3. Assessment of the Sablefish stock in Alaska

by
Dana H. Hanselman, Cara J. Rodgveller, Chris R. Lunsford, and Kari H. Fenske

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 2017 longline survey, relative abundance and length data from the 2016 fixed gear fishery, length data from the 2016 trawl fisheries, age data from the 2016 longline survey and 2016 fixed gear fishery, updated catch for 2016, and projected 2017 - 2019 catches. Estimates of killer and sperm whale depredation in the fishery were updated and projected for 2017 - 2019.

Changes in the assessment methodology:
There were no changes in the assessment methodology. However there is an author's recommended change in projections for this year only.

Summary of Results

The longline survey abundance index increased 14% from 2016 to 2017 following a 28% increase in 2016 from 2015. The lowest point of the time series was 2015. The fishery abundance index decreased 23% from 2015 to 2016 and is the time series low (the 2017 data are not available yet). There was a new Gulf of Alaska (GOA) trawl survey in 2017 which increased 89% from 2015 to 2017. Spawning biomass is projected to increase rapidly from 2018 to 2022, 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 98,332 t (combined across the EBS, AI, and GOA), 0.096, and 0.114, respectively. Projected female spawning biomass (combined areas) for 2018 is 88,928 t (90% of $B_{40\%}$, or $B_{36\%}$), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.086, which translates into a 2018 ABC (combined areas) of 25,583 t. The OFL fishing mortality rate is 0.102 which translates into a 2018 OFL (combined areas) of 30,211 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 2018 ABC of 14,957 t, which is 14% higher than the 2017 ABC. The maximum permissible ABC for 2018 is 89% higher than the 2017 maximum permissible ABC of 13,509 t. The 2016 assessment projected a 1% increase in ABC for 2018 from 2017. The author recommended ABCs for 2018 and 2019 are lower than maximum permissible ABC for two important reasons.

First, the 2014 year class is estimated to be 2.5 times higher than any other year class observed in the current recruitment regime. Tier 3 stocks have no explicit method to incorporate the uncertainty of this new year class into harvest recommendations. While there are clearly positive signs of strong incoming recruitment, there are concerns regarding the lack of older fish and spawning biomass, the uncertainty surrounding the estimate of the strength of the 2014 year class, and the uncertainty about the environmental conditions that may affect the success of the 2014 year class. These concerns warrant additional caution when recommending the 2018 and 2019 ABCs. It is unlikely that the 2014 year class will be average or below average, but projecting catches under the assumption that it is 10x average introduces risk knowing the uncertainty associated with this estimate. Only one large year class since 1999 has been observed, and there is only one observation of age compositions to support the magnitude of the 2014 year class. Future surveys will help determine the magnitude of the 2014 year class and will help detect if there are additional incoming large year classes other than the 2014 year class.

Projections that consider harvesting at the maximum ABC for the next two years, if the 2014 year class is actually average, results in future spawning biomass projections that are very low, where depensation (reduced productivity at low stock sizes) could occur. Recommending an ABC lower than the maximum should result in more of the 2014 year class reaching spawning biomass and achieving higher economic value. Because of these additional considerations, we assume that the recent recruitment is equal to the previous highest recruitment event in the current regime for projections (1977, which is still 4x average.) This results in more precautionary ABC recommendations to buffer for uncertainty until more observations of this potentially large year class are made. Because sablefish is an annual assessment, we will be able to consider another year of age compositions in 2018 and adjust our strategy accordingly. For further explanation and rationale for this approach see section ***Additional ABC/ACL considerations.***

Second, we also recommend a lower ABC than maximum permissible based on estimates of whale depredation occurring in the fishery in the same way that as recommended and accepted in 2017. Because we are including inflated survey abundance indices as a result of correcting for sperm whale depredation, this decrement is needed to appropriately account for depredation on both the survey and in the fishery. This ABC is still 14% higher than the 2017 ABC. The methods and calculations are described in the ***Accounting for whale depredation*** section.

Survey trends support this moderate increase in ABC relative to last year. There was a substantial increase in the domestic longline survey index time series, and a large increase in the GOA bottom trawl survey. These increases offset the continued decline of the fishery abundance index seen in 2016. 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 2015 estimate in 2016, up 5% from 2015. The 2008 year class showed potential to be large in previous assessments based on patterns in the AFSC survey age and length compositions; this year class is now estimated to be about 13% above average. There were preliminary indications of a large incoming 2014 year class, which were evident in the 2016 longline survey length compositions and now are extremely dominant in the 2016 age compositions. This year class appears to be very strong, but year classes have sometimes failed to materialize later and the estimate of this year class is extremely uncertain.

Including the full recruitment estimated for 2014 causes spawning biomass to be projected to climb rapidly through 2022, and then is expected to rapidly decrease assuming a return to average recruitment after 2014. Maximum permissible ABCs are projected to rapidly increase while authors recommended lower ABCs will still increase quickly to 21,648 t in 2019 and 25,836 t in 2020 (see Table 3.18).

Projected 2018 spawning biomass is 36% of unfished spawning biomass. Spawning biomass had increased from a low of 33% of unfished biomass in 2002 to 42% in 2008 and has declined slightly to about 36% of unfished biomass projected for 2018. The last two above-average year classes, 2000 and 2008, each comprise 12% and 15% of the projected 2018 spawning biomass, respectively. These two year classes are fully mature in 2018. The very large estimated year class for 2014 is expected to comprise about 4% of the 2018 spawning biomass, despite only being about 8% mature.

Apportionment

In December 1999, the Council apportioned the 2000 ABC and OFL based on a 5-year exponential weighting of the survey and fishery abundance indices. We have used the same algorithm to apportion the ABC and OFL since 2000. Following the standard apportionment scheme, we have observed that the objective to reduce variability in apportionment was not being achieved. Since 2007, the mean change in apportionment by area has increased annually (Figure 3.60A). 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 3.60B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.60C). 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. In addition, there were no data from the observer program in 2017 for fishery CPUE, and only logbook data were available. 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 three-area spatial model which was developed for research into spatial biomass (see **Movement** section) and apportionment showed different regional biomass estimates than the status quo and 'fixed' apportionment methods which have been used in the past several years for apportionment of ABC to sablefish IFQ holders. Because of the higher proportion of biomass estimated in the Western area (Bering Sea, Aleutian Islands, and Western Gulf of Alaska), using the spatial model biomass for apportionment would have resulted in greater apportionment to the western areas in 2015, compared to the recent 'fixed' apportionment ratios or the traditional exponentially weighted moving average method. Further research on alternative apportionment methods and the tradeoffs is underway. 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 2018, we recommend continuing with the apportionment fixed at the proportions used in 2017.**

Apportionment Table (before whale depredation adjustments)

Area	2017 ABC	Standard apportionment for 2018 ABC	Recommended fixed apportionment for 2018 ABC*	Difference from 2017
Total	13,509	15,380	**15,380**	14%
Bering Sea	1,318	2,686	**1,501**	14%
Aleutians	1,783	2,225	**2,030**	14%
Gulf of Alaska (subtotal)	10,408	10,469	**11,849**	14%
Western	1,457	1,533	**1,659**	14%
Central	4,608	4,201	**5,246**	14%
W. Yakutat**	1,550	1,765	**1,765**	14%
E. Yak. / Southeast**	2,793	2,970	**3,179**	14%

* Fixed at the 2013 assessment apportionment proportions (Hanselman et al. 2012b). ** 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 for these adjustments are either published (Peterson and Hanselman 2017) or accepted for publication (Hanselman et al. 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 2018 and 2019 compared with the standard ABC in 2017. 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 (2014-2016) of whale depredation (t) by the amount that the ABC is increasing or decreasing from 2017to 2018 and 2019. This amount of projected depredation is then deducted from each area ABC to produce new area ABCs for 2018 and 2019 (ABC_w). In this case the 3 year-average depredation is multiplied by 1.139 because the 2018 ABC is recommended to increase by 13.9% from 2017. In 2016 the SSC decided that these calculations should also apply to OFL, so the same procedure is applied to OFLs for 2018 and 2019 below (OFL_w).

The total change in recommended adjusted ABC is a 14% increase from the 2017 adjusted ABC. The increases by area from 2017 were similar to the overall increase. We recommend this method of accounting for whale depredation in the fishery because it is at the stock assessment level and does not create additional regulations or burden on in-season management.

Author recommended 2018 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2017 ABC	1,783	1,318	1,457	4,608	1,550	2,793	13,509
2018 ABC	2,030	1,501	1,659	5,246	1,765	3,179	15,380
2014-2016 avg. depredation	37	33	101	77	81	43	371
Ratio 2018:2017 ABC	1.139	1.139	1.139	1.139	1.139	1.139	1.139
Deduct 3 year adjusted average	-42	-37	-115	-88	-92	-49	-423
****2018 ABC_w**	**1,988**	**1,464**	**1,544**	**5,158**	**1,672**	**3,131**	**14,957**
Change from 2017 ABC_w	15%	15%	14%	14%	14%	14%	14%

[*] Before 95:5 hook and line: trawl split shown below. **ABC_w is the author recommended ABC that accounts for whales and uncertainty in the 2014 year class.

Author recommended 2019 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2017 ABC	1,783	1,318	1,457	4,608	1,550	2,793	13,509
2019 ABC	2,857	2,113	2,335	7,384	2,484	4,475	21,648
2014-2016 avg. depredation	37	33	101	77	81	43	371
Ratio 2019:2017 ABC	1.602	1.602	1.602	1.602	1.602	1.602	1.602
Deduct 3 year adjusted average	-59	-52	-161	-124	-130	-69	-595
****2019 ABC_w**	2,798	2,061	2,174	7,260	2,353	4,407	21,053
Change from 2017 ABCw	61%	62%	61%	61%	60%	61%	61%

[*] Before 95:5 hook and line: trawl split shown below. ** ABC_w is the author recommended ABC that accounts for whales and uncertainty in the 2014 year class.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2018	1,829	2,974
	2019	2,573	4,187

Author recommended 2018/2019 OFLs (with whale depredation adjustments)

Year	**2018**				**2019**			
Area	**AI**	**BS**	**GOA**	**Total**	**AI**	**BS**	**GOA**	**Total**
2017 OFL	2,101	1,551	12,279	15,931	2,101	1,551	12,279	15,931
OFL	3,987	2,949	23,275	30,211	6,320	4,674	36,897	47,891
3 year average depredation	37	33	302	371	37	33	302	371
Ratio	1.896	1.896	1.896	1.896	3.006	3.006	3.006	3.006
Deduct 3 year average	-69.8	-61.9	-572.5	-704	-110.7	-98.2	-907.5	-1,116
***OFL_w**	**3,917**	**2,887**	**22,703**	**29,507**	**6,209**	**4,576**	**35,989**	**46,775**
2017 OFL_w	2,044	1,499	11,885	15,428	2,044	1,499	11,885	15,428
Change from 2017	92%	93%	91%	91%	204%	205%	203%	203%

* OFL_w is the author recommended OFL that accounts for whales.

Summary table

Quantity/Status	As estimated or specified *last* year for: 2017	2018	As estimated or recommended *this* year for: 2018*	2019*
M (natural mortality rate)	0.097	0.097	0.097	0.097
Tier	3b	3b	3b	3b
Projected total (age 2+) biomass (t)	239,244	249,252	330,655	350,850
Projected female spawning biomass (t)	91,553	91,553	88,928	110,974
$B_{100\%}$	264,590	264,590	245,829	245,829
$B_{40\%}$	105,836	105,836	98,332	98,332
$B_{35\%}$	92,606	92,606	86,040	86,040
F_{OFL}	0.097	0.097	0.102	0.114
$maxF_{ABC}$	0.097	0.097	0.086	0.096
F_{ABC}	0.081	0.078	0.077	0.085
OFL (t)	15,931	16,145	30,211	47,891
OFL_w (t)	**15,428**	**15,996**	**29,507**	**46,775**
max ABC (t)	13,509	13,688	25,583	41,044
ABC (t)	13,509	13,688	15,380	21,648
ABC_w (t)**	**13,083**	**13,256**	**14,957**	**21,053**
Status	As determined *last* year for: 2015	2016	As determined *this* year for: 2016	2017
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 13,329 t and 18,461 t used in place of maximum permissible ABC for 2018 and 2019. This was done in response to management requests for a more accurate two-year projection.
**ABC_w and OFL_w are the final recommended ABC and OFL after accounting for whale depredation and using the 1977 value for the 2014 recruitment in the projection model.

Plan Team Summaries

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2016	122,000	10,326	9,087	9,087	9,376
	2017	139,000	11,885	10,074	10,074	10,386
	2018	356,000	22,703	11,505		
	2019	370,000	35,989	16,194		
BS	2016	25,000	1,304	1,151	1,151	532
	2017	24,000	1,551	1,274	1,274	1077
	2018	94,000	2,887	1,464		
	2019	98,000	4,576	2,061		
AI	2016	23,000	1,766	1,557	1,557	349
	2017	43,000	2,101	1,735	1,735	469
	2018	65,000	3,917	1,988		
	2019	68,000	6,209	2,798		

Year	2017				2018		2019	
Region	OFL	ABC	TAC	Catch*	OFL	ABC**	OFL	ABC**
BS	1,499	1,274	1,274	1077	2,887	1,464	4,576	2,061
AI	2,044	1,735	1,735	469	3,917	1,988	6,209	2,798
GOA	11,885	10,074	10,074	8,746	22,703	11,505	35,989	16,194
WGOA	--	1,349	1,349	913	--	1,544	--	2,174
CGOA	--	4,514	4,514	3,887	--	5,158	--	7,260
**WYAK	--	1,605	1,605	1,567	--	1,829	--	2,573
**EY/SEO	--	2,606	2,606	2,379	--	2,974	--	4,187
Total	15,428	13,083	13,083	10,292	29,507	14,957	46,775	21,053

*As of October 1, 2017 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 2017.

"In an effort improve record keeping as assessment authors formulate various stock status evaluation models, the Plan Team has recommended a systematic cataloging convention. Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes are identified by the addition of a letter designation (e.g., 16.1a). The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time." (SSC December 2016)

The sablefish assessment began using these conventions for the 2016 assessment and continues this year.

"…The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock, perhaps following the framework suggested below, during the December Council meeting to aid in identifying areas of concern." (SSC October 2017)

The sablefish assessment attempts to start this process with the proposed Ecosystem Socioeconomic Profile appendix that integrates factors outside of the assessment model and how they may affect current and projected sablefish biological and fishery conditions.

Responses to SSC and Plan Team Comments Specific to this Assessment

"Autocorrelation in residuals of the main indices was discussed and asked if covered in the CIE review (the response was negative). The possibility that the relatively poor pattern of residuals may somehow account for good performance (in terms of retrospective analyses) was raised. The idea here being that retrospective patterns may occur in response to periods of outlier-type survey estimates. The Teams recommended examining ways in which residual patterns can be more objectively considered as part of the data weighting exercise." (Joint Plan Team November 2016)

Since there are no new models being presented for November 2017, no attempt to address this recommendation was made. Inclusion of the very different age composition from the 2016 longline survey this year highlighted some of the fits to the indices that will need to be explored in future years.

"The SSC agrees with the author and Plan Teams that the depredation correction should be made when setting the ABC. The SSC also recommends that the correction is applied to both the ABC and the OFL." (SSC December 2016)

This assessment includes an additional table that adjusts OFL estimates for whale depredation in 2018 and 2019.

"The author recommended no changes be made to the area apportionments until the apportionment scheme is thoroughly re-evaluated and reviewed. The SSC agrees with this approach for 2017, however, they noted that the static apportionments have diverged from biomass-based estimates by as much as 61%, and continue to encourage completion of the analysis of area apportionment options in the near future." (SSC December 2016)

We continue to keep the apportionment fixed as a new alternative algorithm has yet to be developed. There has been some progress on spatial modeling that is described in the section ***Movement.*** Some preliminary work on operating models show that with the high movement rates indicated by our tag-recovery model, that a wide range of spatial apportionments are possible to achieve the majority of maximum yield. Thus, any future apportionment strategies will have non-biological factors built in such as economic value or ecosystem services.

"The SSC supports the author's continued efforts to account for uncertainty in the assessment, specifically through addressing data weighting and estimating natural mortality. The SSC notes that if this stock was managed as a Tier 1 stock, this information would be particularly useful. The prior used for natural mortality, with a CV of 10%, was noted by the author to be necessary to ensure convergence. This suggests it may be constraining to the estimated value; the SSC recommends that a formal prior derived from life history, meta-analyses, or other sources be derived and explored for use in this assessment." (SSC December 2016)

The natural mortality estimate seemed fairly well behaved on initial implementation in 2016, but became unstable during retrospective runs, which caused concern that future data might also create large fluctuations in natural mortality. We will attempt to construct a more informed prior for the 2018 assessment, although given sablefish's unique taxonomy, meta-analysis may not be helpful. However, we can estimate natural mortality with the tag-recovery data which would give a strong semi-independent distribution to work with.

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 occur 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.

Using these data, a three-area spatial sablefish assessment model has been developed to examine regional sablefish biomass, and to use as an estimation model in ongoing apportionment research. The spatial model uses externally estimated movement rates adapted from Hanselman et al. (2015), a shortened time series of data beginning in 1977, and is structurally similar to the assessment model used for management and described in this SAFE chapter. At present, the spatial model uses data through 2015, as the whale depredation effects used in the management model starting in 2016 have not been incorporated in the spatial model. The spatial model also explores the effect of alternative movement rates and model spatial complexity through several sensitivity analyses.

Overall, total and spawning biomass estimated in the base spatial model was similar in trend and scale to the single area model used for management. There were spatial differences in total and spawning biomass for the three modeled regions; the Western region (comprised of the Bering Sea, Aleutian Islands, and Western GOA management areas) had the greatest total age 2+ biomass (45% in the 2015 terminal model year), the Central region (Central GOA management area) contained an estimated 30% of total biomass, and the Eastern region (West Yakutat and East Yakutat/SE regions) was 25% of total biomass. Model explorations examining alternative movement rates and model spatial parameterization suggested that the model was sensitive to both of these axes of uncertainty.

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. However, recent genetic work by Jasonowicz et al. (2017) found no population sub-structure throughout their range along the US West Coast to Alaska, and suggested that observed differences in growth and maturation rates may be due to phenotypic plasticity or are environmentally driven. 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 now legal in in all Alaska federal management regions because of an action taken by the NPFMC in 2015. In 2000, the BSAI 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 declined significantly in recent years in the AI (only 12 t in 2015, Table 3.2). Pot catches began occurring in the Gulf of Alaska in 2017 but make up a small proportion of the fixed gear catch. We will be monitoring the development of this new fishery as it expands.

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 were implemented 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 670 t during 2010 - 2017. 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 (701 t/year, 225 t discarded). Sharks and skates are also taken in substantial numbers and are mostly discarded.

Giant grenadiers, a non-target species that is an Ecosystem Component in both the GOA and BSAI FMPs, make up the bulk of the nontarget species bycatch, with 2013 the highest in the last five years at 11,523 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 (461 t/year on average) and golden king crab (16,020 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	1960-2017
Trawl fisheries	Catch	1960-2017
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. fixed gear fishery	CPUE, length	1990-2016
	Age	1999-2016
U.S. trawl fisheries	Length	1990,1991,1999, 2005-2016
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-2017
	Age	1996-2016
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017

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 have been required for vessels 60 feet and over beginning in 1999 and are voluntary for vessels under 60 ft. Since 2000, a longline fishery catch rate index has been derived from data recorded by observers and by captains in logbooks for use in the model and for 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 two sources are combined into one index by weighting each data set by 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 in federal waters, represented 12% (973 mt) of the total longline catch in federal waters in 2016. The percent of the IFQ catch observed was 0% in the BS (there was no observed longline catch in the BS in 2016), 9% in the EY/SE, 9% in the WG, 11% in WY, 13% in the CG, and 14% in the AI. There was a decrease in the number of vessels with observer coverage in the AI (from 3 to 2) so no data is reported due to confidentiality (Table 3.9). The number of sets in the WG was down in 2016 from 2017. The number of sets with coverage in the WG is variable and so this decrease is not out of the ordinary. The number of vessels with coverage in WY and EY/SE areas declined from 2015 to 2016. In the WY area, the number of vessels with coverage decreased from 39 to 25; however, coverage in 2015 was much higher than average and 2016 was close to the average (average from 1995 to 2016 was 24 vessels and in 2016 it was 25). Coverage in EY was down from 51 vessels in 2015 to 46 in 2016. The number of vessels observed in 2016 is still much higher than average (average from 1995 to 2016 was 20 and in 2016 it was 46).

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 at low levels in the CG. These sets are excluded from catch rate analyses in the observer data set. Whale data are not currently collected in logbooks. The percent of sablefish directed sets that are depredated by killer whales is on average 23% in the BS, 3% in the AI, and 3% in the WG. Although the rate is high in the BS, the average number of sets observed is only 24. Likely because of this small sample size, the annual range in the rate of depredation is 7-100%. The maximum depredation rate in the CG was 4% but the average is only 1%. In 2016 killer whale depredation was average in the CG, WG, and AI. There were only 5 sets observed in the BS and were depredated by killer whales.

Determining if sperm whales are depredating can be subjective because sperm whales do not take the great majority of the catch, like killer whales do. Therefore, measures of depredation in the fishery may not be accurate. Sperm whale depredation has been recorded by observers since 2001. It is most prominent in the CG, WY, and EY/SE areas and less common in the WG. The average percent of sets that are depredated is 6% in the CG, WY, and EY/SE areas, but the average over the past 5 years is higher than the time series average (CG = 9%, WY = 12%, EY = 7%). In 2016, depredation was slightly above the 5-year average in the CG (11%) and in WY (15%) and was 1% below the 5-year average in EY (6%). In the WG, 1% of sets was depredated, which is equal to the average for the time series.

Logbook Data

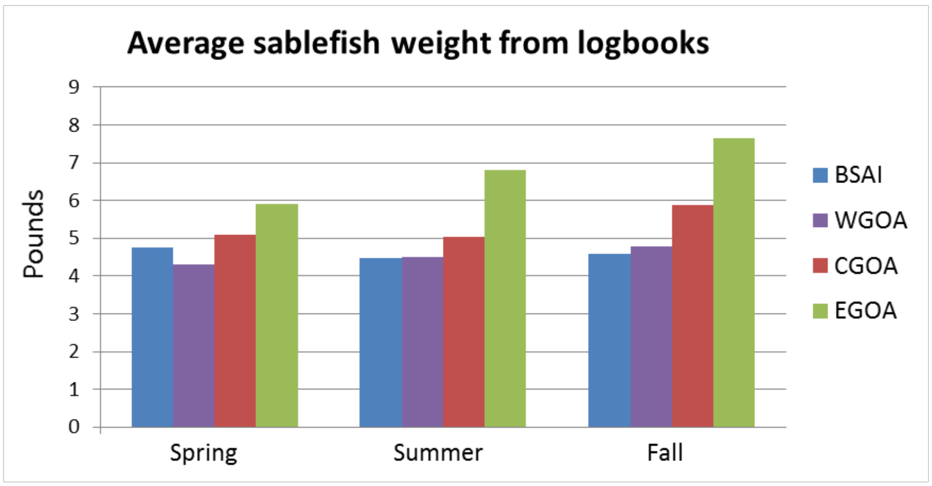
Logbook sample sizes are substantially higher than observer samples sizes, especially since 2004 in the GOA (Table 3.9). Logbooks include the target of the set, so no calculations are required to determine the target, unlike observer data. Logbook participation increased sharply in 2004 in all areas, primarily because the International Pacific Halibut Commission (IPHC) collected, edited, and entered logbook data 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 under 60 feet are now participating in the program voluntarily. In 2016, 53% of sets came from vessels under 60 ft and 72% of the vessels that turned in logbooks were under 60 ft. There is a higher proportion of the catch documented by logbooks than by observers; over 50% of the hook and line catch is documented in logbooks, compared to < 15% for observer data. Some data are 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 and so no data are excluded. In general, in both data sets, catch rates per unit effort (CPUE) 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, the overall CPUE trends in the observer and logbook data have been trending downward. In 2016 both fishery indices decreased in all four areas in the GOA. In the AI there is no observer CPUE reported in 2016, due to confidentiality (fewer than 3 vessels), or the BS, because there were no observed sablefish targeted sets without killer whale depredation. CPUE was at the lowest in the IFQ era in both data sets. Because of larger sample sizes in the logbook data set, there are typically more narrow confidence intervals and so the data are weighted more heavily in the combined fishery index of abundance, as the two data sources are combined into one index by weighting each data set by the inverse of the CV.

Seasonal changes in fish size

From 2012-2016 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 2012-2016 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 if there was weight and count information and if the average weight for the set was reasonable (i.e, the average weight was less than the largest fish ever recorded on the longline survey). There were very small differences between spring, summer, and fall BSAI and WGOA. There was a small increase in average weight in the CGOA in fall (from 5.0 to 5.9 lbs). In the EGOA there was an increase in average weight in the summer and again in the fall (see figure below). In EGOA, the average weight in spring was 5.9 lbs, 6.8 lbs in summer, and 7.6 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	1,427	948	458	2,833
WGOA	759	1,357	416	2,532
CGOA	3,259	1,646	614	5,519
EGOA	2,049	408	281	2,738

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 are 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 they 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 were no pot CPUE data (one vessel turned in data with counts only and no set weights). From 2006-2016, in years where there were data, the average catch rate in logbook data was 27 lbs/pot in the AI and 22 lbs/pot in the BS.

The average catch rate in the observer data from 2000-2015 was 16.0 lbs/pot in the AI and 17.5 lbs/pot in the BS. The effort recorded by observers in the BS has decreased from 4-8 vessels from 2003 to 2012 and decreased again to 1 to 3 vessels from 2013 through 2016. On average there were 246 sets observed from 2003 to 2012; there were on average 52 sets observed annually in the BS from 2013 to 2016. There has been less recorded effort in the AI than in the BS throughout the time series. IFQ catch in pot gear in the BS decreased substantially after 2013; average catch was 519 mt from 2002-2013 and was 143 mt from 2014 to 2016. Catch in the AI was highest from 2003 through 2007 (average 496 mt) and decreased substantially in 2008 (down to an annual average of 90 mt).

A recent regulatory change allowed pot gear to be used in the directed sablefish fishery in the GOA starting in 2017. In data obtained on 10/20/17 there were pot vessels observed in all management areas in the GOA. The low number of vessels renders us unable to share data at this time. There are small amounts IFQ catch in all areas (ranging from 85 to 130 mt per area).

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 2016 there were 12,973 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 every 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 et al. 2017).

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-1980s, 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 and 2017 increases 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 9 affected stations in 2015 and 11 in 2017. 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 2017 there were sperm whales depredating at 17 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 these 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 (Hanselman et al. *accepted*), and was used 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 1990-2017 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 1984-2017 are shown in Table 3.10. The GOA trawl survey index was at its lowest level of the time series in 2013, but has increased 100% by 2017.

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 numbers (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.

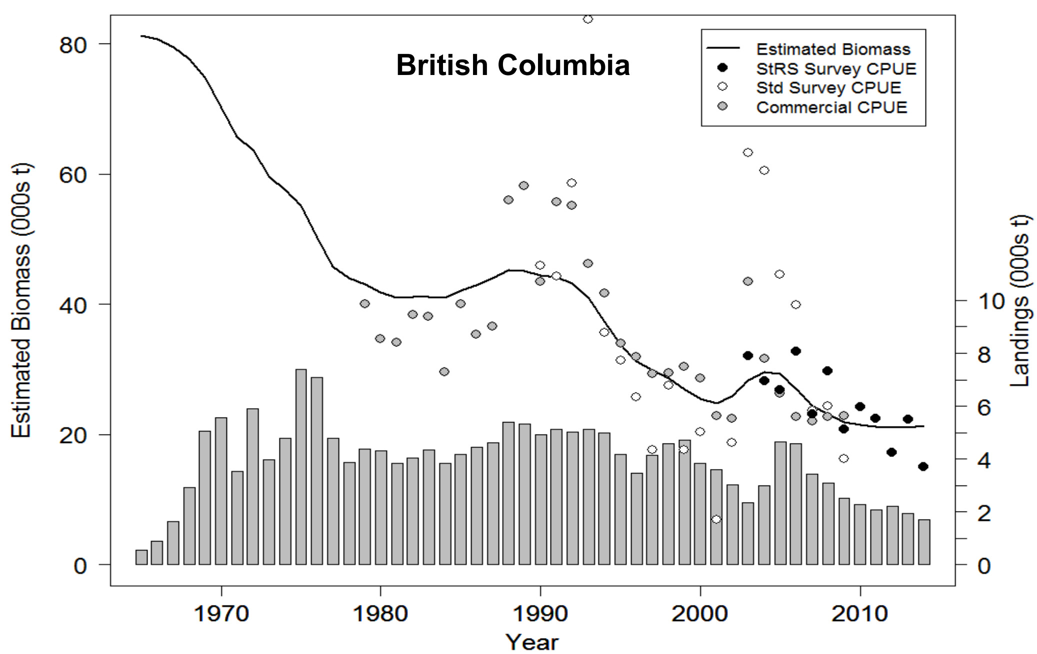
Alaska Department of Fish and Game

The Alaska Department of Fish and Game conducts mark-recapture and a longline survey in Northern Southeast Alaska Inside (NSEI) waters and a longline survey in Southern Southeast Alaska Inside (SSEI) waters. Sablefish in these areas are treated as separate populations from the federal stock, but some migration into and out of Inside waters has been confirmed with tagging studies (Hanselman et al. 2015). The NSEI CPUE seems to be stabilizing after a steep decline from 2011 to 2013, with an uptick in younger fish seen in 2016. In SSEI, survey CPUE has been declining since 2011 but also saw an uptick in 2016. The lowest points in the time series of CPUE for each of these areas is about 2000, confirming the lows in 1999/2000 estimated in our assessment

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 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. The last two surveys have shown some rebound, particularly in the combined Western areas.

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

[2] DFO. 2014. Performance of a revised management procedure for Sablefish in British Columbia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014 /025: http://www.dfo-mpo.gc.ca/csas-sccs/publications/scr-rs/2014/2014_025-eng.html

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. 2005); 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 2016 (Model 16.5, Hanselman et al. 2016). 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

There are no model alternatives to consider for the 2017 assessment. The main features of Model 16.5 from models before 2016 are:

1) New area sizes for the domestic longline survey abundance (Echave et al. 2013)
2) Inclusion of annual variance calculations including uncertainty of whale observations in the domestic longline survey index
3) Additional catch mortality in the longline fisheries from sperm and killer whales
4) Natural mortality is estimated

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	
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. 2012a).

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 (Rodgveller et al. 2016). Ovaries were examined histologically to determine maturity. 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 in the Central Gulf of Alaska from 1996-2012 (mean = 7.0 years) and the estimate currently used in the assessment (6.6 years), when skipped spawners were classified as mature (even though they were not reproducing in the current year). A second survey took place in December 2015 in the same areas that were sampled in 2011. Skip spawning was lower in 2015 (6% of mature fish) than in 2011 (21%). When skip spawners were classified as mature in 2015 the age-at-50% maturity was 7.3 years, which is higher than values from earlier years. When skip spawners were classified as immature, in both 2011 and 2015, the slope was shallower and the age-at-50% maturity was higher (9.8 in 2011 and 7.9 in 2015). Skipped spawners were primarily found in gullies on the shelf. Generally, skip spawning was at ages where a portion of the fish were not yet mature (i.e., the age at which fish were estimated to be <100% mature) and the rate of skip spawning decreased with age ($R^2 = 0.35$). These studies show that skip spawning is variable and may be related to age. In the future, we will explore methods to incorporate new maturity data into stock assessment.

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[3]. A natural mortality rate of M=0.10 has been

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

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 revisited 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

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

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 exist (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 2017, a paper with a comprehensive examination of different modeling techniques was accepted (Hanselman et al. *accepted*).

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 2016, data were collected at 662 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 202 cases (31%). 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. The area-wide model provided stronger inferences and were recommended for use in the stock assessment.

We use these results to inflate catches at survey stations with depredation evidence by a factor of 1.18 (i.e., 1/0.85). The standard error and covariance of this estimate is included in the total variance of the relative population number estimates from the index.

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 published a study 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 2017).

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 2003-2016). 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 the stock assessment model.

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	85
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	116
Fishery selectivity	fs_a	9
Survey selectivity	ss_a	8
Total		231

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 1933-2016.

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 1960-2017 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.

Uncertainty

Since the 1999 assessment, we have conducted a limited Bayesian analysis of assessment uncertainty. The posterior distribution was computed based on one 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 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. 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 1979-2015 age-2 recruitments. The fishing mortality used is the current yield ratio described in the *Catch specification* section multiplied by maxABC for each year. In addition to the projection uncertainty with respect to reference points, we compare the uncertainty of the posterior distributions with the Hessian approximations for key parameters.

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 $\sim \ln(0,\sigma_r)$
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	
$s^g_{a,s}=\left(1+e^{(-\delta_{g,s}(a-a_{50\%,g,s}))}\right)^{-1}$	Logistic selectivity
$s^g_{a,s}=\dfrac{a^{\delta_{g,s}}}{\max\left(s^g_{a,s}\right)}$	Inverse power family
$s^g_{a,s}=\left(\dfrac{a}{a_{\max}}\right)^{a_{\max,g,s}/p}e^{(a_{\max,g,s}-a)/p}$ $p=0.5\left[\sqrt{{a_{\max,g,s}}^2+4{\delta_{g,s}}^2}-a_{\max,g,s}\right]$	Reparameterized gamma distribution
$s^g_{a,s}=\left(1-\varphi^g_s\right)^{-1}\left(\dfrac{\left(1-\varphi^g_s\right)}{\varphi^g_s}\right)^{\varphi^g_s}\dfrac{\left(e^{(\delta_{g,s}\varphi^g_s(a_{50\%,g,s}-a))}\right)}{\left(1+e^{(\delta_{g,s}(a_{50\%,g,s}-a))}\right)}$	Exponential-logistic selectivity
Observation equations	
$\hat{C}_{y,g}=\sum_1^g\sum_1^s w_{a,s}N_{y,a,g,s}F_{y,a,g,s}\left(1-e^{-Z_{y,a,g,s}}\right)Z^{-1}_{y,a,g,s}$	Catch biomass in year *y*
$\hat{I}_{y,g}=q^g\sum_{a_0}^{a_+}\sum_1^s N_{y,a,s}\dfrac{s^g_{a,s}}{\max\left(s^g_{a,s}\right)}w_{a,s}$	Survey biomass index (weight)
$\hat{I}_{y,g}=q^g\sum_{a_0}^{a_+}\sum_1^s N_{y,a,s}\dfrac{s^g_{a,s}}{\max\left(s^g_{a,s}\right)}$	Survey abundance index (numbers)
$\hat{P}^g_{y,a,s}=N_{y,a,s}s^g\left(\sum_{a_0}^{a_+}N_{y,a,s}s^g_{a,s}\right)^{-1}\mathbf{A}_s$	Vector of fishery or survey predicted proportions at age
$\hat{P}^g_{y,a,s}=N_{y,\cdot,s}s^g_s\left(\sum_{a_0}^{a_+}N_{y,a,s}s^g_{a,s}\right)^{-1}\mathbf{A}^l_s$	Vector of fishery or survey predicted proportions at length

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

Results

Model Evaluation

For this assessment, we present last year's model (Model 16.5) updated for 2017 with no model changes. A comparison of the model likelihood components and key parameter estimates from 2016 are compared with the 2017 updated model.

The two models are identical in all aspects except for inclusion of new data. Our usual criteria for choosing a superior model are: (1) the best overall fit to the data (in terms of negative log-likelihood), (2) biologically reasonable patterns of estimated recruitment, catchabilities, and selectivities, (3) a good visual fit to length and age compositions, and (4) parsimony.

Because the models presented have different amounts of data and different data weightings, it is not reasonable to compare their negative log likelihoods so we cannot compare them by the first criterion above. In general we can only evaluate the 2017 model based on changes in results from 2016 and it is unlikely we would reject the model that included the most recent data. The model generally produces good visual fits to the data, and biologically reasonable patterns of recruitment (with the possible exception of 2014 which we discuss below), abundance, and selectivities. The 2017 update shows a slight decrease in spawning biomass and an increase in total biomass from previous projections. Therefore the 2017 version of Model 16.5 is utilizing the new information effectively, and we use it to recommend 2018 ABC and OFL.

Box 2: Model comparison by contribution to the objective function (negative log-likelihood values) and key parameters of the 2016 reference model (16.5) and eight model options for 2017.

Year	**2016**	**2017**
Model Name	16.5	16.5
Likelihood Components		
Catch	2	3
Dom. LL survey RPN	32	30
Coop. LL survey RPN	16	16
Dom. LL fishery RPW	6	6
Jap. LL fishery RPW	7	10
NMFS trawl survey	14	19
Dom. LL survey ages	200	219
Dom. LL fishery ages	218	239
Dom. LL survey lengths	69	67
Coop LL survey ages	142	142
Coop LL survey lengths	45	44
NMFS trawl lengths	332	364
Dom. LL fishery lengths	38	41
Dom. trawl fish. lengths	319	338
Data likelihood	1442	**1537**
Objective function value	1479	1576
Key parameters		
Number of parameters	228	**231**
$B_{next\ year}$ (Female spawning (kt) biomass for next year)	94	81
$B_{40\%}$ (Female spawning biomass (kt))	106	98
B_{1960} (Female spawning biomass (kt))	203	166
$B_{0\%}$ (Female spawning biomass (kt))	265	246
SPR% current	35.6	33.1%
$F_{40\%}$	0.095	0.096
$F_{40\%}$ (Tier 3b adjusted)	0.081	0.086
ABC(kt)	**13.5**	**25.6**
$q_{Domestic\ LL\ survey}$	7.3	7.8
$q_{Japanese\ LL\ survey}$	5.6	5.9
$q_{Domestic\ LL\ fishery}$	5.5	5.9
$q_{Trawl\ Survey}$	1.2	1.2
$a_{50\%}$ (domestic LL survey selectivity)	4.2	3.8
$a_{50\%}$ (LL fishery selectivity)	3.9	3.9
μ_r (average recruitment)	16.5	19.5
σ_r (recruitment variability)	1.2	1.2

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 very large estimate of the 2014 year class is causing estimates of total biomass to increase rapidly in 2017.

Projected 2018 spawning biomass is 36% of unfished spawning biomass. Spawning biomass had increased from a low of 33% of unfished biomass in 2002 to 42% in 2008 and has declined slightly to about 36% of unfished biomass projected for 2018. The last two above-average year classes, 2000 and 2008, each comprise 12% and 15% of the projected 2018 spawning biomass, respectively. These two year classes are fully mature in 2018. The very large estimated year class for 2014 is expected to comprise about 4% of the 2018 spawning biomass, despite only being about 8% mature (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 longline survey age composition is dominated by 2008-2010 year classes which make up more than 35% of the age composition. The 2016 longline survey age composition had an extremely high proportion of age 2 fish and a relatively high proportion of age 3 fish. The 2015 and 2017 trawl survey length compositions also show a high proportion of fish between ages 1 and 3 (Figures 3.20, 3.21, and 3.54). 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). The 2014 year class is appearing early in all areas and strongly in the CGOA and Western areas (Figure 3.23).

Average recruitment during 1979-2017 was 19.5 million 2-year-old sablefish per year, which is slightly less than average recruitment during 1958-2017 (Figure 3.18b). 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.

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 1977-1981 year classes, the 1997-2000 year classes, and the 2014 year class (Figures 3.18, 3.21). The 1977-1981 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). 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, particularly in 2017 where the model expected to see a higher trawl survey index based on the 2014 year class. 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 CPUE index has a higher variance, and had been tracking relatively well until 2015 and 2016 where the model expected higher fishery RPWs. All age compositions were reasonably well 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 and 2016 predicted survey ages expected more middle age fish and fewer fish between ages 5-7. The 2016 longline survey age compositions look dramatically different with the age 2 and 3s having the highest proportions. The model fits these very different data surprisingly well. The aggregated age compositions (Figure 3.25) 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 small fish well that were caught in 2016 (Figure 3.29, 3.30). The aggregated length compositions show good predictions on average but missing a little in the middle sizes (Figure 3.31). 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 (Figure 3.22). 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. In 2016, the fishery is clearly encountering younger fish, but not as many as the surveys.

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 3.8 years for females in the longline survey and 3.9 years in the IFQ longline fishery. The longline survey $a_{50\%}$ shifted almost a half a year left from 2016 likely influenced by the large amount of young fish encountered in 2016. 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 2018 and 2019 spawning biomass is slightly above $B_{35\%}$.

Uncertainty

The model estimates of projected spawning biomass fall near the center of the posterior distribution of spawning biomass. Most of the probability lies between 75,000 and 120,000 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 0.40. During the next three years, the probability of being below $B_{17.5\%}$ is near zero, the probability of being below $B_{35\%}$ is low, and the probability of staying below $B_{40\%}$ is also low in the medium term (Figure 3.48).

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 (2007-2016) 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 0.065 is low (a small positive retrospective bias) relative to most assessments at the AFSC (Hanselman et al. 2013). This is a slight change from 2016 which has a very small (-0.028) negative retrospective. This flip was caused by lower estimates of spawning biomass estimated in 2017 because of a lack of older fish in the age compositions. 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 2008 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 98,332 t (combined across the EBS, AI, and GOA), 0.096, and 0.114, respectively. Projected female spawning biomass (combined areas) for 2018 is 88,928 t (90% of $B_{40\%}$, or $B_{36\%}$), placing sablefish in sub-tier "b" of Tier 3. The maximum permissible value of F_{ABC} under Tier 3b is 0.086, which translates into a 2018 ABC (combined areas) of 25,583 t. The OFL fishing mortality rate is 0.102 which translates into a 2018 OFL (combined areas) of 30,211 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 2017 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2018 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2017. 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 2017 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 2018, 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 2018 and 2019, 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 2014-2016 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.). In addition, the 2014 year class is set to the value of the 1977 year class to provide a buffer to the uncertainty of the extremely high estimate.

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 2012-2016 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 2017, or 2) above ½ of its MSY level in 2017 and above its MSY level in 2027 under this scenario, then the stock is not overfished.)

Scenario 7: In 2018 and 2019, 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 2019, or 2) above 1/2 of its MSY level in 2019 and expected to be above its MSY level in 2029 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 2018 and 2019. 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 2018, it does not provide the best estimate of OFL for 2019, because the mean 2018 catch under Scenario 6 is predicated on the 2018 catch being equal to the 2018 OFL, whereas the actual 2018 catch will likely be less than the 2018 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 (2016) is 10,971 t. This is less than the 2016 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 2017:

a. If spawning biomass for 2017 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2017 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2017 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 2019 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2019 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2019 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2029. If the mean spawning biomass for 2029 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. 2014-2016 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).

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 1,000,000 MCMC (burnt-in and thinned) using the standard Tier 3 harvest rules. The projection shows wide credible intervals on future spawning biomass (Figure 3.49). 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.

Additional ABC/ACL considerations

Achieving optimum yield is the primary goal of fishery management plans under the Magnuson-Stevens Act. Optimum yield is described as:
"The term "optimum", with respect to the yield from a fishery, means the amount of fish which (A) will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems;
(B) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor."
Under Tier 3 management, there is no framework for the explicit consideration of uncertainty in setting levels of ACL and ABC lower than maxABC. Reductions of maximum fishing mortality levels at low levels of spawning biomass relative to the target level is already is already built into the Tier 3 control rule. In addition to concerns over low spawning biomass, there are several types of uncertainty that could be considered when recommending a lower level for the catch recommendation in order to ensure long term optimal yield. The types of uncertainly that might be prudent to consider fall into three broad categories:

1. Data and model uncertainty
2. Ecosystem uncertainty
3. Socioeconomic uncertainty

Data and model uncertainty is what is typically considered first in stock assessment. But even in this case, if the uncertainty of model results rises, either due to input data (e.g., survey effort reductions resulting in an increased survey CV) or due to process error from environmental fluctuations, there is no formulaic way to buffer against this uncertainty in Tier 3. In addition, model uncertainty is usually reported as error estimates from a single model, which ignores a host of structural uncertainties associated with model misspecification or oversimplifications of complicated population dynamics.

The second type of uncertainty is broadly called "ecosystem uncertainty." The components of this uncertainty are limitless. However, the critical assumption that governs the importance of this uncertainty is that the ecosystem in recent years and the next several years are well represented by historical estimates of productivity (i.e., 1977 – present in most groundfish stocks). This assumption can be violated by routine events that become more extreme (e.g., El Nino), or rare events, such as the "Warm Blob" of 2014/2015. If indicators of the ecosystem condition that are specifically related to the growth, reproduction, and mortality of a specific species were available, it might be judicious to adjust harvest recommendations when conditions appear to be improving, degrading, or exhibiting higher variability.

The third type of uncertainty, "socioeconomic uncertainty," is one that is least commonly considered as an adjustment to harvest recommendations at the stock assessment level. However, there are situations where socioeconomic data used in conjunction with data on the population could aid in optimizing future harvest levels. Specifically, integrating data on the size- and age-structure of a population with economic value and considerations of catch and market stability could lead to a considerably different estimate of optimum yield than strictly a maximum ABC calculation.

For the 2018 and 2019 ABC recommendations, we consider all three of these types of uncertainty at some level to recommend a considerably lower ABC than the maximum allowed by the reference model.

Data and model uncertainty

We consider the estimate of the 2014 year class to be the most pertinent uncertainty to consider for the immediate recommendations of harvest levels. With only one observation of the 2014 year class as 2-year-olds in the 2016 longline survey age composition, this estimate is 10x larger than average recruitment and 2.5x larger than the previous highest year class (1977). The presence of 2-year-olds in the age compositions has always been positively correlated with eventual year-class strength. However, it has not always been indicative of the magnitude (Figure 3.50). For example, the 2008 year class showed up strongly as 2-year-olds, but has been now determined to be an average year class. Conversely the 1997 and 2000 year classes were not substantial components of the age composition as 2-year-olds in 1999 or 2002, but they eventually were estimated to be the largest year classes since our time-series of longline survey age compositions began. The strongest (but still not that strong) relationship between 2-year olds and eventual recruitment occurs when 2-year-olds are high in the Western GOA portion of the survey (Figure 3.51). The presence of 3-year-olds in the age composition was not much better of a predictor of eventual recruitment than 2-year-olds Alaska-wide (Figure 3.52). However, the strongest evidence of a good year class was the presence of 3-year-olds in the Eastern GOA (Figure 3.53).

In the assessment model, estimated recruitments are less dependent on the length compositions of the longline and GOA trawl surveys than on the longline survey age compositions. Since we have length compositions a year earlier than the age compositions we examine them for signals of recruitment, but they contribute less to informing recruitment estimates than age compositions. Thus, the model does not estimate recruitment before there are age compositions available. Parallel to the analysis shown above comparing prevalence of young fish in age compositions, we show a similar analysis using length data for presence of small fish in the GOA trawl survey (otoliths are not aged from that survey).

Examining the length compositions for a select group of trawl survey years shows that 2015 and 2017 survey catches were dominated by young fish (Figure 3.54). The 2007 survey shows what the size composition looks like in the absence of any recent large recruitments. The 2001 survey shows the presence of a large group of 1-year-olds (Figure 3.55), but larger fish were much more abundant at that time. The 2017 size composition appears to show the presence of several strong modes of fish that appear younger than the 2014 year class, but a very low proportion of large fish.

The proportion of 1-year-olds in the trawl survey lengths do not always predict a strong year class as more data are collected. We examined recruitment strength compared to the presence of 1 year olds (<32 cm) in the Gulf of Alaska trawl survey from 1984-2017 (Figure 3.56). When compared to the recruitments aligned with those respective surveys that would have detected them, only the 2001 survey detected one year olds at a high level when there was a large year class. Recently, the 2015 and 2017 trawl surveys appear to be showing very strong presence of 1-year-olds (Figure 3.56). However, because trawl survey lengths have not always previously been related to strong recruitment classes, we are unsure how to interpret the large number of age-1 fish in 2015 and 2017.

It is useful to examine the initial size of recruitments and how those estimates changed over time (Figure 3.57). This is an expanded analysis from Figure 3.45 that runs the retrospective analysis back to 2000 so that we can track the progress of estimates of the large 1997 and 2000 year classes over time. These large year classes both follow a similar pattern of appearing to be very large for several years after the first estimation and then dropping off after they have been observed in the age comps for several years, although still remaining above average. This could be related to time-invariant selectivity or an unmodeled age-dependent mortality process.

Finally, it's important to consider the risk to the stock if some unknown process has led to an incorrect estimate of the 2014 year class. If the 2014 estimate of recruitment turns out to be just average, but we were to take catches equal to the maximum ABCs that the model is projecting, future spawning biomass would reach very low levels (Figure 3.58). As an alternative projection, we set the 2014 year class equivalent to the 1977 year class which was the previous highest recruitment in the current recruitment regime (its value is 40% of the 2014 estimate). This alternative projection results in a much steadier forecast of spawning biomass and an earlier return to the $B_{35\%}$ level. This pattern suggests multiple above average recruitment years are needed to stabilize population trends compared to single large recruitment events.

Ecosystem uncertainty

There are concerns about increased variability and predictability of the ecosystem. For example, recent stock assessment estimates of GOA Pacific cod showed an enormous 2012 year class, which seems to have declined severely based on the 2017 GOA bottom trawl survey results. This severe decline could have been related to unforeseen environmental factors. A similar phenomenon could happen for sablefish because both larval, juvenile, and adult sablefish are well known to be sensitive to ocean temperature for both optimal growth and reproduction (e.g., Sogard and Olla 1998, Appendix 3C). While the SAFE continues to include the standard ***Ecosystem Considerations*** section, a new Ecosystem and Socioeconomic Profile (ESP) highlights specific ecosystem indicators that may help explain variability in the stock assessment, particularly recruitment (Appendix 3C). This compilation of process studies and surveys at smaller scales can help give preliminary hints on future stock productivity. For example, samples of body composition in young-of-the-year sablefish might be useful in predicting overwintering success. See Appendix 3C for more details on the current conditions of the ecosystem with respect to sablefish.

Socioeconomic uncertainty

Finally, the economic performance report (Appendix 3C) shows that sablefish ex-vessel value (per pound) has been increasing as the ABC and total catch has dropped. This was likely a result of a combination of the strength of the U.S. dollar and supply and demand. With the emergence of the 2014 year class and numerous small fish in the population, the current size-structure of the population is skewed towards smaller fish. Since sablefish value is size dependent and large fish are worth more, harvesting these smaller fish will not yield as high of a market value when compared to allowing more of the year class to grow several more years (Figure 2 in Appendix 3C). A combination of a much larger catch because of a large increase in ABC that consisted of a high proportion of four-year-old fish would likely result in poor market conditions and reduced profits (Appendix 3C).

Summary of considerations

In summary, while there are clearly positive signs of strong incoming recruitment, there are concerns regarding the lack of older fish and spawning biomass, the uncertainty surrounding the estimate of the strength of the 2014 year class, and the uncertainty about the environmental conditions that may affect the success of the 2014 year class. These concerns warrant additional caution when recommending the 2018 and 2019 ABCs. It is unlikely that the 2014 year class will be average or below average, but projecting catches under the assumption that it is 10x average introduces risk knowing the uncertainty associated with this estimate. Only one large year class since 1999 has been observed, and there is only one observation of age compositions to support the magnitude of the 2014 year class. Future surveys will help determine the magnitude of the 2014 year class and will help detect if there are additional incoming large year classes other than the 2014 year class.

Projections that consider harvesting at the maximum ABC for the next two years, if the 2014 year class is actually average, results in future spawning biomass projections that are very low, where depensation (reduced productivity at low stock sizes) could occur. Recommending an ABC lower than the maximum should result in more of the 2014 year class reaching spawning biomass and achieving higher economic value. Because of these additional considerations, we assume that the recent recruitment is equal to the previous highest recruitment event in the current regime for projections (1977, which is still 4x average.) This results in more precautionary ABC recommendations to buffer for uncertainty until more observations of this potentially large year class are made. Because sablefish is an annual assessment, we will be able to consider another year of age compositions in 2018 and adjust our strategy accordingly.

Acceptable biological catch recommendation

Instead of maximum permissible ABC, we recommend a 2018 ABC of 14,957 t, which is 14% higher than the 2017 ABC. The maximum permissible ABC for 2018 is 89% higher than the 2017 ABC of 13,809 t. The 2016 assessment projected a 1% increase in ABC for 2018 from 2017. The author recommended ABCs for 2018 and 2019 are lower than maximum permissible ABC for two important reasons. First, the 2014 year class is estimated to be 2.5 times higher than any other year class observed in the current recruitment regime. Tier 3 stocks have no explicit method to incorporate the uncertainty of this new year class into harvest recommendations. To buffer against some of the uncertainty about the 2014 year class, we assume that it's value is equal to the previous highest recruitment event in the current regime for projections (1977, which is still 4x average.) For further explanation and rationale for this approach see section **Additional ABC/ACL considerations**.

We also recommend a lower ABC than maximum permissible based on estimates of whale depredation occurring in the fishery in the same way that recommended and accepted for the 2017 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 14% higher than the 2017 ABC. The methods and calculations are described in the **Accounting for whale depredation** section.

Survey trends support this moderate increase in ABC relative to last year. There was a substantial increase in the domestic longline survey index time series in the last two years, and a large increase in the GOA bottom trawl survey. These increases offset the continued decline of the fishery abundance index seen in 2016. 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 2015 estimate in 2016, up 5% from 2015. The 2008 year class showed potential to be large in previous assessments based on patterns in the AFSC survey age and length compositions; this year class is now estimated to be about 13% above average. There were preliminary indications of a large incoming 2014 year class, which were evident in the 2016 longline survey length compositions and now are extremely dominant in the 2016 age compositions. This year class appears to be very strong, but year classes have sometimes failed to materialize later and the estimate of this year class is uncertain.

Including the full recruitment estimated for 2014 causes spawning biomass to be projected to climb rapidly through 2022, and then is expected to rapidly decrease assuming a return to average recruitment after 2014. Maximum permissible ABCs are projected to rapidly increase while authors recommended lower ABCs will still increase quickly to 21,648 t in 2019 and 25,836 t in 2020 (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 were weighted twice as much as the fishery data.

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 3.60A). 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 3.60B). These large annual changes in apportionment result in increased variability of ABCs by area, including areas other than the Bering Sea (Figure 3.60C). 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. In addition, there were no data from the observer program in 2017 for fishery CPUE, and only logbook data were available. 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 three-area spatial model which was developed for research into spatial biomass (see **Movement** section) and apportionment showed different regional biomass estimates than the status quo and 'fixed' apportionment methods which have been used in the past several years for apportionment of ABC to sablefish IFQ holders. Because of the higher proportion of biomass estimated in the Western area (Bering Sea, Aleutian Islands, and Western Gulf of Alaska), using the spatial model biomass for apportionment would have resulted in greater apportionment to the western areas in 2015, compared to the recent 'fixed' apportionment ratios or the traditional exponentially weighted moving average method. Further research on alternative apportionment methods and the tradeoffs is underway. 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 2018, we recommend continuing with the apportionment fixed at the proportions used in 2017.**

Apportionment Table (before whale depredation adjustments)

Area	2017 ABC	Standard apportionment for 2018 ABC	Recommended fixed apportionment for 2018 ABC*	Difference from 2017
Total	13,509	15,380	**15,380**	14%
Bering Sea	1,318	2,686	**1,501**	14%
Aleutians	1,783	2,225	**2,030**	14%
Gulf of Alaska (subtotal)	10,408	10,469	**11,849**	14%
Western	1,457	1,533	**1,659**	14%
Central	4,608	4,201	**5,246**	14%
W. Yakutat**	1,550	1,765	**1,765**	14%
E. Yak. / Southeast**	2,793	2,970	**3,179**	14%

* Fixed at the 2013 assessment apportionment proportions (Hanselman et al. 2012b). ** 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 and adjusting for projected whale depredation results in a value of 29,507 t for the combined stock. The OFL is apportioned by region, Bering Sea (2,887 t), AI (3,917 t), and GOA (22,703 t), by the same method as the ABC apportionment.

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 Ecosystem-Socioeconomic Profile (ESP). This approach utilizes pre-existing data collected through national initiatives to generate an ecosystem baseline of information for Alaska sablefish. A baseline ESP 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). This year the ESP for sablefish is completed and attached as Appendix 3C.

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, such as euphausiids, shrimp, and cephalopods (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 items are also 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 2017 were below the 2012-2017 average, while BSAI golden king crab catches were higher in 2017 than the 2012-2017 average (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.

Economic performance

This year the economic performance report is included in the ESP (Appendix 3C). 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 $99 million in 2016.

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) Re-examine selectivity assumptions, particularly the GOA trawl survey
5) Continue to explore the use of environmental data to aid in determining recruitment.
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.

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Tables

Table 3.1. Alaska sablefish catch (t). The values include landed catch and discard estimates. Discards were estimated for U.S. fisheries before 1993 by multiplying reported catch by 2.9% for fixed gear and 26.9% for trawl gear (1994-1997 averages) because discard estimates were unavailable. Eastern includes West Yakutat and East Yakutat / Southeast. 2017 catches are as of October 1, 2017 (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	11,931	753	1,047	1,354	4,508	4,269	1,578	2,690	0	10,927	1,004
2011	12,978	707	1,026	1,400	4,924	4,921	1,897	3,024	0	11,799	1,179
2012	13,869	743	1,205	1,353	5,329	5,238	2,033	3,205	0	12,767	1,102
2013	13,645	634	1,063	1,384	5,211	5,352	2,105	3,247	0	12,607	1,037
2014	11,588	314	821	1,202	4,756	4,495	1,673	2,822	0	10,562	1,025
2015	10,973	211	431	1,014	4,647	4,670	1,840	2,829	0	9,888	1,085
2016	10,257	532	349	1,058	4,198	4,120	1,656	2,463	0	8,919	1,338
2017	10,670	1,110	470	963	4,082	4,044	1,606	2,438	0	8,712	1,958

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991-2017. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages. Catch as of October 1, 2017 (www.akfin.org).

Aleutian Islands				
Year	Pot	Trawl	Longline	Total
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	914	1,047
2011	141	47	838	1,026
2012	77	148	979	1,205
2013	87	58	918	1,063
2014	160	26	635	821
2015	12	15	403	431
2016	21	30	298	349
2017	209	86	176	470
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	257	707
2012	432	93	218	743
2013	352	133	149	634
2014	164	34	115	314
2015	108	17	86	211
2016	158	257	116	532
2017	336	677	97	1,110

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	11,931	21,400	15,230	15,230	
2011	12,978	20,700	16,040	16,040	
2012	13,869	20,400	17,240	17,240	
2013	13,645	19,180	16,230	16,230	
2014	11,588	16,225	13,722	13,722	
2015	10,973	16,128	13,657	13,657	NPFMC passes Amendment 101 to allow pot fishing in the GOA
2016	10,257	13,397	11,795	11,795	Whale depredation accounted for in survey and fishery
2017	10,670	15,428	13,083	13,083	Pot fishing begins in the GOA

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 2010-2017. Source: NMFS Alaska Regional Office via AKFIN, October 1, 2017.

		BSAI			GOA			Combined		
Year	Gear	Discard	%Discard	Catch	Discard	%Discard	Catch	Discard	%Discard	Catch
2010	H&L	37	3.08%	1,187	371	4.02%	9,231	408	3.92%	10,418
	Other	5	0.88%	613	47	5.27%	900	53	3.49%	1,514
	Total	42	2.33%	1,800	419	4.13%	10,131	461	3.86%	11,931
2011	H&L	21	1.89%	1,096	396	3.90%	10,148	417	3.71%	11,243
	Other	8	1.31%	638	179	16.33%	1,097	187	10.81%	1,735
	Total	29	1.67%	1,733	575	5.12%	11,245	604	4.66%	12,978
2012	H&L	13	1.10%	1,197	253	2.29%	11,060	266	2.17%	12,257
	Other	13	1.67%	751	65	7.52%	861	77	4.80%	1,612
	Total	26	1.32%	1,948	318	2.67%	11,921	344	2.48%	13,869
2013	H&L	28	2.62%	1,067	598	5.39%	11,101	626	5.15%	12,168
	Other	4	0.59%	630	48	5.62%	846	51	3.47%	1,476
	Total	32	1.86%	1,697	646	5.41%	11,947	678	4.97%	13,645
2014	H&L	40	5.29%	750	441	4.65%	9,486	480	4.69%	10,236
	Other	1	0.34%	385	78	8.10%	967	80	5.89%	1,351
	Total	41	3.61%	1,135	519	4.97%	10,453	560	4.83%	11,588
2015	H&L	14	2.93%	489	593	6.40%	9,277	608	6.22%	9,766
	Other	5	3.48%	153	184	17.43%	1,054	189	15.67%	1,207
	Total	20	3.06%	642	777	7.52%	10,331	797	7.26%	10,972
2016	H&L	77	18.54%	415	653	7.85%	8,316	730	8.36%	8,731
	Other	9	1.86%	466	191	17.98%	1,060	199	13.05%	1,526
	Total	86	9.71%	881	843	8.99%	9,376	929	9.06%	10,257
2017	H&L	47	17.23%	273	431	5.97%	7,215	478	6.38%	7,488
	Other	173	13.21%	1,307	335	17.87%	1,875	508	15.96%	3,183
	Total	220	13.90%	1,580	766	8.43%	9,090	986	9.24%	10,670
2010-2017	H&L	35	4.27%	809	467	4.93%	9,479	502	4.88%	10,288
Mean	Other	27	4.41%	618	141	13.01%	1,083	168	9.88%	1,700
	Total	62	4.33%	1,427	608	5.76%	10,562	670	5.59%	11,989

Table 3.5. Bycatch (t) of FMP Groundfish species in the targeted sablefish fishery averaged from 2012-2017. Other = Pot and trawl combined because of confidentiality. Source: AKFIN, October 1, 2017

	Hook and Line			Other Gear			All Gear		
Species	Discard	Retained	Total	Discard	Retained	Total	Discard	Retained	Total
GOA Thornyhead Rockfish	219	451	670	6	24	31	225	476	701
Shark	454	1	454	0	0	0	454	1	455
GOA Shortraker Rockfish	159	100	259	10	1	12	169	102	271
Arrowtooth Flounder	156	14	170	64	11	74	220	25	244
GOA Skate, Other	192	2	194	1	0	1	193	2	195
GOA Skate, Longnose	182	12	194	0	0	0	183	12	194
GOA Rougheye Rockfish	84	83	168	1	2	3	85	85	170
Other Rockfish	63	68	131	1	1	2	63	69	132
Pacific Cod	64	37	100	0	3	4	64	40	104
BSAI Skate	51	1	52	0	0	0	51	1	52
GOA Deep Water Flatfish	14	0	14	22	7	29	35	8	43
Greenland Turbot	19	12	31	3	1	3	22	13	35
BSAI Kamchatka Flounder	16	2	17	2	4	6	18	5	23
Pollock	2	0	2	9	6	15	12	6	18
Sculpin	15	0	15	0	0	0	16	0	16
BSAI Other Flatfish	6	0	6	1	9	9	7	9	15
GOA Demersal Shelf Rockfish	1	10	11	0	0	0	1	10	11
BSAI Shortraker Rockfish	6	3	9	0	0	0	7	3	10
GOA Skate, Big	8	1	8	0	0	0	8	1	8
Pacific Ocean Perch	2	0	2	1	5	5	3	5	8
GOA Rex Sole	0	0	0	6	1	7	6	1	7
Octopus	6	0	6	1	0	1	6	0	6
GOA Shallow Water Flatfish	4	0	4	0	1	1	4	1	5

Table 3.6. Bycatch of nontarget species and HAPC biota in the targeted sablefish fishery. Source: NMFS AKRO Blend/Catch Accounting System via AKFIN, October 1, 2017.

	Estimated Catch (mt)						
Group Name	2011	2012	2013	2014	2015	2016	2017
Benthic urochordata	0.13	1.24	0	0	0.49	0	1.03
Brittle star unidentified	0.47	4.65	0.10	0.67	2.09	0.34	0.52
Corals Bryozoans	5.65	7.64	12.67	5.15	4.51	5.97	1.43
Eelpouts	0.64	0.63	1.13	0.79	0.24	1.08	3.29
Grenadiers	8,464	8,555	11,523	5,985	5,805	7,402	5,081
Invertebrate unidentified	2.26	7.72	0.18	0.11	0.55	0.21	0.10
Large sculpins	0	5.16	0	0	0	0	0
Misc crabs	5.51	0.33	5.84	6.39	3.50	4.87	3.92
Misc fish	8.81	10.93	31.43	27.44	17.62	16.01	15.61
Scypho jellies	0.68	0.00	0.00	5.50	0.24	0.18	0.02
Sea anemone unidentified	3.53	1.02	0.95	3.10	14.25	1.79	1.57
Sea pens whips	1.66	0.28	0.36	2.26	2.86	1.29	0.96
Sea star	3.74	3.11	15.76	11.47	9.68	9.02	18.02
Snails	19.68	12.16	8.83	3.68	3.37	0.18	2.37
Sponge unidentified	2.14	0.97	3.39	1.67	3.48	0.50	0.68
State-managed Rockfish	0	0	0.14	0.12	0.09	0.22	0.67
Urchins, dollars, cucumbers	0.26	0.79	0.87	0.79	2.49	0.22	0.18

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, October 1, 2017.

	Year	Bairdi	Chinook	Golden KC	Halibut	Other salmon	Opilio	Red KC
BSAI								
Hook and Line	2012	5	4	286	35	0	6	43
	2013	0	0	17,055	11	0	121	0
	2014	365	0	858	20	0	314	0
	2015	0	0	3,572	7	0	1,689	0
	2016	0	0	29,032	1	0	26	0
	2017	142	0	11,697	6	0	14	18
	Mean	565	0	15,789	14	0	351	62
Other	2012	179	0	13,000	10	0	419	13
	2013	183	4	13,287	45	0	425	56
	2014	5	4	286	35	0	6	43
	2015	0	0	17,055	11	0	121	0
	2016	365	0	858	20	0	314	0
	2017	0	0	3,572	7	0	1,689	0
	Mean	0	0	29,032	1	0	26	0
BSAI Mean		183	4	13,287	45	0	425	56
GOA								
Hook and Line	2012	0	0	23	602	0	0	0
	2013	82	0	93	272	0	0	21
	2014	6	0	39	250	0	0	0
	2015	164	0	38	292	0	0	12
	2016	0	0	39	277	0	0	0
	2017	25	0	72	301	0	0	0
	Mean	46	0	51	333	0	0	6
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	2	0	47	11	0	0	0
	2017	162	0	0	10	0	0	0
	Mean	5	0	15	6	2	0	0
GOA Mean		78	0	63	340	2	0	6

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	3,472			2,320	20,056		52,110		1,190	1,176
2016				1,630	12,857		63,232		1,197	1,176
2017	4,157						71,202			

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. NA indicates that there was no data.

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
2016	C	C	C	184	2	2016	NA				

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
2016	0.21	0.02	0.09	251	15		2016	0.44	0.03	0.06	732	55

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
2016	0.76	0.07	0.09	140	25	2016	0.66	0.05	0.08	228	46

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
2016	0.22	0.04	0.16	269	5

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
2016	0.16	0.02	0.15	270	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
2016	0.29	0.03	0.11	936	29

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
2016	0.37	0.03	0.08	2313	72

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
2016	0.48	0.03	0.06	2094	77	2016	0.63	0.03	0.05	846	80

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, 2015, and 2017, and Bering Sea 1979-1981, 1995, 1996, 1998, 2000, 2002, 2004, 2006, 2008, 2009, 2010, 2012, 2014, and 2016. 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	641		1,454	2,147	1,201	214
1991	386	578		1,321	2,054	1,066	
1992	402	498		1,390	1,749	908	
1993	395	549		1,318	1,894	904	250
1994	366	476		1,288	1,879	822	
1995		487			1,803	1,243	
1996		507			2,004	1,201	145
1997		477			1,753	1,341	
1998		474			1,694	1,130	
1999		526			1,766	1,326	104
2000		456			1,602	1,139	
2001		535			1,806	1,118	238
2002		550			1,925	1,143	
2003		516			1,759	1,219	189
2004		540			1,664	1,360	
2005		541			1,624	1,313	179
2006		569			1,863	1,216	
2007		508			1,582	1,281	111
2008		461			1,550	1,380	
2009		414			1,606	1,132	107
2010		458			1,778	1,065	
2011		555			1,683	1,056	84
2012		444			1,280	1,034	
2013		420			1,276	908	60
2014		484			1,432	969	
2015		385			1,169	848	67
2016		494			1,389	656	
2017		561			1,400		119

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
2017	0	11			1	2	4	0	3	0	9	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 killer and sperm whale depredation on the longline fishery based on modeled observer data (Peterson and Hanselman 2017).

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	4.7	1	13	297	248	385	138	115	181
1978	5.7	1	15	271	226	351	126	104	166
1979	83.9	62	119	330	275	428	120	99	157
1980	25.7	5	47	364	302	466	115	95	149
1981	11.3	1	33	384	320	487	114	94	146
1982	40.4	18	69	422	356	537	118	98	150
1983	24.8	6	48	450	380	565	130	109	164
1984	43.1	31	61	492	417	614	147	124	184
1985	2.5	0	8	497	424	614	162	137	202
1986	19.3	9	31	504	433	621	176	150	217
1987	18.8	11	29	491	423	604	182	155	224
1988	3.7	1	9	455	392	562	181	154	225
1989	4.7	1	9	410	352	507	174	146	217
1990	7.1	4	12	367	314	457	164	136	205
1991	26.7	19	36	348	296	434	151	125	190
1992	1.4	0	4	318	269	396	139	115	175
1993	23.9	18	32	310	262	387	128	105	161
1994	4.5	1	9	289	244	360	116	95	146
1995	5.4	1	10	268	227	334	108	88	136
1996	7.8	5	12	251	211	312	102	83	129
1997	16.8	13	23	244	206	305	98	81	124
1998	2.5	0	5	231	195	287	95	78	120
1999	30.3	24	41	242	204	301	91	75	114
2000	16.7	10	26	249	210	310	87	72	109
2001	10.9	3	20	249	210	310	84	70	105
2002	41.8	32	58	278	234	348	83	69	104
2003	6.7	2	12	284	238	353	85	71	106
2004	12.9	8	19	287	240	358	88	73	111
2005	6.3	4	10	279	233	349	92	76	116
2006	11.0	7	16	273	228	341	97	81	122
2007	8.1	5	12	263	219	329	101	84	127
2008	8.7	5	13	252	210	315	102	85	128
2009	8.3	5	12	242	202	301	101	84	126
2010	18.8	14	26	243	202	302	98	81	123
2011	5.5	2	9	236	197	294	95	79	119
2012	9.5	6	14	230	192	286	92	77	114
2013	1.0	0	3	215	179	268	88	73	110
2014	8.4	5	12	204	169	255	86	71	107
2015	14.9	10	22	202	167	252	84	69	105
2016	214.4	156	291	392	312	500	81	67	102
2017	16.7	9	45	476	372	603	81	67	101
2018	16.7	9	45	540	407	674	89	71	107
2019	16.7	9	45	575	439	711	113	90	136

Table 3.15. Regional estimates of sablefish total biomass (Age 2+, kilotons). Partitioning was done using RPWs from Japanese LL survey from 1979-1989 and domestic LL survey from 1990-2017 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
1978	50	61	26	73	24	37	271
1979	62	68	31	98	28	43	330
1980	66	86	35	97	31	48	364
1981	69	96	41	85	36	59	384
1982	77	88	54	102	41	61	422
1983	81	94	70	114	37	54	450
1984	92	114	78	118	35	54	492
1985	102	113	71	123	37	50	497
1986	108	106	68	126	43	53	504
1987	80	107	65	131	49	60	491
1988	48	93	61	147	47	60	455
1989	55	80	48	131	43	53	410
1990	56	60	39	113	43	56	367
1991	38	41	37	109	46	76	348
1992	23	36	25	100	50	84	318
1993	15	34	28	102	53	78	310
1994	17	33	31	95	44	67	289
1995	25	31	27	87	38	60	268
1996	24	26	27	90	32	51	251
1997	23	23	26	95	30	48	244
1998	20	29	26	81	27	48	231
1999	20	40	28	80	26	49	242
2000	19	41	32	83	25	48	249
2001	27	39	39	78	21	44	249
2002	38	43	41	90	23	43	278
2003	38	43	40	96	25	41	284
2004	38	44	36	102	26	41	287
2005	40	42	36	91	25	45	279
2006	43	38	38	82	25	46	273
2007	46	33	28	81	28	46	263
2008	48	32	25	79	24	43	252
2009	46	31	28	76	21	39	242
2010	48	27	25	71	27	45	243
2011	31	24	24	83	30	44	236
2012	13	29	27	92	26	44	230
2013	28	30	22	72	20	43	215
2014	43	26	22	58	18	38	204
2015	35	27	22	58	22	38	202
2016	47	69	43	113	51	69	392
2017	59	99	56	136	55	71	476

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
$q_{domesticLL}$	7.77	7.71	7.72	0.35	0.76	6.25	9.18
q_{coopLL}	5.89	5.82	5.82	0.31	0.57	4.69	6.91
q_{trawl}	1.24	1.24	1.23	0.68	0.15	0.94	1.56
$F_{40\%}$	0.10	0.10	0.10	0.024	0.007	0.09	0.11
2018 SSB (kt)	88.9	90.4	89.5	5.92	9.54	73.4	112
2000 Year Class	44.5	43.5	43.0	3.84	6.51	31.6	58.2
2014 Year Class	214.4	215.3	212.2	34.81	34.73	156.8	291.5

Table 3.17. Comparison of 2016 results versus 2017 results. Biomass is in kilotons.

	2016 SAFE	**2017 SAFE**		**2016 SAFE**	**2017 SAFE**	
Year	Spawning Biomass	Spawning Biomass	Difference (%)	Total Biomass	Total Biomass	Difference (%)
1977	143	138	-3%	307	297	-3%
1978	130	126	-3%	281	271	-4%
1979	124	120	-3%	340	330	-3%
1980	119	115	-4%	373	364	-3%
1981	117	114	-3%	395	384	-3%
1982	121	118	-3%	433	422	-2%
1983	134	130	-3%	461	450	-2%
1984	150	147	-2%	503	492	-2%
1985	165	162	-2%	508	497	-2%
1986	179	176	-2%	514	504	-2%
1987	184	182	-1%	502	491	-2%
1988	183	181	-1%	466	455	-2%
1989	175	174	-1%	421	410	-3%
1990	165	164	-1%	378	367	-3%
1991	152	151	0%	358	348	-3%
1992	140	139	-1%	328	318	-3%
1993	128	128	0%	321	310	-3%
1994	117	116	-1%	299	289	-3%
1995	109	108	-1%	279	268	-4%
1996	104	102	-2%	261	251	-4%
1997	100	98	-2%	256	244	-5%
1998	97	95	-2%	242	231	-5%
1999	94	91	-3%	255	242	-5%
2000	90	87	-3%	262	249	-5%
2001	87	84	-4%	264	249	-6%
2002	87	83	-5%	296	278	-6%
2003	89	85	-5%	302	284	-6%
2004	93	88	-5%	307	287	-7%
2005	98	92	-6%	301	279	-7%
2006	105	97	-7%	295	273	-8%
2007	110	101	-8%	286	263	-8%
2008	111	102	-8%	276	252	-9%
2009	110	101	-9%	267	242	-9%
2010	108	98	-9%	269	243	-10%
2011	106	95	-10%	263	236	-10%
2012	103	92	-11%	258	230	-11%
2013	100	88	-12%	243	215	-12%
2014	98	86	-13%	232	204	-12%
2015	97	84	-14%	231	202	-13%
2016	94	81	-13%	232	392	69%
2017		81			476	

Table 3.18. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for seven harvest scenarios. Abundance projected using 1979-2015 recruitments. Author's F scenario fixes the 2014 year class at the 1977 recruitment level.

Year	Maximum permissible F	Author's F* (specified catch)	Half max. F	5-year average F	No fishing	Overfished?	Approaching overfished?
			Spawning biomass (kt)				
2017	81.0	78.9	81.0	81.0	81.0	81.0	81.0
2018	88.9	79.9	88.9	88.9	88.9	88.9	88.9
2019	111.0	88.2	114.7	112.0	118.7	109.6	111.0
2020	145.7	102.6	156.4	149.8	168.9	141.7	145.7
2021	178.4	115.3	199.3	187.1	225.3	170.8	175.4
2022	196.2	123.0	227.9	209.8	269.8	184.9	189.7
2023	199.4	125.6	239.8	217.1	297.3	185.1	189.7
2024	193.9	125.0	240.6	214.7	311.8	177.6	181.7
2025	184.7	122.8	234.9	207.6	318.1	167.1	170.6
2026	174.3	120.1	227.4	198.6	319.5	156.1	159.1
2027	164.1	117.3	220.3	189.2	318.1	145.6	148.2
2028	154.7	114.7	213.4	180.2	314.9	136.2	138.4
2029	146.3	112.5	206.2	171.8	311.0	128.1	129.9
2030	139.0	110.6	198.5	164.4	306.6	121.1	122.6
			Fishing mortality				
2017	0.066	0.075	0.066	0.066	0.066	0.066	0.066
2018	0.086	0.066	0.043	0.074	-	0.102	0.102
2019	0.096	0.073	0.048	0.074	-	0.114	0.114
2020	0.096	0.096	0.048	0.074	-	0.114	0.114
2021	0.096	0.096	0.048	0.074	-	0.114	0.114
2022	0.096	0.096	0.048	0.074	-	0.114	0.114
2023	0.096	0.096	0.048	0.074	-	0.114	0.114
2024	0.096	0.096	0.048	0.074	-	0.114	0.114
2025	0.096	0.096	0.048	0.074	-	0.114	0.114
2026	0.096	0.095	0.048	0.074	-	0.114	0.114
2027	0.096	0.094	0.048	0.074	-	0.114	0.114
2028	0.096	0.093	0.048	0.074	-	0.114	0.114
2029	0.096	0.092	0.048	0.074	-	0.114	0.114
2030	0.096	0.092	0.048	0.074	-	0.112	0.112
			Yield (kt)				
2017	11.6	11.6	11.6	11.6	11.6	11.6	11.6
2018	25.6	15.4	13.0	22.1	-	30.2	25.6
2019	41.0	21.6	21.5	32.3	-	47.9	41.0
2020	43.3	25.9	23.6	34.7	-	49.8	51.0
2021	42.0	25.7	23.8	34.3	-	47.5	48.6
2022	39.6	25.2	23.3	32.9	-	44.2	45.2
2023	37.0	24.5	22.5	31.2	-	40.8	41.6
2024	34.4	23.8	21.6	29.5	-	37.6	38.3
2025	32.1	23.1	20.7	27.8	-	34.7	35.3
2026	30.0	22.4	19.8	26.2	-	32.2	32.7
2027	28.2	21.7	19.0	24.9	-	30.2	30.5
2028	26.8	21.1	18.3	23.7	-	28.5	28.8
2029	25.5	20.7	17.6	22.7	-	27.1	27.3
2030	24.5	20.3	17.1	21.9	-	25.8	26.0

* Projections in Author's F (Alternative 2) are based on estimated catches of 13,329 t and 18,461 t used in place of maximum permissible ABC for 2018 and 2019. 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

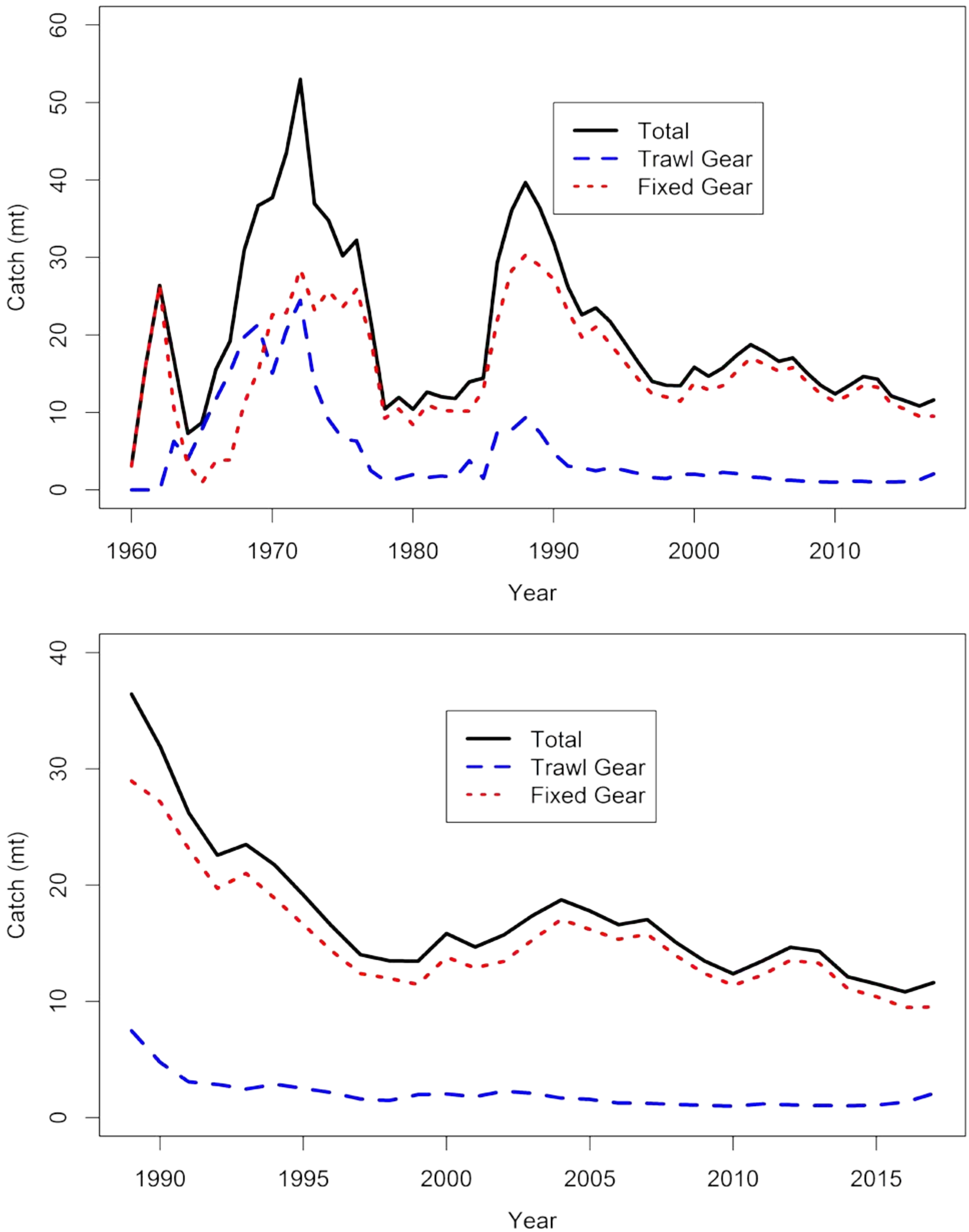


Figure 3.1. Long term and short term sablefish catch by gear type.

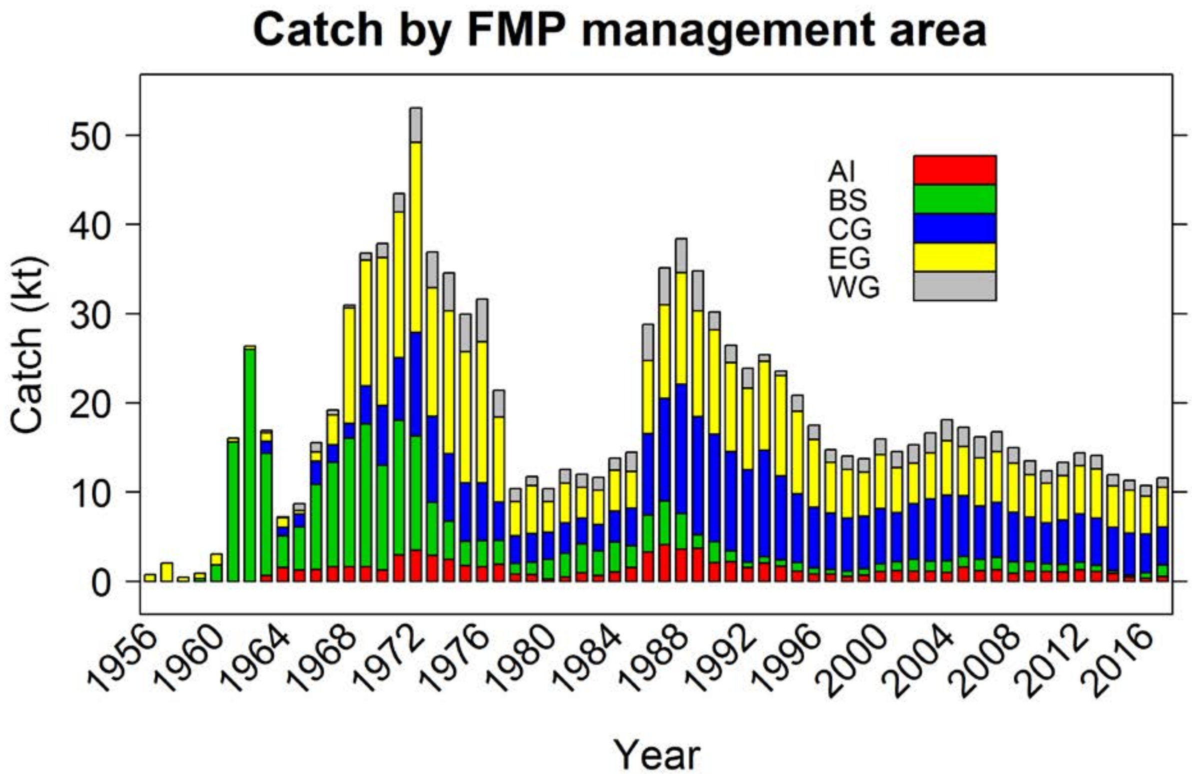


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

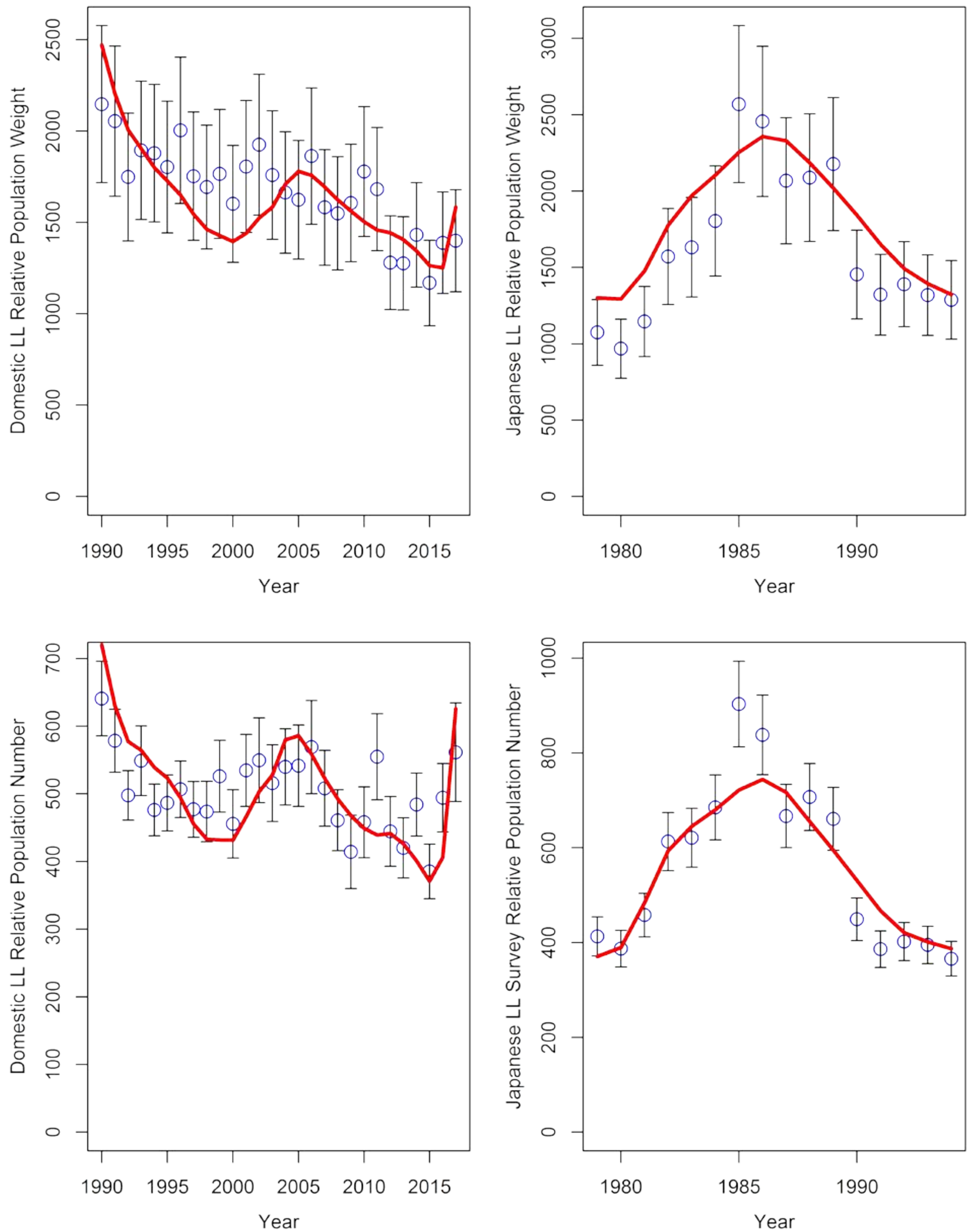


Figure 3.3. Observed and predicted sablefish relative population weight and numbers versus year. Points are observed estimates with approximate 95% confidence intervals. Solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

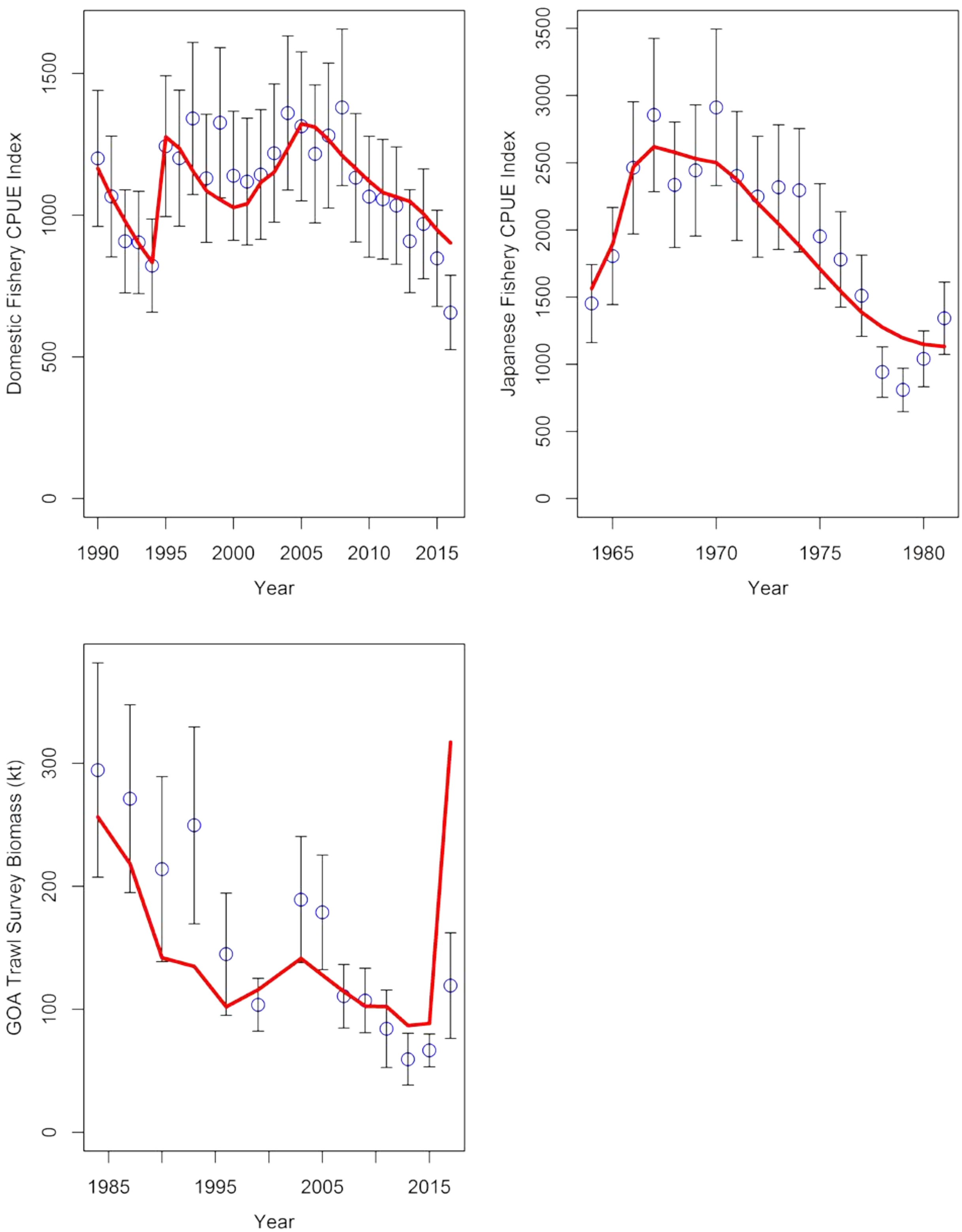


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while solid red lines are model predictions.

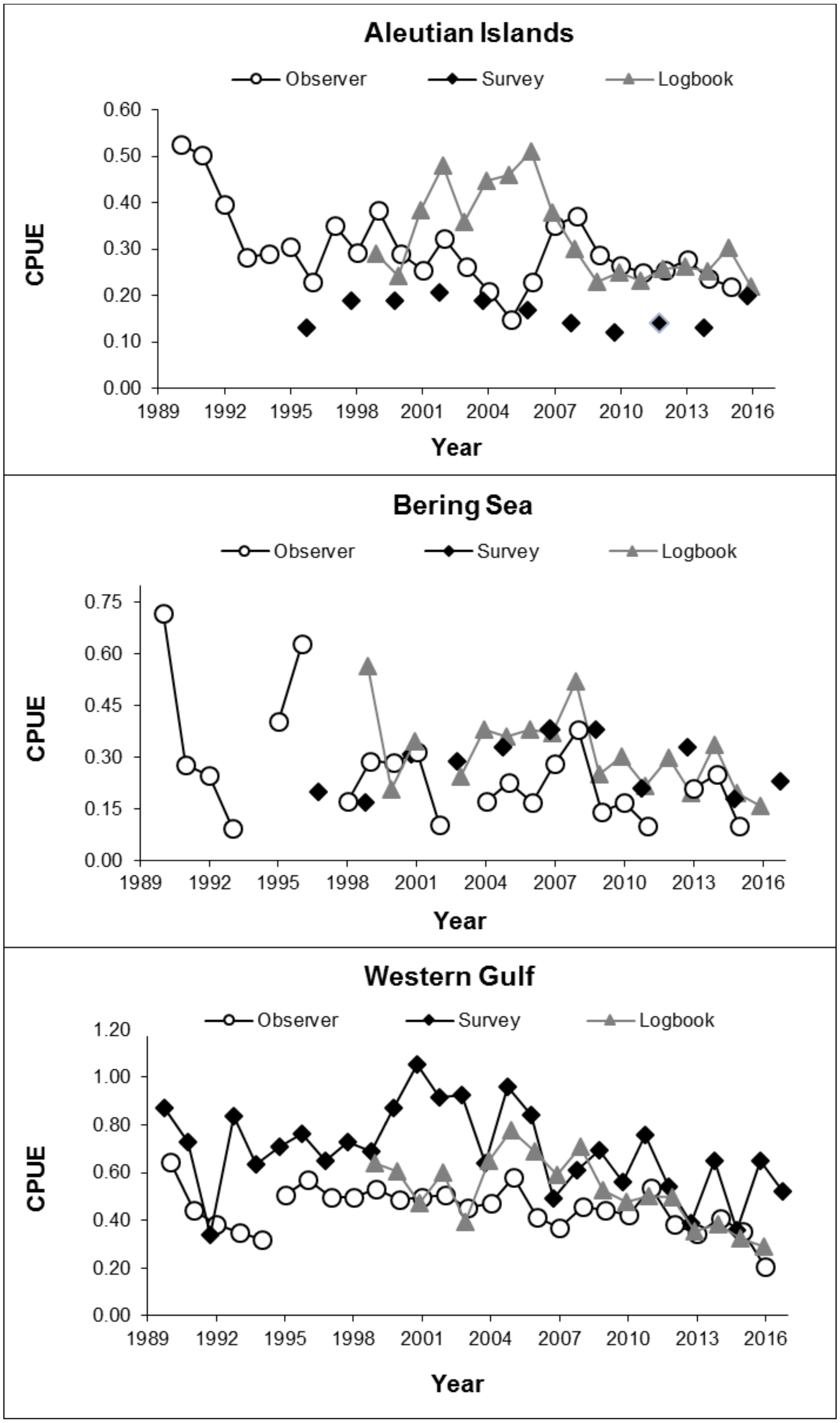


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in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

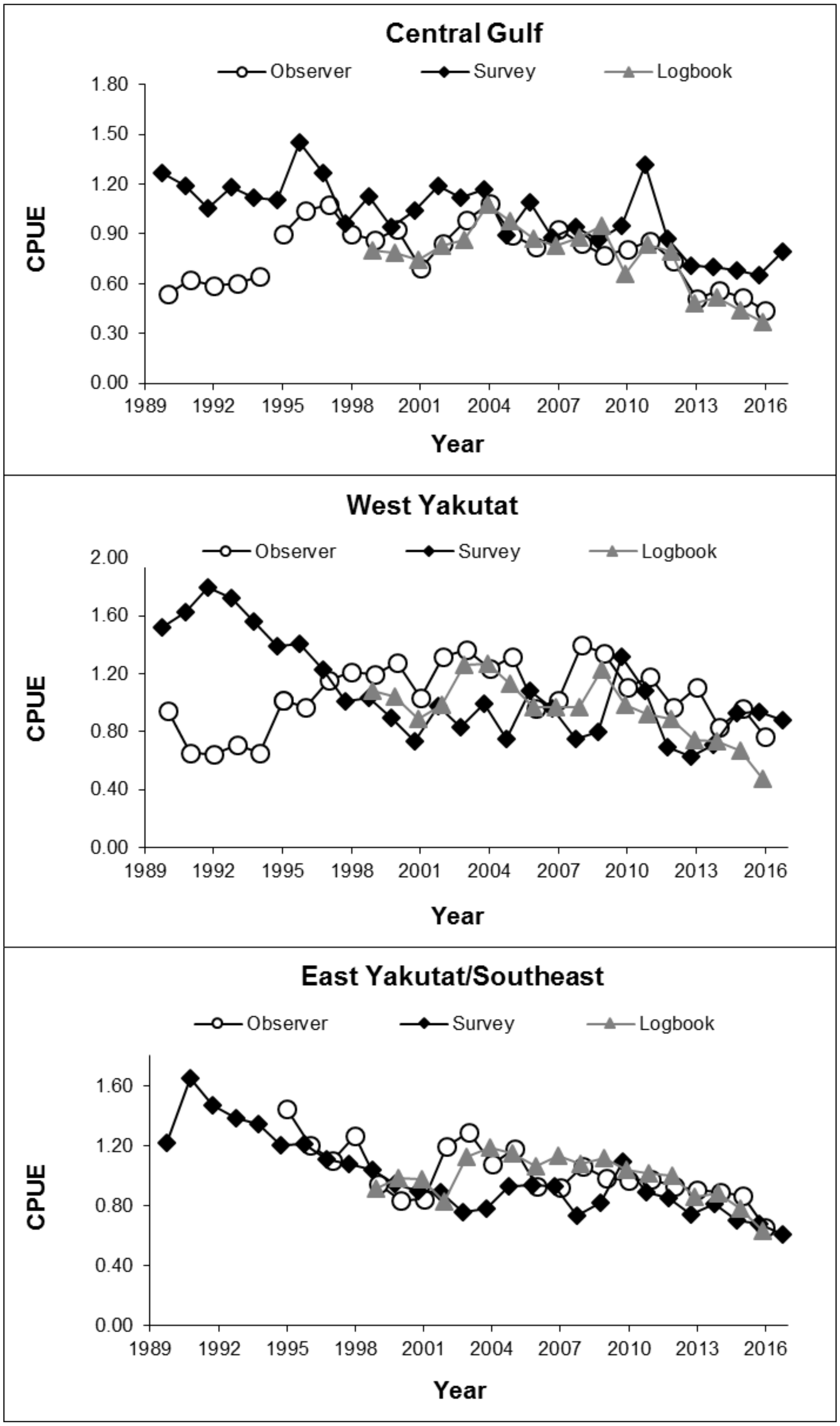


Figure 3.5. (continued)

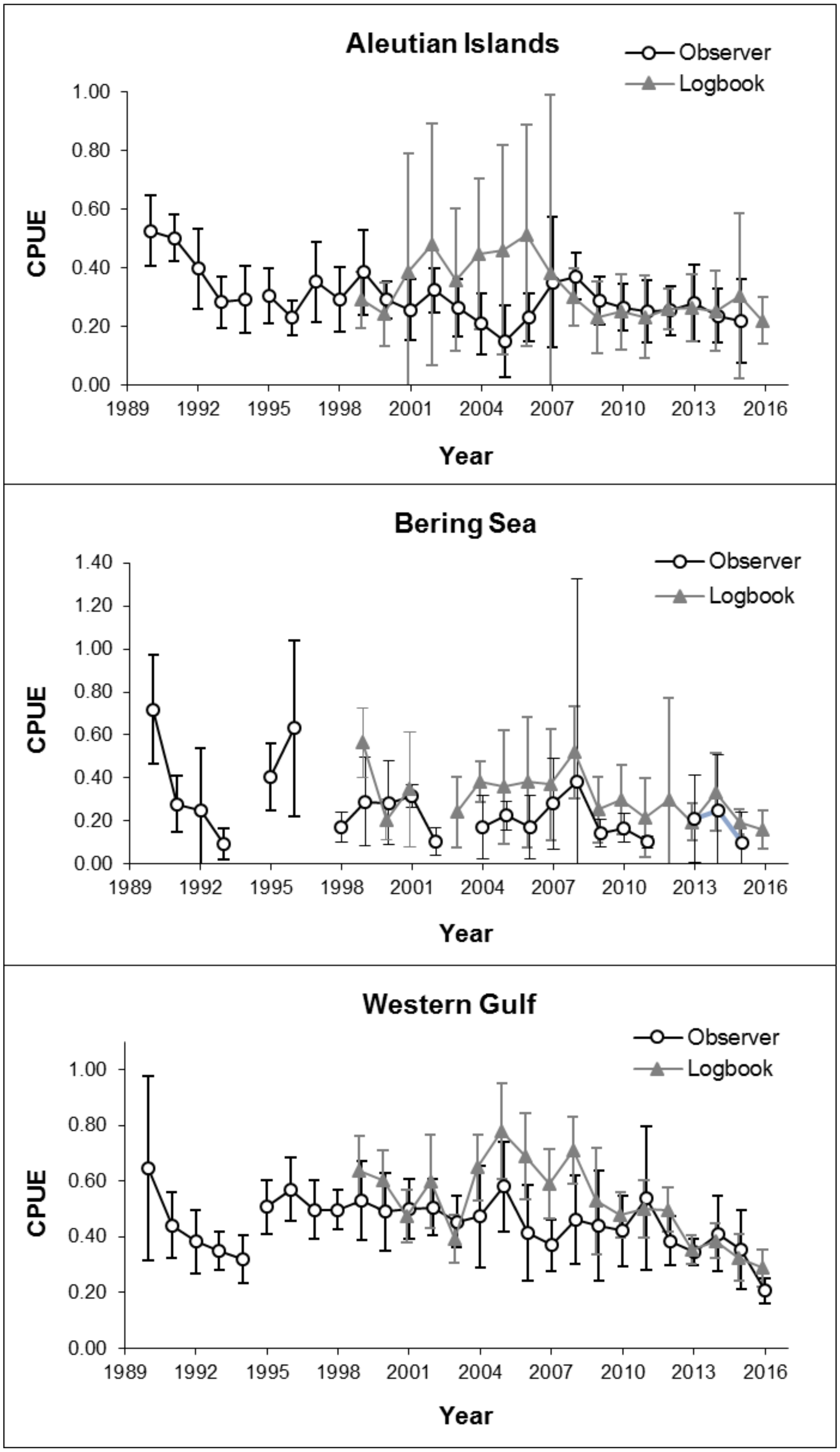


Figure 3.6. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data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

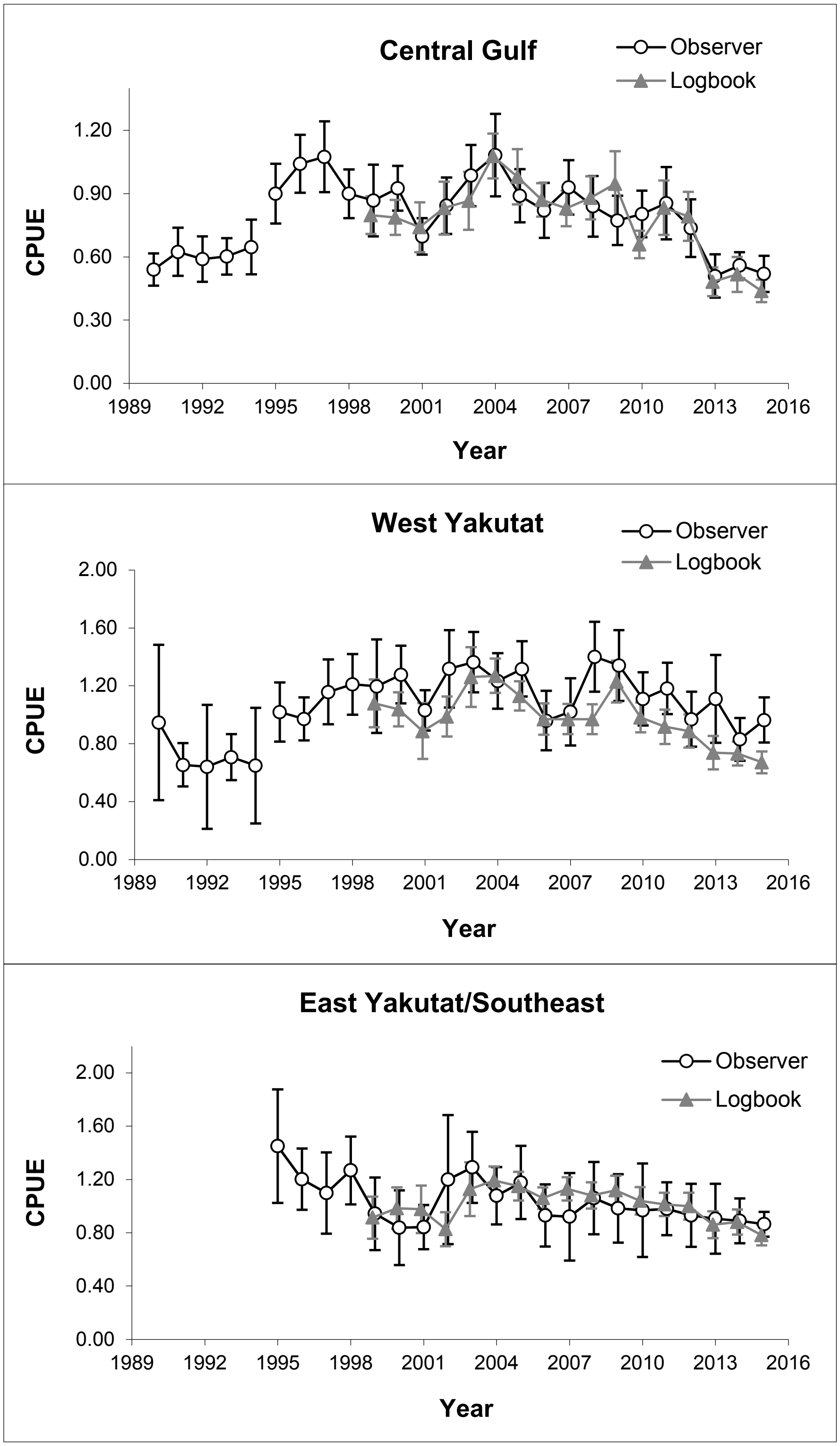


Figure 3.6. (continued)

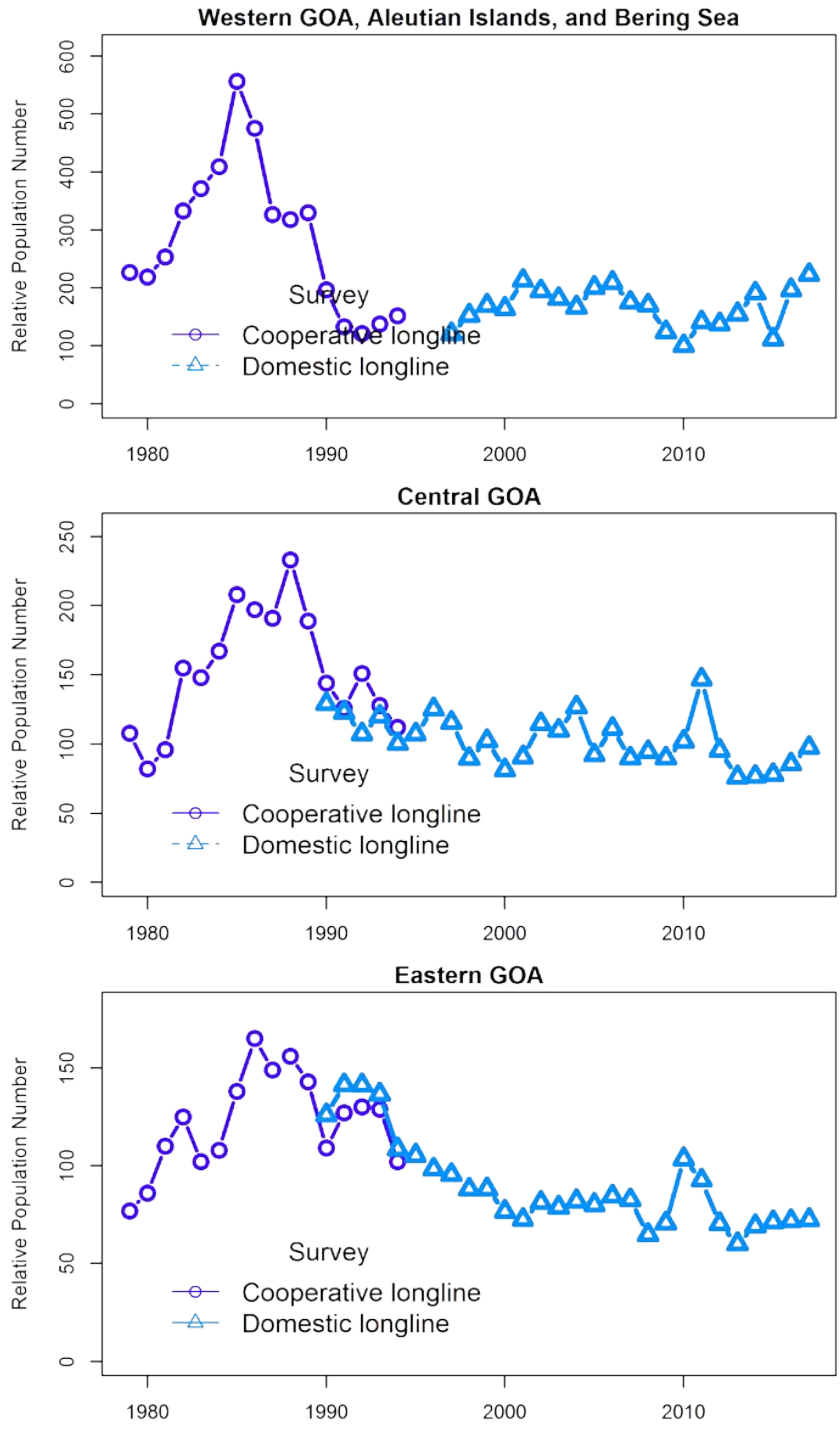


Figure 3.7. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the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

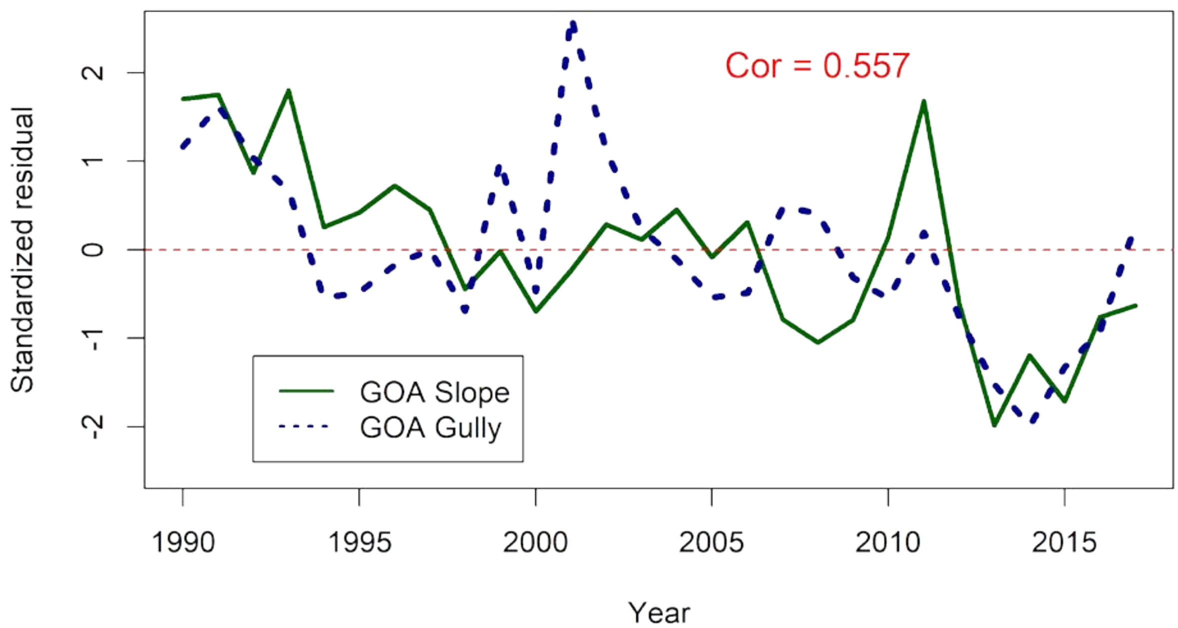


Figure 3.8 Comparison of abundance trends in GOA gully stations versus GOA slope stations.

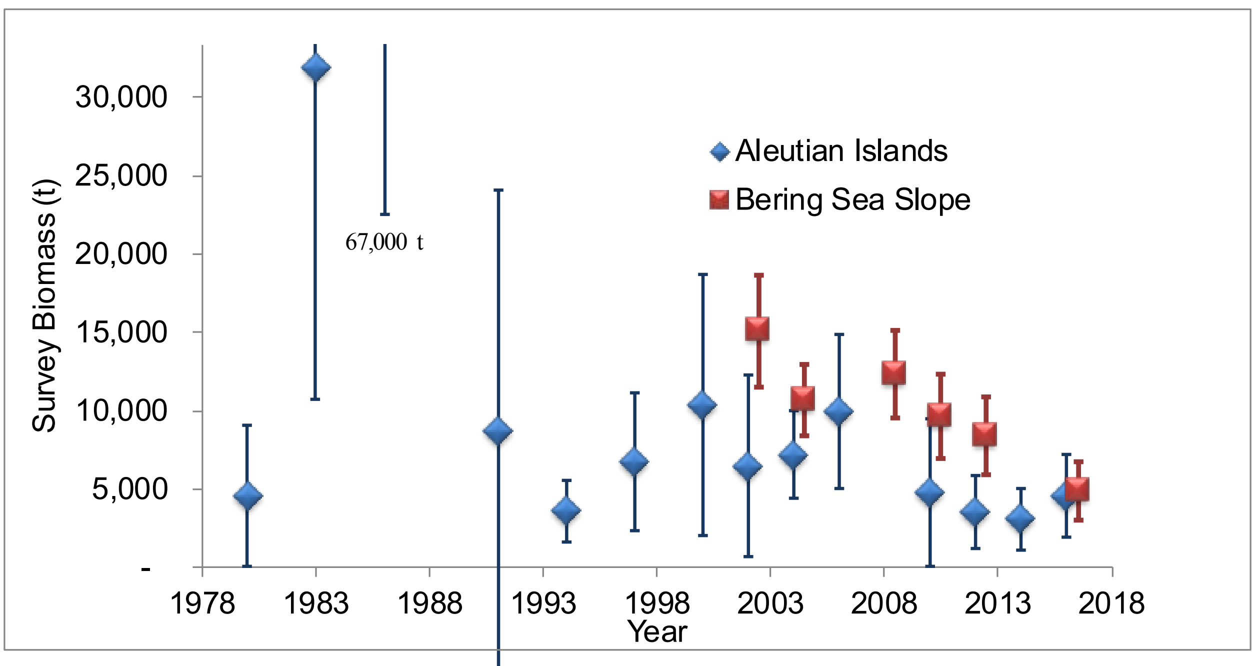


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates. Bering Sea Slope years are jittered so that intervals do not overlap.

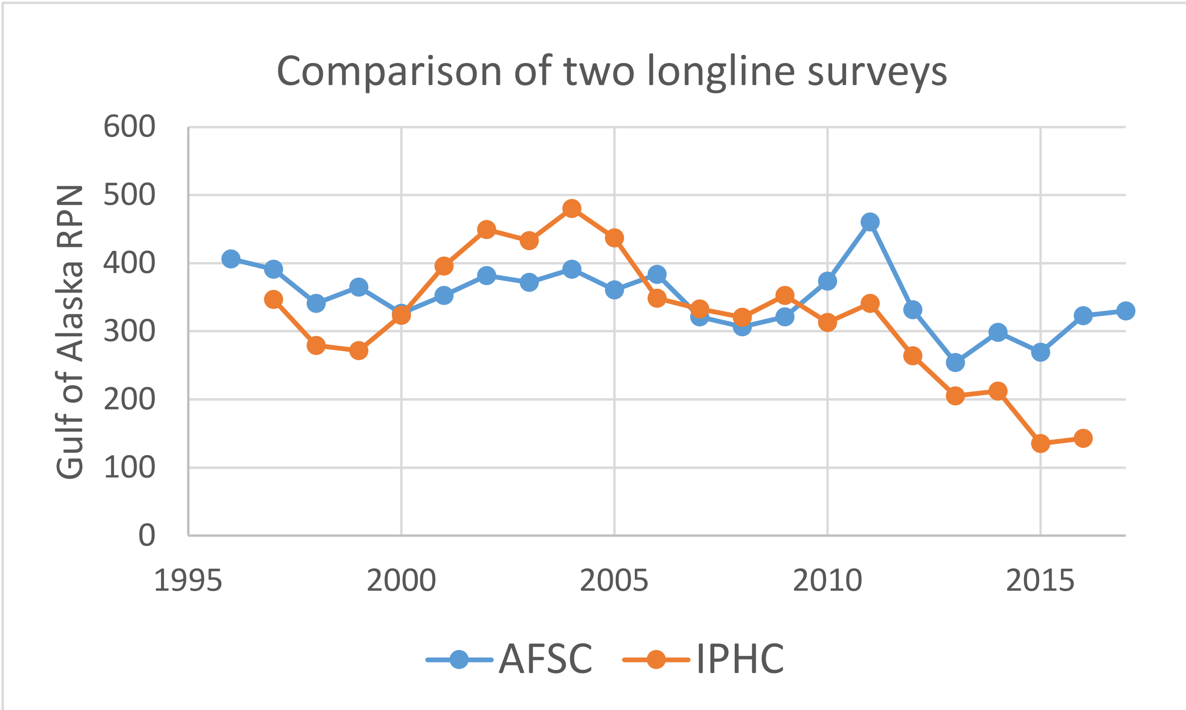


Figure 3.10a. Comparisons of IPHC and AFSC longline survey trends in relative population number of sablefish in the Gulf of Alaska. Years in which both surveys occurred have a correlation coefficient of *r* = 0.63.

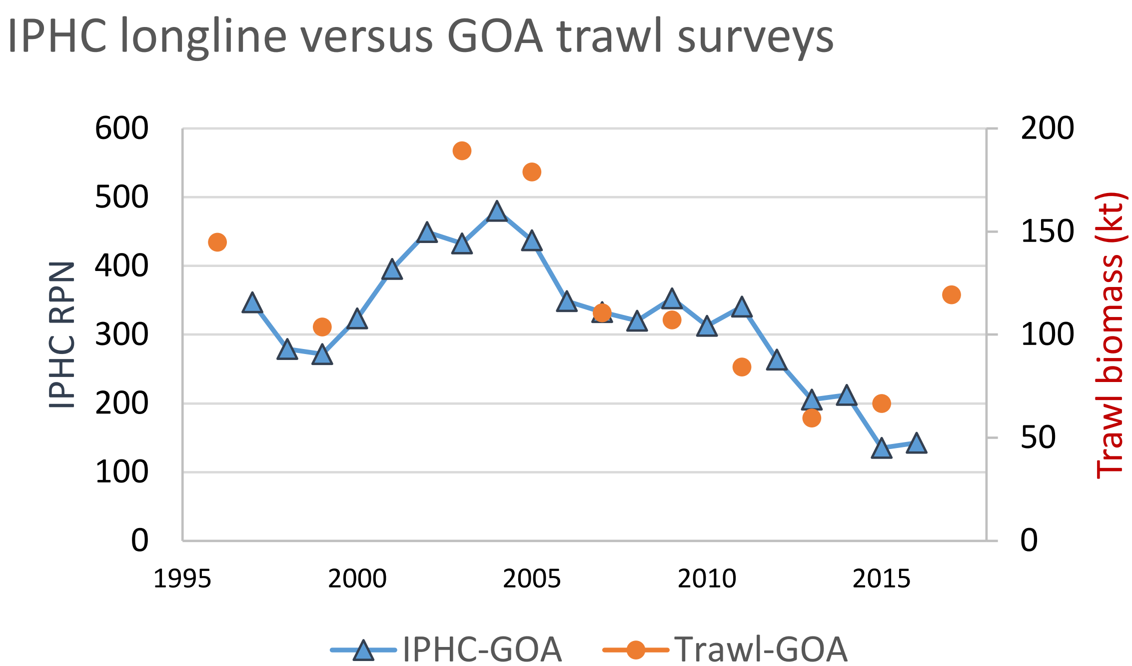


Figure 3.10b. Comparisons of IPHC and AFSC trawl survey trends abundance of sablefish in the Gulf of Alaska. Years in which both surveys occurred have a correlation coefficient of *r* = 0.86.

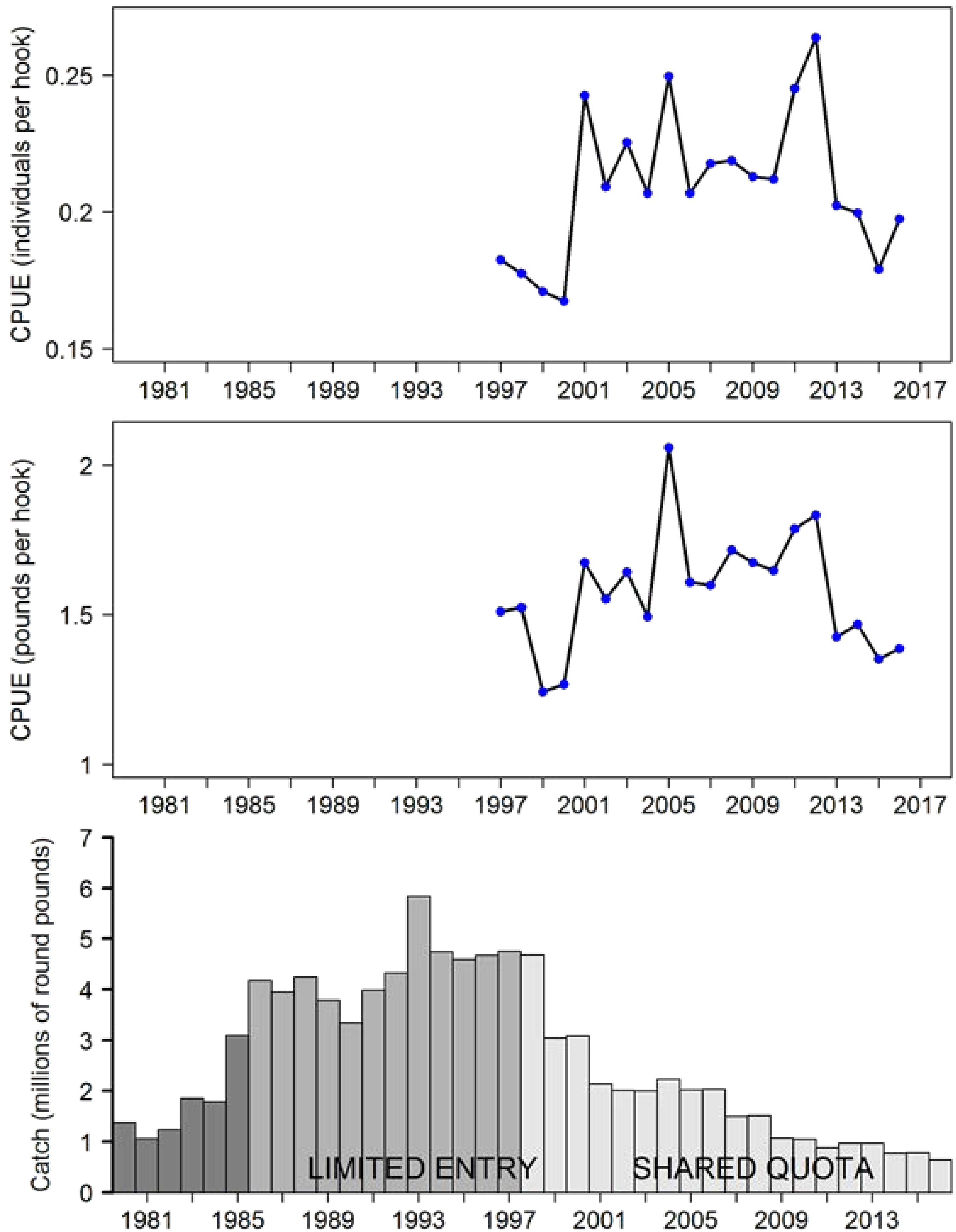


Figure 3.11a. Northern Southeast Inside (NSEI) sablefish longline survey catch-per-unit-effort (CPUE) in (A) individuals/hook, (B) round pounds/hook, and commercial catch from 1980 to 2016. A three-hour minimum soak time was used on the NSEI sablefish longline survey (from A. Olson, November, 2017 ADFG, pers. comm.)

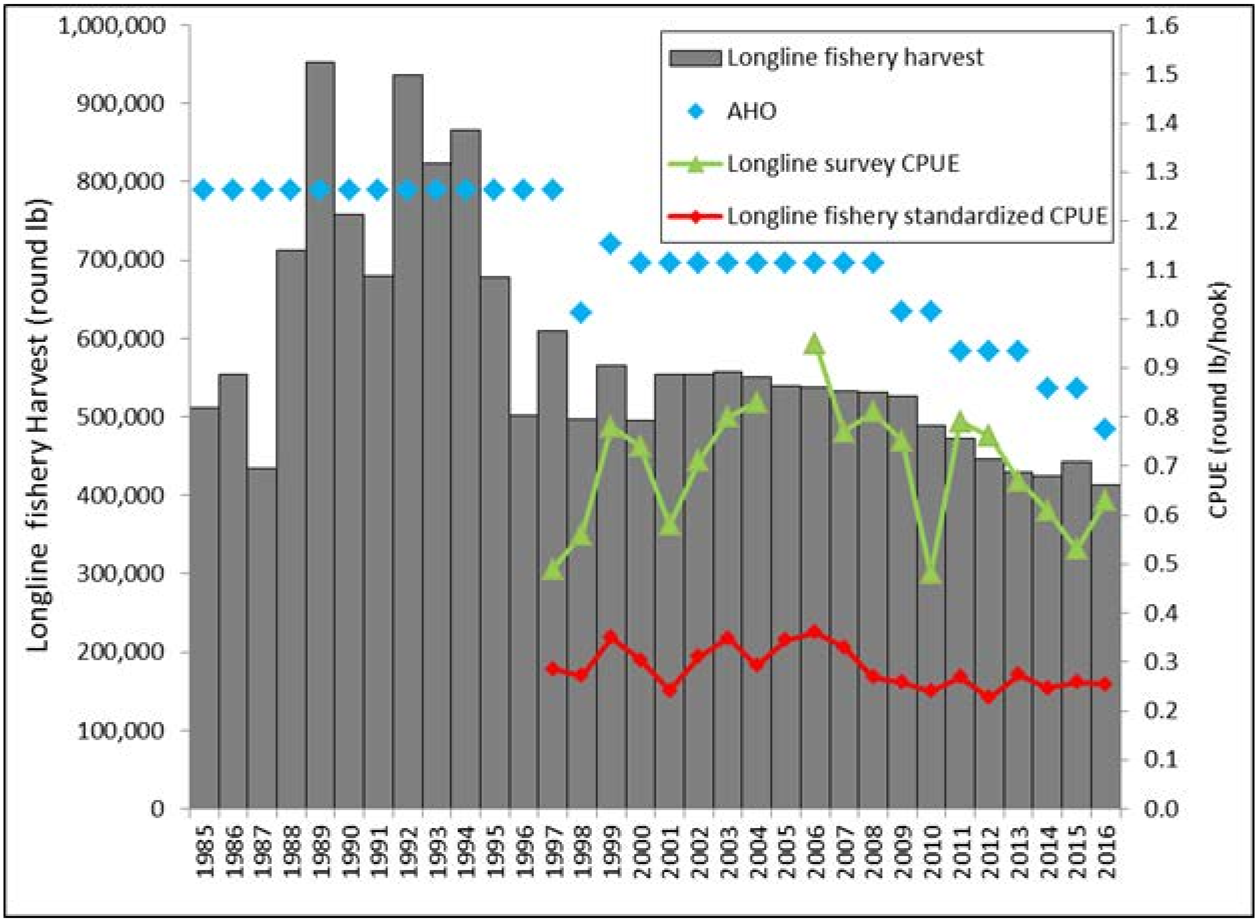


Figure 3.11b. Southern Southeast Inside (SSEI) commercial sablefish longline survey and fishery catch-per-unit-effort (CPUE) in round pounds-per-hook from 1997 to 2016 and commercial catch from 1985 to 2016. AHO is the Annual Harvest Objective (from A. Olson, November, 2017 ADFG, pers. comm.)

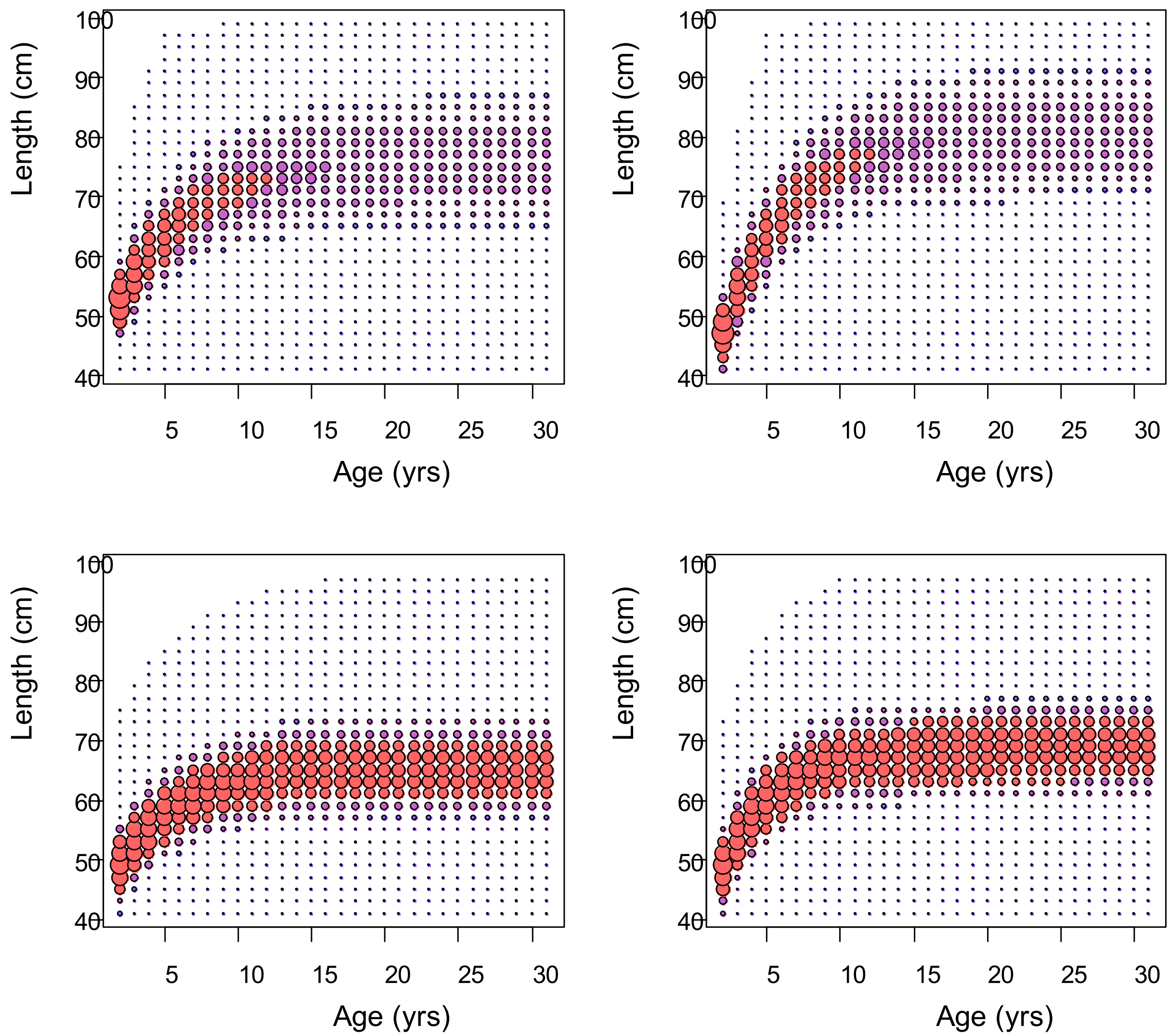


Figure 3.12. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996-2017.

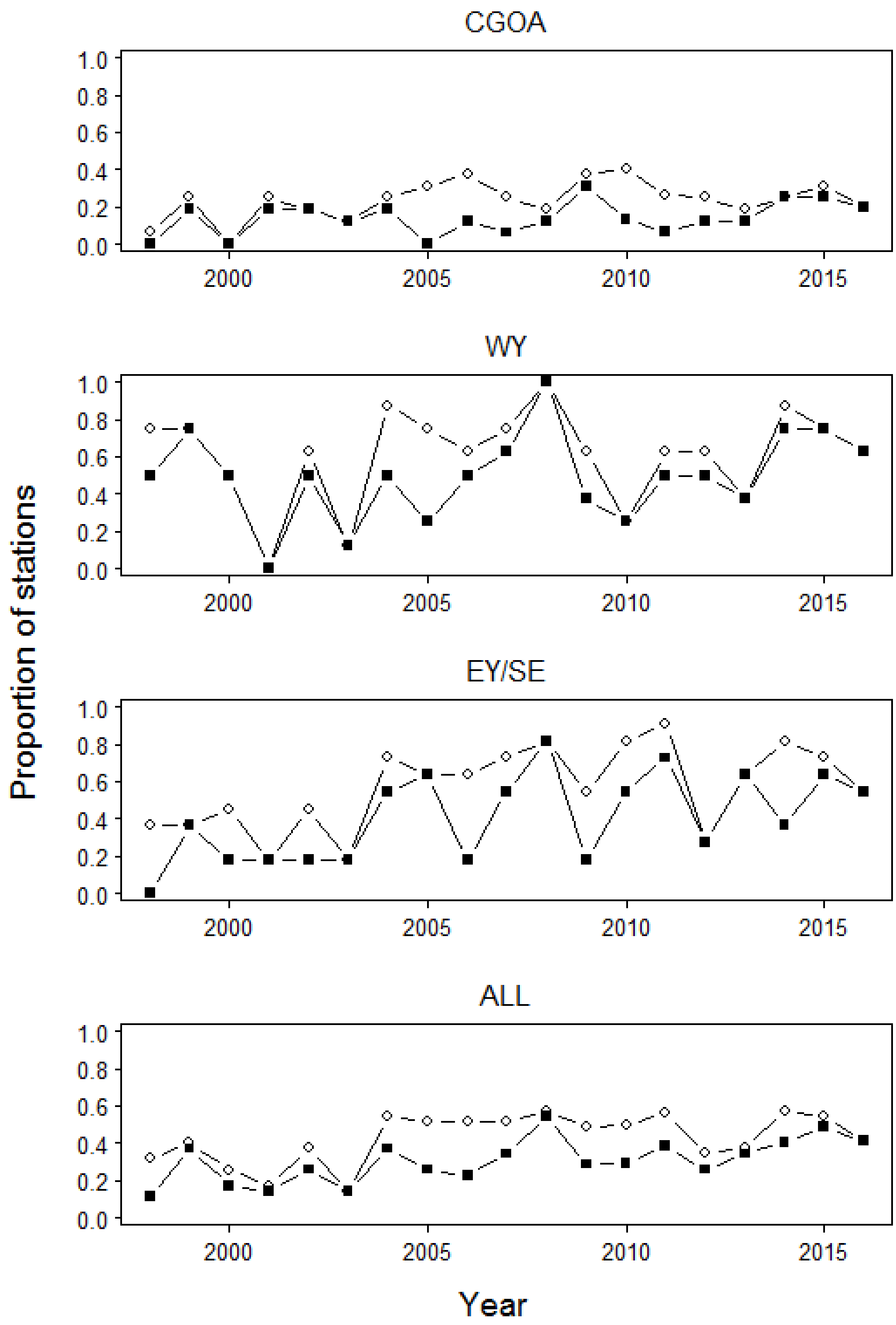


Figure 3.13. Proportion of stations with sperm whale presence (open circles) and evidence of depredation (solid squares) by management area and pooled, 1998-2016.

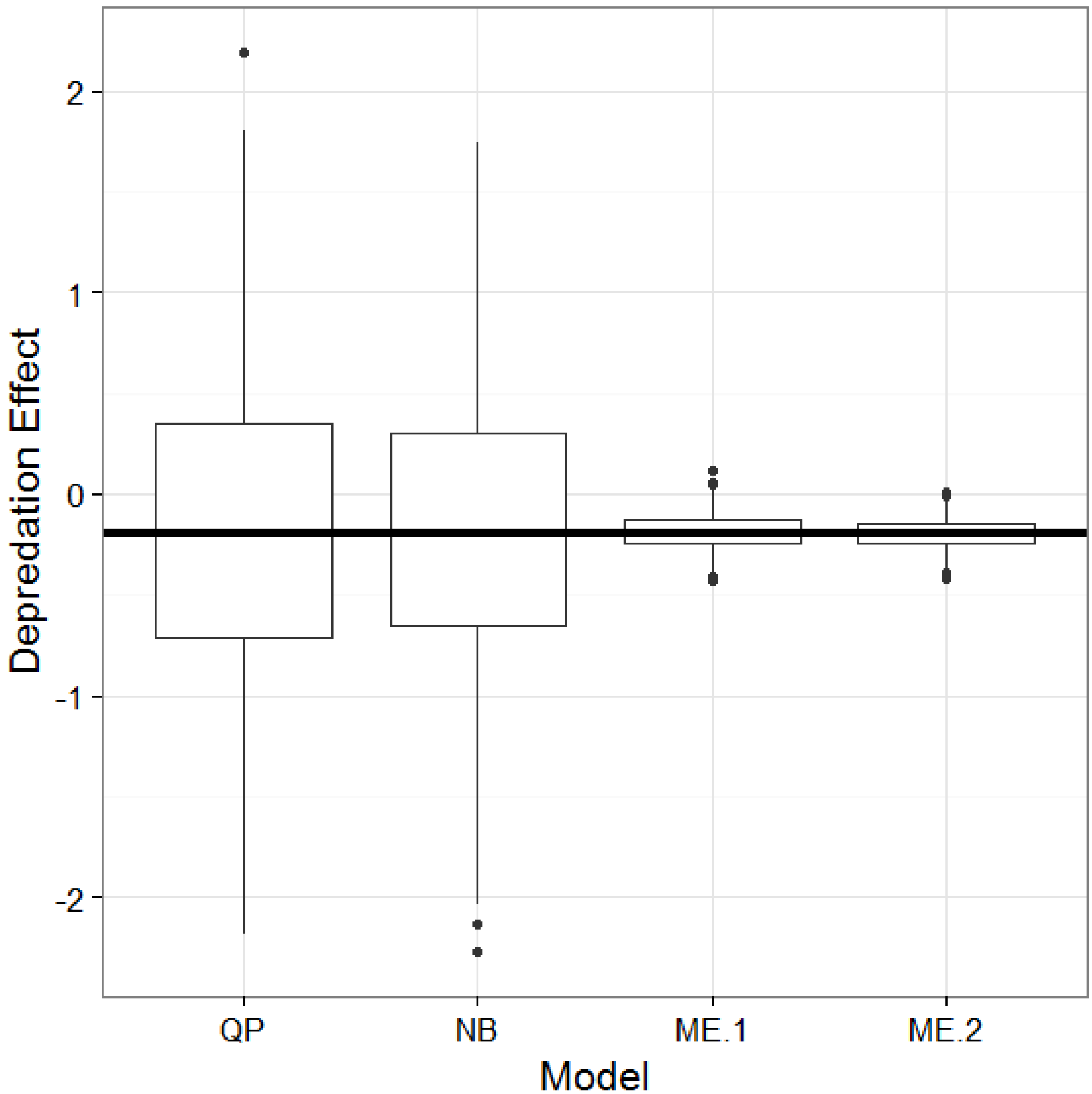


Figure 3.14. Boxplots of simulation estimates (1000 trials) of sperm whale depredation by model for simulation 1 (true simulated value of the depredation effect = -0.2). QP = Quasipoisson GLM, NB = negative binomial GLM, ME.1 = Mixed effects Poisson without interactions, ME.2 = saturated mixed effects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

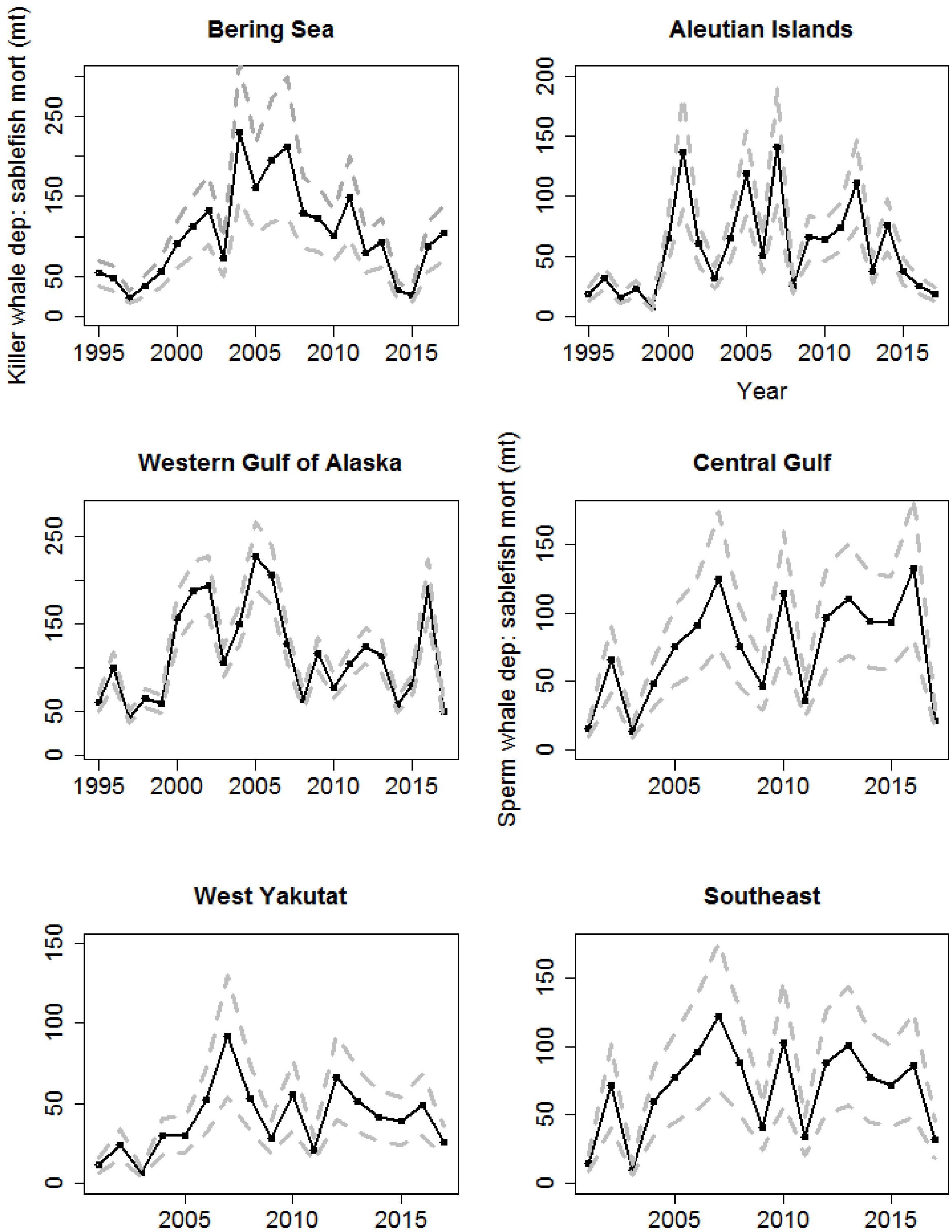


Figure 3.15. Estimated sablefish mortality (t) by year due to killer whales in the Bering Sea, Aleutian Islands, and Western Gulf of Alaska and sperm whales in the Central Gulf of Alaska, West Yakutat, and Southeast Alaska with ~95% confidence bands. Estimated sablefish catch removals (t) due to sperm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

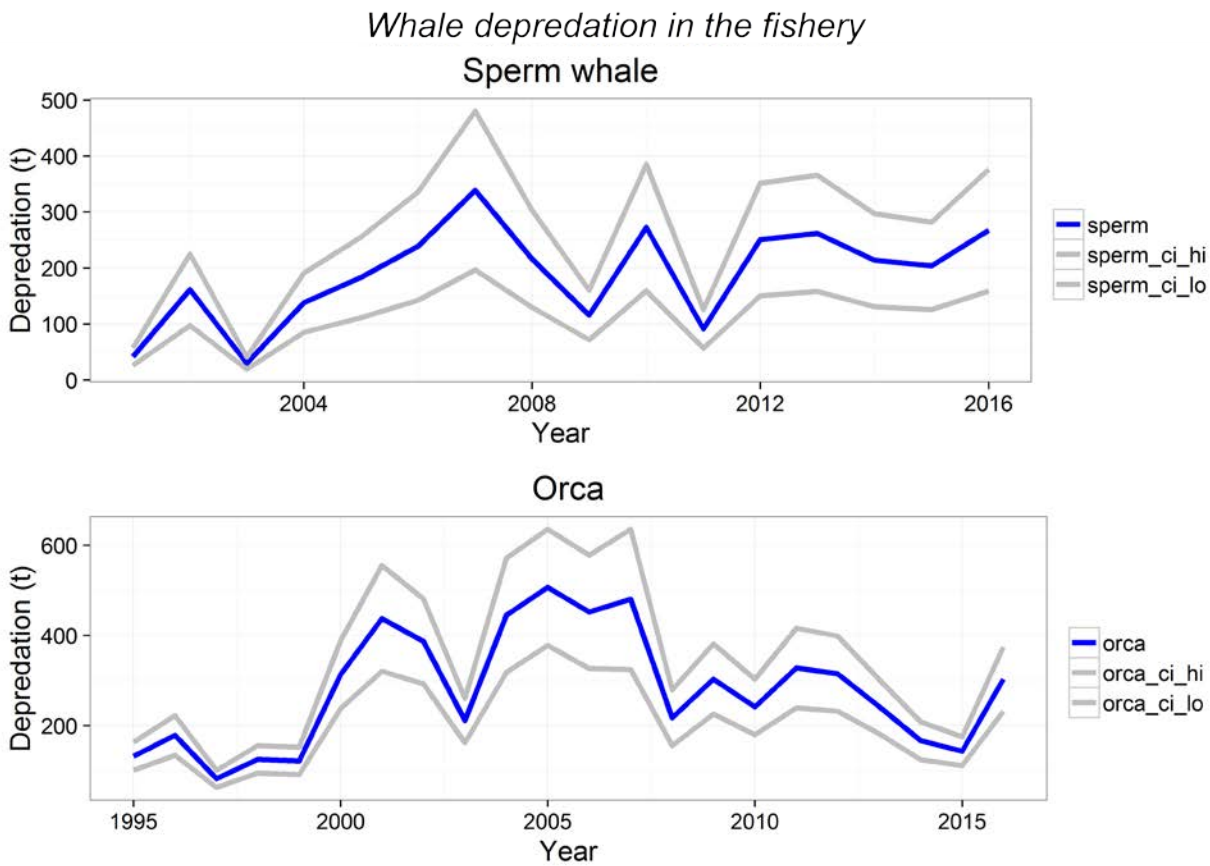
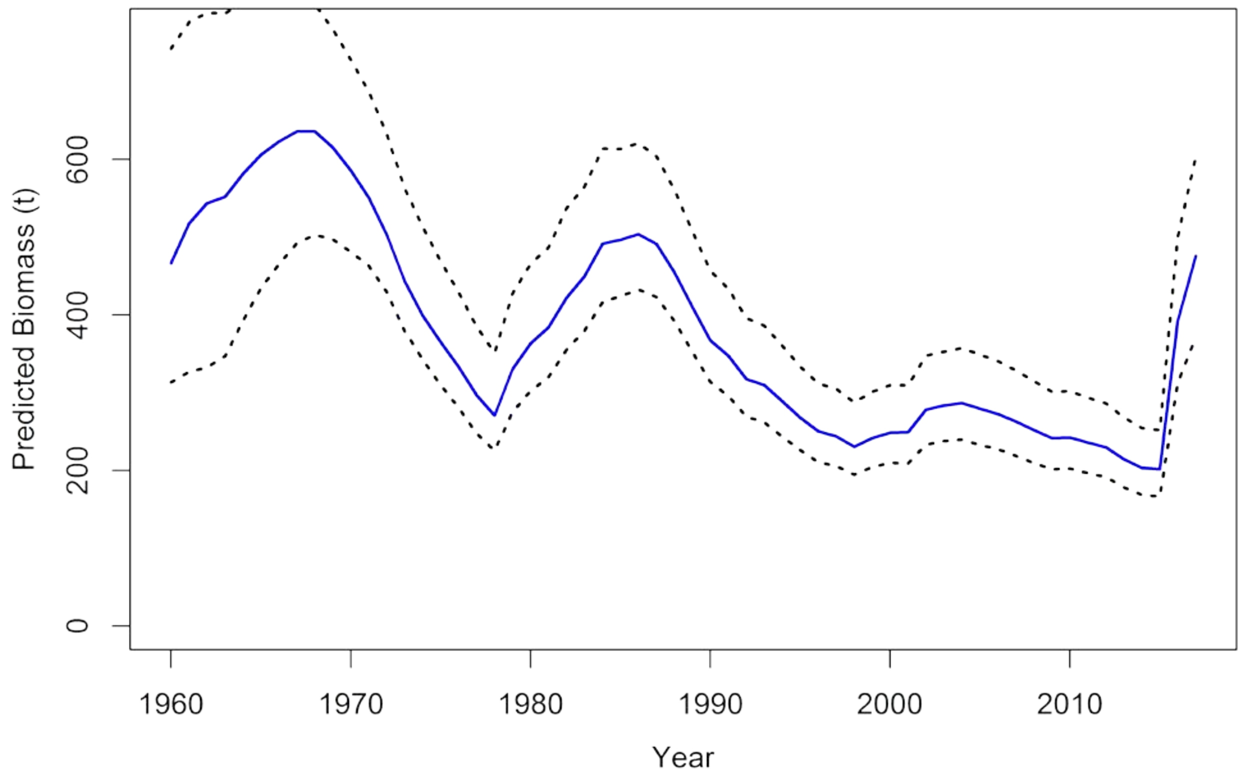


Figure 3.16. Additional estimated sablefish mortality by whale species with 95% asymptotic normal confidence intervals.



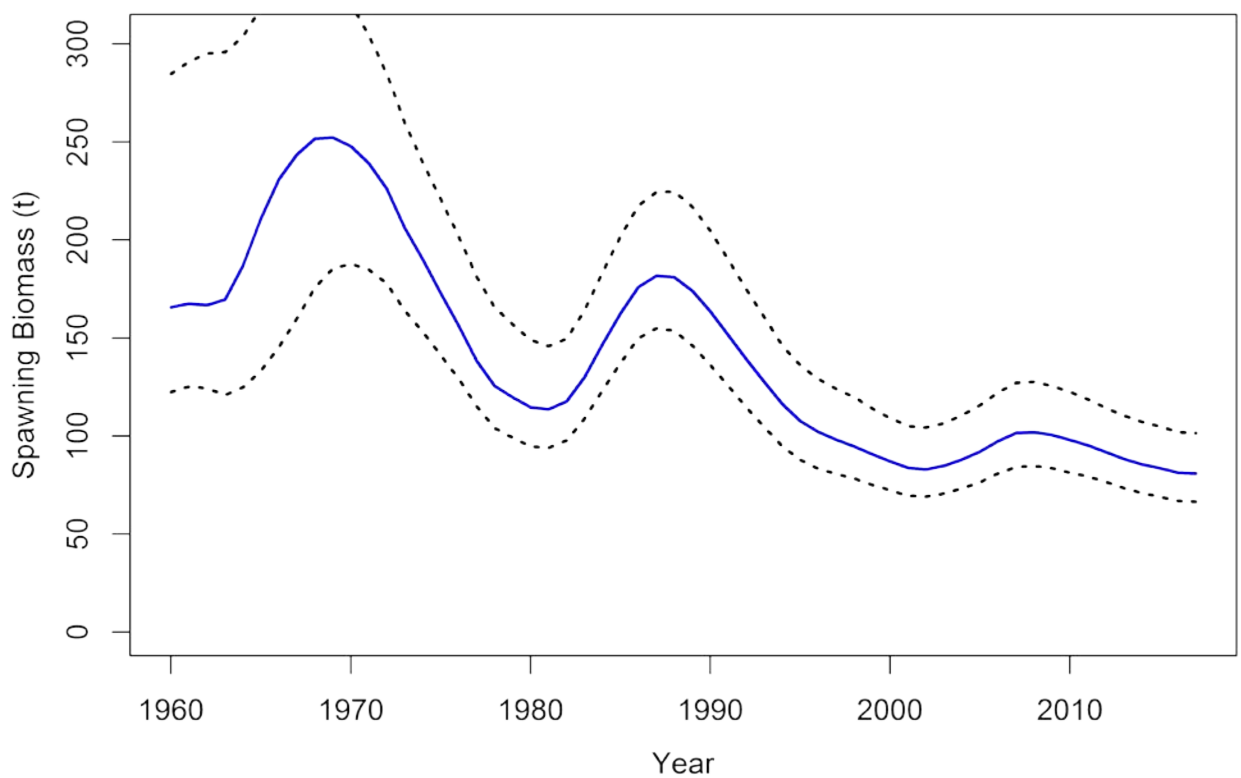


Figure 3.17. Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

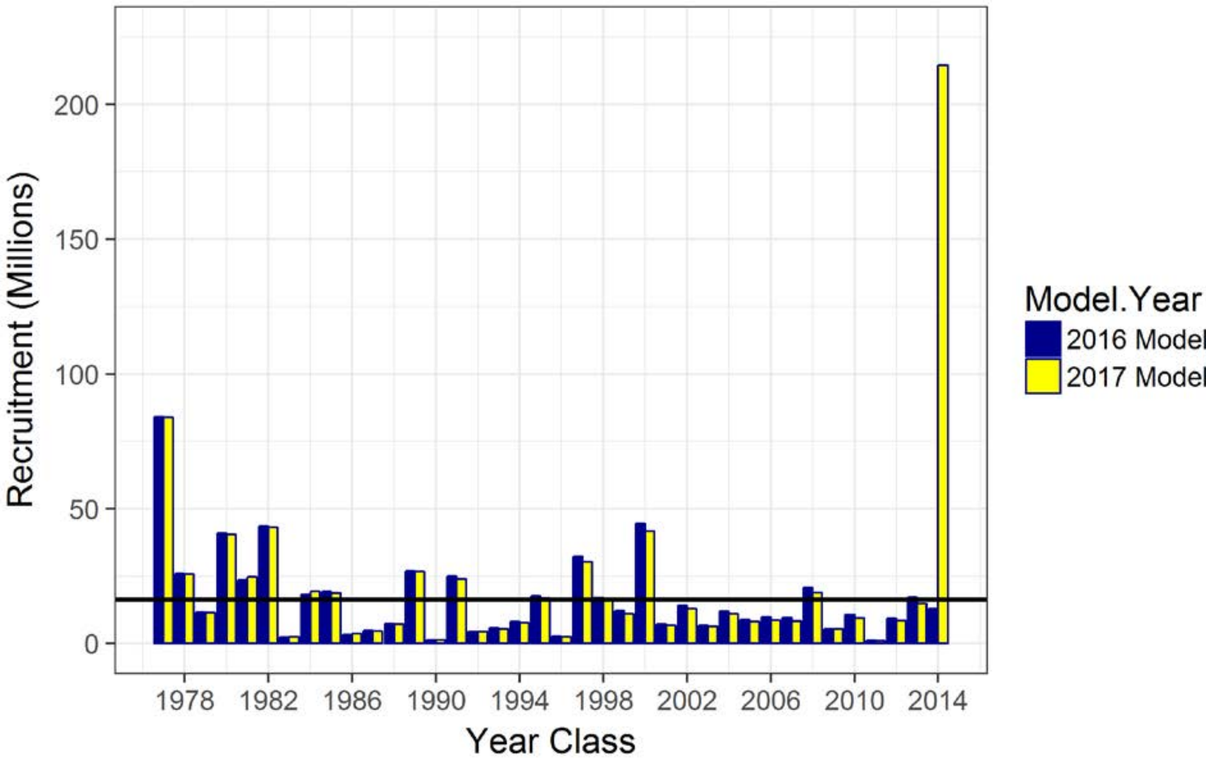


Figure 3.18a. Estimated recruitment by year class 1977-2012 (number at age 2, millions) for 2016 and 2017 models.

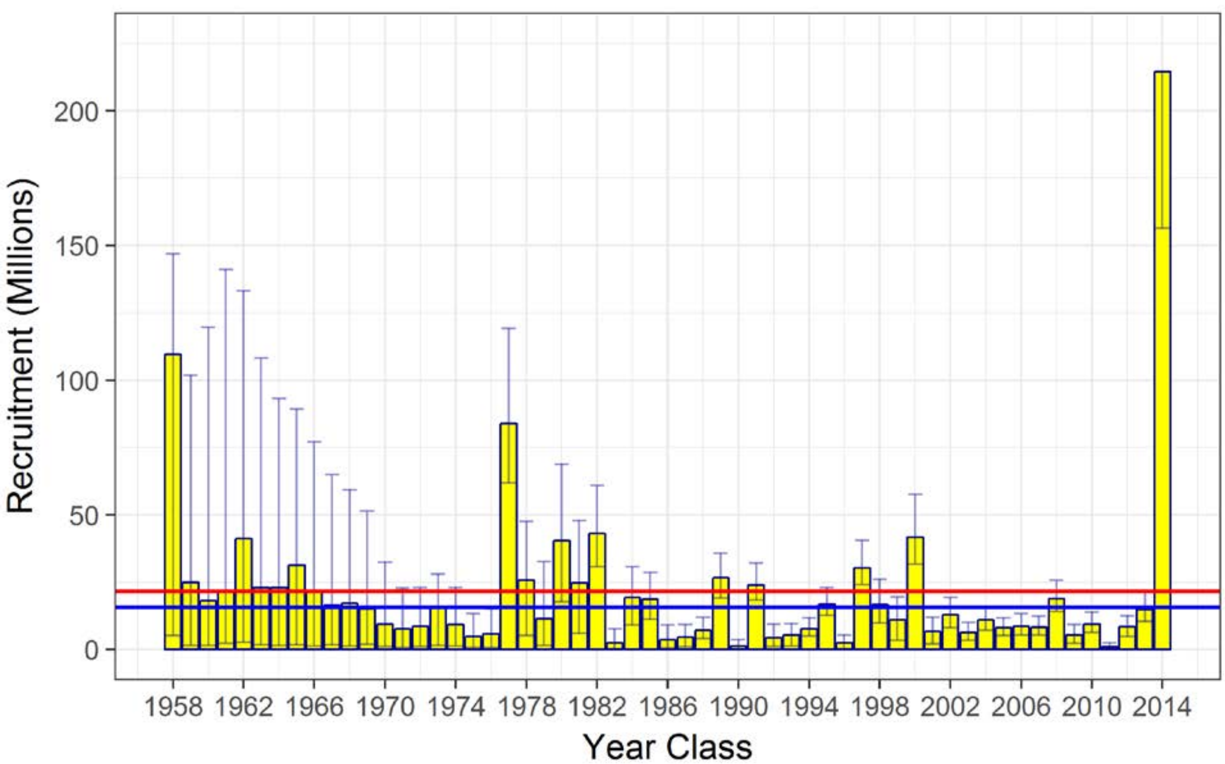


Figure 3.18b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Red line is overall mean, blue line is recruitments from year classes between 1977 and 2013.

Credible intervals are based on MCMC posterior. Upper confidence interval is omitted for the 2014 year class.

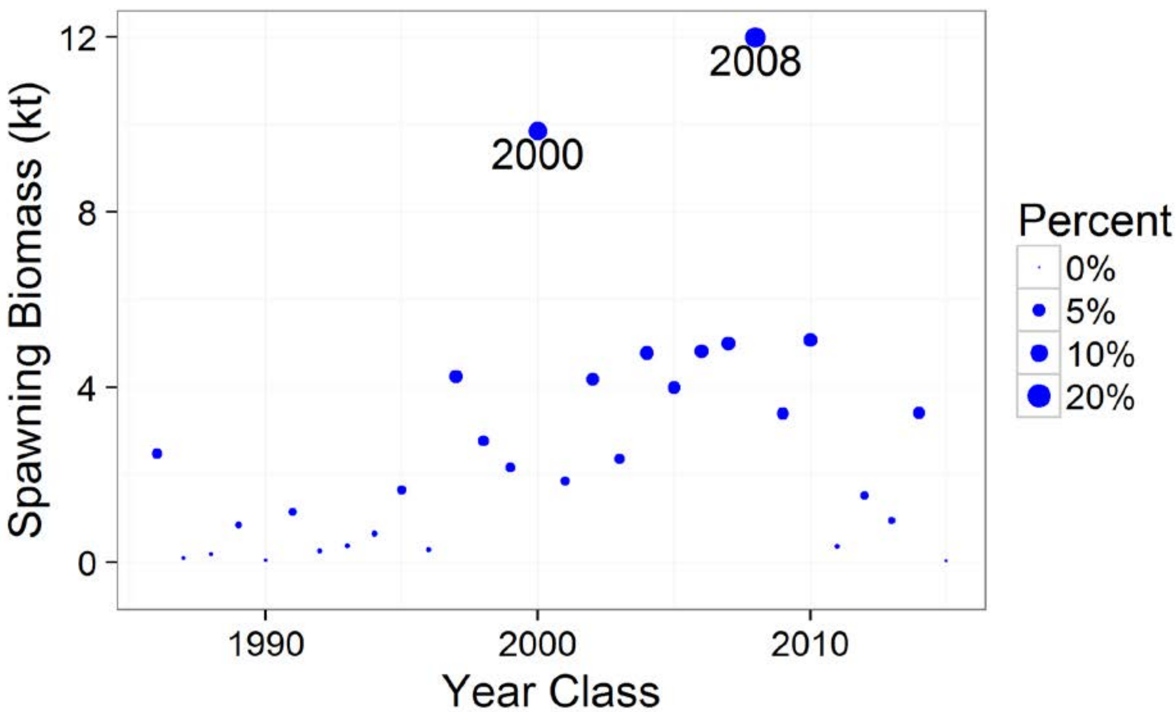


Figure 3.19. Relative contribution of the last 30 year classes to next year's female spawning biomass.

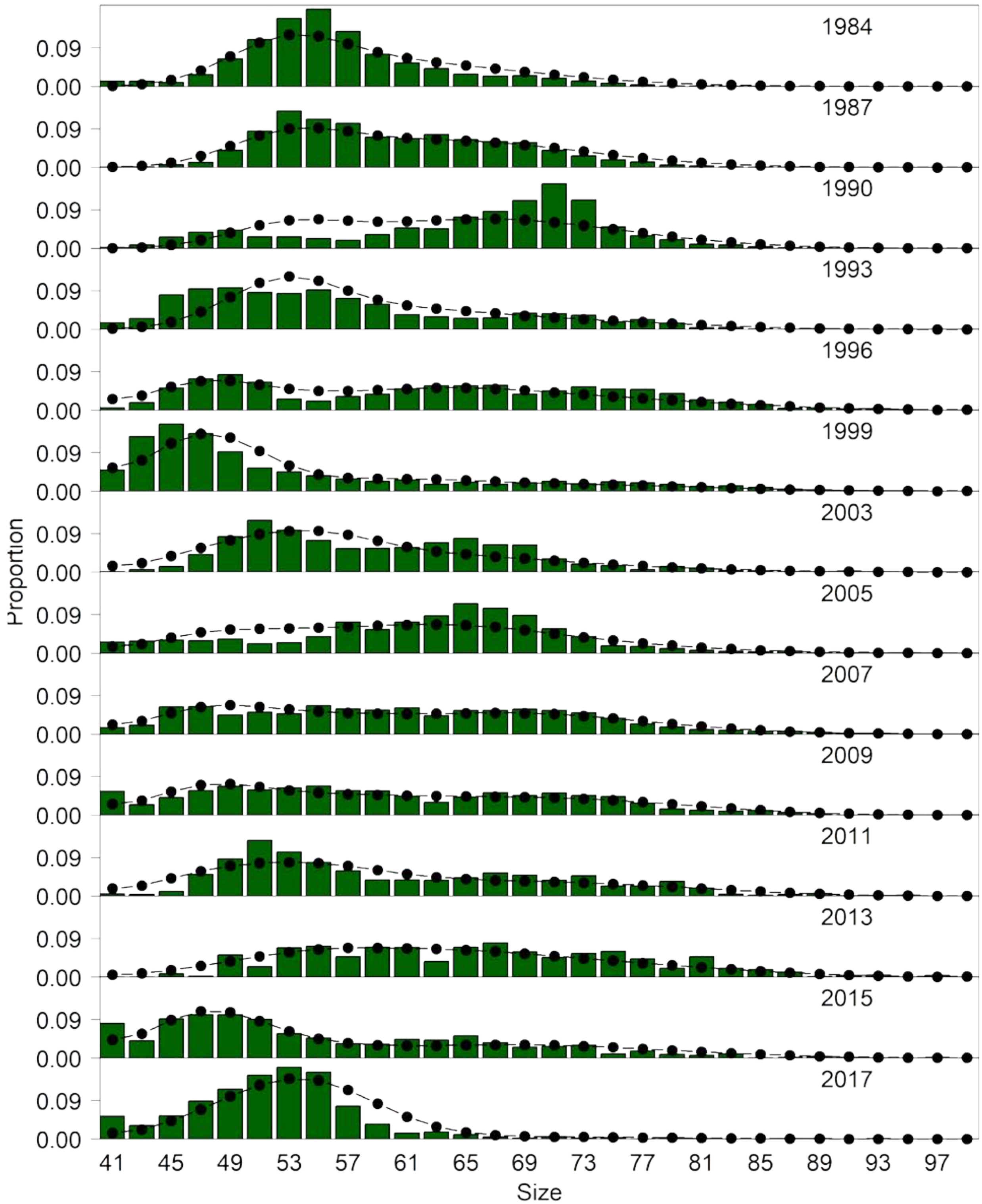


Figure 3.20. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

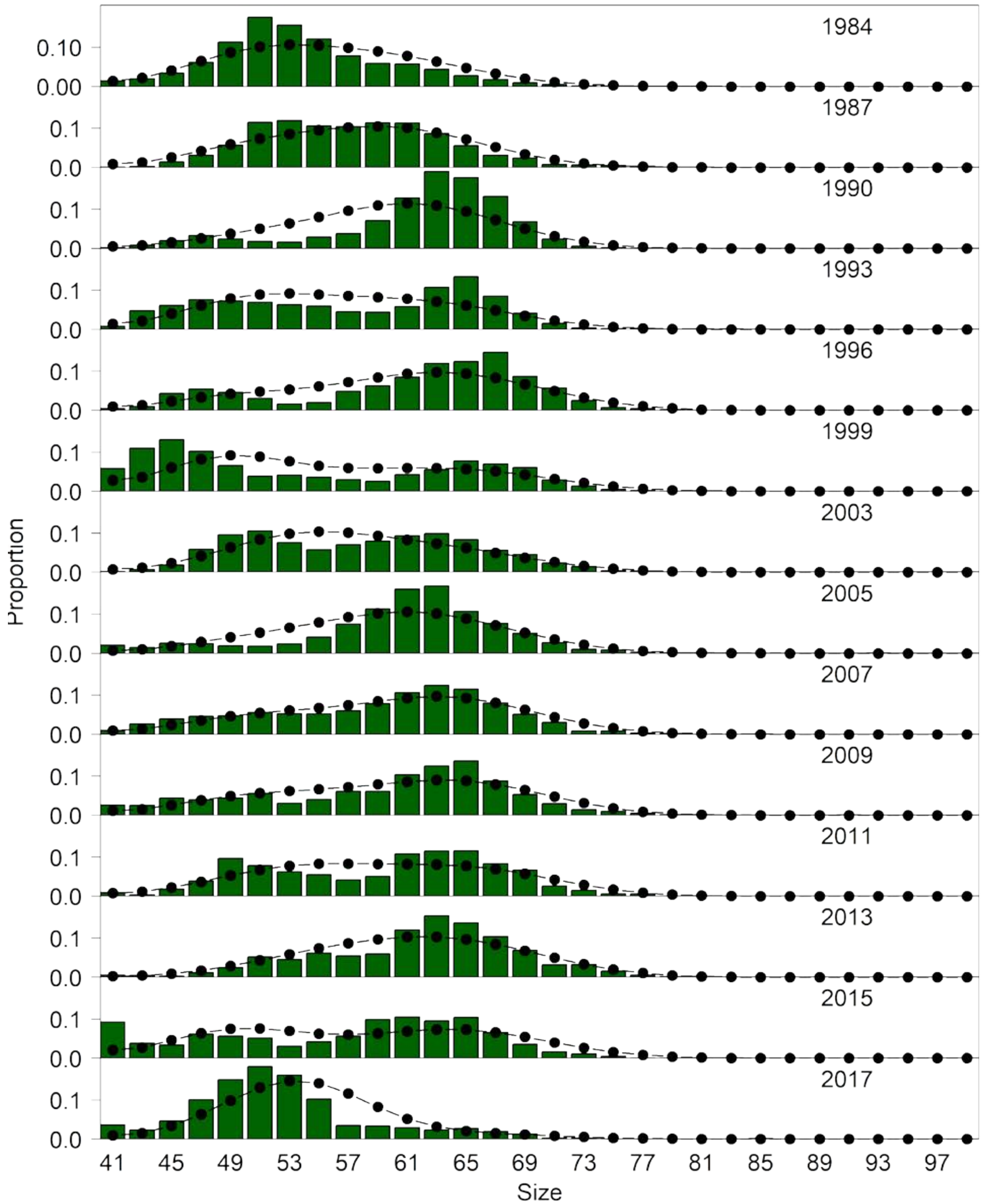


Figure 3.21. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

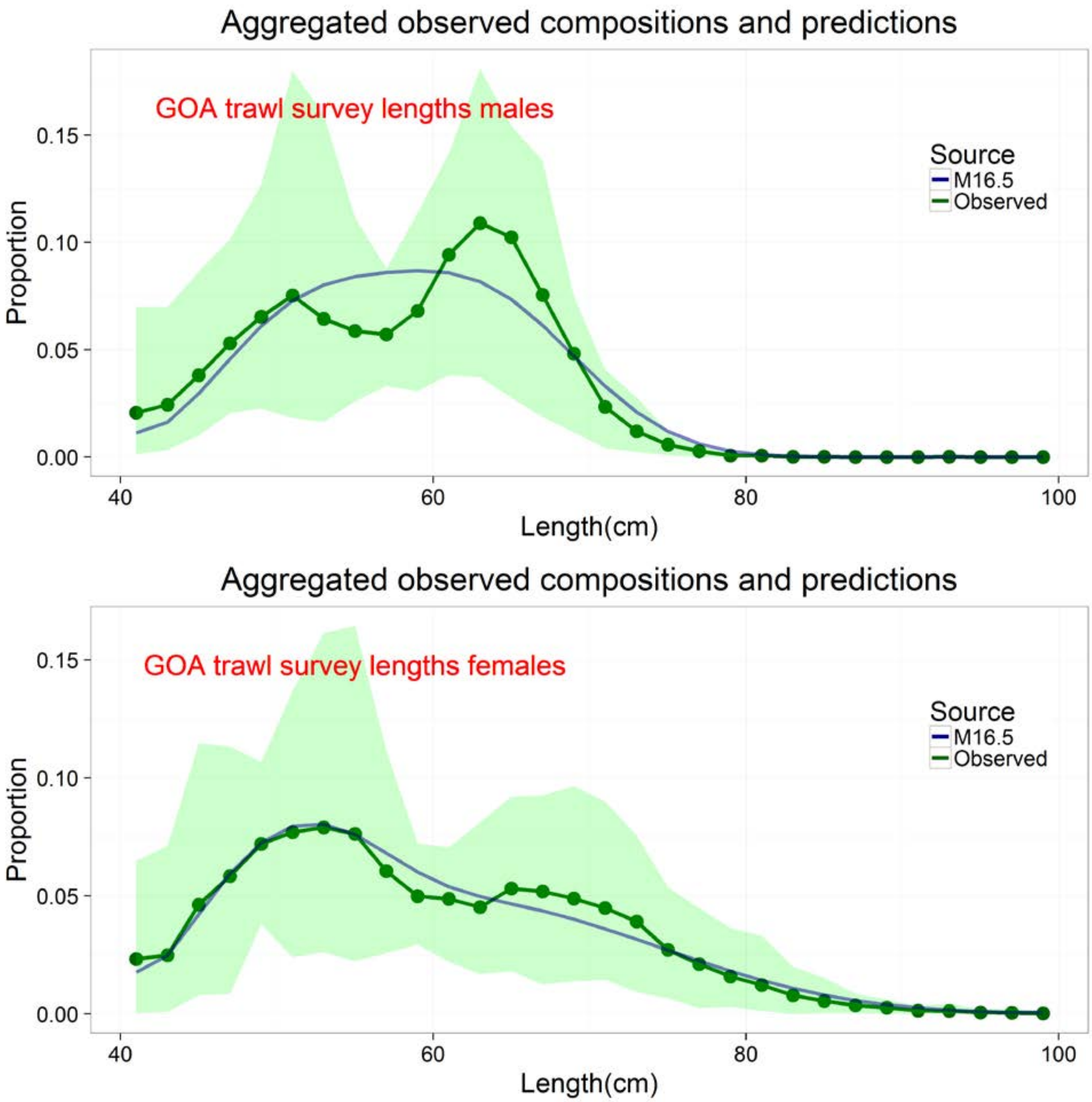


Figure 3.22. Gulf of Alaska trawl survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

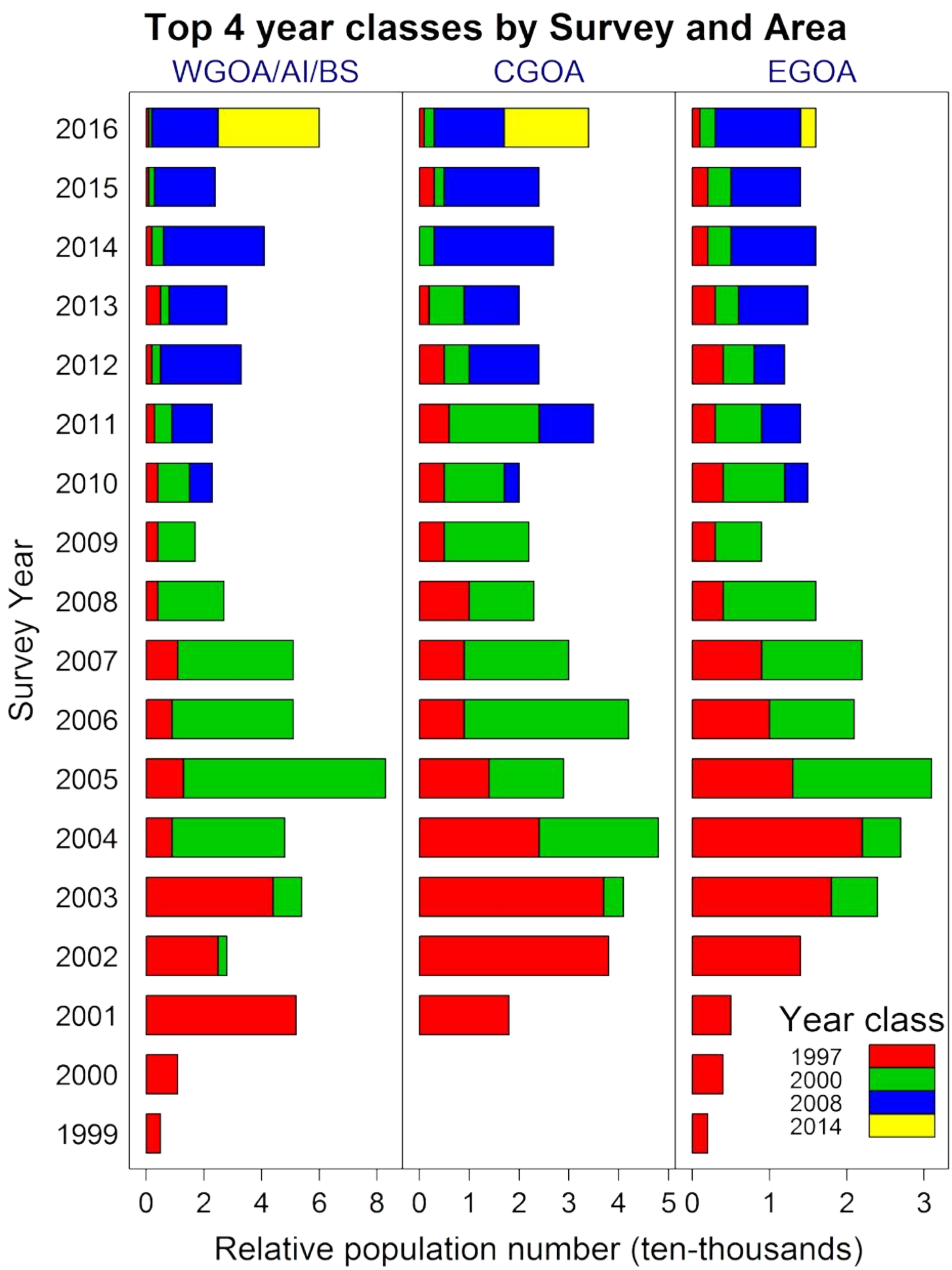


Figure 3.23. Above average 1997, 20002008, and 2014 year classes' relative population abundance in each survey year and area.

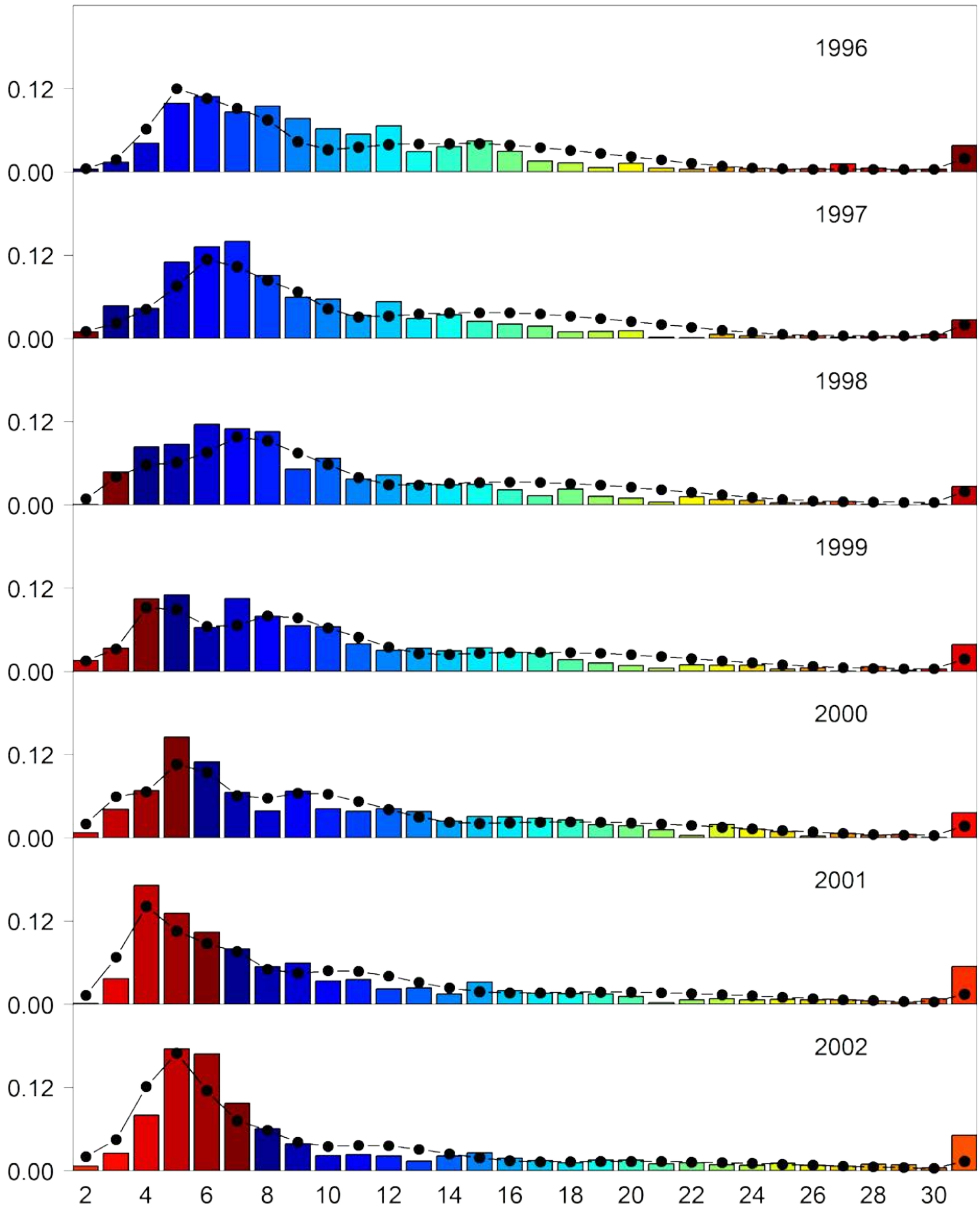


Figure 3.24. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

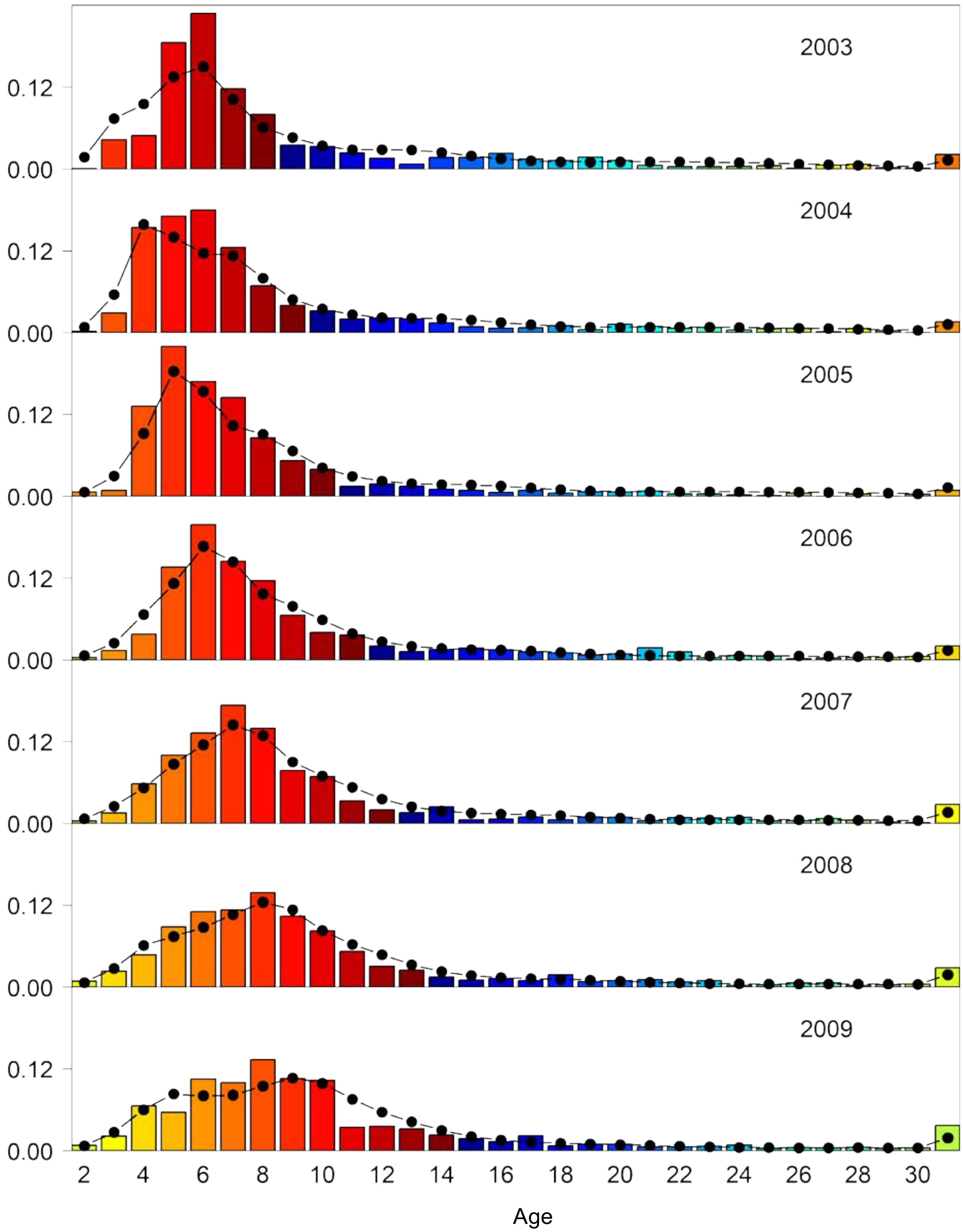


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

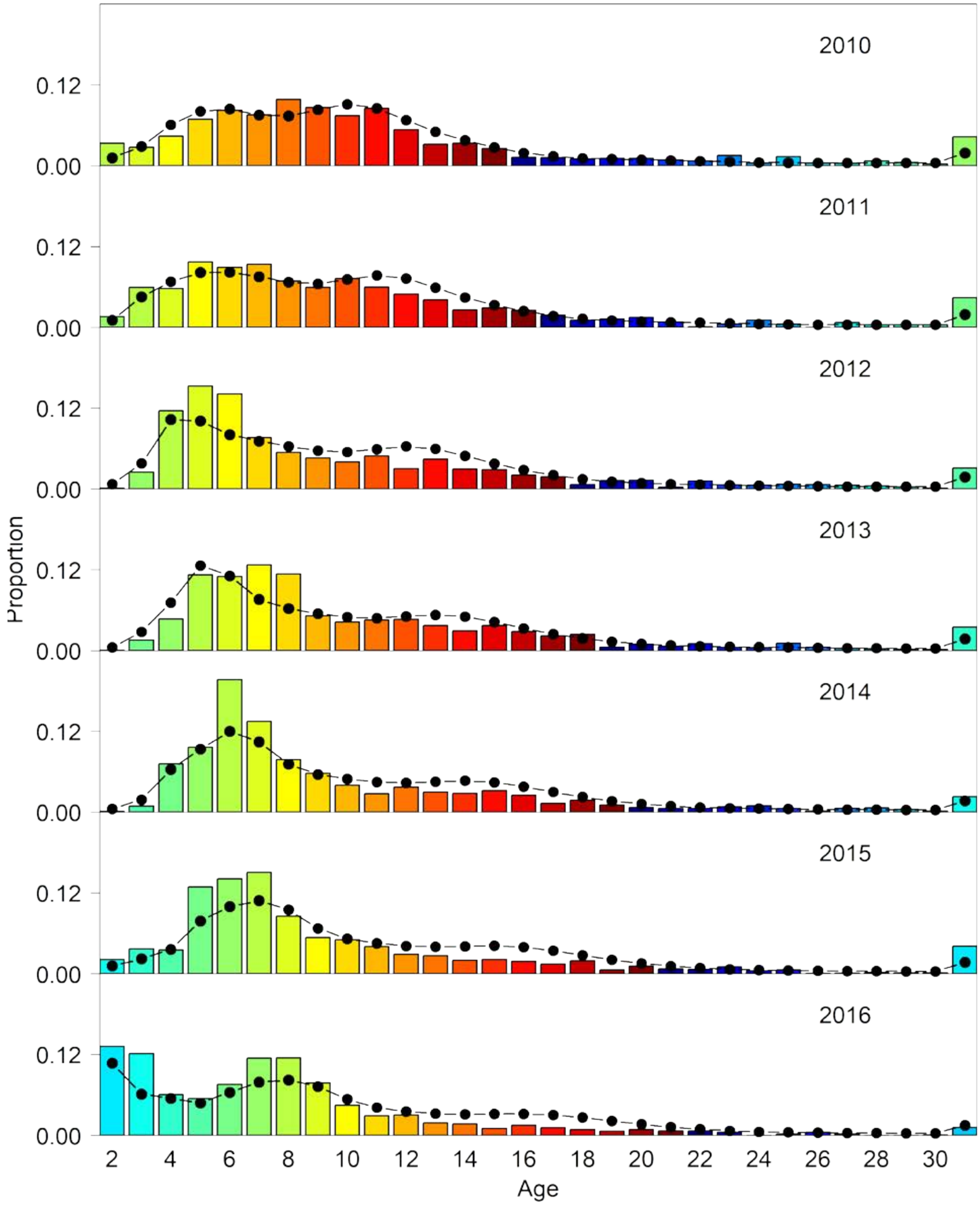


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

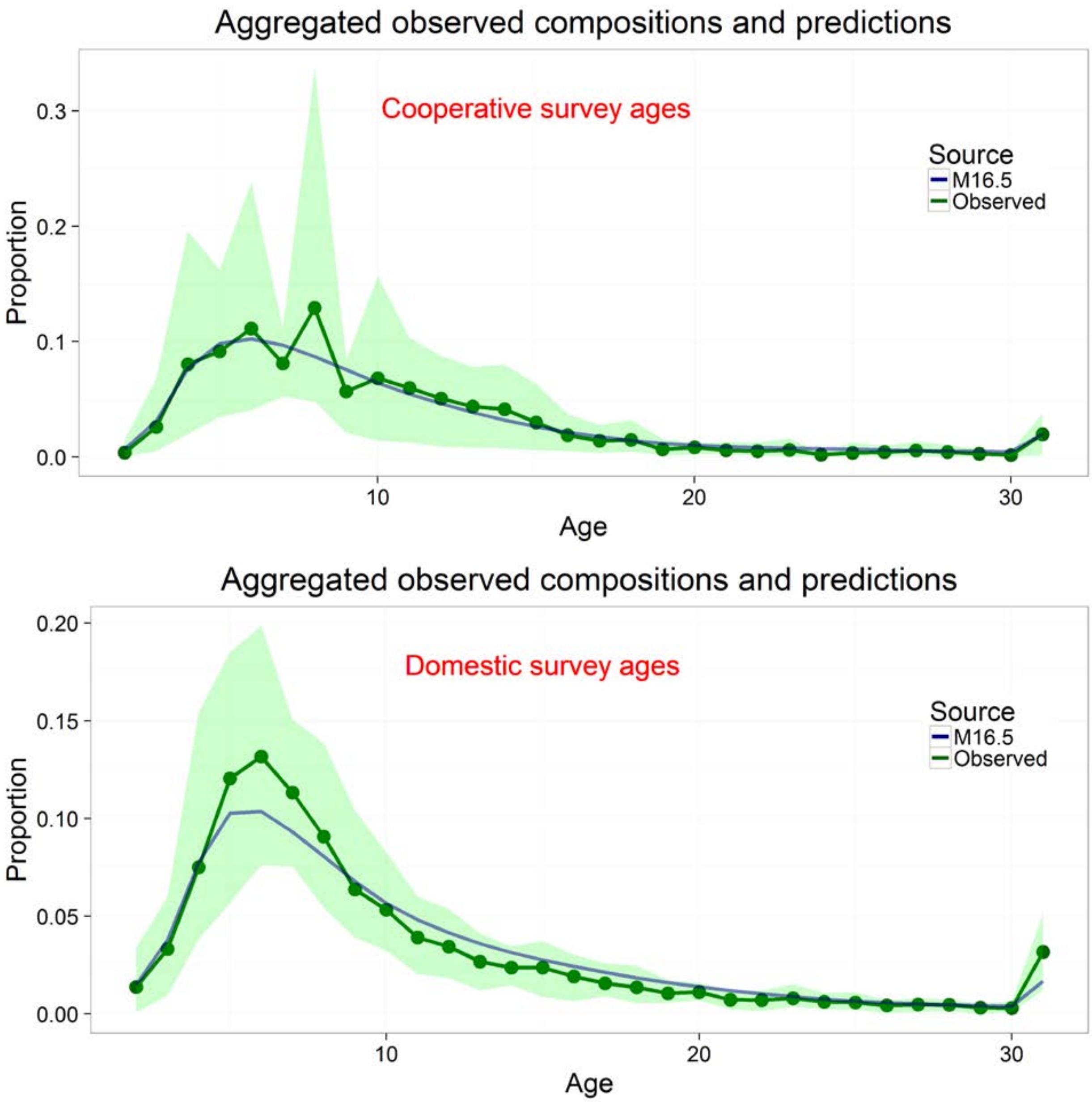


Figure 3.25. Cooperative and domestic survey age compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

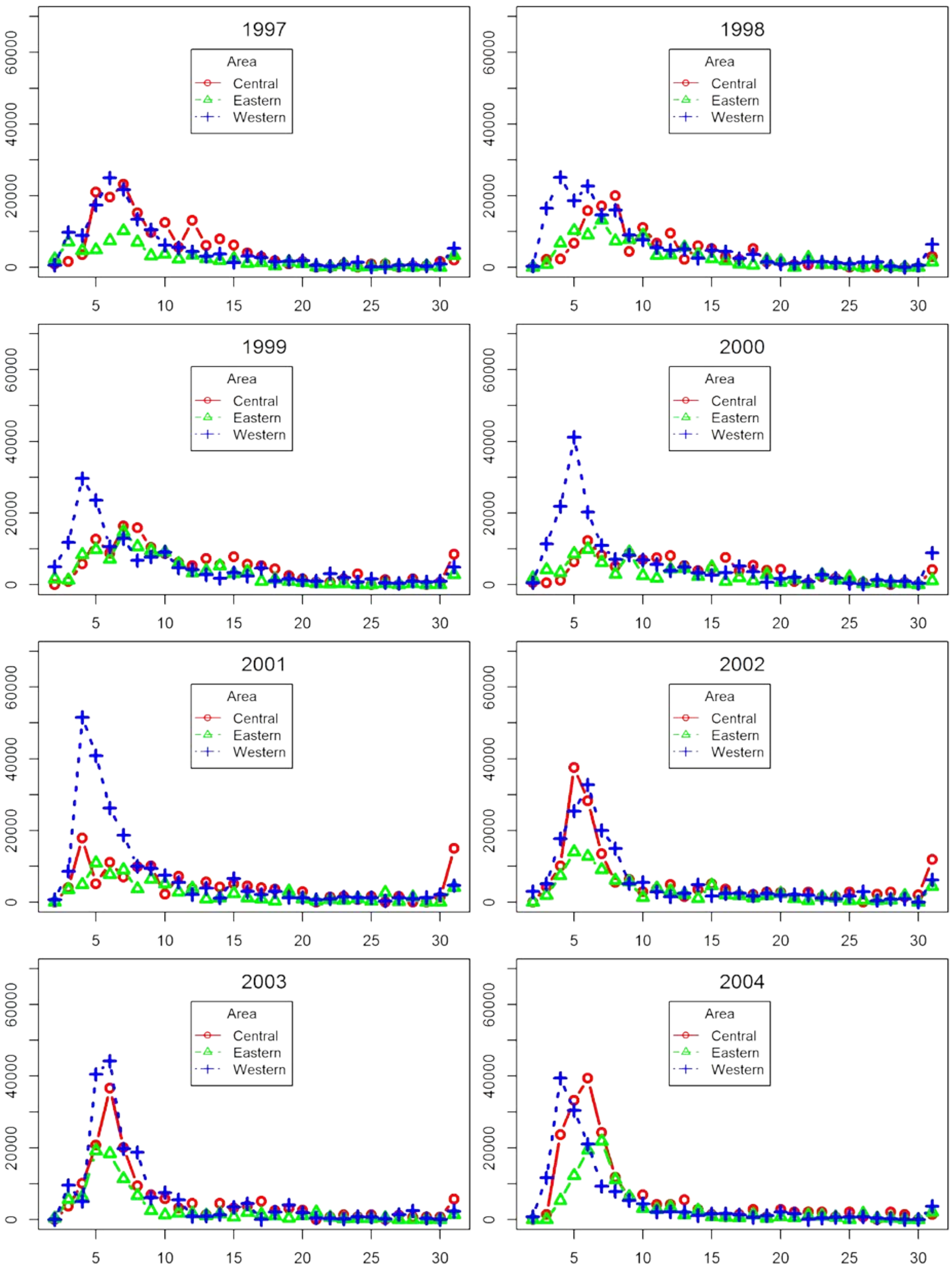


Figure 3.26. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

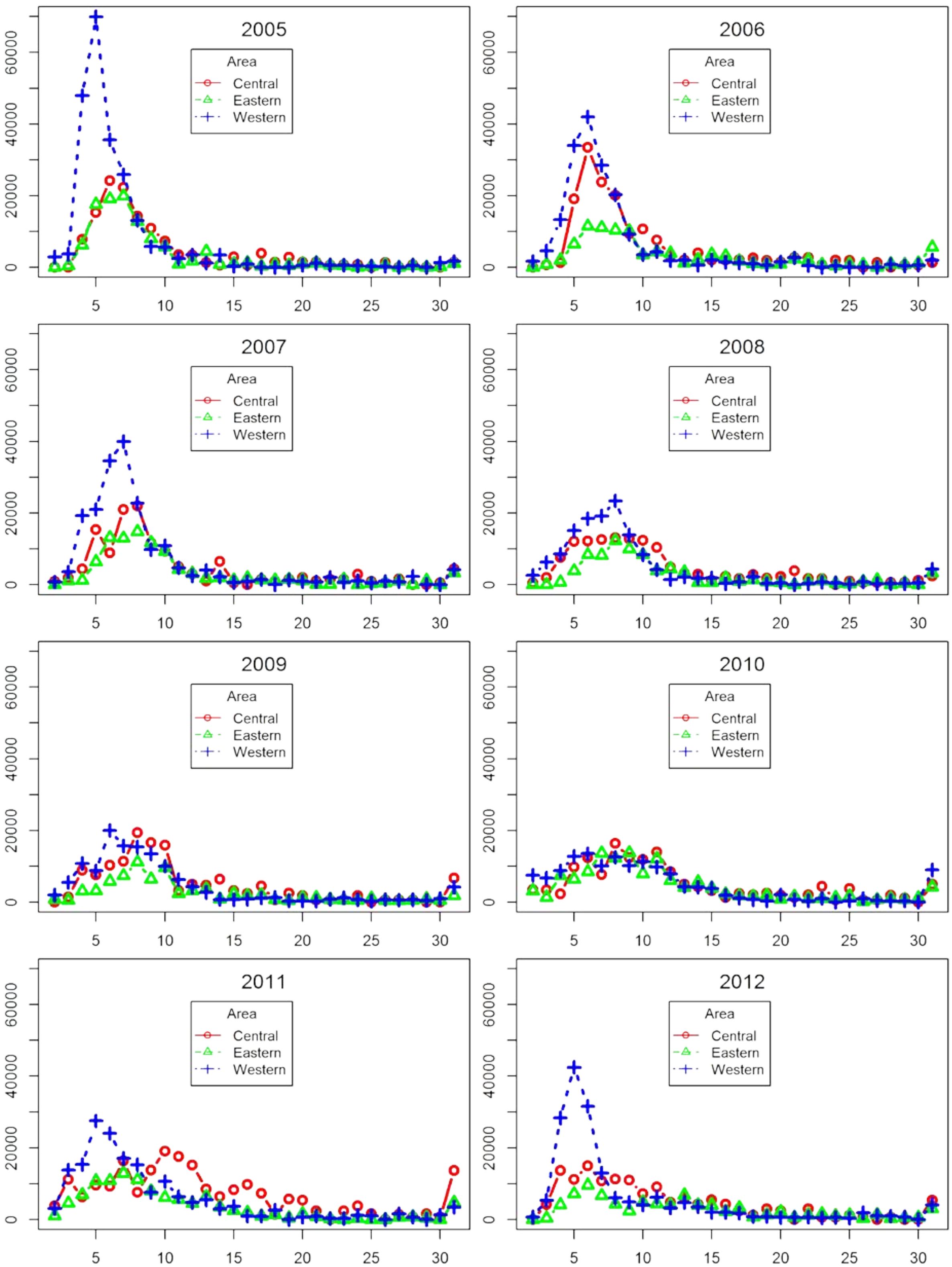


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

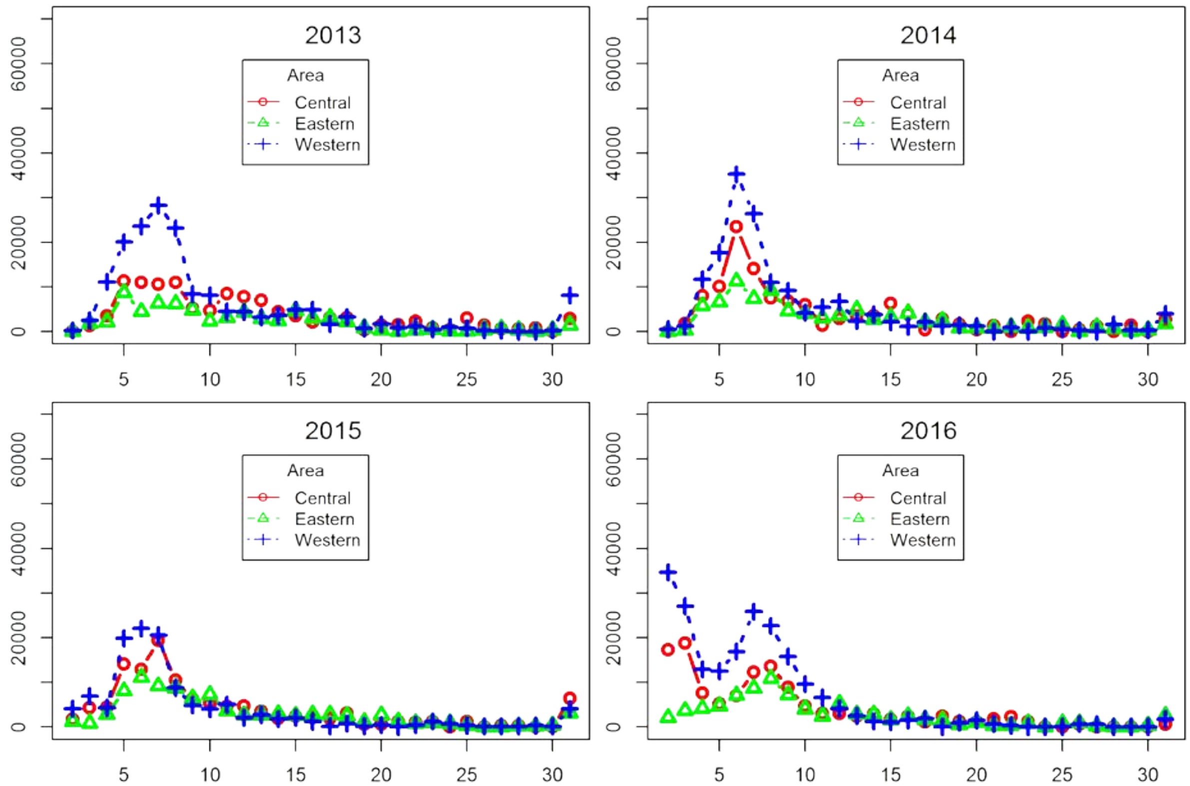


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

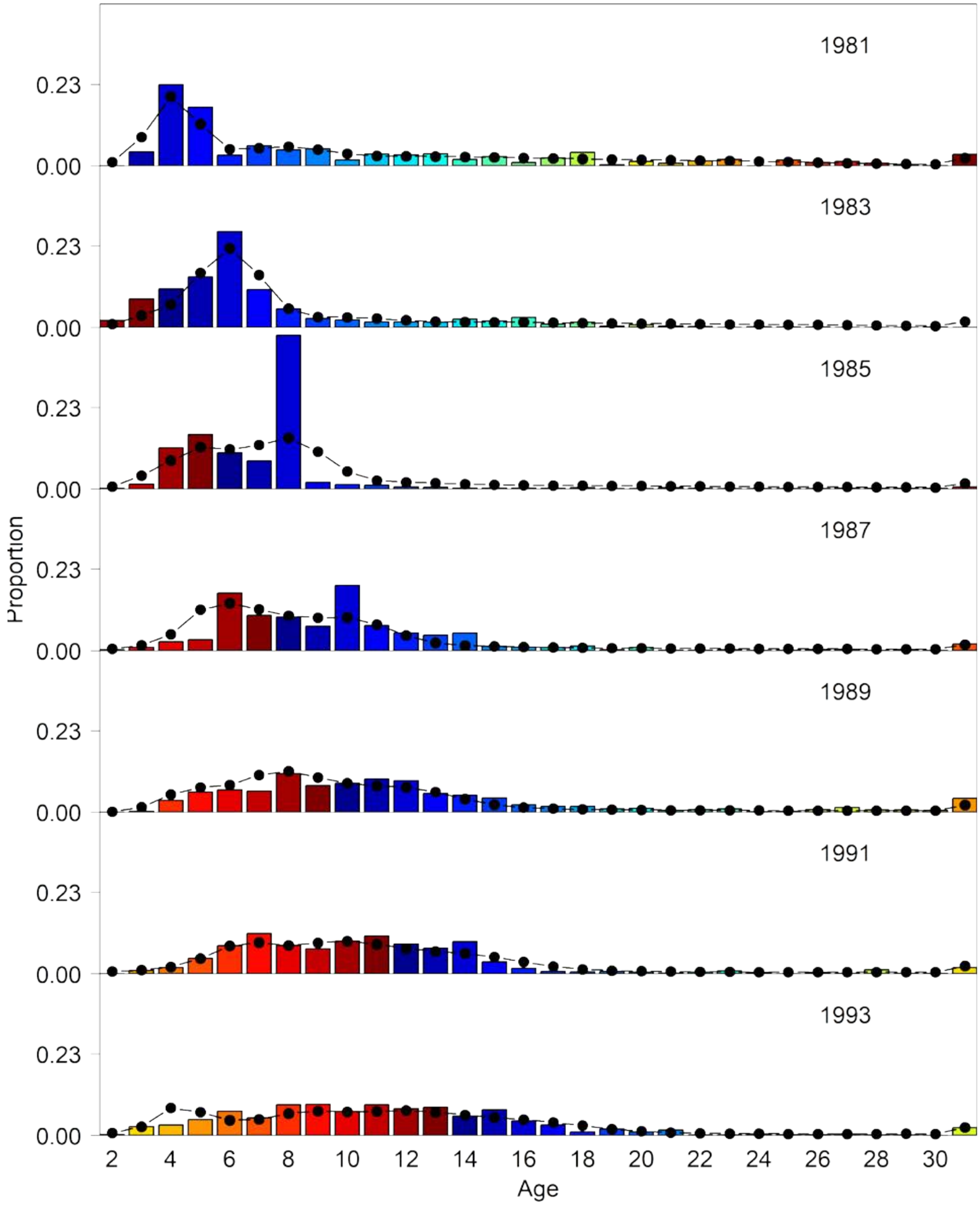


Figure 3.27. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

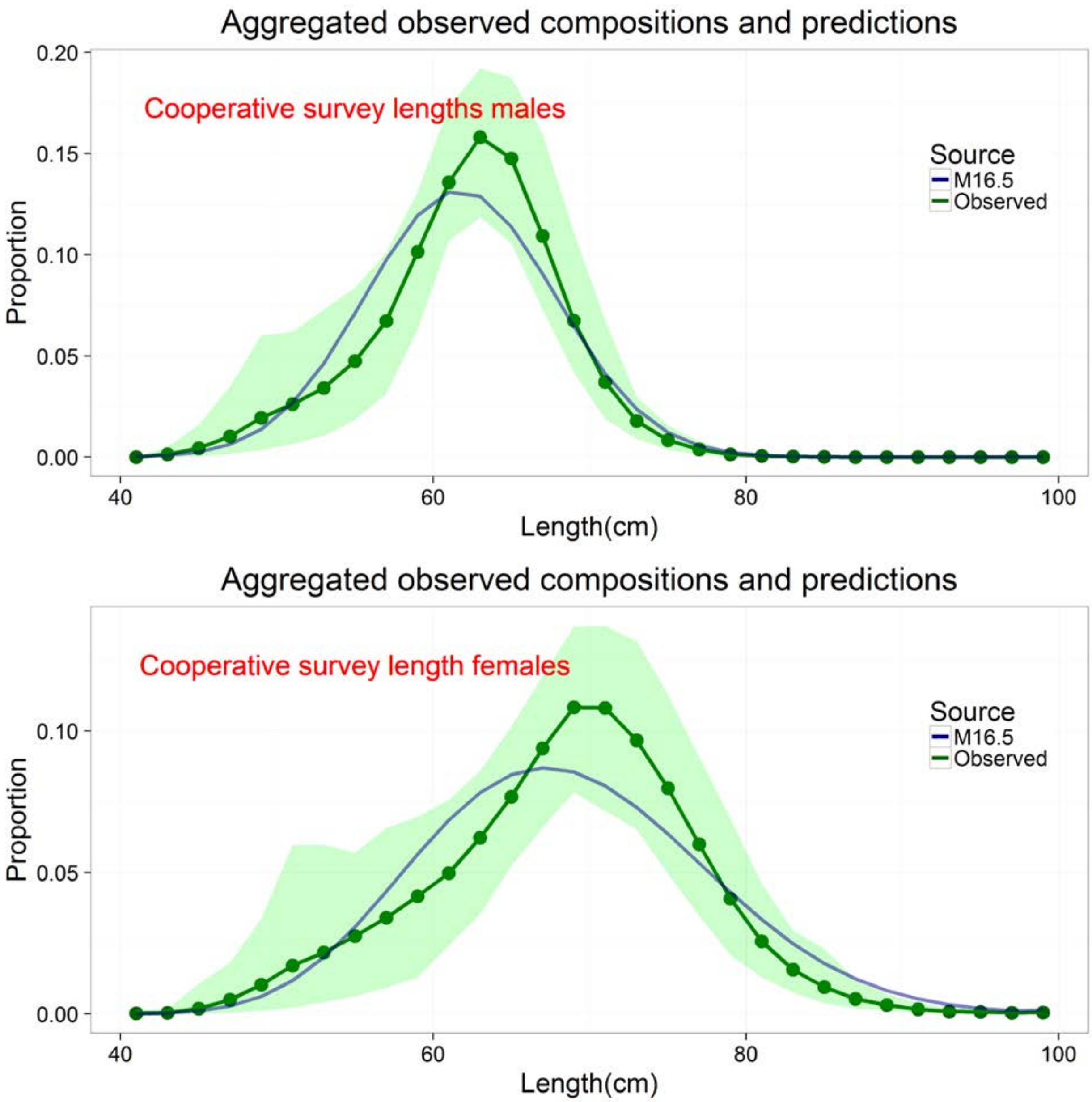


Figure 3.28. Cooperative longline survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

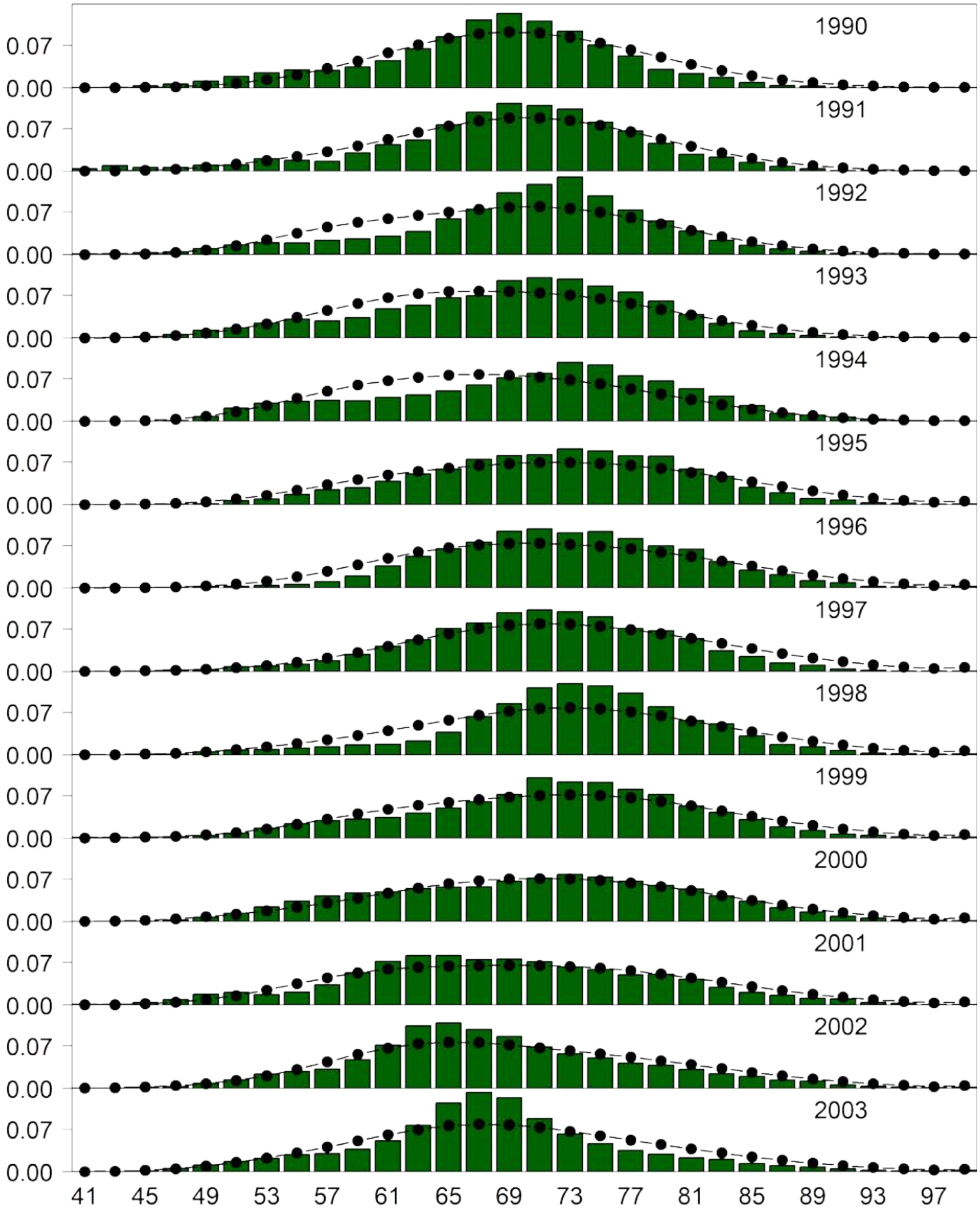


Figure 3.29. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

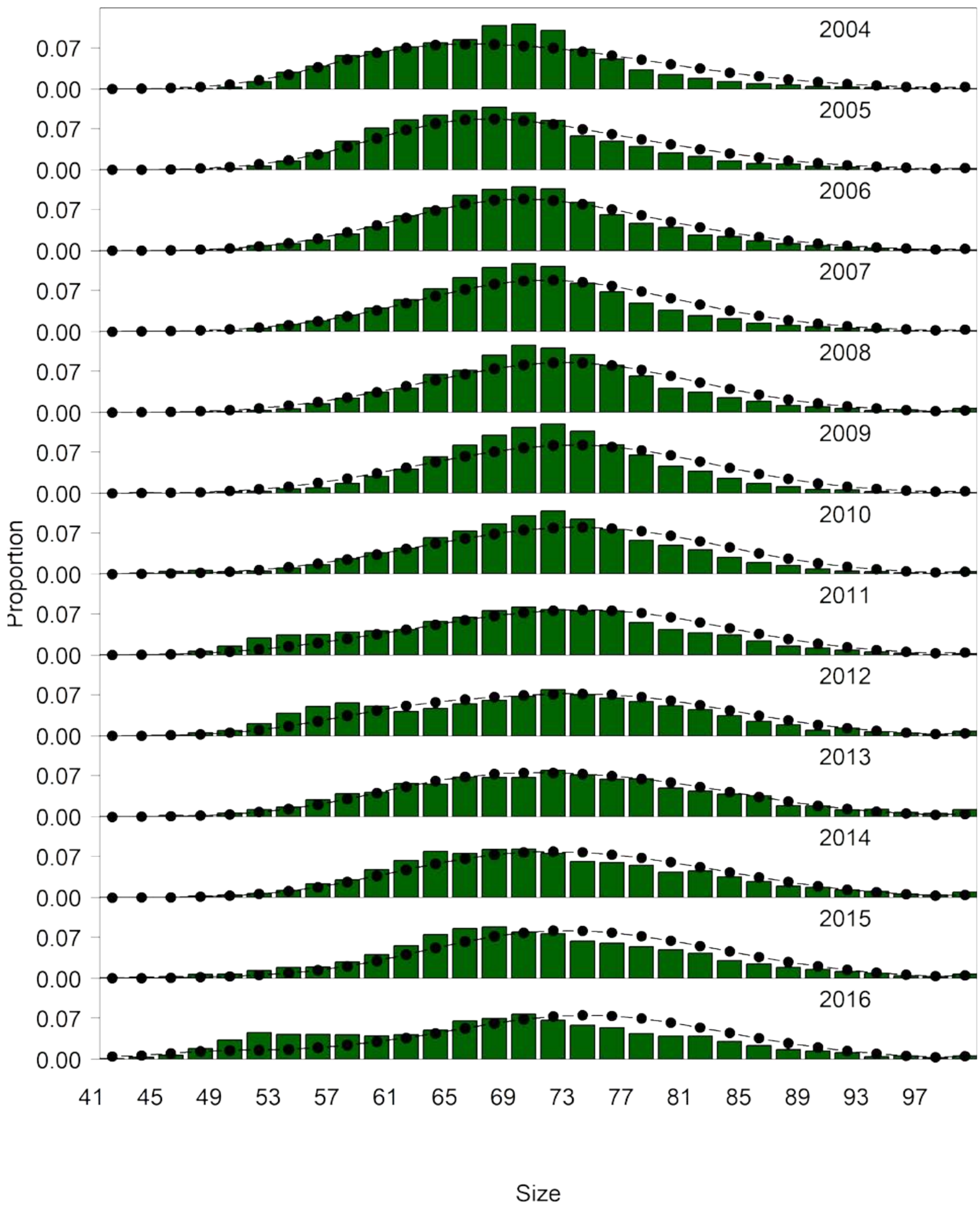


Figure 3.29 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

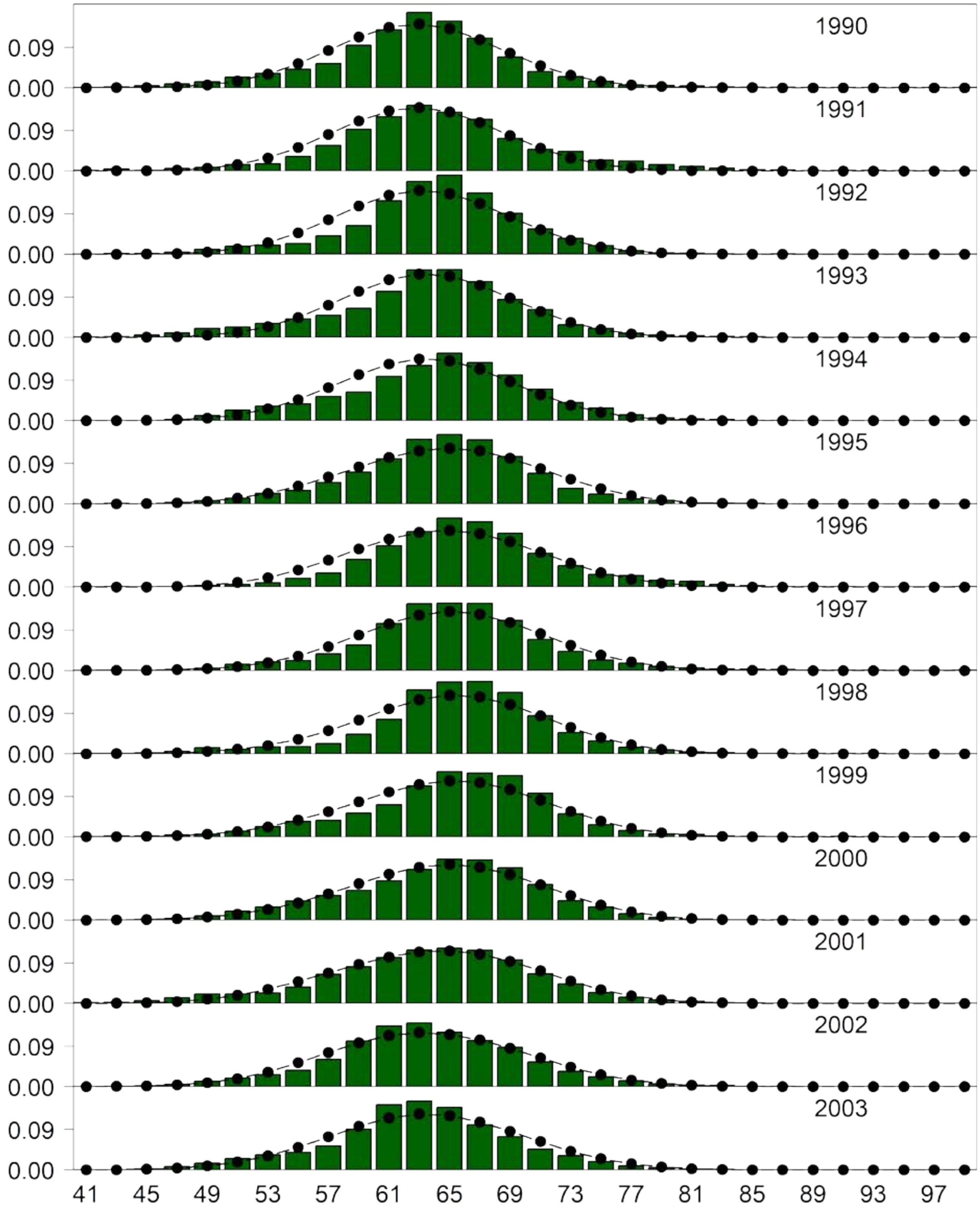


Figure 3.30. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

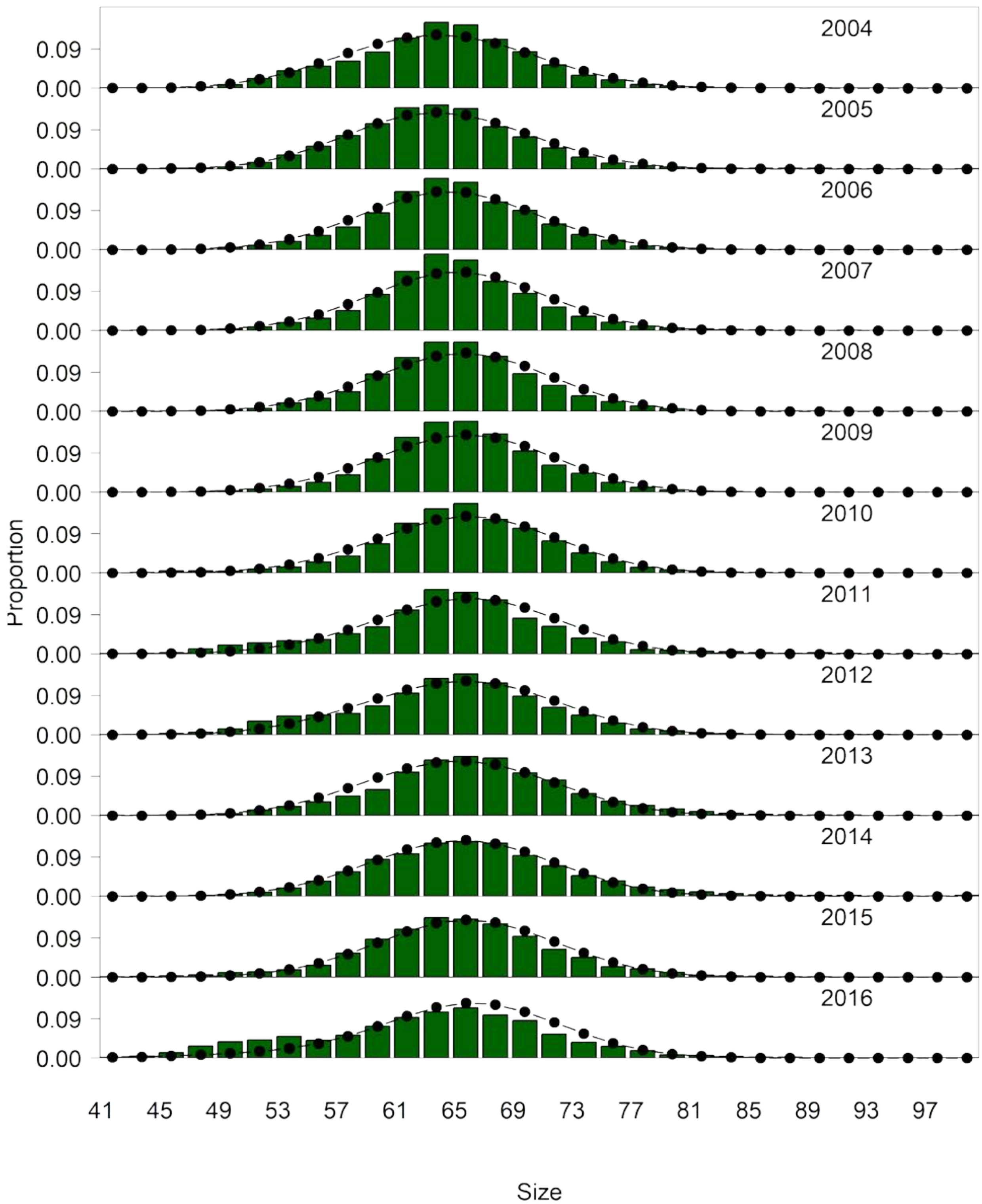


Figure 3.30 (cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

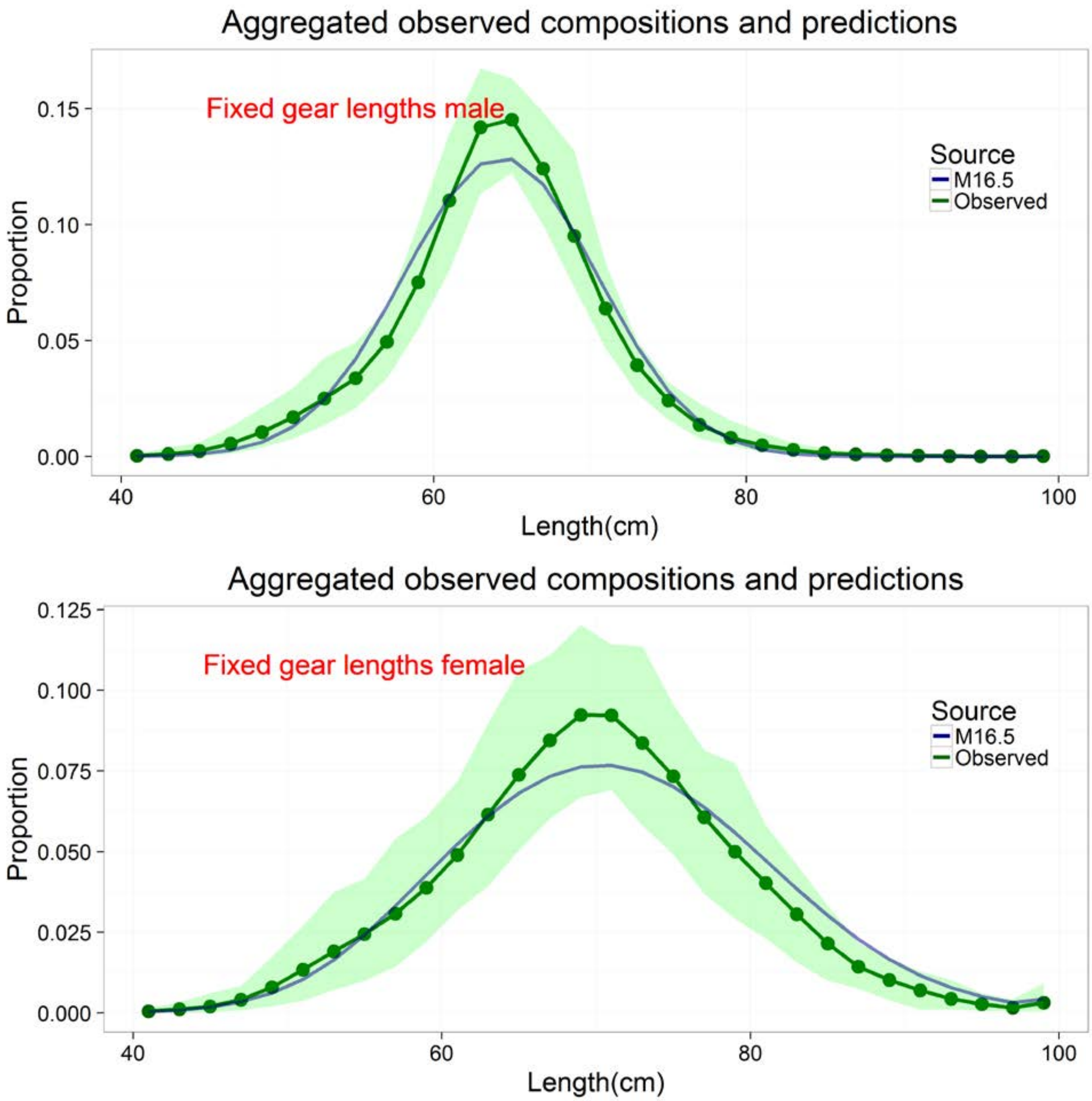


Figure 3.31. Domestic fixed gear fishery length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

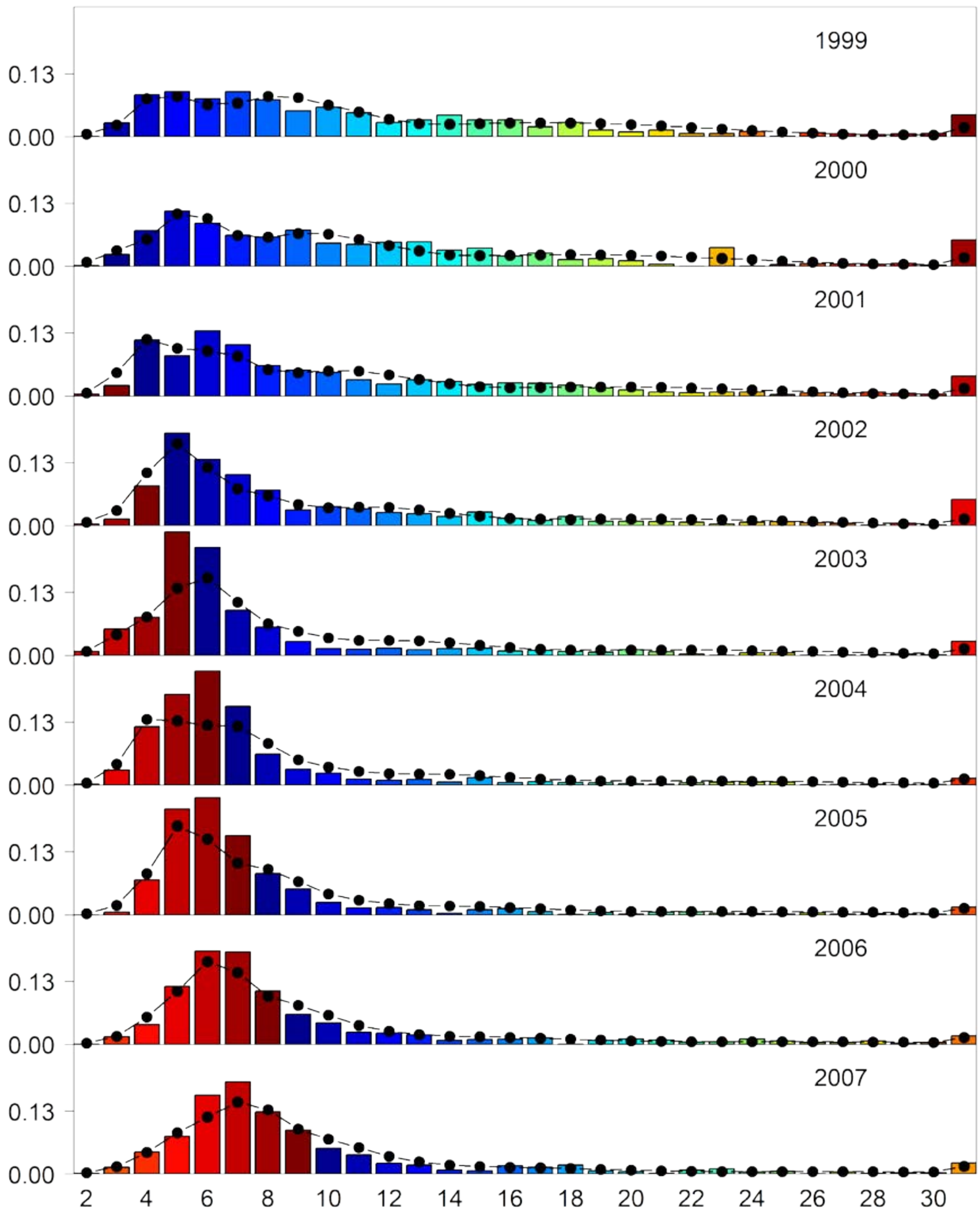


Figure 3.32. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

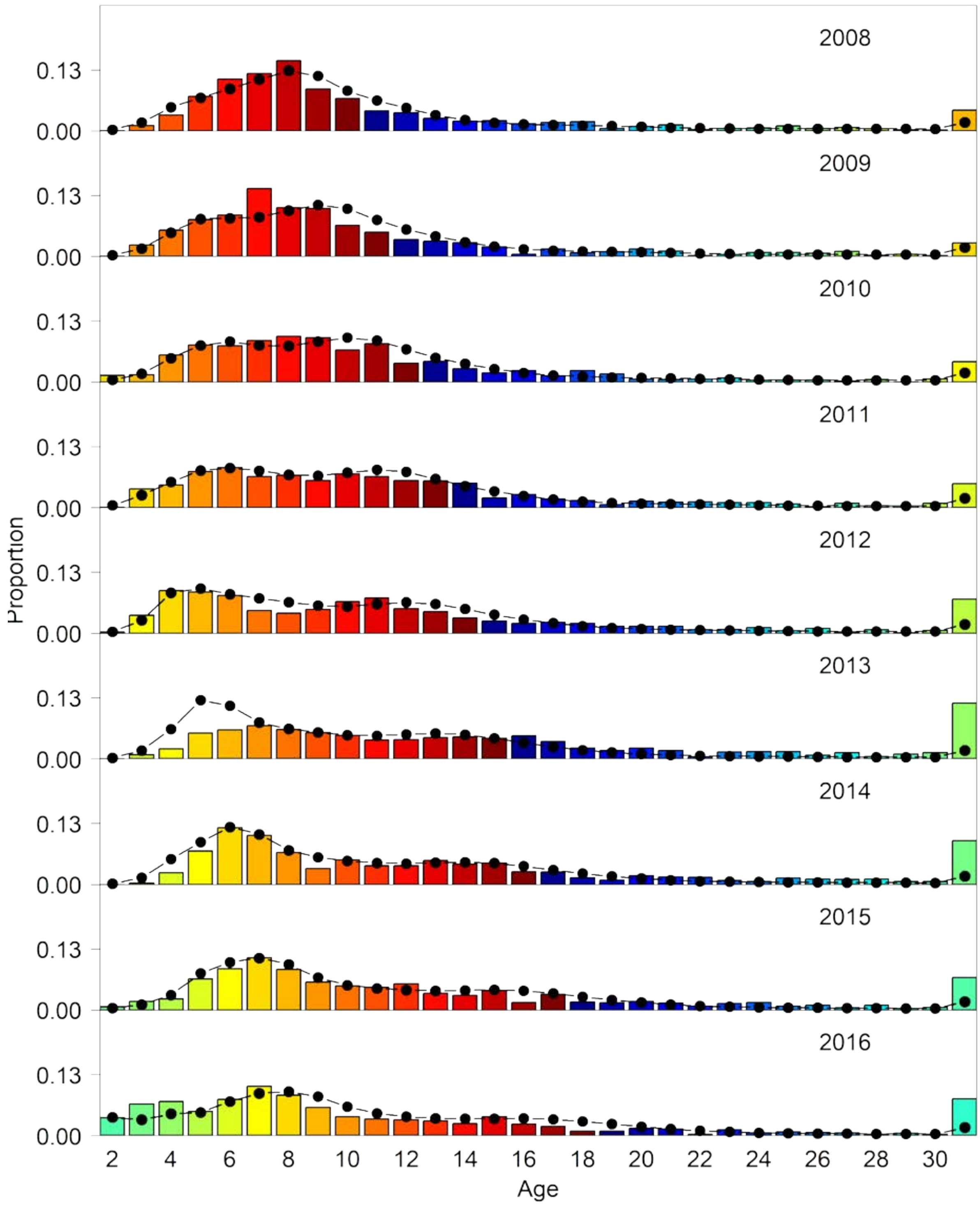


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

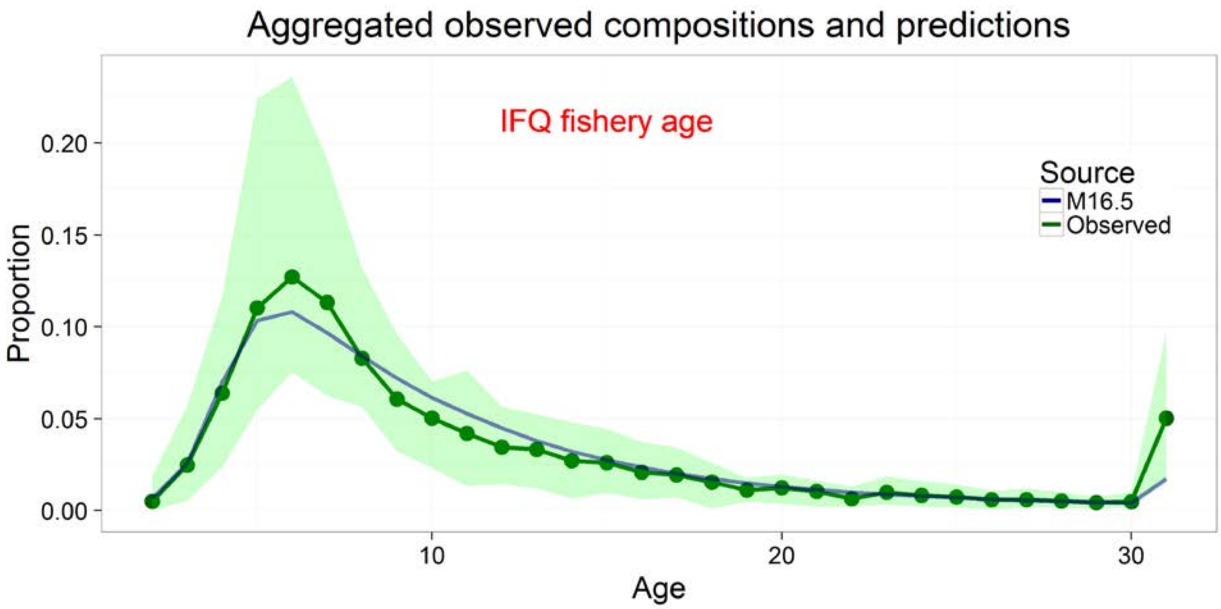


Figure 3.33. Domestic fishery age compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

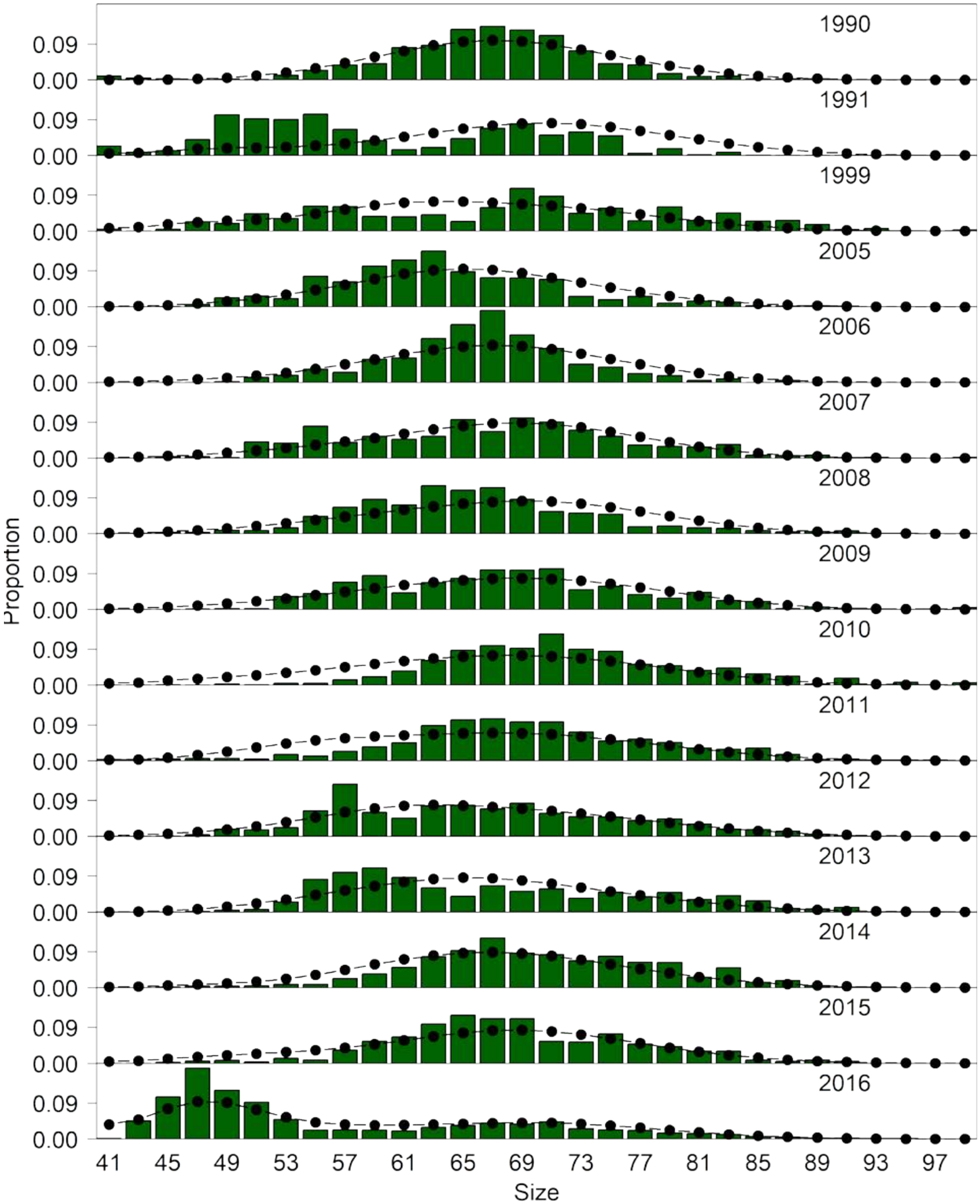


Figure 3.34. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

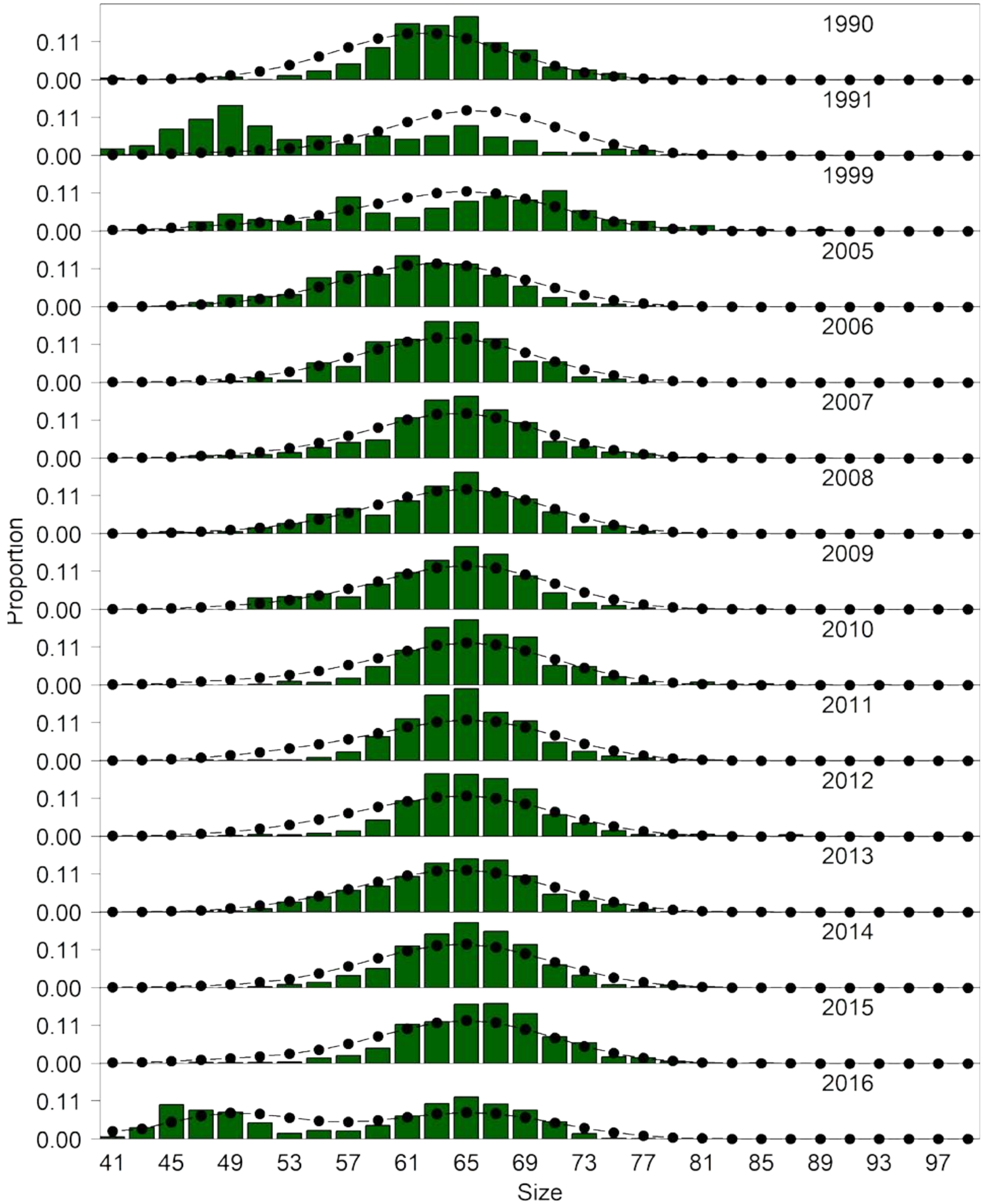


Figure 3.35. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

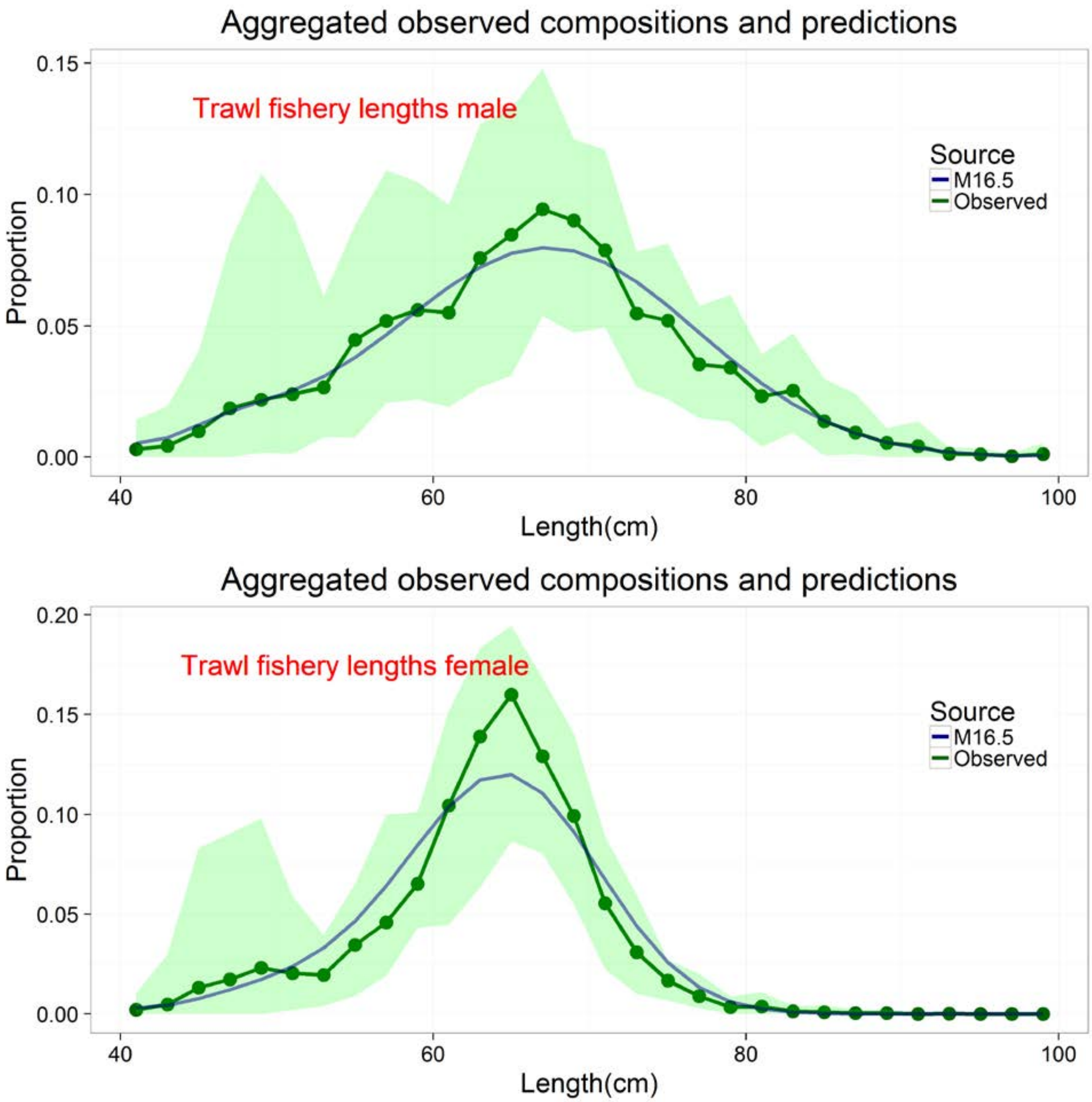


Figure 3.36. Domestic trawl fishery length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

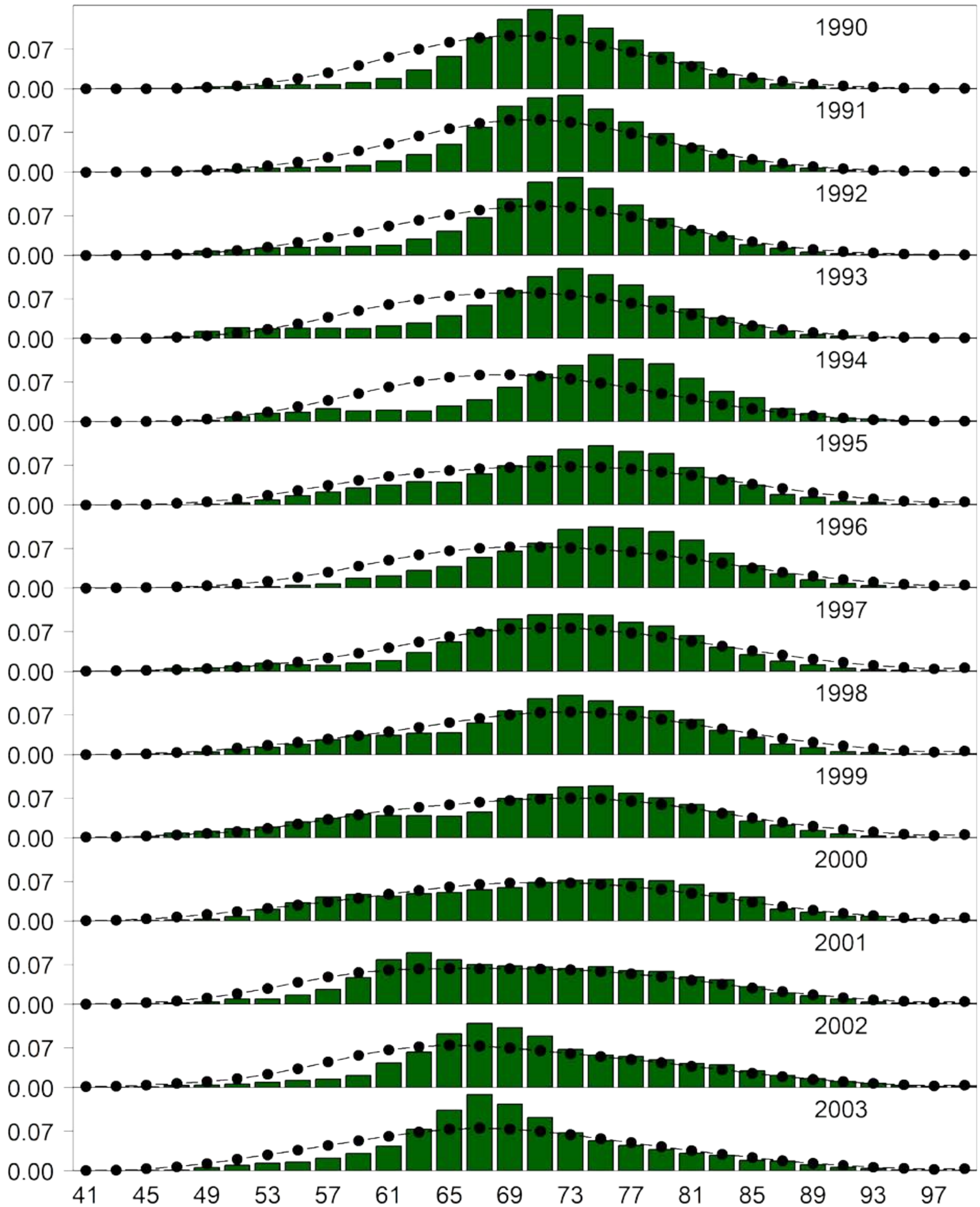


Figure 3.37. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

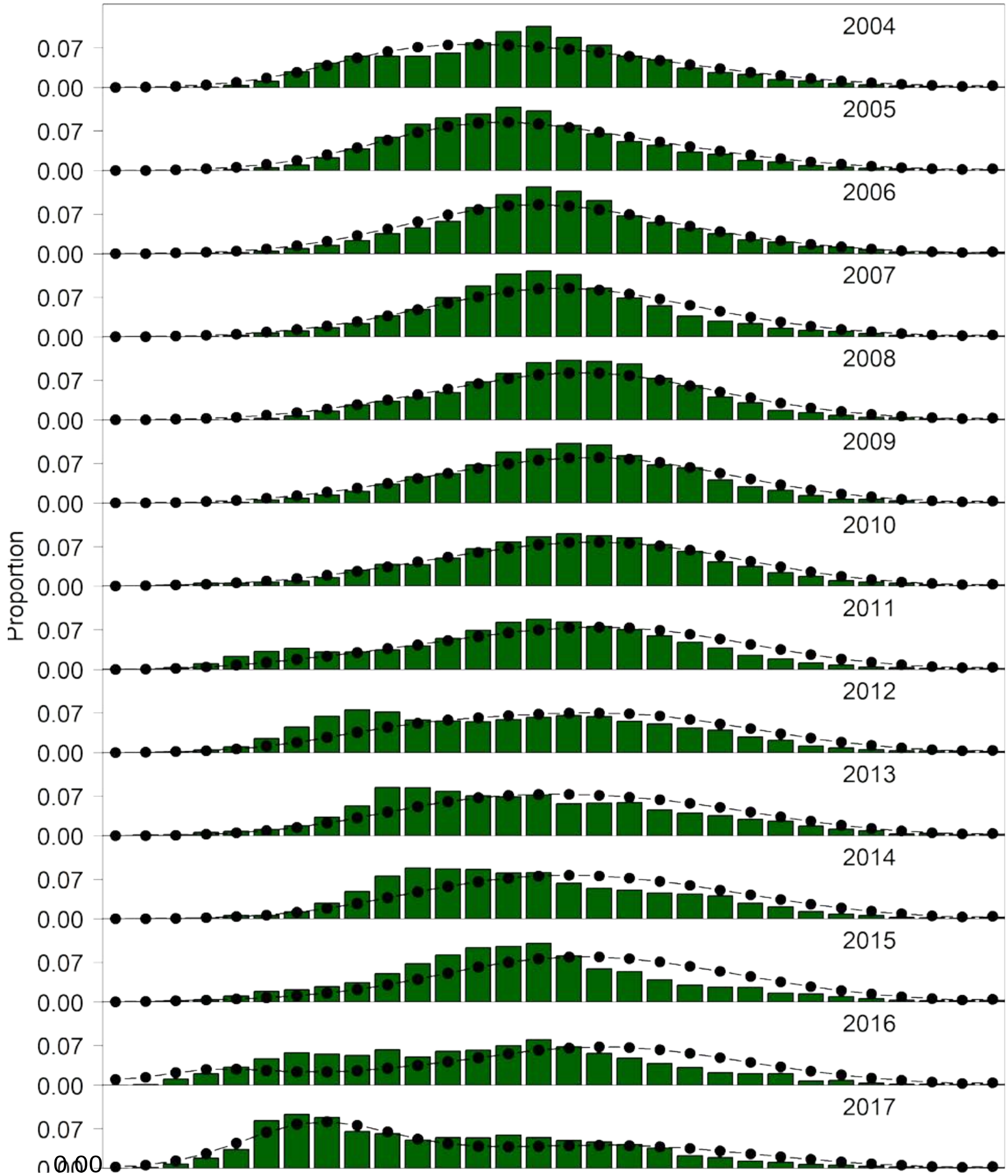


Figure 3.37 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

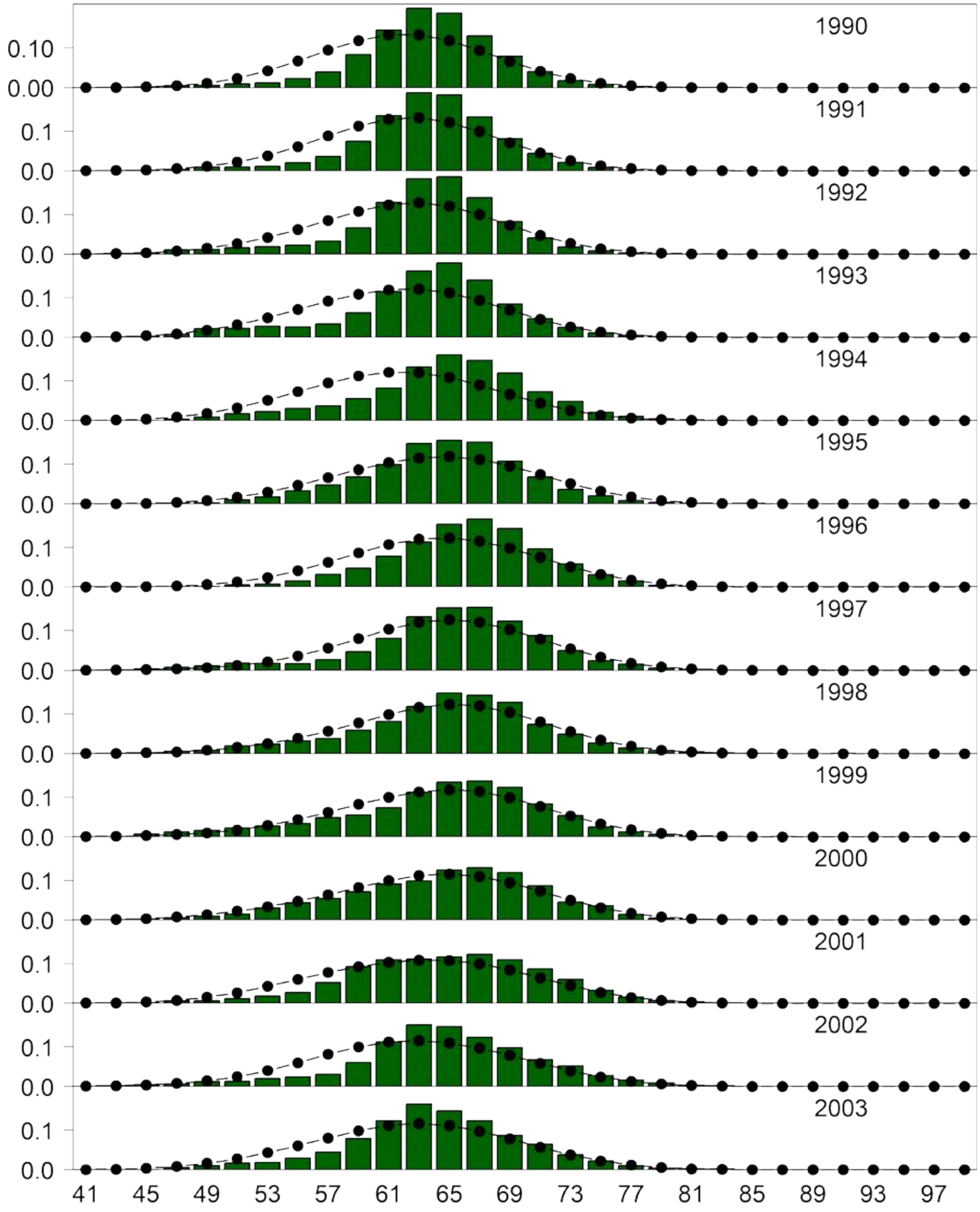


Figure 3.38. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

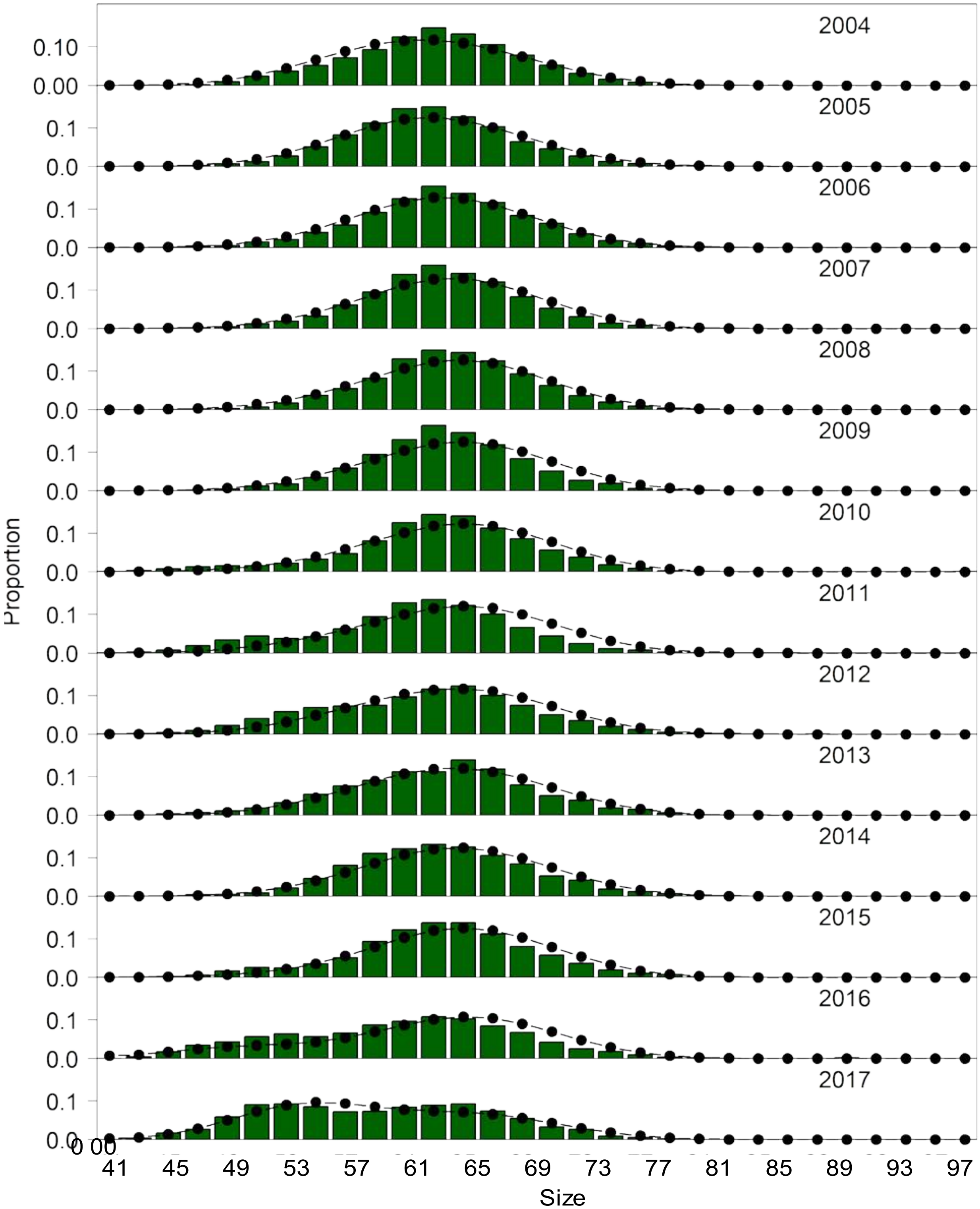


Figure 3.38. (cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

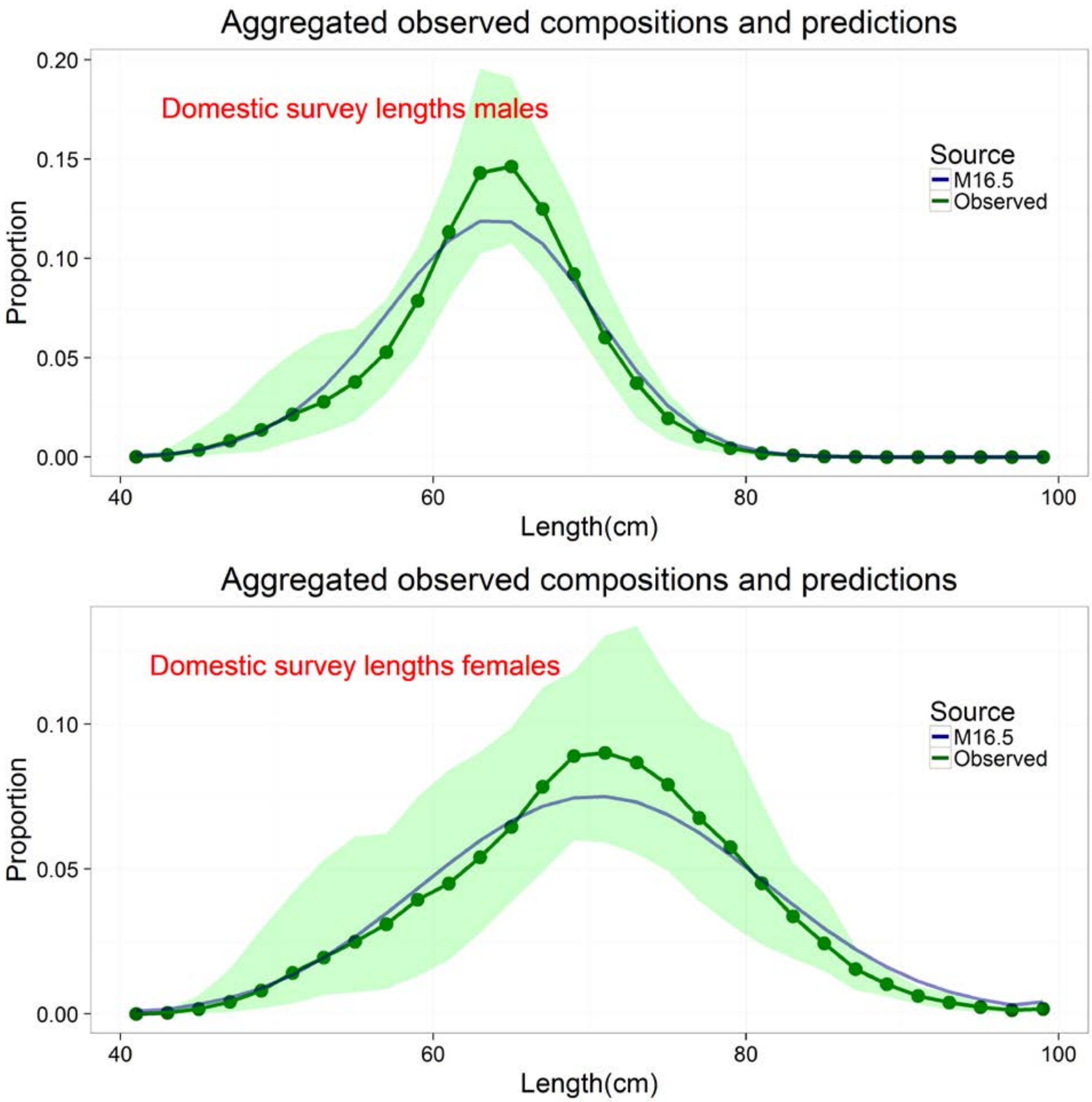


Figure 3.39. Domestic longline survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

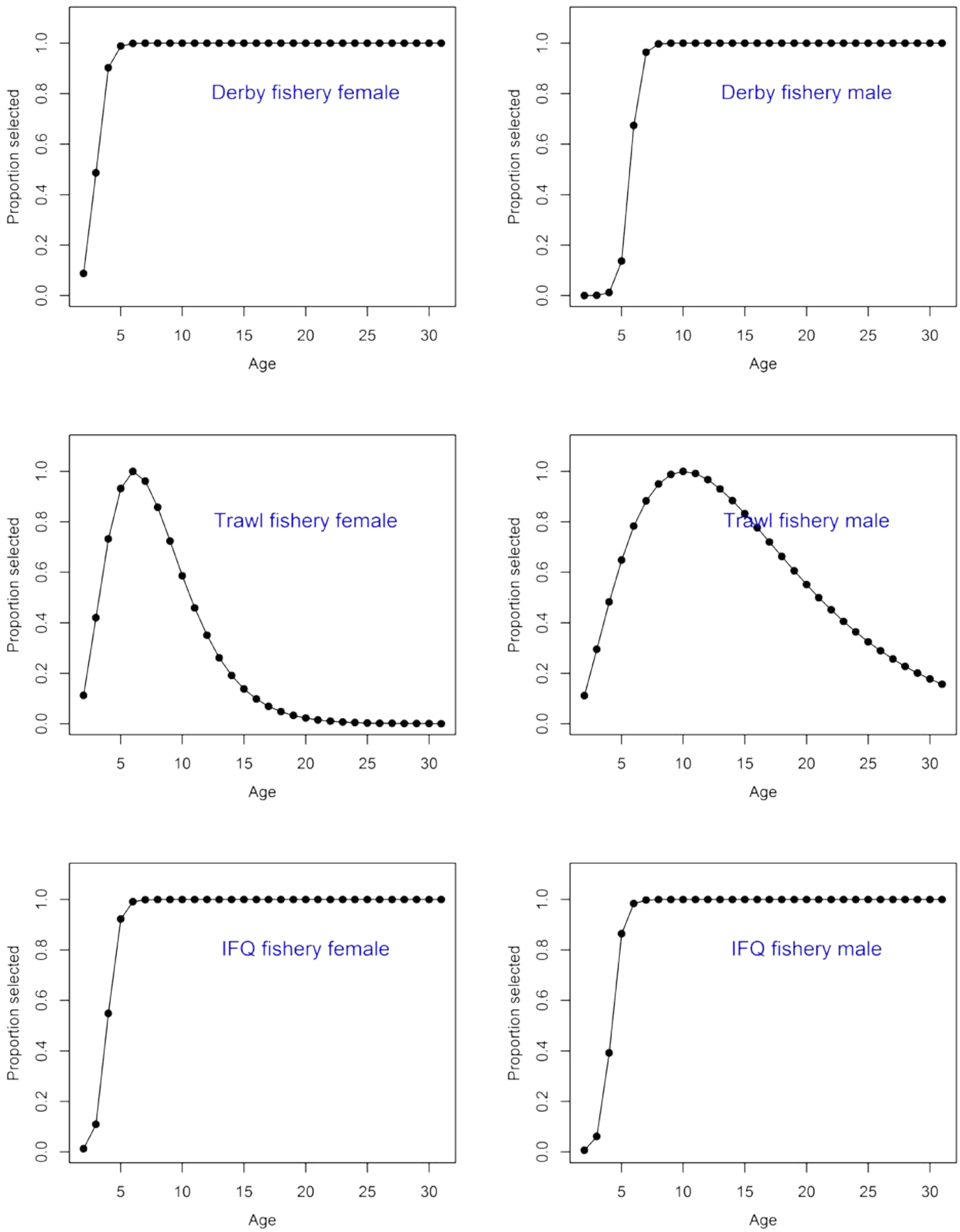


Figure 3.40. Sablefish selectivities for fisheries. The derby longline occurred until 1994 when the fishery switched to IFQ in 1995.

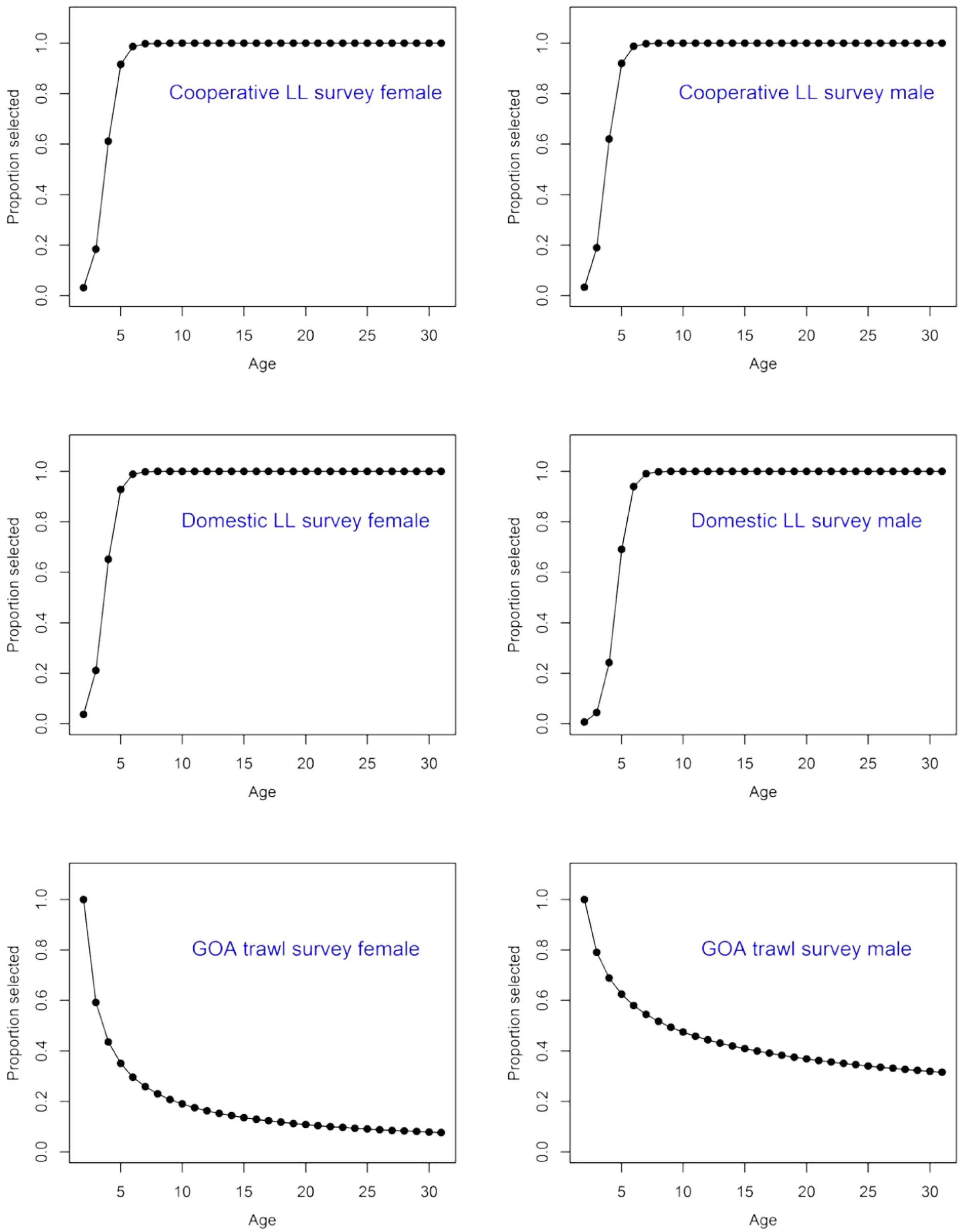


Figure 3.40 (cont.). Sablefish selectivities for surveys.

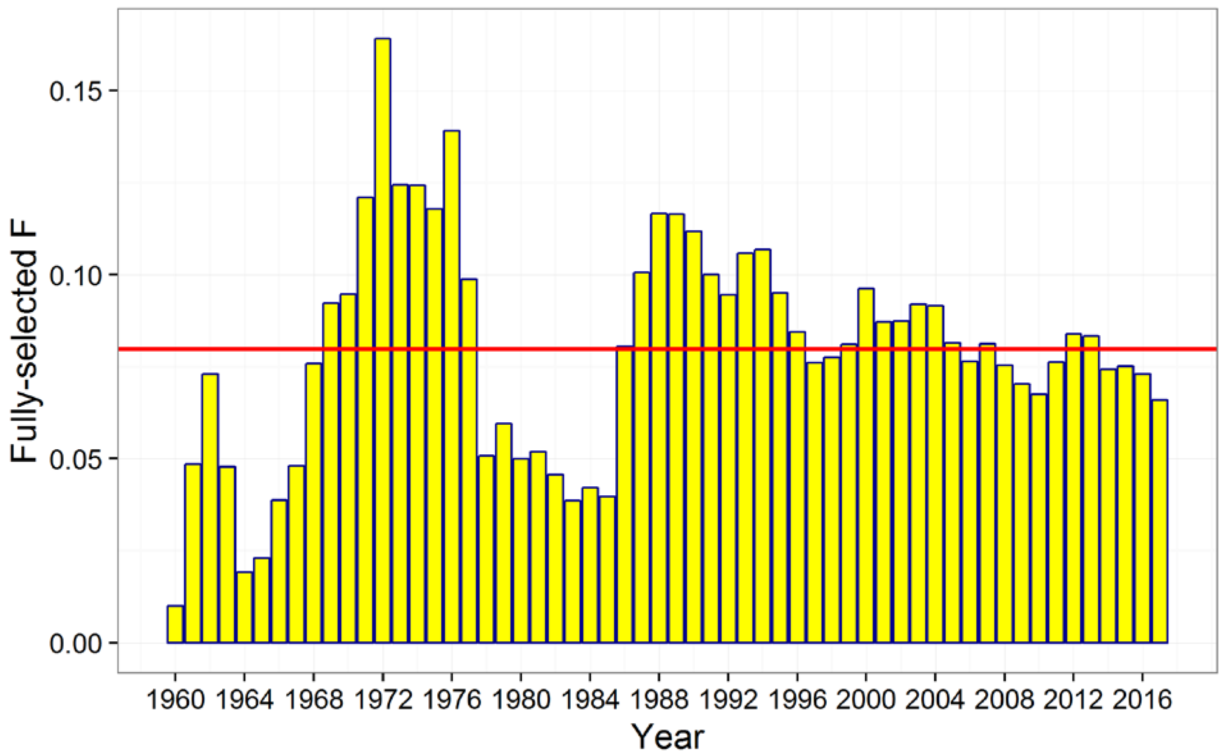


Figure 3.41. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

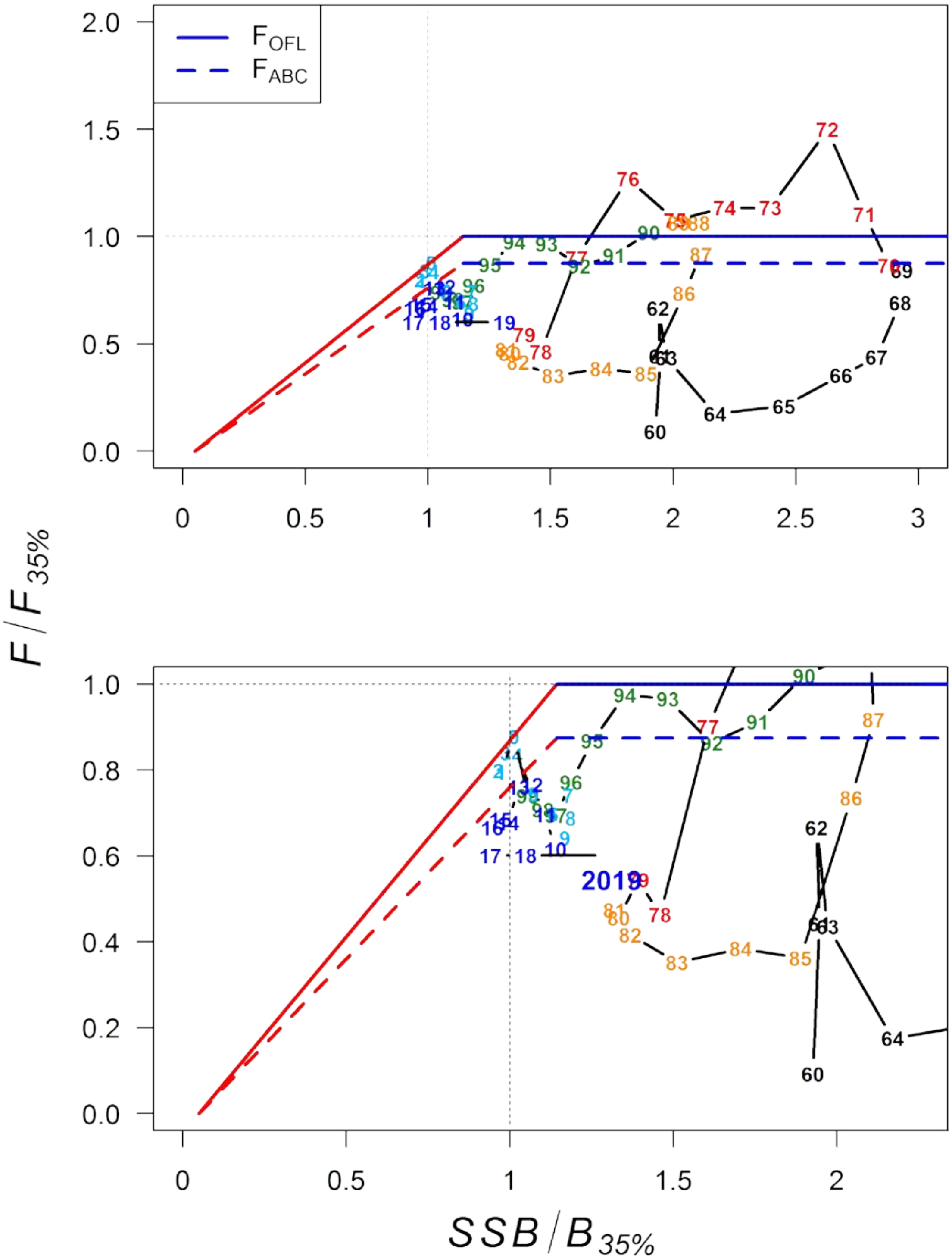


Figure 3.42. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model. Bottom is zoomed in to examine more recent years.

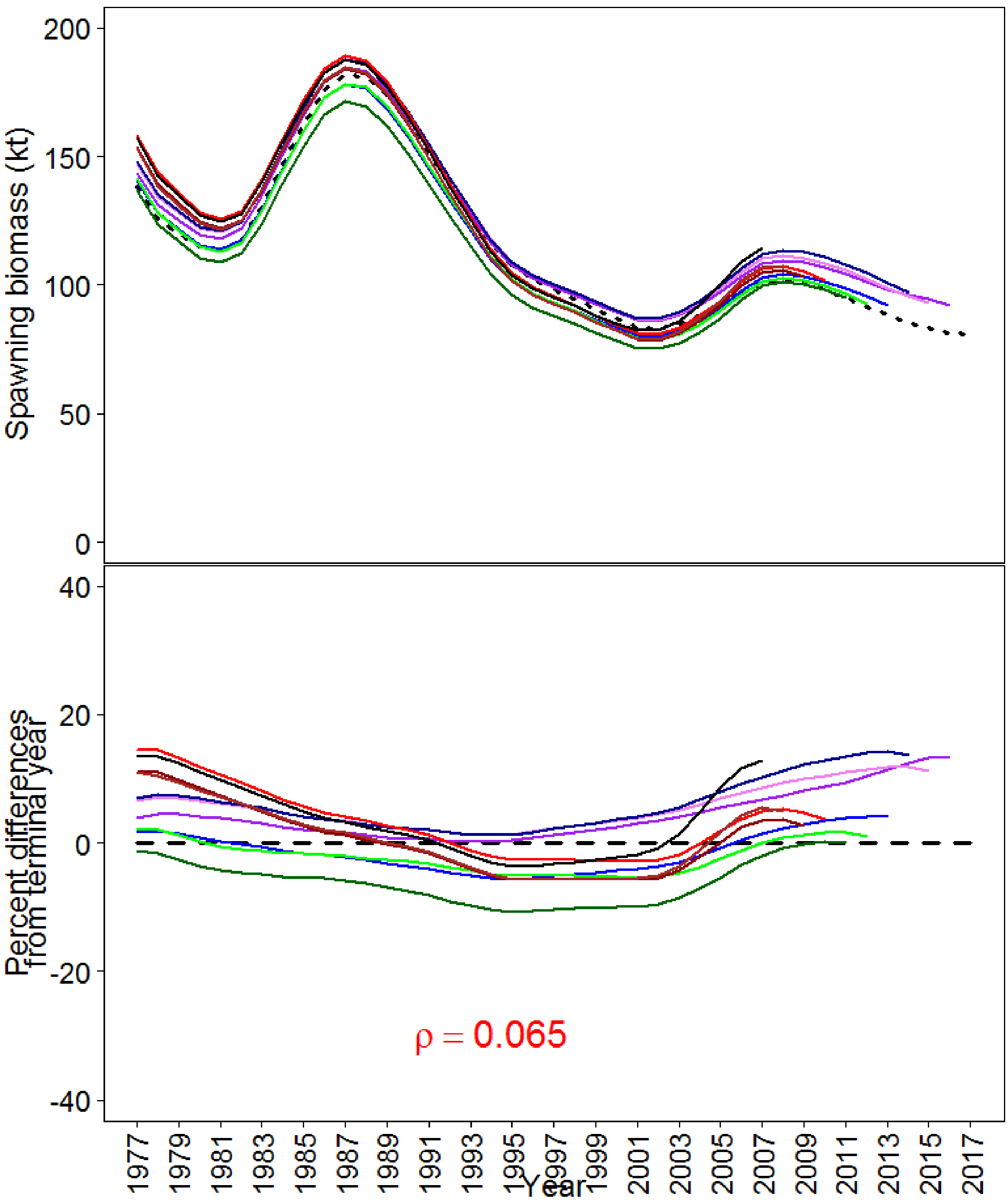


Figure 3.43. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 1977-2017.

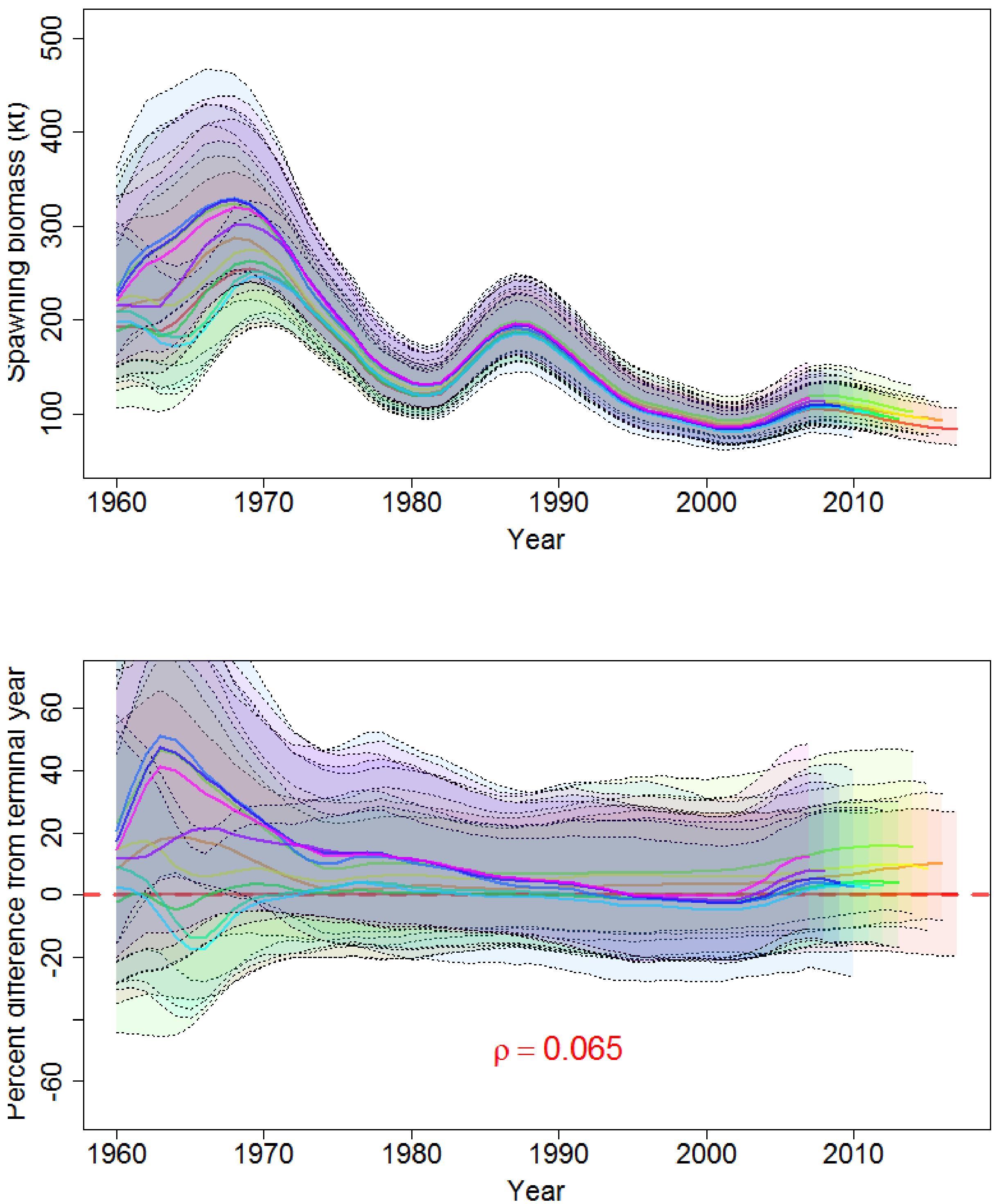


Figure 3.44. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 1960-2016 with MCMC credible intervals per year.

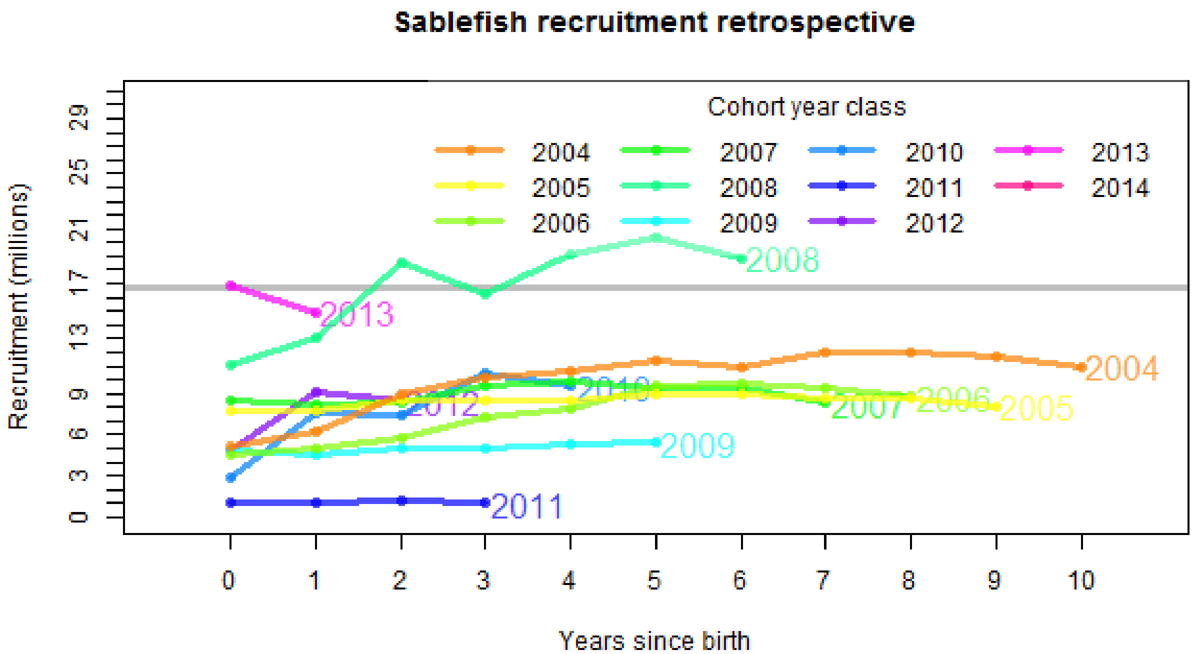


Figure 3.45. Squid plot of the development of initial estimates of age-2 recruitment since year class 2003 through year class 2013 from retrospective analysis. Number to right of terminal year indicates year class.

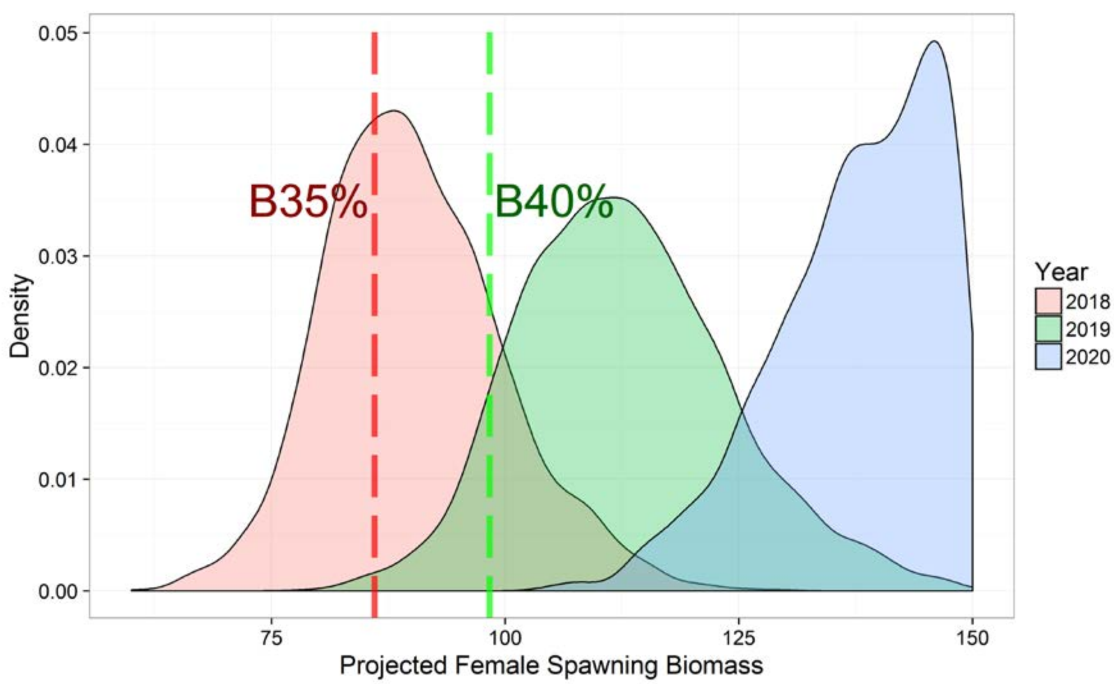


Figure 3.46. Posterior probability distribution for projected spawning biomass (thousands t) in 2018 – 2020.

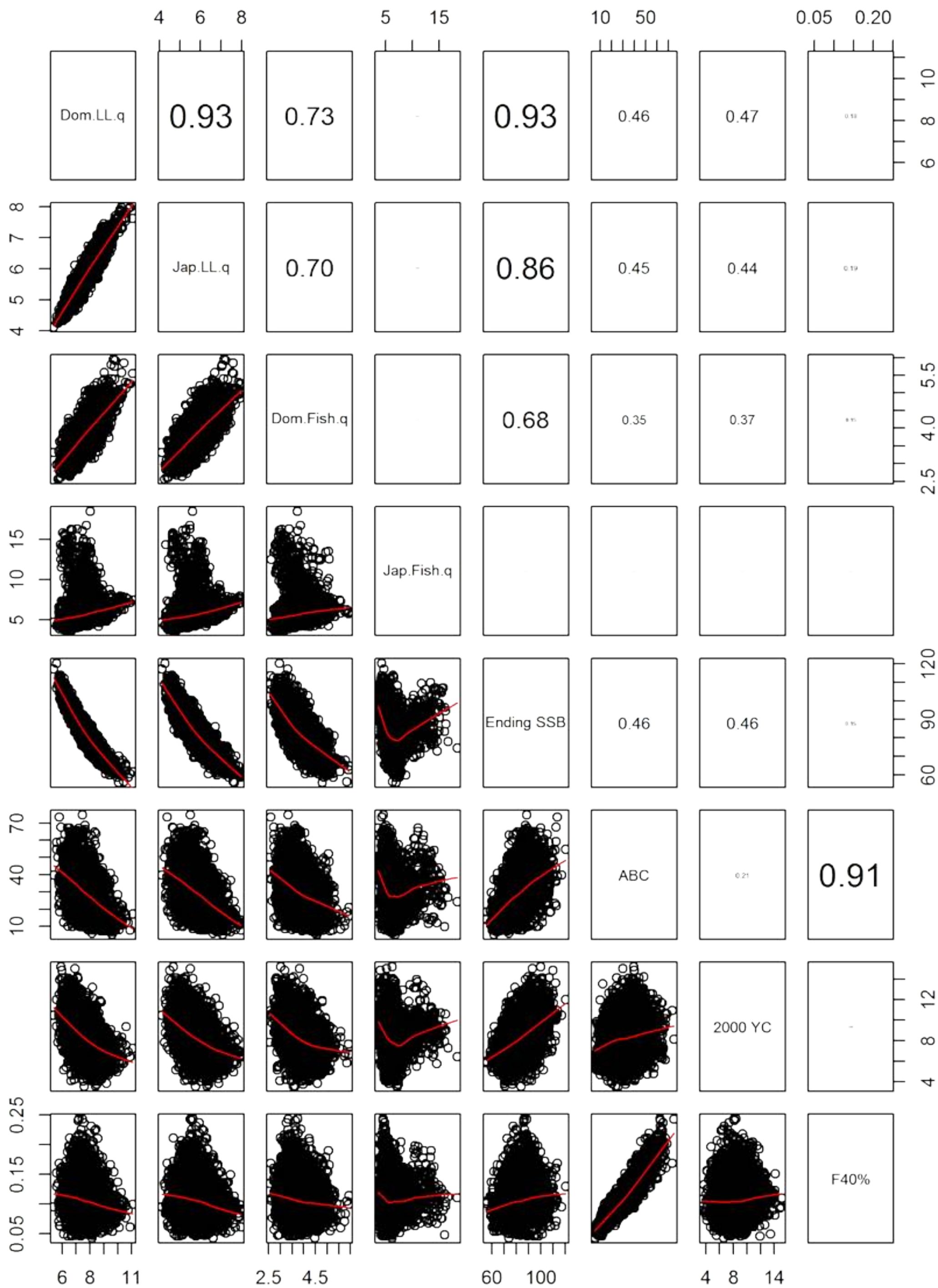


Figure 3.47. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

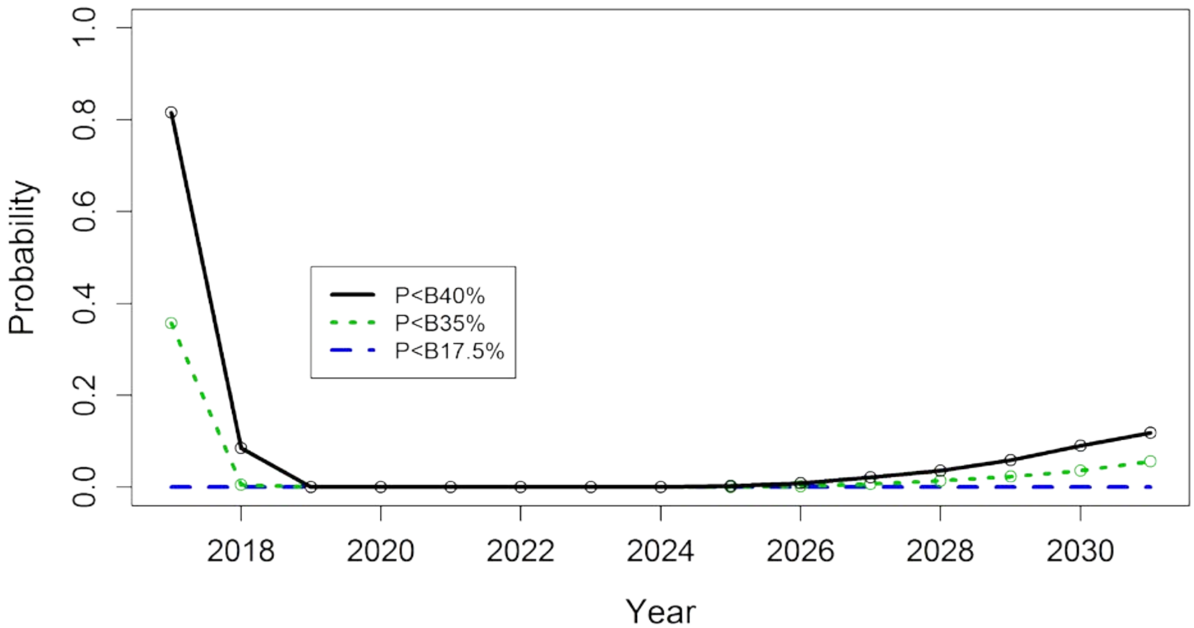


Figure 3.48. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

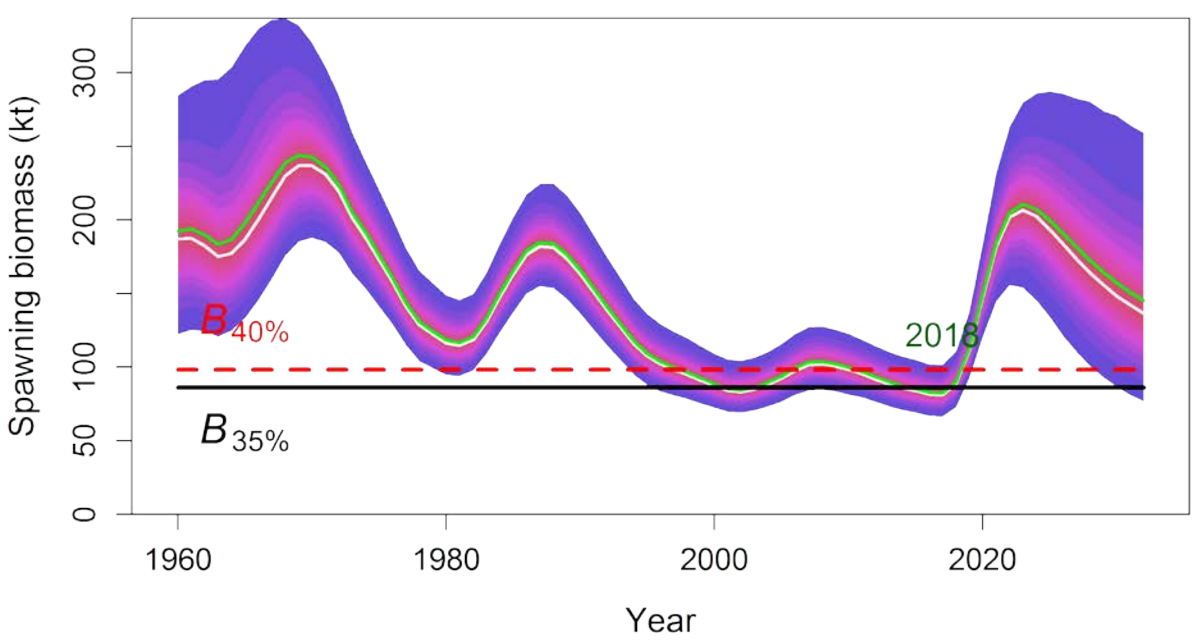


Figure 3.49. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and green line is the mean, shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is the same as the projections in Scenario 1 but with a yield multiplier of 0.867.

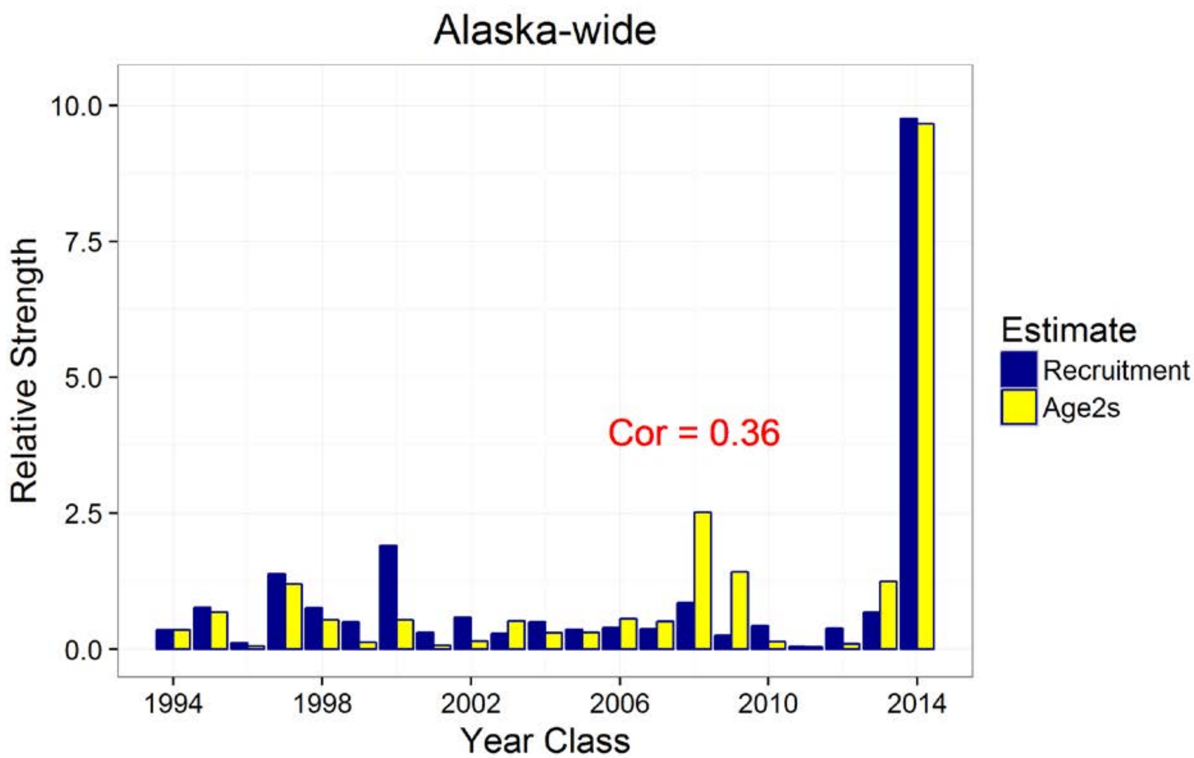


Figure 3.50. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

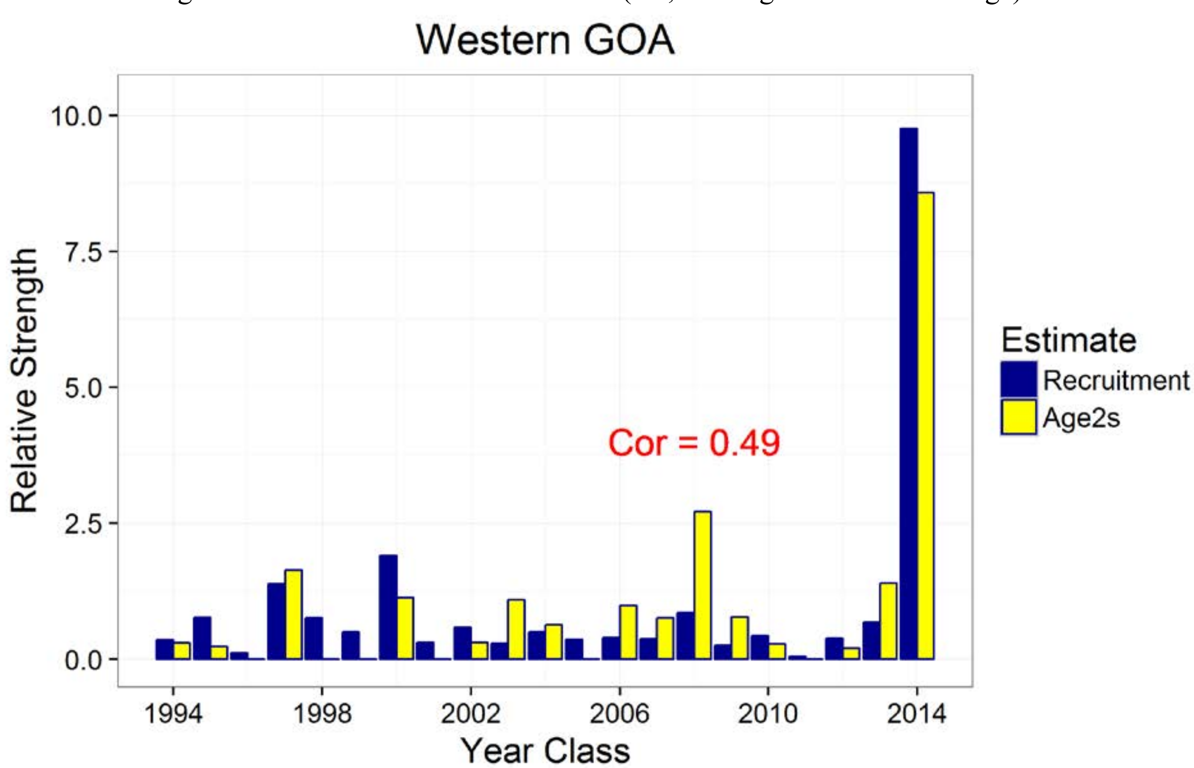


Figure 3.51. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

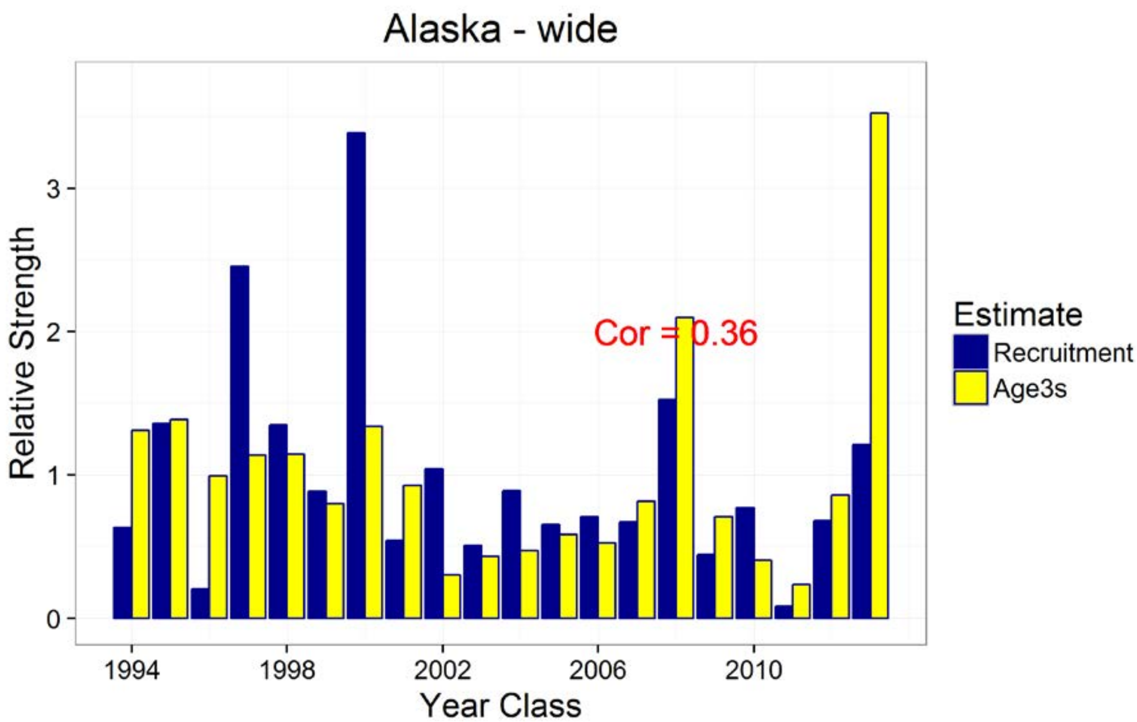


Figure 3.52. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

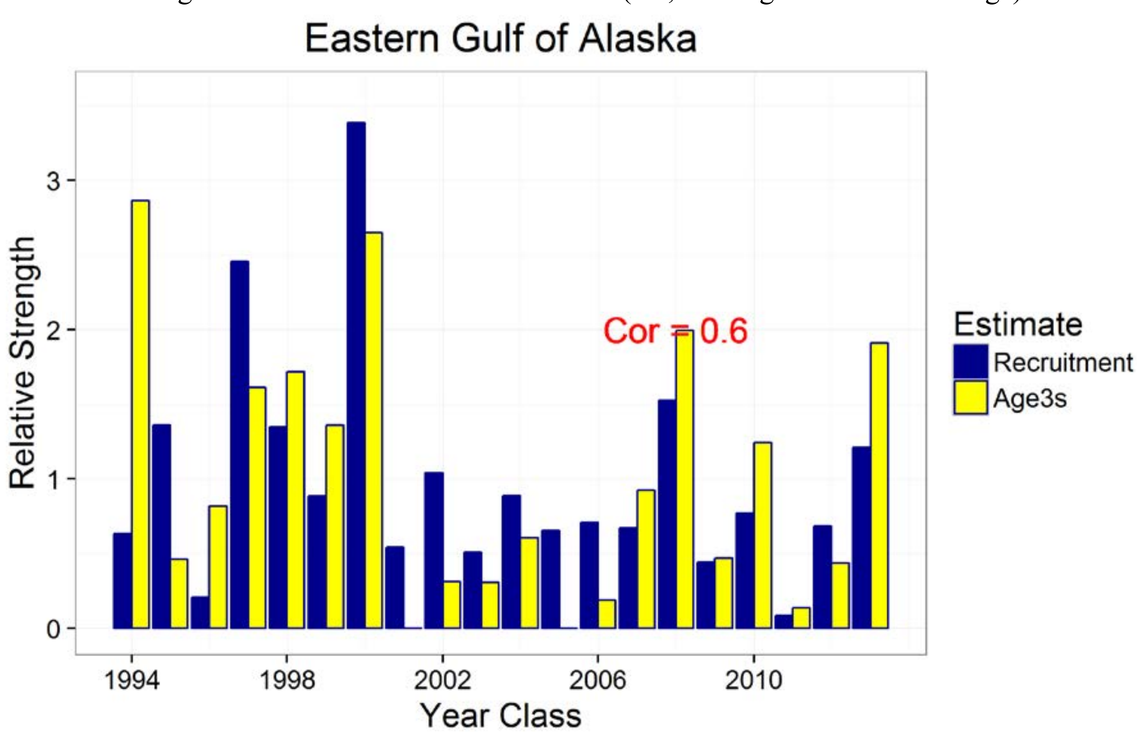


Figure 3.53. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

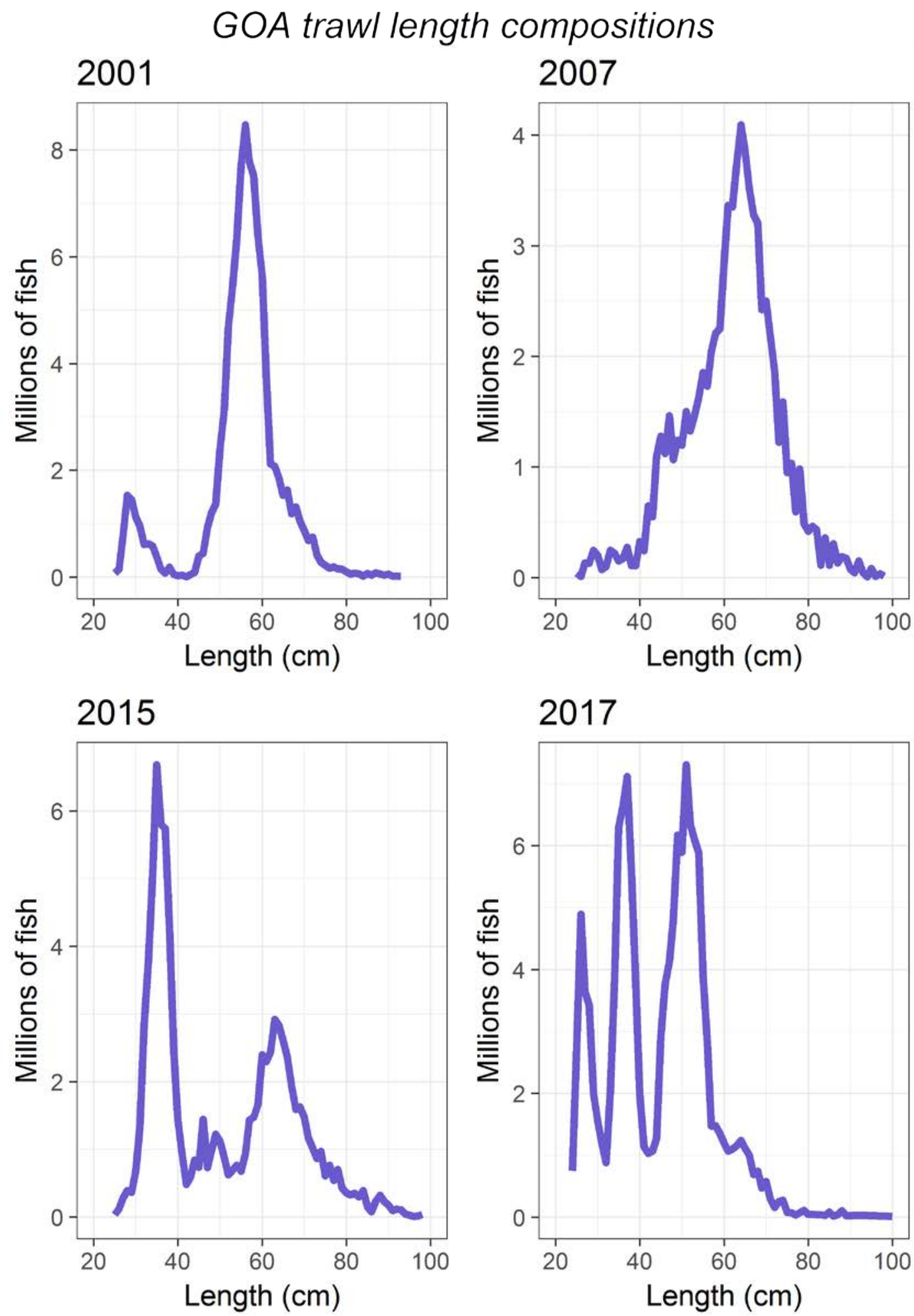


Figure 3.54. Select years of Gulf of Alaska trawl survey length compositions.

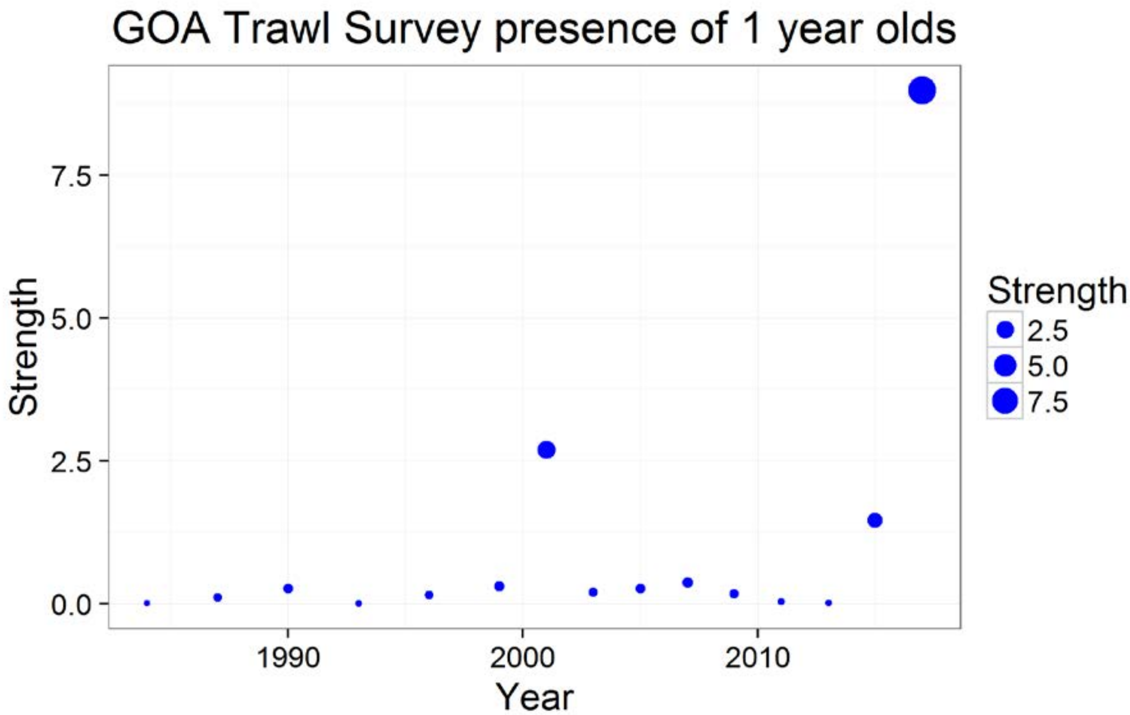


Figure 3.55. Presence of one-year-old (Length < 32 cm) sablefish in the Gulf of Alaska trawl survey. Strength is relative to the mean abundance (i.e., a strength of 7.5 is 7.5x average).

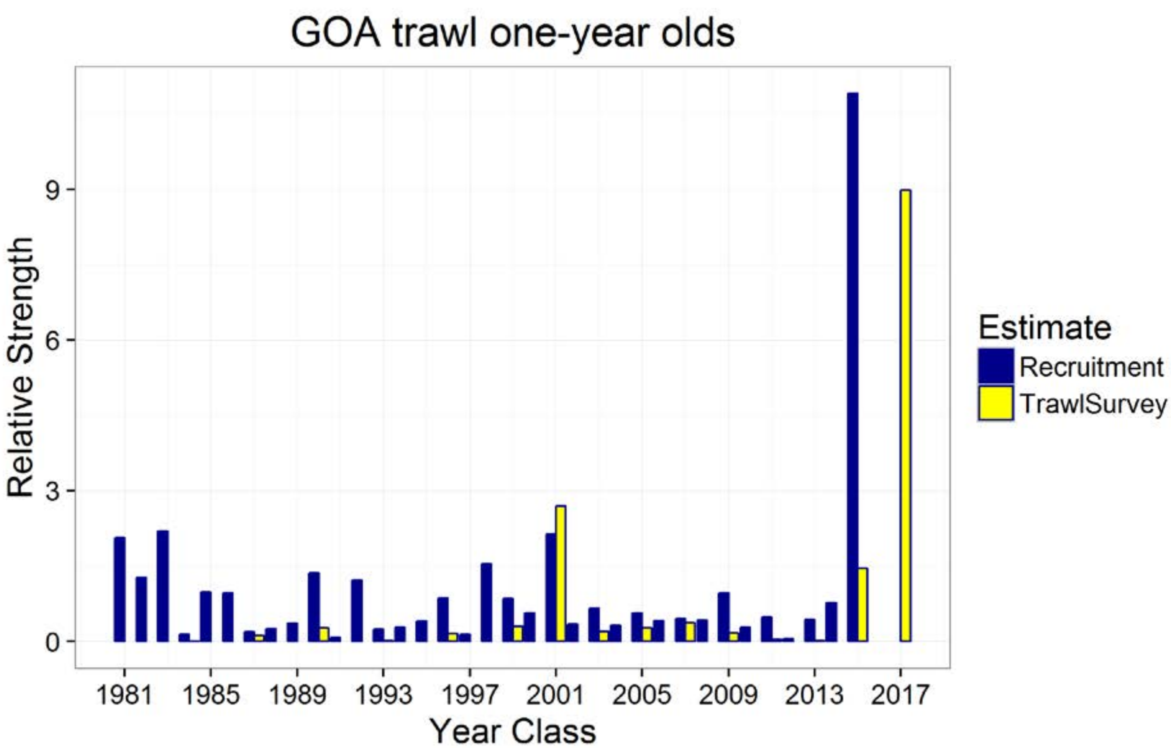


Figure 3.56. Strength of presence of one-year-old (Length < 32 cm) sablefish in the Gulf of Alaska trawl survey compared to the respective year classes of recruitment estimated by the stock assessment. Strength is relative to the mean abundance or recruitment (i.e., a strength of 7.5 is 7.5x average).

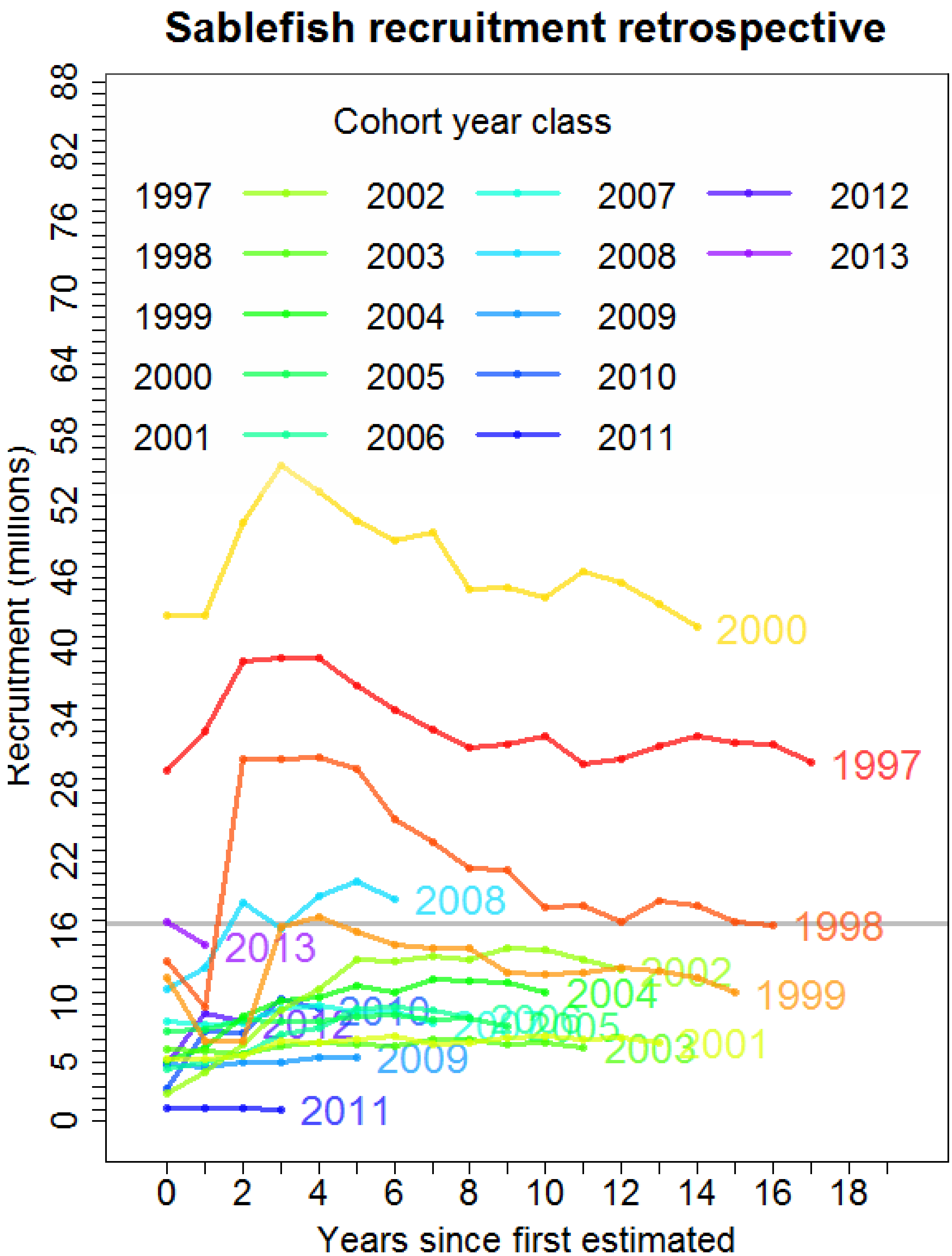


Figure 3.57. Squid plot of the development of initial estimates of age-2 recruitment since year class 1997 through year class 2013 from retrospective analysis. Number to right of terminal year indicates year class.

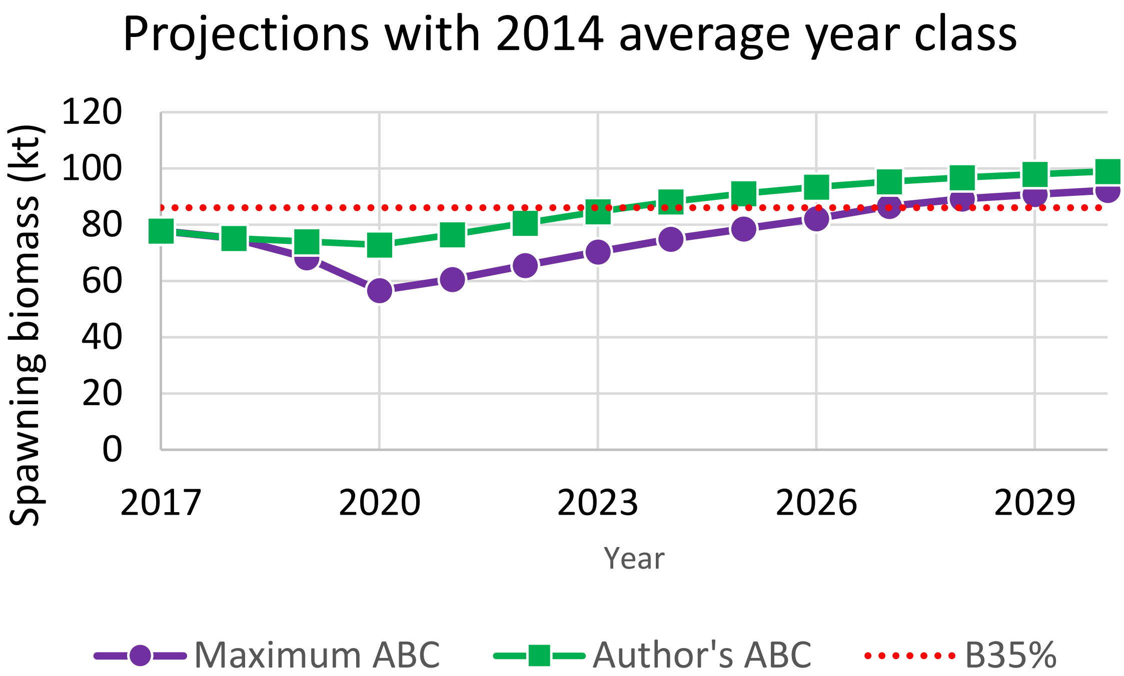


Figure 3.58. Comparisons of author’s recommended ABCs for 2018 and 2019 versus the maximum allowable ABC in projections of future spawning biomass. The 2014 year class is set to average.

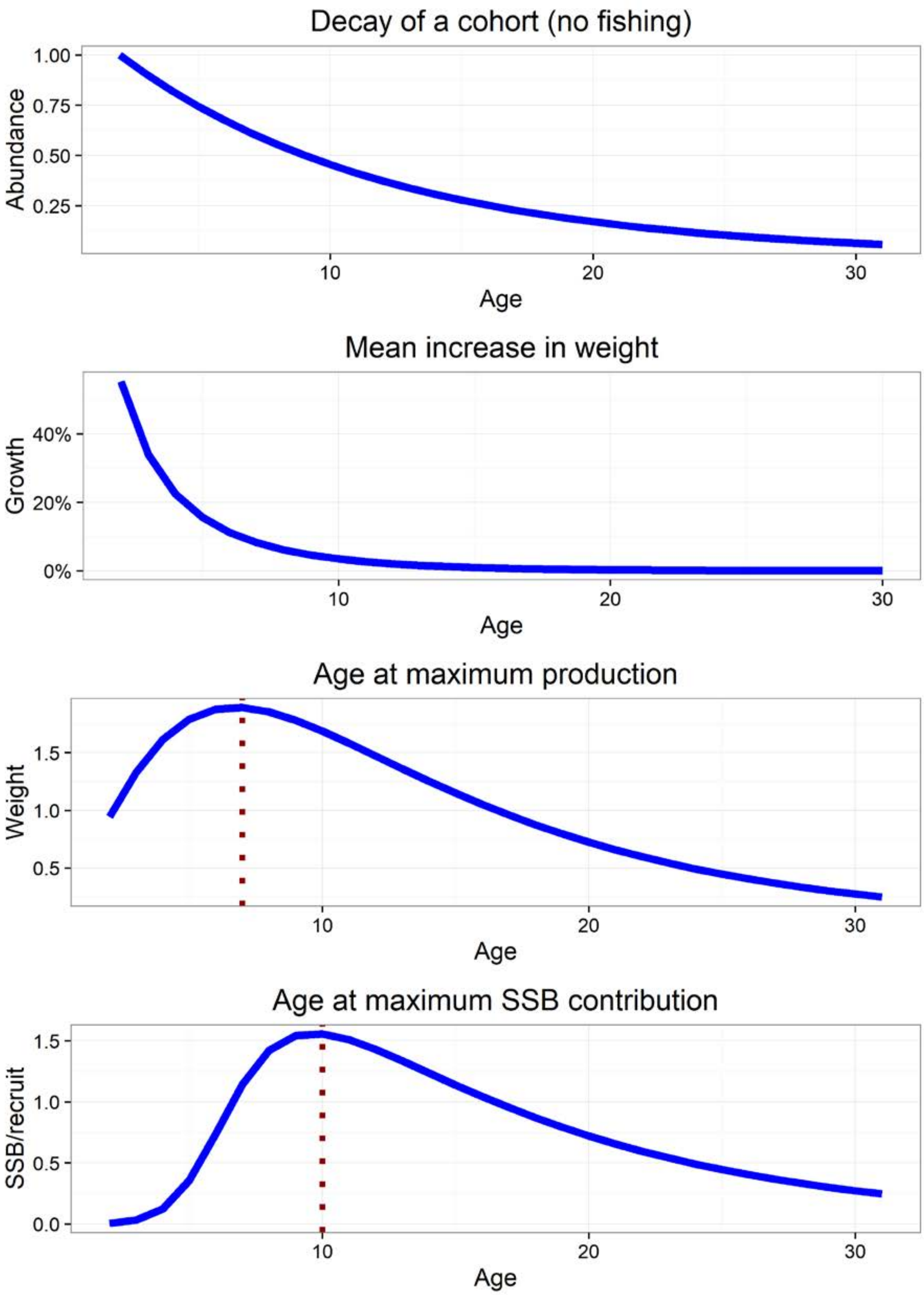


Figure 3.59. Illustrations of where spawning biomass, and production would be maximized under equilibrium conditions.

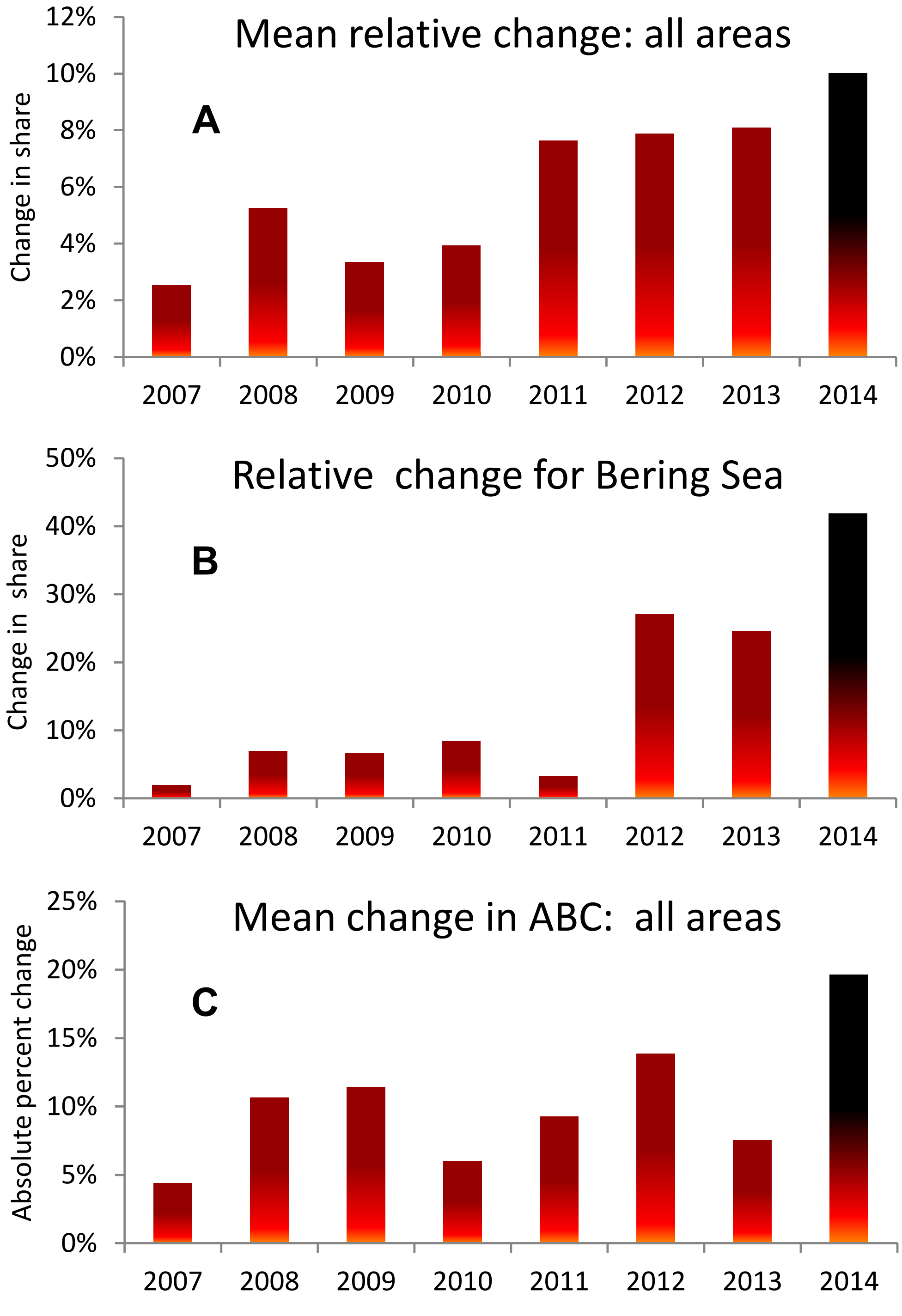


Figure 3.60. (A) The mean relative change in apportionment percentages across areas from 2007-2014. (B) The relative change in the apportionment share for the Bering Sea from 2007-2014. (C) The mean change in ABC for each area from 2007-2014.

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 request that vessels fish at least five nautical miles away from the survey station for 7 days before and 3 days after the planned sampling date (to 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 fisheries.

History of interactions

Fishermen cooperation, distribution of the survey schedule to IFQ permit holders, radio announcements from the survey vessel, and discussions of a regulatory rolling closure have had intermittent success at reducing the annual number of longline fishery interactions. During the past several surveys, fishing vessels were contacted by the survey vessel when they were spotted close to survey stations. Typically, vessels were aware of the survey and were not fishing in the area, were able to communicate where they had set, or were willing to change their fishing location to accommodate the survey. Even with communication there are some instances where the survey gear was fished nearby commercial fishing gear or where commercial fishing had recently occurred, "survey-fishery interactions". There are generally few interactions during the 90-day survey. In 2017 there were more interactions than in recent years. This included vessels fishing all gear types. There were interactions with pot vessels in the BS (2 stations) and in WY (1 station) and trawl vessels in the BS (1 station) and the CG (2 stations).

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
2017	8	10	3	3	3	3	13	16

Recommendation

We have followed several practical measures to alleviate fishery interactions with the survey. 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.

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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		18		255	92		365
2006		2		287	64		352
2007	**Assessment of the sablefish stock in Alaska (Hanselman et al. 2010)**	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		12		174	17	46	249
2016	**AKRO**	3		199	15	31	238

* 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. Ecosystem-Socioeconomic Profile of the Sablefish stock in Alaska

S. Kalei Shotwell, Ben Fissel, Dana H. Hanselman

November 2017

With Contributions from:

Mayumi Arimitsu, Alison Deary, Miriam Doyle, Georgina Gibson, Ron Heintz, Stephen Kasperski, Chris Lunsford, Jamal Moss, Jodi Pirtle, Lauren Rogers, Ashwin Sreenivasan, Kally Spalinger, Lauri Sadorus, Wesley Strasburger, Johanna Vollenweider, Cara Wilson, Sarah Wise, Ellen Yasumiishi

Please Note: This report is a first-generation document for the Ecosystem-Socioeconomic Profile (ESP) framework that is currently under review. The data and document will continue to be refined following feedback from contributors, the Plan Teams for the Groundfish Fisheries of the Bering Sea, Aleutian Islands, and Gulf of Alaska and the North Pacific Fishery Management Council.

Executive Summary

The sablefish ecosystem and socioeconomic profile (ESP) report provides a synopsis of the ecosystem impacts on the stock and economic performance of the fishery. We present information from a variety of data streams available regarding the sablefish stock in Alaska and use a sequential process of analyzing the information for identifying mechanisms and indicators that are most important to the sablefish stock assessment. Results are presented through three main products. First, the factor profile stated recruitment and economic value were of high importance and highlighted a clear data gap in applying ecosystem information within the sablefish stock assessment. The additional energetics profile highlighted bottlenecks in the life history during the first year to settlement and during the post-settlement stage. Second, the conceptual model built on these priorities from the factor profile to identify mechanistic system response and point to potential indicators. Finally, the report card provides the suite of indicators for monitoring, and suggestions for improvement. In future versions of the ESP, the three main products of the profile, conceptual model, and report card along with other relevant visualizations can be easily updated so that the ESP report becomes dynamic and effective for monitoring future changes. This will help with providing efficient warning of impending changes that may impact stock productivity and pave the way for a truly ecosystem linked stock assessment.

Based on this ESP synthesis, our recommendations for future research priorities with regard to the sablefish stock are to 1) develop indicators for large-scale persistent offshore features (such as the Warm Blob) that could provide early warning for extreme recruitment events, 2) consider the applicability of nearshore process studies for monitoring overwinter survival, 3) develop energetics indicators on the vulnerable early life stages just prior and post-settlement, and 4) explore the utility of advancing modeled output (e.g. life cycles, individual based models, habitat suitability, etc.) for evaluating pressures on early life survival. These recommendations are in no particular order and should complement the priorities already specified within the main sablefish stock assessment. As we continue to develop the sablefish ESP and integrate relevant linkages within the stock assessment model, we will ultimately strengthen our understanding of these mechanistic relationships and further the advancement of the sablefish assessment model toward next generation stock assessment.

Introduction

Ecosystem-based science is an important component of effective marine conservation and resource management (Levin et al. 2009) and two main avenues currently exist to satisfy the mandate for considering ecosystem and socioeconomic processes with regard to specifying optimum yield and informing the regional Councils (MSA 2007). The first is through the comprehensive ecosystem status report (ESR) of Alaska's four large marine ecosystems that has been implemented at the AFSC since 1995 (Livingston 1999) and is presented to the Plan Teams and Council concurrent with the individual groundfish stock assessment chapters (Zador et al. 2016). The second avenue is conducting an assessment of the environment inhabited by an individual stock within the fishery (Hollowed et al. 2014), with an ultimate goal of integrating relevant ecosystem data into a stock assessment in order to better inform fisheries managers and provide improved harvest recommendations (Townsend et al. 2008). A standardized framework for conducting a stock-specific ecosystem and socioeconomic profile (ESP) assessment has recently been proposed (Shotwell et al. 2017 *In Review*). Here we adopt this framework and compile supplementary information for the sablefish stock in Alaska.

The report begins with synthesized results from national initiatives as detailed in the new stock assessment improvement plan (SAIP 2017). This creates a baseline ESP that can be compared to any stock within a fisheries management plan (FMP). The baseline includes the following three primary elements: 1) a factors profile to identify stock research priorities, data gaps, vulnerability, and resilience, 2) a descriptive conceptual model of the stock life history for highlighting mechanistic responses, and 3) a report card for monitoring potential indicators relating to the stock dynamics. We further upgrade these baseline elements through supplemental information from a variety of sources. Adopting this new framework should allow for easier comparison of results across different stocks and assist with communicating potential concerns to the North Pacific Fishery Management Council (NPFMC).

Life History and Ecosystem Background

Sablefish are highly fecund, early spring, deep water spawners with an extended spring through summer neustonic (extreme surface) pelagic phase that culminates in nearshore settlement in the early fall of their first year (Doyle and Mier 2016). Larvae are characterized by early development of large pectoral fins to assist with swimming ability but have delayed bone-development in their jaws potentially resulting in non-discriminating prey selection (Matarese et al. 2003; A. Deary pers. comm.). Throughout the first year, larvae and age-0 fish grow very rapidly up until settlement in the nearshore environment (Shenker and Olla 1986; Sigler et al. 2001). Suitable nearshore habitat is described as low-lying areas such as channels, gullies, and flats with fine grain-size sediment, little biogenic structure, and reduced rock presence (Pirtle et al., *Accepted*). Settlement incurs an energetic cost that results in a change in body condition with reduced lipid content that appears to be maintained until the late juvenile stage (R. Heintz pers. comm). At some point following the first overwinter, sablefish juveniles begin movement to their adult habitat arriving between 4 to 5 years later and becoming mature generally within 3 to 6 years (Hanselman et al. 2016). The long duration and widespread exposure to variable surface conditions during their first year represents a vulnerability in their life history. However, their widespread exploitation of available pelagic prey and robust larvae with good swimming ability may also allow some resilience to fluctuating conditions (Doyle et al. *In Review*).

Socio-cultural and Economic Background

As a valuable premium high-priced whitefish, sablefish are an important source of revenue for GOA catcher vessels and catches are at or near the TAC. 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. Given that Alaska is 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 are exported, though the domestic market has grown in recent years. Sablefish are primarily harvested by catcher vessels in the GOA, which typically accounts for upwards of 90% of the annual catch. Most sablefish are caught using hook-and-line gear. A provision for the use of pot gear in the GOA to mitigate whale depredation was made in 2017 for directed fishing on sablefish.

Data

Baseline data for this report consists of information gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 through 2016. These include (but are not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment categorization. A form was submitted to stock assessment authors to gather results from all these initiatives in one location. The resulting synthesis included information from the main stock assessment and currently available published research papers or reports. This information serves as the initial starting point for developing the ESPs for stocks in the BSAI and GOA groundfish FMP. Further supplementary data was collected from a variety of process studies, standardized surveys, laboratory experiments, accounting systems, and regional reports (Table 1).

Surveys

Information for the first year of life was derived from ecosystem surveys run by the Alaska Fisheries Science Center's (AFSC) Recruitment Processes Alliance (RPA) and data from the Gulf of Alaska Integrated Ecosystem Research Program (GOA-IERP). Data pertaining to the larval life history stage were primarily collected from the Western Gulf of Alaska Survey (Kodiak west to Unimak Pass) during late spring (May to early June) from 1978-2017. Larvae are collected in a bongo net that is towed obliquely and a neuston net towed at the surface. Catch-per-unit-effort (CPUE) is measured in numbers per 10 m^2 for the bongo tows and 1000 m^3 for the neuston tows. Young-of-the-year or age-0 sablefish were sampled during the summer in the eastern GOA by the GOA Assessment Survey from 2010-2017. Survey stations were approximately 20 nautical miles apart offshore and 10 nautical miles apart over the shelf and slope. A modified pelagic trawl was towed at the surface for 30 minutes at each station. A Nordic model 264 trawl net was used in 2010 and 2017, while a CanTrawl model 400 trawl net was used from 2011-2016. The Nordic 264 trawl net is more effective at capturing age-0 sablefish because if fishes the upper 10 m to surface, has an additional "scare mesh", and an additional panel of 10 cm mesh running to the headrope to retain animals inhabiting the neuston. Area swept was estimated from horizontal net opening and distance towed and CPUE is measured as numbers per 10 km^2. Values for larval and age-0 surveys were standardized by the mean of each dataset to allow for visual comparisons.

Overwintering juveniles and 1+ juveniles are generally captured in bottom trawl surveys. The Alaska Department of Fish and Game (ADFG)'s large-mesh bottom trawl survey of crab and groundfish has been conducted annually from 1988 to 2017 using a 400-mesh eastern otter trawl net designed to sweep a 12.2 m path. The survey uses a fixed-grid station design, with all areas sampled each year, and is conducted in the Kodiak, Chignik, South Peninsula, and Eastern Aleutian Tanner crab districts. The AFSC Gulf of Alaska bottom trawl survey is a stratified random survey used for the majority of groundfish stock assessment biomass estimates (for more details see AFSC Surveys subsection in main stock assessment Data section). Length composition data are available for many species and juveniles sizes can be separated from adults for more in-depth consideration of the late juvenile stage distribution.

Other

Data from other supplementary sources were provided through personal communication, Ecosystem Status Report contributions, published reports, and peer-reviewed manuscripts. Additionally, remote sensing data were provided through the NOAA ERDDAP servers and CoastWatch program, which provide a simple, consistent way to download subsets of gridded and tabular scientific datasets. Data for the polar regions are now hosted through the PolarWatch website (https://polarwatch.noaa.gov/) and may be a very useful source for developing indicators in the future.

Socioeconomic

The majority of sablefish economic value data were compiled and provided by the Alaska Fisheries Information Network (AKFIN). Sablefish ex-vessel data were derived from the NMFS Alaska Region Blend and Catch-accounting System, the NMFS Alaska Region At-sea Production Reports, and the ADFG Commercial Operators Annual Reports (COAR). Sablefish first-wholesale data were from NMFS Alaska Region At-sea and Shoreside Production Reports and ADFG Commercial Operators Annual Reports (COAR). Global catch statistics were found online at FAO Fisheries & Aquaculture Department of 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), and the U.S. Department of Agriculture (http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx).Information regarding the community involvement and percent value was derived from reports of the Community Development Quota (CDQ) Program.

Results

The results of the ESP are summarized in three main product areas called the 1) factors profile, 2) conceptual model, and 3) report card. Supportive data to help explain hypothesized mechanisms and interactions are also provided where relevant. The factors profile gives context for how sablefish relate to other groundfish stocks in the FMP and highlights the research and data priorities for the sablefish stock. The conceptual model is used to identify the main abiotic and biotic pressures on the sablefish stock. A socio-cultural and economic performance section is linked to the conceptual model to further evaluate the impact of the sablefish fishery. Relevant proxy indicators for the pressures identified in the conceptual model are shown in the report card and data gaps are discussed.

Factors Profile

The sablefish factors profile (Figure 1) identifies the areas for concentrating development of relevant ecosystem and socioeconomic mechanistic relationships and indicators. Bars of each factor show the score or value for sablefish relative to all other stocks in the groundfish FMP. Black dots show the mean value for each factor across all groundfish stocks. Red dots show the target value estimates for sablefish in the most recent data gap analysis (SAIP 2017). The categories of the factors are generally related to how the information was used in the various national initiatives (Shotwell et al. 2016). Sablefish clearly have a large data gap for ecosystem data, with a high target and low available data within the assessment. Additionally, there is very high constituent demand and commercial value for this stock as well as very high recruitment variability. This stock also has low natural mortality, low habitat dependence, and a low ecosystem role when compared to other stocks in the groundfish FMP.

We determined that it was important to consider more in-depth information regarding the recruitment factor in order to understand potential life history bottlenecks for this species, given the large emphasis on recruitment variability in the baseline profile (Figure 1). A preliminary energetics profile based on body composition (wet mass) for percent lipid and percent protein by size shows obvious shifts in body composition and energy allocation through the different life history stages (Figure 2, top graph, Heintz and Vollenweider, pers. comm.). Age-0 sablefish increase in lipid content dramatically during the pelagic phase prior to settlement. Lipid levels decline when fish reach around 200 mm indicating a clear cost for settlement. Protein synthesis remains constant throughout this time period as the fish grow rapidly. Body composition then remains relatively consistent until the fish reach 400 mm (age 2-3), which is the time period in their life history when fish begin to move toward adult habitat. After this point, lipids begin to increase fairly constantly as they get larger with age. The 400 mm length is also the designated maximum body size for the early stage juvenile habitat suitability models and the point where we start to see this size fish and larger in the primary assessment surveys (Pirtle et al. *Accepted*, Hanselman et al. 2016). The high variability of percent lipid in the age-0 pelagic phase just prior to settlement suggests a potential bottleneck in the life history (Heintz and Vollenweider, pers. comm.). A fish with a higher percent lipid composition may have a higher chance for overwinter survival than a fish with a lower percent lipid composition, particularly given the cost of settlement that this fish seems to incur.

Another bottleneck may occur as the fish move from the post-settlement juvenile stage in nearshore habitat to the adult slope habitat. During this time, the percent lipid stays low and constant until about 400 mm where it begins to increase (almost linearly) with size, while the percent protein decreases slightly. This suggests that the fish in the nearshore are still growing quickly with an associated high energetic cost, but as they move offshore the fish have relatively low energetic demands and can begin to allocate surplus lipid to storage with age as they grow (Heintz and Vollenweider, pers. comm.). The juvenile nearshore stage appears to continue to be an energetically-demanding period as all surplus energy is allocated toward growth (protein). Another explanation for this is that food is limited and not a lot of surplus energy is consumed. Later during the early offshore residence for juveniles, the energetic constraints are relieved and fish obtain surplus energy that is stored as lipid. In addition to reducing the pressure for rapid growth, the extreme increase in lipid storage may represent considerably better feeding grounds, and/or life history constraints to increase lipid content as the fish move into the deeper depths of the adult habitat as they age. Juvenile fish that can put on weight faster may have a higher chance for survival than fish experiencing suboptimal conditions. Future investigations should consider comparing composition data in a given year from a regional distribution of samples representing these different life stages of sablefish.

It is also interesting from an economic perspective that the price per kilogram from younger and subsequently smaller size fish starts low and increases with size up to a certain point (Figure 2, middle graph). Multiplying this value against the average size of a fish for a given age (Figure 2, bottom graph) suggests that market value would be maximized if fish were allowed to grow for several years, up to about age 9 (peak of curve at about 700 mm, Figure 2, bottom graph). Given that there is a potential vulnerability in the juvenile stage, where fish are just starting to increase in lipids (Figure 2, top graph), it seems that allowing the fish to grow to a larger size would not only increase chances of survival but also increase overall market value. Considering both the energetics and economics profiles together highlights potentially sensitive aspects of the life history where bottlenecks can be identified and harvest strategies can be considered for the more vulnerable life stages that would not only increase survival but also increase potential value.

Conceptual Model

As a first pass, we utilized descriptive responses from the sablefish lead stock assessment author and relevant literature to create a baseline life history conceptual model which is detailed in Figure 3. It seemed reasonable to divide the time scale of the conceptual model into the first year and subsequent years because of the emphasis on understanding recruitment variability from the factor profile. In the conceptual model graphic, the different abiotic and biotic pressures that were identified by each life stage from the lead author and relevant papers are set in general categories above the life history timeline. Lines connect these pressures to a given life stage box where a potential linkage was identified through the lead author or literature. The potential direction of the relationship is also indicated in some cases. The main categories of the primary pressures influencing the different life stages were identified as sea surface temperature, nearshore transport, age-0 prey conditions, interactions with co-occurring species, impact of predators, habitat suitability, and economic value. Details on why these pressures were highlighted in the conceptual model and the potential relationship between these pressures and the different life stages are described below.

Sablefish are thought to exhibit some thermal intolerance to very cold water (Sogard and Olla 1998) and their upper thermal limit is near their upper limit of survival (Sogard and Olla 2001). Preliminary results from an age-0 and age-1 juvenile energetics experiment suggest that their optimal thermal environment for growth is around 16 ^{o}C (A. Sreenivasan pers. comm.). Also, transport to the nearshore environment during the first year of life is thought to relieve potential vulnerability if conditions are poor (Doyle and Mier 2016). Above average recruitment was associated with a more northerly winter current direction and warmer sea surface temperatures (Sigler et al. 2001). A recent hierarchal cluster analysis of multiple environmental indices on age-0 and age-1 sablefish suggested that sablefish recruitment was positively related to July upwelling favorable winds and negatively related to spring freshwater discharge in the eastern GOA (Coffin and Mueter 2014). Colder than average wintertime sea surface temperatures in the central North Pacific along the North Pacific Polar Front were hypothesized to setup downstream oceanic conditions that create positive recruitment events for sablefish during their early life history (Shotwell et al. 2014). At first this may seem conflicting with the sablefish warm temperature requirements; however, the colder wintertime temperature index may represent a shifting of the polar front spatially rather than any true temperature signal. This sort of mechanism can be seen in a sea surface temperature heat map (Shotwell et al. 2014, Figure 2), during the 1976/77 regime shift and again in the 2000s. This would imply that large ocean scale events that translate temperature signals across domains, such as recently seen with the Warm Blob event being translated from the west coast U.S. to Alaska in 2013 to 2014 (Bond et al. 2015), may create these conditions that sablefish are finely tuned to exploit. The potential vulnerability in their extended pelagic phase may be limiting under average conditions, but may also be a strength under anomalous conditions where their astounding growth capacity and early swimming ability allows widespread exploitation of available resources. Also, under average conditions, enhanced transport to the nearshore environment may be critical for maintaining a base to average level of recruitment. A simple individual based model recently developed for sablefish suggested that overall connectivity to the nearshore nursery areas was highly related to sablefish recruitment over the 1996 - 2011 time period when there were very few high recruitment events (Gibson et al. *In Press*).

During the nearshore and settlement period, research on nearshore conditions and interactions with other surface foragers show positive relationships with sablefish recruitment (Yasumiishi et al. 2016; M. Arimitsu pers. comm.). Age-2 sablefish recruitment was modeled as a function of sea surface temperatures, nearshore production (chlorophyll *a*), and adult pink salmon returns (co-occurring in this environment). The best model described the stock assessment estimates of age-2 recruitment as a function of late August maximum chlorophyll *a* during the age-0 stage, late August maximum sea temperature during the age-0 stage, and pink salmon returns during the age-1 life stage of these sablefish (Yasumiishi et al. 2017). Another interaction can be seen through the use of seabirds as samplers of the marine environment. The proportion of biomass in rhinoceros auklets on Middleton Island seems to fluctuate in response to other more dominant species in the diet such as capelin and sand lance (Hatch et al. 2017). However, in the recent very warm years of 2014-2016, the proportion of other species such as sablefish has increased in the auklet diet. A more direct measure of the sablefish condition has been calculated from the samples taken in the auklet diet. This age-0 sablefish growth index, calculated as the coefficient for the regression of length (mm) by Julian day for each year (Arimitsu pers. comm.), effectively tracks the nearshore age-0 growth rate of sablefish and has a positive relationship with sablefish recruitment.

The main ecosystem impacts on the late juvenile and adult prey and predators are depicted in the current ecosystem considerations section of the sablefish stock assessment (Hanselman et al., 2016). Both stages appear to be generalists and it is not likely that prey abundances have much influence on sablefish dynamics. However, killer and sperm whales are likely major predators of sablefish based on depredation rates estimated on the AFSC longline survey and the in the fishery. This depredation is factored within the assessment as a correction to the survey and an author's adjustment to the ABC. Whale observations are collected on the AFSC longline survey and in the fishery and estimates of whale depredation on sablefish would provide a good indicator of the impact to the sablefish population.

The recent update to the Essential Fish Habitat for Alaska groundfish included models and maps of species habitat suitability distribution (Pirtle et al. *Accepted*, EFH 2017). Models and associated maps for each life history stage were provided and the more fully developed models resulting from model selection methods were provided to the lead assessment authors for review on the early juvenile settlement stage (<400 mm), late juvenile stage (>=400 mm & < 550 mm), and adult stage (>=550 mm). Clear progression from bathymetrically low-lying areas in nearshore bays and inlets to the gullies of the continental shelf and finally to the slope environment can be seen from the three stages (Figure 4). The models indicate that tidally-derived current speed and bottom temperature are important for the early and late juvenile stages, while depth is the primary predictor for the adult stage (Pirtle et al., *Accepted*, EFH 2017). These results suggest that suitable habitat for juvenile sablefish is more influenced by non-static variables than just depth (as with adults). It is then possible that the amount of suitable habitat may vary from year to year and impact the selectivity of sampling gear to these life stages. This concept is somewhat supported in a preliminary analysis of the bottom trawl survey temperature data. We restricted the haul data to the depths predicted by the habitat models for the juvenile stages (approximated by strata less than 200 m and less than 100 m). Average bottom temperature varies both spatially and temporally with higher variability in the western GOA. We also considered the difference between the surface temperature and bottom temperature at each haul as a measure of mixing. This can be thought of as a proxy for the tidal movement habitat variable in that more tidal movement would promote mixing and less would promote stratification. The eastern GOA seems to be dominated by stratification as the difference between surface and bottom temperatures are high and do not fluctuate much over time. In contrast, the western GOA is highly variable with more stratification in the earliest and most recent surveys and more mixing in the 2000s. Based on recent results from a sablefish movement model, the western GOA is an area where small sablefish do not tend to stay, while the eastern GOA is considered more an area of residence (Hanselman et al. 2015). The habitat suitability model results for juvenile sablefish combined with the supportive data from the bottom trawl survey suggest that an indicator of the temporally varying aspects of suitable habitat for this life stage may be useful to monitor and may ultimately link to time-varying selectivity within the stock assessment model.

Socio-cultural and Economic Performance

We provide a separate section on the socioeconomic aspects of the sablefish fishery due to the high importance of this resource in this region. The following describes the economic performance of the sablefish stock over time as well as social and cultural impacts to the most highly involved communities with this resource.

Since the mid-2000s, decreasing biomass has caused the TAC and catch to decrease. This trend continued through 2016 as retained catches decreased 9% to 9.9 thousand t in 2016, down from 10.8 thousand t in 2015 (Table 2). The impact of the decrease in catch and corresponding production on revenues was offset by an 8.2% increase in the ex-vessel price to $4.28/lb. The net effect was a marginal increase in ex-vessel revenue to $92.8 (Table 2). The increase in the ex-vessel price was a reflection of a commensurate increase in first-wholesale price to $7.72 (Table 3). First-wholesale value increased to $99.7 million in 2016. Most sablefish are 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. Persistent declines in catch may have been disruptive to revenue growth in the sablefish fishery. Strong prices have maintained total value in the fishery as catches have declined. The 2016 price was the highest seen since prices peaked in 2011 at $8.71. Twenty percent of the Bering Sea and Aleutian Islands (BSAI) sablefish total allowable catch (TAC) allocated to vessels using hook-and-line or pot gear and 7.5% of the sablefish TAC allocated to trawl gear are reserved for use in the Community Development Quota (CDQ) program, which was implemented in 1995. The Sablefish IFQ program includes a cost recovery provision. Cost recovery has ranged from $0.75 million to $2.30 million and 1% to 3% of the ex-vessel value of the fishery, with 2015 being the first year the fishery reached the 3% limit (Figure 5 top graph).

Japan is the primary export market, but its share of export value has decreased from 82% in 2003-2012 to 59% in 2016 (Table 4). In recent years, industry reports and U.S. import-export figures indicate that the strong demand for sablefish in the U.S. and foreign demand outside of Japan, including Europe, China and Southeast Asia has increased. U.S. exports as a share of U.S. production have declined over time indicating increased domestic consumption. China’s share of export value has been increasing (Table 4). Furthermore, reports indicate inventories at the end of 2015 were depleted. These factors can strengthen the negotiating position of sellers. While strong demand and supply reductions have put upward pressure on wholesale prices, the strength of the U.S. dollar puts downward pressure on the price of exported goods as it further increases prices for foreign importers. The significant increase in the 2015 U.S.-Japanese exchange rate returned to a comparatively more favorable level in 2016, which could have contributed to the increase in the first-wholesale price. Sablefish prices for Japanese consumers were sufficiently high that some industry news reports expressed concern that it would push it outside a consumer's price range, resulting in demand reductions. Nevertheless, Japanese demand appeared strong throughout 2016 and 2017 and prices through mid-2017 indicate that they could be the highest on record.

In order to identify the dominant communities engaged in commercial sablefish fisheries, the Regional quotient was calculated from baseline (1992-1994) until the most recent available data (here, 2013). The four communities most highly engaged with the sablefish fishery: Seward, Kodiak, Sitka, and Homer account for almost 48% of the regional value landed (Figure 5 bottom graph). In comparison, the community Local Quotient metric shows a decline in both pounds and regional value landed in all four of the highly engaged communities. The community Local Quotient, which measures the percentage of sablefish IFQ landed within a community out of the total amount of all species landed within that community, illustrates substantial declines in all highly engaged communities.

Report Card

The information gathered through the construction of the conceptual model provides insight as to the most relevant indicators to monitor for identifying important temporal trends in the sablefish population. Until the recent addition of the whale depredation accounting, indicators have been considered only for contextual value in the sablefish stock assessment model through the ecosystem considerations section. Here we provide a list of potential indicators based on the sablefish profile and conceptual model and an accompanying report card of the time series of indicators (Table 5, Figure 6). If there was an identified potential indicator but no available corresponding proxy, then a placeholder was provided and this can be used as a likely area of future research for this stock.

In the report card plot, we show the most relevant indicators that would have potential linkages to the main stock assessment model. In the report card table, we organized indicators by life stage and provide the title of the indicators along with a description of the dataset. Then the potential area for linkage with the assessment model parameters is provided along with an assessment of the average of the last five years of the indicator and the current year estimate relative to the average for the time series. In many cases the most current year was not available and this demonstrated a potential data gap indicator for setting priorities on ecosystem data research and analysis.

The most important stock assessment model time series output to monitor for sablefish are the recruitment and spawning stock biomass estimates. Relevant proxy indicators identified for monitoring recruitment were sea surface temperatures measured along the North Pacific Polar Front (Shotwell et al., 2014), larval juvenile transport measured by total connectivity from the sablefish individual based model (Gibson et al. *In Press*), larval prey which was a data gap, early juvenile prey conditions measured by the nearshore model (Yasumiishi et al. 2015), and early juvenile growth measured by the auklet samples (Arimitsu and Hatch 2017). Proxy indicators relevant to adult spawning biomass were a temporal measure of juvenile habitat to potentially explain changes in selectivity which was a data gap, whale depredation estimates used in the main stock assessment model for adjusting the recommended ABC (Hanselman et al. *Accepted*), and ex-vessel value measured in millions of dollars relative to 2016 (Fissel et al. 2016).

The five year and current year trend in these time series provide a measure of potential future conditions; however, several of the indicators need to be updated or replaced since the current information is not available at this time. This is particularly true for the sea surface temperature and larval juvenile transport. A high-resolution time series of sea surface temperature from 2003 to present is available from the MUR dataset and shows very high temperature anomalies for 2014 and 2015 in the outer North Pacific domain for the month of May, which is the start of the larval survey season. Data on sablefish captures from larval and age-0 surveys show some coherence of relatively high catches during warm years of 2014 and 2015 but almost none during earlier cold years of 2012 and 2013 (Figure 7). Overall, this information is somewhat confounded by shifting sampling areas from year to year and we present the data on a relative scale for both the larval and age-0 surveys to allow for visual comparisons. Additionally, a gear change in 2017 resulted in higher sablefish catches simply due to increased selectivity of the different net. However, the benefit of sampling more fish with the different gear at this early life stage may assist with potentially developing an energetic index for sablefish as samples may become more reliable regionally in the future. A composite of the MUR SST anomalies during the sampling season may be useful for updating the sea surface temperature time series indicator in the future and could be coupled with a new energetic index to show condition by life stage.

Additional long-term satellite and survey time series are also available with regard to the other data gaps in the report card. Productivity (measured by ocean color) and currents (measured by sea surface height) could be used to develop larval prey and transport time series in the future. Potentially rough counts of small and large zooplankton as well as the community from the spring and summer surveys could be used in the future for larval prey as the time series develops (Ferm et al. 2017, Strasburger et al. 2017). The ADFG large mesh bottom trawl survey of crab and groundfish has been conducted annually from 1988 to 2017 (Figure 8) and samples on a fixed grid in the Kodiak to eastern Aleutian area. Recently, this survey has observed larger catches of smaller sablefish (age-1 and age-2) in the 2015 and 2016 surveys, which corroborates that the 2014 year class was indeed large. However, age-1fish were not in high composition in the 2016 survey implying that year class may not be as big as the GOA trawl survey size compositions indicate (see main sablefish document). This survey may be useful as an early signal of overwinter success and could be considered as an additional process study indicator in future report cards. In development of such an indicator, it would be useful to determine how representative this survey is of the sablefish population as a whole. This could include comparison of temporal patterns with data over similar length compositions in the trawl survey by region.

Finally, a more complete measure of the time varying suitable juvenile habitat with regard to tidal mixing and thermal stratification could be derived from oceanographic profile data taken on the annual International Pacific Halibut Commission (IPHC) longline survey (2009 – 2016). Both surface and bottom temperatures are available for processing from all stations as well as a variety of other oceanographic measures (chlorophyll *a*, dissolved oxygen, etc.). The survey area covers the entire continental shelf to 500 m across the GOA, Aleutian Islands and Bering Sea slope. We reproduced the preliminary view of the bottom thermal environment that is currently available in the Report of Assessment and Research Activities (RARA) from 2012 – 2016 (Figure 9). There appears to be a delayed response in the latent heat on the sea floor resulting from the warm surface temperatures of 2014 as conditions do not seem to be anomalously warm until the 2015 and 2016 surveys. It is also clear that there are spatially-explicit shifting pockets of warmer temperatures throughout the GOA. Index areas, possibly eastern and western GOA, may be suitable locations to develop habitat measures for linking to time-varying selectivity.

For the currently updated indicators, trends are mostly consistent with the large year class of 2014. Based on the current model for early juvenile prey conditions, there was higher chlorophyll *a* content in sea water during late summer in the nearshore areas that sablefish use, which indicates higher primary productivity and a possible late summer phytoplankton bloom. Also for pink salmon, which is a co-occurring species for sablefish in nearshore waters, higher productivity was a positive predictor for sablefish recruitment to age-2. The anticipated implications of this model are that we should expect a weak 2015 year class and a strong 2016 year class of sablefish; however, the 2014 prediction was only slightly above average, which is counter to the current estimates from the stock assessment model. The sablefish growth model from auklet diet also shows positive anomalies for 2014-2016, with the 2015 and 2016 years being higher than 2014. This may reflect some of the potential recruitment in these years seen in the length compositions from the GOA trawl survey (see main stock assessment). The 2017 growth seems to be about average for this time series.

Value in the fishery has been average for the past five years and declining in the most recent year clearly in response to continually lower catch. This has obvious impacts on industry with regard to revenue but perhaps less well-known detrimental impacts on the communities most closely tied to this resource. We plan to explore more socioeconomic indicators in the future to understand these dynamics and downstream impacts.

Discussion and Recommendations

The ESP of sablefish provides a synopsis of the various ecosystem and socioeconomic data sources available. We use a sequential process for identifying mechanisms and indicators that are most important to the sablefish stock assessment. The profile stated recruitment and economic value were of high importance as well as highlighting a clear data gap in applying ecosystem information within the stock assessment process. The additional energetics profiles highlighted bottlenecks in the life history during the first year to settlement and during the post-settlement stage. The conceptual model built on these gaps to highlight mechanistic system response and point to potential indicators. The report card provides the suite of indicators for monitoring and suggestions for improvement. In future versions of the ESP, the three main products of the profile, conceptual model, and report card along with other relevant visualizations can be easily updated so that the ESP report becomes dynamic and effective for monitoring future changes. This will help with providing efficient warning of impending changes that may impact stock productivity and pave the way for a truly ecosystem linked stock assessment.

The primary ecosystem and socioeconomic research priorities from the AFSC annual guidance memo, the 2016 Sablefish CIE, and the main sablefish stock assessment are to:

- Understand mechanisms regarding high recruitment variability including spawning dynamics, oceanographic conditions, early life survival, lipid density and isotope analysis
- Use a spatially-explicit model to examine the effect of movement on population dynamics
- Identify covariates that affect catch rates in either the survey or fishery
- Consider new strategies for incorporating growth data
- Continue research on whale depredation of sablefish
- Consider socioeconomic interactions

The ESP starts the process of addressing many of these research priorities. However, many new research projects are in the works and a recent summit on sablefish research provides some key areas that may be useful for incorporating into future sablefish ESPs (Krieger pers. comm.). A few examples include in-depth laboratory experiments on larval growth (A. Deary pers. comm.), nearshore process studies on feeding and movement ecology of post-settlement juveniles (A. Beaudreau pers. comm.), age-0 laboratory growth and overwinter condition experiment (J. Krieger & A. Sreenivasan pers. comm.), research project on distribution, abundance, diet (fatty acids, stable isotopes), growth, predation, and competition of age-0 fish (W. Strasburger pers. comm.), satellite tagging for spawning locations (K. Echave pers. comm.), skip spawning and spatiotemporal maturity study (C. Rodgveller pers. comm.), spatially-explicit life cycle modeling within stock assessments (D. Goethel pers. comm.), and a coast-wide sablefish assessment model (K. Fenske pers. comm.). Several projects are multi-agency in nature and showcase the broad communication and collaboration among research scientists with regard to sablefish research.

Throughout this ESP we have discussed a variety of mechanisms and indicators that can be used for monitoring and determining the potential for linkage within the stock assessment model. Based on this ESP synthesis, our recommendations for future research priorities with regard to the sablefish stock are provided in the following table:

Product	Recommendation
Factors Profile	• Further develop factors profile to consider sub-intervals of the different ontogentic stages to highlight stock-specific vulnerability and resilience
	• Utilize laboratory experiments and process studies to further develop energetic and economic profiles regarding life history bottlenecks
Conceptual Model	• Consider the applicability of nearshore process studies and long-term surveys for monitoring overwinter survival
	• Explore the utility of advancing modeled output (e.g. life cycles, individual based models, habitat suitability, etc.) for evaluating pressures on early life survival
Report Card	• Develop indicators for large-scale persistent offshore features (such as the Warm Blob) that could provide early warning for extreme recruitment events
	• Develop energetics indicators for all life stages, with emphasis on the vulnerable early life stages just prior and post-settlement
	• Develop habitat indicators depicting suitable juvenile habitat to potentially explain time-varying survey selectivity

These recommendations are in no particular order and should complement the priorities already specified within the main stock assessment. As we continue to develop the sablefish ESP and integrate relevant linkages within the stock assessment model, we will ultimately strengthen our understanding of these mechanistic relationships and further the advancement of the sablefish assessment model toward next generation stock assessment.

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Table 1: List of data sources used in the ESP evaluation. A variety of contributions to the Ecosystem Considerations Report (Zador et al., 2017) and the Economic Status Report (Fissel et al., 2017) also utilize these data sources. Please see these reports for more details.

		Title	Description	Years	Extent
Ecosystem	Survey	EcoFOCI Spring Survey	Shelf larval survey in May-early June using oblique 60 cm bongo tows and periodic 30x50 cm neuston tows	1978-2017	Western GOA (odd yrs) SE Bering Sea (even yrs)
		EMA Summer Survey	Shelf and slope age-0 survey during June and July using Nordic and CanTrawl surface trawls	2010-2017	Eastern GOA
		ADFG Large Mesh Survey	Bottom trawl survey of crab and groundfish on fixed-grid station design using eastern otter trawl	1988-2017	Western GOA to Aleutian Islands
		RACE Bottom Trawl Survey	Bottom trawl survey of groundfish on stratified random sample grid using Poly Nor'Eastern trawl	1984-2017	GOA biennial
	Other	MUR SST	Multi-scale Ultra-high Resolution (MUR) sea surface temperature analysis anomalies from Jet Propulsion Laboratory	2003-2017	Global
		RECA Energetics	Body composition information from laboratory studies	2006-2016	Alaska
		Seabird diet growth index	Length of age-0 sablefish samples in rhinoceros auklets taken from regurgitated food samples	1978-2017	Middleton Island, GOA
		Essential Fish Habitat Models	Habitat suitability MaxEnt models for describing essential fish habitat of groundfish and crab in Alaska, EFH 2016 Update	1970-2016	Alaska
Socioeconomic		NMFS Alaska Regional Office	Catch, economics, and social values for fishing industry, data processed and provided by Alaska Fisheries Information Network	1992-2016	Alaska
		Reports	ADFG Commercial Operators Annual Reports, At-sea Production Reports, Shoreside Production Reports	2011-2015	Alaska
		Online	NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division, FAO Fisheries & Aquaculture Department of Statistics, US Department of Agriculture	2011-2016	Alaska, US, Global
		Community	Community Development Quota Program	1995-2013	Alaska

Table 2. Sablefish ex-vessel data from Alaska Fisheries. Total catch (federal and state) (thousand metric tons), catch in federal fisheries (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), number of vessels, and the proportion of vessels that are catcher vessels, 2003-2012 average and 2013-2016.

	2003-2012 Average	2013	2014	2015	2016
Total Catch K mt	15.9	14.5	12.3	11.7	10.9
Retained Catch K mt	15.09	13.66	11.6	10.8	9.9
Value M US$	$101.0	$90.0	$94.6	$94.0	$92.8
Price/lb US$	$3.04	$2.99	$3.70	$3.95	$4.28
% value GOA	89%	92%	93%	95%	96%
Vessels #	385	303	293	286	285
Proportion CV	96%	96%	96%	97%	96%

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 3. 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, 2003-2012 average and 2013-2016.

	2003-2012 Average	2013	2014	2015	2016
Quantity K mt	8.59	7.83	6.70	6.06	5.86
Value M US$	$101.5	$96.2	$99.0	$91.0	$99.7
Price/lb US$	$5.36	$5.57	$6.70	$6.81	$7.72
H&G share	95%	97%	97%	98%	97%

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 4. 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 and China, 2003-2012 average and 2013-2017.

	2003-2012 Average	2013	2014	2015	2016	2017 (thru July)
Global catch K mt	24.3	19.8	17.8	18.7	-	-
U.S.Share of global	84%	90%	90%	86%	-	-
AK share of global	58%	66%	62%	56%	-	-
Export Volume K mt	10.75	8.67	6.67	6.66	5.58	3.10
Export value M $	$ 82.23	$ 95.57	$ 81.58	$ 82.26	$ 80.82	$ 47.85
Export Price/lb US$	$ 3.47	$ 5.00	$ 5.55	$ 5.60	$ 6.57	$ 6.99
Japan value share	82%	74%	73%	63%	59%	70%
China value share	11%	14%	14%	26%	36%	21%
Exchange rate, Yen/Dollar	101.27	97.60	105.94	121.04	108.79	110.95

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.

Table 3. Report card description for sablefish including indicator title, description, potential stock assessment model linkages, and percent change from time series average for last five years and from the current year.

	Title	Description	Model Linkage	% 5 Year	% 1 Year
Larvae Stage Indicators	**Sea Surface Temperature**	Surface temperature index along the North Pacific Polar Front in central North Pacific (Shotwell et al. 2014)	Recruitment Deviations	NA	NA
	Larvae/Juvenile Transport	Total connectivity index derived from individual based model (Gibson et al. *In Press*)	Recruitment Deviations	NA	NA
	Larvae Prey – GAP	Needed: Measure of secondary production in offshore to nearshore pelagic habitat	Recruitment Deviations	NA	NA
Juvenile Stage Indicators	**Early Juvenile Prey Conditions**	*In situ* measurements of chlorophyll *a* taken from SECM survey in Southeast Alaska (Yasumiishi et al. 2015)	Recruitment Deviations	-54 %	-4 %
	Early Juvenile Growth	Anomalies from regression growth index of sablefish sampled in rhinocerous auklet diet	Recruitment Deviations	38%	-2 %
	Juvenile Habitat	Needed: Measure of late juvenile habitat from bottom trawl and longline surveys	Survey Selectivity	NA	NA
Adult Stage Indicators	**Adult Whale Depredation**	Estimated sablefish mortality by whale species in the fishery (t)	Mortality	-26 %	-34%
	Adult Value	Ex-vessel value of sablefish measured in 2016 dollars	Stock Biomass	0 %	NA

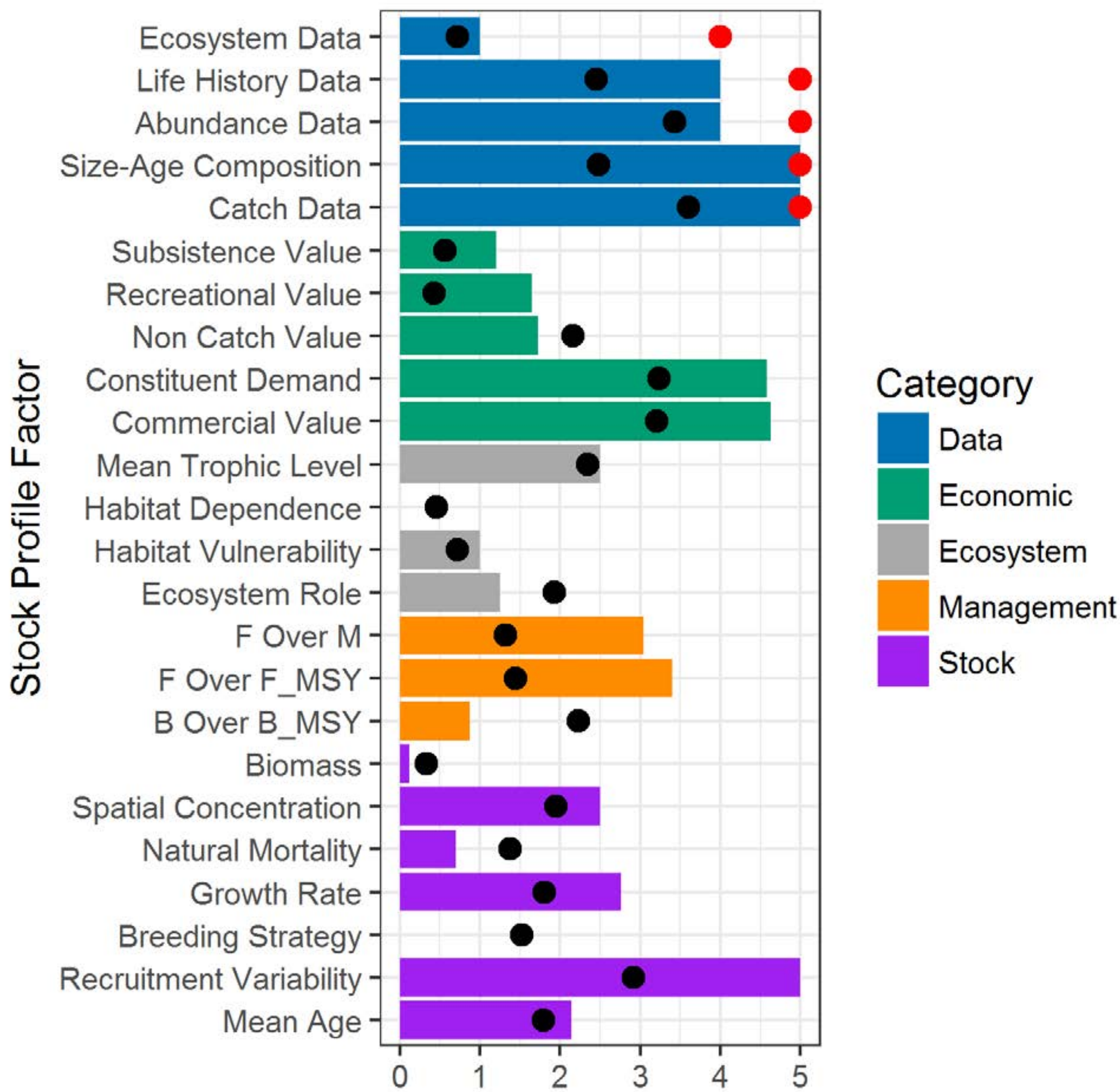


Figure 1: Baseline stock profile for sablefish. Factors are defined in various national initiative reports and SAIP (2017). Bar length measures the score or data value for sablefish, black dots measure the mean score or data value for all groundfish in the FMP, and red dots reflect the target values assessed for the data classification gap analysis as defined in the SAIP (2017).

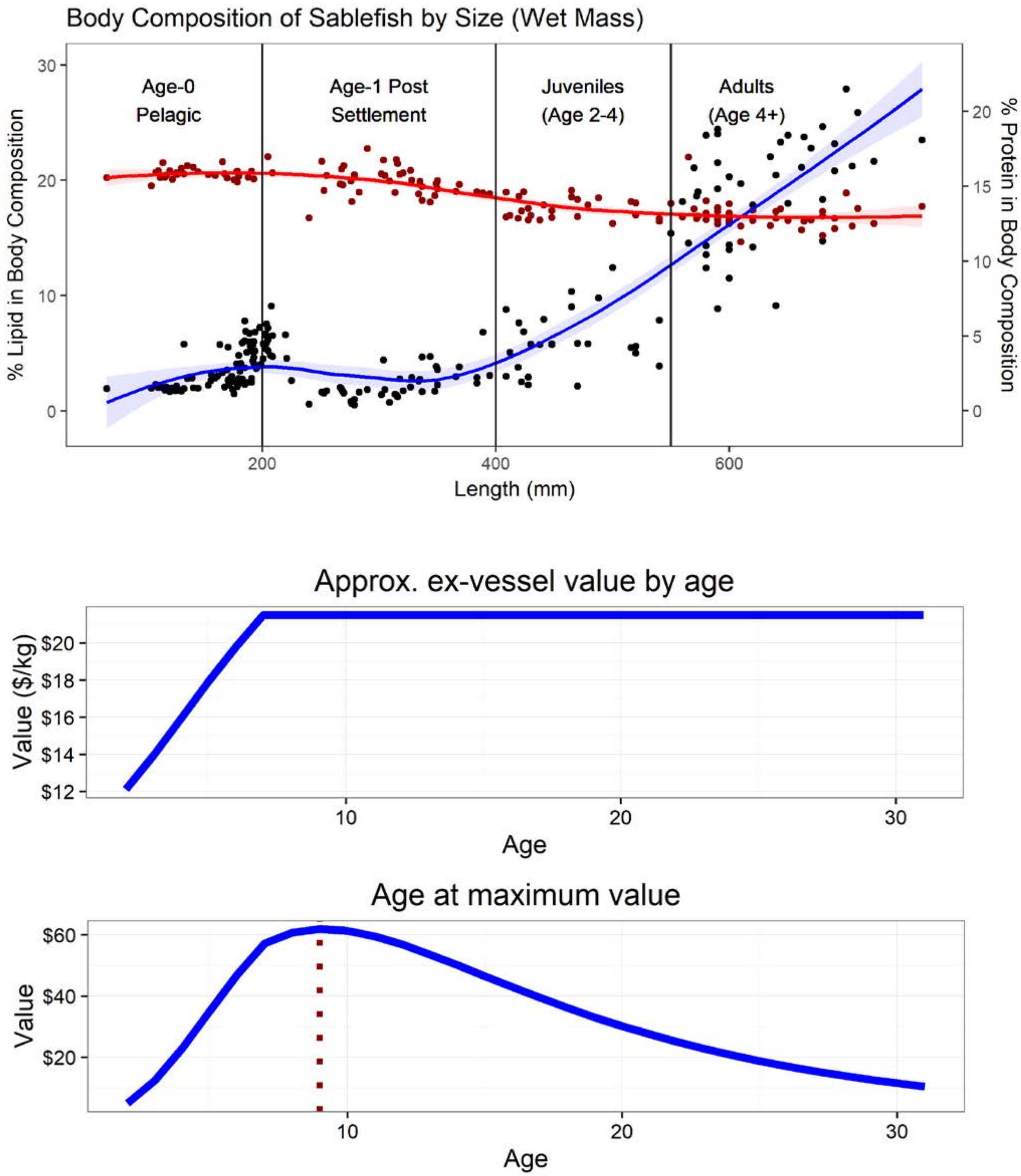


Figure 2: Top graph is the percent body composition by length (mm), black dots are % lipid by size, red dots are % protein by size and lines represent smoother (loess) for trend visualization. Middle graph is an approximate value per kilogram by age, and bottom graph is the value per kilogram multiplied by average weight for a given age. Red dotted line shows approximate age at peak value (age 9).

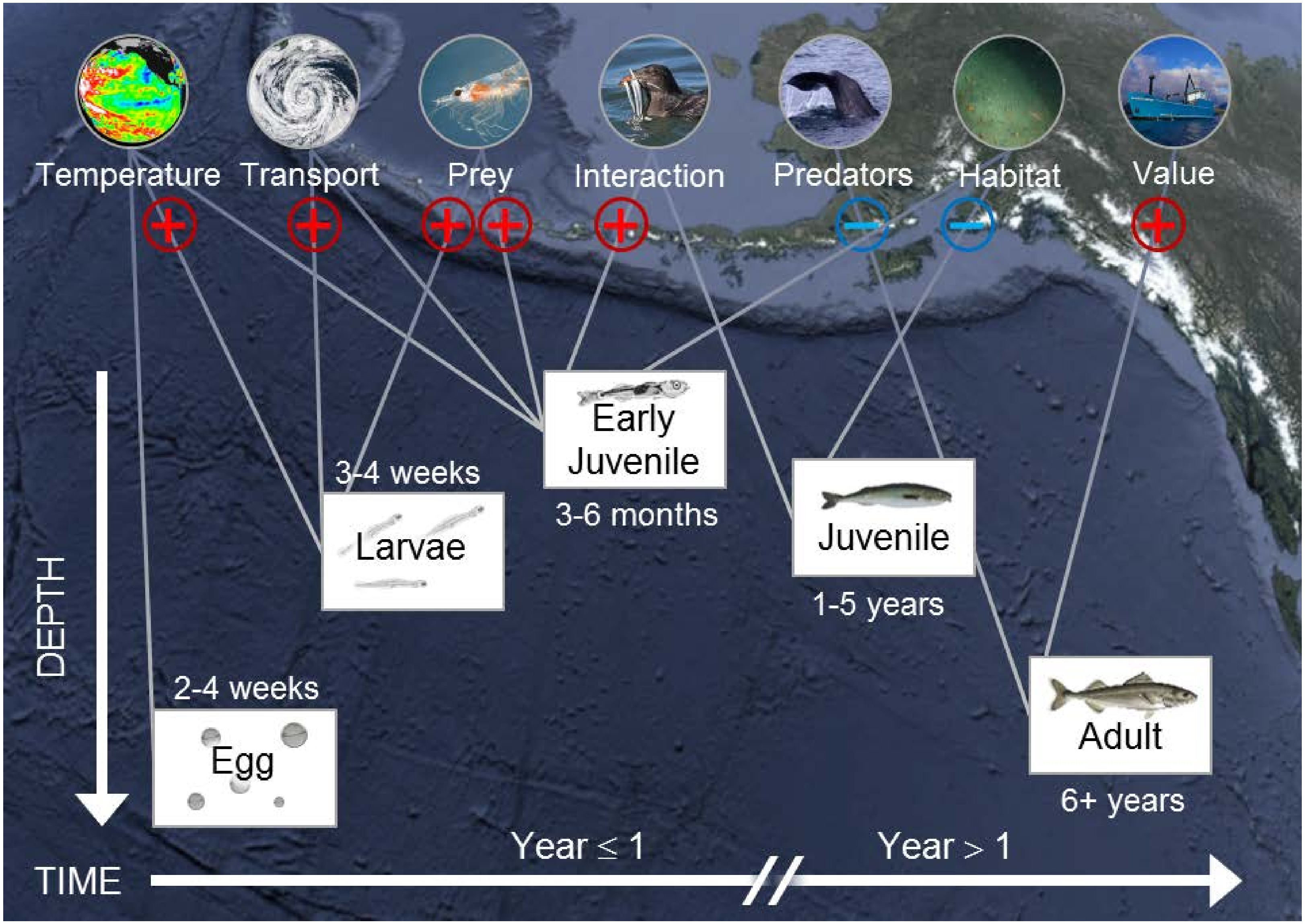


Figure 3: Conceptual model for sablefish by life stage (bottom of picture) and associated ecological pressures (top of picture). Proposed direction of relationship is provided with red positive and blue negative circles.

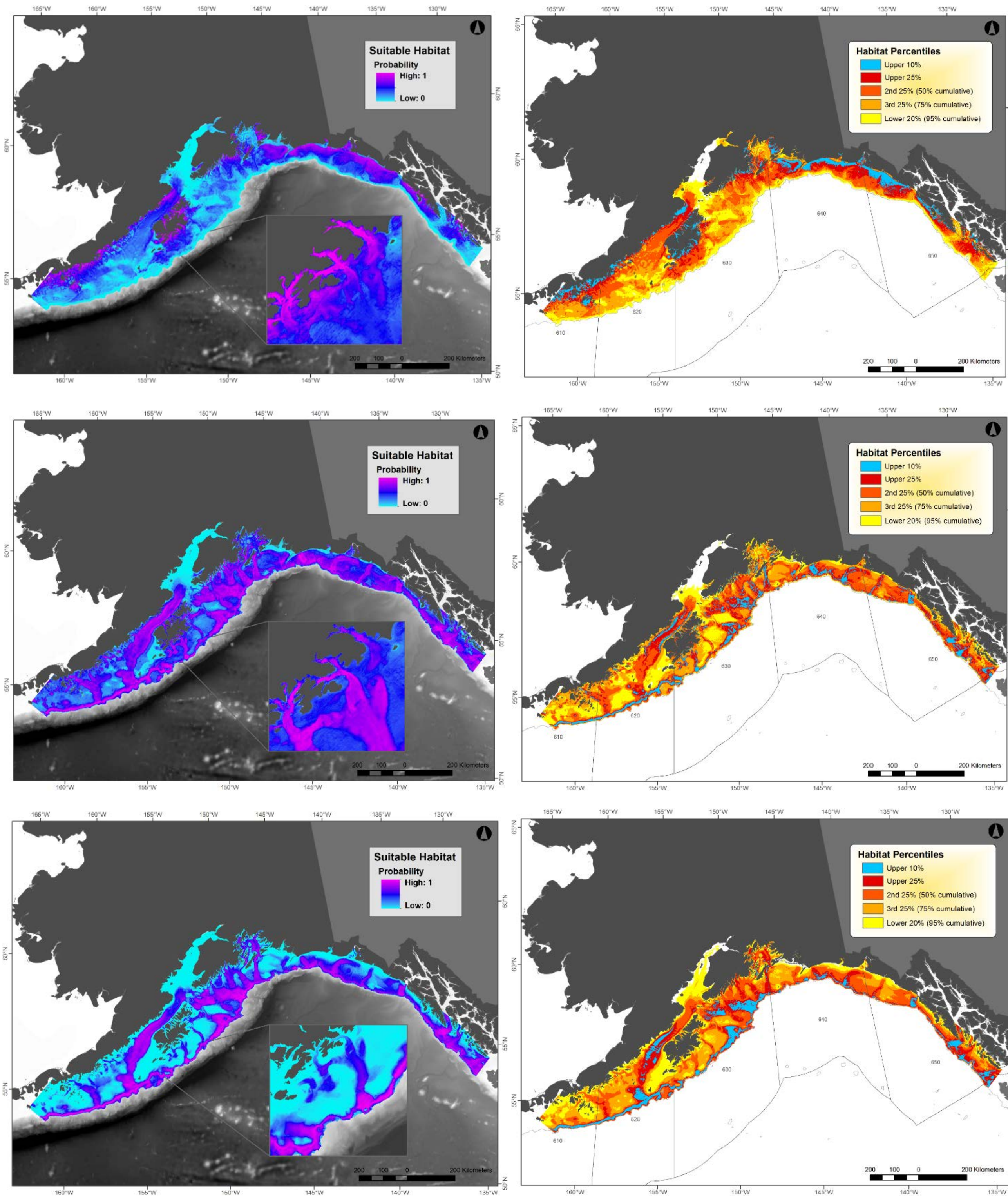
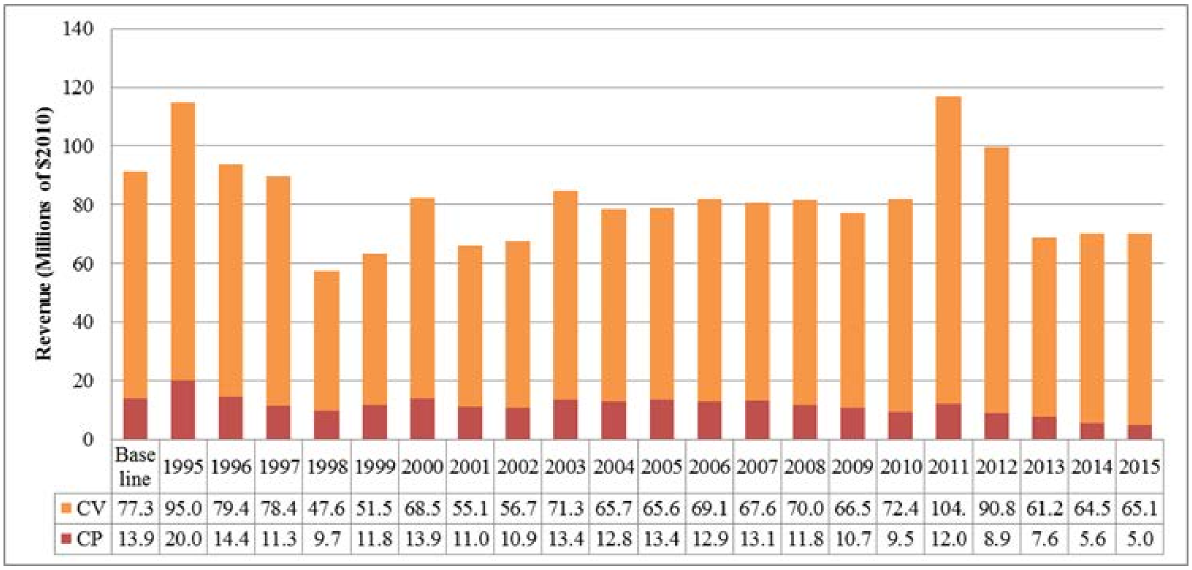


Figure 4: Habitat Suitability by early juvenile (top, fish < 400 mm), late juvenile (middle, fish < 550 & >= 400 mm), and adult (bottom, fish >550 mm) from most recent Essential Fish Habitat update (EFH, 2017). Continuous surface is shown on the left and percentile maps are on the right.



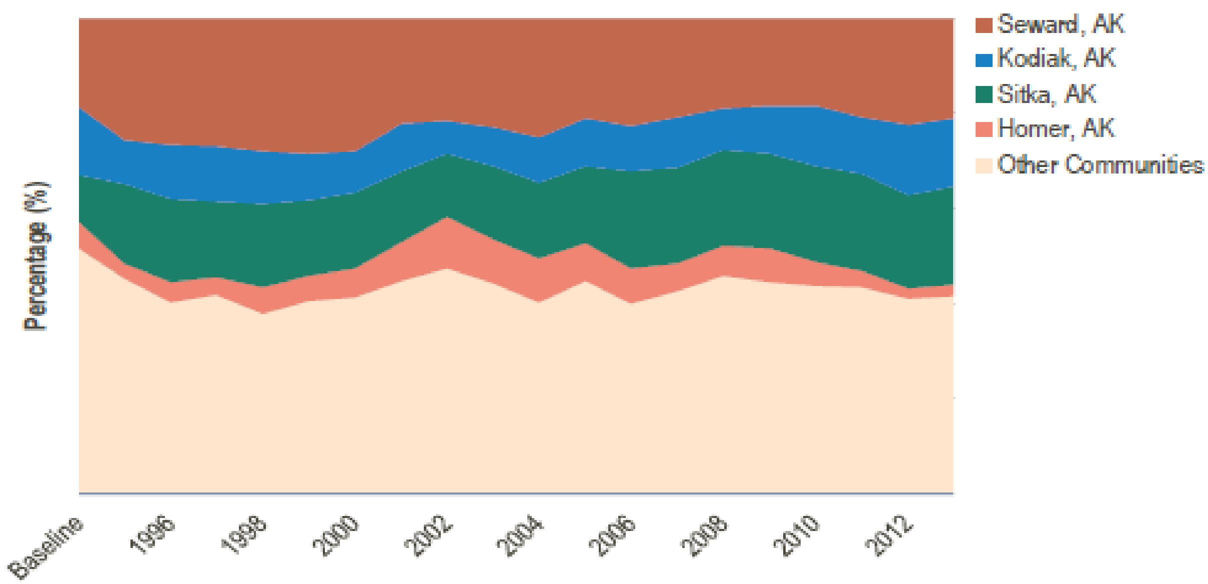


Figure 5. Revenue in millions for sablefish fishery from 1995-2015 (top graph). Regional Quotient (VALUE) for communities highly engaged in the sablefish IFQ portion of the Alaska Halibut and Sablefish Individual Fishing Quota Program from 1996-2013 (bottom graph).

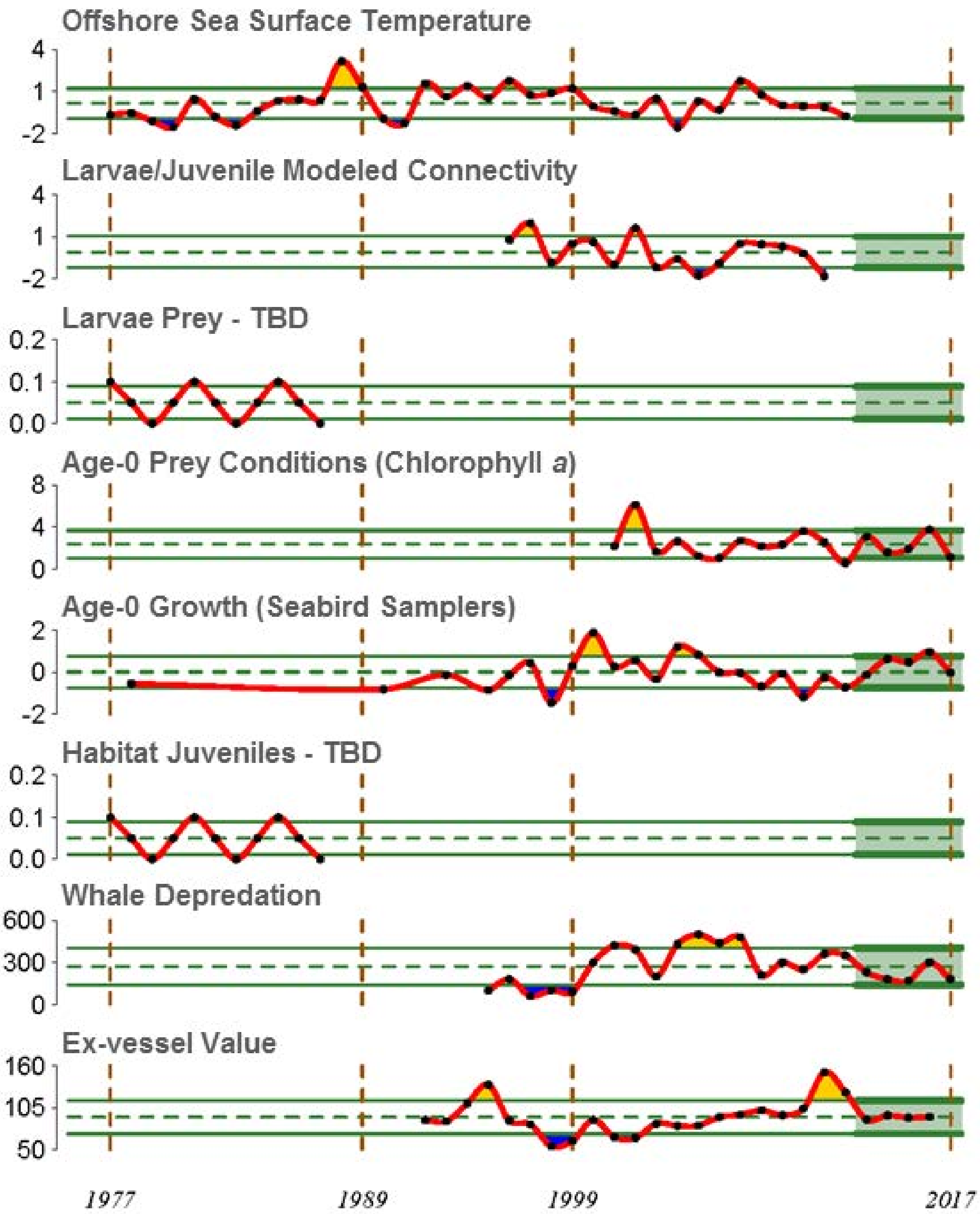


Figure 6. Report card of potential indicators for sablefish with time series ranging from 1977 – present. TBD = To Be Determined and represents an indicator gap. Green lines depict 95% confidence intervals (CI) of series. Yellow fill is above upper CI bound, blue fill is below the lower CI bound. Red hashed lines indicate regime shifts and present year.

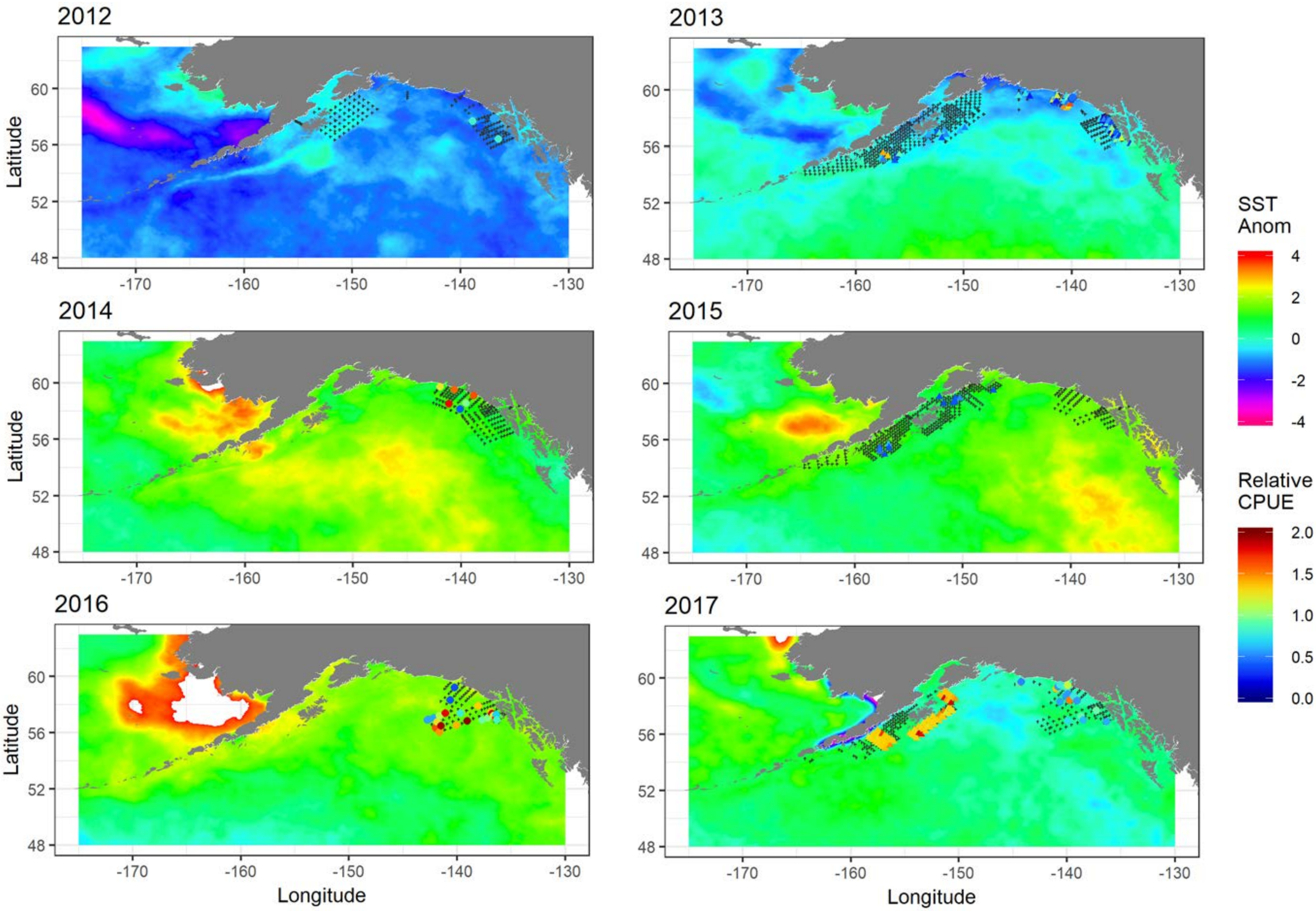
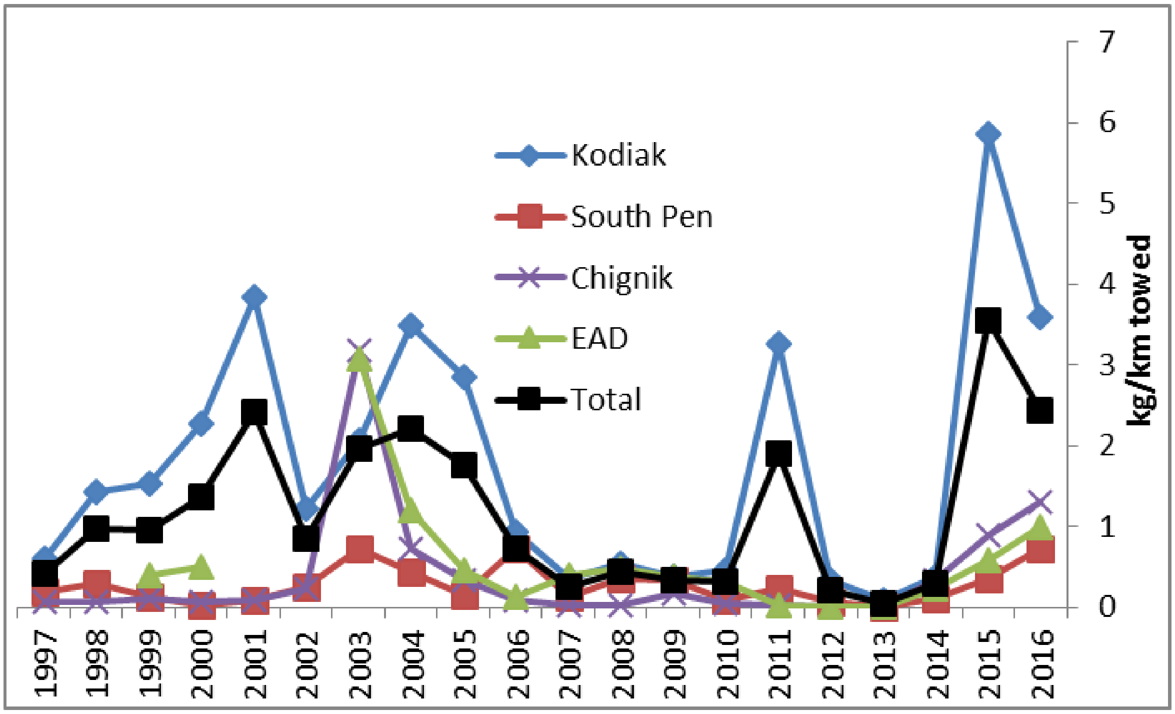


Figure 7: Distribution of larval (triangle), and age-0 (circle) by standardized measure of CPUE, 2012 – 2017 with overlay on MUR sea surface temperature for May. Black plus sign indicates station sampled. Please note that 2017 values are preliminary for larval and juvenile estimates.



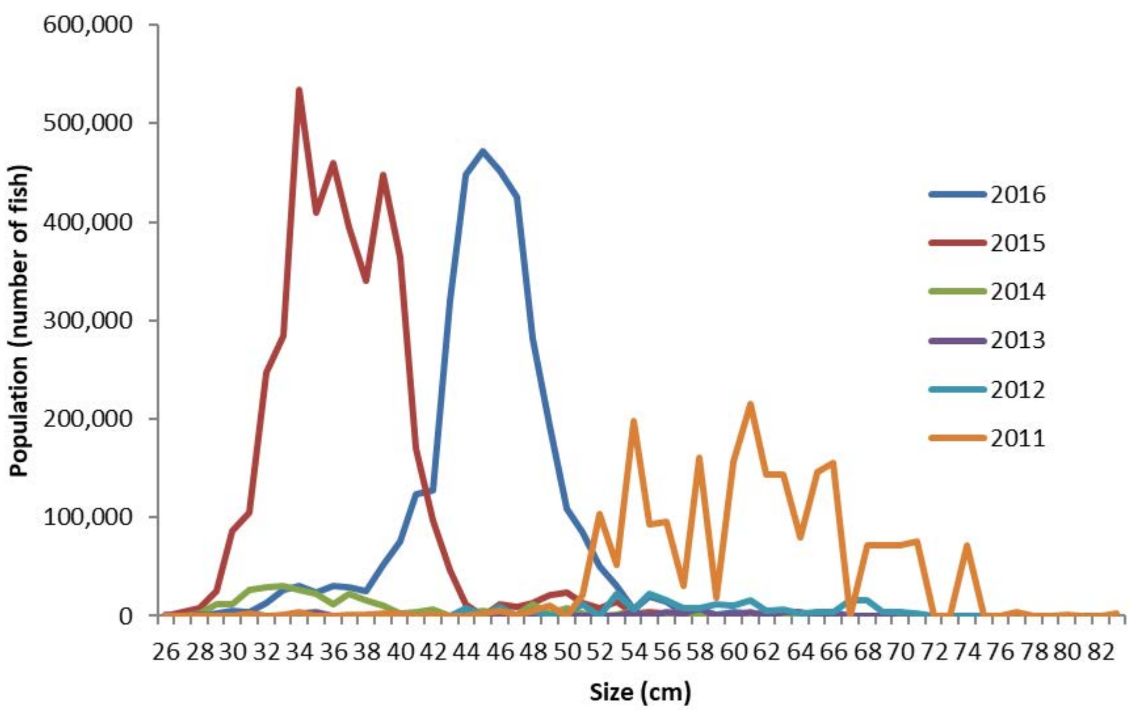


Figure 8: Length (cm) composition (top graph) and catch-per-unit-effort (bottom graph) of sablefish in the ADFG large mesh survey. Please note graphs are for trend comparison only. Values are preliminary and will be recalculated with updated station data in the future.

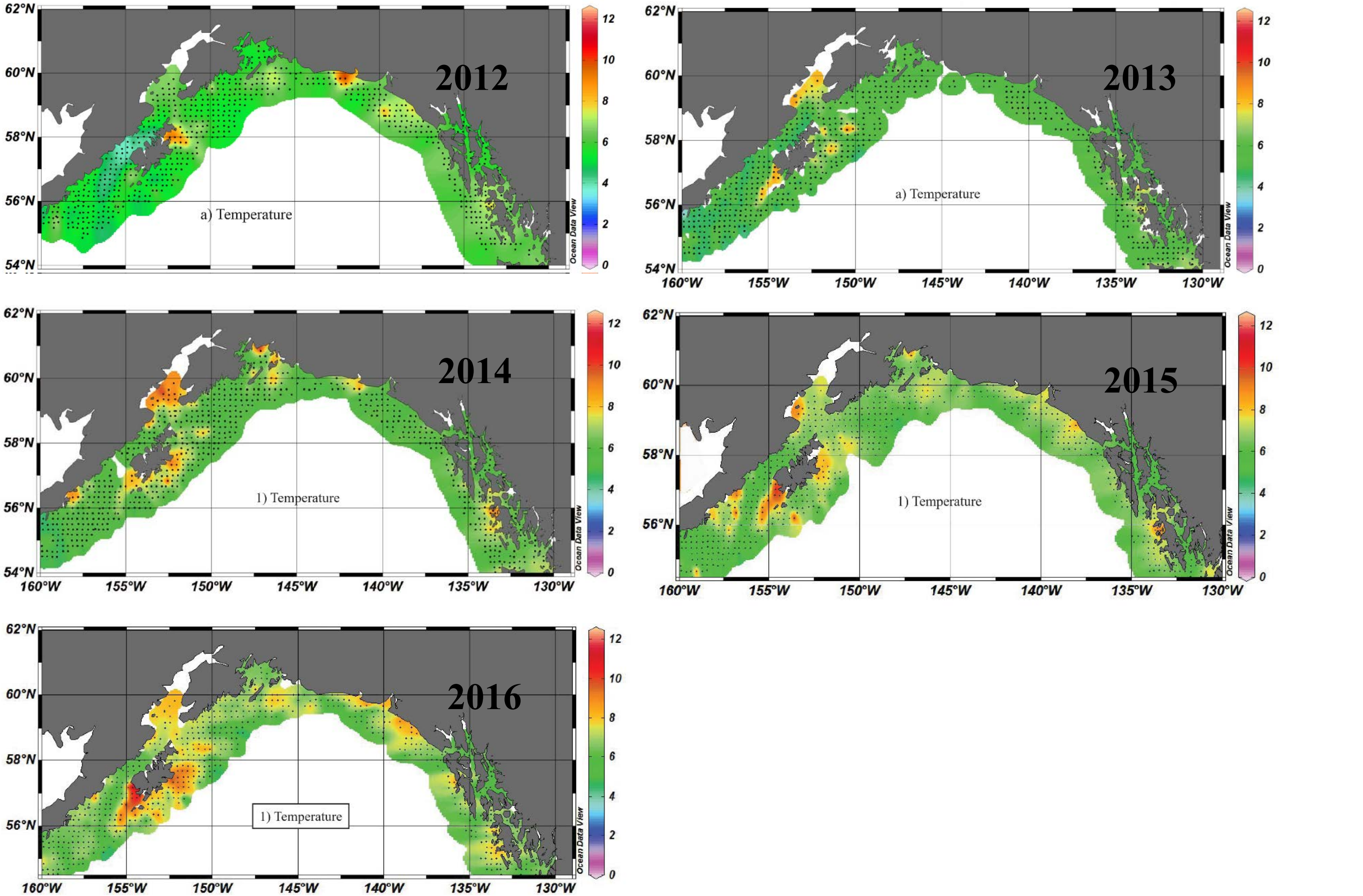


Figure 9: Bottom temperature, reproduced from International Pacific Halibut Commission Report of Assessment and Research Activities (RARA), 2012 – 2016. Please note that data is preliminary and will be finalized in future efforts.