3. Assessment of the sablefish stock in Alaska

by

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Executive Summary

Summary of changes in assessment inputs

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

Changes in the input data: New data included in the assessment model were relative abundance and length data from the 2014 longline survey, relative abundance and length data from the 2013 longline fishery, length data from the 2013 trawl fisheries, age data from the 2013 longline survey and 2013 fixed gear fishery, updated historical catches from 2006 – 2013, and projected 2014- 2016 catches.

Changes in the assessment methodology: There are no model changes.

Summary of results

	As estimated or specified *last* year for:		As estimated or recommended *this* year for:	
Quantity/Status	2014	2015	2015*	2016*
M (natural mortality rate)	0.10	0.10	0.10	0.10
Tier	3b	3b	3b	3b
Projected total (age 2+) biomass (t)	215,446	221,212	219,997	227,042
Projected female spawning biomass (t)	91,212	88,793	91,183	88,345
$B_{100\%}$	265,903	265,903	262,269	262,269
$B_{40\%}$	106,361	106,361	104,908	104,908
$B_{35\%}$	93,066	93,066	91,794	91,794
F_{OFL}	0.095	0.090	0.098	0.091
$maxF_{ABC}$	0.080	0.077	0.082	0.078
F_{ABC}	0.080	0.077	0.082	0.078
OFL (t)	16,225	14,667	16,128	14,658
max ABC (t)	13,722	12,400	13,657	12,406
ABC (t)	13,722	12,400	**13,657**	12,406
Status	As determined *last* year for:		As determined *this* year for:	
	2012	2013	2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

* Projections are based on estimated catches of 11,172 t and 9,862 t used in place of maximum permissible ABC for 2015 and 2016. This was done in response to management requests for a more accurate two-year projection.

Assessment results

The fishery abundance index decreased 13% from 2012 to 2013 (the 2014 data are not available yet). The longline survey abundance index increased 15% from 2013 to 2014 following a 25% decrease from 2011 to 2013. Spawning biomass is projected to decrease from 2015 to 2018, and then stabilize.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1979-2012. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 104,908 t (combined across the EBS, AI, and GOA), 0.095, and 0.112, respectively. Projected female spawning biomass (combined areas) for 2015 is 91,183 t (88% of $B_{40\%}$), placing sablefish in sub-tier “b” of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.082, which translates into a 2015 ABC (combined areas) of 13,657 t. The OFL fishing mortality rate is 0.098 which translates into a 2015 OFL (combined areas) of 16,128 t. Model projections indicate that this stock is not subject to overfishing, overfished, nor approaching an overfished condition.

We recommend a 2015 ABC of 13,657 t. The maximum permissible ABC for 2015 from a Tier 3b adjusted $F_{40\%}$ strategy is 13,657 t. The maximum permissible ABC for 2015 is very similar to the 2014 ABC of 13,722 t. The 2013 assessment projected a 10% decrease in ABC for 2015 from 2014. This smaller decrease is supported by a moderate increase in the domestic longline survey index from the all-time low in 2013 that offset the lowest value of the fishery abundance index seen in 2013. The fishery abundance index has been trending down since 2007. The 2013 IPHC GOA sablefish index was not used in the model, but also declined 21% from 2012. The 2008 year class showed potential to be above average in previous assessments based on patterns in the age and length compositions. However the estimate in this year’s assessment is only average because it is heavily influenced by the recent large overall decrease in the longline survey and trawl indices. Spawning biomass is projected to decline through 2018, and then is expected to increase; assuming average recruitment is achieved in the future. ABCs are projected to decrease in 2016 to 12,406 t and 12,292 t in 2017 (see Table 3.18).

Projected 2015 spawning biomass is 35% of unfished spawning biomass. Spawning biomass has increased from a low of 32% of unfished biomass in 2002 to 35% of unfished biomass projected for 2015 but is trending downward in projections for the near future. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise less than 7% of the 2015 spawning biomass. The 2000 year class is still the largest contributor, with 16% of the spawning biomass in 2015. The 2008 year class is average and will comprise 10% of spawning biomass in 2015 even though it is only 60% mature.

Apportionment

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 have used the same algorithm to apportion the ABC and OFL since 2000. Following the standard apportionment scheme, we have observed that the objective to reduce variability in apportionment was not being achieved. Since 2007, the average change in apportionment by area has increased annually (Figure 3.36A). While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands. For example, the apportionment for the Bering Sea has varied drastically since 2007, attributable to high variability in both survey abundance and fishery CPUE estimates in the Bering Sea (Figure 3.36B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.36C). Because of the high variability in apportionment seen in recent years, we do not believe the standard method is meeting the goal of reducing the magnitude of interannual changes in the apportionment. Because of these reasons, we recommended fixing the apportionment at the proportions from the 2013 assessment until the apportionment scheme is thoroughly reevaluated and reviewed. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2012 with the objectives of re-examining the apportionment strategy and conducting management strategy evaluations. A spatial sablefish model has been developed, but management strategy evaluations have not begun yet. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former scheme until more satisfactory methods have been identified and evaluated. **Therefore**, **for 2015, we recommend keeping the apportionment fixed at the proportions used in 2014.**

Area	2014 ABC	Standard apportionment for 2015 ABC	**Recommended fixed apportionment for 2015 ABC***	**Difference from 2014**
Total	13,722	13,657	**13,657**	-0.5%
Bering Sea	1,339	2,210	**1,333**	-0.5%
Aleutians	1,811	1,840	**1,802**	-0.5%
Gulf of Alaska (subtotal)	10,572	9,607	**10,522**	-0.5%
Western	1,480	1,445	**1,473**	-0.5%
Central	4,681	3,975	**4,658**	-0.5%
W. Yakutat**	1,574	1,428	**1,567**	-0.5%
E. Yak. / Southeast**	2,837	2,759	**2,823**	-0.5%

* Fixed at the 2012 assessment apportionment proportions (Hanselman et al. 2012). ** Before 95:5 hook and line: trawl split shown below.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2015	1,708 t	2,682 t
	2016	1,552 t	2,436 t

Plan team summaries

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2013	167,000	14,780	12,510	12,510	11,945
	2014	149,000	12,500	10,572	10,572	10,391
	2015	130,000	12,425	10,522		
	2016	127,000	11,293	9,558		
BS	2013	19,000	1,870	1,580	1,580	634
	2014	21,000	1,584	1,339	1,339	328
	2015	34,000	1,575	1,333		
	2016	33,000	1,431	1,211		
AI	2013	28,000	2,530	2,140	2,140	1,062
	2014	28,000	2,141	1,811	1,811	757
	2015	24,000	2,128	1,802		
	2016	23,000	1,934	1,637		

Year	2014				2015		2016	
Region	OFL	ABC	TAC	Catch*	OFL	ABC	OFL	ABC
BS	1,584	1,339	1,339	328	1,575	1,333	1,431	1,211
AI	2,141	1,811	1,811	757	2,128	1,802	1,934	1,637
GOA	12,500	10,572	10,572	10,391	12,425	10,522	11,293	9,558
W	--	1,480	1,480	1,090	--	1,474	--	1,338
C	--	4,681	4,681	4,737	--	4,658	--	4,232
**WYAK	--	1,574	1,574	1,707	--	1,708	--	1,552
SEO	--	2,837	2,837	2,857	--	2,682	--	2,436
Total	16,225	13,722	13,722	11,476	16,128	13,657	14,658	12,406

*Extrapolated from October 1, 2014 Alaska Fisheries Information Network, (www.akfin.org). **After 95:5 trawl split shown above.

Responses to SSC and Plan Team Comments on Assessments in General

The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs. (September 2013, Plan Team)

The Joint Plan Teams in September 2014 examined the compilation of current methods for estimating current year's removals and recognized that the best method was stock specific and encouraged authors to choose the best method for their stocks and document them. We estimated current year's removals by multiplying the official catch as of October 1, 2014, by an expansion factor that represents the average additional catch taken between October 1 and December 31 in the last three complete years (2011-2013). (See *Specified catch estimation* section).

During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment. (December 2013, SSC)

These projections are available in the executive summary table and have been added to the phase-plane plots in this assessment. (See *Figure 3.30*)

Responses to SSC and Plan Team Comments Specific to this Assessment

The Teams recommend establishment of an ecosystem/assessment committee to help set up an example report card that is designed to allow the authors to fill in the blanks as an update rather than develop new conceptual models and to have in-house discussion on this topic before future presentations to the Plan Teams.(November 2012, Plan Team)

In September 2014, a document and presentation was made to the joint Plan Teams by the ecosystem/assessment committee with sablefish as an example species. The Plan Team and SSC encouraged development of stock-specific ecosystem consideration sections that have ecosystem indicators specific to particular stocks. We hope to include sablefish as an example stock as this effort moves forward.

The Teams recommend that the authors investigate time-varying selectivity in relation to some of the issues seen in the retrospective pattern. (November 2012, Plan Team)

Selectivity for the longline survey and longline fishery are currently time-varying, but not annually. The time blocks are related to specific changes in the survey (transition from cooperative to domestic) and the fishery (transition from derby to IFQ). The lack of retrospective trend in recent years (see Figure 3.31) does not warrant a change to fishery selectivity. However, the most recent fishery age data in 2013 show a shift to older fish driven by catches in the Aleutian Islands. These data may warrant exploration of annual varying selectivity for the 2015 assessment.

The SSC continues to encourage the development of a spatial assessment model for research purposes and supports the additional collection and analysis of biological samples needed to support a movement model.(December 2012, SSC)

A study on sablefish movement and mortality has been accepted for publication (Hanselman et al. 2014). Additionally, there is a UAF Ph.D. student working on a spatial assessment model for sablefish. We continue to evaluate and progress towards spatially explicit modeling of sablefish.

The Teams recommended following the authors' approach for apportionment as an interim measure (-15% across all areas). The Teams also recommended that the standard approach (used in previous year's assessments) be presented to the SSC and Council and noted that work is underway to select an improved apportionment approach. (November 2013, Plan Team)

For this year we continue to recommend the interim apportionment approach which is explained in detail in the apportionment Section (See Section *Apportionment*).

The SSC reviewed the recommended alteration to the usual algorithm of spatial apportionment. The SSC approves the alternative apportionment for next year. However, the SSC is concerned about removing a data point (2013) without strong justification. The SSC recommends re-examining the method for spatially allocating the sablefish ABC in the next year. To the extent practicable, the SSC requests that the authors try to include preliminary results of the spatial MSE in the 2014 assessment.(December 2013, SSC)

The spatial MSE is not completed at this time. However, we are working closely with a graduate student who has made significant progress toward a spatial assessment model which will be the foundation of the management strategy evaluations.

The SSC reiterates its concern that the current assessment model exhibits a strong retrospective pattern and encourages further exploration of the factors underlying the slow response of the model to shifts in stock status. (December 2013, SSC)

The sablefish model had a period of retrospective bias between 2004-2008, (see *Retrospective Analysis* section) but that bias appears to have dissipated in the last 5 years. In the Plan Team retrospective investigations group report, sablefish had one of the lowest rankings in terms of retrospective problems (17 out of 20). For 2014, the retrospective pattern has lessened further. In previous examinations of the retrospective pattern for sablefish (Hanselman et al. 2011), it was shown that longline survey catchability had a systematic pattern of change relative to the number of retrospective peels. For 2014, there was a substantial increase in past catch estimates during the period with high retrospective bias (see *Catch* section under ***Data****)*. This increase in catch increased our current estimates of spawning biomass during that historically low period which contributed to the reduction in Mohn's revised rho (see *Retrospective Analysis* section for further details).

Introduction

Distribution

Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the Gulf of Alaska (GOA), westward to the Aleutian Islands (AI), and into the Bering Sea (BS) (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 spend their first two to three years on the continental shelf of the GOA, and occasionally on the shelf of the southeast BS. The BS shelf is utilized significantly in some years and seldom used during other years (Shotwell et al. 2012).

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). Along the Canadian coast (Mason et al. 1983) and off Southeast Alaska (Jennifer Stahl, February, 2010, ADF&G, pers. comm.) sablefish spawn from January-April with a peak in February. In a survey near Kodiak Island in December, 2011 that targeted sablefish preparing to spawn, spawning appeared to be imminent, but spent fish were not found. It is likely that they would spawn in January or February (Katy Echave, October 2012, AFSC, pers. comm.). Farther down the coast off of central California sablefish spawn earlier, from October-February (Hunter et al. 1989). An analysis of larval otoliths showed that spawning in the Gulf of Alaska may be a month later than southern sablefish (Sigler et al. 2001). Sablefish in spawning condition were also noted as far west as Kamchatka in November and December (Orlov and Biryukov 2005). In gill nets set at night for several years on the AFSC longline survey, most young-of-the-year sablefish were caught in the central and eastern GOA (Sigler et al. 2001). Near the end of the first summer, pelagic juveniles less than 20 cm move 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).

Movement

A movement model for Alaskan sablefish was developed for Alaskan sablefish by Heifetz and Fujioka (1991) based on 10 years of tagging data. The model has been updated by incorporating data from 1979-2009 in an AD Model Builder program, with time-varying reporting rates, and tag recovery data from ADF&G for State inside waters (Southern Southeast Inside and Northern Southeast Inside). In addition, the study estimated mortality rates from the tagging data (Hanselman et al. *in press*). Annual movement probabilities were high, ranging from 10-88% depending on area of occupancy at each time step, and size group. Overall, movement probabilities were very different between areas of occupancy and moderately different between size groups. Estimated annual movement of small sablefish from the central Gulf of Alaska had the reverse pattern of a previous study, with 29% moving westward and 39% moving eastward. Movement probabilities also varied annually with decreasing movement until the late 1990s and increasing movement until 2009. Year specific magnitude in movement probability of large fish was highly negatively correlated with female spawning biomass estimates from the federal stock assessment. Average mortality estimates from time at liberty were similar to the stock assessment.

Stock structure

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. Significant stock structure among the federal Alaska population is unlikely given extremely high movement rates throughout their lives (Heifetz and Fujioka 1991, Maloney and Heifetz 1997, Kimura et al. 1998).

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 GOA; 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 BS in 1958. The fishery expanded rapidly in this area and catches peaked at 25,989 t in 1962 (Table 3.1, Figures 3.1, 3.2). As the fishing grounds in the eastern Bering were preempted by expanding Japanese trawl fisheries, the Japanese longline fleet expanded to the AI region and the GOA. In the GOA, sablefish catches increased rapidly as the Japanese longline fishery expanded, peaking at 36,776 t overall in 1972. Catches in the AI 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 GOA 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 Fishery Conservation and Management Act (FCMA).

Japanese trawlers caught sablefish mostly as bycatch in fisheries targeting other species. In the BS, the trawlers were mainly targeting rockfishes, Greenland turbot, and Pacific cod, and only a few vessels targeted sablefish. In the GOA, sablefish were mainly caught as bycatch in the directed Pacific Ocean perch fishery until 1972, when some vessels started targeting sablefish in 1972 (Sasaki 1985).

Other foreign nations besides Japan also caught sablefish. Substantial Soviet Union catches were reported from 1967-73 in the BS (McDevitt 1986). Substantial Korean 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 Soviet gear was factory-type stern trawl and the Korean gears were 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 GOA, and by 1988, the U.S. harvested all sablefish taken in Alaska, except minor joint venture catches. Following domestication of the fishery, the previously year-round season in the GOA began to shorten in 1984 from 12 months in 1983 to 10 days in 1994, warranting the label “derby” fishery.

In 1995, Individual Fishery Quotas (IFQ) were implemented for hook-and-line vessels along with an 8-month season. The IFQ Program is a catch share fishery that issued quota shares to individuals based on sablefish and halibut landings made from 1988-1990. Since the implementation of IFQ’s, the number of longline vessels with sablefish IFQ harvests has experienced a substantial anticipated decline from 616 in 1995 to 362 in 2011 (NOAA 2012). This decrease was expected as shareholders have consolidated their holdings and fish them off fewer vessels to reduce costs (Fina 2011). The sablefish fishery has historically been a small boat fishery; the median vessel length in the 2011 fishery was 56ft. In recent years, approximately 30% of vessels eligible to fish in the IFQ fishery participate in both the halibut and sablefish fisheries and approximately 40% of vessels fish in more than one management area. The season dates have varied by several weeks since 1995, but the monthly pattern has been from March to

November with the majority of landings occurring in May - June. The number of landings fluctuates with quota size, but in 2011 there were 1,726 landings recorded in the Alaska fishery (NOAA 2012).

Pot fishing in the IFQ fishery is not allowed in the GOA but is legal in the BSAI regions. In 2000, the pot fishery accounted for less than ten percent of the fixed gear sablefish catch in these areas but effort has increased substantially in response to killer whale depredation. Pots are longlined with approximately 40-135 pots per set. Since 2004, pot gear has accounted for over 50% of the BS fixed gear IFQ catch and up to 34% of the fixed gear catch in the AI.

Sablefish also are caught incidentally during directed trawl fisheries for other species groups such as rockfish and deepwater flatfish. Allocation of the TAC by gear group varies by management region and influences the amount of catch in each region (Table 3.1, Figures 3.1, 3.2). 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 GOA and AI. 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.

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 change to IFQ also decreased harvest and discard of immature fish which improved the chance that these fish will reproduce at least once. Thus, the stock can provide a greater yield under IFQ at the same target fishing rate because of the selection of older fish (Sigler and Lunsford 2001).

Longline gear in Alaska is fished on-bottom. Since the inception of the IFQ system, average set length in the directed fishery for sablefish has been near 9 km and average hook spacing near1.2 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 are usually 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 on bottom.

Management measures/units

A summary of historical catch and management measures pertinent to sablefish in Alaska are shown in Table 3.7. Influential management actions regarding sablefish include:

Management units

Sablefish are assessed as a single population in Federal waters off Alaska because of their high movement rates. Sablefish are managed by discrete regions to distribute exploitation throughout their wide geographical range. There are four management areas in the GOA: Western, Central, West Yakutat, and East Yakutat/Southeast Outside; and two management areas in the Bering Sea/Aleutian Islands (BSAI): the BS and the AI regions. Amendment 8 to the GOA Fishery Management Plan established the West and East Yakutat management areas for sablefish, effective 1980.

Quota allocation

Amendment 14 to the GOA 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 GOA, and 95% to fixed gear and 5% to trawl in the Eastern GOA, effective 1985. Amendment 15 to the BS/AI Fishery Management Plan, allocated the sablefish quota by gear type, 50% to fixed gear and 50% to trawl in the eastern BS, and 75% to fixed gear and 25% to trawl gear in the Aleutians, effective 1990.

IFQ management

Amendment 20 to the GOA Fishery Management Plan and 15 to the BS/AI 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 BS and AI.

Maximum retainable allowances

Maximum retainable allowances for sablefish were revised in the GOA by a regulatory amendment, effective 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, northern rockfish, dusky rockfish, and 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 GOA Fishery Management Plan banned the use of pots for fishing for sablefish in the GOA, 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 BS (57 FR 37906). The prohibition on sablefish longline pot gear use was removed for the BS, 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 AI.

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 BS in 1958 and the GOA in 1963. Catches rapidly escalated during the mid-1960s. Annual catches in Alaska reached peaks in 1962, 1972, and 1988 (Table 3.1, Figure 3.2). 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.

Exceptional recruitment fueled increased abundance and increased catches during the late 1980's, which coincided with the domestic fishery expansion. Catches declined during the 1990's, increased in the early 2000s, and have since declined to near 12,000 t (Figure 3.1). TACs in the GOA are nearly fully utilized, while TACs in the BS and AI are rarely fully utilized.

Bycatch and discards

Sablefish discards by target fisheries are available for hook-and-line gear and other gear combined (Table 3.3). From 1994 to 2004 discards averaged 1,357 t for the GOA and BSAI combined (Hanselman et al. 2008). Since then, discards have been lower, averaging 614 t between 2007 and 2013. The highest discard amounts occur in hook-and-line fisheries in the GOA (Table 3.3).

Table 3.4 shows the average bycatch of Fishery Management Plans’ (FMP) groundfish species in the sablefish target fishery from 2009-2013. The largest bycatch group is GOA thornyhead rockfish (520 t/year, 151 t discarded). Arrowtooth flounder and shark are the 2nd and 3rd most caught species at 348 t/year and 331 t/year. Arrowtooth is the only species that has substantial catch in non-longline gear. The next three groups are GOA Shortraker, GOA Other rockfish, and GOA longnose skate which total 435 t/year.

Giant grenadiers, a non-target species that is soon entering both FMPs as an Ecosystem Component, make up the bulk of the nontarget species bycatch, with 2013 the highest in the last five years at 8,083 t (Table

3.5). Other nontarget taxa that have catches over one ton per year are corals, snails, sponges, sea stars, and miscellaneous fishes and crabs.

Prohibited species catches (PSC) in the targeted sablefish fisheries are dominated by halibut (1,224 t/year on average) and golden king crab (66,000 individuals/year on average). Halibut and golden king crab catches are highly variable from year to year, probably as a result of relatively low observer sampling effort in sablefish fisheries (Table 3.6).

Data

The following table summarizes the data used for this assessment:

Source	Data	Years
Fixed gear fisheries	Catch	1960-2014
Trawl fisheries	Catch	1960-2014
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. fixed gear fishery	CPUE, length	1990-2013
	Age	1999-2013
U.S. trawl fisheries	Length	1990,1991,1999, 2005-2013
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-2014
	Age	1996-2013
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013

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 3.8). The Japanese data were collected by fishermen trained by Japanese scientists (L. L. Low, August 25, 1999, Alaska Fisheries Science Center, pers. comm.). 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).

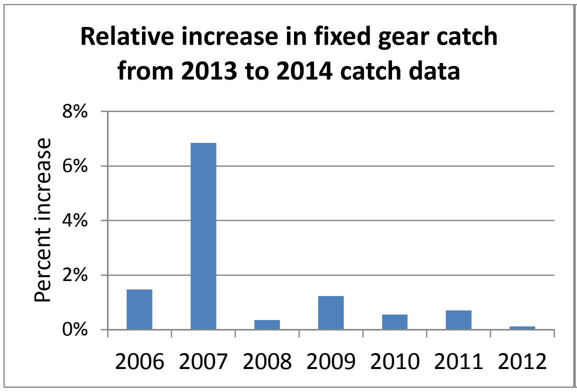
Catch

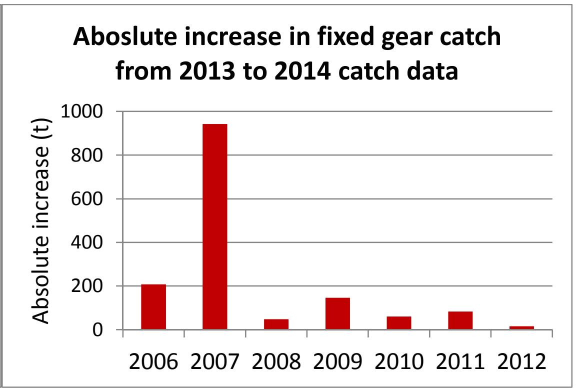
The catches used in this assessment (Table 3.1) include catches from minor State-managed fisheries in the northern GOA and in the AI region because fish caught in these State waters are reported using the area code of the adjacent Federal waters in the Alaska Regional Office catch reporting system (G. Tromble, July 12, 1999, Alaska Regional Office, pers. comm.), the source of the catch data used in this assessment. Minor State fisheries catches averaged 180 t from 1995-1998, about 1% of the average total catch. Most of the catch (80%) is from the AI 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. Catches from state areas that conduct their own assessments and set Guideline Harvest levels (e.g., Prince William Sound, Chatham Strait, and Clarence Strait), are not included 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 3.8, Figures 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 (Sigler et al. 1999). 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).

In response to Annual Catch Limit (ACL) requirements, assessments now document all removals including catch that are not associated with a directed fishery. Research catches of sablefish have been reported in previous stock assessments (Hanselman et al. 2009). Estimates of all removals not associated with a directed fishery including research catches are available and are presented in Appendix 3B. The sablefish research removals are small relative to the fishery catch, but substantial compared to the research removals for many other species. These research removals support a dedicated longline survey. Additional sources of significant removals are bottom trawl surveys and the International Pacific Halibut Commission's longline survey. Other removals are relatively minor for sablefish but the sport fishery catch has been increasing in recent years, but occurs primarily in State waters. Total removals from activities other than directed fishery have been between 239-359 t since 2006. These catches are not included in the stock assessment model. These removal estimates equate to approximately 2% of the recommended ABC and represent a relatively low risk to the sablefish stock.

For the 2014 assessment, sablefish catches since 2006 have been altered substantively in the Alaska Regional Office Catch Accounting System (CAS) revisions. The years 2006-2009 were particularly different than reported in the 2013 SAFE. These estimates of catch have been updated and corrected to account for selected landings and associated catch that were inadvertently not being counted against the Federal ABC. The missing records were a result of the transition to the eLandings system and the fact that not all processors were using the system in those years. During that time, there were paper fish tickets generated from processors who were not using eLandings. Those data were entered into the eLandings system by Alaska Department of Fish and Game, but were missing federal permit information and thus did not get properly captured by the CAS. Recently, changes were made to CAS to enable accounting of groundfish landings with missing federal permit information and CAS has been re-run for the historical years. This resulted in a net total increase of about 1,500 t to the sablefish catch in since 2005, with the biggest relative increase in 2007 (see figures below).


Relative increase in fixed gear catch from 2013 to 2014 catch data


Aboslute increase in fixed gear catch from 2013 to 2014 catch data

Lengths

We use length compositions from the U.S. fixed gear (longline and pot) and U.S. trawl fisheries which are both measured by sex. The fixed gear fishery has large sample sizes and has annual data since 1990. The trawl fishery had low levels of observer sampling in much of the 1990s and early 2000s, and has a much smaller sample size than the fixed gear fishery. We only use years for the trawl fishery that have sample sizes of at least 300 per sex. The length compositions are weighted by catch in each FMP management area to obtain a representative estimate of catch-at-length.

Ages

We use age compositions from the U.S. fixed gear fishery since 1999. Sample sizes are similar to the longline survey with about 1,000 otoliths aged every year. The age compositions are weighted by the catch in each area to obtain a representative estimate of catch-at-age.

Longline fishery catch rate index

Fishery information is available from longline sets 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 is available since 1990. Logbooks are required for vessels over 60 feet beginning in 1999. Since 2000, a longline fishery catch rate index has been derived from observed sets and logbook data for use in the model and in apportionment. The mean CPUE is scaled to a relative population weight by the total area size in each area. In the years that logbook and observer CPUEs are available, the average of the two sources is computed by weighting with the inverse of the coefficient of variation.

Longline sample sizes

The total weight of all sets recorded by observers determined to be targeting sablefish represent on average 14% of the annual IFQ hook and line catch; in 2013 they comprised 12% of the catch (1,389 mt). On average, the percent of the IFQ catch observed is lowest in the EY/SE (5%), highest in WY and AI (~22%), and moderate in the BS, CGOA, and WGOA (10-14%). In 2013 coverage in the BS was only 2% and only 10% in WY. The AI had higher coverage than average (35%). This may partially be due to observer restructuring. Low longline fishery sample sizes in the BS are likely a result of poor observer coverage for sablefish directed trips (Table 3.9). Because of confidentiality concerns, the catch rates with less than three vessels cannot be shown.

Killer whales impact sablefish catch rates in the BS, AI and WGOA and these sets are excluded from catch rate analyses. Since 2009, there has been an increase in killer whale depredation in the WGOA (average 6% from 2010-2013); however, this is only 7-18 sets per year. In the AI and BS, killer whale depredation has been variable, ranging from 0-12 sets per year in each area. Sperm whale depredation occurs in the CGOA, EY/SE, WY, and sometimes in the WGOA. The percent of sets in each area depredated by sperm whales varies greatly and determining if sperm whales are depredating can be subjective because whales do not take the great majority of the catch, like killer whales do. Therefore, measures of depredation in the fishery may not be accurate.

Logbook sample sizes are substantially higher than observer samples sizes, especially since 2004, and have continued to rise annually in many management areas (WGOA, WY, CGOA) (Table 3.9). Logbook participation increased sharply in 2004 in all areas primarily because the International Pacific Halibut Commission (IPHC) was used to collect, 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. There were 5% more sets used for catch rate analyses in 2013 than in 2012. Like in 2012, the number of sets submitted by vessels <60 ft was approximately equal to the number from vessels >60 ft. There is a higher proportion of the catch documented by logbooks than by observers; 54% of the catch was documented in logbooks that were used in calculations of catch rates in 2013, compared to 12% for observer data in 2013. Some data is included in both data sets if logbooks are required and an observer was onboard.

Longline catch rates

Killer whale depredation data is excluded for catch rate calculations in observer data, but whale depredation is not documented in logbooks and so no data is excluded. In general, catch rates are highest in the EY/SE and WY areas and are lowest in the BS and AI (Table 3.9, Figures 3.5 and 3.6). Recently, catch rate trends in the observer and logbook data have been similar in the EBS, CGOA, WGOA, and AI. In 2013 catch rates decreased substantially in both fishery data sets in the WGOA and CGOA. The decrease was larger in the logbook data set (30% drop in WGOA and 39% in CGOA in logbook data; 11% drop in WGOA and 31% in CGOA in observer data). Catch rates in the AI have been pretty stable since 2009 in both data sets. In 2013, WY logbook CPUE was down, while the observer data was up from 2012. EY/SE CPUE decreased in both data sets, but more in logbook data than observer data (14% versus 2%).

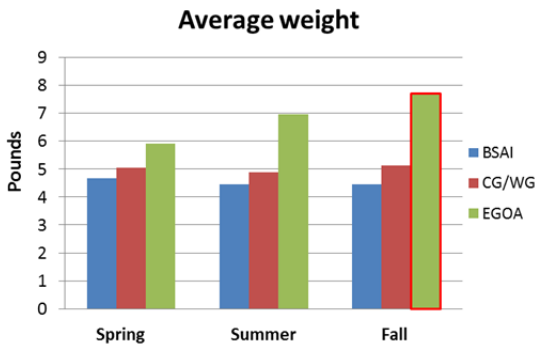
Longline spatial and temporal patterns

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). This could lead to an incorrect interpretation of fishery catch rates, which could remain stable while the area occupied by the stock was diminishing (Rose and Kulka 1999).

We examined fishery longline data for seasonal and annual differences in effort and catch rate (CPUE, lbs/hook). Such changes may cause fishery catch rates to be unrepresentative of abundance. In the observed longline data since 2000, the majority of effort occurs in the spring and less in the summer and fall. Since 1998, catch rates are also highest in the spring, moderate in the summer, and variable in the fall (due to lower sample sizes in the fall). No significant spatial or temporal changes have emerged in the logbook or observer data.

Seasonal changes in fish size

In 2012 and 2013 there was an increase in the quantity of logbook data providing estimates of catch in weight and estimated numbers per set. This enables us to examine change in average weight of fish caught by season. Data from 2012 and 2013 were combined to increase sample sizes. To further increase sample size, areas were aggregated into BS/AI, CG/WGOA, and WY/EY/SE (EGOA). Data were included unless there was missing weight or count information. There were very small differences between spring, summer, and fall in all areas except the EGOA (see figure below). However, this may be a sample size issue as there were very few sets available in the fall in EGOA compared to all other areas/seasons (78 sets; highlighted in red below). In EGOA, weight in spring was 5.9 lbs, 7 lbs in summer, and 7.7 lbs in fall. More data is needed to determine if there actually is an increasing trend in weight in the fall in the EGOA.



Count of logbook sets used for calculations of average sablefish weight by area and season.

Area	Spring	Summer	Fall	Total
BS/AI	560	614	157	1,331
CG/WG	1,563	1,409	403	3,375
EGOA	783	297	78	1,158

Pot fishery catch rate analysis

Pot catch rates: Because pot data is sparser than longline data, and in some years is confidential due to fewer than 3 vessels participating, specific annual data is not presented. In addition, it is difficult to discern trends, since pot catch rates have wider confidence intervals than longline data due to smaller sample sizes. Overall, there are more vessels in both the logbook and observer data from the sablefish pot fishery in the BS than the AI.

Since 2006, in the BS there have been from 5 to 9 vessels in logbook data and 5 to 8 vessels in observer data. In the AI, there have been from 1 to 5 vessels in logbooks and 1 to 4 in observer data. In 2013, CPUE remained stable in logbook data but fewer total pots and sets were recorded during the year, especially in the AI. From 2006-2013 the average catch rate in logbook data was 29 lbs/pot in the AI (number sets (n) = 809) and 24 lbs/pot in the BS (n = 6,164). Pot CPUE has been stable in observer data as well. Average catch rate in the observer data from 2006-2013 was 11 lbs/pot (n = 1,156) in the AI and 18 lbs/pot (n = 2,970) in the BS. Effort is approximately equal throughout the fishing season.

The composition of bycatch species caught in observed pots that retained sablefish in the BS and AI is comprised mostly of arrowtooth/Kamchatka flounder, golden king crab, Greenland turbot, Pacific halibut, and giant grenadier. Almost all of the golden king crab is caught in the AI (Hanselman et al. 2010).

Surveys

A number of fishery independent surveys catch sablefish. The survey indices included in the model for this assessment are the AFSC longline survey and the AFSC GOA bottom trawl survey. For other surveys that occur in the same or adjacent geographical areas, but are not included as separate indices in the model, we provide trends and comparative analyses to the AFSC longline survey. Research catch removals including survey removals are documented in Appendix 3B.

AFSC Surveys

Longline survey

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 GOA annually from 1978 to 1994, adding the AI region in 1980 and the eastern BS 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 GOA in 1987, biennial sampling of the AI in 1996, and biennial sampling of the eastern BS in 1997 (Rutecki et al. 1997). The domestic survey also samples major gullies of the GOA 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 AI and/or BS, Western Gulf, Central Gulf, Eastern Gulf. Starting in 1998, the Eastern Gulf area was surveyed before the Central Gulf area.

Specimen collections: Sablefish length data were randomly collected for all survey years. Otoliths were collected for age determination for most survey years. From 1979-1994 otolith collections were length-stratified; since 1994 otoliths have been collected randomly. Prior to 1996, otolith collections were aged but not consistently from year to year. Since 1996, a sample of otoliths collected during each survey have been aged in the years they were collected. Approximately one-half of the otoliths collected (~1,000) are aged annually. This sample size for age compositions should be large enough to get a precise age composition for the whole survey area, but may be too small to estimate the age composition in smaller areas by sex (P. Hulson, unpublished manuscript).

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 3.9). Kimura and Zenger (1997) attributed the difference to the domestic longline survey not being standardized until 1990.

Survey Trends: Relative population abundance indices are computed annually using survey catch rates from stations sampled on the continental slope. Highest sablefish abundance indices occurred during the Japan-U.S. cooperative survey in the mid-1980's, in response to exceptional recruitment in the late 1970's (Figure 3.7). Relative population numbers declined through the 1990's in most areas during the domestic longline survey. Survey catches and abundance estimates trended down through 2009. Three of the lowest overall abundance estimates in the domestic survey occurred from 2007-2009. Survey estimates in the Eastern Gulf increased in 2010 and in 2011 the high Central Gulf estimate increased the entire index. Survey abundance estimates in 2010 and 2011 were unexpectedly high, while the 2012 and 2013 estimates were below expectations.

The 2013 survey estimate of relative abundance in numbers (RPN) was at the lowest point in the domestic time series; however, in 2014 there was an overall increase of 15% from 2013. The individual areas that contributed to the increase were WGOA (67%), WY (21%), and EY/SE (13%). Although there were modest increases, the index is still below average because of recent weak recruitment.

Whale Depredation: Killer whale depredation of the survey's sablefish catches has been a problem in the BS since the beginning of the survey (Sasaki 1987). Killer whale depredation primarily occurs in the BS, AI, WGOA, and to a lesser extent in recent years in the CGOA (Table 3.11). Depredation is easily identified by reduced sablefish catch and the presence of lips or jaws and bent, straightened, or broken hooks. Since 1990, portions of the gear at stations affected by killer whale depredation during the domestic longline survey have been excluded from the analysis of catch rates, RPNs, and RPWs. The AI and the BS were added to the domestic longline survey in 1996 and this is when killer whale depredation increased. In 2009, 10 BS stations were depredated, which significantly impacted catch and biased the abundance index leading to using the 2007 BS RPN estimate to interpolate the 2009 and 2010 BS RPNs (Hanselman et al. 2009). In 2011, depredation levels in the BS were similar to previous years with catches at 7 of 16 stations affected. In 2013, a new high of 11 stations were depredated, although fewer skates were impacted and therefore removed from the analysis in comparison to what occurred in 2009.

In 2014 there were 3 stations depredated by killer whales in the AI, down from the all time high of 5 in 2012 (Table 3.11). There were 4 stations with killer whale depredation in the WGOA. This is within the normal range of 1 to 5 stations. Although there has been some killer whale depredation in the CGOA in the past (1 - 2 stations), this year there was none. Overall the number of skates affected by killer whale depredation was 2/3 of what it was in 2012 (when the AI was last sampled). In total, there were 7 stations in 2014 with killer whale depredation and 10 in 2012.

Sperm whale depredation affects longline catches, but evidence of depredation is not accompanied by obvious decreases in sablefish catch or common occurrence of lips and jaws or bent and broken hooks. Data on sperm whale depredation have been collected since the 1998 longline survey (Table 3.11). Sperm whales are often observed from the survey vessel during haulback but do not appear to be depredating on the catch. Sperm whale depredation and presence is recorded during the longline survey at the station level, not the skate level like killer whales. Depredation is defined as sperm whales being present during haulback with the occurrence of damaged sablefish in the catch.

Sperm whale depredation has been variable since 1998. Whales are most common in the EGOA (WY and EY/SE). There are 65 stations sampled that are used in calculations of population indices in a year when the AI is sampled. In 2014 there were sperm whales depredating at 15 stations (Table 3.11). The number of stations with sperm whale depredation was typical of the range since 2007 (10-19 per year). In 2014, there were whales depredating at 10 stations in the EGOA (out of a total of 25) and 4 in the CGOA (out of 16). Depredation occurred at one station in the AI, which is rare, but has happened in the past. There were no sperm whales depredating in the WGOA in 2014.

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 was 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, October, 2009, 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 this small 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 sperm whale presence and depredation at survey stations, as indicated by whale observations and significant results of recent studies, we evaluated a statistical adjustment to survey catch rates using a general linear modeling approach (Appendix 3C, Hanselman et al. 2010). This approach had promise but had issues with variance estimation and autocorrelation between samples. A new approach has been developed using a generalized linear mixed model (see Appendix 3C).

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 GOA, AI, or BS.

Previous analyses have shown that on average gully stations catch fewer large fish and more small fish than adjacent slope stations (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). Gully catches may indicate recruitment signals before slope areas because of their shallow depth, where younger, smaller sablefish typically inhabit. Catch rates from these stations have not been included in the historical abundance index calculations because preferred habitat of adult sablefish is on the slope.

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.

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 (Figure 3.8). Overall, gully catches in the GOA from 1990-2014 are moderately correlated with slope catches ($r = 0.51$). There 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 in 1999, which supports the current model estimate that the 2000 year class was larger than 1997. Both gully and slope trends were down in 2012 and 2013, consistent with the overall decrease in survey catch. However, the slope stations increased in 2014, while the gullies continued to decline. 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.

Trawl surveys

Trawl surveys of the upper continental slope that adult sablefish inhabit have been conducted biennially or triennially since 1980 in the AI, and 1984 in the GOA, always to 500 m and occasionally to 700-1000 m. Trawl surveys of the BS slope were conducted biennially from 1979-1991 and redesigned and standardized for 2002, 2004, 2008, 2010, and 2012. Trawl surveys of the BS shelf are conducted annually but generally catch no sablefish. Trawl survey abundance indices were not used in the assessment model prior to 2007 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 BS and AI with the GOA 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 GOA trawl survey biomass estimates (<500 m depth, Figure 3.4) and length data (<500 m depth) as a recruitment index for the whole population. The largest proportion of sablefish biomass is in the GOA so it should be indicative of the overall population. Biomass estimates used in the assessment for 1984-2013 are shown in Table 3.10. The GOA trawl survey index was at its lowest level of the time series in 2013, down 29% from 2011.

AI and BS Slope survey biomass estimates are not used in the assessment model but are tracked in Figure 3.9. Estimates in the two areas have decreased slowly since 2000.

Other surveys/areas not used in the assessment model

IPHC Longline Surveys

The 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.

We do not obtain IPHC survey estimates for the current year until the following year. We compared the IPHC and the AFSC RPNs for the GOA (Figure 3.10). The two series track well, but the IPHC survey RPN has more variability. This is likely because it surveys shallower water on the shelf where younger sablefish reside and are more patchily distributed. 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 above (Figure 3.4).

While the two surveys have shown consistent patterns for most years, they diverged in 2010 and 2011, but the 2013 estimates both show the lowest point in the time series for each index (Figure 3.10). The IPHC estimate for the Gulf of Alaska for 2013 was a 21% decline from 2012. IPHC trends by region were similar, but IPHC data was 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 longline survey, and we recently have computed RPNs for these depths for future comparisons with the IPHC RPNs.

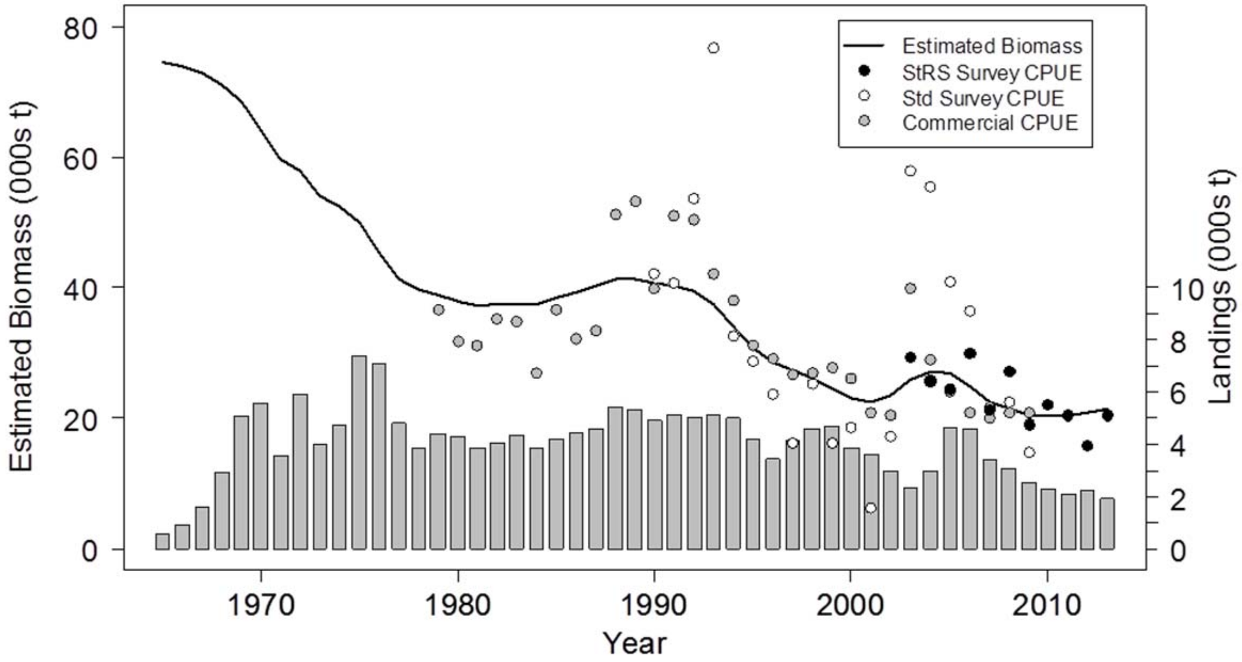
Alaska Department of Fish and Game

The Alaska Department of Fish and Game conducts mark-recapture and a longline survey in Northern Southeast Alaska Inside (NSEI) waters. Sablefish in this area are treated as a separate population, but some migration into and out of Inside waters has been confirmed with tagging studies (Hanselman et al. 2014). Estimates of exploitable population biomass based on mark-recapture estimates show a stable to slightly declining trend. This population seems to be stabilizing from previous steep declines. Their longline survey CPUE estimates (Figure 3.11a) and fishery CPUE estimates (Figure 3.11b) had been slowly increasing since 2000, confirming the lows in 1999/2000 estimated in our assessment. Like the AFSC longline survey, there was a sharp decline in the 2013 longline CPUE estimate for NSEI.

Department of Fish and Oceans of Canada

In a 2011 Science Advisory Report, DFO reported :*"Stock reconstructions suggest that stock status is currently below* B_{MSY} *for all scenarios, with the stock currently positioned in the mid-Cautious to low-Healthy zones."* Under these scenarios, recent harvest rates on adult sablefish potentially have been between 0.06 – 0.15[1].

The stratified random trap survey was up approximately 29% from 2012 to 2013 after a time series low in 2012. The estimated biomass trend in B.C. is similar to the trend in Alaska (see figure below)[2]. The similarly low abundance south of Alaska concerns us, and points to the need to better understand the contribution to Alaska sablefish productivity from B.C. sablefish. Some potential ideas are to conduct an area-wide study of sablefish tag recoveries, and to attempt to model the population to include B.C. sablefish.



Overall abundance trends

Relative abundance has cycled through three valleys and two peaks near 1970 and 1985 (Table 3.10, Figures 3.3 and 3.4). 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 BS, AI, and western GOA and more slowly in the central and eastern GOA (Figure 3.7). The majority of the surveys show that sablefish were at their lowest levels in the early 2000s, with current abundance reaching these lows again.

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[1] Science Advisory Report 2011/25: http://www.dfo-mpo.gc.ca/Csas-sccs/publications/sar-as/2011/2011_025-eng.pdf

[2] DFO. 2014. Performance of a revised management procedure for Sablefish in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014 /025.

Analytic approach

Model Structure

The sablefish population is assessed 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 GOA Pacific ocean perch model (Hanselman et al. 2005a); it includes split sexes and many more data sources 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 2010 (Hanselman et al. 2010). 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 (Fournier et al. 2012).

Parameters Estimated Outside the Assessment Model

The following table lists the parameters estimated independently:

Parameter name	Value	Value	Source
Time period	1960-1995	1996-current	
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)
Ageing error matrix	From known-age tag releases, extrapolated for older ages		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 occur, at age 2, and a fork length of about 45 cm. A higher proportion of young fish are susceptible to trawl gear compared to longline gear because trawl fisheries usually occur on the continental shelf and shelf break inhabited by younger fish, and catching small sablefish may be hindered by the large bait and hooks on longline gear.

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; Hanselman et al. 2012).

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 (first daily otolith mark for larvae) formation, they average 120 mm. Sablefish are currently estimated to reach average maximum lengths and weights of 68 cm and 3.2 kg for males and 80 cm and 5.5 kg for females (Echave et al. 2012).

New growth relationships were estimated in 2007 because many more age data were available (Hanselman et al. 2007); this analysis was accepted by the Plan Team in November 2007 and published in 2012 (Echave et al. 2012). 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 3.12). 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).

Fifty percent of females are mature at 65 cm, while 50 percent of males are mature at 57 cm (Sasaki 1985), corresponding to ages 6.6 for females and 5 for males (Table 3.12). 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, GOA). 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 $m_a = 1/(1+e^{-0.84(a-6.60)})$. In 2011, the AFSC conducted a winter cruise out of Kodiak to sample sablefish when they are preparing to spawn. Ovaries were examined histologically to determine maturity for a study of the age at maturity and fecundity. Skipped spawning was documented for the first time in sablefish. These winter samples provided a similar age at 50% maturity estimate (6.8 years) as the mean of visual observations taken during summer surveys from 1996-2012 (mean = 7.0 years) and the estimate currently used in the assessment (mean =6.6 years), when skipped spawners were classified as mature. Funding for more winter sampling in the same area is being sought for sampling in 2015 to examine the annual variability in skipped spawning rates at age. Future analyses will aim to develop and evaluate methods to incorporate skipped spawning into maturity ogives.

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). Canadian researchers report age determinations up to 113 years[1]. 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 but only with a precise prior imposed. For the 2004 assessment, a more detailed analysis of the posterior probability showed that natural mortality was not well-estimated by the available data (Sigler et al. 2004). Therefore 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

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

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[1] Fisheries and Oceans Canada; http://www.pac.dfo-mpo.gc.ca/fm-gp/commercial/ground-fond/sable-charbon/bio-eng.htm

where σ_i is the input sampling log 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 and rockfish. 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 and endorsed by the Plan Teams and SSC in 2010. We continue to use these weightings. 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 remain fixed for at least several years. The data weights in general continue to do well by these objectives (Table 3.13).

Parameters Estimated Inside the Assessment Model

Below is a summary of the parameters estimated within the recommended assessment model:

Parameter name	Symbol	Number of
Catchability	q	6
Log-mean-recruitment	μ_r	1
Spawners-per-recruit levels	F_{35}, F_{40}, F_{50}	3
Recruitment deviations	τ_y	82
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	110
Fishery selectivity	fs_a	8
Survey selectivity	ss_a	7
Total		219

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:

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 1933-2013.

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 1960-2014 for each fishery.

Selectivity is represented using a function and is separately estimated by sex for the longline survey, fixed-gear fishery (pot and longlines combined), 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 of reference points

Since the 1999 assessment, we have conducted a limited Bayesian analysis of assessment uncertainty. The posterior distribution was computed based on 10 million MCMC simulations drawn from the posterior distribution. A burn-in of 1 million draws was removed from the beginning of the chain and then thinned to 4,000 parameter draws to remove serial correlation between successive draws. 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.

In previous assessments, we estimated the posterior probability that projected abundance will fall below the decision analysis thresholds 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 $B_{40\%}$, $B_{35\%}$, 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. To examine the posterior probability, we project spawning biomass into the future with recruitments varied as random draws from a lognormal distribution with the mean and standard deviation of 1979-2012 age-2 recruitments. The fishing mortality used is the current yield ratio described in the *Catch specification* section multiplied by maxABC for each year.

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 ~ $\ln(0, \sigma_r)$
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
$Z_{y,a}$	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
$s^g_{a,s}$	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 $a_+ \times a_+$
$\mathbf{A}_s^{\,l}$	Age to length conversion matrix by sex s 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
$P^g_{y,l,s}, \hat{P}^g_{y,l,s}$	Observed and predicted proportion at length l for gear g in year y and sex s
$P^g_{y,a,s}, \hat{P}^g_{y,a,s}$	Observed and predicted proportion at observed age a for gear g in year y and sex s
ψ^g_y	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)
$N_{1,a} = \begin{cases} R_1, & a = a_0 \\ e^{\left(\mu_r + \tau_{a_o - a + 1}\right)} e^{-(a-a_0)M}, & a_0 < a < a_+ \\ e^{(\mu_r)} e^{-(a-a_0)M} \left(1 - e^{-M}\right)^{-1}, & a = a_+ \end{cases}$	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*
$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} \dfrac{s_{a,s}^{g}}{\max\left(s_{a,s}^{g}\right)} w_{a,s}$	Survey biomass index (weight)
$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} \dfrac{s_{a,s}^{g}}{\max\left(s_{a,s}^{g}\right)}$	Survey abundance index (numbers)
$\hat{P}_{y,a,s}^{g} = N_{y,a,s} s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s_{a,s}^{g}\right)^{-1} \mathbf{A}_s$	Vector of fishery or survey predicted proportions at age
$\hat{P}_{y,a,s}^{g} = N_{y,\cdot,s} s_s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s_{a,s}^{g}\right)^{-1} \mathbf{A}_s^l$	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
$L_{length} = \lambda_{length} \sum_{1}^{s} \sum_{i=1}^{n_g} -\psi_y^g \sum_{l=1}^{\Omega} \left(P_{i,l,s}^g + v\right) \ln\left(\hat{P}_{i,l,s}^g + v\right)$	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

Results

Model Evaluation

For this assessment, we present last year's model updated for 2013 with no model changes. A comparison of the model likelihood components and key parameter estimates from 2013 are compared with the 2014 updated model.

Box 2: Model comparison of the 2013 and 2014 models by contribution to the objective function (negative log-likelihood values) and key parameters.

Model Likelihood Components (Data)	2013	2014
Catch	8	7
Domestic LL survey RPN	46	47
Japanese LL survey RPN	18	18
Domestic LL fishery RPW	7	10
Japanese LL fishery RPW	12	13
NMFS GOA trawl survey	19	19
Domestic LL survey ages	169	180
Domestic LL fishery ages	192	238
Domestic LL survey lengths	55	59
Japanese LL survey ages	144	144
Japanese LL survey lengths	46	46
NMFS trawl survey lengths	290	286
Domestic LL fishery lengths	198	207
Domestic trawl fishery lengths	186	194
Data likelihood	1391	1469
Total objective function value	1415	1489
Key parameters		
Number of parameters	216	219
$B_{next\ year}$ (Female spawning (kt) biomass for next year)	91	92
$B_{40\%}$ (Female spawning biomass (kt))	106	105
B_{1960} (Female spawning biomass (kt))	161	161
$B_{0\%}$ (Female spawning biomass (kt))	266	262
SPR% current	34.3%	35.1%
$F_{40\%}$	0.094	0.094
$F_{40\%}$ (Tier 3b adjusted)	0.080	0.082
ABC(kt)	13.7	13.7
$q_{Domestic\ LL\ survey}$	7.7	7.6
$q_{Japanese\ LL\ survey}$	6.3	6.2
$q_{Domestic\ LL\ fishery}$	4.1	4.0
$q_{Trawl\ Survey}$	1.4	1.3
$a_{50\%}$ (domestic LL survey selectivity)	3.8	3.8
$a_{50\%}$ (LL fishery selectivity)	3.9	3.9
μ_r (average recruitment)	17.8	18.0
σ_r (recruitment variability)	1.20	1.20

The two models are identical in all aspects except for inclusion of new data. 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.

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. In general we can only evaluate the 2014 model based on changes in results from 2013 and it is unlikely we would reject the model that included the most recent data. The model generally produces good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. An exception to the generally good fits to the data is the fit to the 2013 fishery age composition, which fits poorly (see further discussion in ***Goodness of fit*** below). The 2014 update shows a slight increase in spawning and total biomass from previous projections. Therefore the 2014 model is utilizing the new information effectively, and we use it to recommend 2015 ABC and OFL.

Time Series 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 the 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 3.15, Figure 3.13) due to strong year classes in the early 1960's. Abundance subsequently dropped during the 1970's due to heavy fishing and relatively low recruitment; 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 3.14, Table 3.14) and also recovered at different rates in different areas (Table 3.15); 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, which changed directions again in 2008 (Figure 3.13). The low 2012-2013 longline survey RPN values changed what was a stable trend in 2011 to a downward trajectory in 2014.

Projected 2015 spawning biomass is 35% of unfished spawning biomass. Spawning biomass has increased from a low of 32% of unfished biomass in 2002 to 35% of unfished biomass projected for 2015 but is trending downward in projections for the near future. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise less than 7% of the 2015 spawning biomass. The 2000 year class is still the largest contributor, with 16% of the spawning biomass in 2015. The 2008 year class is average and will comprise 10% of spawning biomass in 2015 even though it is only 60% mature. Figure 3.15 shows the relative contribution of each year class to next year’s spawning biomass.

Recruitment trends

Annual estimated recruitment varies widely (Figure 3.14b). The two recent strong year classes in 1997 and 2000 are evident in all data sources. After 2000, few strong year classes are apparent, but the 2008 year class is currently estimated to be the largest since 2000. Few small fish were caught in the 2005 through 2009 trawl surveys, but the 2008 year class appeared in the 2011 trawl survey length composition (Figures 3.16, 3.17). The 2010 and 2011 longline survey age compositions show the 2008 year class appearing relatively strong in all three areas for lightly selected 2 and 3 year old fish (Figures 3.18-3.20). The 2013 survey age composition is dominated by 2005-2008 year classes where the 2005 and 2006 year classes are larger than model predictions. Large year classes often appear in the western areas first and then in subsequent years in the Central and Eastern GOA. While this was true for the 1997 and 2000 year classes, the 2008 year class is appearing in all areas at approximately the same magnitude at the same time (Figure 3.18).

Average recruitment during 1979-2013 was 17.8 million 2-year-old sablefish per year, which is similar to the average recruitment during 1958-2012. Estimates of recruitment strength during the 1960s are less certain because they depend on age data from the 1980s with older aged fish that are subject to more ageing error. In addition the size of the early recruitments is based on an abundance index during the 1960s based only on the Japanese fishery catch rate, which may be a weak measure of abundance. The 2008 year class is being estimated at about average in this year's model. Because of the very low survey abundance indices in 2012 and 2013, the 2008 year class thus far is only just above average. If the 2008 year class is actually strong, the estimate will increase if the survey abundance estimates become stronger in future years.

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 have been 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, 1995, NOAA, pers. comm.), 1977 (Bracken 1983), 1980, 1984, and 1998 year classes in southeast Alaska, the 1997 and 1998 year classes in Prince William Sound (W. Bechtol, 2004, ADFG, pers. comm.), the 1998 year class near Kodiak Island (D. Jackson, 2004, ADFG, pers. comm.), and the 2008 year class in Uganik Bay on Kodiak Island (P. Rigby, June, 2009, NOAA, pers. comm.). Numerous reports of young of the year being caught in 2014 have been received including large catches in NOAA surface trawl surveys in the EGOA in the summer (W. Fournier, August, 2014, NOAA, pers. comm.) and in Alaska Department of Fish and Game surveys in Prince William Sound (M. Byerly, 2014, ADFG, pers. comm.). Additionally, salmon fishermen in the EGOA reported large quantities of YOY sablefish in the stomachs of troll caught coho salmon in 2014.

Sablefish recruitment varies greatly from year to year (Figure 3.14b), 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 is also coincidental with 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 (Figures 3.14, 3.21). 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 (Hollowed and Wooster 1992). Larger than average year classes were produced again in 1997-2000, when the population was low indicating that recruitment is only weakly related to spawning biomass. 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. Shotwell et al. (2012) used a two-stage model selection process to examine relevant environmental variables that affect recruitment and included them directly into the assessment model. The best model suggested that colder than average wintertime sea surface temperatures in the central North Pacific represent oceanic conditions that create positive recruitment events for sablefish in their early life history.

Goodness of fit

The model generally fit the data well. Abundance indices generally track through the middle of the confidence intervals of the estimates (Figures 3.3, 3.4), with the exception of the trawl survey, where predictions are typically lower in the early years and higher in later years. This index is given less weight than the other indices based on higher sampling error so it does not fit as well. Like the trawl survey index, the fishery CPUE index is not fit well in 2013, primarily because of the increase in the 2014 longline survey index which is fit more precisely. All age compositions were predicted well, except for not quite reaching the magnitude of the 1997 and 2000 year classes in several years (Figures 3.19, 3.21, 3.24). The length frequencies from the fixed gear fishery are predicted well in most years, but the model appears to not fit the smallest fish that appear in 2011 (Figure 3.22, 3.23). The fits to the trawl survey and trawl fishery length compositions were generally mediocre, because of the small sample sizes relative to the longline survey and fishery length compositions (Figures 3.16, 3.17., 3.25). The model fit the domestic longline survey lengths poorly in the 1990s, then fit well until 2011 and 2012 where the smallest and largest fish were not fit well (Figures 3.26, 3.27). By 2014, the 2008 year class has grown large enough (in length) to be included in the main groups in the length compositions. The 2013 fixed gear fishery age composition is fit poorly, particularly in the plus group. This was due to an exceptionally high proportion of the catch caught in the AI being older than 30 years old. Examination of the origin of these older fish showed that this shift in fishery age composition was caused by a westward shift of the observed fishery into grounds that are not surveyed by the longline survey where there is an apparent abundance of older fish that are unknown to the model. We will explore methods to consider these shifts in future spatial assessment models.

Selectivities

We assume that selectivity is asymptotic for the longline survey and fisheries and dome-shaped (or descending right limb) for the trawl survey and trawl fishery (Figure 3.28). The age-of-50% selection is 3.8 years for females in the longline survey and 3.9 years in the IFQ longline fishery. Females are selected at an older age in the IFQ fishery than in the derby fishery (Figure 3.28). Males were selected at an older age than females in both the derby and IFQ fisheries, likely because they are smaller at the same age. 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 because trawling often occurs on the continental shelf in shallower waters (< 300 m) where young sablefish reside. The trawl fishery selectivities are similar for males and females (Figure 3.28). The trawl survey selectivity curves differ between males and females, where males stay selected by the trawl survey longer (Figure 3.28). These trawl survey patterns are consistent with the idea that sablefish move out on the shelf at 2 years of age and then gradually become less available to the trawl fishery and survey as they move offshore into deeper waters.

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 3.29). 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. In this “management path” we plot estimated fishing mortality relative to the (current) limit value and the estimated spawning biomass relative to limit spawning biomass ($B_{35\%}$). Figure 3.30 shows that recent management has generally constrained fishing mortality below the limit rate, and until recently kept the stock above the $B_{35\%}$ limit. Projected 2015 and 2016 spawning biomass is slightly below $B_{35\%}$.

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 (Table 3.16). Mean and median catchability estimates were nearly identical. 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 were 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. The more recent 2008 year class is not estimated as precisely, and the MCMC estimates are slightly higher.

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 ten previous assessment years (2004-2013) compared to estimates from the current preferred model. This analysis is simply removing all new data that have been added for each consecutive year to 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 the first four years of the retrospective plot we see that estimates of spawning biomass were consistently lower for the last few years in the next assessment year (Figure 3.31). In recent years, the retrospective plot of spawning biomass shows only small changes from year to year (e.g., Table 3.17). One common measure of the retrospective bias is Mohn’s revised rho which indicates the size and direction of the bias. The revised Mohn’s rho of 0.019 is very low (a small positive retrospective bias) relative to most assessments at the AFSC (Hanselman et al. 2013). The retrospective patterns are well within the posterior uncertainty of each assessment (Figure 3.31b). Recruitment estimates appear to have little trend over time with the exception of the 2002 year class which increased from a very low value to near average (Figure 3.31c). Only the 2008 year class started near average indicating low presence of 2 year olds in most of the recent data.

Examining retrospective trends can show potential biases in the model, but may not identify 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. This retrospective pattern likely to be considered mild, but at issue is the “one-way” pattern in the early part of the retrospective time series. It is difficult to isolate the cause of this pattern but several possibilities exist. For example, hypotheses could include environmental changes in catchability, time-varying natural mortality, or changes in selectivity of the fishery or survey. One other issue is that fishery abundance and lengths, and all age compositions are added into the assessment with a one year lag to the current assessment. This estimate of rho is down from 0.089 in 2013, which we attribute to two factors: 1) 2003 was dropped out of the retrospective window which had a relatively large change from the terminal year; and 2) The updated catch data that was used in 2014 added a significant amount of catch in the early part of the retrospective window, which increased the estimate of spawning biomass at the recent low point. We will monitor and explore these patterns in the future.

The 2010 Joint Plan Team requested that we examine what the current model configuration would have recommended for ABCs going back in time to see how much model and author changes has affected management advice. We examined this in the 2011 SAFE and concluded that despite many model changes, including growth updates and a split-gender model, the management advice would have been similar (Hanselman et al. 2011).

Harvest Recommendations

Reference fishing mortality rate

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1979-2012. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 104,908 t (combined across the EBS, AI, and GOA), 0.095, and 0.112, respectively. Projected female spawning biomass (combined areas) for 2015 is 91,183 t (88% of $B_{40\%}$), placing sablefish in sub-tier “b” of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.082, which translates into a 2015 ABC (combined areas) of 13,657 t. The OFL fishing mortality rate is 0.098 which translates into a 2015 OFL (combined areas) of 16,128 t. Model projections indicate that this stock is not subject to overfishing, 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 2014 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. 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 2014 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 2015, 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 2015 and 2016, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the realized catches in 2011-2013 to the TAC for each of those years. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In many fisheries the ABC is routinely not fully utilized, so assuming an average ratio of F will yield more realistic projections.)
>
> *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 2009-2013 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 2014 or 2) above ½ of its MSY level in 2014 and above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, 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 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016 and expected to be above its MSY level in 2026 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 3.18). 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 more accurate preliminary ABCs and OFLs for 2015 and 2016. The methodology for determining these pre-specified catches is described below in ***Specified catch estimation.***

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 2015, it does not provide the best estimate of OFL for 2016, because the mean 2015 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. A better approach is to estimate catches that are more likely to occur as described below under *Specified Catch Estimation.* 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 (2013) is 13,582 t. This is less than the 2013 OFL of 20,400 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 (Table 3.18) 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 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2014 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 3.18). If the mean spawning biomass for 2024 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 (Table 3.18):

a. If the mean spawning biomass for 2016 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2016 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 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 the results of the seven scenarios in Table 3.18, the stock is not overfished and is not approaching an overfished condition.

Specified catch estimation

In response to GOA Plan Team minutes in 2010, we have established a consistent methodology for estimating current-year and future year catches in order to provide more accurate two-year projections of ABC and OFL to management. We explained the methods and gave examples in the 2011 SAFE (Hanselman et al. 2011). Going forward, for current year catch, we are applying an expansion factor to the official catch on or near October 1 by the 3-year average of catch taken between October 1 and December 31 in the last three complete catch years (e.g. 2011-2013 for this year).

For catch projections into the next two years, we are using the ratio of the last three official catches to the last three TACs multiplied against the future two years' ABCs (if TAC is normally the same as ABC). This method results in slightly higher ABCs in each of the future two years of the projection, based on both the lower catch in the first year out, and on the amount of catch taken before spawning in the projection two years out.

Bayesian analysis

The model estimates of projected spawning biomass fall near the center of the posterior distribution of spawning biomass. Most of the probability lies between 80,000 and 100,000 t (Figure 3.32). The probability changes smoothly and exhibits a relatively normal distribution. The posterior distribution clearly indicates the stock is below $B_{40\%}$.

Scatter plots of selected pairs of model parameters were produced to evaluate the shape of the posterior distribution (Figure 3.33). The plots indicate that the parameters are reasonably well defined by the data. As expected, catchabilities, $F_{40\%}$, and ending spawning biomass were 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 0.89. During the next three years, the probability of falling below $B_{17.5\%}$ is near zero, the probability of falling below $B_{35\%}$ is 0.97, and the probability of staying below $B_{40\%}$ is near 100% (Figure 3.34).

Alternative Projection

We also use an alternative 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 3.35). The $B_{35\%}$ and $B_{40\%}$ reference points are based on the 1979-2012 recruitments, and this projection predicts that the mean and median spawning biomass will stay below $B_{35\%}$ until 2020, and then return to $B_{40\%}$ if average recruitment is attained. This projection is run with the same ratio for catch as described in Alternative 2 above, except for all future years instead of the next two.

Acceptable biological catch

We recommend a 2015 ABC of 13,657 t. The maximum permissible ABC for 2015 from a Tier 3b adjusted $F_{40\%}$ strategy is 13,657 t. The maximum permissible ABC for 2015 is very similar to the 2014 ABC of 13,722 t. The 2013 assessment projected a 10% decrease in ABC for 2015 from 2014. This smaller decrease is supported by a moderate increase in the domestic longline survey index from the all-time low in 2013 that offset the lowest value of the fishery abundance index seen in 2013. The fishery abundance index has been trending down since 2007. The 2013 IPHC GOA sablefish index was not used in the model, but also declined 21% from 2012. The 2008 year class showed potential to be above average in previous assessments based on patterns in the age and length compositions. However the estimate in this year's assessment is only average because it is heavily influenced by the recent large overall decrease in the longline survey and trawl indices. Spawning biomass is projected to decline through 2018, and then is expected to increase; assuming average recruitment is achieved in the future. ABCs are projected to decrease in 2016 to 12,406 t and 12,292 t in 2017 (see Table 3.18).

Area allocation 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 the biomass distribution, while adapting to current information about the 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, where x is the year index, reduced annual fluctuations in regional ABC, while keeping regional fishing rates from exceeding overfishing levels in a stochastic migratory model (J. Heifetz, 1999, NOAA, 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. 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. Below are area-specific apportionments following the traditional apportionment scheme, which we are **not recommending for 2015:**

Apportionments are based on survey and fishery information	**2014 ABC Percent**	**2014 Survey RPW**	**2013 Fishery RPW**	**2015 ABC Percent**	**2014 ABC**	**2015 ABC**	**Change**
Total					13,722	**13,657**	0%
Bering Sea	10%	21%	14%	10%	1,339	**2,210**	39%
Aleutians	13%	13%	17%	13%	1,811	**1,840**	2%
Gulf of Alaska	77%	66%	69%	77%	10,572	**9,607**	-10%
Western	14%	19%	12%	14%	1,480	**1,444**	-2%
Central	44%	40%	33%	44%	4,681	**3,975**	-18%
W. Yakutat*	15%	13%	19%	15%	1,574	**1,428**	-10%
E. Yakutat / Southeast*	27%	28%	35%	27%	2,837	**2,759**	-3%

Following the standard apportionment scheme, we have observed that the objective to reduce variability in apportionment was not being achieved. Since 2007, the average change in apportionment by area has increased annually (Figure 3.36A). While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands. For example, the apportionment for the Bering Sea has varied drastically since 2007, attributable to high variability in both survey abundance and fishery CPUE estimates in the Bering Sea (Figure 3.36B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.36C). Because of the high variability in apportionment seen in recent years, we do not believe the standard method is meeting the goal of reducing the magnitude of interannual changes in the apportionment. Because of these reasons, we recommended fixing the apportionment at the proportions from the 2013 assessment until the apportionment scheme is thoroughly reevaluated and reviewed. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2012 with the objectives of re-examining the apportionment strategy and conducting management strategy evaluations. A spatial sablefish model has been developed, but management strategy evaluations have not begun yet. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former scheme until more satisfactory methods have been identified and evaluated. **Therefore**, **for 2015, we recommend keeping the apportionment fixed at the proportions used in 2014.**
These apportionments are shown in the following table:

Area	2014 ABC	Standard apportionment for 2015 ABC	**Recommended fixed apportionment for 2015 ABC[*]**	**Difference from 2014**
Total	13,722	13,657	**13,657**	-0.5%
Bering Sea	1,339	2,210	**1,333**	-0.5%
Aleutians	1,811	1,840	**1,802**	-0.5%
Gulf of Alaska (subtotal)	10,572	9,607	**10,522**	-0.5%
Western	1,480	1,445	**1,473**	-0.5%
Central	4,681	3,975	**4,658**	-0.5%
W. Yakutat[**]	1,574	1,428	**1,567**	-0.5%
E. Yak. / Southeast[**]	2,837	2,759	**2,823**	-0.5%

[*] Fixed at the 2012 assessment apportionment proportions (Hanselman et al. 2012). [**] Before 95:5 hook and line: trawl split shown below.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2015	1,708 t	2,682 t
	2016	1,552 t	2,436 t

Overfishing level (OFL)

Applying an adjusted $F_{35\%}$ as prescribed for OFL in Tier 3b, results in a value of 16,128 t for the combined stock. The OFL is apportioned by region, Bering Sea (1,575 t), AI (2,128 t), and GOA (12,425 t), by the same method as the ABC apportionment.

Ecosystem considerations

Ecosystem considerations for the Alaska sablefish fishery are summarized in Table 3.19.

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 consume more euphausiids, shrimp, and cephalopods, while sablefish > 60 cm consume more fish (Yang and Nelson 2000). In the GOA, 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 GOA is Pacific halibut; however, sablefish comprised less than 1% of their stomach contents (M. Yang, October 14, 1999, NOAA, pers. comm.). 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 potential predators such as arrowtooth flounder, halibut, Pacific cod, bigmouth sculpin, big skate, and Bering skate, which are the main piscivorous groundfishes in the GOA (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 AI and GOA. 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 geographic 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 et al. 2012). Juvenile sablefish (< 60 cm FL) prey items overlap with the diet of small arrowtooth flounder. On the continental shelf of the GOA, 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). Shotwell et al. (2012) showed that colder than average wintertime sea surface temperatures in the central North Pacific may represent oceanic conditions that create positive recruitment events for sablefish in their early life history.

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 partly 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.

Fishery effects 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 shark and thornyhead rockfish total catch (Table 3.4). The sablefish fishery catches the majority of grenadier total catch; the annual amount is variable (Table 3.5). The trend in seabird catch is variable, but is substantially low compared to the 1990s, presumably due to widespread use of measures to reduce seabird catch. Prohibited species catches (PSC) in the targeted sablefish fisheries are dominated by halibut (1,224 t/year) and golden king crab (66,000 individuals/year). Halibut catches were low in 2013, while golden king crab catches have dropped precipitously from 210,000 individuals in 2011 to very few in 2013 (Table 3.6).

The shift from an open-access to an IFQ fishery has increased 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. Length frequencies from the pot fishery in the BSAI are very similar to the longline fishery. The trawl fishery, which on average accounts for about 10% of the total catch, often catches slightly smaller fish. The trawl fishery typically occurs on the continental shelf where juvenile sablefish sometimes 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 3.3). 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 (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 trawl gear, a significant effect of longlines on bedrock, cobbles, or sand is unlikely.

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.

Future sablefish research is going to focus on several directions:

1) Evaluating different apportionment strategies for ABC.
2) Refine survey abundance index model for inclusion in future assessment model that accounts for

whale depredation and potentially includes gully abundance data and other covariates.

3) Refine fishery abundance index to utilize a core fleet, and identify covariates that affect catch rates.
4) Improve knowledge of sperm whale and killer whale depredation in the fishery and begin to quantify depredation effects on fishery catch rates.
5) Continue to explore the use of environmental data to aid in determining recruitment
6) An integrated GOA 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.
7) We are developing a spatially explicit research assessment model that includes movement, which will help in examining smaller-scale population dynamics while retaining a single stock hypothesis Alaska-wide sablefish model. This is to include management strategy evaluations of apportionment strategies.

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Tables

Table 3.1. 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 West Yakutat and East Yakutat / Southeast. 2014 catches are estimated for the full year (www.akfin.org).

		BY AREA								**BY GEAR**	
Year	Grand total	Bering Sea	Aleu-tians	Western	Central	Eastern	West Yakutat	East Yak/SEO	Un-known	Fixed	Trawl
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
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	25,417	669	2,078	740	11,955	9,976	4,620	5,356	0	22,912	2,506
1994	23,577	694	1,725	539	9,376	11,243	4,493	6,750	0	20,639	2,938
1995	20,692	930	1,119	1,747	7,673	9,223	3,872	5,352	0	18,079	2,613
1996	17,275	648	764	1,542	6,773	7,548	2,893	4,655	0	15,088	2,187
1997	14,607	552	781	1,374	6,234	5,666	1,930	3,735	0	12,975	1,632
1998	13,867	563	535	1,432	5,915	5,422	1,956	3,467	0	12,380	1,487
1999	13,585	675	681	1,488	5,874	4,867	1,709	3,159	0	11,601	1,985
2000	15,565	742	1,049	1,582	6,173	6,020	2,066	3,953	0	13,546	2,019
2001	14,064	864	1,074	1,588	5,518	5,021	1,737	3,284	0	12,281	1,783
2002	14,748	1,144	1,119	1,865	6,180	4,441	1,550	2,891	0	12,505	2,243
2003	16,411	1,012	1,118	2,118	6,993	5,170	1,822	3,347	0	14,351	2,060
2004	17,518	1,041	955	2,170	7,310	6,041	2,241	3,801	0	15,861	1,656
2005	16,580	1,070	1,481	1,929	6,701	5,399	1,824	3,575	0	15,024	1,556
2006	15,551	1,079	1,151	2,151	5,921	5,251	1,889	3,362	0	14,305	1,246
2007	15,957	1,182	1,168	2,101	6,003	5,502	2,074	3,429	0	14,721	1,235
2008	14,674	1,141	901	1,679	5,543	5,410	2,056	3,354	0	13,552	1,122
2009	13,128	916	1,100	1,423	5,005	4,684	1,831	2,853	0	12,071	1,057
2010	11,980	755	1,094	1,354	4,508	4,269	1,578	2,690	0	10,976	1,004
2011	12,971	705	1,024	1,402	4,919	4,921	1,896	3,024	0	11,792	1,179
2012	13,868	743	1,205	1,353	5,329	5,238	2,033	3,205	0	12,767	1,102
2013	13,642	634	1,062	1,385	5,207	5,354	2,106	3,247	0	12,604	1,038
2014	11,476	328	757	1,090	4,737	4,564	1,707	2,857	0	10,486	990

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991-2013. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages. Catch as of October 24, 2014 (www.akfin.org).

Year	Pot	Trawl	Longline	Total
Aleutian Islands				
1991-1999	6	73	1,210	1,289
2000	103	33	913	1049
2001	111	39	925	1074
2002	105	39	975	1119
2003	316	42	760	1118
2004	384	32	539	955
2005	688	115	679	1481
2006	461	60	629	1151
2007	632	40	496	1168
2008	179	76	646	901
2009	78	75	947	1100
2010	59	74	961	1094
2011	141	47	836	1024
2012	77	148	979	1205
2013	87	58	917	1062
Bering Sea				
1991-1999	5	189	539	733
2000	40	283	418	741
2001	106	336	405	847
2002	382	268	467	1117
2003	363	183	417	964
2004	435	276	313	1024
2005	595	262	202	1059
2006	621	76	373	1070
2007	879	80	211	1170
2008	754	181	204	1139
2009	557	91	266	914
2010	452	30	274	755
2011	405	44	256	705
2012	432	93	218	743
2013	352	133	149	634

Table 3.3. Discarded catches of sablefish (amount [t], percent of total catch, total catch [t]) by gear (H&L=hook & line, Other = Pot, trawl, and jig, combined for confidentiality) by FMP area for 2007-2013. Source: NMFS Alaska Regional Office via AKFIN, October 24, 2014.

		BSAI			GOA			Combined		
Year	Gear	Discard	%Discard	Catch	Discard	%Discard	Catch	Discard	%Discard	Catch
2007	Total	66	2.84%	2,338	556	4.11%	13,547	622	3.92%	15,884
	H&L	16	2.25%	707	256	2.07%	12,379	272	2.08%	13,086
	Other	50	3.09%	1,631	300	25.71%	1,168	351	12.53%	2,799
2008	Total	100	4.90%	2,040	755	5.98%	12,623	855	5.83%	14,663
	H&L	93	10.99%	850	674	5.73%	11,760	768	6.09%	12,610
	Other	6	0.54%	1,189	81	9.35%	863	87	4.24%	2,052
2009	Total	24	1.19%	2,014	739	6.65%	11,112	763	5.82%	13,126
	H&L	17	1.39%	1,213	659	6.44%	10,223	675	5.91%	11,436
	Other	7	0.90%	801	499	4.53%	11,016	88	5.21%	1,690
2010	Total	43	2.31%	1,849	371	4.02%	9,231	461	3.85%	11,976
	H&L	36	2.90%	1,234	47	5.22%	896	407	3.89%	10,465
	Other	7	1.12%	614	574	5.12%	11,222	54	3.57%	1,511
2011	Total	25	1.47%	1,729	396	3.90%	10,145	599	4.63%	12,951
	H&L	18	1.63%	1,092	169	15.84%	1,068	413	3.68%	11,237
	Other	8	1.20%	637	327	2.74%	11,917	186	10.86%	1,714
2012	Total	25	1.30%	1,948	253	2.29%	11,060	343	2.48%	13,856
	H&L	13	1.10%	1,197	65	7.62%	848	266	2.17%	12,257
	Other	12	1.63%	750	626	5.24%	11,944	77	4.81%	1,598
2013	Total	30	1.79%	1,697	579	5.21%	11,099	657	4.81%	13,641
	H&L	27	2.51%	1,066	47	5.60%	845	605	4.98%	12,165
	Other	4	0.59%	630	3987	4.83%	82,482	51	3.47%	1,476
2007-2013	Total	45	2.26%	1,945	521	4.59%	11,259	614	4.48%	13,728
Mean	H&L	31	3.25%	1,051	274	6.93%	5,431	487	4.11%	11,894
	Other	13	1.29%	893	913	8.22%	18,659	128	6.38%	1,834

Table 3.4. Bycatch (t) of FMP Groundfish species in the targeted sablefish fishery averaged from 2009-2013. Other = Pot and trawl combined because of confidentiality. Source: AKFIN, October 31, 2014.

	Hook and Line			Other Gear			All Gear		
Species	Discard	Retained	Total	Discard	Retained	Total	Discard	Retained	Total
GOA Thornyhead Rockfish	147	346	493	4	23	27	151	369	520
Arrowtooth Flounder	198	40	238	106	4	110	304	44	348
Shark	330	0	331	1	0	1	331	0	331
GOA Shortraker Rockfish	127	91	219	11	9	20	138	101	239
Other Rockfish	57	95	153	2	1	3	59	96	156
GOA Skate, Longnose	133	7	139	1	0	1	134	7	140
GOA Rougheye Rockfish	55	80	135	2	3	5	57	83	140
GOA Skate, Other	133	2	136	2	0	2	135	2	137
Pacific Cod	40	46	85	1	4	5	41	50	91
Other Species	84	1	85	1	0	1	85	1	86
Greenland Turbot	23	51	74	10	1	10	33	52	85
BSAI Skate	52	0	52	0	-	0	52	0	52
GOA Deep Water Flatfish	8	0	8	16	5	22	24	5	30
Pacific Ocean Perch	1	0	1	2	15	17	2	15	18
BSAI Kamchatka Flounder	12	2	13	3	0	3	15	2	17
BSAI Shortraker Rockfish	5	8	14	0	0	0	6	8	14
BSAI Other Flatfish	11	0	11	1	0	1	12	0	12
GOA Rex Sole	0	-	0	8	4	11	8	4	11
Sculpin	10	-	10	0	0	0	10	0	10
Total	1,315	728	2,046	220	102	322	1,535	830	2,369

Table 3.5. Bycatch of nontarget species and HAPC biota in the targeted sablefish fishery. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN, October 31, 2014.

	Estimated Catch (t)				
Group Name	**2009**	**2010**	**2011**	**2012**	**2013**
Benthic urochordata	0.01	0.13	0.13	1.08	0.00
Birds	0.47	0.45	1.46	0.22	0.64
Bivalves	0.04	0.04	0.05	0.01	0.00
Brittle star unidentified	0.45	0.12	0.44	4.52	0.10
Corals Bryozoans	2.21	3.33	5.57	7.57	12.75
Dark Rockfish	0.14	0.00	0.00	0.03	0.07
Eelpouts	1.83	1.38	0.58	0.62	1.11
Giant Grenadier	6,011	4,767	6,973	6,993	8,083
Greenlings	0.07	0.00	0.02	0.00	0.00
Grenadier	1,139	864	843	1,020	1,519
Hermit crab unidentified	0.10	0.19	0.21	0.08	0.09
Invertebrate unidentified	1.53	2.08	2.02	6.81	0.18
Misc crabs	3.29	1.89	1.13	0.31	0.51
Misc crustaceans	2.36	0.00	0.00	0.00	0.00
Misc deep fish	0.00	0.00	0.00	0.00	0.00
Misc fish	5.03	6.20	8.43	10.12	28.81
Scypho jellies	0.08	0.11	0.69	0.00	0.00
Sea anemone unidentified	2.26	1.49	3.29	0.99	0.92
Sea pens whips	0.52	0.35	1.58	0.25	0.28
Sea star	2.97	3.91	3.45	2.99	18.79
Snails	10.79	11.49	20.04	12.08	8.77
Sponge unidentified	2.17	1.05	2.08	0.94	3.31
Urchins, dollars, cucumbers	1.64	0.58	0.26	0.78	0.72

Table 3.6. Prohibited Species Catch (PSC) estimates reported in tons for halibut, thousands of animals for crab, by year, and fisheries management plan (BSAI or GOA) area for the sablefish fishery. Other = Pot and trawl combined because of confidentiality. Source: NMFS AKRO Blend/Catch Accounting System PSCNQ via AKFIN, October 31, 2014.

	2010			2011			2012			2013			Mean
	BSAI	GOA	Total	BSAI	GOA	Total	BSAI	GOA	Total	BSAI	GOA	Total	
Hook and Line													
Bairdi Crab	-	0.06	0.06	-	-	-	-	-	-	-	0.09	0.09	0.04
Golden K. Crab	0.94	-	0.94	0.55	0.13	0.68	0.46	0.02	0.48	0.47	0.11	0.58	0.67
Halibut	341	992	1,333	182	889	1,071	129	1,456	1,585	86	708	794	1,196
Red K. Crab	0.01	-	0.01	0.02	-	0.02	0.01	-	0.01	-	0.03	0.03	0.01
Other													
Bairdi Crab	-	0.06	0.06	0.82	-	0.82	-	-	-	0.22	-	0.22	0.27
Golden K. Crab	32	-	32	210	0	210	17	0	17	1	-	1	65
Halibut	34	4	39	18	6	24	11	5	16	20	12	32	28
Red K. Crab	-	-	-	0.31	-	0.31	-	-	-	-	-	-	0.08

Table 3.7. Summary of management measures with time series of catch, ABC, OFL, and TAC.

Year	Catch(t)	OFL	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	25,417			25,000	
1994	23,577			28,840	
1995	20,692			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.
1996	17,275			19,380	Pot fishing ban repealed in Bering Sea except from June 1-30.
1997	14,607	27,900	19,600	17,200	Maximum retainable allowances for sablefish were revised in the Gulf of Alaska. The percentage depends on the basis species.
1998	13,867	26,500	16,800	16,800	
1999	13,585	24,700	15,900	15,900	
2000	15,565	21,400	17,300	17,300	
2001	14,064	20,700	16,900	16,900	
2002	14,748	26,100	17,300	17,300	
2003	16,411	28,900	18,400	20,900	
2004	17,518	30,800	23,000	23,000	
2005	16,580	25,400	21,000	21,000	
2006	15,551	25,300	21,000	21,000	
2007	15,957	23,750	20,100	20,100	
2008	14,674	21,310	18,030	18,030	Pot fishing ban repealed in Bering Sea for June 1-30 (74 FR 28733).
2009	13,128	19,000	16,080	16,080	
2010	11,980	21,400	15,230	15,230	
2011	12,971	20,700	16,040	16,040	
2012	13,868	20,400	17,240	17,240	
2013	13,642	19,180	16,230	16,230	
2014	11,476	16,160	13,722	13,722	

Table 3.8. 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	12,964					100,029				
1985						125,129		1,294		
1986						128,718				
1987	9,610					102,639		1,057		
1988						114,239				
1989						115,067		655		
1990	4,969			1,229	32,936	78,794	101,530			
1991				721	28,182	69,653	95,364	902		
1992				0	20,929	79,210	104,786			
1993	7,282			468	21,943	80,596	94,699	1,178		
1994				89	11,914	74,153	70,431			
1995				87	17,735		80,826			
1996	4,650			239	14,416		72,247		1,176	
1997				0	20,330		82,783		1,214	
1998				35	8,932		57,773		1,191	
1999	4,408			1,268	28,070		79,451		1,186	1,141
2000				472	32,208		62,513		1,236	1,152
2001	*partial			473	30,315		83,726		1,214	1,003
2002				526	33,719		75,937		1,136	1,059
2003	5,039			503	36,077		77,678		1,128	1,185
2004				694	31,199		82,767		1,185	1,145
2005	4,956			2,306	36,213		74,433		1,074	1,164
2006				721	32,497		78,625		1,178	1,154
2007	3,804			860	29,854		73,480		1,174	1,115
2008				2,018	23,414		71,661		1,184	1,164
2009	3,975			1,837	24,674		67,978		1,197	1,126
2010				1,634	24,530		75,010		1,176	1,159
2011	2,118			1,877	22,659		87,498		1,199	1,190
2012				2,533	22,311		63,116		1,186	1,169
2013	1,561						51,586		1,190	
2014	1,561						52,290			

Table 3.9. Average catch rate (pounds/hook) for fishery data by year and region. SE = standard error, CV = coefficient of variation. C = confidential due to less than three vessels or sets. These data are still used in the combined index.

Observer Fishery Data											
Aleutian Islands-Observer						Bering Sea-Observer					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1990	0.53	0.05	0.10	193	8	1990	0.72	0.11	0.15	42	8
1991	0.50	0.03	0.07	246	8	1991	0.28	0.06	0.20	30	7
1992	0.40	0.06	0.15	131	8	1992	0.25	0.11	0.43	7	4
1993	0.28	0.04	0.14	308	12	1993	0.09	0.03	0.36	4	3
1994	0.29	0.05	0.18	138	13	1994	C	C	C	2	2
1995	0.30	0.04	0.14	208	14	1995	0.41	0.07	0.17	38	10
1996	0.23	0.03	0.12	204	17	1996	0.63	0.19	0.30	35	15
1997	0.35	0.07	0.20	117	9	1997	C	C	C	0	0
1998	0.29	0.05	0.17	75	12	1998	0.17	0.03	0.18	28	9
1999	0.38	0.07	0.17	305	14	1999	0.29	0.09	0.32	27	10
2000	0.29	0.03	0.11	313	15	2000	0.28	0.09	0.31	21	10
2001	0.26	0.04	0.15	162	9	2001	0.31	0.02	0.07	18	10
2002	0.32	0.03	0.11	245	10	2002	0.10	0.02	0.22	8	4
2003	0.26	0.04	0.17	170	10	2003	C	C	C	8	2
2004	0.21	0.04	0.21	138	7	2004	0.17	0.05	0.31	9	4
2005	0.15	0.05	0.34	23	6	2005	0.23	0.02	0.16	9	6
2006	0.23	0.04	0.16	205	11	2006	0.17	0.05	0.21	68	15
2007	0.35	0.10	0.29	198	7	2007	0.28	0.05	0.18	34	8
2008	0.37	0.04	0.10	247	6	2008	0.38	0.22	0.58	12	5
2009	0.29	0.05	0.22	335	10	2009	0.14	0.04	0.21	24	5
2010	0.27	0.04	0.14	459	12	2010	0.17	0.03	0.19	42	8
2011	0.25	0.05	0.19	401	9	2011	0.10	0.01	0.13	12	4
2012	0.25	0.10	0.15	363	8	2012	C	C	C	6	1
2013	0.28	0.06	0.22	613	7	2013	0.21	0.10	0.46	27	5

Table 3.9 (cont.)

Western Gulf-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.64	0.14	0.22	178	7
1991	0.44	0.06	0.13	193	16
1992	0.38	0.05	0.14	260	12
1993	0.35	0.03	0.09	106	12
1994	0.32	0.03	0.10	52	5
1995	0.51	0.04	0.09	432	22
1996	0.57	0.05	0.10	269	20
1997	0.50	0.05	0.10	349	20
1998	0.50	0.03	0.07	351	18
1999	0.53	0.07	0.12	244	14
2000	0.49	0.06	0.13	185	12
2001	0.50	0.05	0.10	273	16
2002	0.51	0.05	0.09	348	15
2003	0.45	0.04	0.10	387	16
2004	0.47	0.08	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
2010	0.42	0.06	0.14	198	10
2011	0.54	0.12	0.22	196	12
2012	0.38	0.04	0.11	147	13
2013	0.34	0.02	0.06	325	18

Central Gulf-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.54	0.04	0.07	653	32
1991	0.62	0.06	0.09	303	24
1992	0.59	0.05	0.09	335	19
1993	0.60	0.04	0.07	647	32
1994	0.65	0.06	0.09	238	15
1995	0.90	0.07	0.08	457	41
1996	1.04	0.07	0.07	441	45
1997	1.07	0.08	0.08	377	41
1998	0.90	0.06	0.06	345	32
1999	0.87	0.08	0.10	269	28
2000	0.93	0.05	0.06	319	30
2001	0.70	0.04	0.06	347	31
2002	0.84	0.07	0.08	374	29
2003	0.99	0.07	0.07	363	34
2004	1.08	0.10	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
2010	0.80	0.05	0.07	286	31
2011	0.85	0.08	0.10	213	28
2012	0.74	0.07	0.09	298	27
2013	0.51	0.05	0.10	419	34

West Yakutat-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	0.95	0.24	0.25	75	9
1991	0.65	0.07	0.10	164	12
1992	0.64	0.18	0.27	98	6
1993	0.71	0.07	0.10	241	12
1994	0.65	0.17	0.27	81	8
1995	1.02	0.10	0.10	158	21
1996	0.97	0.07	0.07	223	28
1997	1.16	0.11	0.09	126	20
1998	1.21	0.10	0.08	145	23
1999	1.20	0.15	0.13	110	19
2000	1.28	0.10	0.08	193	32
2001	1.03	0.07	0.07	184	26
2002	1.32	0.13	0.10	155	23
2003	1.36	0.10	0.07	216	27
2004	1.23	0.09	0.08	210	24
2005	1.32	0.09	0.07	352	24
2006	0.96	0.10	0.10	257	30
2007	1.02	0.11	0.11	208	24
2008	1.40	0.12	0.08	173	23
2009	1.34	0.12	0.09	148	23
2010	1.11	0.09	0.08	136	22
2011	1.18	0.09	0.07	186	24
2012	0.97	0.09	0.10	255	24
2013	1.11	0.15	0.13	109	20

East Yakutat/SE-Observer

Year	CPUE	SE	CV	Sets	Vessels
1990	C	C	C	0	0
1991	C	C	C	17	2
1992	C	C	C	20	1
1993	C	C	C	26	2
1994	C	C	C	5	1
1995	1.45	0.20	0.14	101	19
1996	1.20	0.11	0.09	137	24
1997	1.10	0.14	0.13	84	17
1998	1.27	0.12	0.10	140	25
1999	0.94	0.12	0.13	85	11
2000	0.84	0.13	0.16	81	14
2001	0.84	0.08	0.09	110	14
2002	1.20	0.23	0.19	121	14
2003	1.29	0.13	0.10	113	19
2004	1.08	0.10	0.09	135	17
2005	1.18	0.13	0.11	181	16
2006	0.93	0.11	0.11	104	18
2007	0.92	0.15	0.17	85	16
2008	1.06	0.13	0.12	103	17
2009	0.98	0.12	0.12	94	13
2010	0.97	0.17	0.17	76	12
2011	0.98	0.09	0.10	196	16
2012	0.93	0.11	0.12	104	15
2013	0.91	0.12	0.14	165	22

Table 3.9 (cont.)

Aleutian Islands-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.29	0.04	0.15	167	15
2000	0.24	0.05	0.21	265	16
2001	0.38	0.16	0.41	36	5
2002	0.48	0.19	0.39	33	5
2003	0.36	0.11	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
2010	0.25	0.05	0.20	497	9
2011	0.23	0.07	0.30	609	12
2012	0.26	0.03	0.14	893	12
2013	0.26	0.06	0.22	457	7

Bering Sea-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.56	0.08	0.14	291	43
2000	0.21	0.05	0.22	169	23
2001	0.35	0.11	0.33	61	8
2002	C	C	C	5	2
2003	0.24	0.13	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
2010	0.30	0.08	0.27	766	12
2011	0.22	0.03	0.13	500	24
2012	0.30	0.04	0.15	721	21
2013	0.20	0.04	0.18	460	15

Western Gulf-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.64	0.06	0.09	245	27
2000	0.60	0.05	0.09	301	32
2001	0.47	0.05	0.10	109	24
2002	0.60	0.08	0.13	78	14
2003	0.39	0.04	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
2010	0.48	0.04	0.08	1297	46
2011	0.50	0.05	0.10	1148	46
2012	0.50	0.04	0.08	1142	37
2013	0.35	0.03	0.07	1476	32

Central Gulf-Logbook

Year	CPUE	SE	CV	Sets	Vessels
1999	0.80	0.05	0.06	817	60
2000	0.79	0.04	0.05	746	64
2001	0.74	0.06	0.08	395	52
2002	0.83	0.06	0.07	276	41
2003	0.87	0.07	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
2010	0.66	0.03	0.05	1171	80
2011	0.80	0.06	0.07	1065	71
2012	0.79	0.06	0.07	1599	82
2013	0.48	0.03	0.07	2102	73

Table 3.9 (cont.)

West Yakutat-Logbook							East Yakutat/SE-Logbook					
Year	CPUE	SE	CV	Sets	Vessels		Year	CPUE	SE	CV	Sets	Vessels
1999	1.08	0.08	0.08	233	36		1999	0.91	0.08	0.08	183	22
2000	1.04	0.06	0.06	270	42		2000	0.98	0.08	0.08	190	26
2001	0.89	0.09	0.11	203	29		2001	0.98	0.09	0.09	109	21
2002	0.99	0.07	0.07	148	28		2002	0.83	0.06	0.07	108	22
2003	1.26	0.10	0.08	104	23		2003	1.13	0.10	0.09	117	22
2004	1.27	0.06	0.05	527	54		2004	1.19	0.05	0.04	427	55
2005	1.13	0.05	0.04	1158	70		2005	1.15	0.05	0.05	446	77
2006	0.97	0.05	0.06	1306	84		2006	1.06	0.04	0.04	860	107
2007	0.97	0.05	0.05	1322	89		2007	1.13	0.04	0.04	972	122
2008	0.97	0.05	0.05	1118	74		2008	1.08	0.05	0.05	686	97
2009	1.23	0.07	0.06	1077	81		2009	1.12	0.05	0.05	620	87
2010	0.98	0.05	0.05	1077	85		2010	1.04	0.05	0.05	744	99
2011	0.95	0.07	0.07	1377	75		2011	1.01	0.04	0.04	877	112
2012	0.89	0.06	0.06	1634	86		2012	1.00	0.05	0.05	972	102
2013	0.74	0.06	0.07	1953	79		2013	0.86	0.05	0.06	865	88

Table 3.10. 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, 2009, 2011, and 2013, and Bering Sea 1979-1981, 1995, 1996, 1998, 2000, 2002, 2004, 2006, 2008, 2009, 2010, 2012, and 2014. NMFS trawl survey biomass estimates (kilotons) 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		477			1,662	1,130	
1999		520			1,740	1,316	104
2000		462			1,597	1,139	
2001		535			1,798	1,111	238
2002		561			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		580			1,848	1,206	
2007		500			1,584	1,268	111
2008		472			1,550	1,361	
2009		491			1,580	1,152	107
2010		542			1,778	1,054	
2011		556			1,683	1,048	84
2012		438			1,280	1,023	
2013		416			1,276	893	60
2014		479			1,432		

Table 3.11. Count of stations where sperm (S) or killer whale (K) depredation occurred in the six sablefish management areas. The number of stations sampled that are used for RPN calculations are in parentheses. Areas not surveyed in a given year are left blank. If there were no whale depredation data taken, it is denoted with an "n/a". Killer whale depredation did not always occur on all skates of gear, and only those skates with depredation were cut from calculations of RPNs and RPWs.

	BS (16)		**AI (14)**		**WG (10)**		**CG (16)**		**WY (8)**		**EY/SE (17)**	
Year	**S**	**K**	**S**	**K**	**S**	**K**	**S**	**K**	**S**	**K**	**S**	**K**
1996			n/a	1	n/a	0	n/a	0	n/a	0	n/a	0
1997	n/a	2			n/a	0	n/a	0	n/a	0	n/a	0
1998			0	1	0	0	0	0	4	0		0
1999	0	7			0	0	3	0	6	0	4	0
2000			0	1	0	1	0	0	4	0	2	0
2001	0	5			0	0	3	0	2	0	2	0
2002			0	1	0	4	3	0	4	0	2	0
2003	0	7			0	3	2	0	1	0	2	0
2004			0	0	0	4	3	0	4	0	6	0
2005	0	2			0	4	0	0	2	0	8	0
2006			0	1	0	3	2	1	4	0	2	0
2007	0	7			0	5	1	1	5	0	6	0
2008			0	3	0	2	2	0	8	0	9	0
2009	0	10			0	2	5	1	3	0	2	0
2010			0	3	0	1	2	1	2	0	6	0
2011	0	7			0	5	1	1	4	0	9	0
2012			1	5	1	5	2	0	4	0	3	0
2013	0	11			0	2	2	2	3	0	7	0
2014			1	3	0	4	4	0	6	0	4	0

Table 3.12. Sablefish fork length (cm), weight (kg), and proportion mature by age and sex (weights from 1996-2004 age-length data from the AFSC longline survey).

	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	0.999	0.998
27	67.8	80.1	3.2	5.4	0.999	0.999
28	67.8	80.1	3.2	5.4	0.999	0.999
29	67.8	80.1	3.2	5.5	0.999	0.999
30	67.8	80.2	3.2	5.5	0.999	0.999
31+	67.8	80.2	3.2	5.5	1.000	1.000

Table 3.13. Input and output sample sizes and standard deviation of normalized residuals (SDNR) for data sources in the sablefish assessment model.

Multinomial Compositions	Input N/CV	SDNR	Effective N
Domestic LL Fishery Ages	200	1.10	170
Domestic LL Fishery Lengths	120	0.83	364
Trawl Fishery Lengths	50	0.86	89
LL Survey Ages	160	0.86	199
NMFS Trawl Survey Lengths	140	0.96	149
Domestic LL Survey Lengths	20	0.29	227
Japanese/Coop LL Survey Lengths	20	0.32	197
Lognormal abundance indices			
Domestic RPN	5%	3.84	
Japanese/Coop RPN	5%	2.99	
Domestic Fishery RPW	10%	0.91	
Foreign Fishery RPW	10%	1.29	
NMFS Trawl Survey	10-20%	1.85	

Table 3.14. Sablefish recruits, total biomass (2+), and spawning biomass plus lower and upper lower 95% credible intervals (2.5%, 97.5%) from MCMC. Recruits are in millions, and biomass is in kt.

	Recruits (Age 2)			**Total Biomass**			**Spawning Biomass**		
Year	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
1960	4.6	0	52	533	468	629	173	133	236
1961	4.5	0	55	546	479	647	179	149	230
1962	90.0	12	145	614	539	710	192	167	235
1963	8.7	0	80	617	542	714	203	178	245
1964	7.4	0	72	615	539	717	218	191	261
1965	26.5	0	118	629	549	734	235	205	278
1966	74.7	0	139	685	606	770	251	220	294
1967	9.4	0	91	689	627	770	262	230	306
1968	15.0	0	57	682	626	752	268	236	311
1969	6.6	0	36	648	597	710	267	237	308
1970	2.7	0	24	595	549	653	264	236	301
1971	2.6	0	29	536	494	593	255	230	289
1972	26.5	0	60	491	446	546	237	215	268
1973	25.5	0	60	445	410	485	209	189	236
1974	2.5	0	22	401	369	436	185	167	210
1975	5.1	0	31	359	333	393	163	146	186
1976	17.9	0	29	333	310	360	147	131	166
1977	1.5	0	11	294	274	318	131	117	148
1978	2.3	0	11	264	245	286	119	108	135
1979	83.5	66	103	322	302	347	114	104	128
1980	27.5	6	48	355	336	379	109	100	122
1981	8.3	0	29	373	351	396	107	99	119
1982	48.5	29	74	417	398	447	111	103	122
1983	22.1	0	39	445	423	467	123	115	134
1984	43.3	34	58	488	468	512	139	131	150
1985	0.4	0	3	491	472	516	154	146	167
1986	23.2	11	33	502	483	524	168	160	181
1987	19.8	13	30	491	475	513	175	166	187
1988	4.0	0	12	457	443	479	174	165	187
1989	4.6	0	11	415	401	433	167	159	180
1990	5.8	3	10	373	360	389	158	150	171
1991	28.6	23	34	356	343	371	147	139	160
1992	0.3	0	2	326	314	340	136	129	148
1993	26.1	22	31	320	308	335	125	118	137
1994	3.1	0	8	297	285	312	115	108	125
1995	6.5	2	11	277	265	291	106	100	116
1996	7.5	5	10	259	247	273	101	95	111
1997	19.2	16	23	254	243	269	98	92	107
1998	1.2	0	4	240	228	253	96	90	104
1999	31.6	27	36	251	239	266	92	86	100
2000	19.6	13	29	260	248	277	89	83	96
2001	11.6	0	20	262	248	277	86	80	93
2002	43.1	36	54	292	278	310	85	80	92
2003	7.8	2	13	299	284	316	88	82	95
2004	14.5	10	19	303	287	321	91	85	98
2005	6.7	4	10	295	280	314	96	90	103
2006	11.1	7	15	289	274	307	102	96	110
2007	8.6	6	12	280	265	298	107	100	115
2008	10.6	7	14	271	256	288	109	102	117
2009	9.8	7	14	262	247	280	108	101	116
2010	17.7	13	23	263	248	281	106	99	114
2011	3.8	0	7	254	239	272	104	97	112
2012	8.4	4	14	246	231	264	101	94	109
2013	0.3	0	1	228	213	246	98	91	106
2014	11.0	4	18	218	196	229	95	88	103
2015	-	-	-	-	-	-	92	85	100
2016	-	-	-	-	-	-	88	79	96

Table 3.15. 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 1990-2014 using a 2 year moving average. For 1960-1978, a prospective 4:6:9 - year average of forward proportions was used.

Year	Bering Sea	Aleutian Islands	Western GOA	Central GOA	West Yakutat	EYakutat/ Southeast	Alaska
1960	98	118	51	148	46	71	533
1961	101	121	52	152	47	73	546
1962	114	136	59	171	53	82	614
1963	114	136	59	172	54	82	617
1964	114	136	59	171	53	82	615
1965	116	139	60	175	55	84	629
1966	127	151	66	191	60	91	685
1967	127	152	66	192	60	92	689
1968	126	151	65	190	59	91	682
1969	120	143	62	180	56	86	648
1970	110	132	57	166	52	79	595
1971	99	118	51	149	47	71	536
1972	91	108	47	137	43	65	491
1973	82	98	43	124	39	59	445
1974	74	89	38	112	35	53	401
1975	66	79	34	100	31	48	359
1976	62	73	32	93	29	44	333
1977	54	65	28	82	25	39	294
1978	49	60	26	72	23	36	264
1979	61	66	30	95	28	42	322
1980	64	84	34	95	31	47	355
1981	66	93	39	83	35	57	373
1982	76	87	54	101	40	60	417
1983	80	93	69	112	37	54	445
1984	92	113	77	117	35	54	488
1985	101	112	71	122	36	49	491
1986	107	105	68	125	42	53	502
1987	80	107	65	131	49	60	491
1988	48	93	61	147	47	61	457
1989	56	81	48	133	43	54	415
1990	57	61	40	114	43	57	373
1991	39	41	38	112	47	78	356
1992	23	37	25	103	51	86	326
1993	15	35	29	106	54	81	320
1994	18	34	32	98	46	69	297
1995	26	32	28	90	39	62	277
1996	25	27	28	93	33	53	259
1997	24	24	27	99	31	50	254
1998	21	30	27	84	28	50	240
1999	20	41	29	83	27	51	251
2000	20	43	34	87	27	50	260
2001	29	41	41	82	22	46	262
2002	40	45	43	95	24	45	292
2003	40	46	42	101	26	43	299
2004	40	46	38	107	28	43	303
2005	42	45	38	96	26	48	295
2006	45	40	41	87	26	49	289
2007	49	36	30	87	29	49	280
2008	52	34	27	85	26	47	271
2009	50	34	31	82	23	42	262
2010	52	29	28	77	29	49	263
2011	33	26	26	90	33	47	254
2012	14	31	28	98	28	47	246
2013	30	32	23	76	21	46	228
2014	46	27	23	62	19	41	218

Table 3.16. Key parameter estimates and their uncertainty and Bayesian credible intervals (BCI). Recruitment is in millions.

Parameter	μ (MLE)	μ (MCMC)	Median (MCMC)	σ (Hessian)	σ (MCMC)	BCI-Lower	BCI-Upper
$q_{domesticLL}$	7.56	7.55	7.55	0.11	0.22	7.13	7.97
q_{coopLL}	6.22	6.22	6.22	0.11	0.21	5.84	6.65
q_{trawl}	1.34	1.32	1.32	0.32	0.09	1.15	1.52
$F_{40\%}$	0.09	0.11	0.10	0.023	0.029	0.06	0.18
2014 SSB (kt)	95.0	95.2	95.1	3.66	3.86	87.9	103
2000 Year Class	11.6	45.0	44.9	4.26	4.87	35.6	54.5
2008 Year Class	17.7	18.3	18.3	2.30	2.48	13.5	23.1

Table 3.17. Comparison of 2013 results versus 2014 results. Biomass is in kilotons.

Year	2013 SAFE Spawning Biomass	2014 SAFE Spawning Biomass	2013 SAFE Total Biomass	2014 SAFE Total Biomass
1977	129	131	291	294
1978	117	119	261	264
1979	112	114	318	322
1980	107	109	351	355
1981	106	107	367	373
1982	109	111	412	417
1983	121	123	439	445
1984	136	139	481	488
1985	152	154	485	491
1986	165	168	495	502
1987	171	175	484	491
1988	170	174	451	457
1989	164	167	408	415
1990	154	158	367	373
1991	143	147	349	356
1992	132	136	319	326
1993	122	125	313	320
1994	111	115	291	297
1995	103	106	270	277
1996	98	101	252	259
1997	95	98	247	254
1998	92	96	233	240
1999	88	92	244	251
2000	85	89	253	260
2001	82	86	254	262
2002	81	85	284	292
2003	84	88	289	299
2004	87	91	293	303
2005	92	96	285	295
2006	98	102	279	289
2007	103	107	270	280
2008	105	109	261	271
2009	104	108	252	262
2010	102	106	255	263
2011	100	104	247	254
2012	96	101	234	246
2013	93	98	217	228

Table 3.18. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for seven harvest scenarios. Abundance projected using 1979-2012 recruitments.

Year	Maximum permissible F	Author's F* (specified catch)	Half max. F	5-year average F	No fishing	Overfished?	Approaching overfished?
Spawning biomass (kt)							
2014	94.9	94.9	94.9	94.9	94.9	94.9	94.9
2015	92.2	92.2	92.1	92.2	92.2	92.2	92.2
2016	87.1	88.3	90.3	88.4	94.0	85.8	87.1
2017	82.5	84.9	87.8	84.7	95.6	80.4	82.5
2018	80.1	82.1	85.6	82.6	98.4	77.3	79.1
2019	80.6	82.3	84.7	83.4	104.0	77.3	78.8
2020	83.4	84.8	85.5	86.5	112.4	79.6	80.7
2021	87.2	88.3	88.3	90.8	122.3	82.8	83.7
2022	91.1	92.0	91.9	95.5	132.7	86.1	86.8
2023	94.7	95.4	95.9	100.0	143.1	89.1	89.6
2024	97.9	98.4	101.4	104.2	153.1	91.7	92.1
2025	100.6	101.0	106.4	107.9	162.5	93.9	94.2
2026	103.0	103.3	109.8	111.4	171.5	95.7	96.0
2027	105.1	105.3	113.9	114.5	179.9	97.3	97.5
Fishing mortality							
2014	0.064	0.064	0.064	0.064	0.064	0.064	0.064
2015	0.082	0.067	0.041	0.066	-	0.098	0.098
2016	0.078	0.062	0.040	0.066	-	0.091	0.091
2017	0.073	0.075	0.039	0.066	-	0.085	0.085
2018	0.071	0.073	0.038	0.066	-	0.081	0.081
2019	0.070	0.072	0.038	0.066	-	0.080	0.080
2020	0.071	0.072	0.038	0.066	-	0.081	0.081
2021	0.072	0.072	0.039	0.066	-	0.082	0.082
2022	0.073	0.073	0.041	0.066	-	0.083	0.083
2023	0.074	0.074	0.043	0.066	-	0.084	0.084
2024	0.075	0.075	0.046	0.066	-	0.085	0.085
2025	0.076	0.076	0.047	0.066	-	0.087	0.087
2026	0.077	0.078	0.047	0.066	-	0.088	0.088
2027	0.079	0.079	0.047	0.066	-	0.090	0.090
Yield (kt)							
2014	11.4	11.4	11.4	11.4	11.4	11.4	11.4
2015	13.7	13.7	7.0	11.0	-	16.1	13.7
2016	12.1	12.4	6.6	10.5	-	13.8	12.1
2017	11.7	12.3	6.8	10.7	-	13.1	13.8
2018	12.3	12.8	7.4	11.4	-	13.6	14.2
2019	13.3	13.7	8.1	12.2	-	14.7	15.1
2020	14.3	14.6	8.9	12.9	-	15.7	16.0
2021	15.3	15.5	9.5	13.5	-	16.8	17.0
2022	16.1	16.2	10.1	14.1	-	17.6	17.8
2023	16.8	16.9	10.7	14.6	-	18.4	18.5
2024	17.5	17.6	11.2	15.0	-	19.0	19.1
2025	18.0	18.1	11.7	15.4	-	19.6	19.7
2026	18.5	18.6	12.1	15.8	-	20.1	20.2
2027	19.1	19.1	12.5	16.1	-	20.7	20.7

* Projections in Author's F (Alternative 2) are based on estimated catches of 11,172 t and 9,862 t used in place of maximum permissible ABC for 2015 and 2016. This was done in response to management requests for a more accurate two-year projection.

Table 3.19. Analysis of ecosystem considerations for the 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

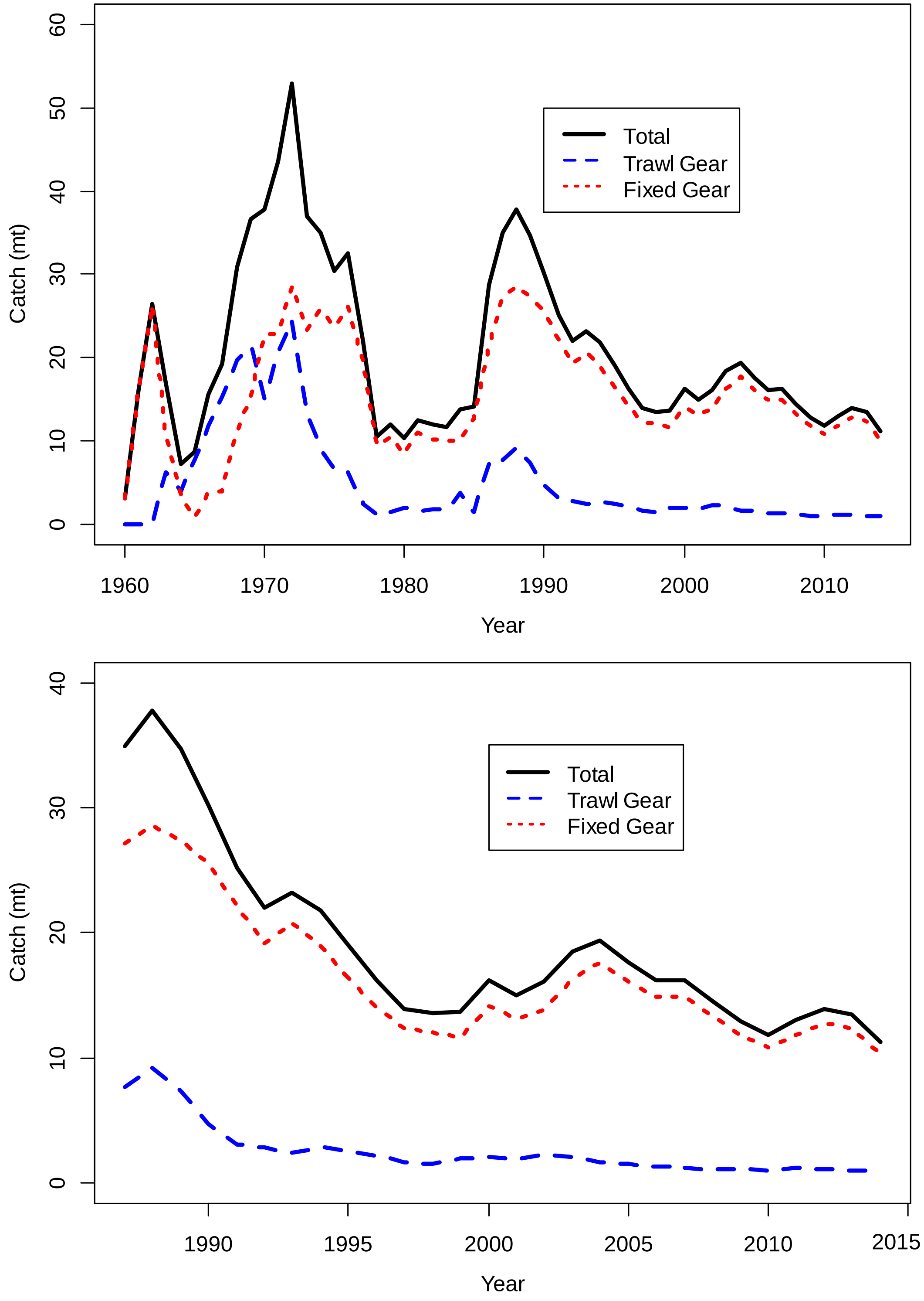


Figure 3.1. Long term and short term sablefish catch by gear type.

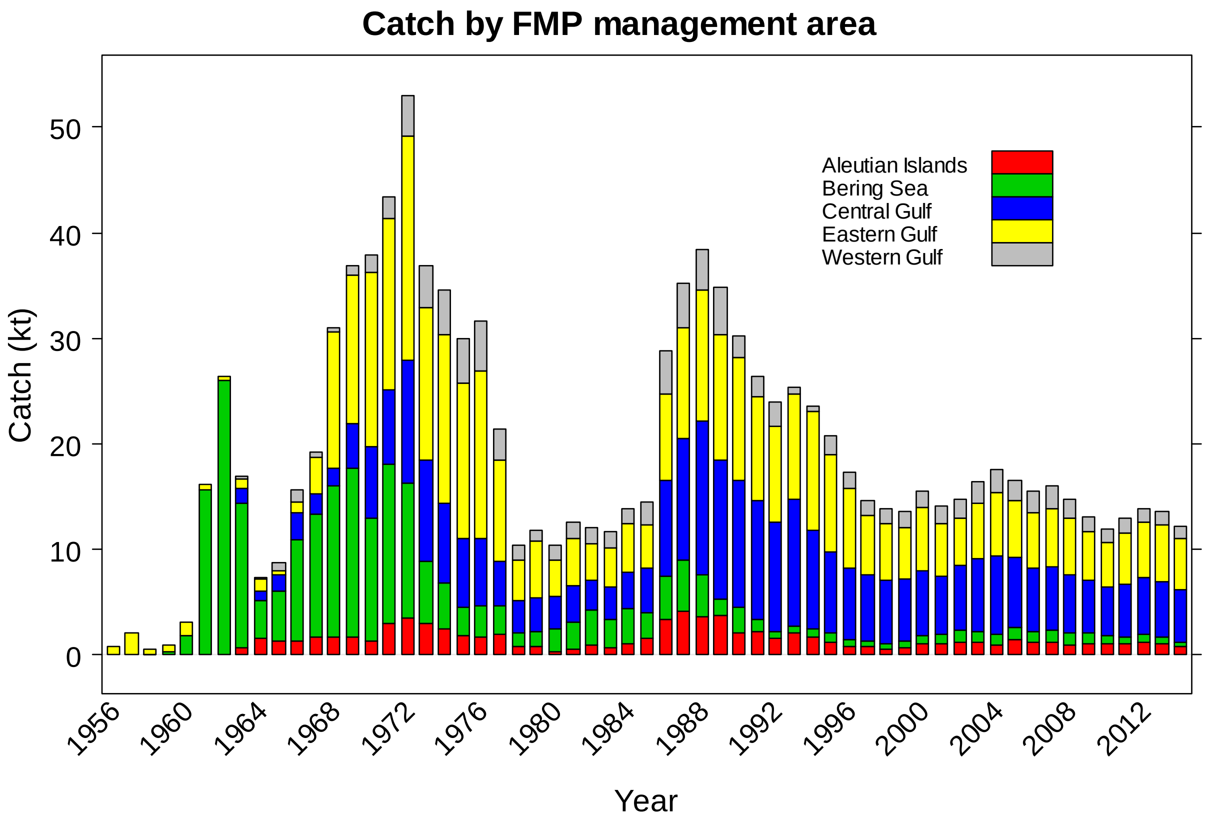


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

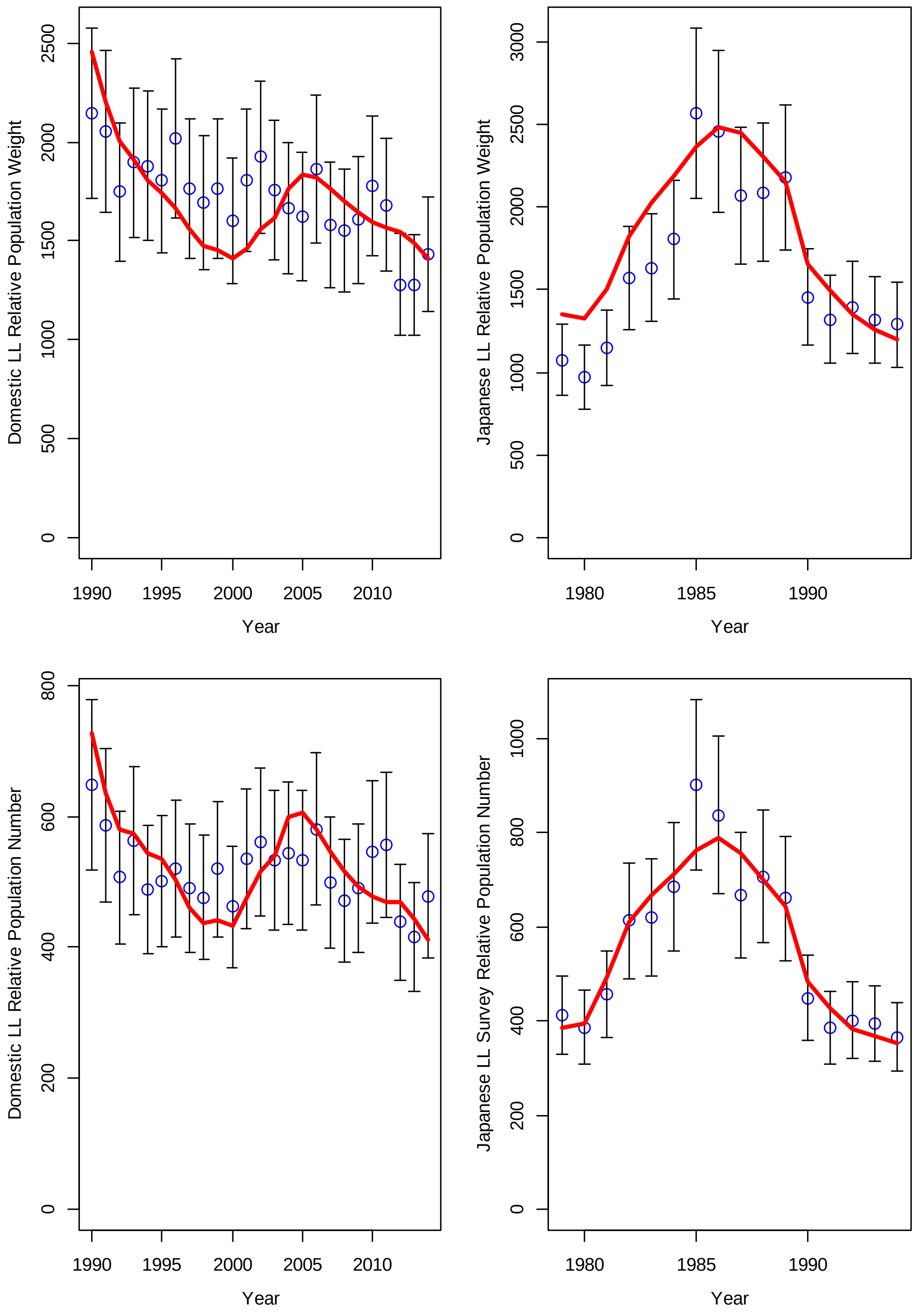


Figure 3.3. Observed and predicted sablefish relative population weight and numbers versus year. Points are observed estimates with approximate 95% confidence intervals, solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

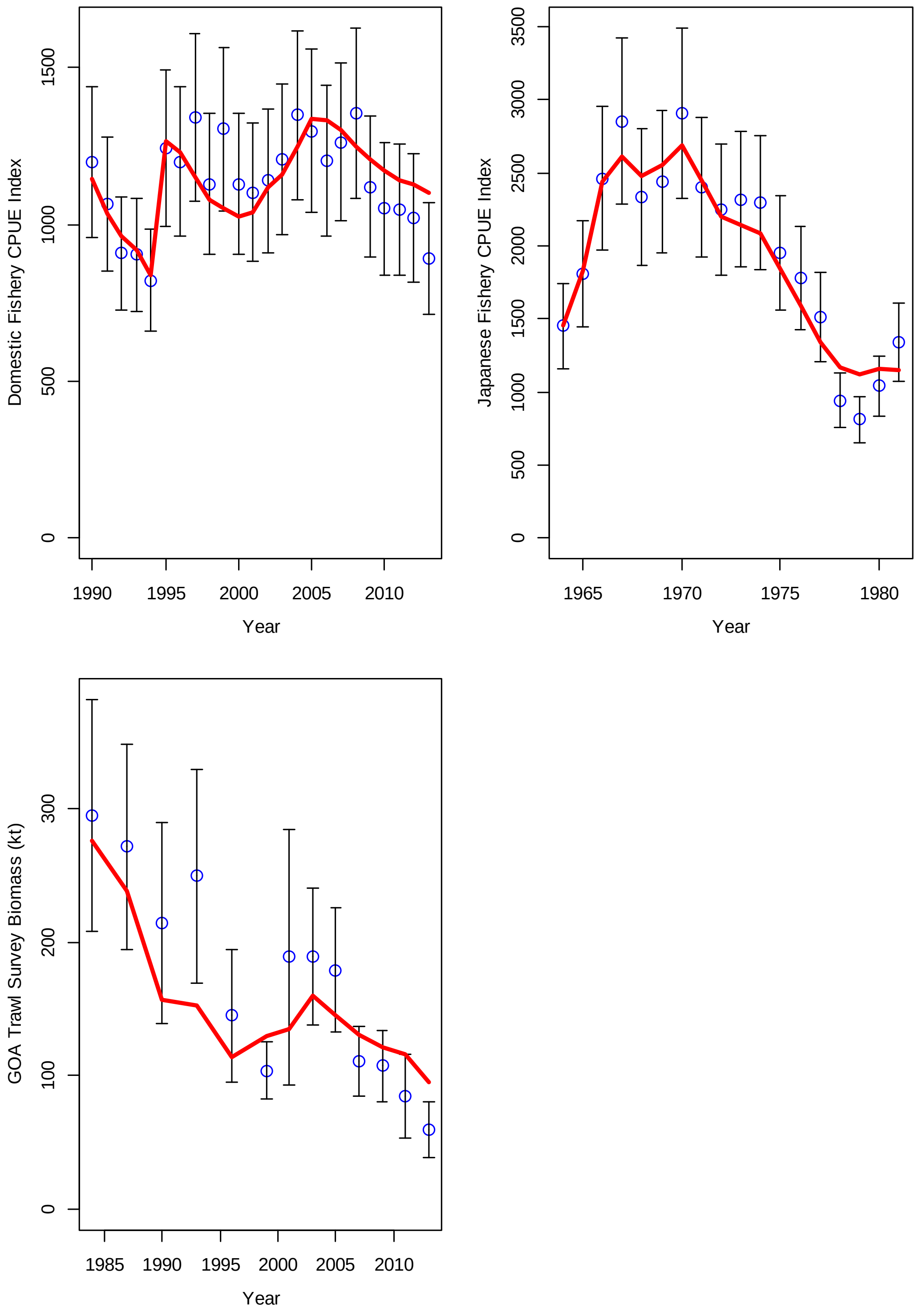


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels, GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while solid red lines are model predictions.

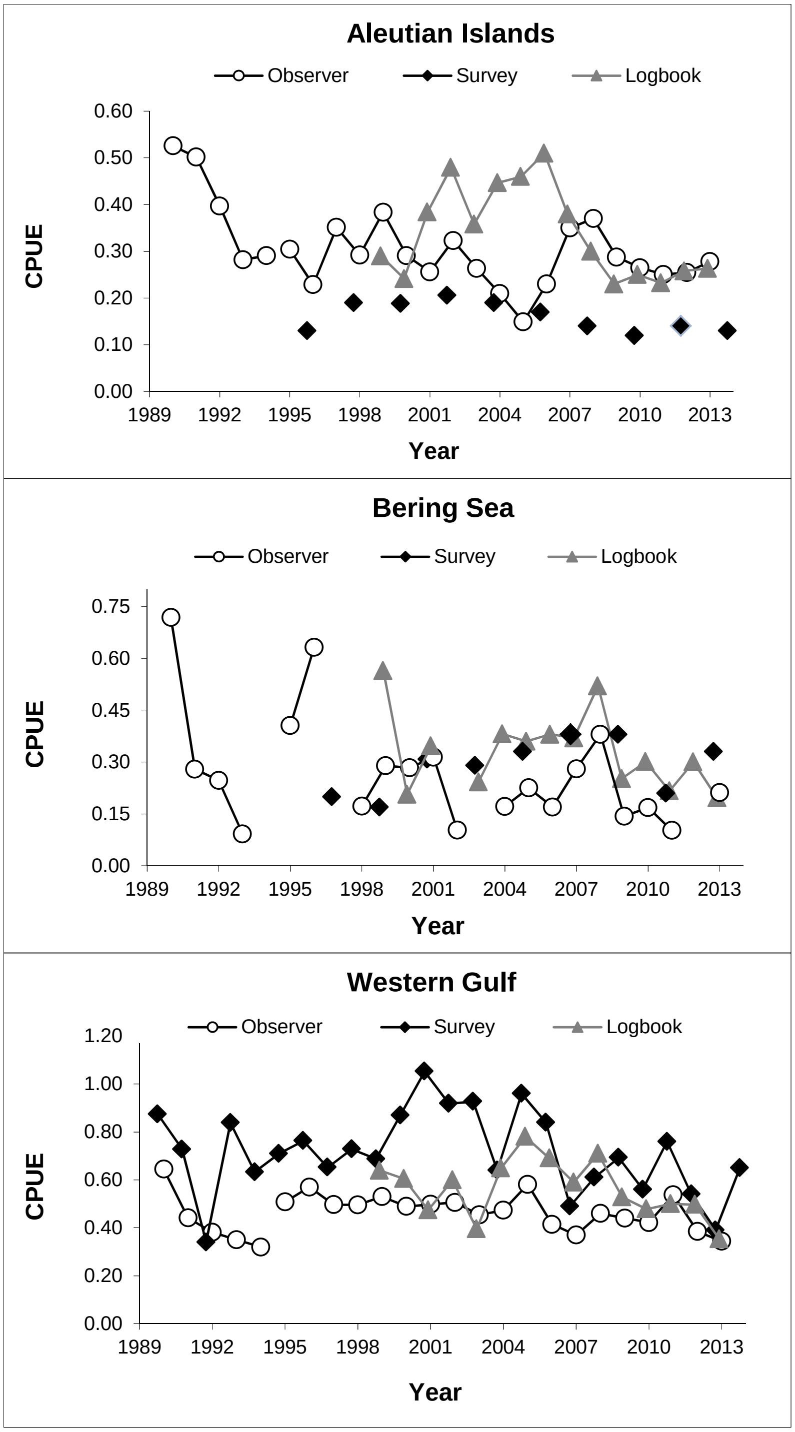


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in the Bering Sea in 1994, 1997, 2003, and 2012, in logbook data in the Bering Sea in 2002, and in East Yakutat observer data from 1990-1994.

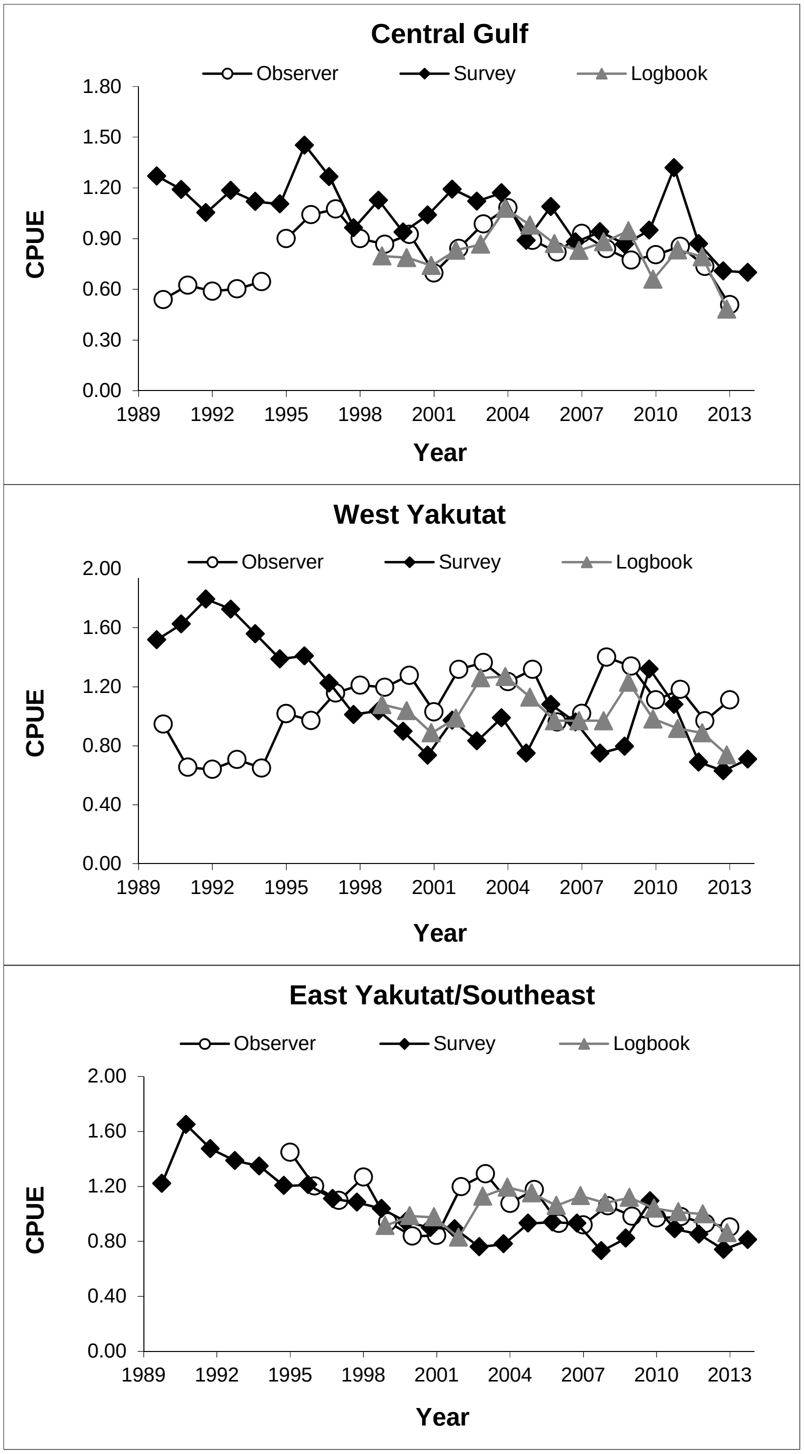


Figure 3.5. (continued)

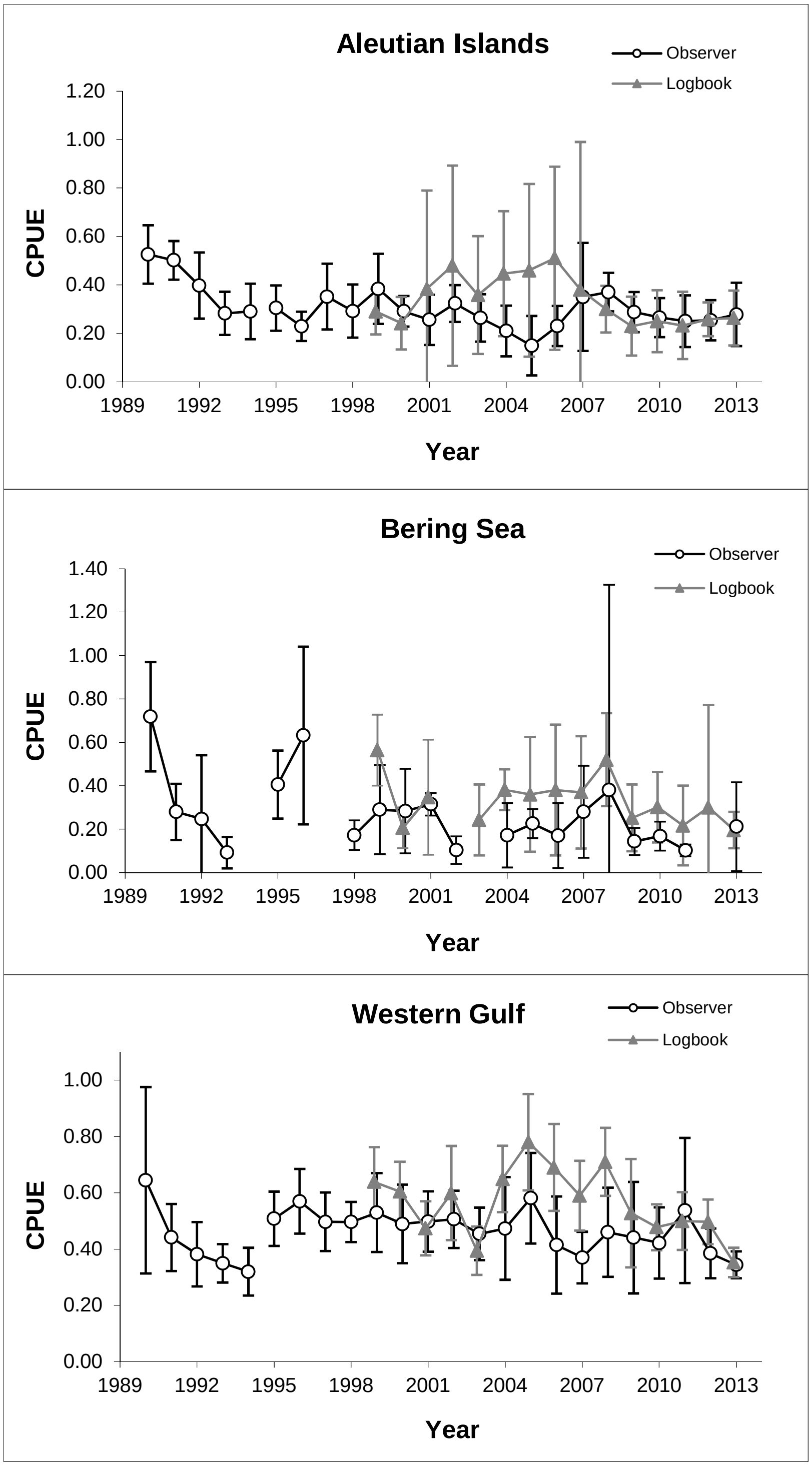


Figure 3.6. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in the Bering Sea in 1994, 1997, 2003, and 2012, in logbook data in the Bering Sea in 2002, and in East Yakutat observer data from 1990-1994.

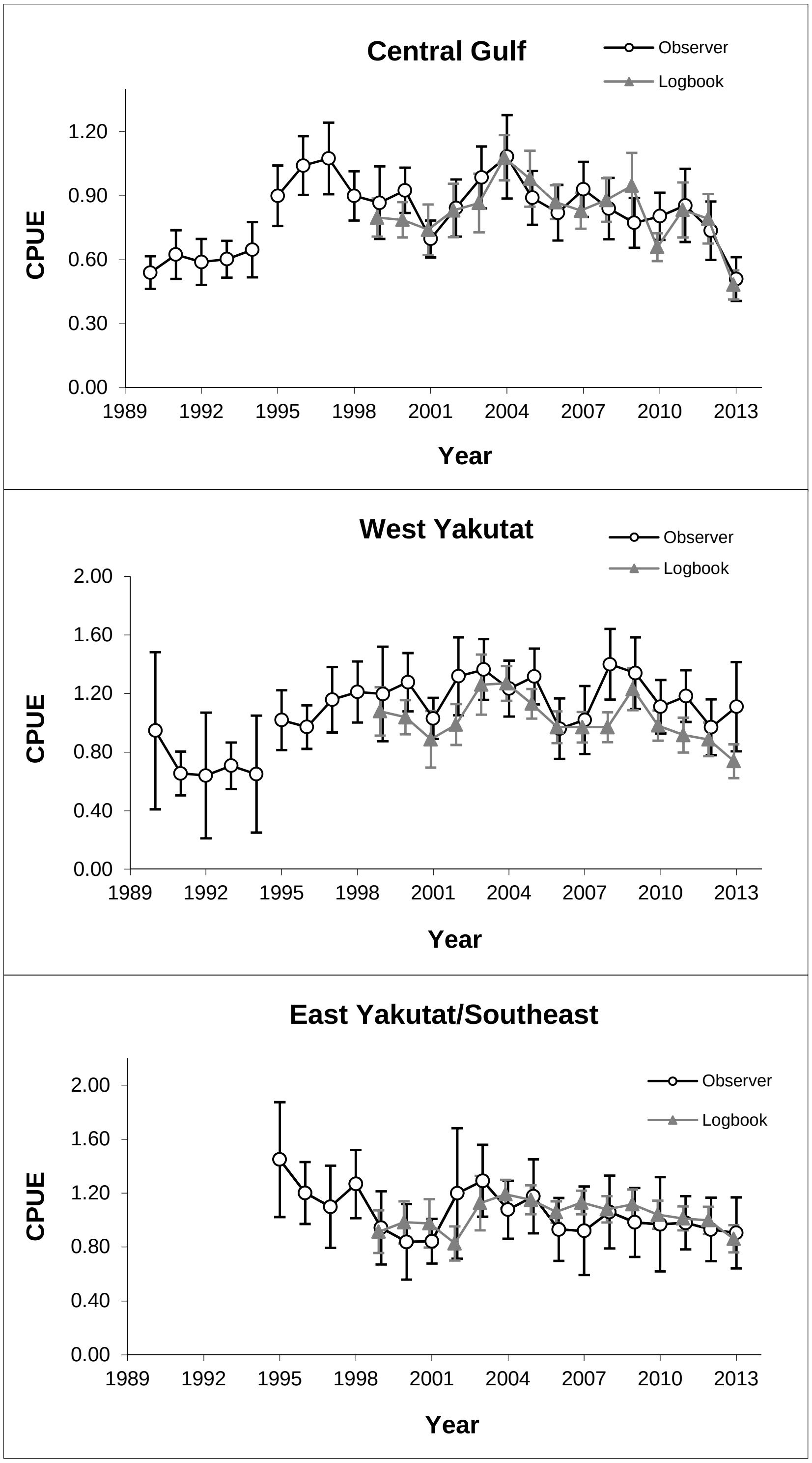
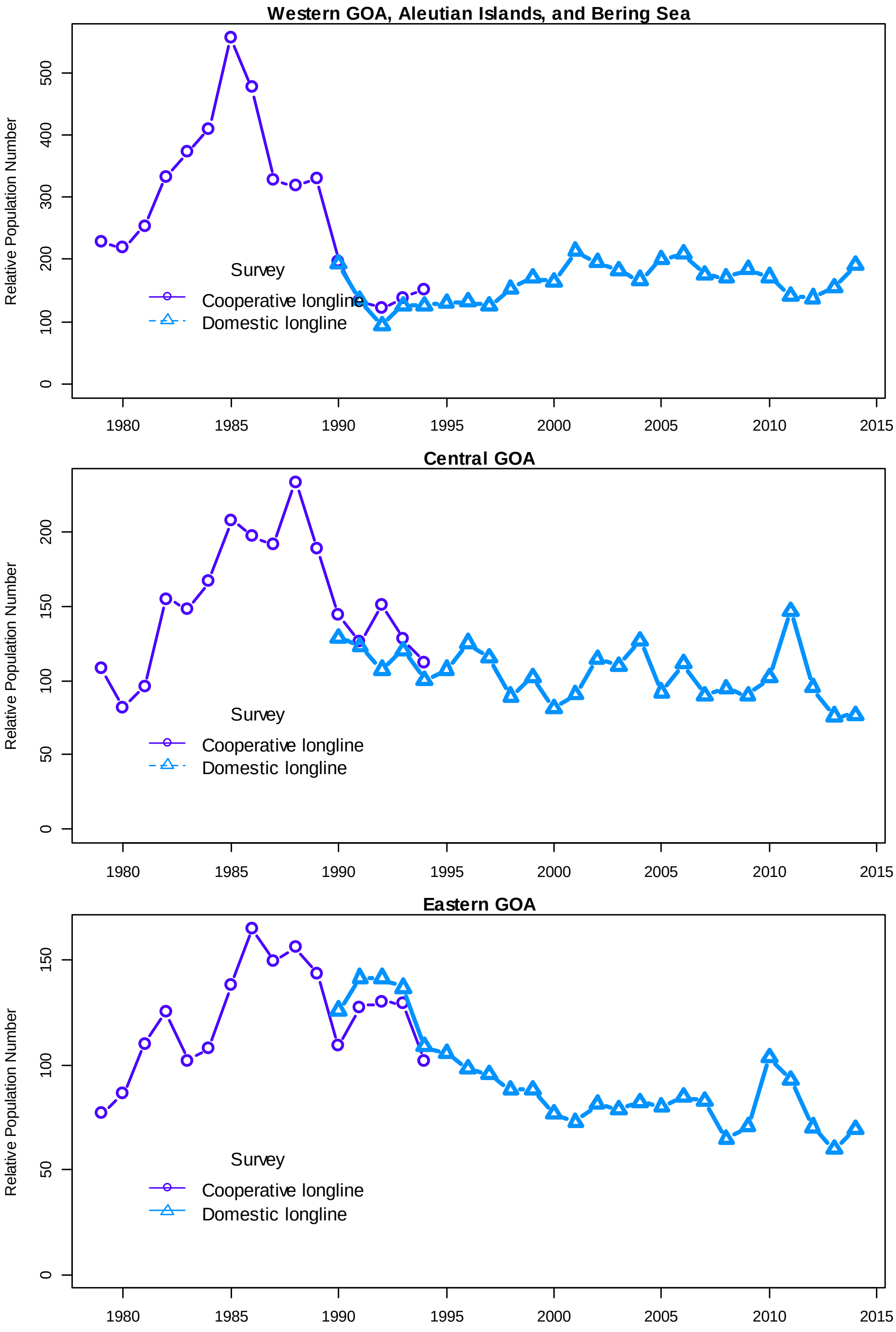


Figure 3.6. (continued)


Western GOA, Aleutian Islands, and Bering Sea

Central GOA

Eastern GOA

Figure 3.7. 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.

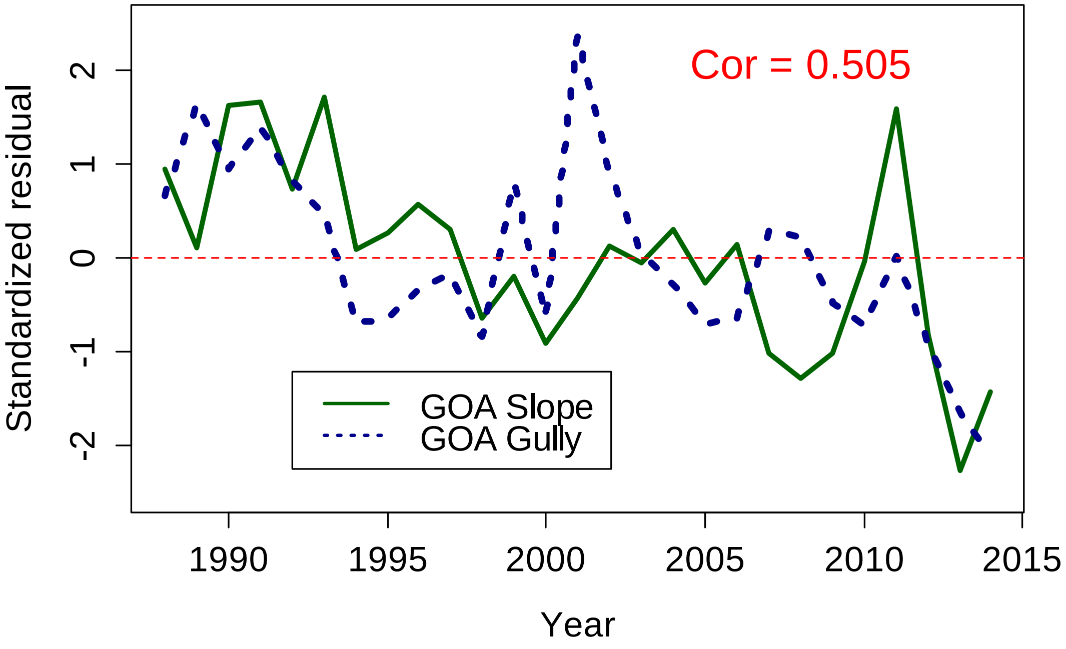


Figure 3.8 Comparison of abundance trends in GOA gully stations versus GOA slope stations.

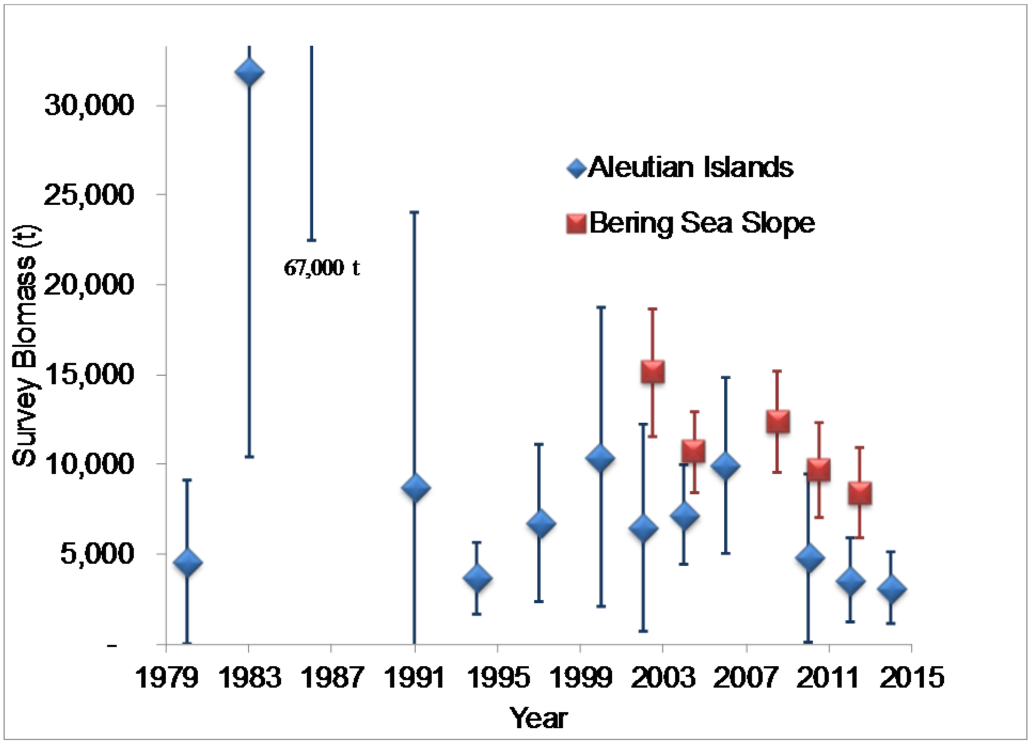


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates. Bering Sea Slope years are jittered so that intervals do not overlap.

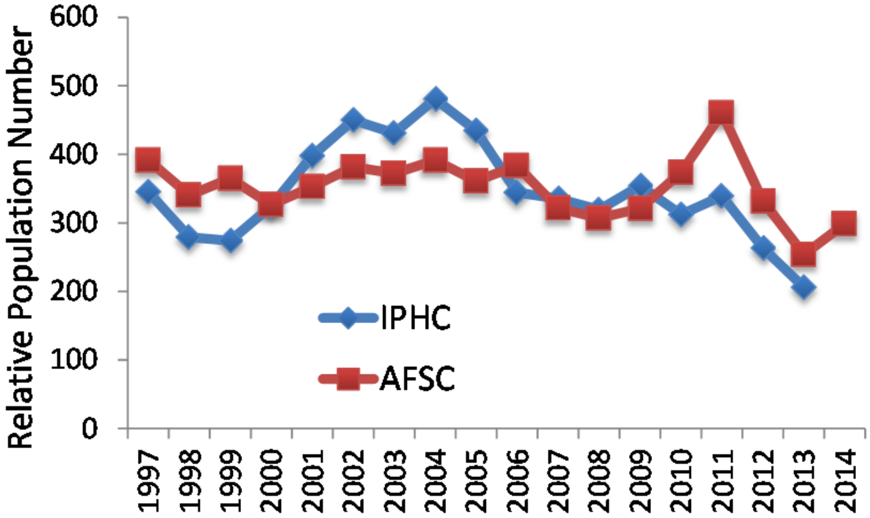


Figure 3.10. Comparisons of IPHC and AFSC longline survey trends in relative population number of sablefish in the Gulf of Alaska.

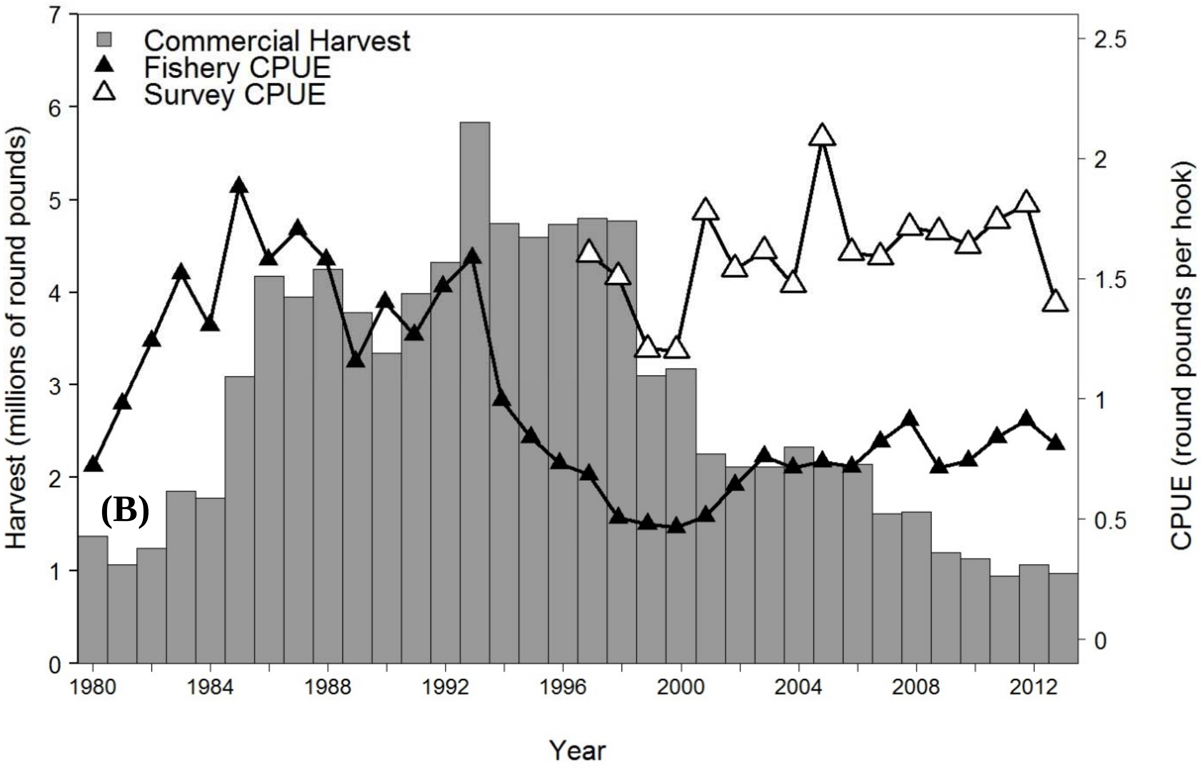


Figure 3.11a. Northern Southeast Inside sablefish long line survey and fishery catch per unit effort (round pounds per hook) and harvest over time (from J. Stahl pers. comm. November, 2014).

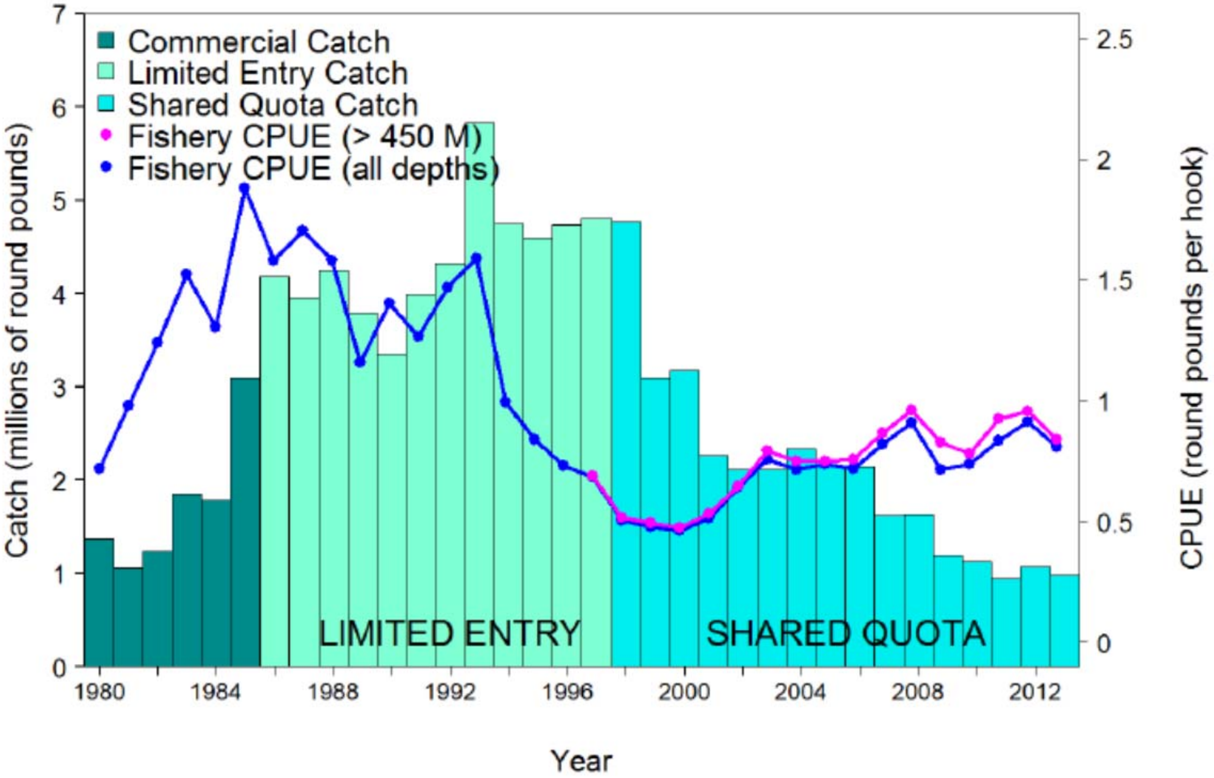


Figure 3.11b. Northern Southeast Inside sablefish long line fishery catch per unit effort (round pounds per hook) and harvest over time (from K. Green pers. comm. September, 2014).

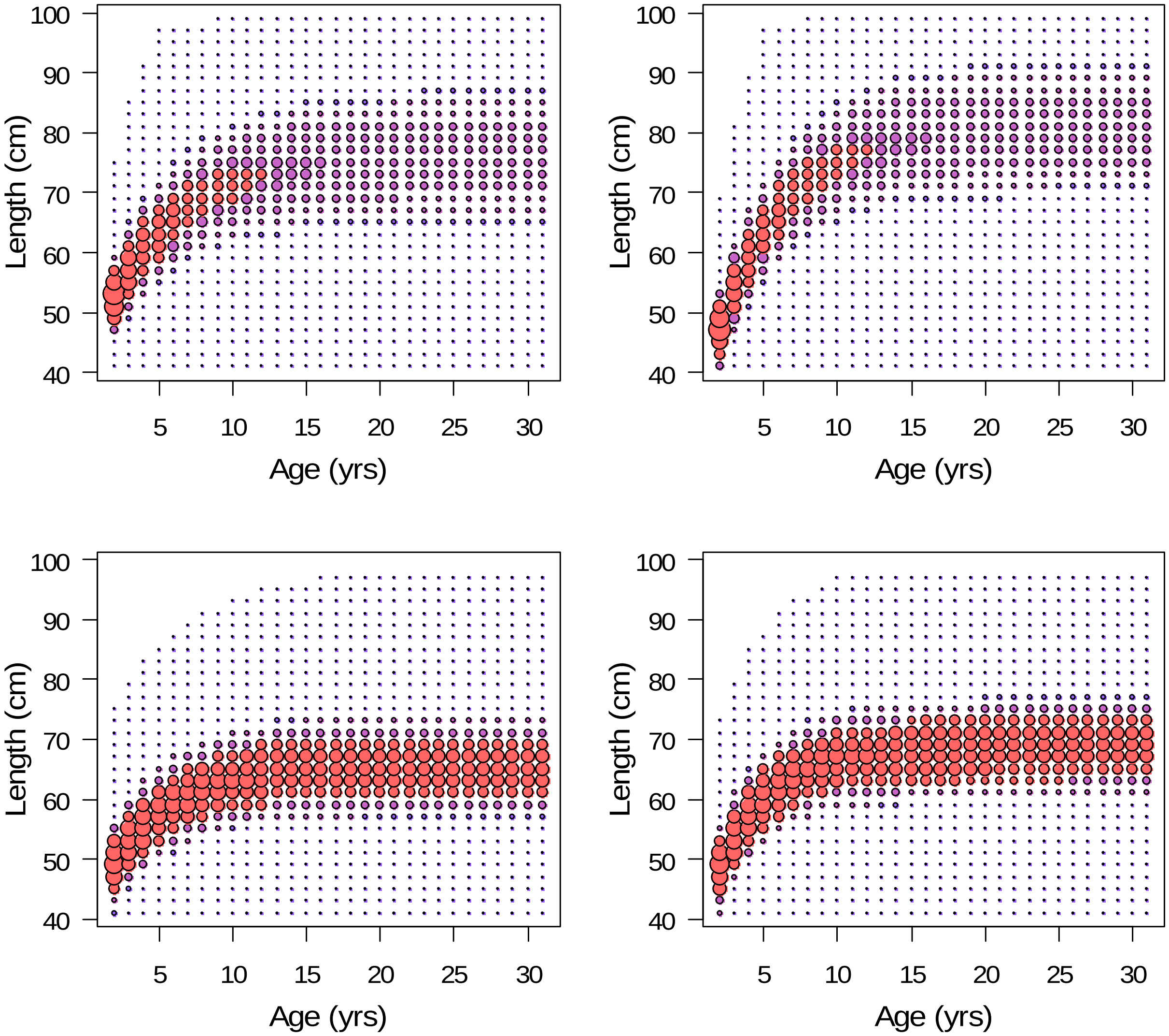


Figure 3.12. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996-2014.

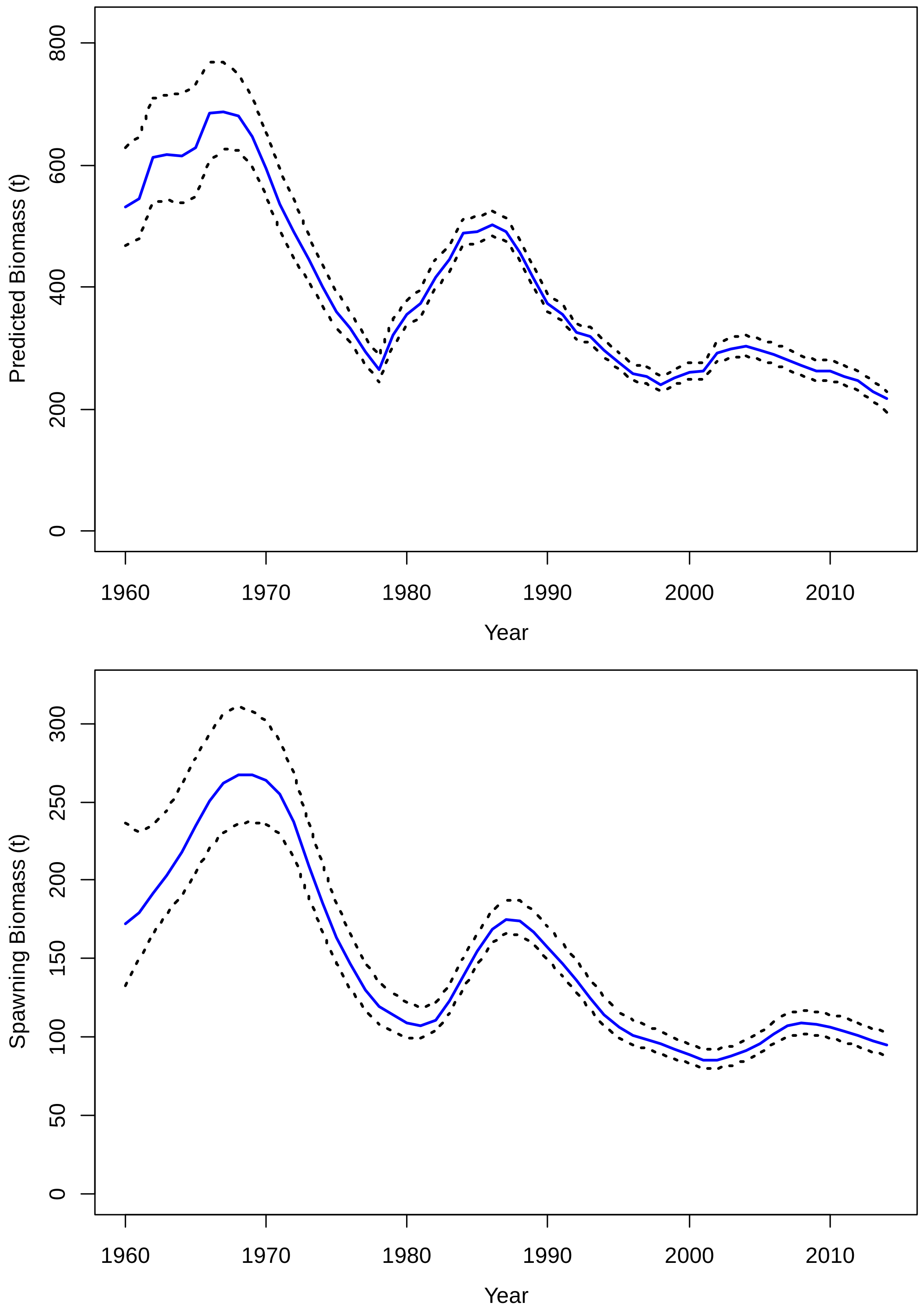


Figure 3.13.--Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

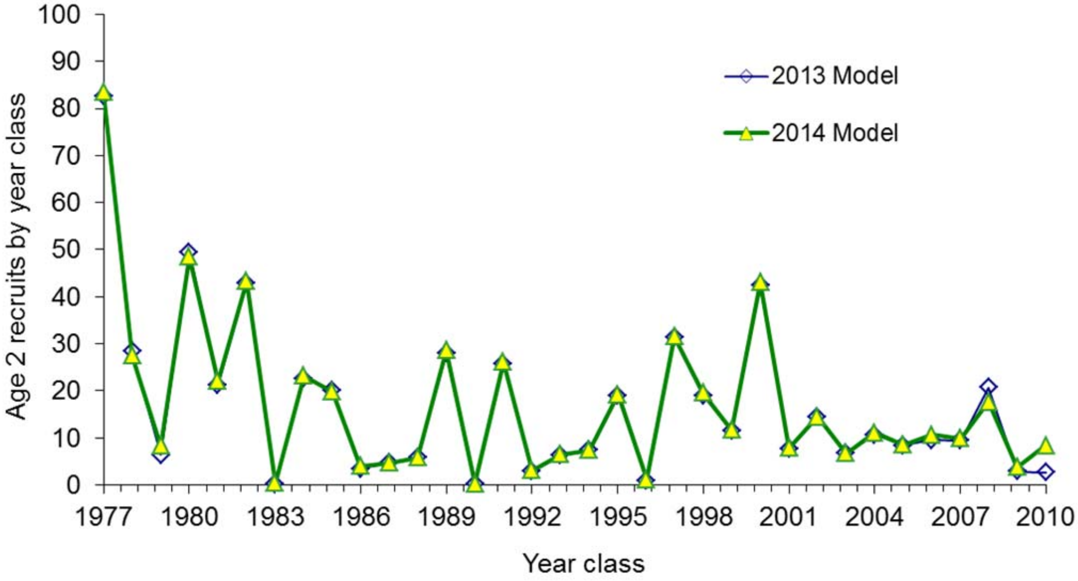


Figure 3.14a. Estimated recruitment by year class 1958-2011 (number at age 2, millions) for 2013 and 2014 models.

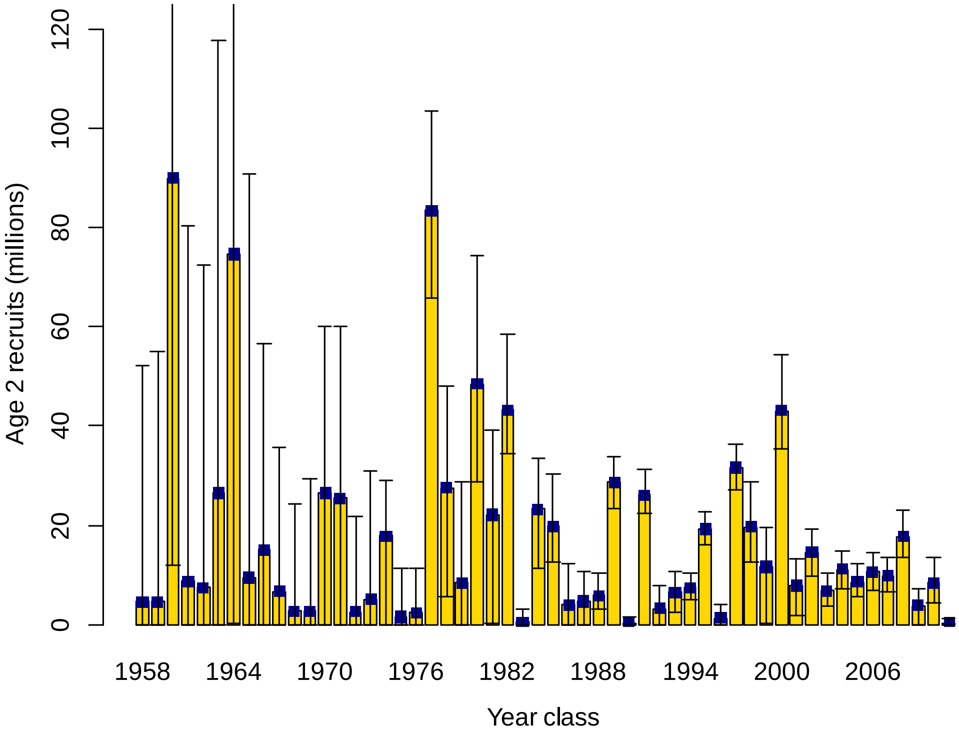


Figure 3.14b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Credible intervals are based on MCMC posterior.

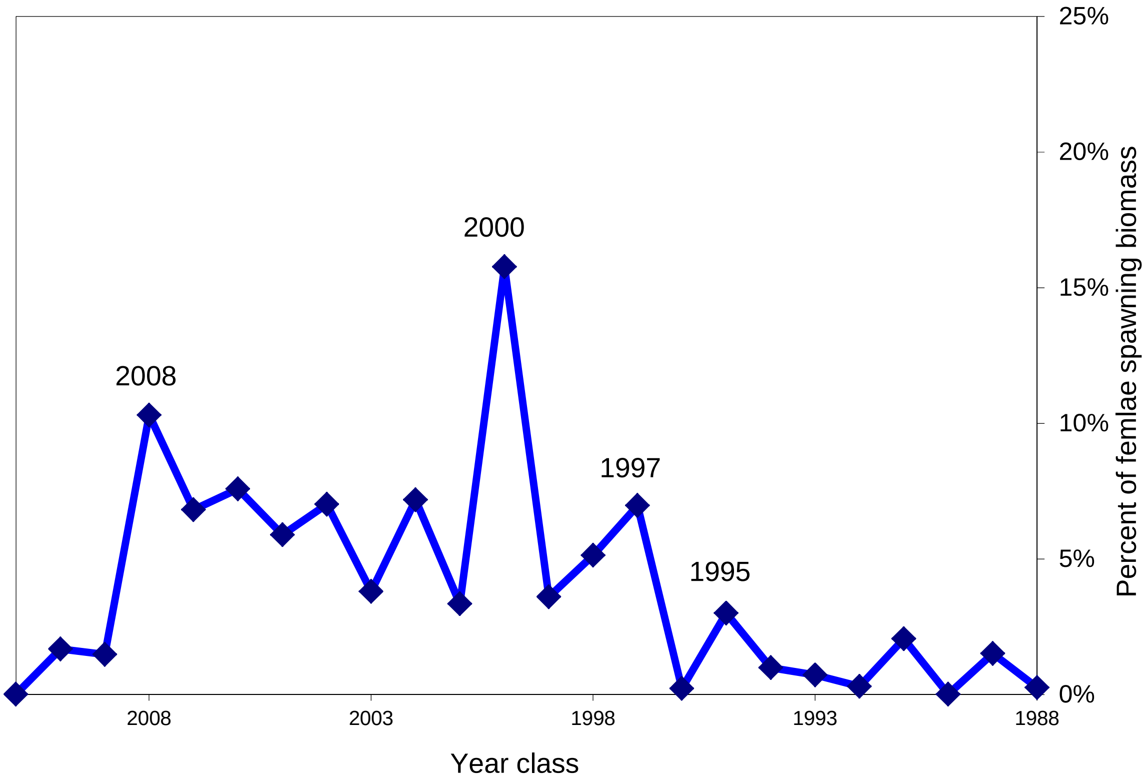


Figure 3.15. Relative contribution of the last 20 year classes to next year's female spawning biomass.

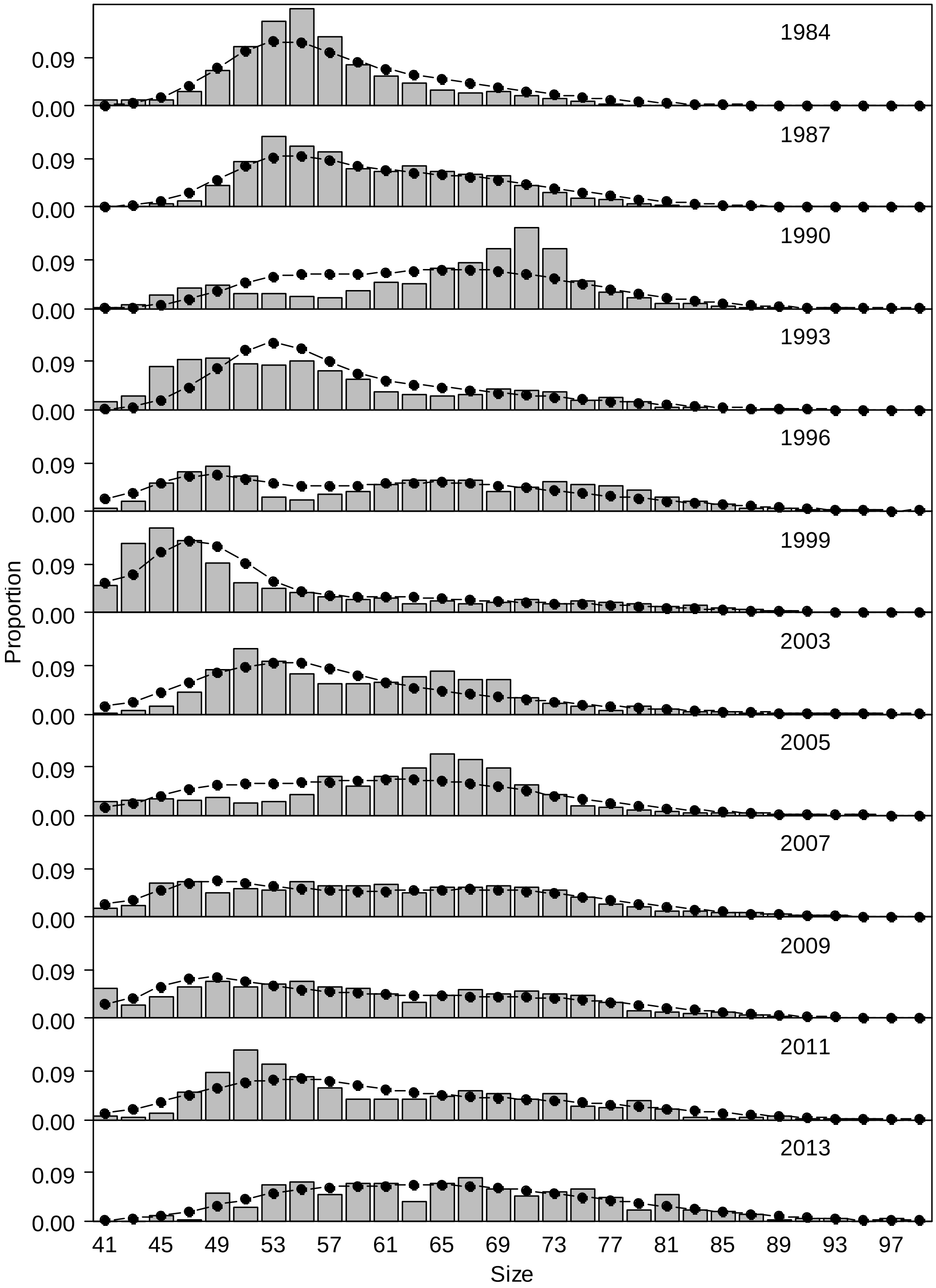


Figure 3.16. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

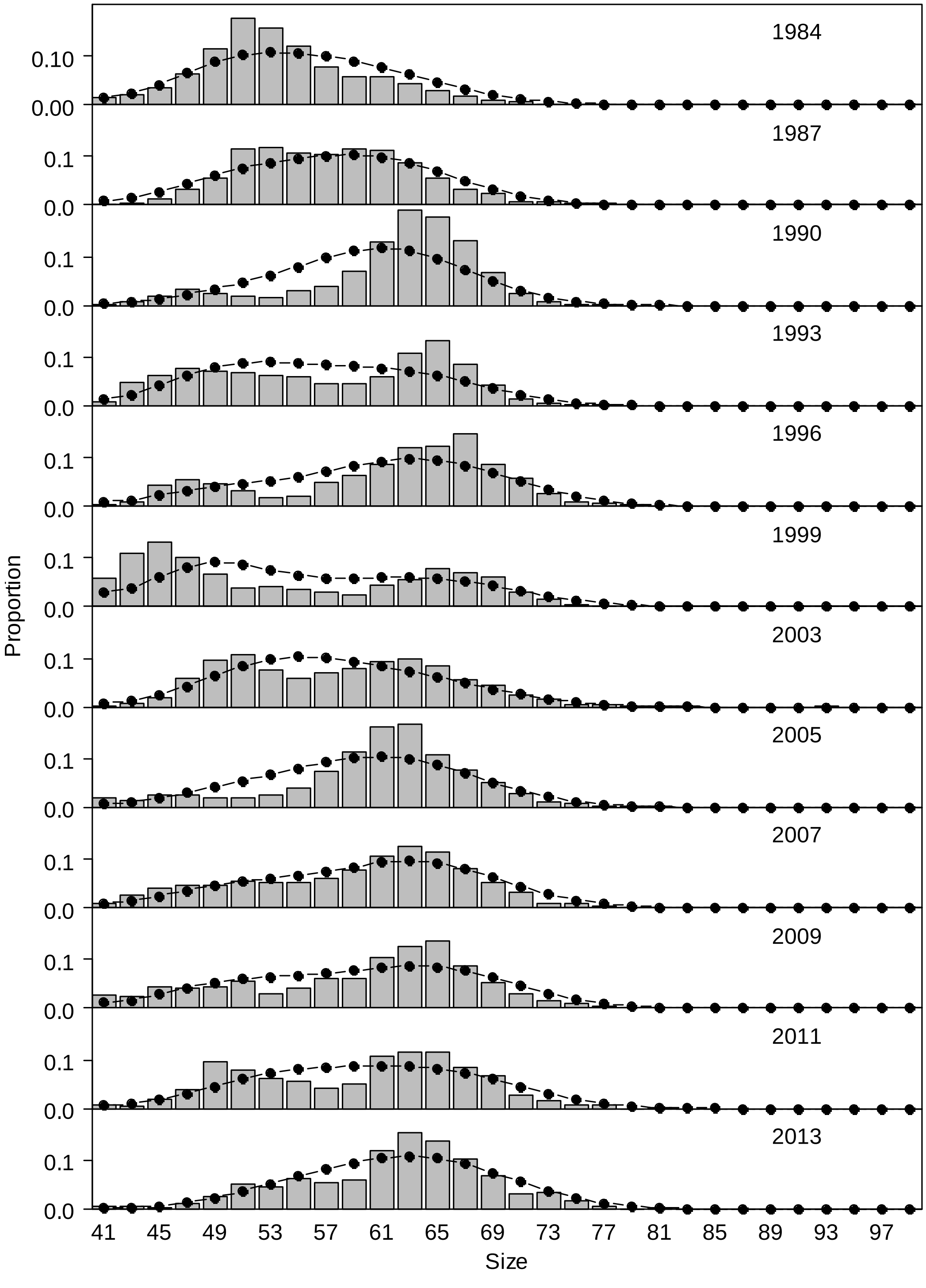


Figure 3.17. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

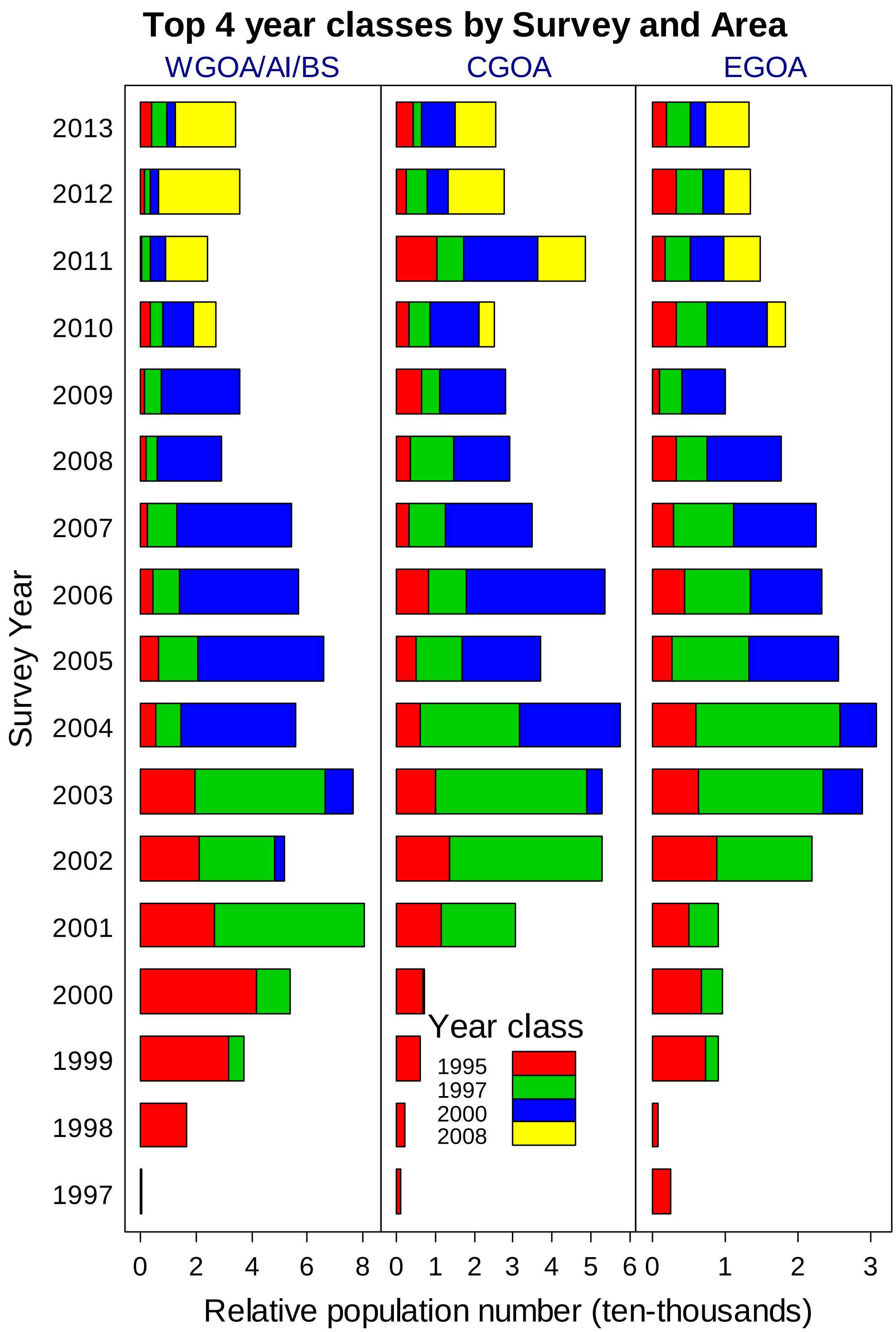


Figure 3.18. Above average 1995, 1997, 2000 and potential above-average 2008 year classes relative population abundance in each survey year and area.

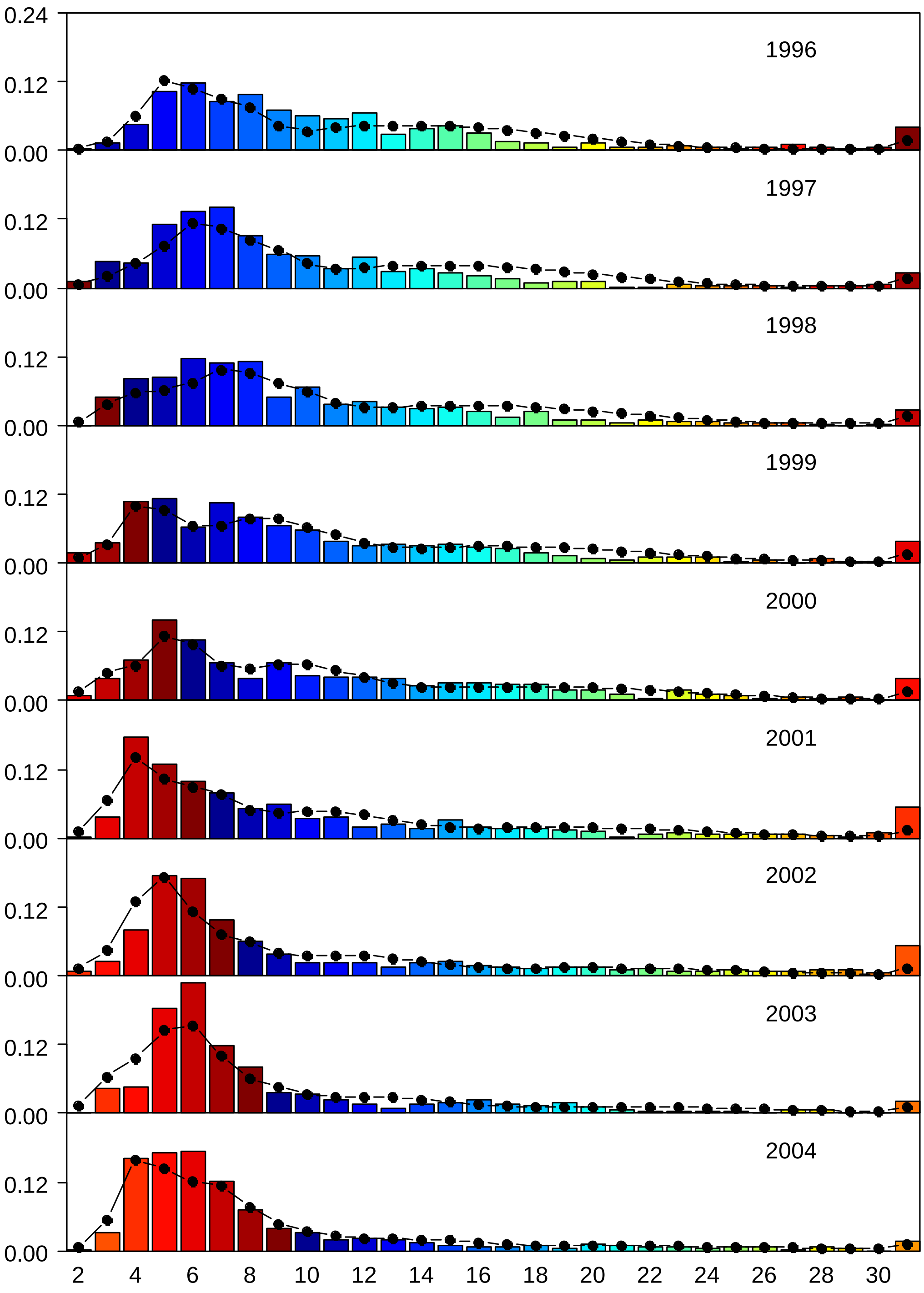


Figure 3.19. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

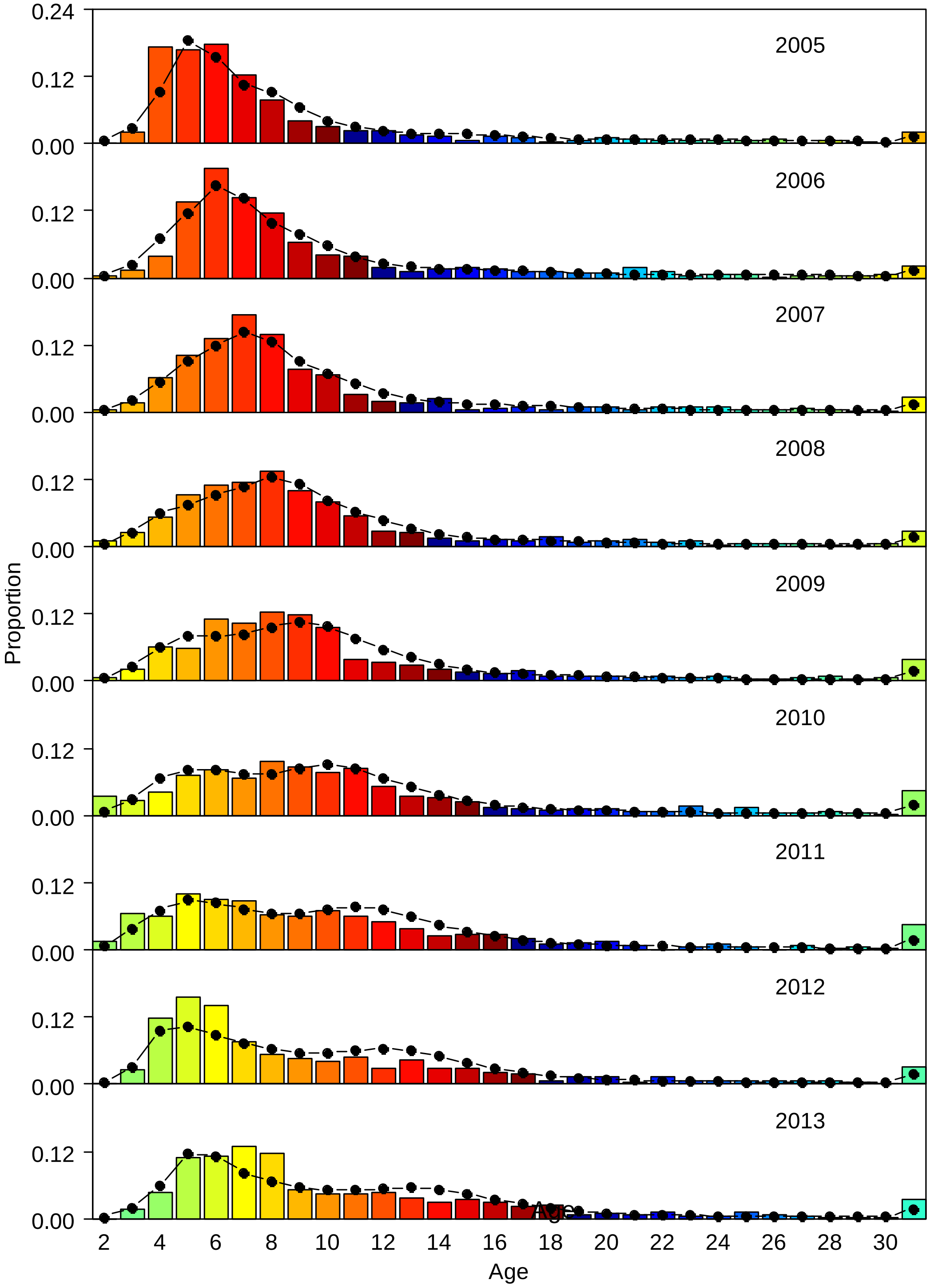


Figure 3.19 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

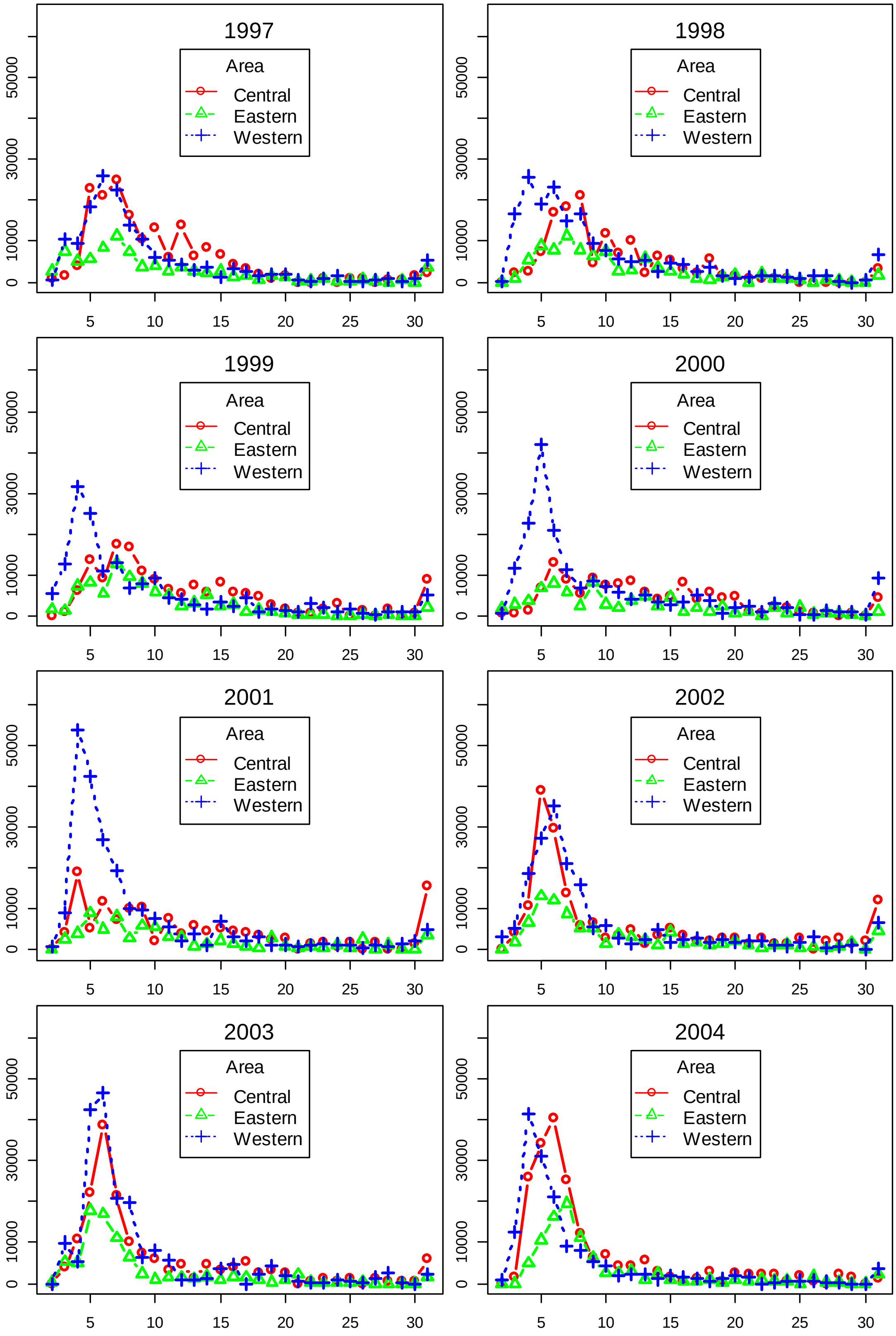
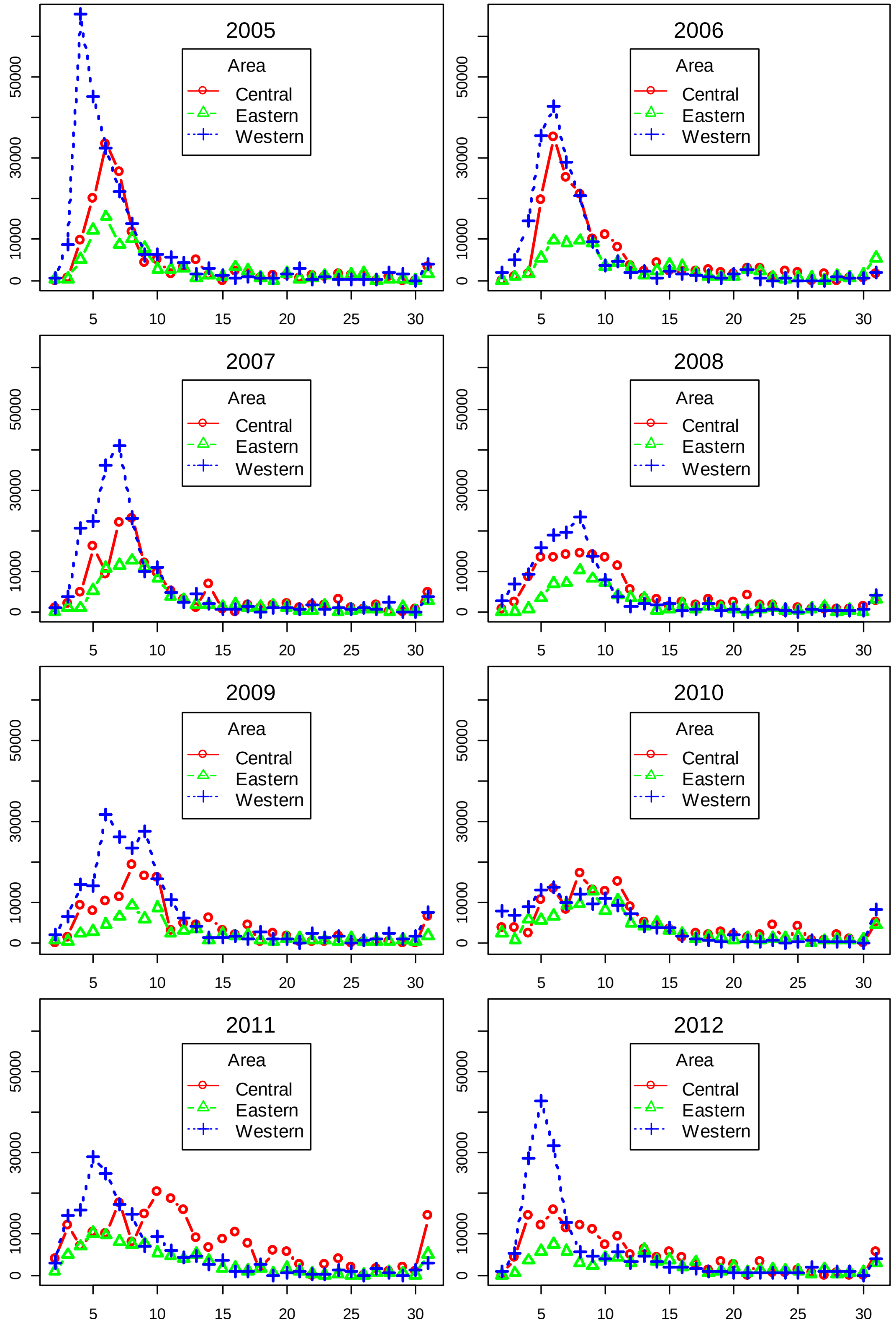


Figure 3.20. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.


2005

2006

2007

2008

2009

2010

2011

2012

Figure 3.20 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

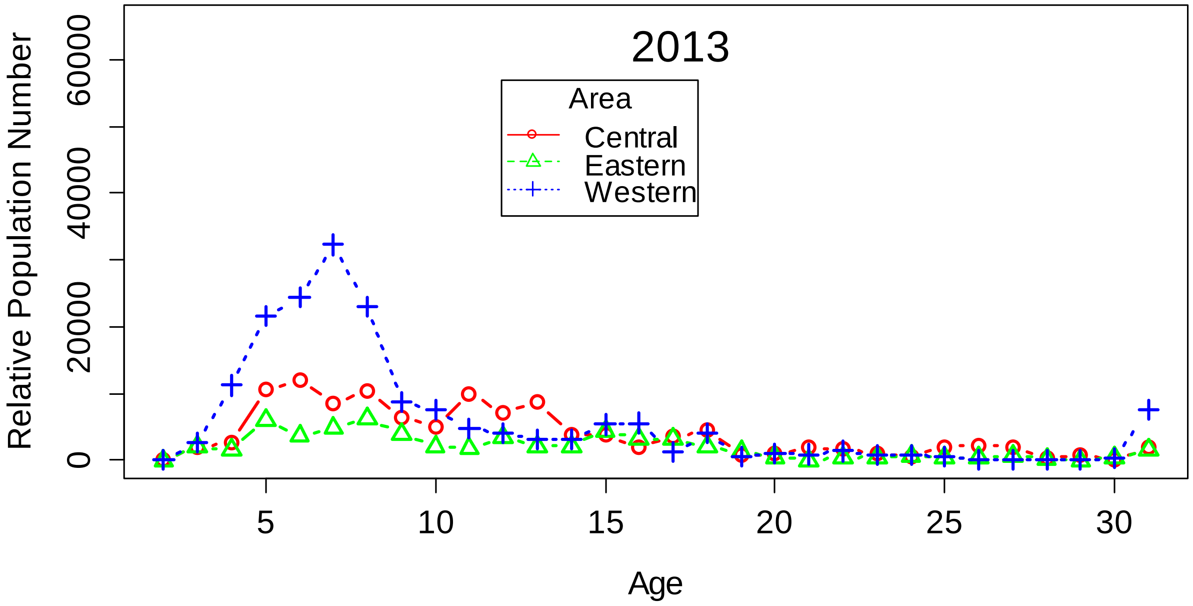


Figure 3.20 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

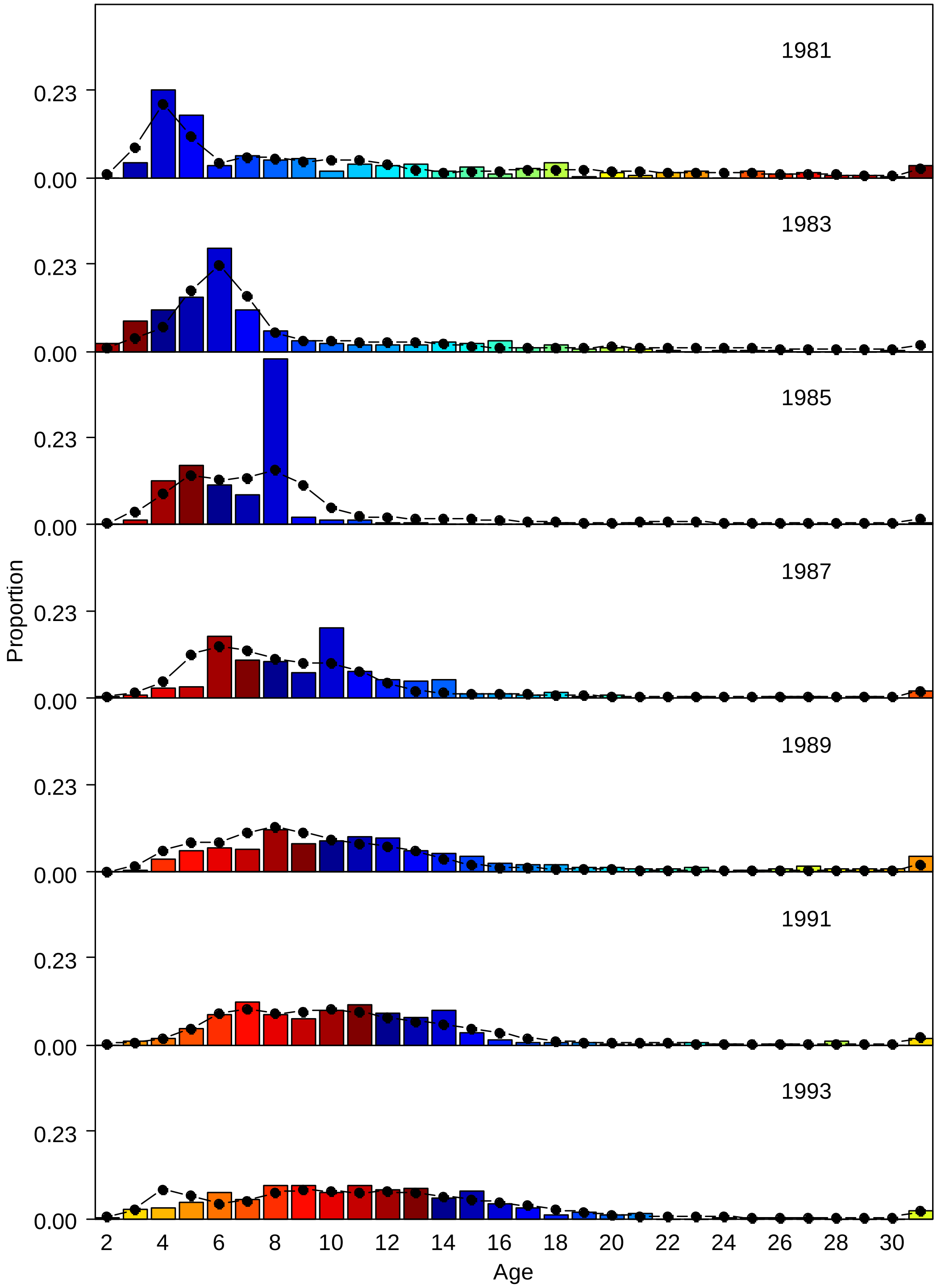


Figure 3.21. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

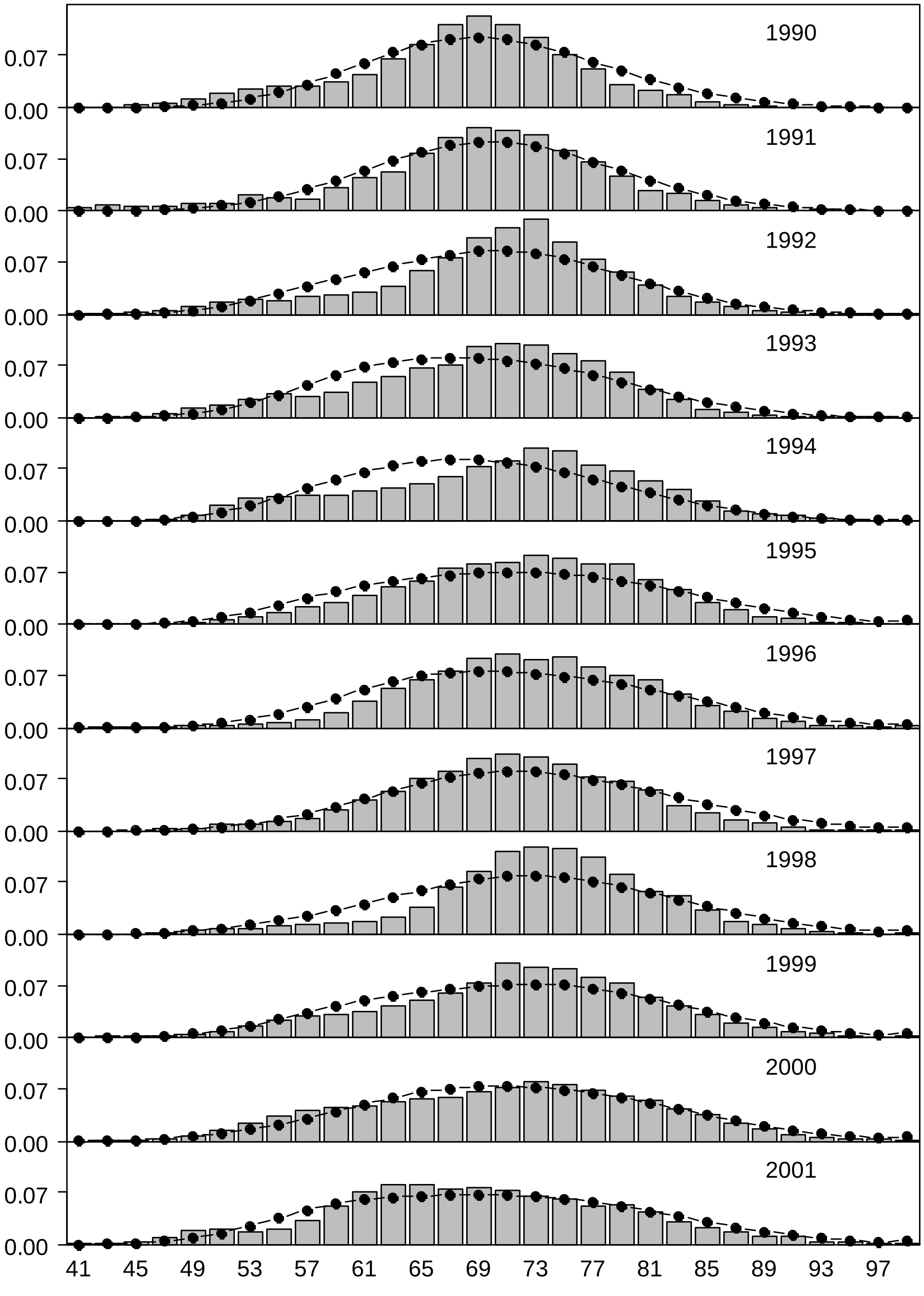


Figure 3.22. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

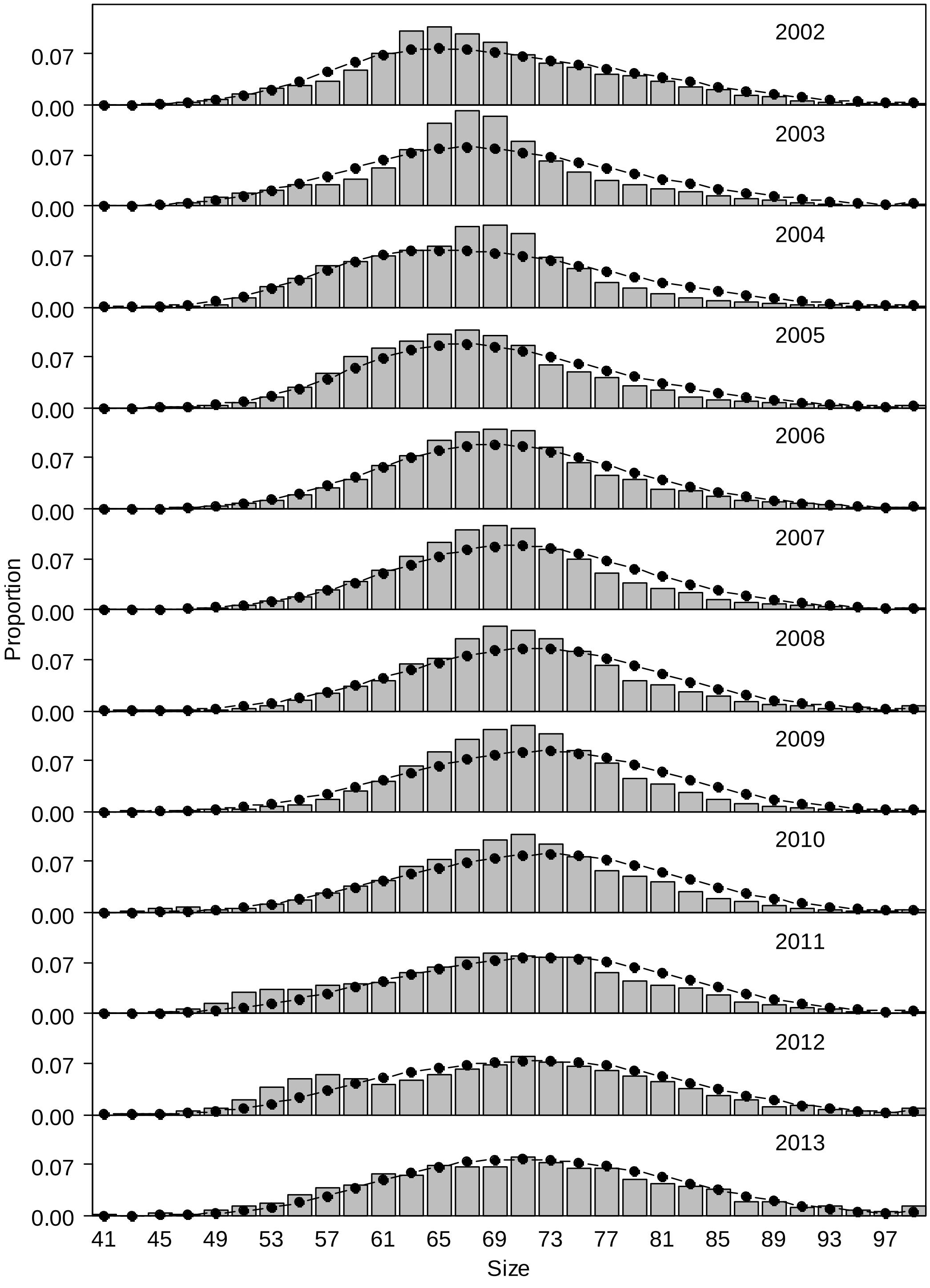


Figure 3.22 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

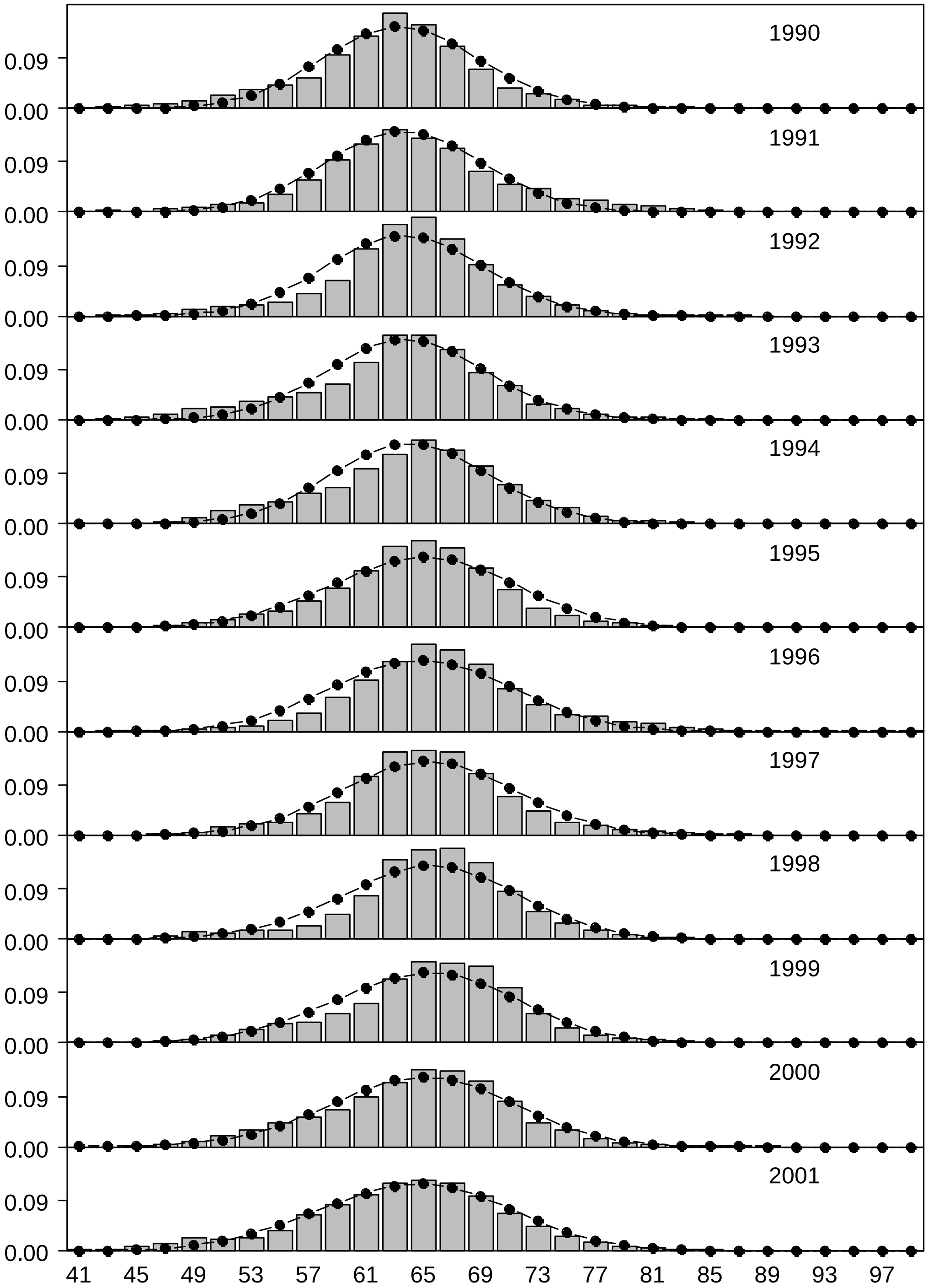


Figure 3.23. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

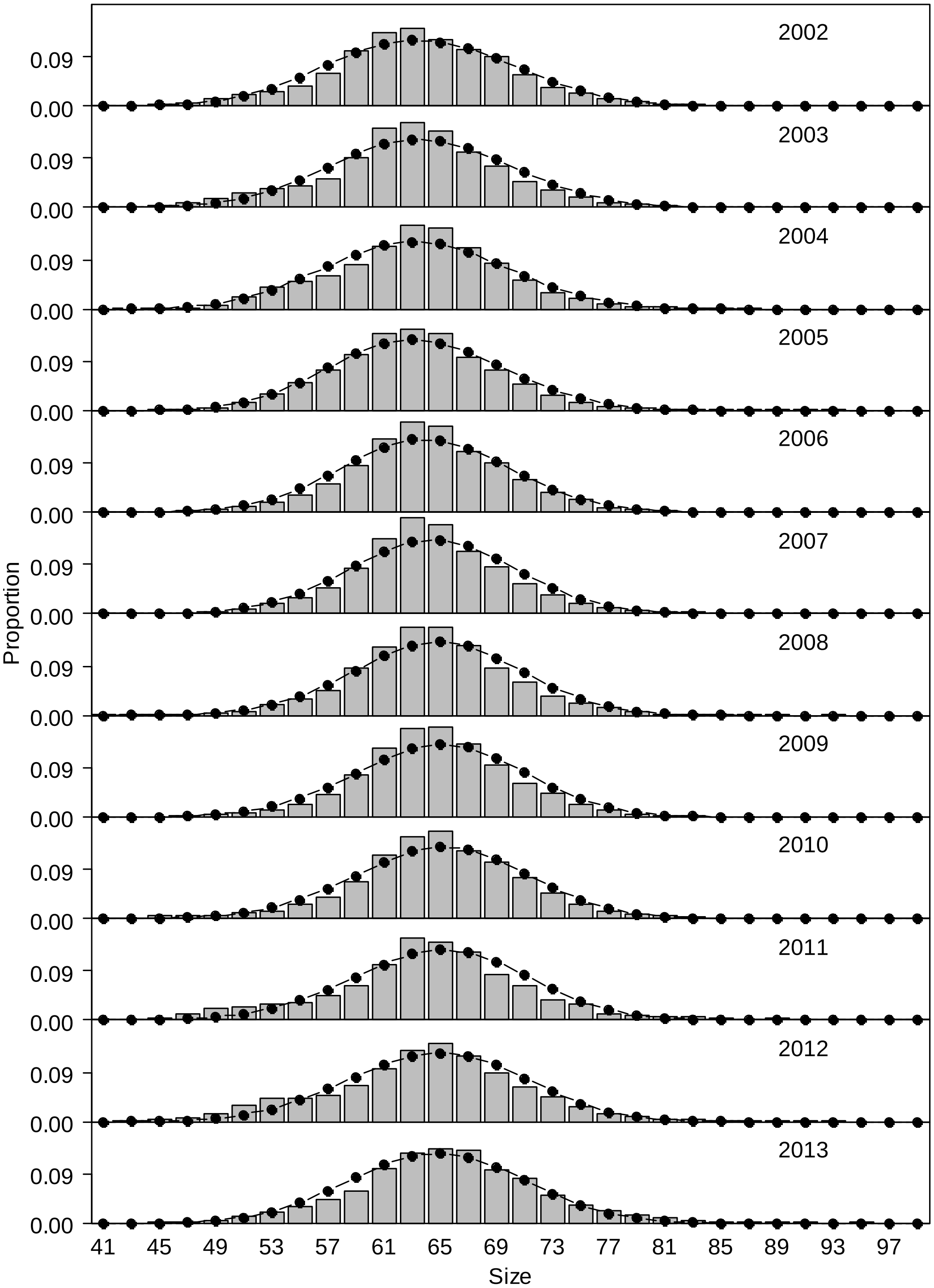


Figure 3.23 (cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

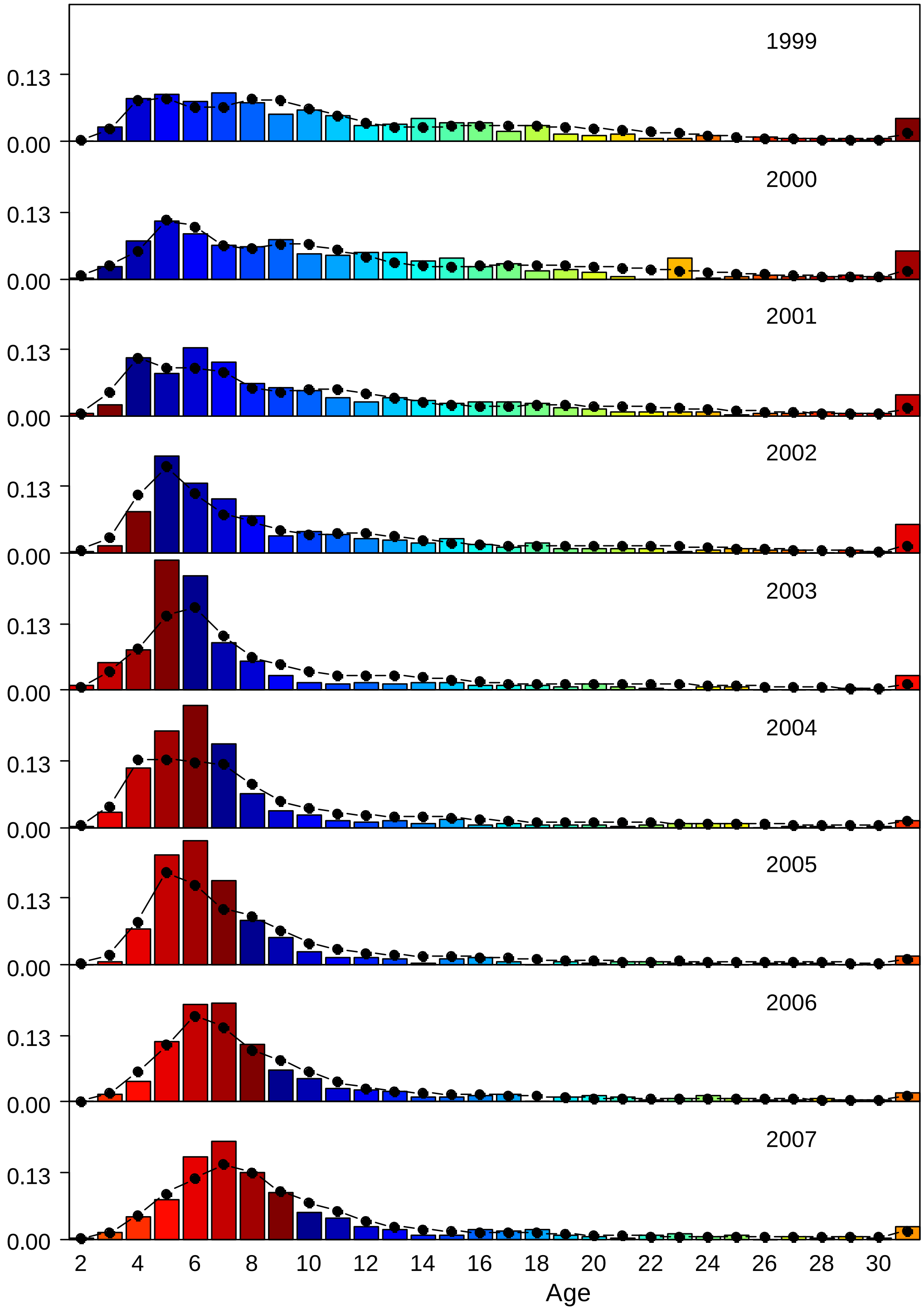


Figure 3.24. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

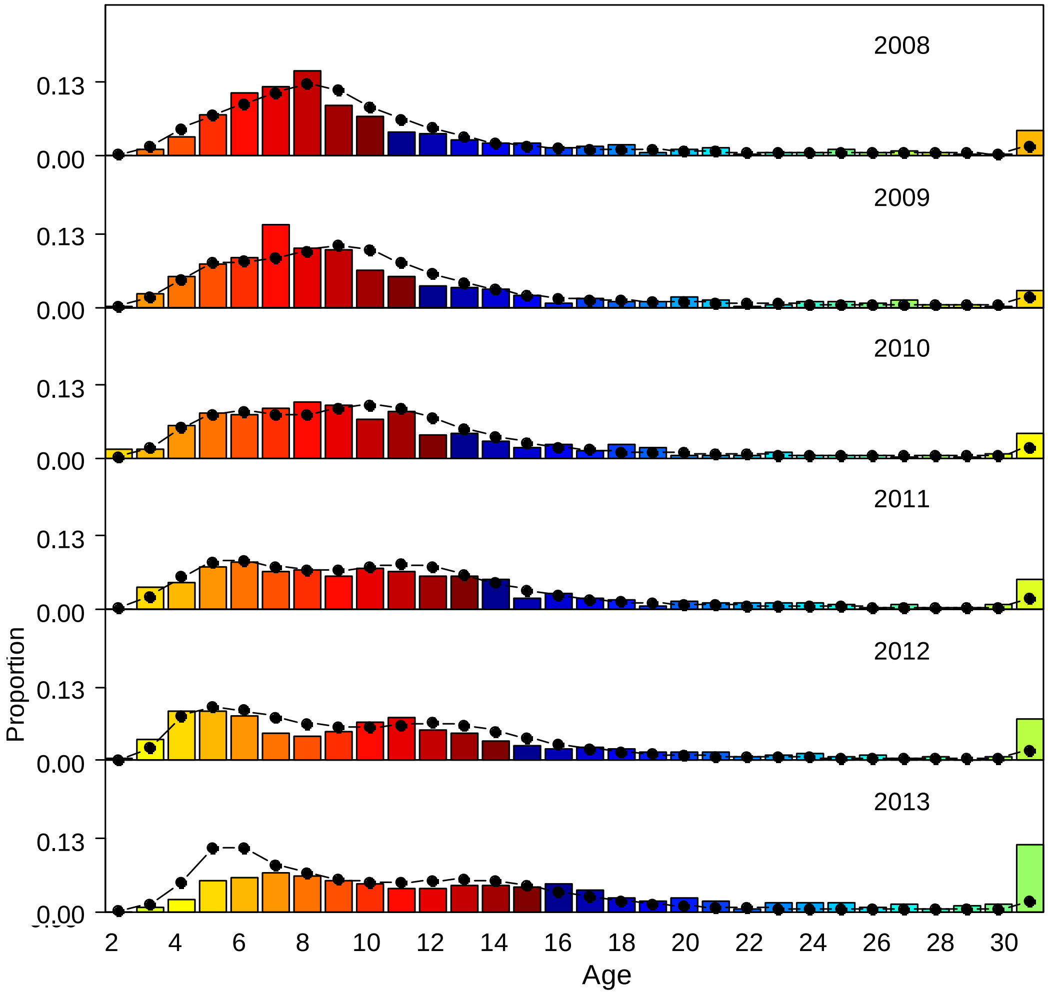


Figure 3.24 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

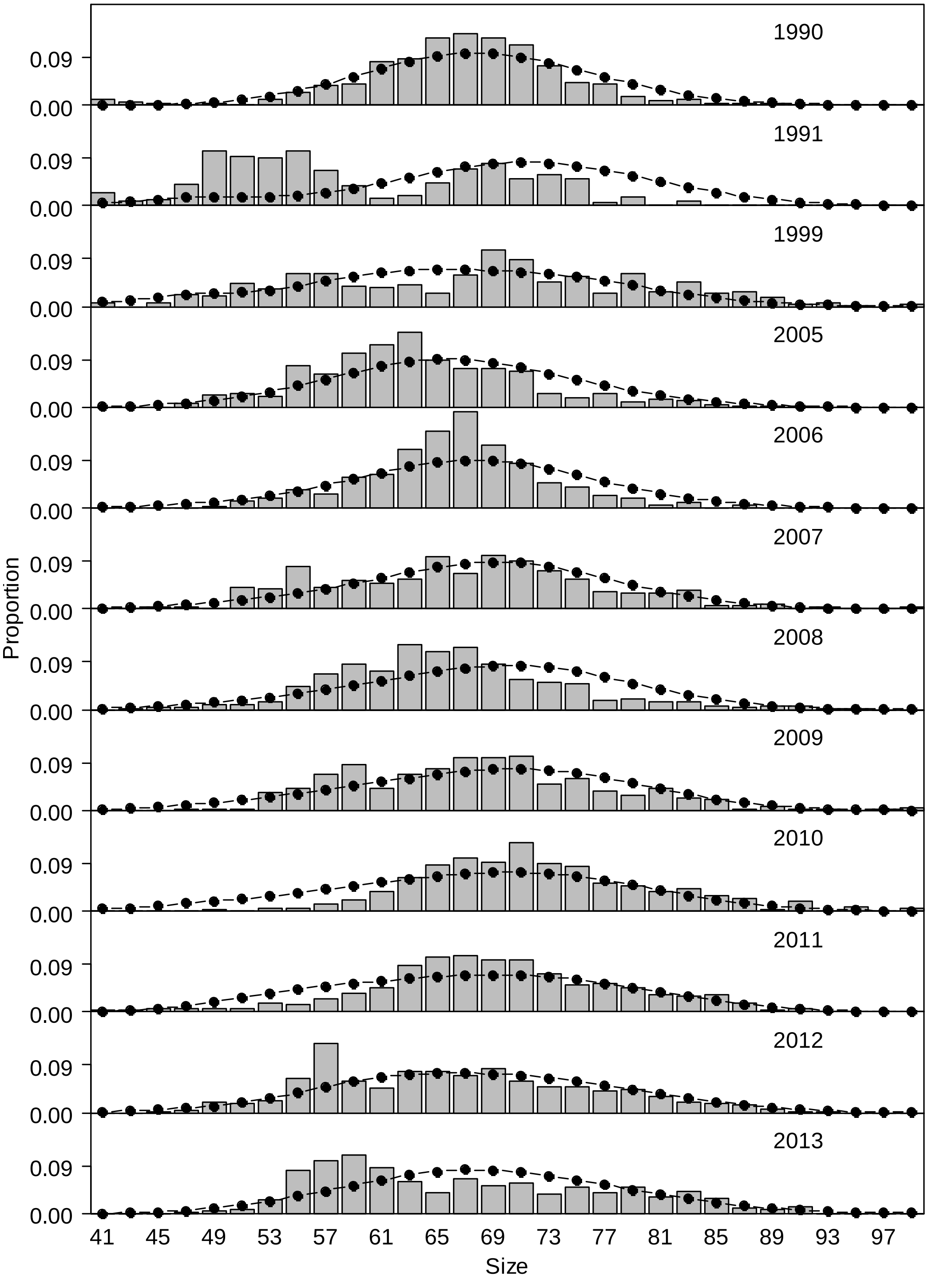


Figure 3.25a. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

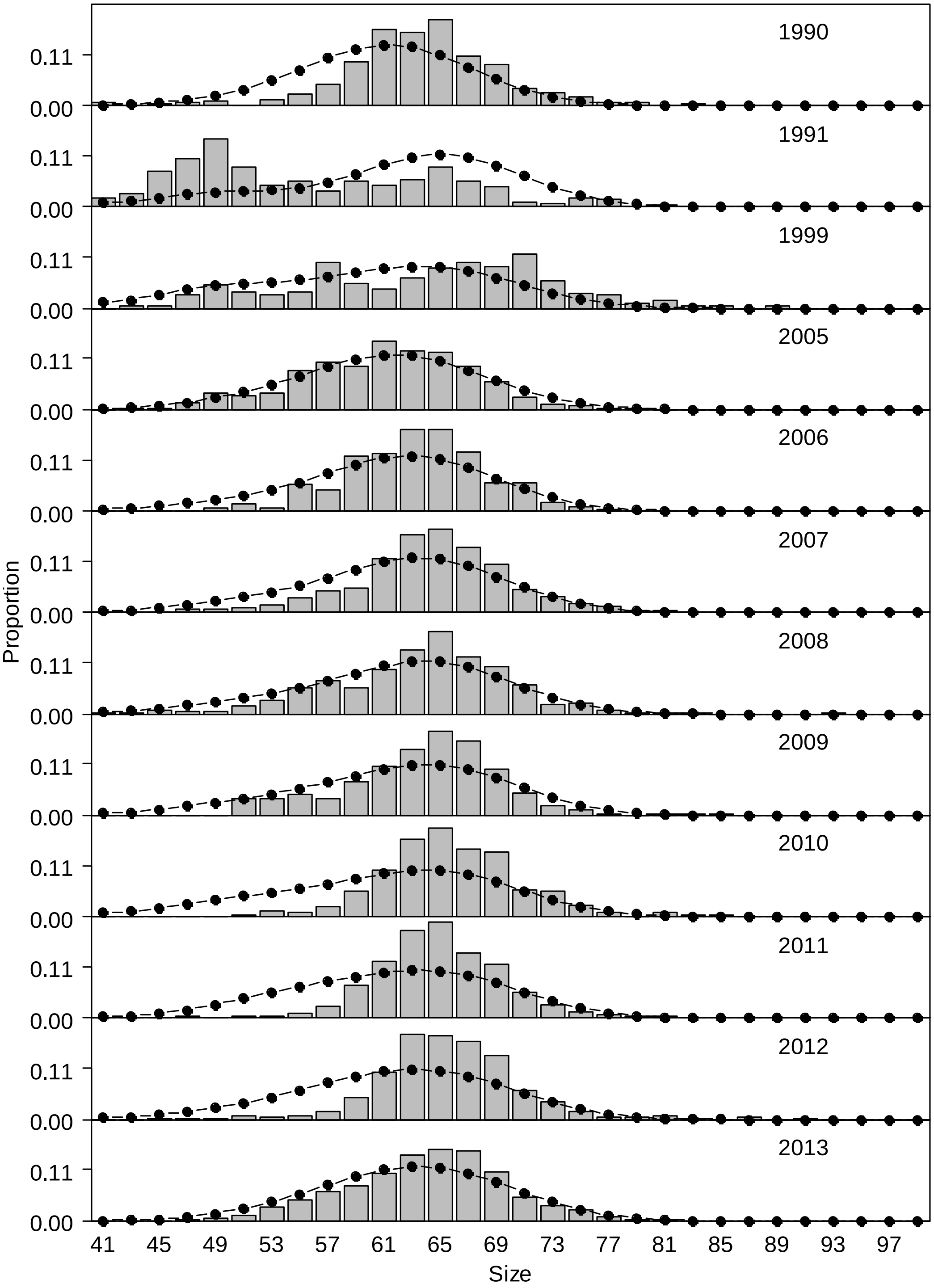


Figure 3.25b. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

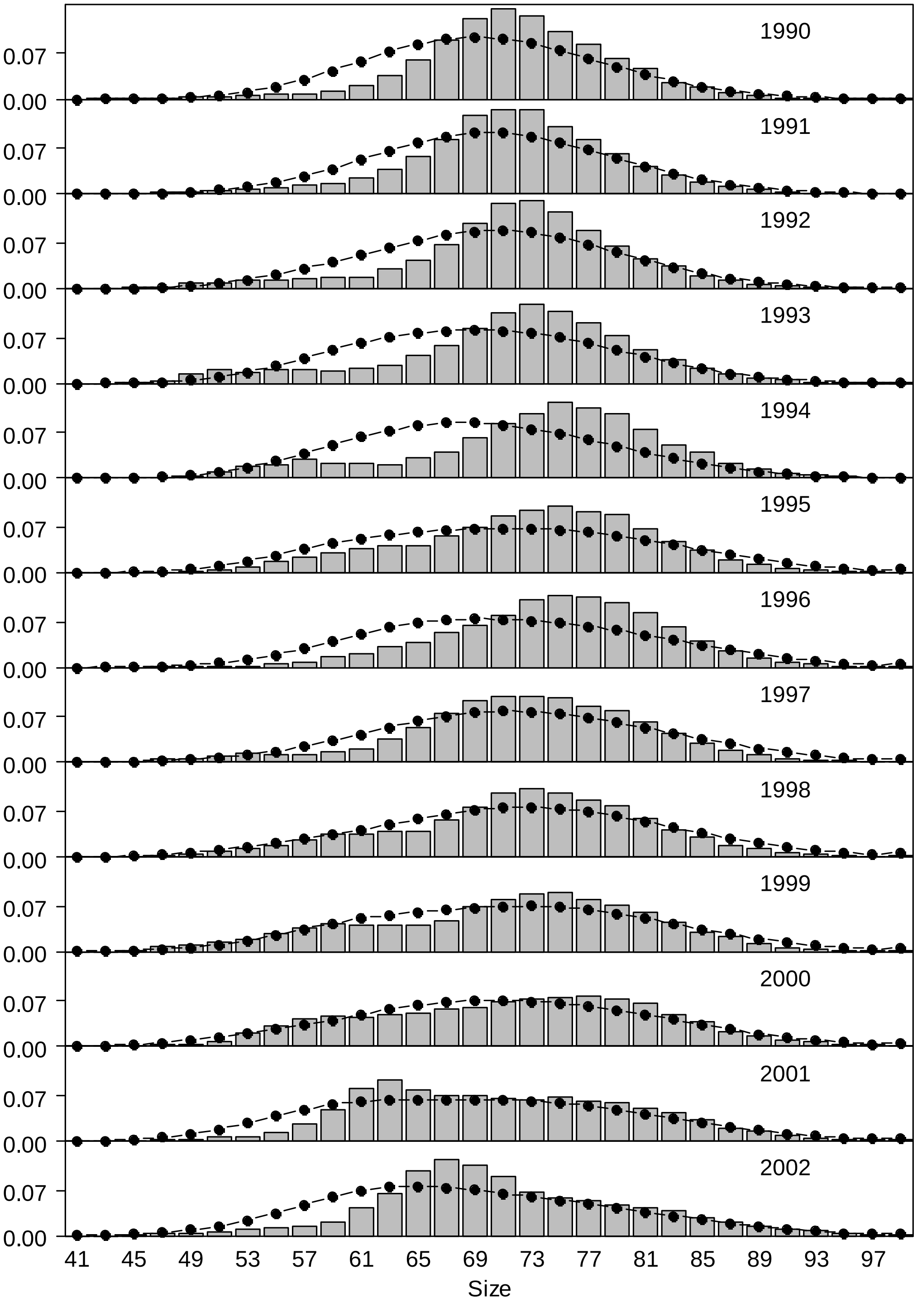


Figure 3.26. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

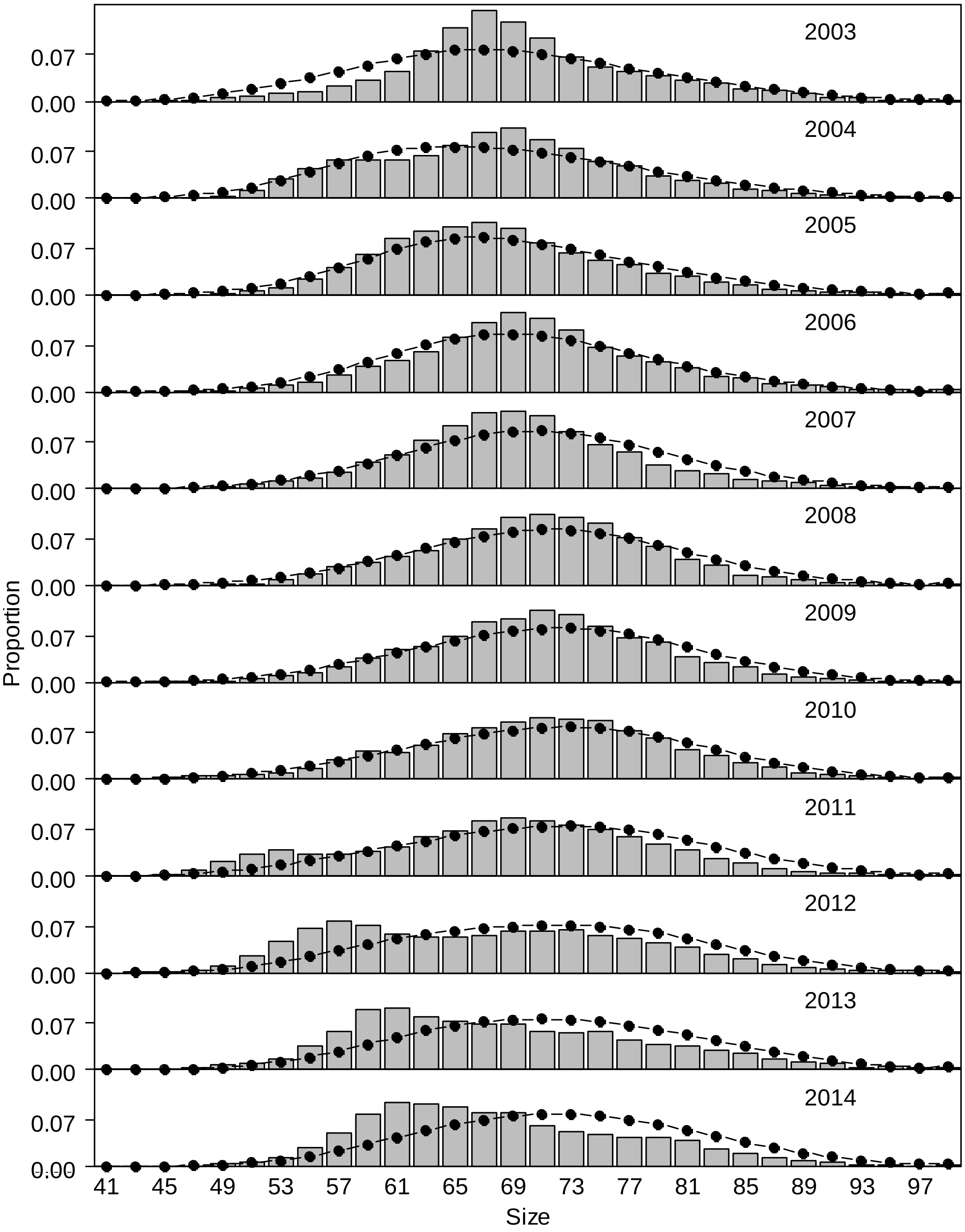


Figure 3.26 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

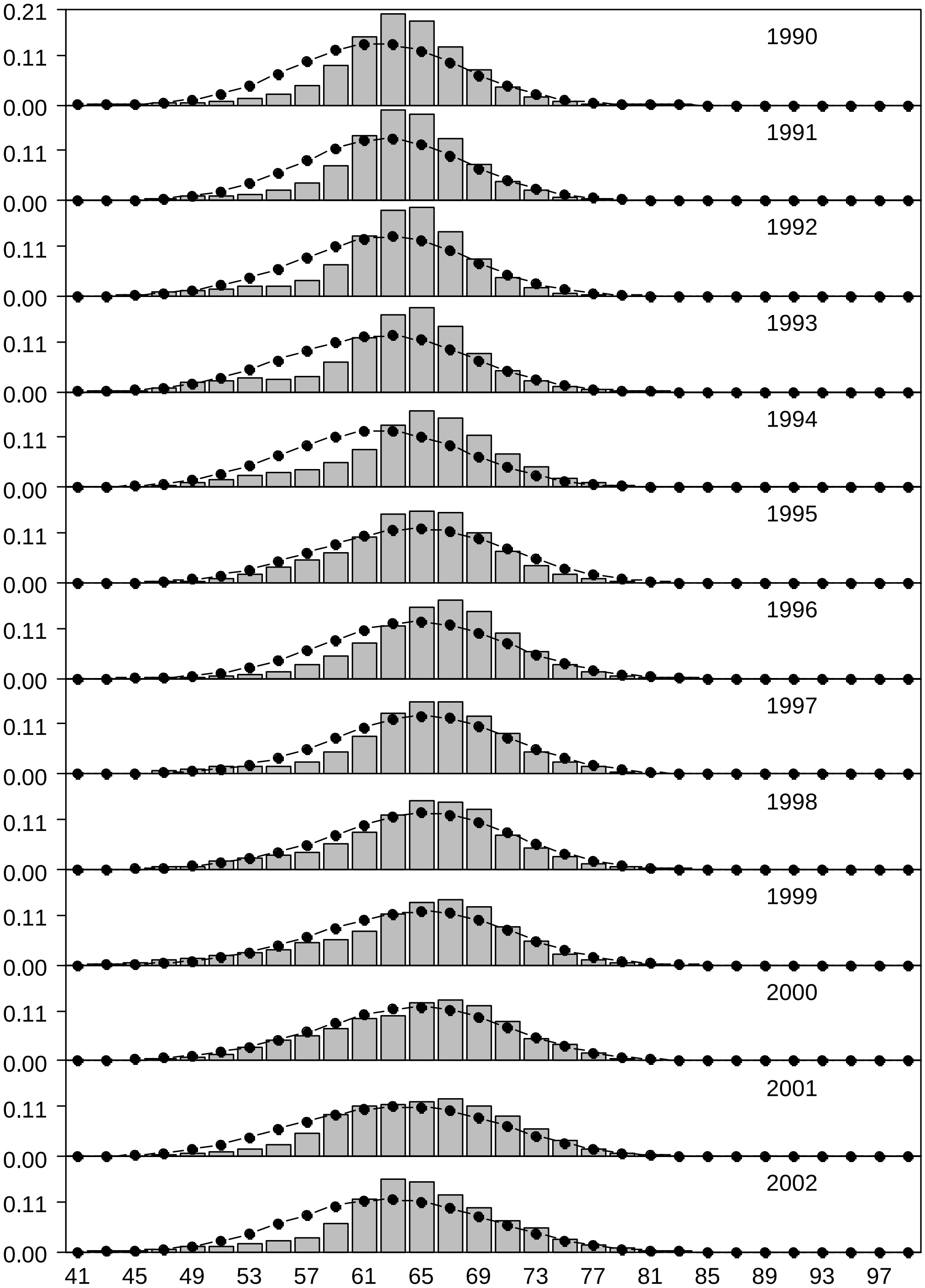


Figure 3.27. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

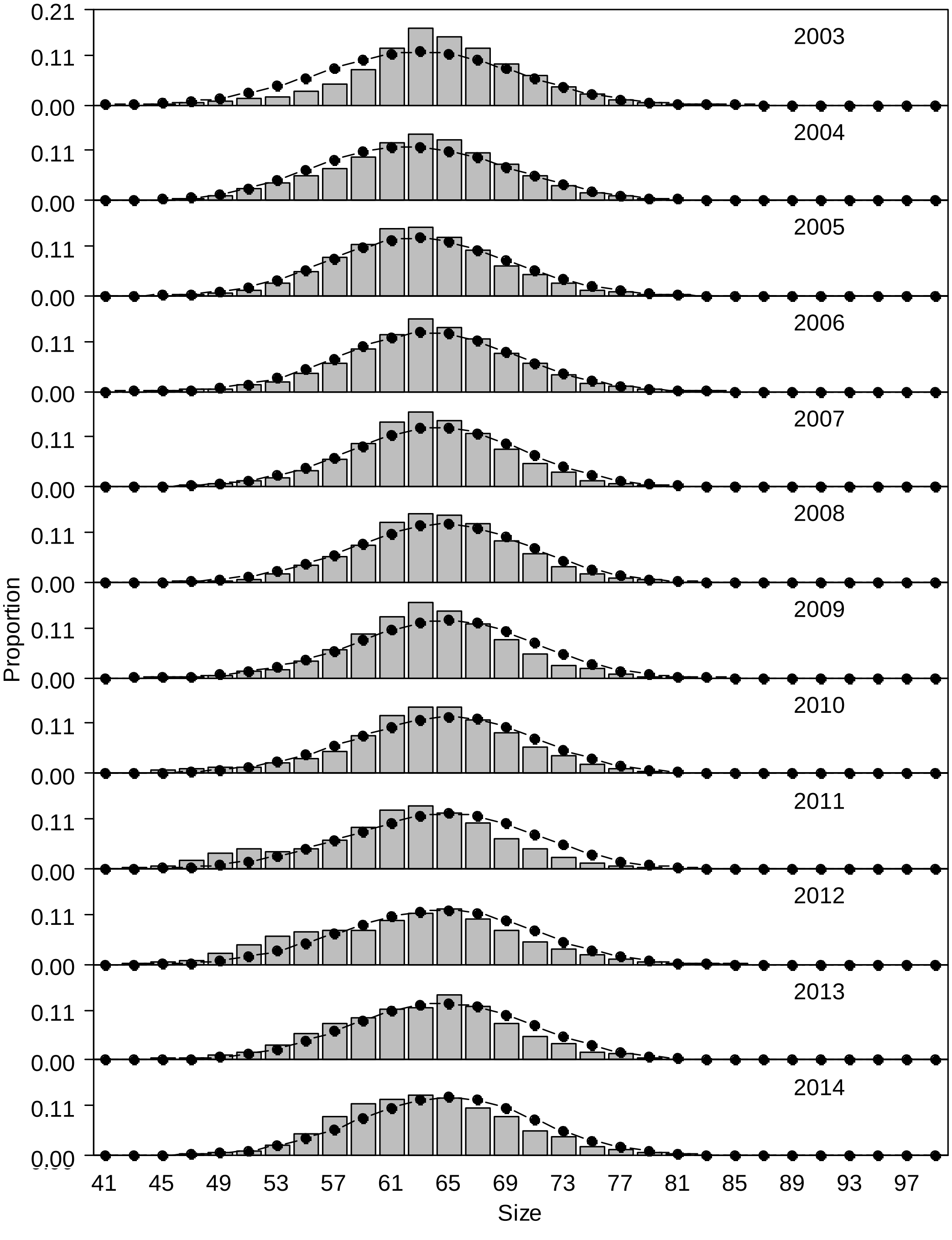


Figure 3.27.(cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

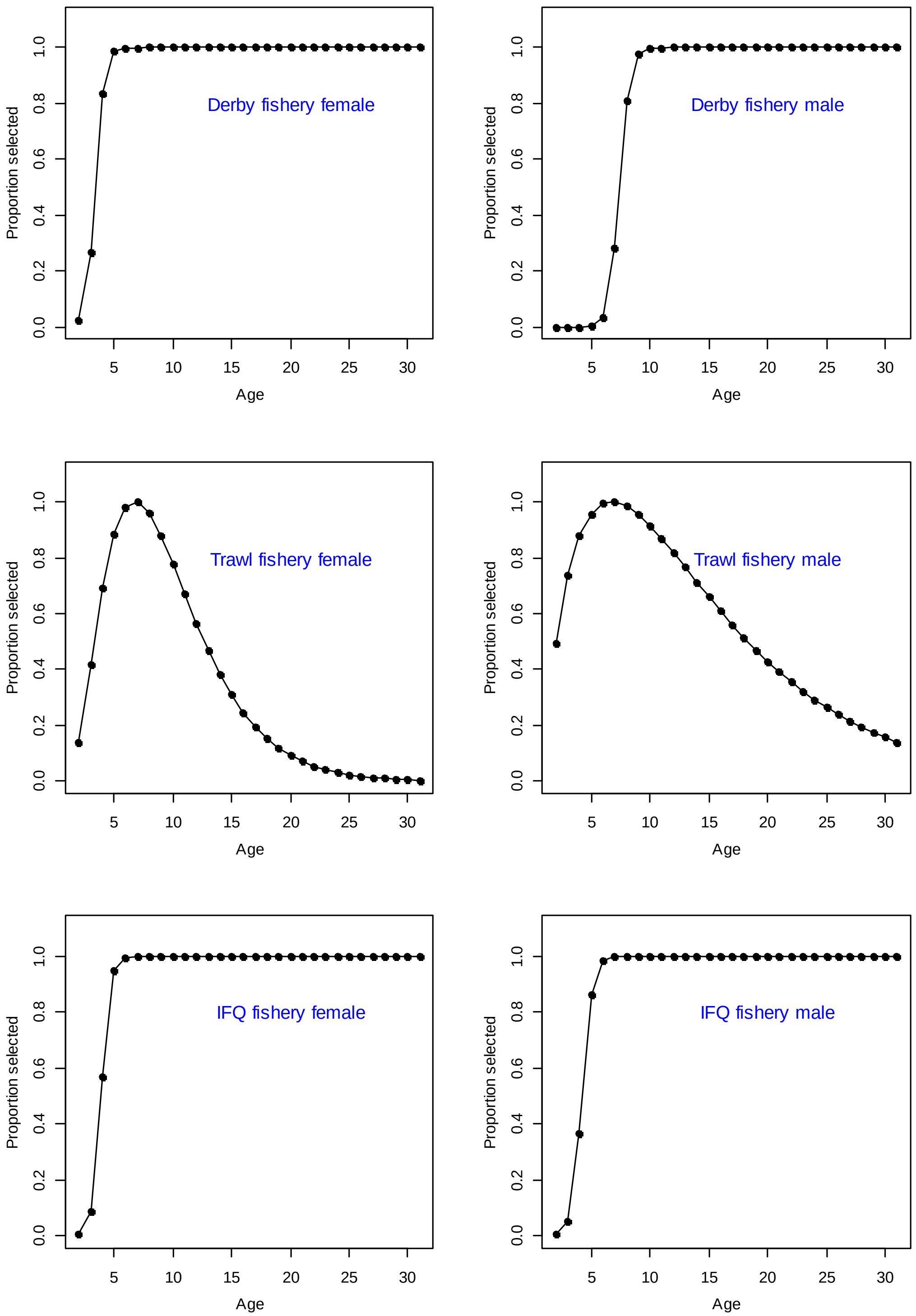


Figure 3.28. Sablefish selectivities for fisheries.

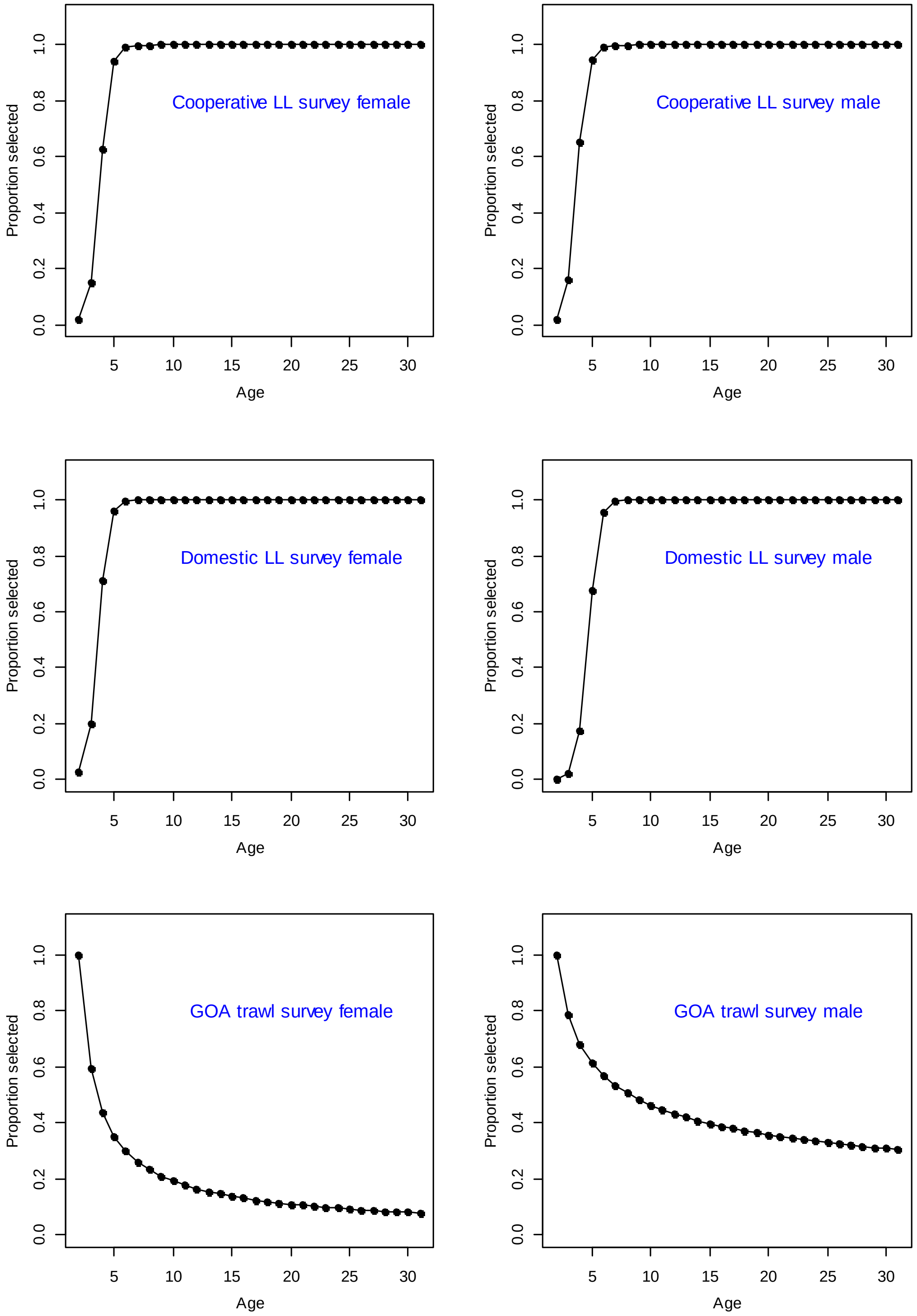


Figure 3.28 (cont.). Sablefish selectivities for surveys.

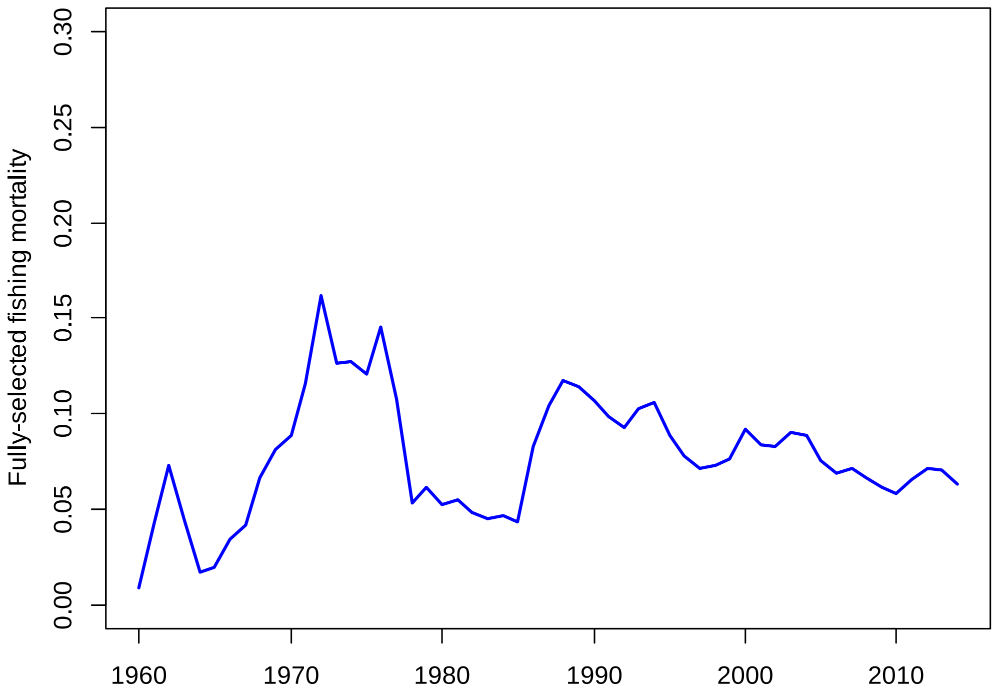


Figure 3.29. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

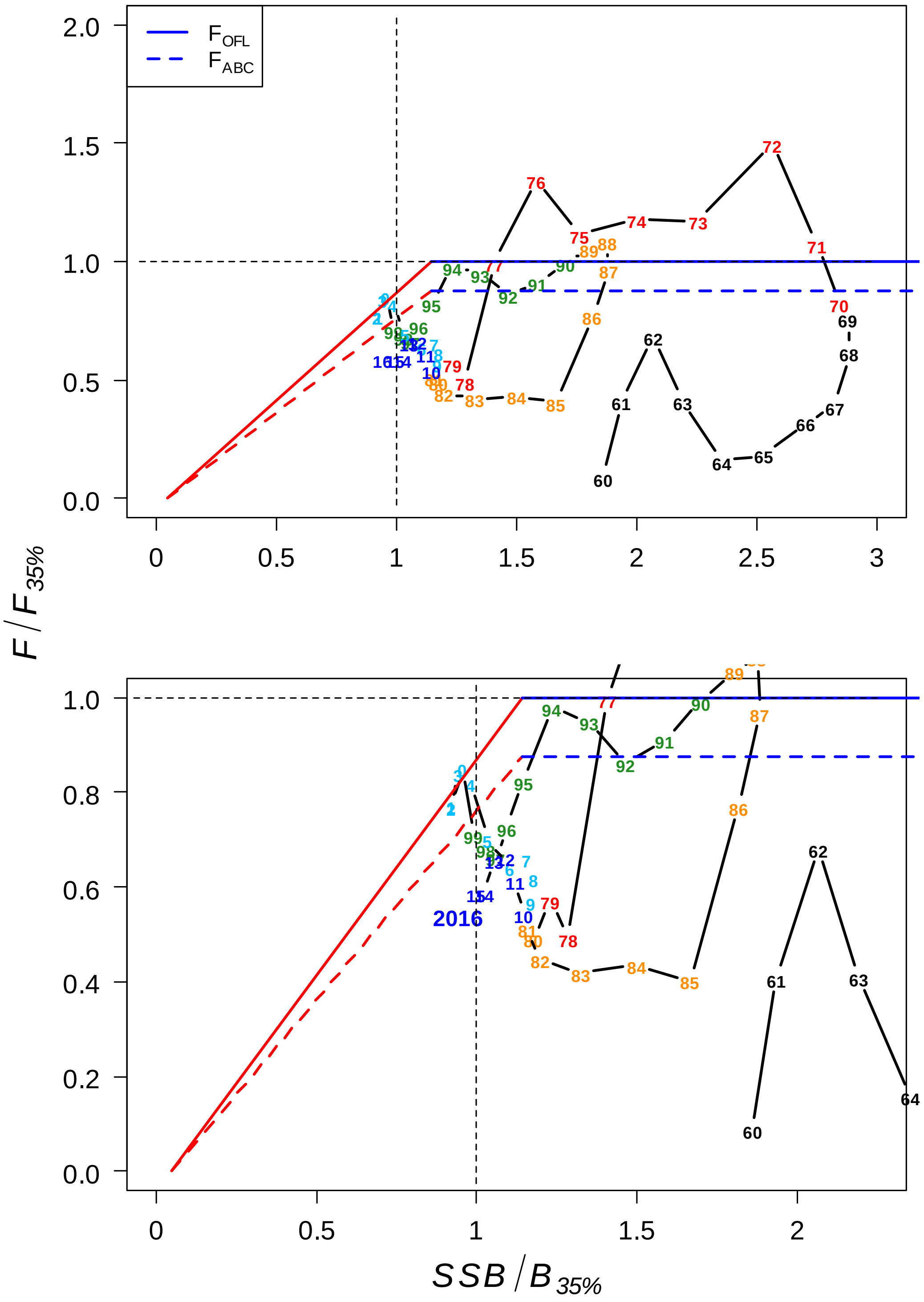


Figure 3.30. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model. Bottom is zoomed in to examine more recent years.

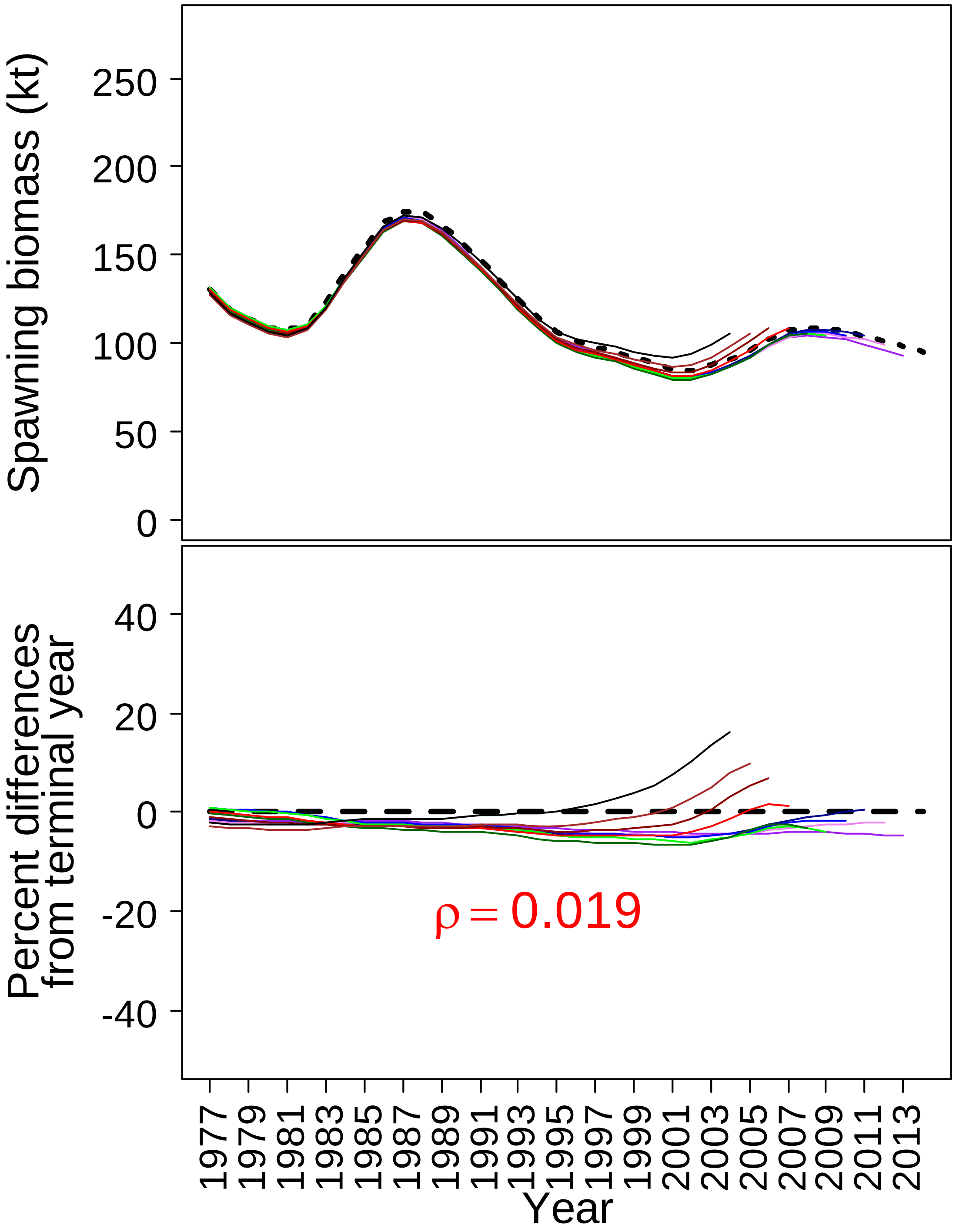


Figure 3.31a. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 2004-2014. Mohn's revised ρ = 0.019.

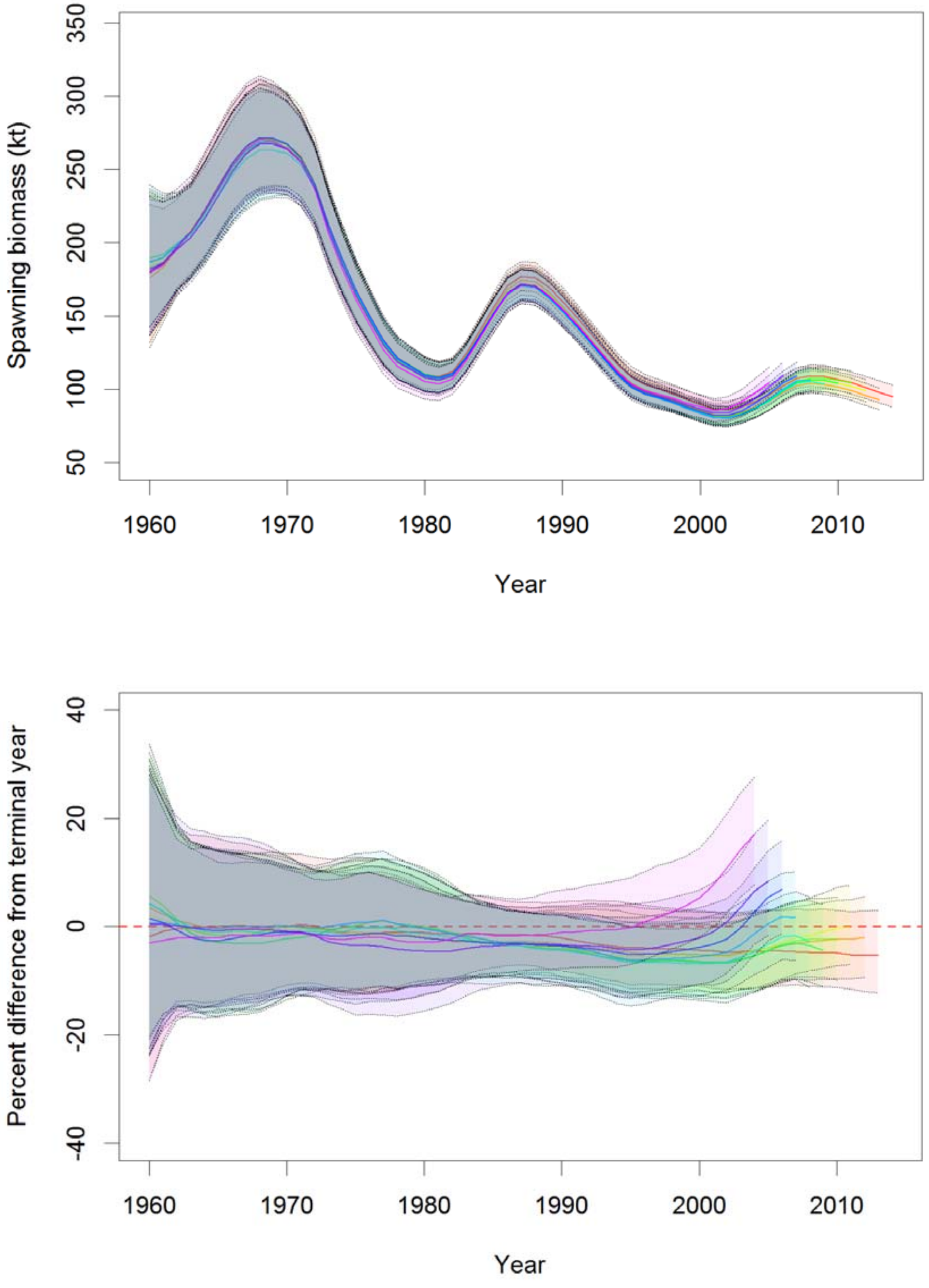


Figure 3.31b. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 2004-2014 with MCMC credible intervals per year. Mohn’s revised ρ = 0.019.

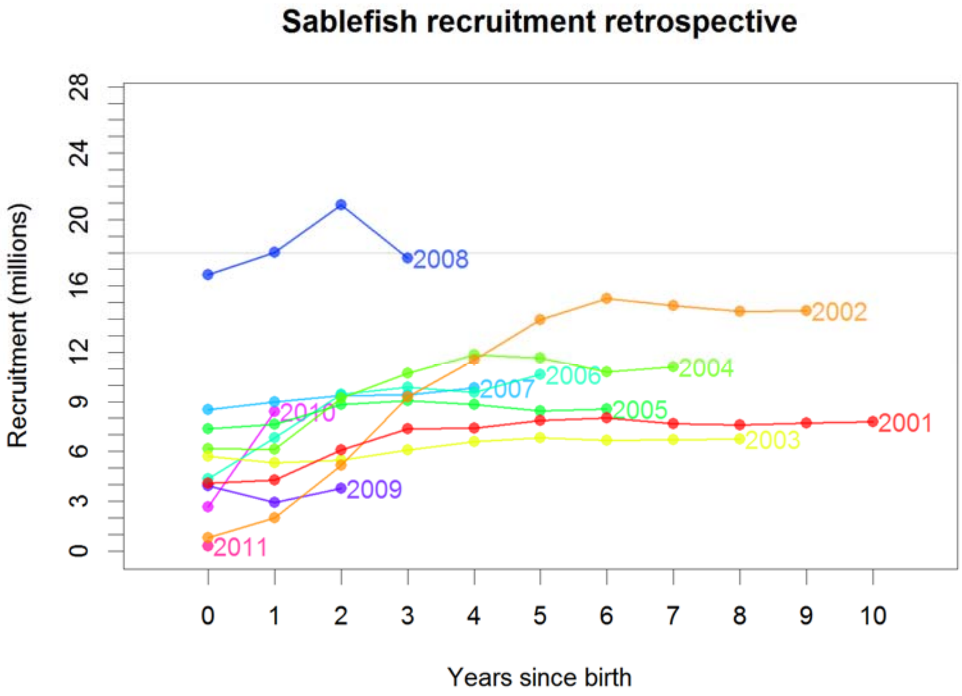


Figure 3.31c. Squid plot of the development of initial estimates of age-2 recruitment since year class 2001 through year class 2011 from retrospective analysis. Number to right of terminal year indicates year class.

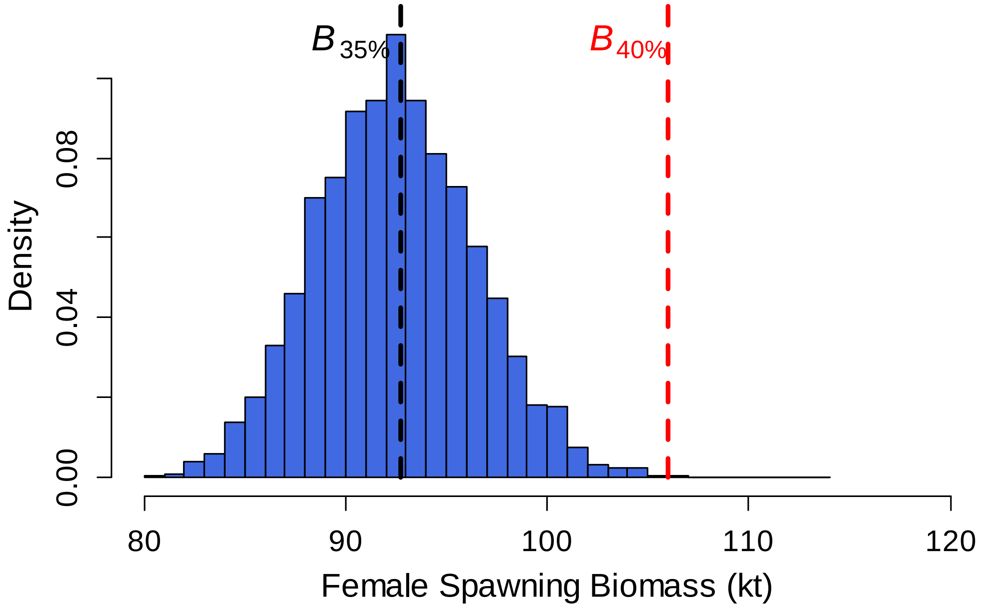


Figure 3.32. Posterior probability distribution for projected spawning biomass (thousands t) in 2014.

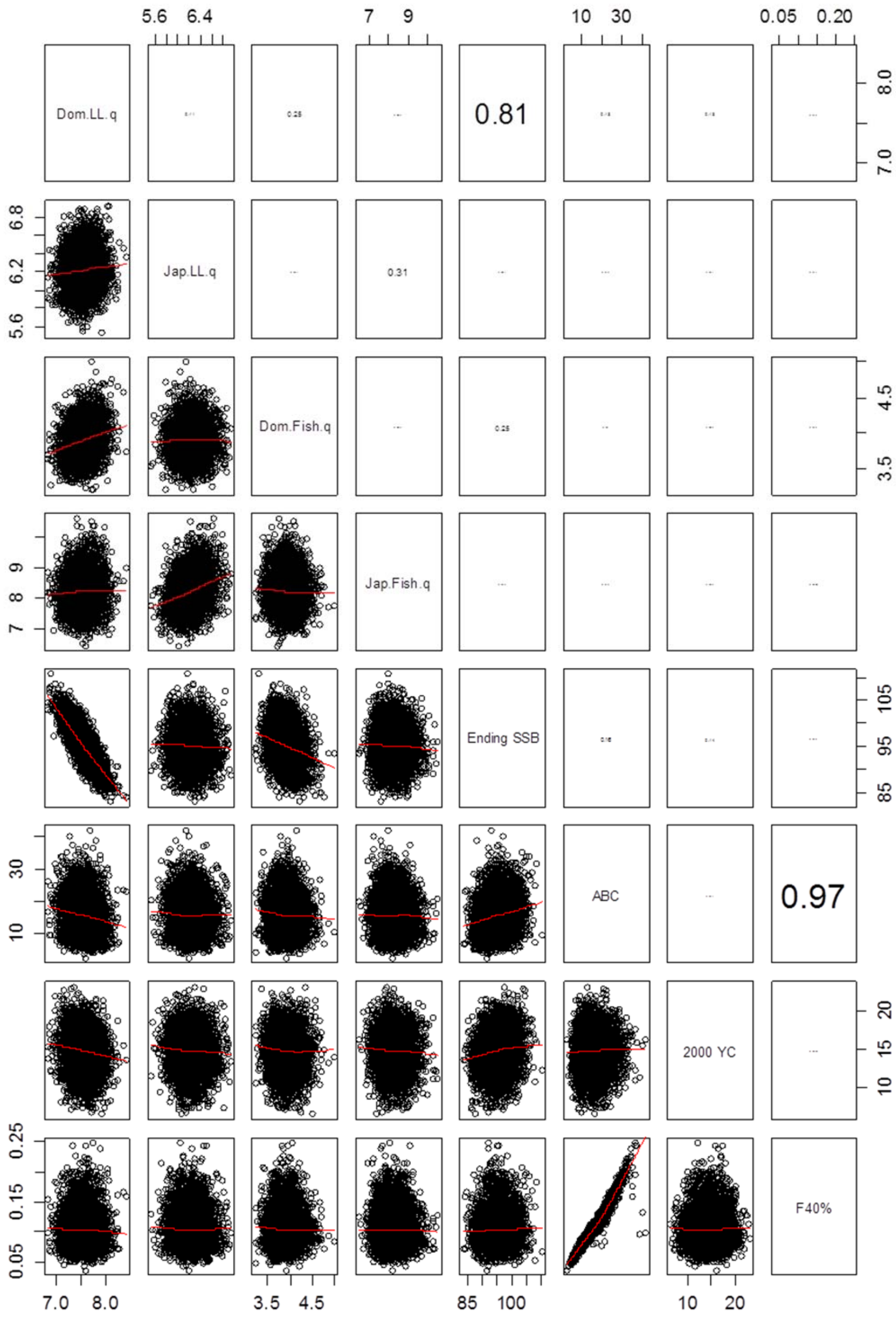


Figure 3.33. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

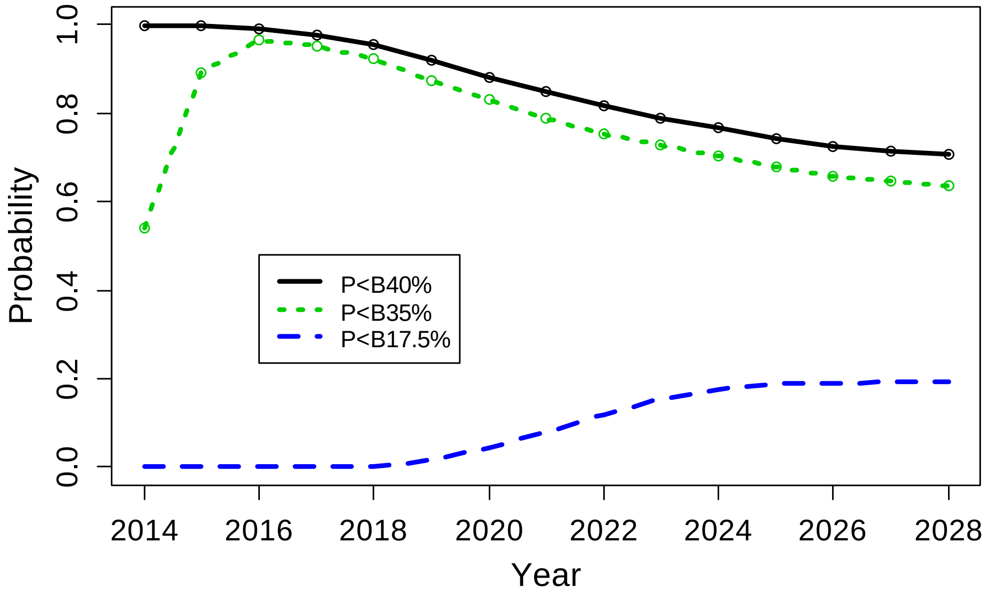


Figure 3.34. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

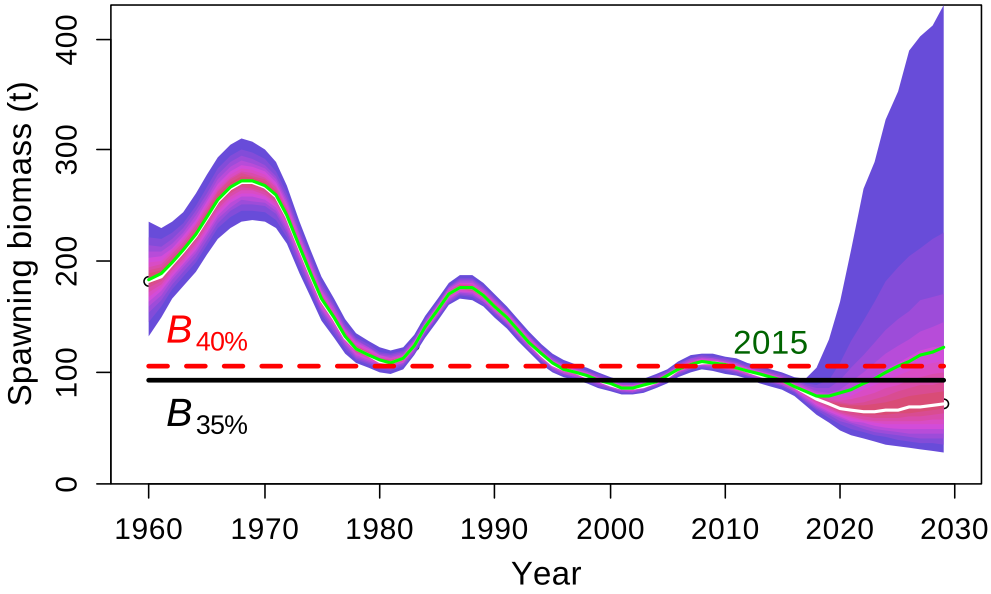


Figure 3.35. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and green line is the mean, shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on 10,000,000 MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is the same as the projections in Scenario 2 (Author’s F).

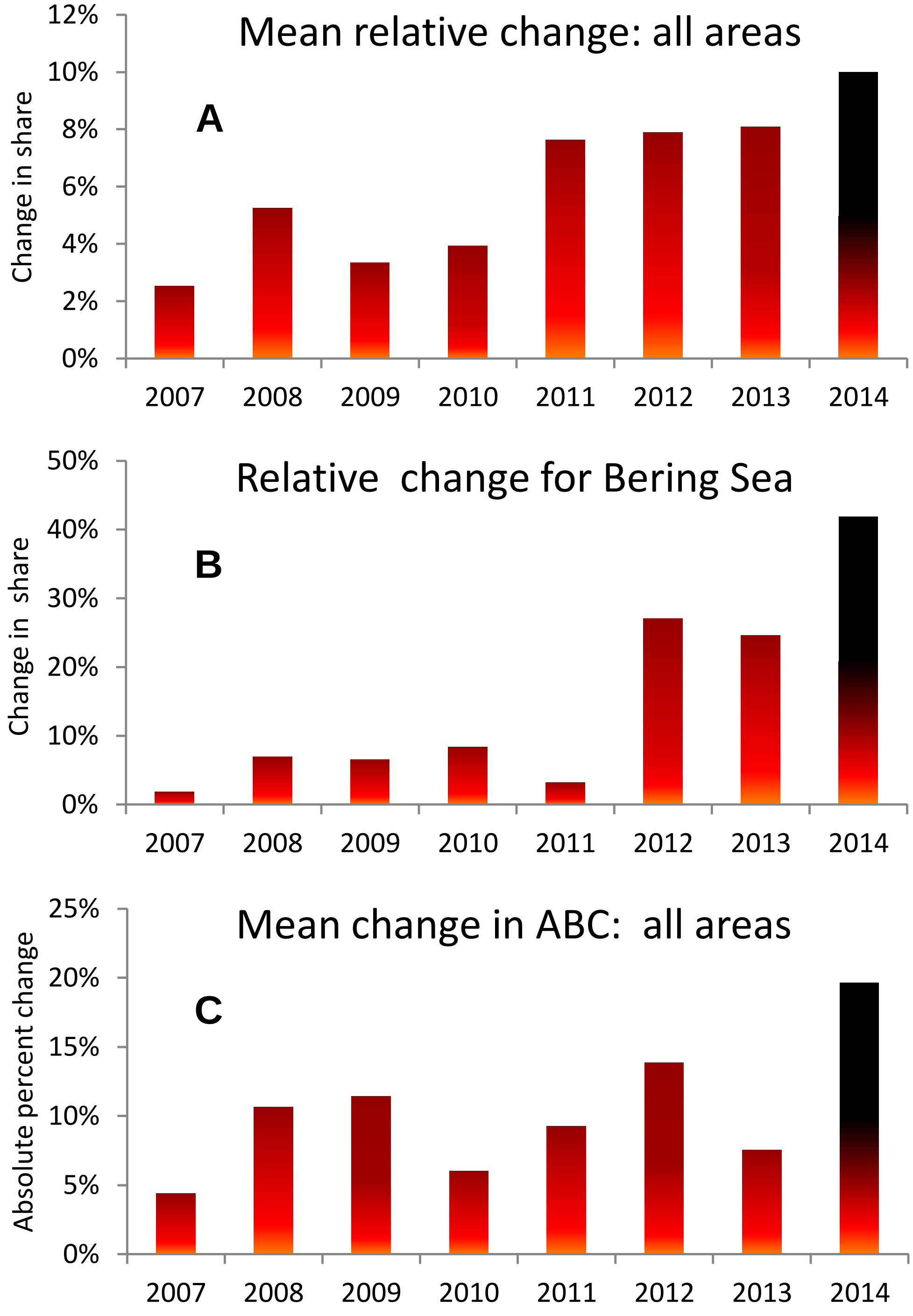


Figure 3.36. (A) The mean relative change in apportionment percentages across areas from 2007-2014. (B) The relative change in the apportionment share for the Bering Sea from 2007-2014. (C) The mean change in ABC for each area from 2007-2014.

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
2011	3	3	0	0	0	0	3	3
2012	5	5	0	0	0	0	5	5
2013	5	5	0	0	0	0	5	5
2014	2	2	0	0	0	0	2	2

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 but continue to occur. Discussions with vessels encountered on the survey indicates an increasing level of “hired” skippers who are unaware of the survey schedule. Publicizing the survey schedule to skippers who aren’t quota shareholders should be improved. 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.—Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska.

The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For sablefish, these estimates can be compared to the research removals reported in previous assessments (Hanselman et al. 2010) (Table 3B.1). The sablefish research removals are substantial relative to the fishery catch and compared to the research removals for many other species. These research removals support a dedicated longline survey. Additional sources of significant removals are bottom trawl surveys and the International Pacific Halibut Commissions longline survey. Recreational removals are relatively minor for sablefish. Total removals from activities other than directed fishery were near 239 tons in 2013. This was 1.7% of the 2014 recommended ABC of 13,722. These removals represent a relatively low risk to the sablefish stock. In 2011, we conducted a model run where these removals were accounted for in the stock assessment model, and it resulted in an increase in ABC of comparable magnitude.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011).

These estimates are for total catch of groundfish species in the halibut IFQ fishery and do not distinguish between "retained" or "discarded" catch. These estimates should be considered a separate time series from the current CAS estimates of total catch. Because of potential overlaps HFICE removals should not be added to the CAS produced catch estimates. The overlap will apply when groundfish are retained or discarded during an IFQ halibut trip. IFQ halibut landings that also include landed groundfish are recorded as retained in eLandings and a discard amount for all groundfish is estimated for such landings in CAS. Discard amounts for groundfish are not currently estimated for IFQ halibut landings that do not also include landed groundfish. For example, catch information for a trip that includes both landed IFQ halibut and sablefish would contain the total amount of sablefish landed (reported in eLandings) and an estimate of discard based on at-sea observer information. Further, because a groundfish species was landed during the trip, catch accounting would also estimate discard for all groundfish species based on available observer information and following methods described in Cahalan et al. (2010). The HFICE method estimates all groundfish caught during a halibut IFQ trip and thus is an estimate of groundfish caught whether landed or discarded. This prevents simply adding the CAS total with the HFICE estimate because it would be analogous to counting both retained and discarded groundfish species twice. Further, there are situations where the HFICE estimate includes groundfish caught in State waters and this would need to be considered with respect to ACLs (e.g. Chatham Strait sablefish fisheries). Therefore, the HFICE estimates should be considered preliminary estimates for what is caught in the IFQ halibut fishery. Improved estimates of groundfish catch in the halibut fishery may become available following restructuring of the Observer Program.

The HFICE estimates of sablefish catch by the halibut fishery are substantial and represent approximately 10% of the annual sablefish ABC (Table 3B.2). Sablefish and halibut are often caught and landed in association with each other by the IFQ fishery. It is unknown what level of sablefish catch reported here is already accounted for as IFQ harvest in the CAS system because the HFICE estimates do not separate retained and discarded catch. If these were strictly additive removals, 10% would represent a significant amount of additional mortality and a potential risk to the stock, but how much is additive is unknown. The HFICE estimates may represent some valuable discard information for sablefish, but that level is unknown until these estimates are separated from the IFQ landings and CAS system.

Literature Cited

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Hanselman, D. H., C. Lunsford, and C. Rodgveller. 2010. 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.pp.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, and K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams of the North Pacific Fishery Management Council.

Table 3B.1 Total removals of sablefish (t) from activities not related to directed fishing, since 1977. Trawl survey sources are a combination of the NMFS echo-integration, small-mesh, GOA, AI, and BS Slope bottom trawl surveys, and occasional short-term research projects. Other is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Japan US longline survey	Domestic longline survey	IPHC longline survey*	Other	Total
1977	**Assessment of the sablefish stock in Alaska (Hanselman et al. 2010)**	3					3
1978		14					14
1979		27	104				131
1980		70	114				184
1981		88	150				238
1982		108	240				348
1983		46	236				282
1984		127	284				412
1985		186	390				576
1986		123	396				519
1987		117	349				466
1988		15	389	303			707
1989		4	393	367			763
1990		26	272	366			664
1991		3	255	386			645
1992		0	281	393			674
1993		39	281	408			728
1994		1	271	395			667
1995		0		386			386
1996		13		430			443
1997		1		396			397
1998		26		325	50		401
1999		43		311	49		403
2000		2		290	53		345
2001		11		326	48		386
2002		3		309	58		370
2003		16		280	98		393
2004		2		288	98		387
2005		18		255	92		365
2006		2		287	64		352
2007		17		266	48		331
2008		3		262	46		310
2009		14		242	47		257
2010	AKRO	3		291	50	15	359
2011		9		273	39	16	312
2012		4		203	27	39	273
2013		4		178	22	35	239

* IPHC survey sablefish removals are released and estimates from mark-recapture studies suggest that these removals are expected to produce low mortality. Some state removals are included.

Table 3B.2. Estimates of Alaska sablefish catch (t) from the Halibut Fishery Incidental Catch Estimation (HFICE) working group. AI = Aleutian Islands, WGOA = Western Gulf of Alaska, CGOA = Central Gulf of Alaska, EGOA = Eastern Gulf of Alaska, PWS = Prince William Sound.

Area	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Western/Central AI	27	19	34	18	14	11	36	44	17	23
Eastern AI	18	16	46	26	20	6	4	13	6	7
WGOA	10	9	12	22	21	16	7	12	3	12
CGOA-Shumagin	184	27	36	65	60	47	21	38	10	37
CGOA-Kodiak/ PWS*	802	107	96	89	82	49	57	33	69	63
EGOA-Yakutat	110	324	291	258	240	149	175	103	207	195
EGOA-Southeast	339	335	389	315	269	242	230	184	242	262
Southeast Inside*	459	1,018	1,181	917	786	739	701	574	731	805
Total	1,948	2,231	2,346	2,469	2,194	2,476	1,937	1,874	1,921	1,594

*These areas include removals from the state of Alaska.

Appendix 3C: Alaska sablefish research update

Dana Hanselman, Brian Pyper, Chris Lunsford, Cara Rodgveller, and Megan Peterson

Executive Summary

In this appendix we describe some completed and ongoing sablefish research related to stock assessment. New modeling results for estimating the effects of whale depredation are described. In addition, a number of sensitivity model scenarios were conducted that incorporated some of the results of this research. Each section below provides a brief summary of current research and includes model scenarios related to that research. We also provide guidance for future research projects.

Whale depredation and survey modeling

Accounting for whale depredation

Background

Whale depredation has been an ongoing source of uncertainty for the sablefish assessment. Killer whale depredation of the sablefish catch on the longline survey has been a problem in the Bering Sea since the beginning of the survey (Sasaki, 1987). Depredation by killer whales has since been documented commonly in the Aleutian Islands, Bering Sea, and Western Gulf of Alaska. Since 1990, the depredated hachis (skates of 45 hooks), which were identified as depredated by a combination of damaged fish and damaged hooks, were excluded from calculations of abundance indices. At some stations this might result a large number of hachis being removed, or the entire station being removed from abundance calculations. From 1998-2012, the percentage of skates depredated ranged from 12.3 - 55.0% per year in the BS, from 0 - 19% per year in the AI and from 0 - 41% in the WGOA. 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 stations where fish are typically most abundant; this can lead to a downward bias of the index.

Sperm whale depredation has only been documented since 1998. Historically, sperm whale depredation was occurring in the two Eastern Gulf of Alaska (GOA) management areas, but has recently become more common in the Central GOA and occasionally occurs in the Western GOA. Apparent sperm whale depredation on the longline survey is defined as sperm whales being observed and the occurrence of damaged fish. In contrast to killer whale depredation, sperm whale depredation is much more difficult to detect because sperm whales often take only a few fish, and rarely leave behind depredation evidence such as damaged fish or hooks like killer whales. Because actual depredation is difficult to detect, and therefore difficult to document by haul or specific hachis, we use sperm whale presence at a station as a proxy for depredation. Sperm whale presence and evidence of depredation has been variable since 1998 (see figure below).

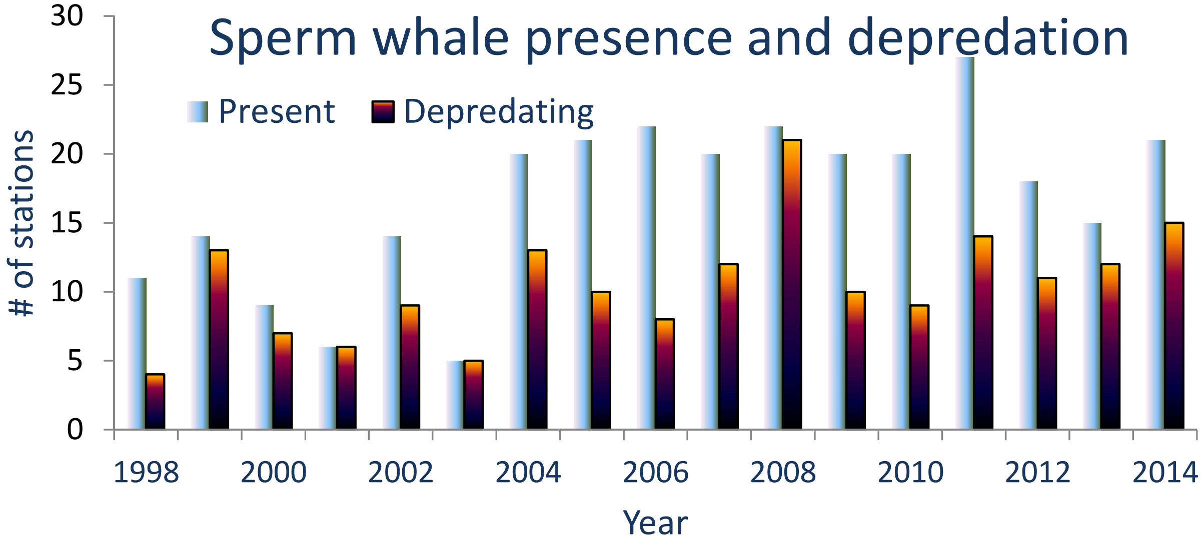


Figure: Sperm whale depredation and presence on the AFSC longline survey since 1998.

A number of studies have examined whale depredation in different ways. 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 completed 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 and general linear models (Sigler et al. 2007). This 2007 study found that 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 was updated through 2009 and showed 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).

Hanselman et al. (2010) applied zero-inflated negative binomial models to estimate the effect of sperm whale and killer whale depredation on the longline survey by individual management areas. They estimated that sperm whales decreased the EY/SE area index by 1-10% annually (which we do not correct for), while killer whales affected the Western GOA index by 5-30% annually (which we do correct for). Peterson et al. (2013) used similar methods to estimate depredation effects of killer whales on fishery catch rates of six species including sablefish, Pacific cod, and halibut. They estimated that killer whales when present removed 54-72% of sablefish.

Given perfect data, most of these studies would have provided adequate estimates of the effects of whales. However, the occurrence of whale depredation is sporadic which creates unbalanced data. Analysis of unbalanced designs using fixed-effects models can result in poor estimation and inference compared to mixed-effects models (Zuur et al. 2009). The utility of accounting for depredation effects on survey estimates depends on the precision of model estimates as well as the nature of depredation effects. In particular, if depredation effects are themselves highly variable (e.g., reductions in catch differ appreciably from one event to the next, like for killer whales), then it may not be advisable to “correct” for depredation using a single point estimate derived across numerous depredation events. Other options, such as discarding data from depredated skates, may provide preferable survey estimates.

Since Hanselman et al. (2010), we have conducted simulations and model comparisons to show that a generalized linear mixed effect model (GLMM) performs better than previous modeling methods, in terms of both accuracy and capturing an appropriate amount of uncertainty. Preliminary simulations suggested that a sperm whale correction derived from a GLMM performs well, whereas the benefits of a GLMM model correction for killer whales performed similarly to the current practice of discarding depredated skates. The methods used for estimating sperm and killer whale depredation were similar, but for the purposes of this document we focus on sperm whales. The following section includes a brief description of models compared for sperm whale depredation.

Model structure

The basic structure of the survey data is as follows: year (*t*), area (*i*), depth stratum (*j*), and station (*k*), where stations are nested within areas. At each station, numerous hachis (skates of 45 hooks) are fished and later assigned to depth strata. Stations are the primary unit of spatial replication, while hachis are essentially pseudo-replicates (subsamples) collected within stations. Modeling data at the hachi level is difficult because of large sample sizes and potential spatial autocorrelation among hachis. Peterson et al. (2013) used a simple and robust alternative, which was to model aggregated data by summing catch and effort (effective hooks fished) across hachis for each year/stratum/station combination. We adopt this approach as well.

A log-linear model of CPUE that accounts for the full structure of the survey data across years (Y_t), areas (A_i), depth strata (D_j), and stations (S_k) is given by:

(1)
$$\begin{aligned}\log(C_{tjk[i]}) = \log(H_{tjk[i]}) + Y_t + A_i + D_j + (YA)_{ti} + (YD)_{tj} + (AD)_{ij} + (YAD)_{tij} \\ + S_{k[i]} + (YS)_{tk[i]} + (DS)_{jk[i]} + (YDS)_{tjk[i]} ,\end{aligned}$$

where the subscript $k[i]$ indicates that station *k* is nested in area *i*, *C* denotes aggregated catch (summed across hachis), and *H* denotes total effective hooks (summed across hachis). The term *H* is a constant that is specified as an "offset" in model fitting (Venables and Ripley 2002, p. 189). Model (1) is "fully saturated" because it includes all main-level effects (Y_t, A_i, etc.) and two-way and three-way interactions, right up to the level of the aggregate data themselves with $(YDS)_{tjk[i]}$. Thus, the theoretical importance of model (1) is that it contains the full factorial structure at which we expect variation in CPUE, that is, up to and including differences among year/stratum/station combinations, i.e., $(YDS)_{tjk[i]}$. With model (1) in mind, we outline the alternative models used to estimate depredation effects of sperm whales.

Model fitting proceeded in two stages, first with area-specific models and then across-area models. Areas with stations flagged for sperm whale depredation included WGOA, CGOA, WY, and EY/SE. For each area, we compared fits of five models. The first three models had a form similar to that used by Peterson et al. (2013):

(2)
$$\log(C_{tjk}) = \log(H_{tjk}) + Y_t + D_j + S_k + (YS)_{tk} + \lambda F_{tk} ,$$

where the coefficient λ denotes the effect of depredation, and *F* is an indicator (dummy) variable for depredation ($F = 1$ when a station is flagged for depredation and $F = 0$ otherwise). The first model was a quasi-Poisson (QP) model, which is an *ad hoc* approach to account for over-dispersion in count data (Venables and Ripley 2002, p. 208; fit using the `glm` function in R). The second model was a negative binomial (NB) model, as used by Peterson et al. (2013), which assumes that aggregate catches C_{tjk} follow a negative binomial distribution (Venables and Ripley 2002, p. 206; fit using the `glm.nb` function of the MASS library in R). The QP and NB models are generalized linear models (GLMs) that treat all terms as *fixed effects* (Venables and Ripley 2002, p. 271). Both models have been widely used to address over-dispersion in count data, although model results and suitability can differ appreciable between them (Ver Hoef and Boveng 2007).

The third model (denoted ME.1), also based on the structure in equation (2), was a mixed-effects model assuming a Poisson distribution for C_{tjk} (in this context, a generalized linear mixed model or GLMM; Zuur et al. 2009). Specifically, the terms for year (Y_t), station (S_k), and their crossed interactions $(YS)_{tk}$ were treated as *random effects* instead of fixed effects. Each random-effects term was assumed to follow a normal distribution, e.g., $Y_t \sim \mathrm{N}(0, \sigma_Y^2)$. With respect to the survey data, the key potential benefit of a mixed model is to obtain robust estimates despite a highly unbalanced design.

The final two models, which were also Poisson mixed models, had a complete factorial structure for the area-specific survey data:

$$(3) \qquad \log(C_{tjk}) = \log(H_{tjk}) + Y_t + D_j + S_k + (YD)_{tj} + (YS)_{tk} + (DS)_{jk} + (YDS)_{tjk} + \lambda F_{tk}.$$

In the fourth model (ME.2), all terms were treated as random effects except for depth strata means (D_j) and the depredation effect (λ). The addition of $(YDS)_{tjk}$ in equation (3) saturates the model, providing an individual random effect for each observation of aggregated catch, C_{tjk}. Such an approach is used to account for overdispersion in Poisson mixed models (e.g., Gelman and Hill 2007, p. 326). In our context, the variance of *YDS* will reflect natural variation in mean CPUE among year/strata/station combinations, as well as additional overdispersion accrued via summing catches across hachi.

The last model (ME.3) examined evidence of variation in depredation effects. Up to this point, it has been assumed that depredation effects are essentially constant across events (i.e., year/station combinations), and thus modelled via a single coefficient λ. However, if there was considerable variation in depredation effects, it would be evident in the data. Such variation would be superimposed upon the natural year/station variation in CPUE, which was modelled as $(YS)_{tk} \sim \mathrm{N}(0, \sigma_{YS}^2)$ in ME.2. Suppose the depredation effect followed $\lambda_{tk} \sim \mathrm{N}(\lambda, \sigma_\lambda^2)$. Assuming independence, the variance of year/station effects would equal $\sigma_{YS}^2 + \sigma_\lambda^2$ with depredation ($F = 1$), and σ_{YS}^2 otherwise ($F = 0$). Thus, to estimate potential variation in depredation effects in ME.3 models, we added a random-effects term $(YS)_{tk,F=1}$ for depredation events only (i.e., the variance of this term represents the *additional* variance associated with depredation events). All mixed-effects models were fit using the restricted maximum likelihood method of the `glmer` function in R (R Core Team 2012).

In summary, we fit five models (QP, NB, ME.1, ME.2, ME.3) to each area to test for depredation effects of sperm whales. In addition, we examined two different depredation flags (F) that have been recorded for year/station combinations. The first flag indicated a sperm whales sighting, while the second, less prevalent flag indicated evidence of depredation (damaged fish, hooks, etc.).

Area-specific model results

Across years 1998-2012, a total of 1154 year/station combinations were examined in models of sperm whale depredation (Table 3C.1). Of these, 241 (21%) were flagged for depredation based on presence (Flag 1), while only 149 (13%) were flagged based on evidence (Flag 2). Proportions of flagged units were lowest for the WGOA region and highest for WY (Table 3C.1).

Based on Flag 1, estimates of sperm whale depredation (λ) differed appreciably among areas, and in particular, among models (Table 3C.2). For WGOA, which had limited depredation data (Table 3C.1), the QP and NB models gave nonsensical estimates (with huge standard errors) that implied huge proportional increases in CPUE due to depredation (Table 3C.2). In contrast, the three ME models provided similar and reasonably precise estimates; however, these estimates implied slight positive effects of depredation (e.g., a proportional change of 1.12 or a 12% increase in CPUE) and were not significant ($P > 0.2$).

Depredation estimates were more consistent for the remaining three regions (Table 3C.2). For CGOA, estimates were generally weak and none were significant (all $P > 0.37$). Estimates for WY varied widely across models implying proportional changes of 0.96 (a 4% reduction of CPUE) for model QP, 0.44 (56% reduction) for NB, and roughly 0.8 (20% reduction) for the ME models. All ME estimates were significant ($P \leq 0.001$). Likewise, for EY/SE, the QP and NB estimates were quite different and imprecise (high SEs), while ME estimates were consistent (~17% reductions), precise, and significant ($P < 0.001$).

Depredation estimates for Flag 2 showed similar patterns (Table 3C.3). Note that WGOA was excluded because this region had only one flagged unit (Table 3C.1). Across regions, the QP and NB models provided imprecise estimates that often differed strongly from those of the ME models. In general, the ME estimates indicated reductions in CPUE due to sperm whale depredation of roughly 10% for CGOA (all $P > 0.14$), 12 to 18% for WY ($P < 0.015$), and 19% for EY/SE ($P < 0.001$).

The components of variation in CPUE data differed considerably across regions. Variance estimates are reported for ME.3 models using Flag 1, with depth strata (D) treated as a random effect (Table 3C.4). For example, differences among depth strata (D) accounted for just 10.5% of the variation in CPUE for CGOA, but 50.5% for EY/SE. Our interest lies in the additional year/station variation due to depredation. Without depredation, the standard deviation of year/station random effects (YS) ranged from a low of 0.21 for EY/SE to a high of 0.36 for WGOA. There was mixed evidence of additional variation due to depredation events. The largest value of SD($YS_{F=1}$) was 0.24 for CGOA, implying an additional 10.6% variation in CPUE among depredated units due to variability in the effect of depredation. Slightly higher estimates for SD($YS_{F=1}$) were found for Flag 2 data (0.30 for CGOA, 0.23 for WY, and 0.16 for EY/SE). However, as noted below, such values for SD($YS_{F=1}$) are likely to have little consequence for model estimation of depredation effects.

Given the often divergent estimates of whale depredation provided by the QP, NB, and ME models, we conducted detailed simulations to determine the expected accuracy and precision of competing model estimates. These simulations demonstrated that for unbalanced datasets (i.e., sporadic whale depredation events across stations and years), the ME models provided vastly superior estimates of whale depredation compared to the QP and NB models (both in terms of point estimates and standard errors). Despite their structural differences, all three ME models performed similarly well, even when the simulated data included random effects for depredation (e.g., simulated SD($YS_{F=1}$) = 0.2), which is a component only included in the ME.3 model structure.

Across-area models

Based on the simulation results noted above, analysis of across-area models was limited to mixed models with complex structure. For sperm whales, four mixed models were fit to data across all areas. These models started with the structure defined in equation (1), treating area (A_i), depth stratum (D_j), and their interaction $(AD)_{ij}$ as fixed effects and all remaining terms as random effects. The first model (S.1) estimated the mean effect of depredation by including the term F_{tk}. Model S.1 also accounting for potential variation in depredation effects across events by including a random-effects term $(YS)_{tk,F=1}$. Building on S.1, the second model (S.2) tested for differences in depredation effects among areas by including the interaction $(AF)_{itk}$. The third and fourth models examined evidence of a time trend in depredation effects. The third model (S.3) included a random-effects term for depredation by year ($Y_{t,F=1}$). The fourth model (S.4) included explicit linear trends (fixed effects) modelled as $T_t + (TF)_{tk}$, where T denotes year treated as a continuous variable. This formulation provides estimates of the trend in non-depredated CPUE and the difference in trend associated with depredation. The four across-area models were fitted separately to data for the two sperm whale flags (“presence” and “evidence”).

Using Flag1 (presence), the across-area estimate for sperm whale depredation implied a proportional change in CPUE of 0.88 (95% CI: 0.83-0.94), that is, a 12% reduction in CPUE (model S.1, Table 3C.5). However, there was evidence of area differences in the depredation effect. Model S.2, which included area effects, had a lower AIC than S.1 (ΔAIC = 8.4) and a significantly better fit based on the likelihood-ratio test (LRT, $P = 0.002$). Area-specific estimates of proportional change ranged from 0.77 for WY to 1.10 for WGOA (Table 3C.5). Obviously, the estimate for WGOA is not biologically valid (i.e., sperm whale depredation cannot increase CPUE). However, after removing WGOA, estimates for models S.1 and S.2 changed little, and areas differences remained significant (ΔAIC = 6.4; LRT P = 0.006).

In contrast, there was weak evidence of area differences for Flag 2 (evidence). (These analyses excluded the WGOA region because it had only one depredated unit.) The across-area estimate of depredation implied a proportional change in CPUE of 0.84 (a 16% reduction; model S.1, Table 3C.5), while area-specific estimates ranged from 0.80 for EY/SE to 0.94 for CGOA (model S.2). However, the area-specific model (S.2) had a slightly higher AIC and did not significantly improve fit (LRT, P = 0.25). In addition, there was stronger evidence of variation in depredation effects using Flag 2 (SD[$YS_{F=1}$] ~ 0.2) than for Flag 1 (SD < 0.06) (Table 3C.5).

There was little evidence of time trends in the effects of sperm whale depredation. There was no discernable pattern in year-specific random effects for depredation (model S.3) for either Flag 1 or Flag 2 models, and linear trend estimates for depredation (model S.4) were positive and weak in both cases (P = 0.35 for Flag 1 and P = 0.24 for Flag 2).

Summary and applications

We conclude that mixed-effects modelling is the most promising method for estimating the effect of depredation for sperm whales. Our results did not show a time varying trend in the effect of depredation or presence when they occur (however, incidence of depredation and presence have been increasing). We also found that it was difficult to estimate depredation effects for data sparse regions (WGOA and CGOA). We found similar results using either sperm whale presence or evidence of depredation, but we are more confident in the quality of the presence data. Given these results, we recommend when implemented that an area-wide effect of sperm whale presence and variance be estimated and used as a correction to abundance indices. **The CPUE expansion factor from this analysis is 1.14 for stations where sperm whales are present.** This expansion factor should be re-estimated every few years to ensure it is not changing from the applied estimate. We show applications of the estimated sperm whale depredation from these GLMM models in the ***Applications to the stock assessment*** section using model runs OAW, NAW, NAWK, and NAWA). The effect on the overall abundance index (e.g., Figures 3C.1, 3C.2) is an increase of between 2-5% after accounting for sperm whale depredation.

While we believe we have determined a useful correction for sperm whales, and possibly killer whales, it remains questionable when and whether to utilize these corrected indices in the assessment. First, we 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, but it is an added uncertainty. Second, 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 in the fishery as the second phase of this project, in which we will use similar modeling methods. The data available to estimate mortality in the fishery are sparse and obtaining precise estimates will be challenging. A post-doctoral researcher from the National Research Council will be starting in December 2014 to aid in this project. Finally, adjusting apportionment in relation to the variable whale depredation across areas is also an important consideration. A more detailed document or journal article addressing modeling sperm whale and killer whale depredation and application to the sablefish stock assessment is forthcoming.

Applications to the stock assessment model

We conducted a number of sensitivity models with different potential mechanisms of accounting for mortality by sperm whale depredation on the survey and in the fishery (Table 3C.6). There are a variety of ways one might consider accounting for this mortality. In Table 3C.6 there are 21 model runs that have some scenario that could be related to whales. The major scenario groups are variations on the following five themes with what we consider to be plausible “low” and “high” states of nature:

1) Whale depredation is a source of fishing mortality, and it occurs on longline gear.
2) Whale depredation is an increase in natural mortality, as in the sablefish vulnerability to predators has been increased
3) Whale depredation began in 1998
4) Whale depredation has occurred throughout the modeled time series
5) Whale depredation has reduced survey catch rates

Most scenarios gave reasonably similar predictions for key parameters (Table 3C.7).The lowest ABC projection was for the ICB scenario which added an increasing amount of catch to the fixed gear fleet since 1998. The highest ABC projections occurred for those scenarios where either natural mortality or survey RPNs was monotonically increasing since 1998 (IMB, ISB, Figure 3C.3). As expected, most scenarios showed higher spawning biomass, ABCs, and recruitment from the reference model (BASE, Table 3C.6, and Figure 3C.3). The range of estimates of female spawning biomass appear to be relatively insensitive to these different accounting of whale depredation (Figure 3C.4, Table 3C.8). However, when we look only at the recent series of female spawning biomass estimates in terms of absolute and relative differences (Figures 5, 6), the effects can be more easily perceived and appear more substantial. We believe that this range of scenarios sets reasonable boundaries on how accounting for whale depredation inside the stock assessment would affect model results. Some of the ABCs resulting from these scenarios are considerably larger than the reference case. However, it would be expected that if ABCs are increased by correcting for survey depredation, it would be necessary to somehow decrement those ABCs for the additional mortality caused by depredation in the fishery.

Variance estimation and missing areas

The longline survey index currently uses a fixed CV of 5% for sablefish in the stock assessment model. Some bootstrap analyses were conducted to arrive at this number (Sigler 2000), but it was an approximation because there is covariance between depth strata within a station and between station depth strata combinations. We have since developed more appropriate analytical variance estimates that include covariances and the additional variance introduced by correcting for whale depredation. For the most part, the coefficients of variation (CVs) for the all-area index were not on average much different than the assumed 5%. However, there is some interannual variability, and the method now provides variance estimates for smaller geographic regions, which will be useful for spatial models and other groundfish assessments that utilize the longline survey index. The estimated coefficients of variation for sablefish from 1990-2013 are shown in Figure 3C.7.

The Aleutian Islands (AI) and Bering Sea (BS) are sampled biennially. The abundance index for the unsampled years are filled in using the previous survey of the area scaled by the average change in the Gulf of Alaska areas, which are sampled annually. In this case, the average GOA index is calculated from the four management areas in the GOA. 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 index is not positively correlated with any of the other areas, and the Aleutian Islands area is significantly negatively correlated with the Central Gulf of Alaska. Therefore, using this approach across all areas may result in a retrospective bias if estimates in unsampled areas do not match the underlying trend for that area. To fill in the missing years, we demonstrated two alternative methods that have been shown to be useful by the Plan Team working group on survey averaging. In our sensitivity results we show the effect of using an ARIMA (0,2,2, local linear smoothing) model and a random effects model to fill in the BS and AI missing years from 1996-2013. The choice of which of these methods is superior is not yet clear, but they have large effects on the overall RPN index in some years (Figure 3C.8). These are shown in models NAWA and NAWK in Table 1.

New survey area sizes

Previous estimates of the size of each geographic area used to estimate RPNs and RPWs were devised before geographic information systems (GIS) and accurate, high resolution bathymetric maps were readily available. Echave et al. (2013) estimated the area sizes currently used in the AFSC longline survey using GIS methods and updated bathymetry. The largest increase in estimated area sizes occurred in Spencer Gully (in the EY/SE management area) and Bering 3 slope areas (Figure 3C.9). The largest negative changes were in the NW Aleutians slope and East Yakutat slope areas. Overall, more areas were calculated to be smaller than the previously used estimates. Only the shallowest depth stratum used in standard RPN/RPW calculations (200-300 meters) increased, while the areas in deeper depths decreased slightly (Figure 3C.10). In addition, Echave et al. (2013) estimated the size of the areas in the depths sampled between 150-200 m which previously were not used in abundance index calculations. The addition of these depths in the RPN/RPW index increases the potential utility of the longline indices for species such as Pacific cod, halibut and rockfish. We show the effect of the area recalculation on the overall sablefish RPN index for the base model (Figures 11, 12) and in model runs beginning with OA, and NA in Table 3C.6.

Maturity research

The first age at maturity and fecundity study of female sablefish sampled in Alaska near their spawning period was undertaken in 2011. Skipped spawning was documented for the first time in sablefish. These winter samples provided a similar age at 50% maturity estimate (6.8 years) as the mean of visual observations taken during summer surveys from 1996-2012 (mean = 7.0 years) and the estimate currently used in the assessment (mean =6.6 years), when skipped spawners were classified as mature. Interestingly, skipped spawning appeared to be occurring for a substantial portion of the older mature population in shallower shelf waters which could have implications for population dynamics. In addition, four female sablefish were fit with pop-off satellite tags during the winter survey. Despite being a highly migratory species throughout their lives, preliminary results of this tagging data suggest that these sablefish exhibited site fidelity during the spawning season. This may be related to whether a fish is spawning in the current season. The paper describing the study is in the process of being submitted for publication.

Movement

A study on sablefish movement and mortality has been accepted for publication. The analysis included over 300,000 tag releases and over 27,000 tag recoveries from 1979-2009. Movement was modeled in three size groups, small (<57 cm), medium (57 – 66 cm), and large (>66 cm) which corresponded approximately to immature, maturing, and mature fish. Annual movement probabilities were high, with annual probabilities ranging from 10-88%, depending on area of occupancy at each time step, and size group. Overall, movement probabilities were very different between areas of occupancy and moderately different between size groups (Figure 3C.13). Estimated annual movement of small sablefish from the Central GOA had the reverse pattern of a previous study using a small subset of these data, with 29% moving westward and 39% moving eastward. The previous study showed movement of small fish to be primarily westward. Movement probabilities in the current study also varied annually with decreasing movement until the late 1990s, and increasing movement until 2009. Year specific magnitude in movement probability of large fish was highly negatively correlated with the total female spawning biomass estimate from the federal stock assessment. This may indicate that slower somatic growth at high population sizes leads to lower movement probabilities. Total average mortality estimates from time at liberty were similar to the values estimated by the stock assessment model. Results do not show an obvious ecologically directed movement pattern. The analysis in this study was conducted using sablefish lengths, but efforts are underway to read ages from a sample of otoliths taken from tag recoveries. These data will aid in estimating age-specific movement and be more useful for conducting management strategy evaluations of spatial stock assessment models.

Fishery abundance index

Estimating abundance from fishery dependent data is a well known challenge. Alaska sablefish is the only model in Alaska that incorporates fishery CPUE data as an index of abundance. Presently, longline CPUE is determined through a targeting algorithm, but not statistically standardized. During a one year National Research Council appointment, Mateo and Hanselman (2014) developed several statistical models that appear to hold promise for modeling fishery CPUE for standardization. Covariates that explained the most variation in the models were CPUE of giant grenadier, depth, longitude, and Pacific halibut CPUE. We wish to extend these models to develop an index for use in the sablefish model, and to potentially estimate whale depredation effects on the fishery. This work will continue as a new postdoctoral researcher from the NRC joins us in December, 2014.

Apportionment

In 2013, we recommended that the apportionment proportions to each area be fixed at 2012 values. We justified this because the apportionment strategy was devised to reduce interannual variability in catch recommendations while still reflecting shifts in abundance. We showed that this variability in catch recommendations by area had been increasing since 2007. While some of these changes may actually reflect interannual changes in regional abundance, they most likely reflect the high movement rates of the population and the high variability of our estimates of abundance in the Bering Sea and Aleutian Islands due to whale depredation and estimating abundance index values in years when these areas are not sampled.

Because of the high variability in apportionment seen in recent years, we suggested that the standard method was not meeting the goal of reducing the magnitude of interannual changes in the apportionment. We, therefore, proposed that the apportionment scheme be reevaluated.

A Ph.D. project with the University of Alaska-Fairbanks was initiated in 2012 to conduct management strategy evaluations to re-examine the apportionment strategy with respect to biological and economic yield. The student involved has been working closely with us and has begun testing spatial sablefish stock assessment models to be used in evaluating apportionment. It will also be important to integrate continuing research into whale depredation effects into analyses regarding the implications of different apportionments. The apportionment strategies being tested will focus on objectives that include but are not limited to:

1) Reduce annual variation in TAC changes
2) Maximizing economic yield by region and for the total fishery
3) Maximizing sustainable yield by region and for the total fishery
4) Maintaining a minimum level of harvest in every region

Some apportionment strategies that may attain these goals may include:

1) Status quo (5 year exponential average of fishery and survey abundance)
2) Apportion from terminal year abundance of a spatially explicit model
3) Apportion based on a longer term (e.g., 10 year) average
4) Equal allocation (Divide TAC by the number of regions)
5) Apportion based on size or numbers (to protect spawning biomass)

Meanwhile, for the same reasons we presented in 2013, until the apportionment scheme has been adequately evaluated it seems prudent to keep the apportionment fixed until there are other viable options to be considered. Therefore, for 2015, we recommend keeping the apportionment fixed from 2014, so that all areas ABCs change equally in accordance with the model results.

Future

There has been much recent research progress on sablefish stock assessment. However, several major challenges remain that include estimating and accounting for whale depredation in the fishery, evaluating the current apportionment strategies, developing a spatial research model of sablefish that includes movement, and determining the ecological basis of year class strength. There is ongoing or planned research for each of these challenges. We are trying to develop a portfolio of complementary model changes before implementing work already accomplished because many changes require other work to balance them. The most obvious example is accounting for whale depredation. We have the potential to correct survey estimates now, but developing estimates for the fishery that account for whale depredation is more difficult. Because it is fishery data, it is noisy, and the observations of depredation are sparse and unbalanced. Thus, we can develop these estimates but they will be less certain than those we can obtain for the survey. In addition, part of our fishery abundance index includes logbook data which do not include whale depredation observations. Until we have both fishery and survey estimates and a good way to use them in concert, it would be unwise to apply one alone. We will be conducting a sablefish CIE review in 2016.This review will provide expert opinion regarding the results of these research projects and provide advice to help integrate the findings into the sablefish stock assessment. We then hope to incorporate this work into the assessment model and bring forward a benchmark assessment.

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Table 3C.1. Number of year/station replicates by area used in models of sperm whale depredation. “Flag 1” corresponds to sperm whale presence; “Flag 2” corresponds to evidence of depredation (damaged fish, hooks, etc.). Data from years 1990 through 2012.

Area	Total	Flag 1	Percent	Flag 2	Percent
WGOA	213	15	7.0	1	0.5
CGOA	366	56	15.3	29	7.9
WY	184	71	38.6	56	30.4
EY/SE	391	99	25.3	63	16.1
Total	**1154**	**241**	**20.9**	**149**	**12.9**

Table 3C.2. Estimates of sperm whale depredation (λ) by model and area using <u>Flag 1</u> (presence). SE = standard error of the estimate. The estimate of proportional change is given by exp(λ) (e.g., a value of 1.0 implies no change; a value of 0.8 implies a 20% reduction in mean CPUE due to depredation).

Area	Model	Estimate	SE	P value	Proportional Change
WGOA	QP	13.4	708	0.985	6.3E+05
	NB	36.9	7.7E+06	1.000	1.0E+16
	ME.1	0.159	0.127	0.211	1.17
	ME.2	0.114	0.131	0.384	1.12
	ME.3	0.113	0.131	0.389	1.12
CGOA	QP	0.161	0.370	0.663	1.17
	NB	-0.015	0.417	0.971	0.99
	ME.1	-0.047	0.053	0.371	0.95
	ME.2	-0.023	0.055	0.674	0.98
	ME.3	-0.026	0.062	0.677	0.97
WY	QP	-0.044	0.388	0.911	0.96
	NB	-0.829	0.547	0.130	0.44
	ME.1	-0.188	0.055	0.001	0.83
	ME.2	-0.259	0.069	<0.001	0.77
	ME.3	-0.257	0.069	<0.001	0.77
EY/SE	QP	-0.193	0.332	0.560	0.82
	NB	0.264	0.515	0.608	1.30
	ME.1	-0.199	0.038	<0.001	0.82
	ME.2	-0.187	0.043	<0.001	0.83
	ME.3	-0.187	0.044	<0.001	0.83

Table 3C.3. Estimates of sperm whale depredation (λ) by model and area using Flag 2 (evidence). SE = standard error of the estimate. The estimate of proportional change is given by exp(λ) (e.g., a value of 1.0 implies no change; a value of 0.8 implies a 20% reduction in mean CPUE due to depredation).

Area	Model	Estimate	SE	P value	Proportional change
CGOA	QP	0.711	0.444	0.110	2.04
	NB	0.751	0.444	0.091	2.12
	ME.1	-0.102	0.069	0.141	0.90
	ME.2	-0.097	0.071	0.173	0.91
	ME.3	-0.096	0.089	0.280	0.91
WY	QP	-0.044	0.388	0.911	0.96
	NB	-0.829	0.547	0.130	0.44
	ME.1	-0.129	0.053	0.015	0.88
	ME.2	-0.195	0.067	0.004	0.82
	ME.3	-0.192	0.071	0.007	0.83
EY/SE	QP	-0.133	0.339	0.695	0.88
	NB	-0.185	0.460	0.688	0.83
	ME.1	-0.208	0.043	<0.001	0.81
	ME.2	-0.218	0.048	<0.001	0.80
	ME.3	-0.216	0.051	<0.001	0.81

Table 3C.4. Estimates of standard deviation and components of variance (%) for random-effects terms in ME.3 models of CPUE with sperm whale depredation using Flag 1 (presence). The shaded row highlights the additional variance due to random depredation effects.

	Standard deviation				Components of variance (%)			
Term	WGOA	CGOA	WY	EY/SE	WGOA	CGOA	WY	EY/SE
Year (Y)	0.19	0.16	0.28	0.21	3.9	4.8	8.3	4.5
Depth (D)	0.59	0.24	0.55	0.72	37.5	10.5	33.2	50.5
Station (S)	0.30	0.14	0.00	0.42	10.0	3.3	0.0	17.2
Y x D	0.24	0.19	0.23	0.09	6.4	6.8	5.5	0.9
Y x S	0.36	0.24	0.24	0.21	13.9	10.6	6.4	4.3
Y x S (F=1)	0.00	0.24	0.07	0.12	0.0	10.6	0.6	1.5
D x S	0.26	0.37	0.47	0.33	7.3	25.0	24.2	10.5
Y x D x S	0.44	0.40	0.45	0.33	20.9	28.3	21.9	10.6
Total					**100.0**	**100.0**	**100.0**	**100.0**

Table 3C.5. Estimates of sperm whale depredation (λ) for across-area models for Flag 1 (presence) and Flag 2 (evidence). SE = standard error of the estimate. Estimates of proportional change are given by exp(λ) with approximate 95% confidence intervals shown (LCI, UCI).

					Proportional change			Random effects	
Flag	Model	Area	Estimate	SE	exp(Est)	LCI	UCI	SD(YS)	SD($YS_{F=1}$)
1	S.1	All	-0.128	0.032	0.88	0.83	0.94	0.264	0.055
	S.2	WGOA	0.096	0.105	1.10	0.90	1.35	0.264	0.000
		CGOA	-0.016	0.055	0.98	0.88	1.10		
		WY	-0.265	0.066	0.77	0.67	0.87		
		EY/SE	-0.199	0.051	0.82	0.74	0.91		
2	S.1	All	-0.173	0.038	0.84	0.78	0.91	0.226	0.209
	S.2	WGOA						0.226	0.203
		CGOA	-0.066	0.075	0.94	0.81	1.09		
		WY	-0.190	0.064	0.83	0.73	0.94		
		EY/SE	-0.223	0.058	0.80	0.71	0.90		

Table 3C.6. List of scenarios with different ways to correct for sperm whale depredation, including new variance estimates for longline survey abundance, and using new area sizes.

Test	***Description***
BASE	Base model
CB	Increase fixed gear catch by 5% in all years
CS	Increase fixed gear catch by 2% in all years
CSB	Increase fixed gear catch and longline RPN by 5% in all years
CSS	Increase fixed gear catch and longline RPN by 2% in all years
EM	Estimate M deviations from 1998
ICB	Increasing trend on fixed gear catch by 1% per year since 1998
ICS	Increasing trend on fixed gear catch by 0.5% per year since 1998
ICSB	Increasing trend of fixed gear catch and longline RPN by 1% since 1998
ICSS	Increasing trend on fixed gear catch and longline RPN by 0.5% since 1998
IMB	Increasing trend of M by 1% per year since 1998
IMS	Increasing trend of M by 0.5% per year since 1998
ISB	Increasing trend on longline RPN by 1% per year since 1998
ISS	Increasing trend on longline RPN by 0.5% per year since 1998
MB	Increase M by 5% in all years
MS	Increase M by 2% in all years
NA	New longline survey area sizes
NAW	New longline survey area sizes with survey sperm whale correction
NAWA	New longline survey area sizes with survey sperm whale correction, and ARIMA area fill
NAWK	New longline survey area sizes with survey sperm whale correction, and random effects area fill
OA	Base model with survey variance estimates
OAW	Base model with survey sperm whale correction
SB	Increase longline RPN by 5% in all years
SS	Increase longline RPN by 2% in all years

Table 3C.7. Key results from various scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Test	-lnL	ABC	Catchability	Projected SSB	2008 YC	B40
BASE	1390.54	13.70	7.75	91.14	20.75	106.36
CB	1389.98	13.52	7.66	91.43	21.28	108.97
CS	1390.12	13.62	7.71	91.26	20.95	107.41
CSB	1389.98	13.53	8.04	91.47	21.29	108.99
CSS	1390.19	13.63	7.86	91.26	20.96	107.41
EMS	1390.54	13.70	7.75	91.14	20.75	106.36
ICB	1385.73	13.09	7.67	89.29	21.69	108.13
ICS	1387.98	13.39	7.71	90.22	21.21	107.22
ICSB	1395.85	17.20	7.63	104.24	25.34	112.51
ICSS	1392.21	15.37	7.69	97.52	22.93	109.36
IMB	1385.89	17.57	7.60	88.72	23.14	85.33
IMS	1387.84	15.84	7.67	90.00	21.87	95.35
ISB	1399.85	17.93	7.70	106.23	24.34	110.79
ISS	1394.55	15.70	7.72	98.47	22.46	108.51
MB	1390.88	14.81	7.61	91.81	21.84	103.78
MS	1390.45	14.14	7.69	91.42	21.18	105.28
NA	1398.37	13.88	7.41	91.61	21.58	106.66
NAW	1403.19	14.79	7.40	95.17	22.01	107.72
NAWA	1399.36	15.75	7.38	98.65	22.89	108.76
NAWK	1426.32	16.92	7.32	101.60	25.65	109.45
OA	1399.74	13.84	7.57	91.57	21.30	106.64
OAW	1404.07	14.74	7.56	95.05	21.75	107.69
SB	1390.54	13.71	8.13	91.18	20.75	106.38
SS	1390.54	13.70	7.90	91.16	20.75	106.37

Table 3C.8. Female spawning biomass trajectories from model scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Year	BASE	CB	CS	CSB	CSS	EMS	ICB	ICS	ICSB	ICSS	IMB
1977	129	132	130	132	130	129	129	129	129	129	129
1978	117	120	119	120	119	117	117	117	118	118	118
1979	112	115	113	115	113	112	112	112	113	113	112
1980	107	109	108	109	108	107	107	107	108	108	107
1981	106	108	106	108	106	106	106	106	106	106	106
1982	109	111	110	111	110	109	109	109	110	109	109
1983	121	123	122	123	122	121	121	121	122	121	121
1984	136	139	138	139	138	136	137	137	138	137	137
1985	152	155	153	155	153	152	152	152	154	153	153
1986	165	169	167	169	167	165	166	166	168	166	167
1987	171	175	173	175	173	171	172	172	174	173	173
1988	170	174	172	174	172	170	171	171	173	172	172
1989	164	167	165	167	165	164	164	164	166	165	165
1990	154	157	155	157	155	154	155	154	157	155	156
1991	143	146	144	146	144	143	144	144	146	145	145
1992	132	134	133	134	133	132	133	133	135	134	134
1993	122	123	122	123	122	122	123	122	125	123	124
1994	111	112	111	112	111	111	112	111	114	113	113
1995	103	104	103	104	103	103	104	103	106	104	105
1996	98	99	98	99	98	98	99	98	101	100	100
1997	95	96	95	96	95	95	96	95	99	97	97
1998	92	93	92	93	92	92	93	93	96	94	94
1999	88	89	89	89	89	88	90	89	93	91	91
2000	85	86	85	86	85	85	87	86	90	87	88
2001	82	83	82	83	82	82	83	83	87	85	84
2002	82	82	82	82	82	82	83	82	87	84	84
2003	84	85	84	85	84	84	85	84	90	87	86
2004	87	88	87	88	87	87	89	88	95	91	90
2005	92	92	92	92	92	92	93	92	100	96	95
2006	98	98	98	99	98	98	99	98	108	103	101
2007	103	104	103	104	103	103	104	103	114	108	106
2008	105	106	105	106	105	105	106	105	117	111	107
2009	104	105	104	105	104	104	105	104	116	110	106
2010	102	103	102	103	102	102	102	102	115	108	103
2011	100	100	100	100	100	100	100	100	112	106	100
2012	96	97	97	97	97	96	96	96	109	103	96
2013	93	94	93	94	93	93	92	93	106	100	92

Table 3C.8 (cont.). Female spawning biomass trajectories from model scenarios for accounting for sperm whale depredation, re-estimating survey variance, and new survey areas (see descriptions of scenarios in Table 1).

Year	IMS	ISB	ISS	MB	MS	NA	NAW	NAWA	NAWK	OA	OAW	SB	SS
1977	129	129	129	134	131	129	129	129	128	129	129	129	129
1978	118	118	118	122	119	117	118	118	117	117	118	117	117
1979	112	113	113	117	114	112	113	113	112	112	113	112	112
1980	107	108	108	111	109	107	108	108	107	107	107	107	107
1981	106	106	106	109	107	105	106	106	105	105	106	106	106
1982	109	110	109	113	110	109	109	109	109	109	109	109	109
1983	121	122	121	125	122	120	121	121	121	120	121	121	121
1984	137	138	137	141	138	136	137	137	137	136	137	136	136
1985	152	153	152	157	154	151	152	152	152	151	152	152	152
1986	166	167	166	171	167	165	166	166	166	165	166	165	165
1987	172	173	172	177	174	171	172	172	172	171	172	171	171
1988	171	172	171	176	173	170	171	171	171	170	171	170	170
1989	164	166	165	169	166	163	164	164	164	163	164	164	164
1990	155	156	155	159	156	154	154	155	155	154	154	154	154
1991	144	145	144	147	145	143	144	144	144	143	144	143	143
1992	133	134	133	136	134	132	133	133	133	132	133	132	132
1993	123	124	123	125	123	121	122	122	122	121	122	122	122
1994	112	113	112	114	112	111	112	112	112	111	112	111	111
1995	104	105	104	105	104	103	103	104	104	103	104	103	103
1996	99	100	99	100	99	98	99	100	100	98	99	98	98
1997	96	98	96	97	96	96	96	97	97	96	97	95	95
1998	93	95	93	94	93	93	94	95	95	93	94	92	92
1999	90	92	90	90	89	90	91	91	91	90	91	88	88
2000	86	89	87	87	86	86	88	88	88	86	88	85	85
2001	83	86	84	84	83	83	85	85	85	83	85	82	82
2002	83	86	84	83	82	83	84	85	84	83	84	82	82
2003	85	89	86	85	84	85	86	88	86	85	87	84	84
2004	88	93	90	89	88	88	90	91	89	88	90	87	87
2005	93	99	95	94	92	92	95	96	93	92	95	92	92
2006	99	106	102	100	98	98	101	103	100	98	101	98	98
2007	104	113	107	105	103	103	106	108	105	103	106	103	103
2008	106	116	110	107	105	105	108	111	108	105	108	105	105
2009	105	116	110	106	105	104	107	110	108	104	107	104	104
2010	103	115	108	104	103	102	105	108	107	102	105	102	102
2011	100	113	106	101	100	99	103	106	106	99	103	100	100
2012	96	110	103	97	97	96	100	103	104	96	100	96	96
2013	93	108	100	94	94	93	97	100	102	93	97	93	93

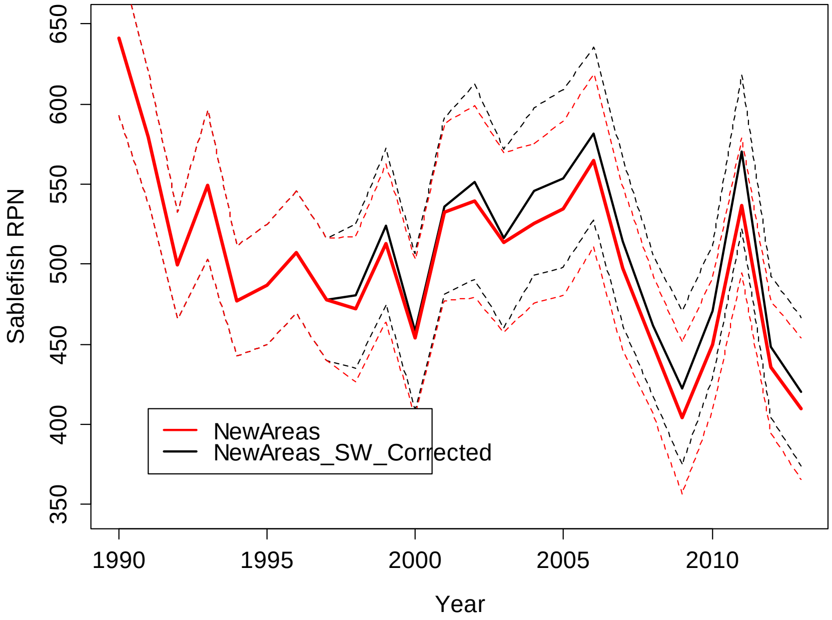

Figure 3C.1. An example of the effect of correcting for sperm whale depredation. Models correspond to NA and NAW in Table 1.

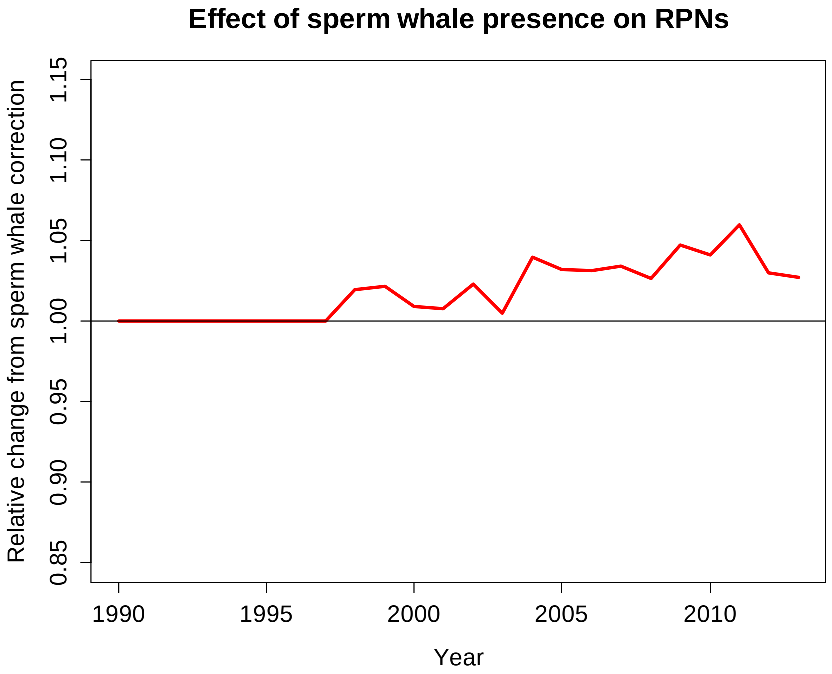

Figure 3C.2. The net increase in the index from the base model after correcting for sperm whale depredation. Black line at 1 corresponds to the NA model, red line is the NAW model in Table 1.

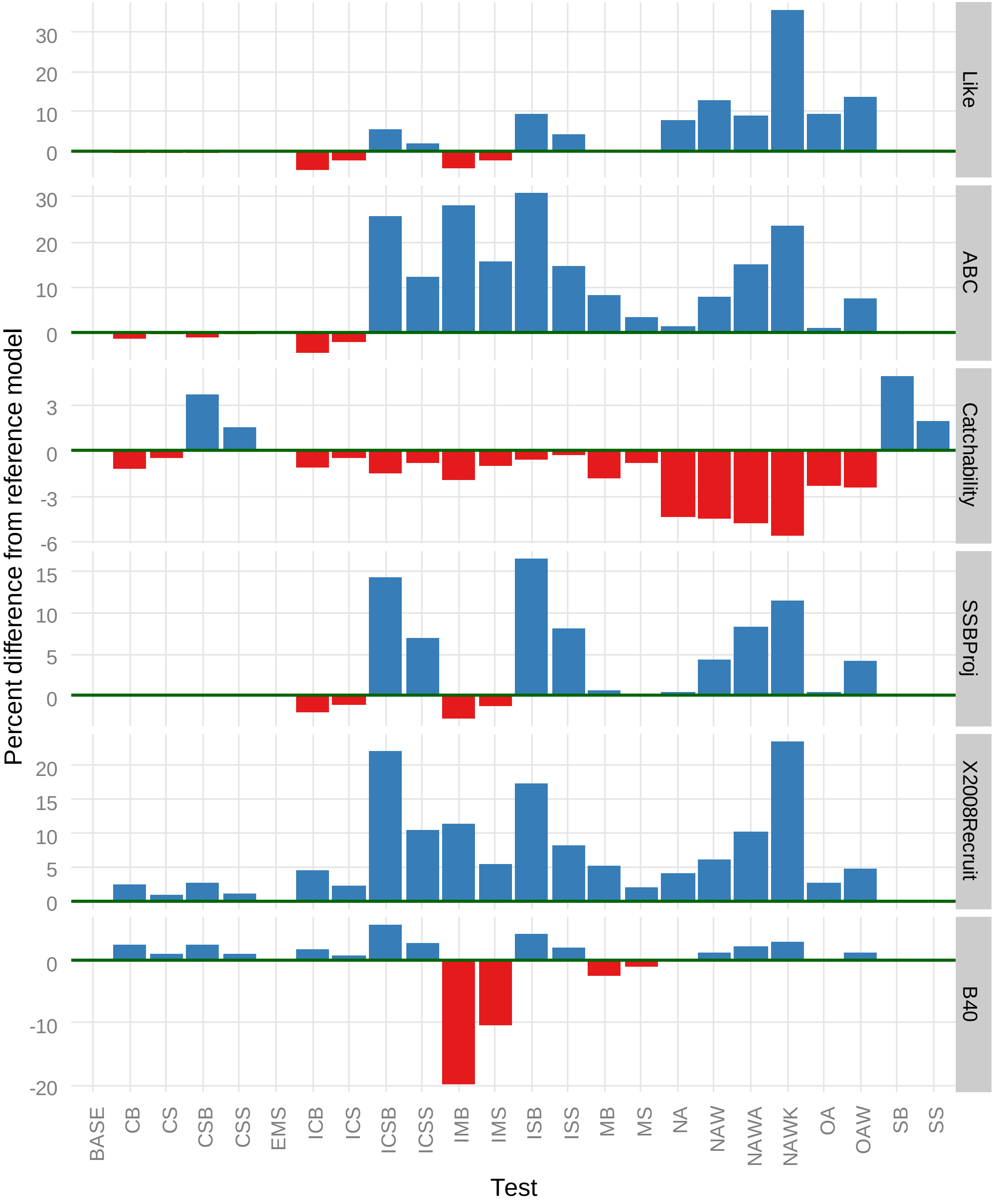

Figure 3C.3. Relative change in key results from sensitivity tests described in Table 1.

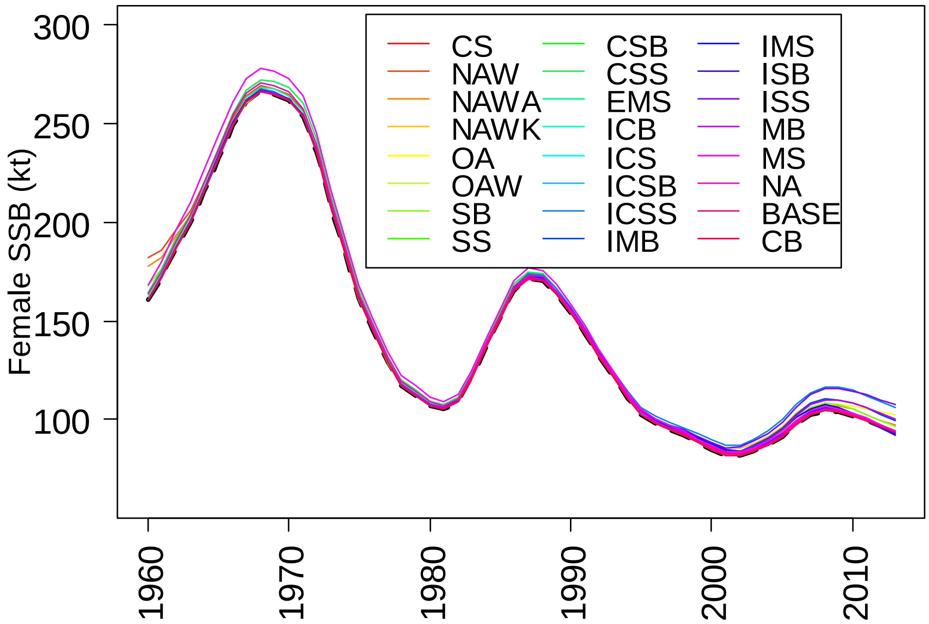

Figure 3C.4. Plots of female spawning biomass for sablefish model sensitivity tests from 1960-2013. Dashed black line is overplotted on the line for BASE model.

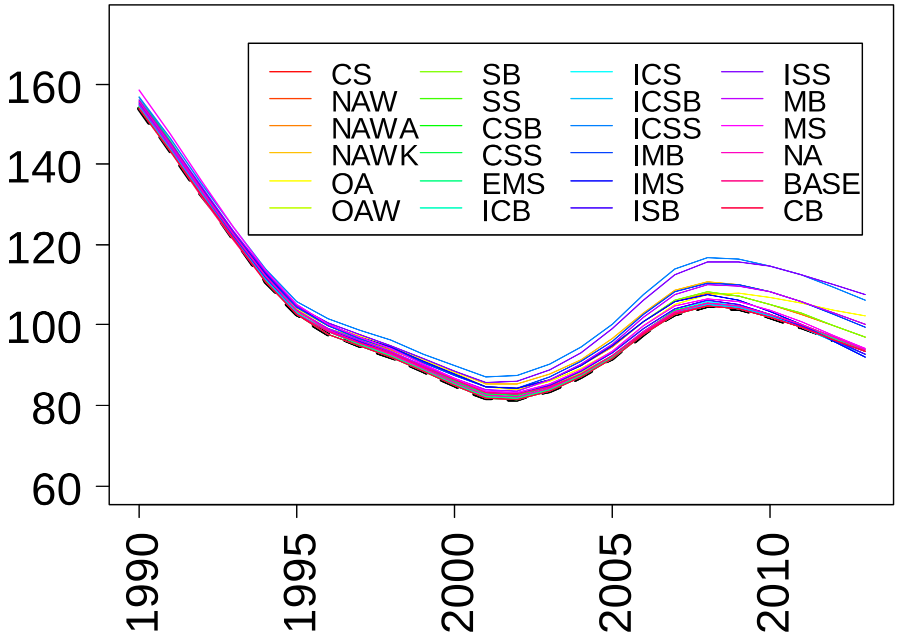

Figure 3C.5. Plots of female spawning biomass for sablefish sensitivity tests from 1990-2013. Dashed black line is overplotted on the line for BASE model.

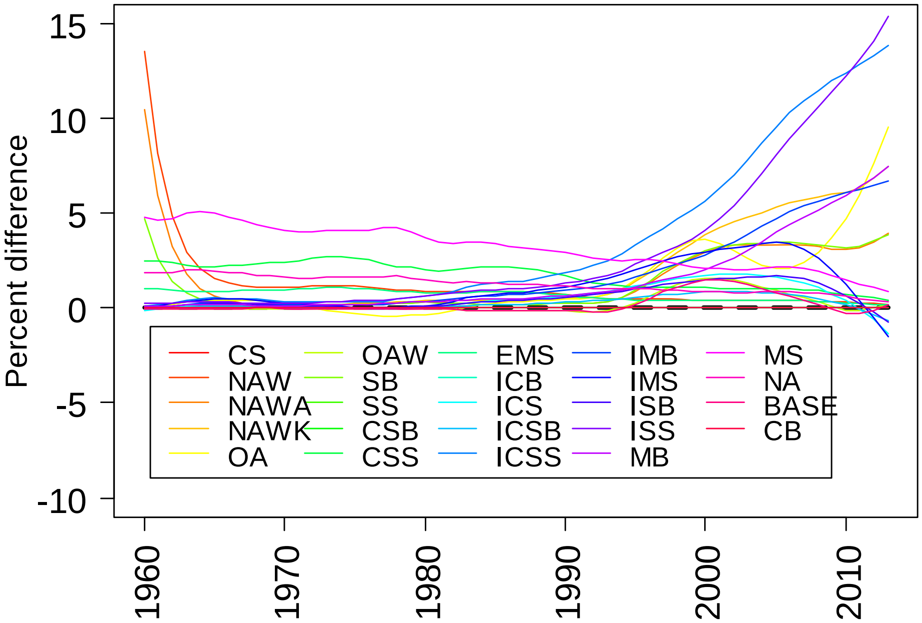

Figure 3C.6. Plots of relative female spawning biomass to reference model for sablefish sensitivity tests from 1990-2013. Dashed black line is overplotted on the line for BASE model.

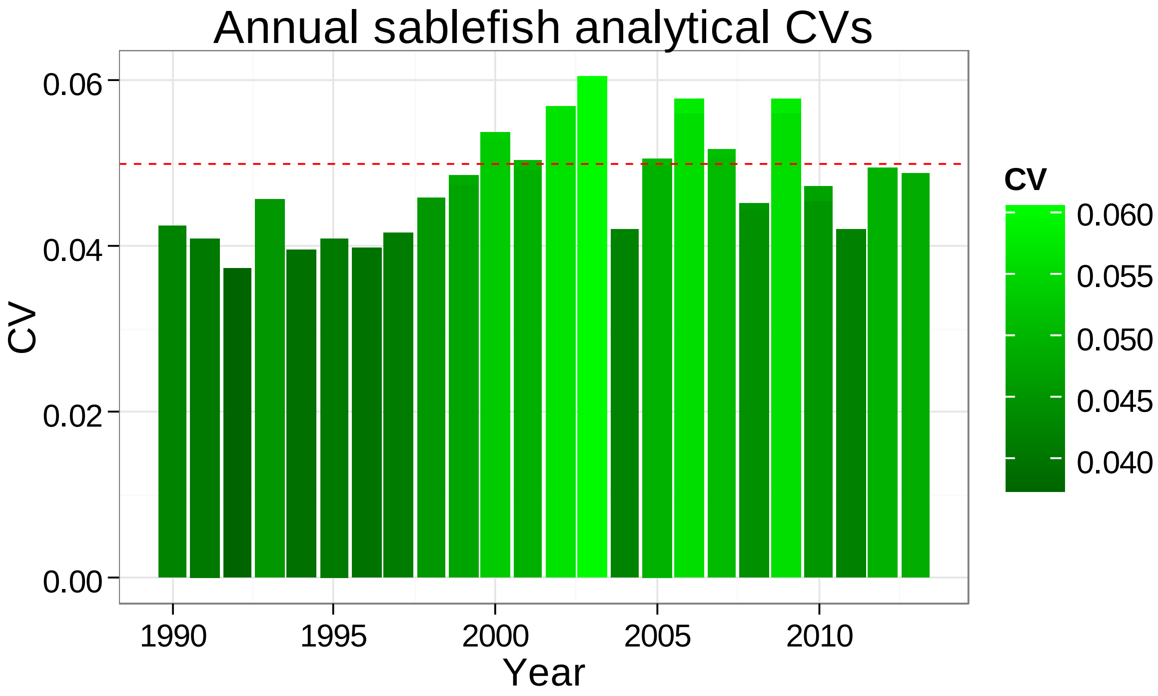

Figure 3C.7. Time series of coefficients of variation (CV) for the all-area sablefish longline RPN index. Five percent CV line is marked as a red dash line.

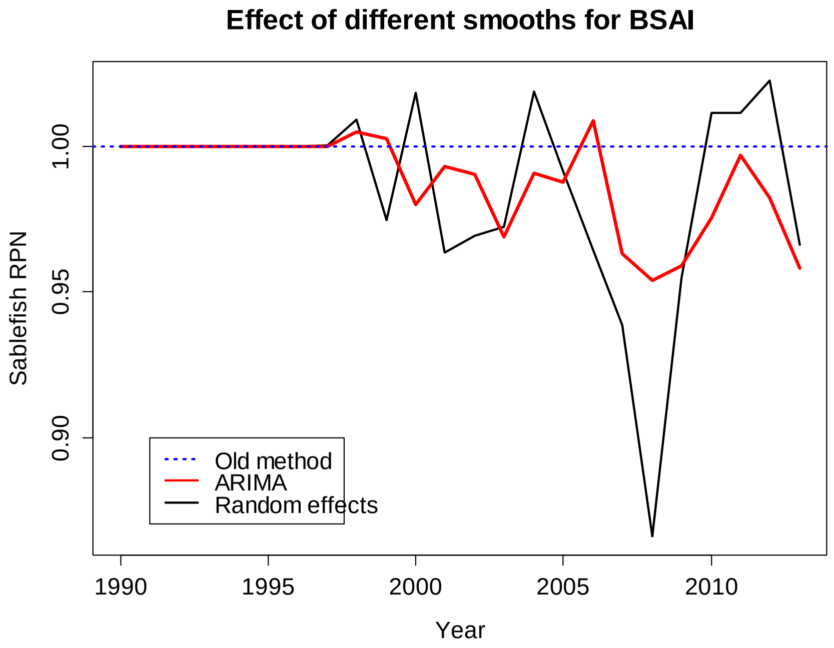

Figure 3C.8. The use of an ARIMA model and a random effects model to fill in missing years for the Bering Sea and Aleutian Islands areas and the effect on the sablefish RPN index.

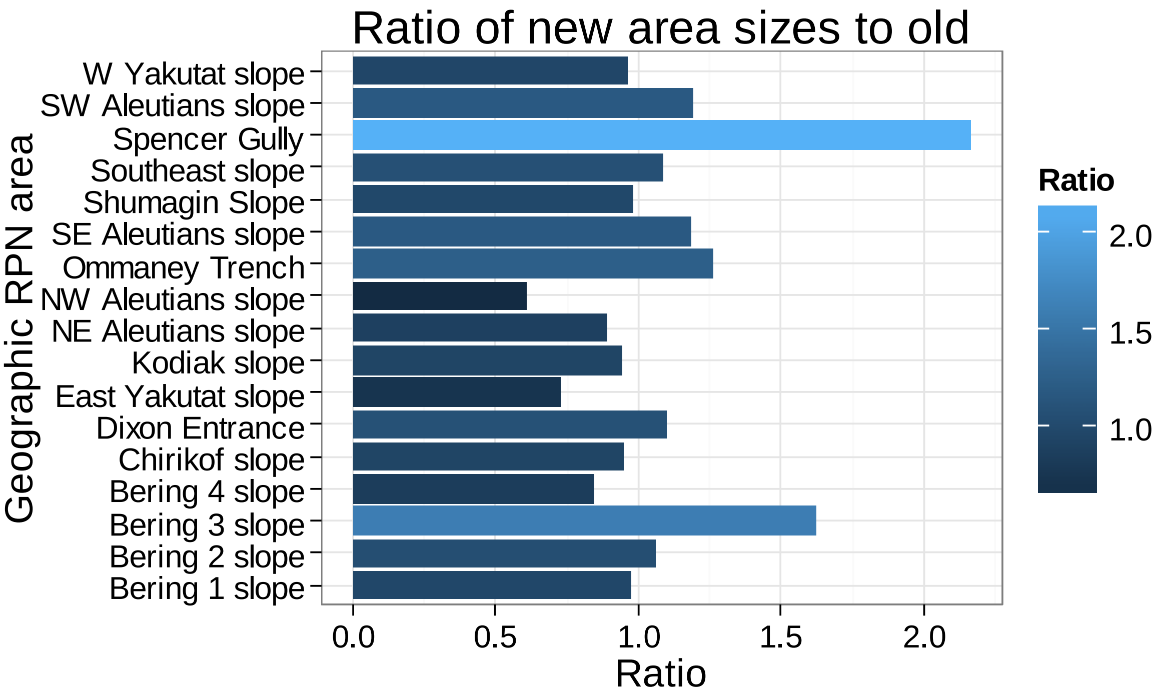

Figure 3C.9. The ratio of new area sizes calculated in Echave et al. (2013) to the area sizes currently used in the sablefish stock assessment by small geographic areas.

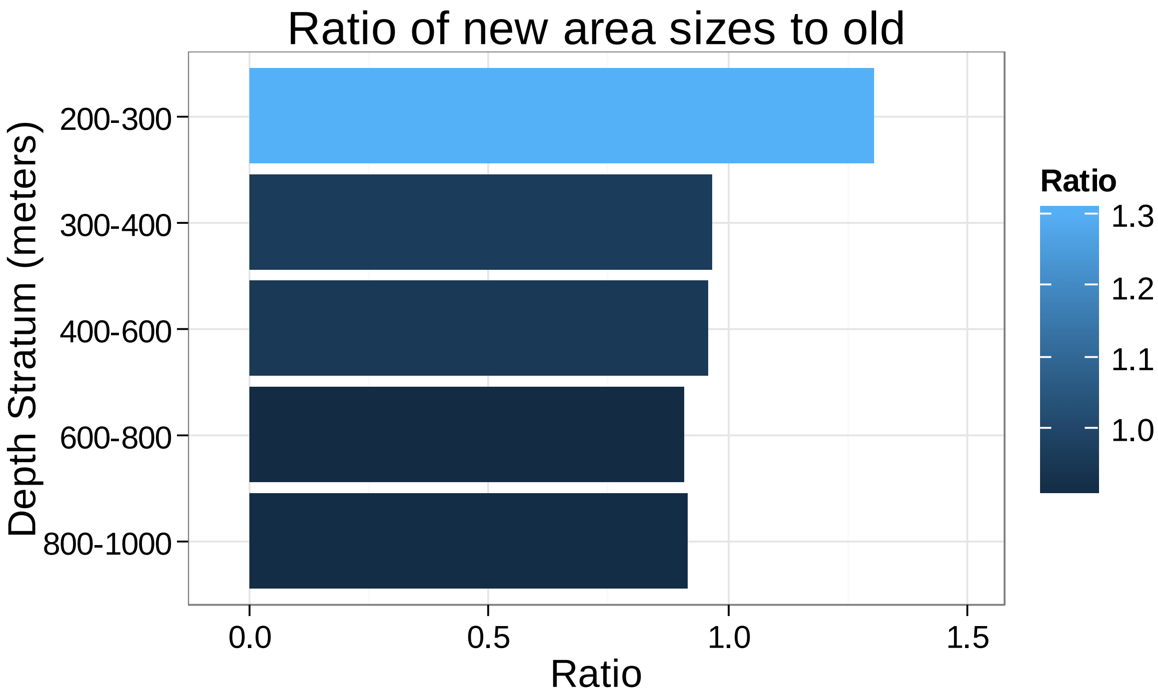

Figure 3C.10. The ratio of new area sizes calculated in Echave et al. (2013) to the area sizes currently used in the sablefish stock assessment by depth strata.

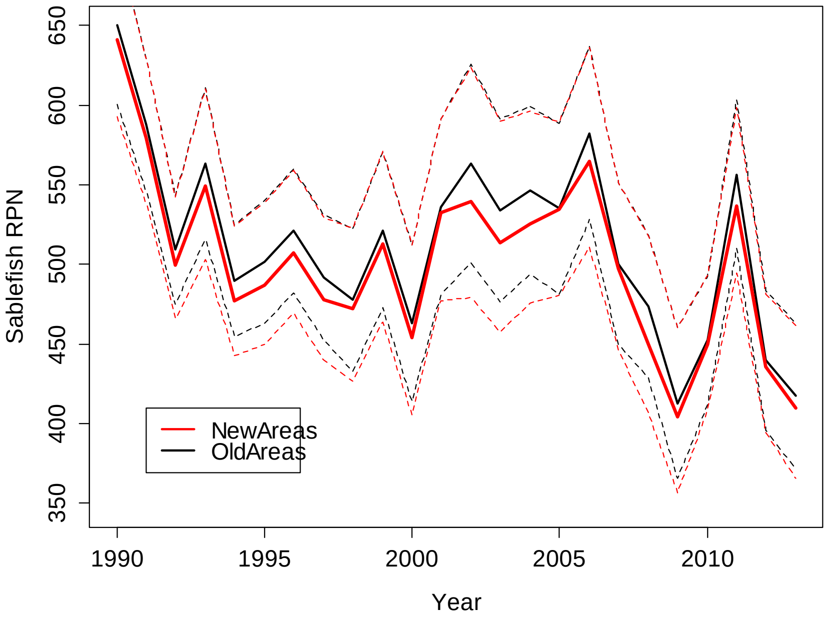

Figure 3C.11. Estimates of sablefish RPNs using new calculated area sizes from Echave et al. (2013) versus using old area sizes used in Hanselman et al. (2013).

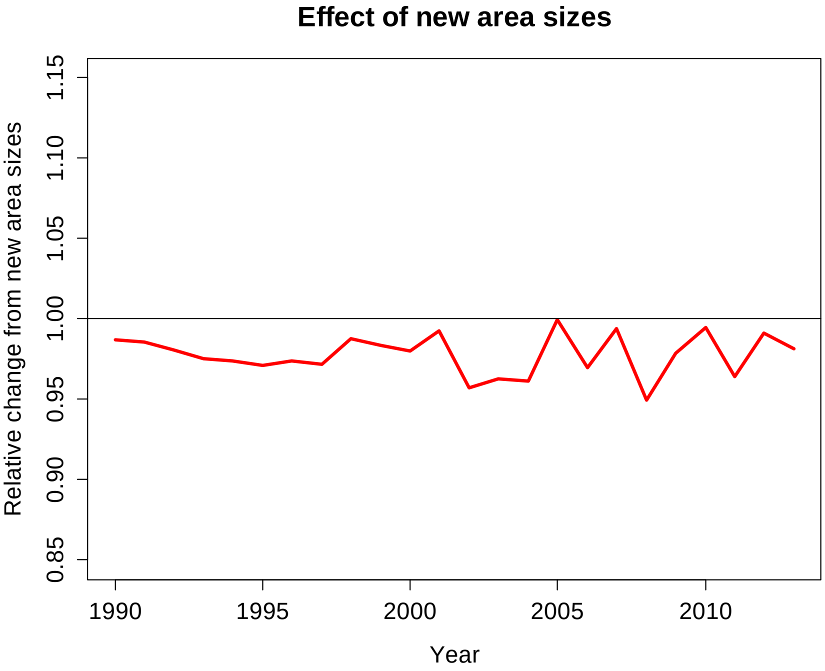

Figure 3C.12. Net effect of new area sizes. Line at 1 is the reference line from the base model in Hanselman et al. (2013).

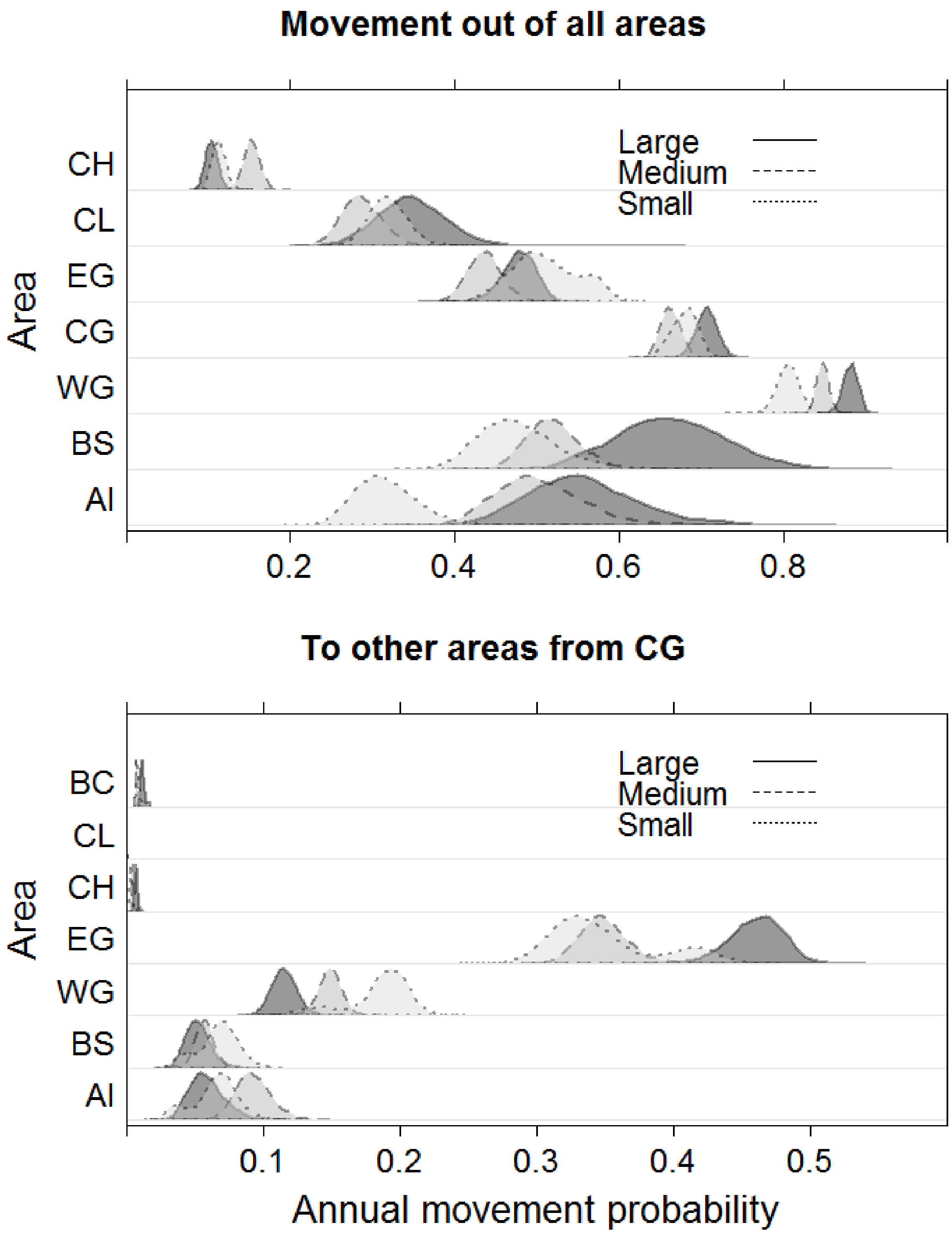

Figure 3C.13. Posterior probability distributions of annual sablefish movement probability by size group and area. Top panel is movement probability out of each area. Bottom panel is movement probability to each area from the central Gulf of Alaska. AI = Aleutian Islands, BS = Bering Sea, WG = western Gulf of Alaska, CG = central Gulf of Alaska, EG = eastern Gulf of Alaska, CH = Chatham Strait, CL = Clarence Strait, Small = <57 cm, Medium = 57-66 cm, Large = >66 cm.