Trawl	Longline	Trawl	Longline					
1963			30,562							
1964		3,337	11,377							
1965		6,267	9,631							
1966		27,459	13,802							
1967		31,868	12,700							
1968		17,727								
1969		3,843								
1970		3,456								
1971		5,848	19,653							
1972		1,560	8,217							
1973		1,678	16,332							
1974			3,330							
1975										
1976			7,704							
1977			1,079							
1978			9,985							
1979			1,292			19,349				
1980			1,944			40,949				
1981						34,699		1,146		
1982						65,092				
1983						66,517		889		
1984	8,590					100,029				
1985						125,129		1,294		
1986						128,718				
1987	3,574					102,639		1,057		
1988						114,239				
1989						115,067		655		
1990	2,778			1,229	33,822	78,794	101,530			
1991				721	29,615	69,653	95,364	902		
1992				0	21,000	79,210	104,786			
1993	3,911			468	23,884	80,596	94,699	1,178		
1994				89	13,614	74,153	70,431			
1995				87	18,174		80,826			
1996	2,890			239	15,213		72,247		1,175	
1997				0	20,311		82,783		1,211	
1998				35	8,900		57,773		1,183	
1999	2,789			1,268	26,662		79,451		1,188	1,145
2000				472	29,240		62,513		1,236	1,152
2001	*partial			473	30,362		83,726		1,214	1,023
2002				526	35,380		75,937		1,136	1,061
2003	2,913			503	37,386		77,678		1,198	1,128
2004				694	31,746		82,767		1,185	1,029
2005	2,884			2,306	33,914		74,433		1,187	1,040
2006				721	30,594		78,625		1,178	1,154
2007	2,190			860	28,650		73,480		1,174	1,115
2008				2,018	23,893		71,661		1,182	1,146
2009	2,189			1,837	25,945		67,978		1,198	1,126
2010							75,010			

Table 3.4. Sablefish abundance index values (1,000's) for Alaska (200-1,000 m) including deep gully habitat, from the Japan-U.S. Cooperative Longline Survey, Domestic Longline Survey, and Japanese and U.S. longline fisheries. Relative population number equals CPUE in numbers weighted by respective strata areas. Relative population weight equals CPUE measured in weight multiplied by strata areas. Indices were extrapolated for survey areas not sampled every year, including Aleutian Islands 1979, 1995, 1997, 1999, 2001, 2003, 2005, and 2007 and Bering Sea 1979-1981, 1995, 1996, 1998, 2000, 2002, 2004, 2006, 2008, and 2009. NMFS trawl survey estimates are from the Gulf of Alaska at depths <500 m.

	RELATIVE POPULATION NUMBER		RELATIVE POPULATION WEIGHT/BIOMASS				
Year	**Coop. longline survey**	**Dom. longline survey**	**Jap. longline fishery**	**Coop. longline survey**	**Dom. longline survey**	**U.S. fishery**	**NMFS Trawl survey**
1964			1,452				
1965			1,806				
1966			2,462				
1967			2,855				
1968			2,336				
1969			2,443				
1970			2,912				
1971			2,401				
1972			2,247				
1973			2,318				
1974			2,295				
1975			1,953				
1976			1,780				
1977			1,511				
1978			942				
1979	413		809	1,075			
1980	388		1,040	968			
1981	460		1,343	1,153			
1982	613			1,572			
1983	621			1,595			
1984	685			1,822			294
1985	903			2,569			
1986	838			2,456			
1987	667			2,068			271
1988	707			2,088			
1989	661			2,178			
1990	450	649		1,454	2,141	1,201	214
1991	386	593		1,321	2,071	1,066	
1992	402	511		1,390	1,758	908	
1993	395	563		1,318	1,894	904	250
1994	366	489		1,288	1,882	822	
1995		501			1,803	1,243	
1996		520			2,017	1,201	145
1997		491			1,764	1,341	
1998		466			1,662	1,130	
1999		511			1,740	1,316	104
2000		461			1,597	1,139	
2001		533			1,798	1,110	238
2002		559			1,916	1,152	
2003		532			1,759	1,218	189
2004		544			1,738	1,357	
2005		533			1,695	1,304	179
2006		576			1,848	1,206	
2007		500			1,584	1,270	111
2008		472			1,550	1,364	
2009		482			1,580	1,130	107
2010		545			1,778		

Table 3.5. Average catch rate (pounds/hook) for fishery data by year and region. SE = standard error, CV = coefficient of variation. The standard error is not available when vessel sample size equals one.

Observer Fishery Data

Aleutian Islands-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.53	0.05	0.10	193	8
1991	0.50	0.03	0.07	246	8
1992	0.40	0.06	0.15	131	8
1993	0.28	0.04	0.14	308	12
1994	0.29	0.05	0.18	138	13
1995	0.30	0.04	0.14	208	14
1996	0.23	0.03	0.12	204	17
1997	0.35	0.07	0.20	117	9
1998	0.29	0.05	0.17	75	12
1999	0.38	0.07	0.17	305	14
2000	0.29	0.03	0.11	313	15
2001	0.26	0.04	0.15	162	9
2002	0.32	0.03	0.11	245	10
2003	0.26	0.04	0.17	170	10
2004	0.21	0.04	0.21	138	7
2005	0.15	0.05	0.34	23	6
2006	0.23	0.04	0.16	205	11
2007	0.35	0.10	0.29	198	7
2008	0.37	0.04	0.10	247	6
2009	0.29	0.05	0.22	335	10

Bering Sea-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.72	0.22	0.15	42	8
1991	0.28	0.11	0.20	30	7
1992	0.25	0.21	0.43	7	4
1993	0.09	0.07	0.36	4	3
1994	0.35	0.31	0.45	2	2
1995	0.41	0.14	0.17	38	10
1996	0.63	0.38	0.30	35	15
1997				0	0
1998	0.17	0.06	0.18	28	9
1999	0.29	0.18	0.32	27	10
2000	0.28	0.18	0.31	21	10
2001	0.31	0.05	0.07	18	10
2002	0.10	0.05	0.22	8	4
2003	0.16	0.09	0.29	8	2
2004	0.17	0.11	0.31	9	4
2005	0.23	0.07	0.16	9	6
2006	0.17	0.07	0.21	68	15
2007	0.28	0.05	0.18	34	8
2008	0.38	0.22	0.58	12	5
2009	0.14	0.04	0.31	24	5

Western Gulf-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.64	0.28	0.22	178	7
1991	0.44	0.11	0.13	193	16
1992	0.38	0.10	0.14	260	12
1993	0.35	0.06	0.09	106	12
1994	0.32	0.07	0.10	52	5
1995	0.51	0.09	0.09	432	22
1996	0.57	0.11	0.10	269	20
1997	0.50	0.10	0.10	349	20
1998	0.50	0.07	0.07	351	18
1999	0.53	0.13	0.12	244	14
2000	0.49	0.13	0.13	185	12
2001	0.50	0.10	0.10	273	16
2002	0.51	0.10	0.09	348	15
2003	0.45	0.09	0.10	387	16
2004	0.47	0.16	0.17	162	10
2005	0.58	0.07	0.13	447	13
2006	0.42	0.04	0.13	306	15
2007	0.37	0.04	0.11	255	12
2008	0.46	0.07	0.16	255	11
2009	0.44	0.09	0.21	208	11

Central Gulf-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.54	0.08	0.07	653	32
1991	0.62	0.11	0.09	303	24
1992	0.59	0.11	0.09	335	19
1993	0.60	0.08	0.07	647	32
1994	0.65	0.12	0.09	238	15
1995	0.90	0.14	0.08	457	41
1996	1.04	0.14	0.07	441	45
1997	1.07	0.17	0.08	377	41
1998	0.90	0.11	0.06	345	32
1999	0.87	0.17	0.10	269	28
2000	0.93	0.10	0.06	319	30
2001	0.70	0.08	0.06	347	31
2002	0.84	0.13	0.08	374	29
2003	0.99	0.14	0.07	363	34
2004	1.08	0.19	0.09	327	29
2005	0.89	0.06	0.07	518	32
2006	0.82	0.06	0.08	361	33
2007	0.93	0.06	0.07	289	30
2008	0.84	0.07	0.08	207	27
2009	0.77	0.06	0.07	320	33

Table 3.5 (cont.)

Observer Fishery Data											
West Yakutat-Observer						East Yakutat/SE-Observer					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1990	0.95	0.47	0.25	75	9	1990				0	0
1991	0.65	0.14	0.10	164	12	1991	0.52	0.37	0.71	17	2
1992	0.64	0.35	0.27	98	6	1992	0.87			20	1
1993	0.71	0.15	0.10	241	12	1993	1.02	0.19	0.19	26	2
1994	0.65	0.35	0.27	81	8	1994	0.36			5	1
1995	1.02	0.20	0.10	158	21	1995	1.45	0.20	0.14	101	19
1996	0.97	0.15	0.07	223	28	1996	1.20	0.11	0.09	137	24
1997	1.16	0.22	0.09	126	20	1997	1.10	0.14	0.13	84	17
1998	1.21	0.20	0.08	145	23	1998	1.27	0.12	0.10	140	25
1999	1.20	0.31	0.13	110	19	1999	0.94	0.12	0.13	85	11
2000	1.28	0.20	0.08	193	32	2000	0.84	0.13	0.16	81	14
2001	1.03	0.14	0.07	184	26	2001	0.84	0.08	0.09	110	14
2002	1.32	0.26	0.10	155	23	2002	1.20	0.23	0.19	121	14
2003	1.36	0.20	0.07	216	27	2003	1.29	0.13	0.10	113	19
2004	1.23	0.19	0.08	210	24	2004	1.08	0.10	0.09	135	17
2005	1.32	0.09	0.07	352	24	2005	1.18	0.13	0.11	181	16
2006	0.96	0.10	0.10	257	30	2006	0.93	0.11	0.11	104	18
2007	1.02	0.11	0.11	208	24	2007	0.92	0.15	0.17	85	16
2008	1.40	0.12	0.08	173	23	2008	1.06	0.13	0.12	103	17
2009	1.34	0.12	0.09	148	23	2009	0.98	0.12	0.12	94	13

Table 3.5 (cont.)

Logbook Fishery Data

Aleutian Islands-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.29	0.09	0.15	167	15
2000	0.24	0.10	0.21	265	16
2001	0.38	0.32	0.41	36	5
2002	0.48	0.37	0.39	33	5
2003	0.36	0.22	0.30	139	10
2004	0.45	0.11	0.25	102	7
2005	0.46	0.15	0.33	109	8
2006	0.51	0.16	0.31	61	5
2007	0.38	0.22	0.58	61	3
2008	0.30	0.03	0.12	119	4
2009	0.23	0.07	0.06	204	7

Bering Sea-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.56	0.16	0.14	291	43
2000	0.21	0.09	0.22	169	23
2001	0.35	0.23	0.33	61	8
2002	0.24	0.30	0.63	5	2
2003	0.24	0.26	0.53	25	6
2004	0.38	0.09	0.24	202	8
2005	0.36	0.07	0.19	86	10
2006	0.38	0.07	0.18	106	9
2007	0.37	0.08	0.21	147	8
2008	0.52	0.20	0.39	94	7
2009	0.25	0.04	0.14	325	18

Western Gulf-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.64	0.12	0.09	245	27
2000	0.60	0.10	0.09	301	32
2001	0.47	0.09	0.10	109	24
2002	0.60	0.16	0.13	78	14
2003	0.39	0.08	0.11	202	24
2004	0.65	0.06	0.09	766	26
2005	0.78	0.08	0.11	571	33
2006	0.69	0.08	0.11	1067	38
2007	0.59	0.06	0.10	891	31
2008	0.71	0.06	0.08	516	29
2009	0.53	0.06	0.11	824	33

Central Gulf-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.80	0.09	0.06	817	60
2000	0.79	0.08	0.05	746	64
2001	0.74	0.12	0.08	395	52
2002	0.83	0.12	0.07	276	41
2003	0.87	0.14	0.08	399	45
2004	1.08	0.05	0.05	1676	80
2005	0.98	0.07	0.07	1154	63
2006	0.87	0.04	0.05	1358	80
2007	0.83	0.04	0.05	1190	69
2008	0.88	0.05	0.06	1039	68
2009	0.95	0.08	0.08	1081	73

West Yakutat-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	1.08	0.16	0.08	233	36
2000	1.04	0.12	0.06	270	42
2001	0.89	0.19	0.11	203	29
2002	0.99	0.14	0.07	148	28
2003	1.26	0.20	0.08	104	23
2004	1.27	0.06	0.05	527	54
2005	1.13	0.05	0.04	1158	70
2006	0.97	0.05	0.06	1306	84
2007	0.97	0.05	0.05	1322	89
2008	0.97	0.05	0.05	1118	74
2009	1.23	0.07	0.06	1077	81

East Yakutat/SE-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.91	0.15	0.08	183	22
2000	0.98	0.15	0.08	190	26
2001	0.98	0.17	0.09	109	21
2002	0.83	0.12	0.07	108	22
2003	1.13	0.19	0.09	117	22
2004	1.19	0.05	0.04	427	55
2005	1.15	0.05	0.05	446	77
2006	1.06	0.04	0.04	860	107
2007	1.13	0.04	0.04	972	122
2008	1.08	0.05	0.05	686	97
2009	1.12	0.05	0.05	620	87

Table 3.6. Sablefish abundance (relative population weight, RPW) from annual sablefish longline surveys (domestic longline survey only) and number of stations where sperm whale (SW) and killer whale (KW) depredation of sablefish catches occurred. Some stations were not sampled all years, indicated by "na". Recording of sperm whale depredation began with the 1998 survey.

Year	Bering			Aleutians			Western		
	RPW	SW	KW	RPW	SW	KW	RPW	SW	KW
1990	na	na	na	Na	na	na	244,164	na	0
1991	na	na	na	Na	na	na	203,357	na	1
1992	na	na	na	Na	na	na	94,874	na	1
1993	na	na	na	Na	na	na	234,169	na	2
1994	na	na	na	Na	na	na	176,820	na	0
1995	na	na	na	Na	na	na	198,247	na	0
1996	na	na	na	186,270	na	1	213,126	na	0
1997	160,300	na	3	Na	na	na	182,189	na	0
1998	na	na	na	271,323	0	1	203,590	0	0
1999	136,313	0	7	na	na	na	192,191	0	0
2000	na	na	na	260,665	0	1	242,707	0	1
2001	248,019	0	4	na	na	na	294,277	0	0
2002	na	na	na	292,425	0	1	256,548	0	4
2003	232,996	0	7	na	na	na	258,996	0	3
2004	na	na	na	267,065	0	0	178,709	0	4
2005	262,385	0	2	na	na	na	267,938	0	4
2006	na	na	na	239,644	0	1	230,841	0	3
2007	305,786	0	7	na	na	na	136,368	0	5
2008	na	na	na	201,300	0	3	171,365	0	2
2009	302,999	0	10	na	na	na	194,172	0	2
2010	na	na	na	165,753	0	3	158,062	0	1

Year	Central			West Yakutat			East Yakutat / Southeast		
	RPW	SW	KW	RPW	SW	KW	RPW	SW	KW
1990	684,738	na	0	268,334	na	0	393,964	na	0
1991	641,693	na	0	287,103	na	0	532,242	na	0
1992	568,474	na	0	316,770	na	0	475,528	na	0
1993	639,161	na	0	304,701	na	0	447,362	na	0
1994	603,940	na	0	275,281	na	0	434,840	na	0
1995	595,903	na	0	245,075	na	0	388,858	na	0
1996	783,763	na	0	248,847	na	0	390,696	na	0
1997	683,294	na	0	216,415	na	0	358,229	na	0
1998	519,781	0	0	178,783	4	0	349,350	0	0
1999	608,225	3	0	183,129	5	0	334,516	4	0
2000	506,368	0	0	158,411	2	0	303,716	2	0
2001	561,168	3	0	129,620	0	0	290,747	2	0
2002	643,363	4	0	171,985	3	0	287,133	2	0
2003	605,417	1	0	146,631	1	0	245,367	2	0
2004	633,717	3	0	175,563	4	0	253,182	6	0
2005	478,685	0	0	131,546	2	0	300,710	8	0
2006	589,642	2	1	192,017	4	0	303,109	2	0
2007	473,217	2	1	169,660	5	0	302,098	6	0
2008	510,094	3	0	133,608	8	0	236,236	10	0
2009	469,323	5	1	141,002	3	0	266,990	2	0
2010	512,132	2	1	233,416	2	0	353,501	4	0

Table 3.7a. Ages that above average year classes became abundant by region (Figure 3.7, relative population number greater than 10,000). “Western” includes the Bering Sea, Aleutian Islands, and western Gulf of Alaska. Age data was not available for the Western areas until 1985. The 1984 year class never was abundant in the Eastern area. The 1995 year class was only moderately abundant in the Central and Eastern areas.

Year class	Western	Central	Eastern
1977	na	4	4
1980-81	5	3	6
1984	5	9	12
1990	6	7	7
1995	4	6	7
1997	4	4	5
2000	4	4	5

Table 3.7b. Years that the above average 1995, 1997, and 2000 year classes became abundant by region RPN>10,000). “Western” includes the Bering Sea, Aleutian Islands, and western Gulf of Alaska. The 1995 year class now is considered average.

Year class	Western	Central	Eastern
1995	1998	2001	2002
1997	2000	2001	2002
2000	2004	2004	2005

Table 3.8. Sablefish fork length (cm), weight (kg), and proportion mature by age and sex (weights from 1996-2004 age-length data).

	Fork length (cm)		Weight (kg)		Fraction mature	
Age	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
2	48.1	46.8	1.0	0.9	0.059	0.006
3	53.1	53.4	1.5	1.5	0.165	0.024
4	56.8	58.8	1.9	2.1	0.343	0.077
5	59.5	63.0	2.2	2.6	0.543	0.198
6	61.6	66.4	2.5	3.1	0.704	0.394
7	63.2	69.2	2.7	3.5	0.811	0.604
8	64.3	71.4	2.8	3.9	0.876	0.765
9	65.2	73.1	2.9	4.2	0.915	0.865
10	65.8	74.5	3.0	4.4	0.939	0.921
11	66.3	75.7	3.0	4.6	0.954	0.952
12	66.7	76.6	3.1	4.8	0.964	0.969
13	67.0	77.3	3.1	4.9	0.971	0.979
14	67.2	77.9	3.1	5.1	0.976	0.986
15	67.3	78.3	3.1	5.1	0.979	0.99
16	67.4	78.7	3.1	5.2	0.982	0.992
17	67.5	79.0	3.1	5.3	0.984	0.994
18	67.6	79.3	3.2	5.3	0.985	0.995
19	67.6	79.4	3.2	5.3	0.986	0.996
20	67.7	79.6	3.2	5.4	0.987	0.997
21	67.7	79.7	3.2	5.4	0.988	0.997
22	67.7	79.8	3.2	5.4	0.988	0.998
23	67.7	79.9	3.2	5.4	0.989	0.998
24	67.7	80.0	3.2	5.4	0.989	0.998
25	67.7	80.0	3.2	5.4	0.989	0.998
26	67.8	80.1	3.2	5.4	0.99	0.998
27	67.8	80.1	3.2	5.4	0.99	0.999
28	67.8	80.1	3.2	5.4	0.99	0.999
29	67.8	80.1	3.2	5.5	0.99	0.999
30	67.8	80.2	3.2	5.5	0.99	0.999
31	67.8	80.2	3.2	5.5	1	1

Table 3.9. Sablefish age 4+ biomass, spawning biomass plus upper and lower 95% credible intervals (LCI, UCI), and catch (thousands t), and number (millions) at age 2 by year. The 2010 catch is estimated.

Year	Age 4+ biomass (kt)	Spawning biomass (SSB,kt)	SSB (LCI)	SSB (UCI)	Number (millions) at age 2	Catch	Catch/Age4+ biomass
1960	452	177	214	251	4.6	3.1	0.007
1961	529	183	138	237	4.9	16.1	0.030
1962	515	193	155	233	88.3	26.4	0.051
1963	482	202	170	238	7.0	16.9	0.035
1964	586	215	177	246	7.5	7.3	0.012
1965	581	231	187	257	39.6	8.7	0.015
1966	566	246	199	273	59.6	15.6	0.028
1967	589	257	214	288	10.1	19.2	0.033
1968	642	264	225	299	20.2	31.0	0.048
1969	608	264	233	306	6.6	36.8	0.061
1970	578	261	235	305	2.2	37.8	0.065
1971	525	252	234	298	2.2	43.5	0.083
1972	458	235	229	287	24.8	53.0	0.116
1973	381	207	214	266	28.7	36.9	0.097
1974	358	184	188	235	2.0	34.6	0.097
1975	348	162	166	209	3.7	29.9	0.086
1976	307	145	145	184	18.3	31.7	0.103
1977	265	130	130	165	1.5	21.4	0.081
1978	257	118	116	147	2.4	10.4	0.040
1979	237	113	106	133	81.5	11.9	0.050
1980	216	108	102	127	28.0	10.4	0.048
1981	323	106	98	120	8.6	12.6	0.039
1982	356	110	98	117	47.4	12.0	0.034
1983	356	121	102	120	23.2	11.8	0.033
1984	412	137	113	132	39.3	14.1	0.034
1985	430	152	129	148	0.5	14.5	0.034
1986	470	166	143	164	20.9	28.9	0.062
1987	433	172	157	179	22.9	35.2	0.081
1988	415	171	163	185	2.8	38.4	0.093
1989	397	163	161	183	4.8	34.8	0.088
1990	352	153	154	175	10.3	32.1	0.091
1991	311	142	145	164	24.0	27.0	0.087
1992	285	131	134	152	0.3	24.9	0.087
1993	284	120	124	140	29.0	25.4	0.089
1994	250	110	113	128	1.0	23.8	0.095
1995	261	102	103	118	6.3	20.9	0.080
1996	235	97	95	109	10.0	17.6	0.075
1997	217	94	91	104	17.2	14.9	0.069
1998	208	92	88	101	3.3	14.1	0.068
1999	212	88	86	98	29.2	13.6	0.064
2000	196	85	82	94	21.8	15.9	0.081
2001	216	82	79	92	14.3	14.1	0.065
2002	231	82	77	88	42.7	14.8	0.064
2003	233	84	76	88	7.4	16.4	0.071
2004	277	88	79	91	13.7	17.7	0.061
2005	268	94	83	95	7.5	16.6	0.062
2006	267	101	88	102	9.7	15.3	0.059
2007	256	107	94	109	7.6	15.0	0.059
2008	247	109	100	115	5.1	14.6	0.059
2009	235	108	101	118	6.4	13.2	0.056
2010	220	106	101	117	12.3	11.3	0.052

Table 3.10. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for seven harvest scenarios. Abundance projected using 1979-2008 recruitments. Sablefish are not classified as overfished because abundance currently exceeds $B_{35\%}$.

Year	Maximum permissible F	Author's F (prespecified catch 2011-12)*	Half max. F	5-year average F	No fishing	Overfished?	Approaching overfished?
			Spawning biomass (kt)				
2010	105.7	105.7	105.7	105.7	105.7	105.7	105.7
2011	102.1	102.1	102.1	102.1	102.1	102.1	102.1
2012	95.3	97.3	99.1	97.5	103.6	93.9	95.3
2013	90.2	91.8	96.3	93.6	105.4	87.7	90.2
2014	87.7	89.1	94.4	91.9	109.1	84.5	86.6
2015	88.3	89.4	93.4	93.1	115.6	84.5	86.1
2016	90.9	91.8	94.0	96.4	124.5	86.5	87.8
2017	94.4	95.1	95.8	100.7	134.8	89.4	90.4
2018	97.9	98.5	99.0	105.2	145.4	92.3	93.1
2019	101.2	101.7	103.5	109.6	155.8	95.0	95.6
2020	104.2	104.5	108.4	113.6	165.8	97.3	97.8
2021	106.8	107.1	112.5	117.4	175.4	99.4	99.8
2022	109.2	109.4	116.2	120.8	184.5	101.3	101.5
2023	111.3	111.4	121.0	124.1	193.1	102.9	103.1
			Fishing mortality				
2010	0.059	0.059	0.059	0.059	0.059	0.059	0.059
2011	0.089	0.067	0.045	0.065	-	0.106	0.106
2012	0.083	0.085	0.043	0.065	-	0.097	0.097
2013	0.078	0.080	0.042	0.065	-	0.090	0.090
2014	0.075	0.077	0.041	0.065	-	0.086	0.086
2015	0.075	0.076	0.041	0.065	-	0.085	0.085
2016	0.075	0.075	0.041	0.065	-	0.085	0.085
2017	0.075	0.075	0.042	0.065	-	0.085	0.085
2018	0.075	0.076	0.043	0.065	-	0.086	0.086
2019	0.076	0.076	0.045	0.065	-	0.087	0.087
2020	0.077	0.077	0.047	0.065	-	0.088	0.088
2021	0.078	0.078	0.048	0.065	-	0.089	0.089
2022	0.079	0.079	0.048	0.065	-	0.090	0.090
2023	0.080	0.080	0.048	0.065	-	0.091	0.091
			Yield (kt)				
2010	11.5	11.5	11.5	11.5	11.5	11.5	11.5
2011	16.0	16.0	8.2	11.9	-	19.0	16.0
2012	14.1	14.7	7.8	11.4	-	16.2	14.1
2013	13.5	14.0	7.9	11.7	-	15.2	16.0
2014	14.1	14.5	8.6	12.4	-	15.7	16.3
2015	15.1	15.3	9.3	13.2	-	16.6	17.1
2016	15.9	16.1	10.0	13.8	-	17.5	17.9
2017	16.8	16.9	10.6	14.4	-	18.4	18.7
2018	17.5	17.6	11.1	14.9	-	19.1	19.3
2019	18.1	18.2	11.6	15.4	-	19.8	19.9
2020	18.8	18.8	12.1	15.8	-	20.4	20.5
2021	19.3	19.4	12.6	16.3	-	21.0	21.0
2022	19.8	19.9	13.0	16.6	-	21.5	21.5
2023	20.4	20.4	13.4	17.0	-	22.1	22.1

* Projections in Author's F (Alternative 2) are based on an estimated catch of 12,225 t used in place of maximum permissible ABC for 2011. This was done in response to management requests for a more accurate two-year projection.

Table 3.11. Regional estimates of sablefish total biomass (Age 2+). Partitioning was done using RPWs from Japanese LL survey from 1979-1989 and domestic LL survey from 1990-2009. For 1960-1978, a retrospective 4:6:9 pseudo-exponential 3 - year average of proportions was used.

Year	Bering Sea	Aleutian Islands	Western GOA	Central GOA	West Yakutat	EYakutat/ Southeast	Alaska
1960	98	117	51	147	46	70	528
1961	100	119	52	150	47	72	540
1962	112	134	58	168	53	80	605
1963	112	134	58	168	53	81	605
1964	111	133	58	168	52	80	603
1965	116	139	60	175	55	84	628
1966	125	149	65	188	59	90	674
1967	125	150	65	188	59	90	677
1968	125	149	65	188	59	90	674
1969	118	142	61	178	56	85	641
1970	109	130	57	164	51	78	589
1971	98	117	51	148	46	71	530
1972	89	107	46	135	42	64	484
1973	81	97	42	123	38	59	440
1974	73	88	38	111	34	53	397
1975	66	78	34	98	31	47	354
1976	61	72	31	92	29	44	329
1977	54	64	28	81	25	38	290
1978	48	59	25	71	23	35	261
1979	60	65	30	94	27	41	317
1980	63	83	34	93	30	46	350
1981	66	92	39	82	34	56	368
1982	75	86	53	100	40	59	412
1983	79	92	69	111	37	53	440
1984	90	111	76	115	34	53	480
1985	100	110	69	120	35	48	483
1986	105	103	67	122	41	52	490
1987	78	104	64	129	48	58	482
1988	47	91	60	144	46	59	448
1989	54	79	47	130	42	52	406
1990	56	61	39	113	43	56	368
1991	38	40	37	109	46	76	347
1992	23	36	25	100	50	83	317
1993	15	34	28	103	53	79	312
1994	17	33	31	95	44	68	289
1995	25	31	27	87	38	60	268
1996	24	26	27	91	33	51	252
1997	23	23	26	96	30	49	247
1998	20	30	26	82	27	48	234
1999	20	40	28	81	26	49	244
2000	20	42	33	85	26	49	255
2001	28	41	41	81	22	45	259
2002	40	44	43	94	24	45	290
2003	40	45	42	101	26	43	297
2004	40	46	37	106	28	43	300
2005	42	45	38	95	26	47	294
2006	45	40	40	86	26	49	286
2007	48	35	29	85	29	49	276
2008	50	33	26	82	25	45	262
2009	48	32	29	78	22	40	248
2010	47	27	25	70	27	44	240

Table 3.12. Analysis of ecosystem considerations for sablefish fishery.

Indicator	***Observation***	***Interpretation***	***Evaluation***
ECOSYSTEM EFFECTS ON STOCK			
Prey availability or abundance trends			
Zooplankton	None	None	Unknown
Predator population trends			
Salmon	Decreasing	Increases the stock	No concern
Changes in habitat quality			
Temperature regime	Warm increases recruitment	Variable recruitment	No concern (can't affect)
Prevailing currents	Northerly increases recruitment	Variable recruitment	No concern (can't affect)
FISHERY EFFECTS ON ECOSYSTEM			
Fishery contribution to bycatch			
Prohibited species	Small catches	Minor contribution to mortality	No concern
Forage species	Small catches	Minor contribution to mortality	No concern
HAPC biota (seapens/whips, corals, sponges, anemones)	Small catches, except long-term reductions predicted	Long-term reductions predicted in hard corals and living structure	Possible concern
Marine mammals and birds	Bird catch about 10% total	Appears to be decreasing	Possible concern
Sensitive non-target species	Grenadier, spiny dogfish, and unidentified shark catch notable	Grenadier catch high but stable, recent shark catch is small	Possible concern for grenadiers
Fishery concentration in space and time	IFQ less concentrated	IFQ improves	No concern
Fishery effects on amount of large size target fish	IFQ reduces catch of immature	IFQ improves	No concern
Fishery contribution to discards and offal production	sablefish <5% in longline fishery, but 30% in trawl fishery	IFQ improves, but notable discards in trawl fishery	Trawl fishery discards definite concern
Fishery effects on age-at-maturity and fecundity	trawl fishery catches smaller fish, but only small part of total catch	slightly decreases	No concern

Figures

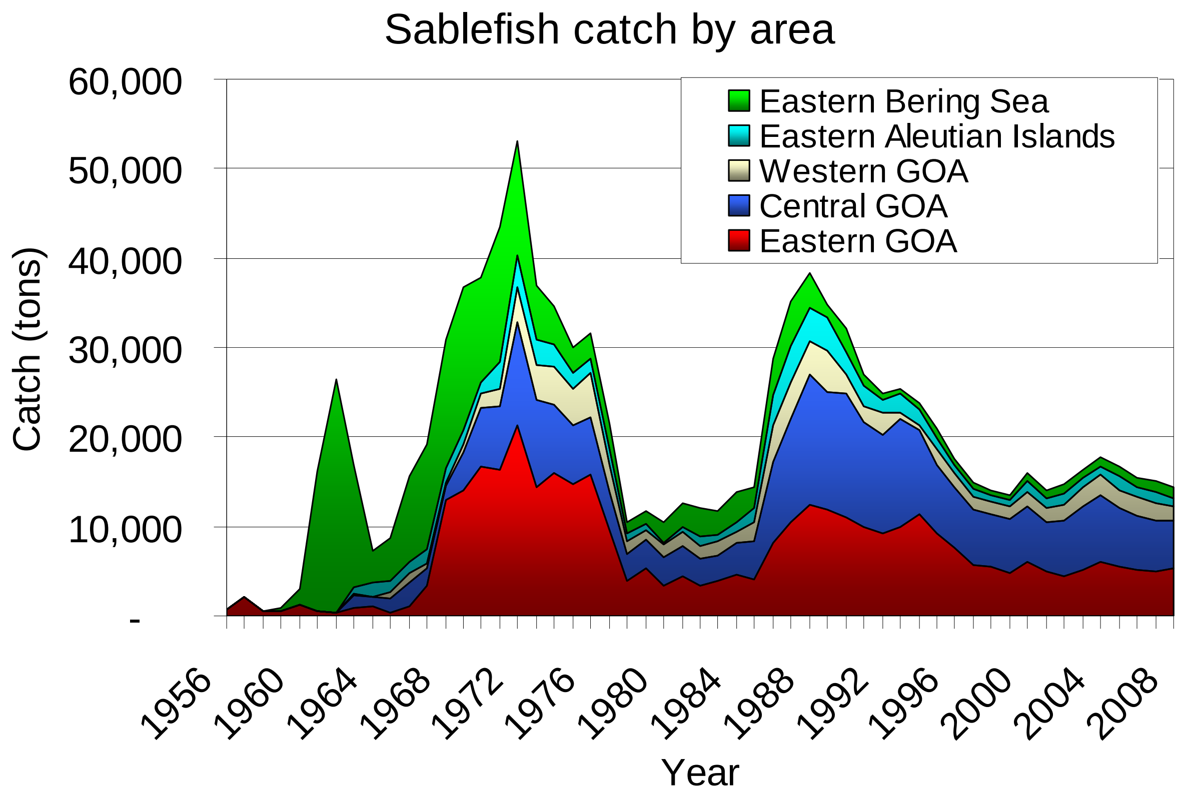


Figure 3.1. Sablefish fishery total reported catch (t) by North Pacific Fishery Management Council area and year.

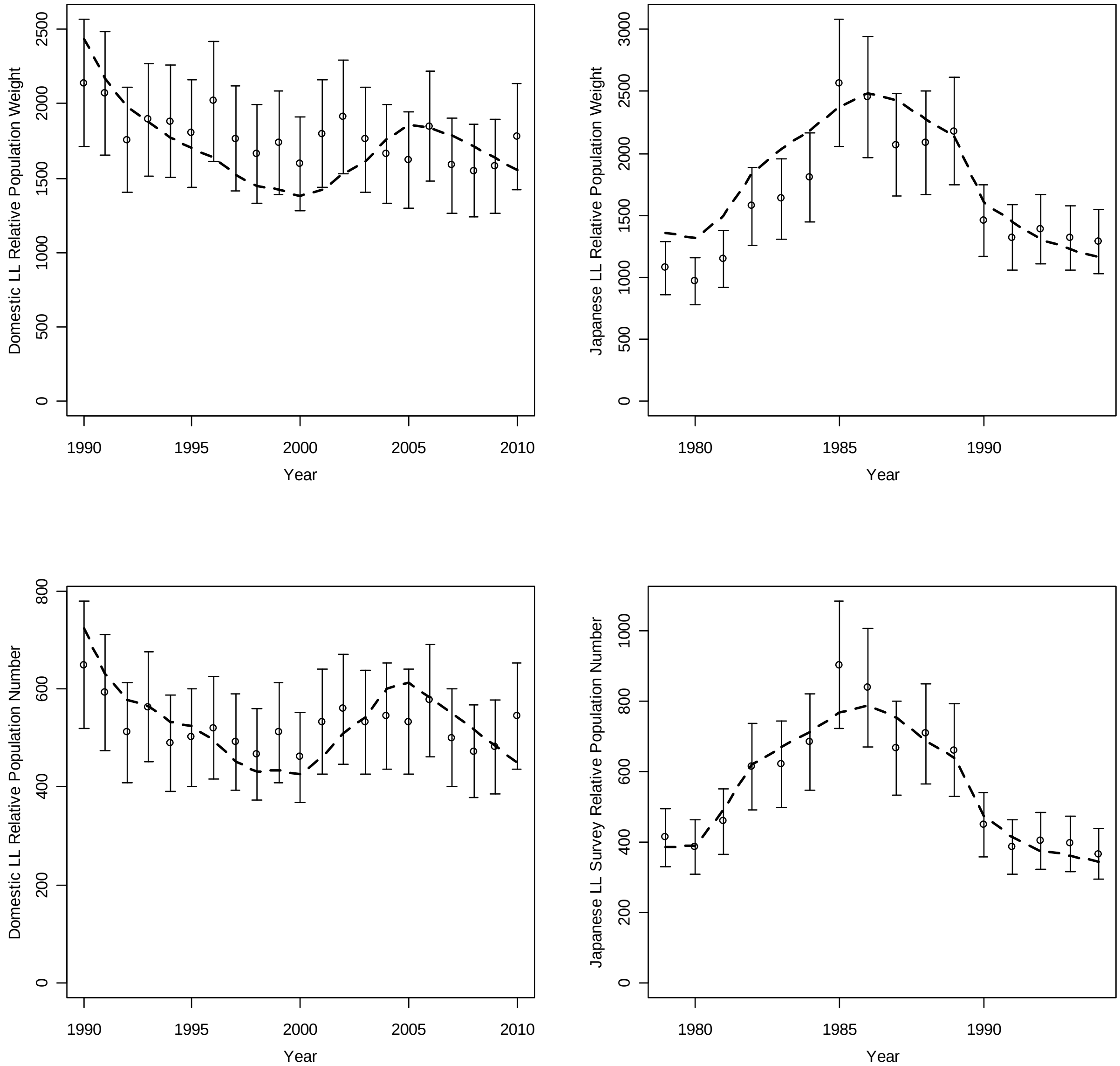


Figure 3.2. Observed and predicted sablefish relative population weight and numbers versus year. Points are observed estimates with approximate 95% confidence intervals, dashed line is model predicted.

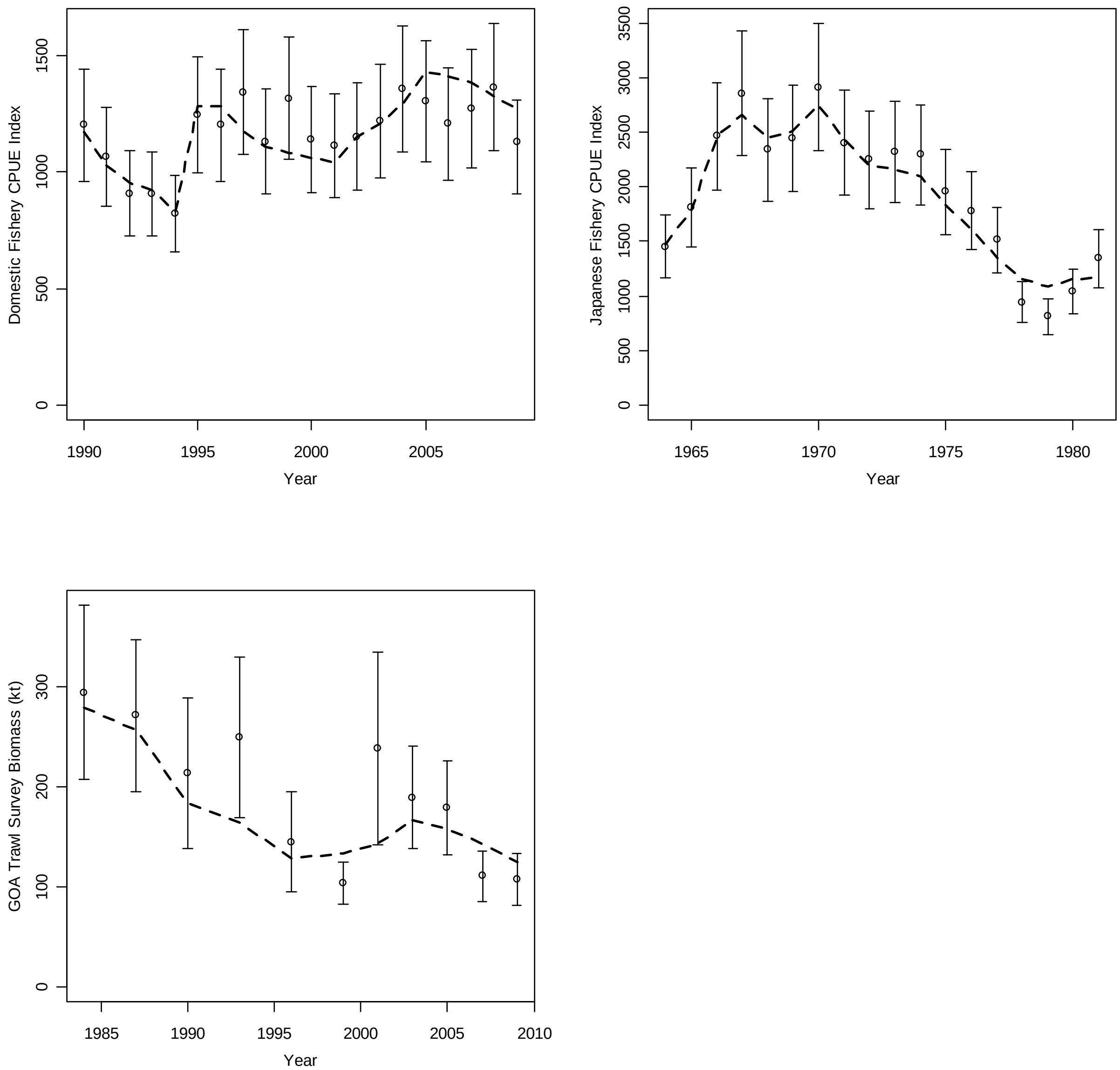


Figure 3.3. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels, GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while dashed lines are model predictions.

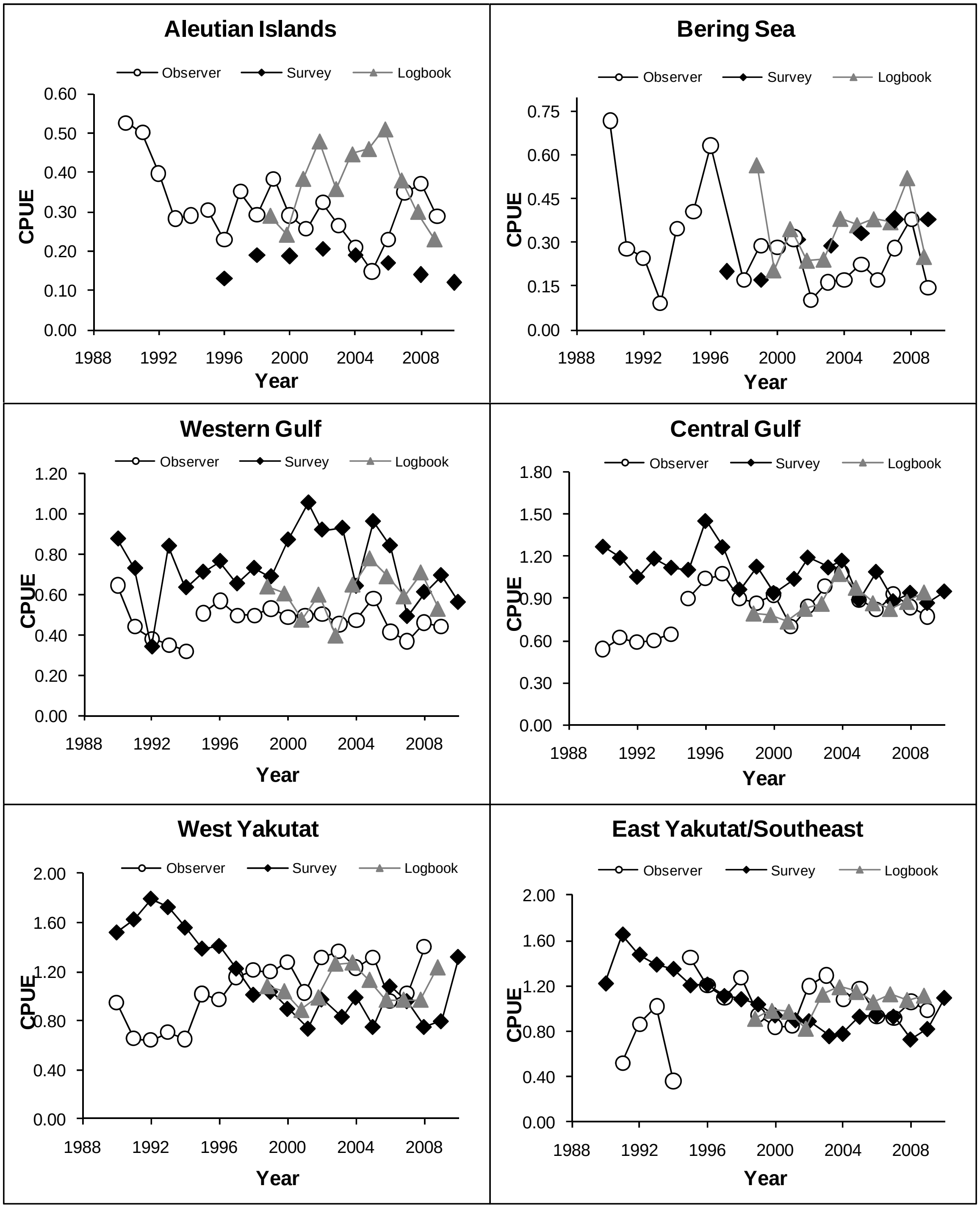


Figure 3.4. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995.

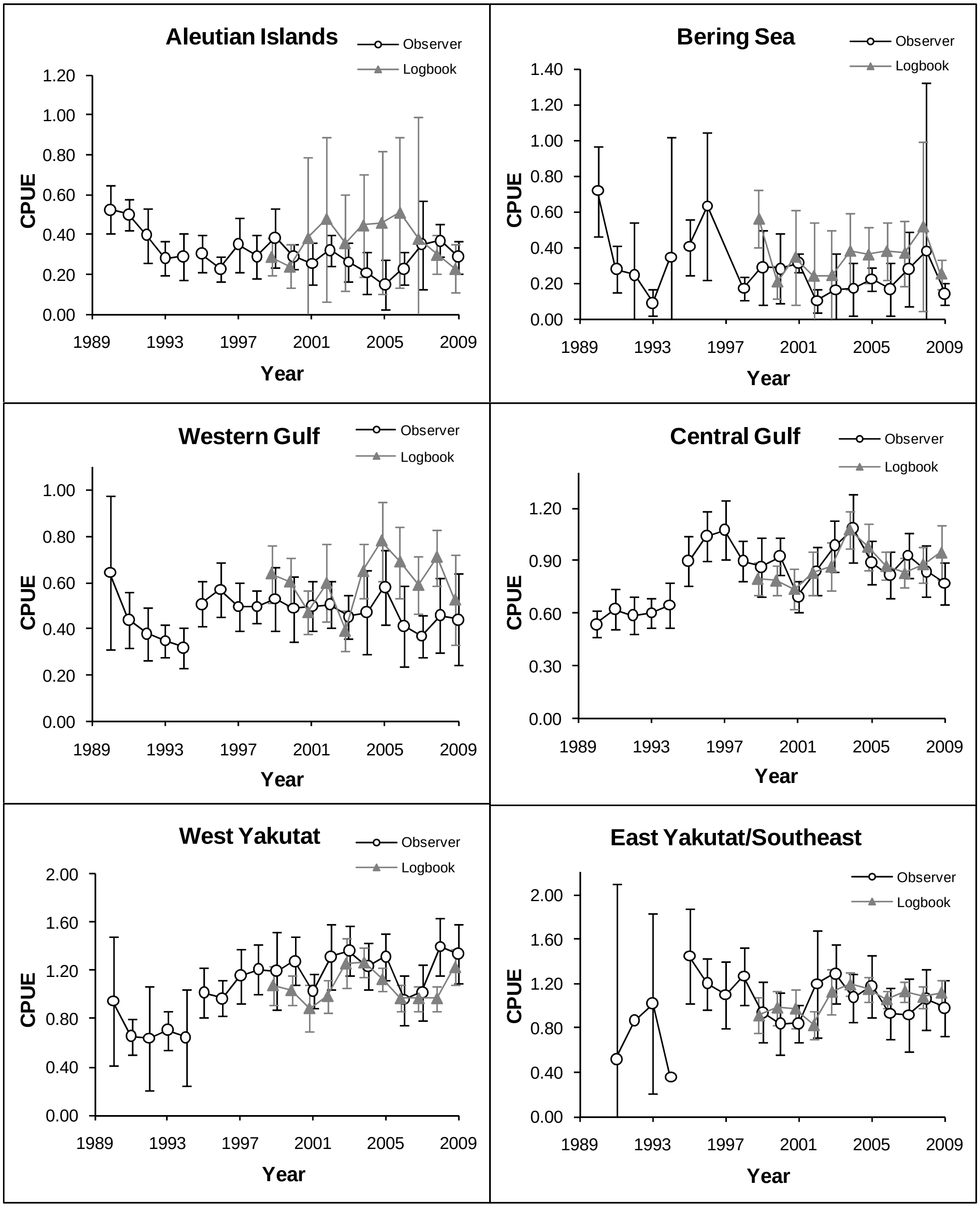


Figure 3.5. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995.

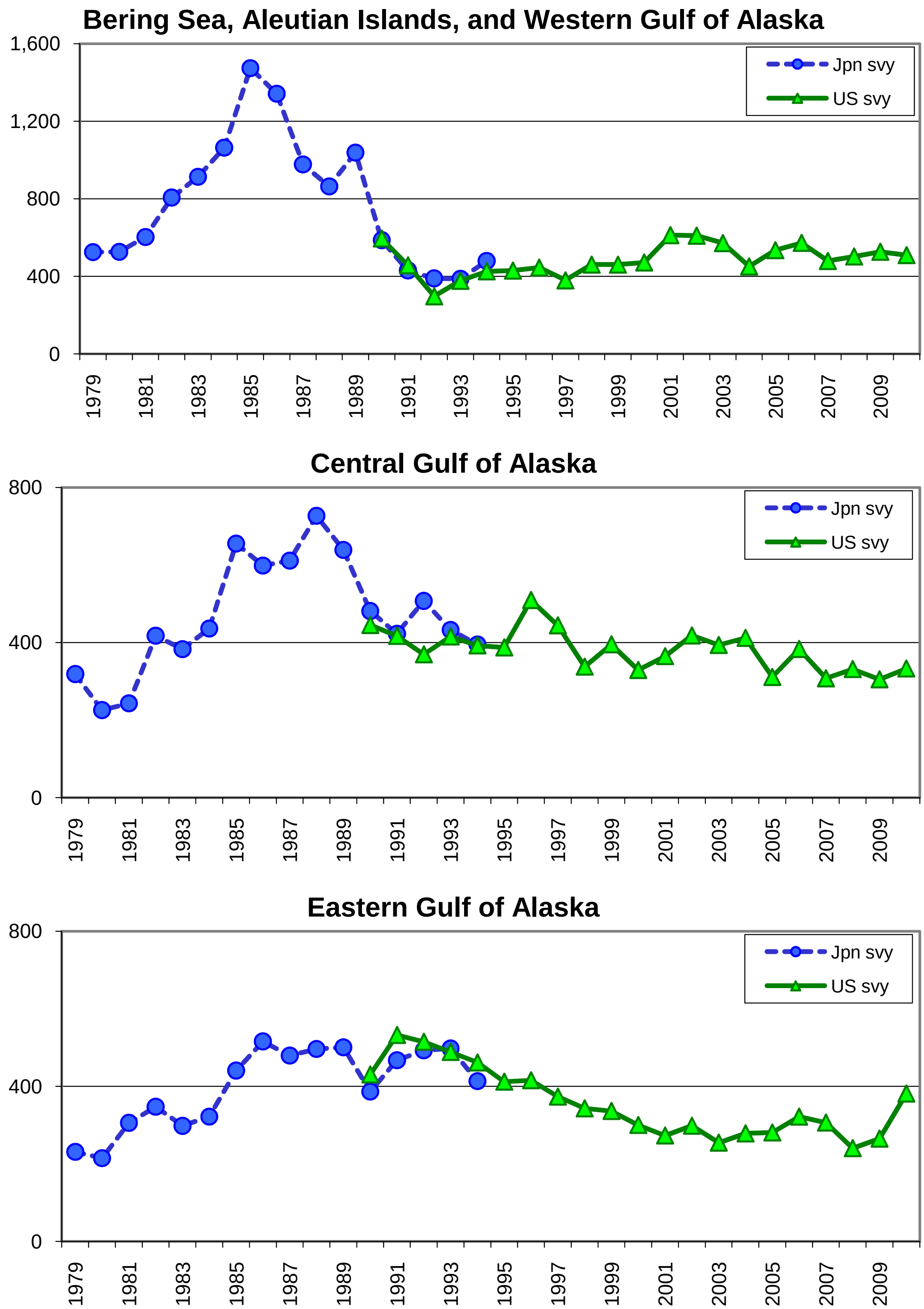


Figure 3.6a. Relative abundance (weight) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the U.S. survey were adjusted to account for the higher efficiency of the U.S. survey gear.

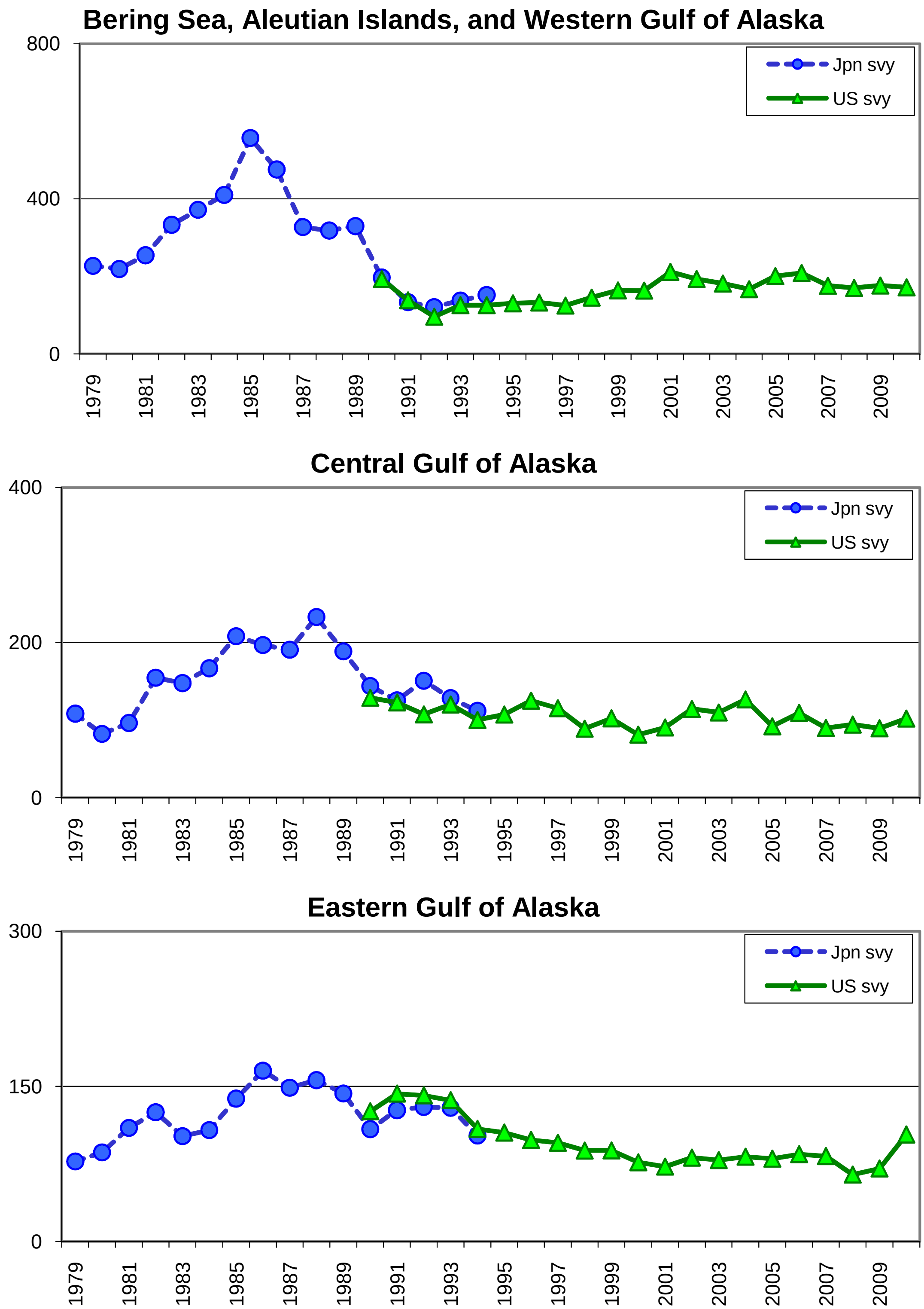


Figure 3.6b. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the U.S. survey were adjusted to account for the higher efficiency of the U.S. survey gear.

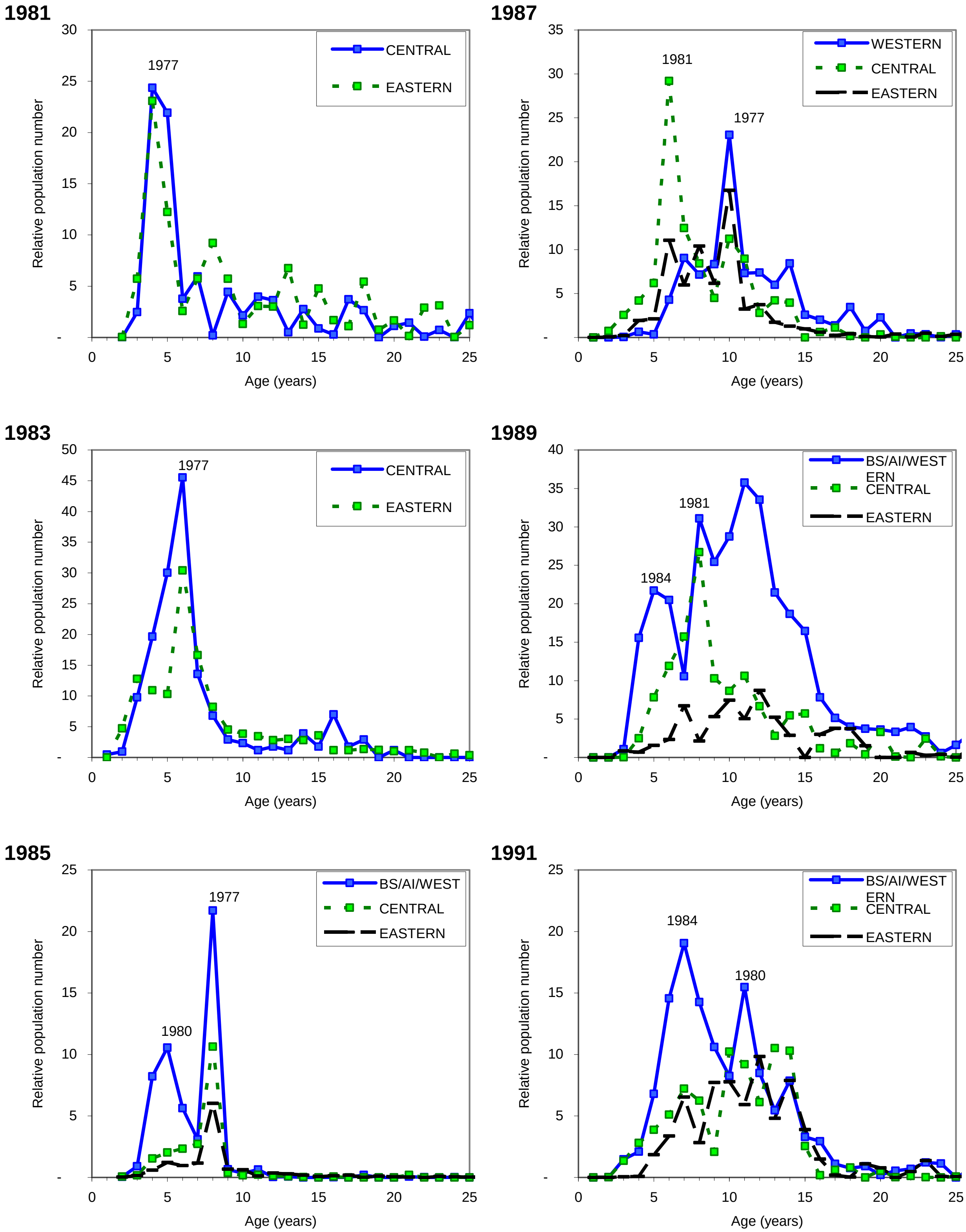


Figure 3.7. Relative abundance (number in thousands) by age and region from two surveys, the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

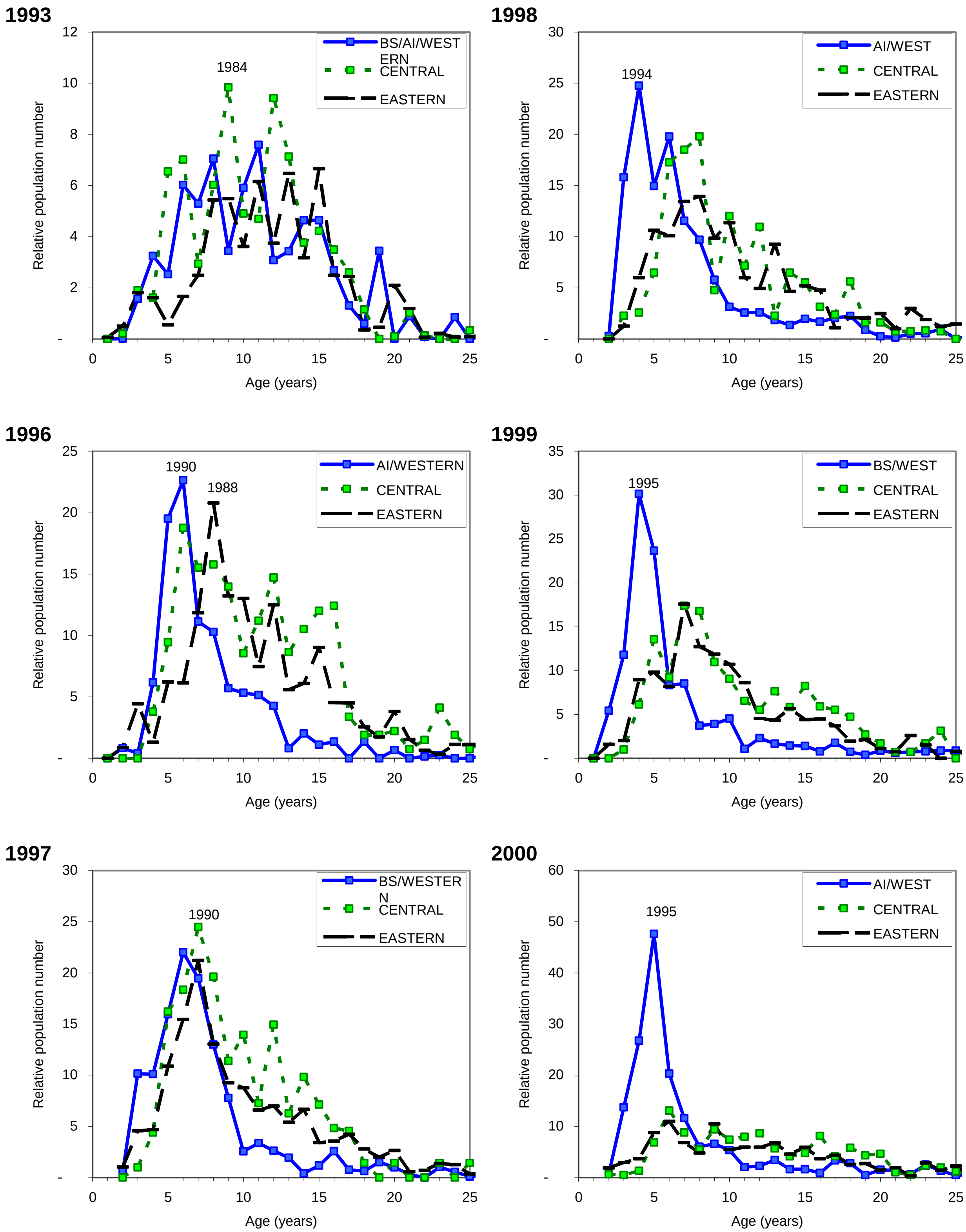


Figure 3.7 cont.

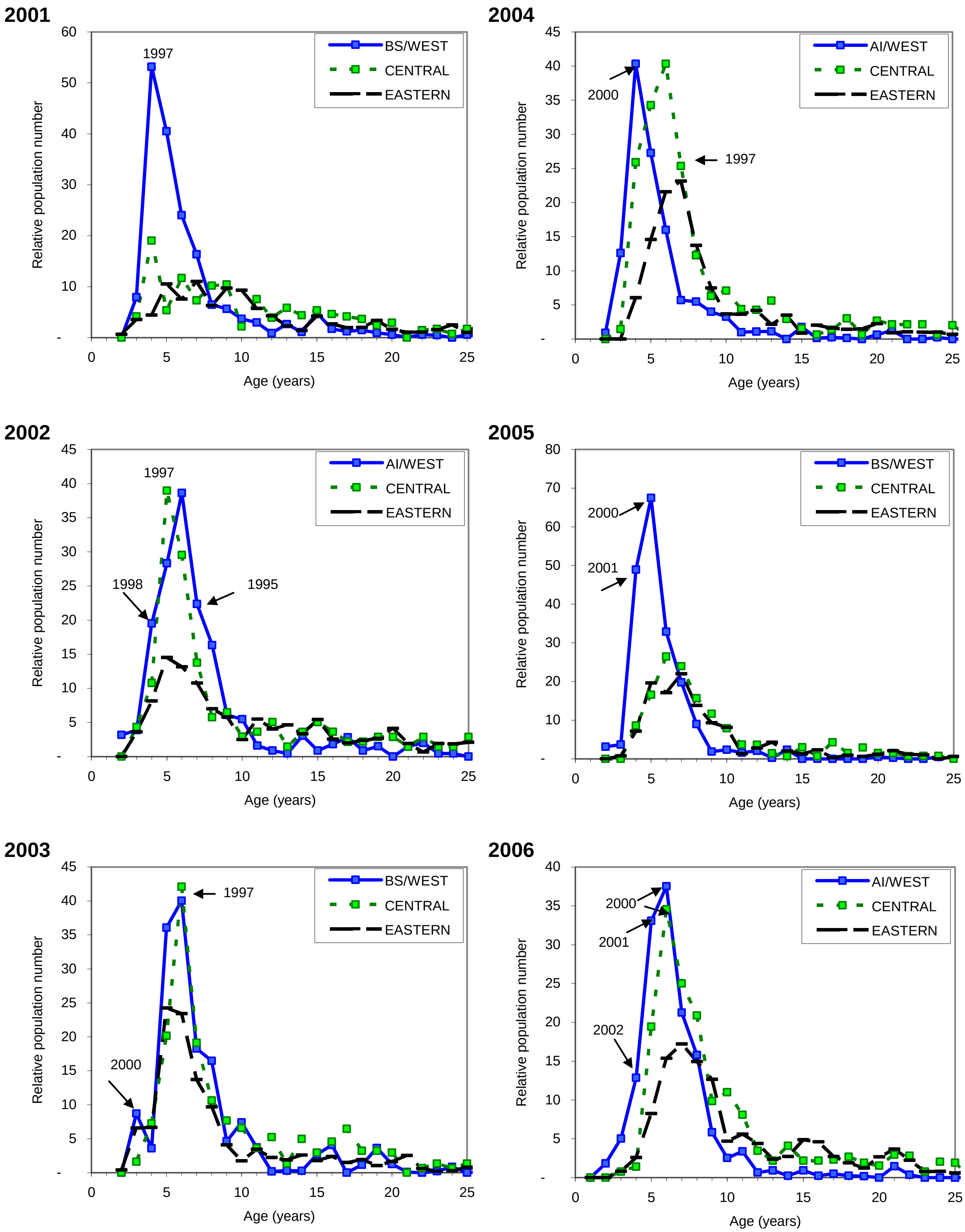


Figure 3.7 cont.

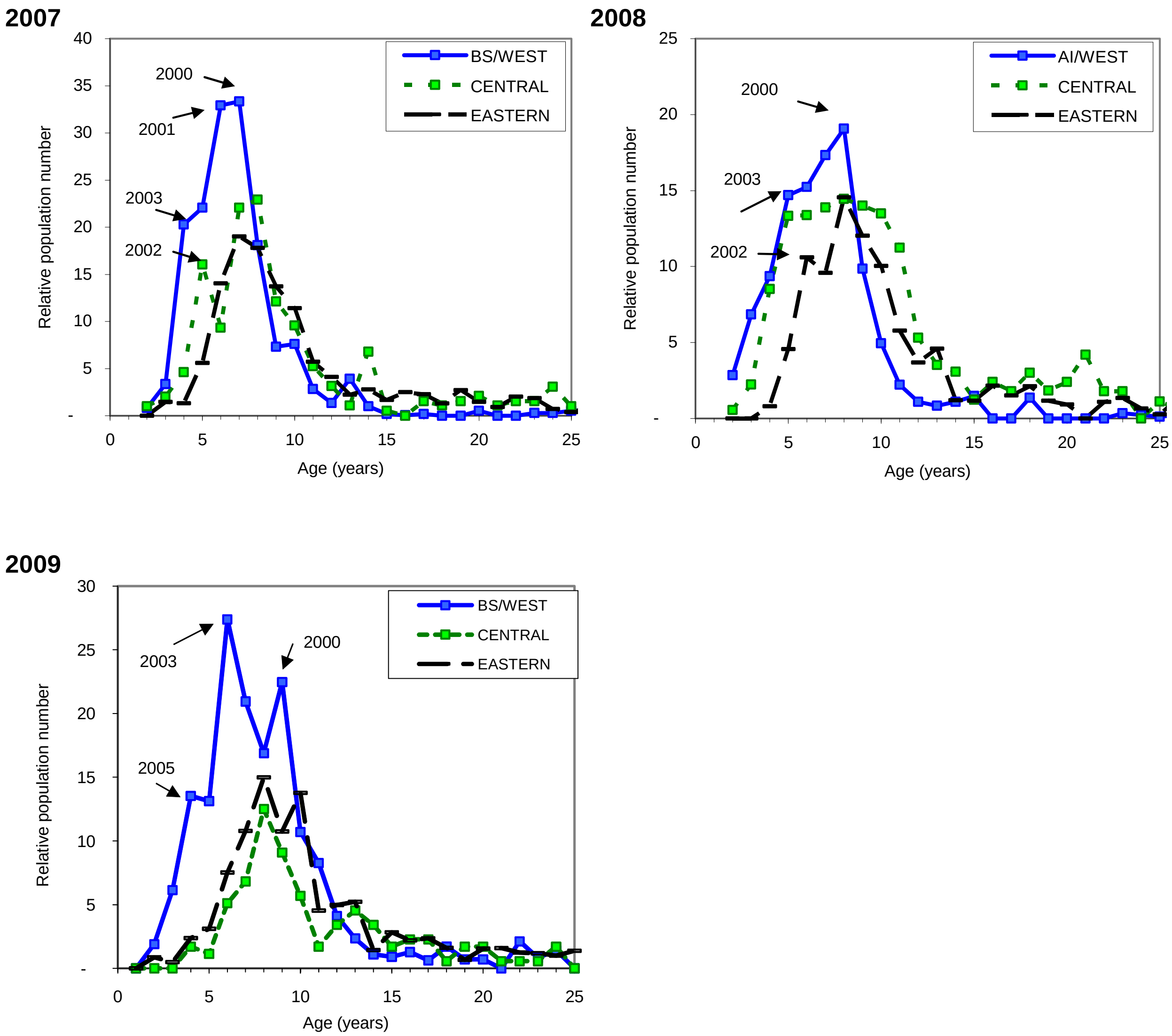


Figure 3.7. cont.

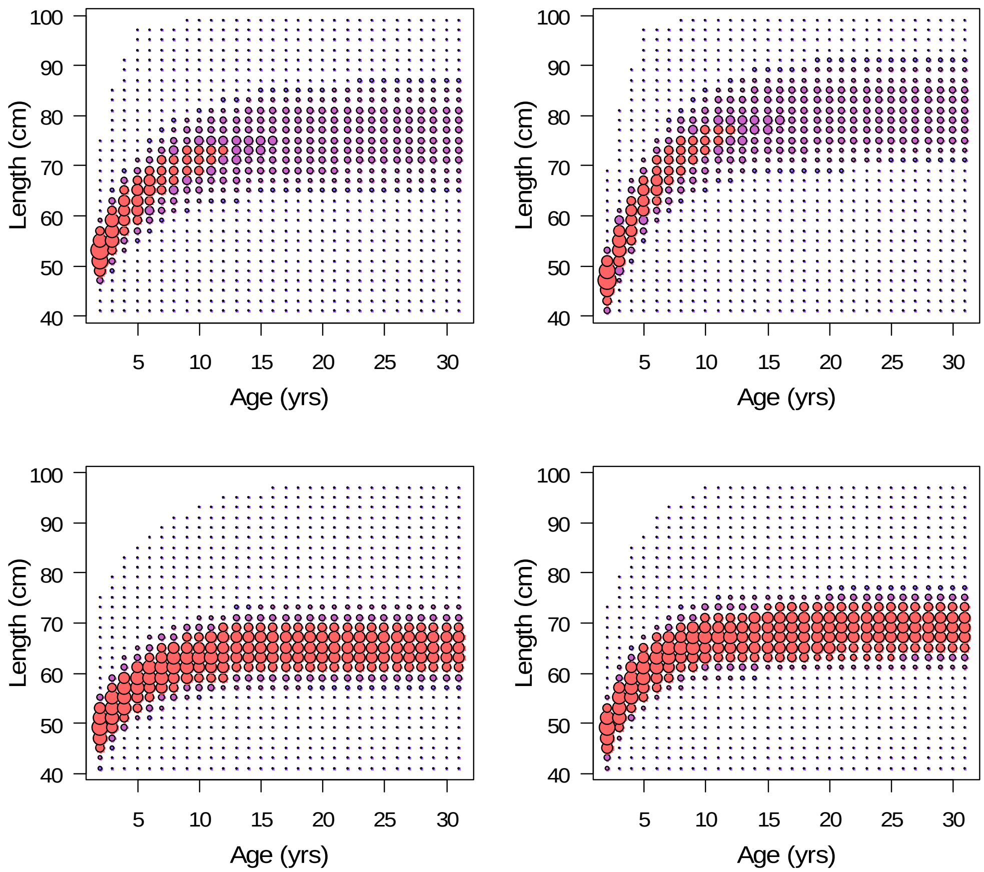


Figure 3.8. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1981-1993, right is 1996-2004.

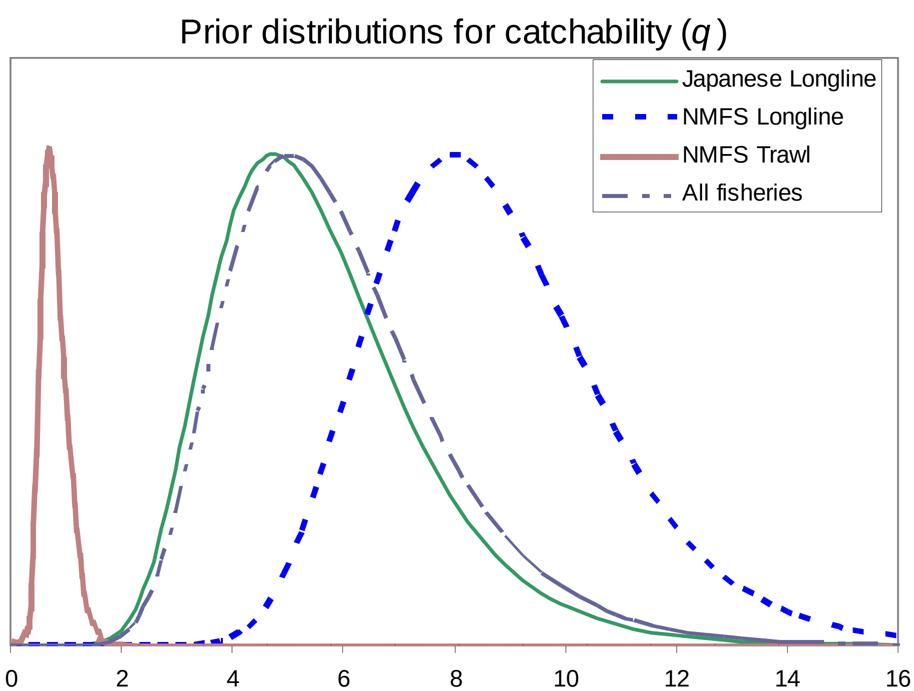


Figure 3.9. Prior distributions for catchability for four sablefish abundance indices.

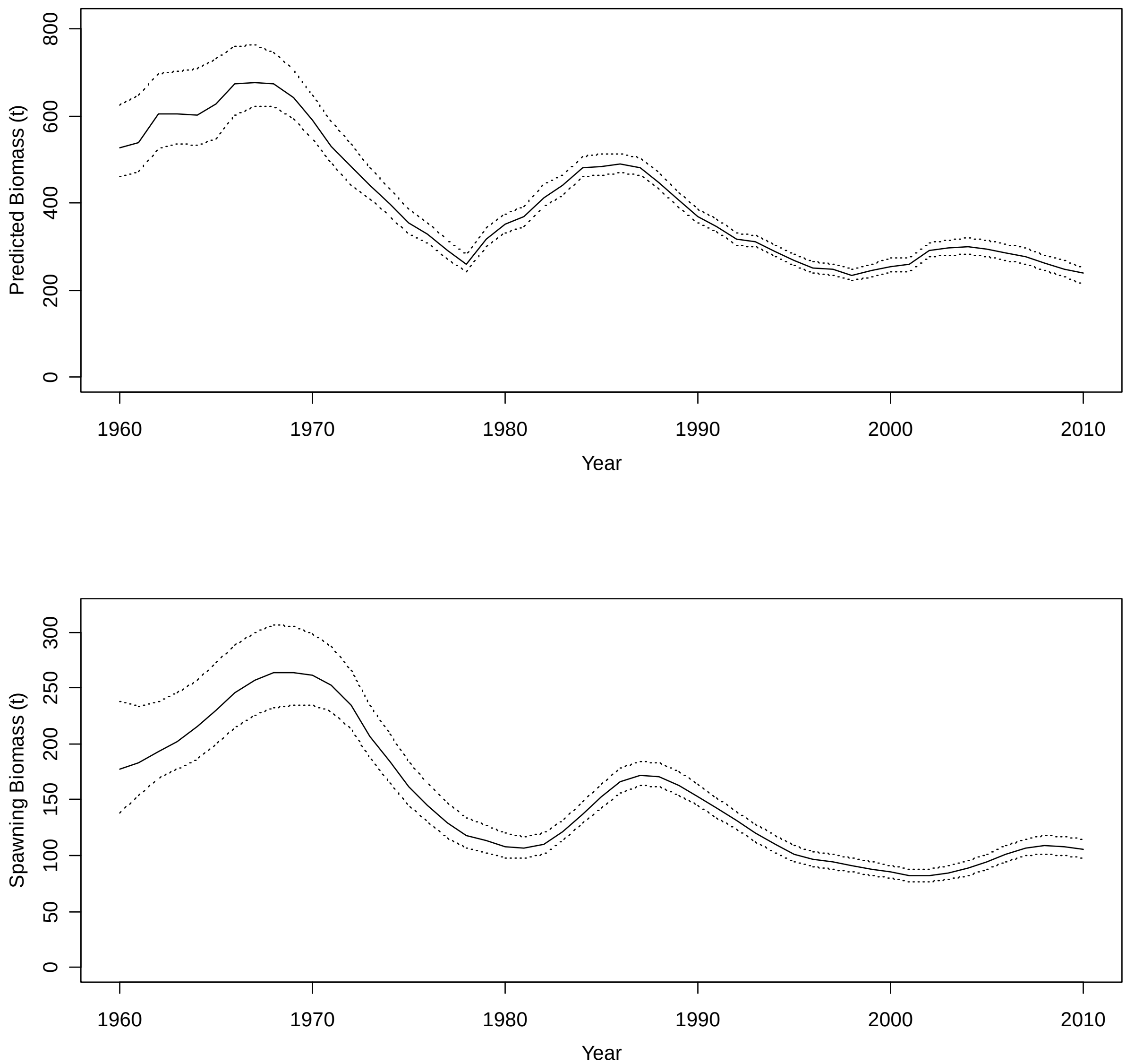


Figure 3.10.--Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

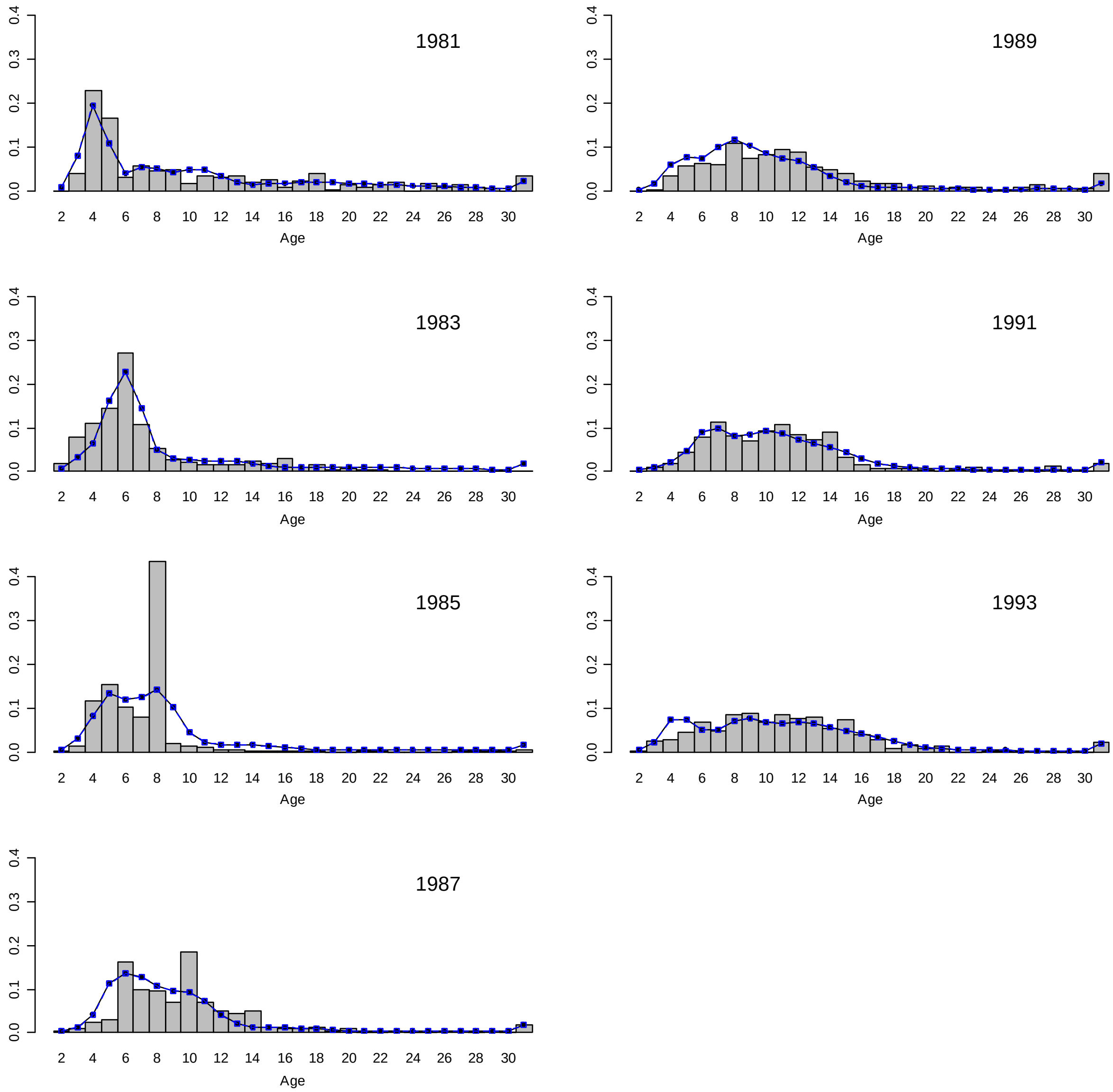


Figure 3.11. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

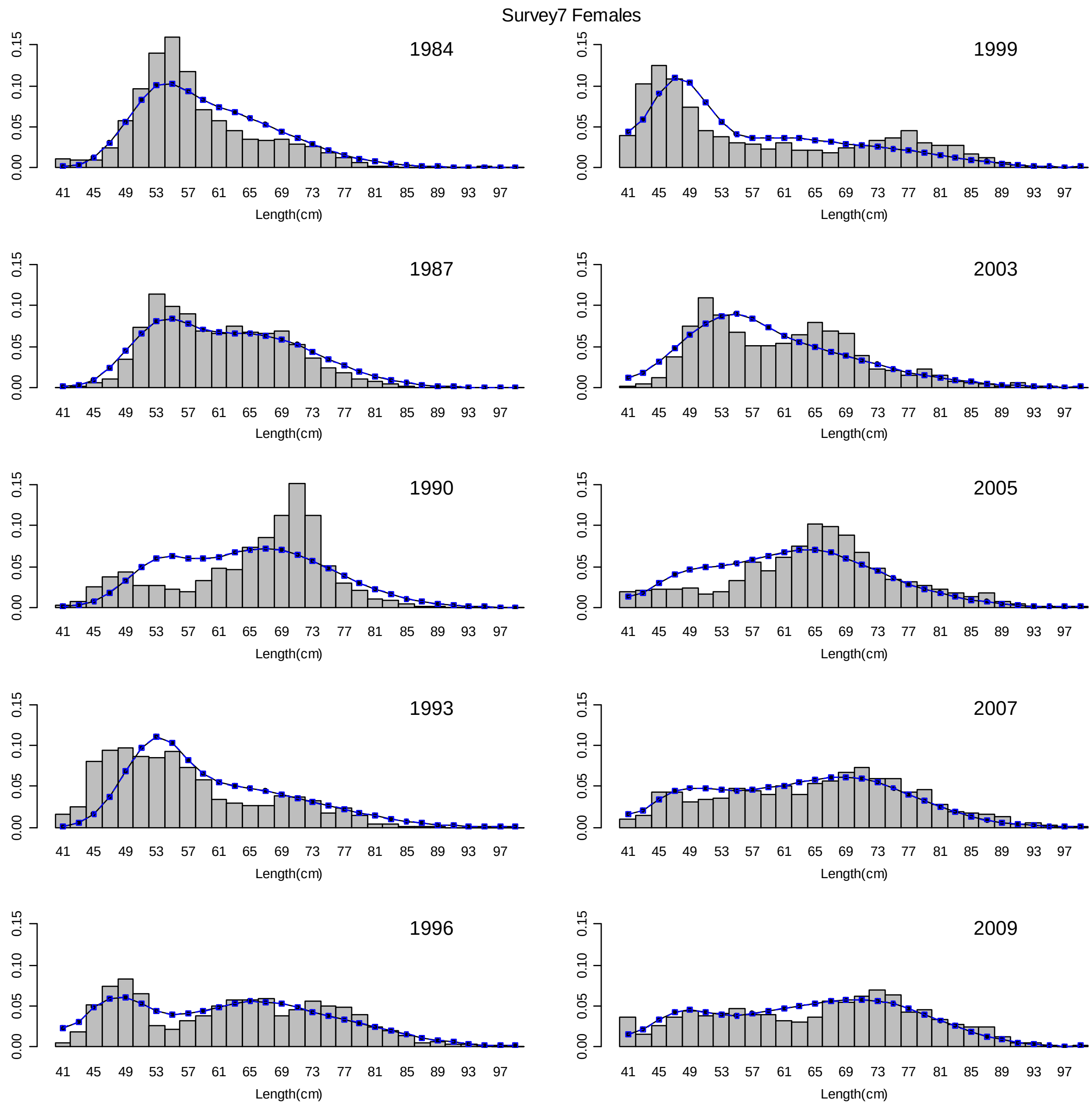


Figure 3.12. Gulf of Alaska bottom trawl survey lengths for female sablefish at depths <500 m. Bars are observed frequencies and line is predicted frequencies.

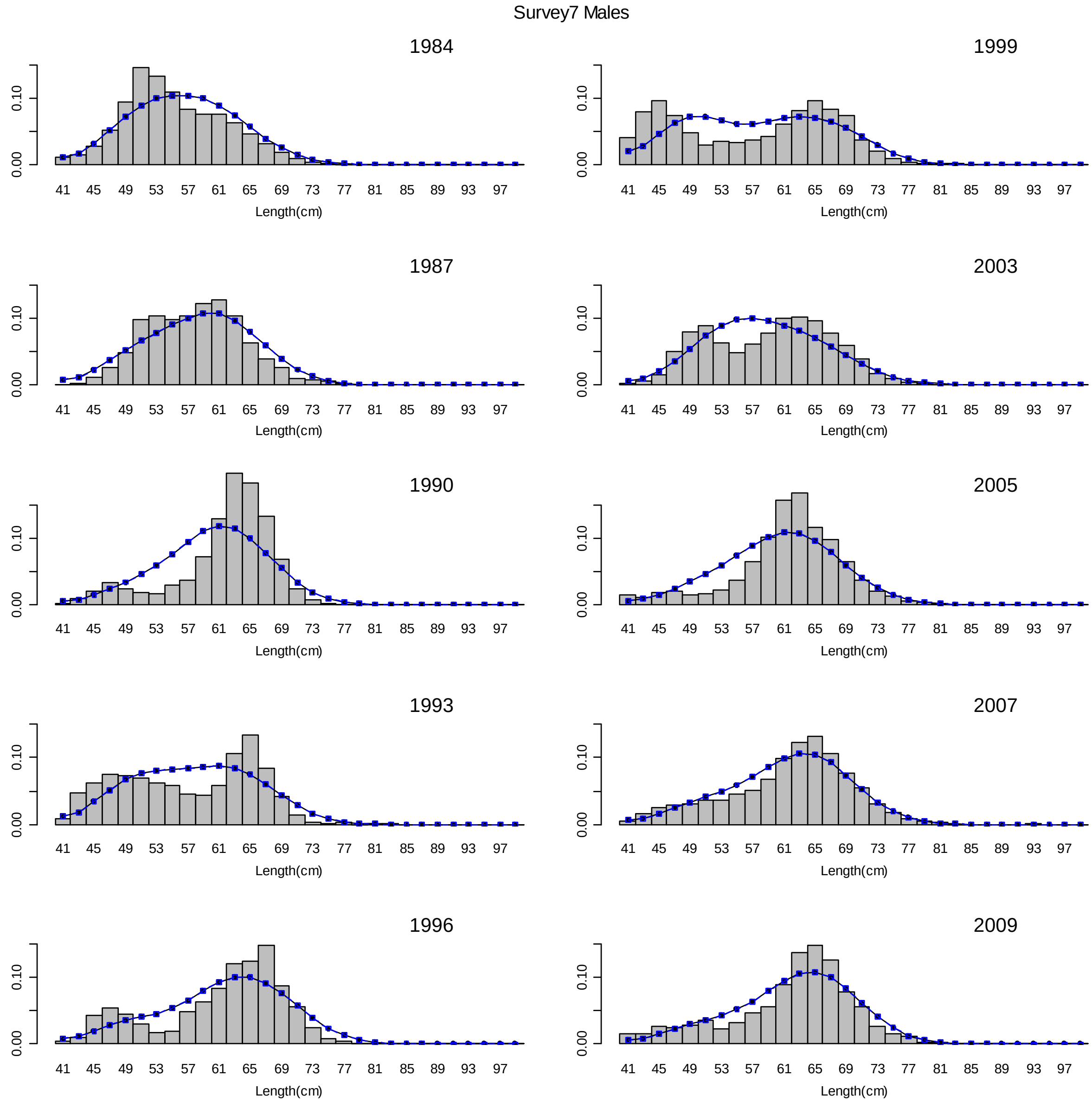


Figure 3.13. Gulf of Alaska bottom trawl survey lengths for male sablefish at depths <500 m. Bars are observed frequencies and line is predicted frequencies.

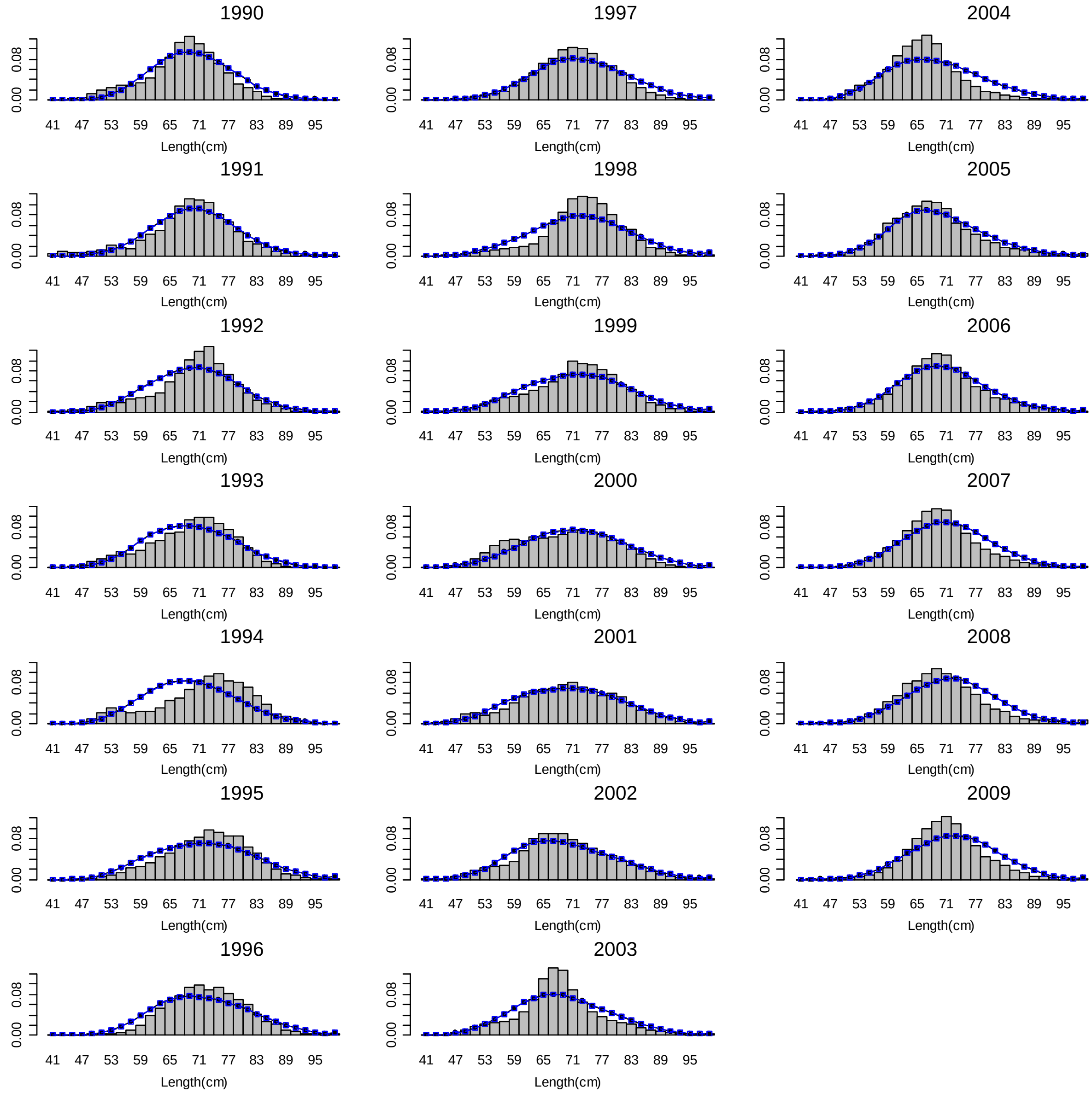


Figure 3.14. Domestic fixed gear fishery lengths compositions for females. Bars are observed frequencies and line is predicted frequencies.

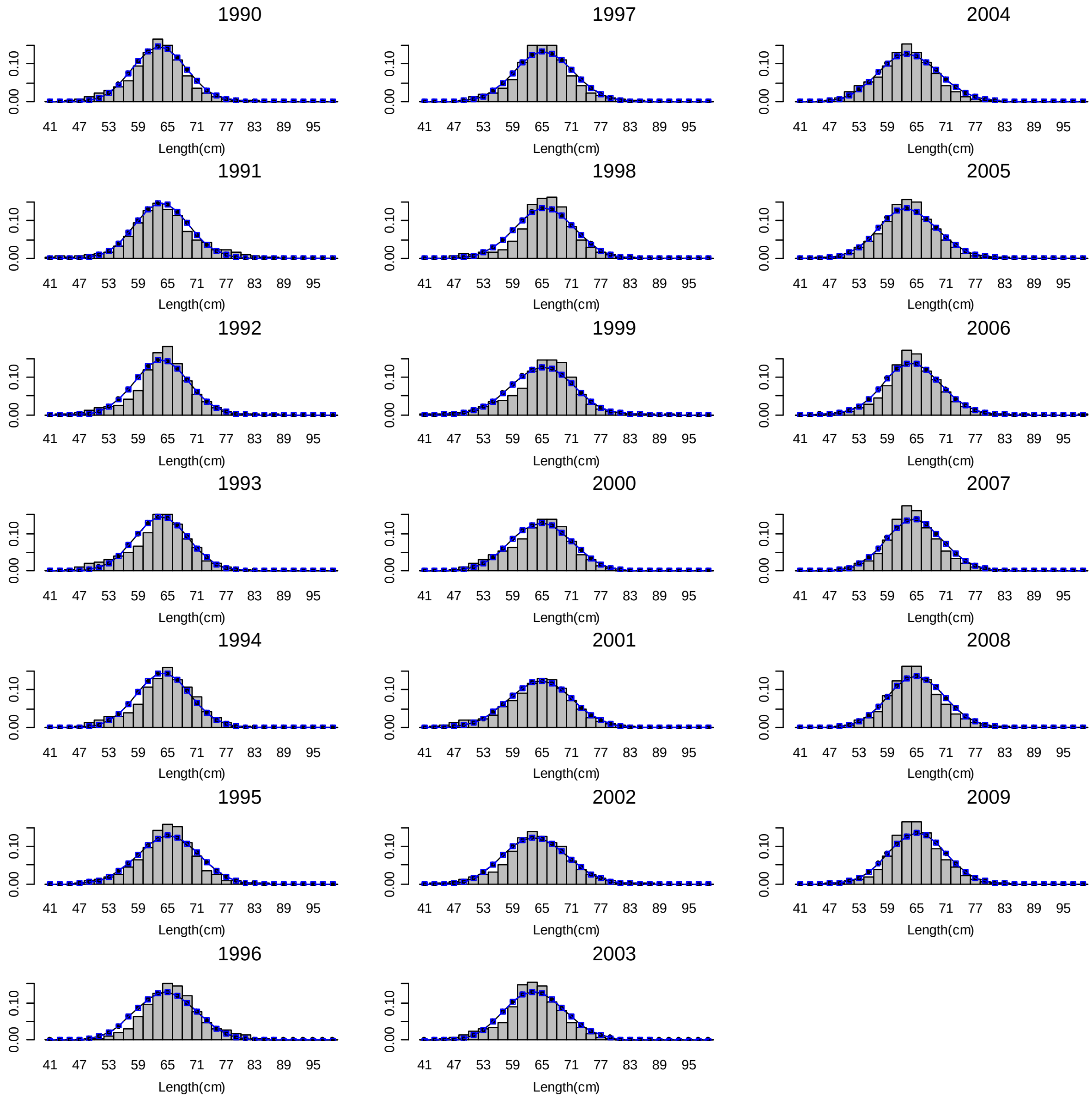


Figure 3.15. Domestic fixed gear fishery lengths compositions for males. Bars are observed frequencies and line is predicted frequencies.

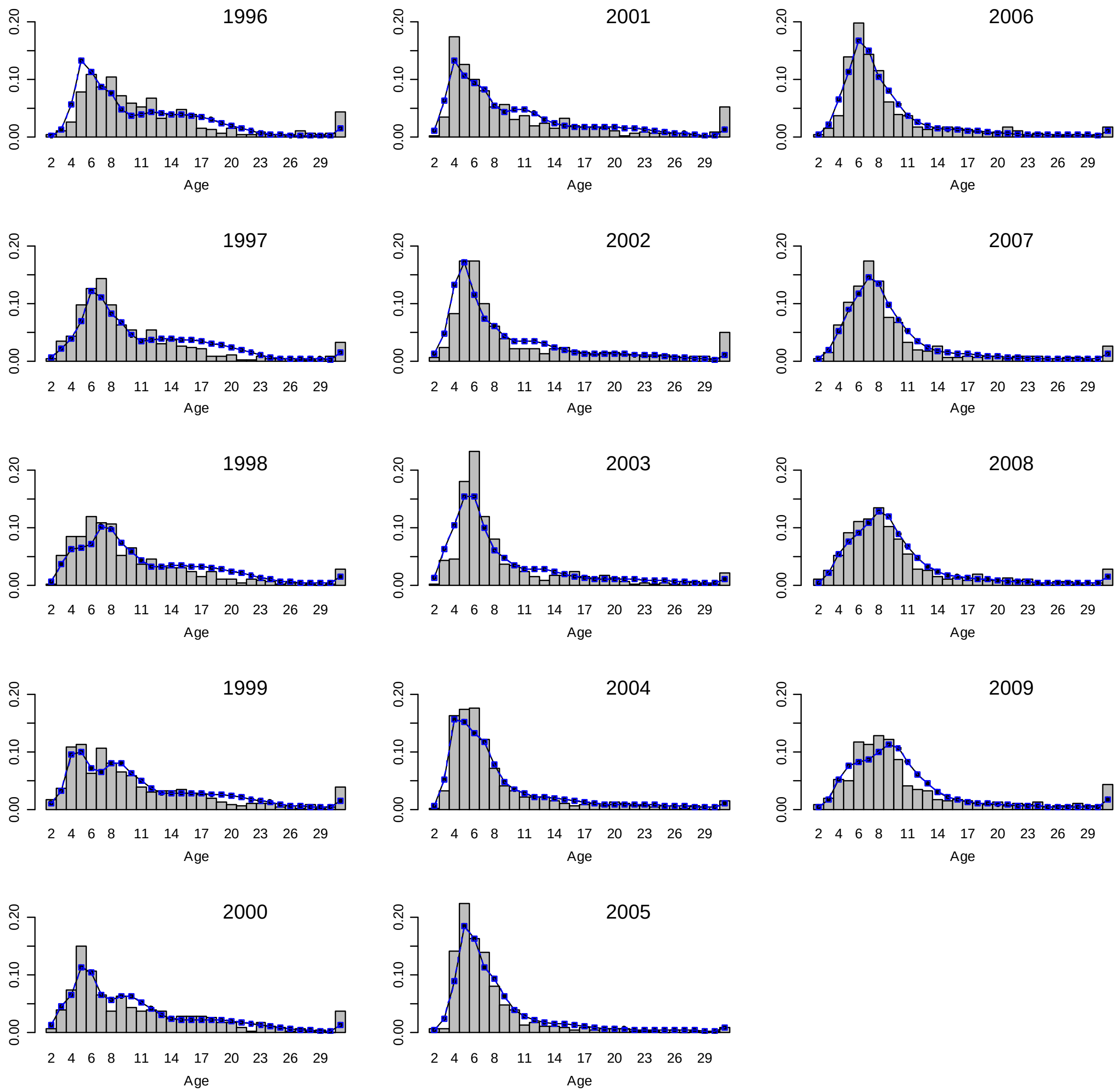


Figure 3.16. Domestic longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

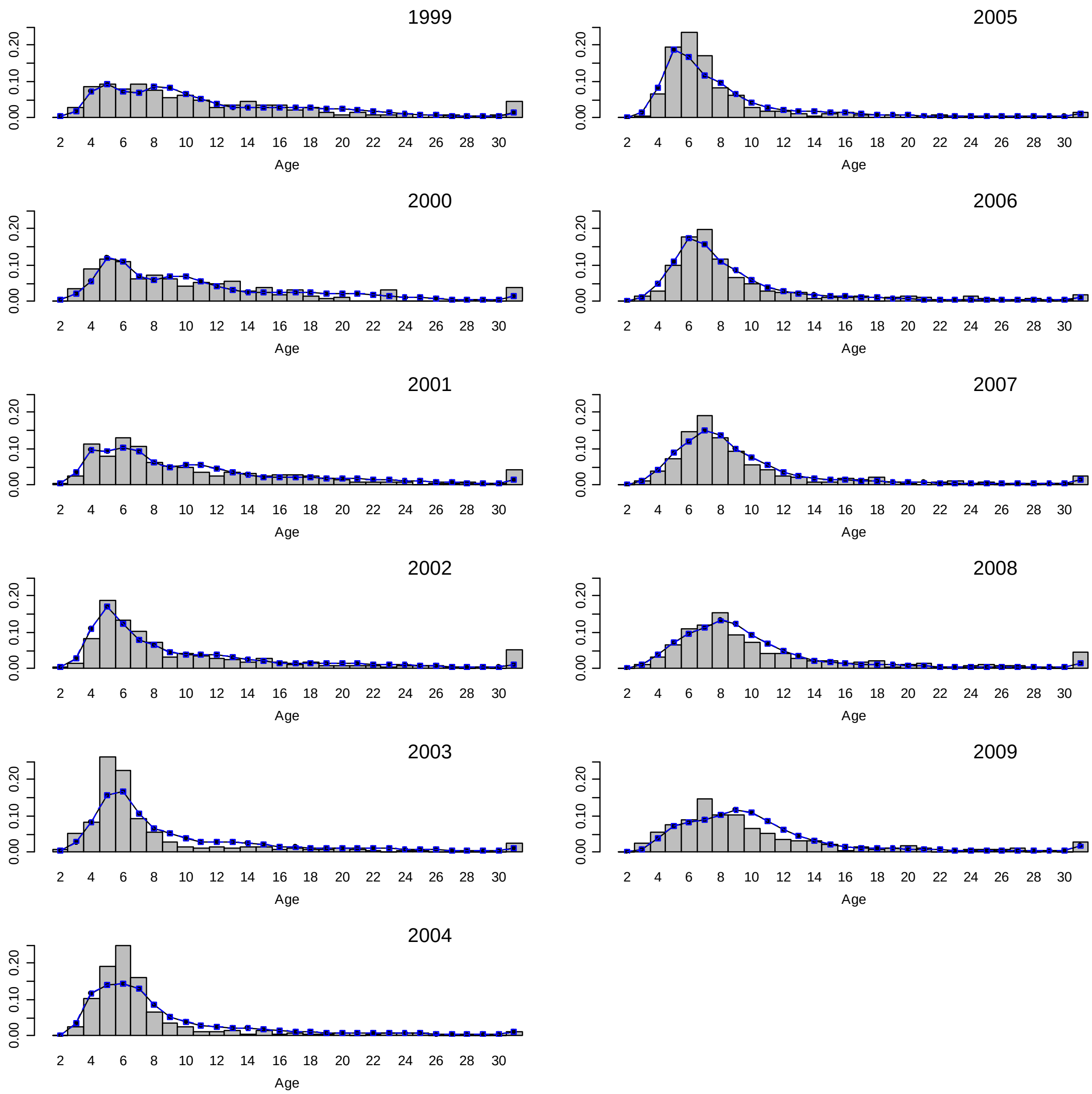


Figure 3.17. Domestic fishery age compositions. Bars are observed frequencies and line is predicted frequencies.

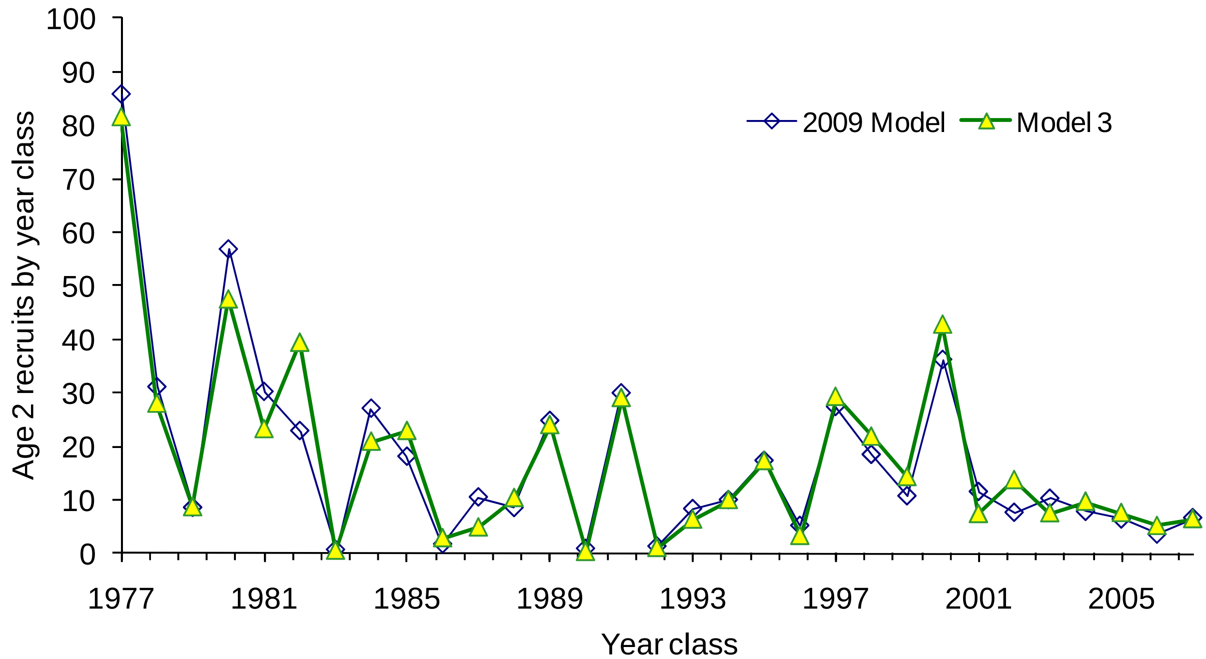


Figure 3.18a. Estimated recruitment (number at age 2, millions) versus year for 2008 and 2009 models.

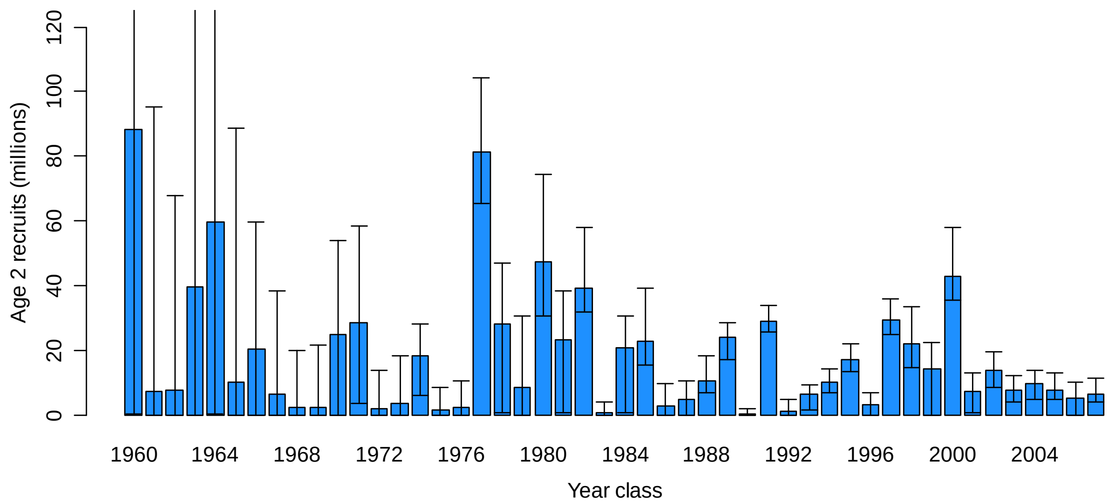


Figure 3.18b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Credible intervals are based on 10,000,000 MCMC runs.

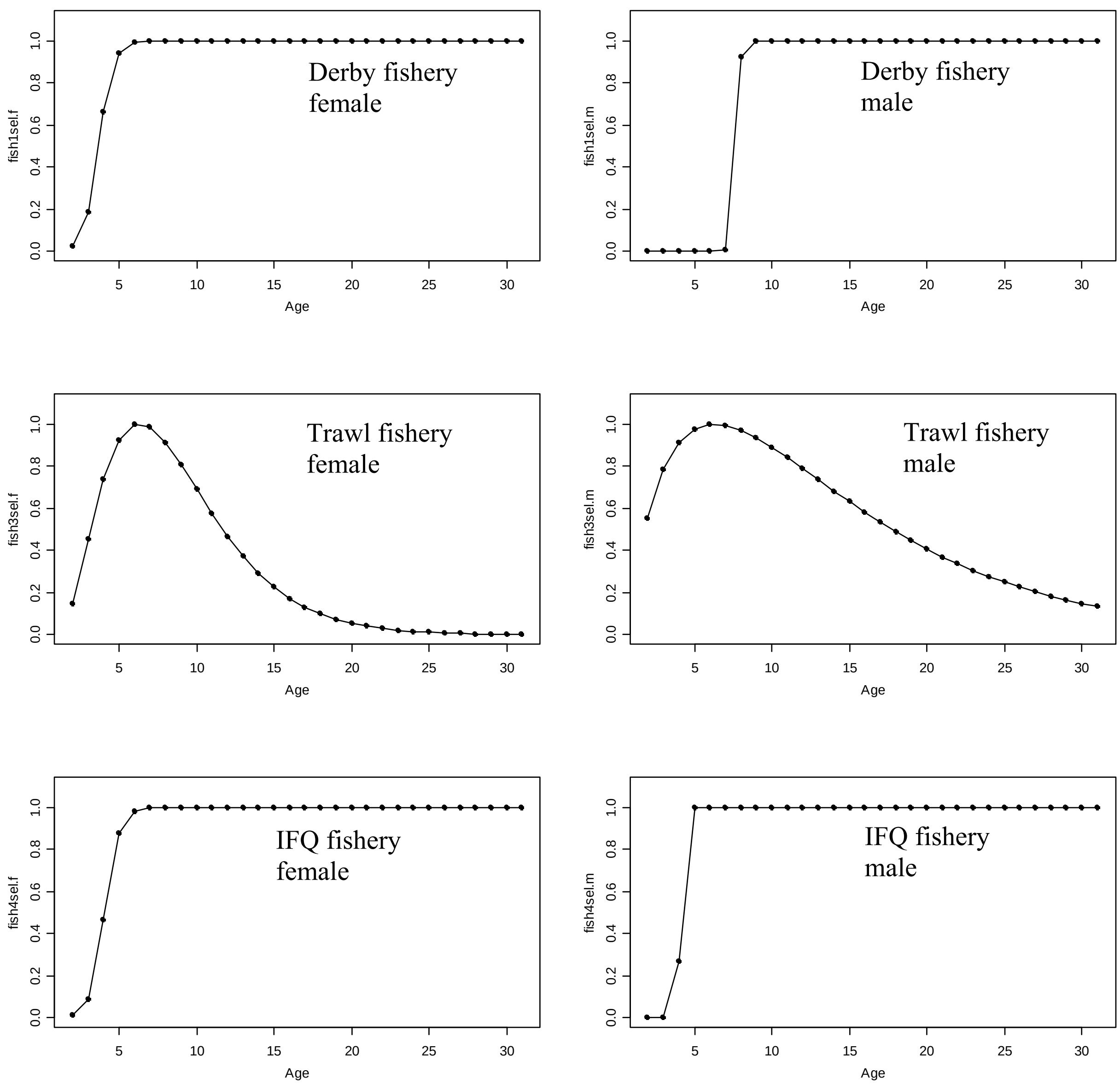


Figure 3.19a. Sablefish selectivities for fisheries.

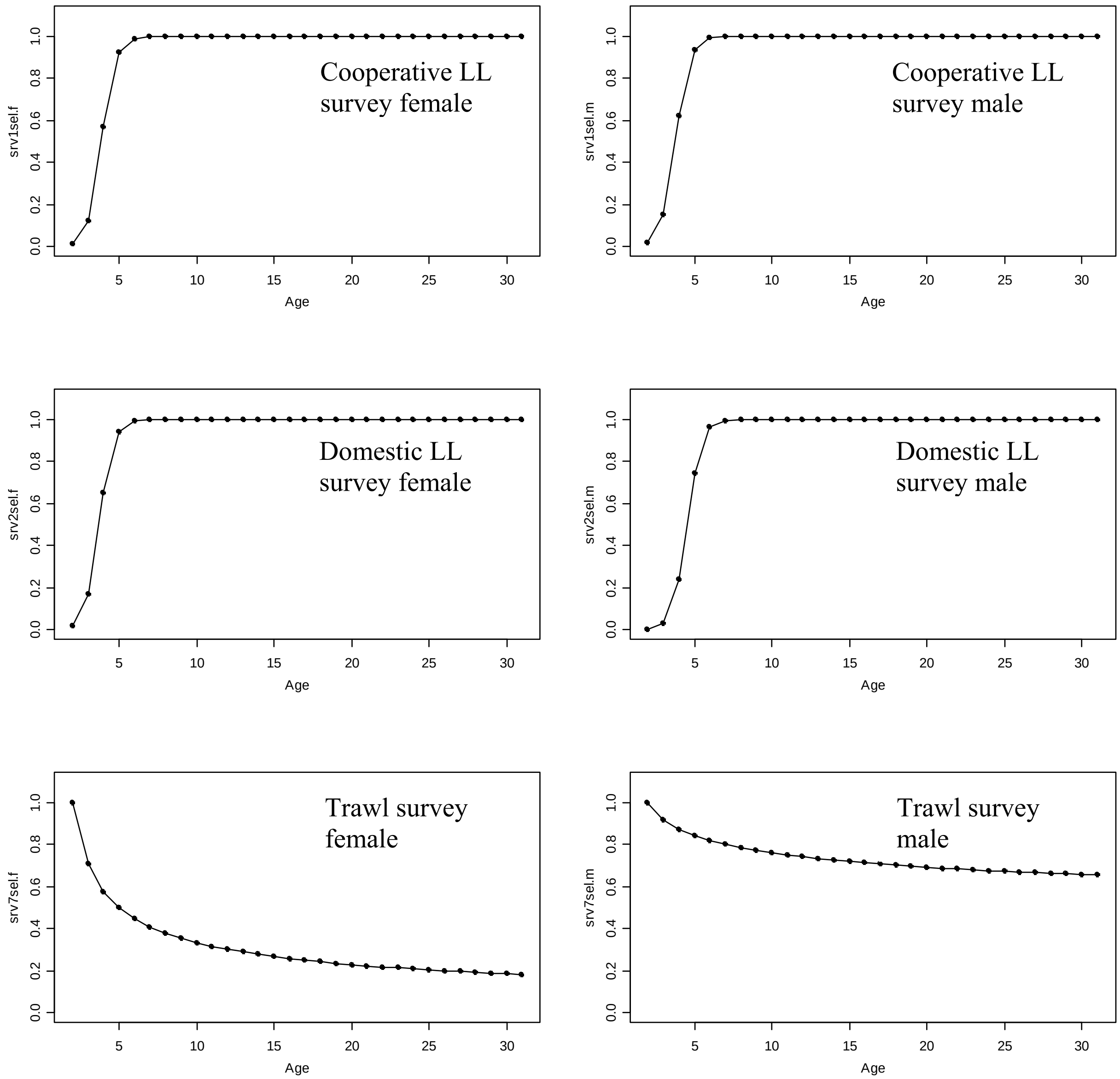


Figure 3.19b. Sablefish selectivities for surveys.

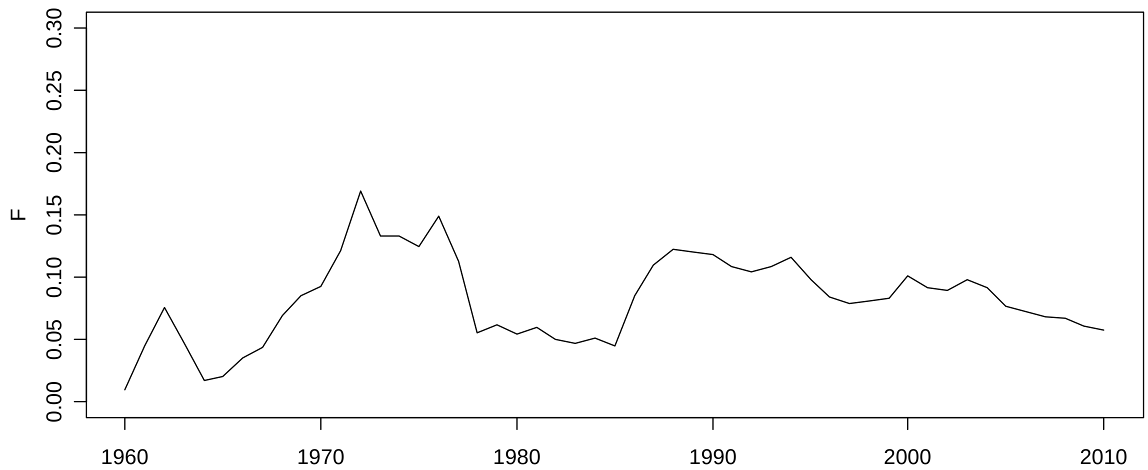


Figure 3.20. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

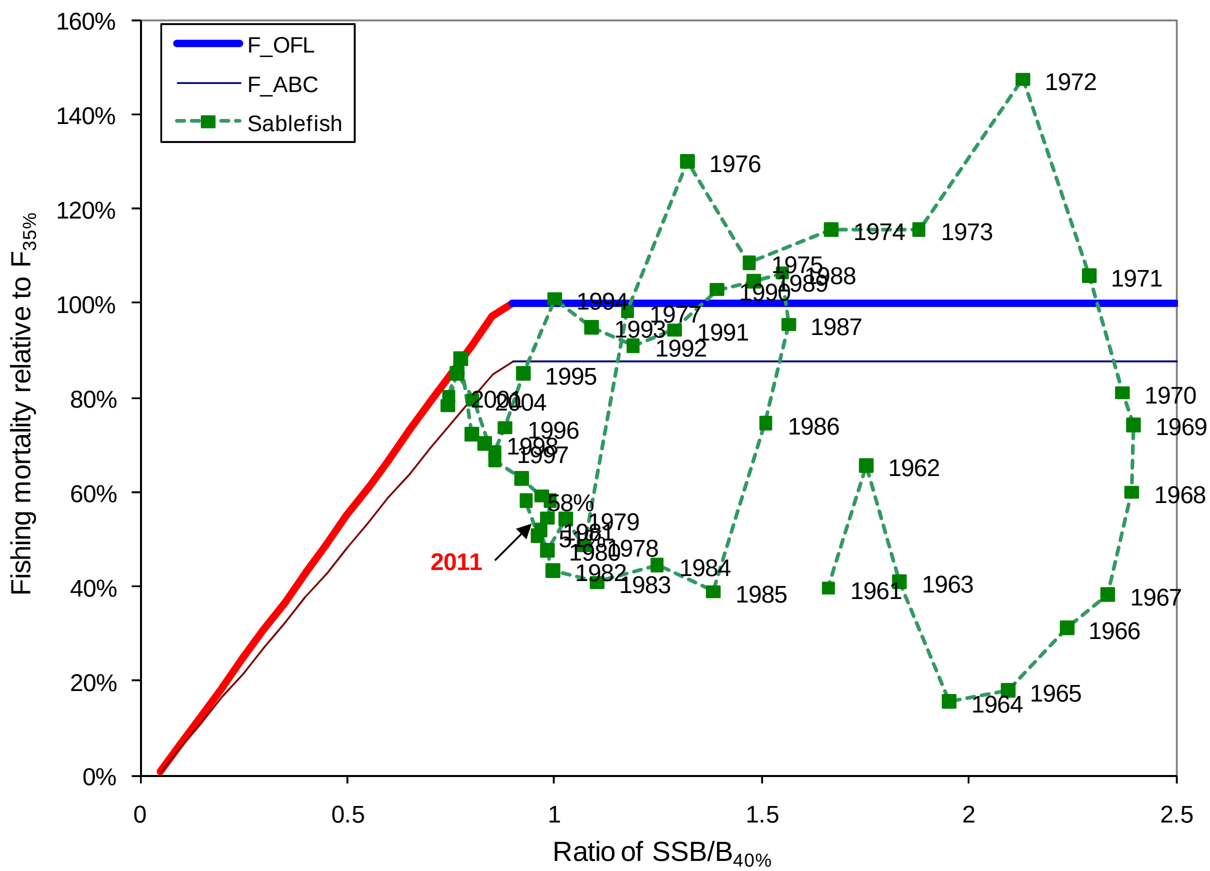
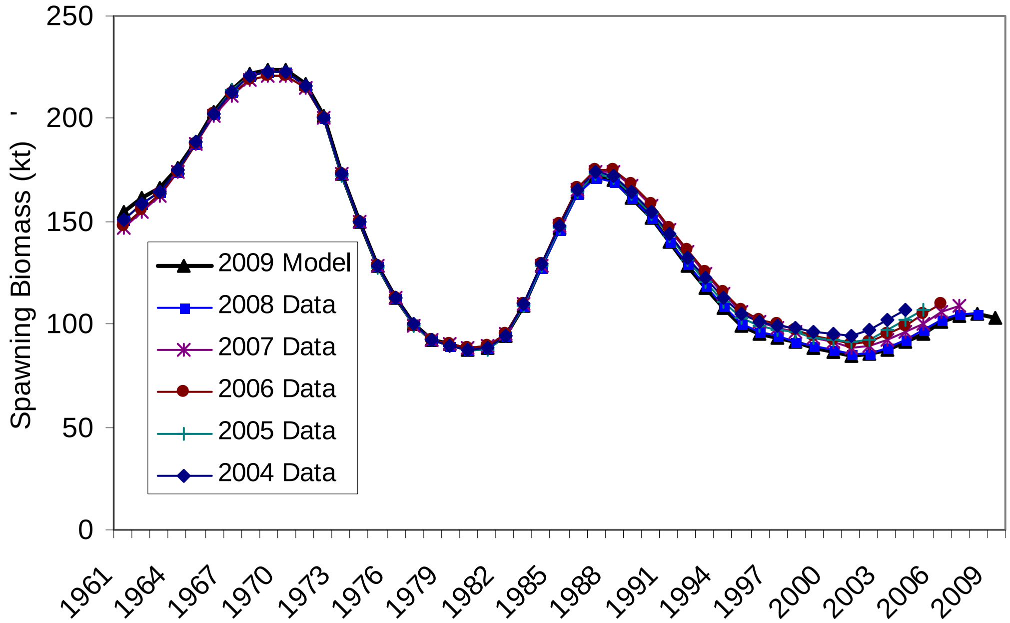


Figure 3.21. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model.



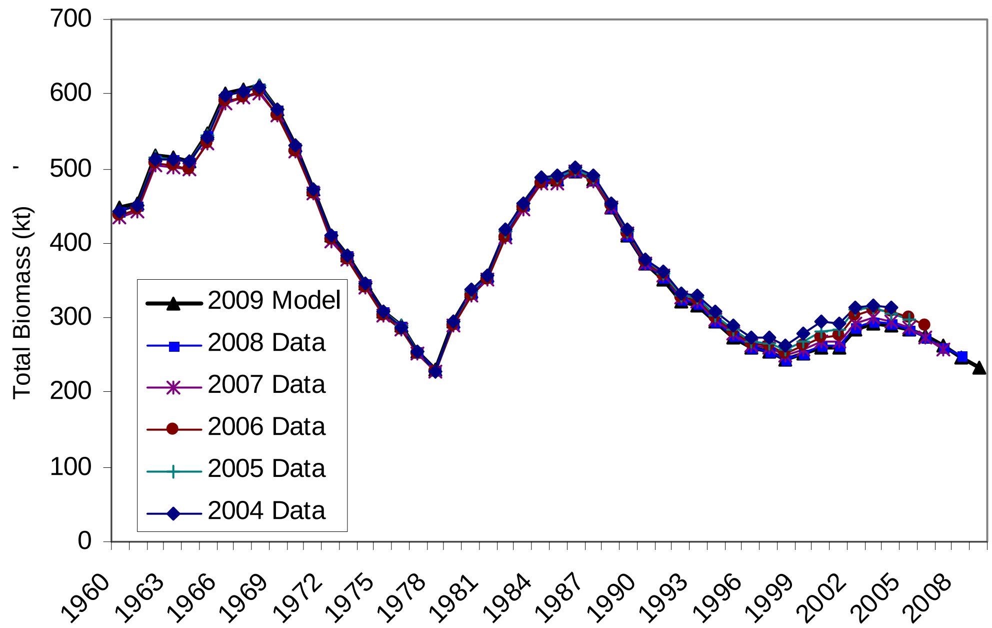
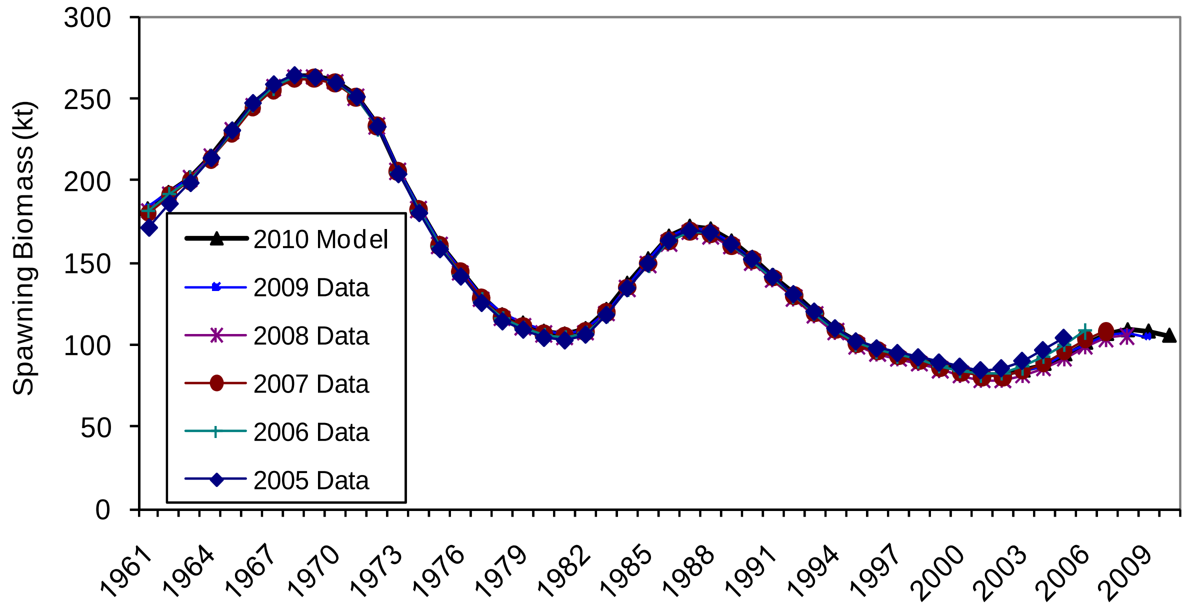


Figure 3.22a. Retrospective trends for spawning biomass (top) and total biomass (bottom) from 2004-2009.



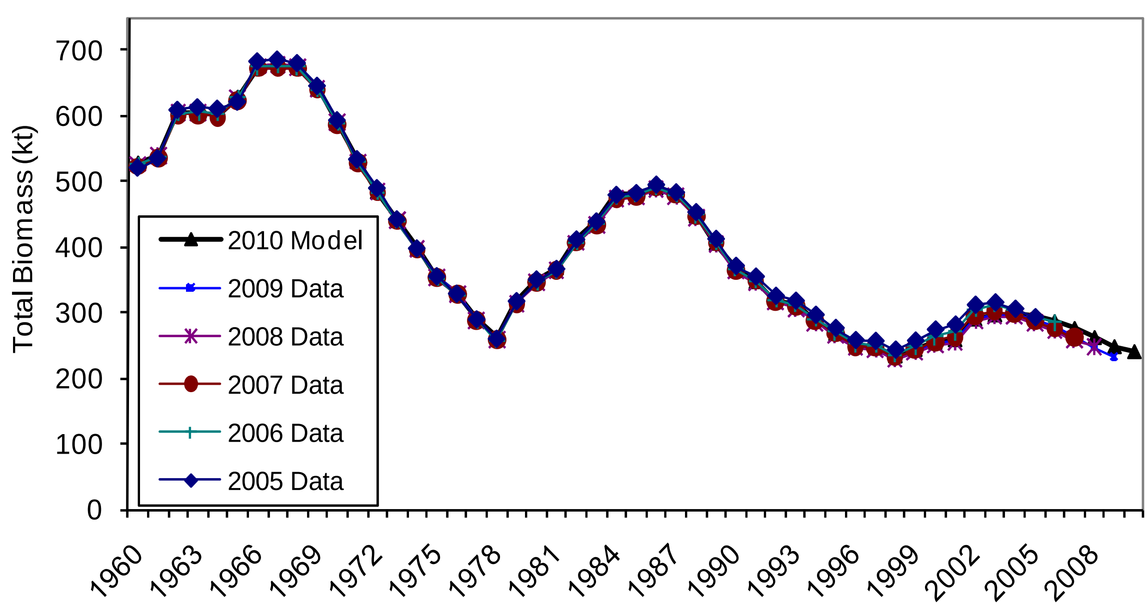


Figure 3.22b. Retrospective trends for spawning biomass (top) and total biomass (bottom) from 2005-2010.

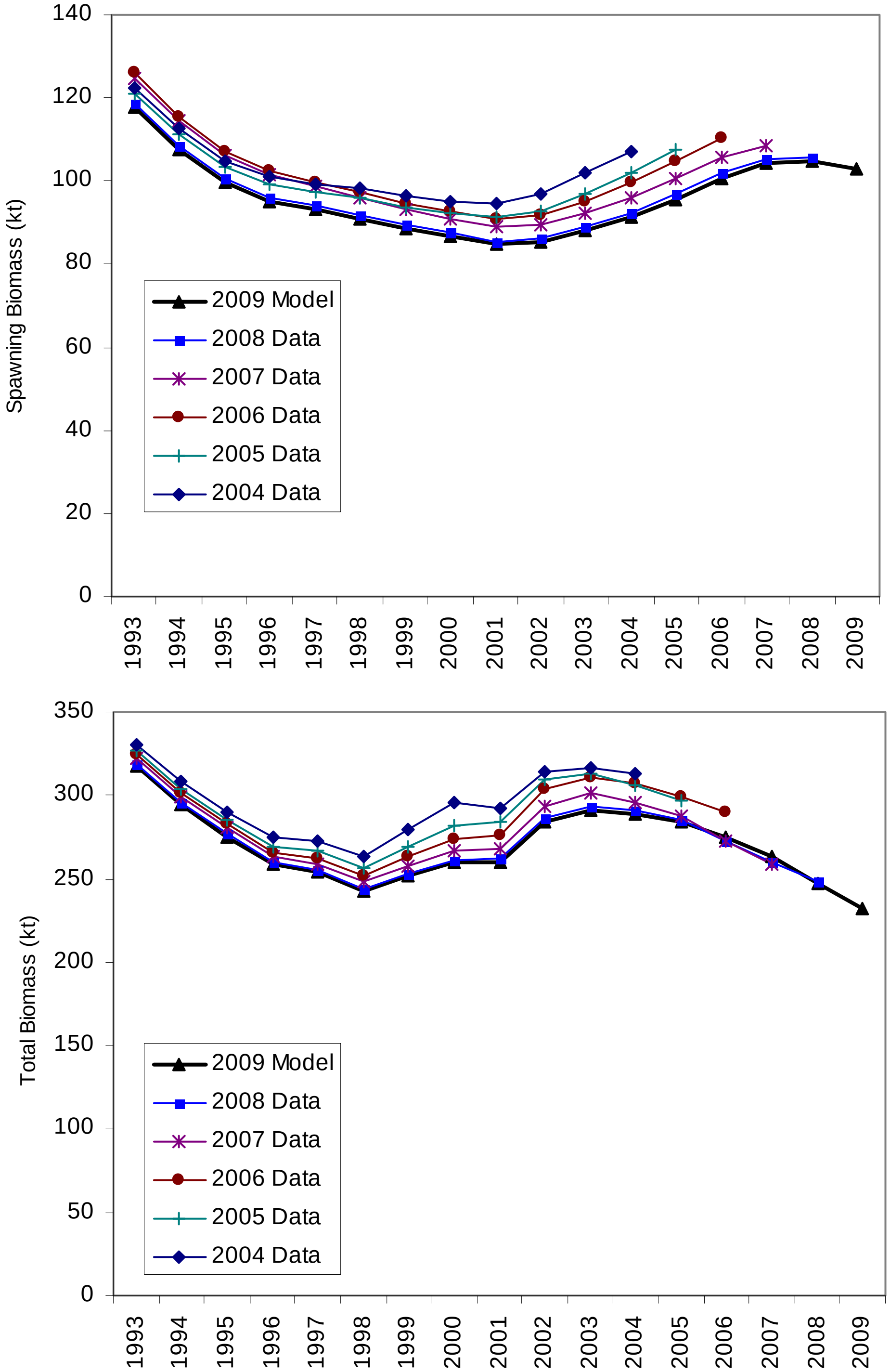


Figure 3.23a. Recent retrospective trends for spawning biomass and total biomass 2004-2009.

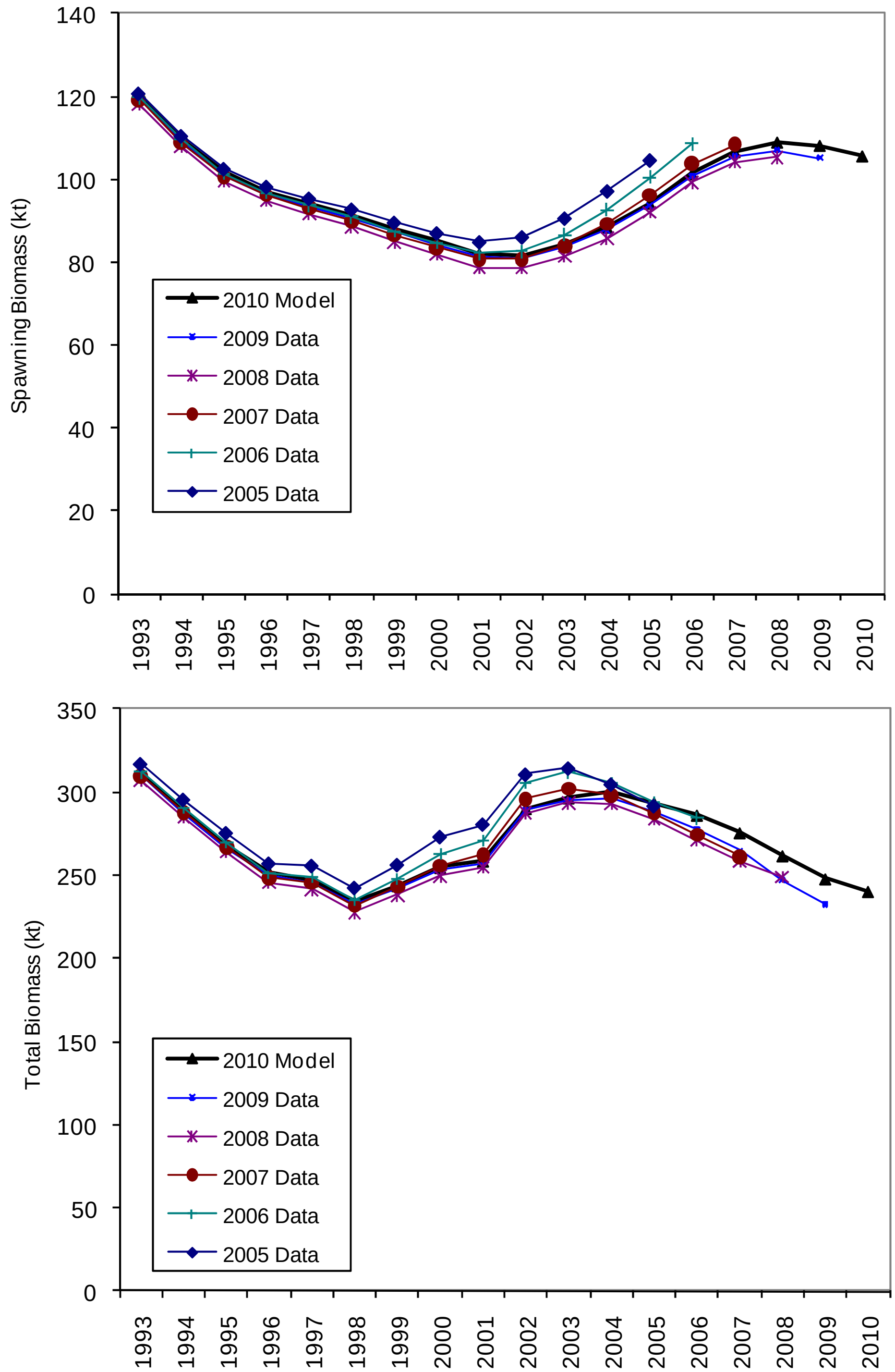


Figure 3.23b. Recent retrospective trends for spawning biomass and total biomass 2005-2010.

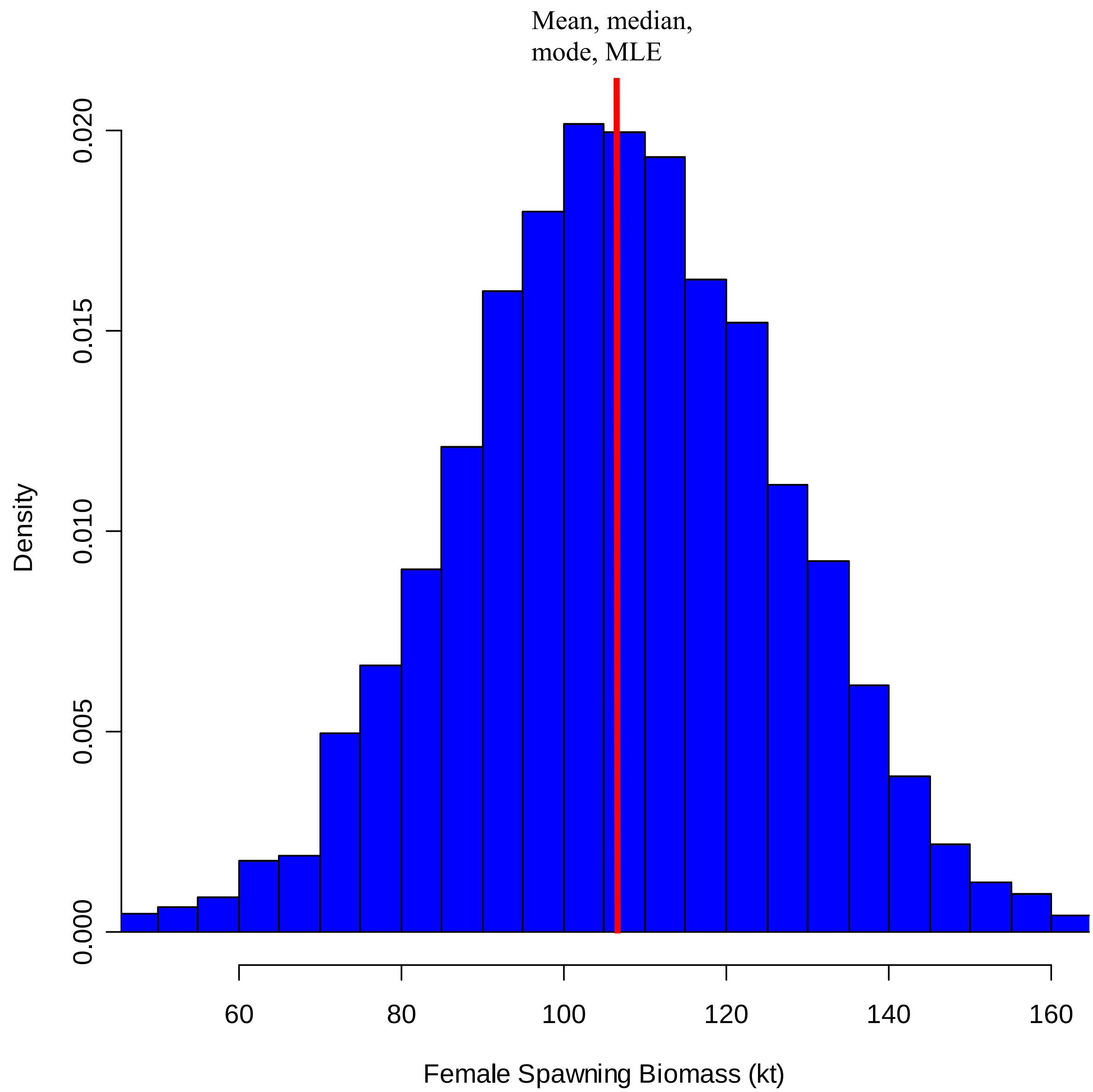


Figure 3.24. Posterior probability distribution for projected spawning biomass (thousands t) in 2011.

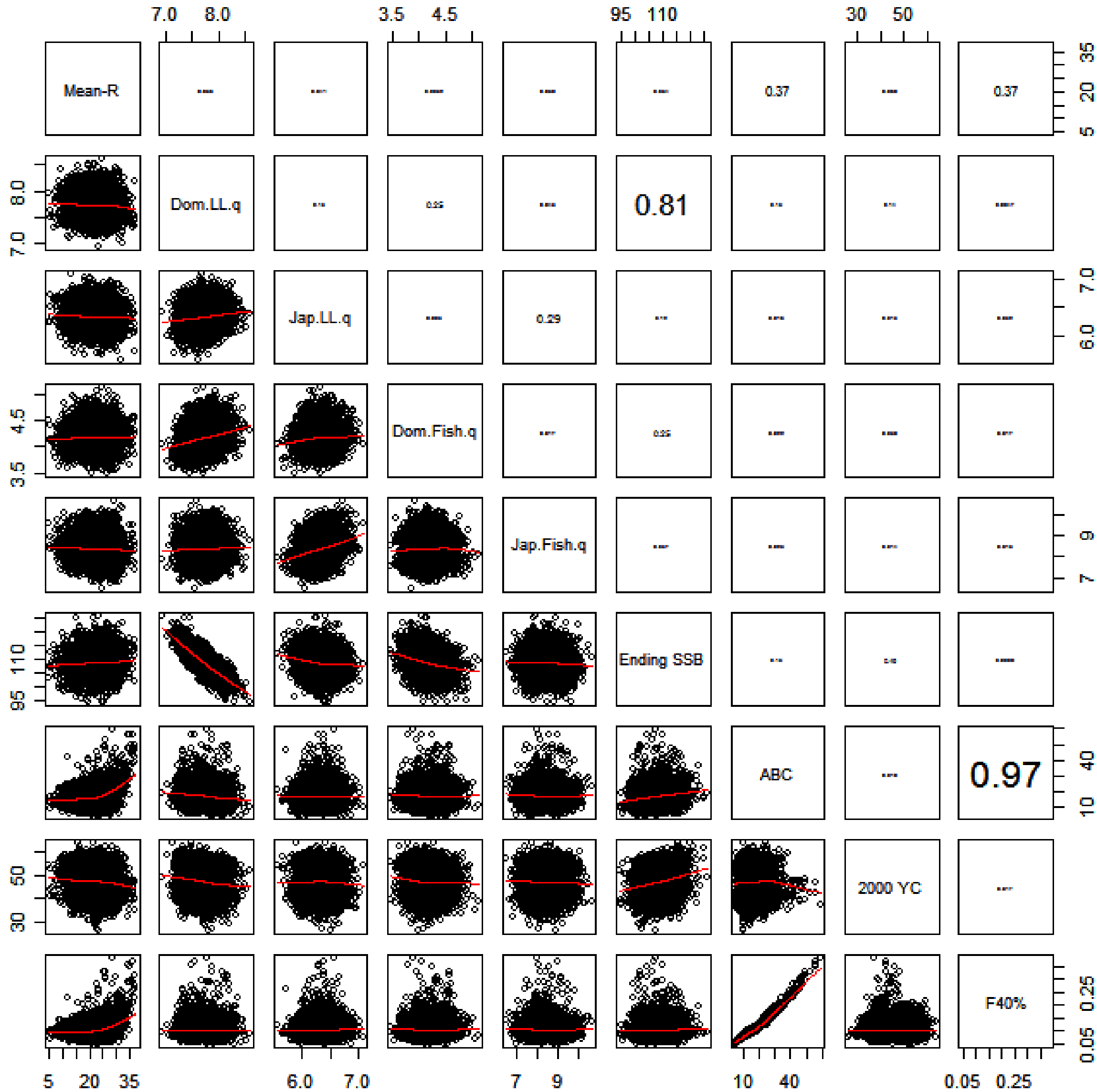


Figure 3.25. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

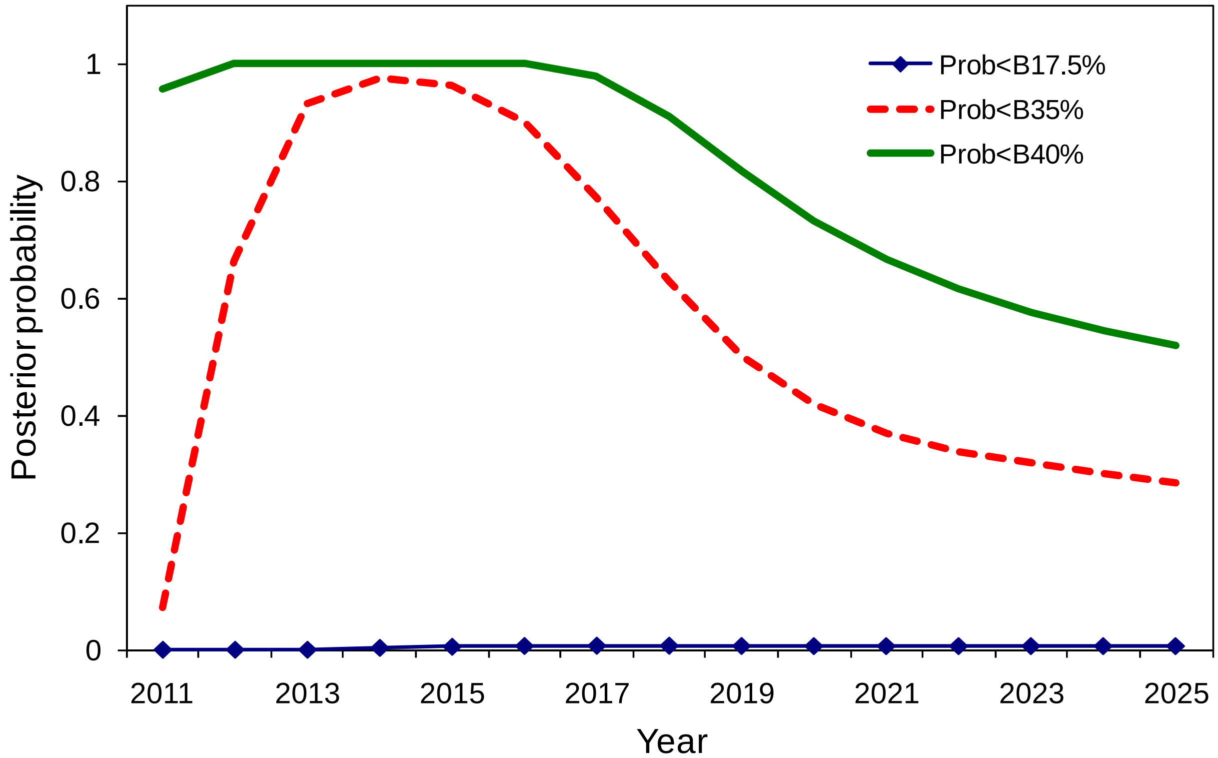


Figure 3.26. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

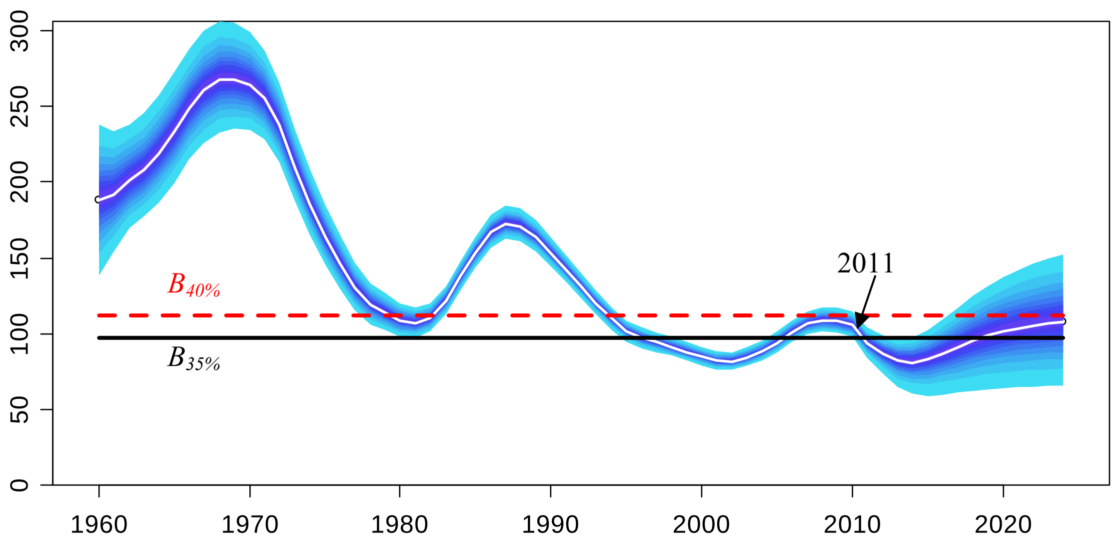


Figure 3.27. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on 10,000,000 MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is least conservative with catch at maximum permissible ABC.

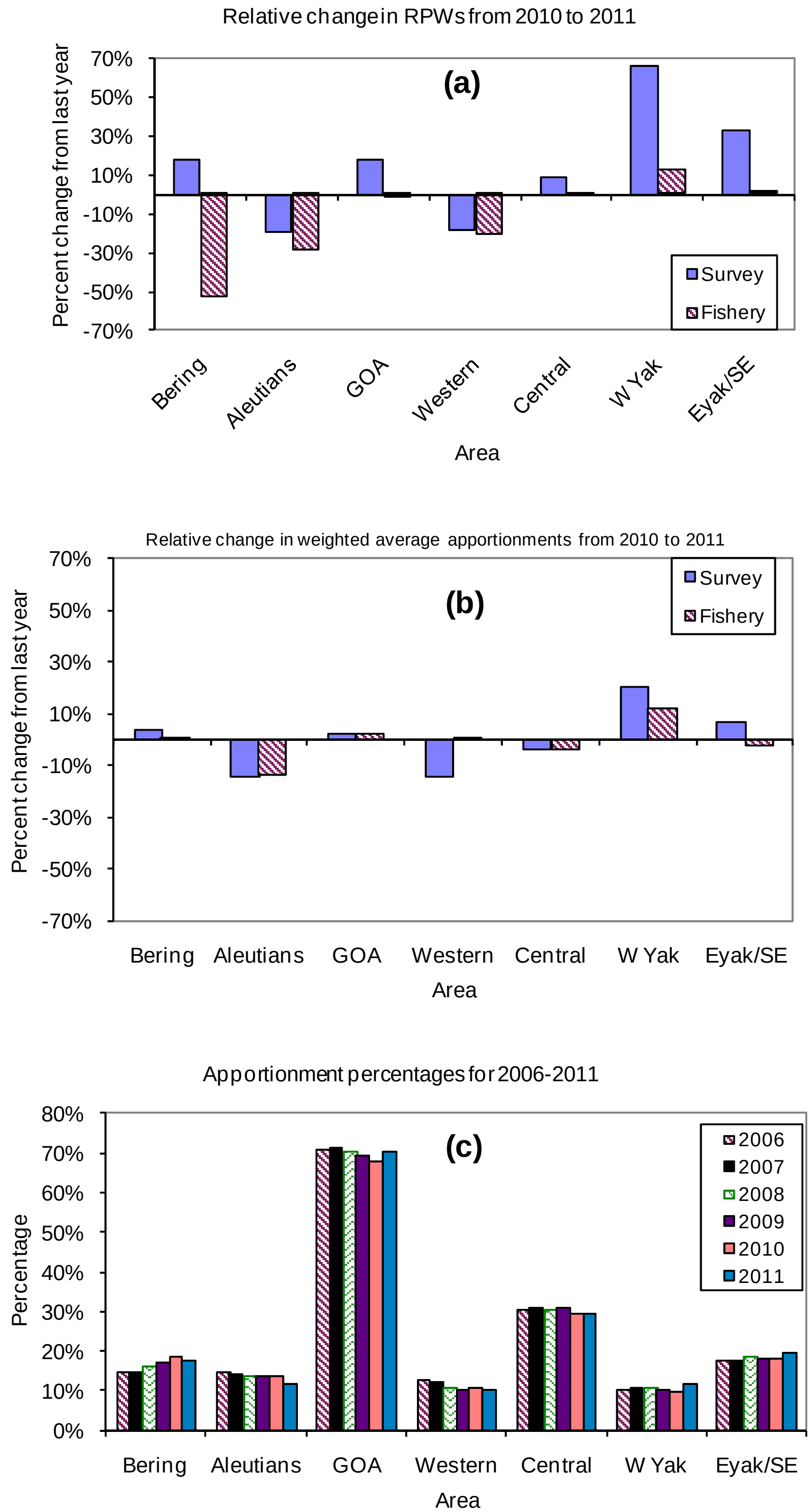


Figure 3.28. (a) The percentage change of each Relative Population Weight (RPW) index by area from 2010 apportionment to the 2011 apportionment. (b) The percentage change of the weighted average of apportionment by area. (c) The apportionment percentages by area of ABCs for 2006-2011.

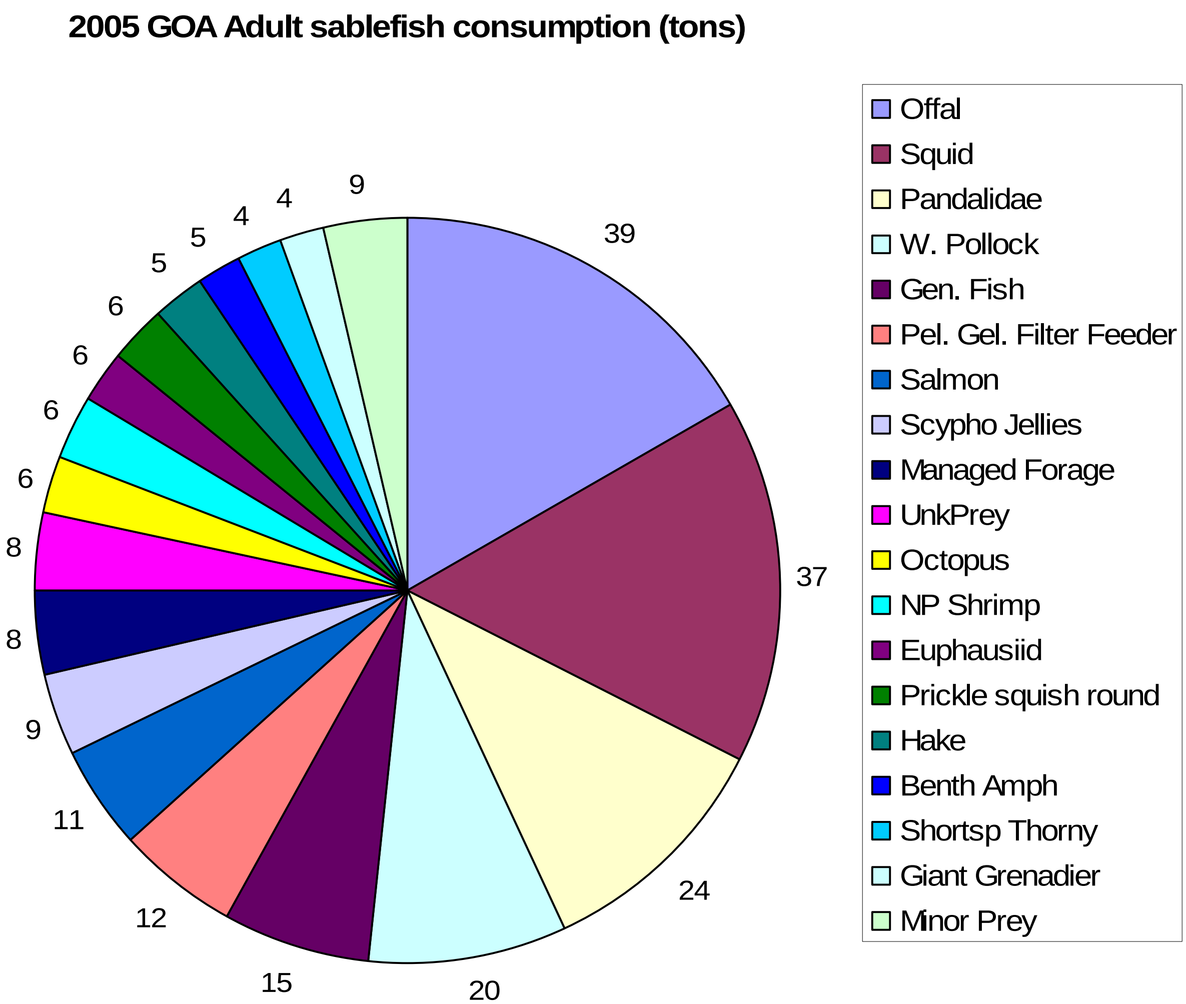


Figure 3.29. Consumption of prey in tons by sablefish in the Gulf of Alaska in 2005. Minor prey category are prey that totaled less than 4 tons of consumption.

Appendix 3A.--Sablefish longline survey - fishery interactions

NMFS has requested the assistance of the fishing fleet to avoid the annual sablefish longline survey since the inception of sablefish IFQ management in 1995. We requested that fishermen stay at least five nautical miles away from each survey station for 7 days before and 3 days after the planned sampling date (3 days allow for survey delays). Beginning in 1998, we also revised the longline survey schedule to avoid the July 1 rockfish trawl fishery opening as well as other short, but less intense fisheries.

History of interactions

Publicity, the revised longline survey schedule, and fishermen cooperation generally have been effective at reducing fishery interactions. Distribution of the survey schedule to all IFQ permit holders, radio announcements from the survey vessel, and the threat of a regulatory rolling closure have had intermittent success at reducing the annual number of longline fishery interactions.

Since 2000, the number of vessels fishing near survey stations has remained relatively low. During the past several surveys, many fishing vessels were contacted by the survey vessel and in most cases fishermen were aware of the survey or willing to help out by fishing other grounds to avoid potential survey interactions.

Longline Survey-Fishery Interactions

	Longline		Trawl		Pot		Total	
Year	Stations	Vessels	Stations	Vessels	Stations	Vessels	Stations	Vessels
1995	8	7	9	15	0	0	17	22
1996	11	18	15	17	0	0	26	35
1997	8	8	8	7	0	0	16	15
1998	10	9	0	0	0	0	10	9
1999	4	4	2	6	0	0	6	10
2000	10	10	0	0	0	0	10	10
2001	1	1	1	1	0	0	2	2
2002	3	3	0	0	0	0	3	3
2003	4	4	2	2	0	0	6	6
2004	5	5	0	0	1	1	6	6
2005	1	1	1	1	0	0	2	2
2006	6	6	1	2	0	0	7	8
2007	8	6	2	2	0	0	10	8
2008	2	2	2	2	0	0	4	4
2009	3	3	0	0	0	0	3	3
2010	2	2	1	1	0	0	3	3

Recommendation

We have followed several practical measures to alleviate fishery interactions with the survey. Trawl fishery interactions generally have decreased; longline fishery interactions have been low except in 2006 and 2007. We will continue to work with association representatives and individual fishermen from the longline and trawl fleets to reduce fishery interactions and ensure accurate estimates of sablefish abundance.

Appendix 3B.--Research survey catches (kg) by survey.

Year	Echo integration trawl	Trawl	Japan US longline survey	IPHC longline survey*	Domestic longline survey
1977		3,126			
1978	23	14,302			
1979		27,274	103,839		
1980		69,738	114,055		
1981	813	87,268	150,372		
1982		107,898	239,696		
1983	44	45,780	235,983		
1984		127,432	284,431		
1985		185,692	390,202		
1986	80	123,419	395,851		
1987		116,821	349,424		
1988		14,570	389,382		302,670
1989		3,711	392,624		367,156
1990	94	25,835	272,274		366,236
1991		3,307	255,057		386,212
1992	168	10	281,380		392,607
1993	34	39,275	280,939		407,839
1994	65	852	270,793		395,443
1995					386,169
1996	0	12,686			430,447
1997	0	1,080			395,579
1998	5	25,528		50,103	324,957
1999	0	43,224		48,648	311,358
2000	0	2,316		53,185	289,966
2001	2	11,411		47,963	326,274
2002	154	2,607		58,174	309,098
2003	141	15,737		97,815	279,687
2004	53	1,826		97,825	287,732
2005	244	17,915		91,730	254,762
2006	19	1,816		63,544	286,518
2007	8	16,670		47,845	266,477
2008	0	3,077		45,783	261,636
2009	18	14,329			242,360
2010	35	3,089			268,652

* IPHC survey sablefish catches are released and estimates from mark-recapture studies suggest that these catches are expected to produce low mortality

Appendix 3C: Development of a longline survey abundance index for Alaska sablefish

by

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Introduction

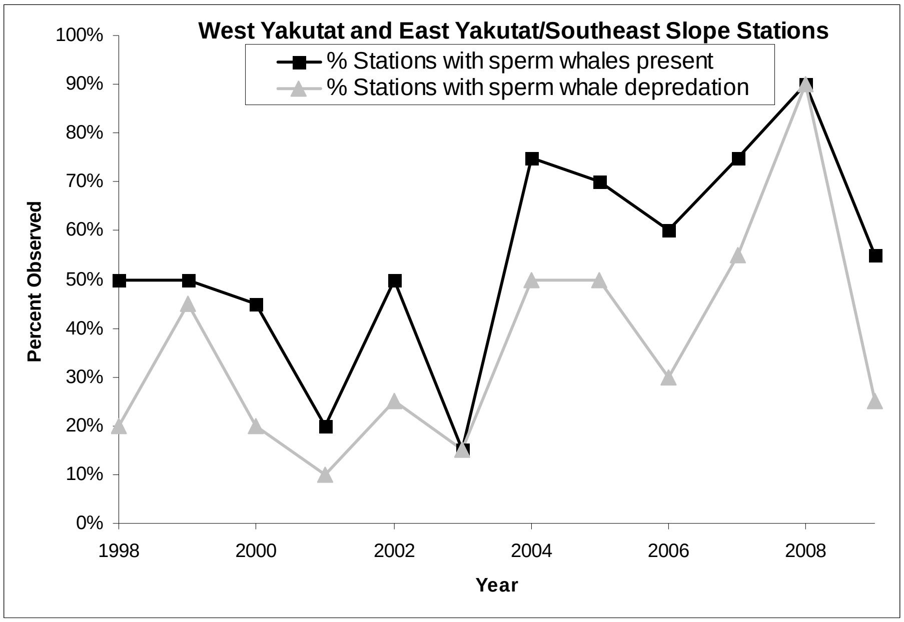
The 2009 Center for Independent Experts sablefish assessment review and the 2010 sablefish modeling workshop both recommended that a new index for the longline survey be developed using statistical methods. The justification for this recommendation was to account for killer whale and sperm whale depredation, make predictions for missing years in the Bering Sea and Aleutian Islands, and compute realistic annual standard deviations for use in the assessment model.

Previously, the index used in the sablefish assessment was computed by averaging catch-per-unit-effort (CPUE) per hachi (a skate of 45 hooks) in a depth stratum and multiplying by the area of that depth stratum in the management area. This was computed in numbers for the Relative Population Number (RPN) index and in weight developed from the length distribution and a growth curve for the Relative Population Weight (RPW) index. The Aleutian Islands and Bering Sea are sampled biennially. Unsampled years are filled in using the previous survey of the area was adjusted by the average change in the Gulf of Alaska areas, which are sampled annually, in the current survey. This approach has an obvious drawback if the six areas are relatively uncorrelated in trend. For example, when the observed mean catch/hachi is plotted by area, it is clear that the Bering Sea are not positively correlated with any of the other areas, and in fact the Aleutian Islands are significantly negatively correlated with the Central Gulf of Alaska (Figure 3C.1). Therefore, using this approach across all areas likely results in a retrospective bias because estimates in off years may not match the true underlying trend for that area.

Killer whale depredation of the survey's sablefish catches has been a problem in the Bering Sea since the beginning of the survey (Sasaki, 1987). The problem occurred mainly east of 170^{o} W in the eastern Bering Sea and to a lesser extent in the northeast Aleutians between 170^{o} W and 175^{o} W. The 1983 (Sasaki 1984), 1986, 1987 (T. Sasaki, pers. commun., Far Seas Fisheries Research Laboratory), and 1988 Bering Sea abundance indices likely were underestimated, although sablefish catches were lower at all stations in 1987 compared to 1986, regardless of whether killer whales were present.

Treatment of killer whale depredation has been consistent since 1990. Since 1990, the depredated data were excluded from the analysis by removing hachis that were identified as depredated by a combination of damaged fish and damaged hooks. On some stations this might result in a large amount of hachis being unused, or whole stations being unused. In management areas like the Bering Sea where there is limited sampling this can lead to very few stations left to calculate abundance. In addition, if killer whales are non-randomly depredating on stations where fish are typically most abundant, this can lead to a downward bias of the index.

Sperm whale depredation likely affects longline catches in the Gulf of Alaska. Sperm whale depredation has only been documented since 1998 and is primarily a problem in the two Eastern GOA management areas. Apparent sperm whale depredation is defined as sperm whales being present with the occurrence of damaged fish. As opposed to killer whale depredation, sperm whale depredation is much more difficult to detect because they take fewer fish than killer whales, and rarely leave behind damaged fish like killer whales. Because actual depredation is difficult to detect, and is not documented by hachi, we use sperm whale presence at a station as a proxy for depredation. Sperm whales are most commonly observed in the Central and Eastern Gulf of Alaska (98% of sightings); the majority of interactions occur in the West Yakutat and East Yakutat/Southeast areas. Sperm whale presence and evidence of depredation has been variable since 1998. A plot of the percentage of sampling days that sperm whales were present and depredating in the West Yakutat and East Yakutat/Southeast slope stations combined is below:



Occurrence of depredation in the Eastern GOA slope stations has ranged from 10% of sampling days that sperm whales were present in 2001 to 90% in 2008. Sperm whales have often been present but not depredating on the gear, except in 2003 and 2008 when depredation occurred every time sperm whales were observed. An early study using data collected by fisheries observers in Alaskan waters found no significant effect on catch (Hill et al. 1999). In the 2002 SAFE, an analysis was done using longline survey data from 1998-2001 and found that sablefish catches were significantly less at stations affected by sperm whale depredation. This work was redone in 2006 using additional data from 2002-2004 which were analyzed by fitting the data to a general linear model (Sigler et al. 2007). Neither sperm whale presence (p = 0.71) nor depredation rate (p = 0.78) increased significantly from 1998 - 2004. Catch rates were about 2% less at locations where depredation occurred, but the effect was not significant (p = 0.34). This analysis has been updated through 2009 and now shows a significant effect of approximately four kilograms per hundred hooks for stations in the CGOA and EGOA, which translates into approximately a 2% decrease in the overall catch rates in those areas (J. Liddle pers. comm.). Another study using data collected in southeast Alaska, found a small, significant effect comparing longline fishery catches between sets with sperm whales present and sets with sperm whales absent (3% reduction, 95% CI of (0.4 – 5.5%), t-test, p = 0.02, Straley et al. 2005). Results of these studies are summarized in the following table:

Study	Measurement	Amount of depredation	Significance
Hill et al. 1999	Fishery by set	3%	No
Sigler et al. 2002	Depredation by station	23%	Yes
Straley et al. 2005	Presence by station	3%	Yes
Sigler et al. 2007	Depredation by station	2%	No
Liddle pers. comm..	Depredation by station, decrease in total	2%	Yes

The longline survey catch rates were not adjusted for sperm whale depredation in the past because we do not know when measureable depredation began during the survey time series, some studies of depredation on the longline survey showed no significant effect, and because sperm whale depredation is difficult to detect (Sigler et al. 2007). Because of recent increases in presence at survey stations and depredation in the survey, as indicated by significant results of recent studies, we investigate a statistical adjustment to the survey catch rates in this study.

The longline survey index currently uses a fixed CV of 5% in the stock assessment model. Bootstrap analyses were conducted to arrive at this number (Sigler 2000), but it may not reflect that the survey is a systematic design and that there is autocorrelation within a station. In this study, we aim to capture interannual variability as well as other unaccounted for uncertainties.

In this study, we apply and compare a set of modeling approaches to the domestic longline survey data. Due to lack of computing power, it was not possible to fit a global model of all areas simultaneously, so each area was fitted separately. This does not take advantage of the "borrow strength from other data" idea, unfortunately, but we will attempt to address the computing power issue later. We show detailed methods and results of two areas, the East Yakutat/Southeast Outside which represents heavy sperm whale presence, and the Western Gulf of Alaska which represents annual surveys and recent high killer whale depredation.

Methods

The recommendation from the CIE and modeling workshop was to use a regression approach from the family of generalized linear models (GLMs, McCullagh and Nelder 1989). A GLM is used when the typical assumptions of standard linear regression are not met. The use of these types of models for modeling CPUE has been increasing and is common outside of Alaska (e.g., Maunder and Punt 2004, Venables and Dichmont 2004). The most important distinction of a GLM is the ability to model the response variable with a distribution other than Gaussian (normal). Secondly, although the predictors are related to the response linearly, they are not necessarily "linked" together through a linear relationship. For example, using categorical explanatory variables like depth strata, we can fit a dome-shaped effect from shallow to deep.

One of the recommendations of the CIE review and the workshop was to choose whether to use an index in weight or numbers. Since the survey catch is fully enumerated, we chose to model numbers. Modeling count variables is a common task in various scientific fields. The Poisson regression model for count data is usually the first and obvious choice but is often of limited use because empirical count data sets typically exhibit over-dispersion and/or an excess number of zeros (Zeileis et al. 2008). Over-dispersion can be addressed by extending the standard Poisson regression model to a quasi-Poisson model which estimates an additional dispersion parameter which then scales the variance. Another more formal way is to use a negative binomial (NB) regression of which the Poisson is a special case (one less parameter). These models typically can capture over-dispersion, but do not perform well when there are excess zeros which is common in fisheries data. Since Mullahy (1986) and Lambert (1992) there is increased interest, both in the fisheries and statistics literature, in zero-augmented models that address this issue by a second model component capturing zero counts (Zeileis et al. 2008). Hurdle models (Mullahy 1986) combine a left-truncated count component with a right-censored hurdle component. Zero-inflation models (Lambert 1992) take a somewhat different approach: they are mixture models that combine a count component and a point mass at zero. Generalized Linear Mixed Effect Models (GLMMs, Zuur et al. 2009) were also considered because of their ability to automatically incorporate the autocorrelation within stations as random effects, but found to be computationally intractable for this size data set.

In this study, we compare five of these model types summarized in Table 3C.1. In this document, we show two complete examples of single area only models, one with sperm whale depredation (Southeast Outside/East Yakutat) and one with killer whale depredation (Western Gulf of Alaska).

The model we intended to use for an overall index was as follows:

$$Catch_{ijklm} = \alpha + Spw_{ijkl} x\ Area_{ij} + Kiw_{ijklm} x\ Area_{ij} + Year_i\ x\ Area_{ij}\ x\ Stratum_{ijk} + Year_i\ x\ Stratum_{ijk}\ x\ Station_{ijkl} + \epsilon_{ijklm}$$

Where α is the intercept, $Catch_{ijklm}$ is number of sablefish per hachi in *Year i*, *Area j*, depth *Stratum k,* and *Station l*, and hachi *m, Spw* is sperm whale presence (at station level), *Kiw* is killer whale depredation (at hachi level), and ϵ_{ijklm} are the residuals. This would allow for area specific whale effects, and ensure appropriate level of variation is included to the station level, which is the main level of replication. Due to computational limitations, we were unable at this time to fit the full model of all areas simultaneously.

The models we fitted for the individual areas presented in full in this document are as follows:

$$Catch_{iklm} = \alpha + Spw_{ikl} + Year_i\ \ x\ Stratum_{ik} + \ Station_{ikl} + \epsilon_{iklm} \qquad \text{(SEO/EY)}$$

$$Catch_{iklm} = \alpha + Kiw_{iklm} + Year_i\ \ x\ Stratum_{ik} + \ Station_{ikl} + \epsilon_{iklm} \qquad \text{(WGOA)}$$

These two areas were chosen because they represent full time series of data with different types of whale depredation. We fitted interactions between year and stratum, but many models would not converge when adding station interactions, so we set station as an independent fixed effect and station interactions were not included. The reason we would have modeled the station interaction is to fully capture that additional variability and so that we would recover the observed means exactly, while isolating the whale effect. Models were fitted with the statistical software R 2.10 (R Development Core Team 2009) and the packages `pscl` (Zeileis et al. 2008) and `MASS` (Venables and Ripley 2002).

We compared between model types using AIC and BIC where available (unavailable for quasipoisson), and used the Wald test to compare between Poisson and quasipoisson. We fitted all fifteen sub-areas, but do not show all individual results here. Instead, we show aggregated results by management areas graphically, and all areas combined compared with the current RPN estimates. We have not developed an elegant method for filling in missing years in the Bering Sea and Aleutian Islands at this time, but we use the trend from the Western GOA to fill in as opposed to the entire Gulf of Alaska because WGOA is at least not negatively correlated with these areas and it is closest in proximity.

Results

The catch data in the SEO/EY area clearly violates the typical Poisson distribution and has too many zeros for either the Poisson or the negative binomial (NB) alone (Figure 3C.2). When we fit the catch data with Poisson, quasipoisson, and negative binomial, the negative binomial provides a much improved fit, in terms of both AIC and BIC, because of its better treatment of the over-dispersion (Table 3C.2). It also fits more zeros than Poisson but far less than the actual number of zeros (874 versus 3090 in Table 3C.2). Thus, evidence from Figure 3C.2 and Table 3C.2 suggest the use of zero-augmented models. This requires the estimation of many more parameters to fit the zero-inflation part of the model, but AIC and BIC take this into account for comparisons. The Zero-Inflated Negative Binomial (ZINB) fits better than the standard negative binomial and produces very close to the correct number of zeros. The Zero-Augmented Negative Binomial (ZANB) by nature produces the exact number of zeros but does not fit the overall data quite as well. By these criteria, we chose the ZINB model to continue for producing the index and estimating effects of whales on the index. However, upon trying to fit more areas, we found that the ZINB model had convergence problems in 11 of 15 subareas. The ZANB model had similar problems. This led us to choose the NB GLM model, which still fitted considerably better than the

Poisson/quasipoisson (Tables 3C.2 and 3C.3) in all areas, and not much differently than the ZINB model relative to the difference in AIC between Poisson and NB. The choice of model type was robust with respect to the estimated whale effects except for in the Bering Sea where the ZINB model gives a very large estimate of killer whale effect (Table 3C.3). The ZANB and ZINB models had better fits to the data when they converged, but were unreliable and sometimes converged only to produce nonsensical results.

Adding the killer whale depredation and sperm whale presence data as a factor was highly significant (Table 3C.2), and gave a better AIC and BIC than the null model, therefore we chose to include the whale data in the final index for the area. In Table 3C.3, we show the whale effect in some of the areas by depredation type. The number presented is the multiplier of the station/hachi with or without whale effects. For example, the 1.20 in Southeast implies that when a sperm whale is present, predicted catches at that station are adjusted by 20%, not the whole area. The sperm whale depredation estimates are consistent across models, but varied slightly by area. Killer whale depredation effects were much higher and varied more between models both in relative and absolute terms (Table 3C.3). Overall, given the better AIC than the Poisson and lack of convergence problems, the NB model seems to capture the depredation types well. Therefore, we use only the NB model in the remainder of the results.

By making predictions of the index with and without whale depredation, the net effect of whales on the index can be produced (Figures 3C.3 and 3C.4). The ratio of the index with and without the whale effect shows the relative effect (Figure 3C.5). Clearly, killer whales in the Western Gulf have a much larger effect than sperm whales in the east, which was expected because killer whale depredation is obvious and they take much of the catch, and depredation was specifically documented directly. Sperm whale presence has an effect from 0-11% between 1998-2009 for the SEO/EY area. Killer whales had an effect 6%-55% in the Western GOA area since 2000 (Figure 3C.5).

General results by area

Approximate 95% confidence intervals were computed for four of the six areas. These were computed as normal symmetric intervals using plus or minus two times the standard error of the GLM predictions at the station level. These intervals should capture the variability of the catch data, but lack the covariance structure of the whale depredation and between strata, and do not incorporate the autocorrelation in the data by hachi. For these reasons they are likely a lower bound on the true uncertainty.

Bering Sea

The Bering Sea abundance estimates are affected by killer whale depredation. The model and traditional RPN estimates are in good agreement except in 2009 (Figure 3C.6). In 2009, depredation was pervasive and led the assessment authors to make an *ad hoc* correction because of the 75% decline in abundance that was deemed unlikely. The model clearly handles this depredation well by comparison with a more reasonable drop in abundance. Confidence intervals were inestimable for one of the subareas, so they were not presented here.

Aleutian Islands

The Aleutian Islands are another area affected by killer whale depredation, but not to the same extent as the Bering Sea. The model and the traditional RPN handle the data in different ways, but appear to indicate a similar amount of killer whale effect, with slightly more in 2009 (Figure 3C.7). In 1996, the NE Aleutians were not sampled for logistical reasons, and is not corrected here but is corrected in the all area index. Confidence intervals were inestimable for one of the subareas, so they were not presented here.

Western Gulf of Alaska

Killer whales are a more recent phenomenon in the WGOA. The model and traditional RPN are consistent until 2003, where the estimates diverge due to an increase in killer whale depredation (Figure 3C.8). The model estimates the effect of killer whale depredation with greater magnitude in 2004 but lesser magnitude in the rest of the recent years when compared to the traditional RPNs. The year 2005 is the only year in which the two indices are significantly different.

Central Gulf of Alaska

The Central GOA estimates between the traditional RPN and the model RPN are identical (Figure 3C.9). Confidence intervals show that interannual variability is consistent. Both types of whales have started to be observed in the Central Gulf of Alaska, but so far appear to have minimal impact. Confidence intervals show that interannual variability is consistent.

West Yakutat

Sperm whale presence is common and has generally increased over time since 1998, and in 2008 sperm whales were observed at all stations. The model shows a correction for this since 2002. The model and traditional RPNs are in good agreement in recent years, but show a perplexing divergence in the early 1990s (Figure 3C.10).

Southeast Outside/East Yakutat

Sperm whale presence is common and has generally increased over time in this area. Starting in 2001, sperm whale presence increased and also began to affect model estimates. By 2005, the effect of sperm whales on the RPNs had increased and continued to remain high (Figure 3C.11). One incidence of killer whale depredation occurred in 2006 in Dixon Entrance which influenced that subarea, but only had a small influence on the overall SEO/EY index.

All Alaska Index

The overall index matches fairly close to the traditional RPN calculation until 2002, when whale effects begin to differentiate the indices (Figure 3C.12). The modeled index indicates that the recent years were not as low as suggested by the traditional RPN calculation, particularly in 2008 and 2009. We ran the 2009 stock assessment model with RPNs and not RPWs (the author recommended model for 2010), as suggested by the CIE and sablefish modeling workshop. We compared spawning biomass trajectories from this model run with a model run using the modeled index from this study. When the modeled index is applied in the assessment model, it results in an increase in current spawning biomass of approximately 10% (Figure 3C.13).

Uncertainty

The predicted coefficients of variation by year are consistent among years (Figure 3C.14) and are on the order of the CV previously determined by bootstrapping and used in the model (5%). Between areas there are some differences, with the Central Gulf of Alaska having the lowest CV and Southeast Outside/East Yakutat having the highest CV (Figure 3C.15). However, the differences are generally not large. The variance here is approximated with the delta method at the station level on the response scale and is symmetric. A more realistic variance should be calculated that extracts the covariance structure and is asymmetric, but this has not been attempted yet. These preliminary results indicate it is reasonable to tentatively proceed with an overall CV of 5%.

Discussion

The modeling framework presented here is still preliminary. However, it seems to do a satisfactory job in both representing the observed data and accounting for both types of whale depredation. There remain several questions as to whether to utilize this index in the assessment model. First, it may not be prudent to adjust for whale depredation in the survey and increase the estimates of spawning biomass and ABC, while still not accounting for the additional mortality in the fishery that can be attributed to whale depredation. We regard accounting for this additional mortality as the second phase of this project to accomplish with similar modeling efforts. We also do not know the extent of sperm whale depredation prior to 1998 in the survey. Considering its apparent increase, we believe historically it may have been a minor impact.

Second, we have yet to determine an appropriate methodology for filling in missing years in the BS/AI management areas. We can continue using prior approaches, or come up with an additional statistical model to fill in these areas. An alternative is to fit the areas separately in the assessment model, and let the model predict the missing years and sum them to the full population. Another consideration is the potential move to a spatially explicit model where these individual modeled indices might be used independently.

Another caveat is that in this analysis we are treating each hachi as an independent subsample of each station mean, where there is almost certainly autocorrelation along each set. This is likely a minor effect on the estimates of abundance, but incorporating autocorrelation could change the variance structure. In addition, there is covariance and possibly whale interactions between strata that needs to be explored. Computing power was an issue when attempting to run global models (the full data set is >500,000 rows). Another approach might be to write the final selected model in AD Model Builder, or to integrate the index estimation directly into the assessment (Maunder 2001). Finally, if we were to use the modeled RPNs in the assessment model that incorporate whale effects, we need to consider whether it is appropriate to use these in the area apportionments as well.

In summary, we believe this is a useful approach for incorporating additional factors that may influence survey estimates of abundance. New research is currently underway to identify actual sperm whale depredation at higher resolution, but in the interim, we believe these methods are the best solution. We will continue to pursue these modeling efforts if they are deemed appropriate by management.

References

Hill, P. S., Laake, J. L., and Mitchell, E. 1999. Results of a pilot program to document interactions between sperm whales and longline vessels in Alaska waters. NOAA Tech. Memo. NMFS-AFSC-108. 42 p.

Lambert D. 1992. Zero-inflated Poisson Regression, With an Application to Defects in Manufacturing. Technometrics, 34, 1-14.

Maunder, M.N., Punt, A.E., 2004. Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70, 141–149.

Maunder, M.N., 2001. A general framework for integrating the standardization of catch per unit of effort into stock assessment models. Can. J. Fish. Aquat. Sci. 58, 795–803.

McCullagh, P. and Nelder J.A.1989. Generalized Linear Models. Chapman & Hall, London, 2nd edition.

Mullahy, J.1986. Specification and Testing of Some Modified Count Data Models." Journal of Econometrics, 33, 341-365.

R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Sasaki, T. 1984. Condition of sablefish stock in the eastern Bering Sea, Aleutian Islands region, and the Gulf of Alaska in 1983. Unpubl. Rep., 18 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Sasaki, T. 1987. Stock assessment of sablefish in the eastern Bering Sea, Aleutian Islands region, and the Gulf of Alaska in 1987. Unpubl. Rep., 33 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Sigler, M. F. 2000. Abundance estimation and capture of sablefish, *Anoplopoma fimbria*, by longline gear. Can. J. Fish. Aquat. Sci. 57: 1270-1283.

Sigler, M.F., Lunsford C.R., Straley, J.M. and Liddle, J.B. 2007. Sperm whale depredation of sablefish longline gear in the northeast Pacific Ocean. Mar. Mammal Sci. doi:10.1111/j.1748-7692.2007.00149.

Straley, J., O'Connell, V., Mesnick, S., Behnken, L. and Liddle, J.B. 2005. Sperm Whale and Longline Fisheries Interactions in the Gulf of Alaska. North Pacific Research Board R0309 Final Report, 15 p.

Venables W.N. and Ripley B. D. 2002. Modern Applied Statistics with S. Springer-Verlag, New York, 4th edition.

Venables WN, Dichmont CM. 2004. GLMS, GAMs and GLMMs: an overview of theory for applications in fisheries research. Fisheries Research 70: 319-337.

Zeileis, A, Kleiber C., and Jackman S. (2008). Regression Models for Count Data in R. Journal of Statistical Software 27(8). URL http://www.jstatsoft.org/v27/i08/.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., and Smith, G.M. 2009. Mixed effects models and extensions in ecology with R. Springer, New York. 574 pp.

Table 3C.1. Overview of discussed count regression models. All GLMs use the same log-linear mean function ($\log(\mu) = x^{T}\beta$) but make different assumptions about the remaining likelihood. The zero-augmented models extend the mean function by modifying the likelihood of zero counts. Table adapted from Zeileis et al. (2008).

Type	Distribution	Method	Description	
GLM	Poisson	ML	Poisson regression: classical GLM, estimated by maximum likelihood (ML)	$f(y;\mu) = \frac{\exp(-\mu) * \mu^{y}}{y!}$
		quasi	"quasi-Poisson regression": same mean function, estimated by quasi-ML (QML), inference adjustment via estimated dispersion parameter	$f(y;\mu,\phi) = \phi\frac{\exp(-\mu) * \mu^{y}}{y!}$
	NB	ML	NB regression: extended GLM, estimated by ML including additional shape parameter	$f(y;\mu,\theta) = \frac{\Gamma(y+\theta)}{\Gamma(\theta) * y!} * \frac{\mu^{y} * \theta^{\theta}}{(\mu+\theta)^{y+\theta}}$
	Poisson	ML	zero-inflated Poisson (ZIP), hurdle Poisson (ZAP)	
zero-augmented	NB	ML	zero-inflated NB (ZINB), hurdle NB (ZANB)	

Table 3C.2. Comparison of model configurations for management area Southeast Outside/East Yakutat (SEO/EY) and Western Gulf of Alaska. ML = maximum likelihood, NB=negative binomial, ZANB=Zero-altered negative binomial, ZINB=zero inflated negative binomial. Standard errors and p-values are in parentheses. The lower shaded half of each section of the table is the presence/absence part of the zero inflated model.

	No whales					Whales
	Southeast Outside/East Yakutat					
Type	GLM			zero-augmented		
Distribution	Poisson		NB	ZANB	ZINB	ZINB
Method	ML	quasi	ML	ML	ML	ML
Intercept	0.704	0.704	0.715	0.903	0.851	0.792
	(0.066, < 2e-16)	(0.135, <0.01)	(0.097, <0.01)	(0.101, < 2e-16)	(0.102, <0.01)	(0.109, <0.01)
Sperm Whale						-0.155
						(0.012, < 2e-16)
Intercept				0.755	-1.532	-2.280
				(0.267, 0.005)	(0.502, <0.01)	(1.024, 0.026)
Sperm Whale						0.623
						(0.071, < 2e-16)
# parameters	110	110	111	221	221	223
logL	-143694.8		-111781.3	-109301.5	-109289.1	-109149.5
AIC	287609.5	NA	223784.6	219045	219020.3	218745
BIC	288540.4	NA	224723.9	220915.1	220890.4	220632
zeros	374	374	851	3090	3088	3088
	Western Gulf of Alaska					
Type	GLM			zero-augmented		
Distribution	Poisson		NB	ZANB	ZINB	ZINB
Method	ML	quasi	ML	ML	ML	ML
Intercept	1.107	1.107	0.976	1.443	1.447	0.490
	(0.025, < 2e-16)	(0.055, < 2e-16)	(0.054, < 2e-16)	(0.049, < 2e-16)	(0.048, < 2e-16)	(0.056, 0.022)
Killer Whale						-0.956
						(0.027, <0.01)
Intercept				0.409	-0.674	-2.113
				(0.135, 0.0025)	(0.154, <0.01)	(0.531, 0.056)
Killer Whale						2.335
						(0.089, <0.01)
# parameters	89	89	90	179	179	181
logL	-95536.38	NA	-70099.95	-67704.62	-67638.95	-66395.35
AIC	191250.8	NA	140379.9	135767.2	135635.9	133152.7
BIC	191969.6	NA	141106.8	137213	137081.7	134614.6
zeros	360	360	1319	3815	3823	3823

Table 3C.3. Whale effect (catch/hachi is multiplied by this amount) when killer whales (K) are depredating a hachi or when a sperm whale (S) is present at a station. Each row is followed by their AIC values. "NA" is when the model would not converge. Poisson/QP has the AIC reported from Poisson as it is unavailable with quasipoisson (QP).

Depredation Type	Area	Poisson/QP	NB	ZANB	ZINB
K	BS	3.89	4.57	NA	9.94
	AIC	59,270	49,924	NA	48,125
K	AI	7.57	7.26	NA	NA
	AIC	20,431	18,864	NA	NA
K	WGOA	4.79	4.48	NA	4.55
	AIC	179,414	139,781	NA	133,153
K	CGOA	2.03	1.90	1.96	1.96
	AIC	379,682	301,976	299,042	298,927
S	West Yak	1.12	1.13	1.14	NA
	AIC	211,380	157,017	152,363	NA
S	East Yak	1.27	1.33	NA	NA
	AIC	81,178	56,595	NA	NA
S	Southeast	1.21	1.19	1.20	1.20
	AIC	201,592	164,787	161,808	161,791

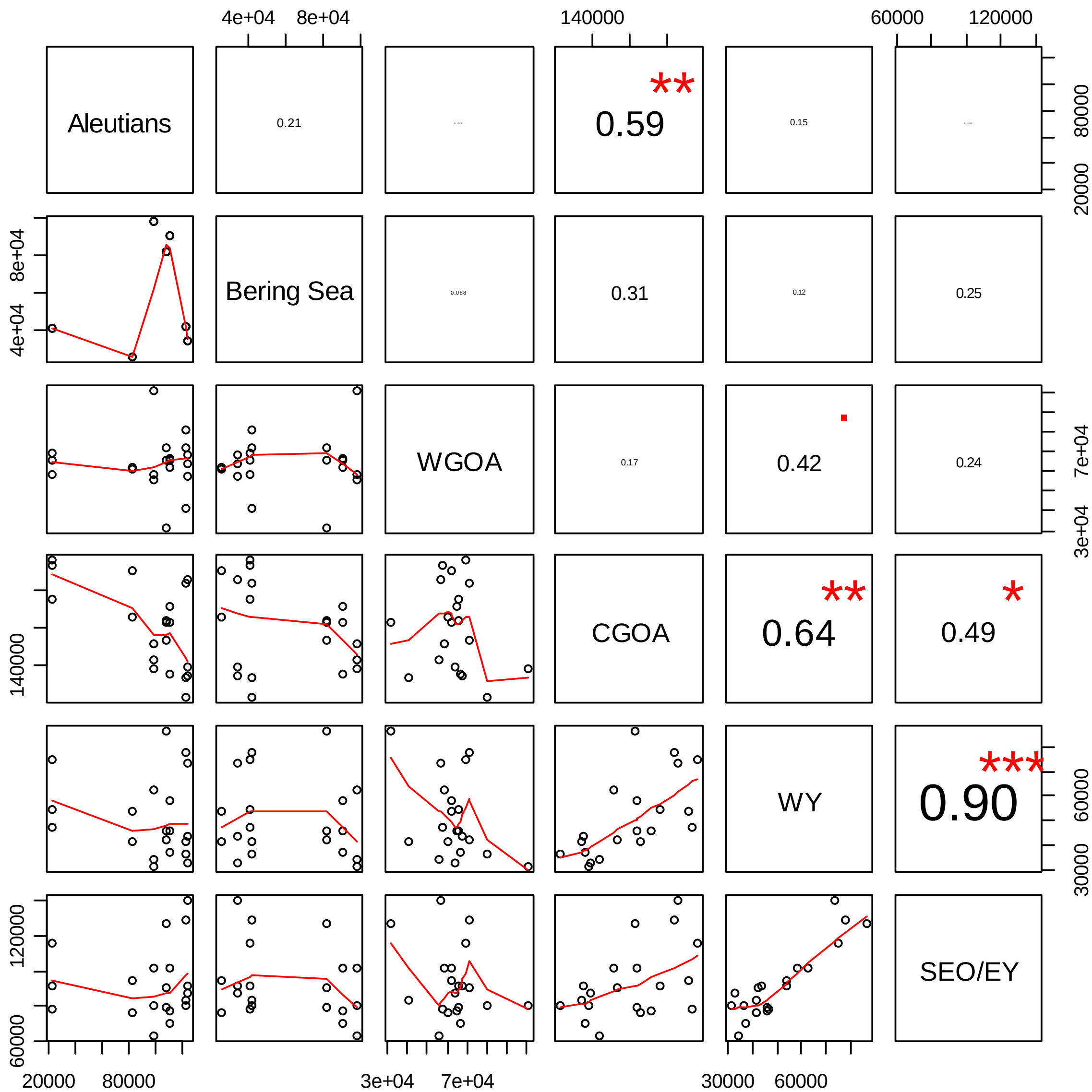


Figure 3C.1. Correlation plot for the 6 management areas for Alaska sablefish of observed mean catch/hachi (expanded by area). Red line is a loess smoother, numbers in upper right are the absolute value of the correlation coefficient, and the red stars indicate significance (1-star=0.05, 2-star=0.01, 3-star=0.001).

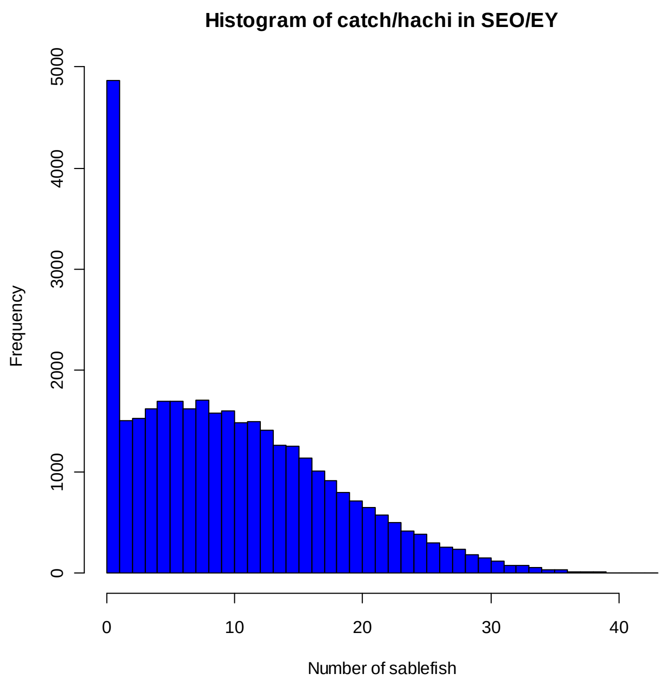


Figure 3C.2. Histogram of number of sablefish per hachi in Southeast Outside/East Yakutat area from 1990-2009 across all depth strata.

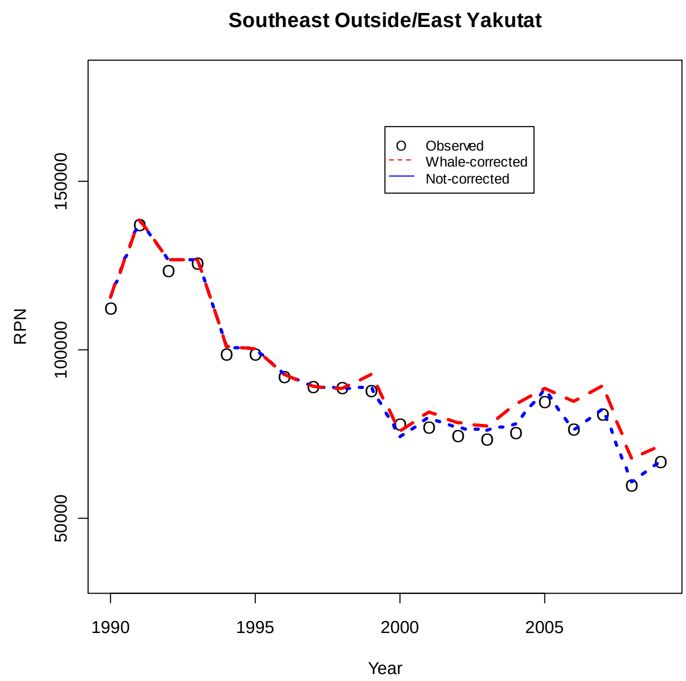


Figure 3C.3. Southeast Outside/East Yakutat observed mean catch/hachi (numbers, open circles), new RPNs calculated in modeled abundance index (red-dashed line, whale effect included), and modeled abundance index with whale depredation excluded (blue dotted line).

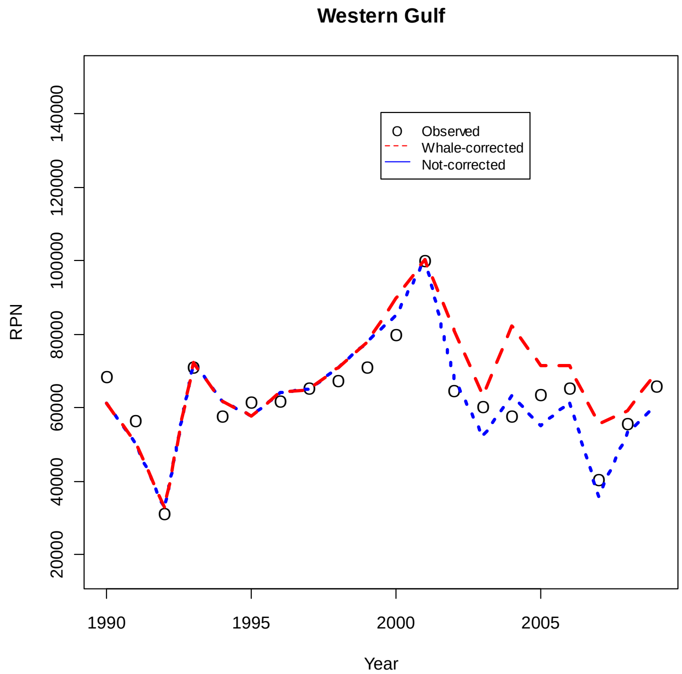


Figure 3C.4. Western Gulf of Alaska observed mean catch/hachi (numbers, open circles), new RPNs calculated in modeled abundance index (red-dashed line, whale effect included), and modeled abundance index with whale depredation excluded (blue dotted line).

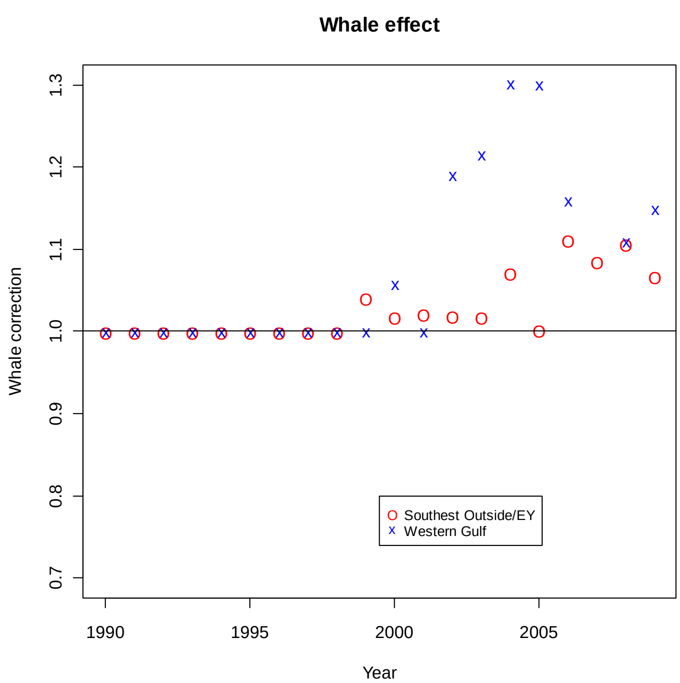


Figure 3C.5. Whale effect is the ratio of predicted model RPNs with and without whales included. Red circles are SEO/EY (sperm whales) and blue 'x's are WGOA (killer whales).

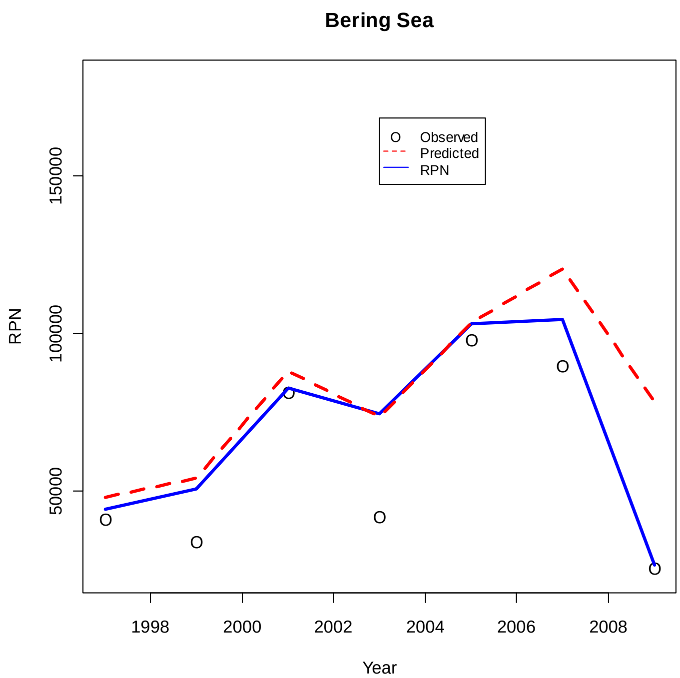


Figure 3C.6. Bering Sea observed mean catch/hachi (numbers, open circles), RPN calculated in traditional way (blue solid line, whale hachis removed), and new RPNs calculated in the modeled abundance index (red-dashed line, whale effect included).

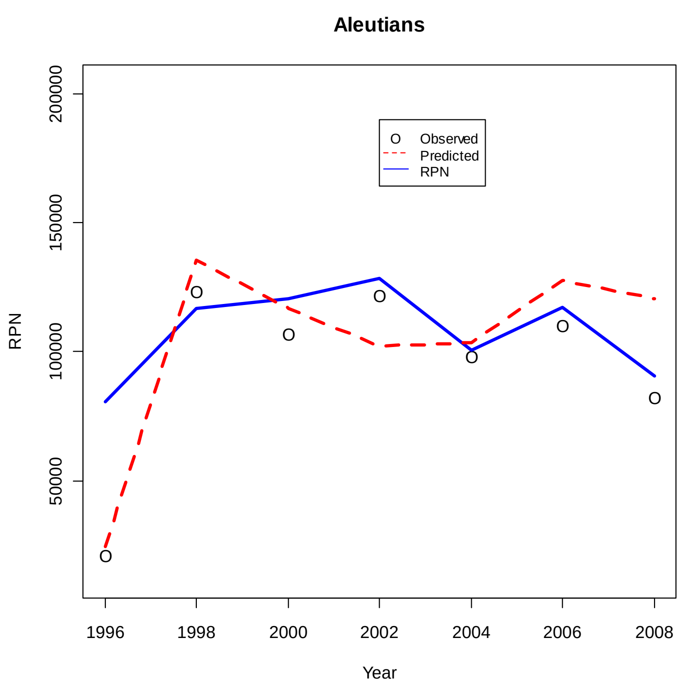


Figure 3C.7. Aleutian Islands observed mean catch/hachi (numbers, open circles), RPNs calculated in traditional way (blue solid line, whale hachis removed), and new RPN calculated in modeled abundance index (red-dashed line, whale effect included).

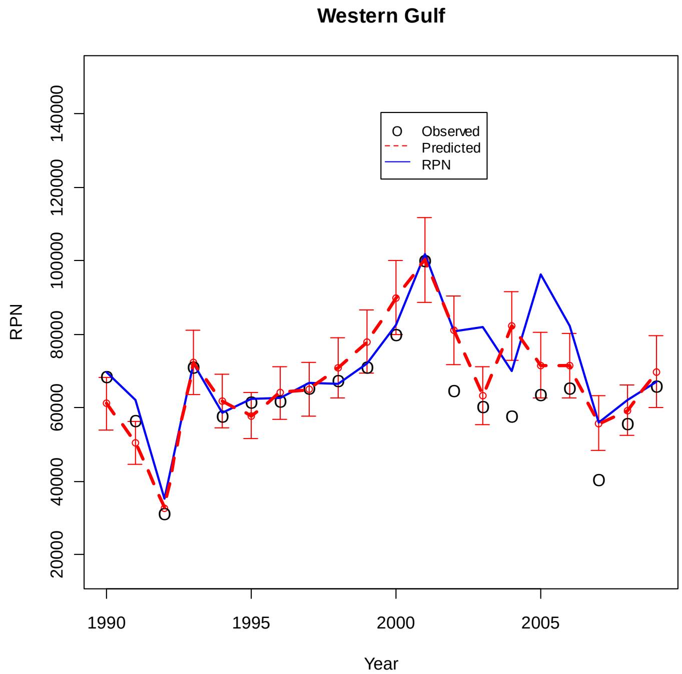


Figure 3C.8. Western Gulf of Alaska observed mean catch/hachi (numbers, open circles), RPNs calculated in traditional way (blue solid line, whale hachis removed), and new RPNs calculated in a modeled abundance index (red-dashed line, whale effect included). Error bars are approximate 95% confidence intervals.

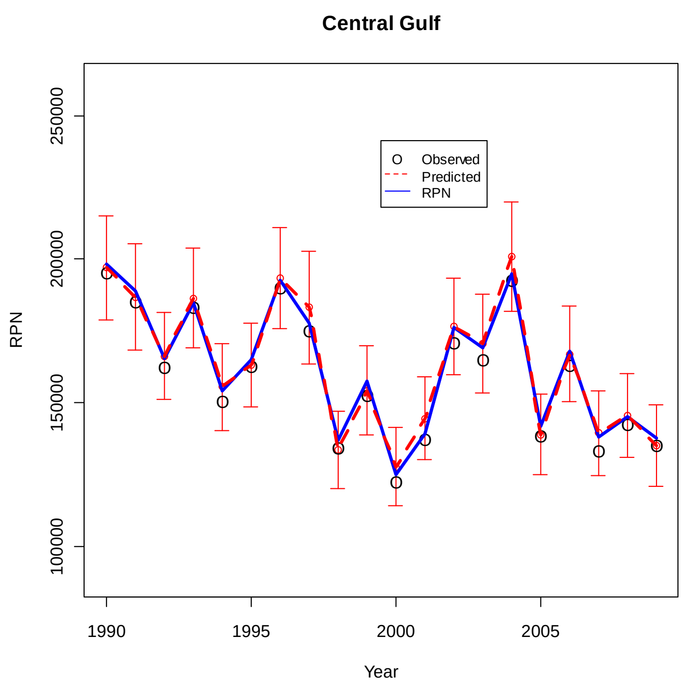


Figure 3C.9. Central Gulf of Alaska observed mean catch/hachi (numbers, open circles), RPNs calculated in traditional way (blue solid line, whale hachis removed), and new RPNs calculated in modeled abundance index (red-dashed line, whale effect included). Error bars are approximate 95% confidence intervals.

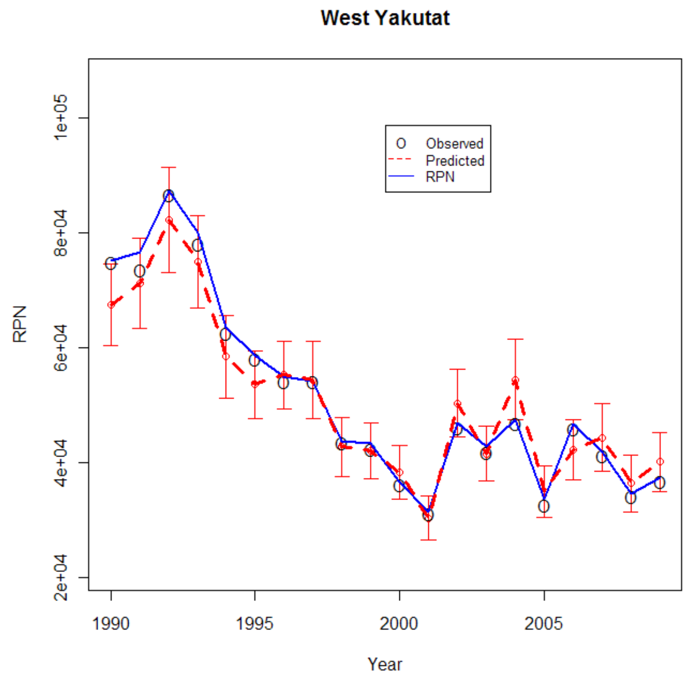


Figure 3C.10. West Yakutat observed mean catch/hachi (numbers, open circles), RPNs calculated in traditional way (blue solid line, sperm whale depredation not accounted for), and new RPNs calculated in a modeled abundance index (red-dashed line, whale effect included). Error bars are approximate 95% confidence intervals.

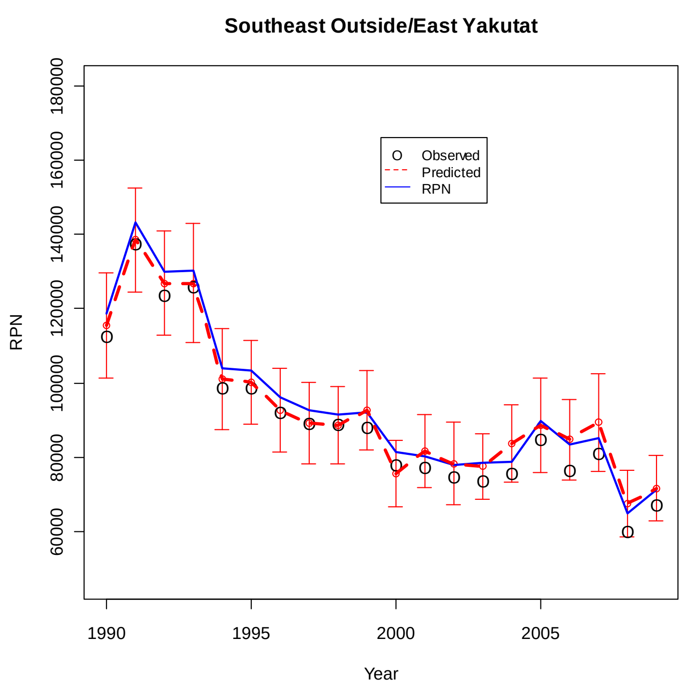


Figure 3C.11. Southeast Outside/East Yakutat observed mean catch/hachi (numbers, open circles), RPNs calculated in traditional way (blue solid line, sperm whale depredation not accounted for), and new RPNs calculated in modeled abundance index (red-dashed line, whale effect included). Error bars are approximate 95% confidence intervals.

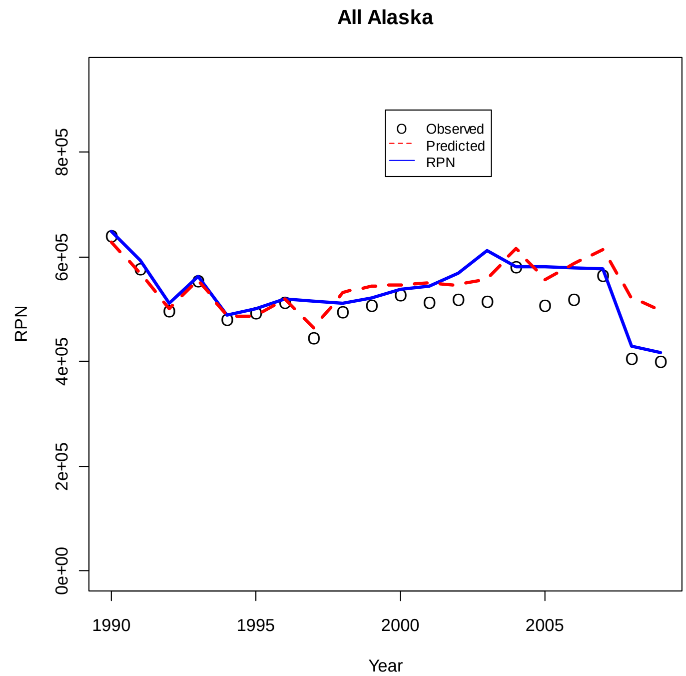


Figure 3C.12. Aggregated Alaska observed mean catch/hachi (numbers, open circles), RPN calculated in traditional way (blue solid line, sperm whale depredation not accounted, killer whale hachis removed), and new RPN calculated in a modeled abundance index (red-dashed line, whale effects included). Error bars are approximate 95% confidence intervals.

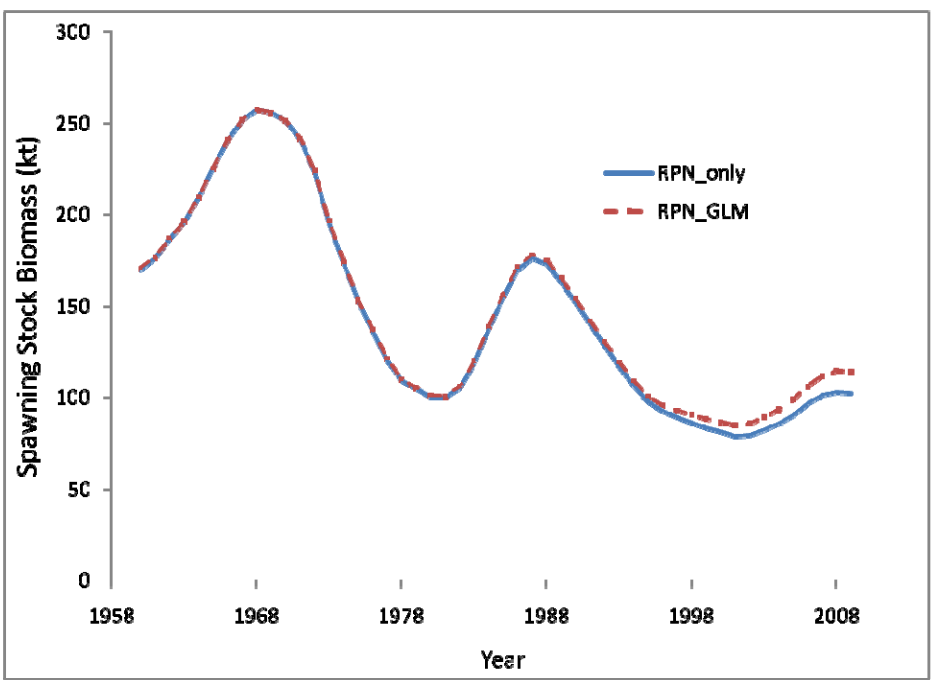


Figure 3C.13. Spawning biomass trajectories from assessment model using traditional RPNs (RPN_only, blue solid line) versus GLM modeled RPNs (RPN_GLM, red-dashed line), where whale effects are included, for all management areas.

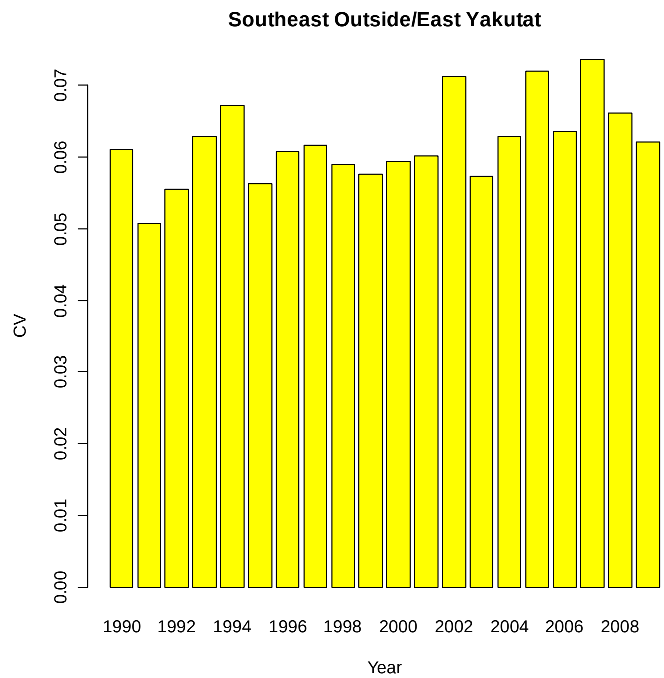


Figure 3C.14. Coefficients of variation of predicted catch by year in Southeast Outside/East Yakutat region.

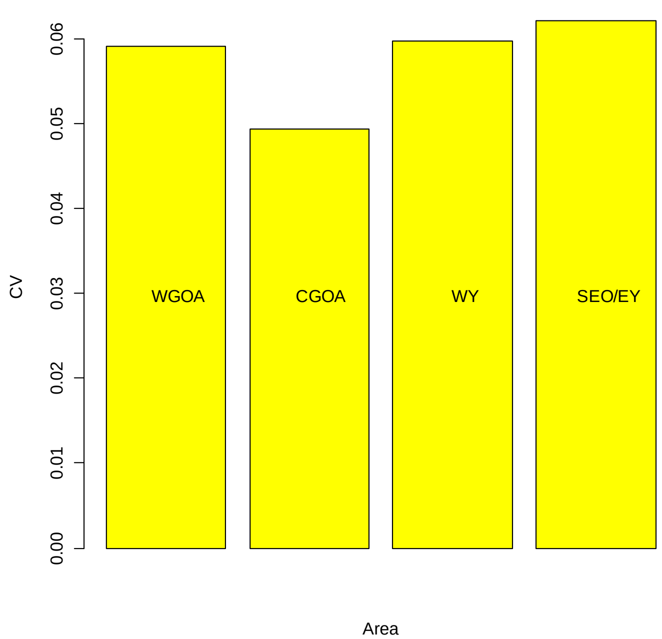


Figure 3C.15. Average coefficients of variation of predicted catches by area.

Appendix 3D: Report on 2010 Alaska sablefish data and modeling workshop

Auke Bay Laboratories, Ted Stevens Marine Research Institute, Juneau AK
January 26-28th, 2010

Background

A 3-day workshop was held by the authors of the Alaska sablefish assessment to consider recent suggestions made during a 2009 Center for Independent Experts review and an industry-sponsored review. Prior to the workshop, all available relevant information pertaining to the sablefish population was synthesized in order to consider alternative modeling approaches. The workshop participants were provided with high resolution data from available scientific surveys as well as age and length information from observed fishing vessels aggregated by time and management area. Simulated datasets that captured the general characteristics of fishery data, but maintained confidentiality requirements, were also provided in a high-resolution format so that detailed spatial models could be considered. The agenda of topics is shown in Table 3D.1.

Stock assessment experts outside of Auke Bay Laboratories participated in the workshop, as well as scientists from within the lab. The list of participants is shown in Table 3D.2.

Two primary products were expected from the workshop. The first is this report describing the key findings and recommendations for further development of research and modeling of sablefish. The second product, yet to be developed, will be a set of potential models to go forward with in 2010 or 2011 for the sablefish assessment.

Key Findings and Recommendations

1.) Natural Mortality (M)
   a. Natural mortality is one of the most influential parameters in assessment
   b. Considerations:
      i. Fixed estimate agrees with mark-recapture data and current model specification
      ii. ABC is sensitive to M
      iii. Other options include using an age and/or sex-specific M
   c. Recommendation: if major re-specification of model is proposed, examine how M changes, present the likelihood for smaller increments of M, decompose for likelihood components, investigate sex-specific M on next model iteration
2.) Age-error
   a. More known age sablefish data available
   b. Considerations:
      i. Distribution of error from different readers is consistent, pattern well defined
      ii. Incorporating ageing error improves fit to age and length data
   c. Recommendation: Update age-error matrix, use pooled age-readers, consider checking consistency in trend over time
3.) Spatially explicit modeling
   a. CPUE, recruitment, and selectivity may vary between areas
   b. Considerations
      i. Simplest approach is to examine separate fisheries by area
      ii. Next approach would be to model specific sub-populations
   c. Recommendations
      i. If model moves toward spatially explicit model, consider three areas (EGOA, CGOA, and WGOA/AI/BS)

ii. Once consistency between current sablefish model and an SS3 model is established, explore estimating area-based age availability with sex-specific length based selectivity by gear type (constant between areas)
iii. Explore sex-specific, area-based fishery availability and if number of age samples is sufficient for spatial models

4.) Migration Models
  a. Issues: Fish do not graduate to larger size groups within the model; comparison of time periods is *ad hoc* based on when data were analyzed
  b. Considerations: wait for SS3 improvements for incorporating tagging data, possible input of migration rates
  c. Recommendations: use time increments that allow fish to grow to different size groups and have different movement probabilities, consider age-specific movement probabilities

5.) Longline survey abundance index
  a. Issues
    i. Depredation
      1. Killer whale – AI, BS, WG – observations by skate – easy to detect
      2. Sperm whale, - EYSE, WY – observations since 1998 – difficult to detect
    ii. Vessel interactions
    iii. Extrapolation of surveyed areas vs. unsurveyed areas
  b. *Current ad hoc* adjustments used for survey index
    i. Killer whale depredated skates are removed from calculations
    ii. In 2009, BS area calcs removed due to depredation and estimate was average of trend in other areas
    iii. An averaging technique is applied to surveyed areas to estimate RPN in unsurveyed areas
    iv. No correction factor is used to account for sperm whale depredation
  c. Considerations:
    i. Pursue statistical adjustment for survey CPUE to avoid *ad hoc* methods
      1. Consider zero-inflated Negative Binomial Distribution for data at skate level for killer whale data and more recent sperm whale data
      2. Consider Generalized Linear Models or Generalized Additive Models (GLM, GAM) with effects such as Year, Depth Strata, Depredation, Country

  d. Recommendations:
    i. Use GAMs for exploration and GLMs for modeling survey data, run GLM framework with interactions to estimate missing years in the AI and BS and account for variable effects such as depth, depredation, etc.
    ii. Explore use of model predicted longline survey abundance indices for apportionment

6.) Stock Synthesis 3 Model Alternative
  a. Stock Synthesis 3 is a standard assessment model that could be useful for sablefish assessment
  b. Considerations:
    i. Results and plots of SS3 configuration were consistent with current sablefish model, overall trend of biomass in SS3 was substantially lower than current model
    ii. Unresolved differences: small size bins, selectivity, growth time blocks, sex ratio, recruitment restriction to resolve differences

   c. Recommendation: At author’s discretion, use SS3 for exploring/validating new model options such as S/R relationship, time-varying selectivity, incorporating tagging data, and examining growth blocks.

7.) Fishery CPUE abundance index
   a. Ways to model fishery CPUE to better reflect changes in abundance
   b. Considerations:
      i. Target definitions for observer data: maximum catch (current), depth restriction, core vessels, IFQ only
      ii. Effects: vessels, region, depths, performance, hook spacing, season
      iii. Whether to model spatially
      iv. Blend of observer with no target and logbook data with defined target, changes in hook spacing within a vessel, CPUE calculation by vessel or by set, total hooks/missing values
   c. Recommendations
      i. Limit data to only IFQ years (1995 on), eliminate vessels that only sample a few years (potential criteria = # years fished and catch), use same depth restriction as survey
      ii. Evaluate differences between core fleet and total fleet for length and age data, sensitivity analysis on depth restriction, core fleet
      iii. The goal is to develop the best CPUE index by adjusting for factors that are known to affect fishery CPUE, use a GLM or GAM combining all data and using observer/logbook source as a factor in the model

8.) Sex Ratios
   a. Sex ratio currently only influenced by differing fishing mortality by sex
   b. Recommendations:
      i. Consider fixing female natural mortality, estimating male
      ii. Include length / age compositions by sex that sum to 1

9.) Other recommendations:
   a. Use only Relative Population Numbers (RPNs) in model, remove RPW
   b. Use of length and age data from same survey/year: since ages are independent sample, then can use both
   c. Inclusion of trawl survey age data: author’s discretion
   d. Use length data from Japanese fisheries
   e. Utilize gully stations that are consistently sampled over time and add to fishery index; consider use of length and ages from this data
   f. Alternate survey data:
      i. Continue to use trawl survey data
      ii. IPHC survey data: consider developing index, continue to monitor
   g. When revising model configuration, improve variance assumptions to achieve better balance between sources and more realistic relative variance among sources.

Workshop Proceedings

Tuesday, January 26, 2010

After introductions were completed, the agenda was approved and priorities for the workshop were established. To help frame the meeting and establish these priorities, Dr. Dana Hanselman reviewed recommendations from the 2009 CIE review as well as concerns raised by a recent industry review. Industry concerns with the survey were highlighted which included lack of age data, whale depredation, and a preference for commercial CPUE data over survey data. The three main priorities established were: 1) The utility of a spatially explicit assessment model; 2) methodology for more appropriately using fishery CPUE data as an index of population abundance; and 3) formulation of a better longline survey abundance index that includes whale depredation and makes statistical predictions for unsurveyed areas. To fully address these priorities, some of the agenda topics were covered briefly.

Dr. Bill Clark led the first topic on natural mortality and ageing error. A history of the calculation of natural mortality (*M*) for sablefish was presented as well as a presentation of the likelihood surface for a grid of natural mortality estimates in the current model. The group thought the fixed estimate in the model agrees with the data and is appropriate given the value of total mortality in the model. It was suggested that there was sufficient contrast in fishing mortality over time and lots of age data, so we might be able to estimate it within the model. Suggestions were to check what parts of likelihood changed with different estimates of *M*, whether *M* changed for different sexes (given differences in growth), and age-specific *M*. One method suggested was to use the Lorenzen method for age-specific M for a model run. It was noted that reference points are quite sensitive to the choice of M. One consideration with examining *M* is that any future changes in model configuration will likely influence the appropriateness of the *M* estimate and this should be revisited if a new model is recommended.

Dr. Jon Heifetz discussed the ageing error matrix used in the model that is calculated from known-age sablefish returns for up to 9 years old and extrapolated up to the pooled age in the model. Preliminary results were shown with updated age data with more readers and known ages to 25 years old. A model was run using no ageing error which did show a degraded fit to the age data. The group recommended updating and including the new age-error data in the next iteration of the model.

Dr. Mark Maunder led the afternoon session on spatially explicit models. Different ways to spatially model a population were presented. One example was having separate fisheries with simultaneous mixing. The group discussed that selectivity by area might be important to capture changes in fishery selectivity when a large cohort moves through areas (e.g. the 2000 year class). Another example is to explicitly model sub-populations with or without movement between them. The first step in determining the utility of a spatially explicit model is to look at the input data first (CPUE, size, age) to see if a spatially explicit model makes sense to pursue. Generally, if size and age differ between regions then we should model fisheries spatially; if survey and fishery CPUE differs spatially, then we should model sub-populations. CPUE differences between areas imply different depletion or productivity. Other important considerations are the extent of movement and the final goals (ABC versus apportionment) of the model.

Some of the data sources were examined by area as presented in SAFE. Some of the observed patterns could be explained by age-based movement and differing recruitment dynamics. Some of these theories should be tested with analysis of the tagging data and movement model. The group also surmised that depth may also be as important of factor as geographic area. However, these differences may be attributed to a number of different reasons, such as price of gas and mixed targets somewhat reflecting changes in a different fishery such as Pacific cod.

Dr. Jon Heifetz provided an overview of an update to the sablefish movement model that was originally used to support the current harvest strategy. The results showed some different patterns of movement, specifically that fish were not moving as westerly as previously reported with more of an even pattern of east-west movement. The group was concerned with a few parts of the model formulation. The group suggested that to use the data for assessment purposes, the tagging model needed to consider growth and age-based movement. Additionally, the periods of comparison for movement should be developed more analytically.

Wednesday, January 27, 2010

Survey data

Chris Lunsford presented an overview of issues related to the longline survey and survey data. The group discussed whale depredation at length. The main depredation from killer whales occurs in the Bering Sea, Aleutian Islands, and Western Gulf of Alaska. This depredation has been consistently recorded since 1996, is obvious when it occurs, and the affected skates are currently removed from data that are used to calculate a relative population index.

The group examined a map of depredation events, which showed that depredation was widespread in the BS especially in an area near Dutch Harbor, throughout the AI, and consistently in an area of the WGOA near Unalaska Island. A list was shown of specific stations that were impacted. The last survey year, 2009, had the largest number of killer whale depredated stations in the BS, at 10. It is common for the whales to find the survey boat even after overnights in bays and when stations are skipped. One other concern is that there are more stations being hit farther east and closer to Kodiak, which may indicate more pods are learning this behavior.

Sperm whale depredation has been recorded since 1998. Most sperm whale depredation has been occurring in the EGOA near Yakutat. Killer whales are more particular in what they eat, preferential to oily fish like sablefish. Sperm whales are more opportunistic and will eat off the line or the offal being released from the stern of the vessel. Compared to killer whales, a sperm whale depredation event is not as distinct, as the whales do not necessarily feed off the line and sometimes are feeding off the head and guts in the back of the boat. When they do depredate off the line, they do not take every fish like killer whales do, so detecting depredation can be difficult. There are no records on sperm whale depredation before 1998. Since 1998 we have information on killer whale depredation unique to the skate level and sperm whale information to the station level.

In 2008, a study was published which compared 1998-2004 longline survey catch rates at stations which had sperm whale depredation to stations that did not. This study found a 1.8% removal rate, which was not significant. Preliminary results of a new study that included the most recent years, 1998-2009, indicate there is now a significant trend over time in depredation and sperm whales remove approximately 4.1 kg of sablefish per 100 hooks. Similar depredation studies have shown an average of about a 1.5% removal rate.

In terms of whale depredation, no known deterrents exist. For sperm whales, the Southeast Alaska Sperm Whale Avoidance Project in collaboration with the AFSC is deploying acoustic receivers on the longline survey to count the number of times a sperm whale creaks, which may be an indication of a depredation event. This project will continue in 2010 to attempt to prove a creak represents a fish removal. If possible, this method of quantifying depredation can also be used to compare survey depredation rates to fishery rates. SEASWAP is also doing some work on deterrents, but any deterrents used could not affect catch rates if they were to be used on the survey.

One problem with the large killer whale depredation event in the BS in 2009 was that the couple of remaining unaffected stations typically had the lowest catches. Because we had high rates of depredation in the BS in 2009, we used the ratio of catch in the BS and the GOA to estimate the catch in 2009 in the BS based on 2009 GOA catch. A problem presented for the workshop was determining a good way to fill in for years and stations when we have depredation events or when the areas are not sampled. Since it is likely to be a continuing problem in future years, a statistically defensible and consistent technique to account for depredation is desirable. The group suggested something else to consider was the effect of this event on length and age frequency data, particularly if the killer whales are attacking a particular part of the set.

The group was concerned with using averages from other areas when areas are not surveyed or when severe depredation could introduce some bias into the index. A related issue is that the trend in Eastern AI biomass is extrapolated to 15% of the area in the Western AI. This is done because the WAI biomass was sampled by the cooperative Japanese survey but is no longer sampled by the domestic survey. If trends in the un-surveyed area are different than the surveyed area of the EAI, this could also introduce bias.

Modeling framework

Dr. Franz Mueter led a discussion of appropriate ways to treat catch-per-unit-effort (CPUE) data. First we are starting with the assumption that abundance is proportional to CPUE. Catchability or abundance may vary, so there can be variability in CPUE as an index of abundance even when true abundance is constant.

He described a generalized modeling approach for both survey and fishery data as follows:

1.) Response variable
    a. Catch rate, CPUE
2.) Explanatory variables
    a. Year (categorical, primary variable)
    b. Spatial location
        i. Discrete regions, strata or management areas
        ii. Lat/long, spatial surface
        iii. Long only, 2D surface which might make more sense for this instance
    c. Day of Year
        i. Because the survey or fishery takes place over a long period
        ii. Confounded with location though, but could examine by area
    d. Effort, if response variable is catch
    e. Depredation, could be categorical (Y/N)

There are several methods for standardizing CPUE. One method is to use a generalized linear model (GLM), which is a flexible generalization of regression. It allows different explanatory variables with different distributions to be statistically related without the constraints of having normally distributed data. If a spatial surface is desired, often a generalized additive model (GAM) is used which replaces linear predictors with some variety of a smooth function. Another model that could be used is a mixed model (GLMM/GAMM) that includes random effects. Year could be treated as a random effect but it is typically considered a fixed effect because it is the variable of interest. When modeling CPUE with these types of models, a number of choices need to be made which include:

1.) Choices
    a. link function (use log, logit)
    b. error distribution (counts of fish by skate, generally a Poisson, if more dispersed than Poisson then neg. binomial; if weight Gaussian or log-Gaussian
2.) Issues
    a. Dealing with high proportion of zeros
        i. could aggregate by something like depth strata
        ii. could use a 2-stage model (delta-lognormal, delta-gamma)
        iii. zero-inflated models (ZIP (Poisson), or ZINB (neg bionom)
            1. modeling “false zero”, and probability of getting a “true zero”
                a. true zero, sablefish not there
                b. false zero, habitat ok, but happen to miss sablefish
    b. spatial correlation

iv. model spatial pattern (because how survey is distributed, it is likely best to model location and depth)
v. model spatial correlation, alternative to modeling the pattern, have smooth pattern and then model the spatial correlation that remains, this only matters if you want to ensure a rigorous confidence interval, and since we just want a good index, may not be as important

In general, we could look at fishery and survey data very similarly, but fishery data will have more nuisance variables. Vessel and gear effects are likely to have a lot of co-linearity so it may be difficult to discern differences between vessel and gear effects. One advantage of these types of approaches is that you can readily include gully stations or depredation and treat these as another categorical variable.

Survey abundance index

Dr. Mueter showed some potential modeling options for survey data. The fit of several models were examined for one area, to decrease model fitting time during the workshop. In the database there are two measures of depth: stratum and interpolated depth. A two-stage logit GAM model was fit using interpolated depth and Julian day as explanatory variables, essentially a curve to the depth data which models the probability of catching a fish at a given depth. Data was filtered by depth (100-1000 m only). Generally, GAMs are more exploratory. From examining the data, depth strata would be more useful as a categorical variable than interpolated depth as a continuous variable. In addition, there does not seem to be a real change in the probability of catching a sablefish throughout the survey period.

When fitting a delta-lognormal GLM, the occurrence probability (binomial part) is highest in the depth stratum from 500-700 meters. One suggestion made by the group was to include the country, since Japanese fishing had higher catch rates, and there were five years of overlap. For the presence/absence model portion of the delta-lognormal GLM, the year effect is smaller than the stratum effect, the killer whale effect is large, but the country effect is small. The portion of the delta-lognormal which models sets where catch rates were positive could use a log or log link transformation. Difference in catch rates between countries is a bit more substantial than in the binomial part, and the year effect is larger. The final product of this model is to multiply the probability of occurrence (binomial model of presence absence) by the adjusted catch rate (from the model of positive CPUEs). These adjusted catch rates can then be used to as the survey index.

The group discussed using the modeling approach to examine depredation, and to see if it was occurring at high density stations. One easy way to examine this might be to compare annual CPUE with and without depredation. It was suggested this would be most easily accomplished with a zero inflated negative binomial because it can be fit with one model, unlike the delta-lognormal.

The group discussed whether the strata were sampled in proportion to their area. If not, then the strata-CPUE estimates would need to be expanded to their area sizes. This could be done within the model, but might lead to double-weighting. Since this would be an expansion weight not a statistical weight, it might be better to do this outside the model. In this method, the best estimate of mean CPUE within the depth stratum by year would be determined by the model and then weighted by the area of the depth stratum. Variances are a straightforward calculation from this method.

The group discussed that presently the way the RPN indices are constructed, a model is implicitly used to formulate the index for the assessment model. This model is basically an adjusted mean CPUE for depredation and other effects that do not represent abundance. One concern raised is that a new modeling approach might be quite acceptable to stakeholders when used inside the assessment model, but might be much more scrutinized if used in the apportionment process.

The group discussed that identifying and accounting for killer whales is straightforward, but sperm whale depredation is not so obvious because there are not enough data to analyze. Sperm whale depredation can be difficult to detect and the effect on catch is smaller than for killer whales. One way to deal with sperm whale depredation is to apply an overall adjustment to the index after the data has been modeled. One useful exercise would be to determine how much sperm whale depredation it would take to account for the current trend in sablefish CPUE in the Eastern Gulf of Alaska. An additional important consideration is that while not accounting for it in the survey, we also are not accounting for the additional mortality in the fishery. While the survey boat cannot avoid sperm whales, it does send out offal, which may keep them from eating off the line. Many of the boats in the fishery do not process on board so when whales do depredate, they may remove more of the catch. Conversely, fishing boats are capable of avoidance by moving when whales occur or fishing earlier in the season. It was also noted that the area affected by sperm whales is around 25% of the population, and if the effect is 4-5% then the effect on the overall population estimate is only around 1%. However, the group agreed that the end-product for the survey index needs to attempt to account for both types of depredation.

Alternatively, a GLM for the survey data could incorporate sperm whale presence/absence and depredation by station as a categorical variable. Although we have this only since 1998, we could model with and without this variable to see what the effect is and use this number to make an overall adjustment to the survey index.

The group discussed that relative population weight (RPW) should be omitted from the assessment model since we are accounting for length and weight in the model already and because relative population number (PRN) is also used as an index in the model. The group was divided on whether to use length data from the survey and fishery when age data is available. While the ages provide information on year class strength, the lengths are taken from a much larger sample size of sablefish. This information might also be useful if we chose to model growth in time blocks or as a random effect.

The group discussed some specifics of modeling survey data using a GLM. There is various information that is available by skate that might be useful to model, and choosing the resolution of data analysis (i.e., by skate or by depth strata) will need to be tested. Some of the whale related factors by skate that could be incorporated include, empty and ineffective hooks, and depredated/damaged sablefish.

The group examined some results from using a zero-inflated negative binomial package in R to model the count data (number of fish per skate). For the purposes of the workshop a thinned data set from the Central GOA was modeled using a GLM with year, depth strata, and depredation as effects. The proportion of area by depth strata was added (2-7) to combine strata estimates and make one index to compare to current RPNs of survey. When the standard survey RPN was compared with the GLM model the results were quite consistent.

Stock Synthesis 3 model

Dr. Mark Maunder led a discussion regarding Stock Synthesis 3, which is an official product of the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov). SS3 is coded in AD Model Builder (as is the current sablefish model) and has numerous modeling options. In theory, it should be able to emulate the current sablefish model and then could be used to test hypotheses without having to write a lot of additional code.

Some of these options and how they are configured in the current assessment model:

1) Initial conditions: virgin or exploited, currently lightly exploited

2) Can also allow parameters to change over time and seasons. Currently starting in 1960 with low catch, similar to virgin year, and no seasons.

3) Fleets: can split up by method, area, depth, vessel size, and season. Currently: derby, trawl, IFQ

4) Areas: can explicitly model different areas, may need to model movement, currently one area

5) Growth morphs: allow different groups to have different growth parameters, currently two time blocks

6) Different ways to use age, weight and length compositions such as just age, age and length, age conditioned on length and length (needed if age is sampled in length bins)

7) Many selectivity options (but not the ones currently used in the model)

8) Can include data that is not sex specific

9) Tagging data can be included, not currently

10) Environmental data, not currently included

The group discussed some of the advantages and disadvantages of using SS3 for sablefish. Some advantages are the availability of many options to test hypotheses, and SS3 can be easier for outside people to review because of the standard nature of the files and inputs. Disadvantages include not being able to make custom options based on the needs of a specific stock, and being reliant on a highly complex code to calculate things correctly. An author's own model coded in ADMB might be less transparent to another author, but usually the author knows the architecture of the model calculations intimately.

The group compared a test SS3 model with the current assessment model. The SS3 model attempted to emulate the same settings as the current model, but the exact options were unavailable. While patterns were generally similar, the SS3 model estimated current spawning stock to be about 40% lower. Recruitment seems to be less variable but similar year classes emerged.

The group discussed some potential ideas to explore based on comparing the results of the two models. It was recommended that all available data is included in models going forward, even if it is not fit, because it shows the consistency of the data based on fit to other data components. Selectivity can be dealt with in different ways, particularly to deal with male and female selectivity being different and not constraining to have maximum of one. It may necessary to combine both age and size selectivity. There is some potential that the fishery selectivity should be domed shaped (a study was discussed showing halibut fishery selectivity was dome-shaped in some areas). Typically, assessment model tends to behave better if at least one selectivity is assumed to be asymptotic. In the test SS3 configuration, only length based selectivity is used (current sablefish model uses age-based selectivity), where trawl methods are dome shaped, others are asymptotic, and all parameters are estimated with no temporal variability.

It was recommended that the effective sample sizes for compositional data reflect annual sample size or variability. For the survey, this is not necessarily a problem because it is similar from year to year, but the fishery has much more variable sample sizes. The group decided that the best first approach is to see if an SS3 model can be configured that very nearly emulates the current sablefish estimates of stock status, and then see what options and assumptions change this view.

Thursday, January 28, 2010

Fishery CPUE abundance index

Dr. Mueter led the group in considering methods for using fishery CPUE as an index of abundance. The group thought it would be good to use the same general approach as the survey. The point was raised that there were some differences between logbook and observer data, such as the availability of hook spacing data, how a target is defined, and whether information on the vessel name, skipper, and size are available. This could be dealt with in a GLM framework with logbook and observer data as a categorical variable. Indices for both data sets could be done independently, but there is then an issue of using some data twice since vessels over 60 feet turn in logbooks and can be observed.

One issue of concern for the group was using maximum catch of the set as the primary indicator of a sablefish target for observer data. An alternative method is to only use data from a core set of vessels that have fished consistently over the domestic fishery. If a core set of boats can be identified that fish through the whole time series and their behavior is consistent, then they should be a better reflection of sablefish CPUE than boats that sporadically fish sablefish. One drawback is that there could be different captains and different behavior between years on the same vessel. In addition, a core vessel group must exist for all management regions. There is a captain code available in the observer data that is not relatable to the code in logbooks. It was noted that most of the catch is caught by a small number of vessels and that about 10-12 boats that are taking nearly 25% of catch. One concern raised is that screening this way would look primarily at large boats that are observed 100% of the time.

Spatial distribution could also be included in models of fishery CPUE. One benefit of fitting a spatial model is that if the vessel is fishing consistently, the trend should reflect the change in sablefish population, regardless of target. Some issues with the spatial model, if fitting over a number of years, is that you have to assume that the general pattern stays the same over all years. If fitting across all years, you don't have to worry about the regional issues. If simple annual means are desired, then the spatial surface is much easier to model. The only requirement is that spatial surface is detailed enough that it captures the spatial pattern.

The group agreed that there were enough data to fit a global surface across years. If you do this across years, assuming the same spatial pattern each year, residuals will be spatially auto correlated because things fluctuate a bit from year to year, and variances will be overly small. This analysis could be done with a generalized additive model if the primary interest is to get a good index, and the variance could be inflated later in the stock assessment model.

It was noted that observed catch on some sets, particularly in the Bering Sea, is dominated by other species and therefore may not be a sablefish target. Since sablefish are a deepwater species, limiting the analysis to a practical depth range may be a reasonable thing to do. A good way to proceed might be to filter the fishery data to the depth range of the survey, limiting from 200-1000 meters. It was suggested that we run three data sets for estimating a CPUE index for observer data: 1) The current approach (target defined by sablefish being the maximum catch of a set); 2) Depth cut off from 200-1000 meters; and 3) Look at the core vessels (e.g. top 25 boats). Then we apply the GLM to these data looking at vessel effects, region, depth, season, and IFQ holders. On initial analysis, seasonal effects seemed unimportant. Initial analyses using the "core vessel" group showed the most promise at the workshop.

The group further discussed the blending of observer and logbook data. Observer and logbook data are very similar in some areas, but diverge in regions where the data is poor (e.g. Aleutian Islands). One suggestion was to consider the two data sources independently. The two CPUE sources could be fitted separately in the assessment model. The concern was raised that we were double weighting a particular portion of the fleet (large vessels) because large and small vessels are both represented in the datasets, whereas vessels <60 feet are only represented in logbooks.

In general, the group agreed that it is best to model the things that you know are most important. It is impossible to include all possible multi-way interactions. Since we are trying to compute the best index, the approach should be reasoned rather than merely a statistical model selection approach.

Some remaining concerns that need to be resolved were:

1) Model only the IFQ observer CPUE data and eliminate pre IFQ years (1990-1994).

2) Is using both logbooks and observer data double counting the data?

3) Currently logbooks and observer data have different influences in different regions based on number of logbooks being turned in and the size of vessels operating in different areas (fewer observed vessels in EGOA).

4) Goal is to get individual estimates by area and year of mean CPUE, and CV over all years. Test sensitivity of different combinations of top IFQ vessels and then omit the ones that were not fishing most years.

5) Test for a difference between small and large vessels in catch rate by comparing logbook and observer data for different vessel sizes. The hypothesis might be that small boats will tend to stay closer to port, and not travel far while large boats will move to wherever the fish are.

6) Hook spacing can change based on the density of fish available or when mixed targets are sought (halibut and sablefish sets), and can dramatically change the CPUE. Hook spacing is not available for all observed vessels.

7) Currently the CPUE data from observer program and logbooks used in the assessment are the average of the mean vessel CPUE's. This may be biasing the results as it gives vessels that catch very little sablefish a disproportionate effect on catch rate, rather than calculating by skate or set.

8) Logbook data does not include vessel name or size. Observer data does not include a target.

Other modeling issues

The group discussed the best way to model the sex ratio of the population. Currently in the model, the sex ratio is only influenced by the differing fishing mortality by sex. However, data exist that could be used to better estimate this ratio. The group recommended that the age and length compositions by sex total to a sum of one and then fit in a joint multinomial likelihood. The selectivity of one gender should not max at 1, or different catchability could be estimated for each sex.

The group discussed using historic unsexed trawl and longline fishery length compositions from the foreign fleets. There were questions about what is gained modeling from 1960, if we are making our benchmarks from 1977 on; whether the historic data is reliable; and whether estimates from good data might be contaminated with bad data. One suggestion was to make an exploratory run from 1977 on and compare with the reference model. In general the group suggested it is good to use whole time series to set up the population and also keeps nuisance recruitments from being estimated near the beginning of the data. If the historic data is less reliable, it can be given a higher variance in the model. The assessment should also show the sensitivity of the model to a stock-recruitment relationship.

The group also discussed whether it was best to use model predicted CPUE indices in the apportionment strategy or continue to use the standard method of computing RPWs. It was suggested that to promote stability in the apportionment, it would be best to add in new model estimates each year while dropping the old estimates out each subsequent year.

The workshop reached the end of the discussion and summarized the recommendations.

Agenda

Table 3D.1.		Presenter
Tuesday February 26th Data inputs		
9:00	Welcome, introductions, workshop plan, background	Hanselman
9:00	Discussion of data provided, any other data needed for workshop	Hanselman
10:30	*Break*	
10:45	Natural mortality and ageing error	Clark
12:00	*Lunch*	Lunsford
1:00	Spatial models (Session leader, **Maunder**)	Maunder
3:00	*Break*	
3:15	Sablefish movement model and updated estimates	Heifetz
4:00	Discussion or application of spatial models	Maunder
Wednesday February 27th Modeling the data		
	Modeling survey data (Session leader, **Mueter**)	Mueter
9:00	Longline survey data use and depredation	Lunsford
9:45	Approaches to modeling the longline survey data	Mueter
10:30	*Break*	
	Incorporating depredation	
10:45	Filling in for off-years in AI and BS	Mueter
12:00	*Lunch*	Hanselman
	Modeling fishery CPUE data (Session leader, **Mueter**)	Mueter
1:00	Current use of fishery CPUE in model and apportionment	Hanselman
1:15	Pros and cons of using fishery CPUE data	Mueter
3:00	*Break*	
3:15	Open for modeling work	
Thursday February 28th Improvements to the assessment approach		
	Model comparisons (Session leader, **Ianelli**)	Ianelli
9:00	Stock Synthesis 3 model runs	Maunder
10:30	*Break*	
10:45	Current assessment approach details, and requested runs during meeting	Hanselman
12:00	*Lunch*	Rodgveller
1:00	Other alternative model runs or modeling work	TBA
3:00	*Break*	
3:15	Recommendations, findings, synthesis	Ianelli

Workshop participants

Table 3D.2.			Specialty/relevant experience
Hanselman	Dana	AFSC	Sablefish and assessment
Lunsford	Chris	AFSC	Sablefish and surveys
Rodgveller	Cara	AFSC	Sablefish and fishery data
Fujioka	Jeff	AFSC	Sablefish and assessment
Maunder	Mark	IATTC	Assessment, ADMB, SS3
Mueter	Franz	UAF/SSC	Modeling, R, GLMs
Clark	Bill	Plan Team, IPHC (retired)	Halibut and assessment
Ianelli	Jim	AFSC	Assessment, modeling, Plan Team chair
Shotwell	Kalei	AFSC	Ecosystem, GIS, rapporteur
Heifetz	Jon	AFSC	Sablefish, assessment, movement modeling
Sigler	Mike	AFSC	Sablefish assessment, ecosystems
Rigby	Phil	AFSC	Groundfish, management