3. Assessment of the Sablefish stock in Alaska

by
Dana H. Hanselman, Chris R. Lunsford, Cara J. Rodgveller, and Megan J. Peterson

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 2016 longline survey, relative abundance and length data from the 2015 longline fishery, length data from the 2015 trawl fisheries, age data from the 2015 longline survey and 2015 fixed gear fishery, updated catch for 2015, and projected 2016 - 2018 catches. In addition to these usual new data updates, the following substantive new changes were made to the data inputs:

1) New analytical variance calculations for the domestic longline survey abundance index
2) New area sizes for the domestic longline survey abundance index
3) Domestic longline survey estimates corrected for sperm whale depredation
4) Estimates of killer and sperm whale depredation in the fishery

Changes in the assessment methodology:
The 2016 Center for Independent Experts (CIE) review panel had a number of recommendations to improve aspects of the reference model. We present the reference model and seven alternatives that sequentially address some of the key recommendations made by the panel. The first five alternative models address the data inputs described above. We consider the first two of these alternatives to be minor model changes (incorporating the area sizes and variance estimates for the domestic longline survey). The next three incorporate corrections of the domestic longline survey and longline fishery for whale depredation, which we consider to be a benchmark change that was recommended by the CIE.

The final two models address the CIE panel's concern that the model provided "overly precise" estimates of management quantities. These models reweight the abundance indices relative to obtaining a standard deviation of normalized residuals of one for the domestic longline survey abundance index, while maintaining a value of one for the previously tuned age and length compositions. These two models increase the uncertainty around estimates of spawning biomass and other key management results. Finally, the recommended model estimates natural mortality with a prior distribution, which further propagates uncertainty. In addition, the recommended model has the best retrospective performance of all models considered.

Summary of Results

Quantity/Status	As estimated or specified *last* year for: 2016	2017	As estimated or recommended *this* year for: 2017*	2018*
M (natural mortality rate)	0.1	0.1	0.097	0.097
Tier	3b	3b	3b	3b
Projected total (age 2+) biomass (t)	204,796	214,552	239,244	249,252
Projected female spawning biomass (t)	86,471	81,986	91,553	89,601
$B_{100\%}$	257,018	257,018	264,590	264,590
$B_{40\%}$	102,807	102,807	105,836	105,836
$B_{35\%}$	89,956	89,956	92,606	92,606
F_{OFL}	0.093	0.086	0.097	0.097
$maxF_{ABC}$	0.078	0.073	0.081	0.078
F_{ABC}	0.078	0.073	0.078	0.076
OFL (t)	13,937	12,747	15,931	16,145
max ABC (t)	11,795	10,782	13,509	13,688
ABC (t)	11,795	10,782	13,083	13,256
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
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 10,348 t and 10,142 t used in place of maximum permissible ABC for 2017 and 2018. This was done in response to management requests for a more accurate two-year projection.

The longline survey abundance index increased 34% from 2015 to 2016 following a 21% decrease from 2014 to 2015 which was the lowest point of the time series. The fishery abundance index decreased 12% from 2014 to 2015 and is the time series low (the 2016 data are not available yet). There was no Gulf of Alaska (GOA) trawl survey in 2016. Spawning biomass is projected to decrease slightly from 2017 to 2019, and then stabilize.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1977-2013. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 105,836 t (combined across the EBS, AI, and GOA), 0.094, and 0.113, respectively. Projected female spawning biomass (combined areas) for 2017 is 91,553 t (87% of $B_{40\%}$, or $B_{35\%}$), placing sablefish in sub-tier “b” of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.081, which translates into a 2017 ABC (combined areas) of 13,509 t. The OFL fishing mortality rate is 0.097 which translates into a 2017 OFL (combined areas) of 15,931 t. If the stock were in Tier 3a (above the $B_{40\%}$ reference point), the 2017 ABC would be 15,745 t. Model projections indicate that this stock is not subject to overfishing, overfished, nor approaching an overfished condition.

Instead of maximum permissible ABC, we recommend a 2017 ABC of 13,083 t. The maximum permissible ABC for 2017 is 15% higher than the 2016 ABC of 11,795 t. The 2015 assessment projected a 9% decrease in ABC for 2017 from 2016. We recommend a lower ABC than maximum permissible based on newly available estimates of whale depredation occurring in the fishery. Because we are including inflated survey abundance indices as a result of correcting for sperm whale depredation, this decrement is needed in conjunction to appropriately account for depredation on both the survey and in the fishery. This ABC is still 11% higher than the 2016 ABC. The methods and calculations are described in the ***Accounting for whale depredation*** section. This relatively large increase is supported by a substantial increase in the domestic longline survey index time series that offset the small decrease in the fishery abundance index seen in 2015. The fishery abundance index has been trending down since 2007. The International Pacific Halibut Commission (IPHC) GOA sablefish index was not used in the model, but was similar to the longline survey, hitting its time series low in 2015, down 36% from 2014. The 2008 year class showed potential to be large in previous assessments based on patterns in the age and length compositions. This year class is now estimated to be about 30% above average. There are preliminary indications of a large incoming 2014 year class, which was evident in the 2016 longline survey length compositions. Spawning biomass is projected to decline through 2019, and then is expected to increase assuming average recruitment is achieved in the future. Maximum permissible ABCs are projected to slowly increase to 13,688 t in 2018 and 14,361 t in 2019 (see Table 3.18).

Projected 2017 spawning biomass is 35% of unfished spawning biomass. Spawning biomass had increased from a low of 33% of unfished biomass in 2001 to 42% in 2009 and has now stabilized near 35% of unfished biomass projected for 2017. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise 5% of the 2017 spawning biomass. The last two above-average year classes, 2000 and 2008, each comprise 13% and 15% of the projected 2017 spawning biomass. The 2008 year class will be about 85% mature in 2017.

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 mean change in apportionment by area has increased annually (Figure 3.50A). 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 3.50B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.50C). 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 re-evaluated and reviewed. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2013 with the objectives of re-examining the apportionment strategy and conducting a management strategy evaluation. A spatial sablefish model has been developed, but the management strategy evaluation is in early stages of development. 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. The 2016 CIE review panel strongly stated that there was no immediate biological concern with the current apportionment, given the high mixing rates of the stock. **Therefore**, **for 2017, we recommend continuing with the apportionment fixed at the proportions used in 2016.**

Apportionment Table (before whale depredation adjustments)

Area	**2016 ABC**	Standard apportionment for 2017 ABC	**Recommended fixed apportionment for 2017 ABC***	**Difference from 2016**
Total	11,795	13,509	**13,509**	14.5%
Bering Sea	1,151	1,856	**1,318**	14.5%
Aleutians	1,557	2,263	**1,783**	14.5%
Gulf of Alaska (subtotal)	9,087	9,390	**10,408**	14.5%
Western	1,272	1,437	**1,457**	14.5%
Central	4,023	3,676	**4,608**	14.5%
W. Yakutat**	1,353	1,617	**1,550**	14.5%
E. Yak. / Southeast**	2,438	2,660	**2,793**	14.5%

* Fixed at the 2013 assessment apportionment proportions (Hanselman et al. 2012). ** Before 95:5 hook and line: trawl split shown below.

Accounting for whale depredation

For the recommended model, we now account for sperm and killer whale depredation on the longline survey and in the longline fishery. The 2016 CIE review panel was unanimously in favor of including whale depredation adjustments for the survey index and fishery catch in the assessment and for calculation of ABCs. Two studies (one for the survey and one for the fishery) that provide estimates and methods to do these adjustments are in journal review at this time, the fishery depredation paper has been recently accepted. The CIE panel had reviewed these papers and provided helpful feedback. They agreed with our proposed approach of increasing the survey CPUE at stations where sperm whales depredated, and including fishery whale depredation as catch in the fixed gear fishery. We briefly describe the methods of these studies in the section *Whale Depredation Estimation* below.

In the tables below, we begin with the standard recommended model apportioned ABC for 2017 and 2018 compared with the specified ABC in 2016. Since we are accounting for depredation in the longline survey abundance estimates, it is necessary to decrement the increased ABCs estimated by our recommended model by a projection of what future whale depredation in the fishery would be. We do this by multiplying the average of the last three complete catch years (2013-2015) of whale depredation (t) by the amount that the ABC is increasing or decreasing from the 2016 to 2017 and 2018. This amount of projected depredation is then deducted from each area ABC to produce new area ABCs for 2017 and 2018. In this case the 3 year-average depredation is multiplied by 1.145 because the 2017 ABC is recommended to increase by 14.5% from 2016.

The total change in recommended adjusted ABC is an 11% increase from the 2016 ABC. Overall, the corrections and the new recommended model result in increases to the ABC in each area between 6% and 12%, with the Western GOA seeing the smallest increase. This is because the killer whale depredation relative to total catch is highest there. The choice of using a three year average is subjective, but some number of years smoothing is needed as the estimates can be variable. We recommend this method of accounting for whale depredation because it is at the stock assessment level and does not create additional regulations or burden on in-season management.

Author recommended 2017 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2016 ABC	1,557	1,151	1,272	4,023	1,353	2,438	11,795
2017 ABC	1,783	1,318	1,457	4,608	1,550	2,793	13,509
2013-2015 avg. depredation	-42	-39	-94	-82	-71	-44	-372
Ratio 2017:2016 ABC	1.145	1.145	1.145	1.145	1.145	1.145	1.145
Deduct 3 year adjusted average	-48	-44	-108	-94	-82	-50	-426
2017 adjusted ABC*	1,735	1,274	1,349	4,514	1,468	2,743	13,083
Change from 2016	11%	11%	6%	12%	9%	12%	11%

* Before 95:5 hook and line: trawl split shown below.

Author recommended 2018 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2016 ABC	1,557	1,151	1,272	4,023	1,353	2,438	11,795
2018 ABC	1,806	1,336	1,477	4,669	1,570	2,830	13,688
2013-2015 avg. depredation	-42	-39	-94	-82	-71	-44	-372
Ratio 2018:2016 ABC	1.160	1.160	1.160	1.160	1.160	1.160	1.160
Deduct 3 year adjusted average	-48	-45	-109	-95	-83	-51	-432
2018 adjusted ABC*	1,758	1,291	1,367	4,574	1,487	2,779	13,256
Change from 2016	13%	12%	7%	14%	10%	14%	12%

* 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
	2017	1,605	2,606
	2018	1,626	2,640

Plan Team Summaries

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2015	130,000	12,425	10,522	10,522	10,330
	2016	122,000	10,326	9,087	9,087	8,886
	2017	139,000	12,279	10,074		
	2018	141,000	12,444	10,207		
BS	2015	34,000	1,574	1,333	1,333	210
	2016	25,000	1,304	1,151	1,151	417
	2017	24,000	1,551	1,274		
	2018	24,000	1,572	1,291		
AI	2015	24,000	2,128	1,802	1,802	430
	2016	23,000	1,766	1,557	1,557	319
	2017	43,000	2,101	1,735		
	2018	44,000	2,129	1,758		

Year	2016				2017		2018	
Region	OFL	ABC	TAC	Catch*	OFL	ABC**	OFL	ABC**
BS	1,304	1,151	1,151	417	1,551	1,274	1,572	1,291
AI	1,766	1,557	1,557	319	2,101	1,735	2,129	1,758
GOA	10,326	9,087	9,087	8,886	12,279	10,074	12,444	10,207
WGOA	--	1,272	1,272	928	--	1,349	--	1,367
CGOA	--	4,023	4,023	3,922	--	4,514	--	4,574
**WYAK	--	1,475	1,475	1,629	--	1,605	--	1,626
**EY/SEO	--	2,316	2,316	2,407	--	2,606	--	2,640
Total	13,397	11,795	11,795	9,623	15,931	13,083	16,145	13,256

*As of September 25, 2016 Alaska Fisheries Information Network, (www.akfin.org). **After 95:5 trawl split shown above and after whale depredation methods described above.

Responses to SSC and Plan Team Comments on Assessments in General

In this section, we list new or outstanding comments on assessments in general from the last full assessment in 2015.

"The SSC reminds the authors and PTs to follow the model numbering scheme adopted at the December 2014 meeting."
(SSC, December 2015)
For this assessment, we use the recommended model naming conventions.

"Secondly, a few assessments incorporate multiple indices that could also be used for apportionment. The Team recommends an evaluation on how best to tailor the RE model to accommodate multiple indices."
(Plan Team, November 2015)

"Finally, an area apportionment approach using the RE model which specifies a common "process error" has been developed and should be considered. This may help in some situations where observation errors are particularly high and/or vary between regions" (Plan Team, November 2015)

The sablefish model has used a 5 year exponential smoothing model of fishery and survey CPUE developed at the Council level that was based on the univariate Kalman filter model. This is similar to the random effects apportionment model, which smooths biomass by balancing process and measurement error. We will examine the random effects apportionment model in the future as different apportionment options are being examined for sablefish.

"*The Team recommends that a workgroup or subset of authors investigate applying the geostatistical approach to selected stocks.*" (Plan Team, November 2015)

"*The SSC supports the GOA PT recommendation to form a study group to explore the criteria necessary for adopting the geostatistical generalized linear mixed model approach in assessments. If this study group is formed, the SSC requests that the group be expanded to include BSAI assessment authors and members from the AFSC survey program. Among the many questions this group could address, the SSC suggests including the following questions:*

1. *Is the stratified random survey design used for the surveys correctly configured for application of the geostatistical approach?*
2. *Should the geostatistical approach be applied to all species or a select suite of species that exhibit aggregated spatial distributions and rockfish-like life histories? If application of this approach is recommended for only a subset of managed species, what life history characteristics or biological criteria would qualify a species for this approach?*
3. *What level of aggregation is necessary for application of the geostatistical approach?*
4. *If the geostatistical approach is adopted should results also be used for area apportionments?*

(SSC, December 2015)

A working group is currently being formed to investigate the criteria for use of the geostatistical generalized linear mixed model, developed by Thorson et al. 2015, within assessments performed by the AFSC. This method uses available catch data more efficiently than conventional design-based estimators resulting in reducing the interannual variability in the biomass estimates. One of the authors (DH) is a principal investigator on a proposal with Dr. Thorson to use sablefish as a case study of using multiple indices in a geostatistical model.

"Many assessments are currently exploring ways to improve model performance by re-weighting historic survey data. The SSC encourages the authors and PTs to refer to the forthcoming CAPAM data-weighting workshop report." (SSC, December 2015)

"The SSC recommends that the Gulf of Alaska Groundfish Plan Team (GOA GPT), BSAI GPT, and CPT encourage the continued use of multiple approaches to data weighting (not just the Francis (2011) method, but also including the harmonic mean and others)." (SSC, October 2016)

This assessment uses the standardized deviation of normalized residuals as a way to evaluate data weightings. Future assessments may explore how these weightings coincide with other weighting schemes discussed during the CAPAM best practices workshop.

"*The SSC requests that stock assessment authors bookmark their assessment documents and commends those that have already adopted this practice.*" (SSC, October 2016)

We have adopted the guideline SAFE document format for headings in the sablefish document including relevant bookmarks. This should allow for development of a consistent table of contents across SAFE chapters in the future.

Responses to SSC and Plan Team Comments Specific to this Assessment

October 2015

"While the SSC agrees that apportionment can remain fixed for one more year, we request that the author place a high priority on updating the apportionment in 2016. We recognize that sablefish will undergo a CIE review in 2016, and the spatially explicit area apportionment model will be reviewed as part of that process."

A Ph.D. student with the University of Alaska-Fairbanks began a project in 2013 with the objectives of re-examining the apportionment strategy and conducting a management strategy evaluation. A spatial sablefish model has been developed, but the management strategy evaluation is in early stages of development. The CIE review concluded that among reasonably distributed catch apportionment approaches, there was unlikely to be a biological concern given the high rates of movement among areas estimated for sablefish (Appendix 3C). We continue to prioritize the ongoing apportionment work and appreciate the SSC's agreement to our proposal to use the recent constant apportionment percentages again for 2017.

December 2015

1. *The SSC recommends that the authors consider updating the data to reflect growth in the recent period.*
2. *In response to increased sperm whale depredation, the NPFMC passed a motion to allow sablefish pot fishing in the GOA (see Council Minutes April 2015). The new regulations are expected to take effect in early 2016. If a pot fishery develops in the GOA, future assessments should consider methods for estimating selectivity and catchability for this new gear/region. This will ensure that projected recommendations for ABC and OFL reflect the best available information regarding the fishery impact on the sablefish population.*
3. *The SSC notes that the population trends for sablefish exhibit a long slow decline in abundance interrupted by a short period of modest population increase in the late 1980s (Figure 3.13). The amplitude of strong-year classes appears to be diminished in the recent time period (Figure 3.14). The SSC requests that in preparation for the upcoming CIE review, the author carefully review the processes believed to underlie this prolonged decline in abundance.*

1. The CIE suggested we consider better methods for handling growth in the model (Appendix 3C). We consider this a high priority, but we will need to evaluate different methods such as the recommendations that came out of the CAPAM growth workshop.
2. Pot fishing regulations are expected to be finalized at the beginning of the 2017 fishery. We will closely monitor the fleet's response to this action and work with the Catch Accounting group at AKRO to ensure we have accurate catch and effort data for examining the effects of this new gear type on selectivity and catchability of sablefish in the GOA.
3. We are working closely with researchers to develop ecosystem metrics and models that should help us further define the conditions under which sablefish exhibit low and high survival. Because of the SSC's recommendation, we included research on recruitment success of sablefish in the Terms of Reference for the recent CIE review (Appendix 3C). The CIE panel recommended to continue to conduct ecosystem research including incorporation of environmental variables in recruitment forecasts, and to conduct

research that helps improve the understanding of spawning dynamics of sablefish. We are involved in several research efforts to continue collection of ecosystem data and how it relates to sablefish health.

SSC, October 2016

"The SSC received a presentation on the recent CIE review of the sablefish stock assessment and the preliminary modelling updates. The SSC notes that the CIE review was very successful and generated some remarkably positive comments from the reviewers along with several important recommendations for model development and apportionment. As the author noted, these recommendations represent a relatively large amount of change for an assessment approach that has been quite stable in recent years. The document and presentation provided the results from a series of developments and proposed an order for these changes to be developed for the November GPT and December SSC meetings.

The SSC recommends a slightly different order of model development than the GPT. Specifically, first addressing the data related issues in an incremental manner (adding each to the previous):

1) *Update spatial areas for the longline survey.*
2) *Add the analytic CVs for the longline survey (instead of the average value obtained from the historical bootstrap analysis).*
3) *Add both the survey corrected for whale depredation, as well as the additional whale depredation estimated to be associated with the fishery. This change will require adjustment of subsequently calculated ABCs (by area) to account for predicted future whale depredation. Predictability of whale depredation may be problematic, as it may depend on apportionment, total magnitude of effort/catch, whale abundance, and other factors. The SSC noted that although the corrections for whale interactions with both the survey and fishery are reasonable, they represent an approximation for a process that cannot be unambiguously measured – inferring what was not caught in a particular place and time. For this reason, it will be important to note there will be additional unquantified uncertainty in the results, even after these corrections have been applied.*

Subsequent to these changes, the SSC recommends evaluating the approaches for incorporating additional uncertainty into the assessment. These alternatives could include tuning the standard deviations of the normalized residuals (SDNRs) for the longline survey, estimating natural mortality, estimating the maturity schedule in the assessment model, and the treatment of dome-shaped or time-varying selectivity for the fishery."

We followed the requested order of model development. For this round of models, we addressed the outstanding data issues, whale depredation, and propagating additional uncertainty. Research on sablefish maturity is currently underway, and did little to propagate uncertainty when estimated within the model, so that development will be something for the future. The aggregated age and length composition graphs that are new to this assessment give some hints as to which selectivity curves may be appropriate to re-evaluate in future models (e.g., Figure 3.24).

"The CIE review concluded that among reasonably distributed catch apportionment approaches, there was unlikely to be a biological concern given the high rates of movement among areas estimated for sablefish. This finding reinforces the strong need to elicit specific fishery objectives for apportionment and examine the performance of alternative approaches, preferably via MSE. Such work is underway by a UAF student working on a collaborative project between UAF and TSMRI/AFSC. Such an analysis may also need to consider the differential effects of whale depredation among regions. In the meantime, the SSC agrees with the proposal to use the recent constant apportionment percentages again for 2017."

We continue to keep the apportionment fixed as we are making substantial changes to the model for 2017 harvest recommendations. The UAF student conducting the MSE/apportionment evaluation is now working for AFSC and should be able to make substantial progress in the near future.

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. 2014).

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). Larval sablefish sampled by neuston net in the eastern Bering Sea fed primarily on copepod nauplii and adult copepods (Grover and Olla 1990). 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 where they exhibit rapid growth, reaching 30-40 cm by the end of their second summer (Rutecki and Varosi 1997). Gao et al. (2004) studied stable isotopes in otoliths of juvenile sablefish from Oregon and Washington and found that as the fish increased in size they shifted from midwater prey to more benthic prey. In nearshore southeast Alaska, juvenile sablefish (20-45 cm) diets included fish such as Pacific herring and smelts and invertebrates such as krill, amphipods and polychaete worms (Coutré et al. 2015). In late summer, juvenile sablefish also consumed post-spawning pacific salmon carcass remnants in high volume, revealing opportunistic scavenging (Coutré et al. 2015). 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. 2015). 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 (r = -0.74) correlated with female spawning biomass estimates from the federal stock assessment (i.e., when spawning biomass is high, they move less). Average mortality estimates from time at liberty were similar to the stock assessment.

Stock structure

Sablefish have traditionally been thought to 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). The northern population inhabits Alaska and northern British Columbia waters and the 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 (Hanselman et al. 2015, 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 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 2015 there were 1,624 landings recorded in the Alaska fishery (NOAA 2016).

Pot fishing in the IFQ fishery is legal in the BSAI regions and will be legal in the GOA likely starting with the 2017 fishery following final action taken by the Council in 2015. 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 (Table 3.2). However, catches in pots have decline significantly in recent years in the AI (only 12 t in 2015, Table 3.2).

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. The trawl fishery in the BS increased substantially in 2016 from 2015 (220 t in 2016 from 17 t in 2015).

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 is approximately 1.2 m. The gear is baited by hand or by machine, with smaller boats generally baiting by hand and larger boats generally baiting by machine. Circle hooks 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 3.3. 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 (MRA) for sablefish as the “incidental catch species” 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%. The MRA for arrowtooth flounder changed effective 2009 in the GOA, to 1% for sablefish as the basis species.

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. In April of 2015 the NPFMC passed a motion to again allow for sablefish pot fishing in the GOA in response to increased sperm whale depredation. The final motion was passed and the final regulations are expected in early 2017. We will carefully monitor the development of this gear type in the Gulf of Alaska.

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 increased during the mid-1960s. Annual catches in Alaska reached peaks in 1962, 1972, and 1988 (Table 3.1, Figure 3.1). 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 11,000 t (Figure 3.2) in 2015. 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 3.4). 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 593 t during 2010 - 2016. Discard rates are generally higher in the GOA than in the BSAI (Table 3.4).

Table 3.5 shows the average bycatch of Fishery Management Plans' (FMP) groundfish species in the sablefish target fishery during 2012 - 2016. The largest bycatch group is GOA thornyhead rockfish (640 t/year, 221 t discarded). Sharks and skates are also taken in substantial numbers and are mostly discarded.

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 9,440 t (Table 3.6). 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 (321 t/year on average) and golden king crab (13,357 individuals/year on average) (Table 3.7). Crab catches are highly variable from year to year, probably as a result of relatively low observer sampling effort in sablefish fisheries.

Data

The following table summarizes the data used for this assessment:

Source	Data	Years
Fixed gear fisheries	Catch	1960-2016
Trawl fisheries	Catch	1960-2016
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. fixed gear fishery	CPUE, length	1990-2015
	Age	1999-2015
U.S. trawl fisheries	Length	1990,1991,1999, 2005-2015
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-2016
	Age	1996-2015
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015

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, AFSC, pers. comm.). The U.S. fishery length and age data were collected by at-sea and plant observers. No age data were 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.

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, Figure 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 in all years prior to 1993 (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.

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 1,200 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 that 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.

Targeted sablefish longline sample sizes

Observer Data

For analysis of observed sablefish catch rates in the sablefish target fishery, we first have to determine the target of the set, because the target is not declared in the observer data set. To do this, we compare the catch of sablefish to other target species that are typically caught on longline gear: Greenland turbot, the sum of several rockfish species, Pacific halibut, and Pacific cod. Whichever target fishery has the greatest weight in the set is regarded as the target. Catch rates and sample sizes for observed fishery data presented here only include sets where sablefish were determined to be the target.

The total weight of all sablefish in targeted longline sets represent on average 14% of the annual IFQ hook and line catch. In 2015, 17% of the hook and line catch was observed (1,651 t). The average 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 2014 and 2015 the proportion of observed catch was higher than average in the AI (28%), lower than average in the BS (3%), and higher than average in the EY/SE (11%). There was an increase in the number of vessels with observer coverage in 2014 and 2015 in the CG (57 and 54 vessels, respectively) whereas the average number of vessels with observer coverage from 1990-2013 was 31 (Table 3.9). This was also true in EY, where the average number of vessels with observer coverage was 14 and in 2014 it increased to 33 and increased again in 2015 to 51 vessels. The number of vessels with observer coverage also increased in 2015 in WY, from an average from 1990-2014 of 21 vessel to 39 in 2015.

Killer whale depredation has been recorded by observers since 1995. Killer whales depredate on longline gear regularly in the BS, AI and WG areas and rarely in the CG. These sets are excluded from catch rate analyses in the observer data set. Whale data is not currently collected in logbooks. The percent of sablefish directed sets that are depredated by killer whales is on average 29% in the BS, 4% in the AI, and 3% in the WG. Although the rate is high in the BS, the average number of sets observed is only 28. Likely because of this small sample size, the annual range in the rate of depredation is 9-73%. In the CG there has been killer whale depredation in 14 out of 21 years (67%), but on average depredation only occurs on 1% of sets. The greatest percent of sets with depredation in the CG was 4% in 1997.

Determining if sperm whales are depredating can be subjective because whales do not take the great majority of the catch, like killer whales do. Sperm whale depredation has been recorded by observers since 2001. It is most prominent in the CG, WY, and EY areas and less common in the WG. The percent of sets that are depredated on average are 6%-7% in the CG, WY, and the EY areas. In the CG the years with the highest percent of sets depredated were 13% in 2013 and 16% in 2010; in 2015 it was closer to the average (8%). In EY the highest percent of sets with depredation were 24% in 2007 and 15% in 2010; in 2015 it was 12%, which was above average. In WY the highest percent of sets depredated was 14% in 2013 and 18% in 2014; in 2015 it was 5%, which was just below average. Sperm whale depredation occurs in the WG, but the average percent of sets is only 2%.

A new study in 2016 has estimated the additional catch mortality in the longline fishery for both sperm whales and killer whales based on observer data. We recommend incorporating this catch in the stock assessment in 2016 and the methods and results are described in the *Whale depredation estimation* section below.

Logbook Data

Logbook sample sizes are substantially higher than observer samples sizes, especially since 2004 in the GOA (Table 3.9). Logbooks include the target of the set, so no calculations are required to determine the target, unlike observer data. 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. In 2015 54% of sets that targeted sablefish came from <60 ft and 73% of the vessels that turned in logbooks were <60 ft. There is a higher proportion of the catch documented by logbooks than by observers; ~50% of the hook and line catch is documented in logbooks, compared to 14% for observer data. Some data is included in both data sets if an observer was onboard and a logbook was turned in.

Longline catch rates

Sets where there was killer whale depredation are excluded for catch rate calculations in observer data, but whale depredation is not documented in logbooks (however, the logbooks are currently being revised to begin collecting this information starting in 2017) and so no data are excluded. In general, catch rates in both data sets 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 all areas, except the WY; in WY there has been a slow downward trend in logbook data since 2009 and catch rates have been trending downward in observer data, but observer data has more annual fluctuations. For example, in 2015 in WY there was an increase in observer CPUE in 2015 and a decrease in logbook data. Because of larger sample sizes in the logbook data set, there is more confidence in these data. Catch rates were down in 2015 from 2014 in the CG, WG, and EY areas. They were up in the BS and in the AI the logbook CPUE set was up and the observer CPUE was down; however the variance was up in 2015 in the AI in both data sets.

Longline spatial and temporal patterns

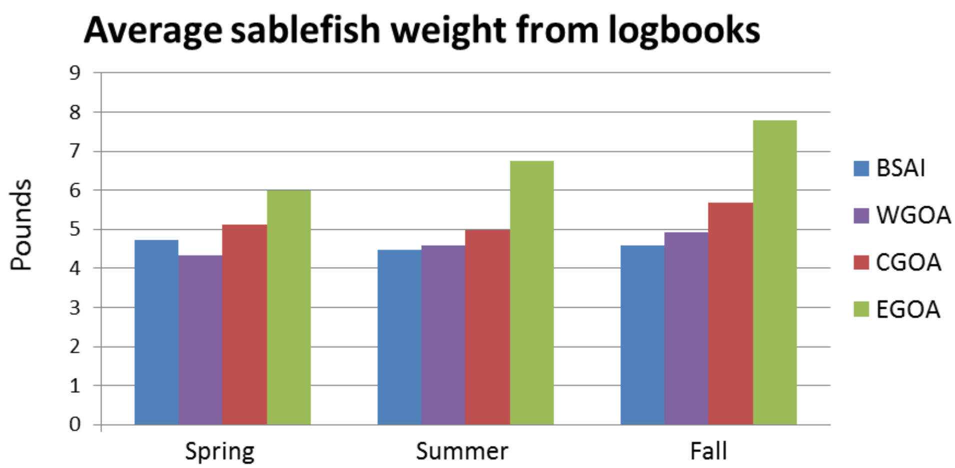
Changes in spatial or temporal patterns of the fishery may cause fishery catch rates to be unrepresentative of abundance. For example, fishers sometimes target concentrations of fish, even as geographic distribution shrinks when abundance declines (Crecco and Oveρltz 1990). This could lead to an incorrect 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, less in the summer, and least in the 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 temporal changes have emerged in the logbook or observer data.

Seasonal changes in fish size

From 2012-2015 there was an increase in the quantity of logbook data providing estimates of catch in weight and numbers. This enables us to examine the average fish weight by season and area. Data from 2012-2015 were combined to increase sample sizes. To further increase sample size, areas were aggregated into BS/AI (BSAI), CGOA, WGOA, and WY/EY/SE (EGOA). Data were included unless there was missing weight or count information or the average weight for the set was unreasonably large (i.e, the average weight was greater than the largest fish ever recorded on the longline survey over 35 years). There were very small differences between spring, summer, and fall in the west and central areas and larger differences in the EGOA (see figure below). In EGOA, the average weight in spring was 6.0

lbs, 6.7 lbs in summer, and 7.8 lbs in fall. Although fish size increases in the fall, catch rates and effort decreases.



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

Area	Spring	Summer	Fall	Total
BS/AI	1,358	948	458	2,764
WGOA	613	1,118	371	6,146
CGOA	2,573	1,242	496	4,311
EGOA	1,632	361	229	2,222

Pot fishery catch rate analysis

Pot fishery sample sizes and catch rates: Because pot data are sparser than longline data, and in some years the data is considered confidential due to fewer than 3 vessels participating, specific annual data are 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. Observed sets are determined to be targeting sablefish if sablefish comprise the greatest weight in the set. Overall, there are more vessels in both the logbook and observer data in the BS than in the AI. Since 2006, in the BS there have been from 0 to 9 vessels in logbook data and 1 to 8 vessels in observer data. In the AI, there have been from 0 to 5 vessels in logbooks and 1 to 4 in observer data.

In logbook data since 2009, the number of pots, sets, and vessels has decreased, and in 2015 there was no pot data. From 2006-2014 the average catch rate in logbook data was 29 lbs/pot in the AI (number sets (n) = 1,271) and 18 lbs/pot in the BS (n = 3,237). The average catch rate in the observer data from 2006-2015 was 11 lbs/pot (n = 1,156) in the AI and 18 lbs/pot (n = 2,996) in the BS. The effort recorded by observers has also been decreasing since 2009 in the BS and since 2011 in the AI. Pot effort has been approximately equal throughout the fishing season, unlike hook and line fishing where effort is highest in the spring.

The composition of bycatch species caught in observed pots that retained sablefish in the BS and AI is comprised mostly of arrowtooth/Kamchatka flounder, Greenland turbot, Pacific halibut, giant grenadier, snails, and golden king crab (in 2015 there were 29,029 individuals caught; Table 3.7).

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 has been aged in the years they were collected. Approximately one-half of the otoliths collected are aged annually (~1,200). 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, AFSC, 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 3.10). 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. The sablefish abundance indices were highest 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. Catches increased in the early 2000’s but have trended down since 2006.

The 2013 and 2015 survey estimates of relative abundance in numbers (RPN) were the lowest points in the domestic time series, but the 2016 increase puts the index near average. The recent low points are because of recent weak recruitment.

Whale Depredation: Killer whale depredation of the survey 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. Since 2009, depredation rates in the Bering Sea have been high, including 11 affected stations in 2013 and 9 in 2015. In the AI depredation was highest in 2012 (5 stations) but has since declined with no stations affected by killer whales in 2016.

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 fish in the catch.

Sperm whale depredation is variable, but has generally been increasing since 1998 (Table 3.11). Whales are most common in the EGOA (WY and EY/SE), but are also seen in the CGOA. In 2016 there were sperm whales depredating at 15 stations (annual range 4-21) (Table 3.11). Although sperm whales are sometimes observed in the WGOA, there was no depredation observed in 2016. Sperm whales have been depredating at one station in the AI since 2012.

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, UA – Sitka, pers. comm.). A retrospective analysis of this data indicates the effect is not significant until the 2009 data are 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 have not been adjusted for sperm whale depredation in the past, because we do not know when measurable 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). However, 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 that resolves these issues (see Appendix 3C in Hanselman et al. 2014), and is recommended starting in 2016 to adjust survey catch rates (see *Whale Depredation Estimation*).

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 the two 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 1990-2016 are moderately correlated with slope catches ($r = 0.56$). 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 2015, the opposite pattern occurred, with the gullies showing a slight uptick while the slope stations declined again. In 2016, both indices went up sharply. 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, 2012, and 2016. 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, Figure 3.10b) 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 1984-2015 are shown in Table 3.10. The GOA trawl survey index was at its lowest level of the time series in 2013, but increased 12% in 2015 from the 2013 estimate.

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. Area sizes used to calculate biomass in the RACE trawl surveys were utilized for IPHC RPN calculations.

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 more closely resembles the NMFS GOA trawl survey index described above which samples the same depths (Figure 3.10b).

While the two longline surveys have shown consistent patterns for most years, they diverged in 2010 and 2011 and again recently. In 2014 the AFSC survey index increased, while the IPHC index was stable. In 2015 the IPHC index decreased substantially and is the lowest in the time series which agrees with the AFSC index which was also at a time series low in 2015 .(Figure 3.10). 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. 2015). 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 survey CPUE estimates for NSEI and a slight uptick in 2014.

Department of Fish and Oceans of Canada

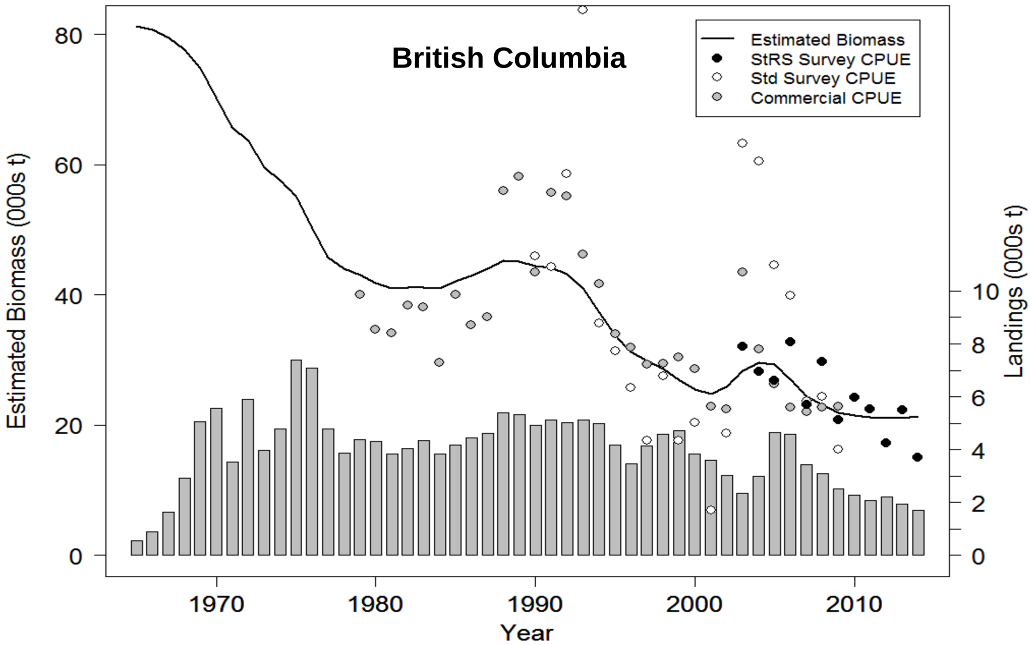
In a 2011 Science Advisory Report, DFO reported :*"Stock reconstructions suggest that stock status is currently below B_{MSY} for all scenarios, with the stock currently positioned in the mid-Cautious to low-Healthy zones."* Under these scenarios, recent harvest rates on adult sablefish potentially have 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 (see figure below) but has registered a new time series low in 2014. 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

[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: http://www.dfo-mpo.gc.ca/csas-sccs/publications/scr-rs/2014/2014_025-eng.html

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 and U.S. West Coast 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 in 2014 in the central and eastern GOA, and in 2015 in the western areas.

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 (“Moonwater”, Hanselman et al. 2010). The parameters, population dynamic, 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).

Model Alternatives

Model	Description
10.3	This is the reference model used from 2010-2015
10.3a	Model 10.3 with the revision of area sizes used to calculate the domestic longline survey abundance index
10.3b	Model 10.3a with the inclusion of analytical annual variance calculations for the domestic longline survey abundance index
16.1	Model 10.3b with domestic longline survey abundance index corrected for sperm whale depredation
16.2	Model 10.3b with additional catch mortality from both sperm and killer whales
16.3	Model 16.1 with additional catch mortality from both sperm and killer whales
16.4	Model 16.3 reweighted so that the SDNR of the domestic longling survey abundance index equals 1
16.5	Model 16.4 with natural mortality estimates with a prior CV of 10%

The models are built sequentially from the reference model 10.3; the new features are described below:

Model 10.3a

The CPUE values for the RPN index are scaled up to area sizes that were originally determined with charts and a planimeter. These area-sizes have been recalculated using modern GIS techniques (Echave et al. 2013). Most of the subareas are not vastly different (see figure below), with the exception of Spencer Gully and Bering 3 slope. Overall, more area was added in the 200-300 meter depth zone (see figure below). Going forward, we recommend adopting these new area sizes for calculation of the longline survey abundance index, and eventually for simulations on apportionment.

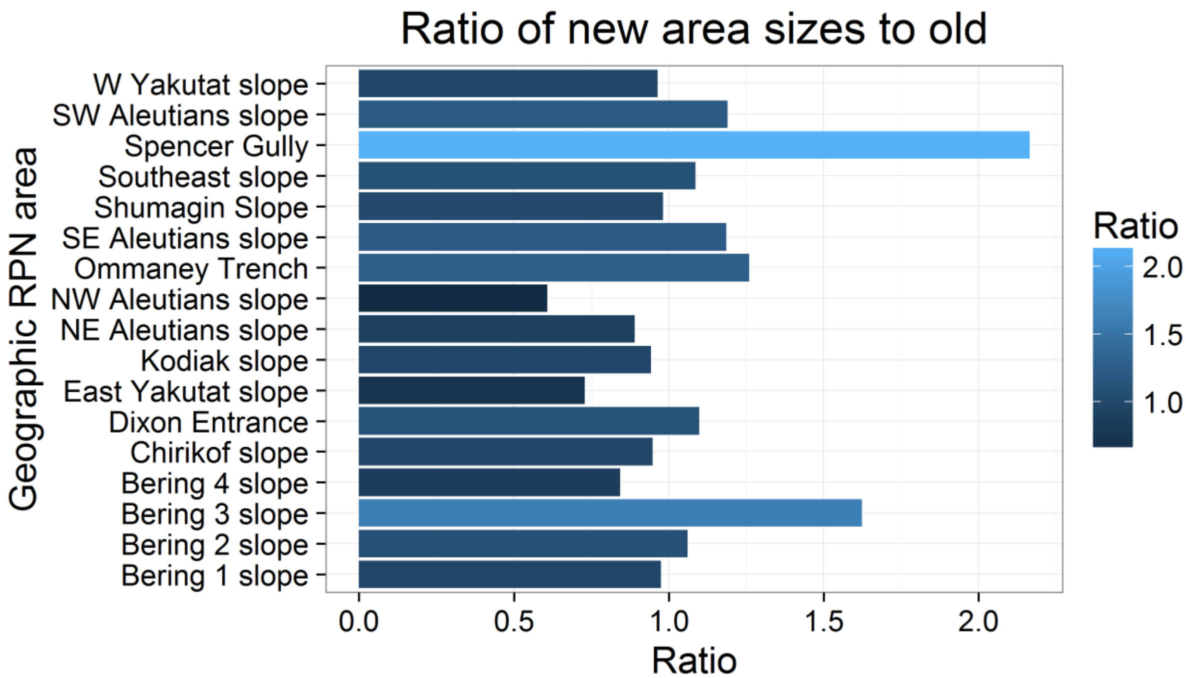


Figure. Comparison of old and new area sizes by sub-area used in calculating the AFSC longline survey relative population numbers index.

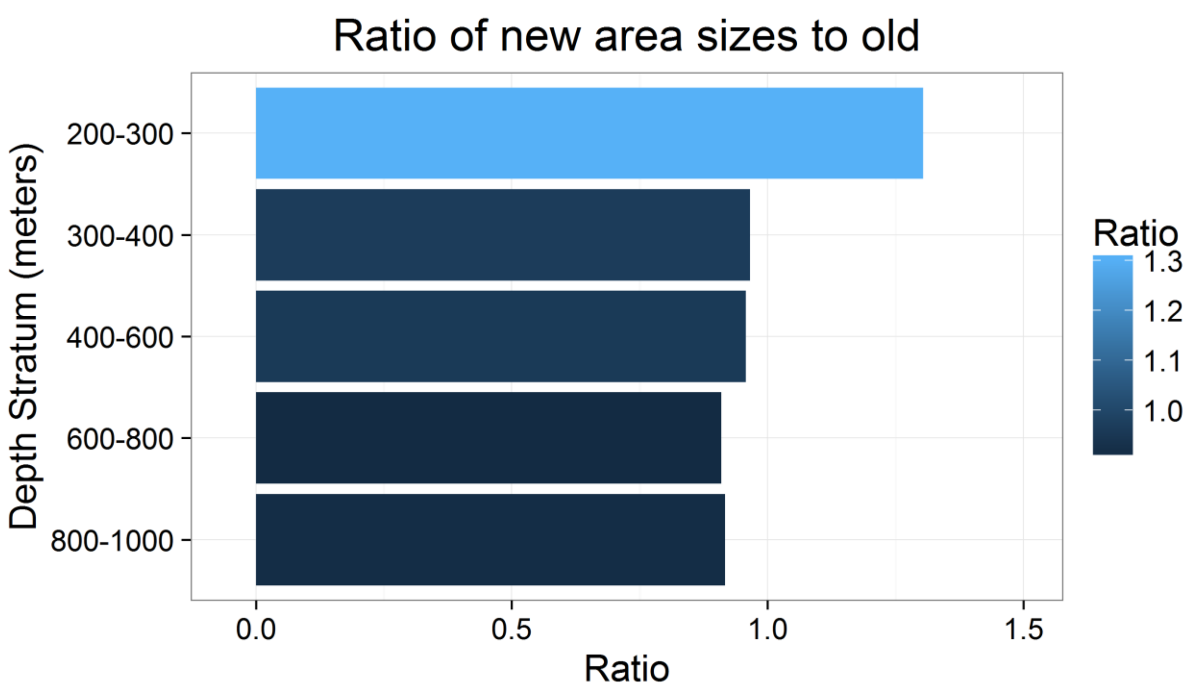


Figure. Comparison of old and new area sizes by depth-stratum used in calculating the AFSC longline survey relative population numbers index.

Model 10.3b

We have had analytically calculated variances for the longline survey relative population numbers (RPNs) available for several years, but in recent assessments we assumed a fixed 5% CV for all years, which was based on a bootstrap analysis. These new analytical variances were derived during the process of estimating the effect of sperm whales on the survey. The equations for estimating the variance of the RPNs are shown in the table below. They follow standard stratified estimation but also include the covariance between station estimates in each depth strata. The full variance equations that include the variance of the effect of whale depredation will be presented in a later document. While they are not a large departure from the previously assumed 5% CV for the domestic longline survey (see figure below), they account for annual variance and make tuning the input variance of the index more meaningful.

Equation	Description
$\hat{V}[\hat{\psi}_i] = \sum_j w_j^2 \hat{V}[\bar{\theta}_j] + 2\sum_j \sum_{m \neq j} w_j w_m \operatorname{cov}[\bar{\theta}_j, \bar{\theta}_m],$	Area variance estimate
$\hat{V}[\bar{\theta}_j] = \frac{s^2\{\hat{\theta}_k\}}{n_k}$	Sample variance for stratum/depth CPUE estimates
$\operatorname{cov}[\bar{\theta}_j, \bar{\theta}_m] = \frac{n_{k \cap z} \operatorname{cov}[\{\hat{\theta}_k\}, \{\hat{\theta}_z\}]}{n_k n_z}$	Covariance between station estimates by depth stratum
$\hat{V}[\hat{\psi}_{Total}] = \sum_i \hat{V}[\hat{\psi}_i]$	Total variance for total RPN

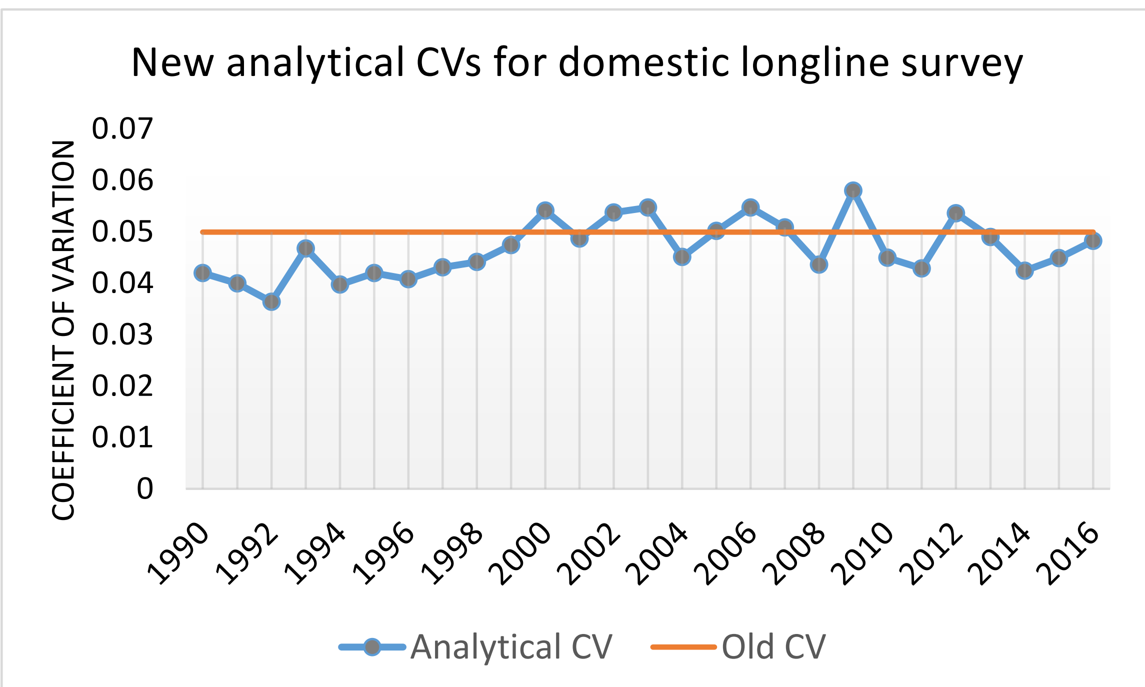


Figure. Coefficients of variation for the domestic longline RPNs for sablefish. Orange line is the traditional assumption of 5% based on historic bootstrap analyses.

Model 16.1

While the killer whale affected skates on the longline survey have always been removed, this model also accounts for sperm whale depredation on the longline survey. The recent CIE review was unanimously in favor of including whale depredation adjustments for the survey index and fishery catch in the assessment and for calculation of ABCs. Two studies (one for the survey and one for the fishery) that provide estimates and methods to do these adjustments are in journal review at this time. The panel reviewed these papers and provided helpful feedback. They agreed with our proposed approach of increasing the survey CPUE at stations where whales depredated from the results of a Generalized Linear Mixed Effects Model. These survey corrections were described in the *Whale Depredation Estimation* section and are presented in Table 3.13.

Model 16.2

Model 16.2 incorporates sperm and killer whale depredation in the fishery as an additional source of catch from the fixed gear fishery. These catch estimates were described in the *Whale Depredation Estimation* section and are presented in Figure 3.16.

Model 16.3

Model 16.3 incorporates sperm and killer whale depredation in the fishery as an additional source of catch from the fixed gear fishery and the corrections to the survey index for sperm whale depredation described in the *Whale Depredation Estimation* section. This model has both whale depredation additions that are included in Models 16.1 and 16.2.

Model 16.4

The CIE suggested three major axes of exploration to address the “overly-precise” estimates of spawning biomass that result from the stock assessment model: 1) estimate more parameters (particularly natural mortality), 2) use the same method used to reweight the compositional data to reweight the index data, and 3) show managers more of the structural uncertainty of assumptions through sensitivity runs and figures. For Model 16.4, we tuned the standardized deviation of the normalized residuals (SDNR) for the domestic longline survey to be one while maintaining the SDNR of near 1 for the compositional data for sources where we had ages, and sources where we only had lengths (e.g., the trawl fishery). We weighted the rest of the abundance indices the same as the domestic longline survey (0.448 versus 1) which resulted in SDNRs close to one for the cooperative survey and the GOA trawl survey, but lower than one for the fishery CPUE indices.

Model 16.5

Natural mortality (M) is one of the most difficult parameters to estimate in stock assessments so it is commonly fixed to avoid confounding with other parameters such as catchability (i.e., it's difficult to estimate both of these at the same time). The sablefish model estimates many catchability parameters and at one time also estimated natural mortality, but with a tight prior to constrain it near 0.10. Because the prior essentially constrained M to 0.10, a fixed value of 0.10 was adopted in recent assessments. For this model we estimate M with a prior CV of 10% and all the catchabilities simultaneously to attempt to further propagate uncertainty.

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 (except Model 16.5)	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, with 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 maturity-length 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. Skipped spawners were primarily found in gullies on the shelf and was positively correlated with age. A second survey will took place in December 2015 in the same areas that were sampled in 2011. Future analyses will aim to develop and evaluate methods to incorporate skipped spawning into maturity ogives and to better utilize the time series of visual maturity estimates.

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. This 2016 assessment recommends returning to estimating natural mortality with a prior CV of 10% to propagate more uncertainty in the model. Efforts to estimate natural mortality as a completely free parameter resulted in model instability because of confounding with the multiple catchability parameters.

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

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

where σ_i is the input sampling 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

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

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

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 used these weightings until this year. The 2016 CIE review panel felt strongly that the model was using the longline survey too precisely in the model which resulted in overly precise model outputs. For the 2016 assessment we tuned the domestic longline survey to have an SDNR of one, while maintaining the other previously tuned size and age compositions at an SDNR of one. The rest of the abundance indices were given the same weight as the domestic longline survey to maintain the relative weighting.

Whale depredation estimation

Sperm whales on the longline survey

Sets on the AFSC longline survey impacted by killer whale depredation have always been removed from calculations because of the significant and variable impacts killer whales can have on catch rates. Sperm whale depredation is more difficult to detect and has not previously been considered when calculating catch rates. Presence and evidence of depredation by sperm whales on the AFSC longline survey have increased significantly over time (Figure 3.13). Fishermen accounts support similar trends in the commercial fishery. This prompted a number of model explorations to estimate the sperm whale effect on the longline survey. In 2016, we submitted for journal review a comprehensive examination of different modeling techniques (Hanselman et al. *In Review*).

Two indicators of sperm whale depredation were tracked at the station level: 1) “presence” of sperm whales (e.g., sightings within 100 m of the vessel); and 2) “evidence” of depredation, when sperm whales were present and retrieved sablefish were damaged in characteristic ways (e.g., missing body parts, crushed tissue, blunt tooth marks, shredded bodies). Depredation estimates were compared for several Generalized Linear Models (GLMs) with fixed-effects and Generalized Linear Mixed Models (GLMMs) including mixed-effects. Model fitting proceeded in two stages, first with area-specific models and then across-area models. Explanatory variables included year, depth strata, station, management area, and total number of effective hooks. Simulations were also conducted to examine the statistical properties of alternative model forms and assess the implications of autocorrelation in the CPUE data.

From 1998 to 2015, data were collected at 628 longline survey year/station combinations across the CG, WY, and EY/SE management areas. Sperm whales were present in 269 cases (43%), with evidence of depredation in 189 cases (30%). The proportion of stations with presence or evidence data varied considerably across years and areas (Figure 3.14), but was generally low for the CGOA area compared to WY and EY/SE. There were significant ($P \leq 0.05$) increasing trends across years for sperm whale presence among CGOA and EY/SE stations, and for evidence of depredation among EY/SE stations (Figure 3.13). Model evaluation and simulations showed that mixed-effect models were superior to fixed-effect models in terms of precision and confidence interval coverage of the true value (Figure 3.14). Depredation estimates for stations with sperm whale presence only (i.e., no evidence of damaged fish) tended to be weaker and more variable than those for stations with evidence of depredation; therefore, the evidence flag was used in the stock assessment application. Sablefish catch rate reductions on the AFSC longline survey ranged from 12%-18% for area-specific and across-area models (Table 3.13). Table 3.13 shows the effect sizes estimated for evidence of sperm whale depredation on the survey at a station for the recommended mixed-effects model, including an area-wide effect and area-specific effects. The area-wide model provided stronger inferences and were recommended for use in the stock assessment.

For Models 16.1, 16.3, 16.4, and 16.5 we use the result of Model 1 (Table 3.13), which inflates catches at survey stations with depredation evidence by a factor of 1.14 (i.e., 1/0.88). The standard error (0.03) and covariance of this estimate is included in the total variance of the relative population number estimate from the index. In the study, correcting for sperm whale depredation in the assessment resulted in a 3% increase in estimated female spawning biomass in the terminal year and a 6% higher quota recommendation.

Killer and sperm whales in the fishery

Killer whales have a long history of depredating the commercial sablefish fishery and AFSC longline survey, while sperm whales have become a problem more recently. In the study described in the section above, we estimated the sperm whale effect and recommended using it to correct survey estimates. Increasing survey estimates of abundance in the sablefish assessment needs to be done in tandem with correcting for depredation in the commercial fishery. We submitted a manuscript for journal review that advances our understanding of the impact of killer whale and sperm whale depredation on the commercial sablefish fishery in Alaska and evaluates the impact depredation in the fishery may have on the annual federal sablefish assessment (Peterson and Hanselman *In Press*).

We used data from the observer program 1995-2016, comparing CPUE data on “good performance” sets with those with “considerable whale depredation.” A two-step approach was used to estimate commercial sablefish fishery catch removals associated with whale depredation in Alaska: 1) a Generalized Additive Mixed Modeling (GAMM) approach was used to estimate the whale effect on commercial sablefish fishery catch rates by management area; 2), the proportion of sets impacted by killer whales and sperm whales was modeled as a function of fishery characteristics to estimate overall catch removals due to whales in gridded areas (1/3° by 1/3°, approximately 36 km by 25 km). Sablefish catches per grid were estimated based on the Catch-in-Area Trends database (S. Lewis, October 2016, NMFS AK Regional Office, pers. comm.), which blends processor-based data, mandatory state of Alaska reported landings data, observer data when available, and Vessel Monitoring System data (available 2003-2014). Due to the limited nature of the observer data (partial coverage in many fisheries), these blended data sets are integrated into the NMFS Catch Accounting System to track groundfish fishery harvests annually.

The final model for estimating CPUE reductions due to whales included depth, location (latitude, longitude), Julian day, grenadier CPUE and Pacific halibut CPUE, whale depredation, year and vessel. Killer whale depredation was more severe (catch rates declined by 45%-70%) than sperm whale depredation (24%-29%; Table 3.13). A Generalized Additive Model (GAM) with a zero-inflated Poisson distribution was next used to evaluate fishery characteristics associated with depredation in order to estimate sablefish catch removals by gridded area; significant covariates included higher sablefish catches, location, set length, and average vessel lengths. Total model-estimated sablefish catch removals during 1995-2016 ranged from 1235 t – 2450 t by killer whales in western Alaska management areas and 651 t – 1204 t by sperm whales in the Gulf of Alaska from 2001-2016 (Figures 3.15, 3.16). For a relative frame of reference on the magnitude of depredation, the model-predicted estimates of catch removals due to killer whales were 6.7% in the AI, 13.3% in the BS, and 7.6% in the WGOA. Sperm whale-associated removals were minimal in comparison to overall fishery catches in the Gulf of Alaska (~1%). We use these estimates as additional fixed gear catch in Models 16.2 – 16.5.

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
Mean recruitment	μ_r	1
Natural mortality	M	1
Spawners-per-recruit levels	F_{35}, F_{40}, F_{50}	3
Recruitment deviations	τ_y	84
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	114
Fishery selectivity	fs_a	9
Survey selectivity	ss_a	8
Total		228

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 1933-2015.

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 1960-2016 for each fishery.

Selectivity is represented using a function and is separately estimated by sex for the longline survey, fixed-gear fishery (pot and longline 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 3 million MCMC simulations drawn from the posterior distribution. The chain was thinned to 5,000 parameter draws to remove serial correlation between successive draws and a burn-in of 10% was removed from the beginning of the chain. This was determined to be sufficient through simple chain plots, and comparing the means and standard deviations of the first half of the chain with the second half.

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 1979-2014 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
$s_{a,s}^g$	Selectivity at age a for gear type g and sex s
$A_{50\%}, d_{50\%}$	Age at 50% selection for ascending limb, age at 50% deselection for descending limb
δ	Slope/shape parameters for different logistic curves
$\mathbf{A}$	Ageing-error matrix dimensioned $a_+ \times a_+$
$\mathbf{A}_s^l$	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
$P_{y,l,s}^g, \hat{P}_{y,l,s}^g$	Observed and predicted proportion at length l for gear g in year y and sex s
$P_{y,a,s}^g, \hat{P}_{y,a,s}^g$	Observed and predicted proportion at observed age a for gear g in year y and sex s
ψ_y^g	Sample size assumed for gear g in year y (for multinomial likelihood)
n_g	Number of years that age (or length) composition is available for gear g
$q_{\mu,g}, \sigma_{q,g}$	Prior mean, standard deviation for catchability coefficient for gear g
M_μ, σ_M	Prior mean, standard deviation for natural mortality
$\sigma_{r_\mu}, \sigma_{\sigma_r}$	Prior mean, standard deviation for recruitment variability

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

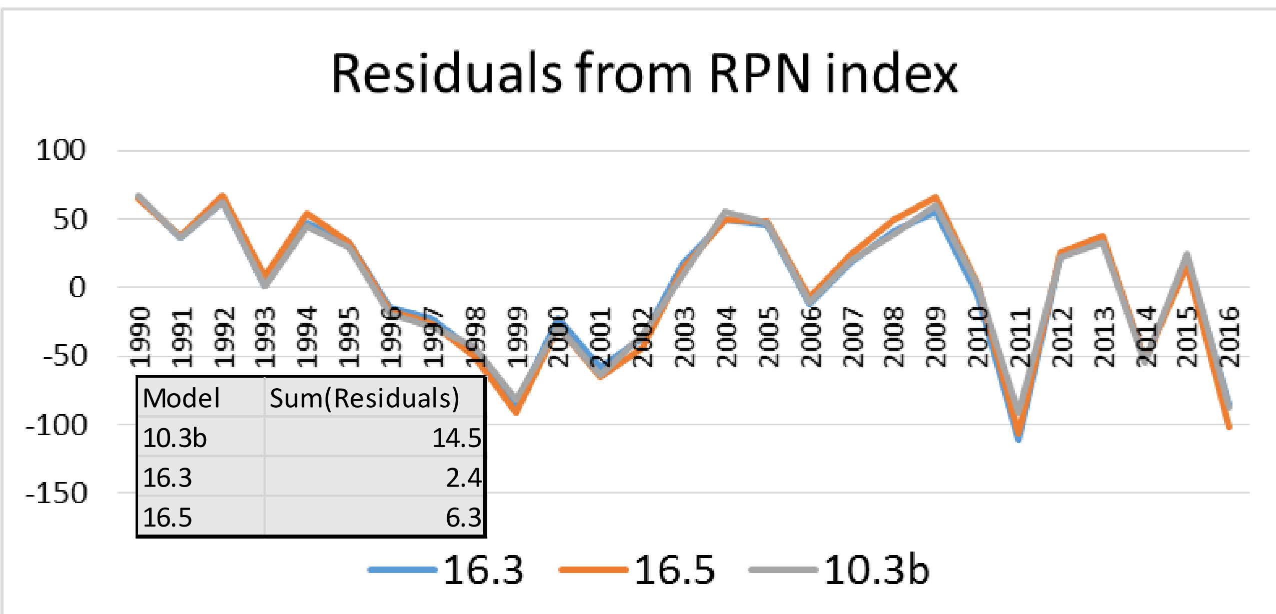
For this assessment, we present the base assessment model and seven new model alternatives. We present the series of 10.3 models as representing minor assessment changes, while the 16 series represent major or benchmark changes in the sablefish assessment.

Box 2: Model comparison by contribution to the objective function (negative log-likelihood values) and key parameters of the 2015 reference model (10.3) and eight model options for 2016.

Year	2015	2016							
Likelihood Components	10.3	10.3	10.3a	10.3b	16.1	16.2	16.3	16.4	16.5
Catch	6	6	7	8	8	8	8	2	2
Dom. LL survey RPN	49	58	57	62	63	62	62	32	32
Coop. LL survey RPN	18	29	30	29	29	30	30	16	16
Dom. LL fishery RPW	10	11	10	11	12	11	12	6	6
Jap. LL fishery RPW	13	19	19	18	19	13	12	10	7
NMFS trawl survey	22	30	30	32	33	32	33	14	14
Dom. LL survey ages	192	202	195	197	196	197	195	200	200
Dom. LL fishery ages	264	284	286	287	286	286	285	219	218
Dom. LL survey lengths	64	68	66	67	67	67	66	69	69
Coop LL survey ages	144	144	145	143	144	144	144	142	142
Coop LL survey lengths	46	45	45	45	45	45	45	45	45
NMFS trawl lengths	314	322	323	323	322	323	323	332	332
Dom. LL fishery lengths	211	217	215	217	218	218	220	38	38
Dom. trawl fish. lengths	204	203	205	204	203	204	204	319	319
Data likelihood	1559	1639	1633	1643	1647	1638	1639	1445	1442
Objective function value	1579	1674	1667	1678	1681	1676	1677	1479	1479
Key parameters									
Number of parameters	224	227	227	227	227	227	227	227	228
$B_{next\ year}$ (Female spawning (kt) biomass for next year)	86	85	82	87	90	88	93	97	94
$B_{40\%}$ (Female spawning biomass (kt))	103	98	97	99	100	100	103	105	106
B_{1960} (Female spawning biomass (kt))	174	184	183	181	185	194	207	189	203
$B_{0\%}$ (Female spawning biomass (kt))	257	246	243	247	250	251	258	263	265
SPR% current	33.6	34.6	33.6	35.1	36.2	35.1	36.1	36.8	35.6
$F_{40\%}$	0.094	0.098	0.098	0.098	0.098	0.098	0.097	0.097	0.095
$F_{40\%}$ (Tier 3b adjusted)	0.078	0.082	0.080	0.084	0.086	0.083	0.085	0.086	0.081
ABC(kt)	**11.8**	**12.8**	**12.1**	**13.3**	**14.2**	**13.5**	**14.7**	**14.7**	**13.5**
$q_{Domestic\ LL\ survey}$	7.6	7.9	7.8	7.6	7.5	7.4	7.3	7.1	7.3
$q_{Japanese\ LL\ survey}$	6.2	5.7	5.8	5.7	5.7	5.6	5.5	5.5	5.6
$q_{Domestic\ LL\ fishery}$	5.7	5.9	6.2	5.9	5.8	5.8	5.5	5.3	5.5
$q_{Trawl\ Survey}$	1.3	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.2
$a_{50\%}$ (domestic LL survey selectivity)	3.8	3.7	3.7	3.7	3.7	3.7	3.8	3.8	4.2
$a_{50\%}$ (LL fishery selectivity)	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
μ_r (average recruitment)	16.8	16.3	16.1	16.4	16.6	16.6	17.1	17.3	16.5
σ_r (recruitment variability)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

The eight models are similar in most aspects except for differences in data inputs and the variance assumptions. 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, (4) parsimony, and (5) retrospective performance. For this assessment, based on the 2016 CIE review recommendations (Appendix 3C), we also consider (6) propagation of uncertainty, and (7) accounting for whale depredation in the longline fishery and longline survey.

Because the models presented have slightly different data and variance assumptions, it is not possible to directly compare their negative log likelihoods so we cannot use the first criterion above. The exception is Models 16.4 and 16.5 which use identical data, but Model 16.5 estimates one more parameter. The negative log likelihood of 16.5 is slightly lower for the data components. All of the models generally produce good visual fits to the data, and biologically reasonable patterns of recruitment, abundance, and selectivities. Rather than compare annual length and age composition fits among models, we show aggregated observed composition data along with predictions from each model (Figures 3.22, 3.25, 3.28, 3.31, 3.33, 3.36, 3.39) It can be seen from these plots that despite substantial downweighting of the abundance indices in models 16.4 and 16.5, it has a minimal effect on the fits to the compositional data. In addition, the fits to the survey indices are compared below as residuals because the three models are fit to different indices. It can be seen that the two whale corrected models (16.3 and 16.5) have a lower sum of residuals than the uncorrected model (10.3b), despite Model 16.5 having a lower weight on the index than Model 10.3b. An exception to the generally good fits to the data is the fit to the recent fishery age compositions, which fit the plus group poorly in the last several years of age composition data (see further discussion in ***Goodness of fit*** below). In terms of parsimony, Model 16.5 is the most complex, but estimates only one additional parameter compared to the other models.



The retrospective performance of the models were all relatively good (see Box 3). The Mohn's revised ρ parameter was negative for all 8 models indicating a slight tendency to underestimate recent spawning biomass (the last 10 years). Model 16.5 was the best in this category and model 16.3 was the worst. Wood's Hole ρ is a measure of the retrospective bias over the entire time series. Model 16.1 was the best, while Model 16.2 was the worst. Root mean squared error is a measure of the total amount of variability from the terminal year of previous model runs. In this category Model 10.3 was the lowest while Model 16.3 was the highest. Finally, Hanselman's φ is the ratio of Mohn's ρ to Wood's Hole ρ. Values less than 1 indicate that more of the retrospective bias is historic, while values above 1 indicate that most of the bias is recent. Hanselman et al. (2013) suggested that since recent estimates are usually more important, this might be a statistic to examine. Only models 16.2 and 16.5 are below 1 in this category. The overall rank is the average of the four rankings across the statistics, in which case 16.5 was the best. The reference case, Model 10.3 was also a reasonably good performer. The Mohn's ρ is the most common statistic examined and Model 16.5 is clearly the best in that respect.

Box 3. Comparison of retrospective statistics across 8 candidate 2016 sablefish models. Statistics are defined in Hanselman et al. (2013) Retrospective Investigations Group report.

Model	Mohn's ρ	Rank	Wood's Hole ρ	Rank	RMSE	Rank	Hansel. φ	Rank	**Overall Rank**
16.5	-0.028	1	-0.032	3	0.122	4	0.878	1	**2.3**
16.1	-0.071	2	-0.018	1	0.121	3	3.985	8	**3.5**
10.3	-0.077	6	-0.050	4	0.113	1	1.547	5	**4.0**
16.4	-0.091	5	-0.067	6	0.115	2	1.344	3	**4.0**
10.3a	-0.090	4	-0.029	2	0.133	5	3.080	7	**4.5**
10.3b	-0.105	6	-0.062	5	0.141	6	1.705	6	**5.8**
16.2	-0.120	7	-0.133	8	0.209	7	0.897	2	**6.0**
16.3	-0.124	8	-0.081	7	0.229	8	1.538	4	**6.8**

In terms of the goal of increasing the uncertainty of model results, models 16.4 and 16.5, while still relatively precise, show a substantial increase in CV on the results with respect to the 2015 and 2016 models 10.3 (see Box 4 below). At the September Plan Team meeting, we presented a model with natural mortality estimated with no prior. Upon further testing, it was deemed necessary to constrain this parameter with a prior because of the confounding between the catchability parameters and M as the joint likelihoods were rather flat (see figure below). The less M is constrained, the more uncertainty is propagated, but also resulted in increasing model instability.

Box 4. Comparisons of standardized deviations of normalized residuals and uncertainty in key parameters across models.

Year	2015	2016							
Model	10.3	10.3	10.3a	10.3b	16.1	16.2	16.3	16.4	16.5
SDNR									
Dom. LL survey RPN	1.92	2.03	2.00	2.10	2.10	2.09	2.08	1.00	**1.00**
Coop. LL survey RPN	1.50	1.91	1.93	1.90	1.91	1.91	1.93	0.95	0.94
Dom. LL fishery RPW	0.87	0.93	0.86	0.92	0.98	0.91	0.95	0.45	0.45
Jap. LL fishery RPW	1.29	1.59	1.62	1.53	1.60	1.30	1.23	0.76	0.62
NMFS trawl survey	1.82	2.24	2.21	2.29	2.34	2.30	2.35	0.99	0.99
Fishery ages	1.14	1.15	1.15	1.15	1.15	1.15	1.15	1.01	**1.00**
Fixed fish. lengths	0.89	0.88	0.88	0.88	0.88	0.88	0.89	0.36	0.36
Trawl fish. lengths	0.84	0.81	0.82	0.81	0.81	0.81	0.81	1.01	**1.00**
Survey ages	1.02	1.01	1.01	1.00	1.01	1.01	1.01	1.00	**1.00**
Dom. LL survey lengths	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Coop. LL survey lengths	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
NMFS trawl survey lengths	0.97	0.98	0.98	0.98	0.98	0.98	0.98	1.00	**1.00**
Precision/parameters									
2016 SSB (kt)	86.6	83.2	80.1	84.9	88.6	86.4	91.3	94.3	91.6
2016 SSB CV	4%	5%	5%	4%	4%	4%	4%	6%	10%
ABC CV	7%	9%	9%	9%	9%	9%	9%	12%	19%
M	0.1	0.1	0.1	0.100	0.100	0.100	0.100	0.100	0.097
Domestic q	7.63	7.91	7.84	7.56	7.54	7.43	7.30	7.09	7.33
-lnL	1,559	1,639	**1,633**	**1,643**	**1,647**	**1,638**	**1,639**	**1,445**	**1,442**

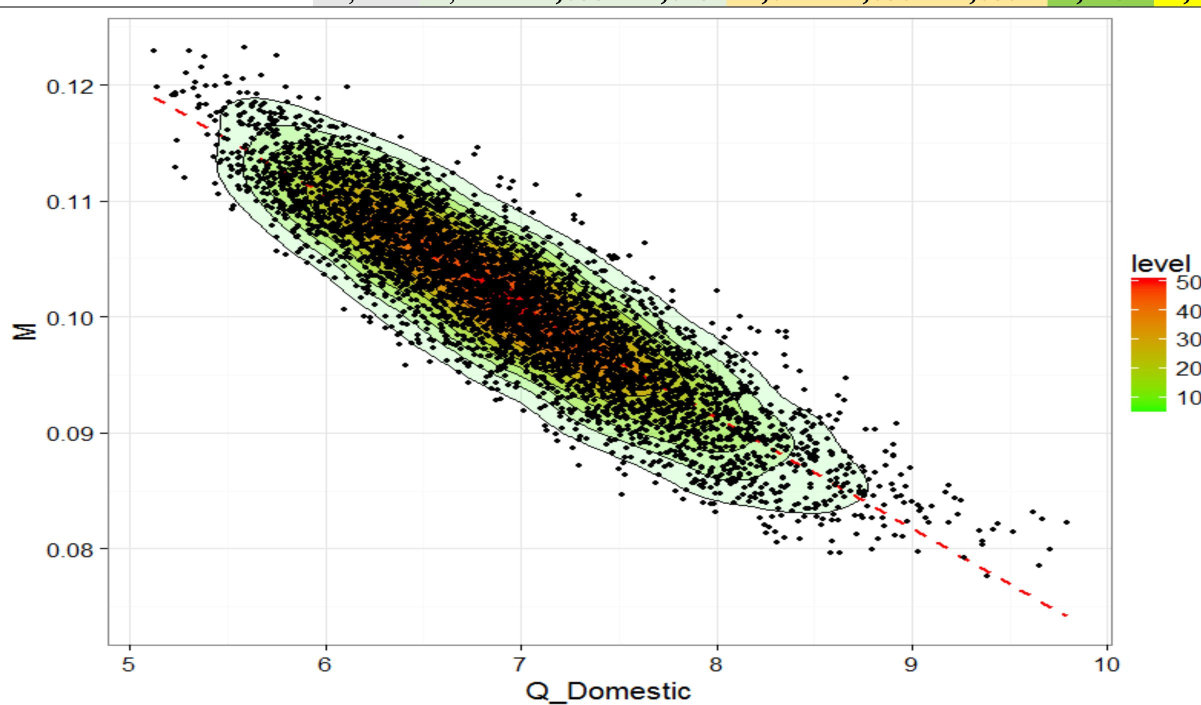


Figure. Joint posterior distribution of natural mortality and catchability for the domestic longline survey.

Models 16.1 – 16.5 incorporate whale depredation estimates. Models 16.1 – 16.3 are closely comparable to Model 10.3b and do not fit the data much differently or offer widely varying views of current stock status or management outcomes. Models 16.1 and 16.5, which include the inflation for sperm whale depredation on the survey, do the best retrospectively. The models that account for additional mortality in the fishery (16.2 and 16.3), but do not reweight the longline survey or estimate natural mortality do relatively poorly retrospectively. Generally, models 16.3 – 16.5 satisfy the criteria of accounting for both types of depredation, and Model 16.5 is the best performer on the one comparable criterion across all models (retrospective bias).

Overall, Model 16.5 is the superior model judged by our criterion. It propagates the most additional uncertainty, accounts for whale depredation, and has good retrospective behavior. Therefore, we recommend Model 16.5 for setting management targets for 2017 and 2018. The following results refer to Model 16.5 unless otherwise noted.

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 3.14, Figure 3.17) 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 3.17, 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 to a decreasing trend in 2008 (Figure 3.17). The low 2012-2013 longline survey RPN values changed what was a stable trend in 2011 to a downward trajectory in 2016.

Projected 2017 spawning biomass is 35% of unfished spawning biomass. Spawning biomass had increased from a low of 33% of unfished biomass in 2001 to 42% in 2009 and has now stabilized near 35% of unfished biomass projected for 2017. The 1997 year class has been an important contributor to the population; however, it has been reduced and is predicted to comprise 5% of the 2017 spawning biomass. The last two above-average year classes, 2000 and 2008, each comprise 13% and 15% of the projected 2017 spawning biomass. The 2008 year class will be about 85% mature in 2017 (Figure 3.19).

Recruitment trends

Annual estimated recruitment varies widely (Figure 3.18). 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. Larger age one sablefish were appearing in the 2015 trawl survey length composition in the 41-43 cm bins (Figures 3.20, 3.21) and are clearly evident at age two in the longline survey length composition in 2016 (Figure 3.37). 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 3.23 -3.27). The 2015 survey age composition is dominated by 2008-2010 year classes which make up more than 35% of the age composition. 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 3.23).

Average recruitment during 1979-2016 was 16.5 million 2-year-old sablefish per year, which is slightly less than average recruitment during 1958-2016. 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. Because abundance is estimated to be slightly higher this year, the 2008 year class is estimated to be higher than last year's result.

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 and 2015. The Gulf of Alaska NMFS bottom trawl survey caught a substantial number of one year old sablefish in 2015, particularly in the Western GOA. Surface trawl surveys in the Gulf of Alaska also reported finding YOY sablefish in Pacific pomfret stomachs in the summer of 2015 (C. Debenham, September, 2015, NOAA, pers. comm.). Charter fishermen in the CGOA also reported frequent catches of one year old sablefish in 2015 while targeting coho salmon (K. Echave, September, 2015, NOAA, pers. comm.).

Sablefish recruitment varies greatly from year to year (Figure 3.18), but shows some relationship to environmental conditions. Sablefish recruitment success is related to winter current direction and water temperature; above average recruitment is more common for years with northerly drift or above average sea surface temperature (Sigler et al. 2001). Sablefish recruitment success 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 3.18, 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. (2014) 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 within 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 does not fit as well as the longline survey, because the index has a higher variance, and had been tracking below model predictions since 2008. All age compositions were predicted well, except for not quite reaching the magnitude of the 1997 and 2000 year classes in several years (Figures 3.24, 3.27, 3.32). The model is not fitting the 2008 year class well in 2014 because of its weak presence in the 2013 age composition. The 2015 predicted survey ages expected more middle age fish and fewer fish between 5-7; this age composition was also associated with the lowest longline survey RPN in the time series. The aggregated age compositions show that the cooperative survey ages are fit extremely well, while the domestic survey ages seem to imply a slight dome-shapedness to the selectivity (missing age 5-7 sablefish, and underestimating the plus group). 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 3.31, 3.32). The aggregated length compositions show good predictions on average. 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 3.21, 3.22., 3.34, 3.35). On average, however the trawl lengths were fit well by the model. 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 3.37, 338). By 2014, the 2008 year class has grown large enough (in length) to be included in the main groups in the length compositions. Until 2013, the fixed gear age compositions were well fit. 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. This problem is similar, but lessened in the 2014 and 2015 age compositions. 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 3.40). The age-of-50% selection is 4.2 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 3.40). 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, younger 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 3.40). The trawl survey selectivity curves differ between males and females, where males stay selected by the trawl survey longer (Figure 3.40). 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 3.41). 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 3.42 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 2017 and 2018 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. MCMC standard deviations were generally slightly higher in all cases which shows that there is more uncertainty captured through MCMC.

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 (2006-2015) 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 several years of the retrospective plot we see that estimates of spawning biomass were slightly higher for the last few years in the next assessment year (Figure 3.43). 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 ρ which indicates the size and direction of the bias. The revised Mohn's ρ of -0.028 is very low (a small negative 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 3.44). Recruitment estimates appear to have little trend over time with the exception of the 2010 year class which appears to be increasing (Figure 3.45). Only the 2008 and 2013 year classes started near average indicating low presence of age 2 sablefish 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.

Harvest Recommendations

Reference fishing mortality rate

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1977-2013. The updated point estimates of $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ from this assessment are 105,836 t (combined across the EBS, AI, and GOA), 0.094, and 0.113, respectively. Projected female spawning biomass (combined areas) for 2017 is 91,553 t (87% of $B_{40\%}$, or $B_{35\%}$), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.081, which translates into a 2017 ABC (combined areas) of 13,509 t. The OFL fishing mortality rate is 0.097 which translates into a 2017 OFL (combined areas) of 15,931 t. If the stock were in Tier 3a (above the $B_{40\%}$ reference point), the 2017 ABC would be 15,745 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 by Amendment 56 for each stock managed under Tiers 1, 2, or 3. 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 2016 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2017 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2016. 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 2016 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 2017, 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 2017 and 2018, 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 2013-2015 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 2011-2015 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, 1) above its MSY level in 2016, or 2) above ½ of its MSY level in 2016 and above its MSY level in 2026 under this scenario, then the stock is not overfished.)

Scenario 7: In 2017 and 2018, 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 2018, or 2) above 1/2 of its MSY level in 2018 and expected to be above its MSY level in 2028 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 2017 and 2018. 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 2017, it does not provide the best estimate of OFL for 2018, because the mean 2017 catch under Scenario 6 is predicated on the 2017 catch being equal to the 2017 OFL, whereas the actual 2017 catch will likely be less than the 2017 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 (2015) is 10,971 t. This is less than the 2015 OFL of 16,128 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 2016:

a. If spawning biomass for 2016 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2016 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2016 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 2026 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 2018 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2018 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2018 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2028. If the mean spawning biomass for 2028 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. 2013-2015 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 (because sablefish are currently in Tier 3b).

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 110,000 t (Figure 3.46). 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 3.47). 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 0.77. During the next three years, the probability of being below $B_{17.5\%}$ is near zero, the probability of being below $B_{35\%}$ is less than 0.80, and the probability of staying below $B_{40\%}$ is near 100% in the short term (Figure 3.48).

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 3,000,000 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 1979-2015 recruitments, and this projection predicts that the mean and median spawning biomass will stay below $B_{35\%}$ until after 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

Instead of maximum permissible ABC, we recommend a 2017 ABC of 13,083 t. The maximum permissible ABC for 2017 is 15% higher than the 2016 ABC of 11,795 t. The 2015 assessment projected a 9% decrease in ABC for 2017 from 2016. We recommend a lower ABC than maximum permissible based on newly available estimates of whale depredation occurring in the fishery. Because we are including inflated survey abundance indices as a result of correcting for sperm whale depredation, this decrement is needed in conjunction to appropriately account for depredation on both the survey and in the fishery. This ABC is still 11% higher than the 2016 ABC. The methods and calculations are described in the ***Accounting for whale depredation*** section. This relatively large increase is supported by a substantial increase in the domestic longline survey index time series that offset the small decrease in the fishery abundance index seen in 2015. The fishery abundance index has been trending down since 2007. The International Pacific Halibut Commission (IPHC) GOA sablefish index was not used in the model, but was similar to the longline survey, hitting its time series low in 2015, down 36% from 2014. The 2008 year class showed potential to be large in previous assessments based on patterns in the age and length compositions. This year class is now estimated to be about 30% above average. There are preliminary indications of a large incoming 2014 year class, which was evident in the 2016 longline survey length compositions. Spawning biomass is projected to decline through 2019, and then is expected to increase assuming average recruitment is achieved in the future. Maximum permissible ABCs are projected to slowly increase to 13,688 t in 2018 and 14,361 t in 2019 (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 are intended to 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 2016:**

Apportionments are based on survey and fishery information	**2016 ABC Percent**	**2016 Survey RPW**	**2015 Fishery RPW**	**2017 ABC Percent**	**2016 ABC**	**2017 ABC**	**Change**
Total					11,795	13,509	15%
Bering Sea	10%	13%	15%	14%	1,151	1,856	61%
Aleutians	13%	17%	16%	17%	1,557	2,263	45%
Gulf of Alaska	77%	70%	69%	70%	9,087	9,390	3%
Western	14%	17%	13%	15%	1,272	1,437	13%
Central	44%	41%	35%	39%	4,023	3,676	-9%
W. Yakutat*	15%	17%	18%	17%	1,353	1,617	20%
E. Yakutat / Southeast*	27%	25%	34%	28%	2,438	2,660	9%

Following the standard apportionment scheme, we have observed that the objective to reduce variability in apportionment was not being achieved. Since 2007, the mean change in apportionment by area has increased annually (Figure 3.50A). 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 3.50B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.50C). 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 re-evaluated and reviewed. A Ph.D. student with the University of Alaska-Fairbanks began a project in 2013 with the objectives of re-examining the apportionment strategy and conducting a management strategy evaluation. A spatial sablefish model has been developed, but the management strategy evaluation is in early stages of development. 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. The 2016 CIE review panel strongly stated that there was no immediate biological concern with the current apportionment, given the high mixing rates of the stock. **Therefore**, **for 2017, we recommend continuing with the apportionment fixed at the proportions used in 2016.**

Apportionment Table (before whale depredation adjustments)

Area	2016 ABC	Standard apportionment for 2017 ABC	**Recommended fixed apportionment for 2017 ABC***	**Difference from 2016**
Total	11,795	13,509	**13,509**	14.5%
Bering Sea	1,151	1,856	**1,318**	14.5%
Aleutians	1,557	2,263	**1,783**	14.5%
Gulf of Alaska (subtotal)	9,087	9,390	**10,408**	14.5%
Western	1,272	1,437	**1,457**	14.5%
Central	4,023	3,676	**4,608**	14.5%
W. Yakutat**	1,353	1,617	**1,550**	14.5%
E. Yak. / Southeast**	2,438	2,660	**2,793**	14.5%

* Fixed at the 2013 assessment apportionment proportions (Hanselman et al. 2012). ** Before 95:5 hook and line: trawl split shown below.

Overfishing level (OFL)

Applying an adjusted $F_{35\%}$ as prescribed for OFL in Tier 3b, results in a value of 15,931 t for the combined stock. The OFL is apportioned by region, Bering Sea (1,551 t), AI (2,101 t), and GOA (12,279 t), by the same method as the ABC apportionment.

Economic performance

This year a new economic performance report is included in Appendix 3D. This report is intended to show a summary of the economic data pertinent to sablefish. The report shows that the sablefish fishery yielded a first wholesale value of $91 million in 2015. In future years, we will fold this report into the main SAFE in this section.

Ecosystem considerations

Ecosystem considerations for Alaska sablefish are summarized in Table 3.19. This section is currently being updated to a new framework termed the Stock Profile and Ecosystem Consideration or SPEC. This approach utilizes pre-existing data collected through national initiatives to generate an ecosystem baseline of information for Alaska sablefish. A baseline SPEC would include a stock-specific ecosystem status rating, a stock life history conceptual model, a stock profile, and a stock report card of relevant indicators. Ecosystem terms of reference (eco-TOR) would also be included to guide priorities for future research (Shotwell et al. 2016). Options for improving the baseline SPEC using information from current ecosystem surveys and research will be evaluated in a dedicated integrated ecosystem research synthesis workshop in February 2017. This workshop will evaluate the results on improving understanding of recruitment processes for sablefish as part of the Gulf of Alaska (GOA) Project, an Integrated Ecosystem Research Program funded by the North Pacific Research Board. Additionally, an executive summary of the SPEC is planned for the Stock Assessment Improvement Plan (SAIP) update scheduled for completion in 2017.

We opted to wait until next year to integrate the new SPEC framework so that we could include any new research from the GOA Project and recommendations on the SPEC process from the regional council review of the SAIP update. We plan to present the new section to the Plan Team either in September or November depending on the complexity of incorporating the SPEC within the SAFE structure.

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. 2014). 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. (2014) 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 3.5). The sablefish fishery catches the majority of grenadier total catch; the annual amount is variable (Table 3.6). 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 and golden king crab. BSAI and GOA halibut catches in 2016 were below the 2012-2016 average , while BSAI golden king crab catches were higher in 2016 than the 5 year mean (Table 3.7). Crab catch fluctuates greatly and is largely driven by the amount of pot gear effort that occurs in the Aleutian Islands region, which varies from year to year.

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 3.4). 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 the ABC.
2) Refine fishery abundance index to utilize a core fleet, and identify covariates that affect catch rates.
3) Consider new strategies for incorporating annual growth data.
4) Continue to explore the use of environmental data to aid in determining recruitment.
5) Include a Species Profile and Ecosystem Considerations (SPEC) report to replace the existing ecosystem considerations section using the results of the GOA project and SAIP review described in the Ecosystem Considerations section above.
6) 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 a management strategy evaluation of apportionment strategies.

Literature Cited

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

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

Coutré, K. M., A.H. Beaudreau, and P.W. Malecha. 2015. Temporal Variation in Diet Composition and Use of Pulsed Resource Subsidies by Juvenile Sablefish. Transactions of the American Fisheries Society, 144(4), 807-819.

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

Echave, K. B., D. H. Hanselman, M. D. Adkison, M. F. Sigler. 2012. Inter-decadal changes in sablefish, *Anoplopoma fimbria*, growth in the northeast Pacific Ocean. Fish. Bull. 210:361-374.

Echave, K., C. Rodgveller, and S. K. Shotwell. 2013. Calculation of the geographic sizes used to create population indices for the Alaska Fisheries Science Center longline survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-253, 93 p. (.pdf, 7.55 MB).

Fina, M. 2011. Evolution of Catch Share Management: Lessons from Catch Share Management in the North Pacific. Fisheries. 36(4):164-177.

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

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27, 233-249.

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

Gao, Y., S.H. Joner, R.A. Svec, and K.L. Weinberg. 2004. Stable isotopic comparison in otoliths of juvenile sablefish (*Anoplopoma fimbria*) from waters off the Washington and Oregon coast. Fisheries Research, 68(1), 351-360.

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

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

Hanselman, D.H., W. Clark, and M. Sigler. 2013. Retrospective investigations group report. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/Retrospectives_2013_final3.pdf

Hanselman, D.H., W. Clark, J. Heifetz, and D. Anderl. 2012. Statistical distribution of age readings of known-age sablefish (*Anoplopoma fimbria*). Fish. Res. 131: 1-8.

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

Hanselman, D.H., J. Heifetz, K.B. Echave, and S.C. Dressel. 2015. Move it or lose it: Movement and mortality of sablefish tagged in Alaska. Canadian Journal of Fish and Aquatic Sciences. http://www.nrcresearchpress.com/doi/abs/10.1139/cjfas-2014-0251

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

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

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

Hanselman, D. H., C.R. Lunsford, and C. Rodgveller. 2010. Assessment of the sablefish stock in Alaska. In Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2011. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D.H., C. Lunsford, and C. Rodgveller. 2011. Assessment of the sablefish stock in Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 307-412.

Hanselman, D.H., C. Lunsford, and C. Rodgveller. 2012. Assessment of the sablefish stock in Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501. pp. 323-432.

Hanselman, D.H., C. Lunsford, and C. Rodgveller. 2014. Assessment of the sablefish stock in Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

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

Hanselman, D.H., B.J. Pyper, and M. J. Peterson. In Review. Comparison of statistical methods to account for whale depredation in longline abundance indices. Submitted Fisheries Research.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Laidig, T. E., P. B. Adams, and W. M. Samiere. 1997. Feeding habits of sablefish, *Anoplopoma fimbria*, off the coast of Oregon and California. *In* M. Saunders and M. Wilkins (eds.). Proceedings of the International Symposium on the Biology and Management of Sablefish. pp 65-80. NOAA Tech. Rep. 130.

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

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

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

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

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

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

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

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

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

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

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

NOAA (National Oceanic and Atmospheric Administration). 2012. NOAA's National Marine Fisheries Service (NMFS), Alaska Region Restricted Access Management (RAM) Pacific Halibut - Sablefish IFQ Report, Fishing Year 2011. Alaskafisheries.noaa.gov/ram/ifqreports.htm. National Marine Fisheries Service, Juneau, Alaska.

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

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

Peterson, M.J. and D.H. Hanselman. *Accepted*. Sablefish mortality associated with whale depredation in Alaska. ICES J. Marine Science.

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

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

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

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

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

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

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

Shotwell, S.K., D.H. Hanselman, and I.M. Belkin. 2014. Toward biophysical synergy: Investigating advection along the Polar Front to identify factors influencing Alaska sablefish recruitment. Deep-Sea Res. II, http://dx.doi.org/10.1016/j.dsr2.2012.08.024.

Shotwell, S.K., D.H. Hanselman, S. Zador, and K. Aydin. 2016. Stock-specific Profiles and Ecosystem

Considerations (SPEC) for Alaska groundfish fishery management plans. Report to Joint Groundfish Plan Team, September 2016. 15 pp.

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

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

Sigler, M. F., 1999. Estimation of sablefish, *Anoplopoma fimbria*, abundance off Alaska with an age-structured population model. Fishery Bulletin, 97: 591-603.

Sigler, M .F., J. T. Fujioka, and S. A. Lowe. 1999. Alaska sablefish assessment for 2000. *In* Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska. http://www.afsc.noaa.gov/refm/docs/historic_assess/sable99.pdf. North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, AK 99510.

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

Sigler, M.F., C.R. Lunsford, and J.T. Fujioka. 2004. Alaska sablefish assessment for 2005. *In* Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, AK 99510.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Tables

Table 3.1. 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. 2016 catches are as of September 25, 2016 (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	26,536	1,209	2,190	1,931	11,178	9,938	4,069	5,869	89	23,438	3,097
1992	24,042	613	1,553	2,221	10,355	9,158	4,408	4,750	142	21,131	2,910
1993	25,417	669	2,078	740	11,955	9,976	4,620	5,356	0	22,912	2,506
1994	23,580	694	1,727	539	9,377	11,243	4,493	6,750	0	20,642	2,938
1995	20,692	930	1,119	1,747	7,673	9,223	3,872	5,352	0	18,079	2,613
1996	17,393	648	764	1,649	6,773	7,558	2,899	4,659	0	15,206	2,187
1997	14,607	552	781	1,374	6,234	5,666	1,930	3,735	0	12,976	1,632
1998	13,874	563	535	1,432	5,922	5,422	1,956	3,467	0	12,387	1,487
1999	13,587	675	683	1,488	5,874	4,867	1,709	3,159	0	11,603	1,985
2000	15,570	742	1,049	1,587	6,173	6,020	2,066	3,953	0	13,551	2,019
2001	14,065	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	6,994	5,170	1,822	3,347	0	14,351	2,060
2004	17,520	1,041	955	2,173	7,310	6,041	2,241	3,801	0	15,864	1,656
2005	16,585	1,070	1,481	1,930	6,706	5,399	1,824	3,575	0	15,029	1,556
2006	15,551	1,078	1,151	2,151	5,921	5,251	1,889	3,362	0	14,305	1,246
2007	15,958	1,182	1,169	2,101	6,004	5,502	2,074	3,429	0	14,723	1,235
2008	14,552	1,141	899	1,679	5,495	5,337	2,016	3,321	0	13,430	1,122
2009	13,062	916	1,100	1,423	4,967	4,656	1,831	2,825	0	12,005	1,057
2010	11,929	753	1,045	1,354	4,508	4,269	1,578	2,690	0	10,924	1,004
2011	12,974	705	1,024	1,400	4,924	4,921	1,896	3,024	0	11,795	1,179
2012	13,867	742	1,205	1,353	5,329	5,238	2,033	3,205	0	12,765	1,102
2013	13,642	634	1,061	1,384	5,207	5,355	2,108	3,247	0	12,605	1,037
2014	11,574	312	812	1,202	4,756	4,492	1,671	2,822	0	10,549	1,025
2015	10,971	210	430	1,014	4,646	4,671	1,841	2,830	0	9,886	1,085
2016	8,818	382	283	803	3,580	3,769	1,573	2,196	0	7,670	1,148

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991-2016. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages. Catch as of September 25, 2016 (www.akfin.org).

Year	Pot	Trawl	Longline	Total
Aleutian Islands				
1991-1999	6	73	1,210	1,289
2000	103	33	913	1,049
2001	111	39	925	1,074
2002	105	39	975	1,119
2003	316	42	760	1,118
2004	384	32	539	955
2005	688	115	679	1,481
2006	461	60	629	1,151
2007	632	40	496	1,169
2008	177	76	646	899
2009	78	75	947	1,100
2010	59	74	912	1,045
2011	141	47	837	1,024
2012	77	148	979	1,205
2013	87	58	916	1,061
2014	160	26	626	812
2015	12	15	403	430
2016	21	22	240	283
Bering Sea				
1991-1999	5	189	539	733
2000	40	284	418	742
2001	106	353	405	864
2002	382	295	467	1,144
2003	363	231	417	1,012
2004	435	293	313	1,041
2005	595	273	202	1,070
2006	621	84	373	1,078
2007	879	92	211	1,182
2008	754	183	204	1,141
2009	557	93	266	916
2010	450	30	273	753
2011	405	44	256	705
2012	431	93	218	742
2013	352	133	149	634
2014	164	34	114	312
2015	108	17	85	210
2016	96	211	75	382

Table 3.3. 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	26,536			28,800	
1992	24,042			25,200	Pot fishing banned in Bering Sea (57 FR 37906).
1993	25,417			25,000	
1994	23,580			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	17,393			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	13,874	26,500	16,800	16,800	
1999	13,587	24,700	15,900	15,900	
2000	15,570	21,400	17,300	17,300	
2001	14,065	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	17,520	30,800	23,000	23,000	
2005	16,585	25,400	21,000	21,000	
2006	15,551	25,300	21,000	21,000	
2007	15,958	23,750	20,100	20,100	
2008	14,552	21,310	18,030	18,030	Pot fishing ban repealed in Bering Sea for June 1-30 (74 FR 28733).
2009	13,062	19,000	16,080	16,080	
2010	11,929	21,400	15,230	15,230	
2011	12,974	20,700	16,040	16,040	
2012	13,867	20,400	17,240	17,240	
2013	13,642	19,180	16,230	16,230	
2014	11,574	16,225	13,722	13,722	
2015	10,971	16,128	13,657	13,657	NPFMC passes Amendment 101 to allow pot fishing in the GOA
2016	8,818	13,397	11,795	11,795	

Table 3.4. 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 2007-2015. Source: NMFS Alaska Regional Office via AKFIN, September 25, 2016.

		BSAI			GOA			Combined		
Year	Gear	Discard	%Discard	Catch	Discard	%Discard	Catch	Discard	%Discard	Catch
2010	Total	39	2.16%	1,798	419	4.13%	10,131	458	3.84%	11,929
	H&L	33	2.82%	1,184	371	4.02%	9,231	405	3.89%	10,415
	Other	5	0.88%	613	47	5.27%	900	53	3.49%	1,514
2011	Total	25	1.44%	1,729	575	5.11%	11,245	600	4.63%	12,974
	H&L	18	1.63%	1,093	396	3.90%	10,147	414	3.68%	11,240
	Other	7	1.12%	637	179	16.33%	1,097	186	10.75%	1,734
2012	Total	24	1.23%	1,947	318	2.67%	11,921	342	2.47%	13,867
	H&L	13	1.10%	1,197	253	2.29%	11,060	266	2.17%	12,257
	Other	11	1.45%	749	65	7.52%	861	76	4.69%	1,610
2013	Total	30	1.75%	1,696	646	5.40%	11,947	675	4.95%	13,642
	H&L	26	2.44%	1,065	598	5.39%	11,101	624	5.13%	12,166
	Other	4	0.59%	630	48	5.62%	846	51	3.47%	1,476
2014	Total	30	2.67%	1,124	516	4.94%	10,450	546	4.72%	11,574
	H&L	29	3.89%	739	438	4.62%	9,483	467	4.57%	10,223
	Other	1	0.33%	385	78	8.09%	967	80	5.88%	1,351
2015	Total	18	2.86%	640	777	7.52%	10,330	795	7.25%	10,971
	H&L	13	2.67%	488	593	6.39%	9,276	606	6.20%	9,764
	Other	5	3.48%	153	184	17.43%	1,054	189	15.67%	1,207
2016	Total	42	6.31%	665	692	8.49%	8,152	734	8.33%	8,818
	H&L	36	11.28%	316	561	7.75%	7,236	597	7.90%	7,552
	Other	6	1.83%	350	131	14.35%	916	138	10.89%	1,266
2010-2016	Total	39	2.16%	1,798	419	4.13%	10,131	458	3.84%	11,929
Mean	H&L	33	2.82%	1,184	371	4.02%	9,231	405	3.89%	10,415
	Other	5	0.88%	613	47	5.27%	900	53	3.49%	1,514

Table 3.5. Bycatch (t) of FMP Groundfish species in the targeted sablefish fishery averaged from 2012-2016. Other = Pot and trawl combined because of confidentiality. Source: AKFIN, September 25, 2016.

	Hook and Line			Other Gear			All Gear		
Species	Discard	Retained	Total	Discard	Retained	Total	Discard	Retained	Total
GOA Thornyhead Rockfish	216	424	640	5	27	32	221	451	671
Shark	426	1	427	0	0	0	427	1	427
GOA Shortraker Rockfish	157	92	249	9	1	11	166	93	260
Arrowtooth Flounder	157	15	172	56	2	58	212	17	229
GOA Skate, Longnose	163	9	172	0	0	0	163	9	172
GOA Rougheye Rockfish	84	82	167	1	2	3	85	84	170
GOA Skate, Other	162	2	164	1	0	1	163	2	165
Other Rockfish	55	75	130	1	1	2	56	76	132
Pacific Cod	63	35	98	0	3	3	63	37	101
BSAI Skate	53	1	54	0	0	0	53	1	54
GOA Deep Water Flatfish	11	0	11	17	9	25	28	9	37
Greenland Turbot	19	15	34	2	0	2	21	15	36
BSAI Kamchatka Flounder	16	2	18	1	0	2	17	2	20
Sculpin	14	0	14	0	0	0	14	0	14
GOA Demersal Shelf Rockfish	1	9	10	0	0	0	1	9	10
BSAI Shortraker Rockfish	7	3	10	0	0	0	7	3	10
Pacific Ocean Perch	3	0	3	1	5	5	3	5	8
GOA Rex Sole	0	0	0	5	2	7	5	2	7
BSAI Other Flatfish	6	0	6	0	0	0	6	0	6
Total	2,090	1,497	3,587	100	51	152	2,191	1,548	3,739

Table 3.6. Bycatch of nontarget species and HAPC biota in the targeted sablefish fishery. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN, September 25, 2016.

	Estimated Catch (t)					
Group Name	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Benthic urochordata	0.13	1.08	0.00	0.00	0.49	0.00
Bivalves	0.05	0.01	0.00	0.00	0.01	0.01
Brittle star unidentified	0.45	4.56	0.10	0.64	2.05	0.13
Corals Bryozoans	5.70	7.55	12.62	4.96	4.49	4.88
Dark Rockfish	0.00	0.03	0.06	0.04	0.05	0.05
Eelpouts	0.63	0.63	1.13	0.77	0.24	0.05
Giant Grenadier	7,051	7,009	9,440	4,839	4,830	5,824
Greenlings	0.02	0.00	0.00	0.00	0.06	0.01
Grenadier	844	1,017	1,469	877	707	352
Hermit crab unidentified	0.21	0.08	0.09	0.16	0.03	0.00
Invertebrate unidentified	2.09	6.81	0.18	0.12	0.53	0.12
Large Sculpins	3.89	5.13	20.48	6.01	7.36	6.29
Misc crabs	1.14	0.32	0.52	0.50	0.07	0.01
Misc crustaceans	0.00	0.00	0.00	0.15	0.00	0.01
Misc fish	8.44	10.11	29.19	25.03	16.61	11.54
Scypho jellies	0.68	0.00	0.00	5.51	0.24	0.11
Sea anemone unidentified	3.29	0.99	0.92	2.92	12.44	1.39
Sea pens whips	1.58	0.25	0.35	2.17	2.65	0.93
Sea star	3.46	3.00	14.94	11.06	9.19	7.17
Snails	19.67	12.15	8.82	3.64	3.37	0.09
Sponge unidentified	2.09	0.94	3.37	1.63	3.48	0.40
Urchins, dollars, cucumbers	0.26	0.78	0.86	0.78	2.47	0.09

Table 3.7. Prohibited Species Catch (PSC) estimates reported in tons for halibut and numbers of animals for crab and salmon, by year, and fisheries management plan (BSAI or GOA) for the sablefish fishery. Other = Pot and trawl combined because of confidentiality. Source: NMFS AKRO Blend/Catch Accounting System PSCNQ via AKFIN, September 25, 2016.

	Year	Bairdi	Chinook	Golden KC	Halibut	Other salmon	Opilio	Red KC
BSAI								
Hook and Line	2012	0	0	420	82	0	0	7
	2013	0	15	465	66	0	0	0
	2014	0	0	460	38	0	0	44
	2015	0	9	177	23	0	0	206
	2016	0	0	108	9	0	0	0
	Mean	0	5	326	44	0	0	51
Other	2012	0	0	16,772	10	0	121	0
	2013	365	0	788	18	0	314	0
	2014	0	0	3,193	6	0	1,679	0
	2015	0	0	29,029	1	0	26	0
	2016	0	0	15,082	1	0	0	0
	Mean	73	0	12,973	7	0	428	0
BSAI Mean		73	5	13,299	51	0	428	51
GOA								
Hook and Line	2012	0	0	23	293	0	0	0
	2013	78	0	93	273	0	0	24
	2014	6	0	39	250	0	0	0
	2015	164	0	38	293	0	0	12
	2016	0	0	36	218	0	0	25
	Mean	50	0	46	265	0	0	12
Other	2012	0	0	9	5	0	0	0
	2013	0	0	0	12	12	0	0
	2014	0	0	18	2	0	0	0
	2015	25	0	0	3	0	0	0
	2016	0	0	32	6	0	0	0
	Mean	5	0	12	5	2	0	0
GOA Mean		55	0	58	271	2	0	12

Table 3.8. Sample sizes for aged fish 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. Trawl survey data from AKFIN. All fish were sexed before measurement, except for the Japanese fishery data.

	LENGTH							AGE		
Year	U.S. NMFS trawl survey (GOA)	Japanese fishery Trawl	Japanese fishery Longline	U.S. fishery Trawl	U.S. fishery Fixed	Cooperative longline survey	Domestic longline survey	Cooperative longline survey	Domestic longline survey	U.S. fixed gear fishery
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	7,168			468	21,943	80,596	94,699	1,178		
1994				89	11,914	74,153	70,431			
1995				87	17,735		80,826			
1996	4,615			239	14,416		72,247		1,176	
1997				0	20,330		82,783		1,214	
1998				35	8,932		57,773		1,191	
1999	4,281			1,268	28,070		79,451		1,186	1,141
2000				472	32,208		62,513		1,236	1,152
2001				473	30,315		83,726		1,214	1,003
2002				526	33,719		75,937		1,136	1,059
2003	5,003			503	36,077		77,678		1,128	1,185
2004				694	31,199		82,767		1,185	1,145
2005	4,901			2,306	36,213		74,433		1,074	1,164
2006				721	32,497		78,625		1,178	1,154
2007	3,773			860	29,854		73,480		1,174	1,115
2008				2,018	23,414		71,661		1,184	1,164
2009	3,934			1,837	24,674		67,978		1,197	1,126
2010				1,634	24,530		75,010		1,176	1,159
2011	2,114			1,877	22,659		87,498		1,199	1,190
2012				2,533	22,203		63,116		1,186	1,165
2013	1,249			2,674	16,093		51,586		1,190	1,157
2014				2,210	19,524		52,290		1,183	1,126
2015	3,277			2,320	20,056		52,110		1,189	1,176
2016							63,434			

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
2014	0.24	0.04	0.18	487	6	2014	0.25	0.12	0.48	8	3
2015	0.22	0.07	0.30	349	3	2015	0.10	0.07	0.66	4	3

Table 3.9 (cont.)

Western Gulf-Observer						Central Gulf-Observer					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1990	0.64	0.14	0.22	178	7	1990	0.54	0.04	0.07	653	32
1991	0.44	0.06	0.13	193	16	1991	0.62	0.06	0.09	303	24
1992	0.38	0.05	0.14	260	12	1992	0.59	0.05	0.09	335	19
1993	0.35	0.03	0.09	106	12	1993	0.60	0.04	0.07	647	32
1994	0.32	0.03	0.10	52	5	1994	0.65	0.06	0.09	238	15
1995	0.51	0.04	0.09	432	22	1995	0.90	0.07	0.08	457	41
1996	0.57	0.05	0.10	269	20	1996	1.04	0.07	0.07	441	45
1997	0.50	0.05	0.10	349	20	1997	1.07	0.08	0.08	377	41
1998	0.50	0.03	0.07	351	18	1998	0.90	0.06	0.06	345	32
1999	0.53	0.07	0.12	244	14	1999	0.87	0.08	0.10	269	28
2000	0.49	0.06	0.13	185	12	2000	0.93	0.05	0.06	319	30
2001	0.50	0.05	0.10	273	16	2001	0.70	0.04	0.06	347	31
2002	0.51	0.05	0.09	348	15	2002	0.84	0.07	0.08	374	29
2003	0.45	0.04	0.10	387	16	2003	0.99	0.07	0.07	363	34
2004	0.47	0.08	0.17	162	10	2004	1.08	0.10	0.09	327	29
2005	0.58	0.07	0.13	447	13	2005	0.89	0.06	0.07	518	32
2006	0.42	0.04	0.13	306	15	2006	0.82	0.06	0.08	361	33
2007	0.37	0.04	0.11	255	12	2007	0.93	0.06	0.07	289	30
2008	0.46	0.07	0.16	255	11	2008	0.84	0.07	0.08	207	27
2009	0.44	0.09	0.21	208	11	2009	0.77	0.06	0.07	320	33
2010	0.42	0.06	0.14	198	10	2010	0.80	0.05	0.07	286	31
2011	0.54	0.12	0.22	196	12	2011	0.85	0.08	0.10	213	28
2012	0.38	0.04	0.11	147	13	2012	0.74	0.07	0.09	298	27
2013	0.34	0.02	0.06	325	18	2013	0.51	0.05	0.10	419	34
2014	0.41	0.06	0.15	190	16	2014	0.56	0.03	0.05	585	57
2015	0.36	0.07	0.18	185	14	2015	0.52	0.04	0.08	793	54

Table 3.9 (cont.)

West Yakutat-Observer						East Yakutat/SE-Observer					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1990	0.95	0.24	0.25	75	9	1990	C	C	C	0	0
1991	0.65	0.07	0.10	164	12	1991	C	C	C	17	2
1992	0.64	0.18	0.27	98	6	1992	C	C	C	20	1
1993	0.71	0.07	0.10	241	12	1993	C	C	C	26	2
1994	0.65	0.17	0.27	81	8	1994	C	C	C	5	1
1995	1.02	0.10	0.10	158	21	1995	1.45	0.20	0.14	101	19
1996	0.97	0.07	0.07	223	28	1996	1.20	0.11	0.09	137	24
1997	1.16	0.11	0.09	126	20	1997	1.10	0.14	0.13	84	17
1998	1.21	0.10	0.08	145	23	1998	1.27	0.12	0.10	140	25
1999	1.20	0.15	0.13	110	19	1999	0.94	0.12	0.13	85	11
2000	1.28	0.10	0.08	193	32	2000	0.84	0.13	0.16	81	14
2001	1.03	0.07	0.07	184	26	2001	0.84	0.08	0.09	110	14
2002	1.32	0.13	0.10	155	23	2002	1.20	0.23	0.19	121	14
2003	1.36	0.10	0.07	216	27	2003	1.29	0.13	0.10	113	19
2004	1.23	0.09	0.08	210	24	2004	1.08	0.10	0.09	135	17
2005	1.32	0.09	0.07	352	24	2005	1.18	0.13	0.11	181	16
2006	0.96	0.10	0.10	257	30	2006	0.93	0.11	0.11	104	18
2007	1.02	0.11	0.11	208	24	2007	0.92	0.15	0.17	85	16
2008	1.40	0.12	0.08	173	23	2008	1.06	0.13	0.12	103	17
2009	1.34	0.12	0.09	148	23	2009	0.98	0.12	0.12	94	13
2010	1.11	0.09	0.08	136	22	2010	0.97	0.17	0.17	76	12
2011	1.18	0.09	0.07	186	24	2011	0.98	0.09	0.10	196	16
2012	0.97	0.09	0.10	255	24	2012	0.93	0.11	0.12	104	15
2013	1.11	0.15	0.13	109	20	2013	0.91	0.12	0.14	165	22
2014	0.83	0.07	0.09	149	22	2014	0.88	0.08	0.09	207	33
2015	0.96	0.08	0.08	278	39	2015	0.86	0.04	0.05	296	51

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
2014	0.25	0.07	0.27	272	5
2015	0.30	0.14	0.46	370	8

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
2014	0.34	0.05	0.15	436	15
2015	0.20	0.03	0.13	309	11

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
2014	0.39	0.03	0.08	1008	28
2015	0.33	0.04	0.13	980	31

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
2014	0.52	0.04	0.08	2051	72
2015	0.44	0.03	0.06	2119	71

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
2014	0.73	0.04	0.06	1591	74	2014	0.88	0.05	0.05	797	83
2015	0.67	0.04	0.06	1921	80	2015	0.78	0.04	0.05	972	84

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, 2013, and 2015, 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	949	
2015		378			1,169	834	67
2016		505			1,389		

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
2015	0	9			0	5	6	0	6	0	7	0
2016			1	0	0	3	3	0	6	0	5	0

Table 3.12. Sablefish fork length (cm), weight (kg), and proportion mature by age and sex (weight-at-age modeled 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. Estimates of the effects of sperm whales on the longline survey (top panel, Hanselman et al. *in review*), and killer and sperm whale depredation on the longline fishery based on modeled observer data (Peterson and Hanselman *in press*).

						Proportional change			Delta
Model	Flag	Area	Estimate (λ)	SE	P value	e^{λ}	LCI	UCI	AIC
1	Evidence	All	-0.133	0.03	<0.001	0.88	0.82	0.94	0
2	Evidence	CGOA	-0.117	0.06	0.07	0.89	0.78	1.01	3.9
		WY	-0.13	0.06	<0.001	0.88	0.78	0.99	
		EY/SE	-0.148	0.05	<0.001	0.86	0.77	0.96	

Estimates of sperm whale depredation for across-area models. Model 2 is an across area model with area as a factor. SE = standard error of the estimate. Estimates of proportional change are given by exp(Estimate) with approximate 95% confidence intervals shown (LCI, UCI).

Area	**Depredation term**	**Depredation coefficient (% CPUE reduction)**	**2 * SE**	**DF**	**n**	**%dev**
Bering Sea	KW	45.7%	34.7% - 56.6%	103	4339	49.7%
Aleutians	KW	57.7%	42.6% - 72.7%	101	6744	37.2%
Western Gulf of Alaska	KW	69.4%	56.5% - 82.1%	103	5950	31.0%
Central Gulf of Alaska	SW	23.8%	15.1% - 32.4%	193	8218	46.4%
West Yakutat	SW	26.3%	16.6% - 36.0%	119	3919	52.7%
Southeast	SW	29.4%	15.8% - 43.0%	124	2865	43.5%

GAMM results by management area and whale depredation term (KW = killer whale depredation), SW = sperm whale depredation. The response variable, catch per unit effort (kg/hook) for sets with sablefish CPUE > 0, followed normal distribution. The results display the depredation coefficient or the model-estimated difference in catch between depredated and non-depredated sets, with 95% CI as 2 * SE, degrees of freedom (DF), the sample size for a given area (n), percentage of deviance explained (%dev).

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%**
1977	4.8	1	15	307	248	420	143	117	201
1978	5.3	1	15	281	226	385	130	106	184
1979	84.0	62	129	340	275	467	124	102	175
1980	26.0	2	52	373	300	508	119	98	166
1981	11.7	1	41	395	318	533	117	97	162
1982	41.0	12	73	433	352	582	121	101	166
1983	23.7	6	51	461	375	613	134	112	182
1984	43.4	32	67	503	414	665	150	126	203
1985	2.3	0	7	508	421	665	165	140	222
1986	18.2	7	32	514	430	670	179	152	237
1987	19.3	13	31	502	420	652	184	156	245
1988	3.3	1	9	466	389	608	183	154	245
1989	4.9	1	11	421	351	551	175	147	237
1990	7.3	4	13	378	315	499	165	137	225
1991	26.9	20	40	358	296	476	152	127	211
1992	1.4	0	4	328	271	436	140	116	195
1993	25.0	19	36	321	264	428	128	106	179
1994	4.4	1	10	299	246	399	117	96	164
1995	5.9	2	11	279	229	373	109	89	154
1996	8.1	5	13	261	215	350	104	85	146
1997	17.6	13	26	256	210	344	100	83	141
1998	2.7	0	6	242	199	325	97	80	136
1999	32.2	25	46	255	209	342	94	77	130
2000	16.9	9	28	262	215	352	90	75	125
2001	12.2	4	22	264	216	353	87	72	120
2002	44.5	34	68	296	242	400	87	72	120
2003	7.1	2	13	302	248	406	89	74	122
2004	14.0	9	23	307	251	414	93	77	127
2005	6.8	4	12	301	245	404	98	80	134
2006	12.0	7	19	295	239	397	105	85	142
2007	8.9	6	15	286	232	385	110	89	149
2008	9.9	5	16	276	223	371	111	90	150
2009	9.6	6	15	267	216	358	110	90	149
2010	20.7	15	31	269	219	362	108	88	146
2011	5.4	1	10	263	215	352	106	86	142
2012	10.6	7	17	258	210	344	103	84	138
2013	1.2	0	3	243	198	323	100	82	134
2014	9.2	4	16	232	188	308	98	80	131
2015	17.2	12	28	231	188	308	97	79	128
2016	12.9	7	41	232	186	305	94	77	125
2017	-	-	-	239	195	283	92	74	109
2018	-	-	-	248	208	287	90	73	106

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 1990-2016 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	115	137	59	172	54	82	620
1961	120	144	62	181	57	87	651
1962	122	146	63	184	57	88	661
1963	123	147	64	185	58	88	664
1964	126	151	65	190	59	91	683
1965	129	154	67	194	61	93	696
1966	129	154	67	195	61	93	699
1967	127	151	66	191	60	91	685
1968	122	145	63	183	57	87	657
1969	113	135	59	171	53	82	613
1970	105	125	54	158	49	75	567
1971	102	121	53	153	48	73	549
1972	94	112	49	141	44	67	507
1973	83	100	43	126	39	60	451
1974	76	90	39	114	36	54	409
1975	69	83	36	104	32	50	374
1976	64	75	33	96	30	46	343
1977	57	68	29	85	27	41	307
1978	52	63	27	76	25	38	281
1979	64	70	32	101	29	44	340
1980	68	89	36	100	32	49	373
1981	70	98	42	87	37	60	395
1982	79	90	56	105	42	62	433
1983	82	96	72	116	38	56	461
1984	94	117	80	121	36	55	503
1985	105	116	73	126	37	51	508
1986	110	108	70	128	44	54	514
1987	82	109	67	134	50	61	502
1988	49	95	63	150	48	62	466
1989	56	82	49	135	44	54	421
1990	58	62	40	116	44	58	378
1991	40	42	38	113	47	79	358
1992	24	37	26	104	52	86	328
1993	15	35	29	106	55	81	321
1994	18	34	33	99	46	70	299
1995	26	32	28	91	39	62	279
1996	25	27	28	94	34	53	261
1997	24	24	27	99	31	51	256
1998	21	31	27	85	28	50	242
1999	21	42	30	84	27	51	255
2000	21	43	34	88	27	50	262
2001	29	42	42	83	22	46	264
2002	41	45	44	96	24	46	296
2003	41	46	42	103	26	44	302
2004	41	47	38	109	28	44	307
2005	43	46	39	97	27	49	301
2006	46	41	42	89	27	50	295
2007	50	36	31	89	30	50	286
2008	53	35	27	86	27	47	276
2009	51	35	31	83	23	43	267
2010	53	30	28	79	30	50	269
2011	34	27	27	93	34	49	263
2012	14	33	30	103	29	49	258
2013	32	34	25	81	22	49	243
2014	49	29	25	66	20	43	232
2015	40	31	25	67	26	44	231
2016	28	41	26	67	30	41	232

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
$q_{domesticLL}$	7.33	7.10	7.03	0.35	0.90	5.48	8.97
q_{coopLL}	5.63	5.45	5.41	0.30	0.67	4.30	6.88
q_{trawl}	1.20	1.15	1.14	0.79	0.18	0.83	1.53
$F_{40\%}$	0.09	0.11	0.11	0.023	0.029	0.06	0.17
2017 SSB (kt)	91.6	95.9	95.2	8.75	12.08	75.0	122
2000 Year Class	44.5	48.3	47.5	6.28	8.57	34.1	67.8
2008 Year Class	20.7	22.2	21.9	3.22	4.14	15.3	31.4

Table 3.17. Comparison of 2015 results versus 2016 results. Biomass is in kilotons.

Year	**2015 SAFE** Spawning Biomass	**2016 SAFE** Spawning Biomass	Difference (%)	**2015 SAFE** Total Biomass	**2016 SAFE** Total Biomass	Difference (%)
1977	130	143	10%	294	307	4%
1978	119	130	10%	265	281	6%
1979	114	124	9%	322	340	6%
1980	109	119	9%	356	373	5%
1981	107	117	10%	373	395	6%
1982	111	121	9%	418	433	4%
1983	123	134	9%	446	461	3%
1984	139	150	8%	488	503	3%
1985	154	165	7%	491	508	3%
1986	169	179	6%	502	514	2%
1987	175	184	5%	491	502	2%
1988	174	183	5%	458	466	2%
1989	167	175	5%	415	421	1%
1990	158	165	4%	372	378	2%
1991	147	152	3%	355	358	1%
1992	136	140	3%	325	328	1%
1993	125	128	3%	318	321	1%
1994	114	117	3%	296	299	1%
1995	106	109	2%	275	279	1%
1996	101	104	3%	257	261	2%
1997	98	100	2%	253	256	1%
1998	95	97	2%	238	242	2%
1999	91	94	3%	249	255	2%
2000	88	90	3%	259	262	1%
2001	85	87	3%	259	264	2%
2002	84	87	4%	290	296	2%
2003	87	89	3%	295	302	2%
2004	90	93	4%	299	307	3%
2005	95	98	3%	291	301	3%
2006	101	105	4%	285	295	4%
2007	106	110	3%	275	286	4%
2008	107	111	4%	266	276	4%
2009	106	110	4%	256	267	4%
2010	104	108	4%	259	269	4%
2011	101	106	5%	251	263	5%
2012	98	103	5%	243	258	6%
2013	95	100	5%	226	243	7%
2014	92	98	7%	208	232	11%
2015	90	97	7%	202	231	15%
2016		94			232	

Table 3.18. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for seven harvest scenarios. Abundance projected using 1979-2014 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)				
2016	94.1	94.1	94.1	94.1	94.1	94.1	94.1
2017	91.6	91.6	91.5	91.6	91.6	91.6	91.6
2018	88.1	89.6	91.2	89.1	94.6	86.9	88.1
2019	86.8	89.7	92.3	88.5	99.5	84.7	86.8
2020	87.5	90.1	94.9	89.9	106.6	84.6	86.4
2021	89.5	91.7	98.6	92.6	115.3	85.9	87.4
2022	92.2	94.0	102.5	96.2	125.1	87.9	89.1
2023	95.0	96.5	106.5	100.0	135.4	90.1	91.0
2024	97.6	98.8	109.6	103.7	145.5	92.0	92.8
2025	99.9	100.8	113.2	107.2	155.2	93.7	94.3
2026	101.8	102.5	117.9	110.3	164.3	95.1	95.5
2027	103.4	103.9	123.4	113.0	172.8	96.2	96.5
2028	104.7	105.1	126.8	115.4	180.7	97.1	97.4
2029	105.8	106.2	130.2	117.6	188.0	97.9	98.1
			Fishing mortality				
2016	0.061	0.061	0.061	0.061	0.061	0.061	0.061
2017	0.081	0.062	0.041	0.068	-	0.097	0.097
2018	0.078	0.058	0.041	0.068	-	0.091	0.091
2019	0.077	0.080	0.041	0.068	-	0.089	0.089
2020	0.078	0.080	0.042	0.068	-	0.089	0.089
2021	0.079	0.081	0.044	0.068	-	0.090	0.090
2022	0.081	0.082	0.046	0.068	-	0.091	0.091
2023	0.081	0.083	0.047	0.068	-	0.093	0.093
2024	0.082	0.083	0.047	0.068	-	0.093	0.093
2025	0.083	0.083	0.047	0.068	-	0.094	0.094
2026	0.084	0.084	0.047	0.068	-	0.095	0.095
2027	0.084	0.085	0.047	0.068	-	0.096	0.096
2028	0.085	0.085	0.047	0.068	-	0.097	0.097
2029	0.086	0.086	0.047	0.068	-	0.097	0.097
			Yield (kt)				
2016	10.1	10.1	10.1	10.1	10.1	10.1	10.1
2017	13.5	13.5	6.9	11.3	-	15.9	13.5
2018	13.2	13.7	7.2	11.7	-	15.2	13.2
2019	13.5	14.4	7.8	12.1	-	15.2	15.9
2020	14.3	15.1	8.7	12.8	-	15.9	16.5
2021	15.3	15.9	9.5	13.3	-	16.8	17.3
2022	16.2	16.6	10.2	13.9	-	17.7	18.1
2023	16.9	17.2	10.7	14.4	-	18.4	18.7
2024	17.4	17.7	11.1	14.8	-	18.9	19.1
2025	17.9	18.0	11.5	15.1	-	19.3	19.5
2026	18.2	18.3	11.8	15.4	-	19.7	19.7
2027	18.5	18.7	12.1	15.7	-	20.0	20.0
2028	18.9	18.9	12.4	16.0	-	20.3	20.3
2029	19.1	19.1	12.6	16.2	-	20.5	20.5

* Projections in Author's F (Alternative 2) are based on estimated catches of 10,348 t and 10,142 t used in place of maximum permissible ABC for 2017 and 2018. 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

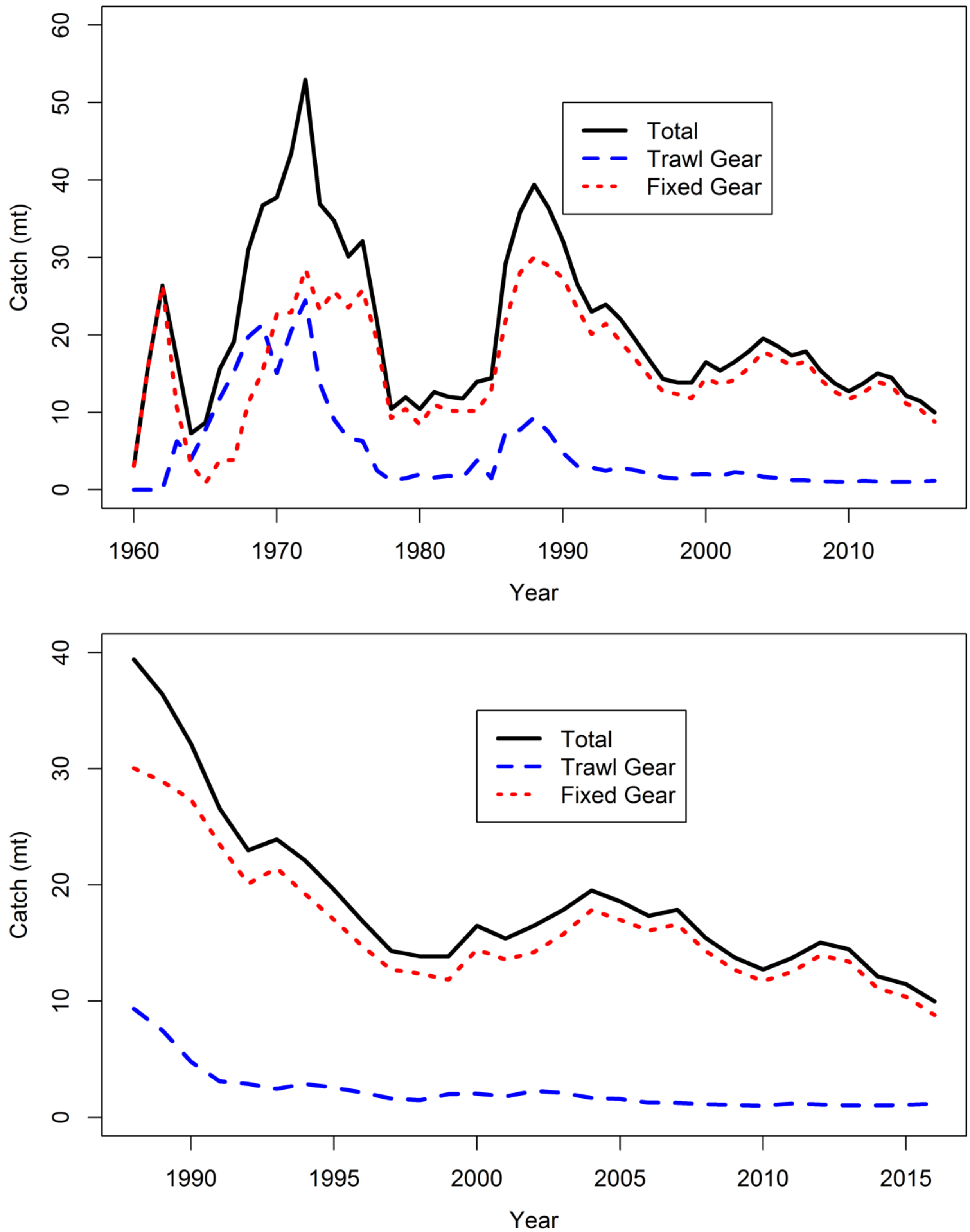


Figure 3.1. Long term and short term sablefish catch by gear type.

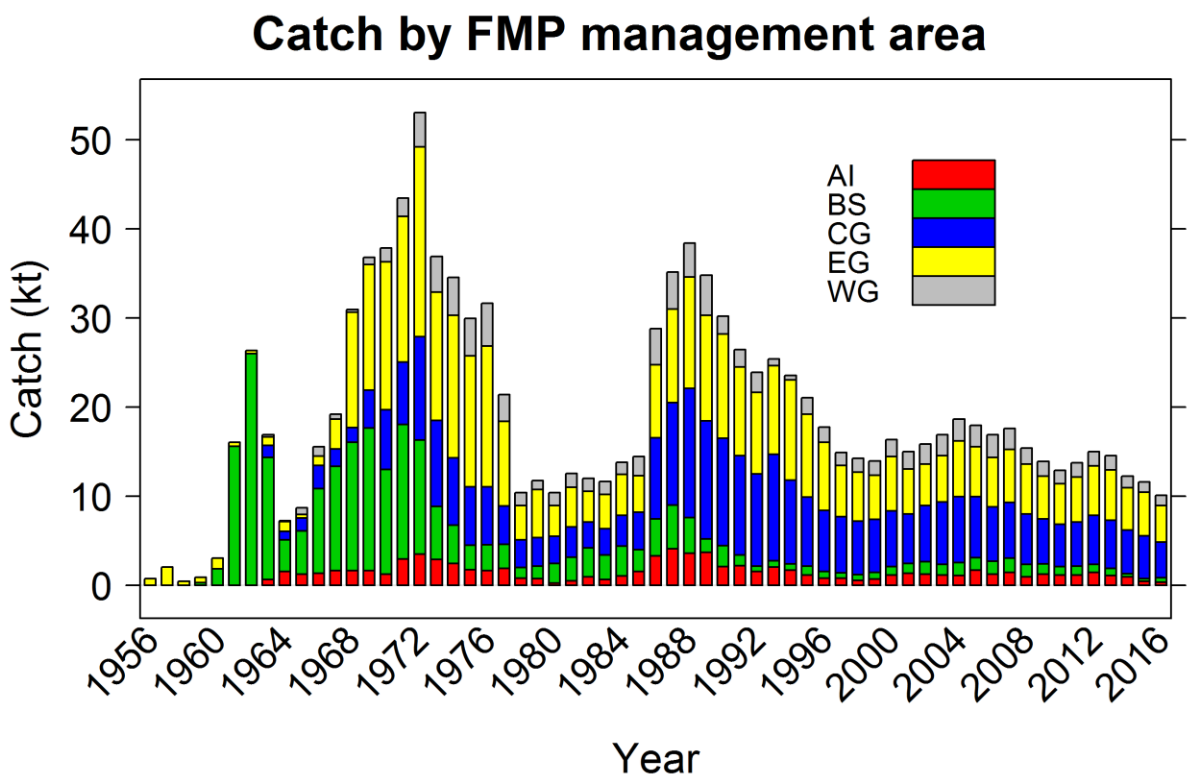


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

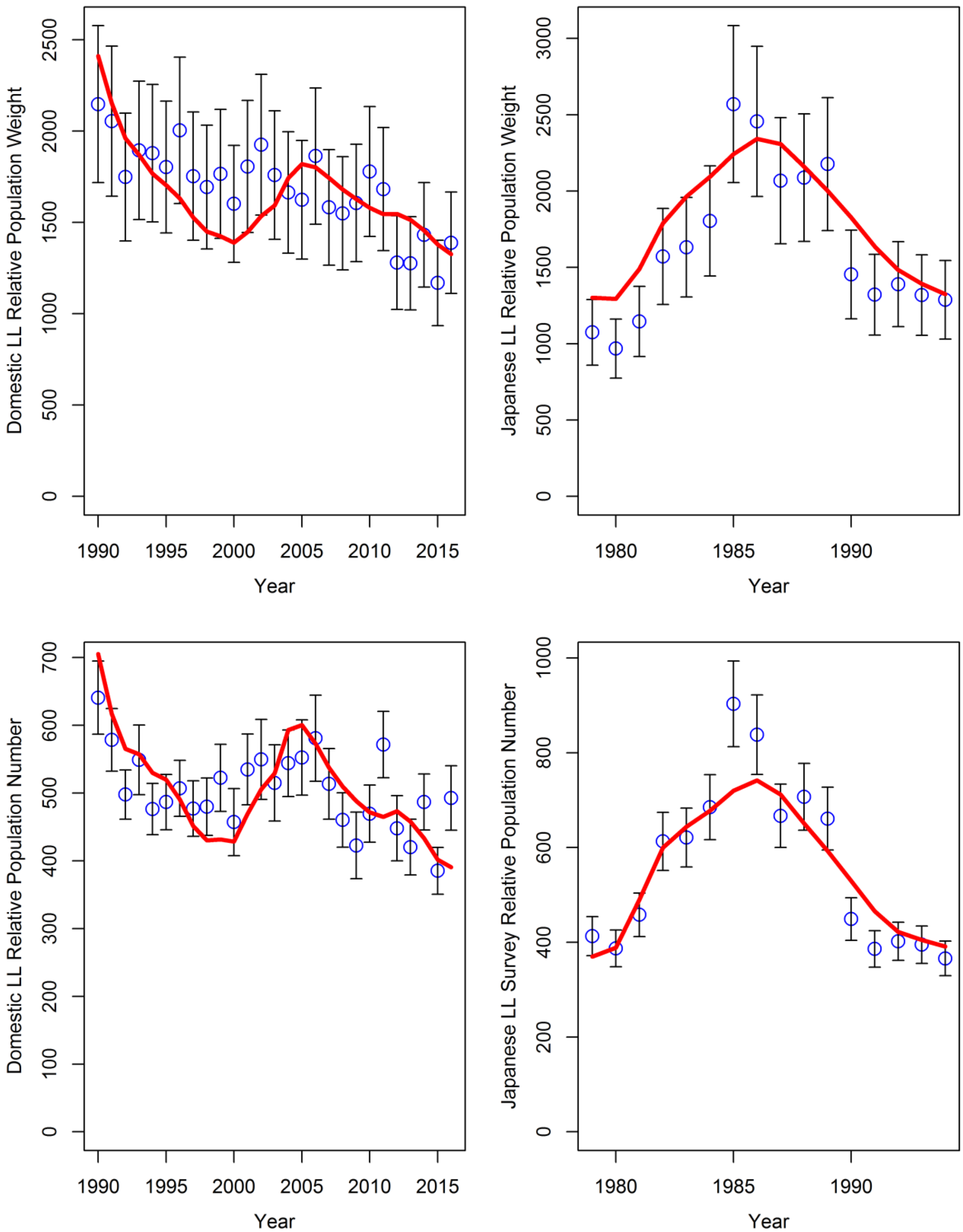


Figure 3.3. Observed and predicted sablefish relative population weight and numbers versus year. Points are observed estimates with approximate 95% confidence intervals. Solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

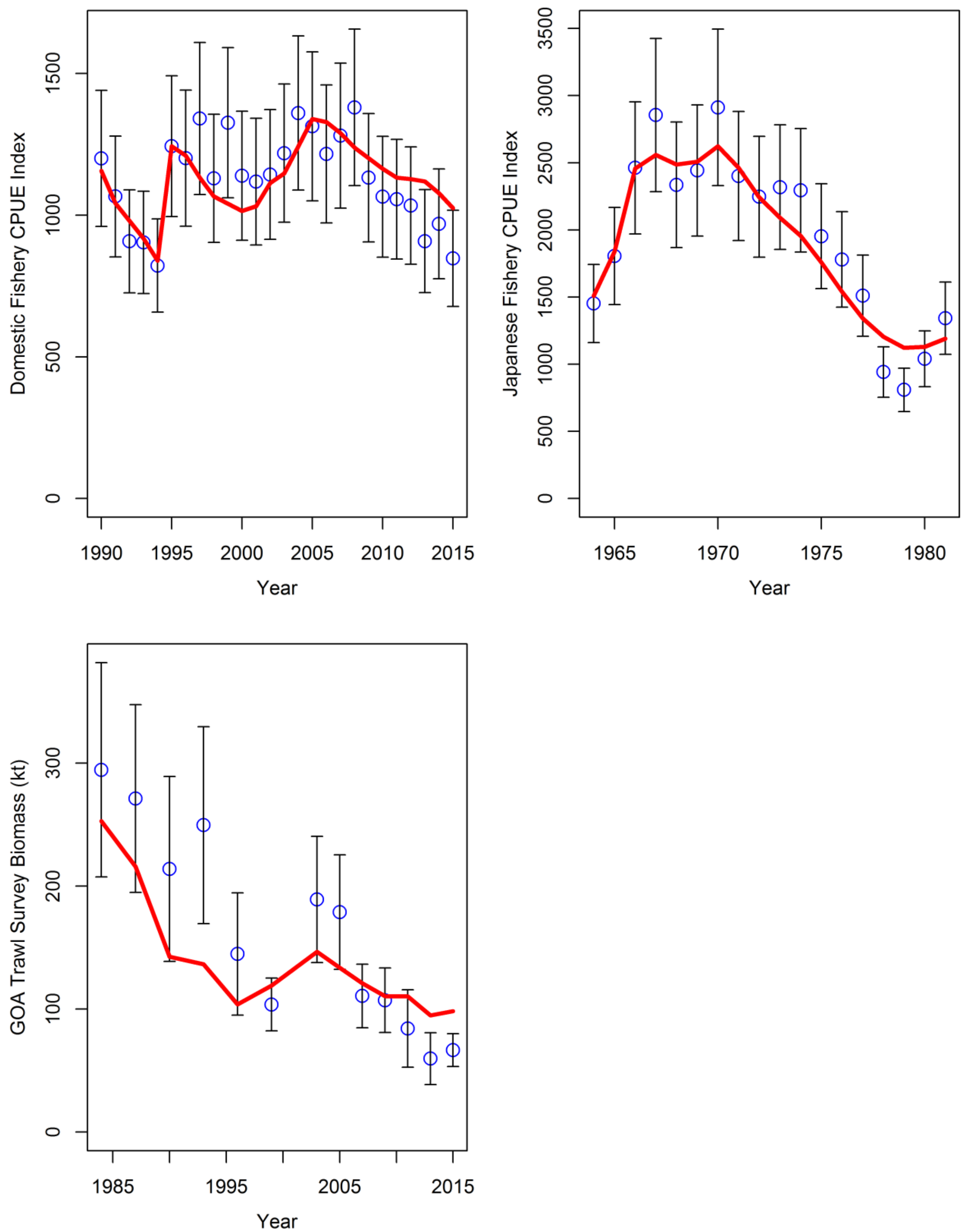


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while solid red lines are model predictions.

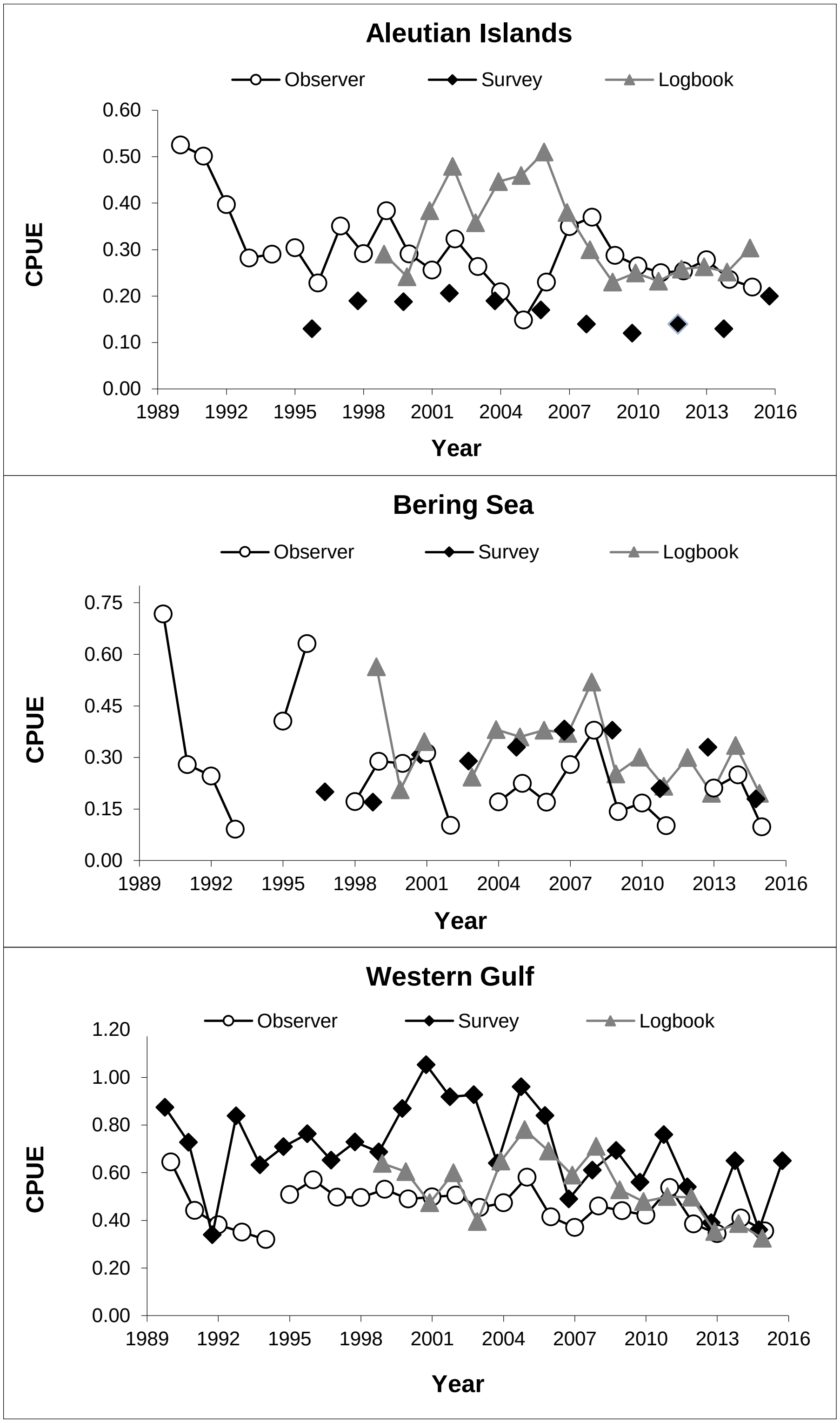


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in 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.

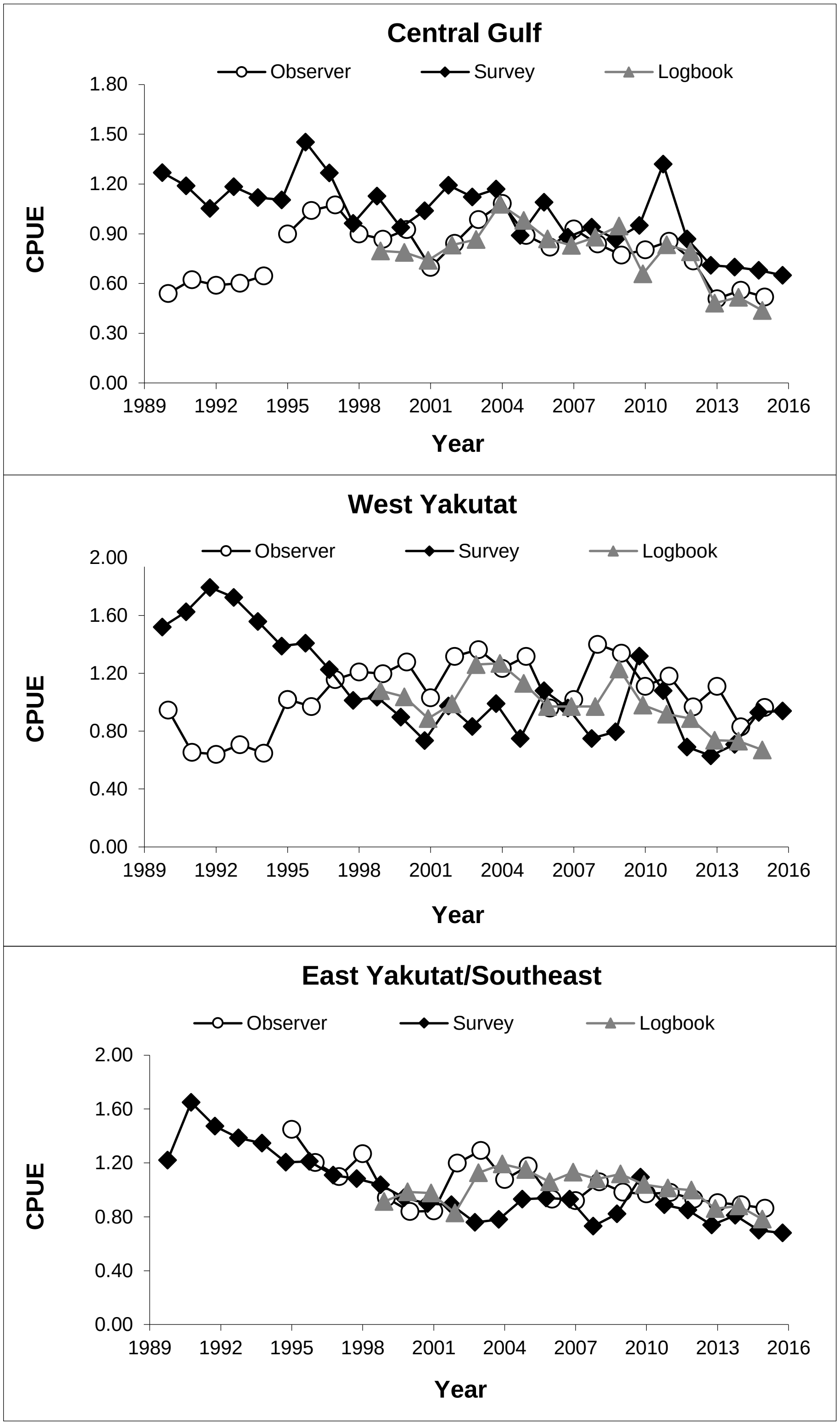


Figure 3.5. (continued)

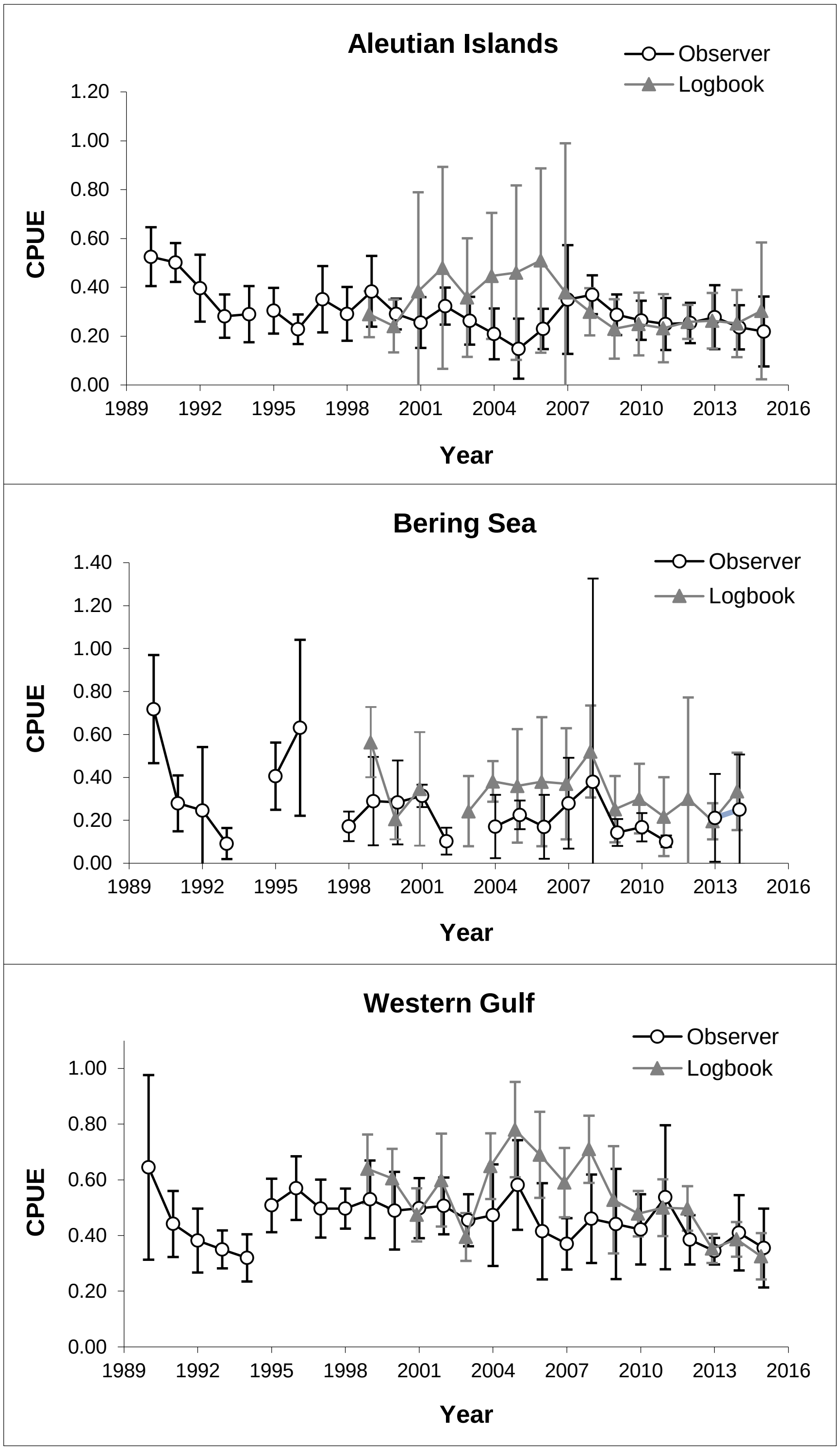


Figure 3.6. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data 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.

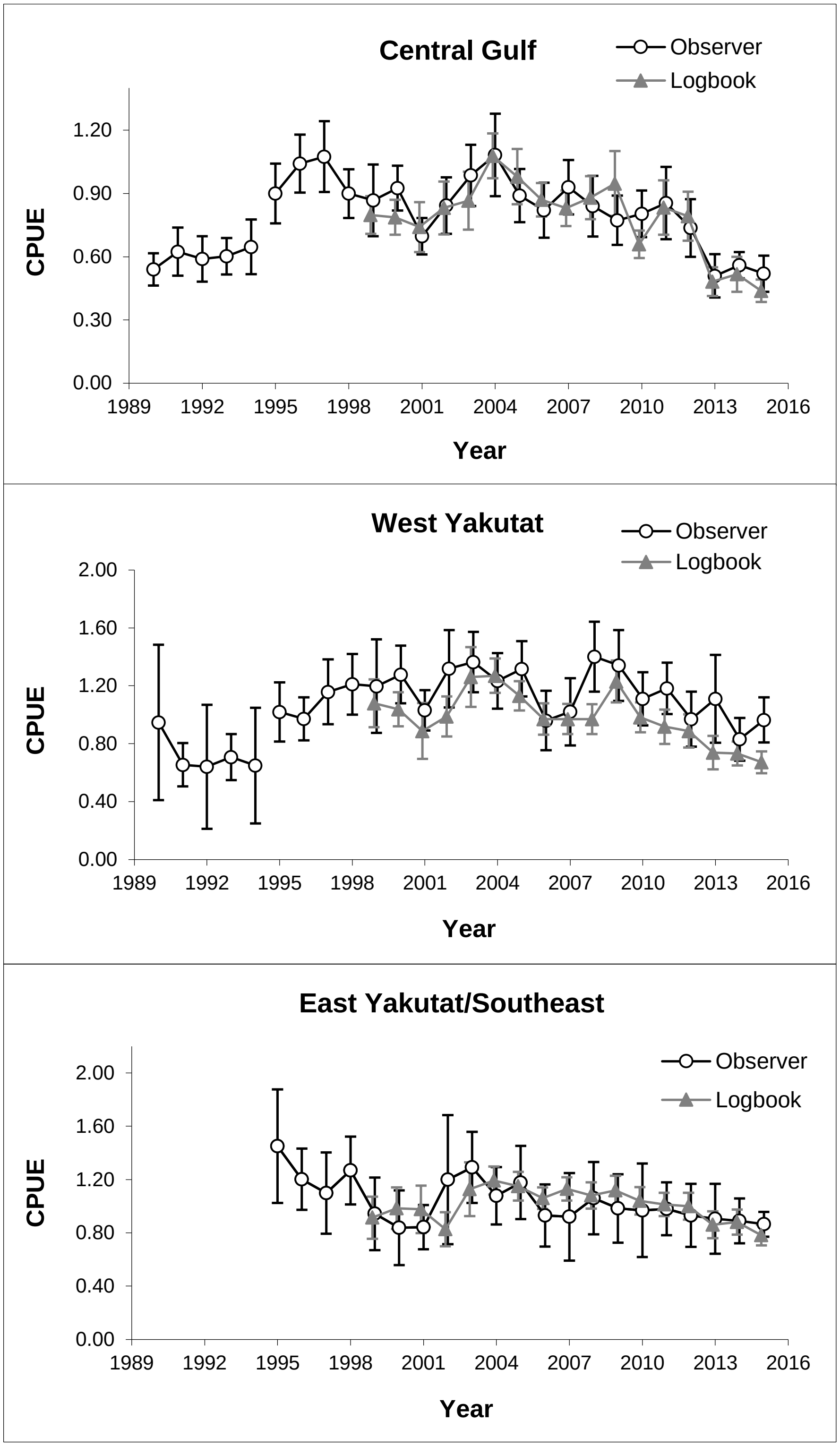


Figure 3.6. (continued)

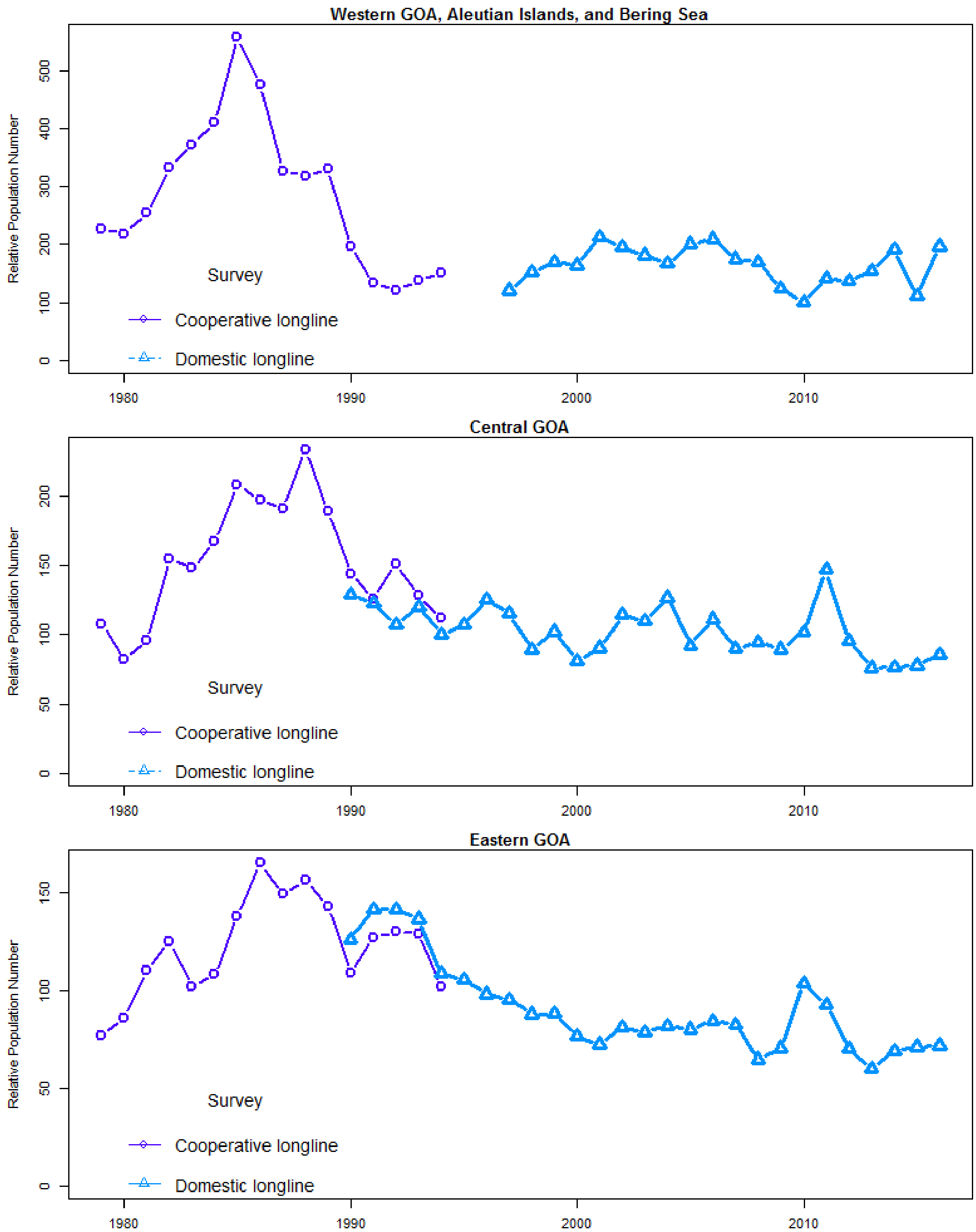


Figure 3.7. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the U.S. survey were adjusted to account for the higher efficiency of the U.S. survey gear.

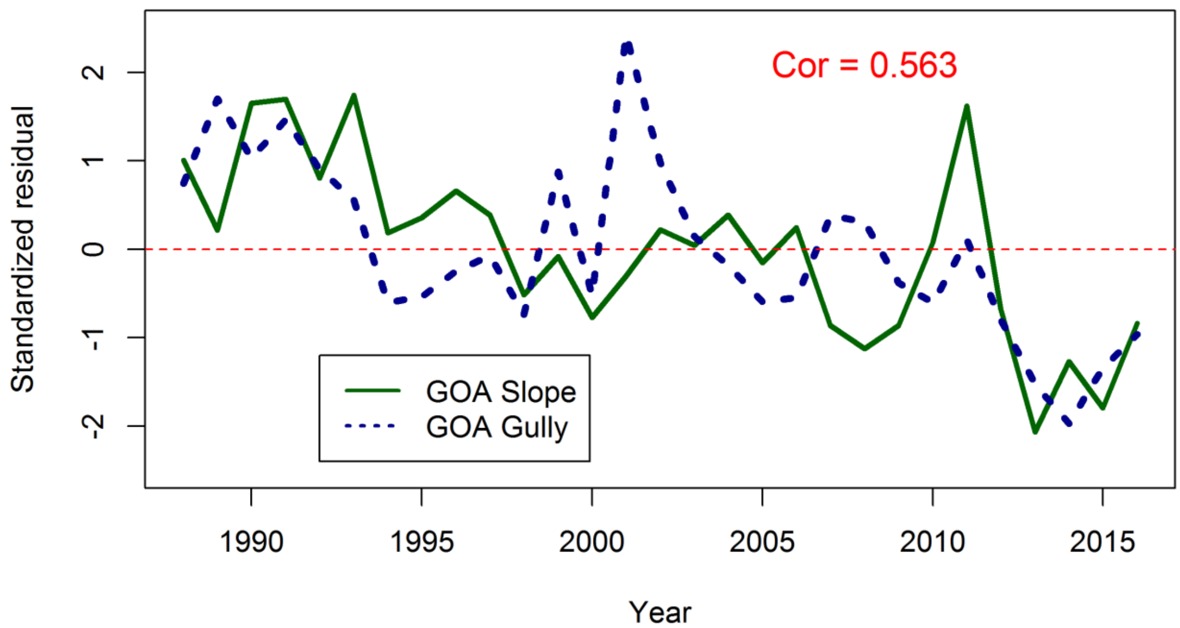


Figure 3.8 Comparison of abundance trends in GOA gully stations versus GOA slope stations.

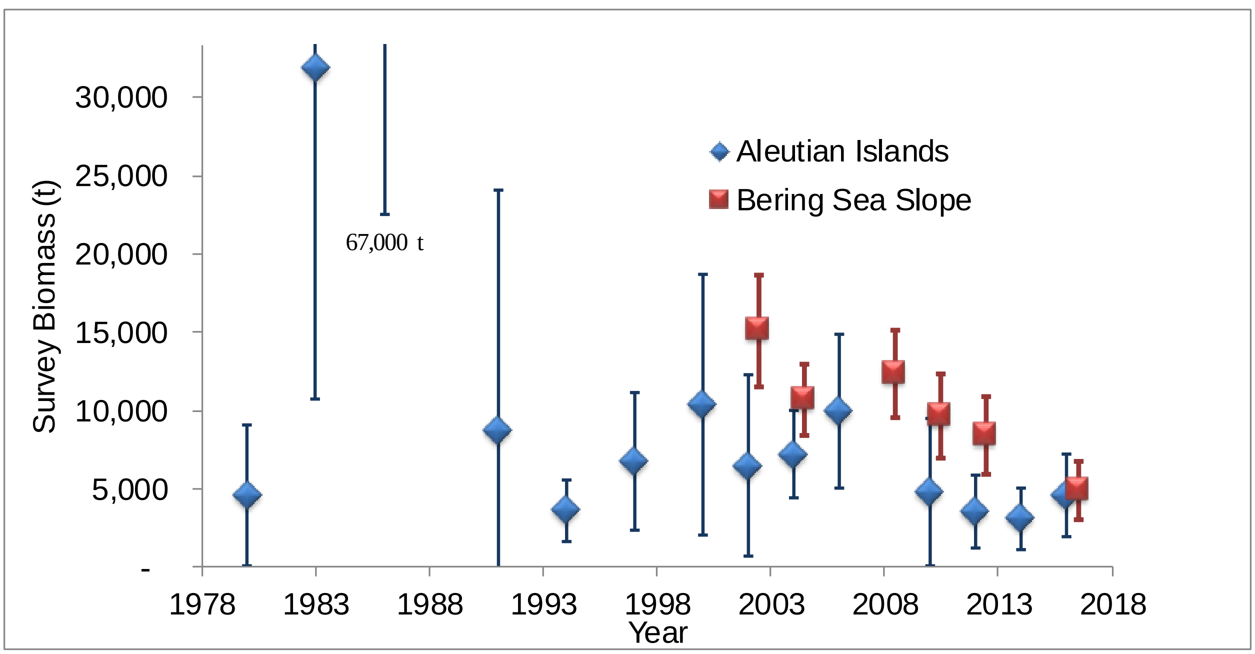


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates. Bering Sea Slope years are jittered so that intervals do not overlap.

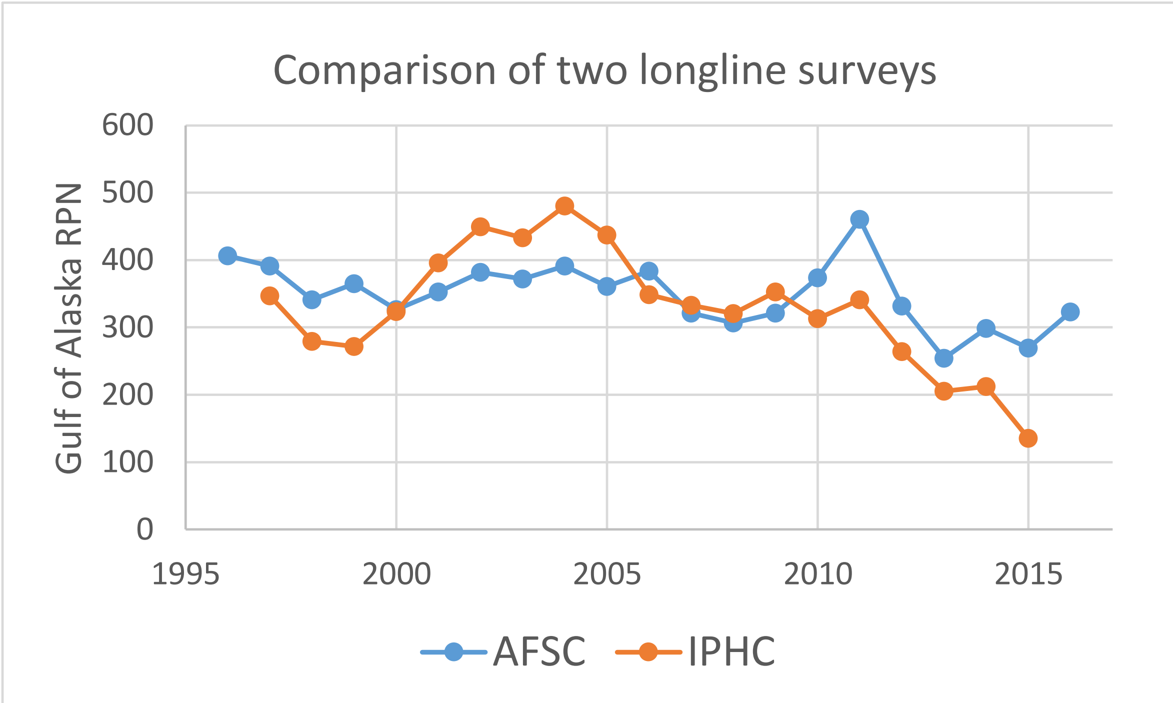


Figure 3.10a. Comparisons of IPHC and AFSC longline survey trends in relative population number of sablefish in the Gulf of Alaska. Years in which both surveys occurred have a correlation coefficient of r = 0.65.

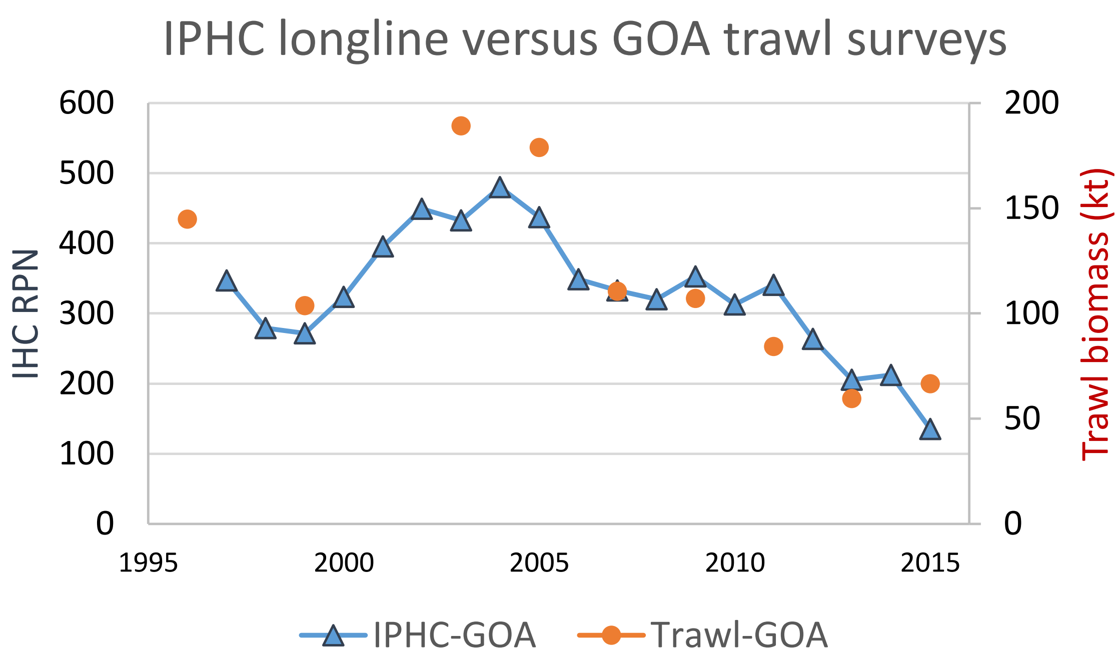


Figure 3.10b. Comparisons of IPHC and AFSC trawl survey trends abundance of sablefish in the Gulf of Alaska. Years in which both surveys occurred have a correlation coefficient of r = 0.86.

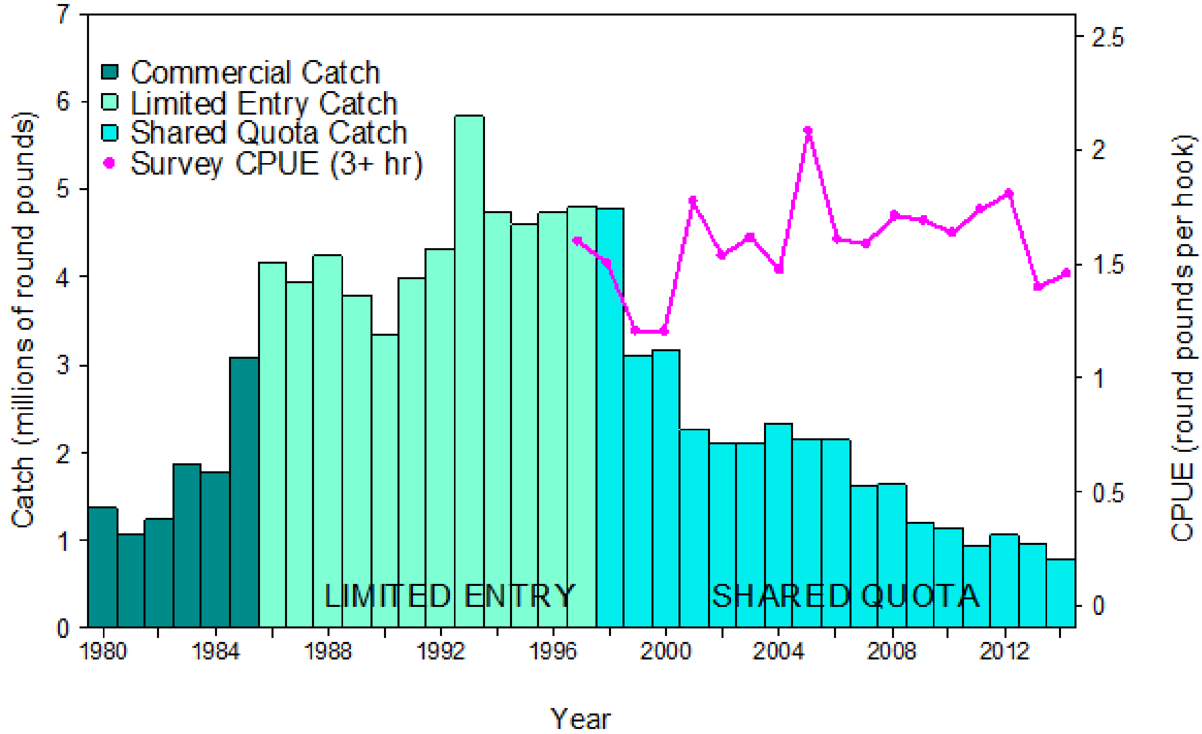


Figure 3.11a. Northern Southeast Inside (NSEI) sablefish longline survey catch-per-unit-effort (CPUE) in round pounds/hook and commercial catch from 1980 to 2014. A three-hour minimum soak time was used on the NSEI sablefish longline survey (from K. Green. ADF&G, pers. comm. October, 2015).

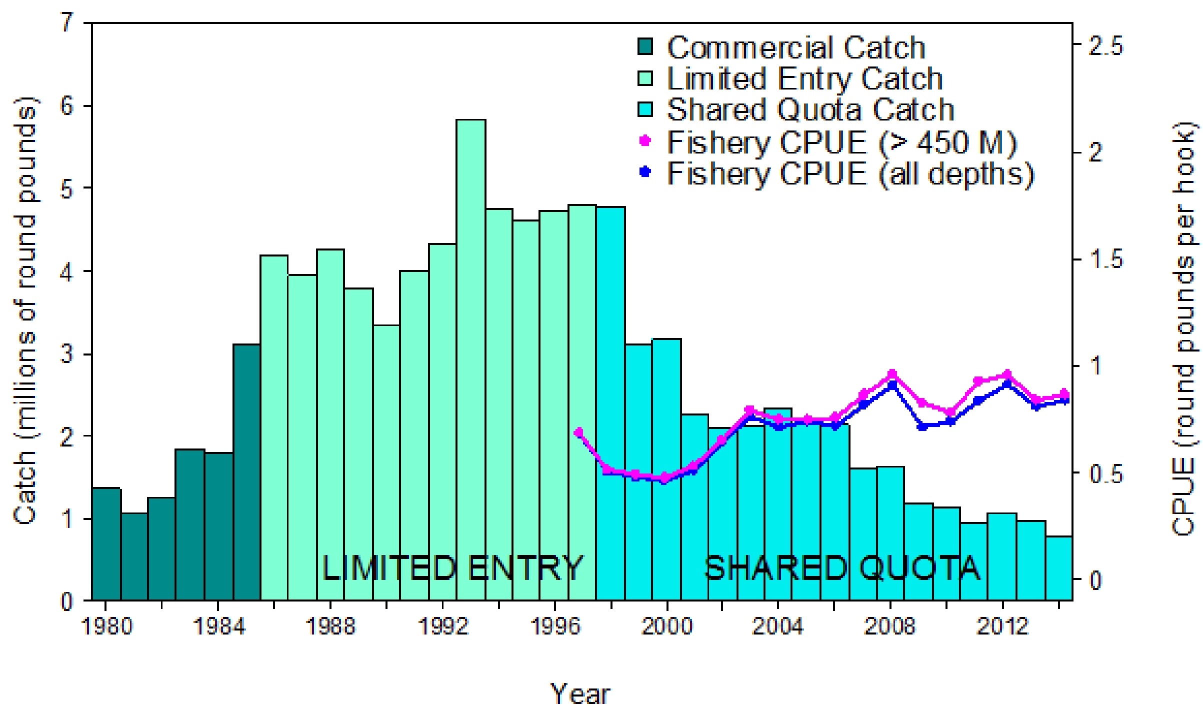


Figure 3.11b. Northern Southeast Inside (NSEI) commercial sablefish longline catch-per-unit-effort (CPUE) in round pounds-per-hook from 1997 to 2014 and commercial catch from 1980 to 2014 (from K. Green, October, 2015 ADF&G, pers. comm.).

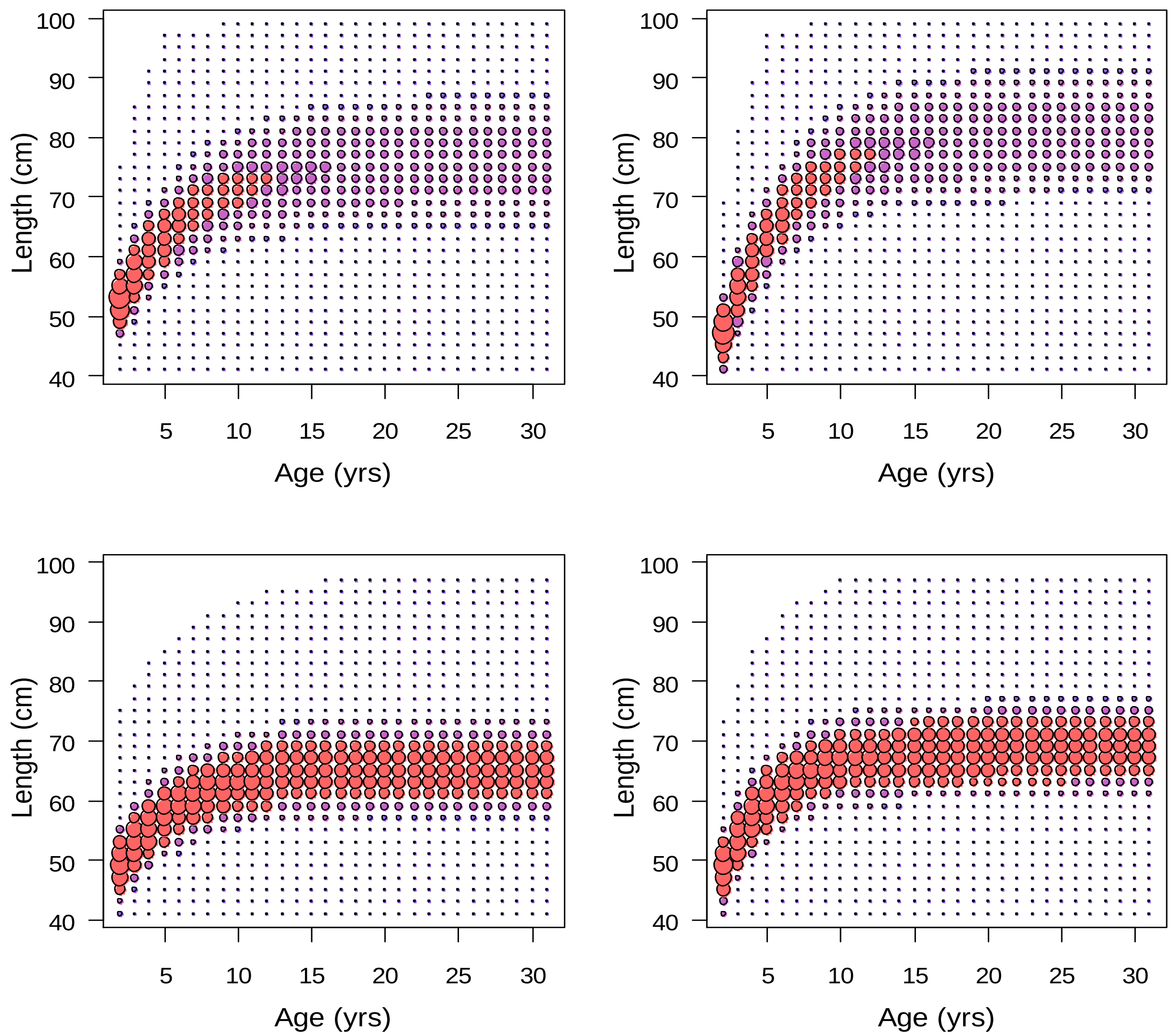


Figure 3.12. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996-2016.

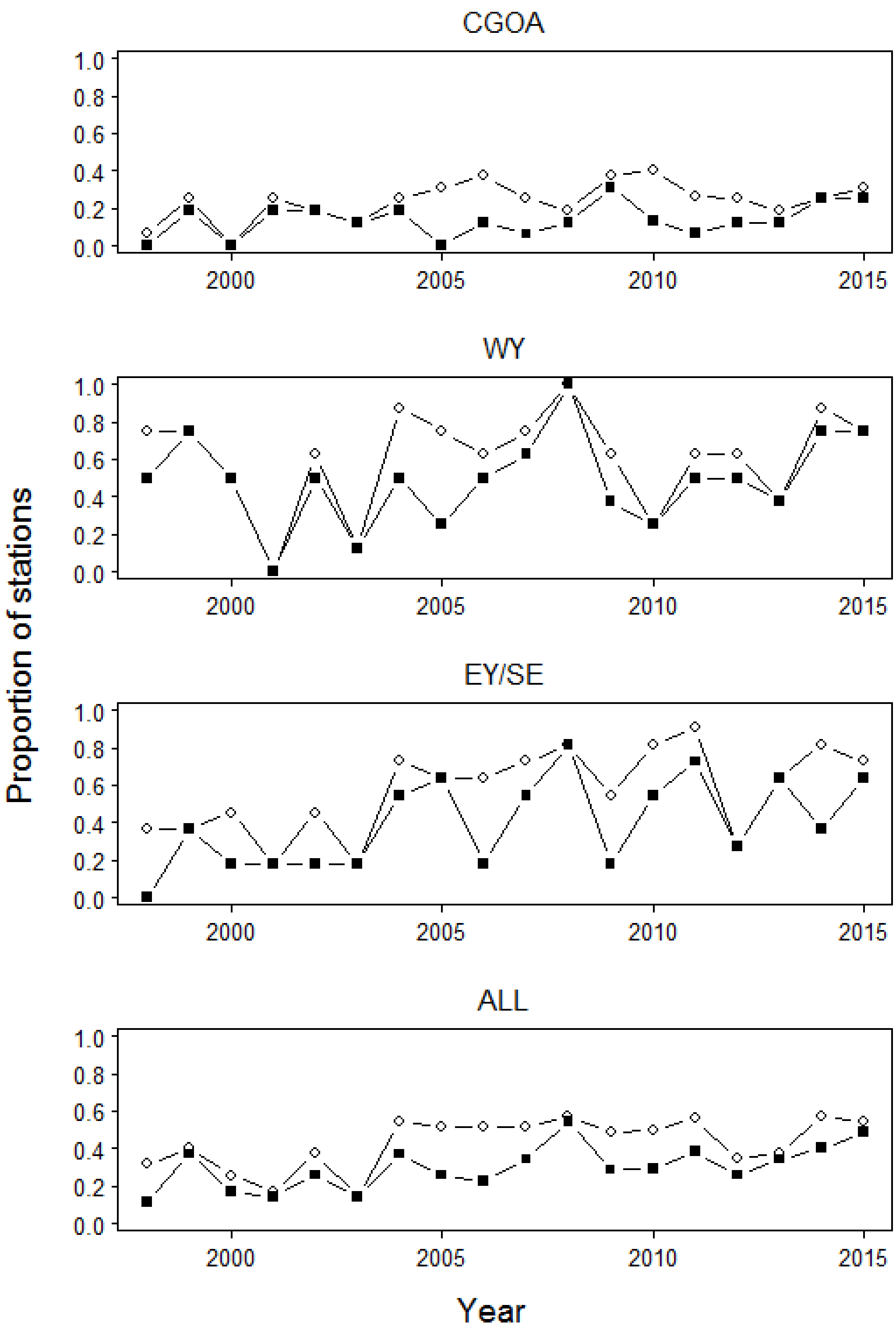


Figure 3.13. Proportion of stations with sperm whale presence (open circles) and evidence of depredation (solid squares) by management area and pooled, 1998-2015.

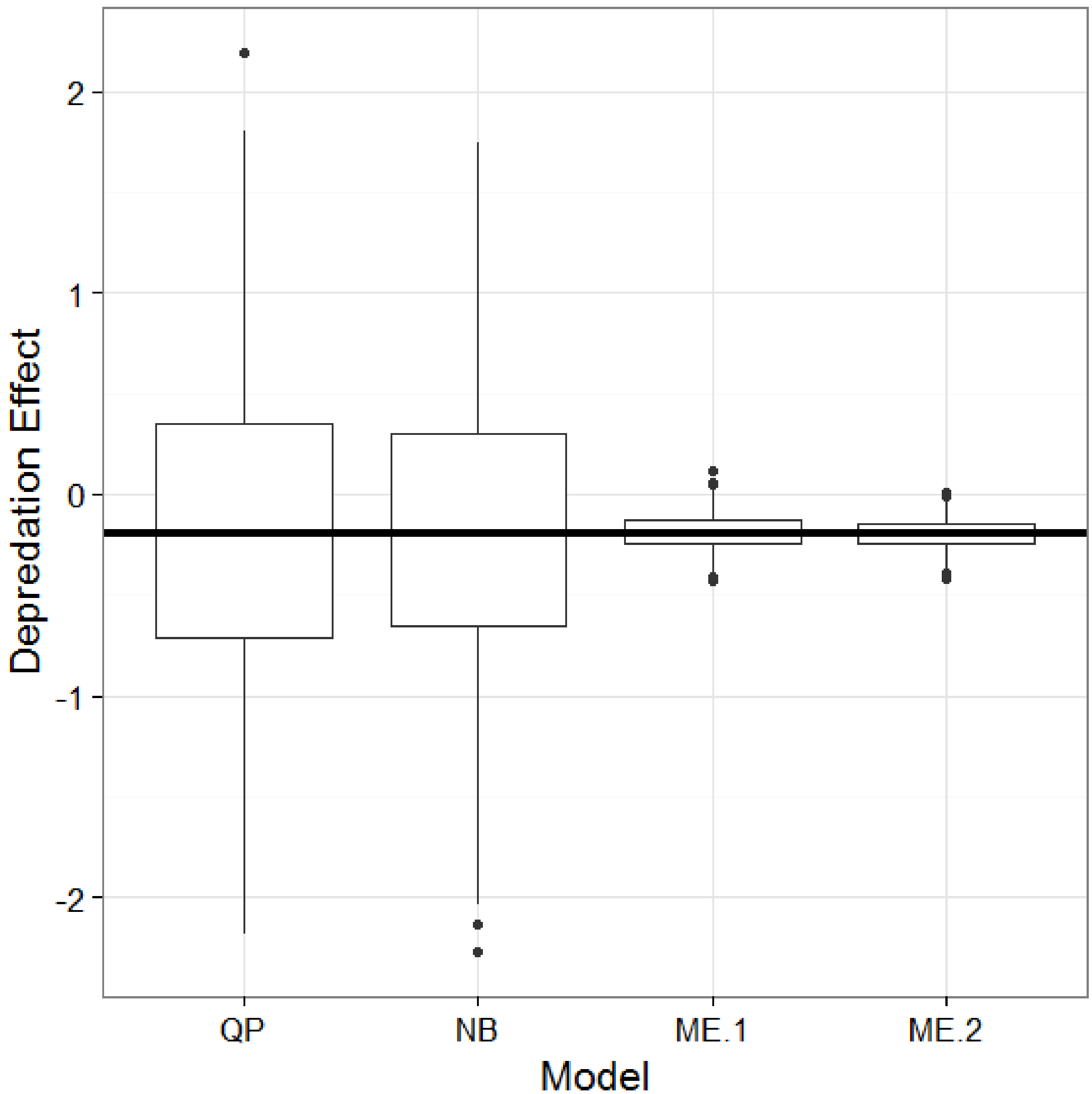


Figure 3.14. Boxplots of simulation estimates (1000 trials) of sperm whale depredation by model for simulation 1 (true simulated value of the depredation effect = -0.2). QP = Quasipoisson GLM, NB = negative binomial GLM, ME.1 = Mixed effects Poisson without interactions, ME.2 = saturated mixed effects Poisson.

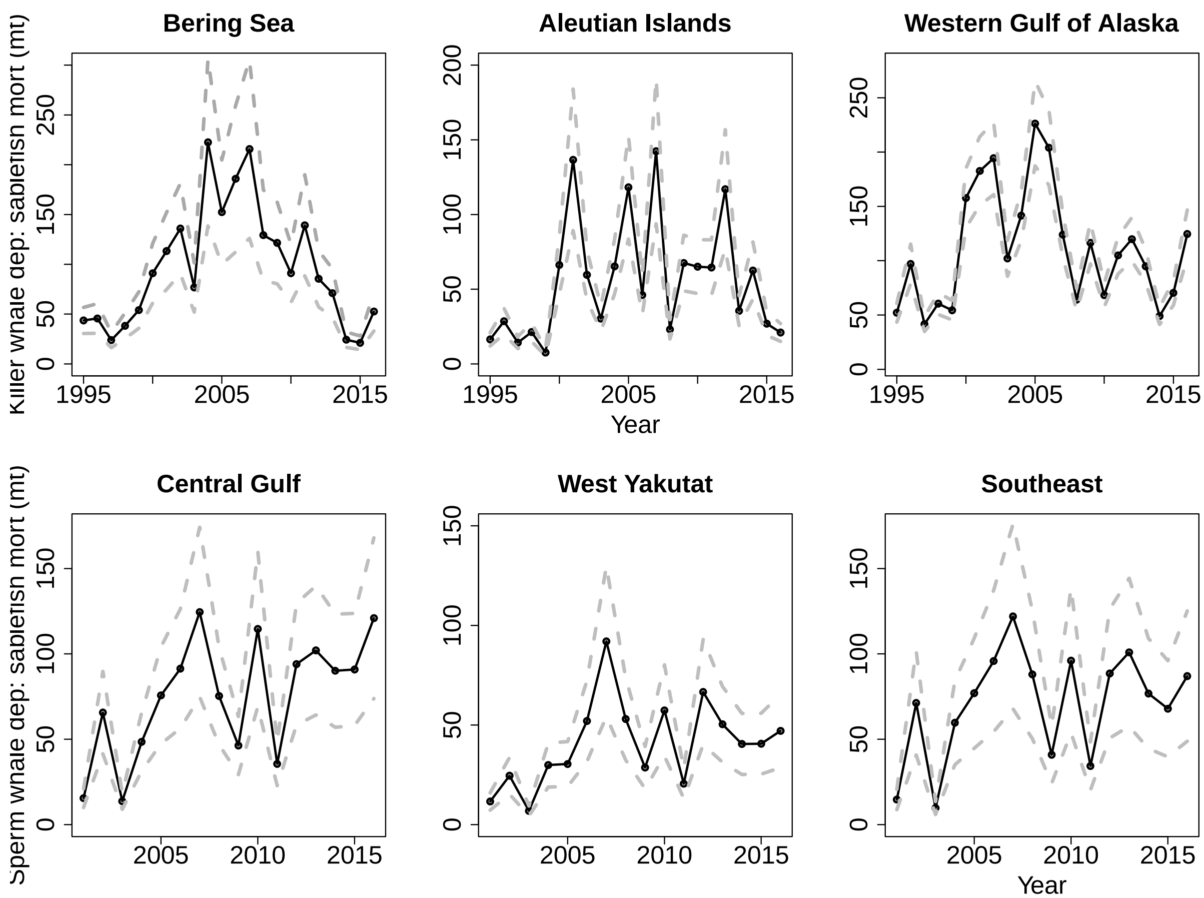


Figure 3.15. Estimated sablefish mortality (t) by year due to killer whales in the Bering Sea, Aleutian Islands, and Western Gulf of Alaska and sperm whales in the Central Gulf of Alaska, West Yakutat, and Southeast Alaska with ~95% confidence bands. Estimated sablefish catch removals (t) due to sperm whale and killer whale depredation 1995-2016.

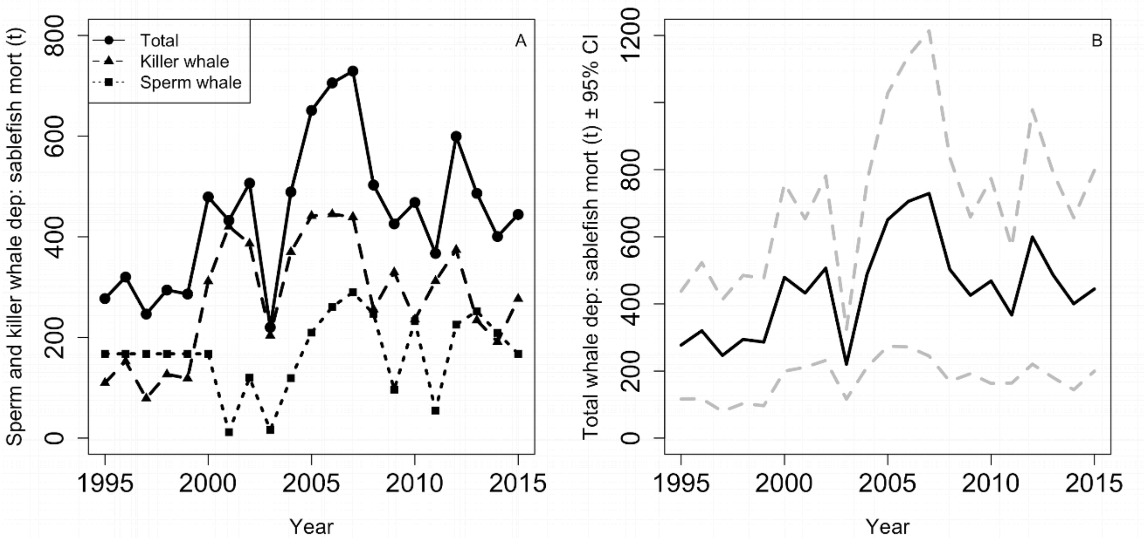


Figure 3.16. Additional estimated sablefish mortality by whale species (A), and total whale mortality by year with 95% asymptotic normal confidence intervals (B).

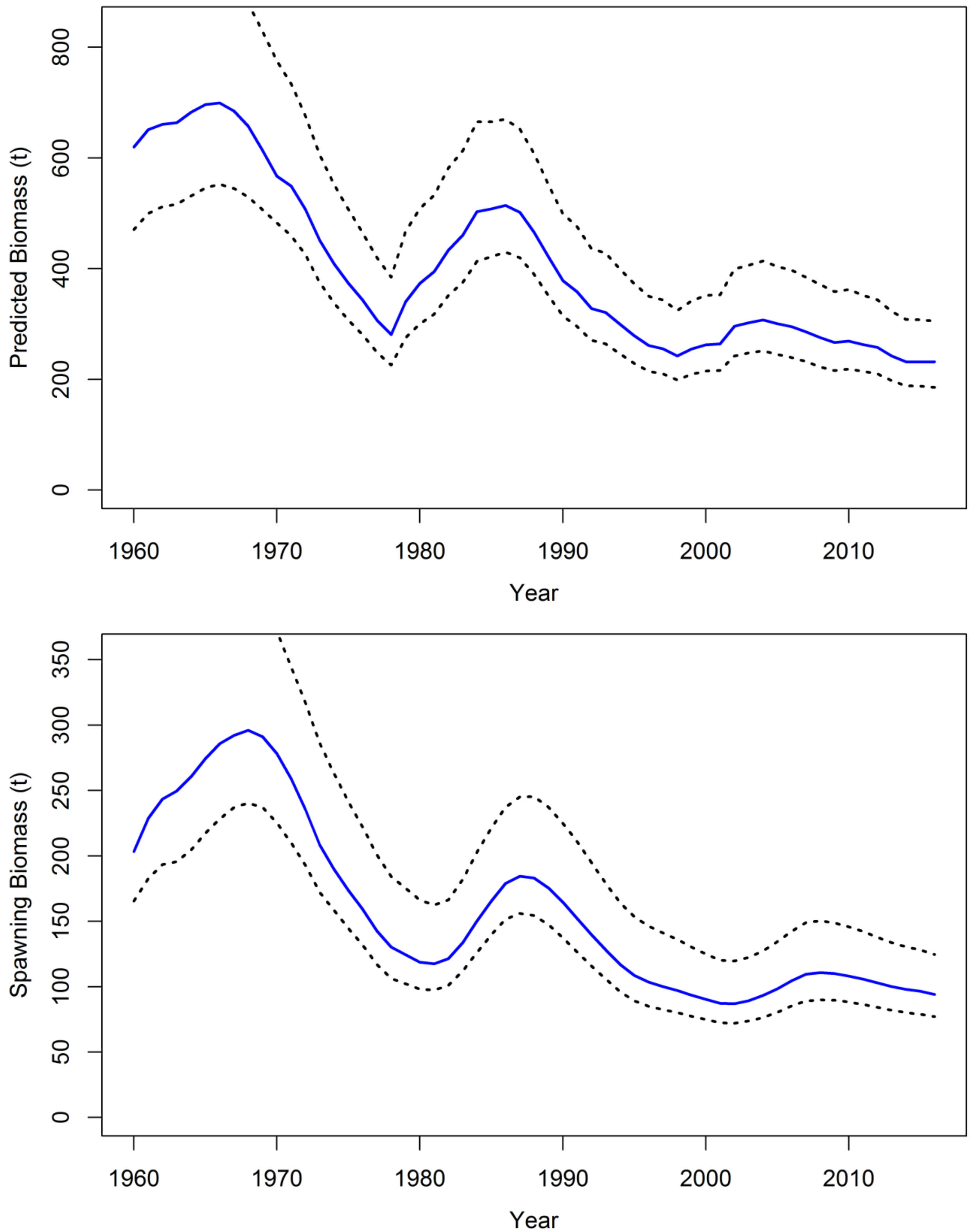


Figure 3.17. Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

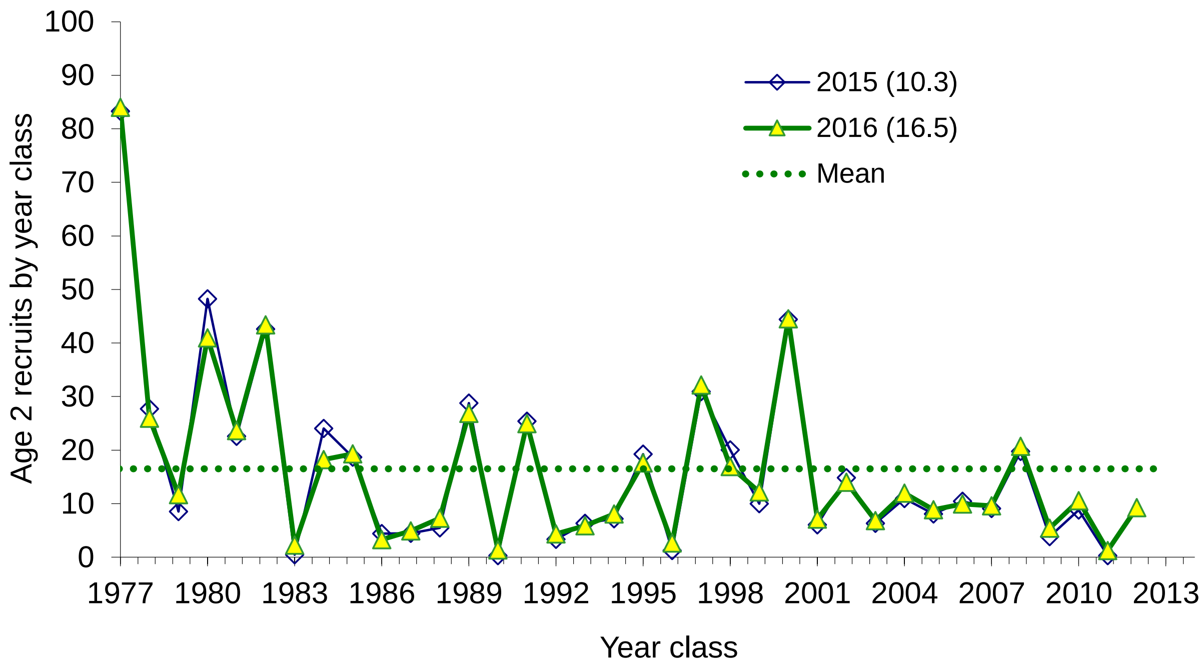


Figure 3.18a. Estimated recruitment by year class 1977-2012 (number at age 2, millions) for 2015 and 2016 models.

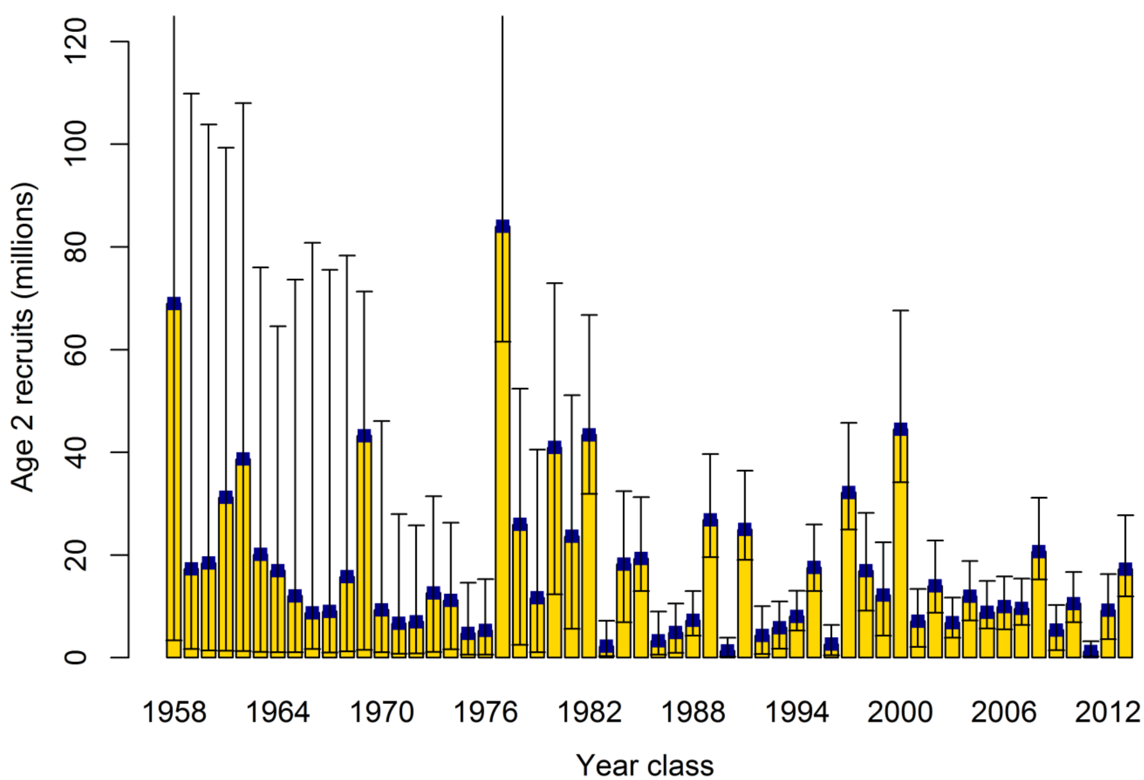


Figure 3.18b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Credible intervals are based on MCMC posterior.

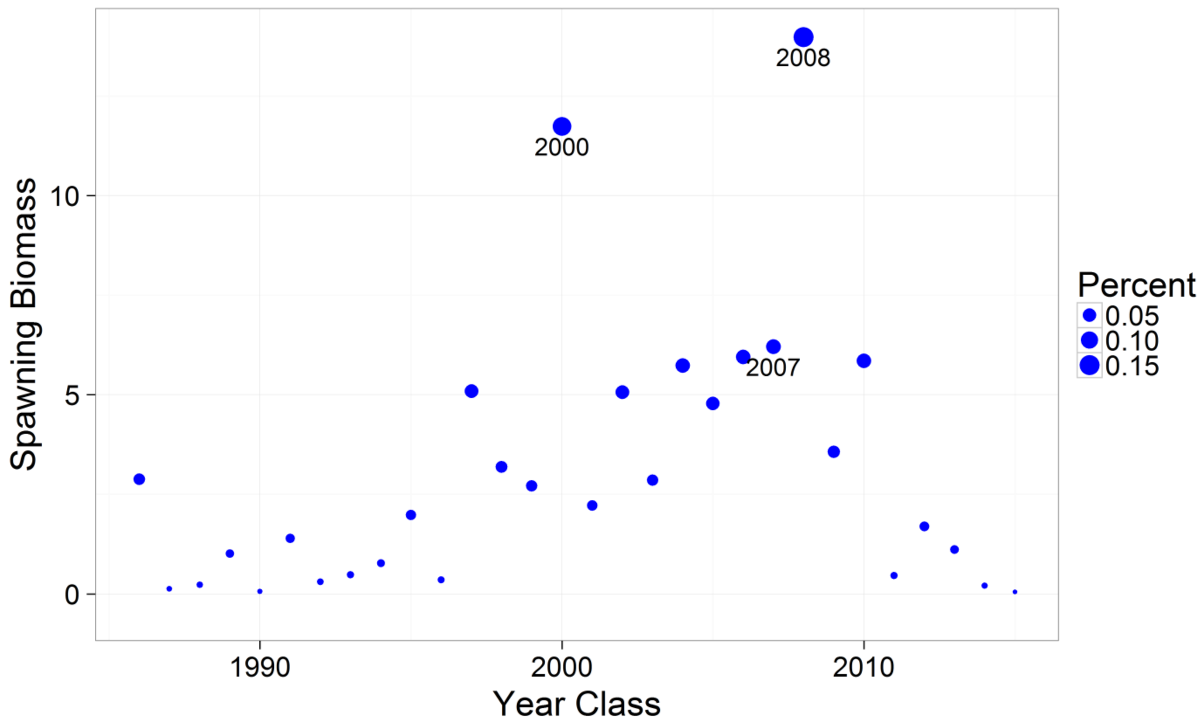


Figure 3.19. Relative contribution of the last 30 year classes to next year's female spawning biomass.

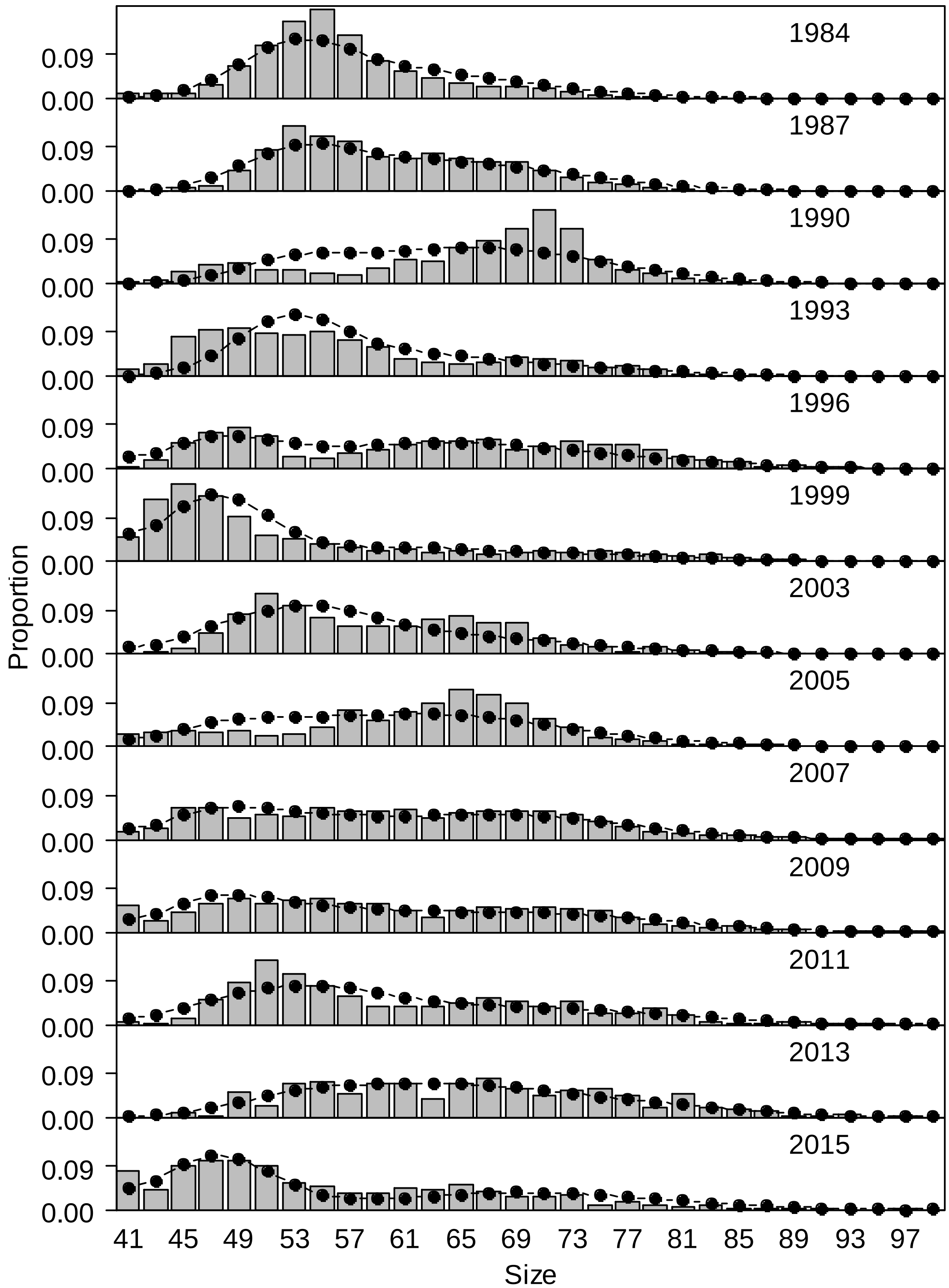


Figure 3.20. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

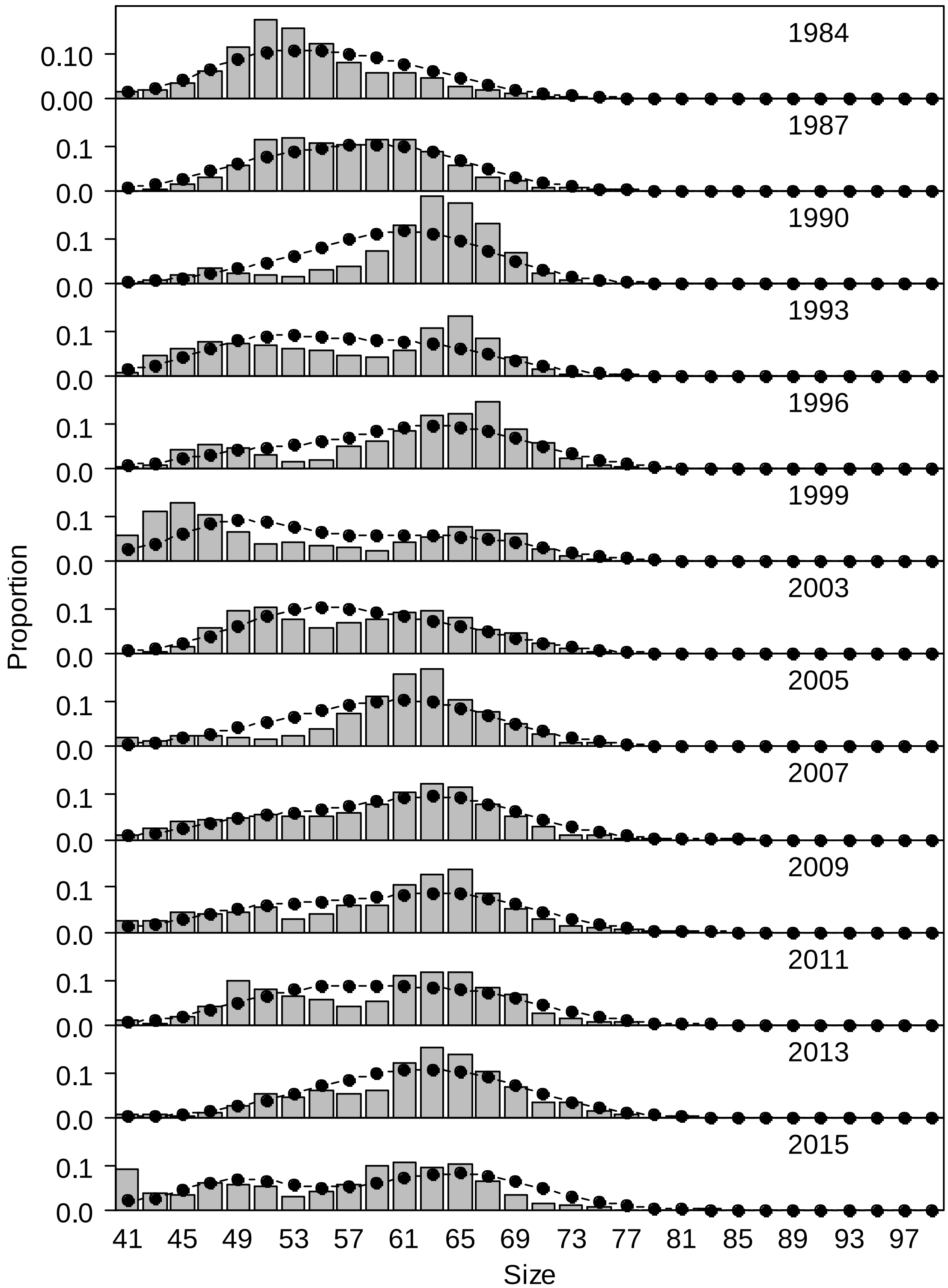


Figure 3.21. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

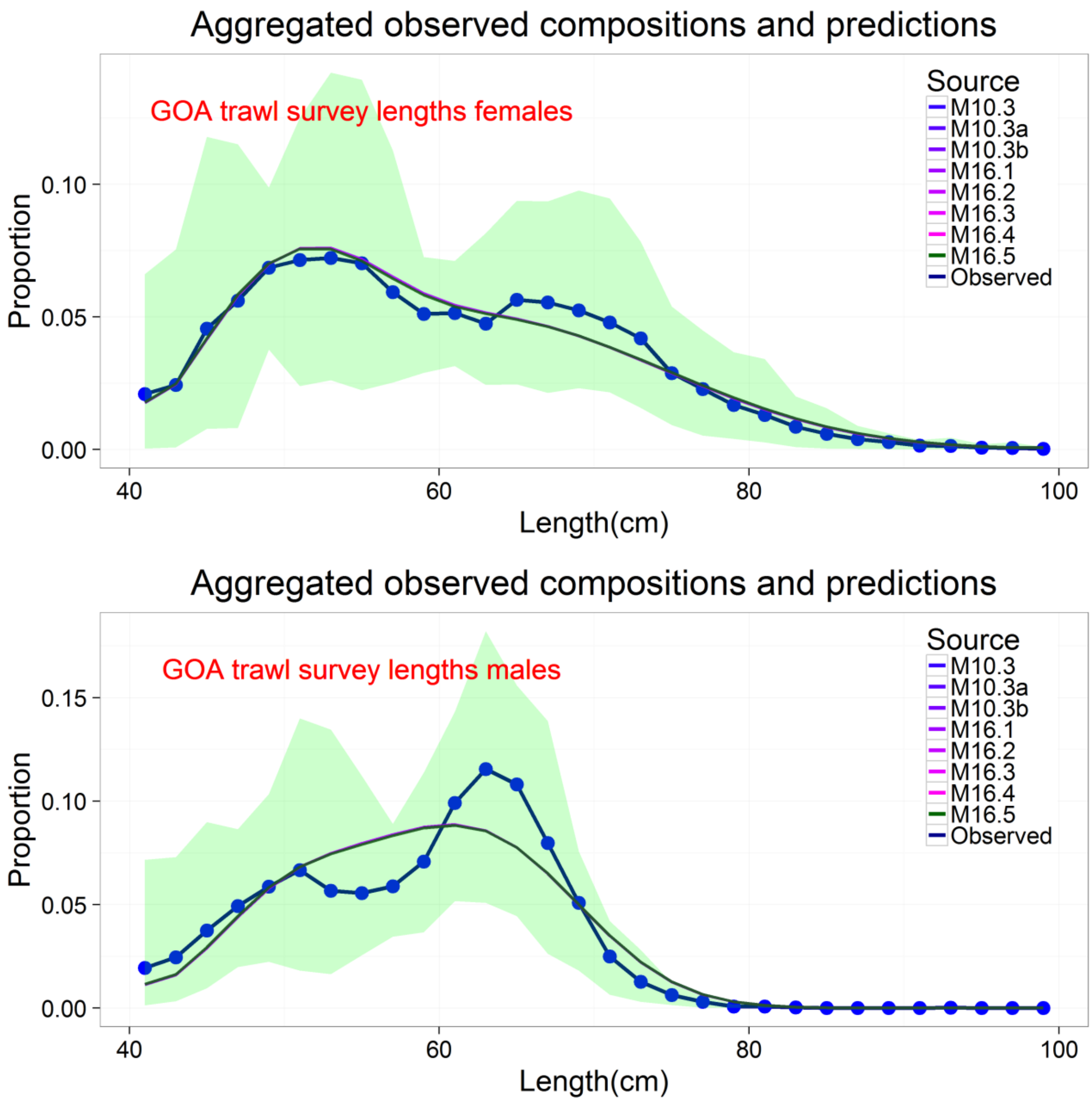


Figure 3.22. Gulf of Alaska trawl survey length compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

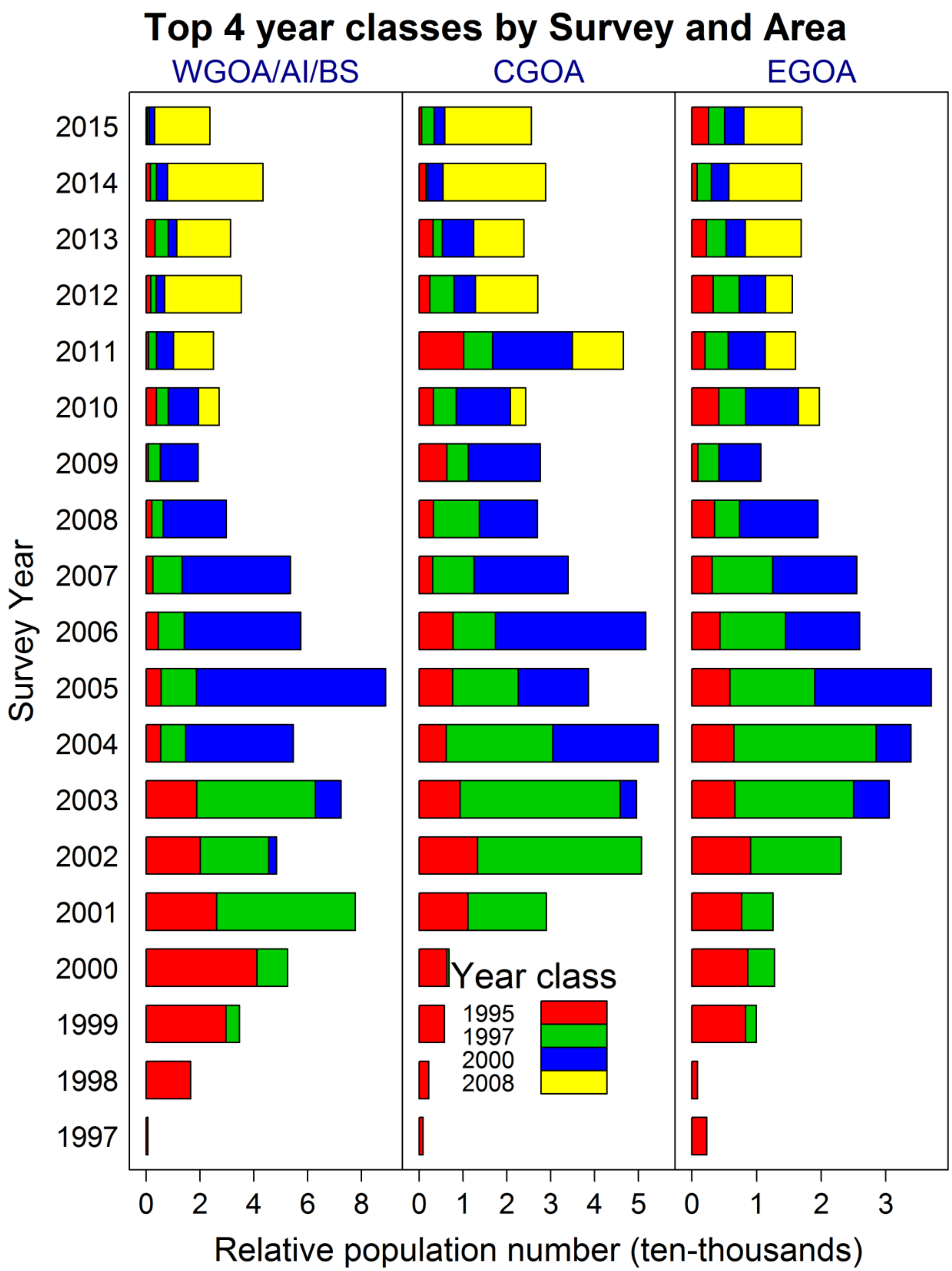


Figure 3.23. Above average 1995, 1997, 2000 and 2008 year classes' relative population abundance in each survey year and area.

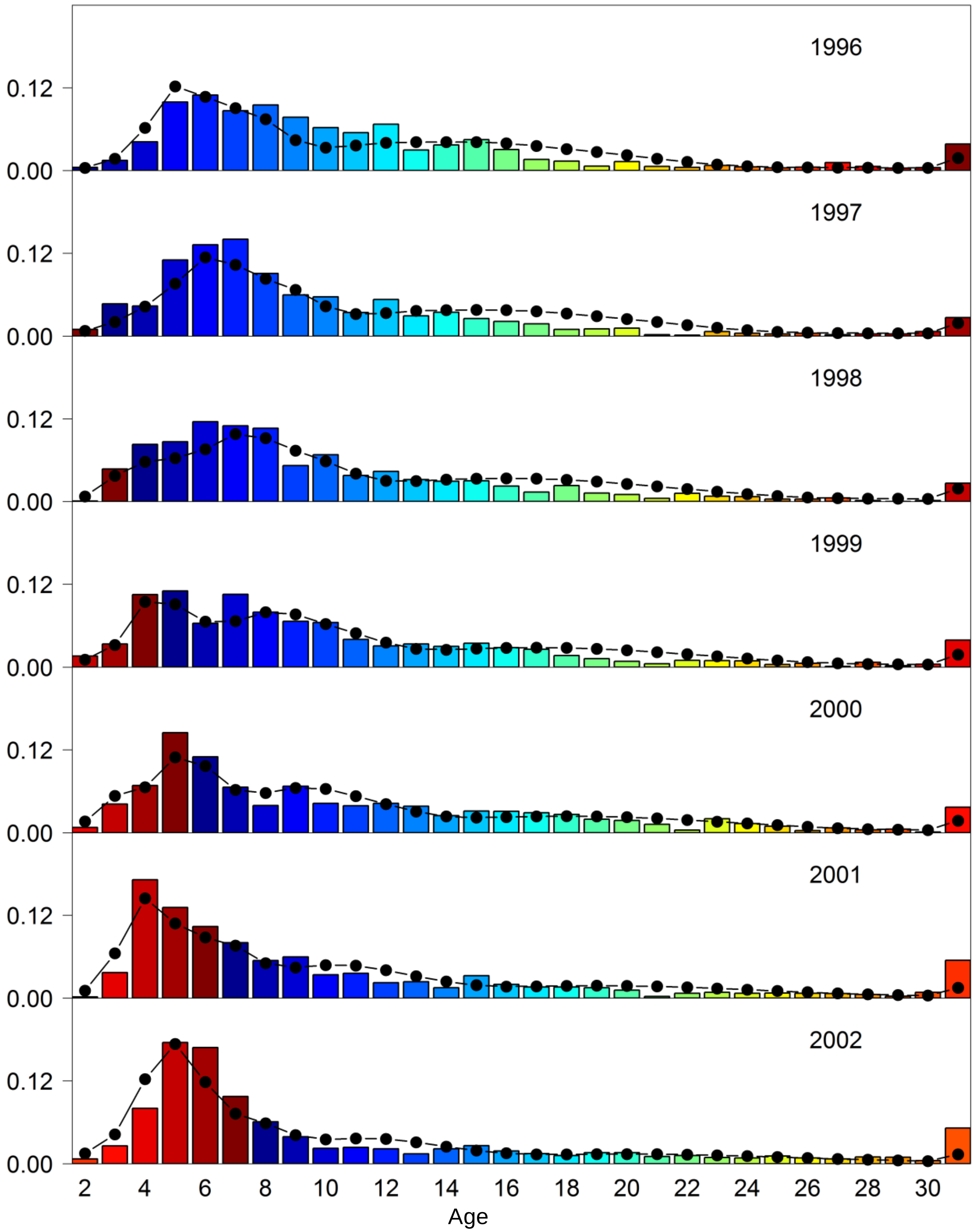


Figure 3.24. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

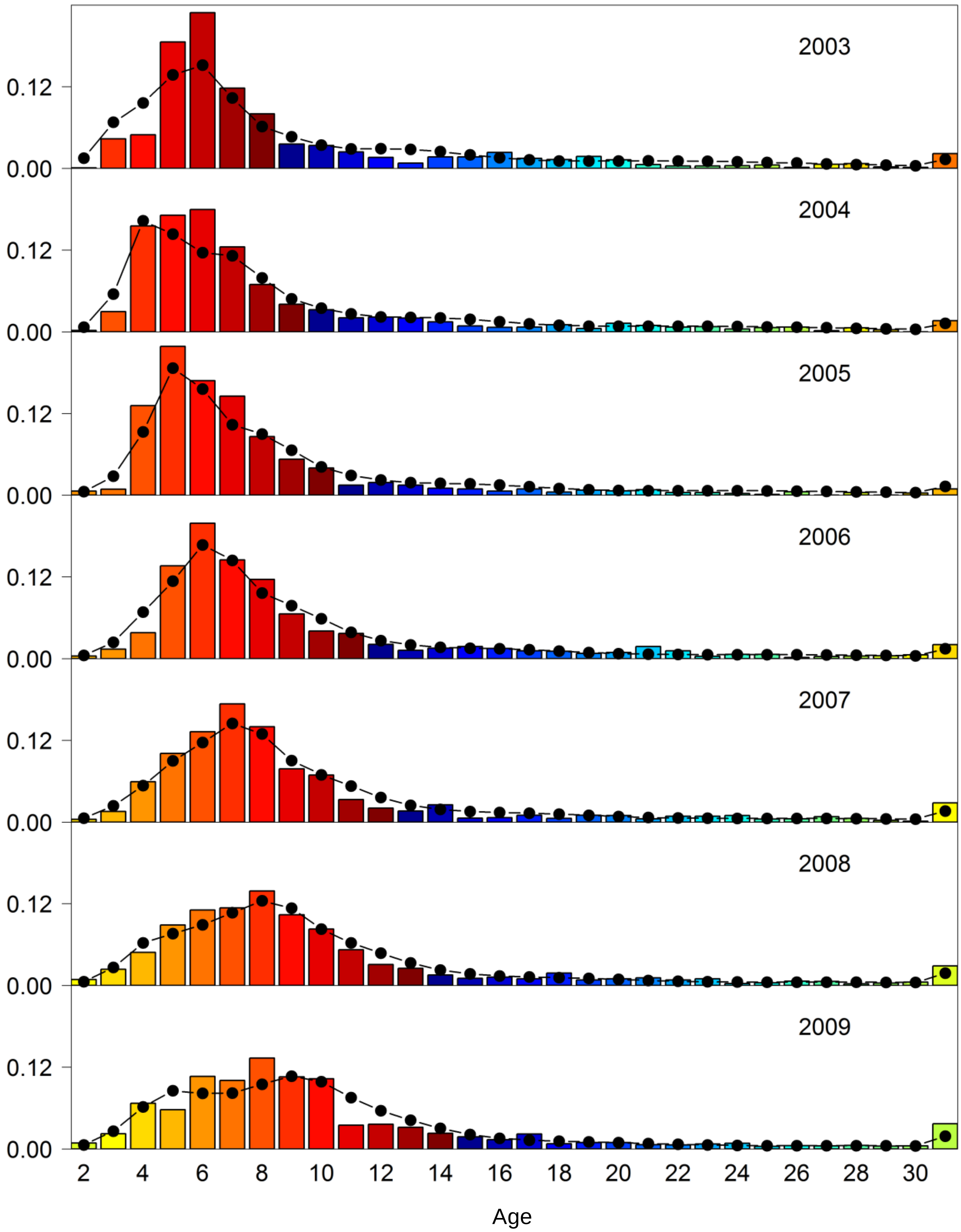


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

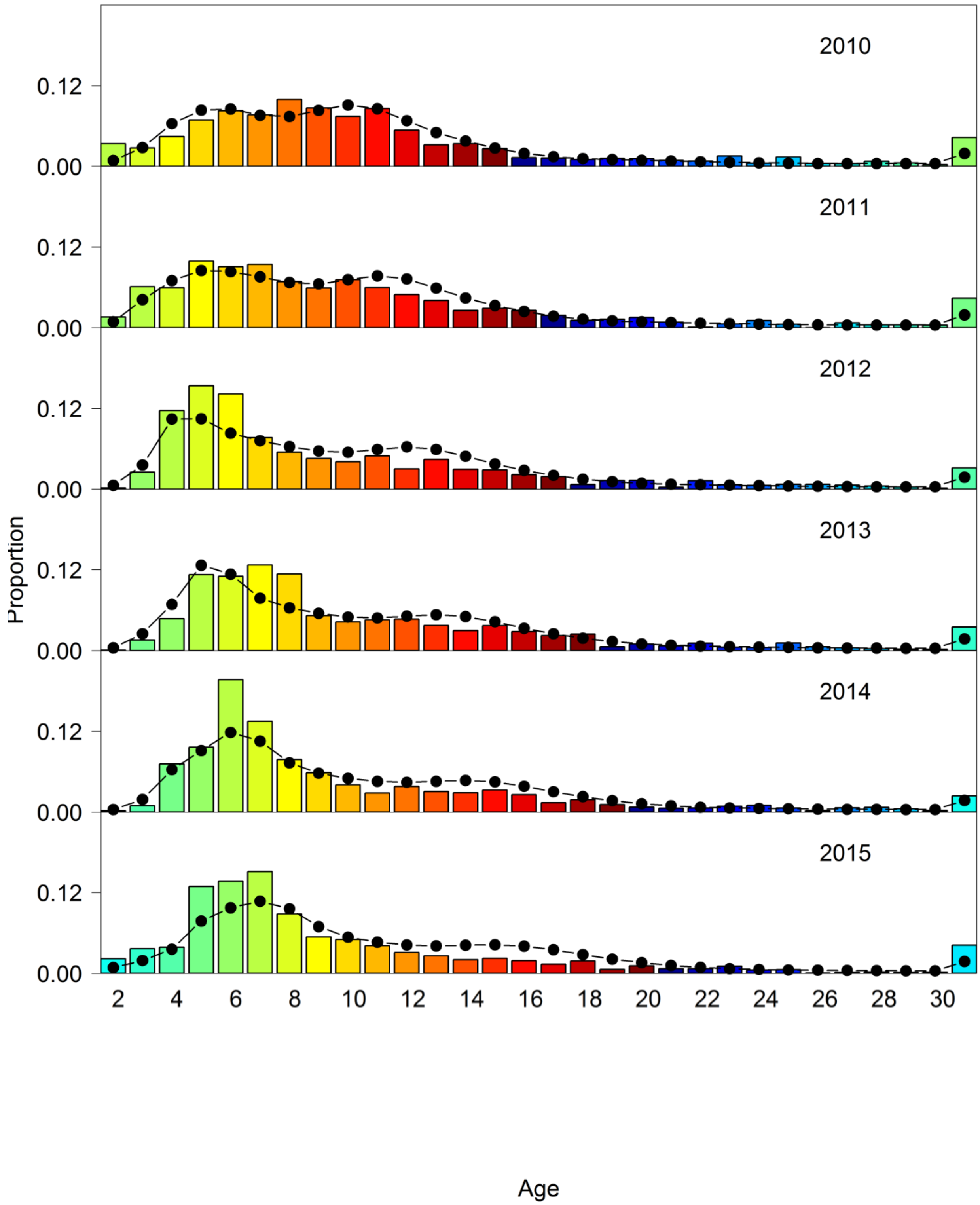
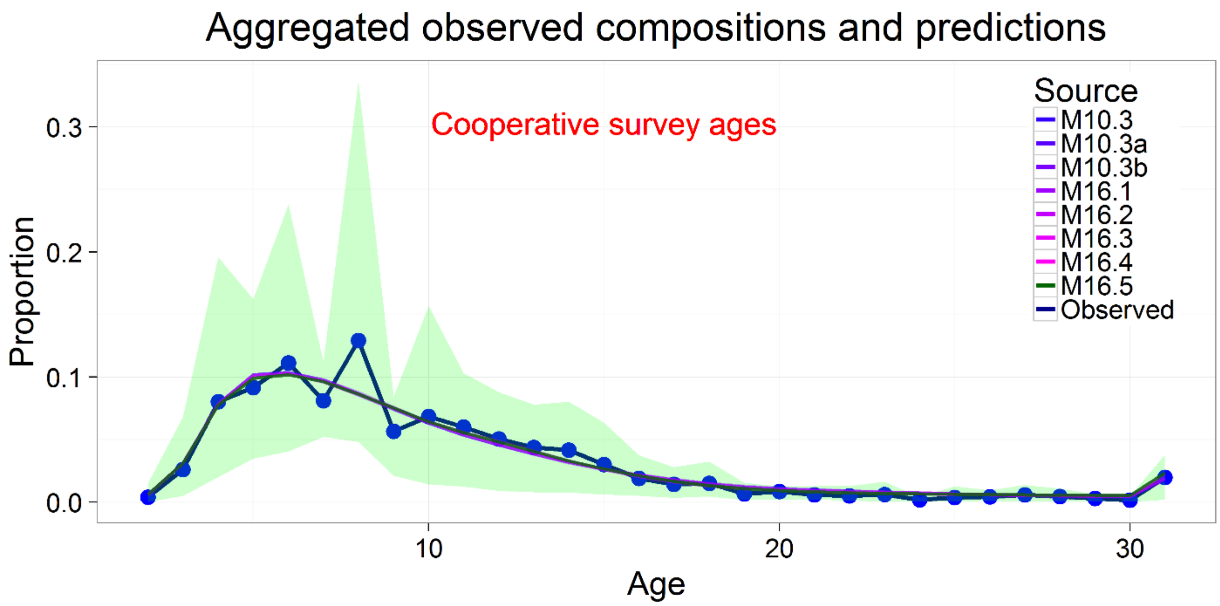


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.



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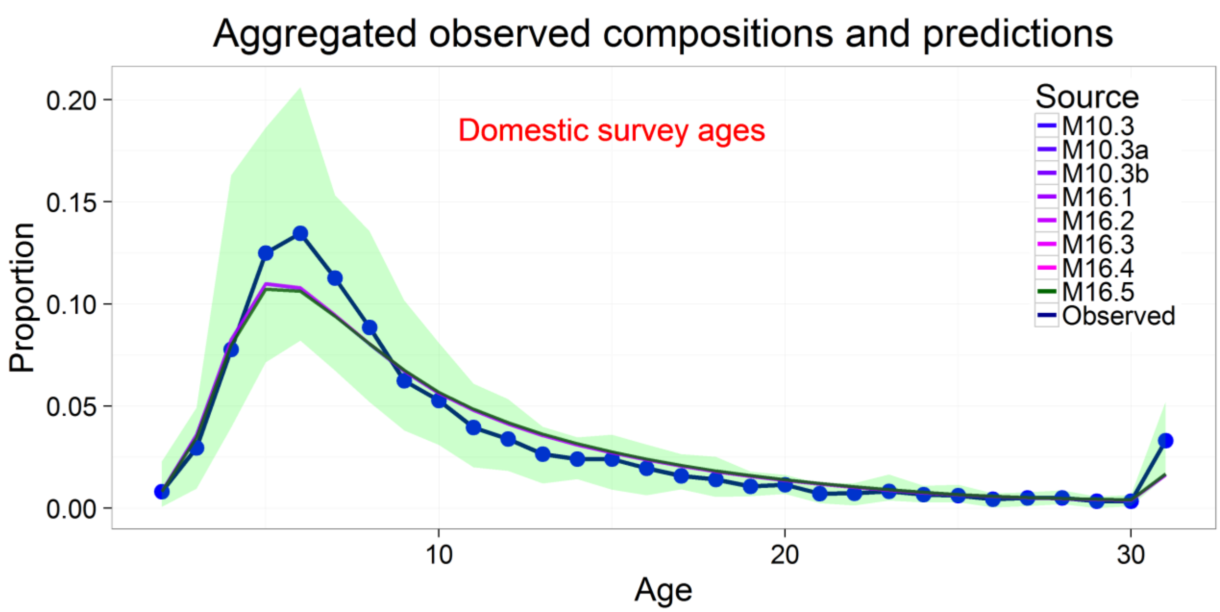


Figure 3.25. Domestic survey age compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

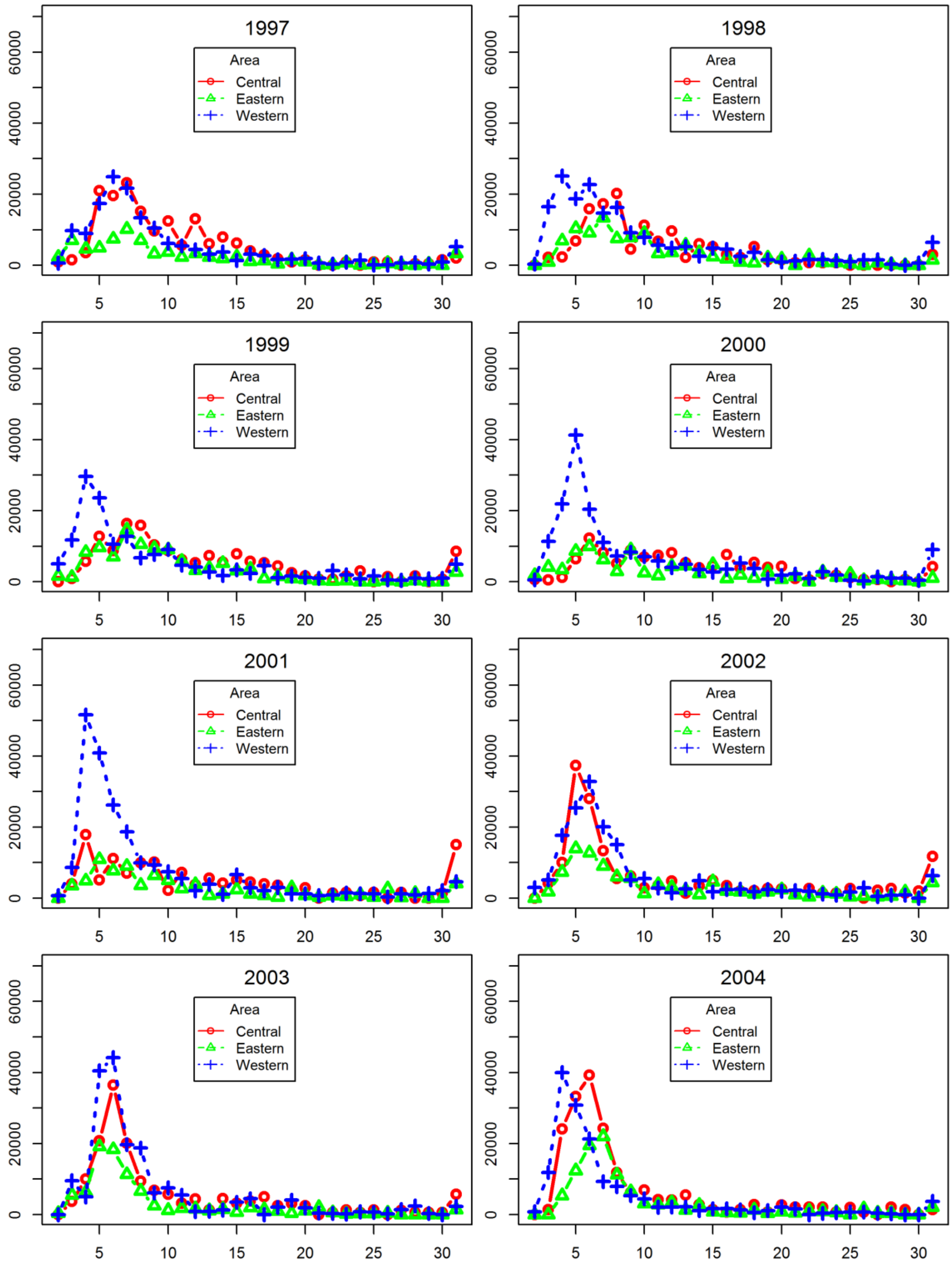


Figure 3.26. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

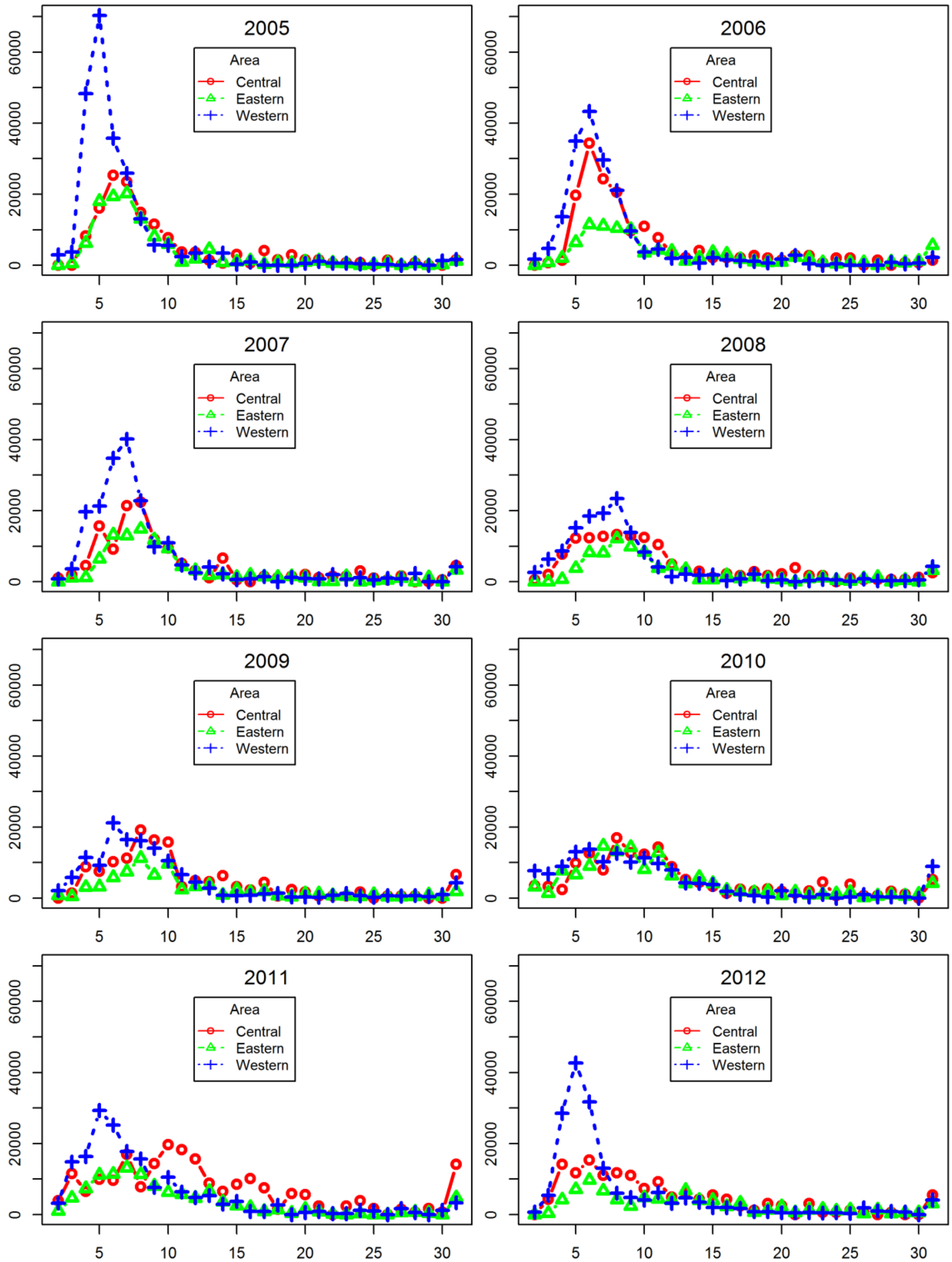


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

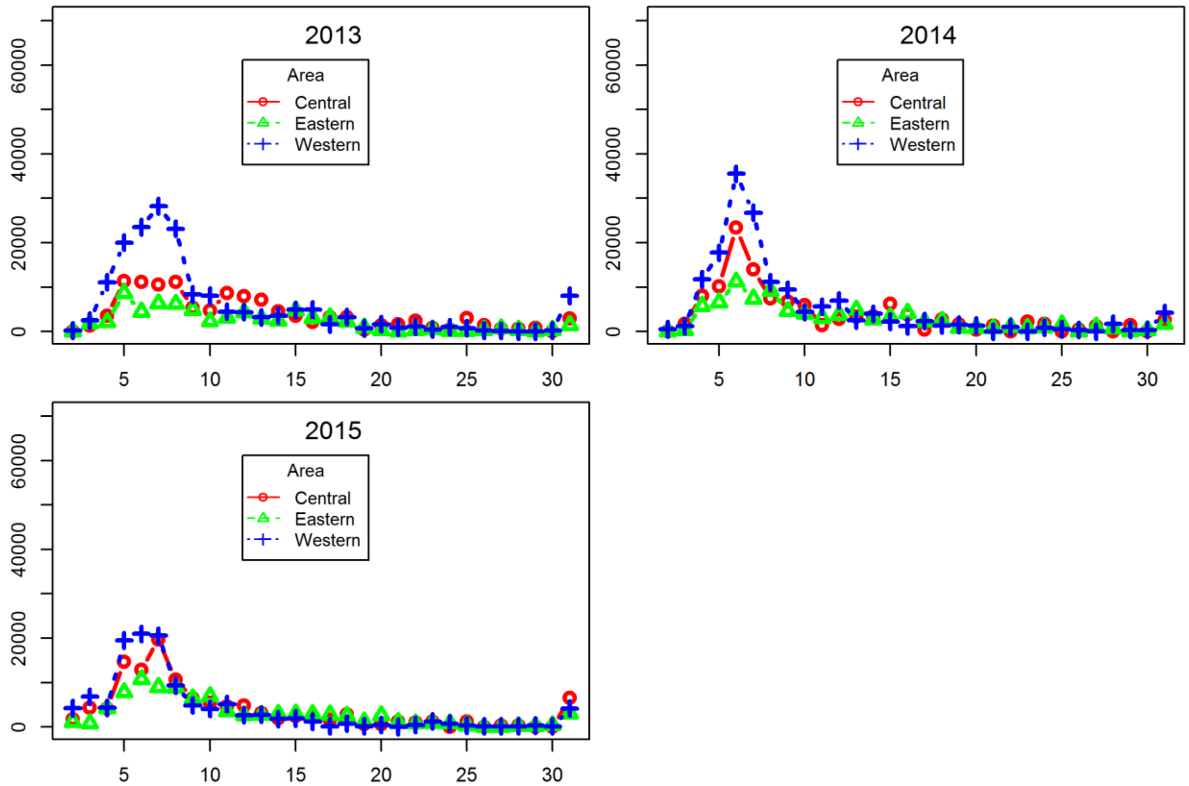


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

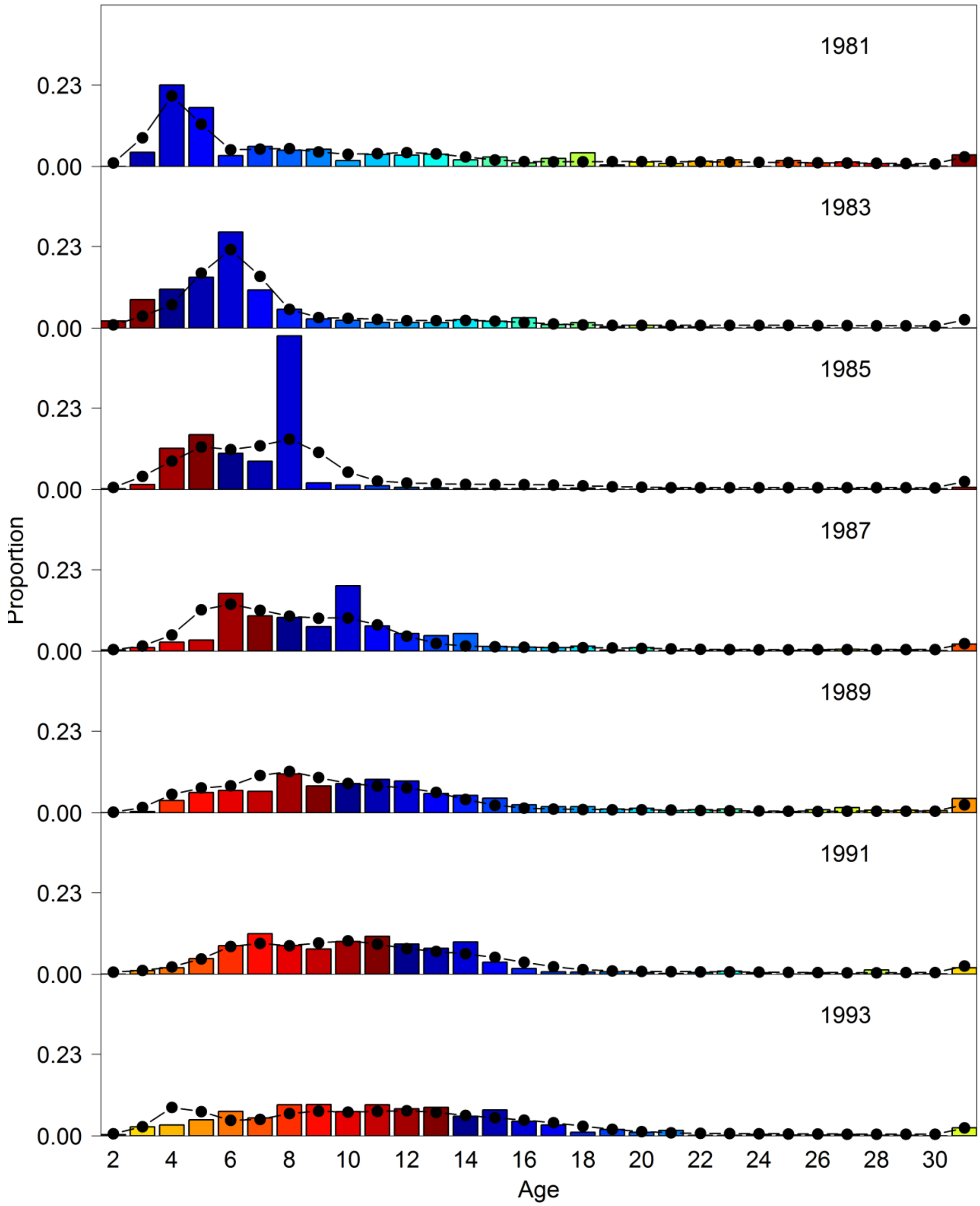
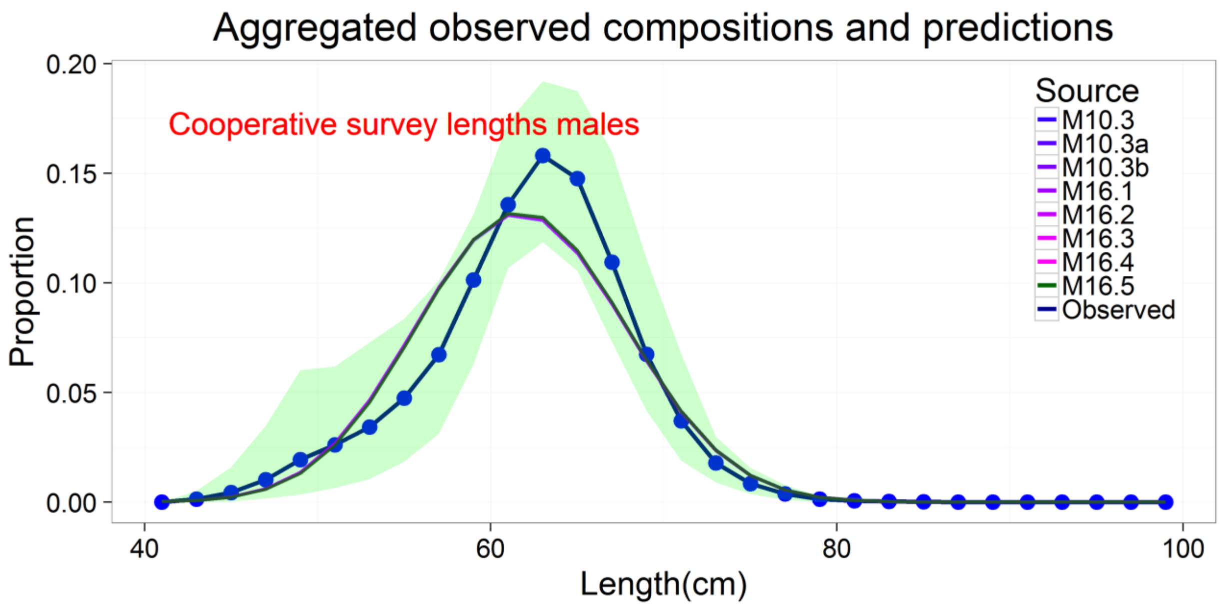


Figure 3.27. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.



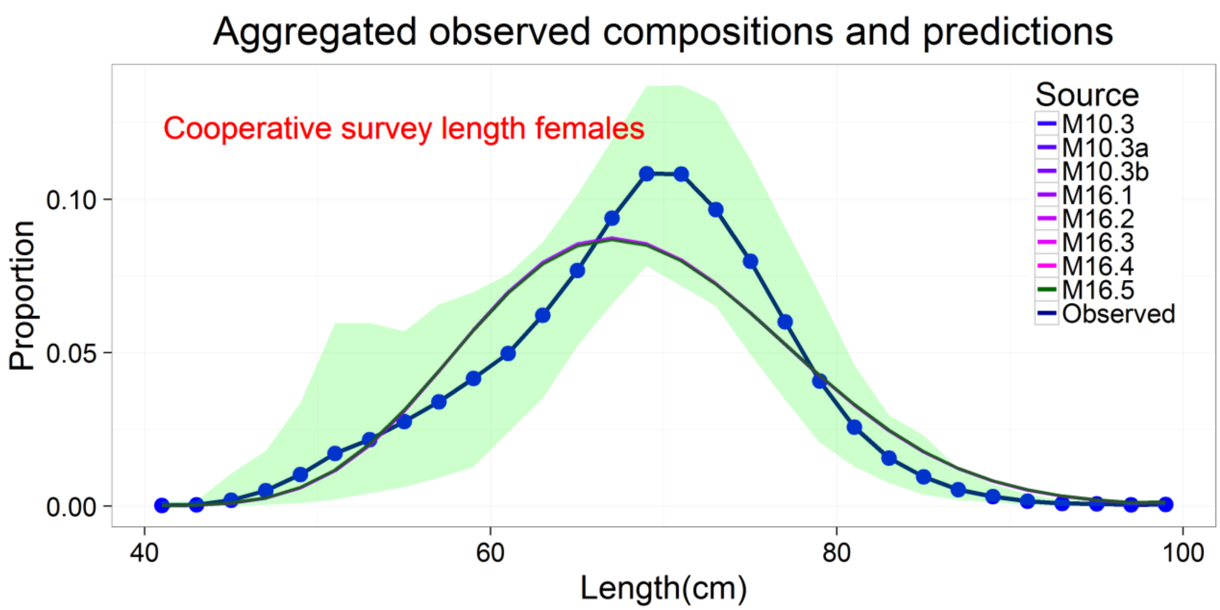


Figure 3.28. Cooperative longline survey length compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

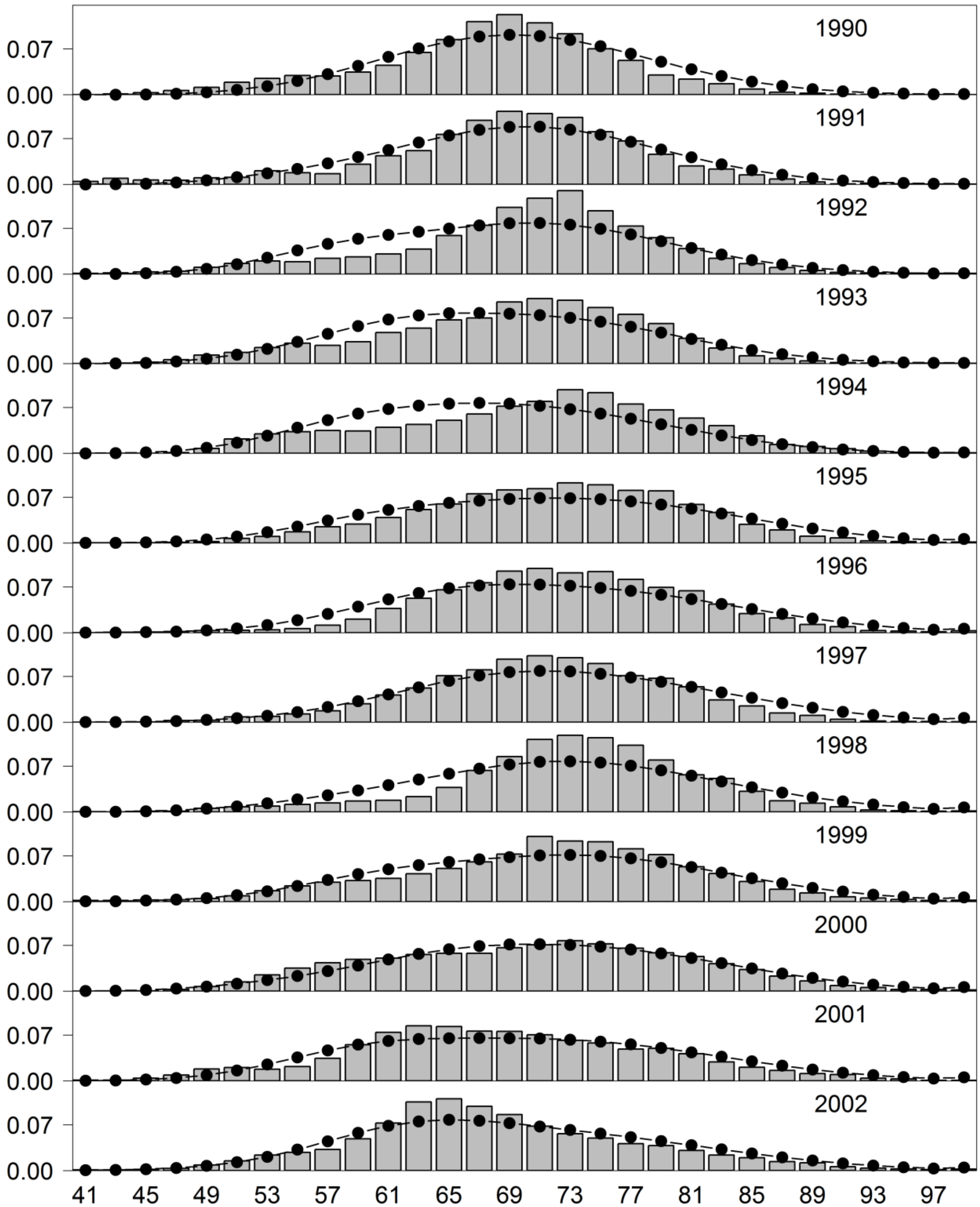


Figure 3.29. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

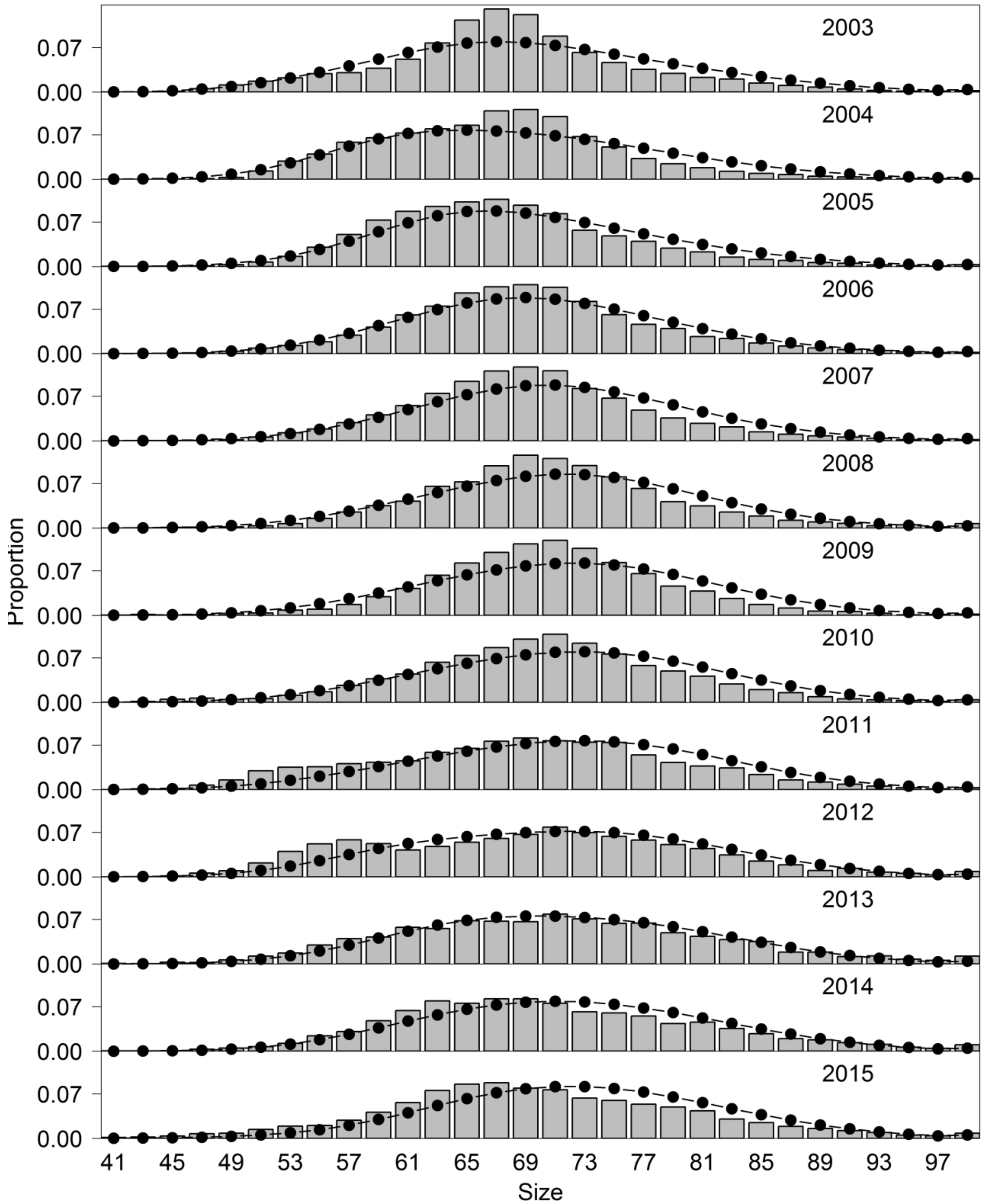


Figure 3.29 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

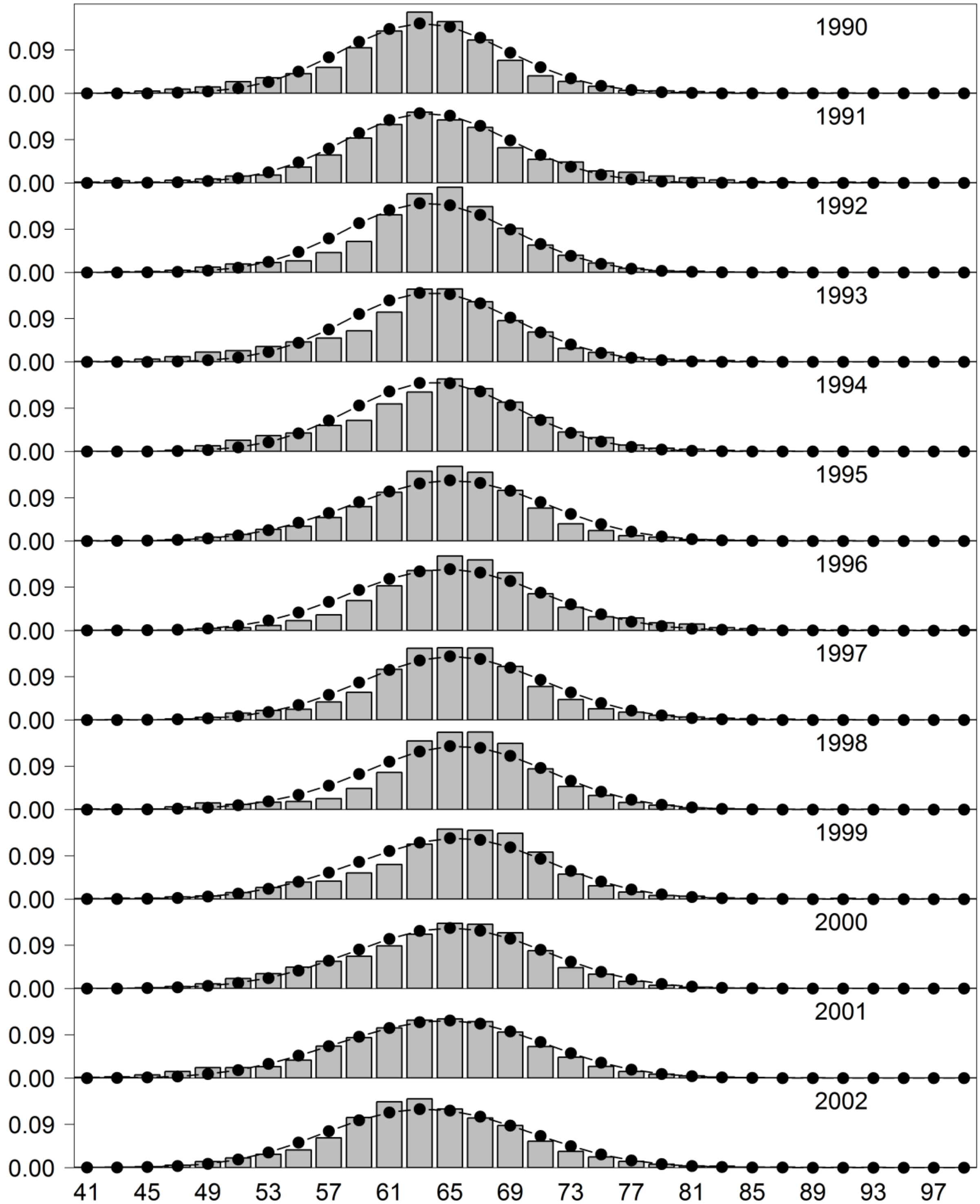


Figure 3.30. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

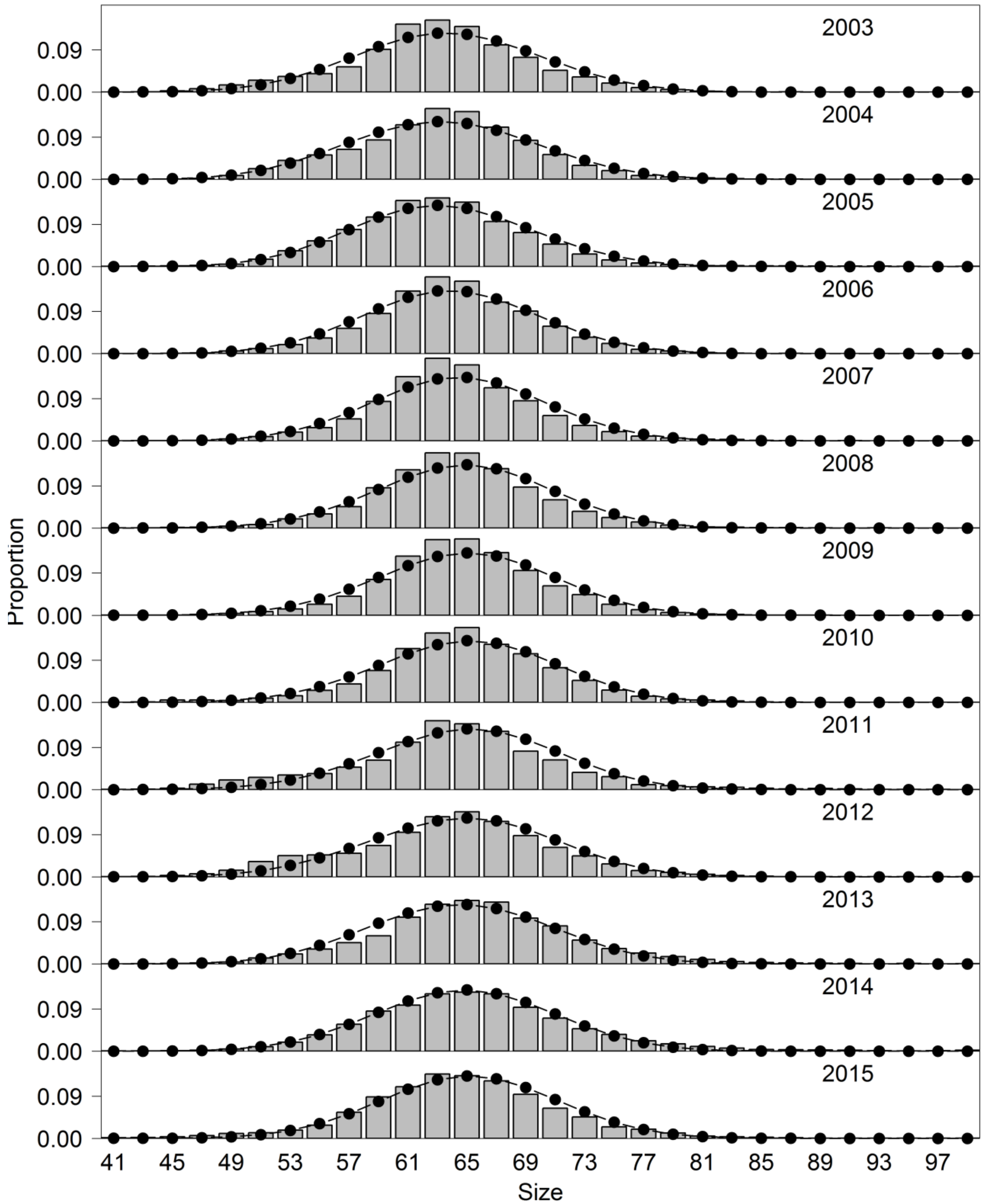


Figure 3.30 (cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

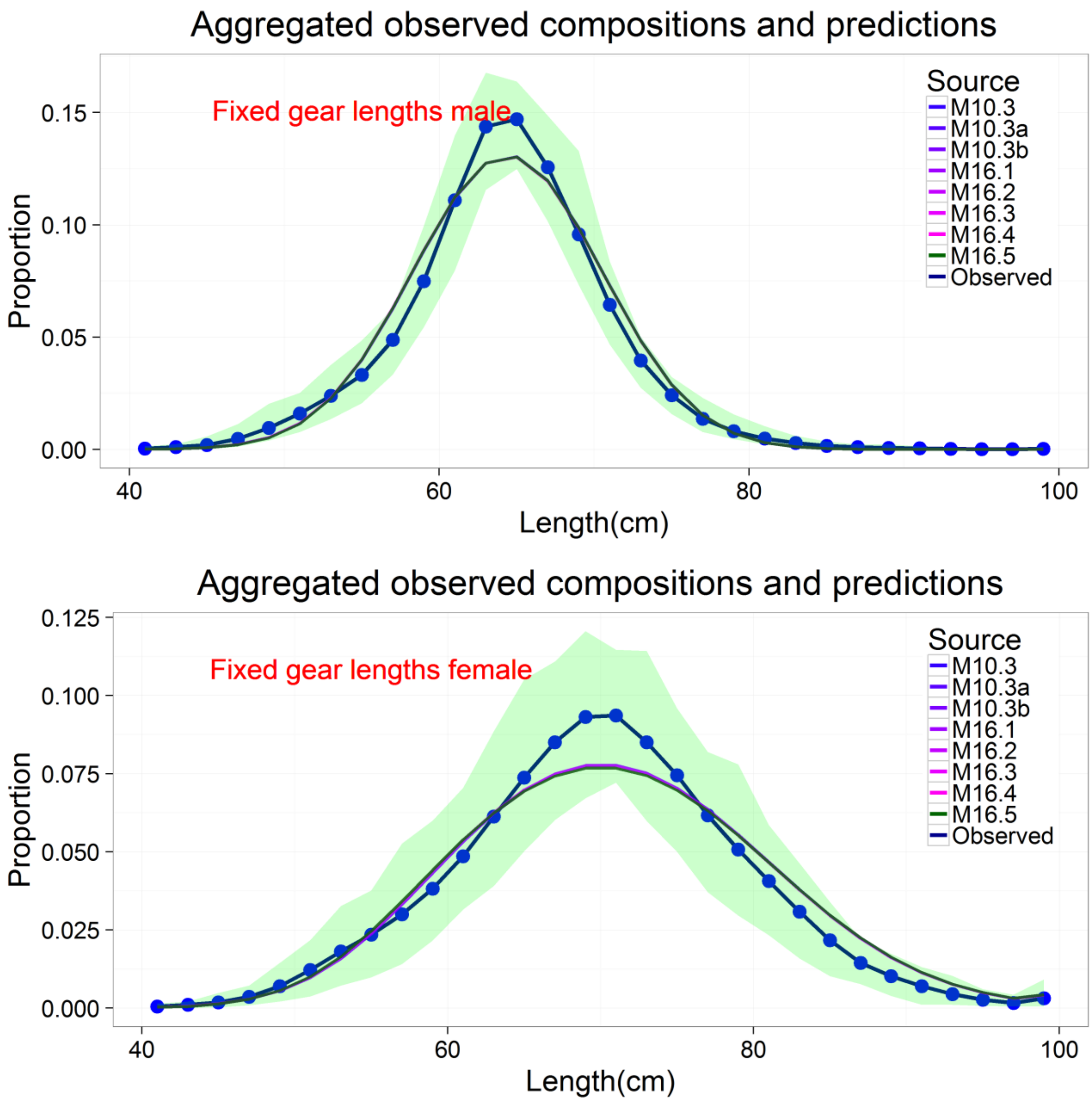


Figure 3.31. Domestic fixed gear fishery length compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

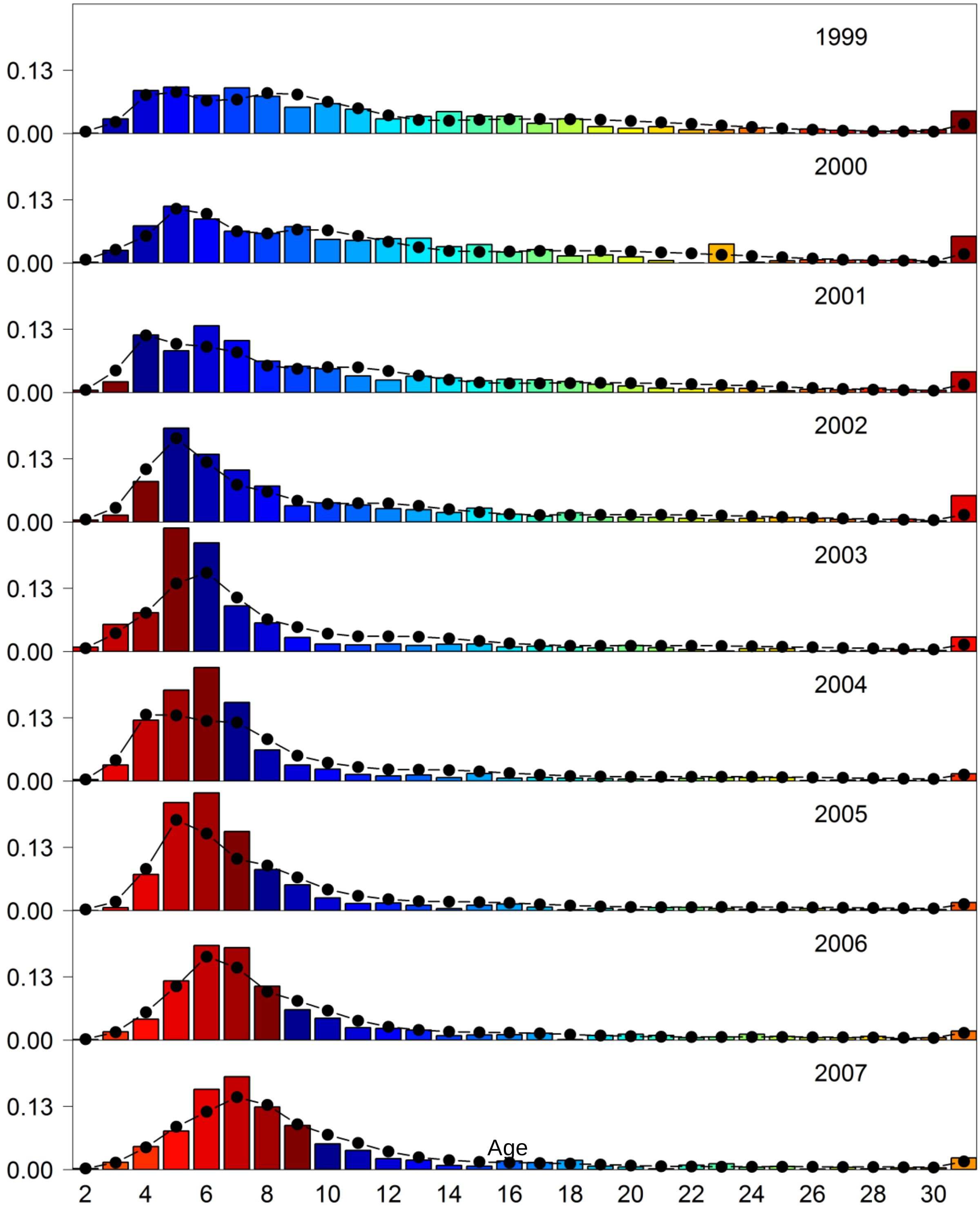


Figure 3.32. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

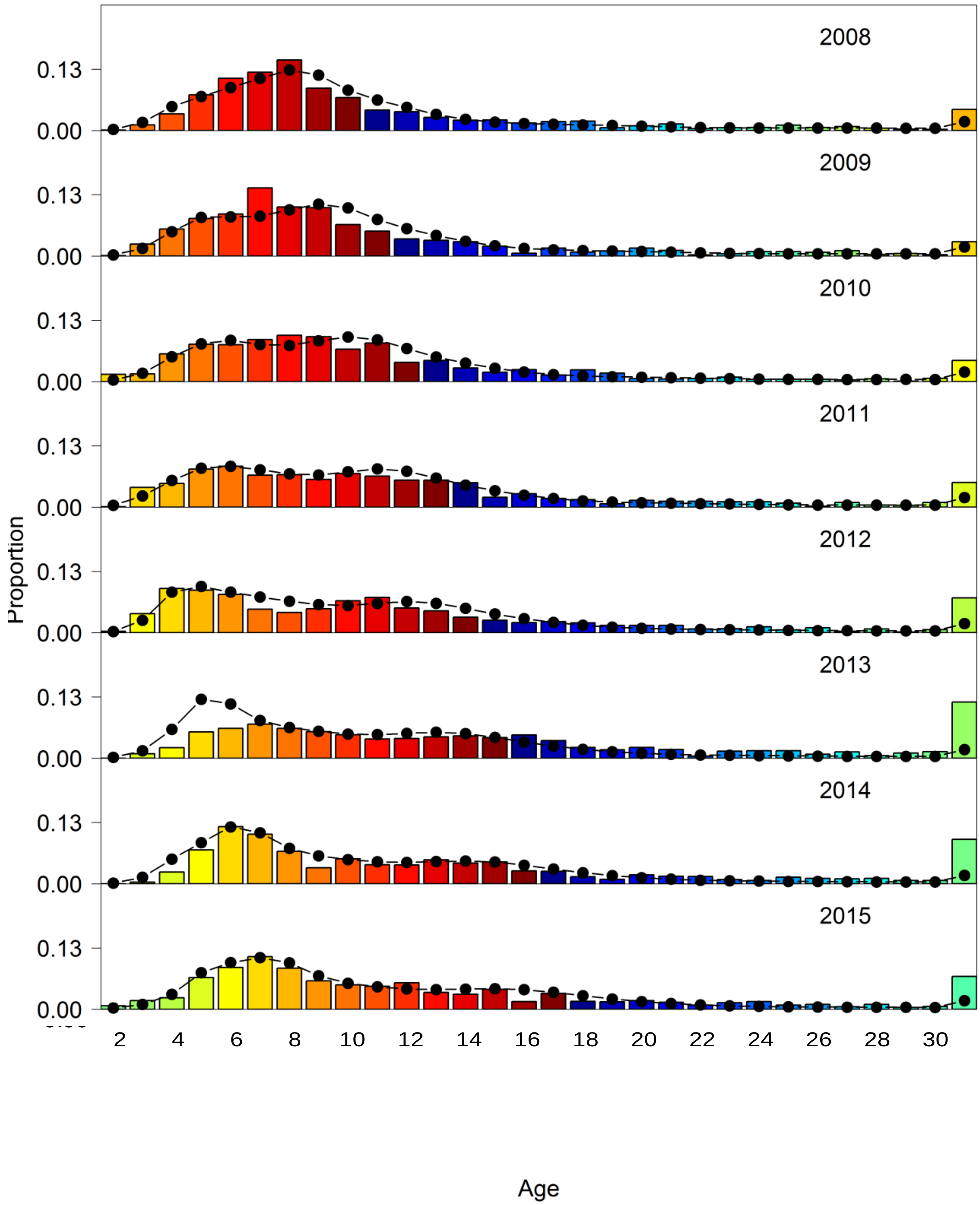


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

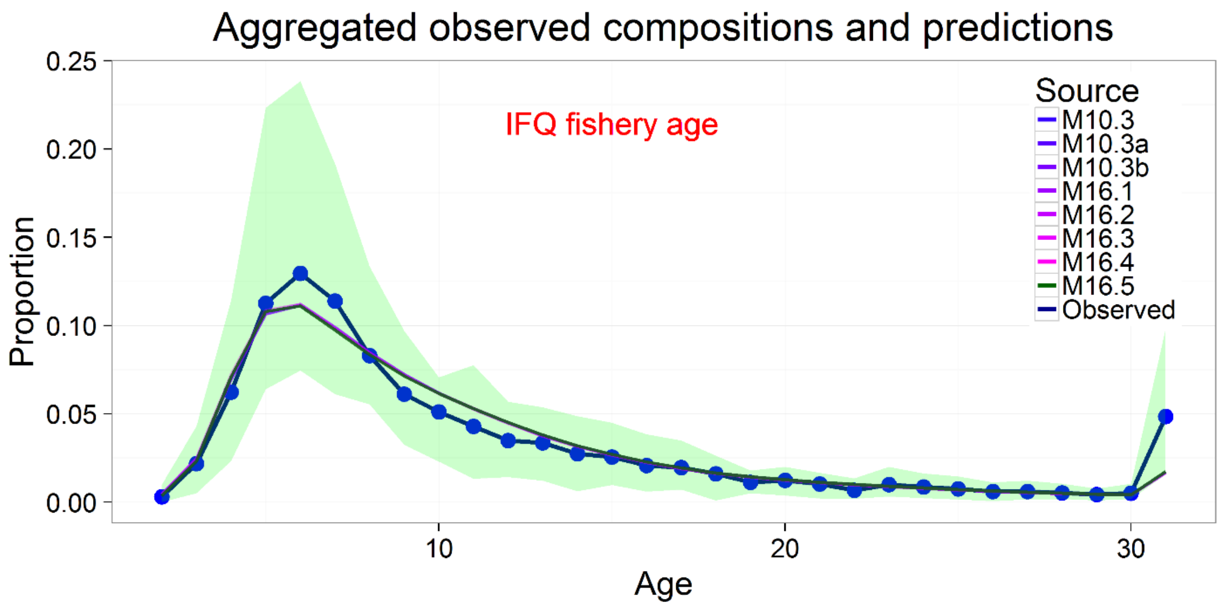


Figure 3.33. Domestic fishery age compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

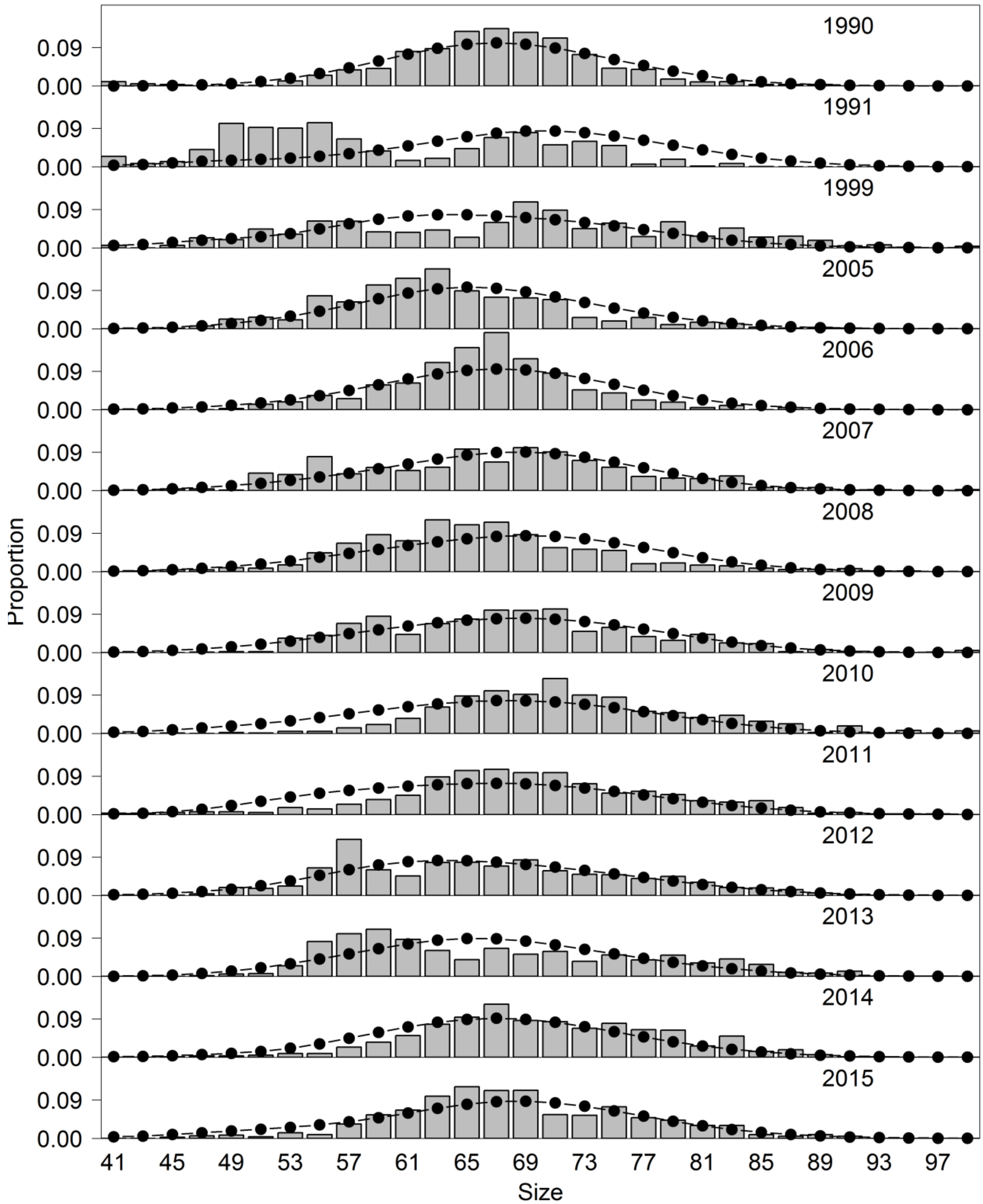


Figure 3.34. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

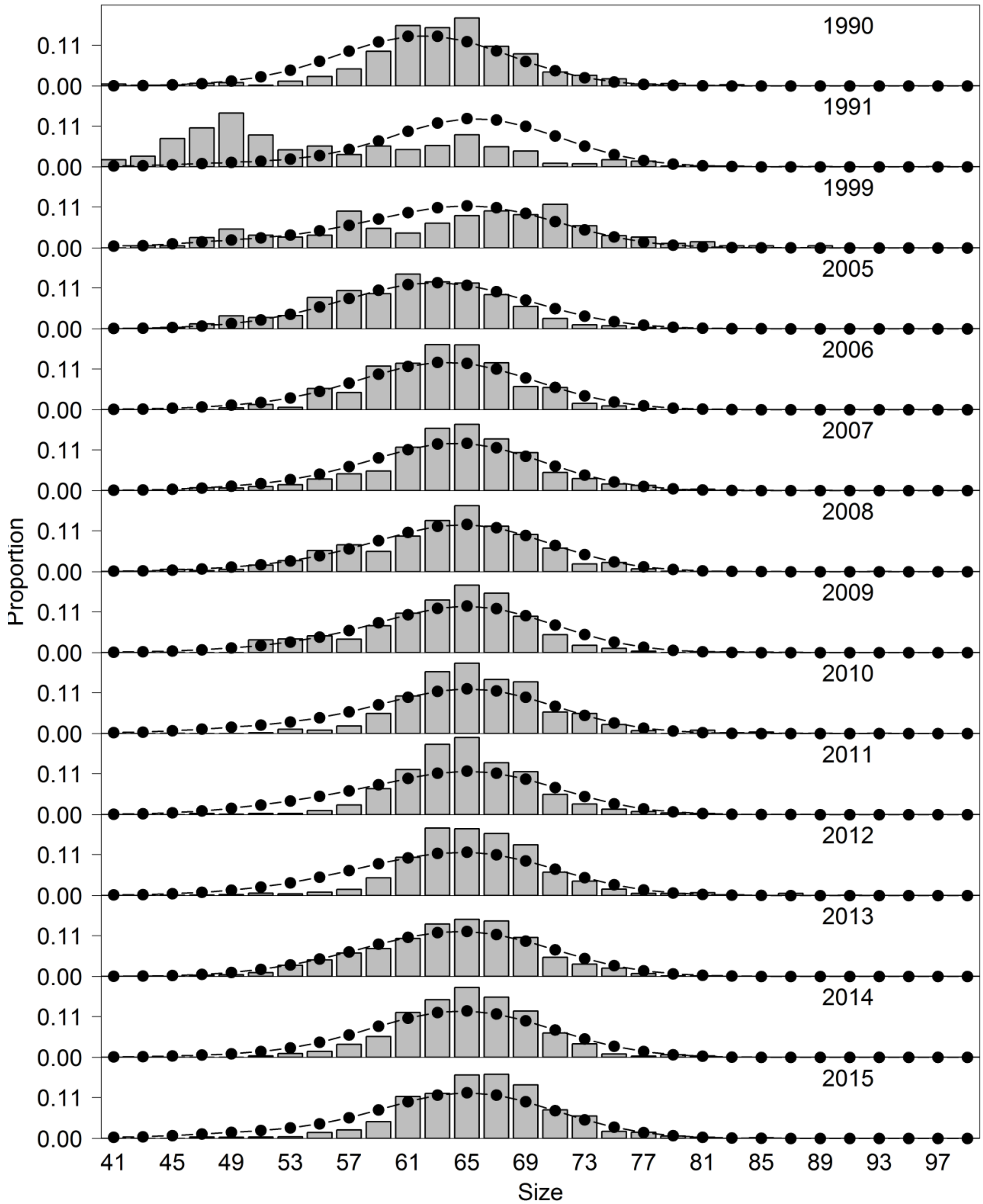


Figure 3.35. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

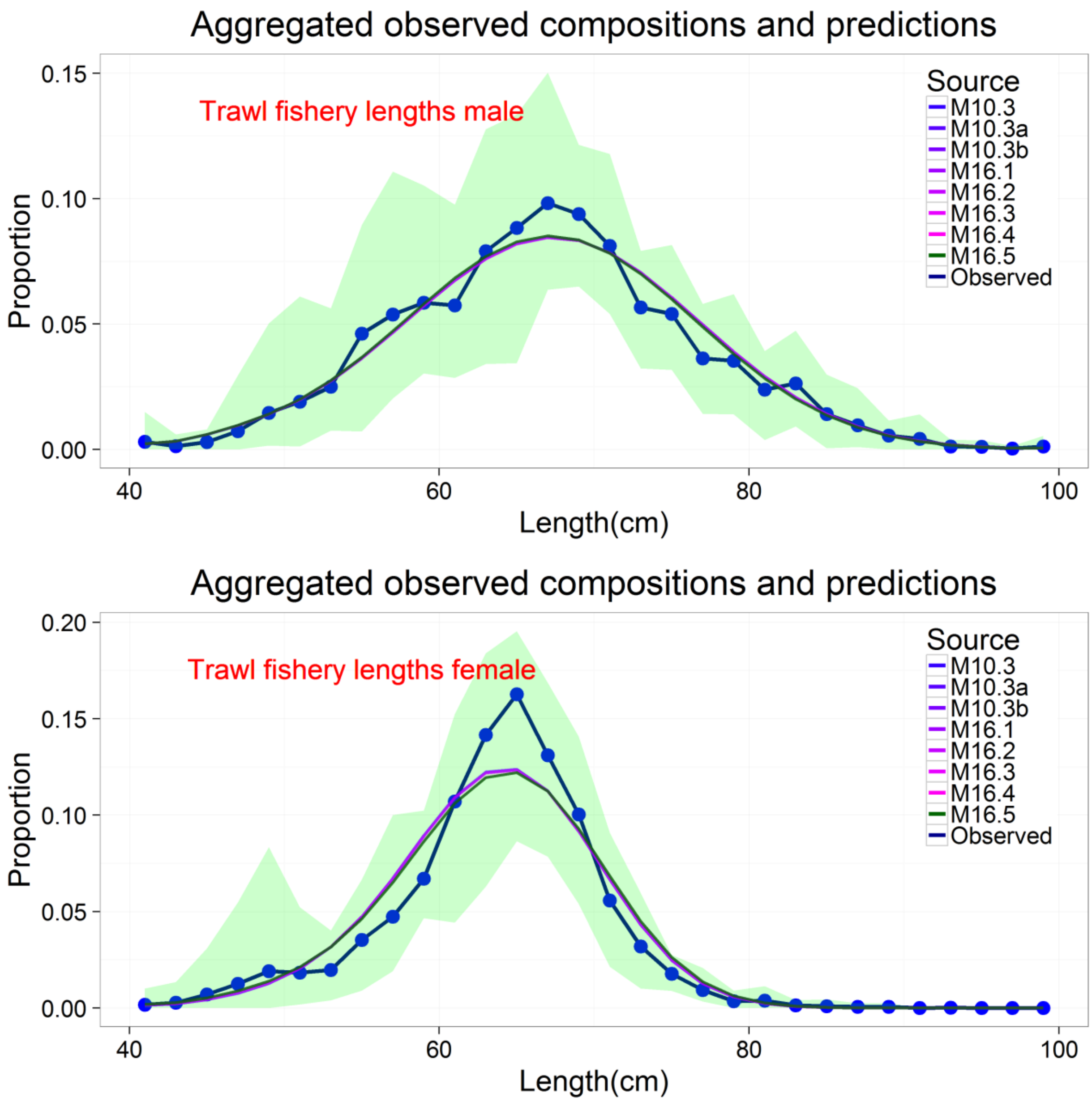


Figure 3.36. Domestic trawl fishery length compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

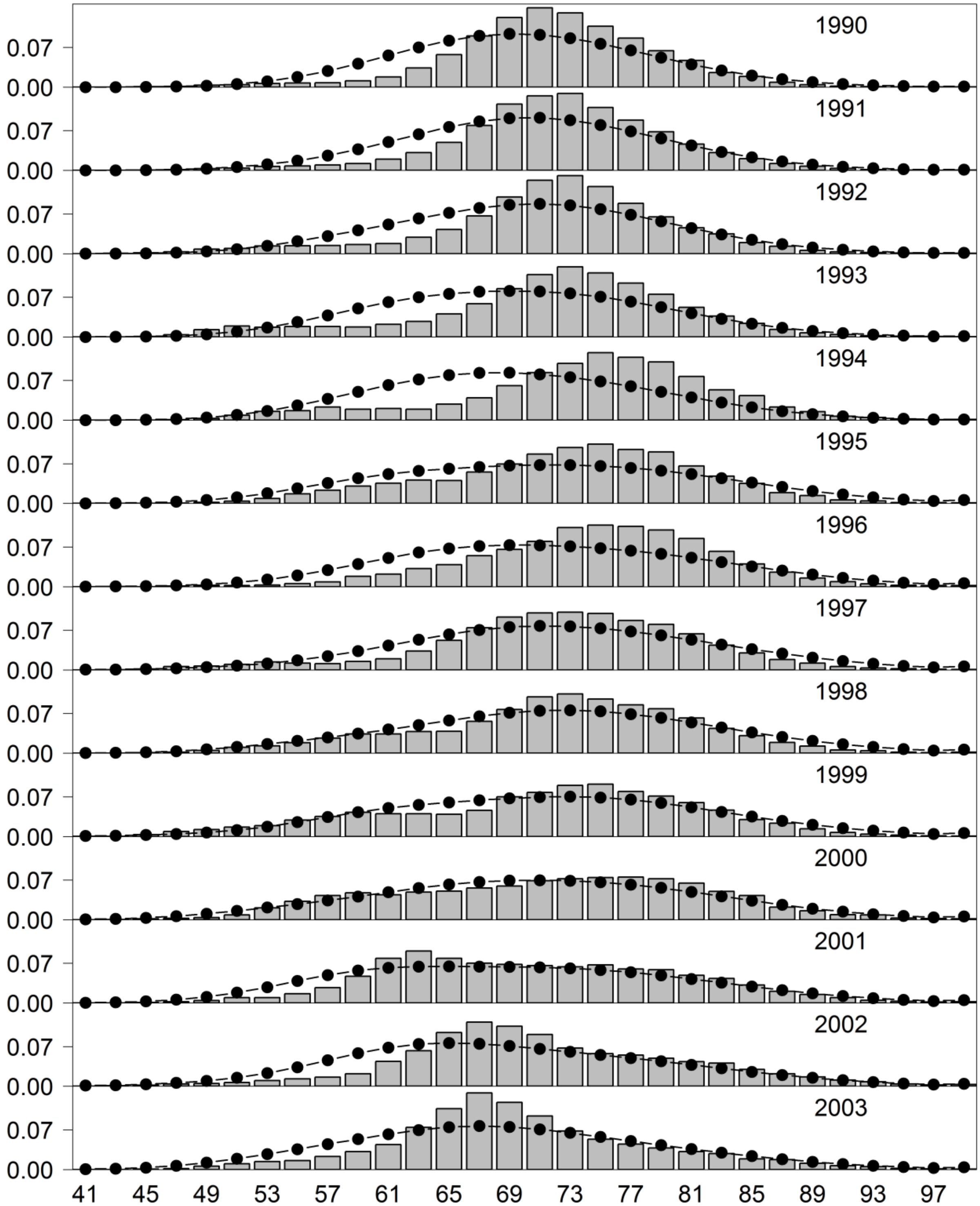


Figure 3.37. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

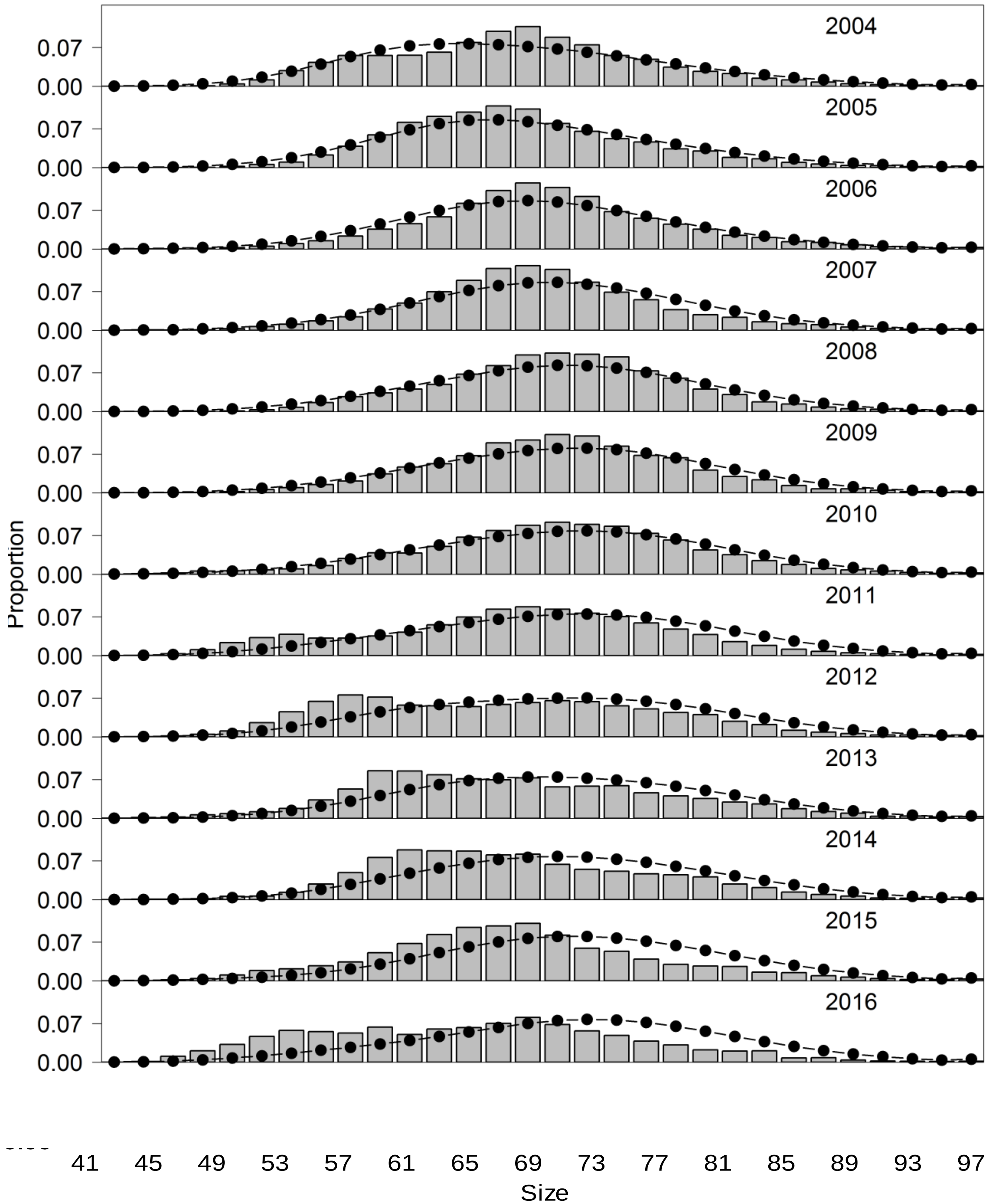


Figure 3.37 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

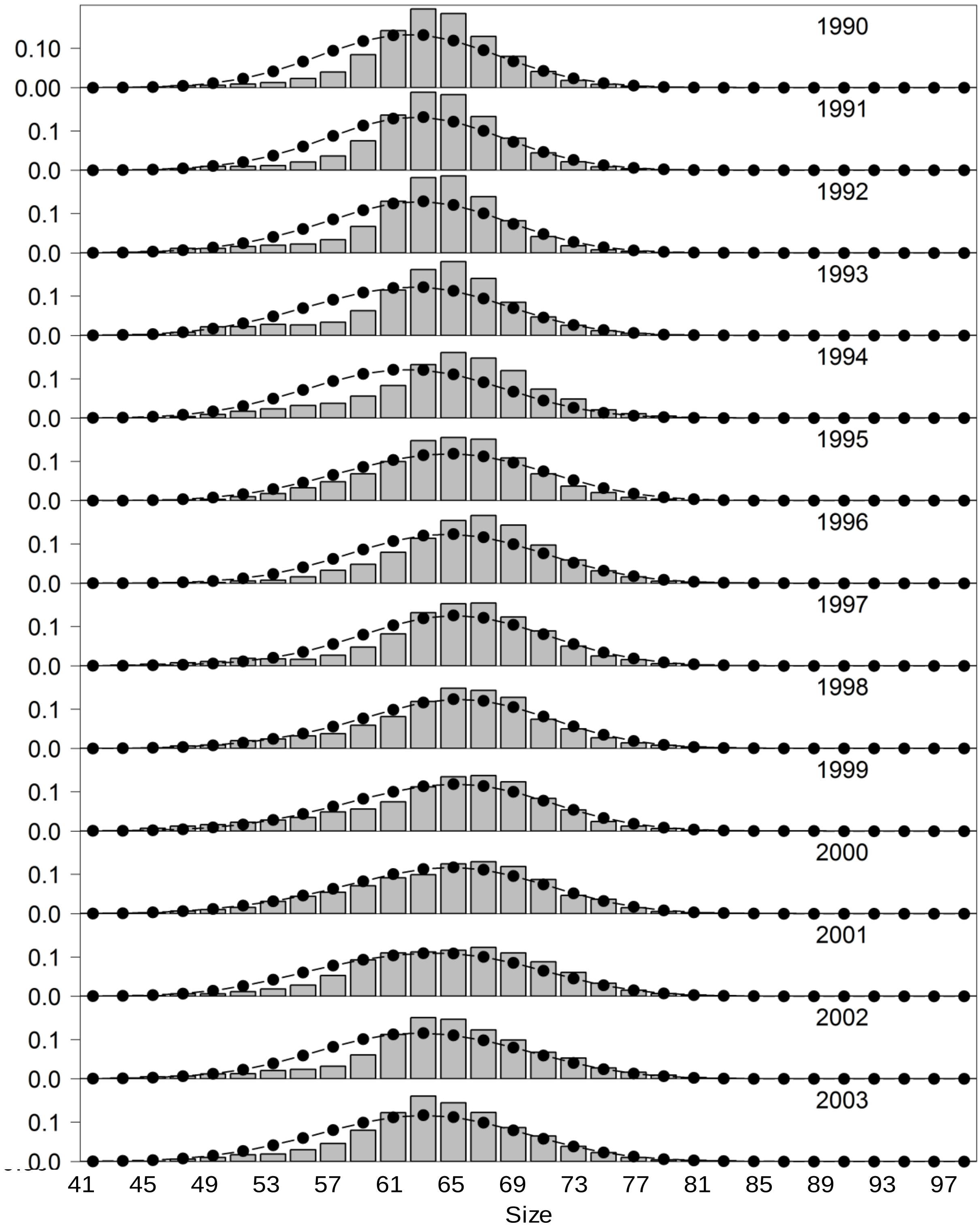


Figure 3.38. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

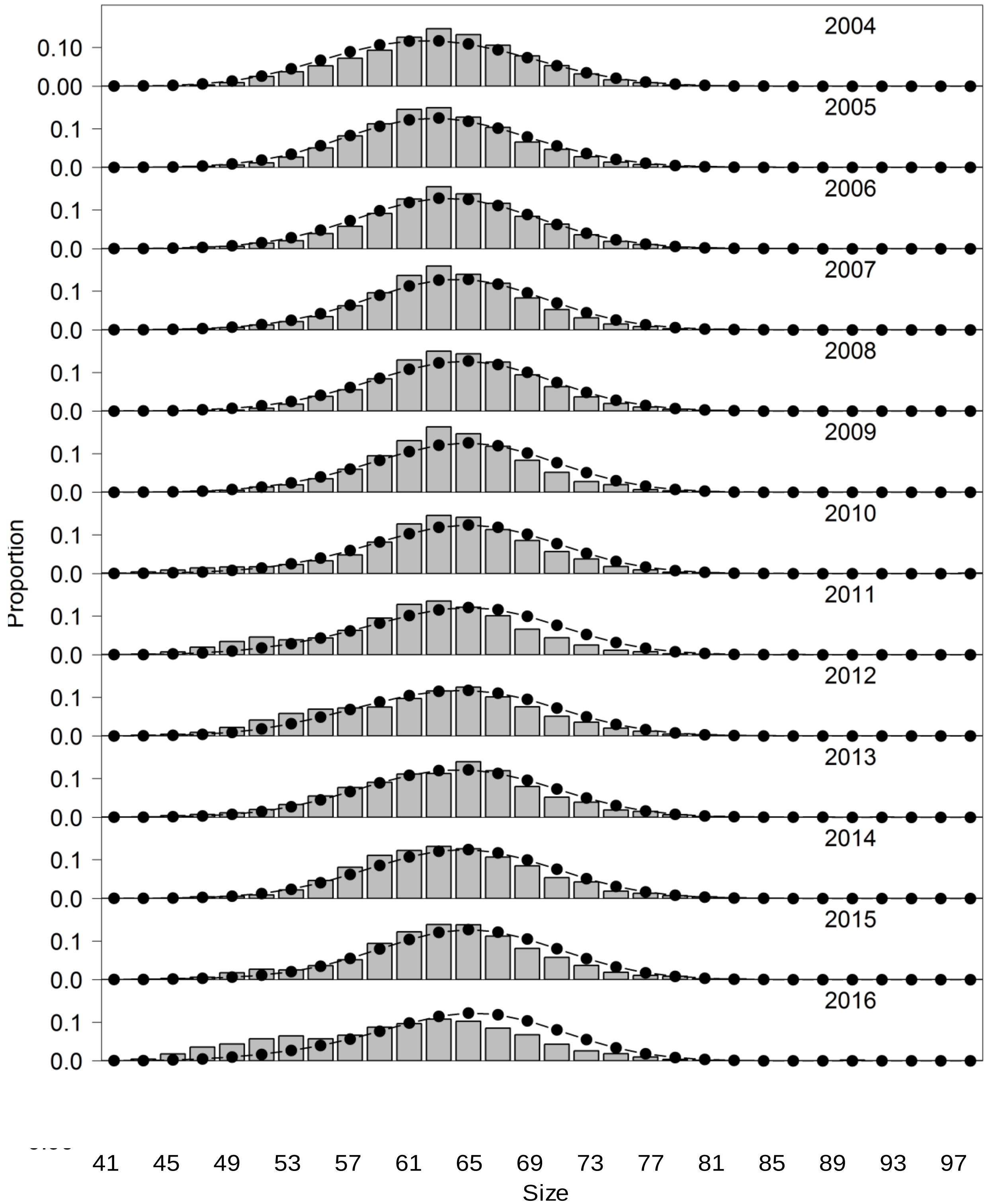


Figure 3.38.(cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

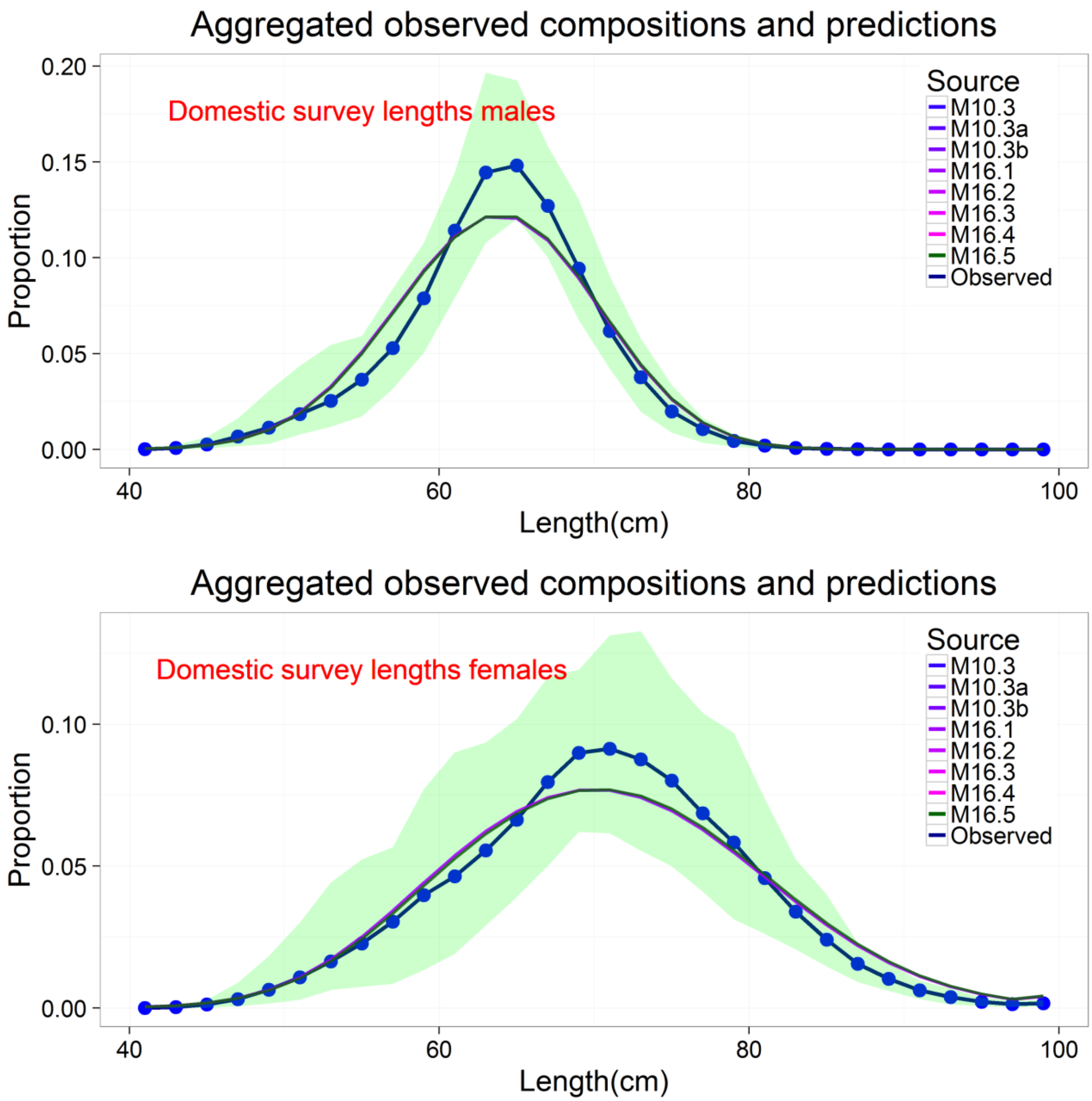


Figure 3.39. Domestic longline survey length compositions aggregated across years and with average fits from the 8 model options. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

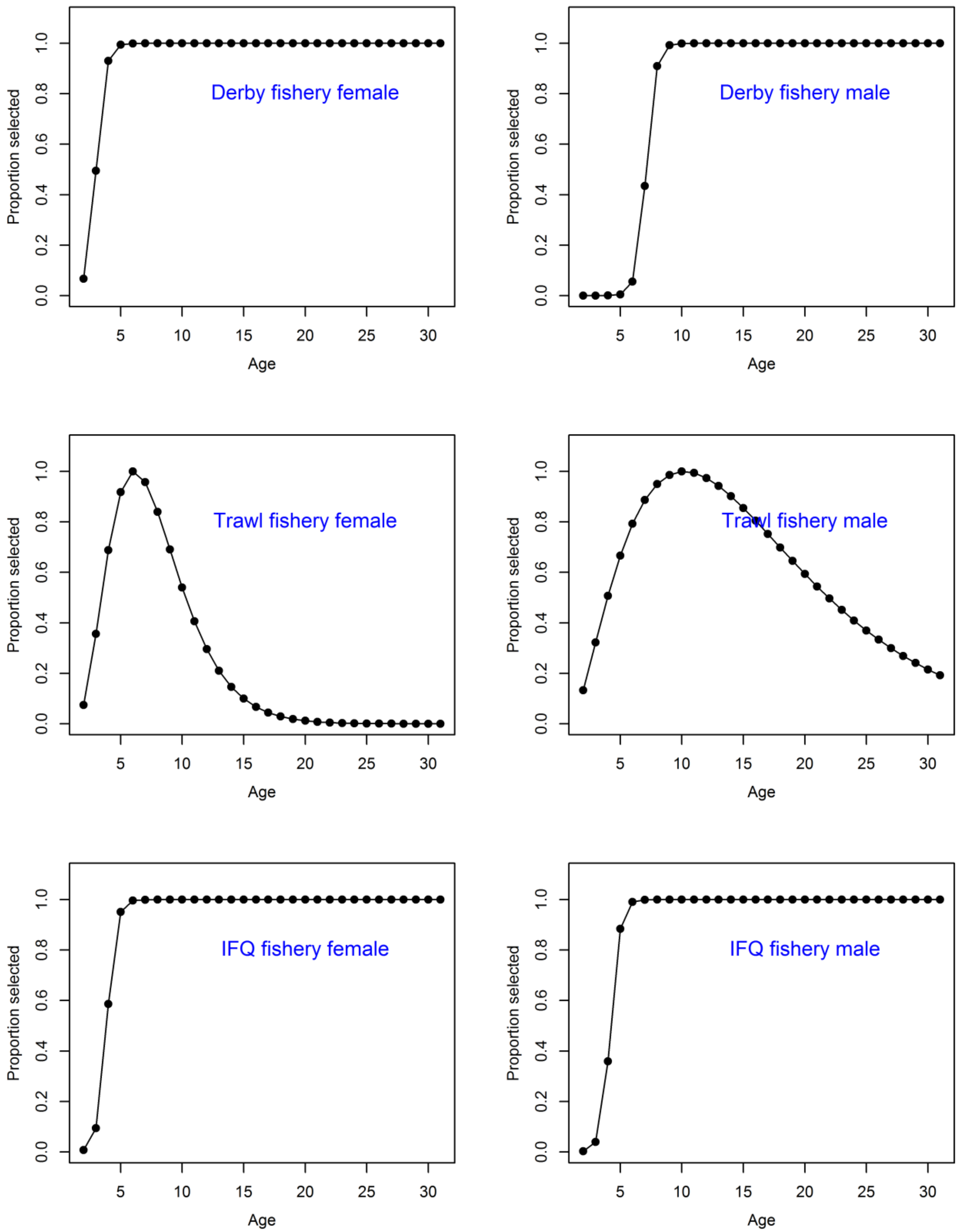


Figure 3.40. Sablefish selectivities for fisheries. The derby longline occurred until 1994 when the fishery switched to IFQ in 1995.

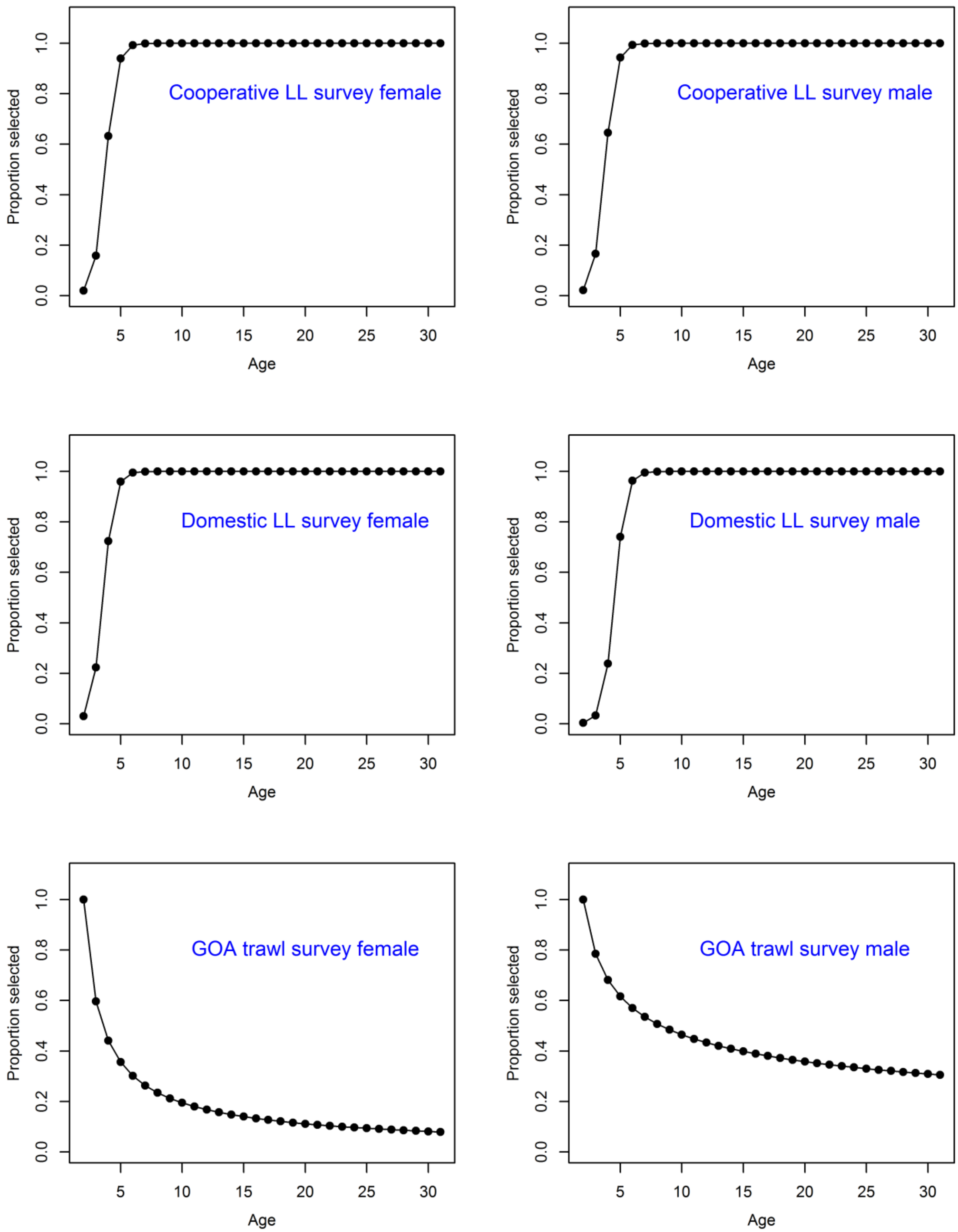


Figure 3.40 (cont.). Sablefish selectivities for surveys.

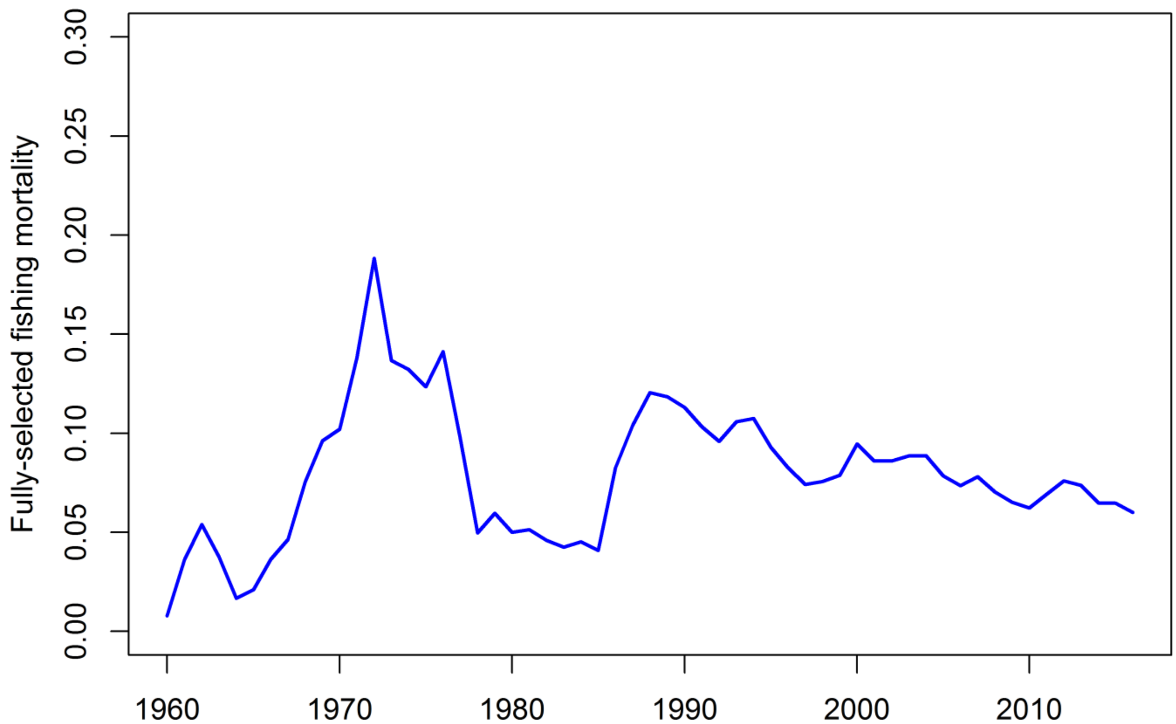


Figure 3.41. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

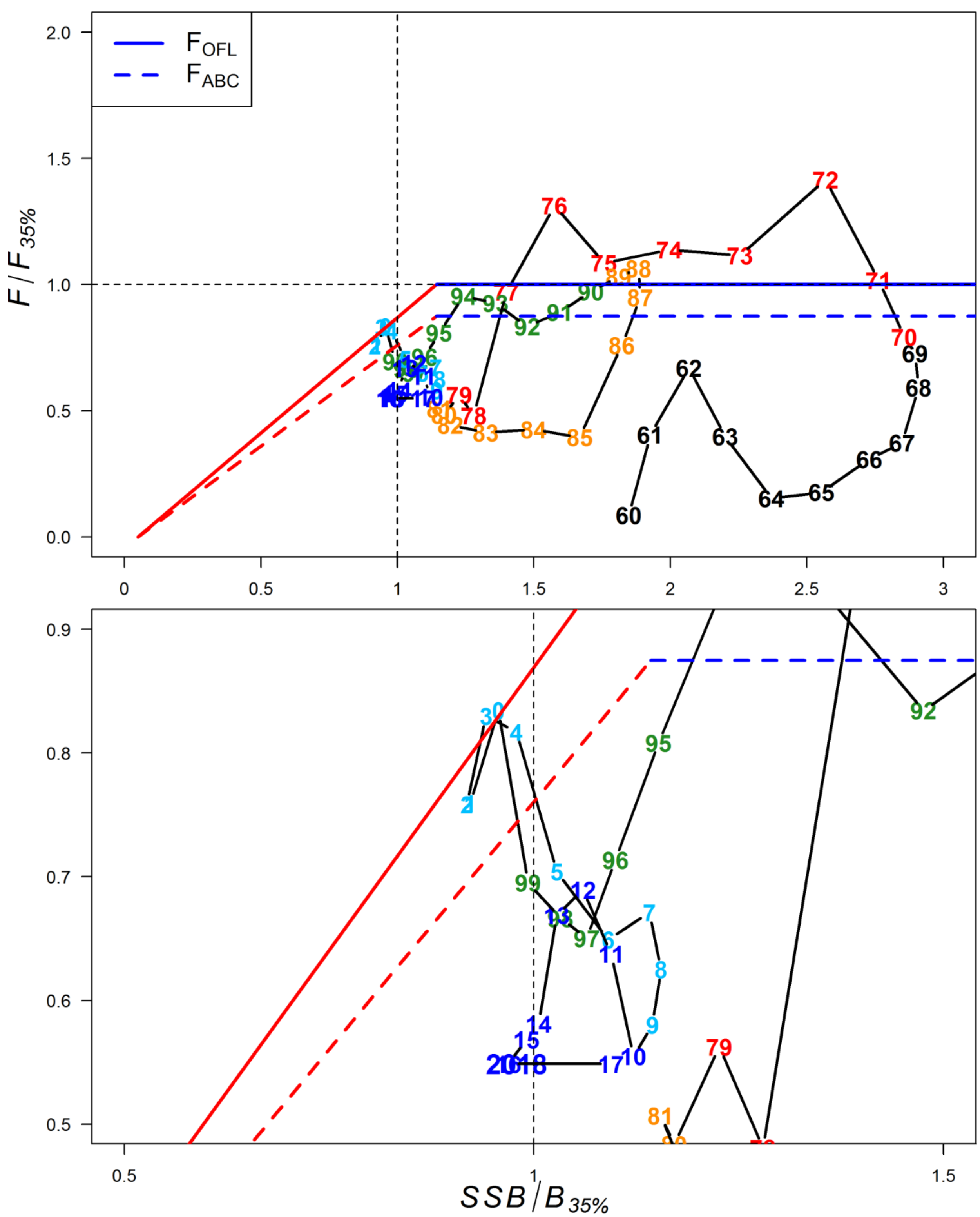


Figure 3.42. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model. Bottom is zoomed in to examine more recent years.

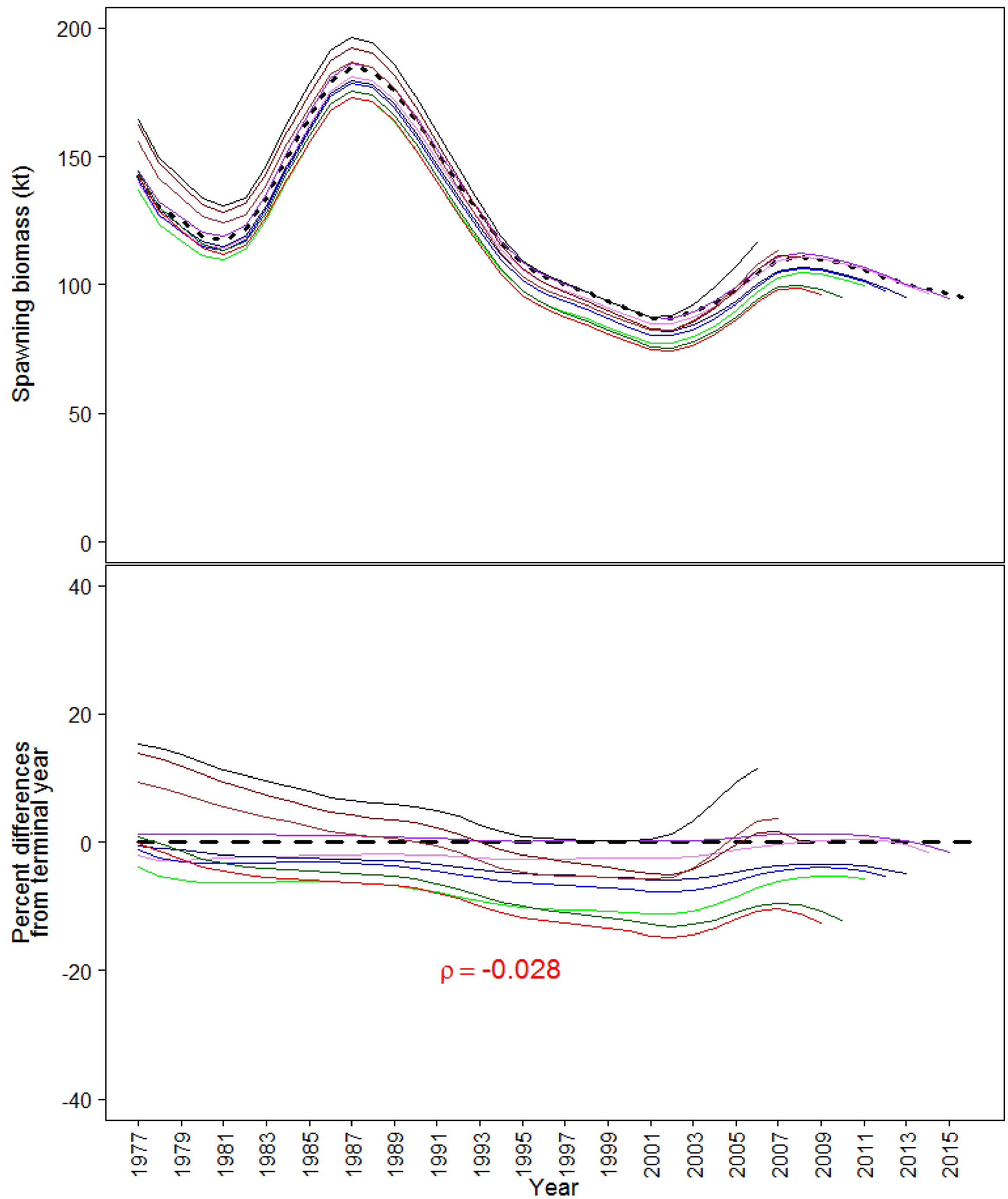


Figure 3.43. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 2005-2015. Mohn's revised ρ = -0.028.

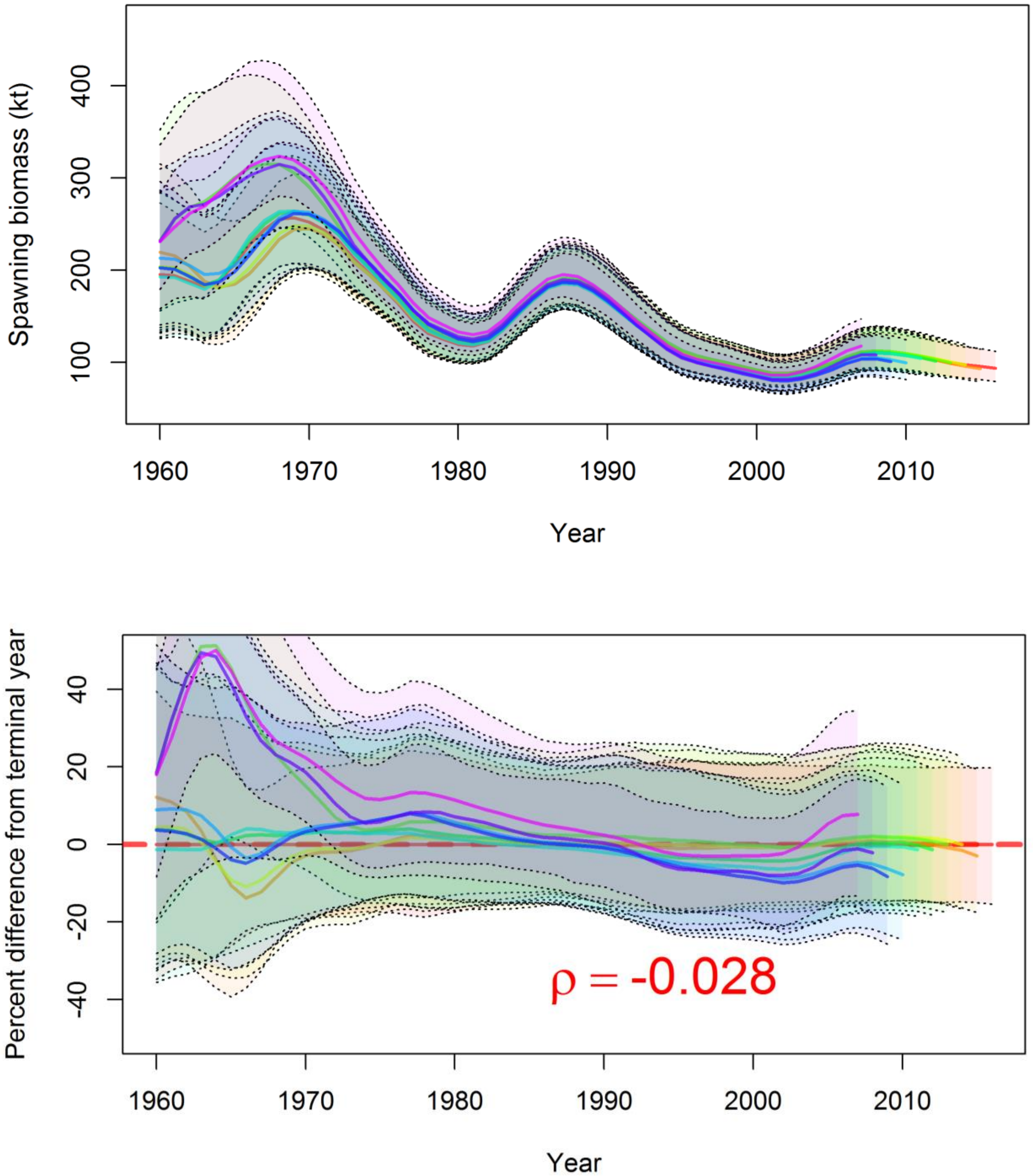


Figure 3.44. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 2005-2015 with MCMC credible intervals per year. Mohn's revised ρ = 0.028.

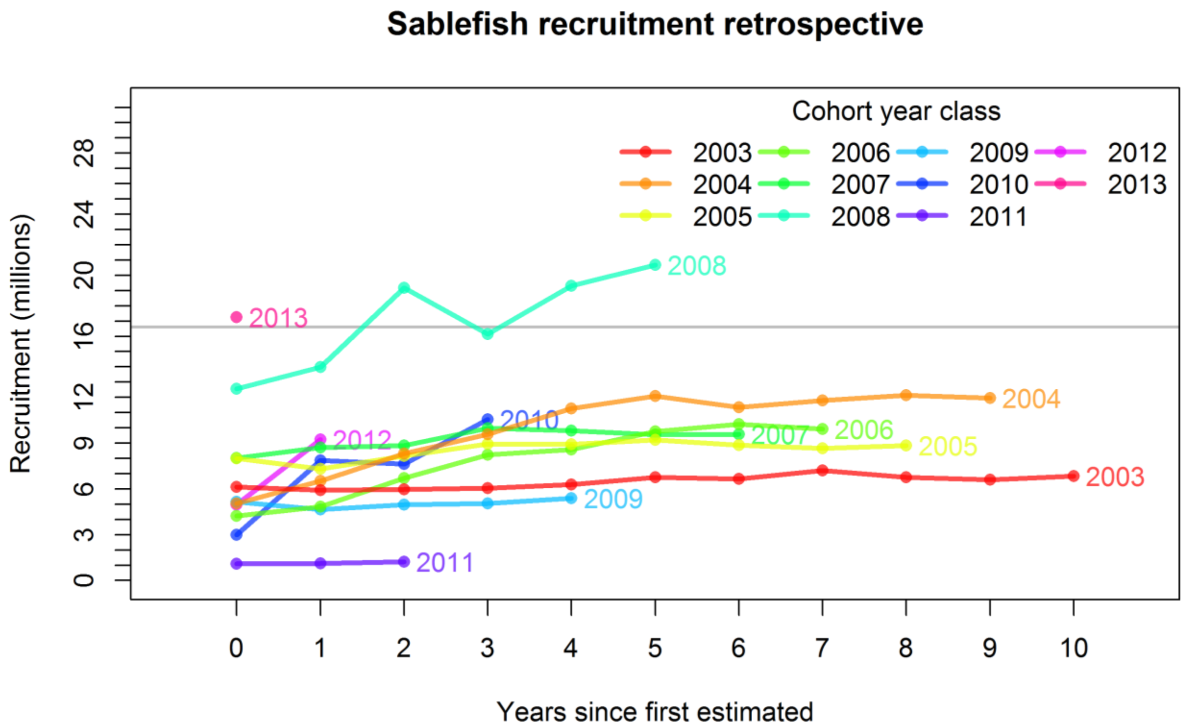


Figure 3.45. Squid plot of the development of initial estimates of age-2 recruitment since year class 2003 through year class 2013 from retrospective analysis. Number to right of terminal year indicates year class.

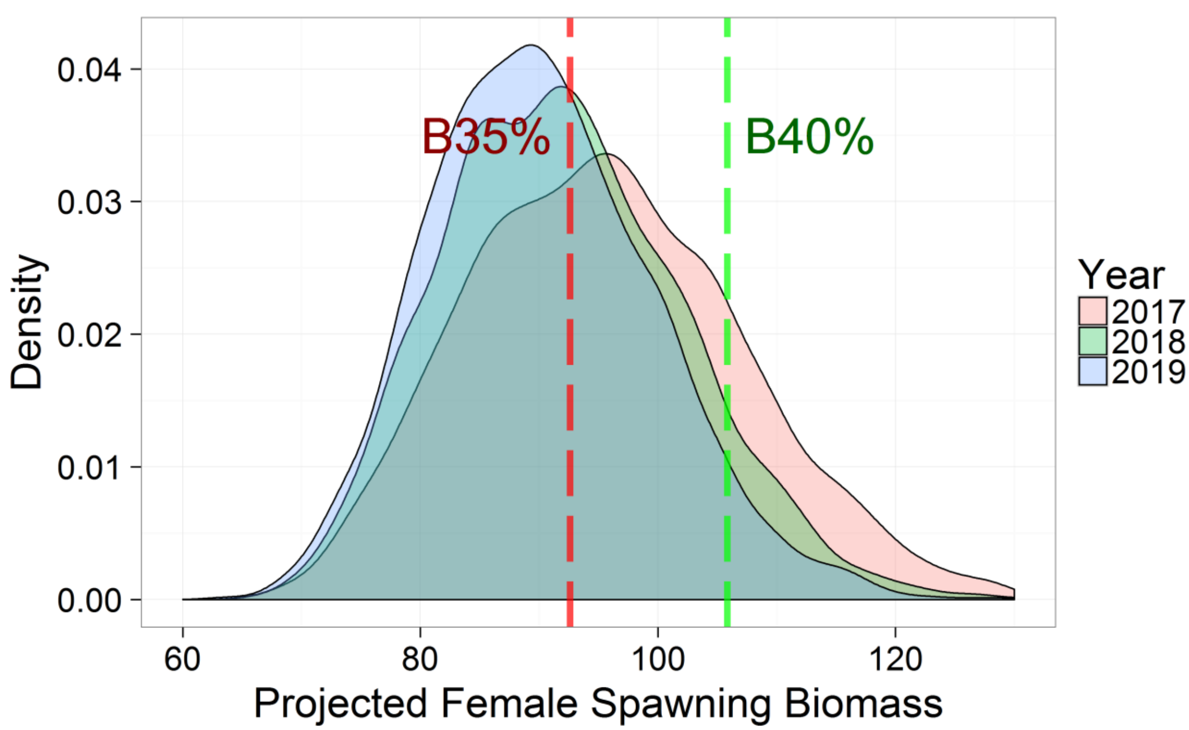


Figure 3.46. Posterior probability distribution for projected spawning biomass (thousands t) in 2017 – 2019.

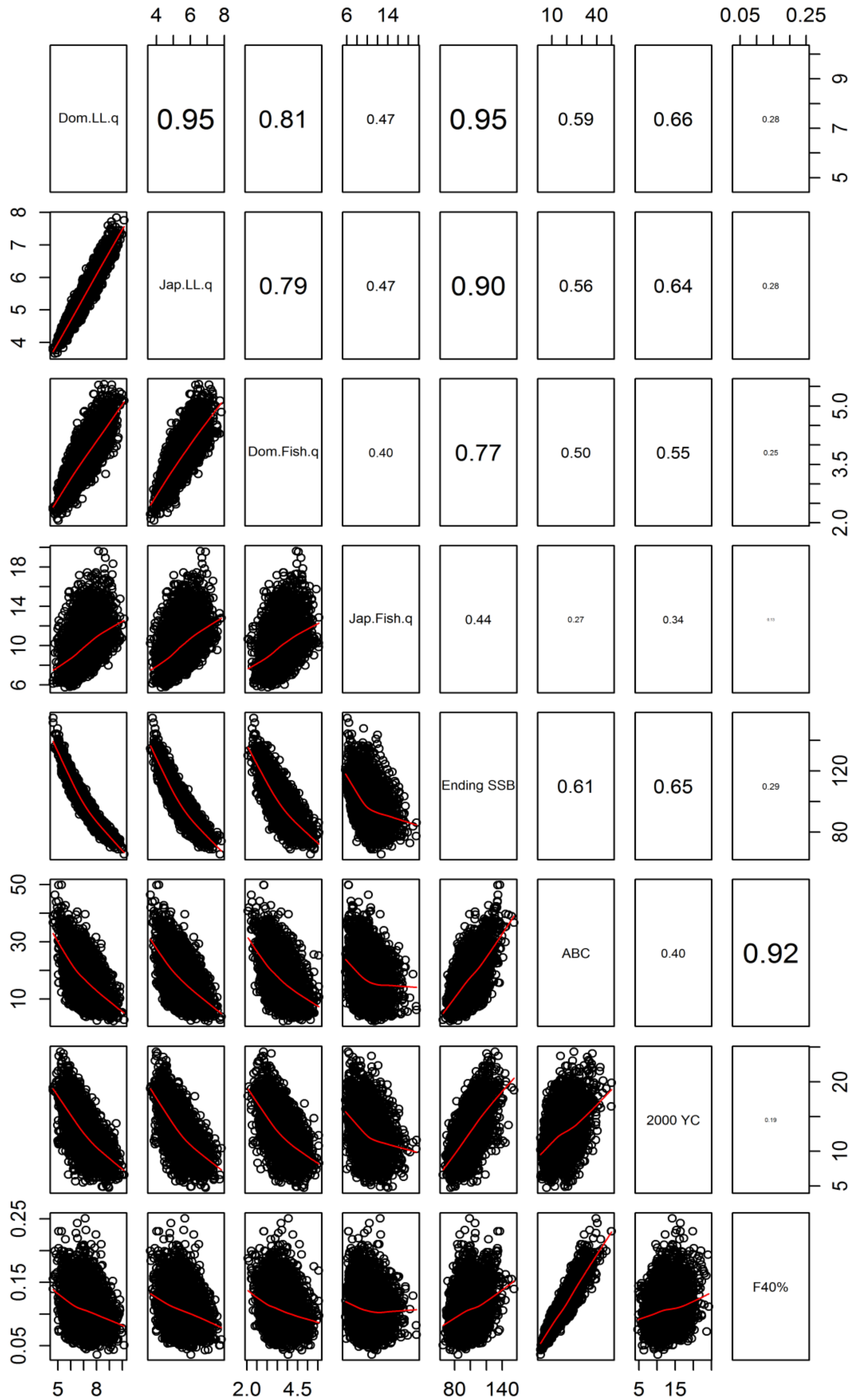


Figure 3.47. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

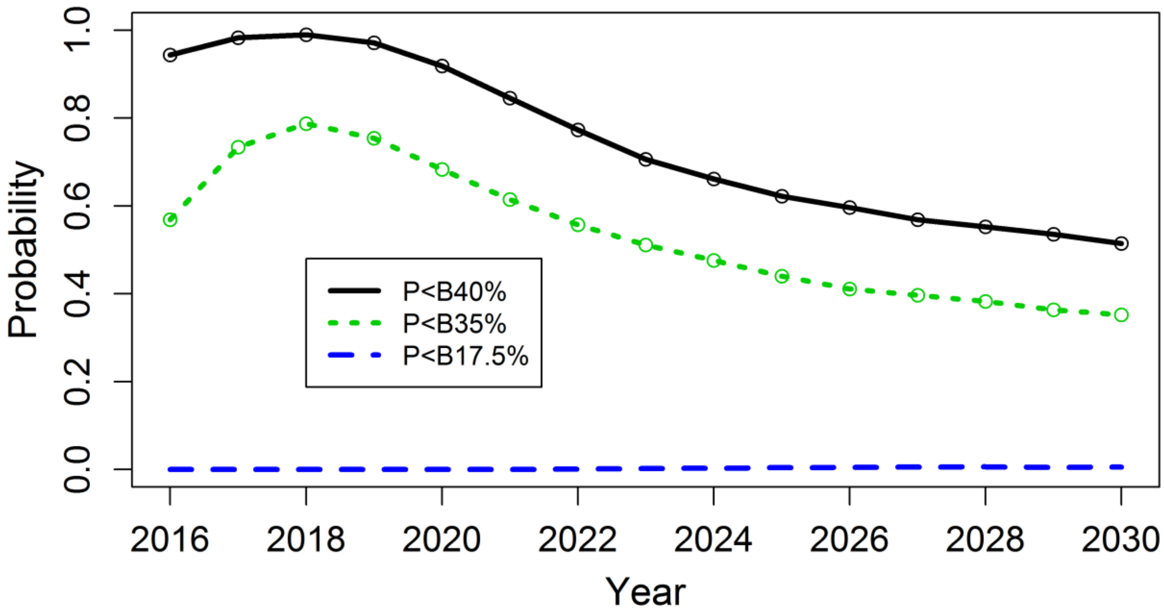


Figure 3.48. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

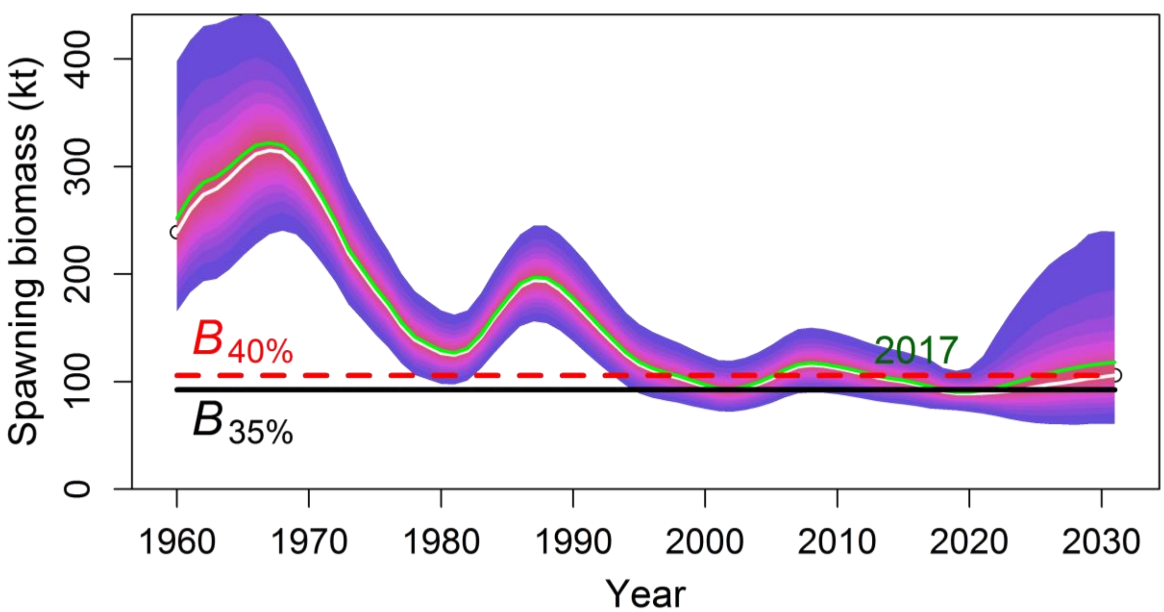


Figure 3.49. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and green line is the mean, shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is the same as the projections in Scenario 2 (Author's F).

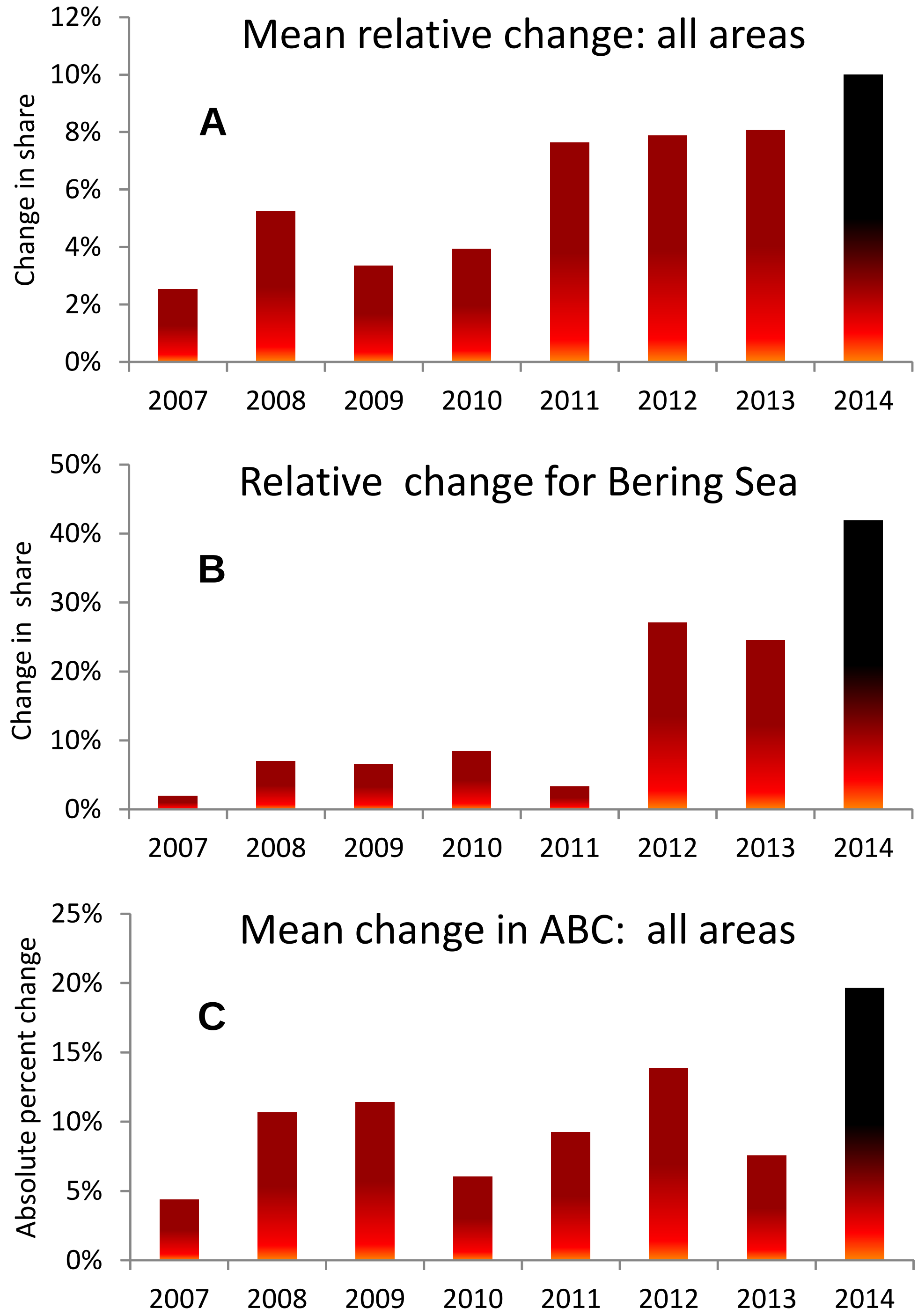


Figure 3.50. (A) The mean relative change in apportionment percentages across areas from 2007-2014. (B) The relative change in the apportionment share for the Bering Sea from 2007-2014. (C) The mean change in ABC for each area from 2007-2014.

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
2015	3	3	1	1	0	0	6	6
2016	5	5	1	1	0	0	6	6

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 indicated 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 has ranged from 239-359 t in recent years. This represents ~1.5 – 2.5 percent of the recommended ABC annually. These removals represent a relatively low risk to the sablefish stock. When an assessment model is fit that includes these removals as part of the total catch, the result is 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 Pacific 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. With restructuring of the Observer Program improved estimates of groundfish catch in the halibut fishery began in 2013. More years of data are needed for an evaluation the effects of observer restructuring on catch of sablefish in the halibut IFQ fishery..

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.

Year	Source	Trawl surveys	Japan US longline survey	Domestic longline survey	IPHC longline survey*	Sport	Total
1977		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	**Assessment of the sablefish stock in Alaska (Hanselman et al. 2010)**	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		3		291	50	15	359
2011		9		273	39	16	312
2012		4		203	27	39	273
2013		4		178	22	35	239
2014		<1		197	32	29	258
2015	**AKRO**	12		174	17	46	249

* 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
Review Panel Summary Recommendations for the 2015 assessment of Alaskan sablefish (*Anoplopoma fimbria*)

Mike Sigler, National Marine Fisheries Service, Alaska Fisheries Science Center (Chair)
Noel Cadigan, Center for Independent Experts
Neil Klaer, Center for Independent Experts
Tom Carruthers, Center for Independent Experts

INCLUDING:
AUTHOR RESPONSES TO SELECTED RECOMMENDATIONS IN BLUE

Review meeting
Ted Stevens Marine Research Institute
17109 Pt. Lena Loop Rd
Juneau, Alaska

May 10th – 12th, 2016

Terms of reference a. Evaluation, findings, and recommendations on quality of input data and methods used to process them for inclusion in the assessment.

Short-term (next 2 years)

i) Develop alternative catch scenarios to provide bounds on uncertainty of historical catches for assessment model sensitivity testing.

This will be presented in the November 2017 assessment.

ii) Use GIS-derived area by depth and region for calculations of stock indices, depredation and apportionment.

A model alternative will include the GIS-derived area estimates from Echave et al. (2013) in November 2016.

iii) Investigate if improved indices of juvenile fish abundance can be created from available survey data by selecting only stations <200m. Selectivity for such data may also be more clearly dome-shaped.

This sensitivity was investigated briefly during the CIE review; the change from stations <500 m to stations <200 m has a negligible impact, but may be worth further exploration for 2017.

Longer term

i) Available IPHC and gully station indices should be considered for inclusion in the assessment.

Given that the IPHC data are closely correlated with the GOA trawl survey data, we expect that their inclusion will have a minimal impact on model results, but may provide further power to estimate other parameters more precisely. The gully stations may assist in providing information on recruitment. We will continue to track these additional indices in the assessment, and work toward evaluating their utility for inclusion in the model.

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ii) In the context of a single area model, consider Kriging or a spatio-temporal survey model (e.g. year + space + year*space) as an additional alternative for filling missing years of sampling in the domestic longline survey.

We have explored several alternatives to fill in data in areas in years they are not sampled (i.e., the Bering Sea in even years and the Aleutian Islands in odd years), but have not come up with a preferred alternative. Exploring spatial models to do so is a top research priority.

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iii) Continuing the recent work to include killer and sperm depredation presence and evidence in the fishery logbooks is encouraged.

Starting in 2017, data on whale presence and depredation will be collected in logbooks.

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iv) Fishery CPUE standardization should be pursued further:

a. Model based approach, standardizing for relevant factors affecting catch rates (season, location, etc).
b. Consider a stratified CPUE index if year*area interactions are important.
c. Consider categorical rather than continuous variables for some factors (e.g. area-habitat definitions rather than continuous variables for longitude and latitude).
d. Consider some factors as random-effects rather than fixed-effects.
e. Consider a CPUE index workshop to evaluate and gain acceptance of proposed methods
f. If continuing with the non-modelling framework:
   - Alternative methods for assignment of target species for multispecies fisheries are available e.g. based on species composition by trip or catch value among vessels fishing common areas/times. Maximum weight/numbers in the catch may not be the best available procedure. Consider possible bias in mis-specification of target species, and whether this procedure is useful or not in a detailed model context.
   - Data filtering may introduce bias and this should be considered in more detail. Factors used to filter could be accounted for in a standardization of model factors.

Improving the fishery CPUE index is an area of active research for us. Mateo and Hanselman (2014) presented some alternative GAM and Boosted Regression Tree standardization approaches, but did not take it far enough to consider whales and apportionment. We appreciate and recognize some of the CIE suggestions and will be attempting to further refine the fishery CPUE index for use in our production model in the coming years.

v) Measurement error in age should be accounted for in growth model analyses and construction of age-length keys. Further consideration of the distribution of measurement errors (i.e. Geometric) will be useful.

vi) The current assessment is based on two time periods for growth (based on two temporally distinct sampling methods). Consider other growth models with time-varying parameters to assess if growth rates have changed over time.

We are currently initiating new research extending the growth analysis of Echave et al. (2012) which informs the growth patterns currently being used in the assessment.

vii) Continue work on skip-spawning and determine whether adjustment to the maturity ogive is required.

A second winter survey was conducted in December 2015 to gather more data on this interesting phenomenon. These histological data are currently being analyzed.

viii) Consider models of maturation data including time varying parameters.

The overall mean maturity ogive from the domestic longline survey is negligibly different from the current ogive used in the assessment. The apparent time-variation may be more of an artefact of annual differences in the initiation of maturation. However, we may attempt a model that fits these data internally to contribute to the propagation of uncertainty in the model.

ix) Use essential fish habitat (EFH) derived area, by depth and region, for calculation of relative abundance indices, depredation and apportionment (subject to validation of EFH).

These habitat suitability models are a work in progress and are currently only available for the Gulf of Alaska. We will monitor the progress of this project and its applicability for computing relative abundance.

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x) Create a data document that summarizes available data series and the methods used to create them. This would be valuable for review and as an archive (this would be useful, for example for comparing indices of abundance and their modelling assumptions).

Documentation exists for all the series in the assessment, but are not aggregated into one document. We will synthesize existing materials into a standalone data document.

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xi) The survey takes 80 days on average. Consider methods to address uncertainty due to fish movement within the time-frame of the survey, esp. in space-aggregated model.

xii) Account for AK sport fishery catches (these are increasing).

Sport fishery catches are reported in the SAFE chapter, but remain an insignificant amount of the total catch (<<1%).

Terms of reference b. Evaluation, findings, and recommendations of the analytical approach used to assess stock condition and stock status.

Short term

i) Model biomass estimates appear very precise due to the fixed M value, high precision on catch and reasonably consistent trends in available abundance indices. An important additional source of uncertainty may be the form of the stock-recruitment relationship.

The current estimation of recruitment has a very low penalty on recruitment deviations (i.e., the model freely fits the compositional data to inform recruitment); imposing a stock recruitment relationship would likely increase the precision of model results as it is imposing a link between stock size and recruitment.

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a) These could form the basis for major axes of uncertainty for sensitivity analyse that may be communicated to management.
b) Consider placing a prior on M.

We will introduce a model in 2016 that estimates *M* with a prior. We are generally skeptical of the utility of fitting a stock-recruitment relationship in the model considering the low contrast in spawning biomass estimates and the existence of large recruitments during periods of low spawning biomass.

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ii) Application of the calculated SNDR weighting to adjust the CV of the domestic longline survey should be considered for this assessment.

We can re-examine the weighting given to the abundance indices. This may naturally result in a decrease in the weight of compositional data if the weight on the surveys is reduced.

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iii) Consider alternative time periods for the current regime of recruitment productivity and the effect on stock status and projections (e.g. the most recent 10 years). The choice of time period could be informed by recruitment covariates.

We will consider alternative recruitment regimes for the 2017 or 2018 assessment. The ongoing GOA integrated ecosystem project may help inform what plausible recruitment regimes and covariates are.

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iv) Consider a sensitivity analysis with respect to Canadian landings in northern B.C. that assigns these to the most appropriate selectivity (e.g. longline).

We will include this sensitivity as part of a broader sensitivity analysis of major uncertainties to be included as standard in future assessments as described in response to item 2 (vi) below.

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v) Consider initializing the model from fishing rates estimated in the early time period of the model rather than an arbitrary rate.

The model is robust to this value as shown during the CIE review. The value was adjusted from 10% to 200% average fishing mortality with little effect on model results. However, we can set this value to the average of the first few years of the model to be less arbitrary.

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vi) Additional model diagnostics should include tables (but possibly plots) of likelihood components for all sensitivities. Unweighted (via lambda) values subtracted from the base model are most useful.

A section and a figure will be added to the SAFE that describes the major axes of uncertainty and sensitivity to parameter assumptions. Sensitivities will include but not be limited to: natural mortality, data weighting, catch accuracy, and whale depredation.

Longer term

The CIE reviewers have provided a number of potential model improvements that we will examine over the next few years. Among them, the development of a tag-integrated model is a high priority.

i) Explore replacement of sex-specific age-based selectivities with length-based selectivity to simplify the model.

ii) Develop an integrated spatial assessment model, including tagging data. In the interim, develop a prior for natural mortality rate (for example based on tagging data).

iii) Include a Canadian component. All available evidence (tagging, comparison of abundance index trends) suggests that the Northern BC area also forms part of the assessed stock and efforts should be made to at least include appropriate BC catches in the assessment. Canada would then become an additional apportionment area for TAC calculations.

iv) External estimation of growth is subject to bias due to selectivity effects and is potentially best estimated in the model – particularly enabled by using available length at age data as a model input.

v) Use predictors of recruitment to define current regime (relevant historical recruitment period) for making projections. (see 2.1 iii)

vi) Investigate time-series models of recruitment to potentially improve short-term forecasting.

vii) Include a density-dependent stock-recruitment relationship in the assessment at least as a sensitivity scenario, and seriously consider the implications for current stock status and projections and bounds of certainty in the base assessment results.

Spatial model

i) It is important to define MSE performance measures that better indicate sociological and economic performance of the fishery including regional CPUE, catch/area of habitat, TAC variability, TAC underages, dollar yield etc.

ii) Consider a spatially implicit model (ie areas as fleets). Since the stock is so well mixed it may be simpler to model a single mixed population (no explicit spatial structure) and estimate area-specific selectivity and catchability by fleet (or potentially link these parameters by hyperpriors).

This may be a useful compromise between fully modeling the spatial dynamics explicitly and the current assumption being made of a fully mixed stock. We will look into this as an intermediate comparison.

iii) Spatial modelling at the scale of the management areas (not just 3 coarse areas) could provide advice at a resolution appropriate to management.

For the estimation model using sablefish data, we found that three areas was the limit of how much the data could be parsed without sample sizes becoming too small. In a 6 area model, there are missing data and areas that have very few ages. Simulations using a 6 area operating model will help test sensitivities to this assumption as well as better understand the trade-offs between spatial resolution and precision.

iv) Update estimation of movement matrix using spatial model F's. Ideally this would be done in a single model formulation.

The reviewers make an excellent suggestion. The movement model is currently parameterized with fishing mortality estimates derived from simply catch divided by estimates biomass for each area. The spatial model estimates of spatial Fs could be fed back into the 3 area movement model and used instead of the Fs that are currently estimated outside of the model. At the very least, this would be a useful sensitivity test.

Terms of reference c. Evaluation, findings, recommendations on estimation and strategies for accounting for whale depredation

Are the data and methods used in estimating depredation effects sufficient?

i) Available adjustments for killer and sperm whale depredation should be applied to both indices and catches.

We will include estimates of whale depredation on the survey and the fishery in the 2016 assessment and at least one model will include corrections for depredation.

---

ii) Develop alternative plausible depredation scenarios for model sensitivity testing (e.g. different plausible values for the depredation effect).

We will include this sensitivity as part of a broader sensitivity analysis of major uncertainties to be included as standard in future assessments as described in response to item 2 (vi) above.

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iii) Explore the relationship between the magnitude of survey cpue and depredation by killer whales regarding the efficacy of deleting depredated sets. If killer whales target high cpue stations then simply deleting depredated sets may not adequately adjust for this effect.

We have explored this to some extent, and this does not appear to be a concern. Correcting for killer whale depredation in a modeling framework is challenging because the effect of killer whale depredation has high variability. One set may lose 95% of the catch while another set appears almost unaffected. The mean effect is quite high, however, and expanding catches by it could result in merely adding much more variability to the index.

Should depredation estimates be used in the assessment model, and if so, how?

i) Depredation should be included in the assessment.

We will include estimates of whale depredation on the survey and the fishery in the 2016 assessment and at least one model will include corrections for depredation.

ii) ABC recommendations should account for depredation.

Including an adjustment for whale depredation will likely result in increases to the overall ABC. Rather than impose an additional burden on catch accounting and in-season management conducted by the Regional Office we would likely recommended an ABC reduction based on our fishery whale depredation estimates. For example, we will likely recommend that the overall maximum ABC produced by the model (that accounts for whale depredation) be decremented by an average amount (e.g. 3 year average) of whale depredation in the fishery adjusted by the increase or decrease in ABC recommended for the following year. This would be done at the stock assessment level. We will present some alternative scenarios in 2016.

Terms of reference d. Evaluation, findings, recommendations of areal harvest apportionment strategy as related to movement and optimizing spawning stock biomass

Are there biological reasons to adjust apportionment by area?

The default biological objective of apportionment should be to achieve equal exploitation rate across the stock to maintain regional spawning biomass. In a highly mixed stock, apportionment may not have strong biological implications relative to the socio-economic implications. Therefore, apportionment strategies that emphasize stability are likely to be well suited to highly mixed stocks.

We have maintained that the apportionment strategy has relatively minor implications for the stock when exploitation rates are relatively low (e.g., <15%) in each area. The CIE strongly agreed that in a stock as well mixed as sablefish appear, other factors, such as stability in the fishery quotas, may be more important. The dominant concerns are likely to be more socioeconomic than biological. In light of the lack of concern by the CIE about the effect of the current static apportionment on the quality and robustness of the assessment results, we will continue to develop an MSE, and refine the objectives of what a good apportionment strategy should accomplish. Meanwhile, we do not have good support for any interim changes in the apportionment, and we will recommend keeping apportionment static for another year while other objectives are investigated.

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i) If spatial models are used for apportionment, alternative scenarios for movement should be considered (sensitivity analysis).

The current developments of the spatial model include extensive testing of alternative movement patterns. These sensitivities will be extended to apportionment calculations during our planned MSE work.

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ii) Use MSE analyses to evaluate the performance of various apportionment strategies (e.g. regional economic performance).

iii) If apportionment is to be ‘optimized’ or evaluated in an MSE, explicit management objectives need to be provided.

We request additional guidance from stakeholders, Plan Teams, SSC and the Council regarding objectives for the apportionment strategy. The CIE reviewers indicated little concern about any apportionment strategy that did not severely spatially concentrate the catch, given the high mixing rate of sablefish.

iv) Investigate the implication of localized depletions for apportionment strategies.

v) Investigate whether certain areas disproportionately contribute to recruitment (e.g. higher recruits per spawner).

The recently developed spatial model, further research into the tagging data, and individual based models developed during the GOA Integrated Ecosystem Research Plan will likely provide better insights on the spatial distribution of recruits. Recent satellite tagging of large female sablefish should also help elucidate the location where spawning occurs and inform how apportionment could affect spawners and recruits alike.

vi) Might consider apportionment by vulnerable biomass

Previously we have suggested that apportioning by a minimum length (related to maturity or value of different fish sizes) would be an easily implementable strategy. Apportioning by fishery selectivity or spatial reference points would also help achieve this goal.

Is stability more important than close alignment to annual areal abundance changes?

In a highly mixed stock like sablefish close alignment to areal abundance may be less important for biological productivity and economic considerations may take precedence.

Other issues

i) Industry priorities for apportionment include minimisation of volatility, stakeholder buy-in, and the effects of changes by area (e.g. in size comps). Need answers in the short-term, not necessarily by MSE.

Terms of reference e. Recommendations for further improvements

General recommendations

See longer-term recommendations

Recommendations relating to recruitment and projections

Currently the assessment is used to project abundance subject to highly uncertain recruitment. Additionally, sablefish recruitment has been relatively low over the most recent 15 years. There is the potential to improve the precision of short-term recruitment forecasts based on covariate data.

i) Continue to research predictors of recruitment including oceanographic conditions and early life survival such as lipid density and isotope analysis.

We are working closely with some of the investigators for the GOA Project, who are currently developing ecosystem metrics and sablefish agent-based models that should help us further define the conditions under which sablefish exhibit low and high survival. This year, YOY, 1 year-old, and 2-year old sablefish were collected for energetics analysis to try to understand why the 2014 year class may be particularly large.

ii) Include model structural uncertainty in management recommendations (e.g. high/low recruitment, high/low natural mortality rate scenarios)

We will include this sensitivity as part of a broader sensitivity analysis of major uncertainties to be included as standard in future assessments as described in response to item 2 (vi) below.

iii) Continue to conduct ecosystem research that may be used to provide improved tactical fisheries management advice (e.g. definition of regimes, improved precision of short term recruitment forecasts, incorporation of environmental variables in long term recruitment forecasts, essential fish habitat).

iv) Continue research to improve understanding of spawning dynamics of sablefish (e.g. timing, location, its relationship with spatial distribution of recruitment).

This comment is responded to in section 4.1.v.

Appendix 3D.

Alaska Sablefish Economic Performance Report for 2015

by Ben Fissel

Sablefish is primarily harvested by catcher vessels in the GOA which typically accounts for upwards of 90% of the annual catch. Most sablefish is caught using the hook-and-line gear type. Starting in 2017 directed fishing for sablefish using pot gear will be allowed in the GOA to mitigate whale depredation. As a valuable premium high-priced whitefish, sablefish is an important source of revenues for GOA catcher vessels and catches are at or near the TAC. Since the mid-2000s, decreasing biomass has ratcheted down the TAC and catch. This trend continued through 2015 as total catches decreased 5% to 11.7 thousand t in 2015, down from 12.3 thousand t in 2014 (Table 3D.1).

Commensurate with this decrease in catch and corresponding production, first-wholesale value was down 8.1% to $91 million in 2015 which was mitigated, in part, by an increase in the first wholesale price. Persistent declines in catch have been disruptive to revenues in the sablefish fishery (Table 3D.2). Strong prices have maintained value in the fishery as catches have declined; however, the peak price levels seen were in 2010. Most sablefish is sold as headed-and-gutted at the first-wholesale level of production. Because of the minimal amount of value added by head-and-gut production and the size of the catcher vessel sector, ex-vessel price is closely linked to the wholesale price. At $94 million in 2015, ex-vessel value in the sablefish fishery decreased because of reduced catch levels, despite a $0.14 increase in ex-vessel price (Table 3D.1).

The U.S. accounts for roughly 90% of global sablefish catch and Alaska accounts for roughly 75%-80% of the U.S. catch. Canada catches roughly 10% of the global supply and a small amount is also caught by Russia. As the primary global producer of sablefish the significant supply reductions in Alaska have had a market impact that has resulted in high wholesale and export prices. Most sablefish caught and produced is exported, though the domestic market has grown in recent years. Japan is the primary export market, but its share of export value has decreased from 77% to 62% from 2011-2015 (Table 3D.3). In recent years industry news and U.S. import-export figures indicate that the strong demand for sablefish in the U.S. and foreign demand outside of Japan has weakened the Japanese negotiating position. While supply reductions have put upward pressure on wholesale prices, the strength of the US dollar puts downward pressure on the price of exported goods as it further increases prices for foreign importers. In 2015 the US-Japanese exchange rate rose as the value of the Dollar increased 12.5% over the Yen between 2014 and 2015, and was 33% higher than its 2011-2014 average. Sablefish prices for Japanese consumers were sufficiently high that some industry news reports expressed concern that it would push it outside consumer's price range, resulting in severe demand reductions. Nevertheless, Japanese demand appeared stable throughout 2015 and the strengthening of the Yen in 2016 should improve Japan's purchasing power.

Table 3D.1. Sablefish ex-vessel data from Alaska Fisheries. Total catch (thousand metric tons), catch in federal fisheries (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), number of vessel, and the proportion of vessels that are catcher vessels, 2011-2015.

	2011	2012	2013	2014	2015
Total Catch K mt	13.7	14.6	14.5	12.3	11.7
Federal Catch K mt	11.2	11.9	11.9	10.4	10.2
Value M US$	$152.4	$127.4	$90.8	$95.5	$93.7
Price/lb US$	$5.290	$4.192	$3.100	$3.841	$3.985
% value GOA	88%	92%	92%	93%	96%
Vessels #	340	333	303	293	286
Proportion CV	96%	97%	96%	96%	97%

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 3D.2. Sablefish first-wholesale data from Alaska Fisheries. Production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut share of production, 2011-2015.

	2011	2012	2013	2014	2015
Quantity K mt	7.67	8.16	7.84	6.70	6.06
Value M US$	$147.4	$116.8	$96.2	$99.0	$91.0
Price/lb US$	$8.72	$6.49	$5.57	$6.70	$6.81
H&G share	89%	92%	94%	94%	96%

Source: NMFS Alaska Region At-sea and Shoreside Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 3D.3. Sablefish global catch (thousand metric tons), U.S. and AK shares of global catch; WA & AK export volume (thousand metric tons), value (million US$), price (US$ per pound) and the share of export value from trade with Japan, 2011-2015.

	2011	2012	2013	2014	2015	2016 (thru June)
Global catch K mt	20.8	21.0	19.8	17.8	-	-
U.S.Share of global	90%	89%	90%	90%	-	-
AK share of global	66%	69%	73%	69%	-	-
Export Volume K mt	12.30	9.66	8.15	5.94	6.13	2.22
Export value M $	$ 97.30	$ 99.09	$ 90.32	$ 73.87	$ 76.28	$ 30.74
Export Price/lb US$	$ 3.59	$ 4.65	$ 5.03	$ 5.64	$ 5.64	$ 6.28
Japan value share	77%	78%	74%	71%	62%	62%
Exchange rate, Yen/Dollar	79.81	79.79	97.60	105.94	121.04	107.32

Note: Exports include production from outside Alaska fisheries.
Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

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