3. Assessment of the Sablefish stock in Alaska

by
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Executive Summary

Summary of Changes in Assessment Inputs

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

Changes in the input data:

New data included in the assessment model were relative abundance and length data from the 2018 longline survey, relative abundance and length data from the 2017 fixed gear fishery, length data from the 2017 trawl fisheries, age data from the 2017 longline survey and 2017 fixed gear fishery, updated catch for 2017, and projected 2018 - 2020 catches. Estimates of killer and sperm whale depredation in the fishery were updated and projected for 2018 - 2020.

Changes in the assessment methodology:

There were no changes in the assessment methodology. However, there is an authors' recommended ABC that is lower than maximum permissible based on the new risk-matrix approach.

There are two additional appendices: the documents on apportionment (3D) and modeling explorations (3E) reviewed at the September 2018 Groundfish Plan Team meeting.

Summary of Results

The longline survey abundance index increased 9% from 2017 to 2018 following a 14% increase in 2017 from 2016. The lowest point of the time series was 2015. The fishery catch-rate/abundance index stayed level from 2016 to 2017 and is at the time series low (the 2018 data are not available yet). Spawning biomass is projected to increase rapidly from 2019 to 2022, and then stabilize.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1977-2014. The updated point estimate of $B_{40\%}$, is 116,738 t. Since projected female spawning biomass (combined areas) for 2019 is 96,687 t (83% of $B_{40\%}$, or $B_{33\%}$), sablefish is in sub-tier "b" of Tier 3. The updated point estimates of $F_{40\%}$, and $F_{35\%}$ from this assessment are 0.099, and 0.117, respectively, but Tier 3b uses the control rule to adjust these values downward. Thus, the maximum permissible value of F_{ABC} under Tier 3b is 0.081, which translates into a 2019 ABC (combined areas) of 28,171 t. The adjusted OFL fishing mortality rate is 0.096 which translates into a 2019 OFL (combined areas) of 33,141 t. Model projections indicate that this stock is not subject to overfishing, overfished, nor approaching an overfished condition.

Instead of maximum permissible ABC, we are recommending the 2019 ABC to be equal to the 2018 ABC, which translates to a 45% downward adjustment from max ABC. The final 2019 ABC of 15,068 t is 1% higher than the 2018 ABC because of updated whale depredation adjustments that are slightly smaller. The maximum permissible ABC for 2019 is 10% higher than the 2018 maximum permissible ABC of 25,583 t. The 2017 assessment projected a 41% increase in ABC for 2019 from 2018. The author recommended ABCs for 2019 and 2020 are lower than maximum permissible ABC for several important reasons that are examined in the new SSC-endorsed risk-matrix approach for ABC reductions.

First, the 2014 year class is estimated to be 2 times higher than any other year class observed in the current recruitment regime (1977 – 2014). Tier 3 stocks have no explicit method to incorporate the uncertainty of this extremely large 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 in the future. These concerns warrant additional caution when recommending the 2019 and 2020 ABCs. It is unlikely that the 2014 year class will be average or below average, but projecting catches under the assumption that it is 7.5x average introduces risk given the uncertainty associated with this estimate. Only one large year class since 1999 has been observed, and there are only two observations of age compositions to support the magnitude of the 2014 year class. Our caution in 2017 seems justified as the estimate of the 2014 year class has decreased 30% since last year's estimate. The cause of this decrease could be simply imprecision in the age compositions for the first year it was seen, or something real like an increase in natural mortality. Future surveys will help determine the magnitude of the 2014 year class and will help detect additional incoming large year classes other than the 2014 year class; there are indications that subsequent year classes may also be above average.

This is the first time we have used the risk-matrix approach to assess reductions in ABC from maximum permissible ABC. The overall score of level 4 indicates at least one "extreme concern" and suggests that setting the ABC below the maximum permissible is warranted. The SSC recommended against using a table that showed example alternatives to select buffers based on that risk level. Thompson (unpublished Sept 2018 plan team document) tabulated the magnitude of buffers applied by the Groundfish Plan Teams for the period 2003-2017, and found that the more extreme buffers were 40 – 80% reductions in ABC. For the 2019 and 2020 ABC recommendations, we consider all three of these types of uncertainty at some level to recommend that the 2019 ABC should be set equal to the 2018 ABC, which translates to a reduction of about 45% from the maximum ABC allowed by the reference model. Recommending an ABC lower than the maximum should result in more of the 2014 year class entering into the spawning biomass. This more precautionary ABC recommendation buffers 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 composition in 2019 and allow this extremely young population to further mature so they can fully contribute to future spawning biomass. The following bullets summarize the conclusions reached in ***Additional ABC/ACL considerations*** and the ***Ecosystem and Socioeconomic Profile*** in Appendix 3C:

1. The estimate of the 2014 year class strength declined 30% from 2017 to 2018.
2. Despite projected increases in spawning biomass in 2017, the 2018 spawning biomass and stock status is lower than in 2017.
3. Despite conservative fishing mortality rates, the stock has been in Tier 3b for many years.
4. Fits to survey abundance indices are poor for recent years.
5. The AFSC longline survey Relative Population Weight index, though no longer used in the model, has strongly diverged from the Relative Population Number index, indicating few large fish in the population.
6. The retrospective bias has increased in the last two years, and the bias is positive (i.e., historical estimates of spawning biomass increase as data is removed).
7. The amount of older fish comprising the spawning biomass has been declining rapidly since 2011.
8. The very large estimated year class for 2014 is expected to comprise about 10% of the 2019 spawning biomass, despite being less than 20% mature.
9. The projected increase in future spawning biomass is highly dependent on young fish maturing in the next few years; results are very sensitive to the assumed maturity rates.

10. The body condition of maturing sablefish in the recent years of high recruitment is lower than average, and much lower than during the last period of strong recruitments.
11. Another potential marine heat wave is forming in 2018, which may have been beneficial for sablefish recruitment in 2014, but it is unknown how it will affect current fish in the population or future recruitments.
12. Small sablefish are being caught incidentally at unusually high levels shifting fishing mortality spatially and demographically, which requires more analysis to fully understand these effects.

Second, as is now standard practice, we also recommend a lower ABC than maximum permissible based on estimates of whale depredation occurring in the fishery in the same way as recommended and accepted starting in 2016. 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. The methods and calculations are described in the ***Accounting for whale depredation*** section.

Survey trends support keeping ABC level relative to last year. Although there was a modest increase in the domestic longline survey index time series in the last two years, and a large increase in the GOA bottom trawl survey in 2017, these increases are offset by the very low status of the fishery abundance index seen in 2016 and 2017. The fishery abundance index has been trending down since 2007. The IPHC GOA sablefish index was not used in the model, but was similar to the 2015 and 2016 estimates in 2017, about 50% below average abundance. 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 average. The 2014 year class appears to be very strong, but year classes have sometimes failed to materialize later and the estimate of this year class is still uncertain and has declined by 30% since the 2017 assessment.

Because of the estimated size of the 2014 year class, spawning biomass is projected to climb rapidly through 2022, and then is expected to rapidly decrease assuming a return to average recruitment in the future. Maximum permissible ABCs are projected to rapidly increase while authors' recommended lower ABCs will still increase quickly to 20,144 t in 2020 and 40,000 t in 2021 (see Table 3.18).

Projected 2019 spawning biomass is 33% of unfished spawning biomass. Spawning biomass had increased from a low of 28% of unfished biomass in 2002 to 34% in 2008 and has declined again to about 26% of unfished in 2018 but is projected to increase in 2019. The last two above-average year classes, 2000 and 2008, each comprise 8% and 11% of the projected 2019 spawning biomass, respectively. These two year classes are fully mature in 2019. The very large estimated year class for 2014 is expected to comprise about 10% of the 2019 spawning biomass, despite being less than 20% 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. This apportionment strategy was used for over a decade. However, following the 5-years exponential apportionment scheme after 2010, we had 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 3.57A). 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 3.57B). These large annual changes in apportionment result in increased annual variability of ABCs by area, including areas other than the Bering Sea (Figure 3.57C). Because of the high variability in apportionment seen prior to 2013, 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 that was developed for research into spatial biomass (see ***Movement and tagging*** section) and apportionment showed different regional biomass estimates than the 5-year exponential weighted method approved by the Council and the 'fixed' apportionment methods which has been used since 2013 for apportionment of ABC to sablefish IFQ holders. Further research on alternative apportionment methods and the tradeoffs is underway and is summarized in ***Appendix 3D***. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former apportionment method until the proposed range of methods have been identified and evaluated (See *Appendix 3D*). 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 2019, we recommend continuing with the apportionment fixed at the proportions used for 2013-2018.**

Apportionment Table (before whale depredation adjustments)

Area	2018 ABC	Standard apportionment for 2019 ABC	Recommended fixed apportionment for 2019 ABC*	Difference from 2018
Total	15,380	15,380	**15,380**	0%
Bering Sea	1,501	3,085	**1,501**	0%
Aleutians	2,030	2,064	**2,030**	0%
Gulf of Alaska (subtotal)	11,849	10,231	**11,849**	0%
Western	1,659	1,877	**1,659**	0%
Central	5,246	3,978	**5,246**	0%
W. Yakutat**	1,765	1,506	**1,765**	0%
E. Yak. / Southeast**	3,179	2,870	**3,179**	0%

* 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 final recommended model ABC, we 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 published (Peterson and Hanselman 2017; Hanselman et al. 2018). We briefly describe the methods of these studies in the section ***Whale Depredation Estimation***.

In the tables below, we begin with the recommended model apportioned ABC for 2019 and 2020 compared with the specified ABC in 2018. 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 (2015-2017) of whale depredation (t) by the amount that the ABC is increasing or decreasing from 2018 to 2019 and 2020. This amount of projected depredation is then deducted from each area ABC to produce new area ABCs for 2019 and 2020 (ABC_w). In this case the 3 year-average depredation is multiplied by 1.00 because the 2019 ABC is not recommended to increase from 2018. In 2016 the SSC decided that these calculations should also apply to OFL, so the same procedure is applied to OFLs for 2019 and 2020 below (OFL_w).

The total change in recommended adjusted ABC is a 1% increase from the 2018 adjusted ABC. This small increase was because more of the recent catch has been from pot and trawl gear which is not subject to depredation, so the total decrement from ABC is smaller. We continue to 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 2019 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2018 ABC	2,030	1,501	1,659	5,246	1,765	3,179	15,380
2019 ABC	2,030	1,501	1,659	5,246	1,765	3,179	15,380
2015-2017 avg. depredation	21	13	78	67	94	39	312
Ratio 2019:2018 ABC	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Deduct 3 year adjusted average	-21	-13	-78	-67	-94	-39	-312
****2019 ABC_w**	**2,008**	**1,489**	**1,581**	**5,178**	**1,671**	**3,141**	**15,068**
Change from 2018 ABC_w	1%	2%	2%	0%	0%	0%	1%

* Before 95:5 hook and line: trawl split shown below. **ABC_w is the author recommended ABC that accounts for whales.

Author recommended 2020 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2018 ABC	2,030	1,501	1,659	5,246	1,765	3,179	15,380
2020 ABC	2,721	2,013	2,224	7,033	2,366	4,263	20,620
2015-2017 avg. depredation	21	13	78	67	94	39	312
Ratio 2020:2018 ABC	1.341	1.341	1.341	1.341	1.341	1.341	1.341
Deduct 3 year adjusted average	-33	-20	-119	-101	-144	-59	-476
****2020 ABC_w**	**2,688**	**1,993**	**2,105**	**6,932**	**2,222**	**4,204**	**20,144**
Change from 2018 ABCw	35%	36%	36%	34%	33%	34%	35%

* Before 95:5 hook and line: trawl split shown below. ** ABC_w is the author recommended ABC that accounts for whales.

Adjusted for 95:5 hook-and-line: trawl split in EGOA	Year	W. Yakutat	E. Yakutat/Southeast
	2019	1,828	2,984
	2020	2,433	3,993

Author recommended 2019/2020 OFLs (with whale depredation adjustments)

Year	2019				2020			
Area	AI	BS	GOA	Total	AI	BS	GOA	Total
2018 OFL	3,987	2,949	23,275	30,211	3,987	2,949	23,275	30,211
OFL	4,373	3,235	25,532	33,140	6,030	4,460	35,203	45,692
3 year average depredation	21	13	278	312	21	13	278	312
Ratio	1.097	1.097	1.097	1.097	1.512	1.512	1.512	1.512
Deduct 3 year average	-23.5	-13.8	-305.0	-342	-32.4	-19.1	-420.5	-472
***OFL_w**	**4,350**	**3,221**	**25,227**	**32,798**	**5,997**	**4,441**	**34,782**	**45,220**
2018 OFL_w	3,987	2,949	23,275	30,211	3,987	2,949	23,275	30,211
Change from 2018	9%	9%	8%	9%	50%	51%	49%	50%

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

Summary table

Quantity/Status	As estimated or specified *last* year for: 2018	2019	As estimated or recommended *this* year for: 2019*	2020*
M (natural mortality rate)	0.097	0.097	0.100	0.100
Tier	3b	3a	3b	3a
Projected total (age 2+) biomass (t)	330,655	350,850	488,273	513,502
Projected female spawning biomass (t)	88,928	110,974	96,687	129,204
$B_{100\%}$	245,829	245,829	291,845	291,845
$B_{40\%}$	98,332	98,332	116,738	116,738
$B_{35\%}$	86,040	86,040	102,146	102,146
F_{OFL}	0.102	0.114	0.096	0.117
$maxF_{ABC}$	0.086	0.096	0.081	0.099
F_{ABC}	0.077	0.085	0.044	0.051
OFL (t)	30,211	47,891	33,141	45,692
OFL_w (t)**	**29,507**	**46,775**	**32,798**	**45,220**
max ABC (t)	25,583	41,044	28,171	38,916
ABC (t)	15,380	21,648	15,380	20,620
ABC_w (t)**	**14,957**	**21,053**	**15,068**	**20,144**
Status	As determined *last* year for: 2016	2017	As determined *this* year for: 2017	2018
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 15,380 t and 20,620 t (Author's ABC) used in place of maximum permissible ABC for 2019 and 2020. This was done in response to management requests for a more accurate two-year projection. **ABC_w and OFL_w are the final author recommended ABCs and OFLs after accounting for whale depredation.

Summary tables by region

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2017	139,000	11,885	10,074	10,074	10,521
	2018	356,000	22,703	11,505	11,505	9,175
	2019	264,000	25,227	11,571		
	2020	266,000	34,782	15,462		
BS	2017	24,000	1,499	1,274	1,274	1,159
	2018	94,000	2,887	1,464	1,464	1,460
	2019	52,000	3,221	1,489		
	2020	52,000	4,441	1,994		
AI	2017	43,000	2,101	1,735	1,735	590
	2018	65,000	3,917	1,988	1,988	474
	2019	98,000	4,350	2,008		
	2020	99,000	5,997	2,688		

Year	**2018**				**2019**		**2020**	
Region	OFL	ABC	TAC	Catch*	OFL	ABC**	OFL	ABC**
BS	2,887	1,464	1,464	1,460	3,221	1,489	4,441	1,994
AI	3,917	1,988	1,988	474	4,350	2,008	5,997	2,688
GOA	22,703	11,505	11,505	9,175	25,227	11,571	34,782	15,462
WGOA	--	1,544	1,544	1,005	--	1,581	--	2,105
CGOA	--	5,158	5,158	4,100	--	5,178	--	6,931
**WYAK	--	1,829	1,829	1,645	--	1,828	--	2,433
**EY/SEO	--	2,974	2,974	2,425	--	2,984	--	3,993
Total	29,507	14,957	14,957	11,109	32,798	15,068	45,220	20,144

*As of October 1, 2018 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.

*"...that authors balance the desire to improve model fit with increased risk of model misspecification." (***SSC December 2017***)*

"The tradeoff between model complexity and parsimony, and therefore between bias and precision of estimates, represents a basic and fundamental ecological modelling challenge. In the context of fisheries stock assessment, we are frequently faced with the choice of assigning lack of fit to process error (actual changes in the mechanisms generating the data) and observation error (our imprecise ability to measure the underlying processes). In the former case, it is often appropriate to add model complexity in order to reduce bias, in the latter, adding parameters will decrease model precision and could add bias. There are no completely objective criteria that can be employed in the search for a model that is complex enough, without being overly parameterized, making final model formulation the result of a subjective analysis informed by the author's training and professional experience.

"The SSC would prefer that new assessments should start as simple as practicable, and additional model complexity should be evaluated using all diagnostic tools available to authors. Even existing assessments should be periodically evaluated for "complexity creep" and consistency with similar assessments. Diagnostic tools can include evaluation of: residual patterns, consistency with biological hypotheses, plausibility of estimated values, model stability, retrospective patterns, consistency with modelling of similar species (or the same species in other areas), model predictive skill, and even expert judgment. It is essential that analysts utilize a comprehensive evaluation and not rely on a single model selection criterion. The SSC notes that simple parameter counts may not always be appropriate when parameter values are constrained via informative prior probabilities, or distributional assumptions (recruitment and other constrained deviations). Further, likelihood-based model complexity criteria (e.g., AIC, likelihood ratios, DIC) can be very sensitive to data-weighting and penalized likelihoods, and are therefore not sufficient to justify or discourage additional model complexity.

*"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases." (***SSC June 2018***)*

We agree with the SSC on the need to justify added complexity, and add no new complexity in this year's assessment model.

"...that the metric (or metrics) used to describe fish condition be consistent among assessments and the Ecosystem Status Report where possible. "

To help coordinate author responses to this request, a committee was established earlier this year, consisting of all Ecosystem Status Report (ESR) and assessment authors who currently report fish condition. The committee agreed that the "weight-length residual" method currently used in the ESR should be the standard. Chris Rooper has offered to share his R code for doing the necessary calculations and making plots. Of course, assessment authors are not required to report fish condition, but if they choose to do so, conforming to the weight-length residual method will ensure that this SSC request is satisfied.

We report fish condition using longline survey specimens in the Ecosystem and Socio-economic profile (ESP, Appendix 3C) using the length-weight residual method used in the ESR.

"...that authors investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations, with consideration of a two-step approach including a

projection using F to find the catch associated with that F and then a second projection using that fixed catch. More specifically: step 1 would consist of using the target F for each forecast year to obtain a distribution of catch levels due to parameter and model uncertainty; and step 2 would consist of running a new set of projections conditional on each year's catch being fixed at the mean or median of the corresponding distribution computed in step 1, so as to obtain a distribution of F for each forecast year"

The sablefish model has for many years evaluated the full parameter uncertainty by conducting projections within the assessment model. However, the suggested method by the SSC isn't directly implemented for sablefish. We do note, though, that there is still no practical application for stocks in tier 3 for the current or future uncertainty distributions produced in the assessment, until an approach like P* is adopted. SSMA and MESA leadership will facilitate coordinated responses to this request by issuing specific guidance and individual tasking for future projection models.

Part 1:" ...that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC along with an integrated analysis of the indices. These integrated analyses are to be produced by the respective assessment author(s) and presented at the October Council meeting." (SSC October 2017)

The co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from SSMA and MESA leadership, suggest that authors address this request as follows:

Part 2: "...explicit consideration and documentation of ecosystem and stock assessment status for each stock, to be presented at the December Council meeting." (SSC October 2017)

This request was recently clarified by the SSC (in December 2017) by replacing the terms "ecosystem status" and "stock assessment status" with "Ecosystem Status Report information" and "Stock Assessment Information," where the potential determinations for each will consist of "Okay" and "Not Okay," and by issuing the following guidance (emphasis added):

- *"The SSC clarifies that "stock assessment status" is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.*
- *"Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the "Okay" or "Not Okay" determinations.*
- *"The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.*
- *"Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC.*
- *"In consideration of this request to examine stock status information and ecosystem status report information, the leadership of the joint Teams recommended that a group be formed to work with the editors of the ecosystem status report to develop these ecosystem thresholds for action. Moreover, they asked the SSC to assign members to participate in this effort. If the workgroup is formed, the SSC nominates the following SSC members to participate in this workgroup: Franz Mueter and George Hunt.*
- *"Finally, one SSC member indicated that there were multiple groups doing this or a very similar exercise (i.e., trying to explicitly use ecosystem data to anticipate changes in stock status) at present, with*

several products in the pipeline. The SSC requests that the Alaska Fisheries Science Center coordinate these efforts so as to avoid duplication of efforts, and determine whether a new group is necessary."

No later than the summer of each year, the lead author of each assessment will review the previous year's ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where "severe decline" means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely and if that decline was not anticipated in the most recent stock assessment, he or she will summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become available after the document is produced but prior to the October Council meeting of that year, the document will be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary.

The ESR was examined for details pertaining to sablefish during the summer of 2018. No indications of a severe decline in stock biomass were found.

"In the absence of a clear recommendation from the PT on the inclusion of socio-economic factors as a basis for ABC reductions, the SSC recommends that economic considerations should NOT contribute to ABC reductions, but should instead be considered during the TAC setting process. Stock assessment authors and others may have important information to contribute to this step (e.g., potential for foregone yield when large young year classes are present in the stock) and should be given an opportunity to convey this information in a manner that is timely and conducive to use by the Council for setting TACs." (SSC October 2018)

"The risk matrix approach (i.e., Table 1 of the workshop report) includes four increasing levels of concern crossed with three types of contributing factors: assessment, population dynamics, and ecosystem. This framework provides a clear classification of degree and basis for any potential reduction. Although assignment to a specific cell in this matrix will be subjective, clearly delineating the categories should improve transparency and help the PTs and SSC structure future decisions. The SSC recommends that this approach be used qualitatively (not from the example percentages presented in Table 2) in December if any reductions to the ABC are recommended (but please drop the emojis)." (SSC October 2018)

We employ the new risk-matrix approach to aid in recommending an ABC lower than the maximum permissible in this document. See *Additional ABC/ACL considerations*.

Responses to SSC and Plan Team Comments Specific to this Assessment

"The authors and the JPT agreed that the fixed area apportionments used in 2016 should be applied again this year. The author noted that the CIE reviewers concluded that continued use of the fixed area approach did not appear to pose a conservation concern. The SSC notes that the authors have indicated that a complete review of the method to be used for spatial allocation will be forthcoming. The SSC requests conduct of this analysis in 2018." **(SSC December 2017)**

The SSC noted the recommendation to continue the static apportionment using 2013 values in light of continued analysis and the conclusion from the CIE review that extremely high migration rates remove any appreciable biological concern. The SSC agrees with the authors continued use of the static apportionment for 2019, but continues to request progress be made." **(SSC October 2018)**

"The Teams recommend continued development of the apportionment MSE." **(Plan Team September 2018)**

We recommend continuing with fixed apportionment as apportionment alternatives have yet to be fully investigated. Apportionment comparisons examining retrospective behavior of multiple apportionment options were presented to the September Joint Plan Team, and are detailed in Appendix 3D. Work to develop the operating model for an MSE-style examination of apportionment is proceeding.

*"The authors noted that "recent genetic work by Jasonowicz et al. (2017) found no population substructure 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." The SSC notes that there may well be other reasons to delineate separate stock units, but suggests that the assessment authors should consider the merits of a single coastwide assessment in light of these recent findings." (***SSC December 2017***)*

In April 2018 scientist from AFSC, Alaska Department of Fish and Game, NWFSC, and Fisheries and Oceans Canada met to discuss and compare sablefish research and assessment for each region. The group continues to meet regularly to discuss development of a coastwide operating model and life history review, which would allow further exploration of sablefish across management areas.

"The assessment authors noted that sablefish exhibit skip spawning at ages at which less than 100% of the fish are mature; the rate of skip spawning is variable and decreases with age. The SSC encourages continued exploration of methods to incorporate new maturity data into the stock assessment." (**SSC December 2017**)

We continue to research ways to use the longline survey platform to improve our maturity estimates for the assessment. We illustrate the sensitivity to these maturity estimates in the ***Additional ABC/ACL Considerations*** section.

Comments related to Producing ESPs

"The SSC discussed whether this information should go into the SAFE but concluded that the best place for this information would be Environmental Socio-economic Profiles (ESPs), if ESPs are developed for crabs." (**SSC, February 2018**)

Several manuscripts are in development that describe what an ESP is and provide guidelines on how and when to create an ESP. These manuscripts also include options for creating advanced elements of an ESP for high priority stocks. The case studies provided in the manuscripts include elements of the ESPs for the five GOA-IERP focal species namely sablefish, GOA pollock, GOA Pacific cod, GOA arrowtooth flounder, and GOA Pacific ocean perch. As the ESPs develop at the AFSC we also anticipate including a data-limited stock such as "other rockfish" or "sharks" and coordinating with the Crab Plan Team to develop ESPs for crab stocks.

"The SSC notes that the current version of the ESP contains a considerable amount of background information that is redundant to text already included in the assessment. This background information detracts from the utility of the ESP as a clear testing ground for the implementation of environmentally or socioeconomically linked assessments." (**SSC, December 2017**)

"The SSC also notes that the conceptual model and the literature review are not particularly useful for the process of developing environmentally or socio-economically linked assessments. The assessment authors certainly should be aware of the life history and potential environmental and socio-economic linkages impacting their stock. This type of conceptual information should be moved to the Ecosystem Considerations Chapter." (**SSC, December 2017**)

"To be useful in informing the status determination process, the ESP must shift from a collection of references about sablefish to a suite of core indicators that would be updated every year in September." (**SSC, December 2017**)

A new baseline ESP manuscript previewed in September 2018 details how the ESP has shifted from being reference driven to identifying and monitoring a core suite of indicators specific to the stock. Additionally, the manuscript provides options for improving the timeline for ecosystem or socio-economic data delivery so that ESPs can be maintained on a schedule appropriate for the stock assessment cycle. A set of workshops is also funded that are intended to streamline and coordinate data contributions to the ESPs.

"The author should examine what the predicted year-class strength in 2014 would have been based on current knowledge of environmental linkages listed in the ESP. This prediction should be presented in the 2018 SAFE document to assess the process error surrounding the stock-recruit curve and an evaluation of whether the information contributed by the ESP is sufficient to change the management of this stock to tier 1." (**SSC December 2017**)

The ESPs are still in development and the AFSC is supporting several workshops in the future to work on data contributions, indicator development, and modeling applications. Guideline documents will be produced from these ESP workshops to assist future ESPs. We will consider these guidelines for evaluating indicators to be used in the operational stock assessment in the future.

With respect to estimating what the 2014 year class would have been based on current linkages in the ESP, we are unclear what the SSC is requesting. The sablefish assessment model does not use a stock-recruit curve, and given the observation of another giant year class at very low spawning biomass, it is unlikely that a "reliable stock-recruit relationship" will be established for Tier 1 consideration. We hope to present alternative models in the ESP that include the top indicators developed to assist in setting management targets in the future.

The following three recommendations are grouped since they are related:

"The SSC also suggests that the next assessment include further investigation of the lack of fit to the plus group in recent fishery age compositions, and development of a prior for natural mortality." **(SSC December 2017**)

"The Teams recommended that further evaluations of selectivity options be pursued." (**Plan Team November 2017**)

"The Teams recommend continued investigations on selectivity." (**Plan Team September 2018**)

"The SSC agreed with the PT recommendation to retain time-invariant selectivity for 2018, but encouraged further work to improve the poor fit to the compositional data. The SSC also supports the use of the new and more objective prior distribution for natural mortality (M). (**SSC October 2018**)

The natural mortality estimate seemed fairly well behaved on initial implementation in 2016 with no prior distribution, but became unstable during retrospective runs, which caused concern that future data might also create large fluctuations in natural mortality. In 2016, we constrained M with a prior distribution with a CV of 10%. We have constructed a more informed prior and presented results at the September Plan Team in 2018. We did a thorough investigation of different fishery selectivity options, but did not reach any specific recommendations for options that improved some of the plus group and age composition fits noted by the Plan Teams and the SSC (Appendix 3E). We showed the results of some of these models applied to 2018 data in the ABC Recommendation section but concluded that none of the models were ready for implementation due to instability introduced with the new natural mortality prior and dome-shaped selectivity that warranted further exploration. We look forward to exploring additional options in upcoming assessments.

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 surveys near Kodiak Island in December of 2011 and 2015, spawning appeared to be imminent and spent fish were not found. 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 for more 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 their 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, Rodgveller et al. 2016).

Movement and tagging

2018 Sablefish Tag Program Recap

The Auke Bay Laboratory continued the 40+ year time series of sablefish tagging in 2018. Approximately 3,600 sablefish were tagged on the annual NMFS longline survey, and approximately 400 sablefish tags have been recovered in 2018 to date. Of those recovered tags, the tagged sablefish at liberty the longest was for approximately 39 years (14,155 days), the shortest recovered tag at liberty was for 9 days, and the greatest distance traveled was 1,907 nm. This was a fish tagged in the Aleutian Islands on 6/6/2010 and recovered off Washington State on 4/13/2018).

Movement

Using tag-recapture data, a movement model for Alaskan sablefish was developed for Alaskan sablefish by Heifetz and Fujioka (1991) based on 10 years of data. The model has since 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 using 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, the development of a three-area spatial sablefish assessment model is ongoing that can be used to examine regional sablefish biomass, and be used 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 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 U.S. 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 Bering 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 IFQs, the number of longline vessels with sablefish IFQ harvests experienced a substantial anticipated decline from 616 in 1995 to 362 in 2011 (NOAA 2016). 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 BSAI IFQ fishery is legal and landings have increased dramatically since 2000. The average catch in pots in the BS and AI was on average 0.5-0.7% of total catch from 1991-1999 (Table 3.2). The percent of catch from pots in the AI has varied from 10-47% since 2000 and was near the peak in 2017 and 2018 (average 44%). Catch in pots has been consistently high in the BS since 2000; the average percent of catch in pots in the BS since 2000 is 45%, but was below average in 2017 and 2018 (average 27%). As a proportion of fixed gear catch, since 2000 pot gear makes up 24% of the catch in the AI and 62% in the BS. In 2017 and 2018 the average was 58% in the AI and 76% in the BS. Pots in these areas are longlined with approximately 40-135 pots per set.

Because of an action taken by the NPFMC in 2015, pot fishing has been permitted in the GOA since 2017, but makes up a small proportion of the fixed gear catch (9% of the catch in the GOA in 2017 and 2018). The number of pots per set ranged from 2-74.

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. Catch in the trawl fishery increased sharply in the BS and AI in 2017 and 2018. In the AI it increased from 30 t in 2016 to 129 t in 2018 and 152 t in 2018. In the BS it increased from 257 t in 2016 to 685 t in 2017 and 1,043 t in 2018 (Table 3.2).

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 12,000 t in 2017 and 2018 (Table 3.3, Figure 3.2). 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 847 t during 2010 - 2018. Discard rates are generally higher in the GOA than in the BSAI (Table 3.4). In 2017 and 2018 there was a large increase in discards in the non-HAL gears, mostly because of the high encounter rates with young fish.

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 (672 t/year, 215 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 recent years at 11,554 t but has decreased by more than half in in the last few years (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 (331 t/year on average, mostly in the GOA) and golden king crab (16,025 individuals/year on average, mostly in the BSAI) (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. Years in **bold** are data new to this assessment.

Source	**Data**	**Years**
Fixed gear fisheries	Catch	1960-**2018**
Trawl fisheries	Catch	1960-**2018**
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. fixed gear fishery	CPUE, length	1990-**2017**
	Age	1999-**2017**
U.S. trawl fisheries	Length	1990,1991,1999, 2005-**2017**
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-**2018**
	Age	1996-**2017**
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.

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 1.5% 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. Only logbook data that is voluntarily given to IPHC to be given to Auke Bay Laboratories is used in the assessment (i.e., data from vessels that are required to keep logs are not required to give them to Auke Bay Laboratories). 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 when both 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.

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 observed targeted longline sets in federal waters, represented 9% (688 mt) of the total longline catch in federal waters in 2017. The percent of the IFQ catch observed was 2% in the BS, 10% in the EY/SE, 8% in the WG, 7% in WY, 10% in the CG, and <1% in the AI. There was a decrease in the number of vessels with observer coverage in the AI (1 vessel) so no data is reported due to confidentiality (Table 3.9). The number of observed sets in the WG was down in 2017 and was the lowest in the time series. The number of vessels with coverage in WY and EY/SE areas declined from 2015 to 2016 and again in 2017; in WY the number of vessels in 2015 was 39 and in 2017 it was 18; in EY/SE the number of vessels in 2015 was 51 and in 2017 it was 38. However, coverage in EY/SE was still much higher than average (average from 1995 to 2017 was 21).

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. The percent of sablefish directed sets that are depredated by killer whales is on average 23% in the BS, 3% in the AI, 3% in the WG, and 1% in the CG. Although the rate is high in the BS, the average number of sets observed is only 20. Likely because of this small sample size, the annual range in the rate of depredation is 7-100%. In 2017 killer whale depredation was average in the CG, WG, and AI. It was 30% in the BS, which is near average.

Observers also record sperm whale depredation, however, determining if sperm whales are depredating can be subjective because they do not take the great majority of the catch like killer whales do. Sperm whale depredation has been recorded by observers since 2001. It is most prominent in the CG, WY, and EY/SE areas and less common in the WG. The average percent of sets that are depredated is 7% in the CG, WY, and EY/SE areas, but the average over the past 5 years is higher than the time series average (CG = 10%, WY = 12%, EY/SE = 9%). In 2017, depredation was above the 5-year average (CG = 15%, WY = 13%, EY/SE = 20%). In the WG, 2% of sets were depredated, which is the same as the 5-year average.

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 2017, of the sets with a declared sablefish target, after the data was screened for missing data fields, 56% of sets came from vessels under 60 ft and 70% 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; in 2017 50% of the hook and line catch was documented in logbooks and 9%

of the catch was covered by observers. Some data are included in both data sets if an observer was onboard and a logbook was turned in.

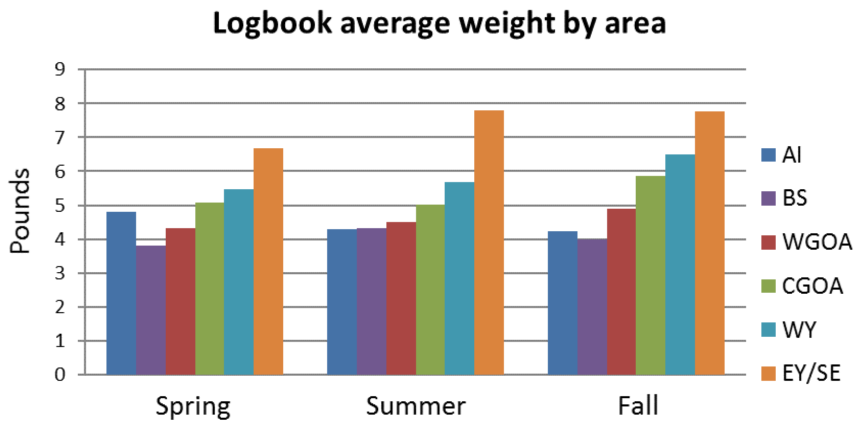
In 2017, whale presence and gear depredation was included in logbooks. Some vessels were not yet using these new logbooks and only a portion of logbooks included data on whales, because it is not a required field. For longline sets that targeted sablefish (prior to filtering any data out for quality or lack of catch or effort data), 69% of sets (5,190 sets) had data on whale presence (either not present, sperm whale, or killer whales). Of these sets, 25% had sperm whales present, 1% had killer whales present, and 73% had no whales present. For sets where there was whale data, in the AI 7% had sperm whales present; in the BS 19% had killer whales present; in the WG 15% had sperm whales and 4% had killer whales; in the CG 28% had sperm whales; in WY 26% had sperm whales and 4% had killer whales; in EY/SE 29% had sperm whales and 1% had killer whales. These rates are higher than most of the average rates in the observe data set. However, it is also possible that whale data in logbooks was more likely to be filled out if there were whales present. In future years we will be able to see trends in whale presence we expect to see an increase in the quantity of whale observations as the fleet continues to adopt the new logbooks.

Longline catch rates

Sets where there was killer whale depredation are excluded for catch rate calculations in observer data, but whale depredation has only recently been documented in logbooks (starting in 2017). To date no data have been excluded from logbooks due to whale depredation. 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). There was a declining trend in the AI from 2015 to 2017. The general trend in the CG has been declining since 2012 and in 2017 the CPUE was the lowest in the time series. There has also been on downward trend in WY since 2008 and the CPUE in 2017 was at its lowest point since the early 1990s. There was a slight uptick in EY/SE in 2017 and a large increase in CPUE in the WG in 2017, which is the first area where strong year classes usually appear, as young, small fish. Catch rates in the AI and BS were also the lowest in the time series in the logbook data set. 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

Data are now available on the average fish weight by set from logbook data from 2012-2017. 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 recorded on the longline survey). When the data are aggregated for all years, there is an increasing trend in weight as you head east, with the largest fish in the EY/SE area. The largest fish are caught in the fall in the GOA, fish size stays consistent in the BS, and the largest fish in the AI are caught in the spring.



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

Area	Spring	Summer	Fall	Total
BS	784	534	308	1,626
AI	1,069	610	364	2,043
WGOA	918	1,616	476	3,010
CGOA	3,704	1,974	871	6,549
WY	1,489	264	122	1,875
EY/SE	932	245	245	1,422

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 2017 pot fishing was introduced into the GOA. In the logbook dataset, there were 17 vessels fishing pots in the GOA; 10 of these vessels were <60 ft. Many of these vessels fished in more than one area: 3 vessels fished in the WGOA; 9 in the CGOA; 10 in WY; and 8 in EY/SE. In the observer data set, there were 9 vessels fishing pots in the GOA.

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 (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 U.S. 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 (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 RPNs and RPW indices have strongly diverged in 2017 and 2018 because of the young fish affecting RPNs, while the lack of old fish affects the RPWs (Figure 3.10b),

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 put the index near average, and 2018 is well above average. The recent low points are because of recent weak recruitment. In the GOA, there were increases in the western CG and the WG, and decreases in the EGOA from 2017 (Figure 3.8a).

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, and 2 stations in 2018.

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 19 stations (annual range 4-21) (Table 3.11). Although sperm whales are sometimes observed in the WGOA, there has only been depredation observed twice, in 2012 and 2016. Sperm whales have been depredating at one station in the AI since 2012, but none in 2018.

Longline survey catch rates had not been adjusted for sperm whale depredation in the past, because we did 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. 2018), 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 3.8b). Overall, gully catches in the GOA from 1990-2018 are moderately correlated with slope catches ($r = 0.54$). 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 2017 and 2018, the GOA gullies continued to increase while the GOA slope stations stayed level. 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 relative abundance of adult sablefish because they do not always sample below 500 m and adult sablefish were thought to outswim the net. However, the survey has always sampled to a depth of 500 m and usually catches small sablefish so this index is good at tracking abundance of smaller and younger fish.

We could potentially use the AI and EBS slope surveys in the assessment model, but given their relatively low biomass estimates and high sampling error, we do not think that these data would be particularly helpful. 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. However, the Aleutian Islands biomass doubled from 2016 – 2018.

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. In addition, the larger hook size (16/0 versus 13/0) used on the IPHC setline survey versus the AFSC longline survey may prevent the smallest fish from being caught.

For comparison to the AFSC survey, IPHC RPNs 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 3.10a). 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 3.10a).

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 was the lowest in the time series which agrees with the AFSC index which was also at a time series low in 2015 (Figure 3.10a). The index from 2015 - 2017 are all about 50% below average abundance. 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.

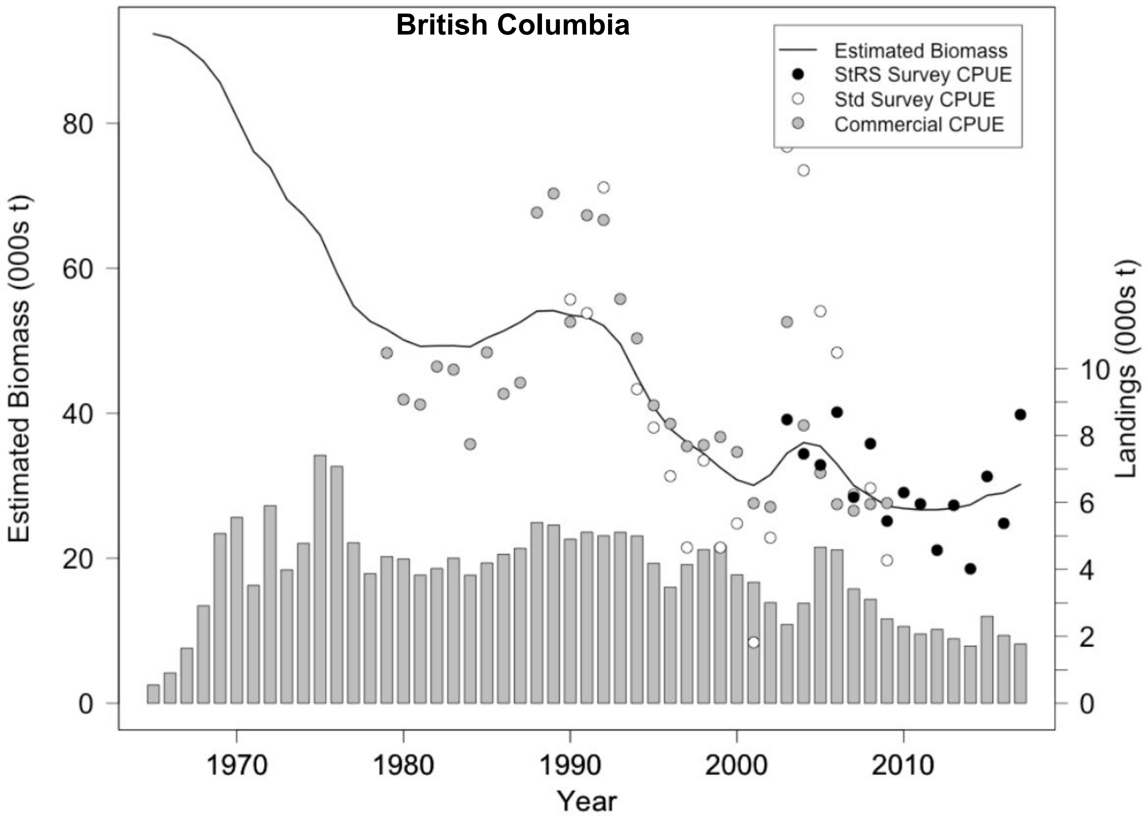
Alaska Department of Fish and Game

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 and 2017. In SSEI, survey CPUE has been declining since 2011 but also saw an uptick in 2016 and 2017. 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

The stratified random trap survey was up approximately 29% from 2012 to 2013 after a time series low in 2012 (see figure below) and then registered a new time series low in 2014. However, 2015 – 2017 represent a considerable increase in biomass in the trap survey and a modest uptick in model estimated biomass. The overall estimated biomass trend in B.C. is similar to the trend in Alaska (see figure below)[1]. The similarly low abundance south of Alaska concerns us, and highlights the need to better understand the contribution to Alaska sablefish productivity from B.C. sablefish. A workgroup has formed between the U.S., Canada and the state of Alaska to attempt to model the population to include B.C. sablefish and U.S. West Coast sablefish.

[1] Brendan Conners, pers. commun. Nov. 7, 2018. Department of Fisheries and Oceans, Canada.



Juvenile Sablefish Tagging and Age-0 Observations

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.). Fishermen reported high numbers of YOY sablefish again in 2018.

Beginning in 1985, juvenile sablefish (age-1 and 2) have been tagged and released in a number of bays and inlets in southeast Alaska, ranging from Ketchikan to Juneau. Following reports of high catch rates in recent years, tagging efforts have expanded to several areas of the CGOA, however, St. John Baptist Bay (SJBB) outside of Sitka on Baranof Island is the only area to have been sampled annually since 1985 and to have consistently had juvenile sablefish. For this reason, the annual sampling in SJBB can be viewed as an indicator of the potential strength of an upcoming cohort. In addition, potentially large recruitment events in recent years have all been first “reported” by sport and commercial fishermen. As communication between scientists/management and fishermen continues to improve, this source of anecdotal information has proven to be extremely effective when forecasting upcoming recruitment trends.

The time series of sampling in SJBB continued in 2018 with three sampling trips. These corresponded with University of Alaska graduate work collecting diet and energetic samples. The first sampling trip occurred April 30 - May 5, 2018. Four rods fished approximately 10hrs/day. No sablefish were caught. The second sampling trip occurred July 17 – 20, 2018. Four rods fished approximately 10 hrs/day, and a total of 65 fish were caught. Average size of fish was 35 cm. In their first two years, the age of a sablefish can easily be determined by the length and time of year. In July, fish within the size range of 35 cm are generally age-1. The third sampling trip occurred October 20 – 23, 2018. Four rods fished approximately 8 hrs/day, and a total of 250 fish were caught. Average size of fish tagged was 25 cm, indicating that these fish were young of the years (YOYs). Historically, sampling within SJBB during fall months have produced a mixture of YOY and age-1 fish, but generally the majority of fish caught are age-1. Based on length data, the October 2018 sampling only caught YOYs (2018 year class). This follows several reports received in August and September from commercial seiners in Southeast Alaska catching lots of “6 inchers,” everywhere from Deep Inlet near Sitka to Cross Sound. Fish during the October sampling were up in the water column, feeding mostly on herring and to a lesser extent tomcod and lingcod (pers. comm. M. Callahan).

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 WGOA and more slowly in the CGOA and EGOA (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 CGOA and EGOA, and in 2015 in the western areas. The last two surveys have shown some rebound, particularly in the combined Western areas.

Analytic approach

Model Structure

The sablefish population is assessed with an age-structured model. The analysis presented here extends earlier age structured models developed by Kimura (1990) and Sigler (1999), which all stem from the work by Fournier and Archibald (1982). The current model configuration follows a more complex version of the GOA Pacific ocean perch model (Hanselman et al. 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 2018 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).

For the model used in this assessment, 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. Skipped spawners were primarily found in gullies on the shelf. When skipped spawners were classified as mature 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). However, when skip spawners were classified as immature, not contributing to the spawning population, the slope was shallower and the age at 50% maturity was 9.8 years, which is 3.2 years older than the assessment value. 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%) (Rodgveller et al. 2018) and there were no fish in gullies, where the majority of skip spawners were located in 2011. When skip spawners were classified as mature in 2015 the age at 50% maturity was 7.3 years, which is 0.7 years older than what is used currently. When skip spawners were classified as immature the slope was shallower and the age at 50% maturity was 7.9 years, which is 1.3 years older than what is used currently. Generally, skip spawning was at ages where a portion of the fish were not yet mature (i.e., at ages when fish were estimated to be <100% mature) and the rate of skip spawning decreased with age (R^2 = 0.35) (Rodgveller et al. 2018).

The difference between 2011 and 2015 may be related to differing environmental conditions. The North Pacific Ocean was in a cool phase during the 2011 sablefish collection and was in a warm, positive Pacific Decadal Oscillation (PDO) during 2015 (Zador 2015; North Pacific Marine Science Organization 2016a). Although the warm water in 2015 negatively affected many taxa in shallow water, such as crab, salmon, birds, and mammals (North Pacific Marine Science Organization 2016b), our results from 2015 show that skip spawning was less prevalent during this warm period. It is unknown how changes in temperature and productivity closer to the surface may affect animals that reside in deeper water. However, it is possible that the colder surface water was associated with the higher skip spawning rate in 2011 and the warmer water with lower skip spawning rate in 2015.

In 2015 histology slides were used to classify maturity of all female sablefish that were collected for aging on the longline survey in the Eastern and Central Gulf of Alaska. The East Yakutat/Southeast area is sampled early in July, West Yakutat in late July, and the Central Gulf in August. The results demonstrated that maturity can be assessed near the end of the survey (late in August in the Central Gulf), but on earlier portions of the survey there is a higher chance that fish are still in the resting phase and not yet showing signs of development toward a future spawning, and therefore, fish that will spawn could be classified as skip spawning or immature. However, skip spawning fish cannot yet be identified without histology. A second result was that at-sea macroscopic classifications did not always match well with histological classifications and that photographs of ovaries taken at-sea and evaluated by an expert in sablefish maturity after the survey ended matched more closely to histological results.

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[2]. A natural mortality rate of M=0.10 has been assumed for previous sablefish assessments, compared to M=0.112 assumed by Funk and Bracken (1984). Johnson and Quinn (1988) used values of 0.10 and 0.20 in a catch-at-age analysis and found that estimated abundance trends agreed better with survey results when M=0.10 was used. Natural mortality has been modeled in a variety of ways in previous assessments. For sablefish assessments before 1999, natural mortality was assumed to equal 0.10. For assessments from 1999 to 2003, natural mortality was estimated rather than assumed to equal 0.10; the estimated value was about 0.10 but only with a precise prior imposed. For the 2004 assessment, a more detailed analysis of the posterior probability showed that natural mortality was not well-estimated by the available data (Sigler et al. 2004). Therefore in 2006, we returned to fixing the parameter at 0.10. This 2016 assessment 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

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

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. 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 2018, a paper with a comprehensive examination of different modeling techniques was published (Hanselman et al. 2018).

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 random-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.

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.

Beginning in 2016, we have used 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. Because sperm whale depredation only occurs on a subset of the 80 annual stations, the overall increase in the RPN index is modest, ranging from 1 -5 % over time (Figure 3.13). The correction by area is most important in WY and EY in 2018 (Figure 3.14).

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 advanced 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 1995-2017, 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 2018, 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 2003-2018). 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 1995-2017 ranged from 1235 t – 2450 t by killer whales in western Alaska management areas and 651 t – 1204 t by sperm whales in the GOA from 2001-2017 (Figures 3.15, 3.16). 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 and use them to adjust the recommended ABC. There appeared to be a big decline in depredation in some areas in 2017 and 2018. We have not fully investigated this, but could be partly because more of the catch was taken with trawls and pots.

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	87
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	118
Fishery selectivity	fs_a	9
Survey selectivity	ss_a	8

Total	234

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 1933-2017. These deviations are lightly restricted with a standard deviation fixed at 1.2.

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 1960-2018 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 of falling below these reference points, we project spawning biomass into the future with recruitments varied as random draws from a lognormal distribution with the mean and standard deviation of 1979-2016 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 ~ $\ln(0, \sigma_r)$
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

Model Description (continued)

Equations describing state dynamics

$$N_{1,a} = \begin{cases} R_1, & a = a_0 \\ e^{\left(\mu_r + \tau_{a_0 - a+1}\right)} e^{-(a-a_0)M}, & a_0 < a < a_+ \\ e^{(\mu_r)} e^{-(a-a_0)M} \left(1 - e^{-M}\right)^{-1}, & a = a_+ \end{cases}$$

Initial year recruitment and numbers at ages.

$$N_{y,a} = \begin{cases} R_y, & a = a_0 \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}}, & a_0 < a < a_+ \\ N_{y-1,a-1} e^{-Z_{y-1,a-1}} + N_{y-1,a} e^{-Z_{y-1,a}}, & a = a_+ \end{cases}$$

Subsequent years recruitment and numbers at ages

$$R_y = e^{\left(\mu_r + \tau_y\right)}$$

Recruitment

Selectivity equations

$$s_{a,s}^g = \left(1 + e^{\left(-\delta_{g,s}\left(a - a_{50\%,g,s}\right)\right)}\right)^{-1}$$

Logistic selectivity

$$s_{a,s}^g = \frac{a^{\delta_{g,s}}}{\max\left(s_{a,s}^g\right)}$$

Inverse power family

$$s_{a,s}^g = \left(\frac{a}{a_{\max}}\right)^{a_{\max,g,s}/p} e^{\left(a_{\max,g,s} - a\right)/p}$$

$$p = 0.5\left[\sqrt{a_{\max,g,s}{}^2 + 4\delta_{g,s}{}^2} - a_{\max,g,s}\right]$$

Reparameterized gamma distribution

$$s_{a,s}^g = \left(1 - \varphi_s^g\right)^{-1} \left(\frac{\left(1 - \varphi_s^g\right)}{\varphi_s^g}\right)^{\varphi_s^g} \frac{\left(e^{\left(\delta_{g,s}\varphi_s^g\left(a_{50\%,g,s} - a\right)\right)}\right)}{\left(1 + e^{\left(\delta_{g,s}\left(a_{50\%,g,s} - a\right)\right)}\right)}$$

Exponential-logistic selectivity

Observation equations

$$\hat{C}_{y,g} = \sum_1^g \sum_1^s w_{a,s} N_{y,a,g,s} F_{y,a,g,s} \left(1 - e^{-Z_{y,a,g,s}}\right) Z_{y,a,g,s}^{-1}$$

Catch biomass in year *y*

$$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} \frac{s_{a,s}^g}{\max\left(s_{a,s}^g\right)} w_{a,s}$$

Survey biomass index (weight)

$$\hat{I}_{y,g} = q^g \sum_{a_0}^{a_+} \sum_1^s N_{y,a,s} \frac{s_{a,s}^g}{\max\left(s_{a,s}^g\right)}$$

Survey abundance index (numbers)

$$\hat{P}_{y,a,s}^g = N_{y,a,s} s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s_{a,s}^g\right)^{-1} \mathbf{A}_s$$

Vector of fishery or survey predicted proportions at age

$$\hat{P}_{y,a,s}^g = N_{y,\cdot,s} s_s^g \left(\sum_{a_0}^{a_+} N_{y,a,s} s_{a,s}^g\right)^{-1} \mathbf{A}_s^l$$

Vector of fishery or survey predicted proportions at length

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

Results

Model Evaluation

While we explored a number of possible models in September 2018, none were satisfactory for implementation this year (Appendix 3E). For this assessment, we present last year's model (Model 16.5) updated for 2018 with no model changes. A comparison of the model likelihood components and key parameter estimates from 2017 are compared with the 2018 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 2018 model based on changes in results from 2017 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 2018 update shows a slight decrease in spawning biomass and an increase in total biomass from previous projections. Therefore the

2018 version of Model 16.5 is utilizing the new information effectively.

Box 2: Model comparison by contribution to the objective function (negative log-likelihood values) and key parameters of the 2017 reference model (16.5) and the same model updated for 2018."% of –lnL" is the contribution of each data component to the negative log likelihood.

Year Model Name	2017 Value	 % of -lnL	2018 Value	 % of -lnL
Likelihood Components				
Catch	3	0.2%	5	0.3%
Dom. LL survey RPN	30	1.9%	48	3.0%
Coop. LL survey RPN	16	1.0%	15	1.0%
Dom. LL fishery RPW	6	0.4%	8	0.5%
Jap. LL fishery RPW	10	0.6%	9	0.6%
NMFS trawl survey	19	1.2%	16	1.0%
Dom. LL survey ages	219	14.3%	237	14.8%
Dom. LL fishery ages	239	15.5%	253	15.8%
Dom. LL survey lengths	67	4.3%	72	4.5%
Coop LL survey ages	142	9.3%	142	8.9%
Coop LL survey lengths	44	2.9%	43	2.7%
NMFS trawl lengths	364	23.7%	351	22.0%
Dom. LL fishery lengths	41	2.7%	42	2.6%
Dom. trawl fish. lengths	338	22.0%	356	22.3%
Data likelihood	**1537**		1596	
Objective function value	1576		1646	
Key parameters				
Number of parameters	**231**		234	
$B_{this\ year}$ (Female spawning (kt) biomass for current year)	81		76	
$B_{40\%}$ (Female spawning biomass (kt))	98		117	
B_{1960} (Female spawning biomass (kt))	166		166	
$B_{0\%}$ (Female spawning biomass (kt))	246		292	
SPR% current	33.1%		26.0%	
$F_{40\%}$	0.096		0.099	
$F_{40\%}$ (Tier 3b adjusted)	0.086		0.081	
ABC(kt)	**25.6**		28.2	
$q_{Domestic\ LL\ survey}$	7.8		7.9	
$q_{Japanese\ LL\ survey}$	5.9		6.0	
$q_{Domestic\ LL\ fishery}$	5.9		6.0	
$q_{Trawl\ Survey}$	1.2		1.3	
$a_{50\%}$ (domestic LL survey selectivity)	3.8		3.8	
$a_{50\%}$ (LL fishery selectivity)	3.9		3.9	

μ_r (average recruitment)	19.5		18.1	
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.

Biomass trends

Sablefish abundance increased during the mid-1960's (Figure 3.17) due to strong year classes in the early 1960's. Biomass 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 biomass 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 2018.

Projected 2019 spawning biomass is 33% of unfished spawning biomass. Spawning biomass had increased from a low of 28% of unfished biomass in 2002 to 34% in 2008 and has declined again to about 26% of unfished in 2018 but is projected to increase in 2019. The last two above-average year classes, 2000 and 2008, each comprise 8% and 11% of the projected 2019 spawning biomass, respectively. These two year classes are fully mature in 2019. The very large estimated year class for 2014 is expected to comprise about 10% of the 2019 spawning biomass, despite being less than 20% mature (Figure 3.19).

Recruitment trends

Annual estimated recruitment varies widely (Figure 3.18). The last two (before 2014) strong year classes in 1997 and 2000 are evident in all data sources. After 2000, few strong year classes occurred until 2014 and 2015. 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-1 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 showed the 2008 year class appearing relatively strong in all three areas for lightly selected two and three 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 ages 1-3 (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 CGOA and EGOA. While this was true for the 1997 and 2000 year classes, the 2008 year class appeared 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 1979-2018 was 18.1 million 2-year-old sablefish per year, which is slightly less than average recruitment during 1958-2018 (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.

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 until the last two years. 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 2016 and 2017 where the model expected higher fishery RPWs. This is also true for the longline survey RPN, which fits poorly in the last two years where predictions are greatly increased because of the influence of the large 2014 year class. It should be noted that at the request of the 2016 CIE review, the abundance indices were significantly downweighted relative to the compositional data to help propagate uncertainty which contributes to the recent poor fits to the abundance data.

All age compositions were reasonably well predicted well, except for not quite reaching the magnitude of the 1997, 2000, and 2014 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 2017 longline survey age compositions look dramatically different with the age 3 and 4s 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 that were caught in 2016 and 2017 (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, likely 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 improved (Figures 3.37, 3.38). By 2014, the 2008 year class has grown large enough (in length) to be included in the main groups in the length compositions though fit to the smaller sizes remained poor. For 1999-2013, the fixed gear age compositions were well fit (Figure 3.32), though the model under-predicted peak ages during 2002-2007.

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 2014-2016 age compositions. In 2016 and 2017, 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 to 2017, 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 2019 and 2020 spawning biomass is above $B_{35\%}$.

Uncertainty

The model estimates of projected spawning biomass for 2019 (96,687 t) and 2020 (129,204 t) fall near the center of the posterior distribution of spawning biomass. Most of the probability lies between 75,000 and 120,000 t for 2019 (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 0.37. 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 (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 similar to Hessian approximations in most cases in all cases which shows that there is not much more uncertainty captured through MCMC. The exception is for projected spawning biomass which is much less precise during MCMC because of our internal projection model adding recruitment uncertainty in addition to the model parameter uncertainty.

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 for ten previous assessment years (2008-2017) 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 0.094, an increase from 0.065 in 2017, is still relatively low (a small positive retrospective bias) compared to most assessments at the AFSC (Hanselman et al. 2013). This increasing retrospective bias is a concern, and is likely related to the model's difficulty reconciling the massive recruitment estimates with low levels of older fish. However, 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. However, the 2014 year class significantly decreased from 2017 to 2018.

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 1977-2014. The updated point estimate of $B_{40\%}$, is 116,738 t. Since projected female spawning biomass (combined areas) for 2019 is 96,687 t (83% *of* B40%, *or* B33%), sablefish is in sub-tier "b" of Tier 3. The updated point estimates *of F40%, and* F35% from this assessment are 0.099, and 0.117, respectively, but Tier 3b uses the control rule to adjust these values downward. Thus, the maximum permissible value of FABC under Tier 3b is 0.081, which translates into a 2019 ABC (combined areas) of 28,171 t. The adjusted OFL fishing mortality rate is 0.096 which translates into a 2019 OFL (combined areas) of 33,141 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 2018 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2019 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2018. 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 2018 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 2019, 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 2019 and 2020, F is set equal to the author's recommended whale corrected ABCs. For the remainder of the future years, maximum permissible ABC is used. (Rationale: In sablefish, the full TAC is routinely not fully utilized, but uncertainty about increased discards may increase total catch closer to the TAC in 2019 and 2020).
>
> *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 2013-2017 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 2018, or 2) above ½ of its MSY level in 2018 and above its MSY level in 2027 under this scenario, then the stock is not overfished.)

Scenario 7: In 2019 and 2020, 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 2020, or 2) above 1/2 of its MSY level in 2020 and expected to be above its MSY level in 2030 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 2019 and 2020. 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 2019, it does not provide the best estimate of OFL for 2020, because the mean 2019 catch under Scenario 6 is predicated on the 2019 catch being equal to the 2019 OFL, whereas the actual 2019 catch will likely be less than the 2019 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 (2017) is 12,270 t. This is less than the 2017 OFL of 15,428 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 2018:

a. If spawning biomass for 2018 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2018 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2018 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 2028 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 2020 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2020 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2020 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2030. If the mean spawning biomass for 2030 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. 2015-2017 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 1979-2016 recruitments, and this projection predicts that the mean and median spawning biomass will be above both $B_{35\%}$ and $B_{40\%}$ by 2020, and continue to rise. 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.

Ecosystem considerations

This section has been replaced by a new framework termed the Ecosystem and Socioeconomic Profile (ESP) located in Appendix 3C. This effort is to replace this infrequently updated section to this new approach that provides more contemporary and informative analysis to guide ABC and TAC considerations. The last complete ecosystem considerations for sablefish can be found in Hanselman et al. (2017).

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 $124 million in 2017.

Additional ABC/ACL considerations

Should the ABC be reduced below the maximum permissible ABC?

The SSC in its October 2018 minutes recommended that assessment authors and plan teams use the risk matrix table below if they are intending to recommend an ABC lower than the maximum permissible.

	Assessment-related considerations	Population dynamics considerations	Environmental/ecosystem considerations
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals but the pattern is not consistent across all indicators.
Level 3: Major Concern	Major problems with the stock assessment, very poor fits to data, high level of uncertainty, strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level, and/or b) up or down trophic levels (i.e., predators and prey of stock)
Level 4: Extreme concern	Severe problems with the stock assessment, severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented. More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock. Potential for cascading effects on other ecosystem components

The table is applied by evaluating the severity of three types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, and environmental/ecosystem considerations. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations
    a. Data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data
    b. Model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs

   c. Model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds
   d. Estimation uncertainty: poorly-estimated but influential year classes
   e. Retrospective bias in biomass estimates
2. Population dynamics considerations
   a. Decreasing biomass trend
   b. Poor recent recruitment
   c. Inability of the stock to rebuild
   d. Abrupt increase or decrease in stock abundance
3. Environmental/ecosystem considerations
   a. Adverse trends in environmental/ecosystem indicators
   b. Ecosystem model results
   c. Decreases in ecosystem productivity
   d. Decreases in prey abundance or availability
   e. Increases in predator abundance

Assessment considerations

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 Alaska sablefish assessment has typically had one of the lowest retrospective bias issues of assessments at the AFSC. However, in the last two years, the bias has increased from 0.02 to 0.06 to 0.09. The sablefish assessment is one of only a few assessments in the North Pacific that is fit to multiple abundance indices. Historically, the sablefish assessment fitted the longline survey in both numbers and in weight. Since the 2010 CIE, it was recommended that only one of these indices should be fit and it was deemed that numbers was the better index. Generally, these two indices tracked relatively closely, but due to at least one massive year class (2014) entering the indices, these two indices have greatly diverged in 2018 (Figure 3.10b). The sablefish assessment is the only assessment in the North Pacific that fits a fishery CPUE (in weight) index. This index, which lags the longline survey by one year, has been at an all-time low for 2016 and 2017. On the other hand, the biomass index from the GOA trawl survey has shown a strong increase from its low in 2015, doubling in the 2017 survey. Some of this conflict in indices it to be expected as indices in numbers respond quickly to incoming year classes because they are high in numbers, but indices in weight take longer to respond because those young fish have low weight. In addition, surveys like the GOA trawl survey capture fish at earlier life stages on shallower grounds, so the index will respond to a large incoming recruitment before indices in weight (the longline survey RPW and fishery RPW). Thus, the model in the past two years is unable to fit the contrasting trends well and reconcile the severe transition to the incoming year classes comprised of young fish in the age and length comps. This has resulted in very poor model fits to the most recent survey indices (Figures 3.3 and 3.4). Although this poor fit is a recent phenomenon, it is worth mentioning that when fitting multiple indices and data sources, there are clear tradeoffs in fit to some indices in some periods. Specifically, in the early part of the GOA trawl survey time series, the model underestimates survey biomass for multiple consecutive years (Figure 3.4). It should be noted that at the request of the 2016 CIE review, the abundance indices were significantly downweighted relative to the compositional data to help propagate uncertainty which contributes to the recent poor fits to the abundance data.

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 3.55). 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, which also corresponded to the large 2000 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, except for moderately in 2001, 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 3.45). The assessment model has typically performed well where the initial estimate of year class strength was similar as more data was added. However, the large 2014 year class has decreased 30% in its second year of being estimated. We showed in 2017 in a 20 year retrospective analysis, that large year classes 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 remaining above average. This could be related to time-invariant selectivity or an unmodeled age-dependent mortality process.

We rated the assessment-related concern as level 2, a substantially increased concern, because the contrasting trends and poor fits to the survey indices add to the uncertainty of the assessment relative to other North Pacific assessments that only fit one index. In addition, the substantial decrease in this year's estimate of the 2018 year class from last year is concerning. However, the model has been robust to most situations historically and has relatively good fits to most data given the balance between data components and the lack of time-varying aspects of the model, so we could not justify going to a higher risk level for assessment concerns.

Population dynamics considerations

The age structure of sablefish is being strongly perturbed by an unprecedented surge in recruitment. Preliminary length data had raised expectations of increased recruitment starting in 2013 or 2014. First estimated by the assessment model in 2017, it was shown that there was a very strong recruitment event in 2014. The current assessment estimates this year class as the strongest ever to recruit and is currently estimated to be more than 7x average. 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 two observations of the 2014 year class in the 2016 and 2017 longline survey age composition, this estimate is 7.5x larger than average recruitment and two times 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 WGOA 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 EGOA (Figure 3.53). The 2014 year class has appeared in the EGOA as 3-year-olds, but not in remarkably high numbers yet (Figure 3.26).

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.

This recruitment was estimated to be 10x average in 2017 and has decreased considerably. However, there is evidence from length compositions and industry reports of strong 2015 and 2016 year classes now entering the survey and directed fishery. Moreover, there has been a dramatic increase of incidental catch in trawl fisheries in both the GOA and BS. Recruitment since 2000 had been weak, so this sudden transition to high recruitment is causing tension from what appears to be very low spawning stock biomass with one or two year classes emerging and beginning to mature. The stock has been below its target reference point since the mid 2000s, and there has been a precipitous decline in older fully mature and fully grown fish since 2011 (see figure below). Because of this sequence of events, the age-diversity of sablefish has dropped rapidly, and both the fishery and population are now becoming dominated by these incoming year classes. These signs of high recruitment hold long-term promise for the recovery of the spawning stock biomass, but the stocks persistence below the target reference points is concerning. Since the magnitude of the 2014 year class is so much higher than anything seen historically and the estimate's decline from 2017 to 2018, we should proceed with caution because the estimate may continue to decline. For example, there may be density dependence or other concerns that effect survival differently than previous year classes. Currently, much of the projected recovery of the spawning biomass is dependent on the maturation of the 2014 year class. The assessment model employs a static maturity curve, but visual estimates of maturity from the longline survey suggest that there may be significant variability (see figure below). The 2014 year class will be 5 years old in 2019 and the annual longline survey data maturity curves indicate that these females could be between 9 and 38% mature. This range has a significant effect on our perception of stock status and ABC (see table in projections).

Spawning biomass estimated in 2018 is lower than spawning biomass estimated for 2017 despite the expectation of a rapid increase. Because of the uncertainty in the unprecedented size of the 2014 recruitment, the hollowing out of the older ages, and the uncertainty of how quickly the 2014 class will succeed in entering the spawning biomass, there are many population dynamics concerns. Overall, we rated the population-dynamic concern as level 4, an extreme concern.

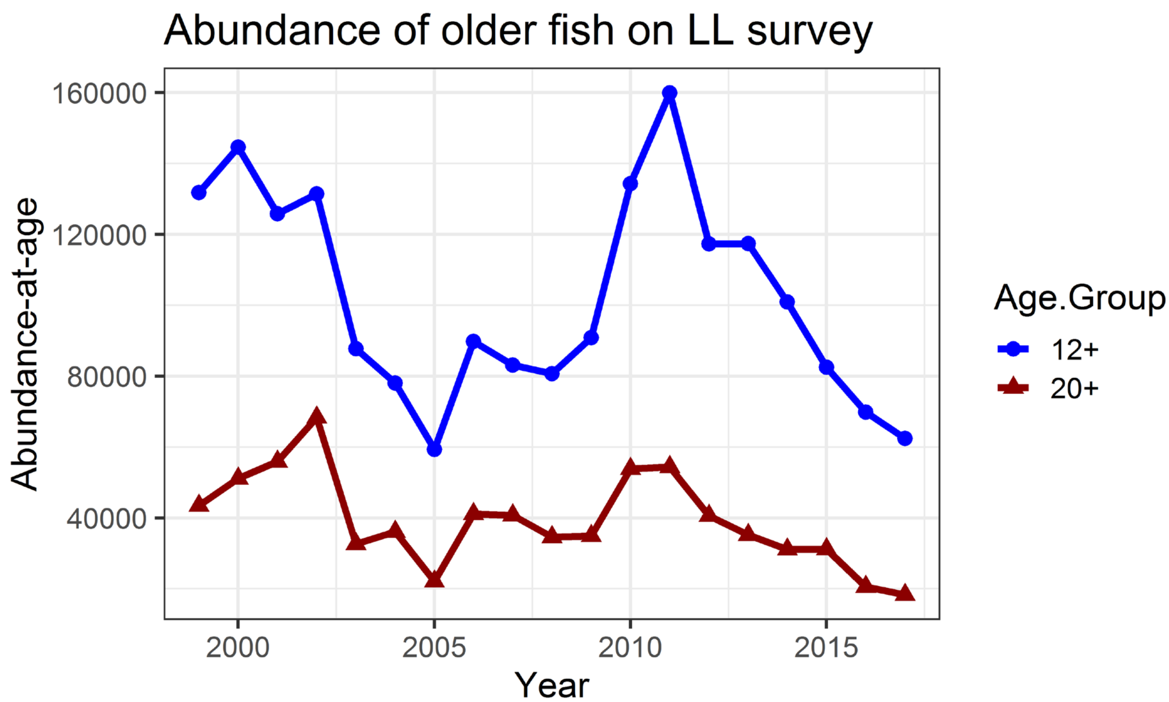


Figure. Relative population numbers of pooled fish 12 and greater (blue circles) and 20 and greater (red triangles) caught on the AFSC longline survey during 1999 – 2017.

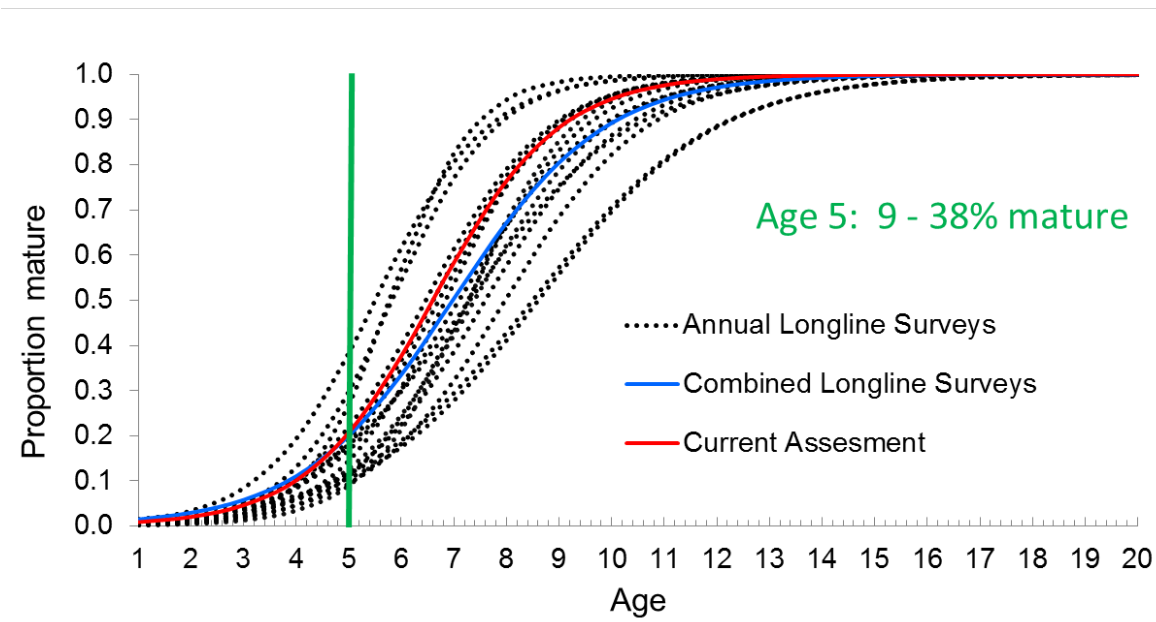


Figure. Logistic maturity curves estimated from annual longline survey macroscopic scans. Dashed lines illustrate the annual variability, the red solid line is the estimate from the pooled data which is similar to the static value used in the assessment. Age 5 is highlighted to show the range of maturity estimates for the large 2014 year class.

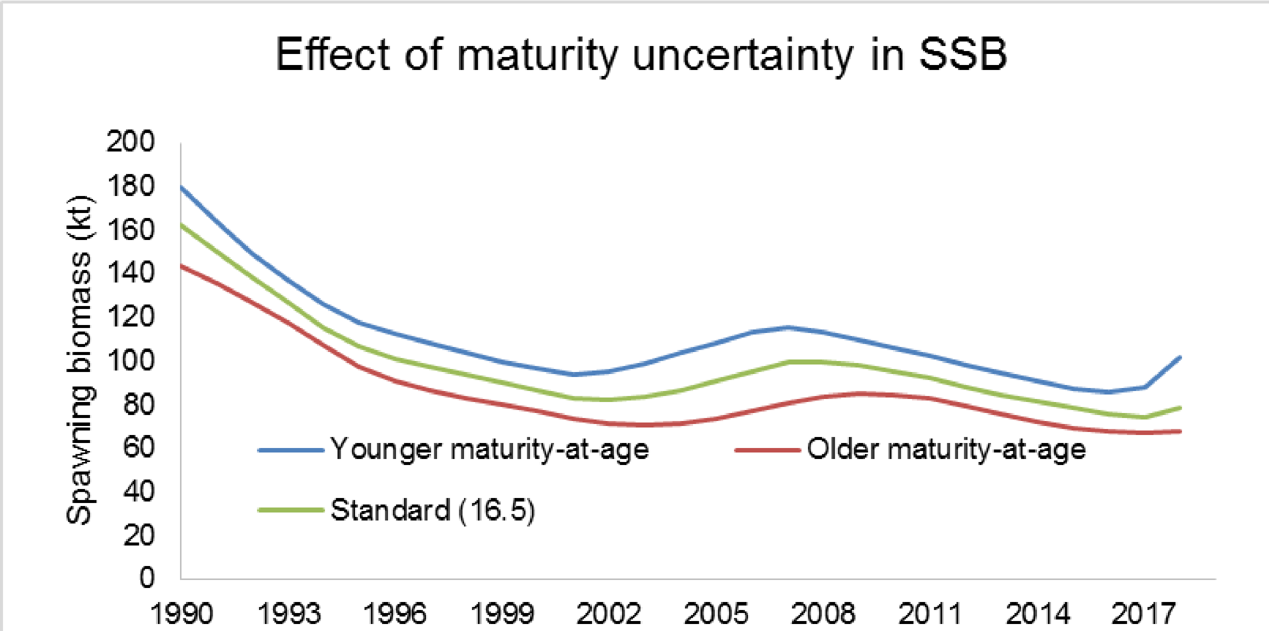


Figure. Spawning biomass trajectories of Model 16.5 using the range of potential maturity estimates from the longline survey.

Environmental/Ecosystem considerations

The potential components of ecosystem 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 prudent to adjust harvest recommendations when conditions appear to be improving, degrading, or exhibiting higher variability.

Beginning with this SAFE, the standard ***Ecosystem Considerations*** section has been eliminated, and a new Ecosystem and Socioeconomic Profile (ESP) is included, which 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. Therefore, this category of the risk-matrix is evaluated in the ESP and summarized here.

There are concerns about increased variability and decreased predictability of the ecosystem. For example, recent stock assessment estimates of GOA Pacific cod showed an enormous 2012 year class. This estimate declined severely when the 2015 - 2017 GOA bottom trawl survey biomass estimates and the 2016 – 2018 longline survey abundance estimates were included in the assessment. 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). It is possible that the increased recruitment in 2014-2016 is due to the marine heat wave, perhaps due to higher productivity and increased food supply for larval sablefish (or competitive release because of mortality or movement of other predators from the marine heat waves). If marine heat waves become a regular occurrence perhaps this bodes well for future sablefish recruitment, but if this is a one-time unrelated recruitment success, then it is critical that these fish survive to contribute to the depleted spawning biomass.

However, the effects of the marine heat wave and changing ecosystem have not yet been evaluated carefully for sablefish. Fish condition has declined since the appearance of these large year classes, and is much worse than during the last period of larger recruitments (1997 – 2000, Appendix 3C) which may affect the ability of these fish to survive or mature. **Given the current uncertainty in the ecosystem, we rated the environmental/ecosystem concern as level 2, indicating a substantially increased concern.**

The results of this 3 category template are summarized in the table below:

Assessment-related considerations	Population dynamics considerations	Environmental/ecosystem considerations	Overall score (highest of the individual scores)
Level 2: Substantially increased concern	Level 4: Extreme concern	Level 2: Substantially increased concern	Level 4: Extreme concern

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 in the future. These concerns warrant additional caution when recommending the 2019 and 2020 ABCs. It is unlikely that the 2014 year class will be average or below average, but projecting catches under the assumption that it is 7.5x average introduces risk given the uncertainty associated with this estimate. Only one large year class since 1999 has been observed, and there are only two observations of age compositions to support the magnitude of the 2014 year class. Our caution in 2017 seems justified as the estimate of the 2014 year class has decreased 30% since last year's estimate. The cause of this decrease could be simply imprecision in the age compositions for the first year it was seen, or something real like an increase in natural mortality. Future surveys will help determine the magnitude of the 2014 year class and will help detect additional incoming large year classes other than the 2014 year class; there are indications that subsequent year classes may also be above average.

This is the first time we have used the risk-matrix approach to assess reductions in ABC from maximum permissible ABC. The overall score of level 4 indicates at least one "extreme concern" and suggests that setting the ABC below the maximum permissible is warranted. The SSC recommended against using a table that showed example alternatives to select buffers based on that risk level. Thompson (unpublished Sept 2018 plan team document) tabulated the magnitude of buffers applied by the Groundfish Plan Teams for the period 2003-2017, and found that the more extreme buffers were 40 – 80% reductions in ABC. For the 2019 and 2020 ABC recommendations, we consider all three of these types of uncertainty at some level to recommend that the 2019 ABC should be set equal to the 2018 ABC, which translates to a reduction of about 45% from the maximum ABC allowed by the reference model. Recommending an ABC lower than the maximum should result in more of the 2014 year class entering into the spawning biomass. This more precautionary ABC recommendation buffers 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 composition in 2019 and allow this extremely young population to further mature so they can fully contribute to future spawning biomass.

Acceptable biological catch recommendation

Instead of maximum permissible ABC, we are recommending the 2019 ABC to be equal to the 2018 **ABC, which translates to a 45% adjustment from max ABC. The final 2019 ABC of 15,068 t is 1% higher than the** 2018 **ABC because of updated whale depredation adjustments that are slightly lower.** The maximum permissible ABC for 2019 is 10% higher than the 2018 maximum permissible

ABC of 25,583 t. The 2017 assessment projected a 41% increase in ABC for 2019 from 2018. The author recommended ABCs for 2019 and 2020 are lower than maximum permissible ABC for several important reasons that are examined in the new SSC-endorsed risk-matrix approach for ABC reductions.
The following bullets summarize the conclusions that helped reach the conclusion of "extreme concern" reached in ***Additional ABC/ACL Considerations*** and the ***Ecosystem and Socioeconomic Profile*** in Appendix 3C:

1. The estimate of the 2014 year class strength declined 30% from 2017 to 2018.
2. Despite projected increases in spawning biomass in 2017, the 2018 spawning biomass and stock status is lower than in 2017.
3. Despite conservative fishing mortality rates the stock has been in Tier 3b for many years.
4. Fits to survey abundance indices are poor for recent years.
5. The AFSC longline survey Relative Population Weight index, though no longer used in the model, has strongly diverged from the Relative Population Number index, indicating very few large fish in the population.
6. The retrospective bias has increased in the last two years, and the bias is positive (i.e., historical estimates of spawning biomass increase as data is removed).
7. The amount of older fish comprising the spawning biomass has been declining rapidly since 2011.
8. The very large estimated year class for 2014 is expected to comprise about 10% of the 2019 spawning biomass, despite being less than 20% mature.
9. The projected increase in future spawning biomass is highly dependent on young fish maturing in the next few years; results are very sensitive to the assumed maturity rates.
10. The body condition of maturing sablefish in the recent years of high recruitment is lower than average, and much lower than during the last period of strong recruitments.
11. Another potential marine heat wave is forming in 2018, which may have been beneficial for sablefish recruitment in 2014, but it is unknown how it will affect current fish in the population or future recruitments.
12. Small sablefish are being caught incidentally at unusually high levels shifting fishing mortality spatially and demographically, which requires more analysis to fully understand these effects.

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 starting in 2016. 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. The methods and calculations are described in the ***Accounting for whale depredation*** section.

Survey trends support keeping ABC level relative to last year. Although there was a modest increase in the domestic longline survey index time series in the last two years, and a large increase in the GOA bottom trawl survey in 2017, these increases are offset by the very low status of the fishery abundance index seen in 2016 and 2017. The fishery abundance index has been trending down since 2007. The IPHC GOA sablefish index was not used in the model, but was similar to the 2015 and 2016 estimates in 2017, about 50% below average abundance. 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 average. The 2014 year class appears to be very strong, but year classes have sometimes failed to materialize later and the estimate of this year class is still uncertain and has declined by 30% since the 2017 assessment.

We considered a number of alternative models and projection scenarios to explore if there was an appropriate author's ABC to recommend in the interim while some of the uncertainties in the current assessment could be addressed. In the table below, we present what the ABC, spawning biomass, reference point, and stock status are under different models and different projections. In September of 2018, we presented 23 different models exploring selectivity options for the fixed gear fishery, and a new prior on natural mortality. Our recommendation in September was to use the new prior distribution for natural mortality we developed, but generally to avoid any models with new selectivity options, except for perhaps a model that had a time-invariant, non-parametric selectivity that allowed dome-shaped selectivity (16.5d, Appendix 3E). We explored making these changes once new data were added, and had reservations about the variability of the harvest recommendations and unexpected behavior of these models.

The inclusion of the natural mortality prior distribution on its own had minor effects on the harvest recommendations and model fit under the base model, but when we combined the non-parametric selectivity and the natural mortality prior in the same model (16.5ds), the change in results were striking. Model 16.5d had what seemed like a more reasonable result given our current perception of spawning biomass, but when we looked retrospectively, it failed to converge with data as recent as 2010. It also resulted in an ABC that was nearly 40% lower in 2014 than the reference model, which seemed very low given the accepted recommendation in that year. Given how variable the results were retrospectively and how sensitive the model became with the inclusion of the new natural prior distribution when using new selectivity curves, we concluded that more research was needed before adopting new modeling approaches, both with respect to natural mortality and new selectivity curves. We were also concerned that all of the models' optimistic projections were operating under the assumption that the 2014 year class would remain at the current level and would be rapidly becoming mature and contributing to the spawning biomass. We ran two sensitivity runs using results from the longline survey maturity estimates. Since the 2014 year class would be 5 in 2019, we chose to illustrate this uncertainty by choosing the youngest-maturing ogive and the oldest-maturing ogive from the longline survey to bracket the uncertainty. Clearly, the static maturity assumed in the model is an important axis of uncertainty since the estimated spawning biomass for 2019 ranges from 75 – 133 kilotons.

The inclusion of the 2014 year class into the calculation of $B_{40\%}$ results in a much larger (22%) estimate of target spawning biomass. The following table shows sensitivities of the reference points and ABCs with respect to different scenarios used in the projection model. Using the reference point from last year that did not yet include the 2014 year class, the stock is expected to exceed $B_{40\%}$, which results in a much higher ABC. Scenario 3 is the one we used in 2017 to address the uncertainty in the 2014 year class by setting the 2014 year class equivalent to what the 1977 year class was estimated to be as age 4. This resulted in an ABC that was near what was projected for 2019 last year. Because of concerns that the fishery may be only targeting the older fish, and avoiding the smaller fish, we also ran a projection with knife-edge selectivity for the fixed gear fishery starting at age 10. This is a 'worst case' scenario showing potential effect of removing the entire ABC from mature fish only. This resulted in an ABC similar to that of reducing the 2014 year class to the magnitude of the 1977 year class, but implied much higher spawning exploitation rate than the status quo.

Table. Sensitivity of harvest recommendations, reference point, and stock status to alternative models, data inputs, and projection scenarios. *DNC = Did Not Converge.

Model	Description	ABC	SSB	$B_{40\%}$	SPR%
16.5	Recommended in 2016 and 2017	28.2	96.7	116.7	33%
16.5s	16.5 with new natural mortality prior	29.4	98.3	116.6	34%
16.5d	16.5 with non-parametric dome-shape	16.1	79.6	119.2	27%
16.5ds	16.5d with new natural mortality prior	10.2	64.3	108.4	24%
16.5d (2008)	16.5d using 2008 data for 2009 ABC	DNC* (with data before 2010)			
16.5 (2008)	16.5 using 2008 data for 2009 ABC	18.7	97.3	104.9	37%
16.5d (2014)	16.5d using 2014 data for 2015 ABC	8.6	78.4	105.6	30%
Base (2014)	16.5 using 2014 data for 2015 ABC	13.9	93.2	104.2	36%
16.5	Oldest LL maturity at age (2011)	21.4	74.8	107.1	28%
16.5	Youngest LL maturity at age (2003)	37.4	133.0	126.3	42%
Scenario	**Alternative projection scenarios (16.5)**				
1	Recruitments from 1977-2014	**28.2**	**96.7**	**116.7**	**33%**
2	Recruitments from 1977-2013	34.1	96.7	95.5	40%
3	2014 set to 1977 year class strength, and in B40	20.0	84.0	93.3	36%
4	2014 set to 1977 year class strength, 2015 set to average, and in B40	18.2	82.6	93.3	35%
5	Fixed selectivity set knife-edge at 10+	19.5	95.5	116.7	33%

TAC considerations

Outside of the ABC recommendation, there may be situations where the assessment can address, "socioeconomic uncertainty." There may be 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.

Finally, the economic performance report (Appendix 3C) shows that sablefish ex-vessel value (per pound) had 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. Specifically, the 2014 year class will not approach maximum value for several more years because somatic growth occurs more rapidly than fish dying from natural mortality (Figures 5 and 6 in Appendix 3C). A combination of a much larger catch because of a large increase in ABC that consisted of a high proportion of five-year-old or younger fish would likely result in poor market conditions and reduced profits (Appendix 3C).

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 (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. The variance for the fishery data has thought to be uncertain relative to the survey data, so the survey data were weighted twice as much as the fishery data.

However, following the 5-years exponential apportionment scheme after 2010, we had 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 3.57A). 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 3.57B). These large annual changes in apportionment result in increased annual variability of ABCs by area, including areas other than the Bering Sea (Figure 3.57C). Because of the high variability in apportionment seen prior to 2013, 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 that was developed for research into spatial biomass (see ***Movement and tagging*** section) and apportionment showed different regional biomass estimates than the 5-year exponential weighted method approved by the Council and the 'fixed' apportionment methods which has been used since 2013 for apportionment of ABC to sablefish IFQ holders. Further research on alternative apportionment methods and the tradeoffs is underway and is summarized in ***Appendix 3D***. Meanwhile, it seems imprudent to move to an interim apportionment or return to the former apportionment method until the proposed range of methods have been identified and evaluated (See *Appendix 3D*). 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 2019, we recommend continuing with the apportionment fixed at the proportions used for 2013-2018.**

Apportionment Table (before whale depredation adjustments)

Area	2018 ABC	Standard apportionment for 2019 ABC	Recommended fixed apportionment for 2019 ABC*	Difference from 2018
Total	15,380	15,380	**15,380**	0%
Bering Sea	1,501	3,085	**1,501**	0%
Aleutians	2,030	2,064	**2,030**	0%
Gulf of Alaska (subtotal)	11,849	10,231	**11,849**	0%
Western	1,659	1,877	**1,659**	0%
Central	5,246	3,978	**5,246**	0%
W. Yakutat**	1,765	1,506	**1,765**	0%
E. Yak. / Southeast**	3,179	2,870	**3,179**	0%

* 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 32,798 t for the combined stock. The OFL is apportioned by region, Bering Sea (3,221 t), AI (4,350 t), and GOA (25,227 t), by the same method as the ABC apportionment.

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) Refine fishery abundance index to utilize a core fleet, and identify covariates that affect catch rates.
2) Consider new strategies for incorporating annual growth data.
3) Re-examine selectivity assumptions, particularly the fishery and GOA trawl survey
4) Continue to explore the use of environmental data to aid in determining recruitment.
5) 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.
6) Evaluate differences in condition (weight at length and energetic storage) among management areas and years to evaluate if they relate to spawning, recruitment, and environmental conditions.

Acknowledgments

The authors wish to acknowledge the many additional contributors that help make this sablefish assessment possible each year. Thank you to our internal reviewer Cody Szuwalski for his thorough and thought-provoking review. The feedback we receive from industry participants is vital in aiding our understanding of patterns in the fishery and the stock. The careful data collection by fishery observers and survey biologists is greatly appreciated and form the backbone of all of our assessments. We thank Cathy Tide and Mary Furuness of the AKRO for detective work on catch accounting issues. Finally, our excellent AFSC Age and Growth program, particularly Delsa Anderl and Jon Short.

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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. 2018 catches are as of October 1, 2018 (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	10,259	532	349	1,058	4,200	4,120	1,656	2,463	0	8,920	1,338
2017	12,270	1,159	590	1,181	4,843	4,497	1,698	2,798	0	9,990	2,280
2018	11,109	1,460	474	1,005	4,100	4,070	1,645	2,424	0	8,271	2,838

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991-2018. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages. Catch as of October 1, 2018 (www.akfin.org).

Year	Pot	Trawl	Longline	Total
Aleutian Islands				
1991-1999	6	73	1,210	1,289
2000	103	33	913	1,049
2001	111	39	925	1,074
2002	105	39	975	1,119
2003	316	42	760	1,118
2004	384	32	539	955
2005	688	115	679	1,481
2006	461	60	629	1,151
2007	632	40	496	1,169
2008	177	76	646	899
2009	78	75	947	1,100
2010	59	74	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	270	129	191	590
2018	170	152	152	474
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	368	685	106	1,159
2018	309	1,043	107	1,460

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	12,270	15,428	13,083	13,083	Pot fishing begins in the GOA
2018	11,109	29,507	14,957	14,957	

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 2010-2018. Source: NMFS Alaska Regional Office via AKFIN, October 1, 2018.

		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	53	17.90%	297	565	6.93%	8,157	619	7.32%	8,454
	Other	179	12.30%	1,273	502	21.21%	2,365	680	18.70%	3,638
	Total	232	13.25%	1,749	1,067	10.14%	10,521	1,299	10.59%	12,270
2018	H&L	41	15.64%	259	432	6.44%	6,713	473	6.78%	6,973
	Other	632	37.74%	1,042	850	34.53%	2,462	1,482	42.29%	3,504
	Total	673	34.78%	1,934	1,282	13.98%	9,175	1,955	17.60%	11,109

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, 2018

	Hook and Line			**Other Gear**			**All Gear**		
Species	D	R	Total	D	R	Total	D	R	Total
GOA Thornyhead Rockfish	208	432	640	7	25	32	215	457	672
Shark	454	0	455	0	0	0	454	0	455
GOA Shortraker Rockfish	173	83	255	12	2	14	185	84	269
Arrowtooth Flounder	132	12	145	63	18	81	196	30	226
GOA Skate, Other	162	2	164	1	0	1	163	2	165
GOA Skate, Longnose	157	7	165	1	0	1	158	7	166
GOA Rougheye Rockfish	92	78	170	1	2	3	93	80	172
Other Rockfish	59	59	118	2	3	5	60	62	123
Pacific Cod	57	29	86	0	9	9	58	38	95
BSAI Skate	46	1	47	0	0	0	47	1	47
GOA Deep Water Flatfish	12	0	12	22	7	28	33	7	40
Greenland Turbot	16	11	27	4	1	5	20	12	32
BSAI Kamchatka Flounder	13	1	15	4	11	15	18	12	30
Pollock	2	0	2	9	13	22	11	13	24
Sculpin	12	0	12	1	0	1	13	0	13
BSAI Other Flatfish	5	0	5	1	10	11	6	10	16
GOA Demersal Shelf Rockfish	1	10	11	0	0	0	1	10	11
BSAI Shortraker Rockfish	5	3	8	0	0	0	6	3	8
GOA Skate, Big	6	0	7	0	0	0	6	0	7
Pacific Ocean Perch	2	0	2	1	6	7	3	7	9
GOA Rex Sole	0	0	0	7	1	8	7	1	8
Octopus	4	0	4	1	0	1	5	0	5
GOA Shallow Water Flatfish	4	0	4	1	1	2	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, 2018.

Group Name	2011	2012	2013	2014	2015	2016	2017	2018
Benthic urochordata	0.13	1.25	0.00	0.00	0.49	0.00	1.06	0.91
Brittle star unidentified	0.48	4.66	0.11	0.67	2.09	0.34	0.59	0.34
Corals Bryozoans	5.75	7.66	12.70	5.17	4.55	5.96	1.61	9.61
Eelpouts	0.64	0.63	1.14	0.79	0.24	1.08	2.35	10.92
Grenadiers	8,640	8,586	11,554	5,916	5,789	7,346	5,623	4,041
Invertebrate unidentified	2.29	7.78	0.18	0.12	0.53	0.21	0.19	0.59
Misc crabs	8.51	6.77	5.83	6.40	3.50	4.87	5.13	4.14
Misc fish	15.92	10.98	31.21	28.31	17.58	15.99	17.38	21.64
Scypho jellies	0.68	0.00	0.00	5.51	0.24	0.18	0.02	0.14
Sea anemone unidentified	3.48	1.03	0.95	3.07	14.11	1.79	2.11	8.11
Sea pens whips	1.59	0.28	0.38	2.33	2.84	1.29	1.14	0.39
Sea star	3.95	3.13	15.73	11.58	9.68	8.99	21.83	9.08
Snails	20.02	12.25	8.83	3.66	3.37	0.18	2.88	2.37
Sponge unidentified	2.16	0.98	3.39	1.67	3.52	0.50	0.72	0.29
State-managed Rockfish	0.00	0.03	0.12	0.12	0.09	0.22	0.43	0.02
Urchins, dollars, cucumbers	0.26	0.79	0.87	0.79	2.49	0.22	0.22	1.11

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, 2018.

				BSAI				
Hook and Line	Year	Bairdi	Chinook	Golden KC	Halibut	Other salmon	Opilio	Red KC
	2013	-	15	540	64	-	-	-
	2014	-	-	577	34	-	-	40
	2015	-	9	177	23	-	-	206
	2016	23	0	49	7	0	28	5
	2017	3	0	0	1	0	4	1
	2018	7	0	0	5	0	14	10
	Mean	5	4	224	22	0	8	43
Other	2013	365	-	858	20	-	315	-
	2014	-	-	3,573	7	-	1,689	-
	2015	-	-	29,039	1	-	26	-
	2016	142	-	11,700	2	-	14	18
	2017	709	-	16,034	9	-	504	51
	2018	416	98	39,162	12	-	208	816
	Mean	272	16	16,727	8	-	459	147
	BSAI	**277**	**20**	**16,951**	**31**	**0**	**467**	**191**
				GOA				
HAL	2013	78	-	93	273	-	-	24
	2014	6	-	39	249	-	-	-
	2015	166	-	38	293	-	-	12
	2016	0	-	39	272	-	0	0
	2017	25	-	72	337	-	-	-
	2018	-	-	71	330	-	-	-
	Mean	46	-	59	292	-	0	6
Other	2013	-	-	-	12	12	-	-
	2014	-	-	18	2	-	-	-
	2015	25	-	-	3	-	-	-
	2016	2	0	47	11	0	0	-
	2017	153	0	26	10	0	-	-
	2018	93	1	-	12	-	-	-
	Mean	45	0	15	8	2	0	-
	GOA	**91**	**0**	**74**	**300**	**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		1,191	1,176
2016				1,633	12,857		63,434		1,197	1,169
2017	4,157			2,628	12,345		67,721		1,190	1,190
2018							69,218			

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				
2017	C	C	C	2	1	2017	0.12	0.03	0.22	14	4

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
2017	0.41	0.10	0.24	81	10	2017	0.42	0.04	0.11	389	30

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
2017	0.73	0.13	0.18	86	18	2017	0.77	0.06	0.08	229	38

Table 3.9 (cont.)

Logbook Fishery Data

Aleutian Islands-Logbook						Bering Sea-Logbook					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1999	0.29	0.04	0.15	167	15	1999	0.56	0.08	0.14	291	43
2000	0.24	0.05	0.21	265	16	2000	0.21	0.05	0.22	169	23
2001	0.38	0.16	0.41	36	5	2001	0.35	0.11	0.33	61	8
2002	0.48	0.19	0.39	33	5	2002	C	C	C	5	2
2003	0.36	0.11	0.30	139	10	2003	0.24	0.13	0.53	25	6
2004	0.45	0.11	0.25	102	7	2004	0.38	0.09	0.24	202	8
2005	0.46	0.15	0.33	109	8	2005	0.36	0.07	0.19	86	10
2006	0.51	0.16	0.31	61	5	2006	0.38	0.07	0.18	106	9
2007	0.38	0.22	0.58	61	3	2007	0.37	0.08	0.21	147	8
2008	0.30	0.03	0.12	119	4	2008	0.52	0.20	0.39	94	7
2009	0.23	0.07	0.06	204	7	2009	0.25	0.04	0.14	325	18
2010	0.25	0.05	0.20	497	9	2010	0.30	0.08	0.27	766	12
2011	0.23	0.07	0.30	609	12	2011	0.22	0.03	0.13	500	24
2012	0.26	0.03	0.14	893	12	2012	0.30	0.04	0.15	721	21
2013	0.26	0.06	0.22	457	7	2013	0.20	0.04	0.18	460	15
2014	0.25	0.07	0.27	272	5	2014	0.34	0.05	0.15	436	15
2015	0.30	0.14	0.46	370	8	2015	0.20	0.03	0.13	309	11
2016	0.22	0.04	0.16	269	5	2016	0.16	0.02	0.15	270	11
2017	0.15	0.03	0.18	219	4	2017	0.14	0.03	0.23	200	9

Western Gulf-Logbook						Central Gulf-Logbook					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1999	0.64	0.06	0.09	245	27	1999	0.80	0.05	0.06	817	60
2000	0.60	0.05	0.09	301	32	2000	0.79	0.04	0.05	746	64
2001	0.47	0.05	0.10	109	24	2001	0.74	0.06	0.08	395	52
2002	0.60	0.08	0.13	78	14	2002	0.83	0.06	0.07	276	41
2003	0.39	0.04	0.11	202	24	2003	0.87	0.07	0.08	399	45
2004	0.65	0.06	0.09	766	26	2004	1.08	0.05	0.05	1676	80
2005	0.78	0.08	0.11	571	33	2005	0.98	0.07	0.07	1154	63
2006	0.69	0.08	0.11	1067	38	2006	0.87	0.04	0.05	1358	80
2007	0.59	0.06	0.10	891	31	2007	0.83	0.04	0.05	1190	69
2008	0.71	0.06	0.08	516	29	2008	0.88	0.05	0.06	1039	68
2009	0.53	0.06	0.11	824	33	2009	0.95	0.08	0.08	1081	73
2010	0.48	0.04	0.08	1297	46	2010	0.66	0.03	0.05	1171	80
2011	0.50	0.05	0.10	1148	46	2011	0.80	0.06	0.07	1065	71
2012	0.50	0.04	0.08	1142	37	2012	0.79	0.06	0.07	1599	82
2013	0.35	0.03	0.07	1476	32	2013	0.48	0.03	0.07	2102	73
2014	0.39	0.03	0.08	1008	28	2014	0.52	0.04	0.08	2051	72
2015	0.33	0.04	0.13	980	31	2015	0.44	0.03	0.06	2119	71
2016	0.29	0.03	0.12	936	29	2016	0.37	0.03	0.08	2313	72
2017	0.35	0.04	0.11	618	25	2017	0.35	0.03	0.08	1958	59

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
2017	0.51	0.04	0.07	1792	73	2017	0.66	0.04	0.06	968	81

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. 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	656	119
2018		611			1,247		

*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, 2016, and 2018.

Table 3.11. Count of stations where sperm (S) or killer whale (K) depredation occurred and the number of stations sampled (in parentheses) by management area. Only stations used for RPN calculations are included. 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	0	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	4	0	6	0	7	0
2016			1	0	0	3	3	2	5	0	6	0
2017	0	11			1	2	4	0	3	0	9	0
2018			0	2	0	3	3	0	7	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	4.4	2	24	295	250	380	137	115	177
1978	5.3	1	14	269	227	346	125	105	162
1979	86.4	1	15	330	281	428	119	101	154
1980	25.4	66	123	363	308	467	114	96	147
1981	9.9	5	50	383	326	489	112	96	144
1982	42.3	1	31	422	363	536	117	100	149
1983	24.0	21	72	449	387	565	129	112	164
1984	43.5	3	48	491	426	614	146	127	184
1985	2.3	33	64	496	433	614	162	141	202
1986	19.5	0	7	503	441	617	175	153	218
1987	18.8	7	32	490	430	599	181	158	224
1988	3.6	12	30	453	398	555	180	157	224
1989	4.5	1	9	408	357	501	173	150	215
1990	6.9	1	10	365	318	450	163	140	203
1991	27.3	4	12	345	299	429	150	129	189
1992	1.3	21	37	316	274	393	138	118	174
1993	23.8	0	4	308	267	383	127	108	160
1994	4.6	19	33	287	248	358	115	98	146
1995	5.3	1	10	266	230	332	107	90	136
1996	7.7	2	10	248	214	310	101	86	129
1997	16.9	5	12	242	209	303	97	83	124
1998	2.3	13	23	228	198	286	94	80	119
1999	29.9	0	6	239	207	299	90	77	114
2000	16.9	24	40	246	213	308	86	74	109
2001	10.2	10	27	246	212	307	83	71	105
2002	41.5	2	19	274	236	344	82	70	104
2003	6.3	33	58	279	240	349	84	72	106
2004	12.7	2	12	281	242	352	87	74	110
2005	6.1	8	19	274	235	343	91	78	114
2006	10.7	4	10	267	229	335	96	82	120
2007	7.8	7	16	257	220	323	99	85	125
2008	8.4	5	12	245	210	309	100	86	126
2009	7.8	5	13	234	201	295	98	84	124
2010	17.8	5	12	234	200	295	95	82	120
2011	5.0	14	25	227	194	285	92	79	116
2012	9.3	2	9	220	189	277	88	75	112
2013	1.0	7	14	204	175	258	84	72	107
2014	8.0	0	3	193	164	244	81	69	103
2015	13.2	5	12	189	160	240	79	67	100
2016	150.3	10	19	318	266	411	76	64	97
2017	40.1	119	203	399	333	518	74	63	95
2018	12.5	25	64	449	373	579	79	66	101
2019	15.9	11	21	488	339	629	97	56	126
2020	15.9	13	18	513	370	661	129	83	155

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 1990-2018 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
1977	54	65	28	82	26	39	295
1978	49	60	26	73	24	36	269
1979	62	68	31	98	28	43	330
1980	66	86	35	97	31	48	363
1981	68	95	40	85	36	58	383
1982	77	88	54	102	41	61	422
1983	80	94	70	114	37	54	449
1984	92	114	78	118	35	54	491
1985	102	113	71	123	36	50	496
1986	108	106	68	125	43	53	503
1987	80	106	65	131	48	59	490
1988	47	93	61	146	46	60	453
1989	55	80	47	131	43	53	408
1990	56	60	39	112	42	56	365
1991	38	40	37	109	46	76	345
1992	23	36	25	100	50	83	316
1993	15	33	28	102	52	78	308
1994	17	33	31	94	44	67	287
1995	25	30	27	87	38	59	266
1996	24	25	27	90	32	51	248
1997	23	22	25	94	30	48	242
1998	20	29	26	80	26	47	228
1999	19	39	28	79	25	48	239
2000	19	40	32	82	25	47	246
2001	27	39	39	77	21	43	246
2002	38	42	41	89	22	43	274
2003	38	43	39	95	24	40	279
2004	37	43	35	100	26	40	281
2005	39	41	36	89	24	44	274
2006	42	37	38	80	24	45	267
2007	45	33	27	79	27	45	257
2008	47	31	24	77	24	42	245
2009	45	30	27	73	21	38	234
2010	46	26	25	68	26	43	234
2011	29	23	23	80	29	42	227
2012	12	28	25	88	25	42	220
2013	27	28	21	68	19	41	204
2014	41	24	21	55	17	36	193
2015	33	25	20	54	21	36	189
2016	38	56	35	91	41	56	318
2017	49	83	47	114	46	60	399
2018	57	106	58	128	40	60	449

Table 3.16. Key parameter estimates and their uncertainty and 95% Bayesian credible intervals (BCI). Recruitment year classes are in millions.

Parameter	μ (MLE)	μ (MCMC)	Median (MCMC)	σ (Hessian)	σ (MCMC)	BCI-Lower	BCI-Upper
$q_{domesticLL}$	7.91	7.65	7.62	0.74	0.73	6.32	9.22
q_{coopLL}	5.96	5.76	5.72	0.56	0.55	4.77	6.95
q_{trawl}	1.29	1.24	1.23	0.15	0.15	0.97	1.56
M	0.100	0.102	0.102	0.007	0.007	0.087	0.115
$F_{40\%}$	0.099	0.111	0.107	0.024	0.029	0.068	0.183
2019 SSB (kt)	96.7	91.9	92.1	10.0	17.5	56.3	125.8
2008 Year Class	17.8	18.8	18.7	2.7	2.8	13.6	24.8
2014 Year Class	150.3	157.1	156.2	20.1	21.3	118.9	202.7

Table 3.17. Comparison of 2017 results versus 2018 results. Biomass is in kilotons.

Year	**2017 SAFE** Spawning Biomass	**2018 SAFE** Spawning Biomass	Difference (%)	**2017 SAFE** Total Biomass	**2018 SAFE** Total Biomass	Difference (%)
1977	138	137	-1%	297	295	-1%
1978	126	125	-1%	271	269	-1%
1979	120	119	-1%	330	330	0%
1980	115	114	-1%	364	363	0%
1981	114	112	-1%	384	383	0%
1982	118	117	-1%	422	422	0%
1983	130	129	-1%	450	449	0%
1984	147	146	0%	492	491	0%
1985	162	162	0%	497	496	0%
1986	176	175	0%	504	503	0%
1987	182	181	0%	491	490	0%
1988	181	180	0%	455	453	0%
1989	174	173	0%	410	408	-1%
1990	164	163	-1%	367	365	-1%
1991	151	150	-1%	348	345	-1%
1992	139	138	-1%	318	316	-1%
1993	128	127	-1%	310	308	-1%
1994	116	115	-1%	289	287	-1%
1995	108	107	-1%	268	266	-1%
1996	102	101	-1%	251	248	-1%
1997	98	97	-1%	244	242	-1%
1998	95	94	-1%	231	228	-1%
1999	91	90	-1%	242	239	-1%
2000	87	86	-1%	249	246	-1%
2001	84	83	-1%	249	246	-1%
2002	83	82	-1%	278	274	-2%
2003	85	84	-1%	284	279	-2%
2004	88	87	-2%	287	281	-2%
2005	92	91	-2%	279	274	-2%
2006	97	96	-2%	273	267	-2%
2007	101	99	-2%	263	257	-3%
2008	102	100	-2%	252	245	-3%
2009	101	98	-3%	242	234	-3%
2010	98	95	-3%	243	234	-4%
2011	95	92	-3%	236	227	-4%
2012	92	88	-4%	230	220	-4%
2013	88	84	-4%	215	204	-5%
2014	86	81	-5%	204	193	-5%
2015	84	79	-6%	202	189	-6%
2016	81	76	-7%	392	318	-19%
2017	81	79	-3%	476	399	-16%
2018		79			449	

Table 3.18. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for seven harvest scenarios (columns). Abundance projected using 1979-2016 recruitments. Author's F scenario uses the author recommended ABCs for 2018 and 2019 as the realized catch.

Year	Maximum permissible F	Author's F* (specified catch)	Half max. F	5-year average F	No fishing	Overfished?	Approaching overfished?
			Spawning biomass (kt)				
2018	78.6	78.6	78.6	78.6	78.6	78.6	78.6
2019	96.7	96.7	96.7	96.7	96.7	96.7	96.7
2020	125.1	129.2	128.4	125.6	134.1	121.2	123.1
2021	152.1	164.0	162.7	155.8	178.1	144.8	149.5
2022	168.6	181.5	187.3	175.8	215.1	157.4	162.4
2023	174.0	186.7	199.4	183.7	239.9	158.9	163.8
2024	172.5	184.4	202.1	183.6	254.6	153.9	158.3
2025	167.9	178.5	199.7	179.4	262.6	146.1	150.1
2026	162.2	171.6	194.1	173.4	266.5	137.8	141.2
2027	156.5	164.6	188.4	167.0	267.9	129.9	132.8
2028	151.0	157.9	183.6	160.6	267.8	122.7	125.2
2029	146.0	151.9	179.8	154.7	266.8	116.5	118.5
2030	141.6	146.6	175.4	149.3	265.3	111.2	112.9
2031	137.9	142.0	171.5	144.7	263.7	106.8	108.2
			Fishing mortality				
2018	0.056	0.056	0.056	0.056	0.056	0.056	0.056
2019	0.081	0.044	0.050	0.076	-	0.117	0.117
2020	0.099	0.051	0.050	0.076	-	0.117	0.117
2021	0.099	0.099	0.050	0.076	-	0.117	0.117
2022	0.099	0.099	0.050	0.076	-	0.117	0.117
2023	0.099	0.099	0.050	0.076	-	0.117	0.117
2024	0.099	0.099	0.050	0.076	-	0.117	0.117
2025	0.099	0.099	0.050	0.076	-	0.117	0.117
2026	0.099	0.099	0.050	0.076	-	0.117	0.117
2027	0.099	0.099	0.050	0.076	-	0.117	0.117
2028	0.099	0.099	0.050	0.076	-	0.117	0.117
2029	0.098	0.098	0.050	0.076	-	0.116	0.116
2030	0.097	0.098	0.050	0.076	-	0.114	0.114
2031	0.096	0.097	0.050	0.076	-	0.113	0.113
			Yield (kt)				
2018	13.7	13.7	13.7	13.7	13.7	13.7	13.7
2019	28.2	28.2	17.4	26.4	-	40.1	34.1
2020	37.8	38.9	19.8	29.2	-	43.0	37.1
2021	37.3	40.0	20.2	29.3	-	41.5	42.8
2022	36.0	38.4	20.0	28.4	-	39.0	40.1
2023	34.4	36.4	19.5	27.1	-	36.2	37.2
2024	32.7	34.4	18.8	25.8	-	33.6	34.3
2025	31.2	32.7	18.1	24.5	-	31.3	31.9
2026	29.9	31.1	17.5	23.3	-	29.2	29.8
2027	28.7	29.7	16.9	22.2	-	27.5	28.0
2028	27.6	28.5	16.3	21.4	-	26.1	26.5
2029	26.6	27.4	15.9	20.6	-	24.9	25.3
2030	25.8	26.5	15.5	20.0	-	23.8	24.1
2031	25.1	25.7	15.1	19.5	-	22.9	23.1

* Projections in Author's F (Alternative 2) are based on estimated catches of 15,380 t and 20,620 t (Author's ABC) used in place of maximum permissible ABC for 2019 and 2020. This was done in response to management requests for a more accurate two-year projection.

Figures

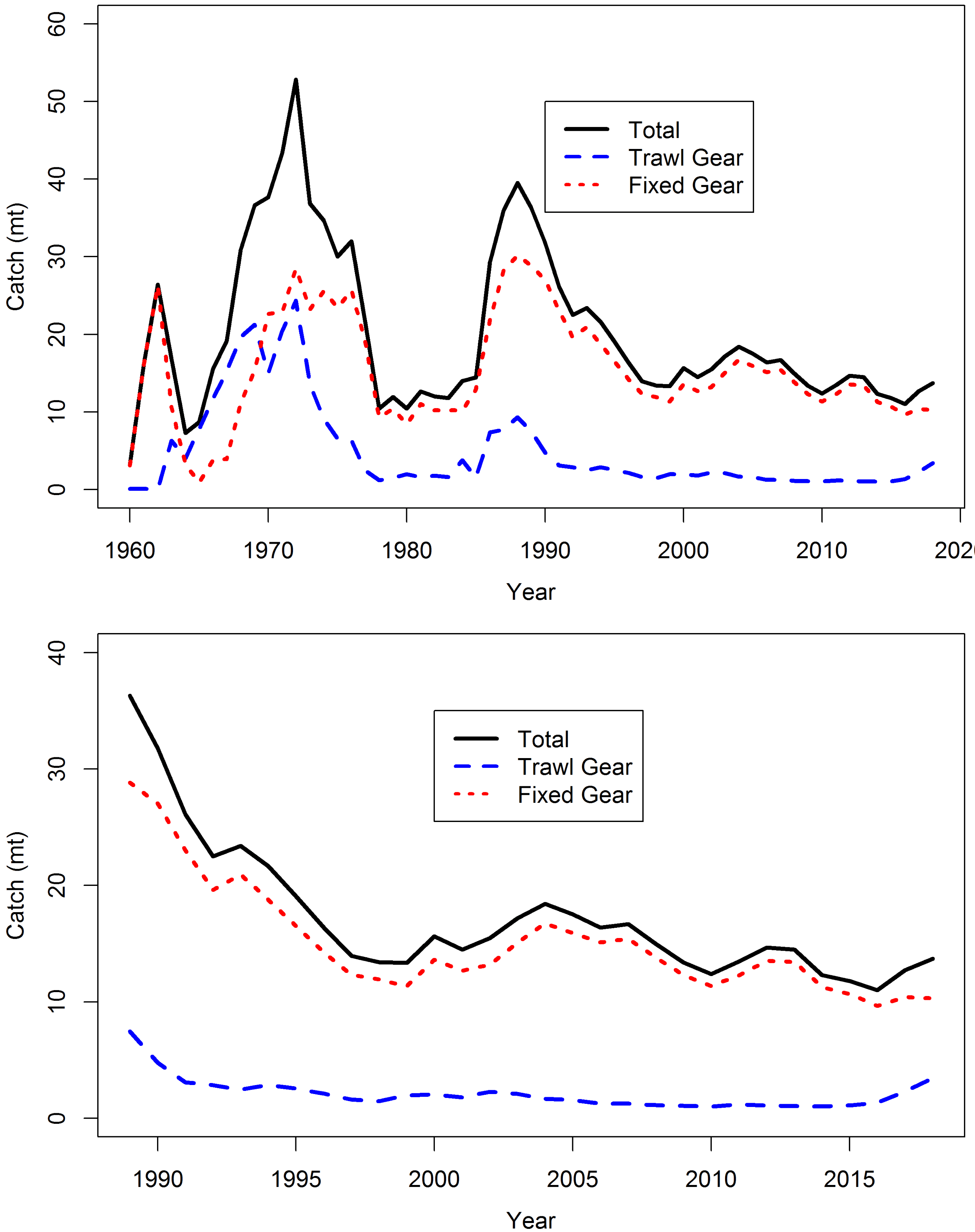


Figure 3.1. Long term and short term sablefish catch by gear type.

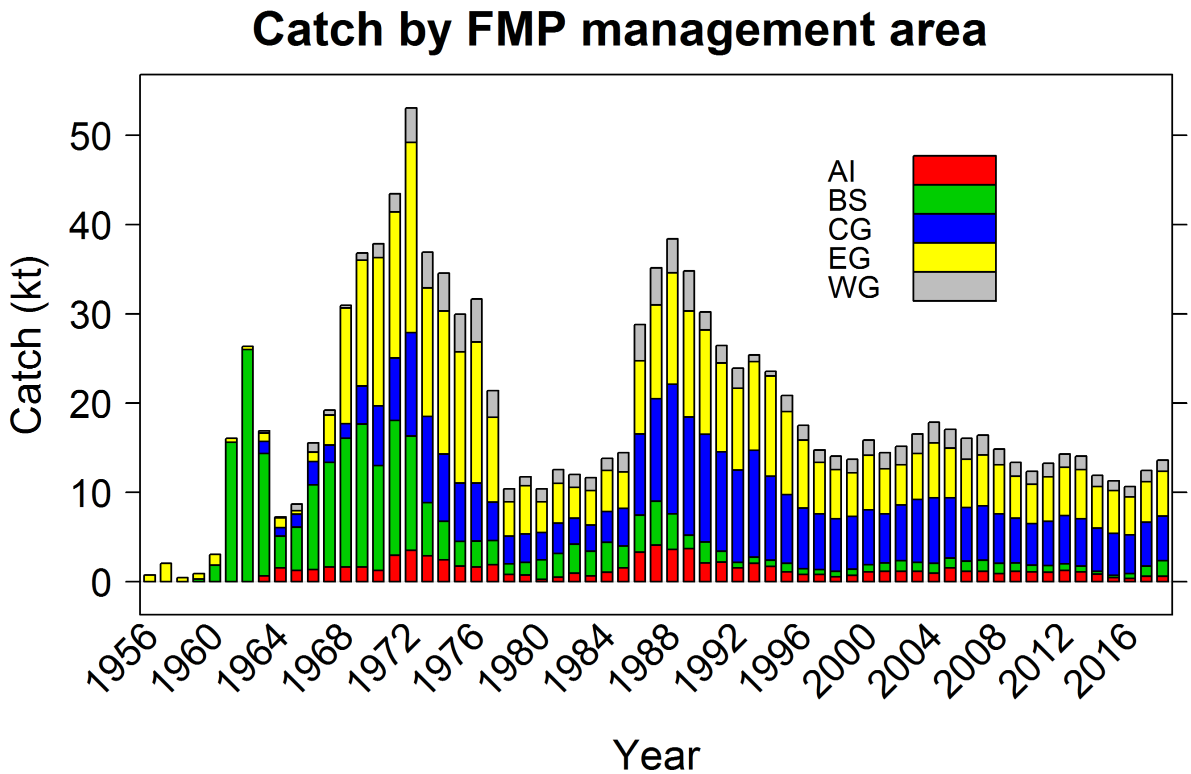


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

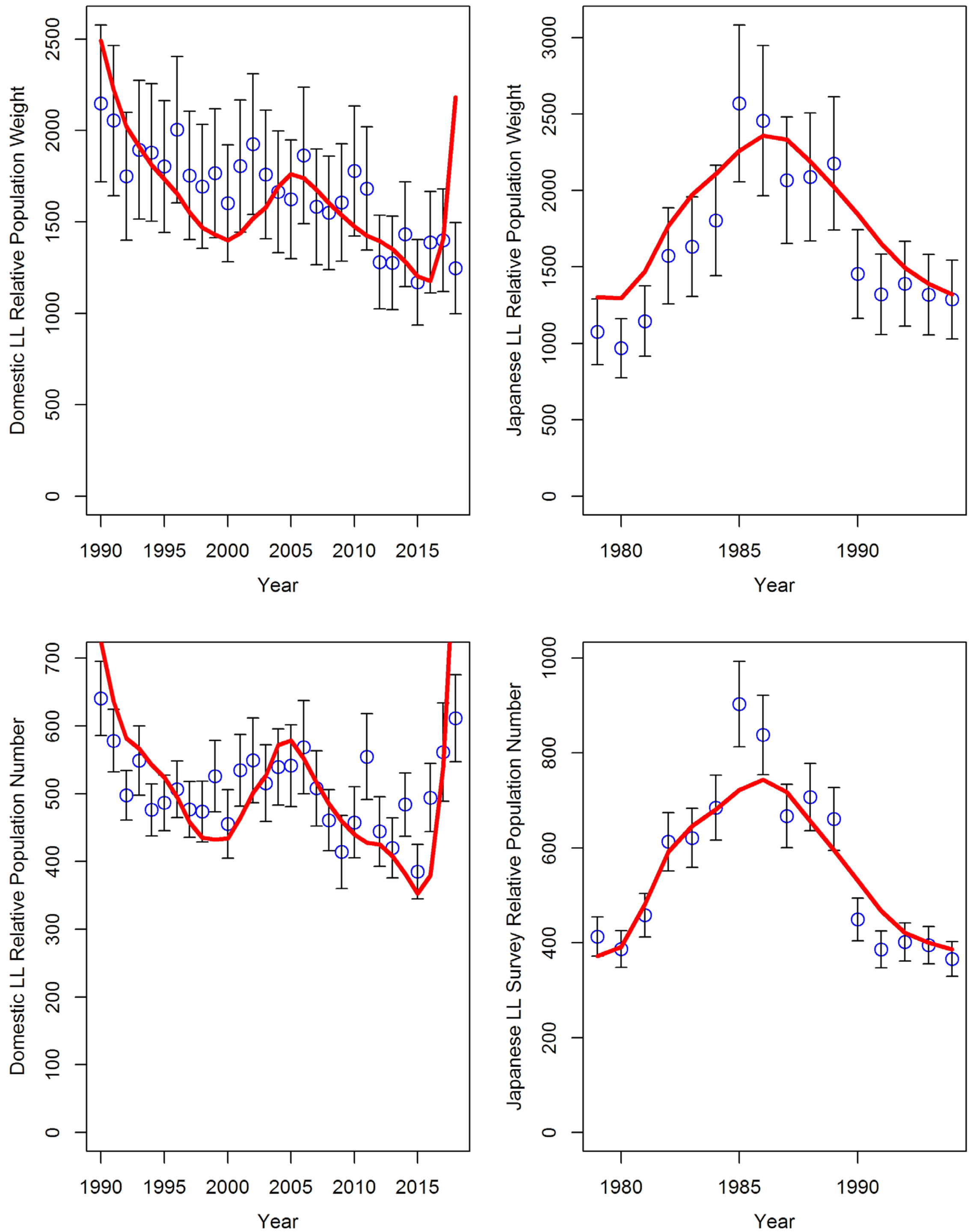


Figure 3.3. Observed and predicted sablefish relative population weight and numbers for 1990-2018 for U.S. longline survey and for 1979-1994 for U.S.-Japan cooperative survey. Points are observed estimates with approximate 95% confidence intervals. Solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

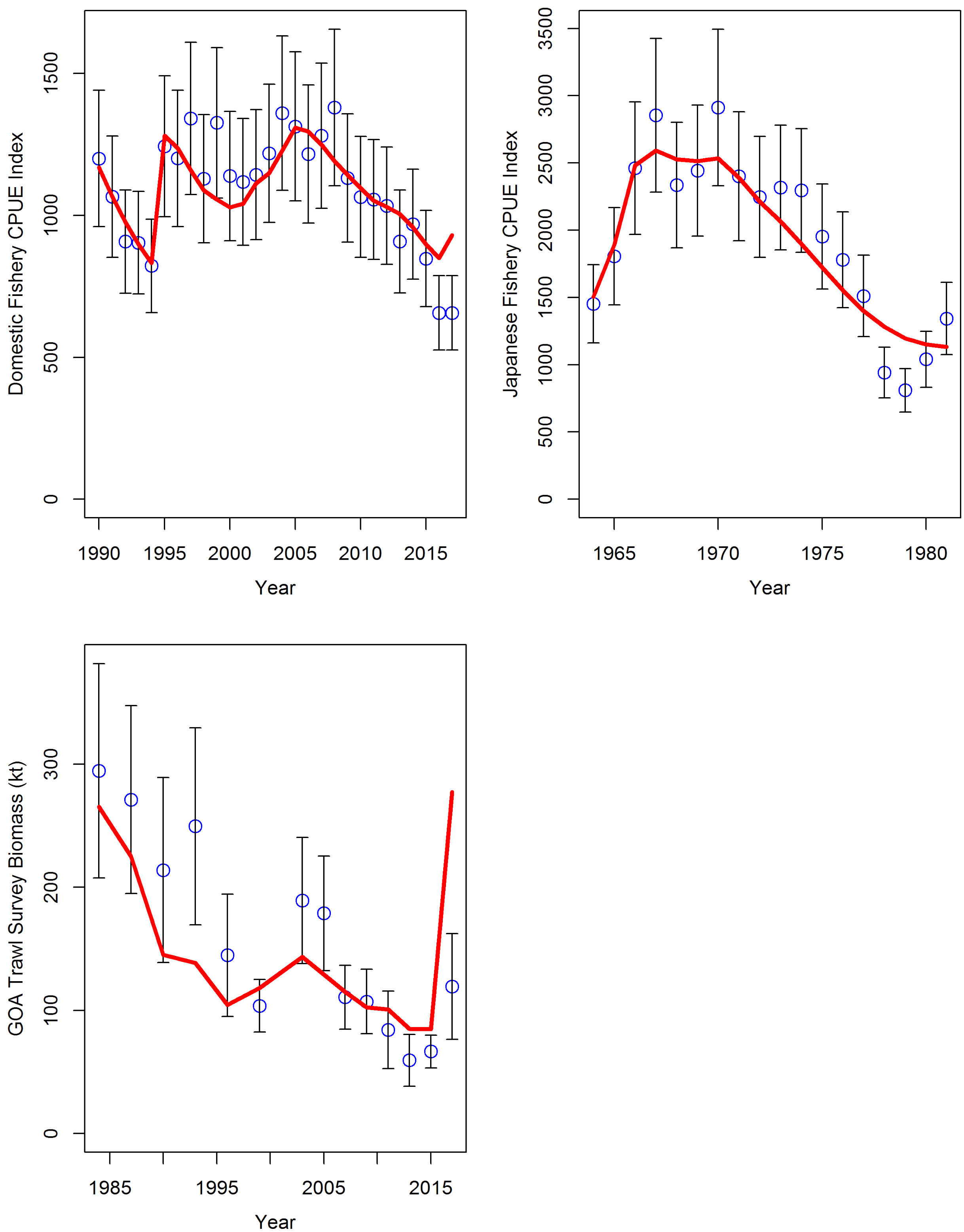


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while solid red lines are model predictions.

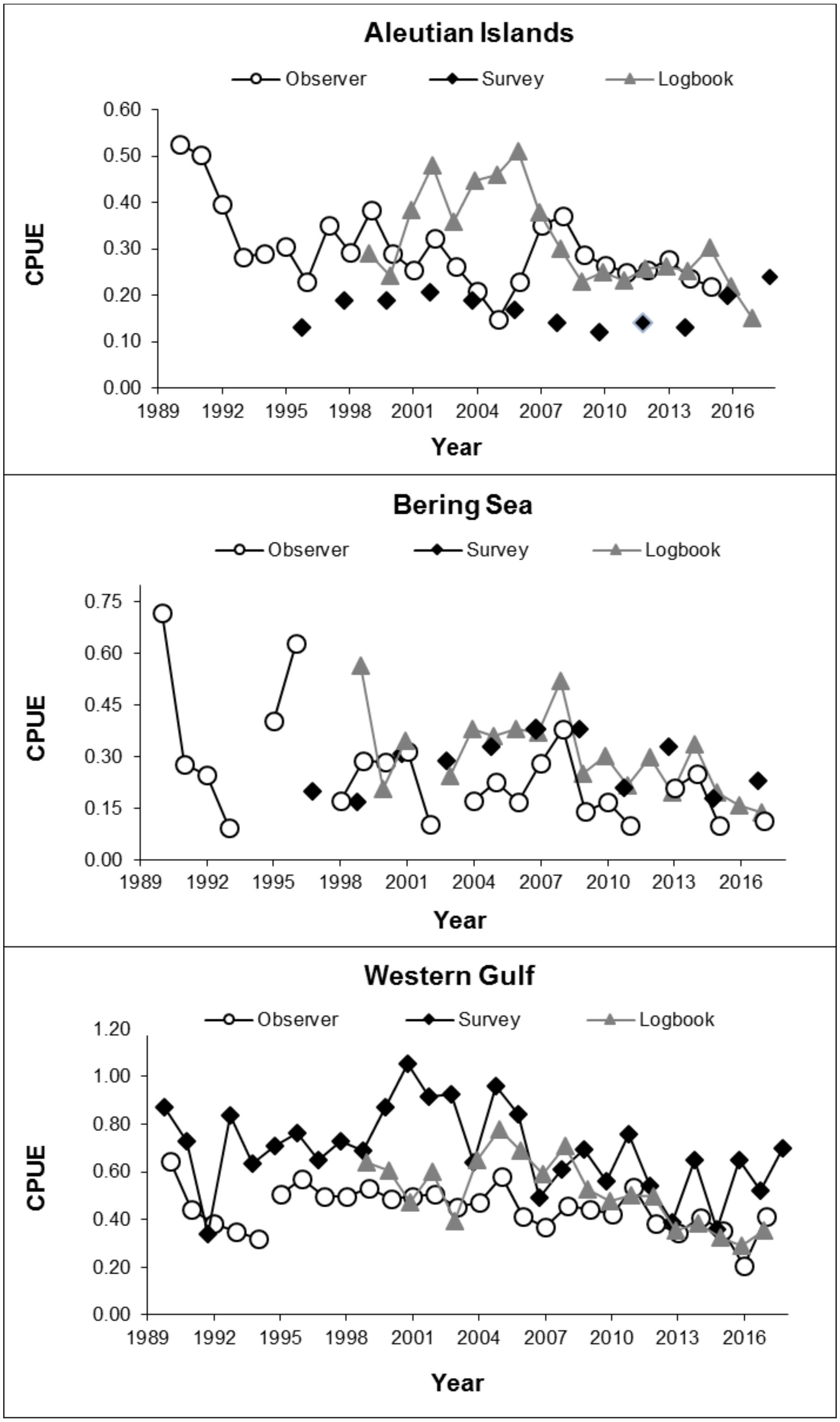


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in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

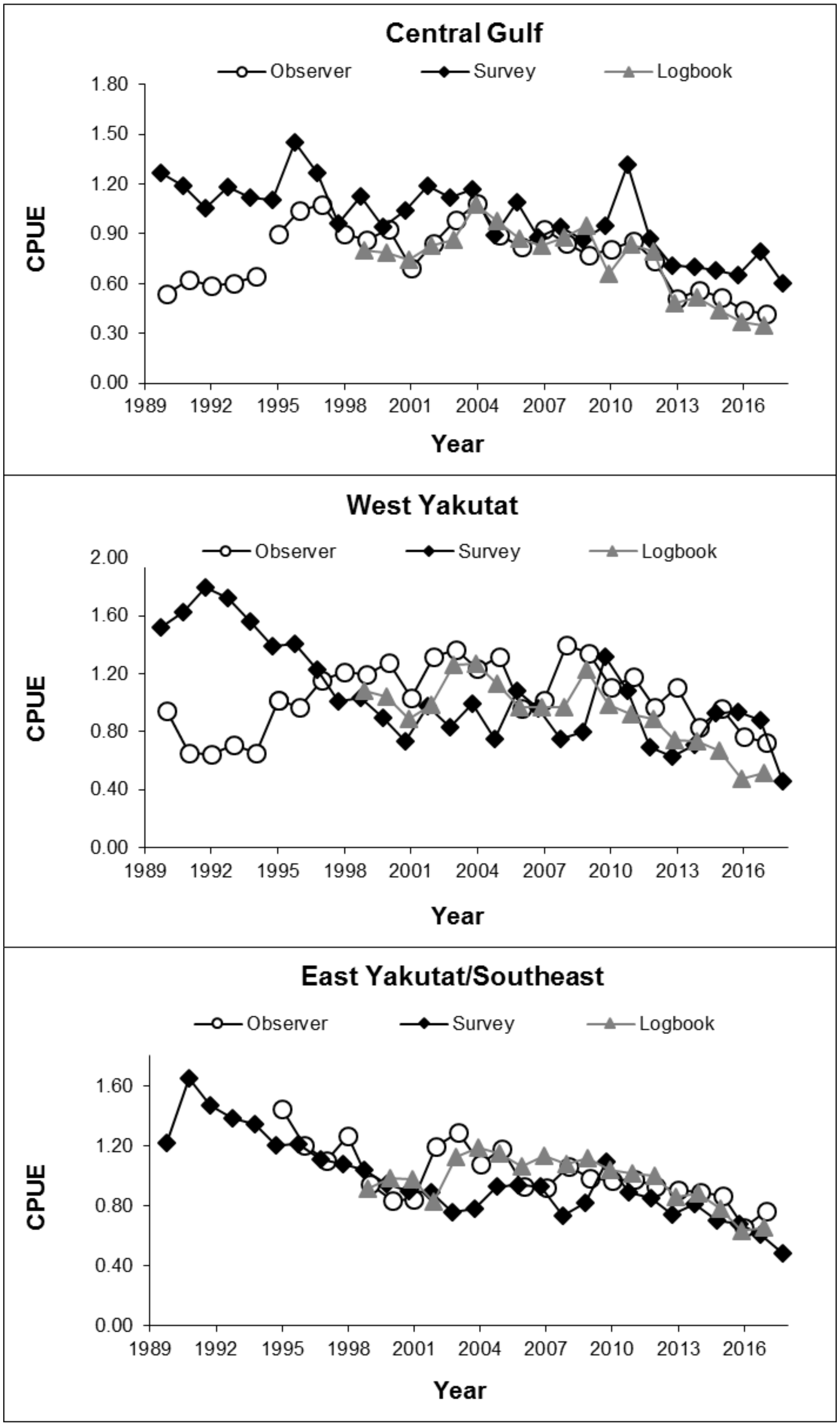


Figure 3.5. (continued).

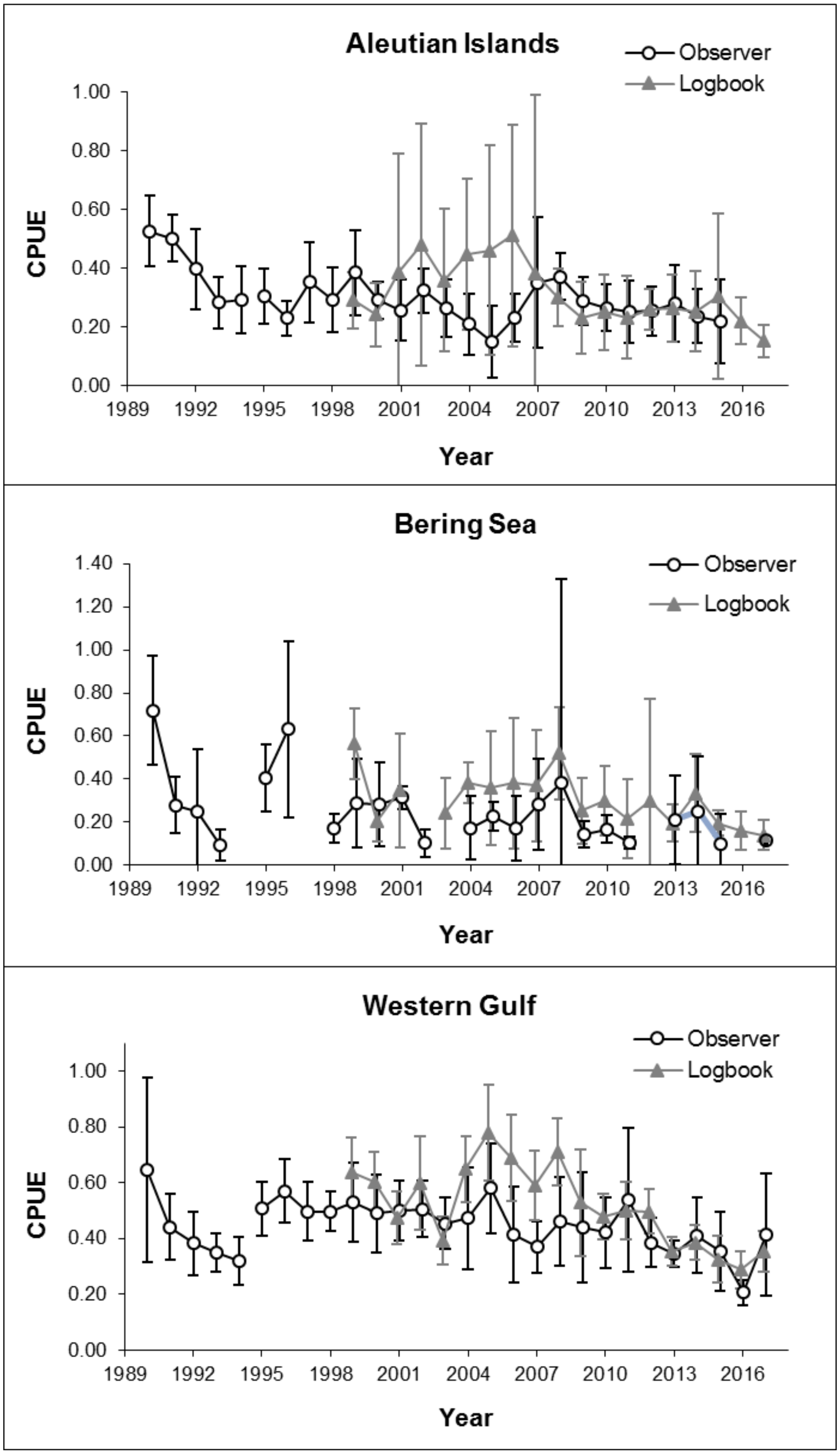


Figure 3.6. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data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

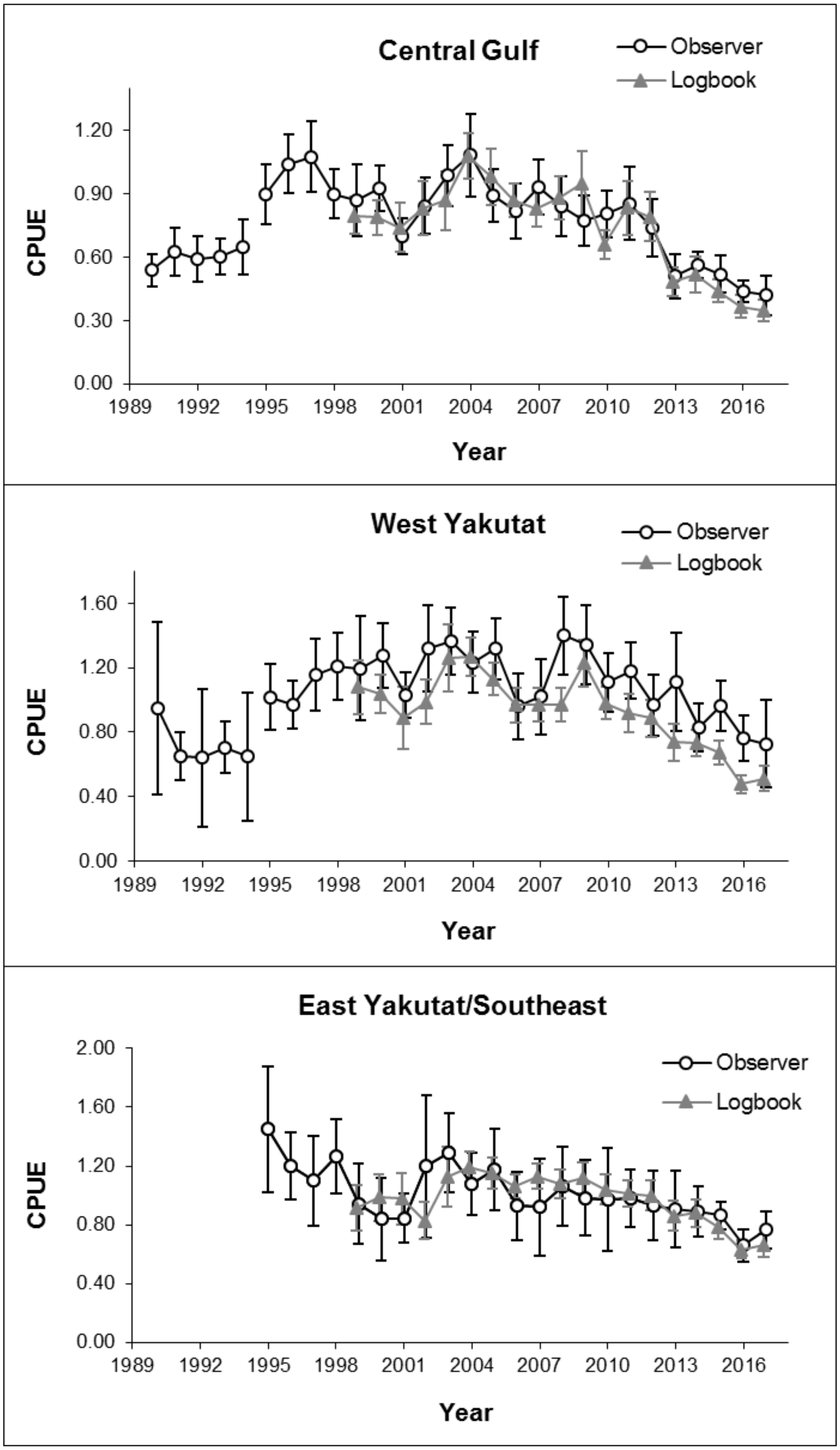


Figure 3.6. (continued)

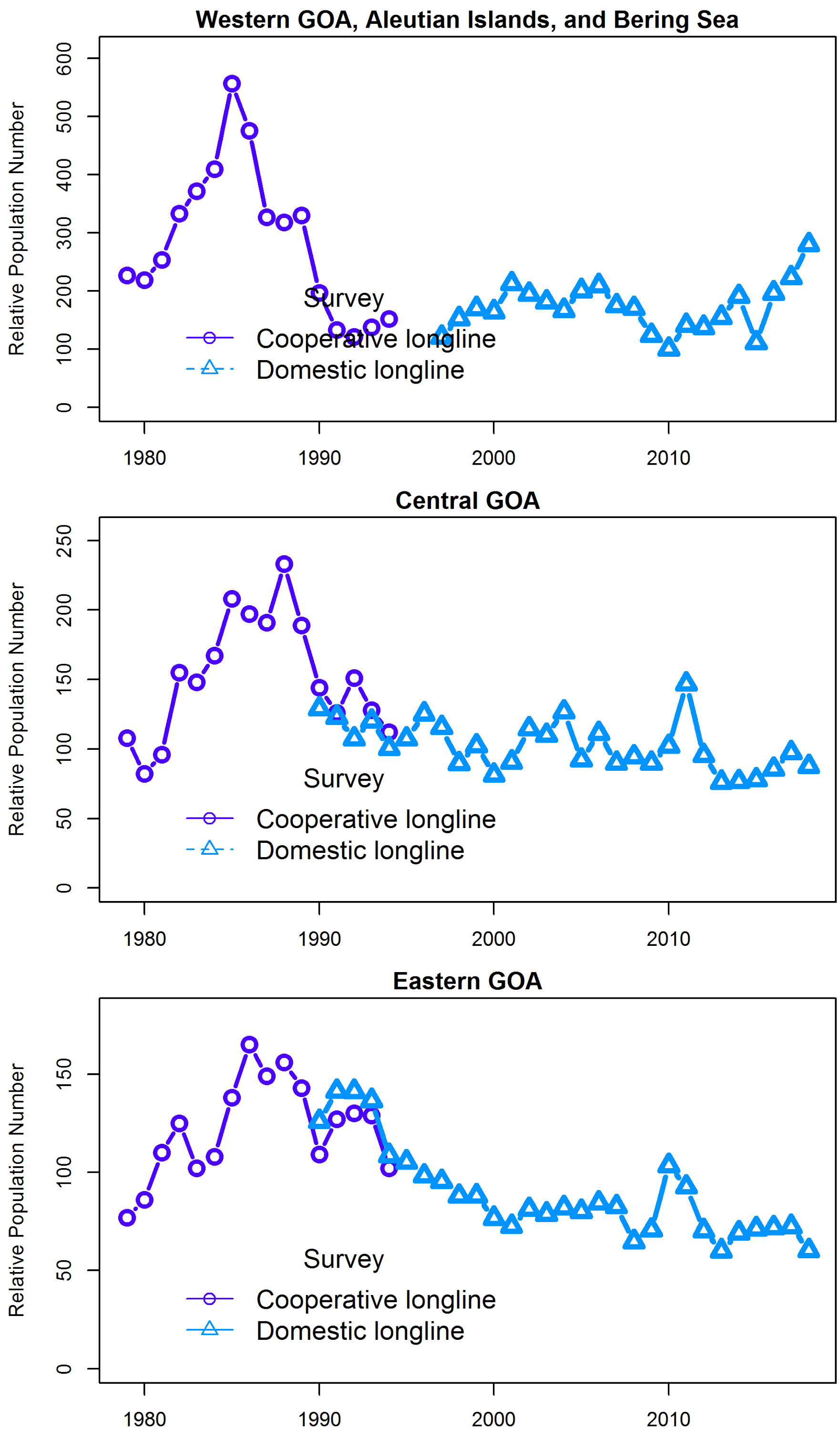


Figure 3.7. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the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

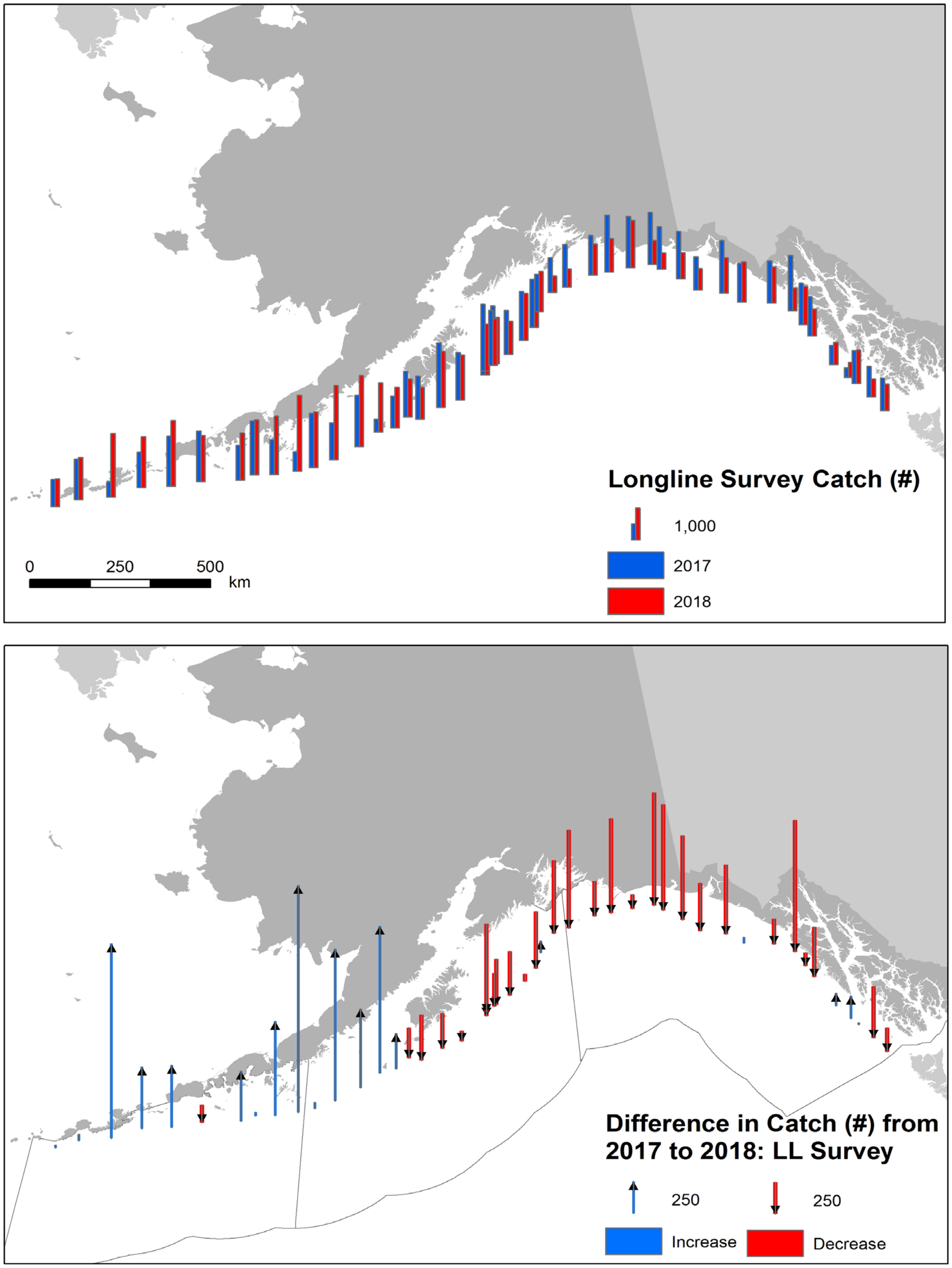


Figure 3.8a. Comparison of the 2017 and 2018 longline survey in the Gulf of Alaska. Top panel is in absolute numbers of fish caught; bottom panel is the difference from 2017 in 2018. Numbers are not corrected for sperm whale depredation.

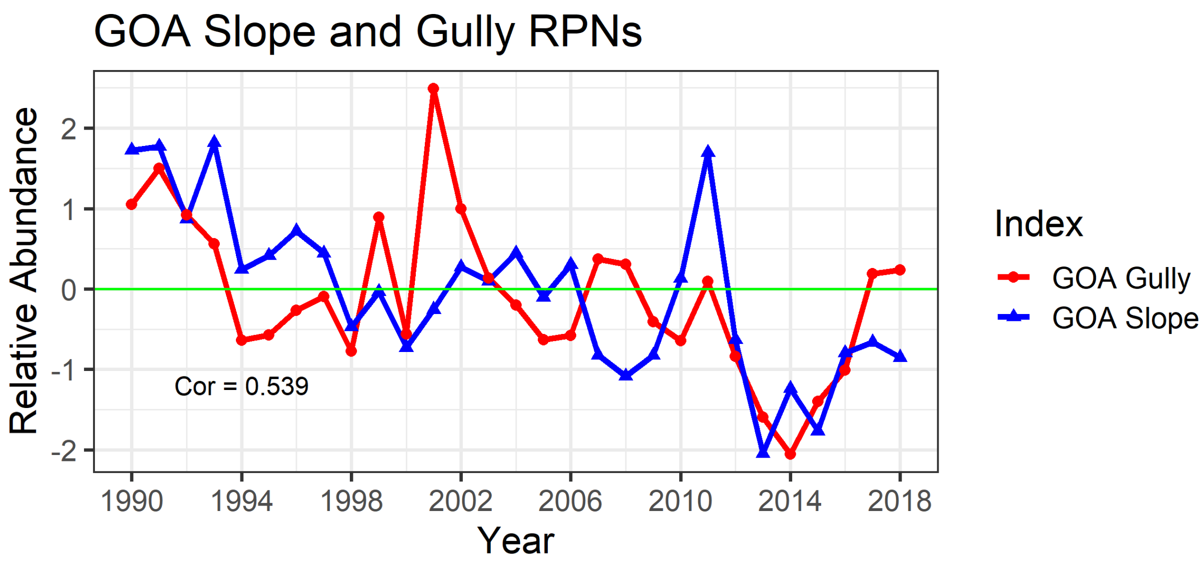


Figure 3.8b. Comparison of abundance trends in GOA gully stations versus GOA slope stations.

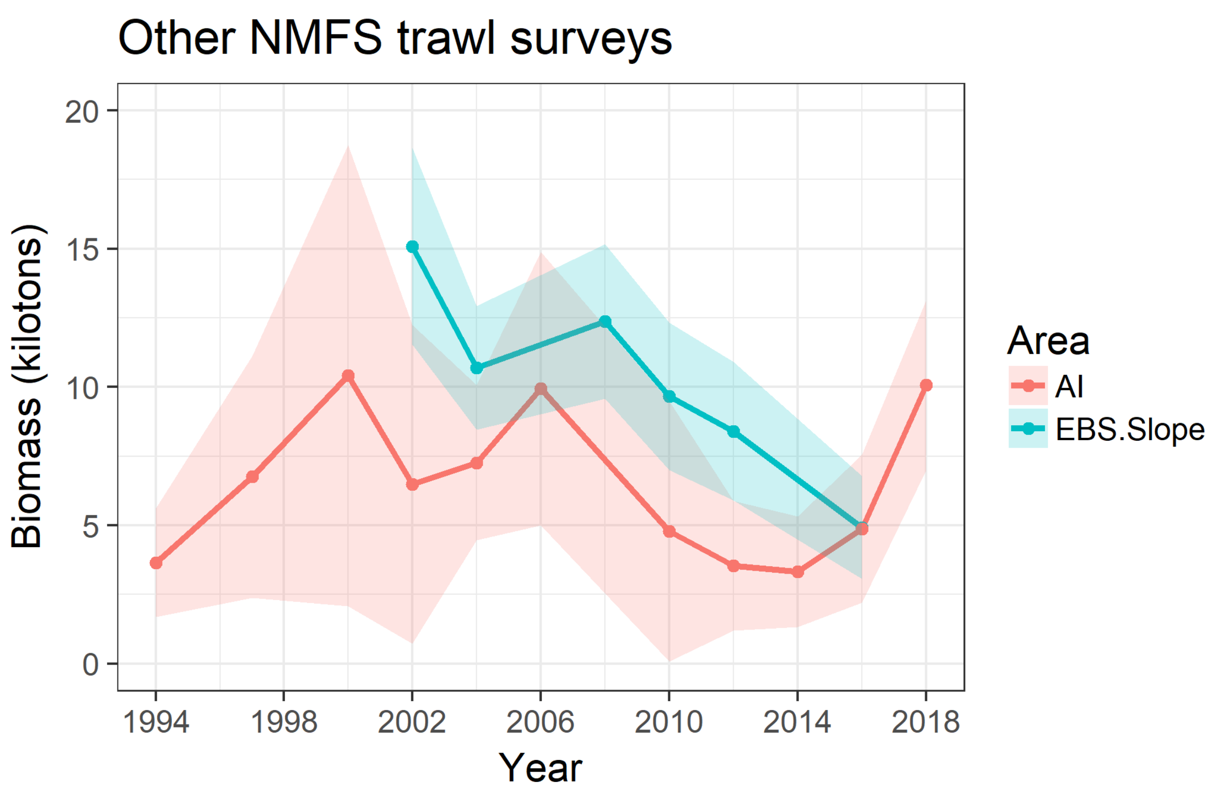


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates.

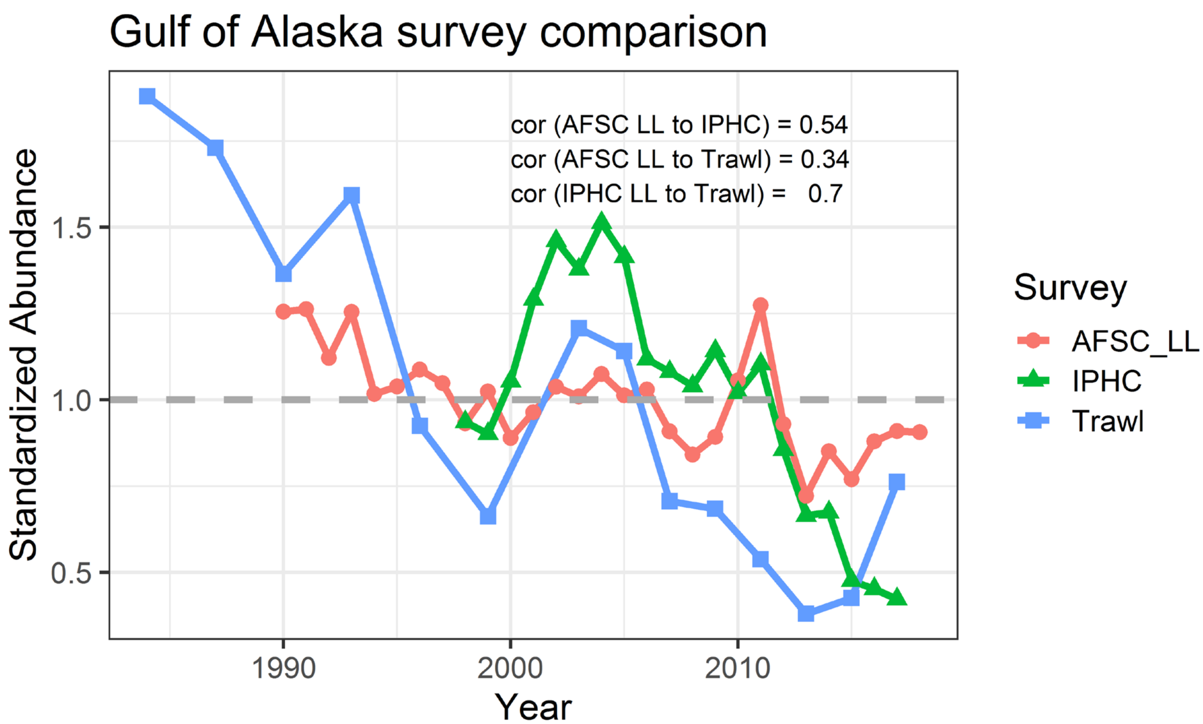


Figure 3.10a. Comparisons of IPHC and AFSC longline surveys, and the NMFS trawl survey trends in relative abundance of sablefish in the Gulf of Alaska. Correlation coefficients shown are when surveys occurred in the same years.

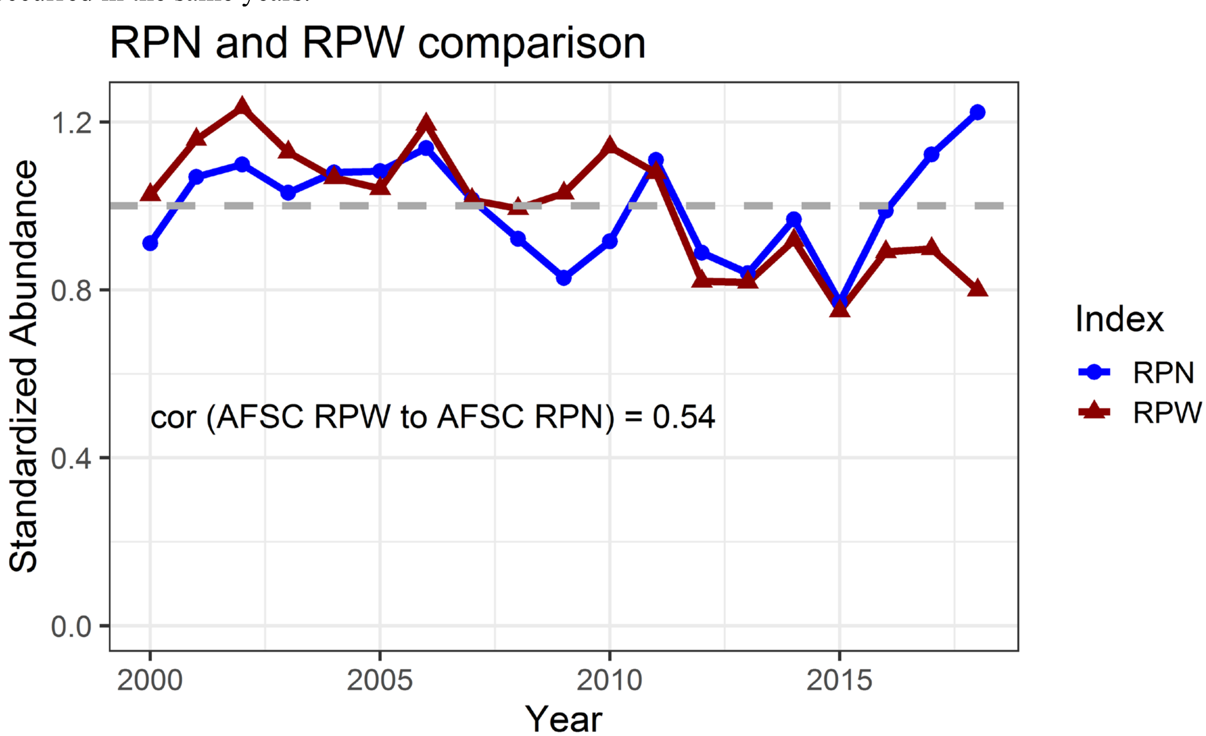


Figure 3.10b. Comparisons of AFSC longline survey indices. Relative Population Weight (RPW) is in weight and Relative Population Numbers (RPN) is in numbers. Only the RPN index is fit in the assessment model.

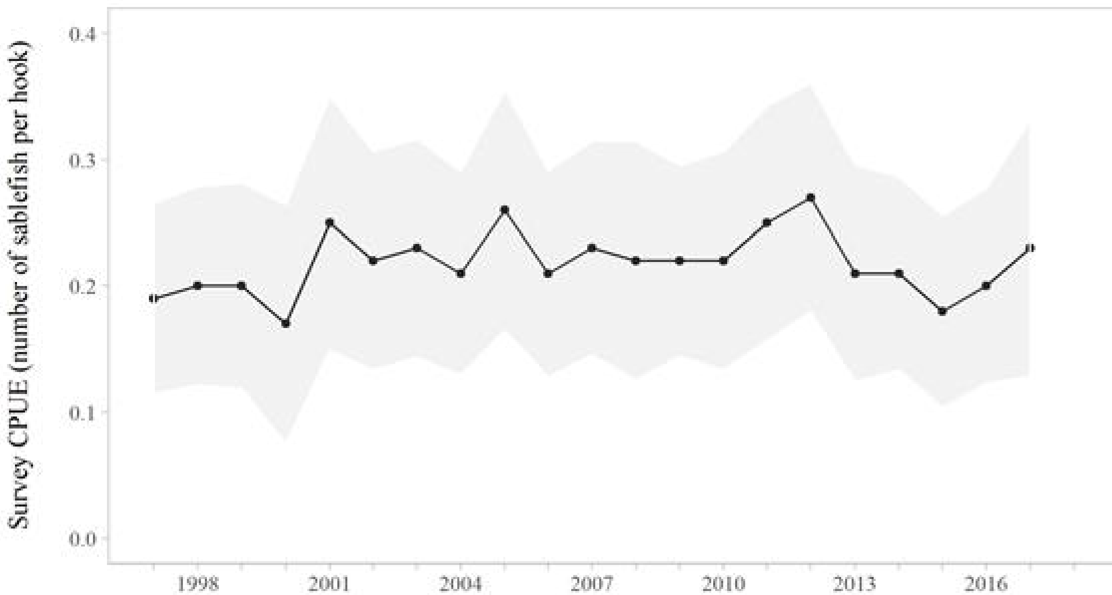


Figure 3.11a. Northern Southeast Inside (NSEI) sablefish longline survey catch-per-unit-effort (CPUE) in individuals/hook from 1997 to 2017. A three-hour minimum soak time was used on the NSEI sablefish longline survey (from A. Olson, November, 2018 ADFG, pers. comm.)

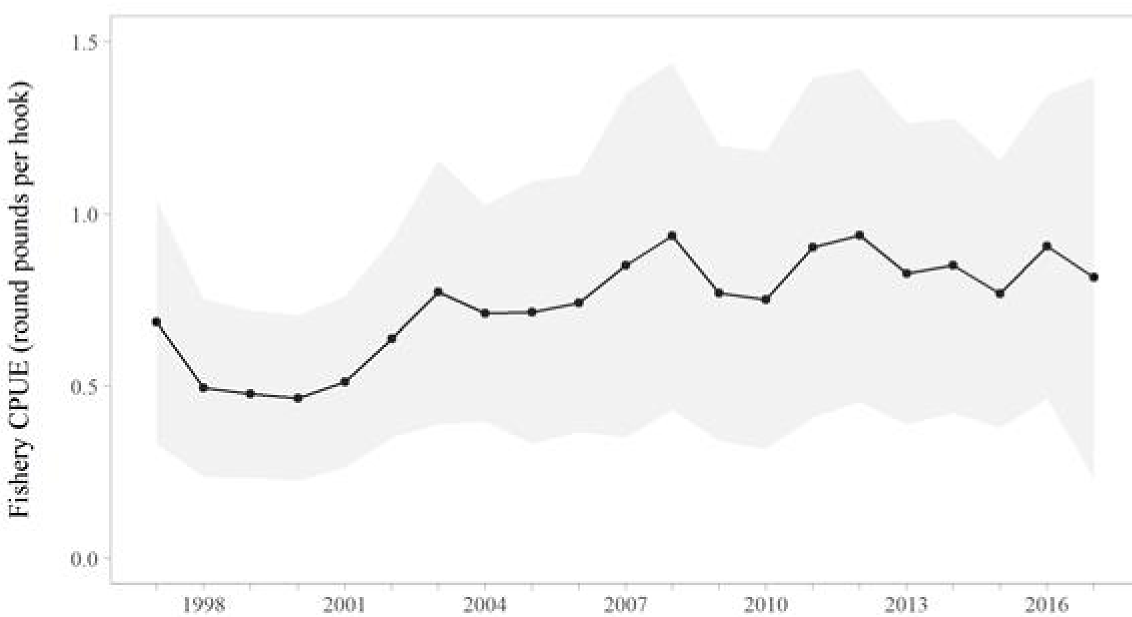


Figure 3.11b. Northern Southeast Inside (NSEI) commercial sablefish fishery catch-per-unit-effort (CPUE) in pounds/hook from 1997 to 2017 (from A. Olson, November, 2018 ADFG, pers. comm.)

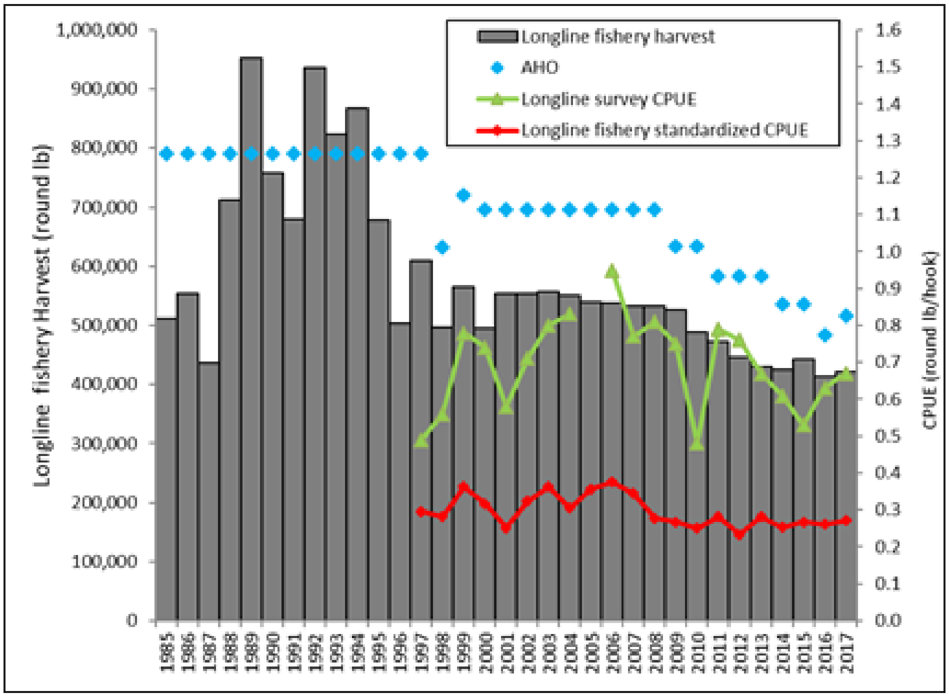


Figure 3.11c. Southern Southeast Inside (SSEI) commercial sablefish longline survey and fishery catch-per-unit-effort (CPUE) in round pounds-per-hook from 1997 to 2017 and commercial catch from 1985 to 2017. AHO is the Annual Harvest Objective (from A. Olson, November, 2018 ADFG, pers. comm.)

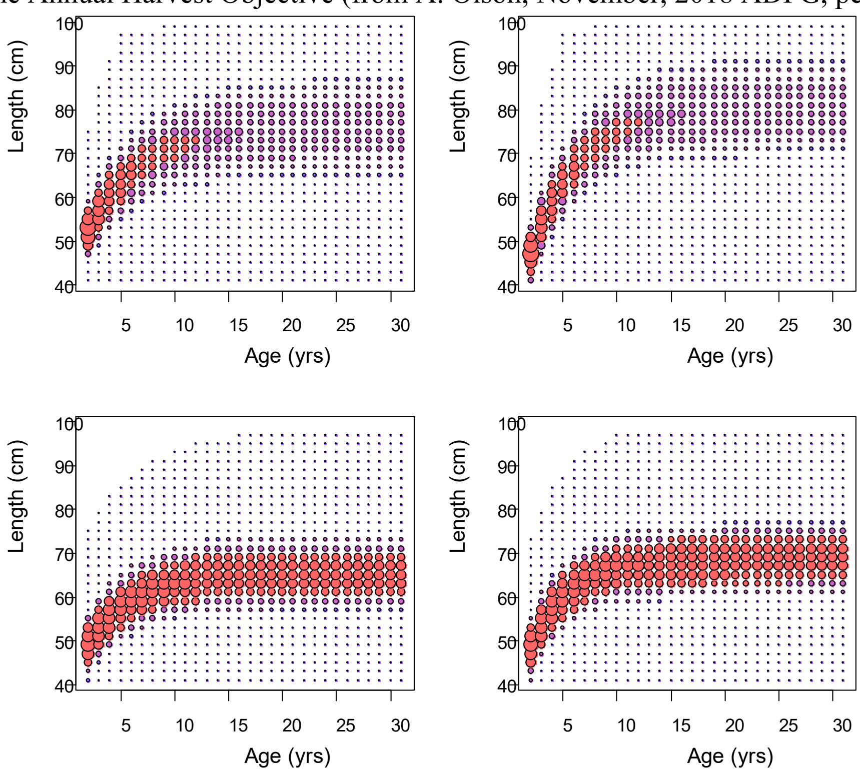


Figure 3.12. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996-2018.

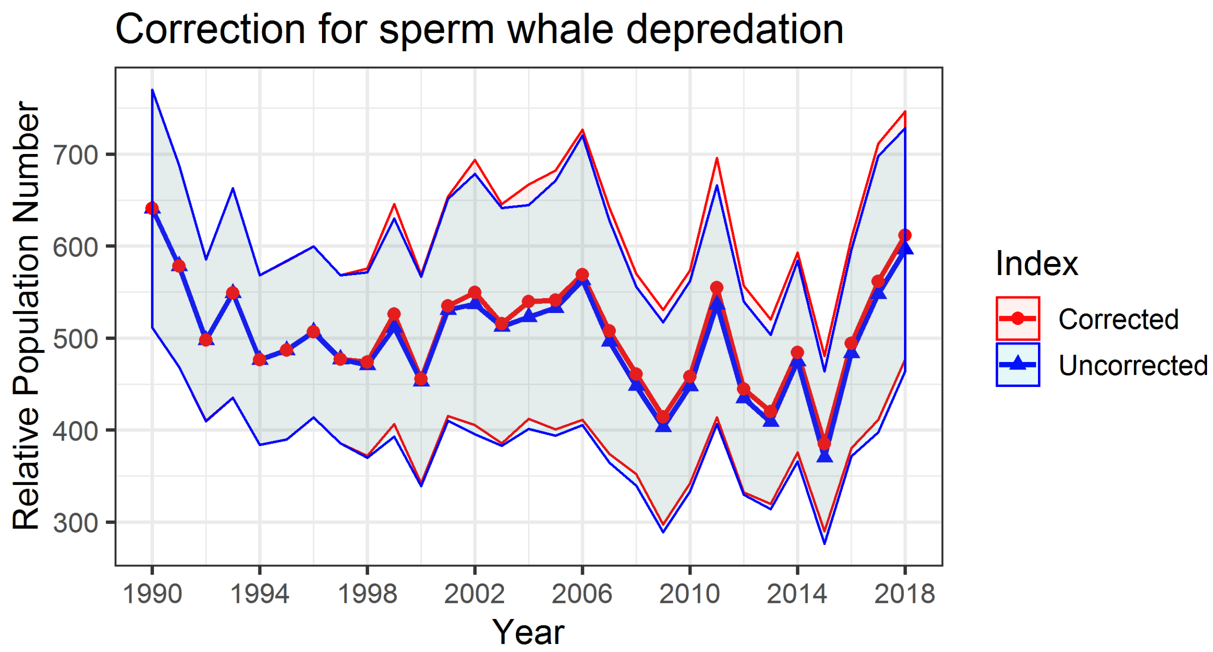


Figure 3.13. Total longline sablefish RPN index with (red circles) and without (blue triangles) sperm whale corrections 1990-2018. Shaded regions are approximate 95% confidence intervals.

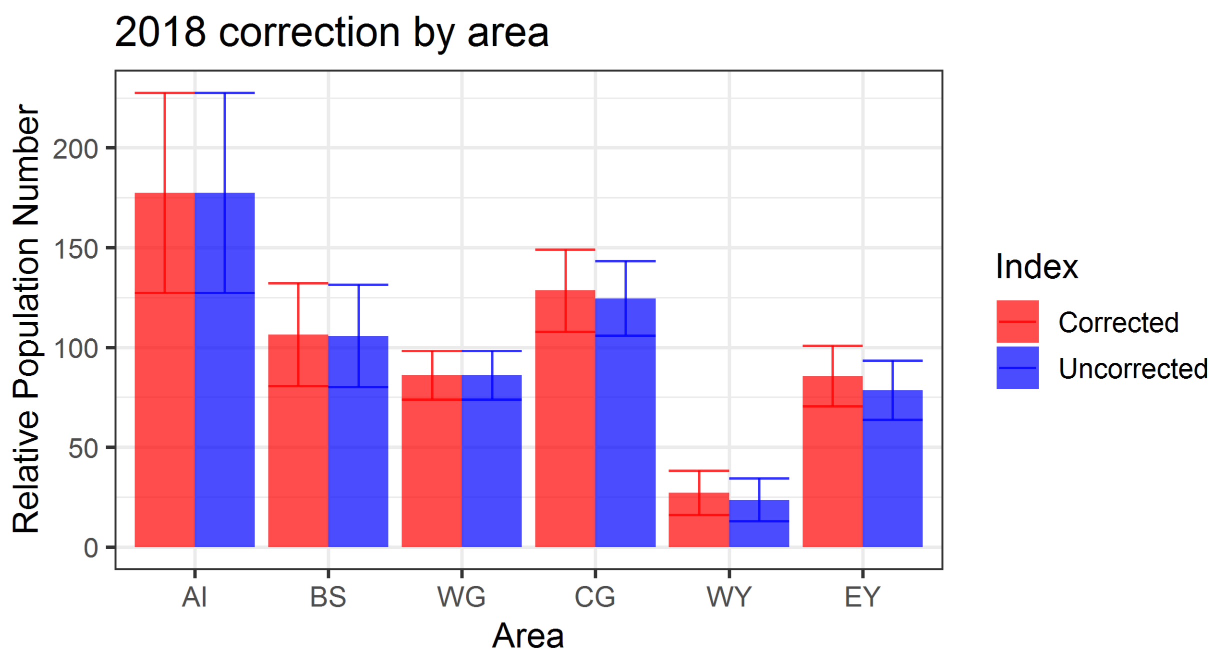


Figure 3.14. Longline sablefish RPN index by area with (red bars) and without (blue bars) sperm whale corrections 1990-2018. Error bars are approximate 95% confidence intervals.

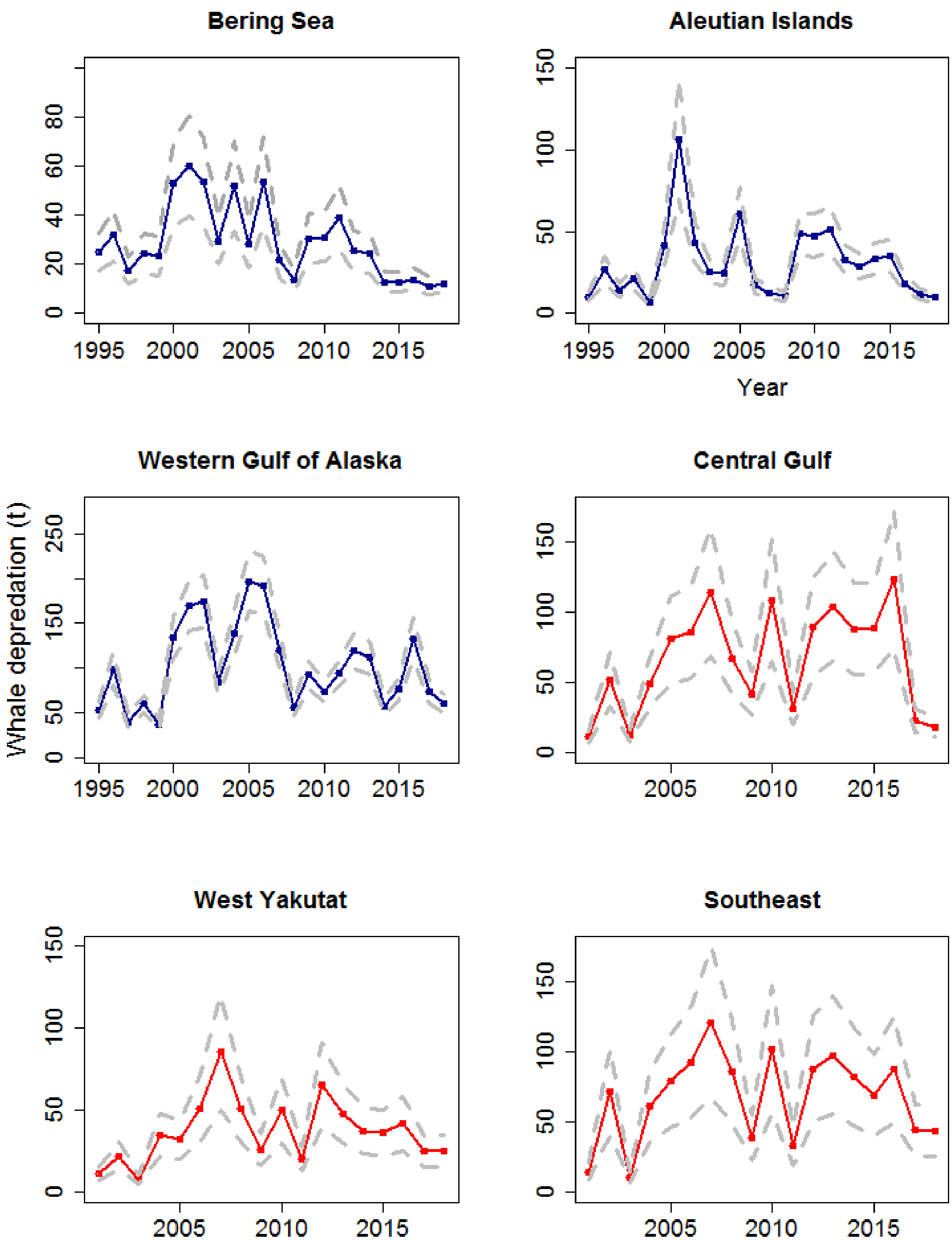


Figure 3.15. Estimated sablefish mortality (t) by year due to killer whales (blue) in the Bering Sea, Aleutian Islands, and Western Gulf of Alaska and sperm whales (red) in the Central Gulf of Alaska, West Yakutat, and Southeast Alaska with ~95% confidence bands. Estimated sablefish catch removals (t) due to sperm whale and killer whale depredation 1995-2018. 2018 is not a complete estimate.

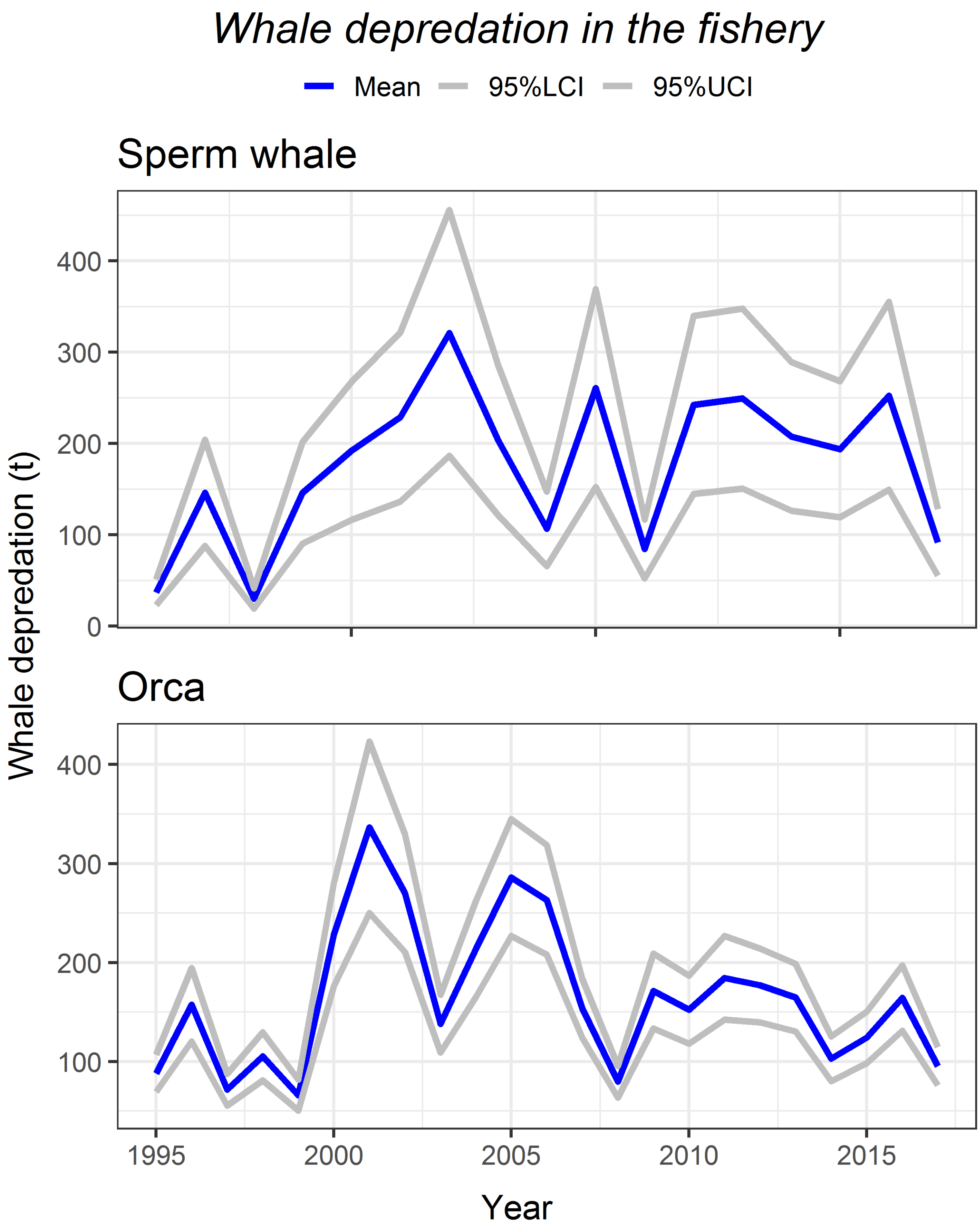


Figure 3.16. Additional estimated sablefish mortality (blue) by two whale species with 95% asymptotic normal confidence intervals (grey lines).

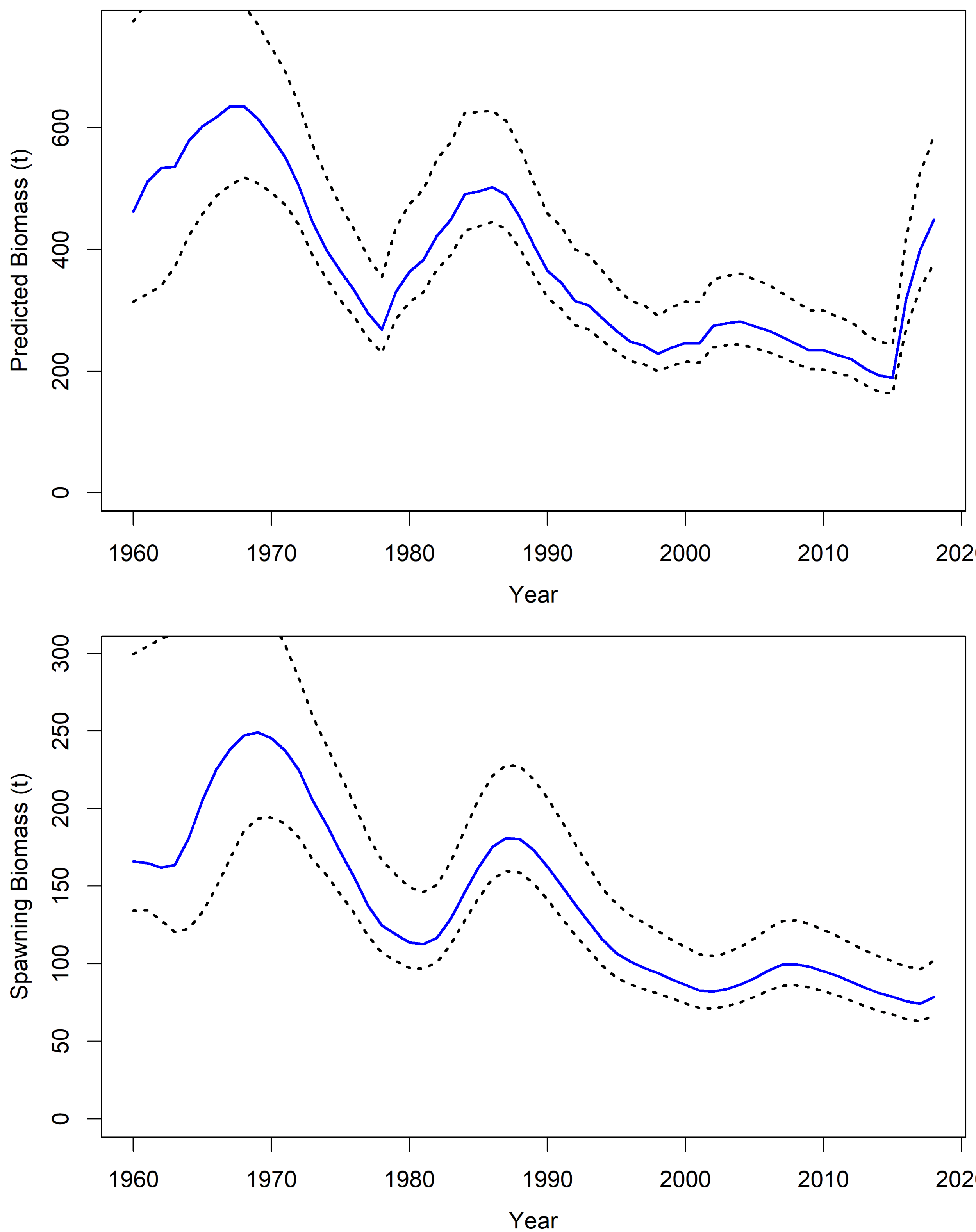


Figure 3.17. Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

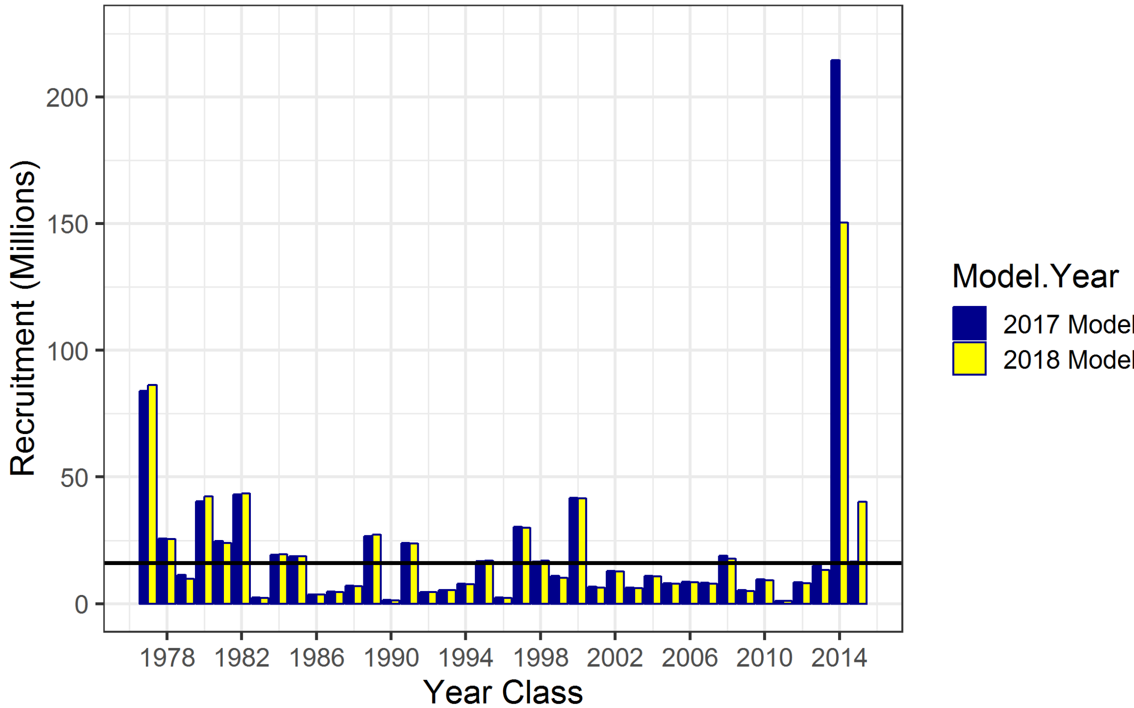


Figure 3.18a. Estimated recruitment by year class 1977-2012 (number at age 2, millions) for 2017 and 2018 models.

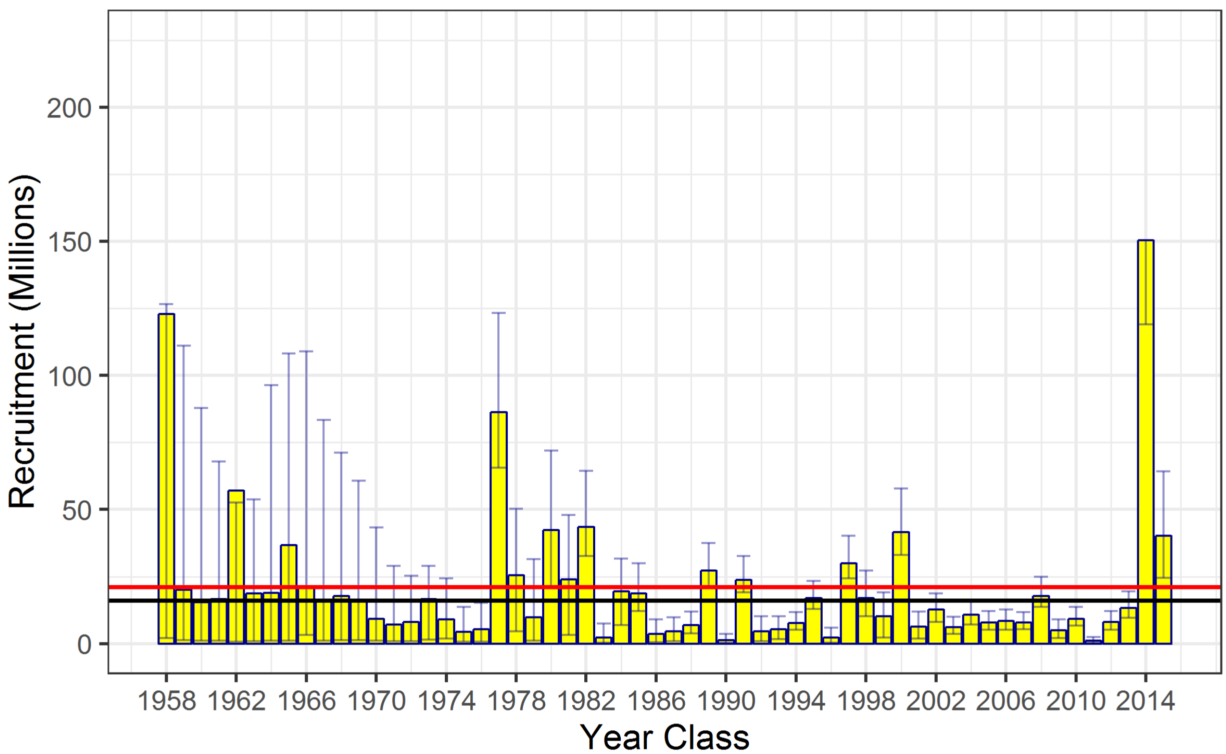


Figure 3.18b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Red line is overall mean, blue line is recruitments from year classes between 1977 and 2014.

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

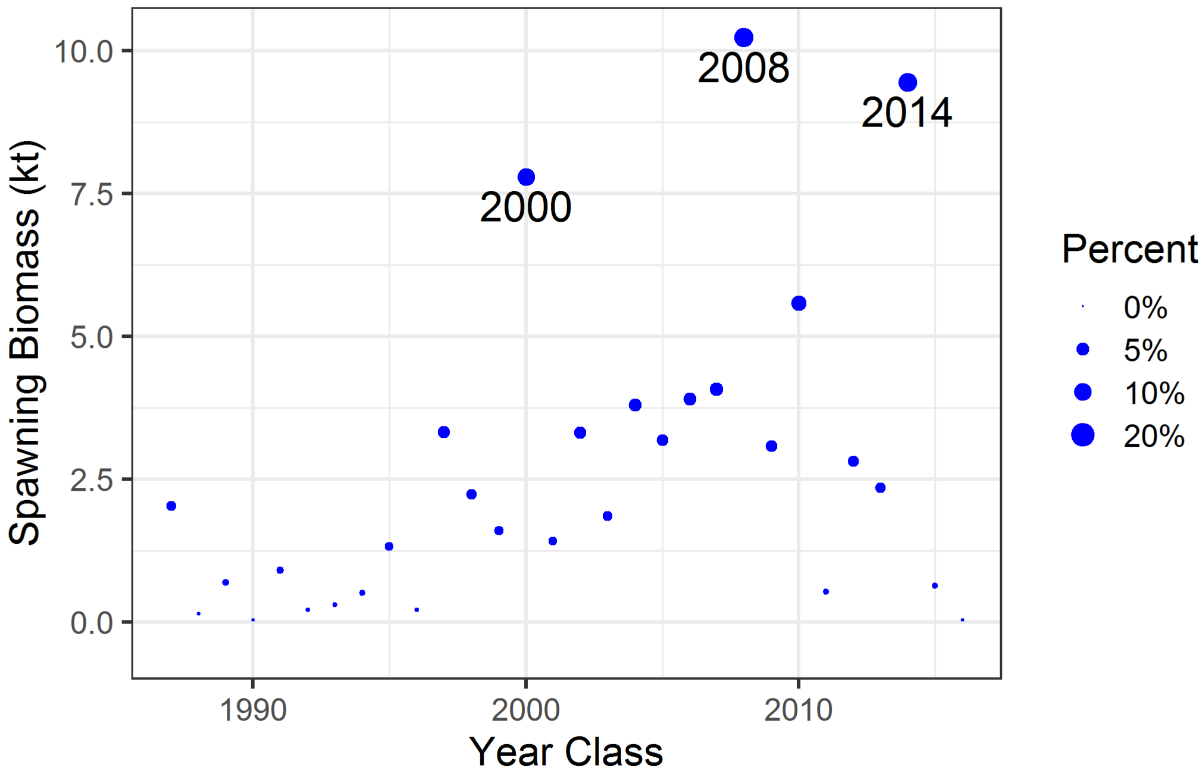


Figure 3.19. Relative contribution of the last 30 year classes to next year's female spawning biomass.

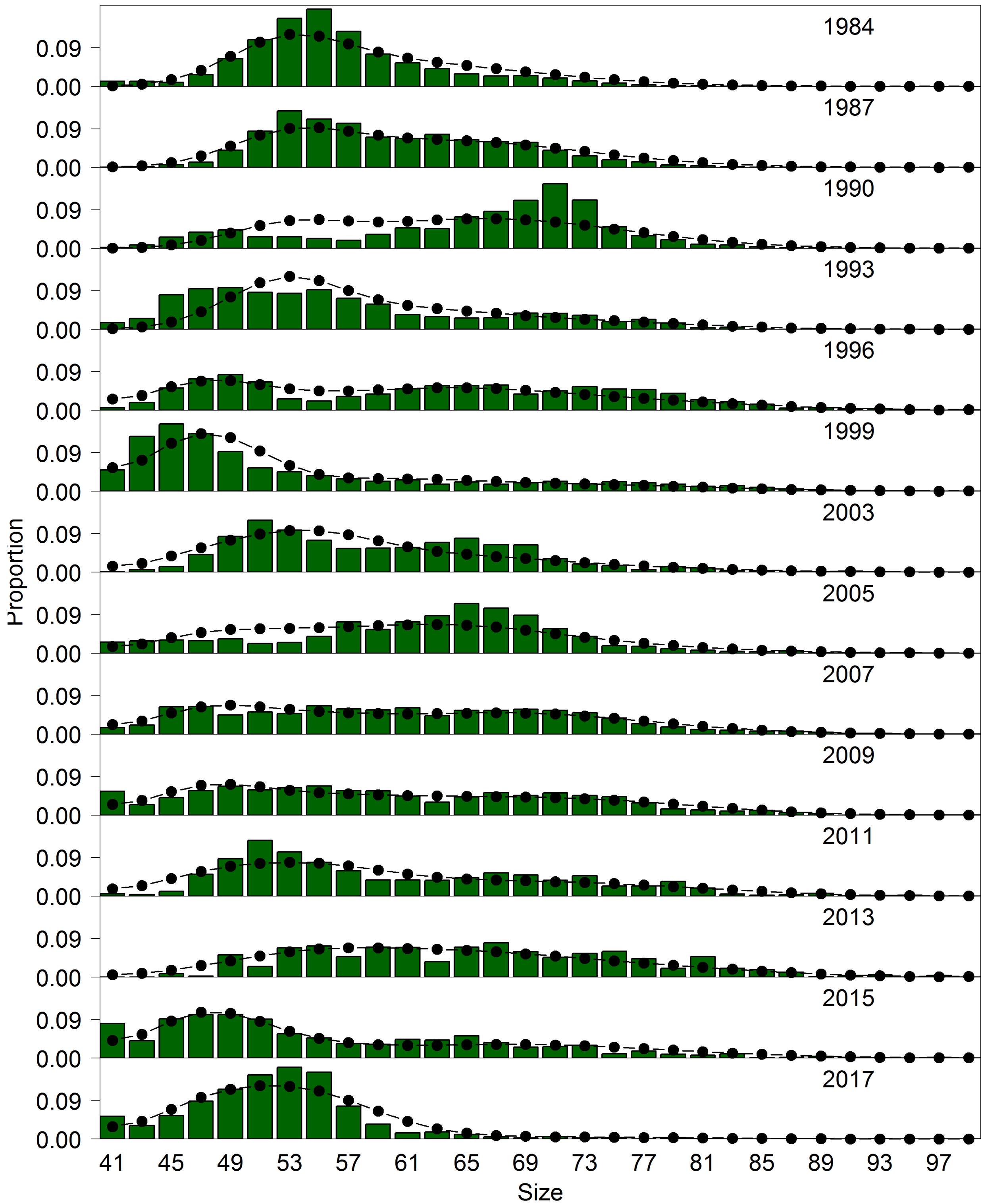


Figure 3.20. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

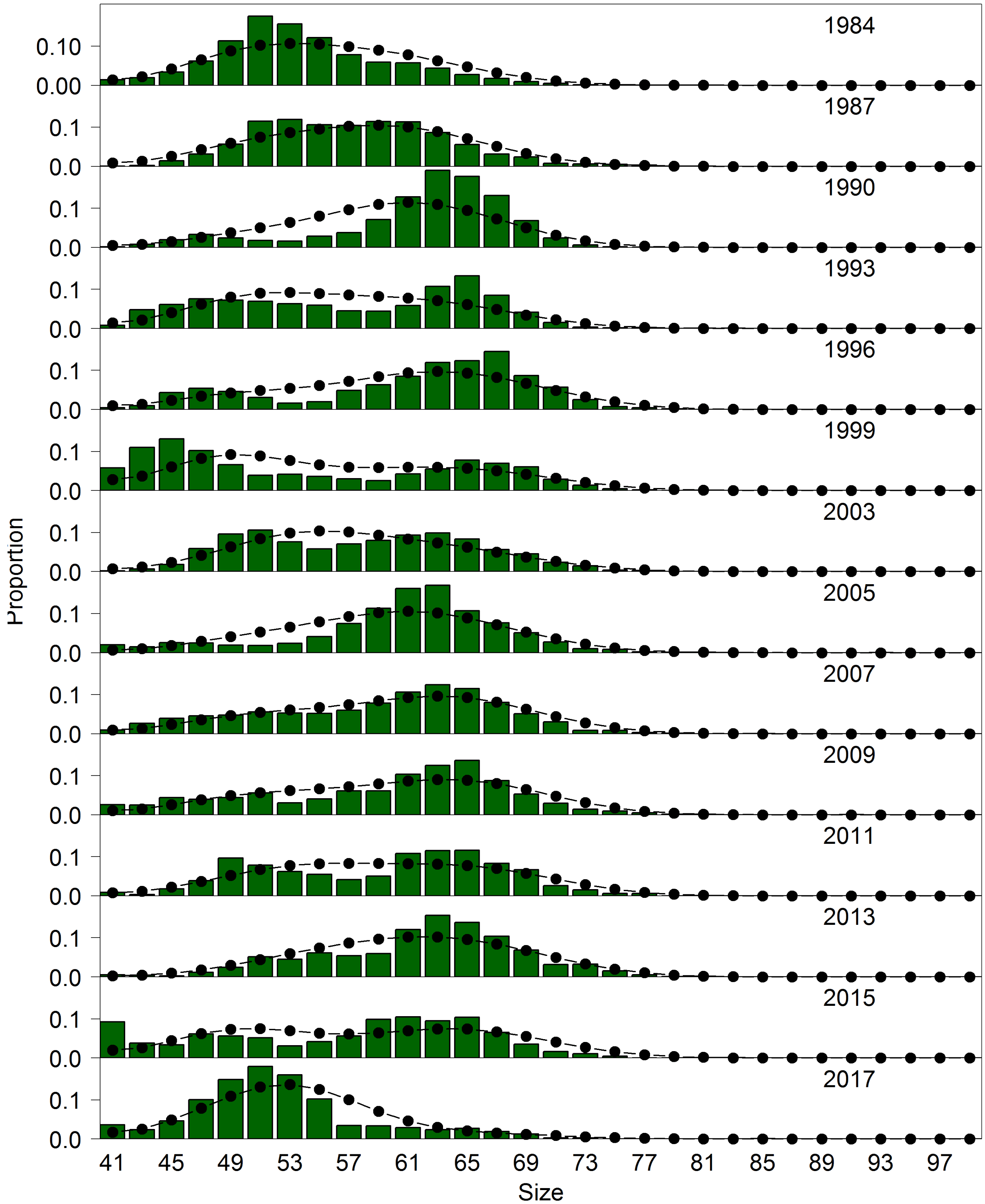


Figure 3.21. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

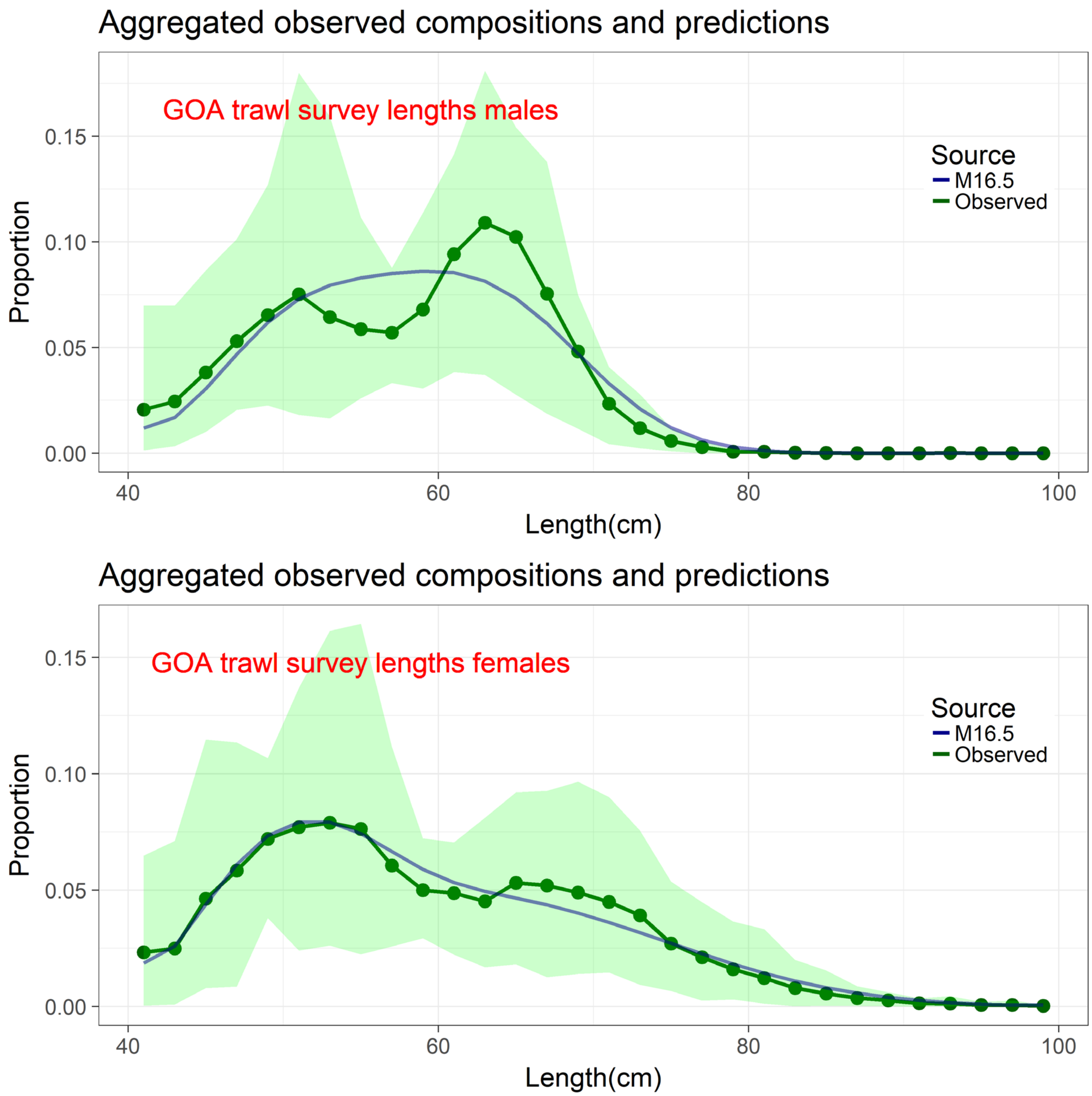


Figure 3.22. Gulf of Alaska trawl survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

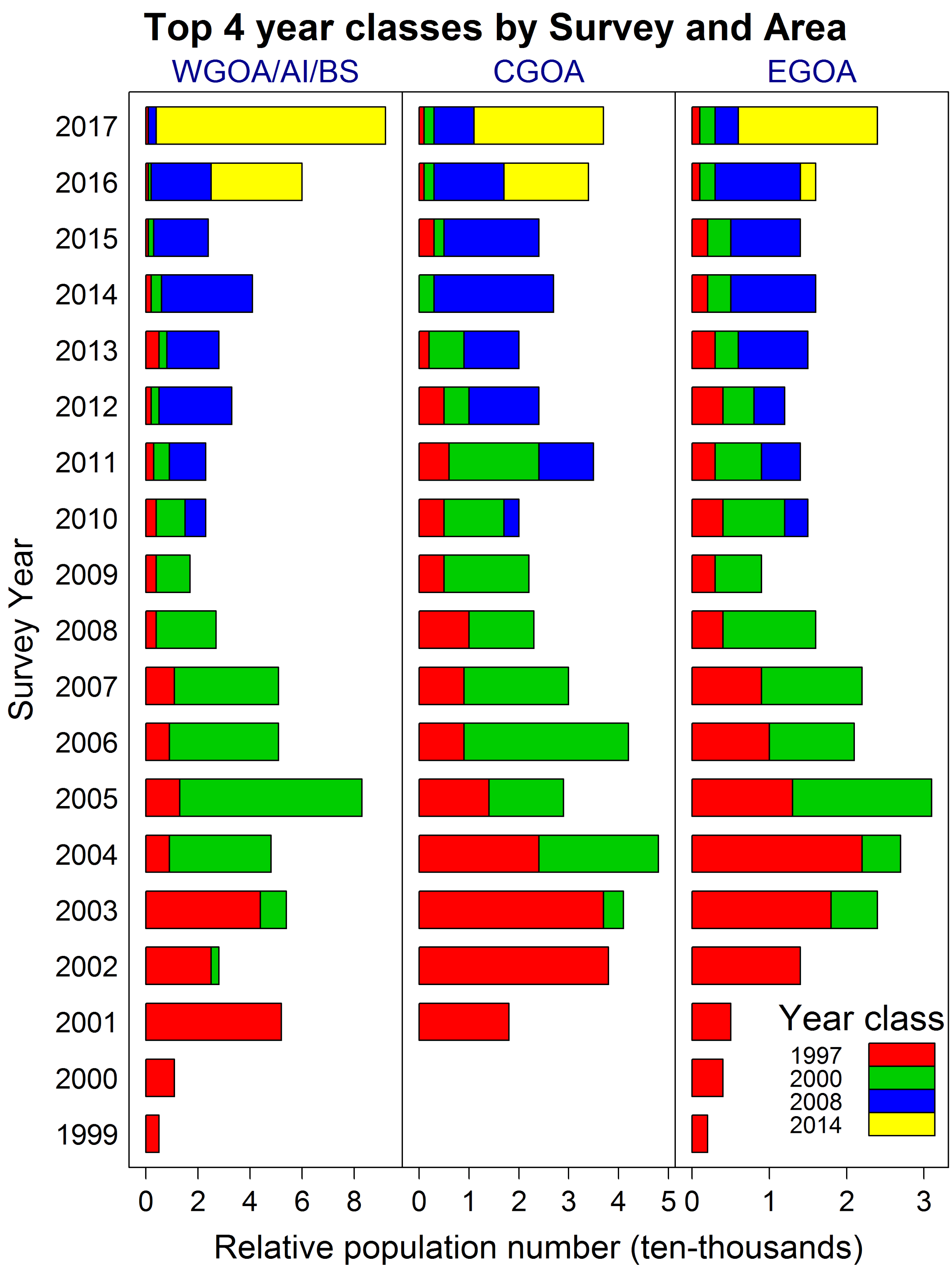


Figure 3.23. Above average 1997, 2000, 2008, and 2014 year classes' relative population abundance in each survey year and area.

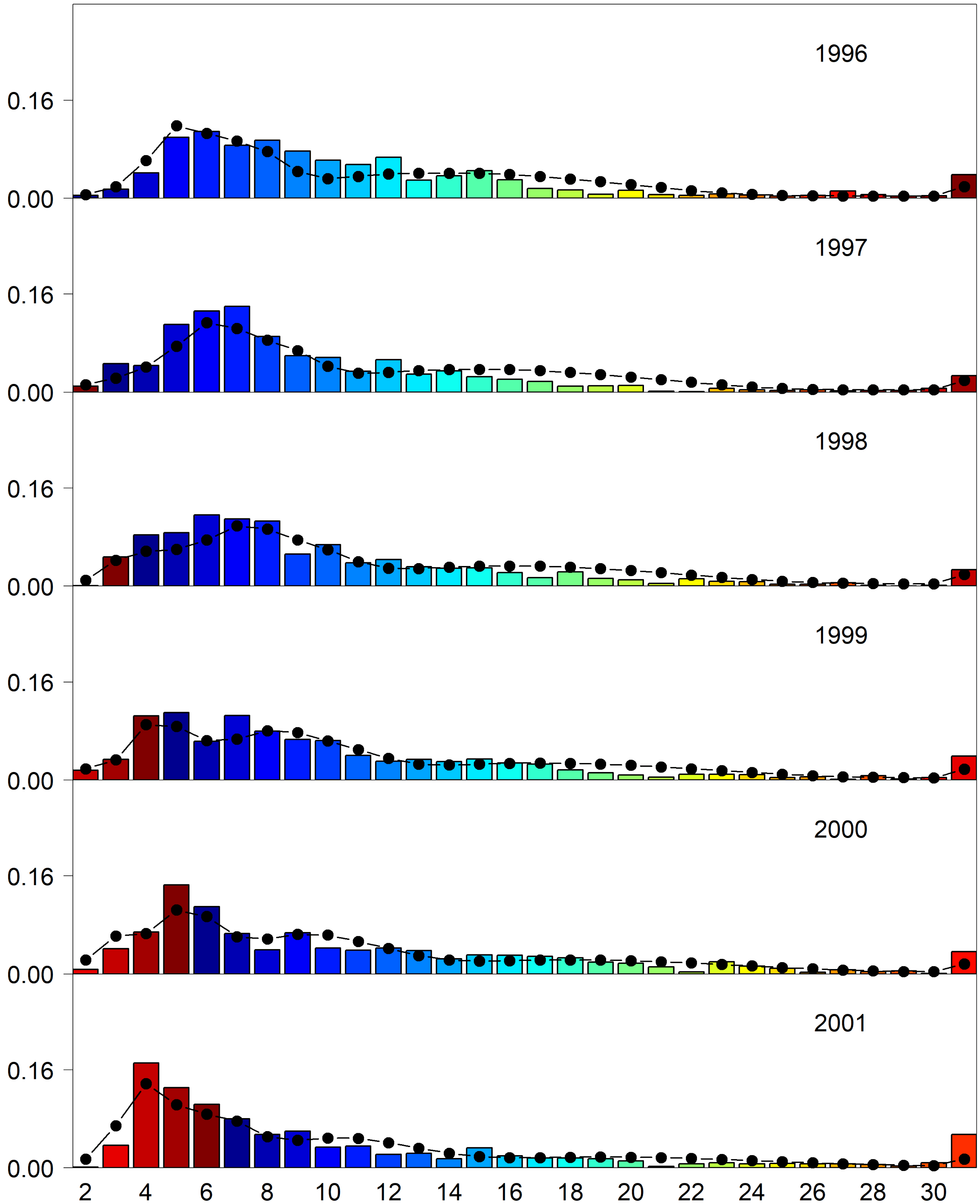


Figure 3.24. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

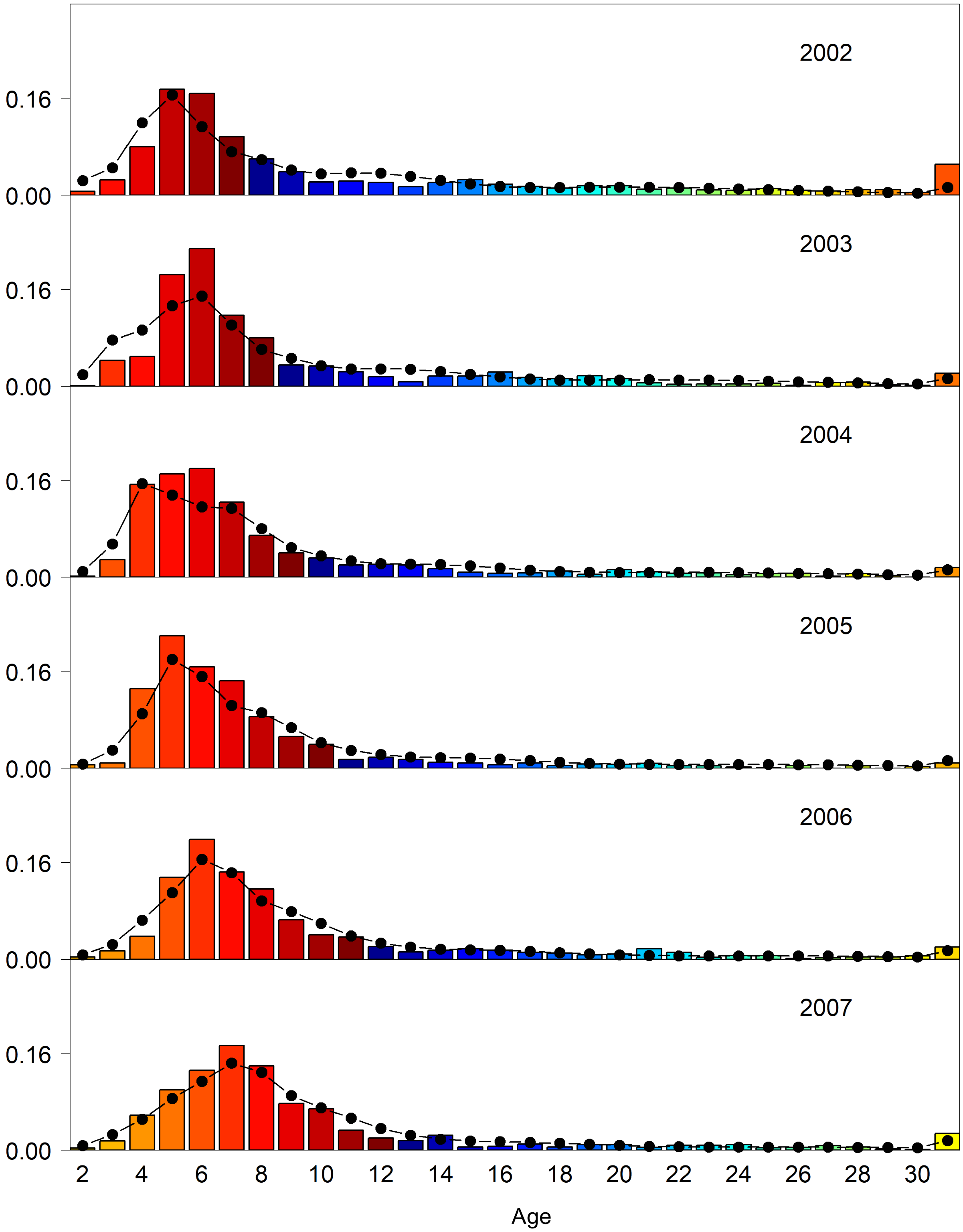


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

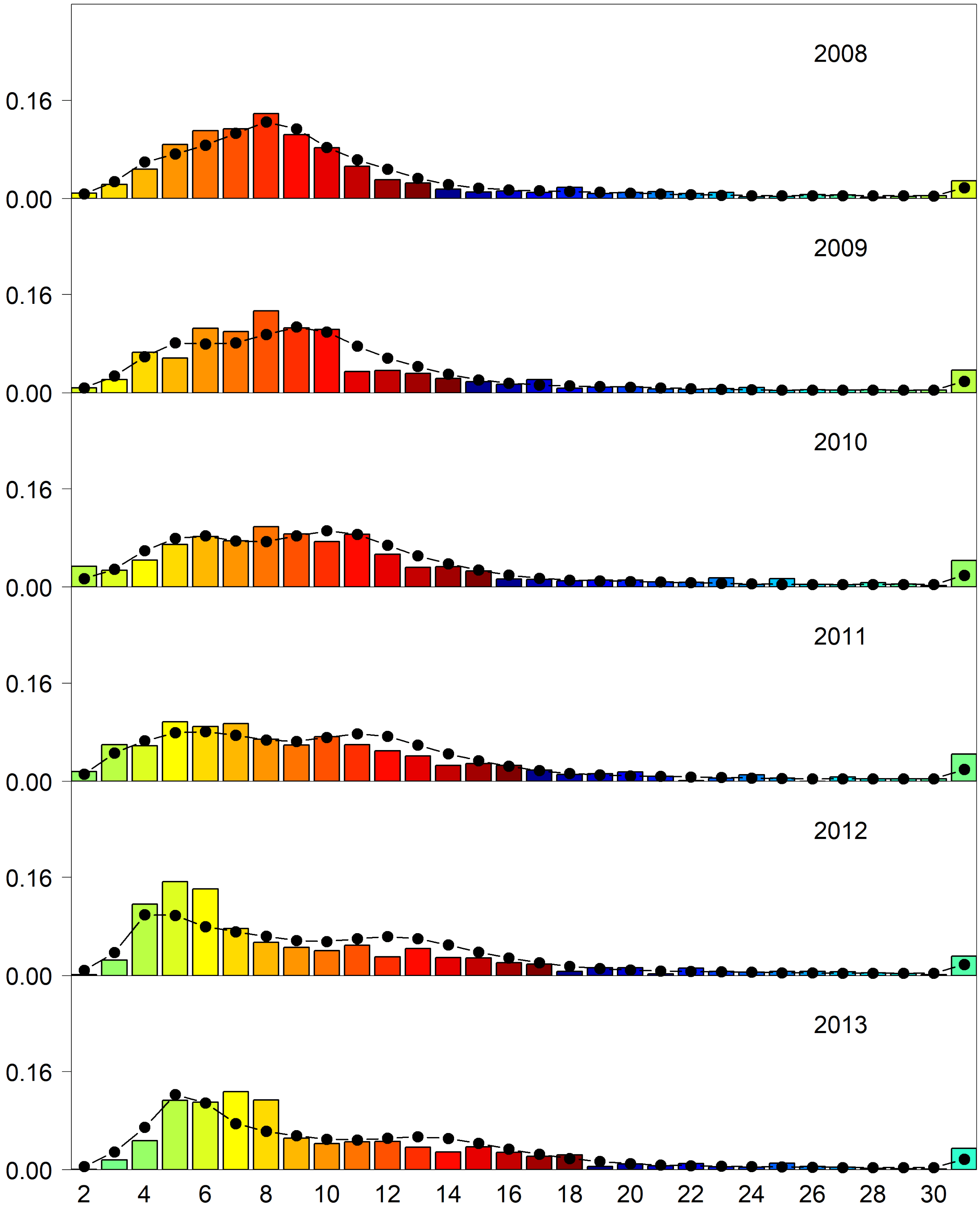


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

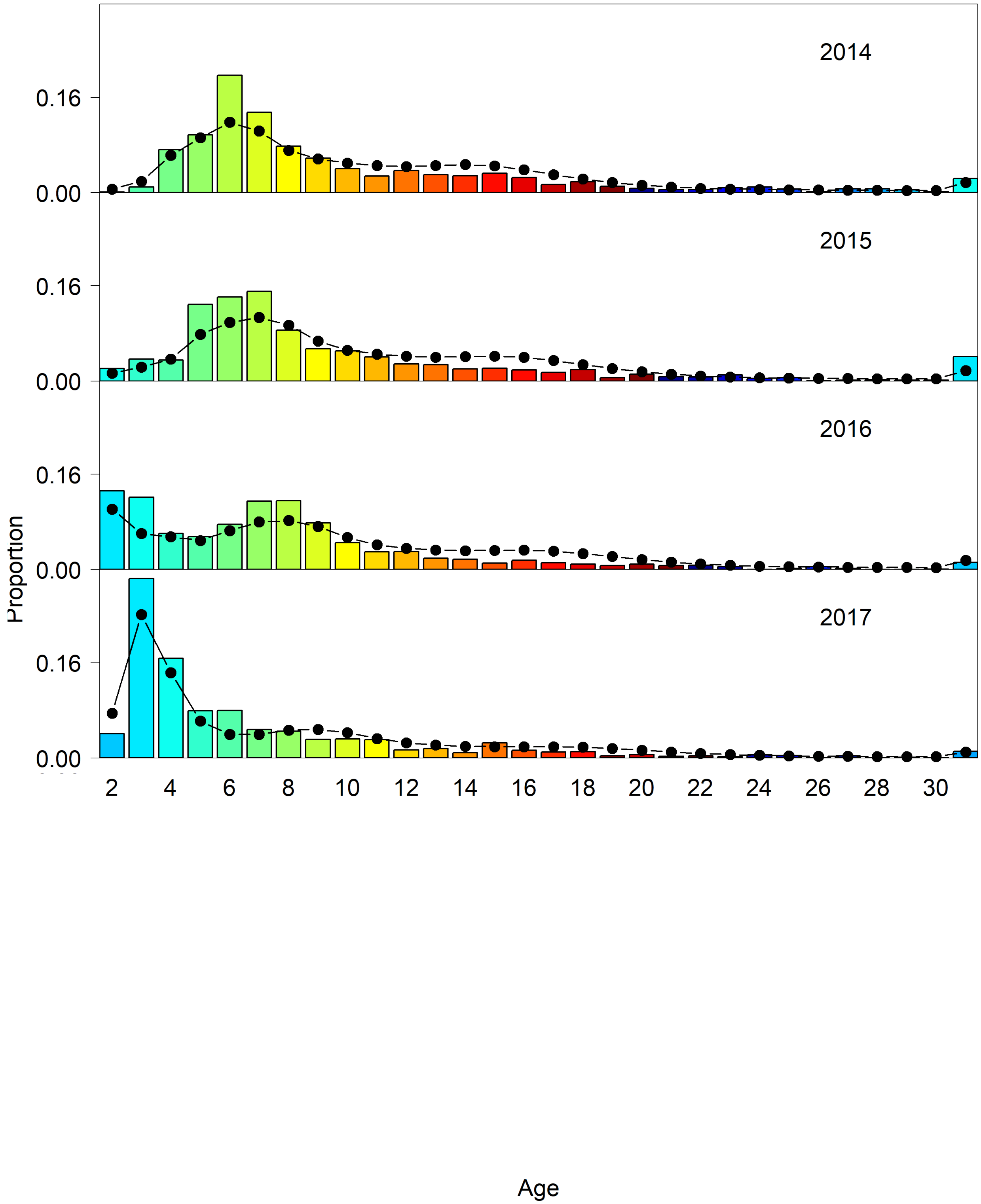


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

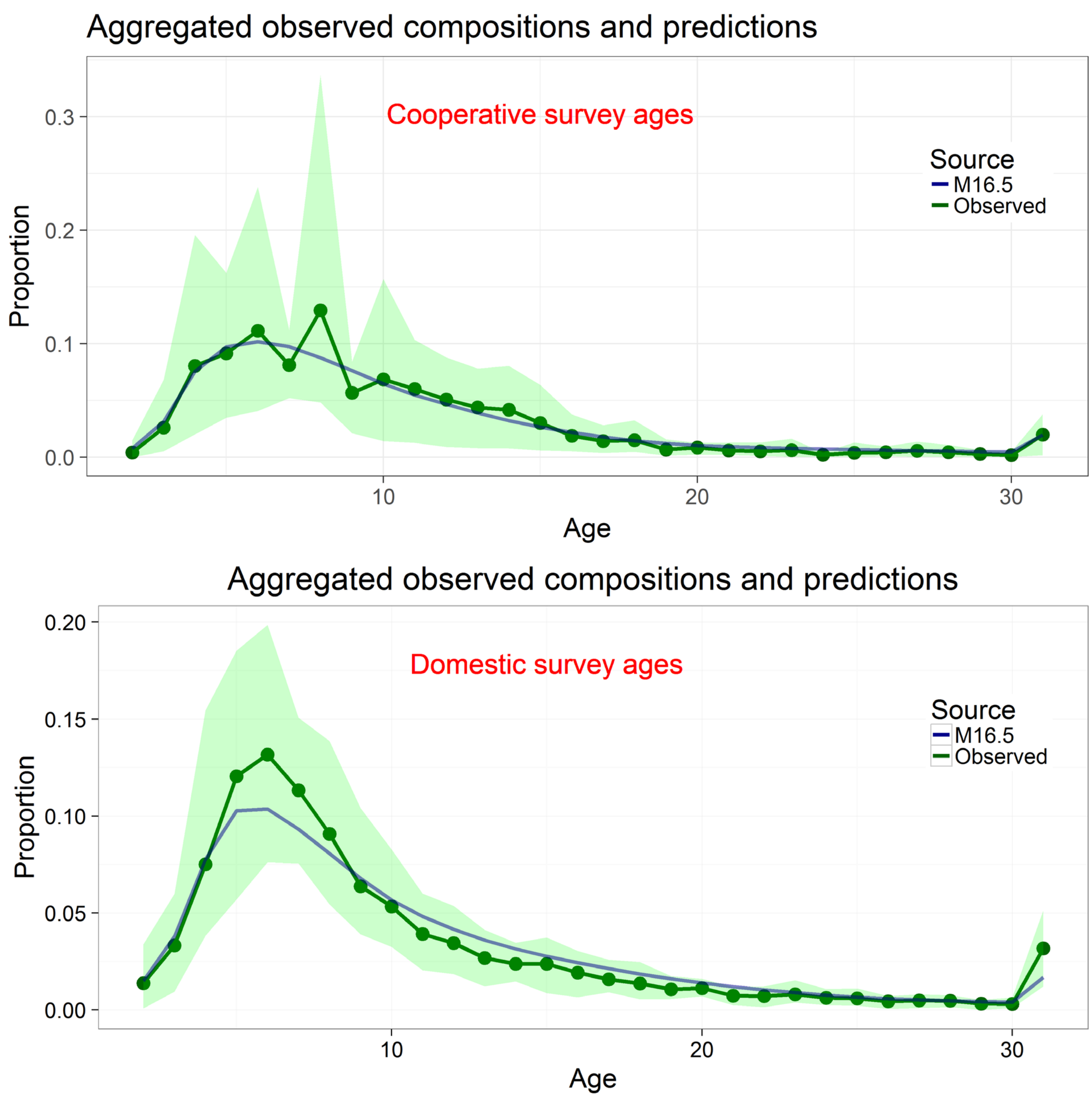


Figure 3.25. Cooperative and domestic survey age compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

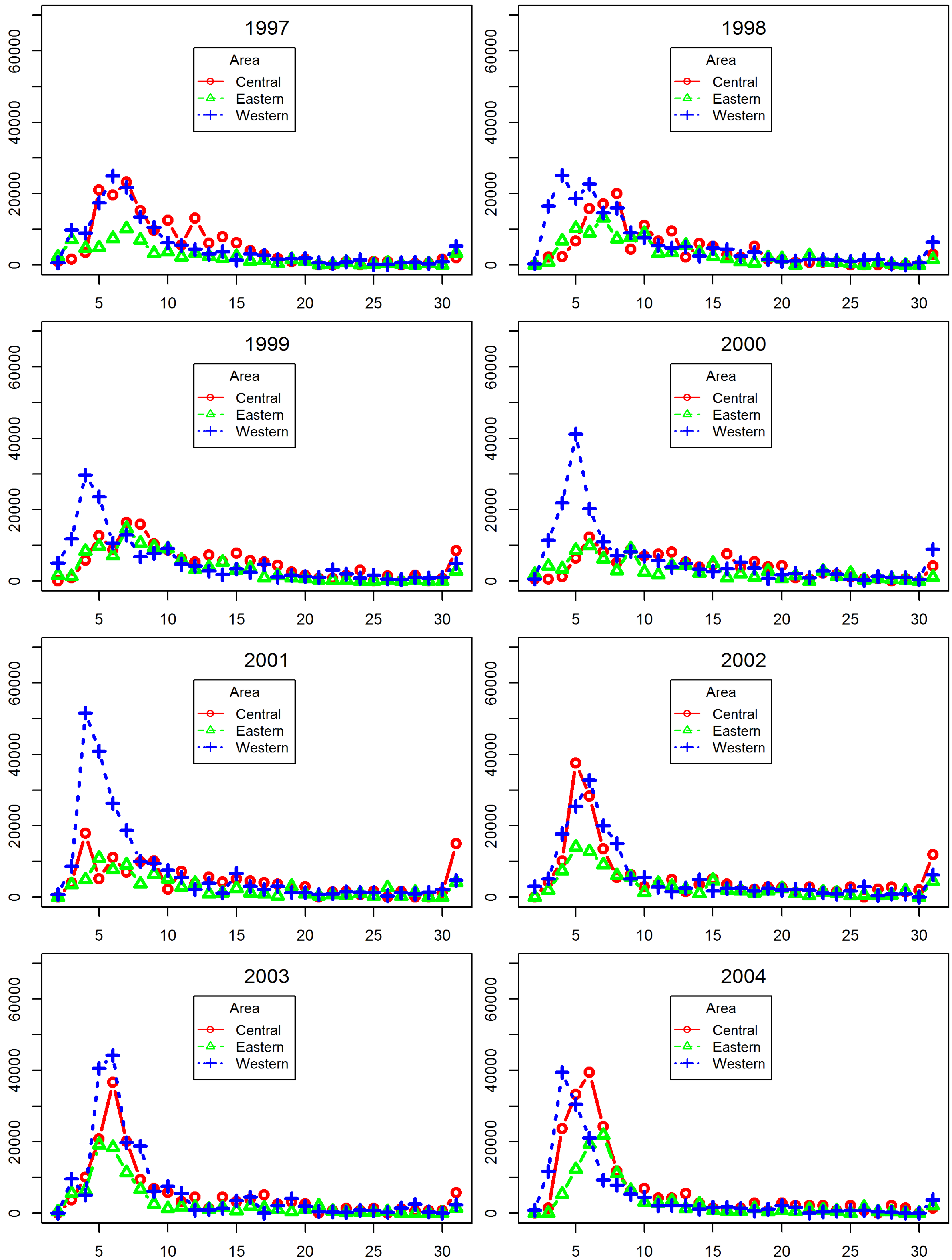


Figure 3.26. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

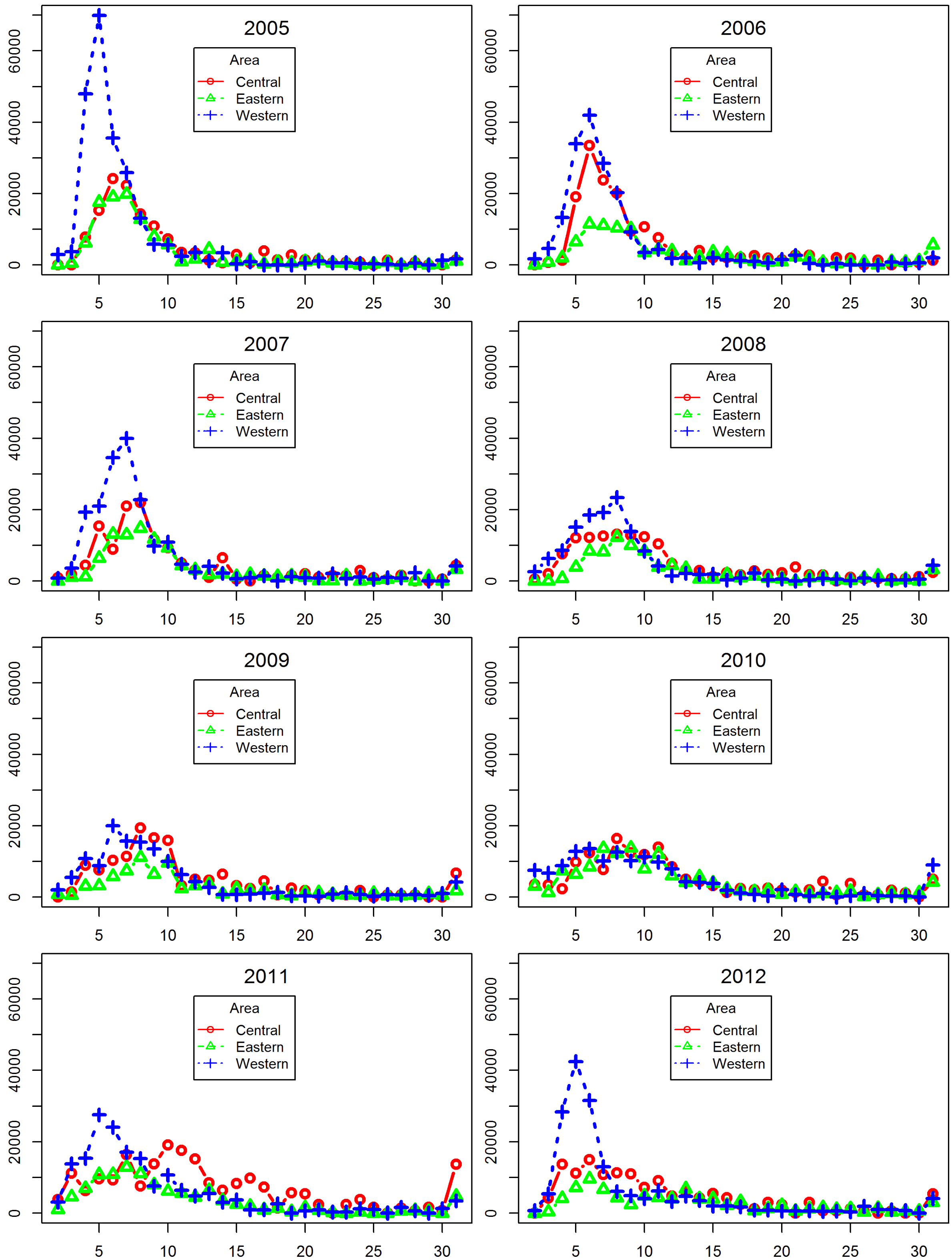


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

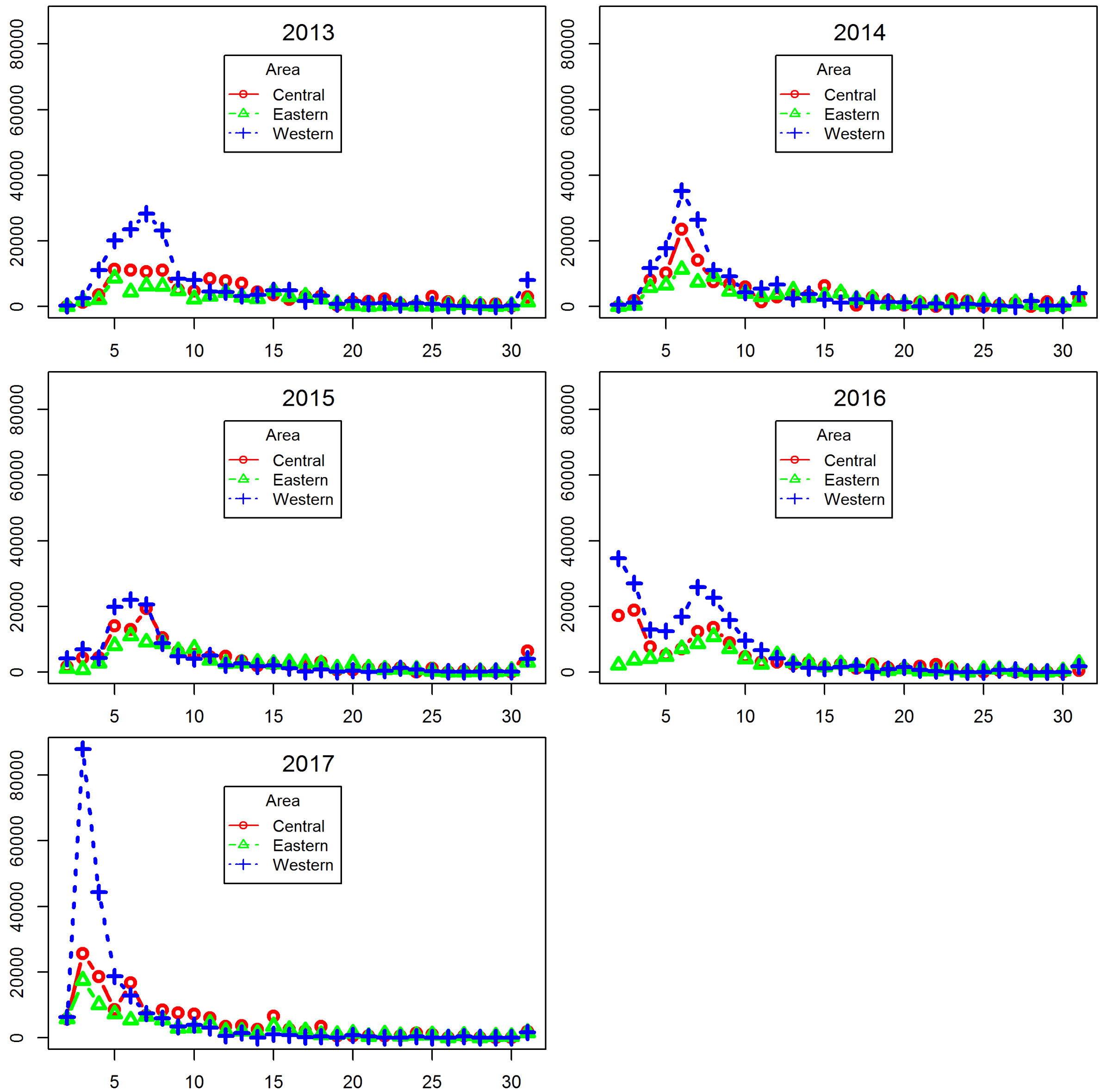


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

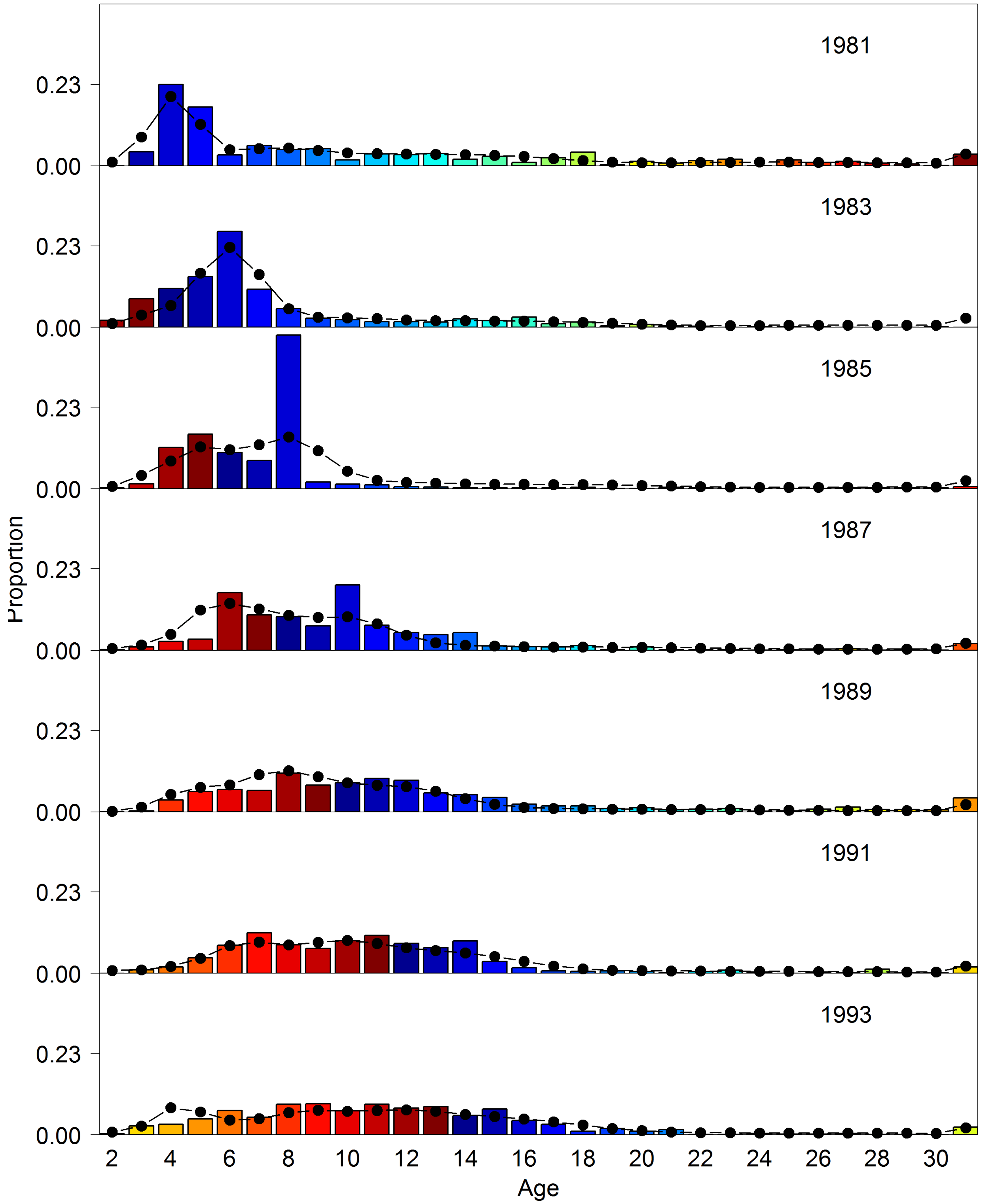


Figure 3.27. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

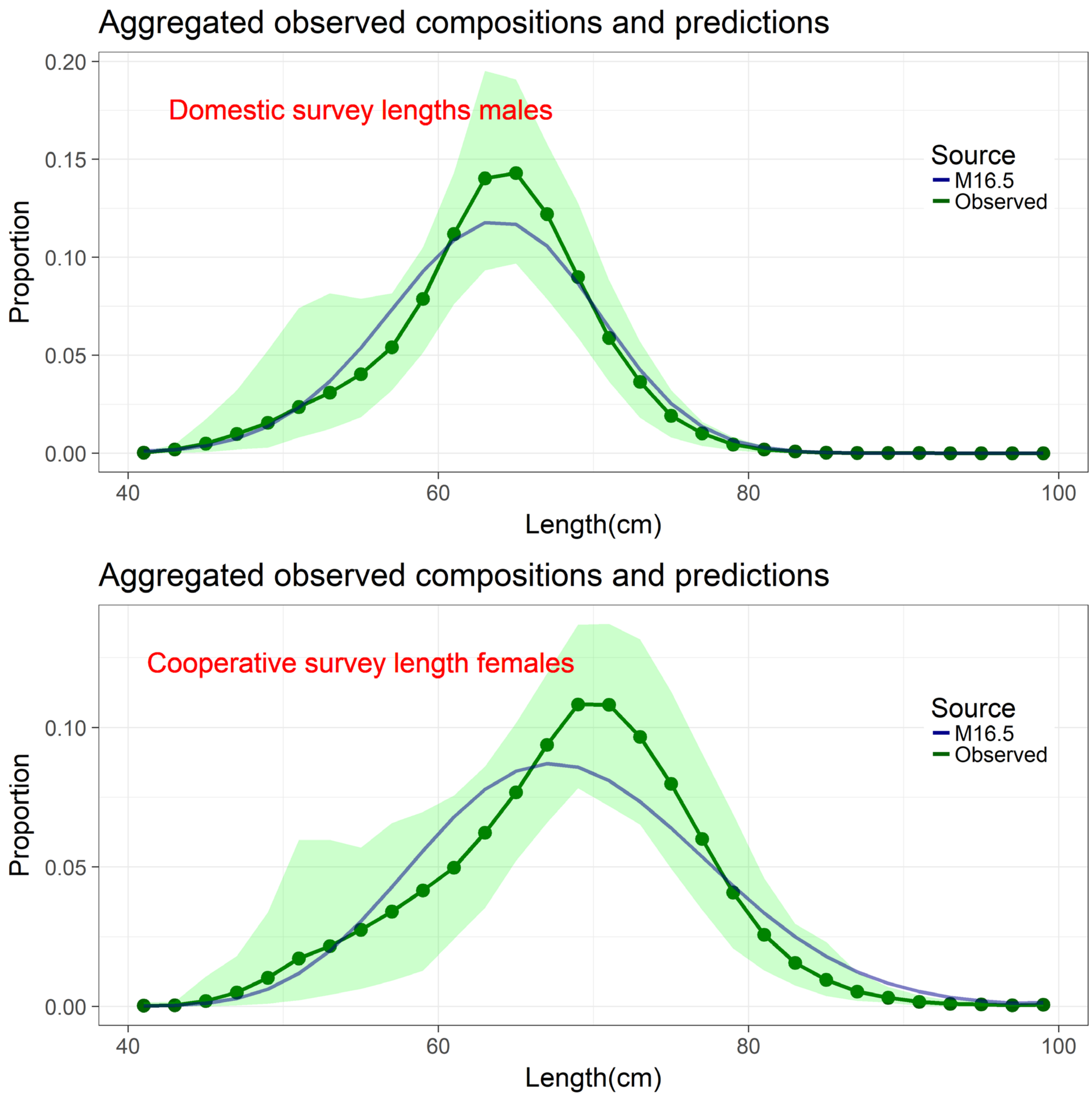


Figure 3.28. Cooperative longline survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

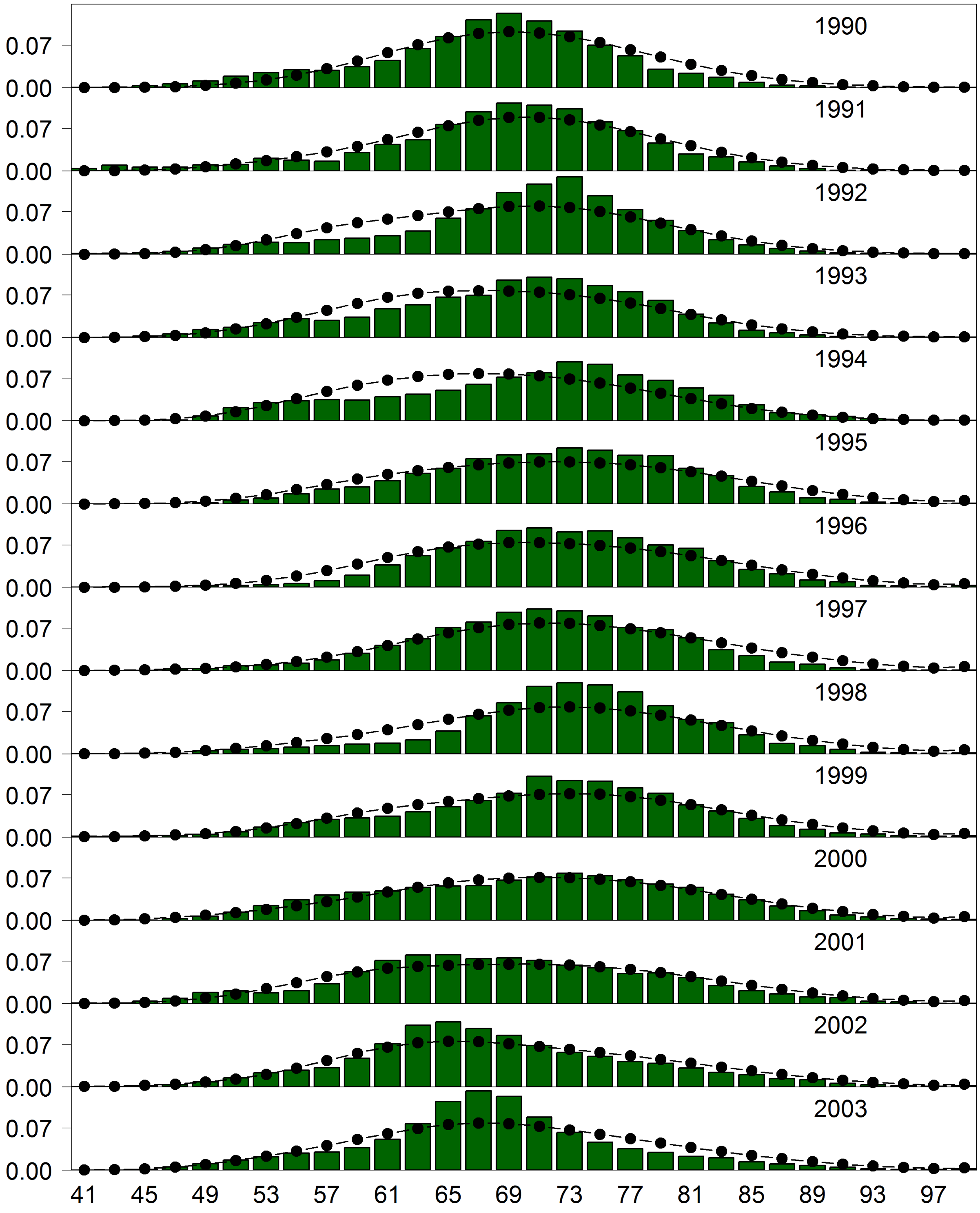


Figure 3.29. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

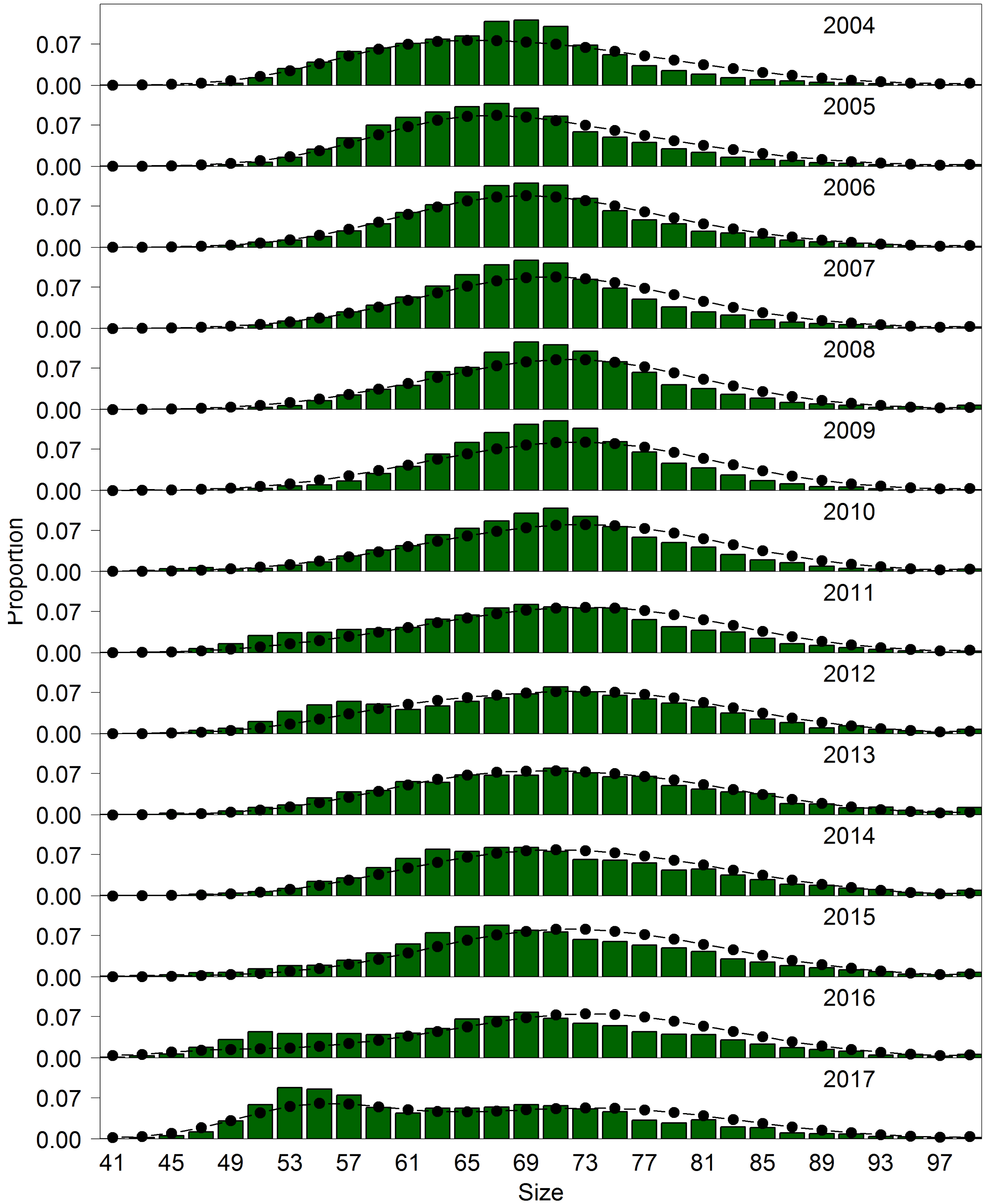


Figure 3.29 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

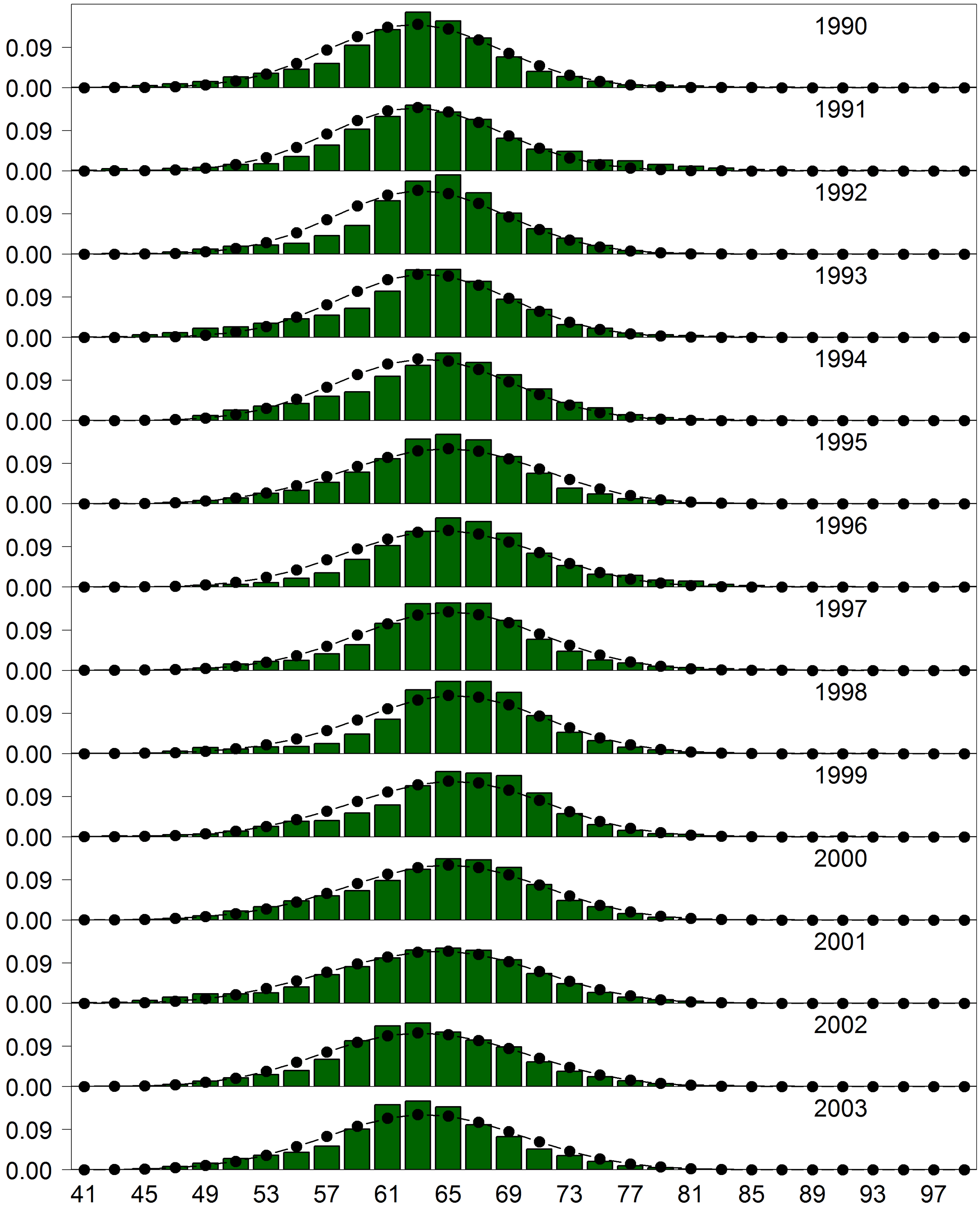


Figure 3.30. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

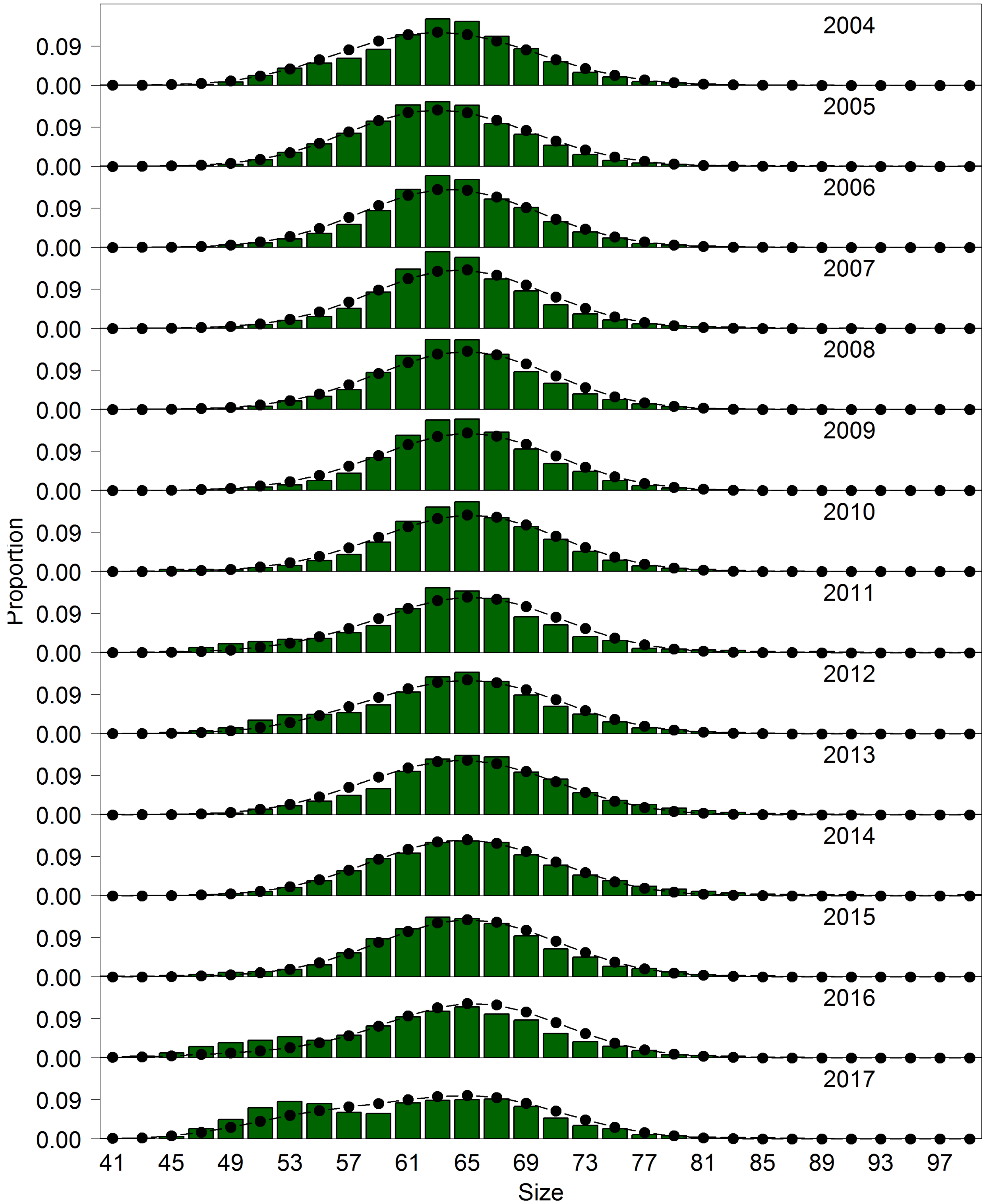
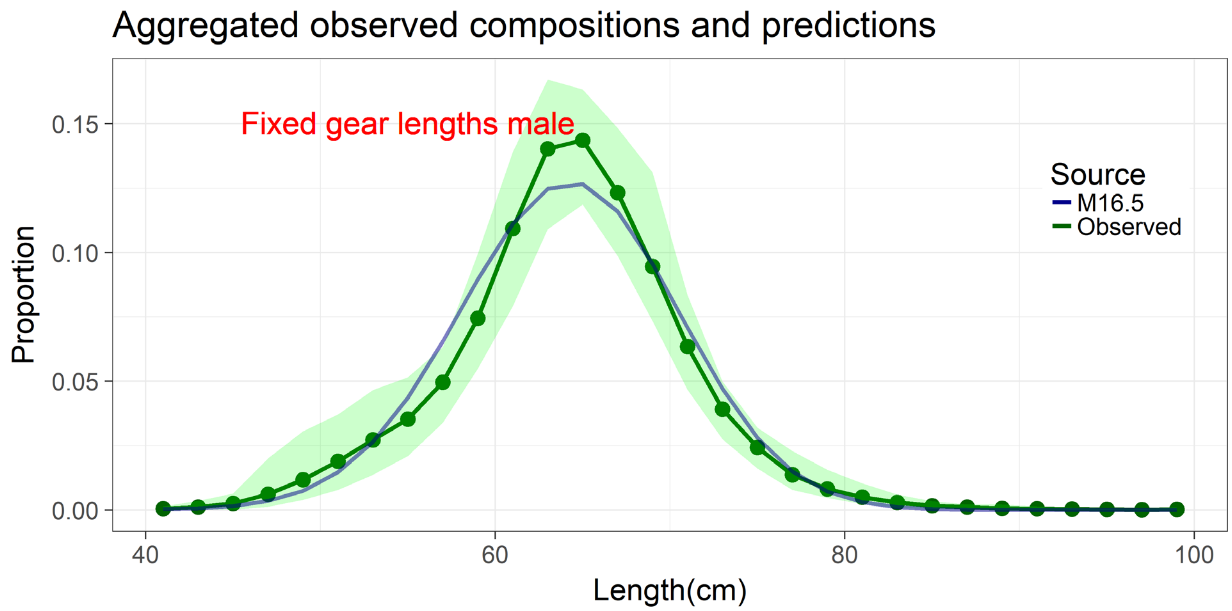


Figure 3.30 (cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.



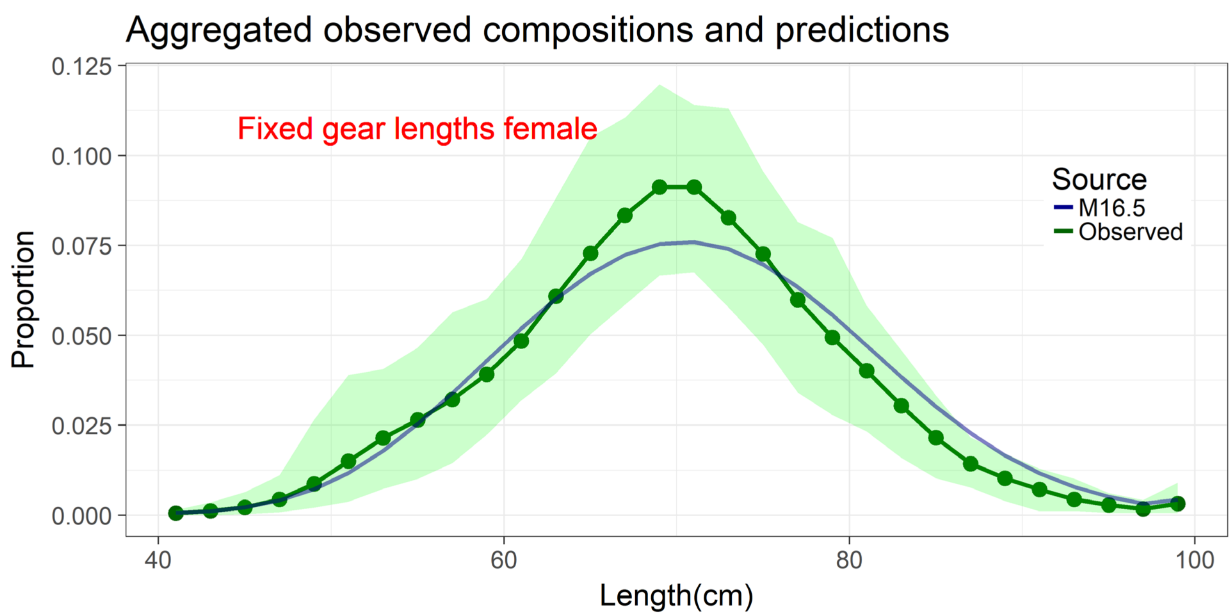


Figure 3.31. Domestic fixed gear fishery length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

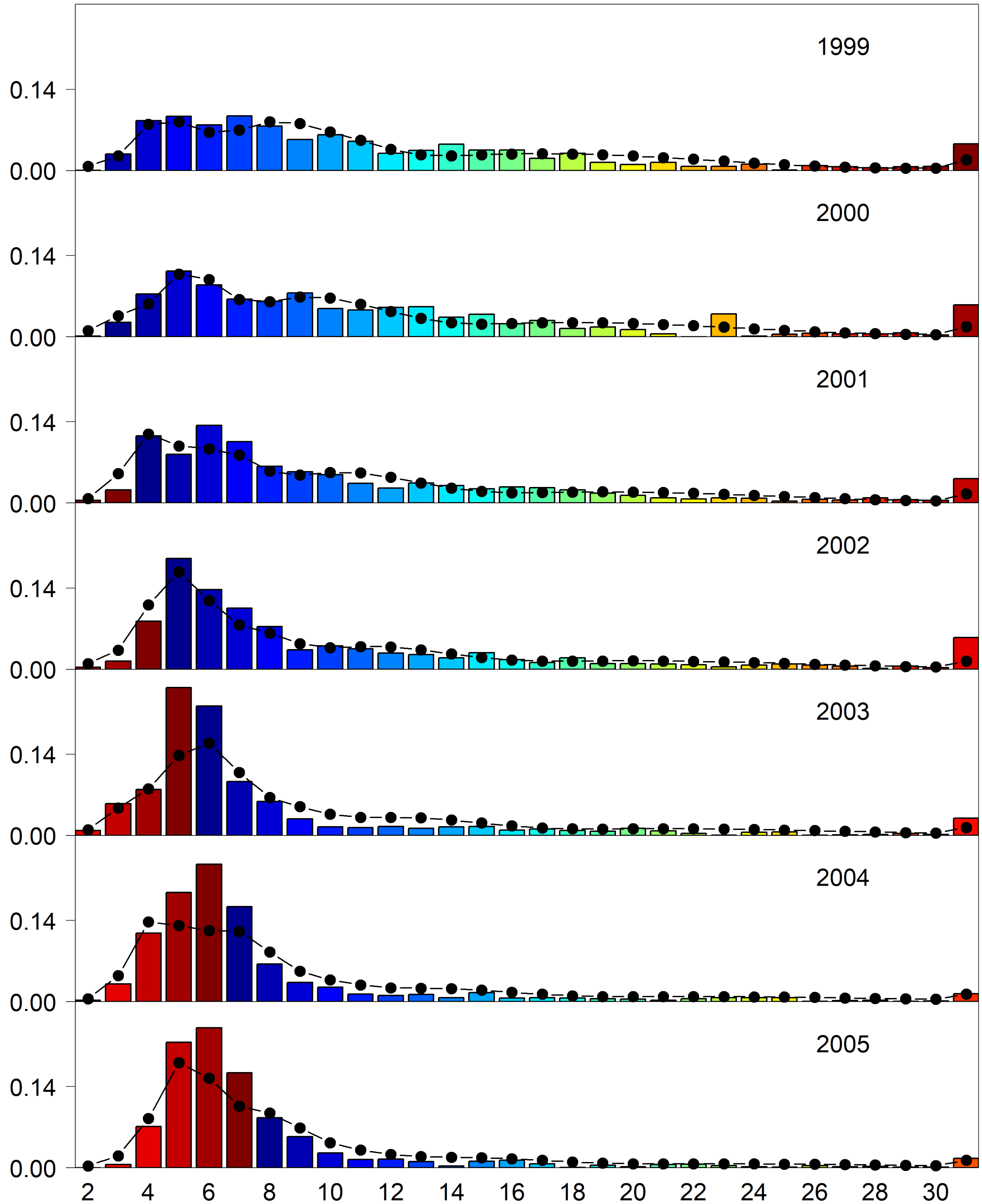


Figure 3.32. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

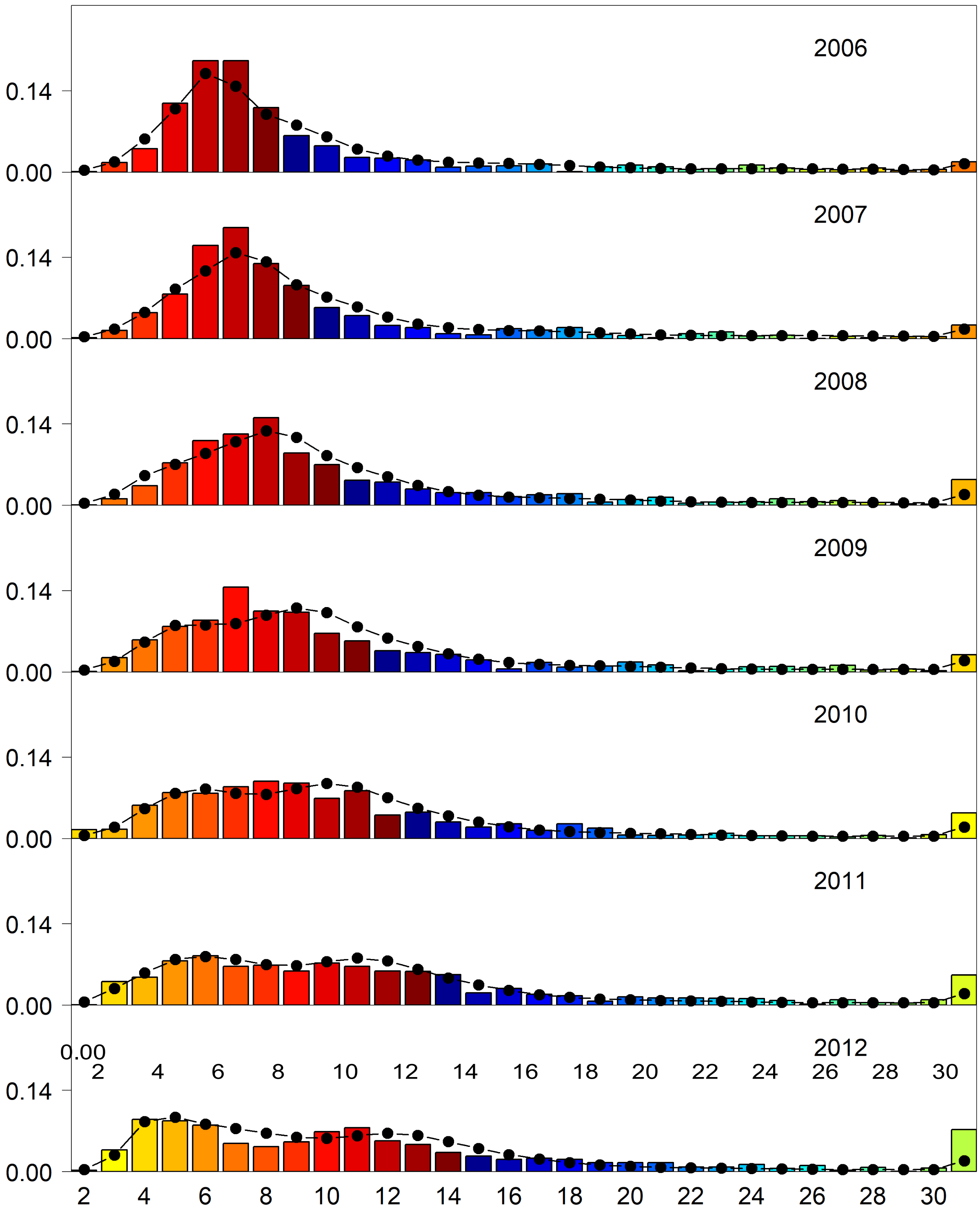


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

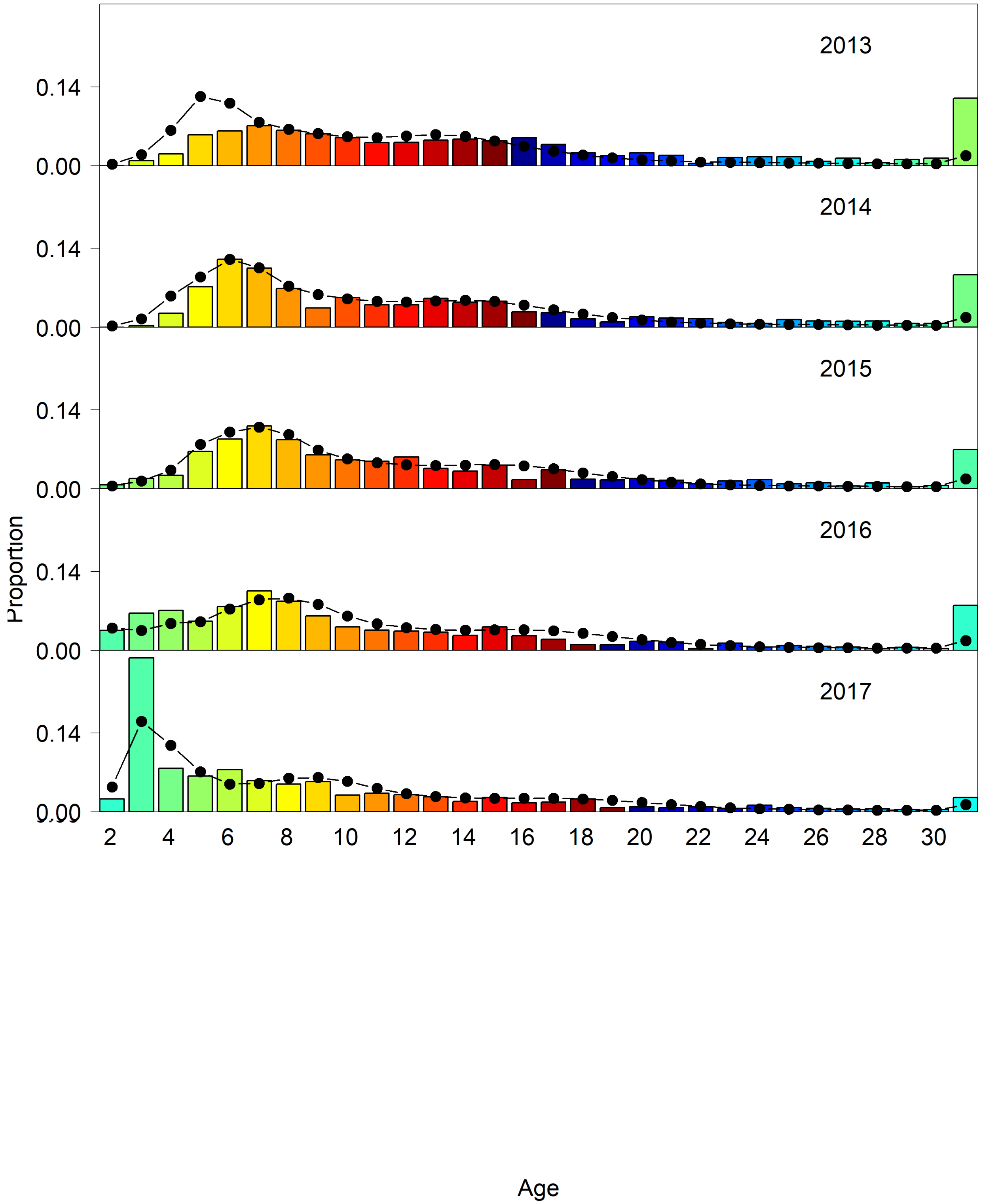


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

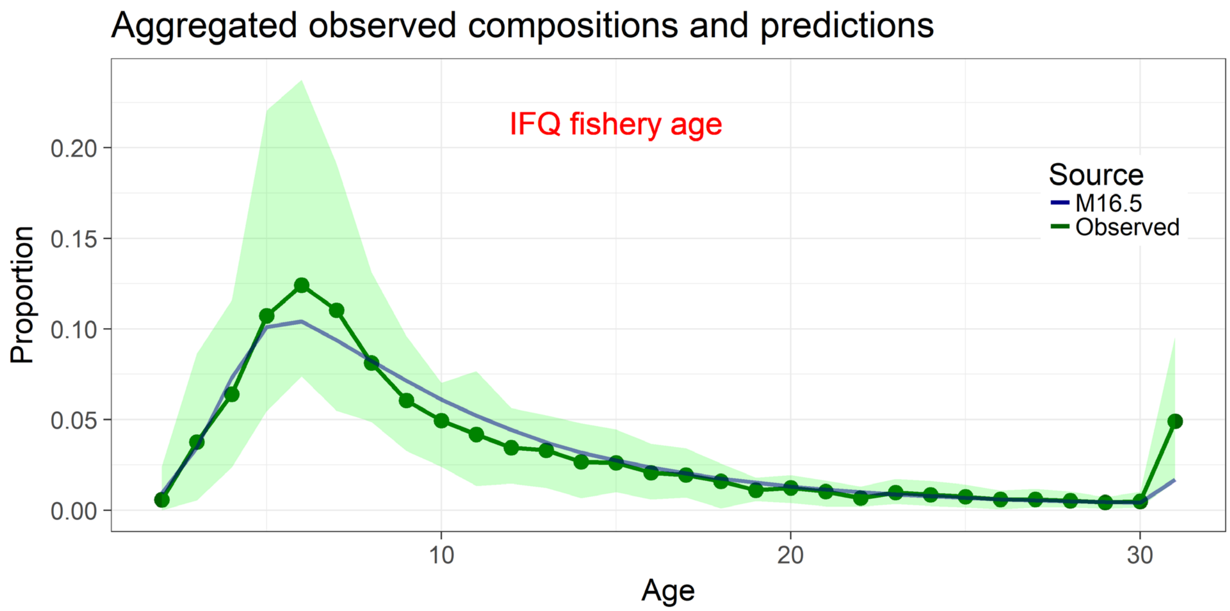


Figure 3.33. Domestic fishery age compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

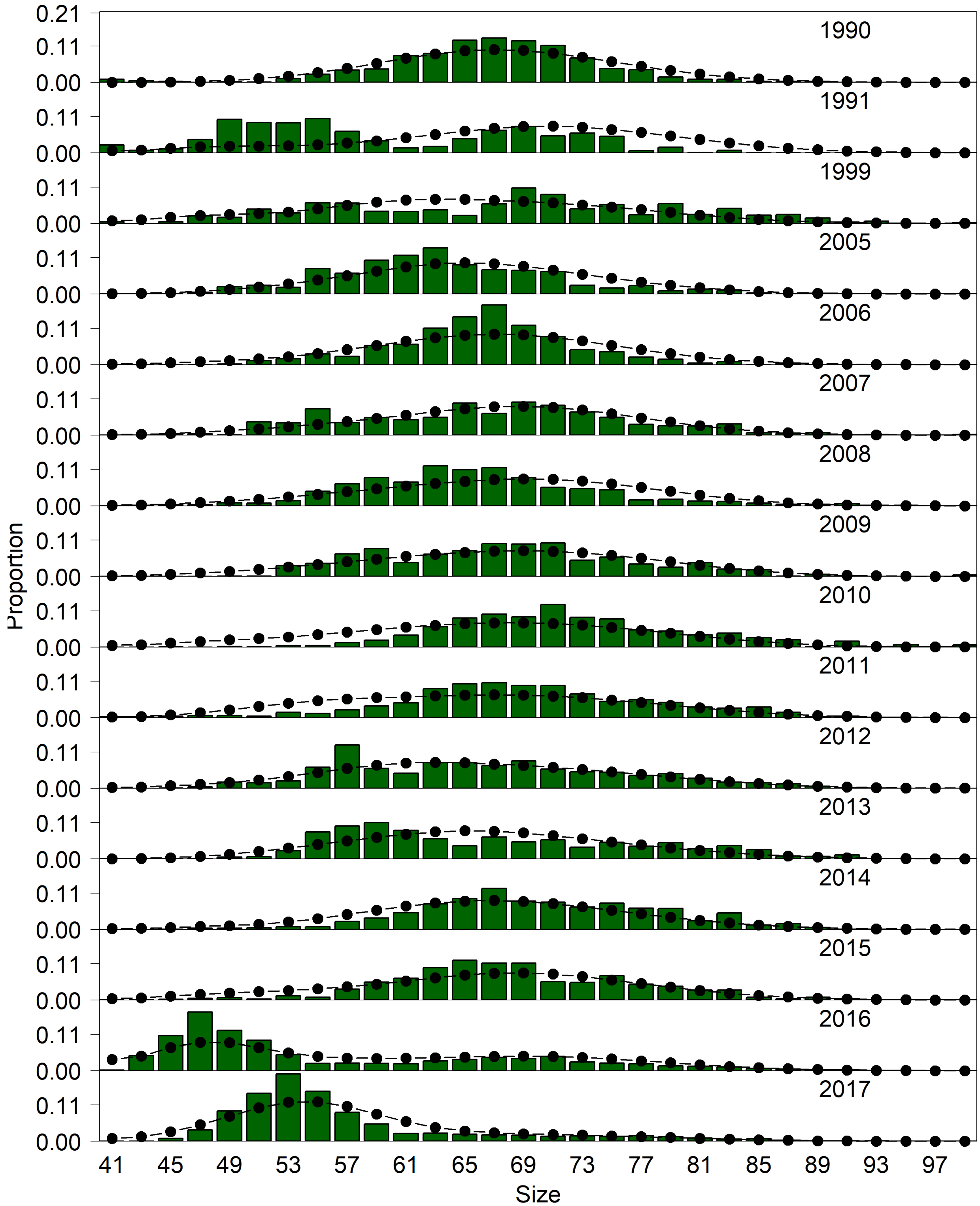


Figure 3.34. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

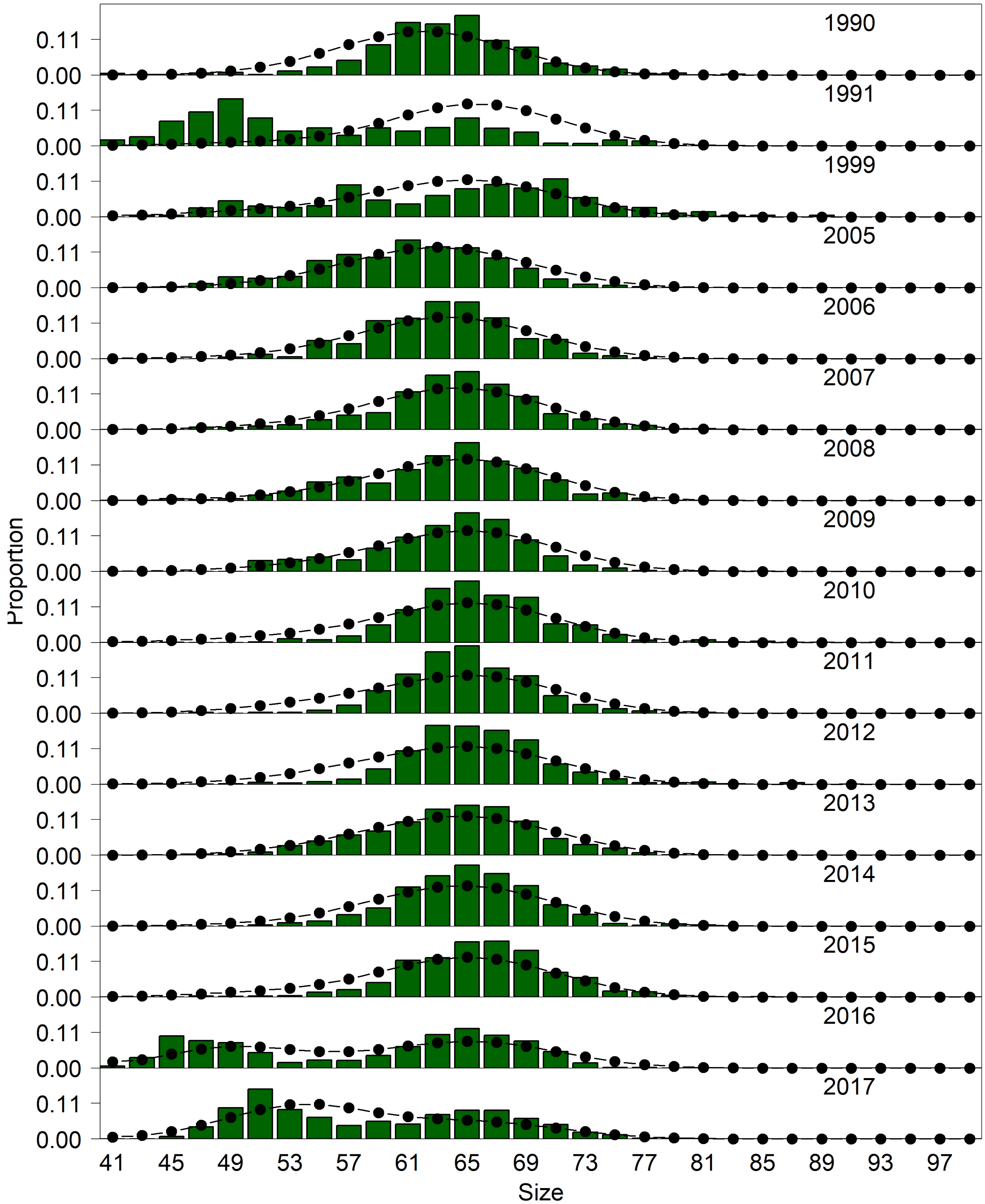


Figure 3.35. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

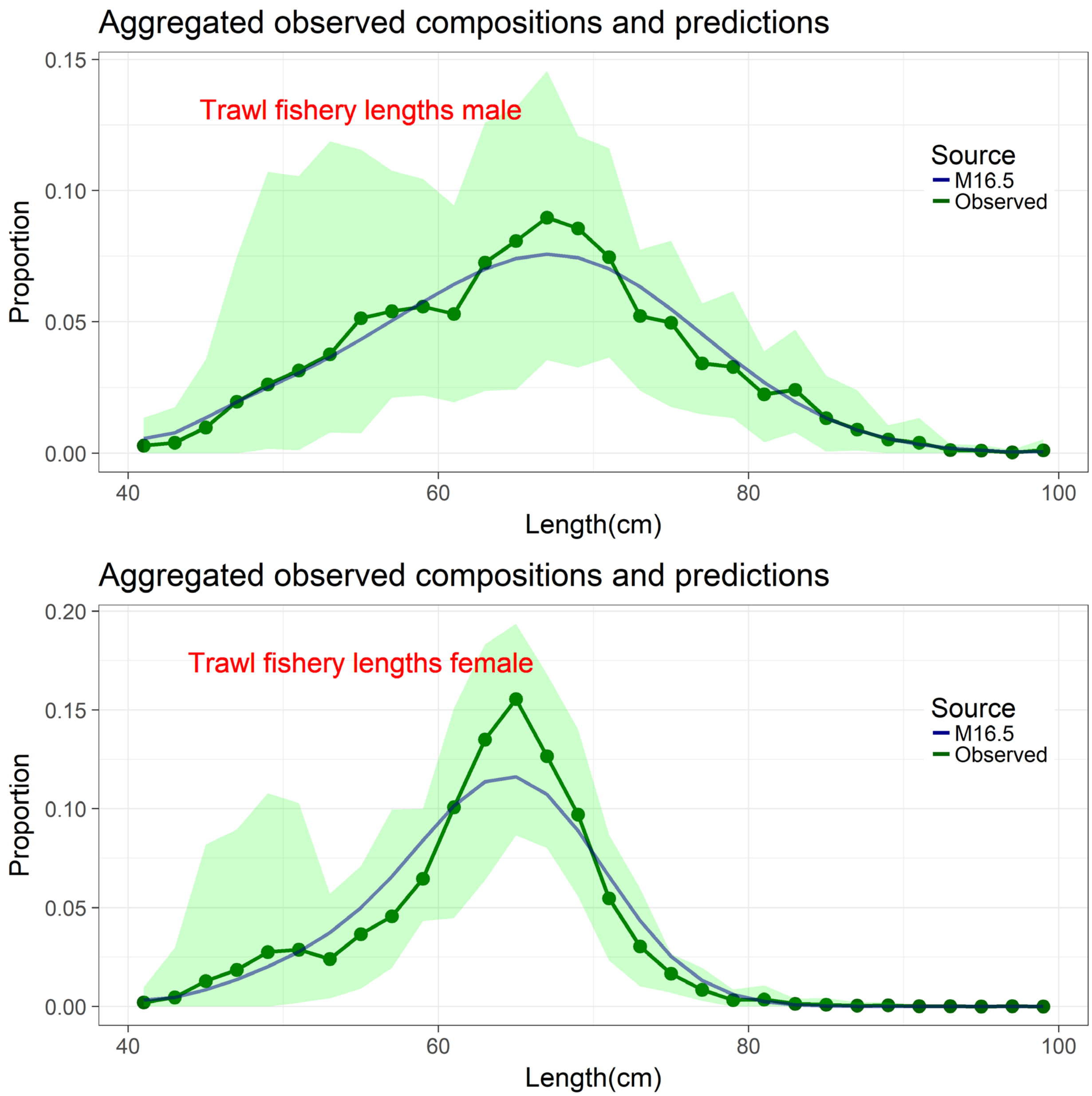


Figure 3.36. Domestic trawl fishery length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

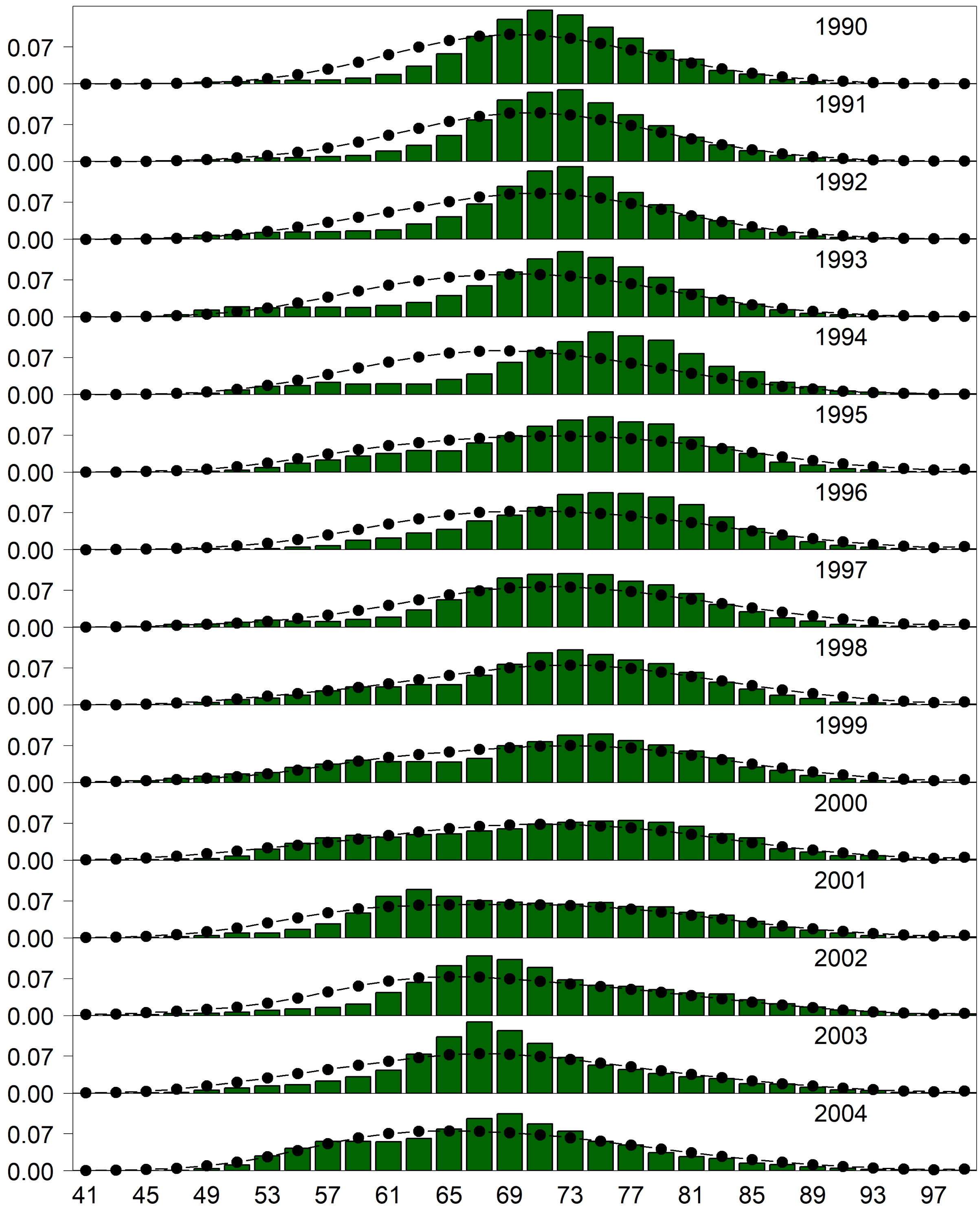


Figure 3.37. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

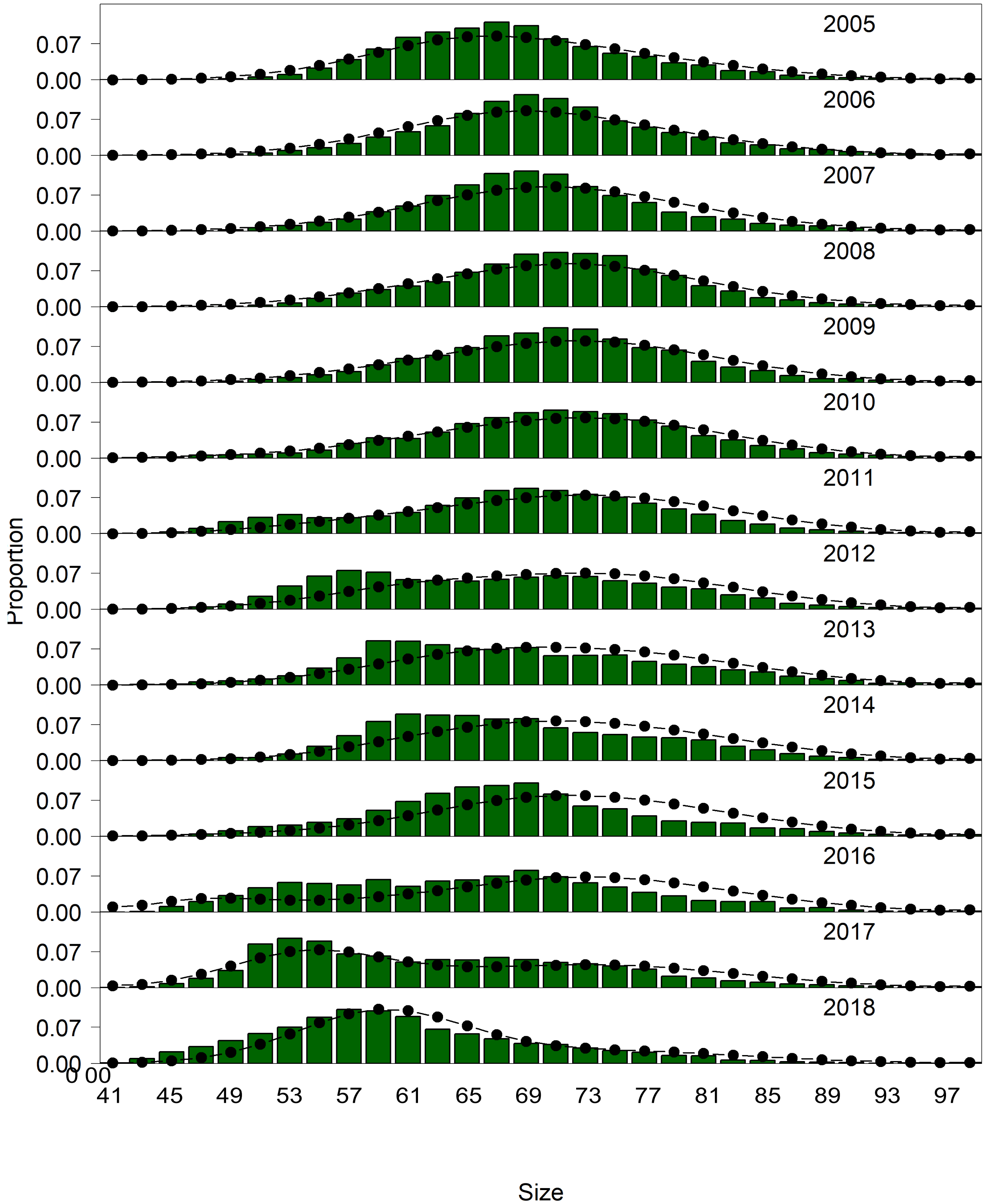


Figure 3.37 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

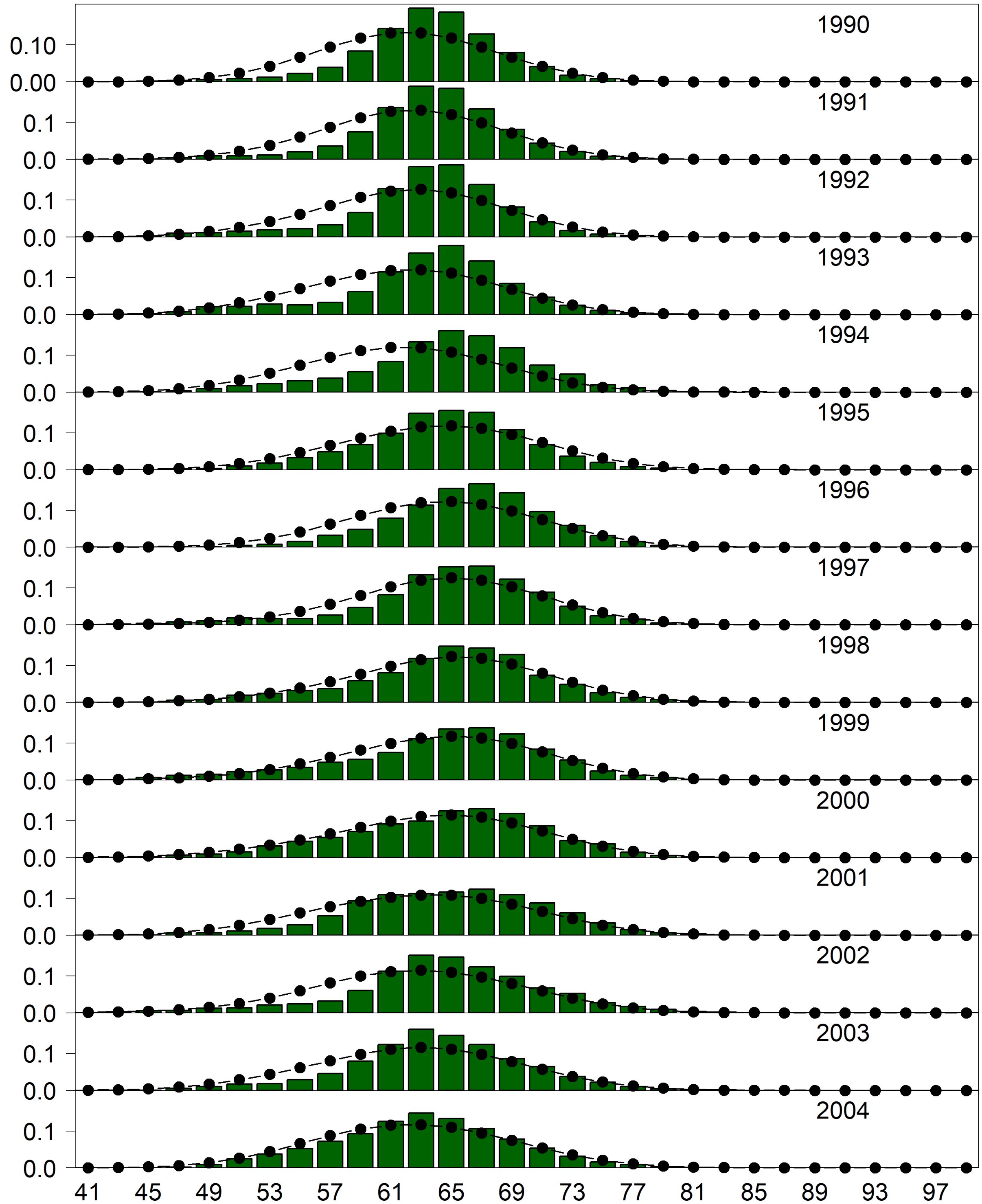


Figure 3.38. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

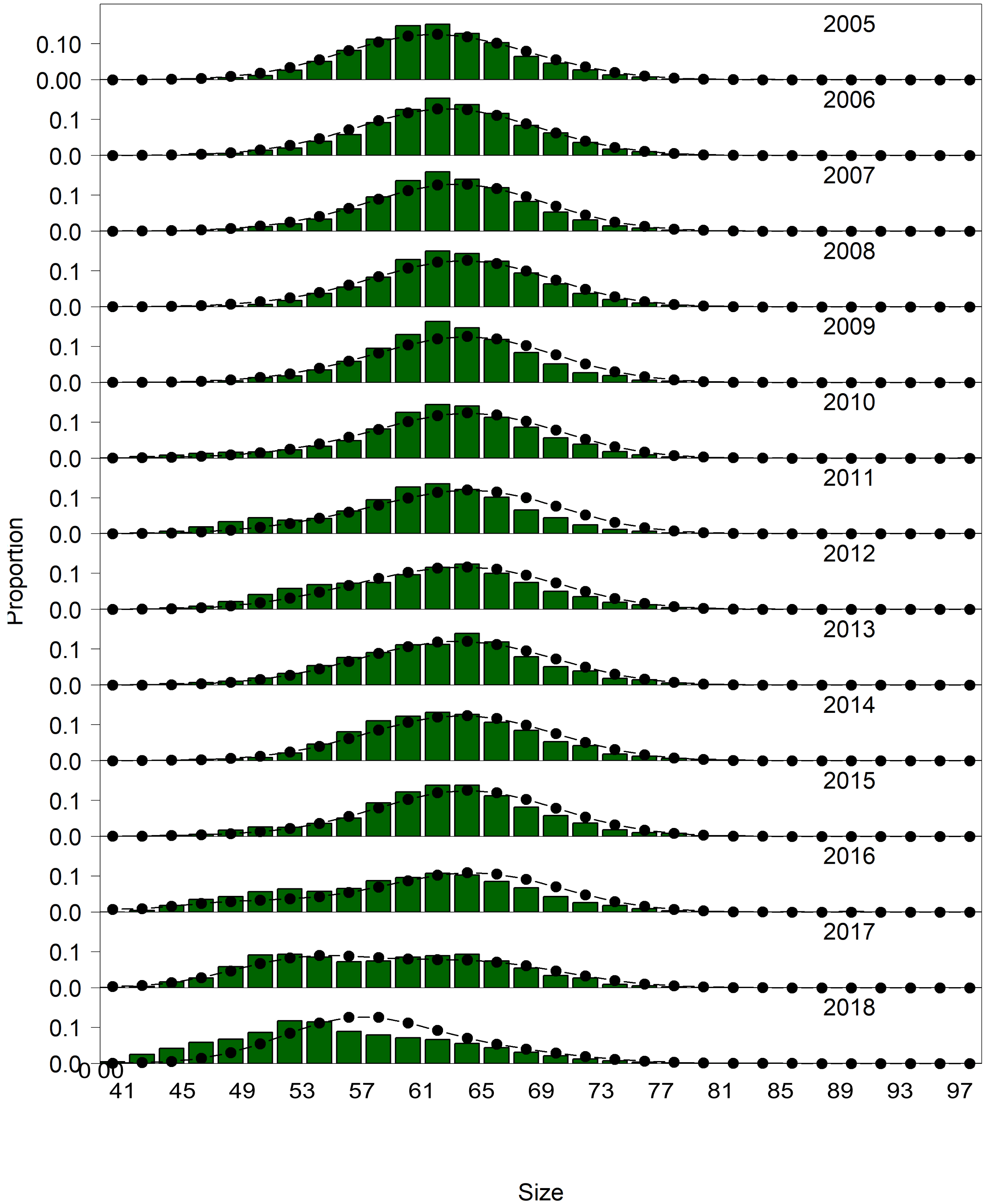


Figure 3.38. (cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

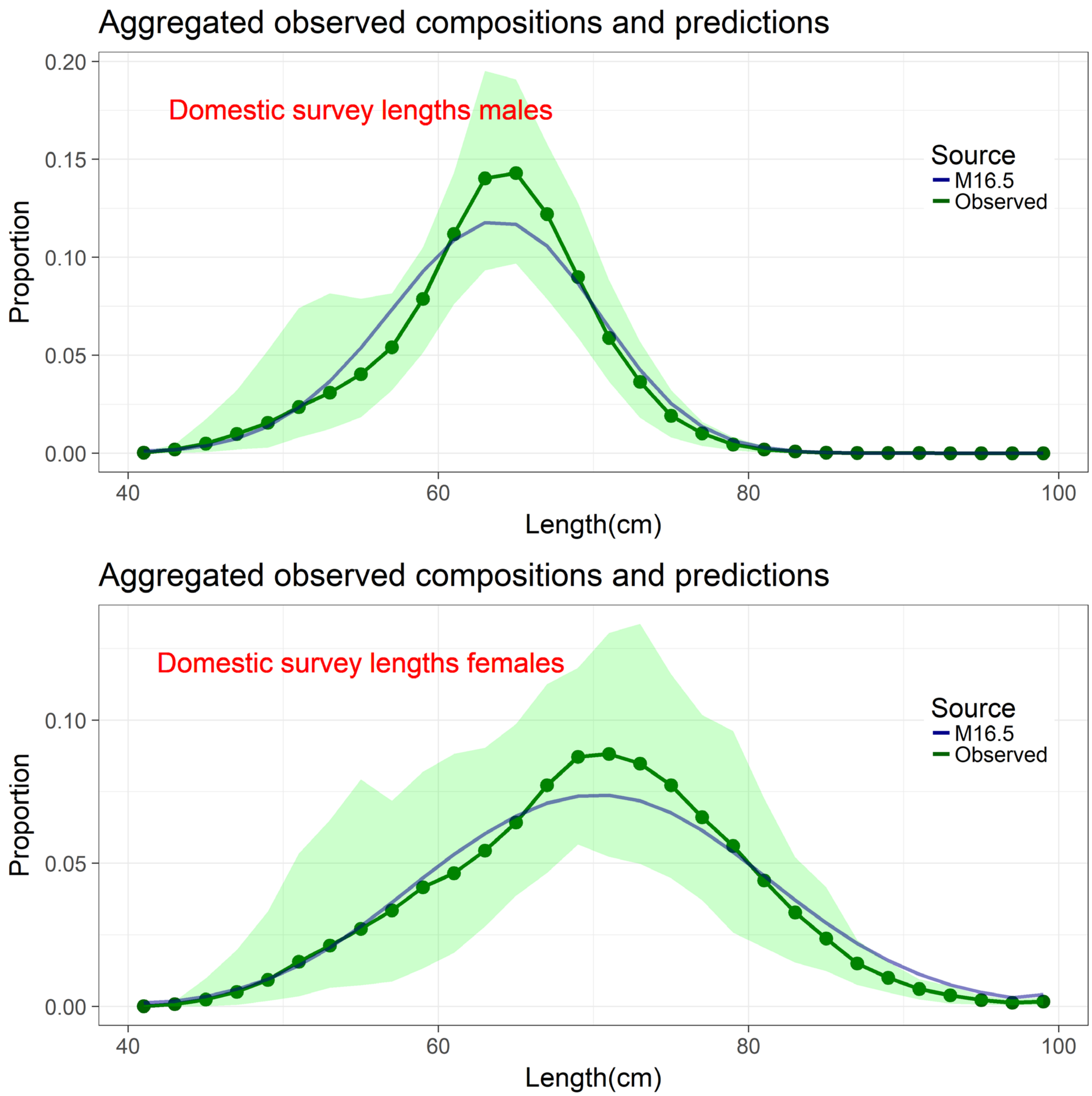


Figure 3.39. Domestic longline survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

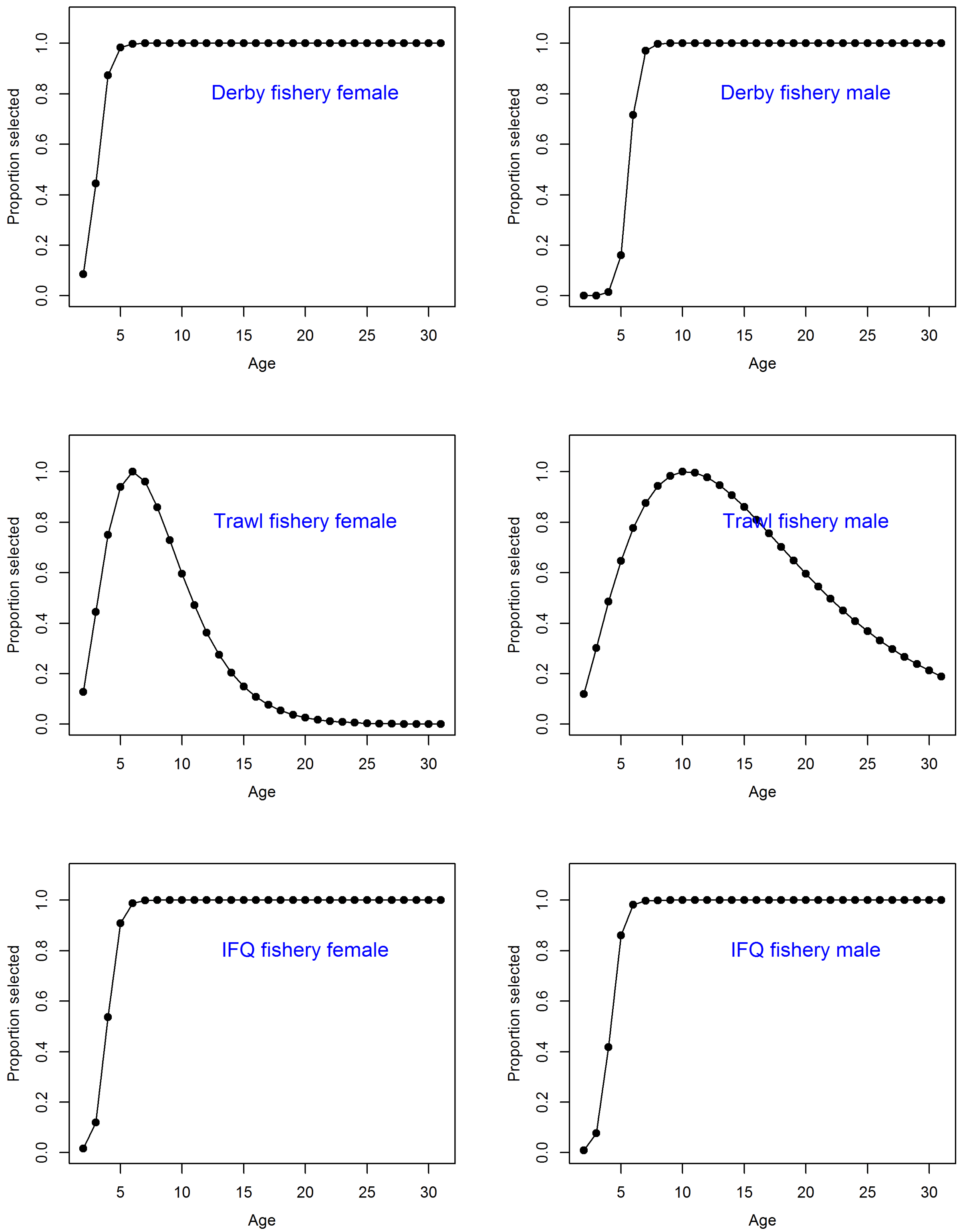


Figure 3.40. Sablefish selectivities for fisheries. The derby longline occurred until 1994 when the fishery switched to IFQ in 1995.

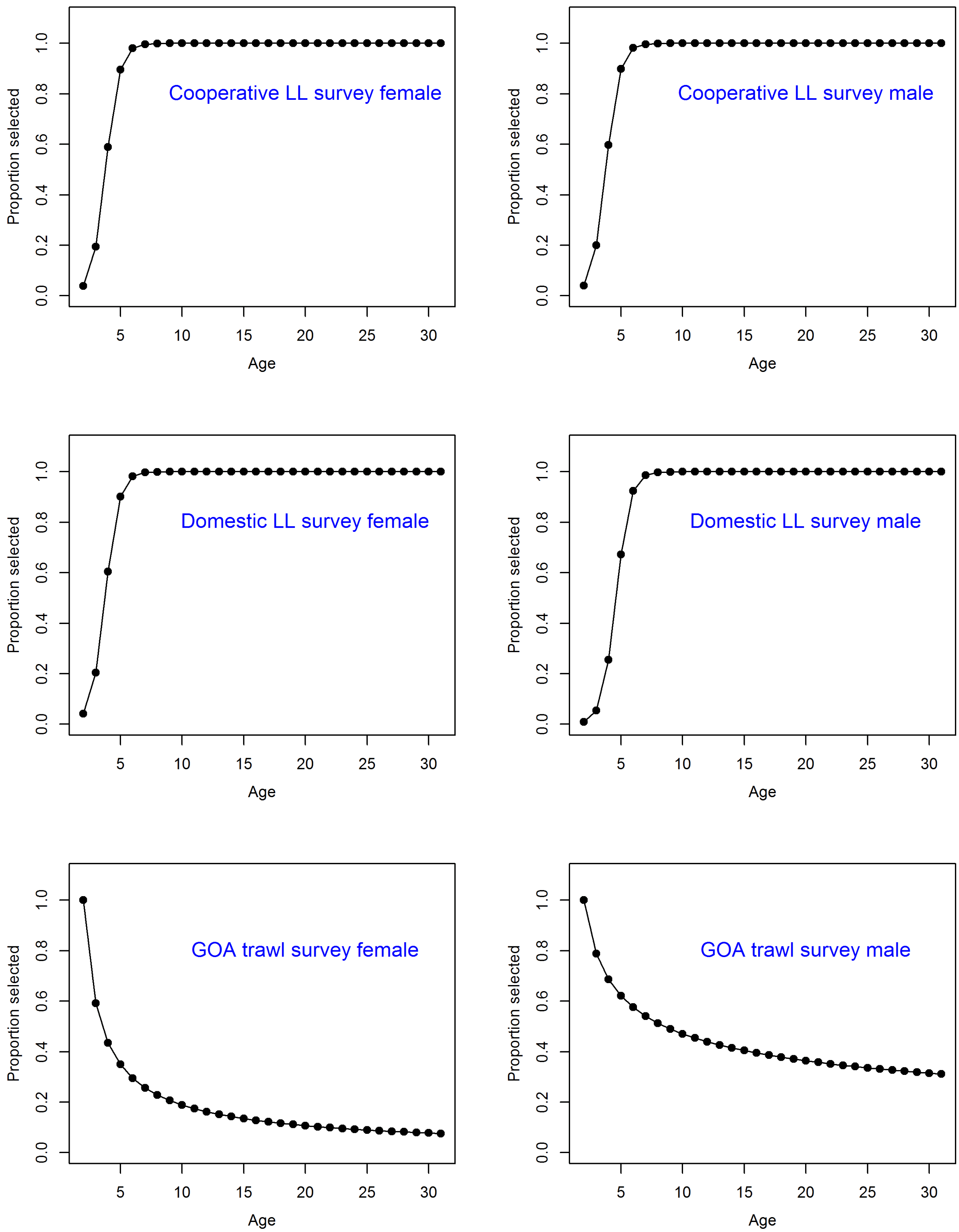


Figure 3.40 (cont.). Sablefish selectivities for surveys.

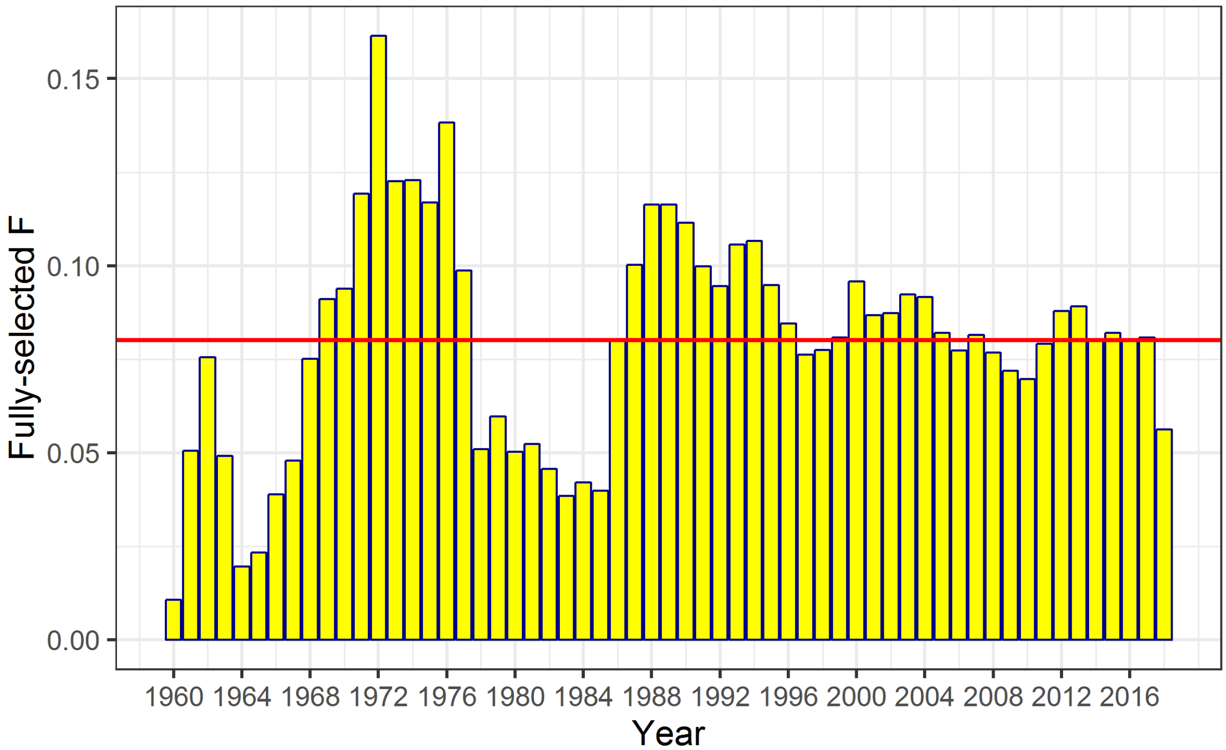


Figure 3.41. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

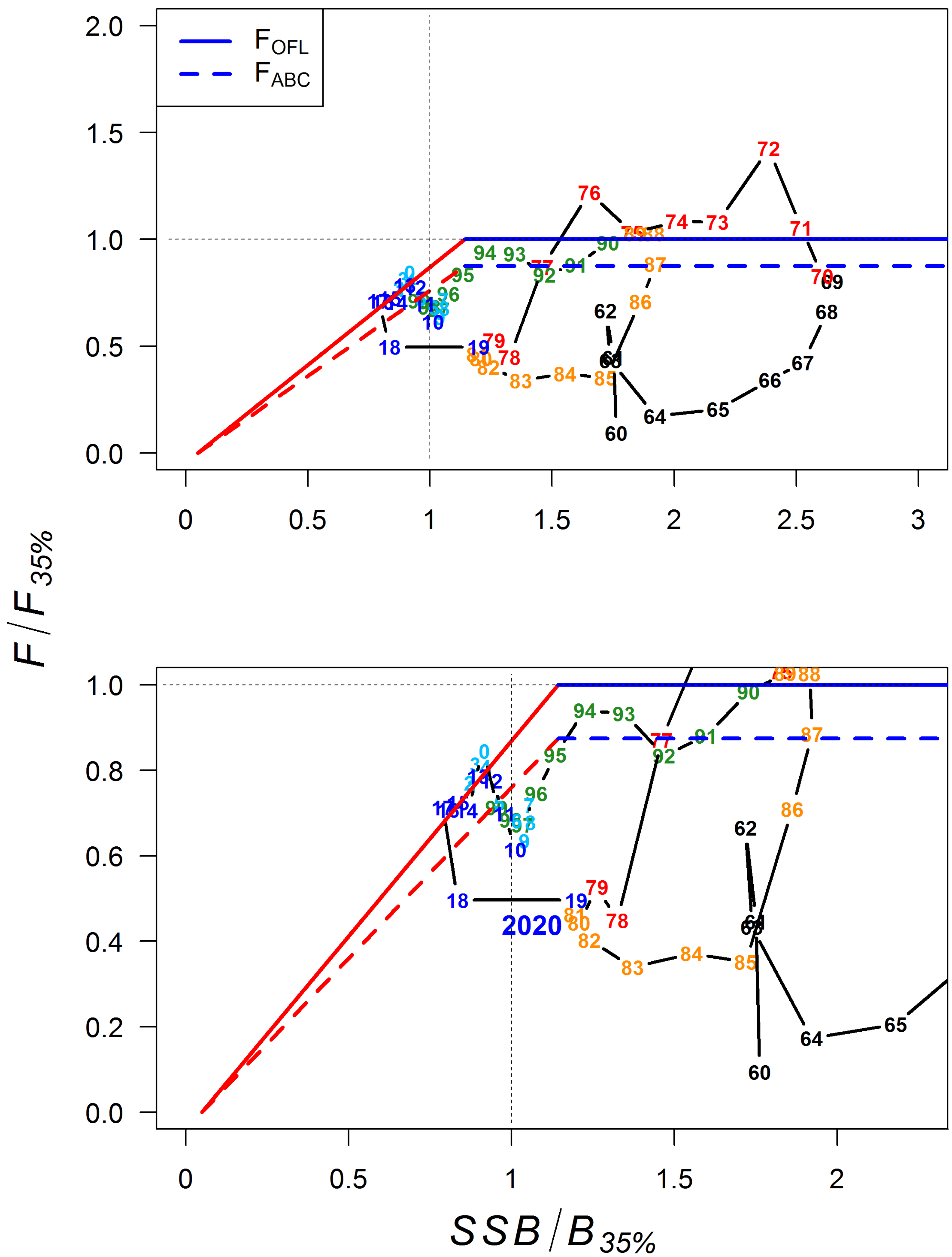


Figure 3.42. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model. Bottom is zoomed in to examine more recent years.

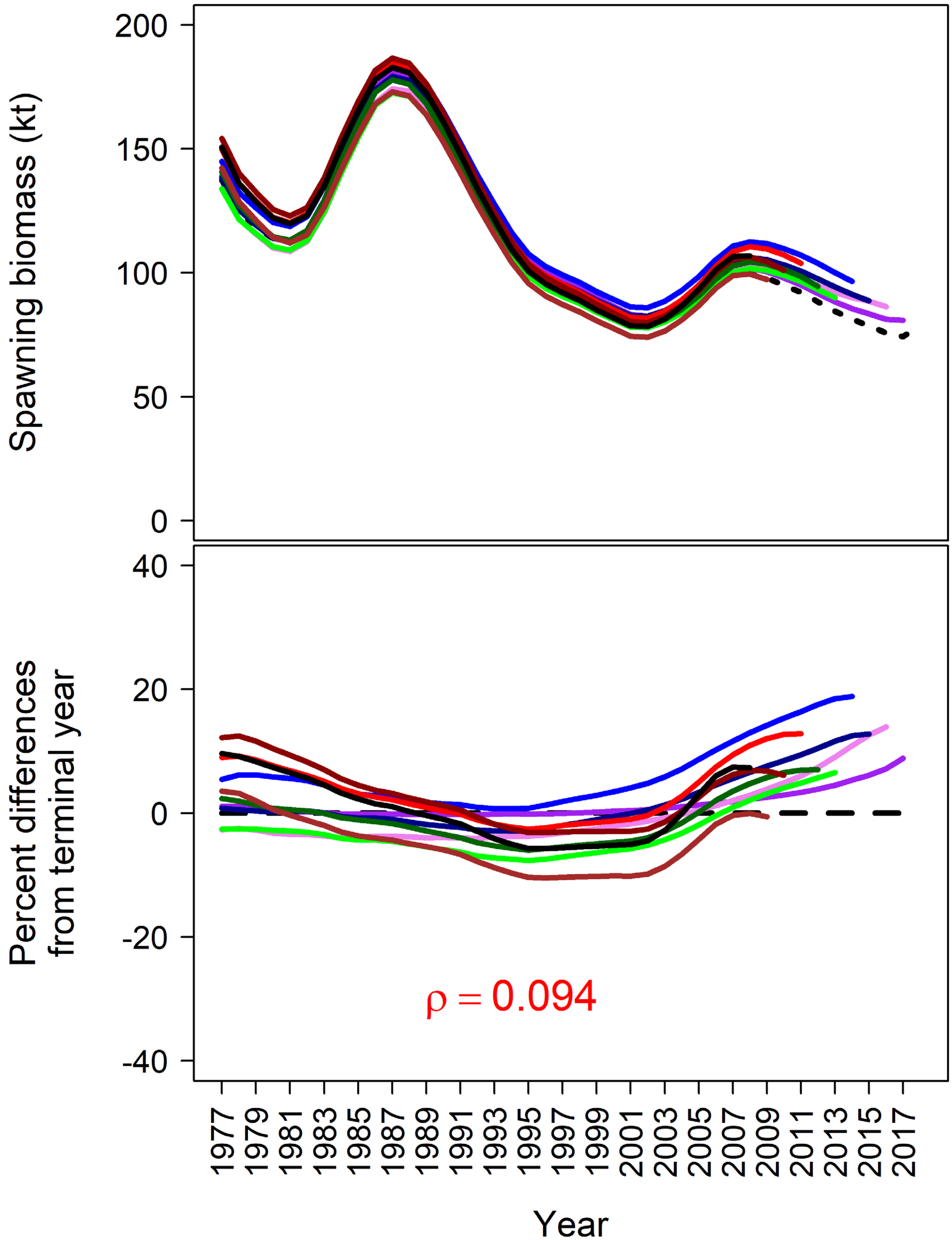


Figure 3.43. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 1977- 2018.

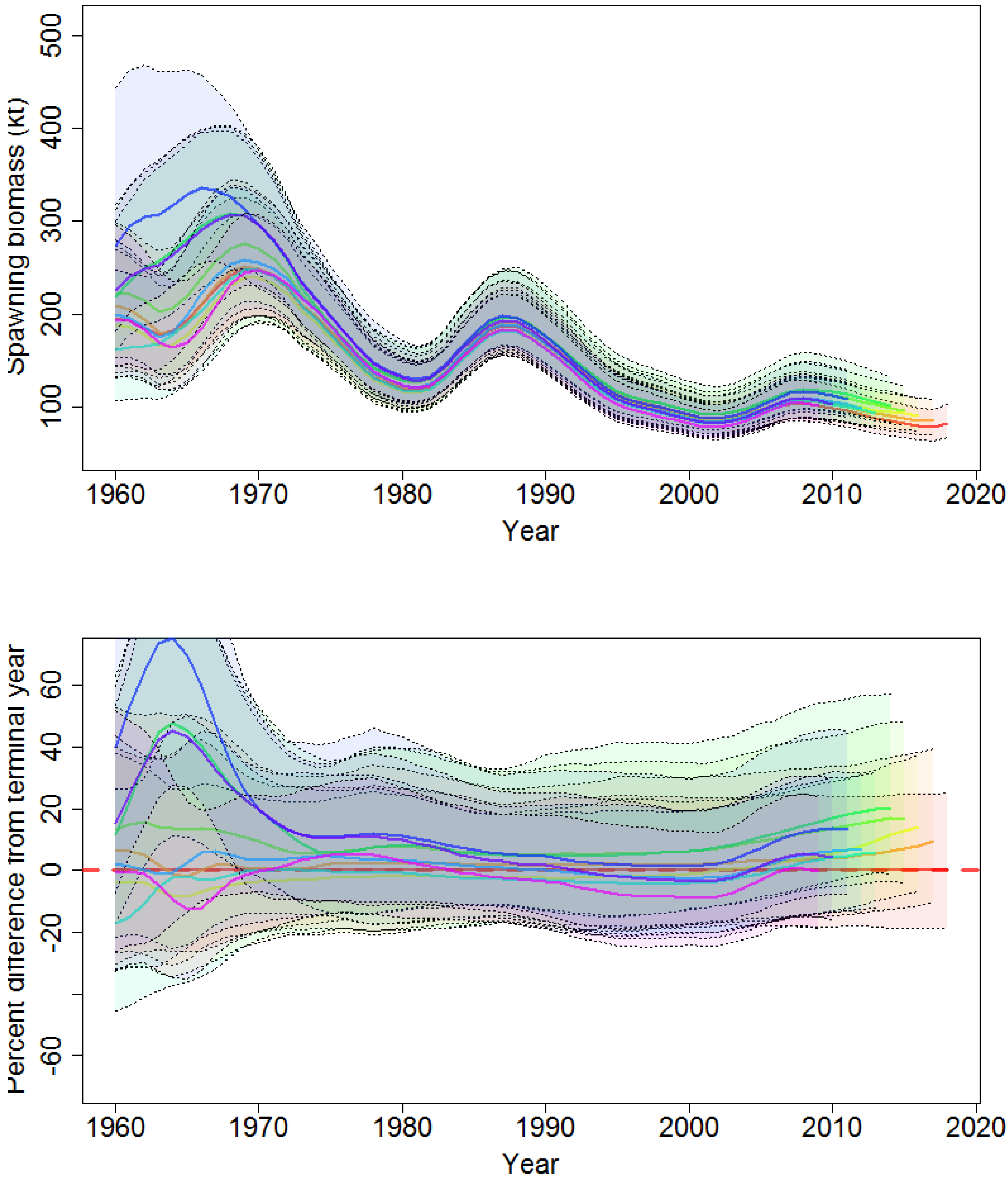


Figure 3.44. Retrospective trends for spawning biomass (top) and percent difference (bottom) from terminal year (2018) from 1960-2017 with 95% MCMC credible intervals.

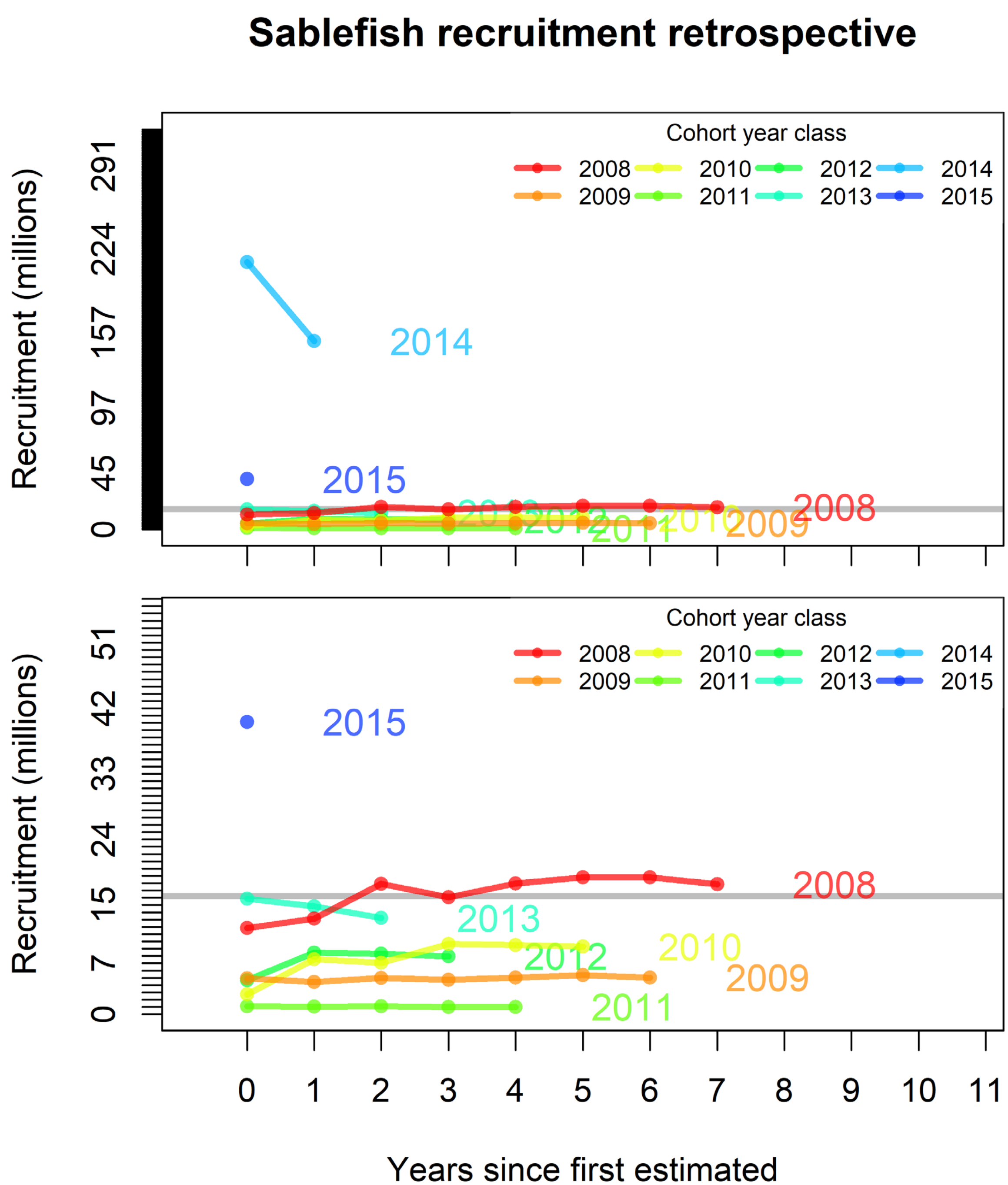


Figure 3.45. Squid plot of the development of initial estimates of age-2 recruitment since year class 2008 through year class 2015 from retrospective analysis. Top panel includes 2014 year class. Number to right of terminal year indicates year class. Bottom panel excludes the 2014 year class.

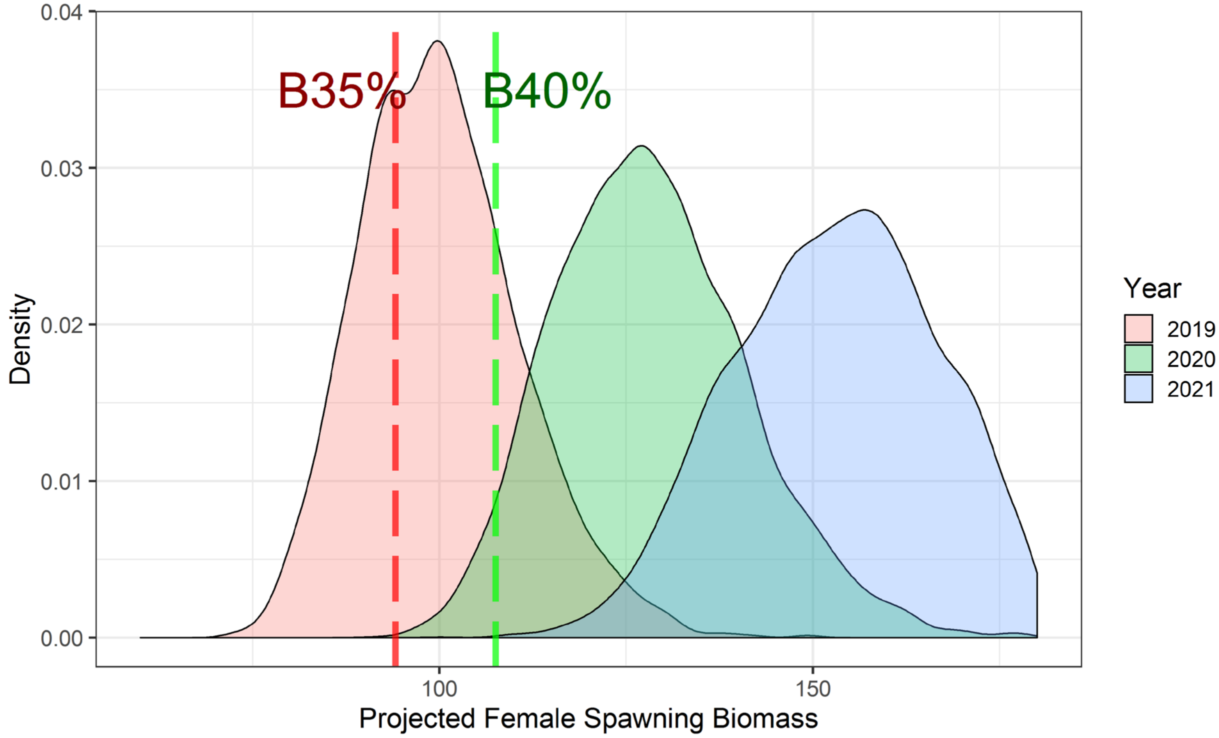


Figure 3.46. Posterior probability distribution for projected spawning biomass (thousands t) in years 2019 – 2021. The dashed lines are estimated B35% and B40% for 2019.

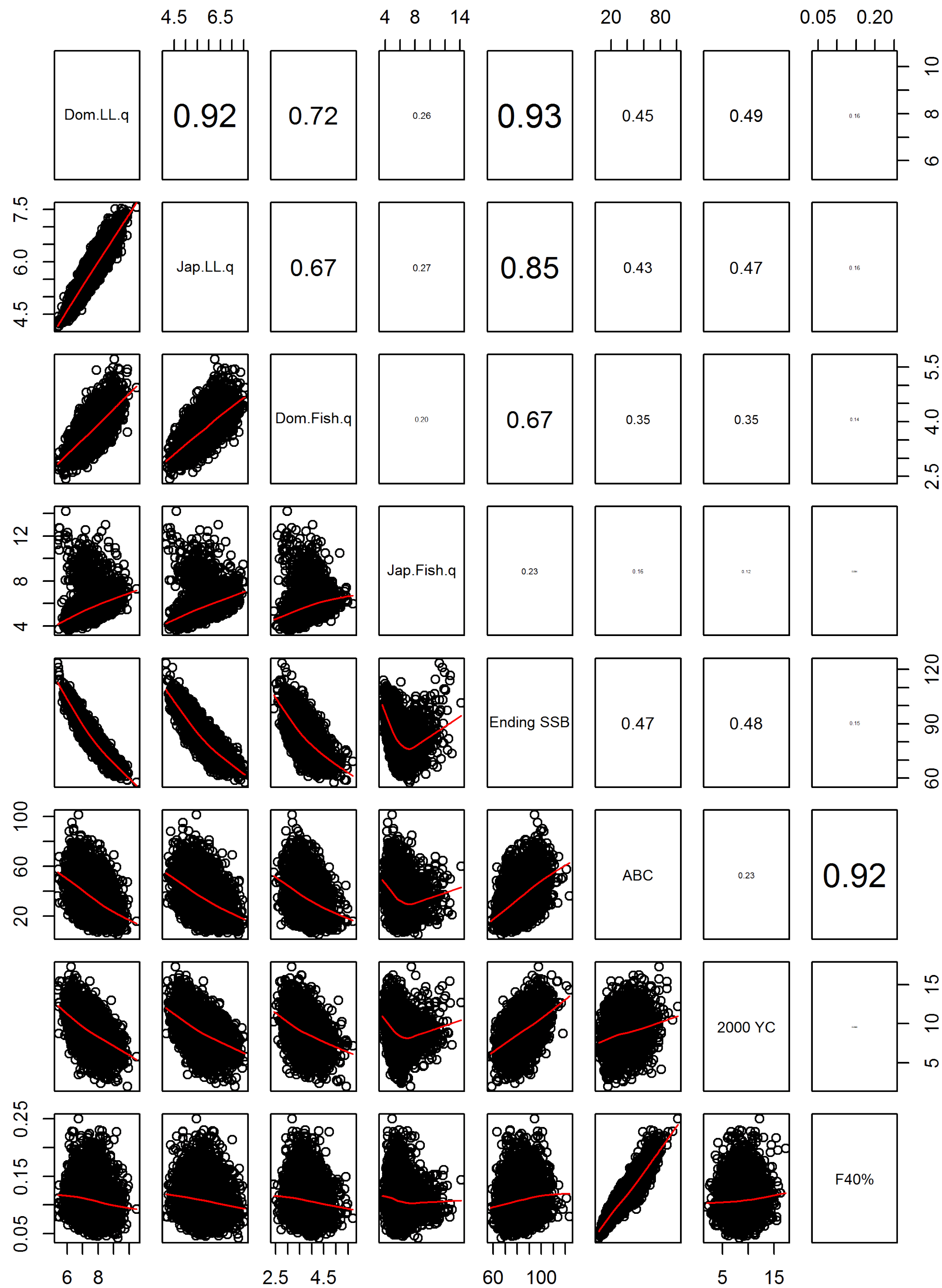


Figure 3.47. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

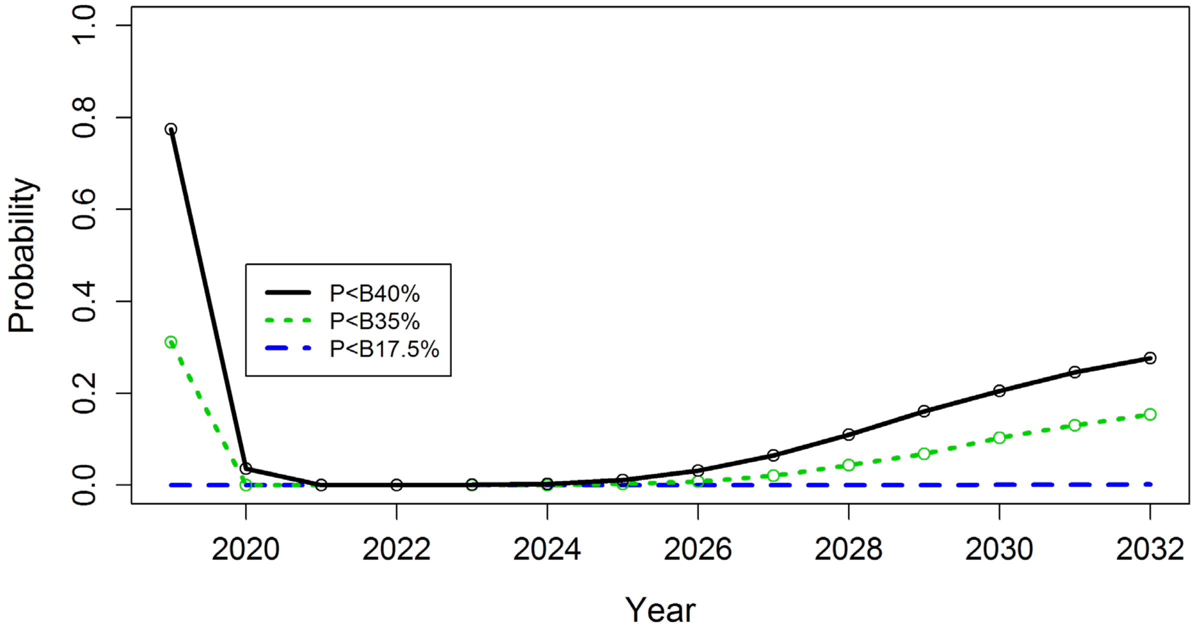


Figure 3.48. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

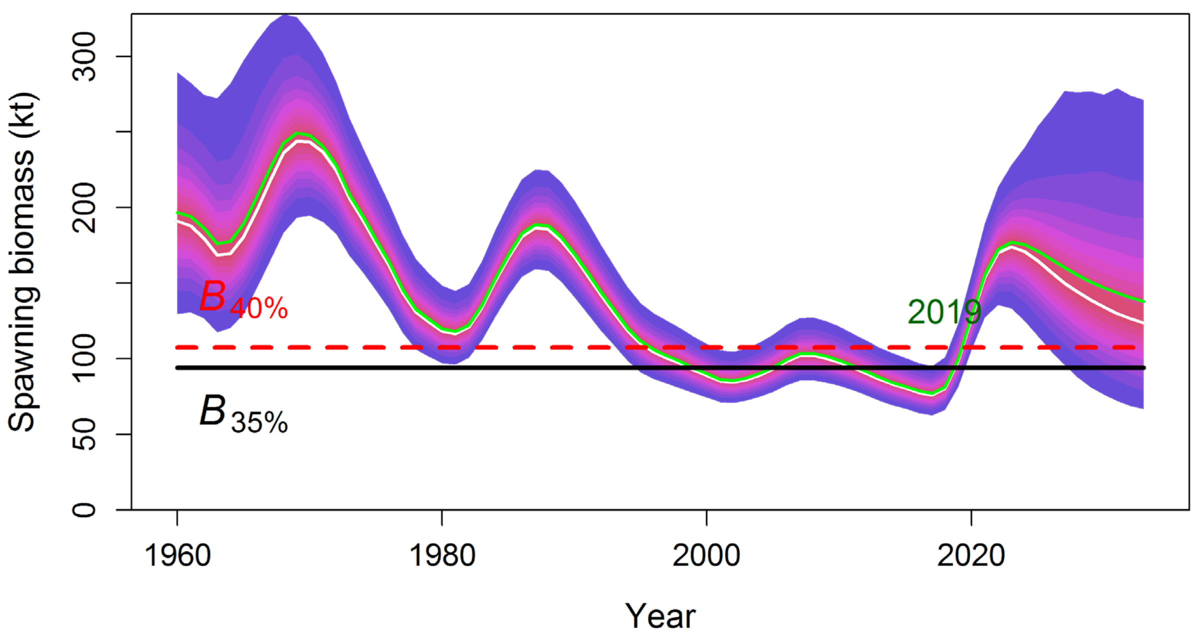


Figure 3.49. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and green line is the mean, shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is the same as the projections in Scenario 1 but with a yield multiplier of 0.89.

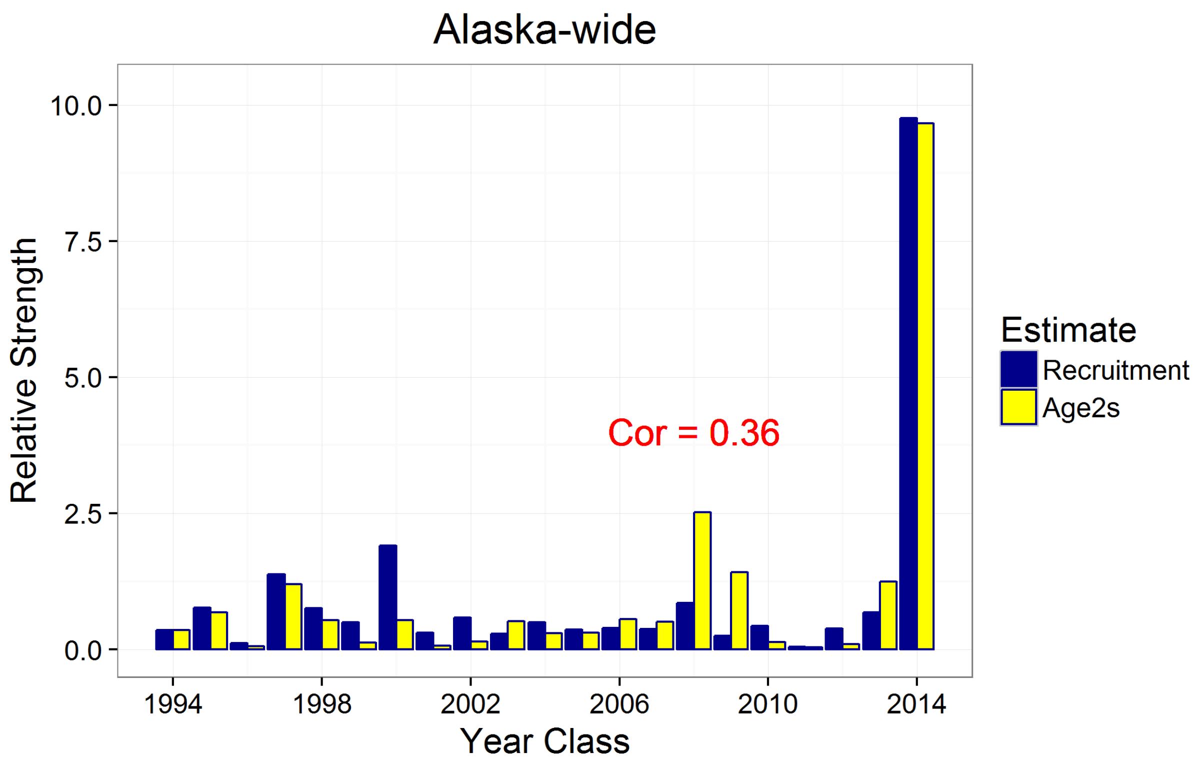


Figure 3.50. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

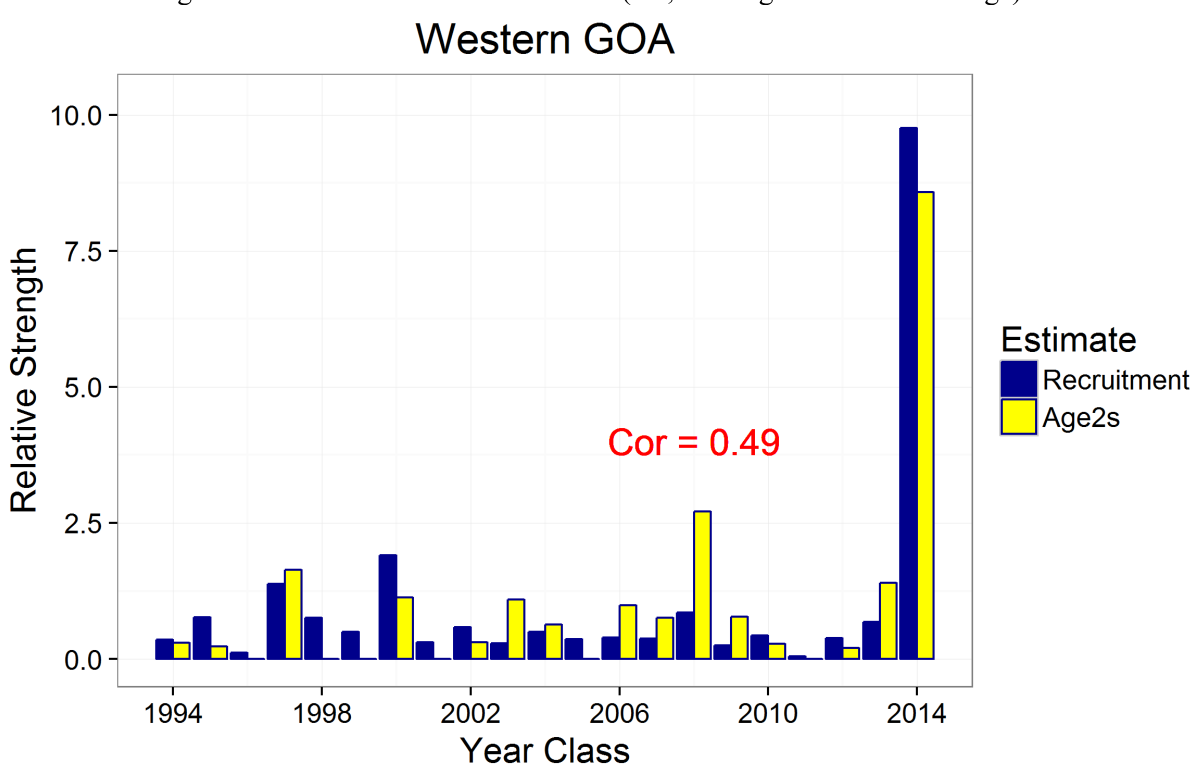


Figure 3.51. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

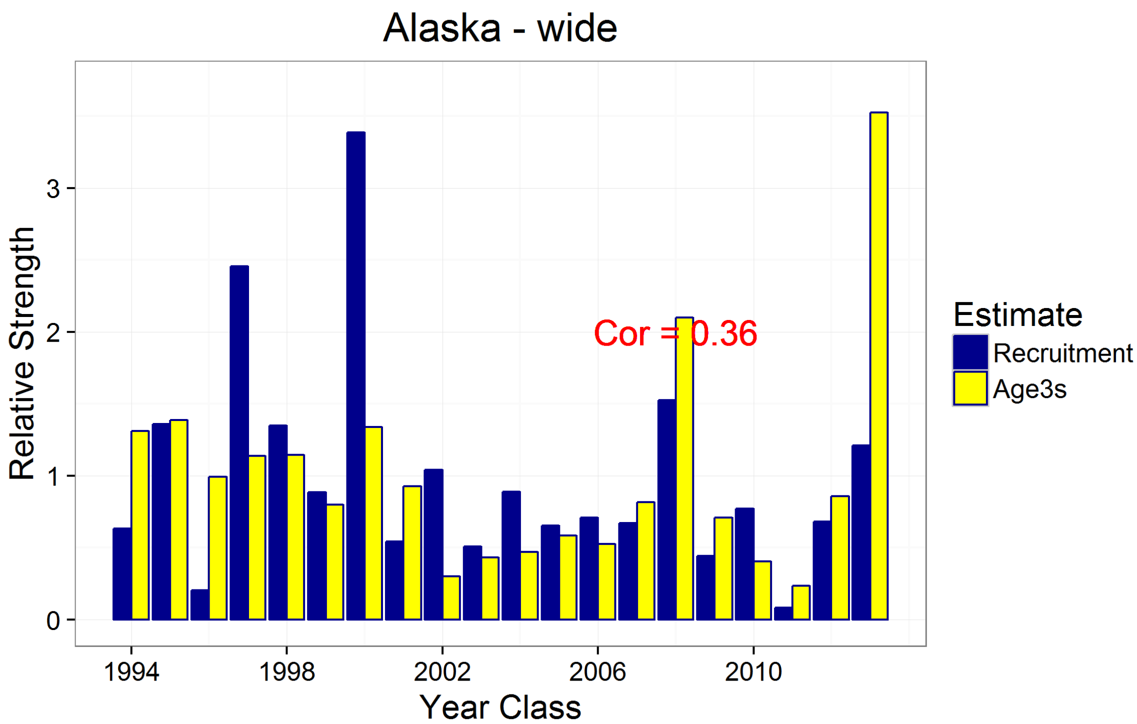


Figure 3.52. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

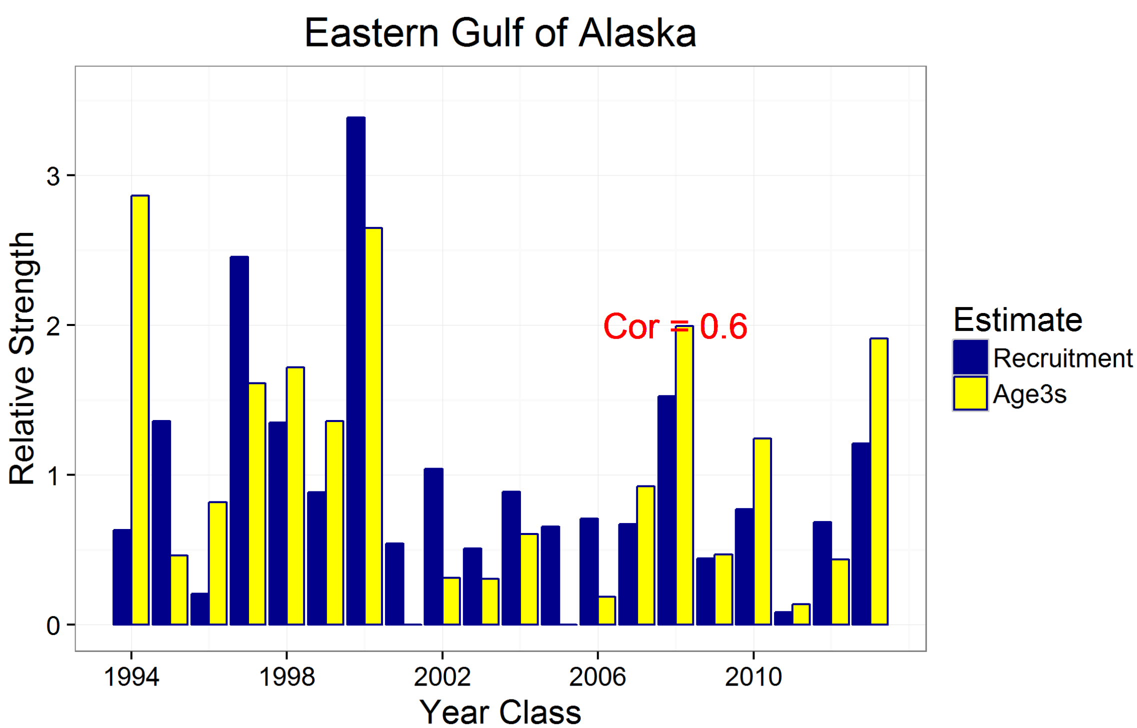


Figure 3.53. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

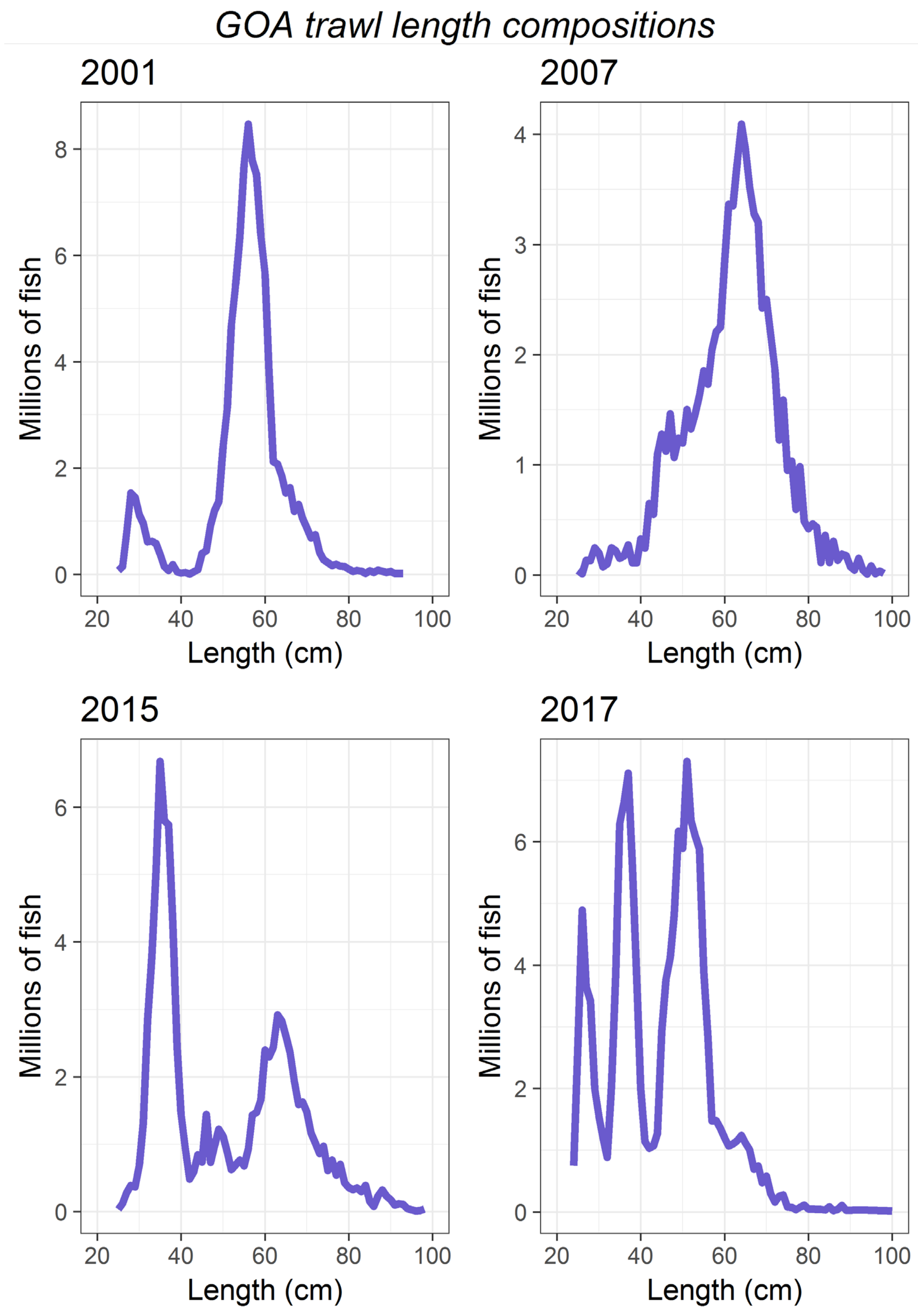


Figure 3.54. Select years of Gulf of Alaska trawl survey length compositions.

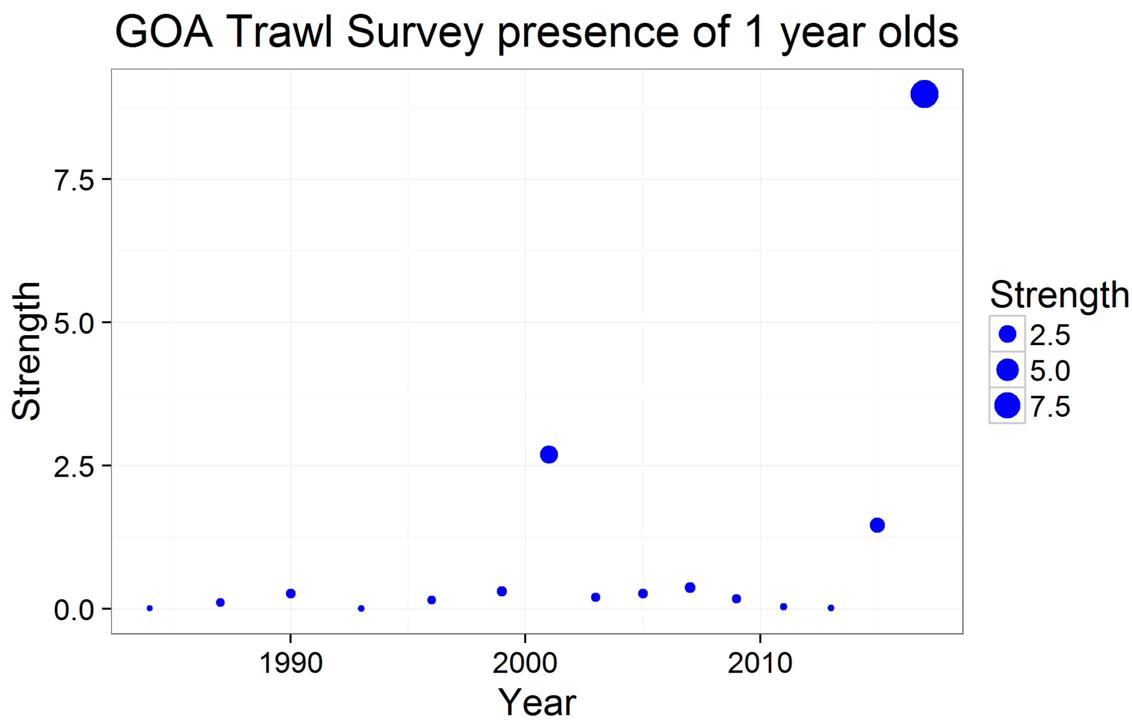


Figure 3.55. Presence of one-year-old (Length < 32 cm) sablefish in the Gulf of Alaska trawl survey. Strength is relative to the mean abundance (i.e., a strength of 7.5 is 7.5x average).

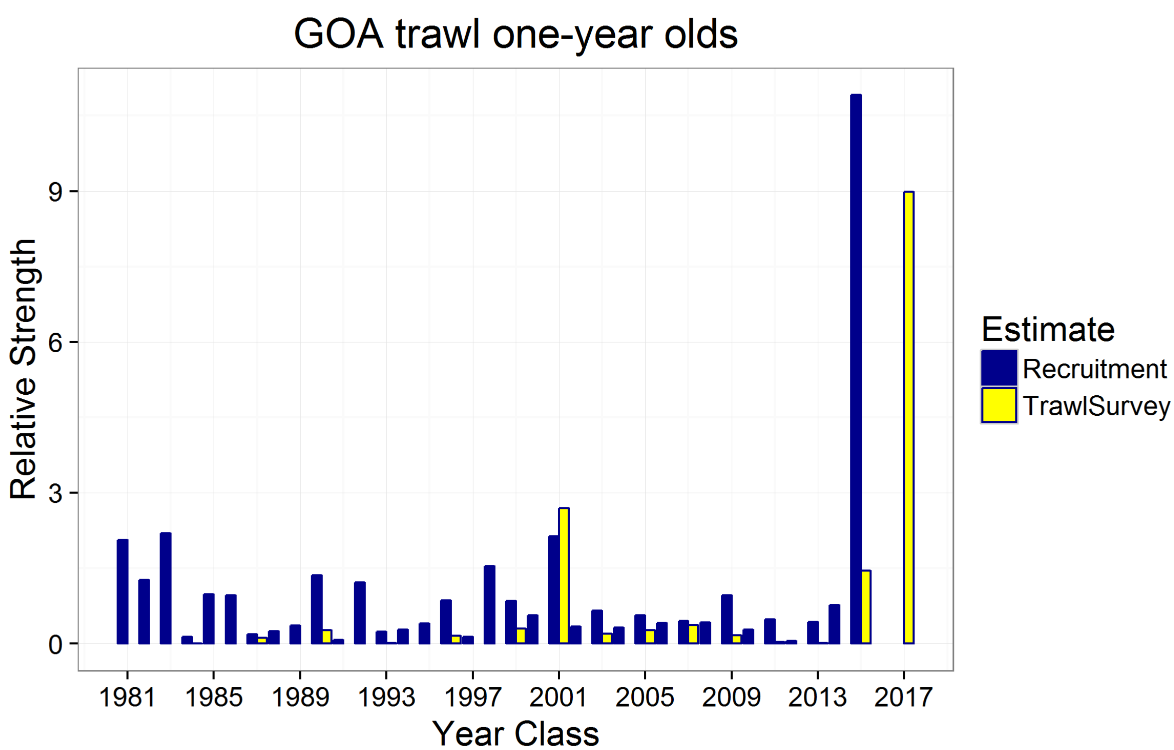


Figure 3.56. Strength of presence of one-year-old (Length < 32 cm) sablefish in the Gulf of Alaska trawl survey compared to the respective year classes of recruitment estimated by the stock assessment. Strength is relative to the mean abundance or recruitment (i.e., a strength of 7.5 is 7.5x average).

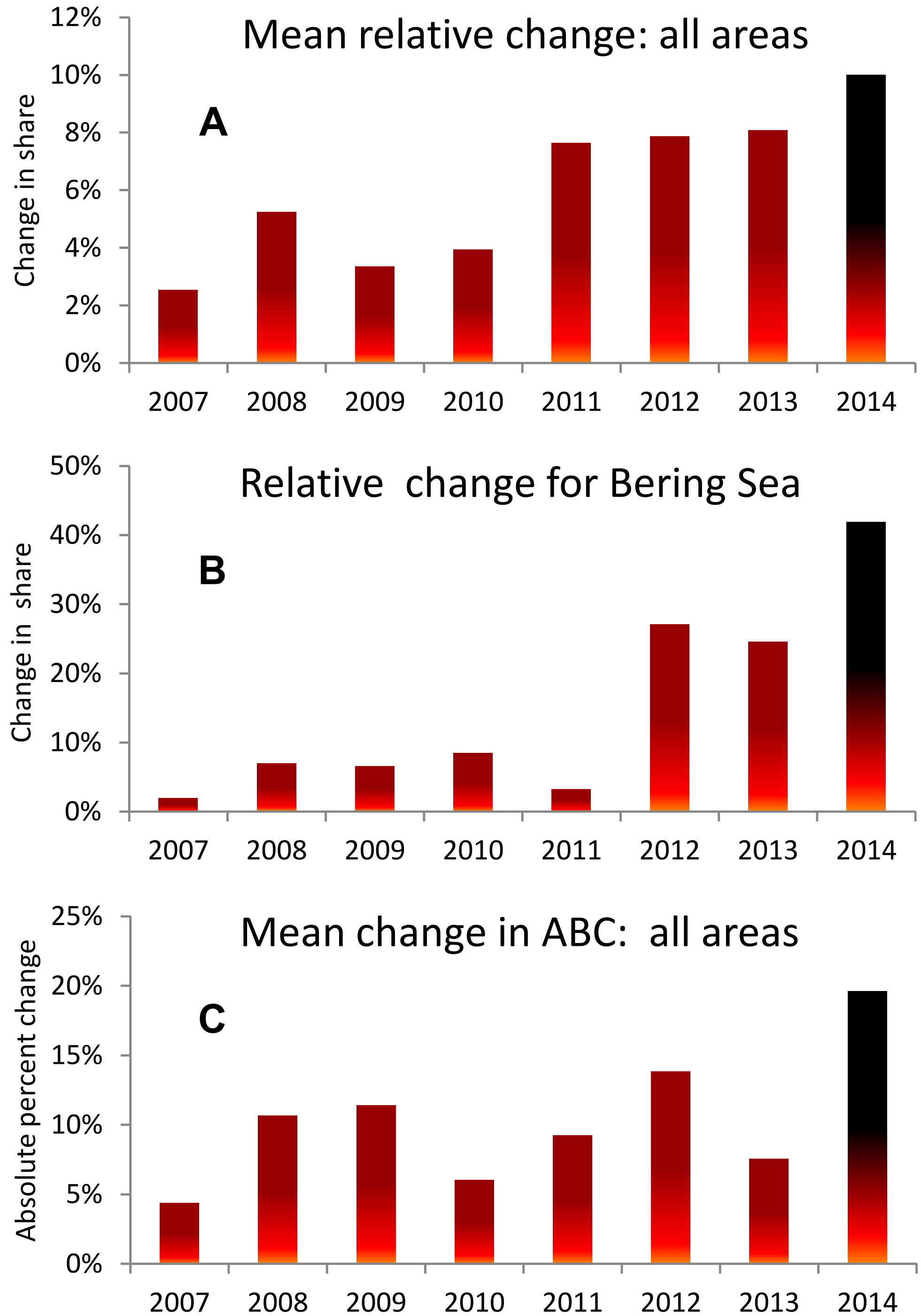


Figure 3.57. (A) The mean relative change in apportionment percentages across areas from 2007-2014. (B) The relative change in the apportionment share for the Bering Sea from 2007-2014. (C) The mean change in ABC for each area from 2007-2014.

Appendix 3A. Sablefish longline survey - fishery interactions

NMFS has requested the assistance of the fishing fleet to avoid the annual longline survey stations since the inception of sablefish IFQ management in 1995. We request that fishermen stay at least 5 nm away from each survey station for 7 days before and 3 days after the planned sampling date (3 days allow for survey delays). Survey calendars are mailed to each IFQ holder before the beginning of each fishing season. Additionally, throughout the survey, the skipper of the survey vessel makes announcements on the radio detailing the planned set locations for the upcoming days. 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 survey/fishery interactions. During the past several surveys, fishing vessels have been contacted by the survey vessel when they were spotted close to survey stations. Typically, vessels have been aware of the survey and have not been fishing close to survey locations. Vessels usually are willing to communicate where they had set and/or are willing to change their fishing locations to accommodate the survey. Even with communication there are some instances where survey gear was fished nearby commercial fishing gear or where commercial fishing had recently occurred. There are generally few interactions during the 90-day survey. However, in 2018 there were more interactions than in recent years. In the GOA, there were 8 interactions with longliners (1 in Western GOA, 2 in Central GOA, 2 in West Yakutat and 3 in Southeast) and 3 interactions with trawlers (2 in Central GOA and 1 in West Yakutat). There was also one interaction with a longliner in the Aleutian Islands.

Longline Survey-Fishery Interactions

Year	Longline Stations	Longline Vessels	Trawl Stations	Trawl Vessels	Pot Stations	Pot Vessels	Total Stations	Total 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
2018	9	9	3	3	0	0	12	12

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 other supplemental catch sources 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 235-249 t in recent years. This represents ~1.5 percent of the recommended ABC annually. These removals represent a 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

Literature Cited

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

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

Year	Source	Trawl surveys	Japan US longline survey	Domestic longline survey	IPHC longline survey*	Sport	Total
1977		3					3
1978		14					14
1979		27	104				131
1980		70	114				184
1981		88	150				238
1982		108	240				348
1983		46	236				282
1984		127	284				412
1985		186	390				576
1986		123	396				519
1987		117	349				466
1988		15	389	303			707
1989		4	393	367			763
1990		26	272	366			664
1991		3	255	386			645
1992		0	281	393			674
1993		39	281	408			728
1994		1	271	395			667
1995		0		386			386
1996		13		430			443
1997		1		396			397
1998		26		325	50		401
1999		43		311	49		403
2000		2		290	53		345
2001		11		326	48		386
2002		3		309	58		370
2003		16		280	98		393
2004		2		288	98		387
2005	**Assessment of the**	18		255	92		365
2006	**sablefish stock in**	2		287	64		352
2007	**Alaska**	17		266	48		331
2008	**(Hanselman et al.**	3		262	46		310
2009	**2010)**	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	28		197	29	254
2015		14	15		175	46	249
2016		3	12		199	31	245
2017	**AKRO**	9	10		216	NA**	235

* 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. **Sport catch was not available for 2017.

Appendix 3C. Ecosystem and Socioeconomic Profile of the Sablefish stock in Alaska

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November 2018

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Executive Summary

National initiative and AFSC research priorities suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish. Scores for stock assessment prioritization, habitat prioritization, productivity/susceptibility analysis, climate vulnerability assessment, and data classification analysis were moderate to very high. Annual guidelines for the AFSC also support ecosystem research on Alaska Sablefish for understanding recruitment. The sablefish ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for sablefish and may be considered a proving ground for potential operational use in the main stock assessment.

We use information from a variety of data streams available for the sablefish stock in Alaska and present results of applying the ESP process in two main sections regarding analysis of metrics and subsequent indicators. Metrics were averaged measures or scores of population dynamics, life history, or economic data for a given stock over the whole life history. A set of metrics may also be enhanced by an evaluation over ontogenetic shifts within the life history (e.g., egg, larvae, juvenile, adult). Ecosystem metrics help to identify vulnerabilities in the life history that provide insight on potential bottlenecks. Socioeconomic metrics reveal areas of market resilience and volatility. Analysis of the ecosystem and socioeconomic metrics for sablefish along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metrics and indicators analyses are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment. This ESP report will continue to improve with feedback on the ESP process and evolve into a dynamic and effective tool for monitoring future changes of stock productivity.

Ecosystem Considerations

- Early larval non-discriminating prey selection, seasonal match to zooplankton prey resources, rapid growth at specific thermal thresholds, and early strong swimming ability suggest monopolization of resources when environmental conditions align for sablefish
- The first overwintering in the nearshore may incur an energetic cost that results in reduced lipid content that does not change until the ontogenetic shift to deeper adult habitat where lipids increase rapidly as sablefish mature
- Long-term, annually conducted nearshore surveys may provide an early signal of overwinter success and age-specific condition of juveniles may provide an early signal of optimal foraging environment and potential contribution to the spawning population
- Trend modeling for sablefish ecosystem indicators revealed average to good conditions for the larval and early juvenile stages of the 2016 year class but potentially suboptimal foraging conditions for the juvenile maturing stage of the 2014 year class

Economic Considerations

- Value increases with size up to a certain point and market value can be maximized if maturing fish are allowed to grow several years
- Increased instability in price data for smaller fish versus larger fish may significantly increase the age at maximum economic value
- Increased incidental catch in fisheries at the northern range extent of sablefish may imply expanded use of habitat when year classes are large
- Trend modeling for sablefish economic indicators revealed substantially reduced prices for smaller fish in 2018, and increased incidental catch in BSAI fisheries in 2017 and 2018 that were the highest in the time-series

Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating with the stock assessment. A consistent approach is lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. A new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process (Shotwell et al., *In Prep*). The ESP uses data collected from a large variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Sigler et al., 2017; Dorn et al., 2018; Lynch et al., 2018) and recommended by the North Pacific Fishery Management Council's (NPFMC) groundfish and crab Plan Teams and the Scientific and Statistical Committee (SSC).

Where applicable, the ESP may replace the existing ecosystem considerations section described in the current Alaska Fisheries Science Center (AFSC) stock assessment and fishery evaluation (SAFE) report guidelines. Here, we replace the previous sablefish ecosystem considerations section with the sablefish ESP following the recommended framework (Shotwell et al., *In Prep*); however, information from the original ecosystem considerations section may be found in Hanselman et al. (2017). The four-step ESP process begins with an initial evaluation of the stock to assess the priority for conducting an ESP. Once it is established to conduct an ESP, the second step is to analyze a set of metrics to determine vulnerabilities throughout the life history of the stock and assist with indicator development. The third step is to follow a testing procedure potentially consisting of three stages (depending on the data availability of the stock) to determine the relevant ecosystem and socioeconomic indicators for monitoring. The final step of the ESP is to report potential ecosystem and socioeconomic recommendations to effectively and efficiently communicate the results of the ESP metrics and indicators analyses to a wide variety of user groups.

Priority to Conduct an ESP

The national initiative prioritization scores for Alaska sablefish are overall relatively high due to the high commercial importance of this stock and early life history habitat requirements (Hollowed et al., 2016; McConnaughey et al., 2017). The vulnerability scores were in the moderate range of all groundfish scores based on productivity, susceptibility (Ormseth and Spencer, 2011), and sensitivity to future climate exposure (P. Spencer, AFSC, *pers. commun.*). The new data classification scores for Alaska sablefish suggest a data-rich stock with high quality data over all categories (Lynch et al., 2018). Current data availability attribute levels were five for both the catch and size/age composition attributes, and four for abundance, life history, and ecosystem linkage attributes. These initiative scores and data classification levels suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish. Recent priorities set in the annual guidance memorandum for the AFSC also support ecosystem research on Alaska sablefish.

Metrics Analysis

We first provide information on the data sources used to generate the metrics for this second step of the ESP process and then provide the results of the metrics analysis.

Data

Initially information on sablefish was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 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 the initiatives in one location. Data from an earlier productivity susceptibility analysis conducted for all groundfish stocks in Alaska were also included in this form (Ormseth and Spencer, 2011). The form data serves as the initial starting point for developing the ESP metrics for stocks in the BSAI and GOA groundfish fishery management plans (FMP).

Further supplementary data were collected from the literature and a variety of process studies, surveys, laboratory analyses, accounting systems, and regional reports (Table 1). We provide details on these different data sources below.

Surveys

Information for the first year of life was derived from ecosystem surveys run by the 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 using a fixed-grid station design. 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 (YOY) or age-0 sablefish were sampled during the summer in the eastern GOA by the GOA Assessment Survey from 2010-2017. However, standardization for this survey has not yet been applied to the catch estimates due to the differences in selectivity between the nets used throughout the sampling period. Information from this survey is used qualitatively to compare to data from the western GOA. Data for early stage juveniles (less than 400 mm) through adult (greater than 550 mm) were consistently available from both bottom trawl and longline surveys. The Alaska Department of Fish and Game's (ADF&G) large-mesh bottom trawl survey of crab and groundfish has been conducted annually since 1988 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 has conducted both bottom trawl and longline surveys since the 1980s and the information is used for the majority of groundfish stock assessments in Alaska. The bottom trawl surveys have been conducted annually since 1982 on the Bering Sea (BS) shelf and triennially or biennially since 1980 in the Aleutian Islands (AI) and 1984 in the Gulf of Alaska (GOA). The longline survey has been conducted annually since 1987 in the GOA and biennially since 1996 in the AI and 1997 in the BS. The BS shelf bottom trawl survey is a fixed-grid design, while the AI and GOA bottom trawl surveys are random stratified sampling design. The longline survey is a systematic fixed station design. Please see Data section of the main stock assessment for more details on AFSC surveys. Length composition data are available for sablefish from the ADF&G and AFSC surveys. Age, length, and weight data are available for otolith specimens taken from the AFSC bottom trawl and longline surveys.

Laboratory and Models

Information from larval and early juvenile laboratory analyses on sablefish were provided through personal communication with the Recruitment Processes (RP) program in the Resource Assessment and Conservation Engineering (RACE) Division and the Recruitment Energetics and Coastal Assessment (RECA) program in the Auke Bay Laboratory (ABL) Division. Data from Ecosystem Status Report (ESR) contributions were provided through personal communication with the contact author of the contribution (e.g., Arimitsu and Hatch, 2017). Essential fish habitat (EFH) model output and maps were provided by personal communication with the editors of the EFH update (e.g., Rooney et al., 2018). High resolution regional ocean modeling system (ROMS) and nutrient-phytoplankton-zooplankton (NPZ) data were provided through personal communication with authors of various publications concerning individual based models and EFH (Gibson et al., In Press; Laman et al., 2017) that use this data.

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.

Metrics Analysis Results

We first provide results from the analysis of the initial form data termed the baseline metric analysis following the ESP framework (Shotwell et al., *In Prep*). Supplementary data were then collected to provide support of the baseline analysis and highlight more specific areas for indicator development.

Baseline Metric Analysis

The national initiative form data were summarized into a metric panel (Figure 1) that acts as a first pass ecosystem and socioeconomic synthesis. Metrics range from estimated values to qualitative scores of population dynamics, life history, or economic data for a given stock. To simplify interpretation the metrics are rescaled by using a percentile rank for sablefish relative to all other stocks in the groundfish FMP. Additionally, some metrics are reversed so that all metrics can be compared on a low to high scale between all stocks in the FMP. These adjustments allow for initial identification of vulnerable (percentile rank value is high) and resilient (percentile rank value is low) traits for sablefish. Data quality estimates are also provided from the lead stock assessment author (0 or green shaded means no data to support answer, 4 or purple shaded means complete data), and if there are no data available for a particular metric then an “NA” will appear in the panel. Sablefish did not have any data gaps for the metric panel and the data quality was rated as good to complete for nearly all metrics. The metric panel gives context for how sablefish relate to other groundfish stocks in the FMP and highlights the potential vulnerabilities for the sablefish stock.

The 80th and 90th percentile rank areas are provided to highlight metrics that cross into these zones indicating a high level of vulnerability for sablefish (Figure 1, yellow and red shaded area). For ecosystem metrics, recruitment variability for sablefish fell within the 90th percentile rank of vulnerability. Maximum age, length at 50% maturity, maximum length, size at transformation, and predation stressors fell within the 80th percentile rank when compared to other stocks in the groundfish FMP. For socioeconomic metrics, commercial value fell within the 90th percentile rank and constituent demand fell within the 80th percentile rank. Sablefish were relatively resilient for adult growth rate, age at first maturity, range in latitude, range in depth, fecundity, breeding strategy, adult mobility, habitat dependence, and prey specificity.

Recruitment variability for the sablefish stock is one of the highest among the Alaska groundfish stocks. Additionally, the older maximum age, larger size at transition, 50% maturity, and maximum length are all characteristics of low productivity stocks (Patrick et al., 2010). Predation pressures on adult sablefish are also high due to the recent increases in whale depredation (Hanselman et al., 2017). Sablefish is one of the most highly valued Alaska groundfish stocks relative to other Alaska groundfish stocks. The high value also explains the high constituent demand for excellence in the stock assessment. These initial results suggest that more in-depth information regarding mechanisms for the extreme recruitment variability and an evaluation of economic performance would be valuable for sablefish.

Supplementary Data for Recruitment Variability

Supportive data evaluated over ontogenetic shifts (e.g., egg, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity to identify relevant indicators for monitoring. Three complete life history panels along the categories of distribution, phenology, and condition were recently developed for sablefish (Shotwell et al., *In Review*). We provide these panels to help pinpoint the life history stages that may be highly influential on recruitment variability. Information from the literature, surveys, process studies, laboratory analyses, and modeling applications are also provided to explain mechanisms and interactions where applicable.

The recent EFH update for Alaska groundfish included models and maps of habitat suitability distributions by species (Rooney et al., 2018; Pirtle et al., *In Press*). We collected model output on the depth ranges, percent contribution of predictor variables, sign of directional deviation from the mean predictor value, and associated maps for the larval, early juvenile (<400 mm), late juvenile (>=400 mm & < 550 mm), and adult stages (>=550 mm) of sablefish (Figure 2). Highly suitable larval habitat was characterized by bottom depth (250-850 m, 38% contribution), low surface temperature (33%), and low ocean color (a measure of primary productivity, 12%). However, the sampling for the larval stage was not synoptic for the GOA and large gaps exist between survey grids. Recent surveys in the eastern GOA show higher abundance and larval size relative to those captured in western GOA surveys during the same season suggesting different population pressures in the eastern survey areas (Siddon et al., *In Press*). Early juvenile suitable habitat was less reliant on depth (10-260 m, 10% contribution) with low tidal current (30%), low bottom temperature (21%), and low sponge presence (11%), characterizing the early juvenile habitat as colder, low-lying areas (e.g., channels, gullies, and flats) with little biogenic structure and less current. Depth becomes more important and deeper for the late juvenile stage (135-590 m, 37% contribution), with continued low bottom temperature (23%), low tidal current (12%), and low-lying areas (8%). Finally, depth is the primary predictor for adults (180-770 m, 89% contribution) with minor contribution (<5%) from other predictor variables. A clear ontogenetic habitat shift occurs between the early juvenile and later juvenile to adult stages with progression from nearshore bays and inlets to the colder continental shelf and slope (Figure 2 b-d).

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). At some point following the first overwinter, sablefish juveniles begin movement to their adult habitat arriving between 4 to 5 years later and starting to mature within 3 to 6 years (Hanselman et al., 2017). The phenology of the pre-adult life stages can be examined seasonally to understand match or mismatch with both physical and biological properties of the ecosystem (Figure 3). Information on the egg and larval life stages were from the EcoFOCI data and restricted to the core sampling area (western GOA only) for consistency across years. Data from the early and late juvenile stages were derived from bottom trawl and longline surveys. Physical and biological habitat indices were derived from ROMS/NPZ model output used in an individual based model and the EFH update (Laman et al., 2017; Rooney et al., 2018, Gibson et al., *In Press*). Sablefish eggs caught in 60 cm bongos are in the water column from February to April when there is lower bottom temperature, lower indication of mesoscale variability as measured by current variability (e.g., eddies), and higher potential transport to the nearshore. Pelagic eggs in deep water over the slope and basin may provide a relatively stable environment for embryonic development as cold temperatures during winter favor slow development. Relatively large size at hatching (~6 mm) and rapid growth of larvae with good swimming ability likely confers an advantage in terms of larval feeding at the sea surface. Larvae are most abundant in neuston samples and are caught in shelf and slope waters, so larval abundance was provided for neuston samples only. Peak abundance of larvae (May–Jun) coincides with advanced development of the spring peak in zooplankton production following the onset of stratification (measured by a shallowing of the mixed layer) which likely means a plentiful supply of larval prey. Sablefish 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; Deary et al., *In Press*). With the lack of overall ossification of the skeleton, pre-flexion sablefish larvae lack the rigidity in their jaw elements to quickly open and expand their mouths to suck in prey. Sablefish in this pre-flexion larval stage are only able to pick prey from the water and are thus restricted to prey that is small and prevalent. The clear match with the onset of the zooplankton bloom supports this need to be at the highest peak of productivity due to their vulnerability for non-discriminating prey selection. Although juveniles are captured in all months of the survey, there are more early juveniles (<400 mm) present at the start of summer when there are lower current speeds, which may assist with transition to the adult habitat.

Information on body composition, percent lipid and percent protein by size, can be used to understand shifts in energy allocation through the different life history stages (Figure 4). Throughout the first year, larvae and age-0 fish grow very rapidly up until settlement in the nearshore environment (Sigler et al. 2001). Fish from 0 to 400 mm (Figure 4, pre-settlement and settlement phases), have a fairly stable lipid and protein content. These fish are putting energy toward growth and not toward lipid energy storage. A potential bottleneck may occur pre-settlement as overwintering during the first year of life may incur an energetic cost that results in a change in body condition with reduced lipid content at about 200 mm that appears to be maintained until the late juvenile stage at about 400 mm (R. Heintz, *pers. commun.*). At lengths greater than 400 mm where fish are maturing (i.e., a portion of fish are mature) and at lengths were fish are all presumably adult (>650 mm), the percent lipid is much higher than at lengths less than 400 mm. This is likely because mature fish have a higher lipid content than immature fish. These data show that there is an ontogenetic shift that is related to how sablefish store energy and may be related to the size at which fish migrate from nearshore to offshore waters. The variability in lipid content at lengths greater than 400 mm could be attributed to some fish being mature and some being immature or skip spawning. For example, relative condition (body weight relative to length) and relative liver size (liver weight related to total weight), are higher in fish that will spawn than in skip spawning and immature female sablefish (Rodgveller, *In Review*). Variability could also be an effect of sex, sampling date, sampling area, and year. However, these data show a strong shift in lipid accumulation as fish grow and enter the late juvenile to adult stage.

Supplementary Data for Economic Performance

We provide a section on the socioeconomic aspects of the sablefish fishery due to the high importance of the resource in this region. The following describes the economic performance of the sablefish stock over time and highlights vulnerabilities in value for potential indicator monitoring.

Sablefish are primarily harvested by catcher vessels in the GOA, which typically accounts for the majority of the annual catch. Most sablefish are caught using the hook-and-line gear type. Starting in 2017, directed fishing for sablefish using pot gear was allowed in the GOA to mitigate whale depredation. As a valuable premium high-priced whitefish, sablefish is an important source of revenues for GOA catcher vessels and catches are at or near the TAC. Fisheries in the BSAI have been far below the TAC from a combination of low catch rates, whale depredation, and long run times. Since the mid-2000s, decreasing biomass resulted in decreased TACs and catch, a trend that continued until 2016. In 2017, the total TAC for the GOA and BSAI increased as a result of an increase in the longline survey abundance index and retained catches increased 17% to 11.5 thousand t, up from 9.9 thousand t in 2016 (Table 2).

Revenues increased 28.2% to $119 million as ex-vessel prices remained strong at $5.00/lb for 2017 (Table 2). The increase in the ex-vessel price reflected a commensurate increase of first-wholesale price to $8.52/lb (Table 3). First-wholesale value increased to $123.8 million in 2017. Most sablefish is sold as headed-and-gutted at the first-wholesale level of production. Because of the minimal amount of value added by head-and-gut production and the size of the catcher vessel sector, the 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 through the mid-2000s to 2016, although strong prices maintained a stable total value for the fishery as catches declined. The 2017 price was the highest seen since prices peaked in 2011 at

$8.71/lb. The 2017 price increase comes despite reported smaller average fish size as the 2014 year class has not fully grown to a higher marketable price. Export prices through July 2018 (which are typically a strong indicator of first-wholesale prices) show a 10% decrease.

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 caught by Russia. As the primary global producer of sablefish, the significant supply changes in Alaska have market impact that influence wholesale and export prices. Most sablefish caught and produced is exported, though the domestic market has grown in recent years. Japan is the primary export market, but its share of export value has decreased from 82% in 2003-2012 to 66% in 2017 (Table 4). U.S. exports as a share of U.S. production has declined over time indicating increased domestic consumption. In recent years industry reports and U.S. import-export figures indicate that there is strong demand for sablefish in the U.S. and in foreign markets outside of Japan, including Europe, China, and Southeast Asia. China's share of export value has also been increasing (Table 4). Furthermore, this strong demand internationally, may put upward pressure on wholesale prices. The U.S.-Japanese exchange rate has remained relatively stable since 2016. Some segments of the supply chain may have been squeezed out by higher prices; but these concerns that high sablefish prices would reduce demand were not apparent in 2017.

Combining basic population dynamics with current pricing data by size can give insights into the value of immediately harvesting a year class or allowing it to grow in size and contribute to future spawning biomass. The critical concept, before dealing with the value of different sizes of fish is to consider the trade-off between natural mortality and somatic growth. In Figure 5A, we show the decrease in a year class of fish due to natural mortality. Sablefish grow very rapidly in the first 5-6 years of life, with growth in weight far exceeding the decline in numbers of fish due to natural mortality (Figure 5B). Combining these two curves, we can calculate at which age the maximum total weight of the cohort is attained (Age 7, Figure 5C). Finally, we can use the maturity curve to calculate at which age the maximum amount of contribution to spawning stock biomass would be obtained (Age 10, Figure 5D).

Next, we can combine these results and the selectivity curves and projections from the 2018 assessment model with the 2018 pricing data to determine where a cohort reaches maximum value. For sablefish in 2018, the average price per pound was more than 5x higher for the largest size group (7+ pounds) than the smallest marketable size group (1 to 2 pound). We translate price-per-pound data into price-at-age data using a simple log-linear model that peaks at the price group with the maximum price (7+ pounds). The price per kilogram from younger and subsequently smaller size fish starts low and increases with size up to a certain point (Figure 6, top graph). Multiplying this value against the average weight of a fish for a given age (Figure 5C) suggests that market value would be maximized if fish were allowed to grow for a number of years before harvest, up to about age 12 (Figure 6, middle panel). However at least 85% of the economic yield would be obtained if harvest began at age 7 (Figure 6, bottom panel, using the 2014 year class in 2019 as a starting point). By including the data that the prices for smaller fish are much lower, this significantly increases the age at maximum economic value. By this age, the fish would be beginning to reach higher lipid content at around 600-700 mm (Figure 4, blue line). Given the high variability in percent lipids in juvenile sablefish (Figure 4), allowing the fish to grow to a larger size would not only increase chances of survival but also potentially increase overall market value, if price is dependent on flesh quality in addition to size.

Indicators Analysis

We first provide information on how we selected the indicators for this third step of the ESP process and then provide results on the indicators analysis.

Ecosystem Indicators

Indicators representing temperature, transport, and stratification (via freshwater discharge) for the offshore pelagic life stages have been related to recruitment fluctuations of sablefish (Coffin and Mueter, 2014; Shotwell et al., 2014; Gibson et al., *In Press*). Young-of-the-year (YOY) sablefish exhibit some thermal intolerance to very cold water (Sogard and Spencer 2004) and laboratory studies have shown a narrow optimal thermal range and a shift with size in thermal performance (Sogard and Olla 2001, Krieger et al., 2019). Transport to the nearshore during the first year of life is thought to relieve potential vulnerability if conditions are poor (Doyle and Mier 2016). The larval match to the onset of stratification and height of zooplankton production may provide a potential buffer against high predation in the epipelagic zone if thermal conditions were sufficient to allow sablefish to monopolize on their very high growth potential (Krieger et al., 2019). 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. 2017; Arimitsu and Hatch, 2017). An age-0 sablefish growth index, calculated as the coefficient for the regression of length (mm) by Julian day for each year (Arimitsu and Hatch, 2017), effectively tracks the nearshore age-0 growth rate of sablefish and has a positive relationship with sablefish recruitment. A fish with a good food supply and positive environmental conditions may have good overall condition and higher overwinter survival. The ADF&G large mesh bottom trawl survey (Figure 7) has recently observed larger catches of smaller sablefish (age-1 and age-2) in the 2015 through 2018 surveys. These catches corroborate the large 2014 year class, the return to average recruitment in 2015 and another potential large year class in 2016. This survey may be useful as an early signal of overwinter success for the early juvenile stage. Estimates of the pelagic and benthic forager biomass provide information on the relative fluctuations of these guilds (BSAI ESR, 2017) and may represent optimal foraging conditions that would also impact sablefish as they transition from the nearshore to offshore environments.

The clear increase in lipids as fish enter the later juvenile stage suggests that condition may impact the ability of these fish to mature and potentially contribute to the spawning population. Data to calculate the relative condition of sablefish, residuals from a length-weight relationship (Boldt et al., 2018), are available from the AFSC longline survey since 1996. These data can be used as an indicator of health and foraging conditions in a time-series of the relative condition of fish from 550-590 mm, the length range at which most fish are likely to be age-4 (in 2018 these fish would be from the 2014 year class). Age-4 fish are generally only about 10% mature and so the effect of maturation on this condition index is minimal, but may indicate their likelihood of becoming mature. In the future, we would like to explore the utility of condition indices of fish from different life stages as indices of health and productivity. Annual condition differences should be evaluated for each life stage separately because energy storage strategies differ (Figure 4). Because measures of body condition are related to spawning status, condition measures may be useful for predicting the maturity of sablefish on the longline survey and could provide annual estimates of the age-at-maturity (Rodgveller, *In Review*).

In the 2017 ESP for sablefish (Hanselman et al., 2017, Appendix C) several ecosystem indicators were included that will no longer be in the ESP. First, the transport indicator on total connectivity (Gibson et al., *In Press*) and the early juvenile prey conditions (Yasumiishi et al., 2017) are currently being reevaluated and the indicators will undergo a fundamental change so they would not be comparable to the previous indices. Second, an indicator on whale depredation was included to consider the importance of the predation pressures that were highlighted in the baseline metric analysis. Information on whale depredation is included in the main sablefish stock assessment report and in the assessment model to provide harvest recommendations (Hanselman et al., 2017). We remove indicators in an ESP when they are in the main stock assessment model because the ESP is a pre-operations testing framework and the whale indicator is now operational.

Socioeconomic Indicators

The evaluation of economic performance suggests some areas for continued monitoring with regard to catch and value of small fish in the fishery. A recent discussion paper on sablefish discard allowance (Armstrong et al., 2018) provides information on biological and economic impacts for introducing minimum size regulations for sablefish. In 2018, there was a marked increase in sablefish landings for small (1-3 pound) sablefish in the BSAI fisheries, most notably the midwater pollock fishery, and an associated large decrease in value for these same sized fish (Armstrong et al., 2018). This size range is the likely age for the 2014 to 2016 year classes (age 2-4, Figure 5C). Estimates of sablefish incidental catch in the BSAI fisheries and associated value of small sized fish in this area may be useful to monitor as an early signal for potential shifts in economic yield during large year classes as this area represents the northern edge of the sablefish population distribution.

Indicators Analysis

The suite of indicators is tested using a sequential procedure. There are potentially three stages for testing indicators depending on the stability of the indicator for monitoring and the data availability for the stock (Shotwell et al., *In Prep*). At this time, we report the results of the first and second stages of the indicator testing procedure for sablefish. The third stage will require more indicator development and review of the ESP modeling applications.

We provide the list and time-series of indicators based on the information evaluated in the metric analysis, and subsequent review of supporting data (Table 5, Figure 8). The first stage of the indicator analysis is a simple assessment of the trend and variance of the most recent five years and a traffic-light evaluation of the most current year where available (Table 5). The five-year trend and variance analysis follow the report card analysis presented in the ESRs (e.g., Zador and Yasumiishi, 2017). The traffic-light ranking of the current year is based on the 20th and 80th percentiles of the time series and the color of blue, yellow, or red related to being below, within, or above the two percentiles (Caddy et al., 2015). The blue or red coloring may be reversed if a positive value of the index has a negative impact on sablefish. In many cases the most current year was not available and this demonstrates a significant data gap for evaluating ecosystem and socioeconomic data for sablefish.

For the currently updated indicators, trends are mostly consistent with the unusually large 2014 year class. Offshore thermal conditions were warm for 2014 in all areas, indicative of good conditions for larval sablefish. Conditions have since returned to average in the central North Pacific along the Polar Front but remained warm in the Bering Sea. The age-0 sablefish growth model also shows positive anomalies for 2014-2016, with 2016 being higher than 2014. This is consistent with the large 2018 catch of age-2 fish in the ADF&G juvenile survey. Pelagic and benthic foraging biomass is down from the high in 2015, potentially indicating average conditions for foraging. Condition of maturing fish was at an all-time low in 2017 and remained below average in 2018. This is in contrast to relatively good condition of previous high recruitment years (2001, 2002, and 2004 for the 1997, 1998, and 2000 year classes). Preliminary 2018 price per pound of small fish in the BSAI fisheries was 25% of the 2017 price and 2018 incidental catch in the BSAI pollock fishery was 4 times higher than in 2017 and well above the long-term average.

Bayesian adaptive sampling (BAS) was used for the second stage modeling application to quantify the association between hypothesized predictors and sablefish recruitment, along with the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this second stage, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment (first seven indicators listed in Table 5). We then provide the mean relationship between each predictor variable and log sablefish recruitment over time (Figure 9, top graph left side), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 9, top graph right side). A higher probability indicates that the variable is a better candidate predictor of sablefish recruitment. The model ranking procedure samples from the suite of potential models and weights predictions across models incorporating different combinations of variables. We show the suite of ranked models with selected covariates in colored cells and non-selected covariates in black cells (Figure 9, bottom graph). The highest ranked predictor variables based on this process were the freshwater discharge index and the ADF&G juvenile survey index (Figure 8). In the future, highly ranked predictor variables could be evaluated in the third stage of the modeling application which analyzes predictor performance and estimates risk probabilities within the operational stock assessment model. The freshwater discharge index could help explain the variability in recruitment deviations and predict pending recruitment events (e.g., Shotwell et al., 2014); however, this index could not be used further without more consistent updating. The ADF&G index could be used directly in the model as a survey for age-1 sablefish and is updated on an annual basis.

Recommendations

The sablefish ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Prep*). While the metric grading and subsequent indicator analysis provide a relevant set of proxy indicators for evaluation at this time, there are certainly areas for improvement. Development of high-resolution remote sensing indicators would assist with the current one-year data gap for many indicators and additional refinement on hypothesized bottlenecks for larval, young-of-the-year, and maturing adults would help improve the growth, condition, and foraging indicators. An updated set of indicators may then be used in the third stage modeling application that evaluates performance and risk within the operational stock assessment model.

With these future priorities in mind, we provide the following set of considerations:

Ecosystem Considerations

- Early larval non-discriminating prey selection, seasonal match to zooplankton prey resources, rapid growth at specific thermal thresholds, and early strong swimming ability suggest monopolization of resources when environmental conditions align for sablefish
- The first overwintering in the nearshore may incur an energetic cost that results in reduced lipid content that does not change until the ontogenetic shift to deeper adult habitat where lipids increase rapidly as sablefish mature
- Long-term, annually conducted nearshore surveys may provide an early signal of overwinter success and age-specific condition of juveniles may provide an early signal of optimal foraging environment and potential contribution to the spawning population
- Trend modeling for sablefish ecosystem indicators revealed average to good conditions for the larval and early juvenile stages of the 2016 year class but potentially suboptimal foraging conditions for the juvenile maturing stage of the 2014 year class

Economic Considerations

- Value increases with size up to a certain point and market value can be maximized if maturing fish are allowed to grow several years
- Increased instability in price data for smaller fish versus larger fish may significantly increase the age at maximum economic value
- Increased incidental catch in fisheries at the northern range extent of sablefish may imply expanded use of habitat when year classes are large
- Trend modeling for sablefish economic indicators revealed substantially reduced prices for smaller fish in 2018, and increased incidental catch in BSAI fisheries in 2017 and 2018 that were the highest in the time-series

Future work

There are a series of three AFSC sponsored workshops scheduled during 2019 – 2021 with the goal of improving the ESP framework and process, and the use of indicators in stock assessment models. In the 2017 ESP, we presented some preliminary analyses on the interactions of communities and the sablefish fishery. While economics play a central role in communities, we hope at upcoming ESP workshops that we will be able to develop time series indices that track community-level effects and the influences of communities on patterns in the fishery.

In the future, a partial ESP may be requested as an update to the full ESP report provided here when no new information except indicator updates are available. A simplified one-page template (Figure 10) may be useful for evaluating the ESP considerations during a partial update year.

Acknowledgements

We would like to thank all the contributors for their timely response to requests and questions regarding their data, report summaries, and manuscripts. We also thank sablefish main assessment co-authors Chris Lunsford, Kari Fenske, Cara Rodgveller, and Pat Malecha, and AFSC internal reviewer Cody Szuwalski for reviewing this ESP and the Groundfish Plan Teams and SSC for their helpful insight on the development of this report and future reports.

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Table 1: List of data sources used in the ESP evaluation. Please see the main sablefish document, the Ecosystem Considerations Report (Zador and Yasumiishi, 2017) and the Economic Status Report (Fissel et al., 2017) 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
		ADF&G Large Mesh Survey	Bottom trawl survey of crab and groundfish on fixed-grid station design using eastern otter trawl	1988-2018	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
		ABL Longline Survey	Longline survey of groundfish on stratified stations set 20-30 km apart using standard groundline	1987-2018	GOA annual
	Other	ROMS/NPZ Model Output	Coupled hydrographic Regional Ocean Modeling System and lower tropic Nutrient-Phytoplankton-Zooplankton dynamics model	1996-2013	Alaska
		RECA Energetics	Body composition information from laboratory studies	2006-2017	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	1992-2018	Alaska
		Reports	ADFG Commercial Operators Annual Reports, At-sea Production Reports, Shoreside Production Reports	2011-2017	Alaska
		Online	NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division, FAO Fisheries & Aquaculture Department of Statistics, U.S. Department of Agriculture	2011-2018	Alaska, U.S., Global

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 U.S.$), price (U.S.$ per pound), number of vessels, and the proportion of vessels that are catcher vessels, 2003-2012 average and 2013-2017.

	2003-2012 Average	2013	2014	2015	2016	2017
Total Catch K mt	15.9	14.5	12.3	11.7	10.9	13.0
Retained Catch K mt	15.1	13.7	11.6	10.8	9.9	11.5
Value M US$	$101.2	$90.2	$94.6	$94.0	$92.9	$119.0
Price/lb US$	$3.07	$3.12	$3.82	$3.97	$4.38	$5.00
% value GOA	89%	92%	93%	95%	96%	97%
Vessels #	393	307	298	290	288	281
Proportion CV	85%	87%	89%	90%	88%	85%

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 U.S.$), price (U.S.$ per pound), and head and gut share of production, 2003-2012 average and 2013-2017.

	2003-2012 Average	2013	2014	2015	2016	2017
Quantity K mt	8.59	7.83	6.70	6.06	5.86	6.59
Value M US$	$101.5	$96.2	$99.0	$90.9	$100.3	$123.8
Price/lb US$	$5.36	$5.57	$6.70	$6.80	$7.76	$8.52
H&G share	95%	97%	97%	98%	97%	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), export value (million U.S.$), export price (U.S.$ per pound) and the share of export value from trade with Japan and China, 2003-2012 average and 2013-2018.

	2003-2012 Average	2013	2014	2015	2016	2017	2018 (thru July)
Global catch K mt	24.3	19.8	17.8	18.7	17.2	-	-
U.S.Share of global	84%	90%	90%	86%	89%	-	-
AK share of global	58%	66%	62%	56%	56%	-	-
Export Volume K mt	10.75	8.67	6.67	6.66	5.58	5.73	3.30
Export value M $	$ 82.23	$ 95.57	$ 81.58	$ 82.26	$ 80.82	$ 86.48	$ 45.05
Export Price/lb US$	$ 3.47	$ 5.00	$ 5.55	$ 5.60	$ 6.57	$ 6.84	$ 6.19
Japan value share	82%	74%	73%	63%	59%	66%	60%
China value share	9%	11%	10%	17%	21%	18%	21%
Exchange rate, Yen/Dollar	101.3	97.6	105.9	121.0	108.8	112.2	109.1

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 5. First stage indicator analysis for sablefish including indicator title and short description. The recent five-year trend (up, down, or stable) and recent five-year mean (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) are provided following the ESR methods. Fill is based on current year conditions for sablefish relative to the 20th and 80th percentiles of the time series (yellow = average, blue = good, red = poor, no fill = no current year data). NA = data gap.

	Title	Description	5-year Trend	5-year Mean
Ecosystem Indicators	Surface Temperature Polar Front	Sea surface temperature index along the North Pacific Polar Front in central North Pacific (Shotwell et al. 2014)	Down	●
	Surface Temperature Bering Sea	Average surface temperature (ºC) over all hauls of the RACE Bering Sea shelf bottom trawl survey	Stable	+
	Freshwater Index Gulf of Alaska	Low-resolution model estimate of annually-averaged monthly discharge (GOA ESR, 2017)	NA	NA
	Early Growth YOY Sablefish	Anomalies from growth index of sablefish sampled in rhinoceros auklet diet (Arimitsu and Hatch, GOA ESR, 2017)	Stable	●
	Juvenile Sablefish Index	Catch-per-unit-of-effort for sablefish in the ADF&G large-mesh survey (Spalinger, *pers. commun.*, 2018)	Up	+
	Pelagic Forager Gulf of Alaska	Combined relative population weights from the pelagic foragers (see EBS ESR, 2017) on the ABL longline survey	Down	+
	Benthic Forager Gulf of Alaska	Combined relative population weights from the benthic foragers (see EBS ESR, 2017) on the ABL longline survey	Down	●
	Condition of Maturing Fish	Sablefish condition inferred from length-weight residuals for maturing fish (550-590 mm) on ABL longline survey	Down	●
Socioeconomic Indicators	Price Small Fish Fishery	Average price per pound of small sablefish in BSAI fixed gear fisheries (Armstrong et al., 2018)	Down	●
	Sablefish Bycatch in Pollock Fishery	Incidental catch of sablefish (tons) in the BSAI pollock midwater fishery (AKFIN)	Up	●

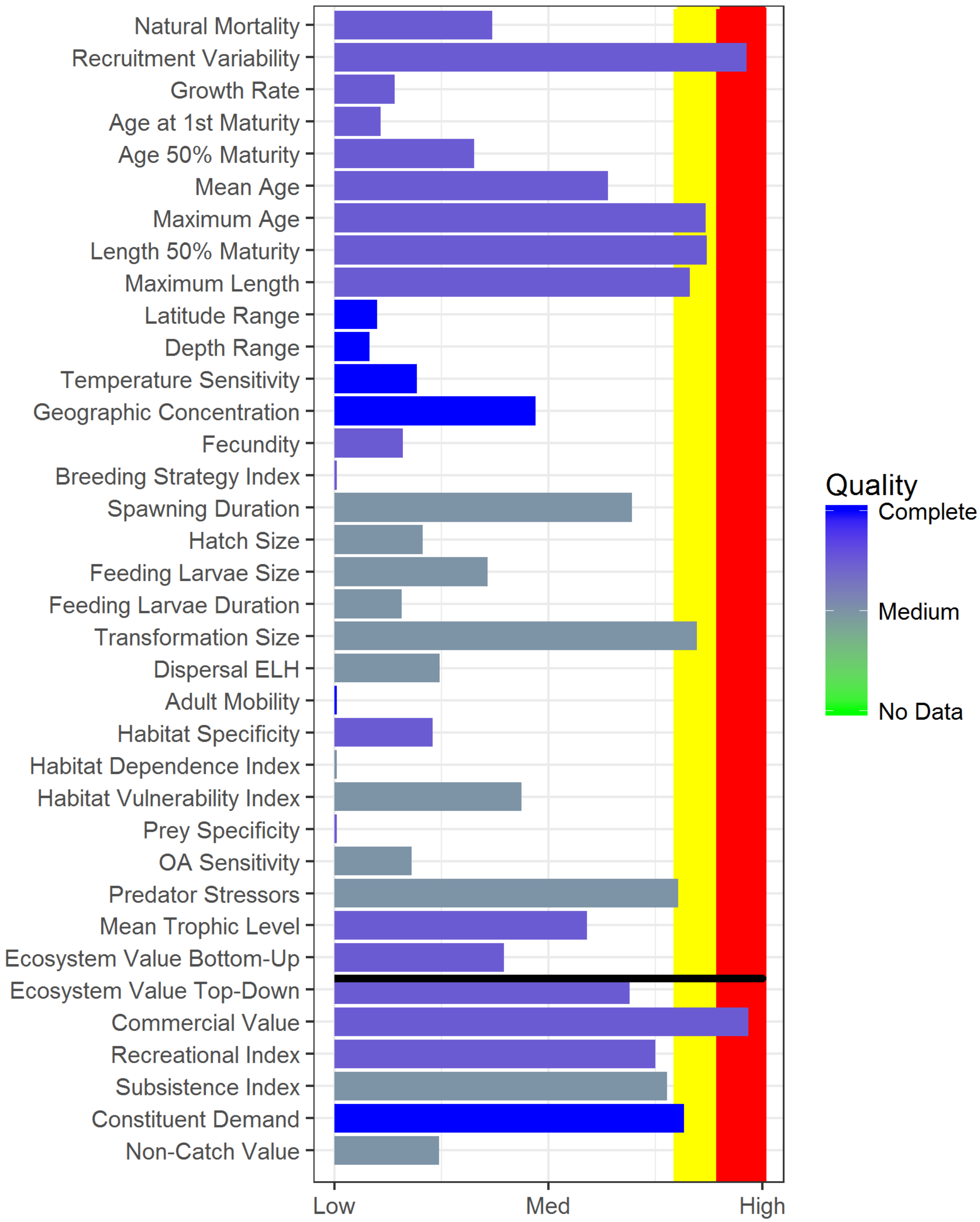


Figure 1. Baseline metrics for sablefish graded as percentile rank over all groundfish in the FMP. Red bar indicates 90th percentile, yellow bar indicates 80th percentile. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Prep*, for more details on the metric definitions). Ecosystem indicators above and socioeconomic indicators below the horizontal black line.

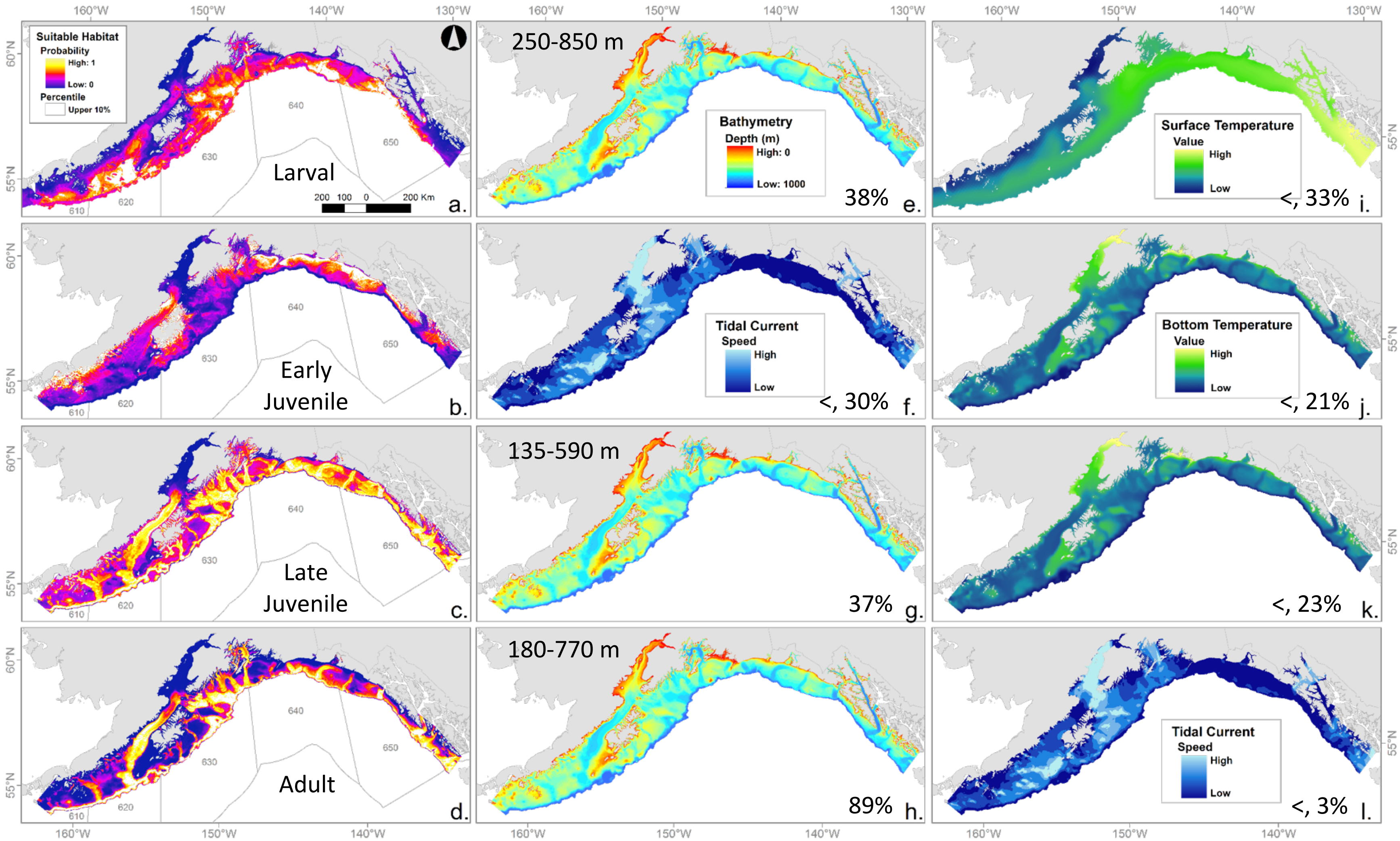


Figure 2. Sablefish probability of suitable habitat by life stage (a = larval, b = early juvenile, c = late juvenile, and d = adult) with corresponding predictor habitat variables representing the highest (e = depth, f = tidal current speed, g = depth, h = depth) and second highest contribution (i = surface temperature, j = bottom temperature, k = bottom temperature, and l = tidal current speed). Upper 10 percentile of suitable habitat is shown in white within the probability of suitable habitat range (yellow to purple). Sign (<, >, <>) of the deviation from mean direction and the percent of contribution to predict suitability provided for each non-depth variable. Range provided for depth. See Shotwell et al., *In Review* for more details.

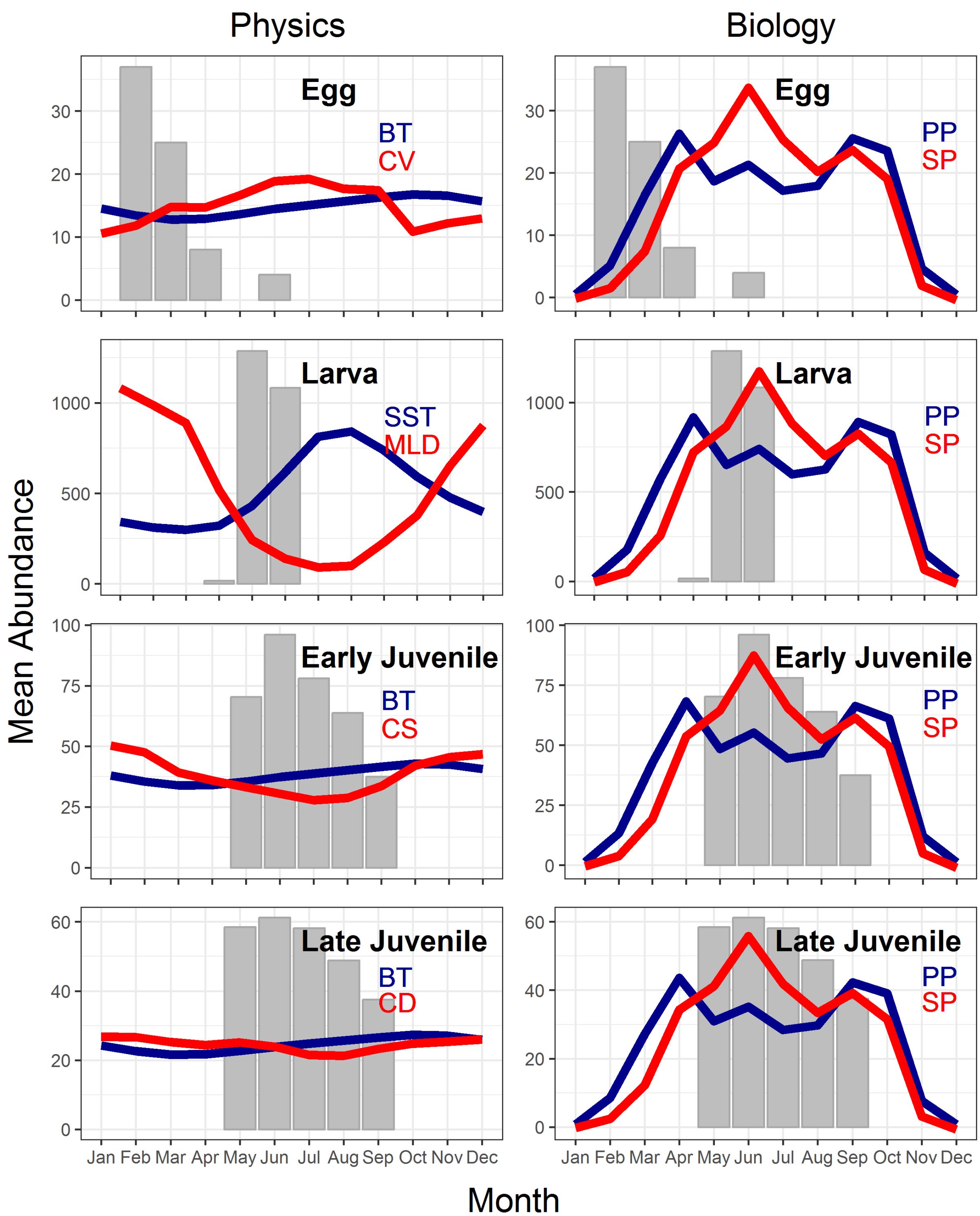


Figure 3. Sablefish average abundance by month over all years available for the egg, larval, early juvenile, and late juvenile stages. Relevant climatologies from the hydrographic and plankton models provide physical and biological indices (SST = surface temperature, MLD = mixed layer depth, BT = bottom temperature, CD/CS/CV are current direction, speed and variability, PP/SP are primary and secondary productivity, see Laman et al., 2017, Gibson et al., *In Press*, for more details).

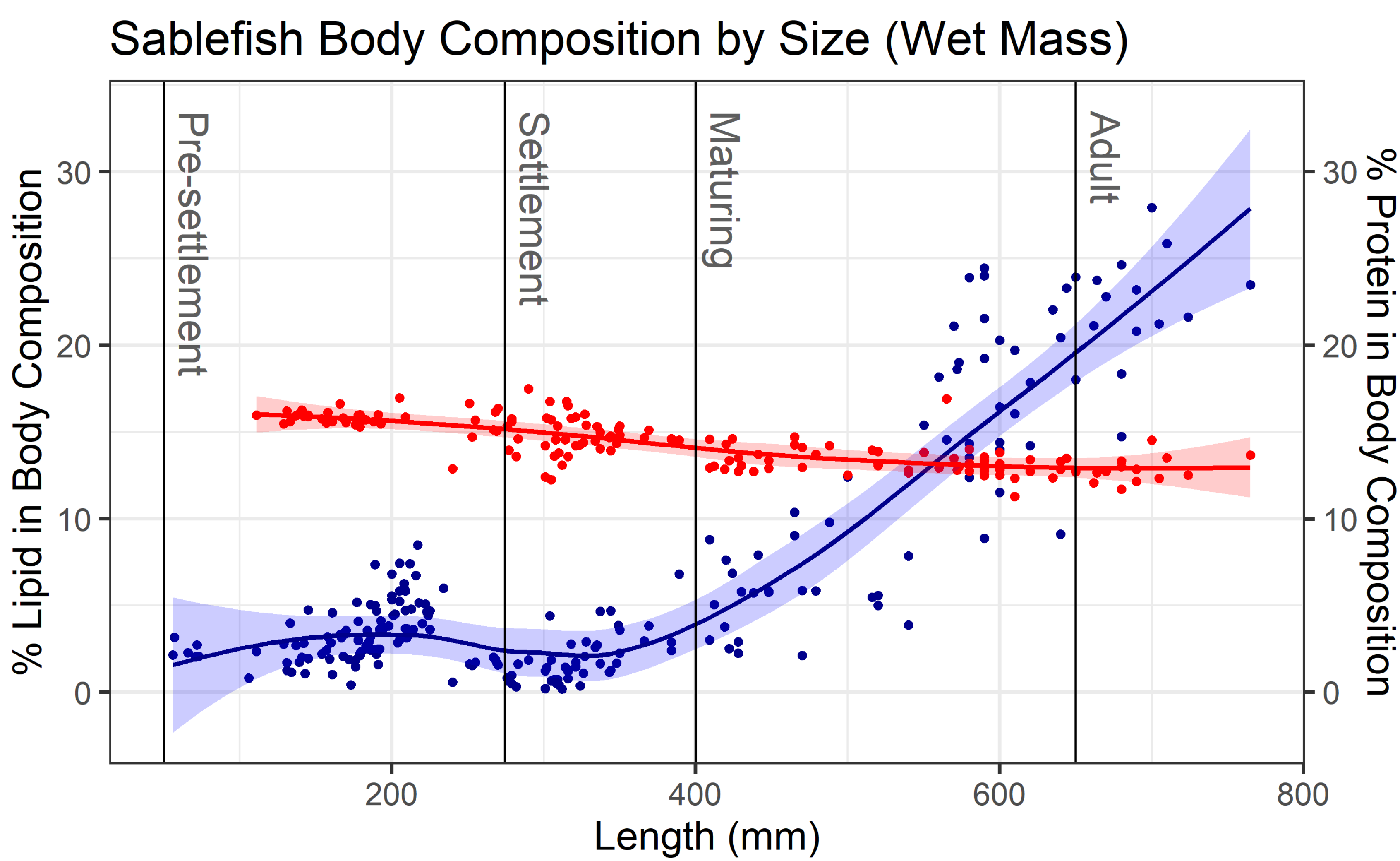


Figure 4. Percent body composition by length (mm), blue dots are % lipid by size, red dots are % protein by size and lines represent smoother (loess) for trend visualization. Horizontal lines depict the average size at different life stage transitions and the adult transition is based on size at 50% female maturity.

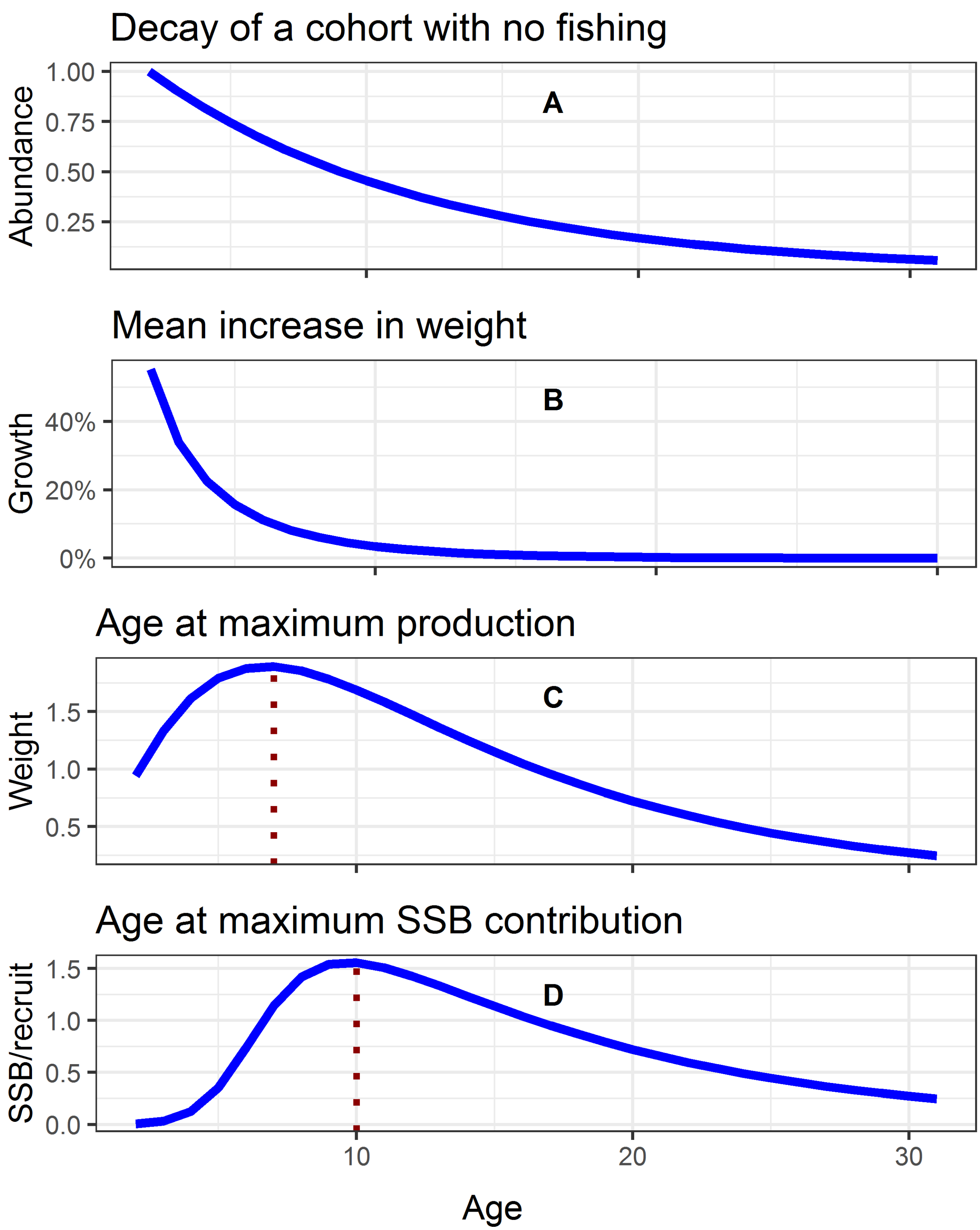


Figure 5. Illustrations of at what age spawning biomass, and production would be maximized under equilibrium conditions.

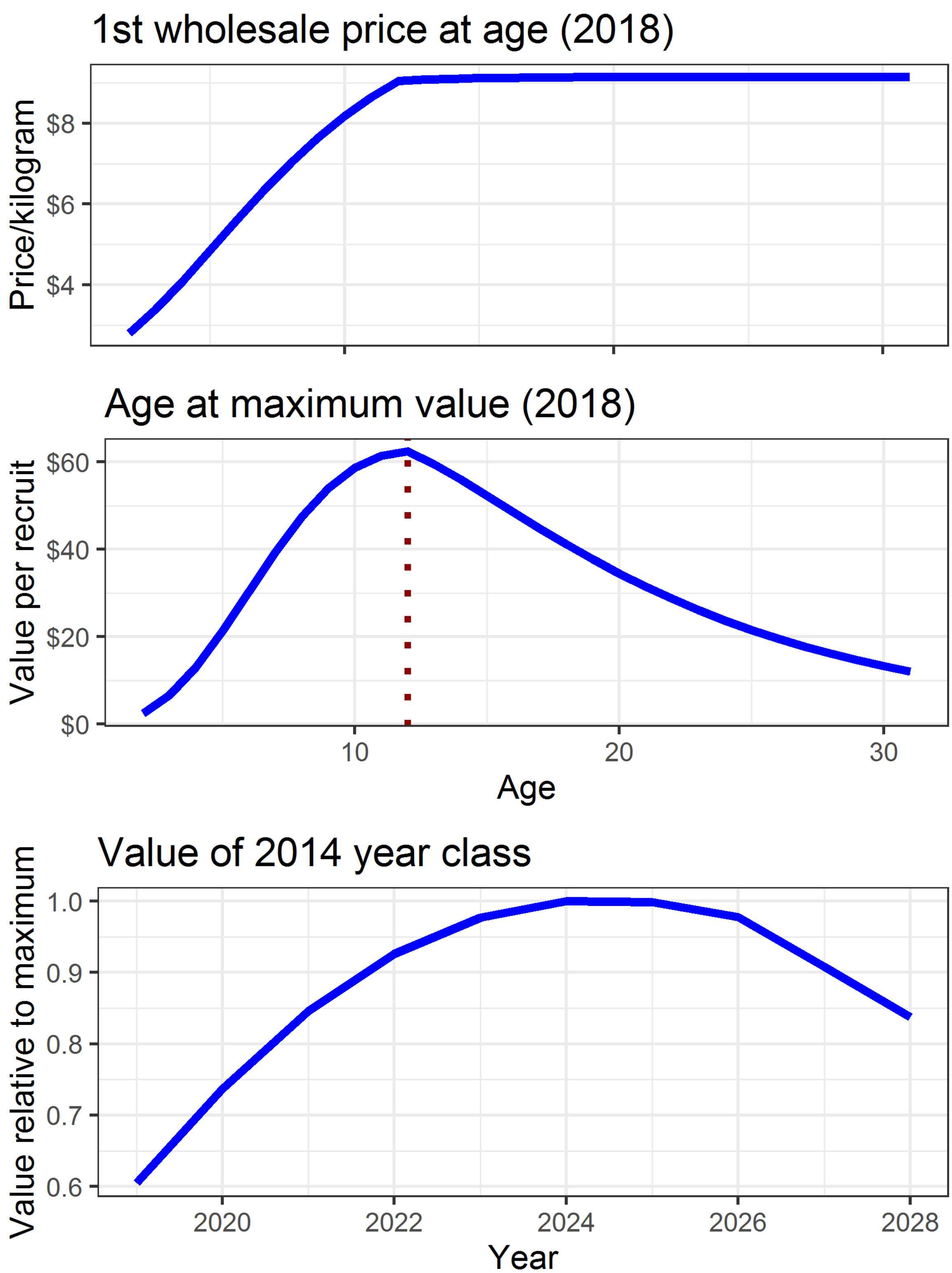


Figure 6: Top graph is an approximate value per kilogram by age. Middle graph is the value per kilogram multiplied by average weight for a given age. Red dotted line shows approximate age at peak value (age 12). Bottom graph shows when the 2014 year class maximizes in value under only natural mortality. Pricing data from AKFIN (www.akfin.org) as of August 2018.

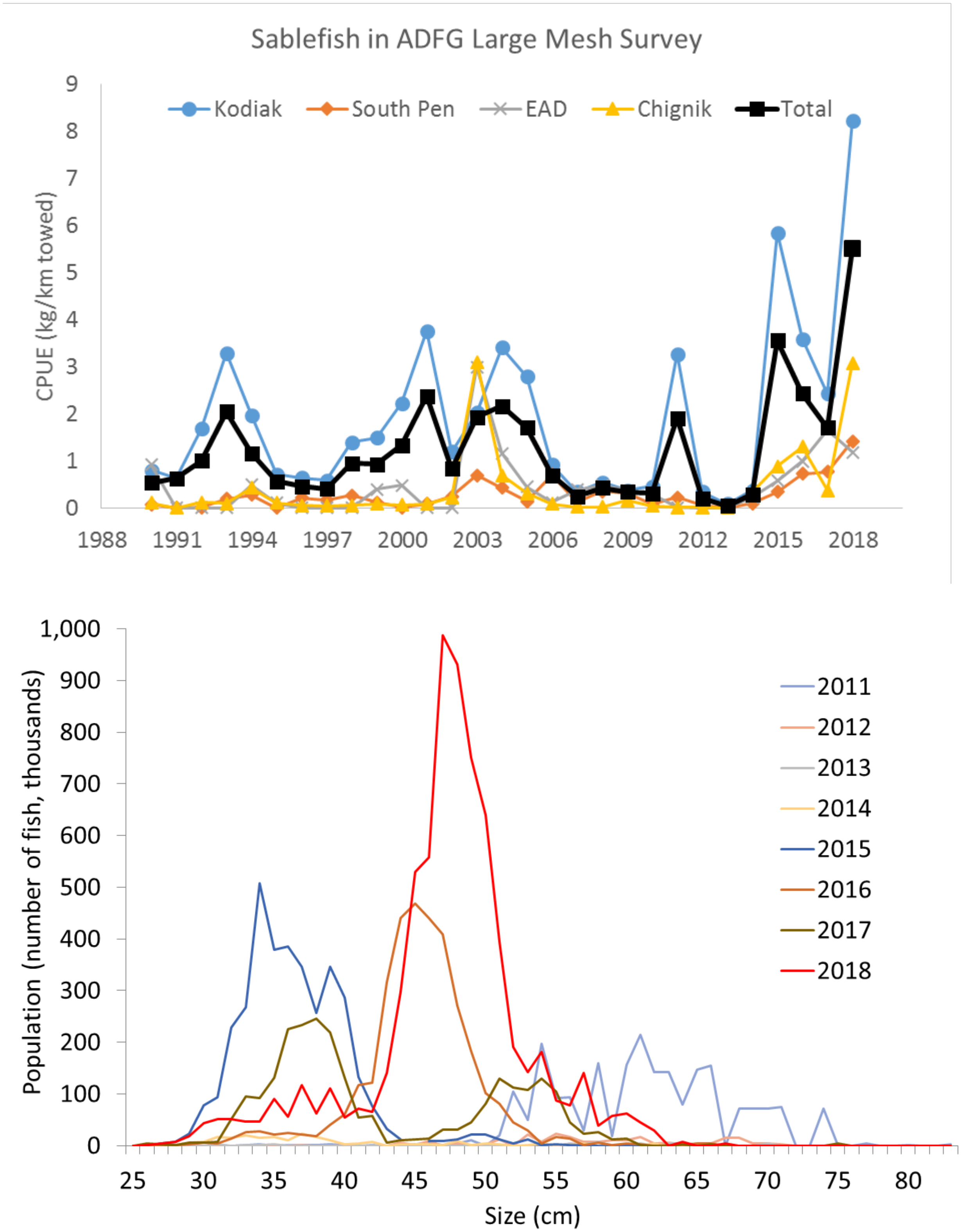


Figure 7: Catch-per-unit-effort (top graph) from 1990 to present and length (cm) composition (bottom graph) from 2011 to 2018 of sablefish in the ADF&G large-mesh survey.

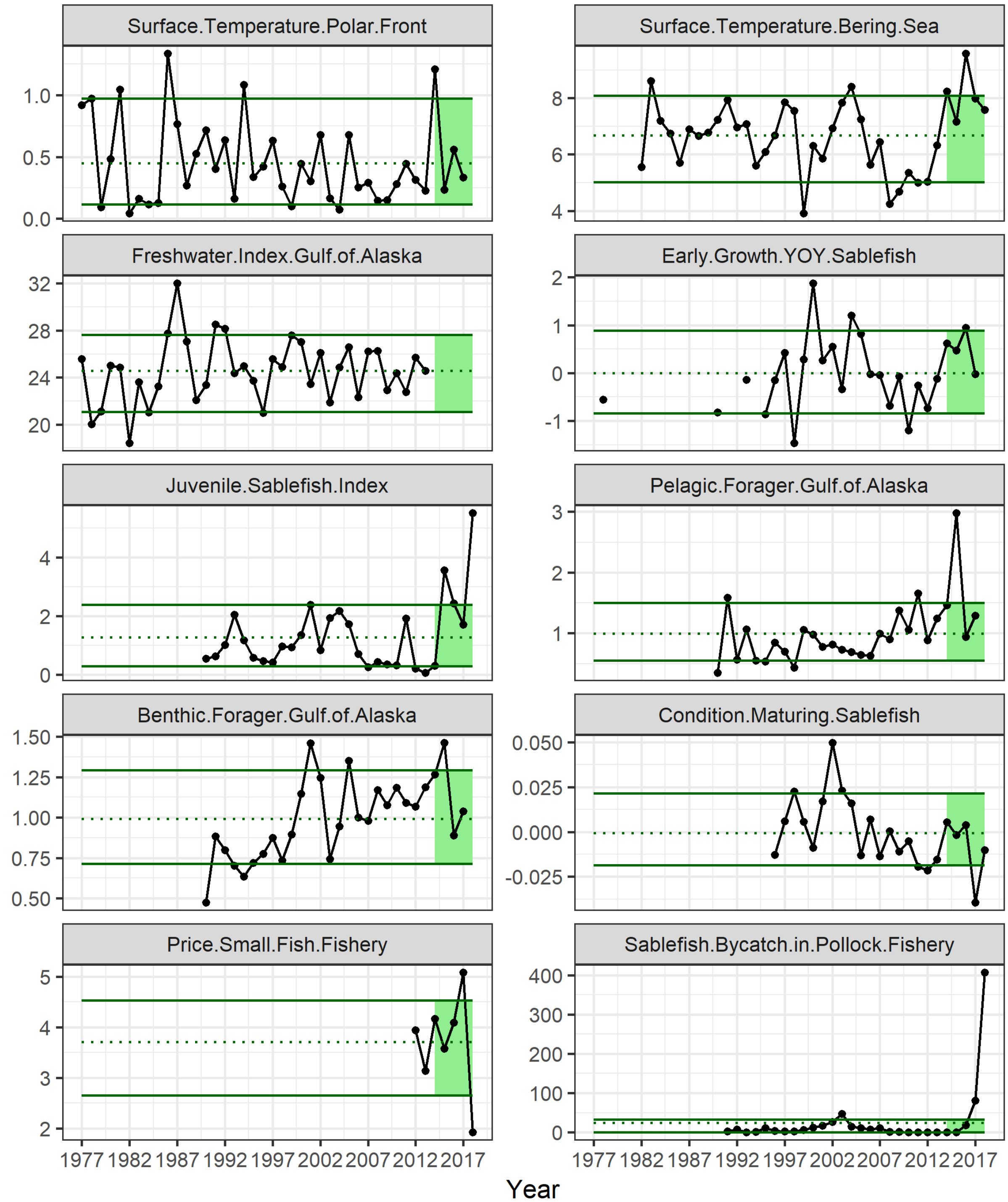


Figure 8. Selected indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent five years for trend, variance, and traffic light analysis.

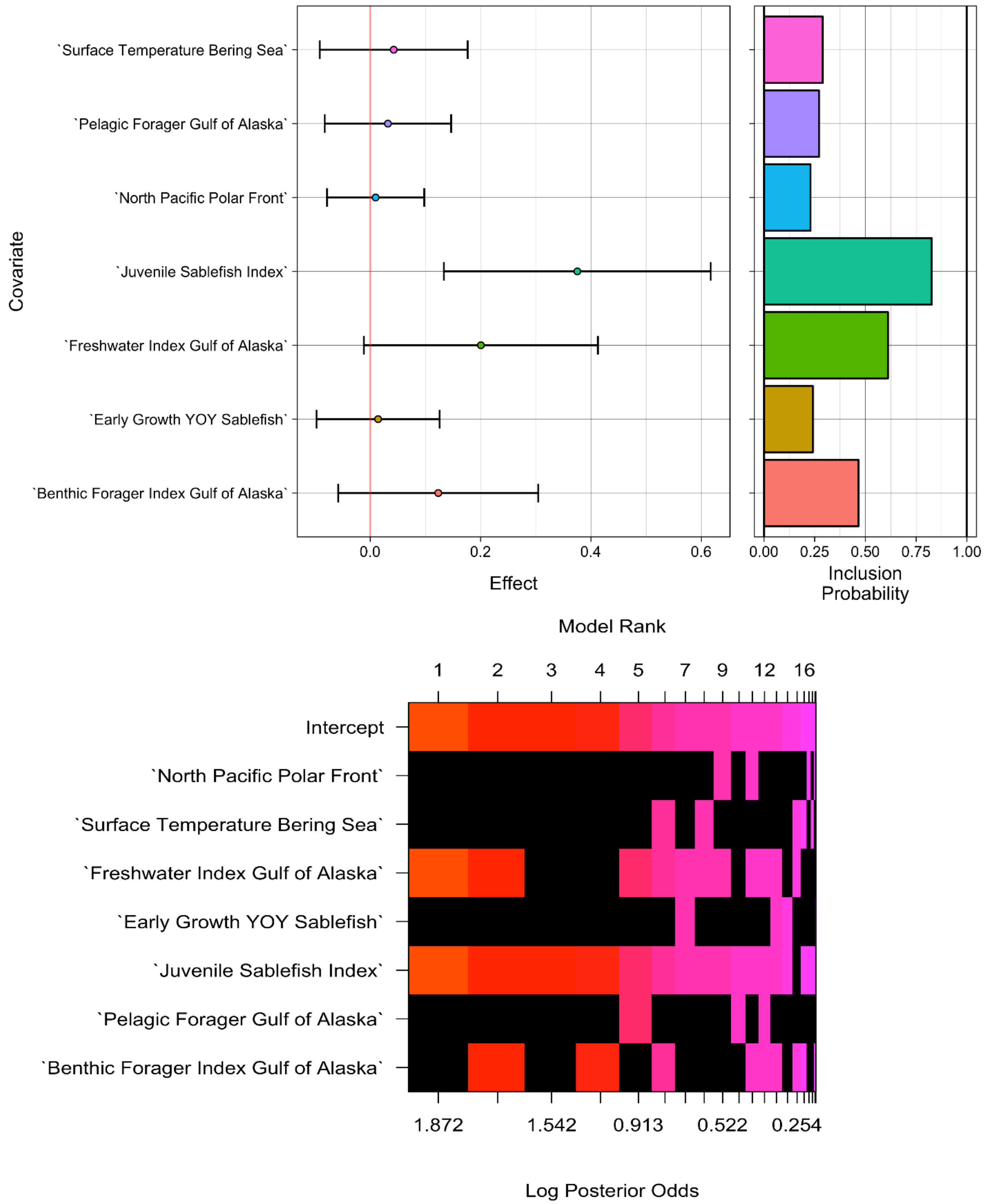
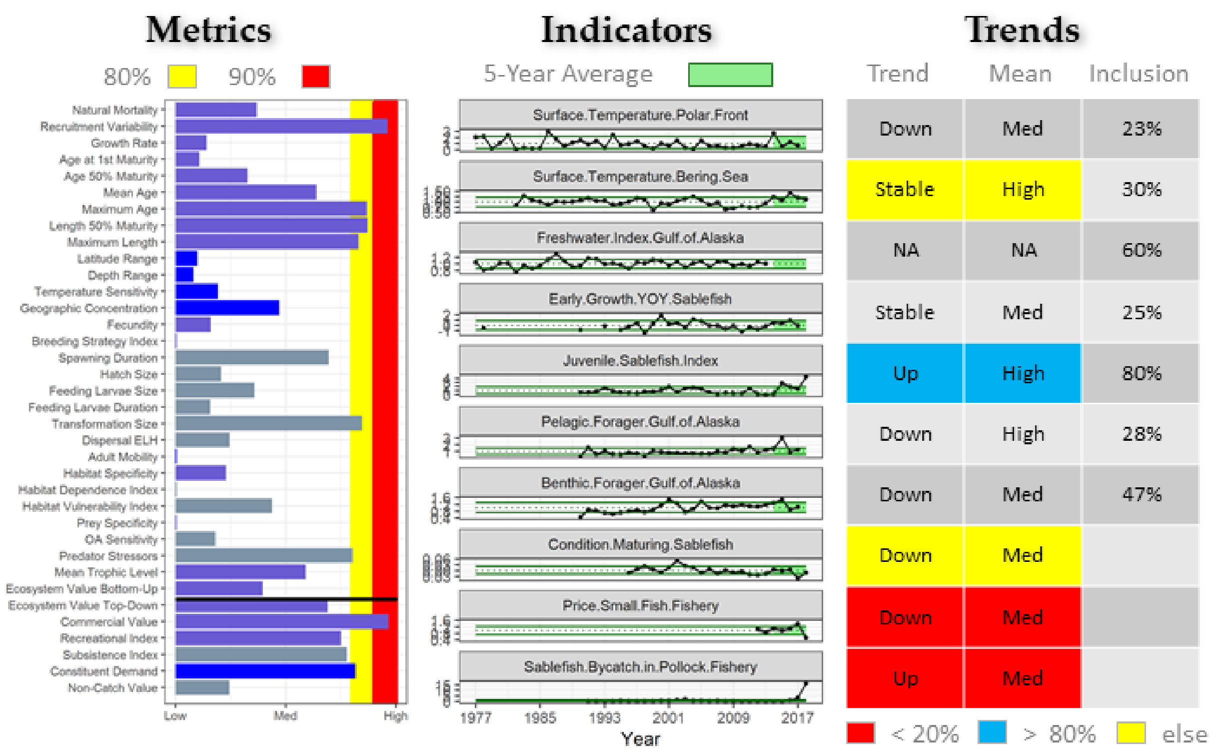


Figure 9: Bayesian adaptive sampling output showing the mean relationship and uncertainty (1 standard deviation) with log sablefish recruitment, in each estimated effect (left top graph), and marginal inclusion probabilities (right top graph) for each predictor variable, and model rank by covariate (bottom graph). Covariates included in the ranked models have a colored cell, while covariates not included have a black cell. Top ranked models start at the left and move to lower ranking at the right.

Sablefish (*Anoplopoma fimbria*)

Classification	Catch	Size/Age	Abundance	Life History	Ecosystem
Current / Target	5/5	5/5	4/5	4/5	4/4

- Data rich stock near target in all classification categories, stock recommended for ESP (summary below)



Considerations

- High recruitment variability and low productivity metrics coupled with rapid growth in thermal thresholds, larval match to stratification and prey resources, first overwinter energetic costs, optimal foraging habitat, and juvenile body condition resulted in 8 indicators for monitoring
- High economic value and constituent demand metrics coupled with instability in small fish price and incidental catch in fisheries at the sablefish northern range resulted in 2 indicators for monitoring
- Ecosystem trend modeling revealed average to good conditions for larvae/juveniles of the 2016 year class but potentially suboptimal foraging conditions for maturing juveniles of the 2014 year class while economic trend modeling revealed substantially reduced small fish prices in 2018 and increased incidental catch in the BSAI fisheries in 2017 and 2018

ESP: https://www.afsc.noaa.gov/REFM/Docs/2018/GOAsablefish.pdf, Contact: Kalei.Shotwell@noaa.gov

Figure 10: Example one-page template for conducting a partial ESP of sablefish

Appendix 3D. Sablefish apportionment

K.H. Fenske, D.H. Hanselman, C. Cunningham, C.R. Lunsford, C. Rodgveller

September 2018

At the December 2017 SSC meeting, the SSC requested that a review be conducted of the method to be used for spatial allocation (apportionment) of sablefish ABC and OFL. This document summarizes progress and outlines planned analyses to evaluate alternative options for apportionment of sablefish ABC/OFL to IFQ holders by management area.

> ***"The SSC approved the authors and Joint Plan Team's recommendations for Tier, ABC and OFL. These recommendations include adjustments for the magnitude of the 2014 year-class and whale depredation.*** *The authors and the JPT agreed that the fixed area apportionments used in 2016 should be applied again this year. The author noted that the CIE reviewers concluded that continued use of the fixed area approach did not appear to pose a conservation concern. The SSC notes that the authors have indicated that a complete review of the method to be used for spatial allocation will be forthcoming. The SSC requests conduct of this analysis in 2018."*

As specified in the 2013 (November) Groundfish Plan Team minutes,

> *"Apportionment of the sablefish ABC has two goals: 1) to take into account the actual changes in the distribution of the population, and 2) to reduce interannual variability in area ABCs. These goals are not being met because recent changes in apportionment are too large to reflect actual distributional shifts. The problem is thought to be due to the approach not taking into account measurement error, leading to rapid changes in some area estimates and large swings in apportionments. As an example, the status quo apportionment would increase the 2014 Bering Sea ABC by 20% although ABCs for all the other areas would decline by 15–20%. There is higher uncertainty in the data for the Bering Sea because this area is only surveyed every other year and fishery CPUE is estimated with limited observer and logbook data. A possible solution is to use a random effects model, which the authors will explore next year. Two options were proposed for this year's assessment: 1) go with the model ABC and standard apportionment, or 2) use the model ABC and fix apportionment at the same values as used last year and apply a 15% decrease across the board, which the authors recommended. This would be an interim measure to smooth ABC variability until more analyses are completed."*

The 2014 apportionment of recommended ABC to management areas was fixed at 2013 ABC apportionment values. Each year since, both 'status quo' (exponentially weighted moving average) and 'fixed' values (fixed at 2013 proportions) have been presented in the SAFE chapter, and the 'fixed' values have been used in apportionment. In 2018, two projects regarding sablefish apportionment have been completed and a third, more comprehensive project has been initiated. The completed projects are 1) a Spatial Processes and Stock Assessment Methods (SPASAM) workgroup project, which applied spatial simulations to a sablefish-like species, and 2) a second project which provided a 'retrospective' analysis of sablefish apportionment. A more comprehensive project, which is in progress, is 3) a sablefish Management Strategy Evaluation focusing on apportionment.

SPASAM workgroup spatial processes simulation (manuscript in prep)

The SPASAM group is a multi-Center collaboration comprised of Katelyn Bosley (NRC Post-Doc), Aaron Berger (NWFSC), Jon Deroba (NEFSC), Dan Goethel (SEFSC), Dana Hanselman (AFSC), Brian Langseth (PIFSC), and Amy Schueller (SEFSC). The SPASAM project modeled spatial processes for three test species (menhaden, hake, and sablefish). The simulation study using a sablefish-like operating model parameterization, found that a wide-range of fishing mortality combinations across management regions achieved >90% of the long-term maximum system yield when simulation accounted for movement between regions. When the stock was considered to be a meta-population with little or no-movement, the range of optimal fishing mortalities for each region became much more restricted, with a general tendency to fish harder in the areas with the oldest selectivity-at-age. Since sablefish are known to have a high level of interchange between management areas, this work suggests that socioeconomic factors may be more important in determining harvest apportionment between regions, because high yields can be achieved by a number of apportionment strategies.

Retrospective apportionment

Each year the sablefish stock assessment model estimates ABC and OFL values that are subsequently apportioned to IFQ shareholders in six management regions. A simple method for comparing the suite of alternative apportionment alternatives is to apply each alternative option to the annual ABCs estimated by past assessments. This approach can help highlight the underlying characteristics of each apportionment alternative (e.g., interannual variability, spatial variability). A caveat to this retrospective approach is that there is no feedback between apportioned harvest and the underlying fish population. The status of the stock and historic ABCs were a result of the actual strategy applied and not the apportionment alternative being examined. As such these retrospective analyses only intended illustrate differences in annual apportionment, not evaluate the relative performance of alternatives.

We have applied a suite of apportionment options identified by the sablefish stock assessment authors. Further refinement of apportionment alternatives will continue with input from stakeholders. Apportionment options were applied, retrospectively, to sablefish ABC values from 2005-2018 stock assessments. The apportionment options presented here are a subset of the options that may be selected for use in the full apportionment MSE that is under development. Retrospective apportionment alternatives include:

Name of option	Description	Rationale
Status quo	5-yr exponentially weighted moving average of fishery and survey indices; survey weight is 2x fishery weight	This is the original, NPFMC-approved method
Static	The apportionment proportions from the 2013 assessment that have been applied as fixed proportions for 2014-2018	This has been used for several years to reduce interannual variability
Equal	Each region receives 1/6 of the ABC	A simple option to use as a basis for comparisons
Equilibrium	Based on the stationary distribution of the movement rates (using approximate but realistic values for EY and WY until a 6 area movement model is configured. The EG proportion is 0.372 (EY+WY), split 37% to 63% for WY and EY/SEO for now)	Will provide interannual stability, has biological basis
Partially fixed	BS and AI receive 10% of the ABC each, WG, CG, WY, and EY are apportioned based on status quo	By fixing the BS and AI at 10% (or another value), the areas that generally have high interannual variation are fixed, ideally stabilizing the other management areas. Ten percent is a reasonable placeholder value; other values based on historical proportions of apportionment may be explored.
Non-exponential status quo	A 5-yr moving average of fishery and survey indices	Will reduce interannual variability by reducing high weights on recent years by using 5 year, unweighted mean
Biomass based	Based on the proportion of the estimated biomass in each region from the most recent year of the NMFS sablefish longline survey	Uses most current biomass estimates only and may be most adaptable to rapid changes in biomass (spatially and overall)
Exponential, fishery only	Similar to ‘status quo’ option but using fishery index only	Examines the impact of a single data source (fishery)
Exponential, survey only	Similar to ‘status quo’ option but using survey index only	Examines the impact of a single data source (survey)
Maturity based, non-exponential	Based on the proportion of females in each region larger than the length at 50% maturity (~65.1 cm) using longline survey data; BS and AI data carried forward from previous sampled year in the ‘off’ sampling year, 5-year running average	This approach attempts to approximate the relative distribution of both the spawning biomass and higher-valued fish
Maturity based, exponential	Based on the proportion of females in each region larger than the length at 50% maturity (~65.1 cm) using survey data, BS and AI data carried forward from previous sampled year in the ‘off’ sampling year, 5-year exponentially weighted running average	This approach attempts to approximate the relative distribution of both the spawning biomass and higher-valued fish, but would be more focused on current distribution of female SSB
Random effects	Apportionment to region based on the proportions of biomass estimated by the RE model applied to the longline survey, using 0.05 CV	This option is used for apportionment in some other species

Apportionment options that may be considered for the MSE but are not used in retrospective apportionment analyses:

Penalized	ABC cannot increase or decrease for a given area by more than 5% (or other specified value)	Any value can be chosen for the cap on interannual change, however, this option could be in conflict with the established NPFMC harvest control rule
Measurement error	Interannual changes in apportionment for an area are tied to the CV of the survey	Changes with high CVs should be given less weight in the annual apportionment process (e.g., the Bering Sea area consistently has higher larger changes with a higher CV than areas in the GOA)

It is not possible to examine regional biological sustainability via 'retrospective' type analyses of apportionment because of the lack of feedback in the ABC-setting process. However, interannual stability in ABC and a minimum threshold for regional ABC have been discussed as potential performance metrics and can be examined for previous years. Full tables of annual ABC values for each retrospective apportionment option are presented in Appendix 3D.1. The proportion by area of ABC values for each retrospective apportionment option are in Appendix 3D.2.

For these alternative apportionment options, we examined 'stability' in ABC for each apportionment option as the proportion of years and management areas where the absolute change in ABC between adjacent years was less than *X*% (Table 1); a higher *X%* is representative of a higher tolerance for larger interannual change in ABC. We examined stability threshold values *X* ranging from 1-50% for illustrative purposes. For example, for the Status Quo apportionment option the absolute interannual change in ABC is less than 1% for only 6% of years and management areas (relatively unstable when tolerance for interannual change is low), but all years and areas have less than a 50% change in ABC from year to year. Generally speaking, higher values at each threshold for interannual ABC variation (columns, Table 1) are 'better', indicating a greater proportion of year-area combinations would have resulted in less variation.

At the 5% threshold for interannual change in ABC, the Non-exponential-, Maturity-, and Exponential Maturity-based apportionment options were the most stable when looking retrospectively at ABC values; about 1/3 of area-year combinations had less than 5% change in ABC between years (Table 1). Most apportionment options were not very stable when the threshold of acceptable interannual change was below 15%. The Biomass-based and Random Effects apportionment options, where ABC/OFL is apportioned to management areas using information from the longline survey biomass estimates, were the least stable under most of the interannual change thresholds examined and is likely undesirable from a stakeholder perspective. However, this suggests that the Biomass-based and Random effects options might also be the most responsive to changes in biomass, if that was the primary goal. Comparison of the Status quo and Static apportionment methods shows that the Static method is generally more stable (more area-years fall under the specific threshold) than the Status quo method, which is expected and was the desired outcome when moving to the Static method.

Table 1. The proportion of year (2005-2018) and management area combinations where the absolute value of the change in ABC between two adjacent years for each management region is less than the % indicated (1% to 50%). A higher cell value means that apportionment option is more stable, and less subject to interannual changes in ABC. Color scale is by column; green shades have more interannual stability, yellow and orange are moderate, and red is the least stable.

	Maximum absolute interannual change in ABC:							
Apportionment Method:	**1%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**50%**
Status quo								
Static								
Equal								
Equilib								
Partially fixed								
Non-exponential								
Biomass based								
Exp Fishery wt								
Exp Survey wt								
Mature								
Exp Mature								
RE model								

The average values of absolute interannual change for each management area and apportionment method are also informative (Table 2). The Static, Equal, Equilibrium, and Non-exponential options have the lowest interannual variation. The Biomass based, Random effects, Exponential survey, and Exponential maturity options are generally the most unstable for many management areas.

Table 2. Average absolute interannual percent change in ABC across years 2005-2018, for each management area and apportionment method.

	Management area					
Apportionment Method:	**Bering Sea**	**Aleutian Islands**	**Western GOA**	**Central GOA**	**West Yakutat**	**East Yakutat/SEO**
Status quo	12%	10%	14%	12%	11%	9%
Static	9%	9%	9%	9%	9%	9%
Equal	9%	9%	9%	9%	9%	9%
Equilib	9%	9%	9%	9%	9%	9%
Partially fixed	9%	9%	14%	10%	10%	8%
Non-exponential	10%	10%	9%	9%	10%	8%
Biomass based	38%	17%	36%	17%	18%	14%
Exp fishery wt	10%	10%	9%	12%	13%	11%
Exp survey wt	17%	12%	17%	12%	12%	8%
Mature	10%	12%	12%	10%	10%	7%
Exp Mature	19%	9%	18%	12%	10%	9%
RE model	38%	16%	35%	16%	17%	13%

A minimum threshold for ABC in each region may be another management target of interest to stakeholders and managers. Table 3 shows a range of potential minimum per-region ABC values and the proportion of years and areas where the minimum value is obtained, for each of the retrospective apportionment options. All of the apportionment options presented maintain ABC levels above 500 tons for all years and areas examined. No apportionment method results in an ABC above 2000 tons in 100% of years and areas.

Table 3. Proportion of year (2005-2018) and management areas combinations where the minimum ABC is greater than the specified minimum threshold *X* (*X* ranges from 100-2500 tons).

	Mean proportion of years and areas that ABC is greater than *X* tons:								
Apportionment Method:	**100**	**250**	**500**	**1000**	**1250**	**1500**	**1750**	**2000**	**2500**
Status quo	100%	100%	100%	100%	99%	90%	81%	65%	47%
Static	100%	100%	100%	100%	99%	87%	72%	56%	36%
Equal	100%	100%	100%	100%	100%	100%	100%	92%	69%
Equilib	100%	100%	100%	100%	97%	90%	83%	67%	45%
Partially fixed	100%	100%	100%	100%	97%	87%	67%	55%	37%
Non-exponential	100%	100%	100%	100%	99%	90%	76%	65%	50%
Biomass based	100%	100%	100%	97%	92%	86%	73%	64%	45%
Exp Fishery wt	100%	100%	100%	100%	96%	90%	77%	68%	47%
Exp Survey wt	100%	100%	100%	100%	99%	91%	81%	60%	47%
Mature	100%	100%	100%	97%	85%	71%	58%	55%	29%
Exp Mature	100%	100%	100%	96%	87%	67%	59%	53%	32%
RE model	100%	100%	100%	97%	92%	87%	73%	64%	45%

Based on these simple retrospective analyses, it's evident that there will be tradeoffs between stability and maintaining a minimum level of catch in each region, and these analyses don't yet include other more complex socioeconomic or biological factors for consideration of performance metrics. These will be examined to the extent possible in the full apportionment MSE that is under development.

Apportionment MSE

Work has begun to develop a generalized, six-area, age-structured, sex-specific Operating Model (OM) which will be used to generate 'true' sablefish data for a Management Strategy Evaluation under several alternative movement scenarios. This will allow us to assess the sensitivity of apportionment outcomes to alternative movement rates among areas (states of nature). The OM will be parameterized based on demographic parameters estimated by the current assessment model (i.e. our best picture of stock dynamics). Two Estimation Models (EMs) have been developed; one is a single area, panmictic model similar to the model currently used for management, the other is a three area sablefish assessment model splitting management areas into the western area (BS/AI/WG), Central Gulf area, and Eastern Gulf area. Having two EMs to compare allows us to identify the key tradeoffs to alternative methods of apportionment under two different stock assessment models.

This work is focused around two questions:

1. What are the tradeoffs among the different apportionment options and is there one (or more) option that maintain regional and overall biomass at or above B40 reference point, with acceptable stability in ABC for stakeholders?
2. What are the tradeoffs in using a single area EM vs a spatial EM with respect to how well the EM describes the 'true' underlying population?

A preliminary list of management objectives and performance metrics have been identified that will serve as the basis for examination of tradeoffs between each candidate apportionment method. There will be ongoing discussion with stakeholders and managers to identify specific values for threshold and targets used in performance metrics, and to identify additional objectives and performance metrics.

Management Objective	Performance Metric
Reduce variation in regional ABC changes from year to year.	Percent of time ABC apportioned to a region changes by no more than *X*%.
Maintain a sustainable population of sablefish for all Alaska	Percent of time spawning biomass is above B40% and B35% for management areas summed.
Maintain a sustainable population of sablefish in each management area	Percent of time spawning biomass is above a specific level (such as B40% or other threshold) for each region.
Maintain a minimum level of harvest ABC in every region.	Percent of time ABC in region *r* is greater than specified threshold *x*.
Minimize fishing on immature fish.	Proportion of the total population that is larger than the length at 50% maturity for each region.

Ongoing and iterative discussions with stakeholders will be a critical component of this project. In March 2018, stock assessment staff attended the annual Alaska Department of Fish and Game (ADFG) sablefish meeting in Sitka, AK and gave a short presentation on progress of the sablefish apportionment MSE. This presentation included a brief overview of Management Strategy Evaluation, covered the potential apportionment options to be tested, the objectives and performance measures that will be analyzed in an MSE, and presented some preliminary results on the 'apportionment retrospective' analyses. Based on these initial discussions with a small subset of stakeholders, we will work on restructuring how these complex topics are presented to maximize stakeholder understanding of the objectives of the MSE process and foster stakeholder buy-in and participation. We will also continue to seek input from stakeholders and managers regarding management objectives and ways to measure performance of the apportionment options to ensure they fully reflect stakeholder objectives.

Timeline

We have mapped out a tentative timeline for completion of this project:

November 2018: Continue static apportionment, while presenting standard (status-quo) apportionment for reference.

Spring 2019: Meet with stakeholders in-person or over video conference to further refine objectives and metrics to test.

September 2019: Update Plan Team with preliminary results of simulations for feedback.

November 2019: Continue with static apportionment unless directed to adopt something early from preliminary results.

2020: Finalize MSE, recommend alternatives based on desired properties of apportionment for potential adoption for 2021 fishing season.

Appendix 3D.1. Apportionment by management region (in tons) for each 'retrospective' apportionment method applied to ABC values for 2005-2018.

Apportionment method:	**Area**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Status quo	BS	2697	2969	2976	2936	2792	2852	2885	2284	1632	1940	2254	1860	1902	2224
Status quo	AI	2899	2677	2570	2343	2138	2011	1870	2024	2111	1775	1821	1611	2243	2686
Status quo	WG	2364	2651	2442	1910	1638	1714	1605	1831	1776	1353	1419	1125	1423	1533
Status quo	CG	6971	6609	6233	5414	4898	4385	4610	5641	5457	4325	3851	3349	3594	4201
Status quo	WY	2243	2089	2082	1886	1579	1448	1849	2000	1784	1412	1401	1349	1585	1765
Status quo	EY/SEO	3827	4005	3797	3541	3035	2820	3221	3469	3469	2916	2911	2501	2763	2970
Equal	BS	3500	3500	3350	3005	2680	2538	2673	2875	2705	2287	2276	1966	2252	2563
Equal	AI	3500	3500	3350	3005	2680	2538	2673	2875	2705	2287	2276	1966	2252	2563
Equal	WG	3500	3500	3350	3005	2680	2538	2673	2875	2705	2287	2276	1966	2252	2563
Equal	CG	3500	3500	3350	3005	2680	2538	2673	2875	2705	2287	2276	1966	2252	2563
Equal	WY	3500	3500	3350	3005	2680	2538	2673	2875	2705	2287	2276	1966	2252	2563
Equal	EY/SEO	3500	3500	3350	3005	2680	2538	2673	2875	2705	2287	2276	1966	2252	2563
Part.fixed	BS	2100	2100	2010	1803	1608	1523	1604	1725	1623	1372	1366	1180	1351	1538
Part.fixed	AI	2100	2100	2010	1803	1608	1523	1604	1725	1623	1372	1366	1180	1351	1538
Part.fixed	WG	2592	2912	2703	2156	1888	2011	1834	1950	1846	1480	1626	1280	1651	1808
Part.fixed	CG	7602	7231	6889	6126	5655	5150	5251	5966	5650	4741	4379	3775	4137	4945
Part.fixed	WY	2440	2280	2298	2135	1820	1704	2094	2143	1863	1549	1596	1525	1828	2072
Part.fixed	EY/SEO	4166	4376	4189	4007	3501	3319	3653	3741	3624	3207	3324	2856	3191	3479

Apportionment method:	Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Biom.based	BS	2905	3392	3188	3484	3084	2873	3206	968	868	2885	2873	1485	1563	2017
Biom.based	AI	2431	2366	2585	2224	2088	1986	1495	1897	2460	1736	1719	1643	2821	3156
Biom.based	WG	2255	3464	2490	1554	1778	2043	1426	2190	1929	1167	1734	1012	1775	1616
Biom.based	CG	7997	6189	6495	5392	5292	4461	4619	7297	5947	4153	3635	3703	3585	4704
Biom.based	WY	2216	1701	2071	1933	1386	1337	2105	1958	1542	1193	1188	1655	1627	1718
Biom.based	EY/SEO	3195	3888	3270	3442	2451	2531	3188	2940	3484	2588	2508	2297	2138	2169
Exp.Surv.wt	BS	2810	3143	3098	3126	2939	2839	3097	2168	1453	2055	2464	1753	1785	2100
Exp.Surv.wt	AI	2833	2592	2533	2249	2028	1952	1783	1904	2129	1768	1723	1572	2328	2891
Exp.Surv.wt	WG	2666	3071	2696	1994	1758	1881	1683	1979	1908	1400	1544	1187	1564	1682
Exp.Surv.wt	CG	7505	6844	6537	5634	5177	4641	4768	6199	5905	4557	4083	3664	3867	4523
Exp.Surv.wt	WY	2004	1835	1925	1827	1519	1376	1788	1943	1674	1305	1262	1366	1588	1759
Exp.Surv.wt	EY/SEO	3181	3516	3310	3200	2659	2541	2921	3056	3160	2636	2580	2252	2378	2425
Exp.Mature	BS	2087	1994	2375	2521	1555	1161	993	913	1260	1367	1597	1474	1156	985
Exp.Mature	AI	1599	1432	1443	1418	1413	1438	1383	1387	1337	1205	1235	1082	1834	2415
Exp.Mature	WG	1994	2335	2095	1380	1302	1559	1494	1620	1388	1081	1215	979	1420	1476
Exp.Mature	CG	10610	10004	9108	7810	7415	6538	6346	7407	6785	5307	4905	4127	4207	5346
Exp.Mature	WY	2325	2310	2270	2175	2106	2150	2878	2840	2406	1872	1805	1743	2181	2469
Exp.Mature	EY/SEO	2385	2925	2809	2727	2290	2385	2946	3083	3054	2890	2900	2391	2710	2690

Appendix 3D.2. Proportion of ABC by area and year, for each 'retrospective' apportionment type.

Apportionment method:	**Area**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Status quo	BS	0.13	0.14	0.15	0.16	0.17	0.19	0.18	0.13	0.10	0.14	0.17	0.16	0.14	0.14
Status quo	AI	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.13	0.13	0.13	0.14	0.17	0.17
Status quo	WG	0.11	0.13	0.12	0.11	0.10	0.11	0.10	0.11	0.11	0.10	0.10	0.10	0.11	0.10
Status quo	CG	0.33	0.31	0.31	0.30	0.30	0.29	0.29	0.33	0.34	0.32	0.28	0.28	0.27	0.27
Status quo	WY	0.11	0.10	0.10	0.10	0.10	0.10	0.12	0.12	0.11	0.10	0.10	0.11	0.12	0.11
Status quo	EY/SEO	0.18	0.19	0.19	0.20	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.20	0.19
Static	BS	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Static	AI	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Static	WG	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Static	CG	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Static	WY	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Static	EY/SEO	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Equal	BS	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Equal	AI	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Equal	WG	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Equal	CG	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Equal	WY	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Equal	EY/SEO	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Equilibrium	BS	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Equilibrium	AI	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Equilibrium	WG	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Equilibrium	CG	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Equilibrium	WY	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Equilibrium	EY/SEO	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Part.fixed	BS	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Part.fixed	AI	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Part.fixed	WG	0.12	0.14	0.13	0.12	0.12	0.13	0.11	0.11	0.11	0.11	0.12	0.11	0.12	0.12
Part.fixed	CG	0.36	0.34	0.34	0.34	0.35	0.34	0.33	0.35	0.35	0.35	0.32	0.32	0.31	0.32
Part.fixed	WY	0.12	0.11	0.11	0.12	0.11	0.11	0.13	0.12	0.11	0.11	0.12	0.13	0.14	0.13
Part.fixed	EY/SEO	0.20	0.21	0.21	0.22	0.22	0.22	0.23	0.22	0.22	0.23	0.24	0.24	0.24	0.23
Non-exp	BS	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.16	0.14	0.14	0.14	0.14	0.14	0.16
Non-exp	AI	0.15	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.13	0.12	0.13	0.13	0.15	0.16
Non-exp	WG	0.12	0.13	0.12	0.11	0.11	0.11	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10
Non-exp	CG	0.31	0.32	0.32	0.31	0.31	0.29	0.29	0.31	0.32	0.31	0.31	0.31	0.28	0.27
Non-exp	WY	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Non-exp	EY/SEO	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.20	0.20	0.21	0.21	0.21	0.21	0.20
Biom.based	BS	0.14	0.16	0.16	0.19	0.19	0.19	0.20	0.06	0.05	0.21	0.21	0.13	0.12	0.13

Apportionment method:	Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Biom.based	AI	0.12	0.11	0.13	0.12	0.13	0.13	0.09	0.11	0.15	0.13	0.13	0.14	0.21	0.21
Biom.based	WG	0.11	0.16	0.12	0.09	0.11	0.13	0.09	0.13	0.12	0.09	0.13	0.09	0.13	0.11
Biom.based	CG	0.38	0.29	0.32	0.30	0.33	0.29	0.29	0.42	0.37	0.30	0.27	0.31	0.27	0.31
Biom.based	WY	0.11	0.08	0.10	0.11	0.09	0.09	0.13	0.11	0.09	0.09	0.09	0.14	0.12	0.11
Biom.based	EY/SEO	0.15	0.19	0.16	0.19	0.15	0.17	0.20	0.17	0.21	0.19	0.18	0.19	0.16	0.14
Exp.Fish.wt	BS	0.12	0.12	0.14	0.14	0.16	0.19	0.15	0.15	0.12	0.12	0.13	0.18	0.16	0.16
Exp.Fish.wt	AI	0.14	0.14	0.13	0.14	0.15	0.14	0.13	0.13	0.13	0.13	0.15	0.14	0.15	0.15
Exp.Fish.wt	WG	0.08	0.09	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08
Exp.Fish.wt	CG	0.28	0.29	0.28	0.28	0.27	0.25	0.27	0.26	0.28	0.28	0.25	0.23	0.23	0.23
Exp.Fish.wt	WY	0.13	0.12	0.12	0.11	0.11	0.10	0.12	0.12	0.12	0.12	0.12	0.11	0.12	0.12
Exp.Fish.wt	EY/SEO	0.24	0.24	0.24	0.23	0.24	0.22	0.24	0.25	0.25	0.25	0.26	0.25	0.26	0.26
Exp.Surv.wt	BS	0.13	0.15	0.15	0.17	0.18	0.19	0.19	0.13	0.09	0.15	0.18	0.15	0.13	0.14
Exp.Surv.wt	AI	0.13	0.12	0.13	0.12	0.13	0.13	0.11	0.11	0.13	0.13	0.13	0.13	0.17	0.19
Exp.Surv.wt	WG	0.13	0.15	0.13	0.11	0.11	0.12	0.10	0.11	0.12	0.10	0.11	0.10	0.12	0.11
Exp.Surv.wt	CG	0.36	0.33	0.33	0.31	0.32	0.30	0.30	0.36	0.36	0.33	0.30	0.31	0.29	0.29
Exp.Surv.wt	WY	0.10	0.09	0.10	0.10	0.09	0.09	0.11	0.11	0.10	0.10	0.09	0.12	0.12	0.11
Exp.Surv.wt	EY/SEO	0.15	0.17	0.16	0.18	0.17	0.17	0.18	0.18	0.19	0.19	0.19	0.19	0.18	0.16
Mature.appt	BS	0.10	0.10	0.11	0.12	0.11	0.10	0.09	0.07	0.06	0.07	0.09	0.11	0.11	0.09
Mature.appt	AI	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.08	0.09	0.11	0.13
Mature.appt	WG	0.11	0.11	0.11	0.09	0.09	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.09
Mature.appt	CG	0.50	0.49	0.48	0.46	0.46	0.44	0.42	0.43	0.42	0.40	0.38	0.38	0.34	0.34
Mature.appt	WY	0.10	0.10	0.11	0.11	0.12	0.13	0.15	0.16	0.16	0.15	0.15	0.14	0.14	0.15
Mature.appt	EY/SEO	0.11	0.12	0.12	0.14	0.15	0.15	0.16	0.17	0.18	0.20	0.21	0.20	0.21	0.20
Exp.Mature	BS	0.10	0.09	0.12	0.14	0.10	0.08	0.06	0.05	0.08	0.10	0.12	0.12	0.09	0.06
Exp.Mature	AI	0.08	0.07	0.07	0.08	0.09	0.09	0.09	0.08	0.08	0.09	0.09	0.09	0.14	0.16
Exp.Mature	WG	0.09	0.11	0.10	0.08	0.08	0.10	0.09	0.09	0.09	0.08	0.09	0.08	0.11	0.10
Exp.Mature	CG	0.51	0.48	0.45	0.43	0.46	0.43	0.40	0.43	0.42	0.39	0.36	0.35	0.31	0.35
Exp.Mature	WY	0.11	0.11	0.11	0.12	0.13	0.14	0.18	0.16	0.15	0.14	0.13	0.15	0.16	0.16
Exp.Mature	EY/SEO	0.11	0.14	0.14	0.15	0.14	0.16	0.18	0.18	0.19	0.21	0.21	0.20	0.20	0.17
RandomEffects	BS	0.14	0.16	0.16	0.19	0.19	0.19	0.20	0.06	0.05	0.21	0.21	0.13	0.12	0.13
RandomEffects	AI	0.12	0.11	0.13	0.12	0.13	0.13	0.09	0.11	0.15	0.13	0.13	0.14	0.21	0.21
RandomEffects	WG	0.11	0.16	0.13	0.09	0.11	0.13	0.09	0.13	0.12	0.09	0.13	0.09	0.13	0.11
RandomEffects	CG	0.38	0.30	0.32	0.30	0.33	0.29	0.29	0.42	0.37	0.30	0.27	0.31	0.27	0.30
RandomEffects	WY	0.10	0.08	0.10	0.11	0.09	0.09	0.13	0.12	0.10	0.09	0.09	0.14	0.12	0.11
RandomEffects	EY/SEO	0.15	0.18	0.16	0.19	0.16	0.16	0.20	0.17	0.21	0.19	0.18	0.20	0.16	0.14

Appendix 3E: Alaska Sablefish Model Update

September 2018

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Introduction

This preliminary assessment document attempts to address some recent comments and recommendations made by reviewers of the Alaska sablefish assessment including the Center for Independent Experts (CIE), the Joint Groundfish Plan Team (JGPT) of the North Pacific Fishery Management Council (NPFMC), and the Science and Statistical Committee (SSC) of the NPFMC. In this document we focus primarily on alternative modeling approaches for fishery selectivity and developing a more informative prior on natural mortality. Both of these analyses were done in response to the primary criticism of the 2016 CIE review that the sablefish assessment model provides "unrealistically precise estimates of absolute stock size and should better account for uncertainties relating to natural mortality rate…" and other fixed quantities (Carruthers 2016 CIE Report).

Fishery selectivity

The sablefish assessment model moved from a single-sex model to a split-sex model in 2006 (Hanselman et al. 2006). Because the sablefish assessment estimates selectivity at age (not length), this doubled the number of selectivity parameters which led to some difficulty in estimating all of the parameters simultaneously. Also in 2006, the Gulf of Alaska (GOA) trawl survey was included for the first time as a recruitment index which added two more selectivity curves. The trawl fishery was previously estimated with the exponential-logistic curve to allow it to be dome-shaped. This three parameter functional form that can become unstable when the parameters are highly correlated. In 2008, a number of simplifications were implemented to the selectivity functions with the objective of addressing model instability and high selectivity parameter CVs and correlations (Hanselman et al. 2008). In that assessment, the exponential-logistic selectivity function was replaced by the two parameter gamma function for the trawl fishery and a one parameter power function for the GOA trawl survey. Several of the selectivity shape parameters were linked (the males and females used the same shape parameter) for the fixed gear logistic curves. These changes resulted in higher parameter precision and lower parameter correlations, a more stable model, and a reduction of 13 parameters.

A decade later, some of the fits to the compositional data have degraded. This could be due to changes in spatial patterns in the fishery and unusual recruitment events. In the meantime, 10 more years of data may now allow for better estimation of additional selectivity parameters. This has led to several accumulated recommendations from the Plan Teams, SSC, and 2016 CIE review regarding selectivity that this preliminary assessment will attempt to address. These comments include:

1) "The SSC also suggests that the next assessment include further investigation of the lack of fit to the plus group in recent fishery age compositions, and development of a prior for natural mortality." – December 2017
2) "The Teams recommended that further evaluations of selectivity options be pursued." – November 2017
3) "Aggregated summary observed versus expected age compositions by fleet and survey from the model are acceptable, but do indicate that there is room for further improvement through selection of alternative selectivity functional shapes or adjustment of the value of fixed or number of estimated selectivity parameters." – Klaer, 2016 CIE review

Two studies on sablefish (Jones and Cox 2018, Maloney and Sigler 2008) and one on Pacific halibut (Clark and Kaimmer 2011) have used mark-recapture data to suggest that their respective longline fisheries have some degree of dome-shaped selectivity. Jones and Cox (2018) showed that the dome-shaped gamma distribution provided the best fit to tagging data from British Columbia (Figure 1). It should be noted that they were fitting selectivity-at-length models, so the shape may not translate, but evidence of dome-shapedness would. Maloney and Sigler (2008) used tagging data from known-age sablefish to suggest that a dome-shaped exponential-logistic function provided the best fit to the longline fishery recaptures (Figure 2) for selectivity at age. Finally, Clark and Kaimmer (2006) showed for halibut, that while a gear may be asymptotic within an area, the spatial distribution of the fishery may result in a dome-shaped selectivity curve for the longline fishery based on where the fishery operates relative to the overall population (Figure 3). These studies and requests by review bodies are the rationale for re-examining sablefish fixed-gear fishery selectivities.

Natural mortality

Natural mortality has been modeled in a variety of ways in previous Alaska sablefish assessments, and in other management areas (British Columbia and U.S. West Coast). For Alaska sablefish assessments before 1999, natural mortality was assumed equal to 0.10. For assessments from 1999 to 2003, natural mortality was estimated rather than assumed equal to 0.10; the estimated value was about 0.10. For the 2004 assessment, a more detailed analysis of the posterior probability showed that natural mortality was not well-estimated by the available data. The posterior distribution of natural mortality was very wide, ranging to near zero. Parameter estimates even for MCMC chains thinned to every 1000th value showed some serial correlation. For the 2005 assessment we assumed that we knew the approximate value of natural mortality very precisely (CV of 0.1% for prior probability distribution) and that the approximate value was 0.10. At this level of prior precision, it was essentially a fixed parameter. Using such a precise prior for a parameter that we do not think is estimable serves no purpose except to acknowledge that we do not know the parameter value exactly. It was pointed out during review that estimating *M* this way was misleading and an improper use of Bayesian priors, so in 2006 we returned to fixing the parameter at 0.10. However, in 2016, in response to the 2016 CIE review, we once again estimated natural mortality, this time with a less precise prior (CV = 10%) resulting in an estimate that deviated from 0.10, but not greatly (M = 0.097 in 2017). Nonetheless, it was still a wholly *ad hoc* estimate of prior precision. In this document, we attempt to develop a more informed prior based on life history methods and a mark-recapture estimate from the movement model of Hanselman et al. (2015).

Methods

Fishery selectivity

We present a number of scenarios to explore whether there are time-invariant or time-variant selectivity alternatives that produce a substantively better fit to the data while still considering model parsimony. The base model 16.5 from the 2017 assessment (Hanselman et al. 2017) should be the standard of comparison. However, because the shape parameters of the logistic curves for male and female selectivities were shared in Model 16.5, we had to estimate these two parameters so subsequent models could be compared on common ground. Thus, a very similar model (16.5a) is the standard of comparison for the models. We evaluated three groups of alternative models:

1) Time-invariant selectivities for the IFQ fixed gear fishery (1995 – 2017),
2) Time-variant selectivities for the IFQ fixed gear fishery (1995 – 2017),
3) Time-variant selectivities for all fixed gear catch (1960 – 2017).

A fourth group exploring more complex time-invariant selectivities for the GOA trawl survey (1984 - 2017) was attempted but we found that there were serious estimability and convergence issues, so we narrowed the focus to fixed-gear fishery selectivity only.

We examined parametric and non-parametric selectivity forms (Table 1). The parametric selectivities that we compared were the logistic, exponential-logistic, and gamma functions (Hanselman et al. 2017). For the time-varying parametric selectivity models we only use the logistic and gamma function where the $a_{50\%}$ (age at 50% selectivity for the logistic) and $a_{100\%}$ (the peak of the gamma function) parameters, respectively, are allowed to vary each year.

The non-parametric selectivities used are similar to those used for fishery selectivity in the EBS pollock model (Ianelli et al. 2017). Non-parametric selectivity means estimating an additional parameter for each age, and in time-varying methods up to one additional parameter for each age every year. For all of the nonparametric selectivity models, ages after 15 are set to be equal. Sablefish by this age are fully mature and fully grown (>95% mature and L_{inf}), and would be expected to behave similarly, and have similar availability to the gear. Selectivity at age is forced to have a mean value of one within a year and are constrained by penalties of analyst specified magnitudes to prevent large changes between ages and extreme dome-shaped behavior. The full suite of different selectivity options explored in this analysis paper can be found in Table 1.

Natural Mortality

Natural mortality (*M*) is notoriously difficult to estimate, but a number of life-history correlates have been used to approximate its value. An online tool[3] has been developed that compiles the primary life-history based estimators and weights them by groups of input data. The life-history parameters used to populate the tool are shown in Table 2. Since multiple estimators may use the same life history data, the results were divided by the number of related estimators. For example, there were four estimators based on maximum age, so they were each weighted by 0.25 in the composite value. The tool then compiles all the estimates to make a composite prior density using the empirical cumulative distribution (ECD) of the point estimates. We use this tool here as a first step to a more informative prior. The results of the estimates are shown in Table 3. Several of the estimators produced very low (sometimes negative) and very high estimates so we omitted the highest two (Jensen LVB estimators) and the lowest two (Alverson and Carney; Chen and Watanabe). The mean and coefficient of variation (CV) of the ECD were 0.187 and 0.429, respectively (Table 3). The references behind these various life-history estimators are shown in Table 4.

The second step is combining the composite density with an estimate of *M* from the sablefish tag-recapture data set which was used to estimate movement rates from 1979 – 2011 (Hanselman et al. 2015). For the purpose of this analysis, we used this movement model with no size delineations (i.e., all tag-release-recovery data) and instead of fixing *M* as in the original study, it is estimated (with no prior). The estimate from this model was 0.0852 with a Hessian derived CV of 0.0183. The prior for the assessment model was then derived by sampling from the tool-based and movement model-based distributions and combining them with equal weighting. The lognormal mean and CV of this distribution then becomes the prior to be tested in the assessment model which has an arithmetic mean of 0.116 and CV of 0.208 (Figure 4).

We compared assessment models with different priors for natural mortality to the model used for the 2017 assessment (16.5). Model 16.5 used a prior distribution with a mean of 0.10 and a CV of 10%. Model 16.5r used the new prior developed in this analysis. In addition, results were compared with a model with natural mortality fixed at the new prior mean (16.5s), and a model with the new prior mean and a non-informative prior (16.5t) (Table 5).

[3] Natural mortality estimators in The Barefoot Ecologist's Toolbox: http://barefootecologist.com.au/shiny_m

Results

Fishery selectivity

While we looked at many models, we only included those that had a maximum gradient <0.001 and those that had a positive definite Hessian. We compared the models across a number of criteria, including fit to the data ('data -lnL'), number of parameters, improvement of fit to the plus group, retrospective statistics as recommended in Hanselman et al. (2013) including the typical 'Mohn's rho', and tradeoffs between fits to individual important data sets (survey and fishery age composition, fishery length composition, and longline survey index fit). The models range in complexity, with the most complex estimating over 1,000 parameters (Models 16.5n, 16.o). However, these parameters are constrained random walks so their effective number of parameters is probably considerably less. One advantage of the last group of models (Models 16.5n – 16.5z) is that while they have more parameters, they make less rigid assumptions about what time blocks to fit for selectivity throughout the history of the fixed gear fleet (e.g., foreign, derby, and IFQ), and instead allow the selectivity to change over time as informed by the data. Models discussed below will focus primarily on models that show an improvement in the overall fit to the data compared to Model 16.5a.

The time invariant models for fixed gear selectivity from 1995 – 2017 had a range of improvements or degradations of fits to the data as shown by the delta-lnL (the change in likelihood of the data components from 16.5a, Table 6). Only two of the models (16.5c and 16.5d) showed an improvement over 16.5a (delta-lnL of -8 and -11, respectively). These models used the exponential-logistic function and a minimally constrained non-parametric selectivity at age as compared to the logistic function used in 16.5a. Model 16.5c did not improve the fit to the fishery age data, but did improve the fit to the survey age data, and worsened the fit to the plus group. Model 16.5c has poor retrospective performance (Table 7), primarily due to lack of convergence in some years because of instability of the exponential-logistic function. Model 16.5d showed a better fit to the fishery ages, a slight improvement to the plus group, and better retrospective performance in all categories than Model 16.5a, with only a slight degradation in fit to the survey ages. The selectivity shape seems quite reasonable for females (Figure 5), and still plausible for males.

The time-varying models mostly showed an improvement in fit compared to Model 16.5a (Table 6). These improvements came at a cost of adding between 18 and 878 parameters (Table 6). Two models that did not show an improved fit (16.5l and 16.5o) were those that put a high constraint on allowing selectivity at older ages to be dome-shaped, indicating that some dome-shapedness is important in describing fixed gear fishery selectivity. The two time-varying parametric selectivity models (16.5i and 16.5j) showed a small improvement in overall fit to the data (delta-lnL). Model 16.5i (logistic selectivity) improved the fit to the fishery ages, but had a minimal improvement in fit to the plus group. The time-varying selectivity curves seem plausible (Figures 6 and 7). Model 16.5j (gamma selectivity) showed a large improvement in the fit to the fishery ages, but somewhat at the expense of fitting the fishery size data. This model also gave the greatest improvement of fit to the plus age group. This is likely a result of the extreme-dome shapedness (Figure 8) and the large increase in M that only occurred when the gamma model was used (Table 1). The retrospective performance of Model 16.5i was similar to Model 16.5a, while Model 16.5j was poor.

Of the time-varying models that improved the fit to the data, the best fitting model is the very lightly constrained Model 16.5n, which estimates annual parameters at age for every year since 1960 (npar = 1111, Table 6). The –lnL for the fit to the fishery age composition decreases by about 50% and it has the next best fit to the plus group from Model 16.5j. While the increased flexibility of estimating so many parameters results in a good fit to the data, the shape and annual variability of the resulting selectivity curves may be implausible (Figures 9 and 10). Recognizing this, several models were presented with time blocks and higher constraints that seemed to show an improvement relative to Model 16.5a in terms of fit and produced more plausible selectivity patterns than Model 16.5n (e.g., Model 16.5z, Figures 11 and

12). Model 16.5z is a model with 2-year time blocks that also uses the natural mortality prior developed in this document. The effect of that less precise prior can be observed as it produces the lowest value of M and has the 3rd best fit to the plus group. However, other than perhaps Model 16.n, all of the time-varying models for the full time series of fishery selectivity produce undesirable retrospective performance, particularly in recent years (high values of Phi, Table 7). Qualitatively, it is interesting that the time-varying selectivities all show a markedly different pattern starting in about 2013 with lower selectivity of younger fish. This is similar to the pattern shown in Hanselman et al. (2017) where the fishery has recently caught a lower proportion of fish than expected relative to the survey age compositions.

Natural Mortality

The assessment model with the new prior for natural mortality (16.5r) was compared to the 2017 assessment (16.5), a model with natural mortality fixed at the prior mean (16.5s), and a model with the new prior mean and a non-informative prior (16.5t) (Table 5). The new prior had a minor influence on the point estimate of natural mortality, but actually resulted in a slightly degraded fit. This may indicate that the age data in the sablefish assessment has informative data on natural mortality, and that information is more consistent with the mark-recapture estimate of M. In fact, the posterior distribution of natural mortality estimated by MCMC from Model 16.5r is very precise relative to the prior distribution (Figure 13).

Fixing the estimate of M at the point estimate of the prior had a more substantial effect on the model results and fits, with a slight decrease in model fit (‘data –lnL’), and a relatively large increase in total biomass (+27%). Finally, estimating natural mortality essentially freely (CV = 10, Model 16.5t), results in a minor improvement in fit to the data. All methods that estimate M produced very similar values. Incidentally, the estimates of *M* produced by all of the different selectivity model runs were relatively robust to the choice of fishery selectivity (Table 1) as well.

Discussion

Fishery selectivity

The exploration of new time-invariant selectivity curves showed some potential for modest improvement in the fit to recent fishery age compositions. Whether these modest improvements are worth adopting a new model is unclear. However, it is likely worth considering adopting Model 16.5a, where it appears that the previously linked selectivity parameters can now be well-estimated and improves the (already small) retrospective patterns in Model 16.5. None of these models made significant progress towards improving the fit to the plus group of the fishery age data. Model 16.5d is also worthy of consideration, but is not a dramatic improvement and adds additional complexity. The shape of female selectivity in Figure 5 for Model 16.5d is similar to the selectivity shapes authors of past sablefish assessments and sablefish assessments in other regions have proposed (Figures 1 – 3).

The time-varying alternatives in general performed well in terms of the fits to the data, but this came at the cost of adding many more parameters. Some of the models shown, and many that were not shown, resulted in selectivity shapes that seemed implausible. The models that fit time-varying selectivity for all years were intuitively pleasing because they unified the estimation of selectivity for the fixed gear fisheries under the same assumption throughout the history of the fishery. Model 16.5z seemed to help balance model fit without adding the full number of potential parameters by using 2-year time blocks. However, the retrospective performance of all of the time-varying selectivity models that fit the data better than Model 16.5a, with the exception of the time-varying logistic model, was poor. Beyond consideration of parsimony alone, this should suggest caution before introducing these high-parameter models. Despite recent suggestions that time-varying selectivity should be best practice (Martell and Stewart 2013) and claims that retrospective patterns can be alleviated (Szuwalski et al. 2017), these results specific to sablefish suggest otherwise. The Plan Team Retrospective Investigations Group (Hanselman et al. 2013) also showed that models with a high number of parameters tended to be more likely to exhibit poor retrospective performance. One additional uncertainty when adopting one of these time-varying methods is determining what selectivity curve should be used for projecting ABCs and OFLs in the following years, given that the estimates are highly dependent on fishery age data that only exist up to one year prior to the current model year. This is often chosen to be a short or long term average. An additional tactic that we explored was using the estimate of selectivity from a year where the numbers-at-age most closely matches the projected numbers-at-age.

In conclusion, there is evidence from other studies and the analyses shown here that there is likely at least some dome-shapedness in the fixed gear selectivity curve. The time-varying explorations do indicate that in recent years there does appear to be some different patterns in selectivity than historically. However, at this time, the inclusion of time-varying selectivity may be premature and of minimal benefit to the overall performance of the sablefish stock assessment. For the 2018 sablefish assessment, we may attempt to include an alternative similar to Model 16.5d.

Natural Mortality

The previously used prior mean for natural mortality for sablefish was based on estimates from older literature and past practice. The variance of that prior was *ad hoc* based on the senior author's judgment. The prior developed in this paper is more rigorous and includes a number of peer-reviewed methods, as well as an estimate from our large independent tag-recapture database for sablefish. Other ways of weighting the various estimates of M for the prior could have been employed, but it is clear that the natural mortality prior should be more uncertain than the current prior. The effect on the stock assessment of inclusion of this prior is negligible, as the model estimate of natural mortality is becoming well informed as more and more age data accumulate. The estimation of M alone was not helpful in resolving the poor fit to the fishery age plus group in some years.

In conclusion, we recommend the inclusion of this prior in the 2018 assessment. While it may have a low impact on the results, it was a useful exercise to explore the various life history methods and the tagging data to show the wide-range of possible values that natural mortality could be. These results should also provide comfort that the previous and current estimates of natural mortality were reasonable approximations.

Literature Cited

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Maloney, N.E. and Sigler, M.F., 2008. Age-specific movement patterns of sablefish (Anoplopoma fimbria) in Alaska. *Fishery Bulletin*, *106*(3), pp.305-316.

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Szuwalski, C.S., Ianelli, J.N., Punt, A.E. and Handling editor: Jan Jaap Poos, 2017. Reducing retrospective patterns in stock assessment and impacts on management performance. *ICES Journal of Marine Science*, *75*(2), pp.596-609.

Tables

Table 1. Models with different forms of selectivity and associated natural mortality values.

Model #	Selectivity form	Time-varying	Years	Blocks	Const-rained	Smooth Penalty	Dome-shaped Penalty	M
16.5	Logistic	No	1995-2017	--	No	--	--	0.098
16.5a	Logistic	No	1995-2017	--	No	--	--	0.097
16.5b	Gamma	No	1995-2017	--	No	--	--	0.138
16.5c	Exponential-logistic	No	1995-2017	--	No	--	--	0.086
16.5d	Coefficients	No	1995-2017	--	No	1	1	0.097
16.5e	Coefficients	No	1995-2017	--	Yes	10	10	0.095
16.5f	Coefficients	No	1995-2017	--	Yes	50	10	0.091
16.5g	Coefficients	No	1995-2017	--	Yes	10	50	0.090
16.5h	Coefficients	No	1995-2017	--	Yes	50	50	0.094
16.5i	Logistic	Yes	1995-2017	Annual	No	--	--	0.097
16.5j	Gamma	Yes	1995-2017	Annual	No	--	--	0.136
16.5k	Coefficients	Yes	1995-2017	Annual	Yes	10	10	0.088
16.5l	Coefficients	Yes	1995-2017	Annual	Yes	50	50	0.096
16.5m	Coefficients	Yes	1995-2017	Annual	Yes	1	1	0.086
16.5n	Coefficients	Yes	1960-2017	Annual	Yes	1	1	0.078
16.5o	Coefficients	Yes	1960-2017	Annual	Yes	20	100	0.089
16.5p	Coefficients	Yes	1960-2017	5 year	Yes	3	10	0.083
16.5q	Coefficients	Yes	1960-2017	2-year	Yes	5	5	0.080
16.5z	Coefficients	Yes	1960-2017	2-year	Yes	3	3	0.073

Table 2. Parameters used in the Barefoot Ecologist natural mortality tool (http://barefootecologist.com.au/shiny_m) for developing a sablefish natural mortality prior. Values are the mean of the male and female parameters.

Life history parameter	Value
Maximum age (years):	84
VBGF Growth coeff. k_l:	0.255
Age at maturity (years)	6.5
VBGF Growth coeff. wt. (k_w, in g):	0.255
Linf (in cm):	74.0
VBGF age at size 0 (t_0)	-2.11
Asym. weight (Winf, in g):	4.32
Water temperature (in C):	6

Table 3. Estimates of natural mortality from the life history based estimators and their respective weights in the composite posterior. Tag-recapture (highlighted yellow) is integrated directly with the posterior of the rest of the weighted estimates. The top two and bottom two estimators were given zero weight (greyed out cells). References for each estimator are given in Table 4.

Method	M	Weight
Then_Amax 1	0.0844	0.25
Then_Amax 2	0.0608	0.25
Then_Amax 3	0.0634	0.25
Hamel_Amax	0.0643	0.25
AnC	0.0000	0
Then_VBGF	0.1713	1
Jensen_VBGF 1	0.3825	0
Jensen_VBGF 2	0.4080	0
Pauly_lt	0.2780	0.5
Chen-Wat	-0.0156	0
Roff	0.1800	0.333
Jensen_Amat	0.2538	0.333
Ri_Ef_Amat	0.2350	0.333
Pauly_wt	0.3080	0.5
GSI	0.2820	1
Tag-Recapture	0.0852	CV = 0.0183
Overall	**0.1163**	**CV = 0.208**

Table 4. References for natural mortality estimators used in Table 3.

Then_Amax 1, Then_Amax 2, Then_Amax 3, Then_VBGF	Then, A.Y., J.M. Hoenig, N.G. Hall, D.A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J. of Mar. Sci. 72(1); 82-92.
Hamel_Amax	Hamel, O.S., 2014. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES Journal of Marine Science, 72(1), pp.62-69.
AnC	Alverson, D. L. and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer 36: 133-143.
Jensen_VBGF1, Jensen_VBGF 2, Jensen_Amat	Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Fish. Aquat. Sci. 53: 820-822. Jensen, A.L. 1997. Origin of the relation between K and Linf and synthesis of relations among life history parameters. Can. J. Fish. Aquat. Sci. 54: 987-989.
Roff	Roff, D. A. 1984. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41: 989-1000.
Ri_Ef_Amat	Rikhter, V.A., Efanov, V.N., 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc. 79/VI/8, 12.
Pauly_lt,Pauly_wt	Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer: 175-192.
Chen-Wat	Chen, S. and S. Watanabe. 1989. Age Dependence of Natural Mortality Coefficient in Fish Population Dynamics. Nippn Suisan Gakkaishi 55(2): 205-208.
GSI	Gunderson, D. R. and P. H. Dygert. 1988. Reproductive effort as a predictor of natural mortality rate. J. Cons. Int. Explor. Mer 44: 200-209.
Tag-Recapture	Hanselman, D.H., Heifetz, J., Echave, K.B. and Dressel, S.C., 2015. Move it or lose it: movement and mortality of sablefish tagged in Alaska. Canadian journal of fisheries and aquatic sciences, 72(2), pp.238-251.

Table 5. Assessment models with different priors for natural mortality with the prior mean and CV on the arithmetic scale shown. Log likelihood values overall ('-lnL'), total for the data ('Data-lnL'), and important subcomponents across selectivity models. 'delta-lnL' is the reduction in -lnL from Model 16.5.

Model #	M estimation (mean, CV)	-lnL	Data -lnL	delta-lnL	# Pars	**M**
16.5	0.1, 0.1	1575.64	1536.76	--	231	**0.098**
16.5r	0.116	1577.96	1540.16	3.4	230	**0.116**
16.5s	0.116, 0.206	1575.93	1537.04	0.28	231	**0.100**
16.5t	0.116, 10	1575.65	1535.37	-1.39	231	**0.102**

Table 6. Log likelihood values overall ('-lnL'), total for the data ('Data-lnL'), and important subcomponents across selectivity models. 'delta-lnL' is the reduction in -lnL from Model 16.5a, '-lnL/par' is the reduction in -lnL per additional parameter from Model 16.5a, 'PlusGroup' is the sum of the squared residuals of the plus group fit (age 31), and '% of base' is the percent of the sum of squares relative to Model 16.5a.

Model #	-lnL	Data-lnL	delta -lnL	Parameters	-lnL/par	Fishery Ages	Surv Ages	Fish Size	LL Surv Index	Plus Group	% of base
16.5	1576	1537		231	--	239	219	41	30	0.032	100%
16.5a	1559	1521	0	233	--	240	207	40	29	0.032	100%
16.5b	1610	1558	38	233	--	262	207	63	26	0.033	102%
16.5c	1555	1513	-8	235	-3.87	236	201	38	29	0.033	102%
16.5d	1554	1509	-11	258	-0.46	211	226	35	29	0.032	98%
16.5e	1579	1535	14	258	0.56	223	222	36	29	0.032	98%
16.5f	1617	1572	51	258	2.05	239	221	36	29	0.032	98%
16.5g	1587	1547	26	258	1.06	233	218	38	29	0.032	99%
16.5h	1628	1584	63	258	2.52	251	220	38	29	0.032	100%
16.5i	1541	1501	-19	276	-0.45	207	218	42	30	0.032	98%
16.5j	1561	1506	-14	276	-0.33	182	218	62	27	0.020	60%
16.5k	1517	1474	-47	603	-0.13	162	202	35	28	0.025	76%
16.5l	1599	1548	27	603	0.07	209	207	39	28	0.027	85%
16.5m	1460	1416	-105	603	-0.28	125	199	33	27	0.023	71%
16.5n	1430	1385	-136	1111	-0.15	118	173	31	15	0.022	68%
16.5o	1580	1536	16	1111	0.02	201	198	41	30	0.027	85%
16.5p	1515	1472	-49	436	-0.24	168	197	36	27	0.026	80%
16.5q	1500	1456	-65	691	-0.14	155	191	33	27	0.028	87%
16.5z	1481	1435	-86	691	-0.19	142	185	33	26	0.022	69%

Table 7. Retrospective statistics for female spawning biomass across models with different selectivities. Mohn's ρ is the measure of bias in the estimates in the last 10 years, Wood's hole ρ is the bias in full the time series, RMSE is the root mean squared error of the spawning biomass over all years, and ϕ is the ratio of recent (Mohn's ρ) to historic (Wood's hole ρ) which indicates whether retrospective bias is higher recently rather than overall.

Model #	Mohn's ρ	Wood's Hole ρ	RMSE	ϕ
16.5	0.068	0.063	0.412	1.079
16.5a	0.047	0.066	0.427	0.712
16.5b	0.228	-0.245	2.016	-0.931
16.5c	0.598	0.446	1.318	1.341
16.5d	0.006	-0.006	0.186	-1.000
16.5e	0.054	-0.007	0.460	-7.714
16.5f	0.055	-0.009	0.423	-6.111
16.5g	0.136	0.181	0.692	0.751
16.5h	0.025	-0.041	0.472	-0.610
16.5i	0.105	0.104	0.411	1.010
16.5j	0.282	-0.160	1.379	-1.762
16.5k	0.213	0.142	0.505	1.500
16.5l	0.063	-0.045	0.496	-1.400
16.5m	0.274	0.195	0.611	1.405
16.5n	0.160	0.091	0.367	1.758
16.5o	0.226	0.124	0.434	1.823
16.5p	0.191	0.157	0.522	1.217
16.5q	0.228	0.159	0.544	1.434
16.5z	0.244	0.195	0.676	1.251

Table 8. Summary statistics across assessment models with different natural mortality priors. Columns 2-6 show the fits to important data components. 'PlusGroup' is the sum of the squared residuals of the plus group fit (age 31), and '% of base' is the percent of the sum of squares relative to Model 16.5.

Model #	Fishery Ages	Survey Ages	Fishery Size	Dom LL Survey Index	PlusGroup	%Change
16.5	239	219	41	30	0.032	100%
16.5r	242	221	40	30	0.033	103%
16.5s	239	219	41	30	0.032	100%
16.5t	239	220	41	30	0.032	100%

Table 9. Retrospective statistics for female spawning biomass across models with natural mortality assumptions. Mohn's ρ is the measure of bias in the estimates in the last 10 years, Wood's hole ρ is the bias in full the time series, RMSE is the root mean squared error of the spawning biomass over all years, and ϕ is the ratio of recent (Mohn's ρ) to historic (Wood's hole ρ) which indicates whether retrospective bias is higher recently rather than overall.

Model #	Mohn's ρ	Wood's Hole ρ	RMSE	ϕ
16.5	0.068	0.063	0.412	1.079
16.5r	-0.018	-0.004	0.491	4.500
16.5s	0.098	0.094	0.485	1.043
16.5t	-0.014	-0.095	0.506	0.147

Figures

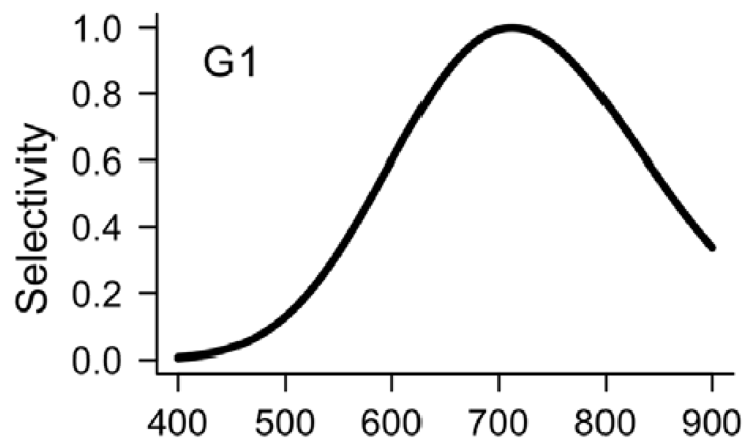

Figure 1. Size-selectivity (gamma, by length) for British Columbia Sablefish (Anoplopoma fimbria) estimated from a long-term tagging study. Source: Jones MK, Cox S. Fisheries Research. 2018 Mar 31;199:94-106.

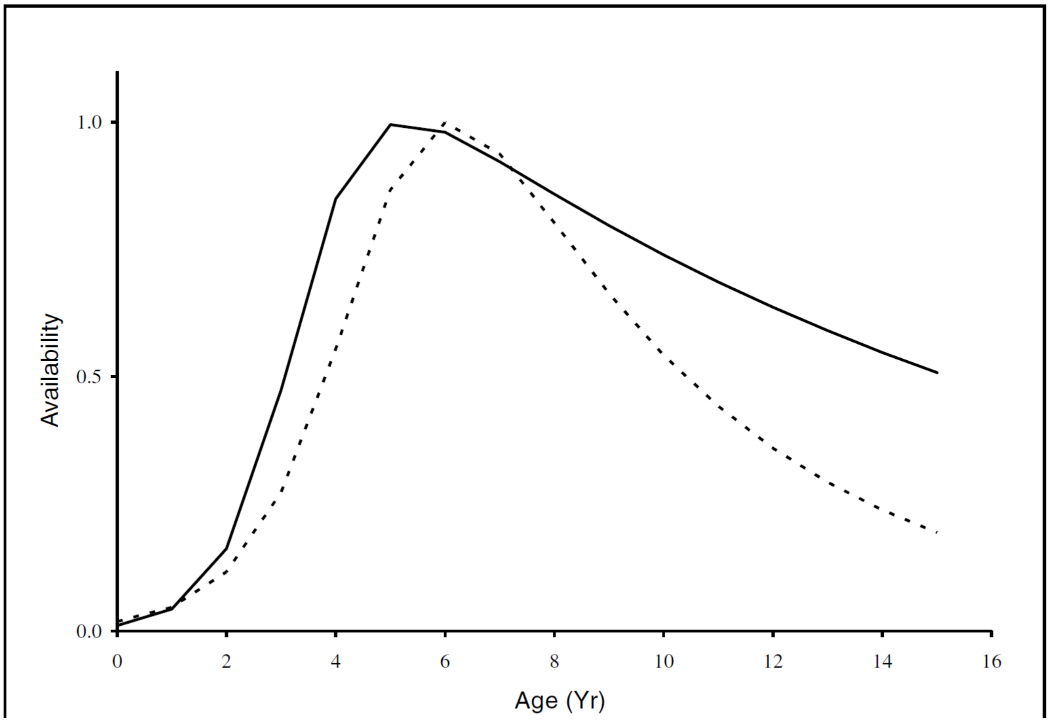

Figure 2. Estimated selectivity at age from tagging data for Alaska sablefish. Dashed line is IFQ (1995-2005), and solid line is from the derby fishery (1979 – 1994). Source: Maloney NE, Sigler MF. Age-specific movement patterns of sablefish (*Anoplopoma fimbria*) in Alaska. Fishery Bulletin. 2008;106(3):305-16.

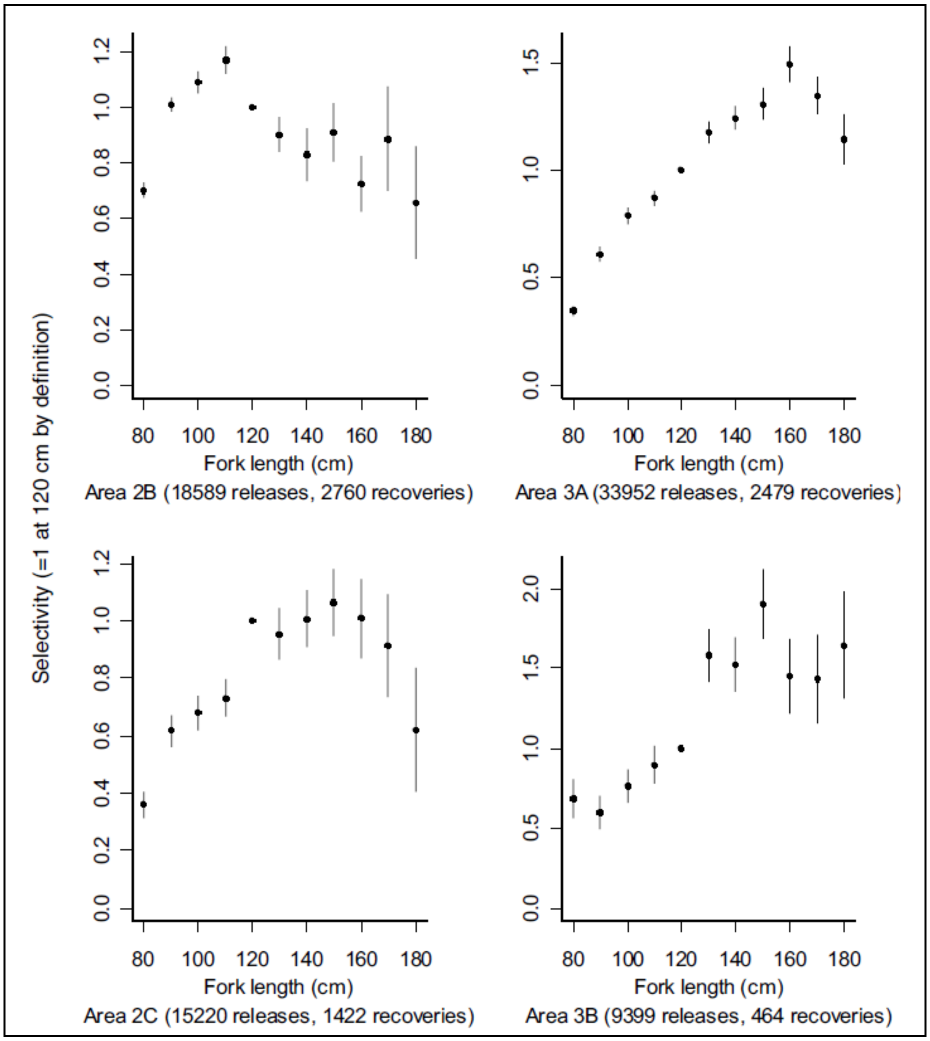

Figure 3. Estimates of length-specific selectivity for Pacific halibut by area from tag release data from 1960-1990. Source: Clark WG, Kaimmer SM. Estimates of commercial longline selectivity for Pacific halibut (*Hippoglossus stenolepis*) from multiple marking experiments. Fishery Bulletin. 2006;104(3):465-7.

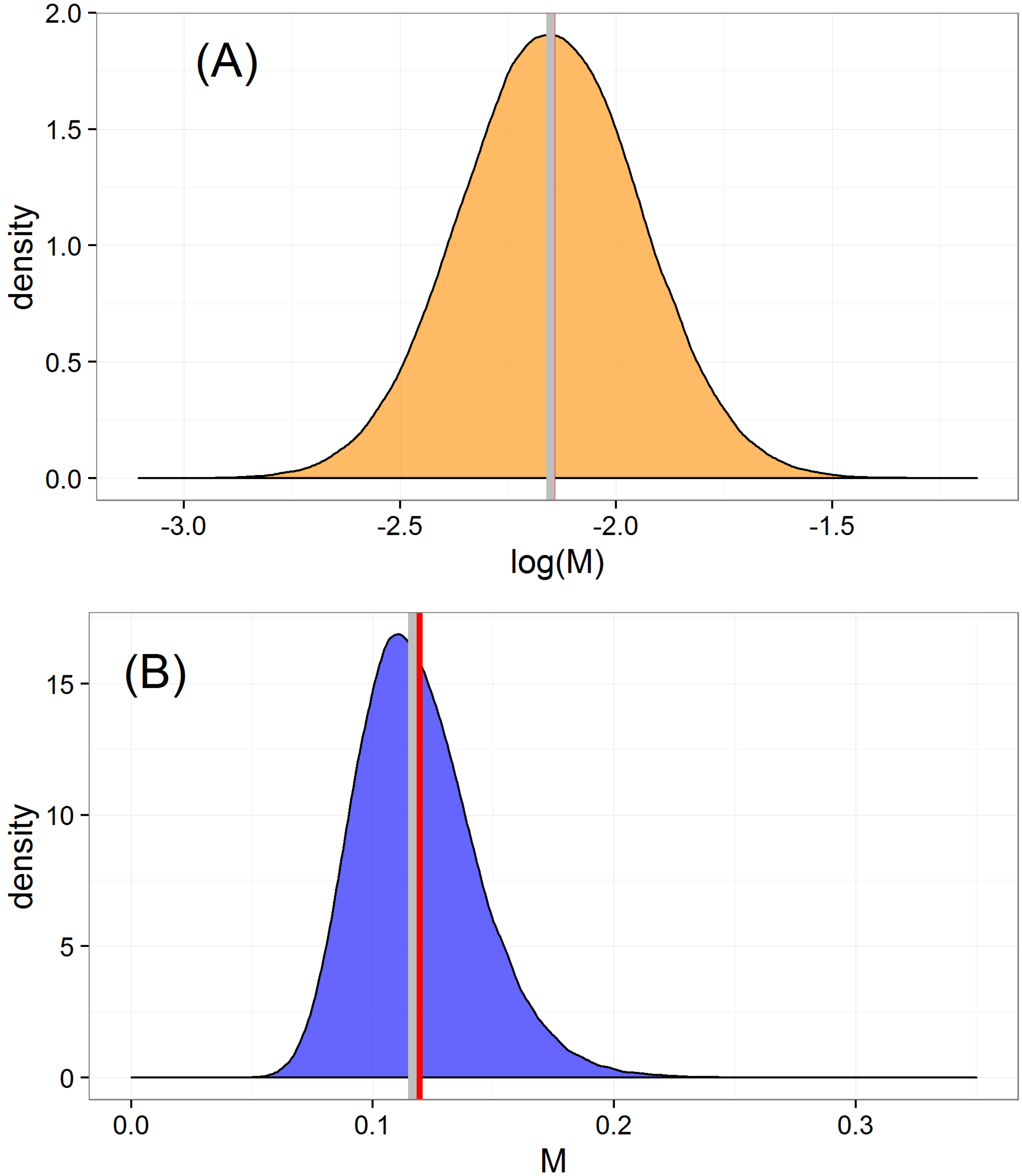

Figure 4. Lognormal prior distribution on log-scale (A) and natural scale (B) for natural mortality derived from multiple life history estimators and an independent mark-recapture estimate. The grey vertical line is the median and the red vertical line is the mean.

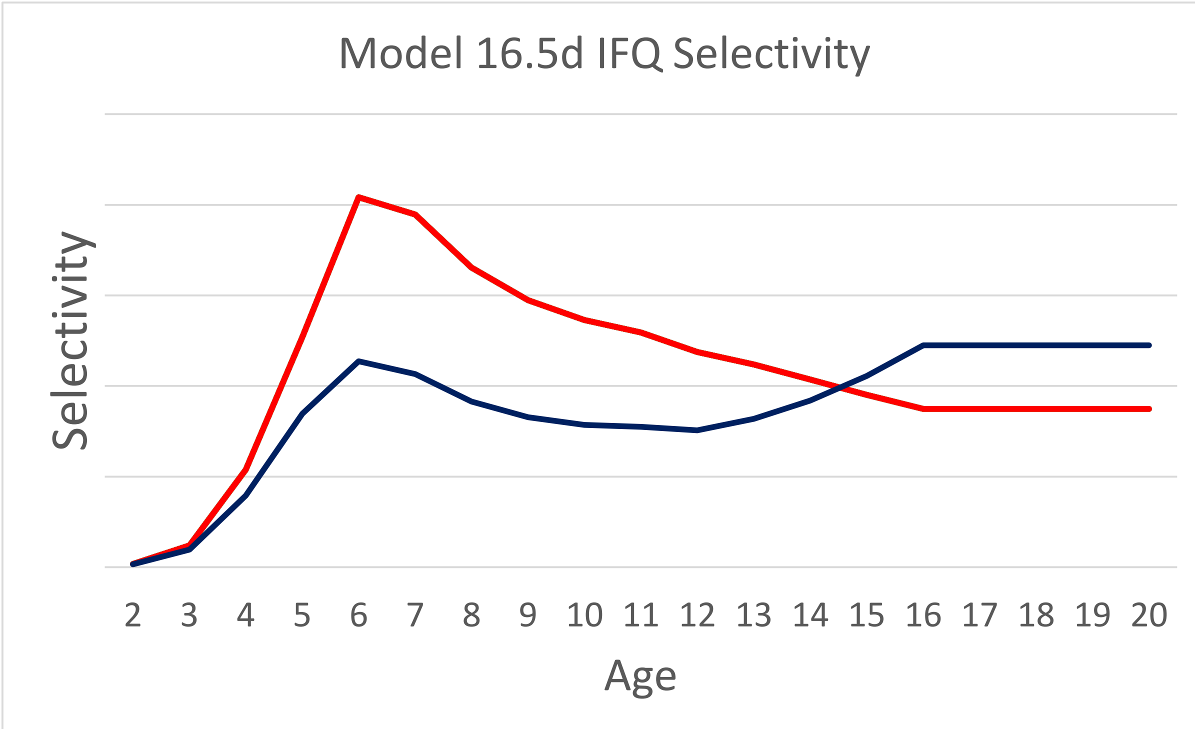

Figure 5. Female (red) and male (blue) selectivity for Model 16.5d with time-invariant non-parametric selectivity.

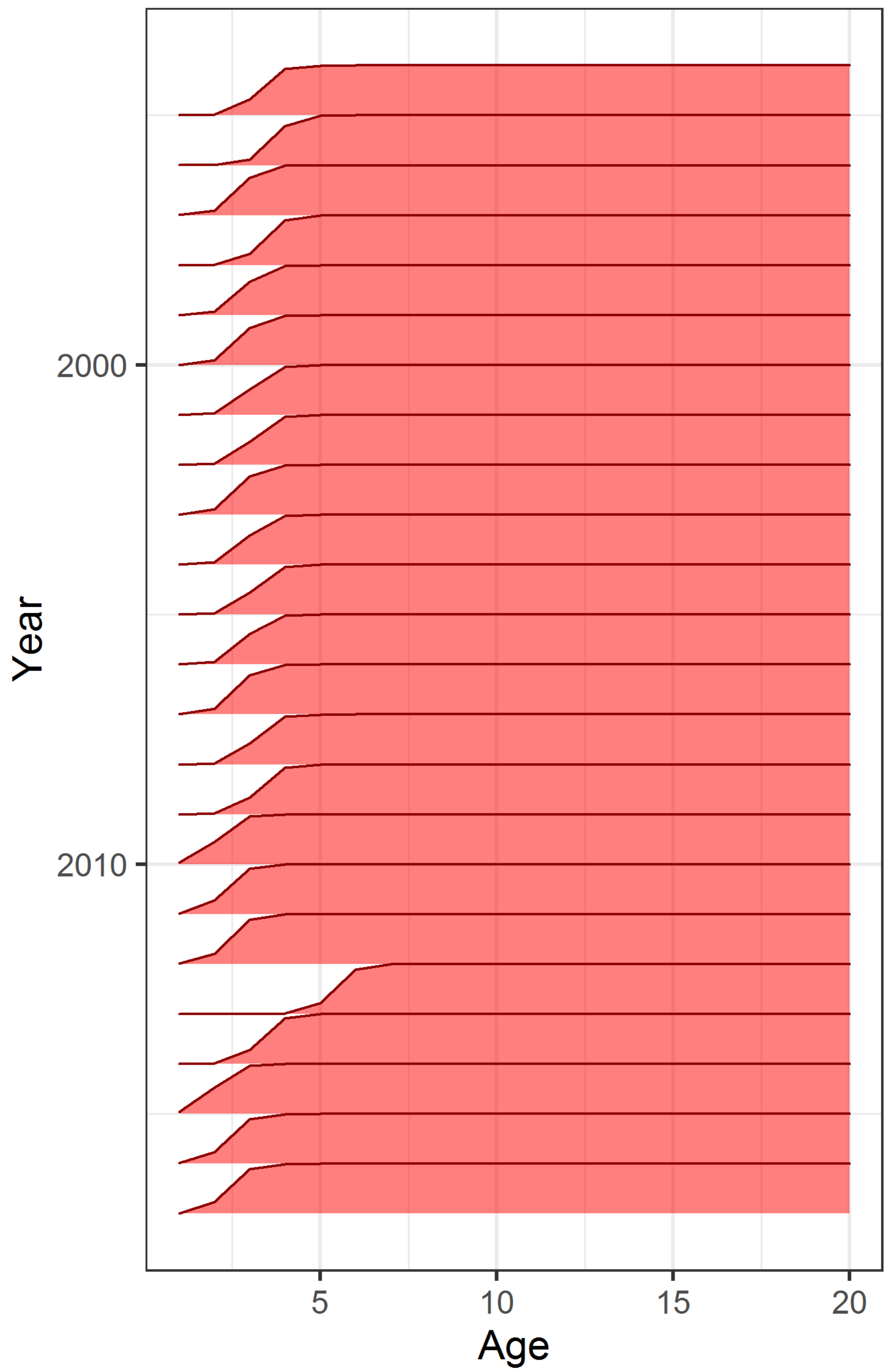

Figure 7. Female fishery selectivities for model 16.5i (time-varying logistic).

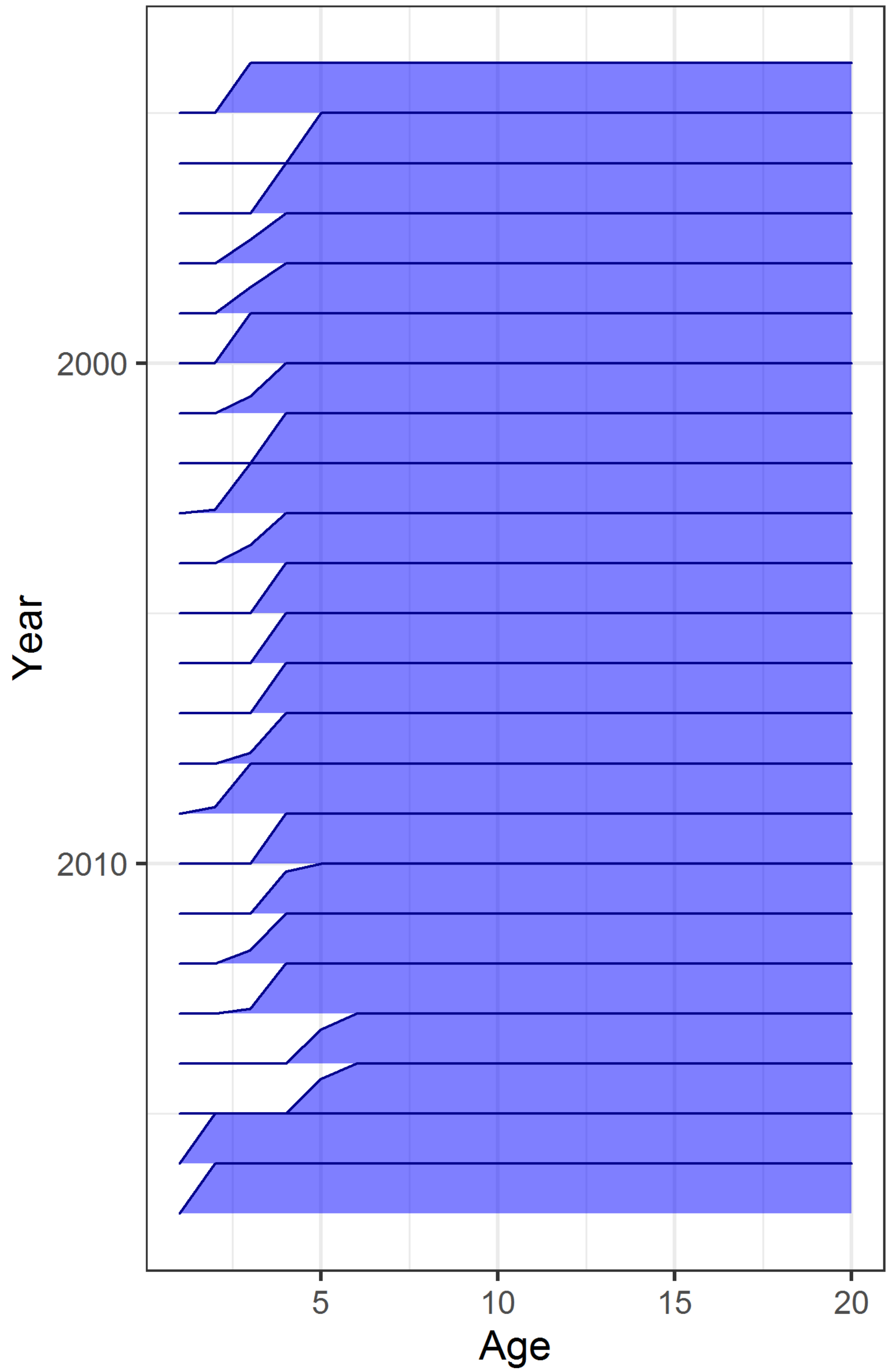

Figure 7. Male fishery selectivities for model 16.5i (time-varying logistic).

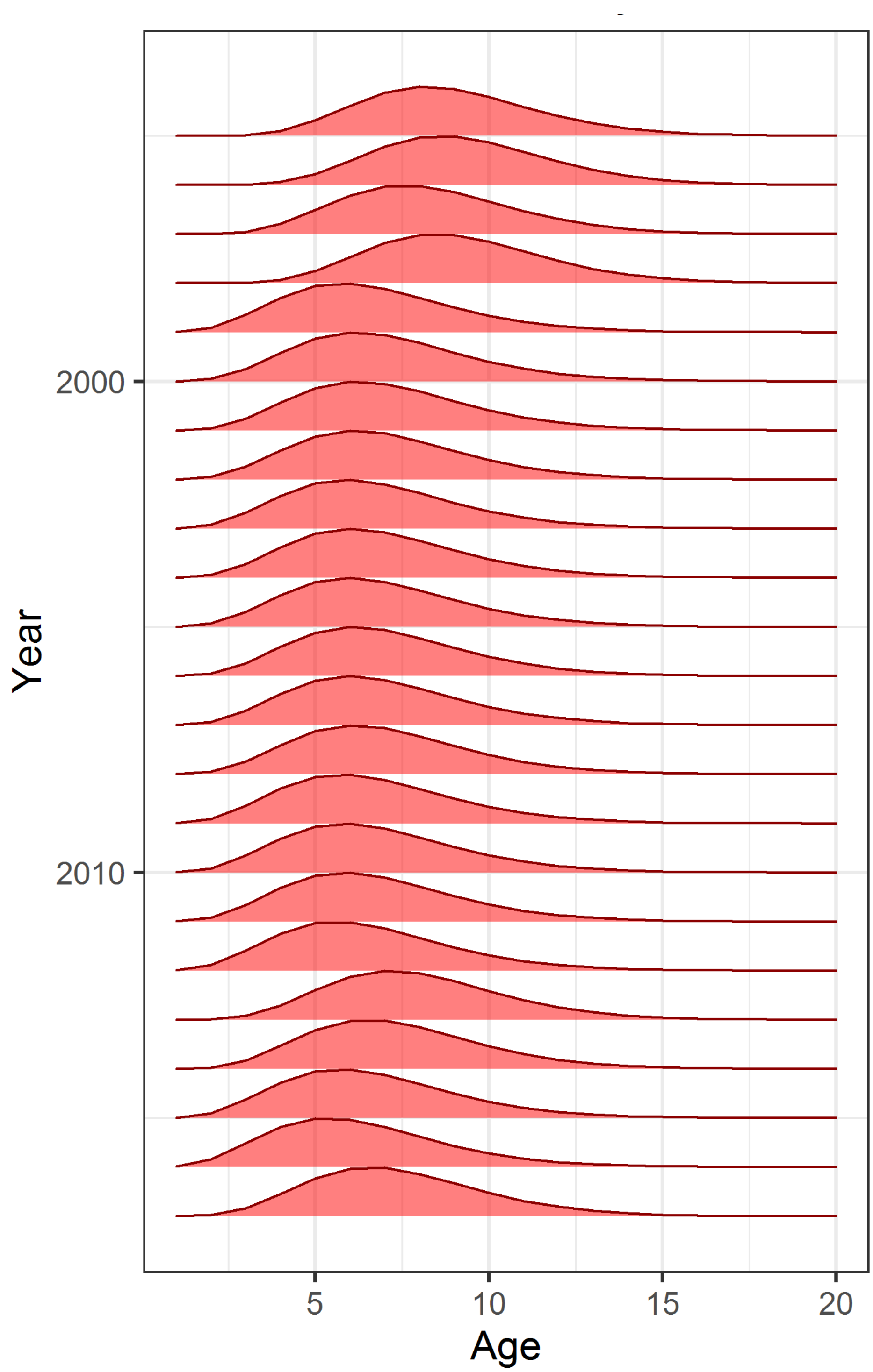

Figure 8. Female selectivity for Model 16.5j (time-varying gamma selectivity).

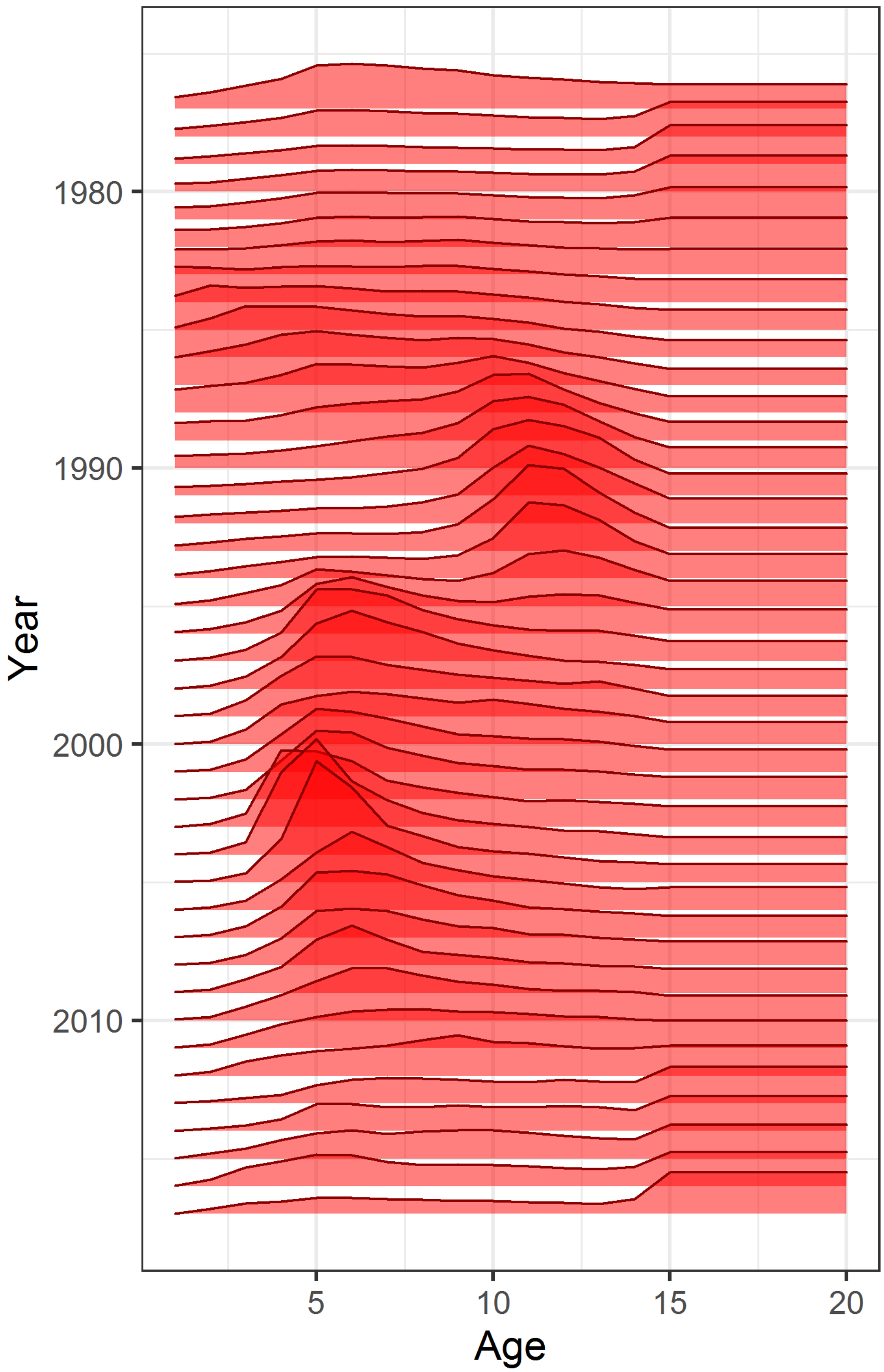

Figure 9. Female fishery selectivities for model 16.5n (time-varying non-parametric selectivity).

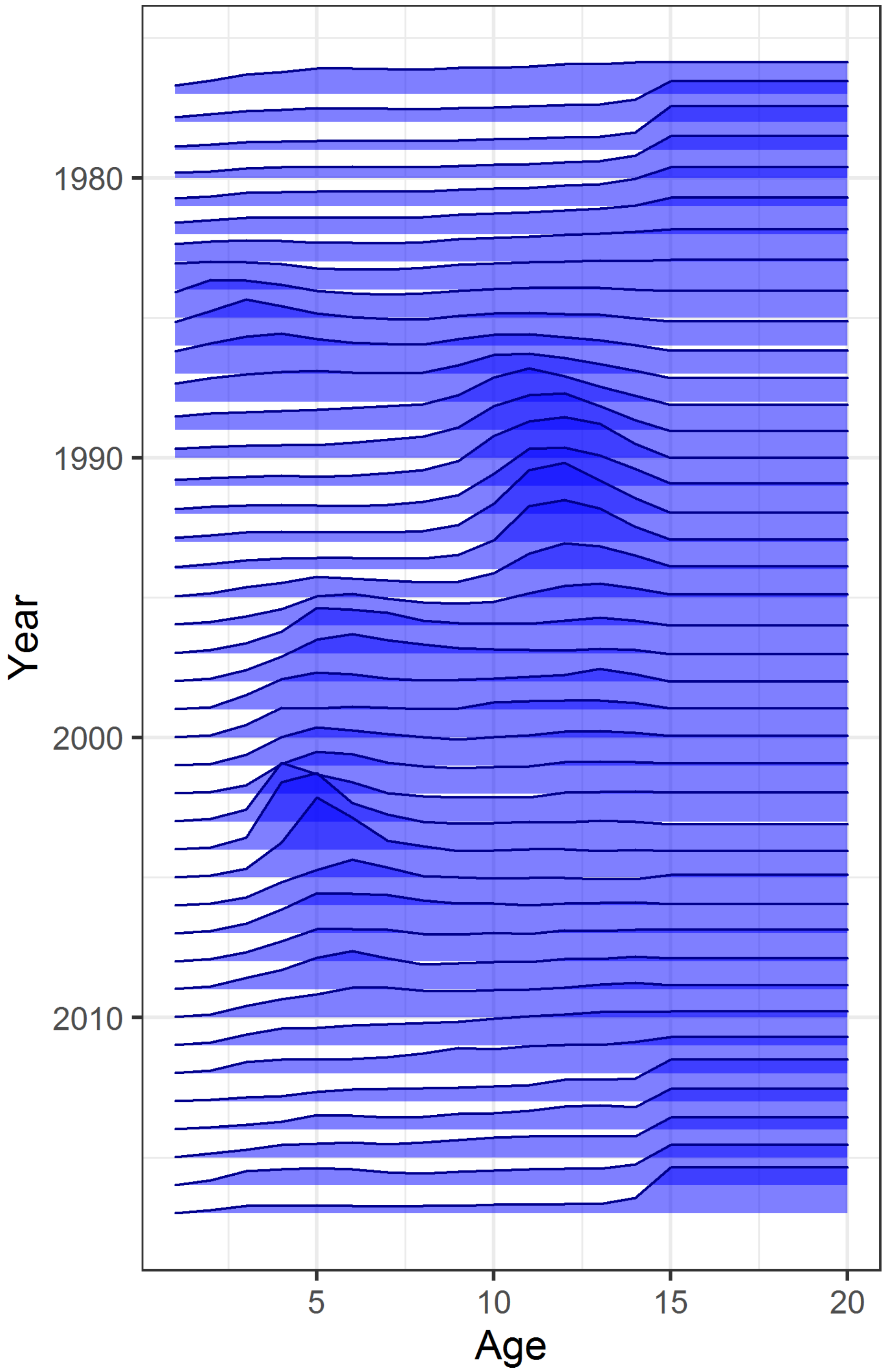

Figure 10. Male fishery selectivities for model 16.5n (time-varying non-parametric selectivity).

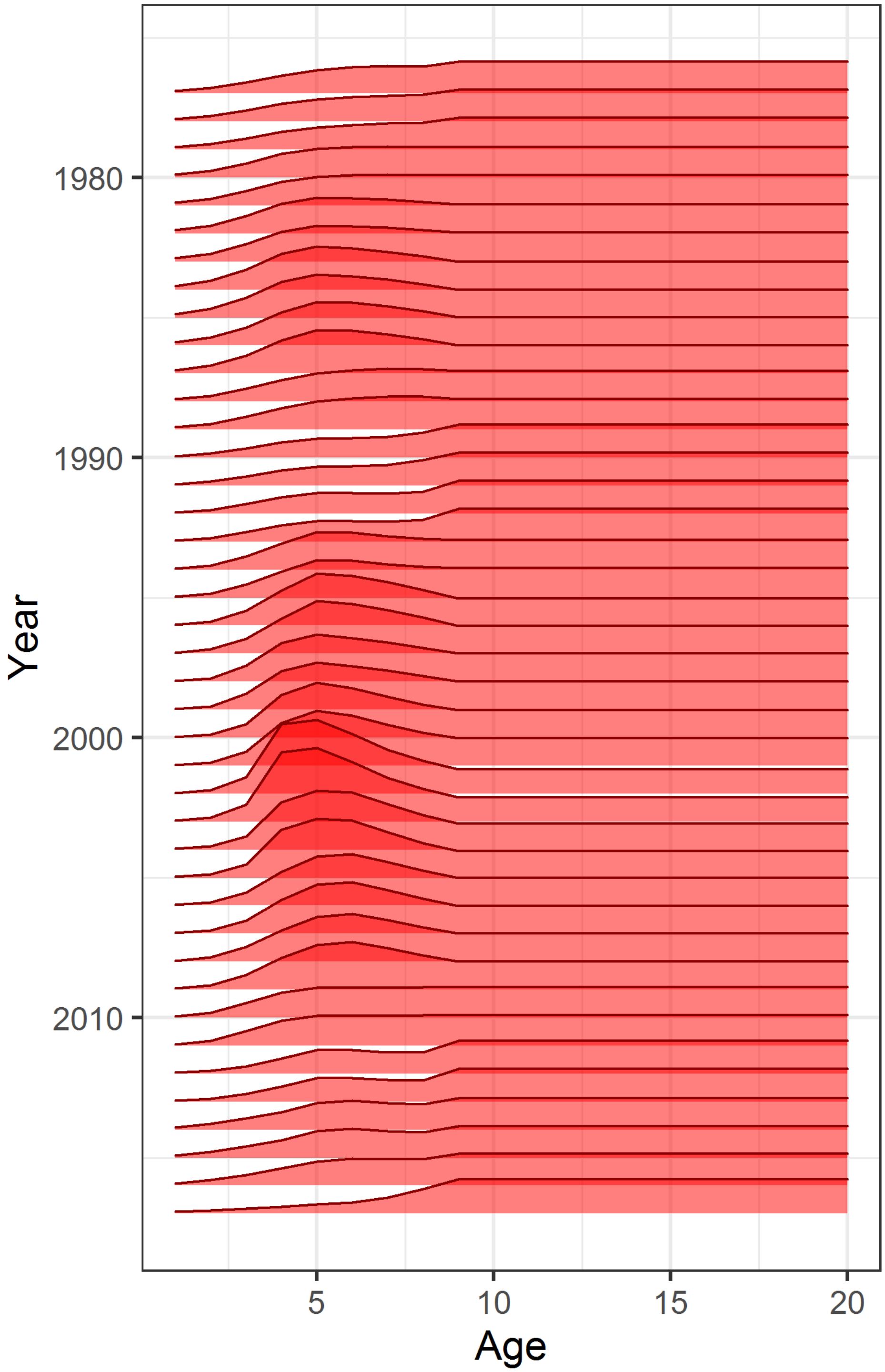

Figure 11. Female fishery selectivities for model 16.5z (time-varying non-parametric with 2-year blocks).

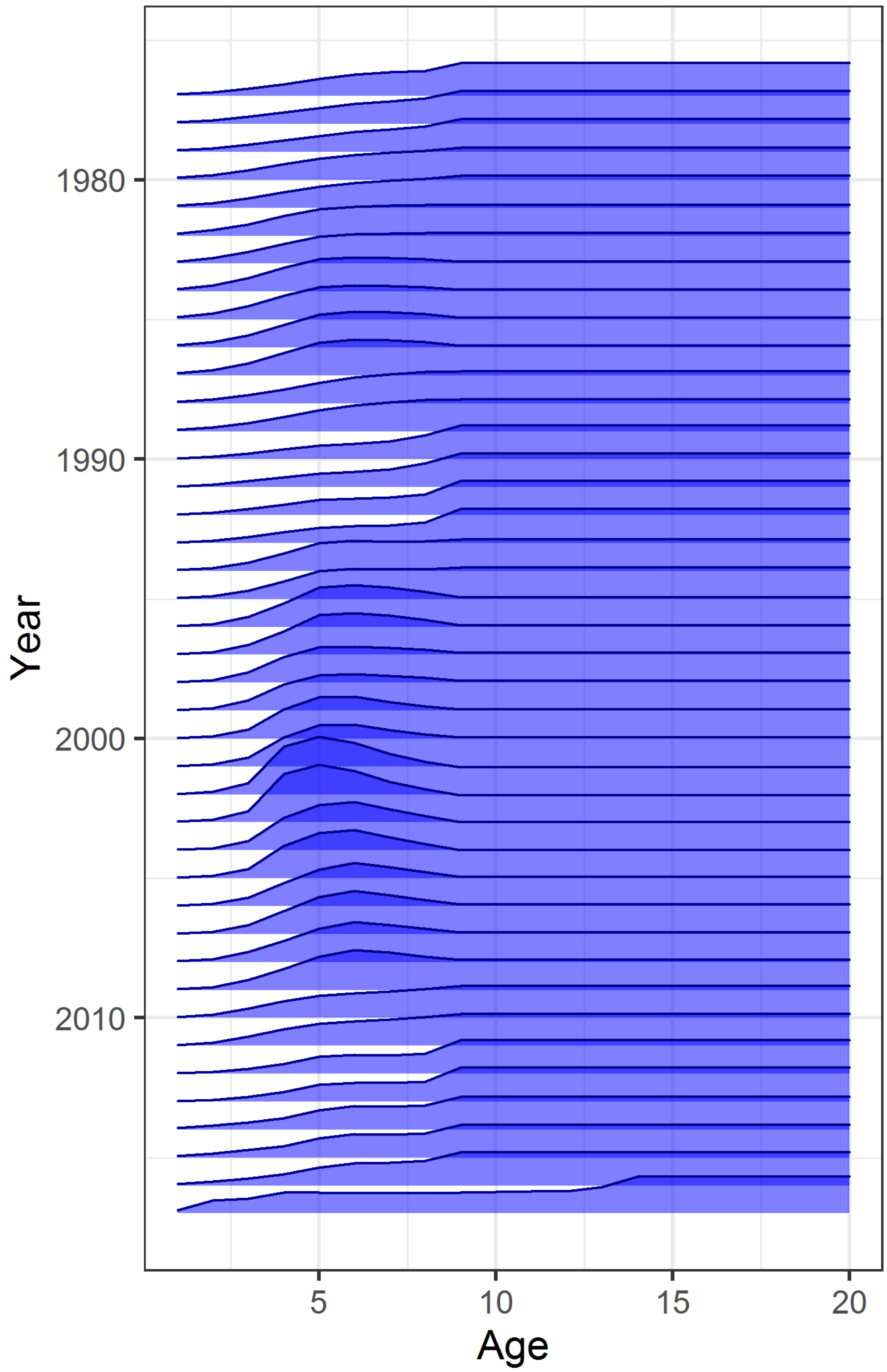

Figure 12. Male fishery selectivities for model 16.5z (time-varying non-parametric with 2-year blocks).

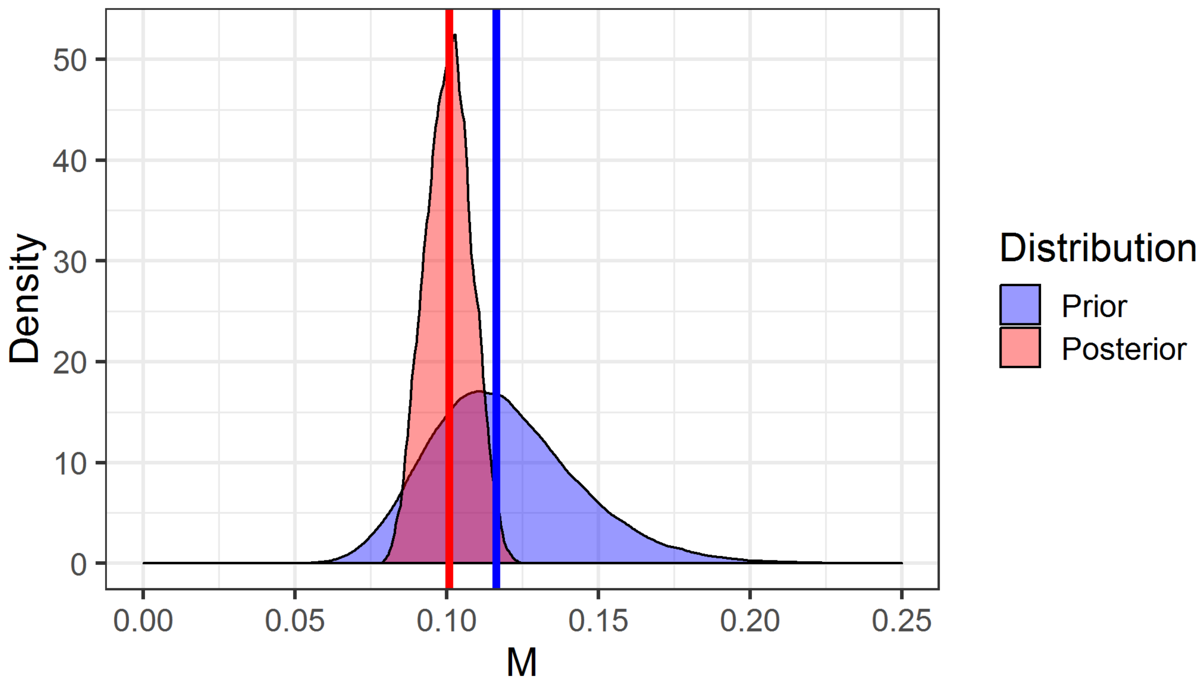

Figure 13. Prior (blue) and posterior (red) distributions of natural mortality for Model 16.5r which estimates natural mortality with the newly developed prior distribution.