3. Assessment of the Sablefish stock in Alaska

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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 2019 longline survey, relative abundance and length data from the 2018 fixed gear fishery, length data from the 2018 trawl fisheries, age data from the 2018 longline survey and 2018 fixed gear fishery, updated catch for 2018, and projected 2019 - 2021 catches. Estimates of killer and sperm whale depredation in the fishery were updated and projected for 2019 - 2021. In 2019, there was a NMFS Gulf of Alaska trawl survey. Biomass estimates and length compositions from this survey were also added.

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 is one additional appendix on simulation modeling to evaluate apportionment alternatives (3D).

Summary of Results

The longline survey abundance index increased 47% from 2018 to 2019 following a 14% increase in 2018 from 2017. The lowest point of the time series was 2015. The fishery catch-rate/abundance index stayed level from 2017 to 2018 and is at the time series low (the 2019 data are not available yet). Spawning biomass is projected to increase rapidly from 2020 to 2022, and then stabilize.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using recruitments from 1977-2015. The updated point estimate of $B_{40\%}$, is 105,976 t. Since projected female spawning biomass (combined areas) for 2020 is 113,368 t (7% higher than $B_{40\%}$, or $B_{43\%}$), sablefish is in sub-tier "a" of Tier 3. The updated point estimates of $F_{40\%}$, and $F_{35\%}$ from this assessment are 0.102 and 0.121, respectively. Thus, the maximum permissible value of F_{ABC} under Tier 3a is 0.102, which translates into a 2020 ABC (combined areas) of 44,065 t. The adjusted OFL fishing mortality rate is 0.121, which translates into a 2020 OFL (combined areas) of 51,726 t. An important consideration is that these reference points do no yet include the 2016 year class and next year. When the 2016 year class enters the recruitment time series, relative stock status will decline because the $B_{40\%}$ reference point will increase substantially. Model projections indicate that this stock is not subject to overfishing, not overfished, nor approaching an overfished condition.

Instead of maximum permissible ABC, we are recommending the 2020 ABC to be 25% higher than the 2019 ABC, which translates to a 57% reduction from maximum ABC. The final whale-adjusted 2020 ABC of 18,763 t is 25% higher than the 2019 whale-adjusted ABC. The maximum permissible ABC for 2020 is 56% higher than the 2019 maximum permissible ABC of 28,171 t. The 2018 assessment projected a 38% increase in ABC for 2020 from 2019. The author recommended ABCs for 2020 and 2021 are lower than maximum permissible ABC for several important reasons that are examined in the new SSC-endorsed risk-matrix approach for ABC reductions. Below is a discussion of the risks of raising the ABC based on preliminary estimates of large recruitments and a description of the 2019 risk table and the take-home points from the ESP in relation to the potential vulnerability of sablefish to harvests at the maximum ABC level.

One reason for a more conservative ABC recommendation is the potential for overestimation of the 2016 year class, which is estimated to be 2.5x times higher than any other year class observed in the current recruitment regime. The estimated recruitment for the 2014 year class, which was initially estimated to be very large, has subsequently been estimated to be lower in each subsequent assessment, when ages were available for 2017 and 2018, and it is possible that the same will occur for the 2016 recruitment estimate. 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 contributing to spawning biomass, the uncertainty surrounding the estimates of the strength of the 2014 and 2016 year classes, and the uncertainty about the environmental conditions that may affect the success of these year classes in the future. These concerns warrant additional caution when recommending the 2020 and 2021 ABCs. It is unlikely that the 2014 or 2016 year classes will be average or below average, but projecting catches under the assumption that these year classes are 4x and 10x average introduces substantial risk given the uncertainty associated with these estimates. Prior to these two year classes, only one other large year class since 1999 has been observed and the population is becoming dependent on these two recent year classes. There is only one observation of the 2016 year class in the age compositions to support the magnitude of this estimate. Our caution in reducing ABC in 2019 seems justified as the estimate of the 2014 year class has decreased 56% since first estimated. The cause of this decrease could be imprecision in the age composition measurement for the first year it was seen, or a biological factor, such as an increase in natural mortality. Future surveys will help determine the magnitude of the 2014 and 2016 year classes; there are indications that subsequent year classes may also be above average.

This is the second time we have used the risk-matrix approach to assess reductions in ABC from maximum permissible ABC. The overall score of level 3 indicates at least one “major 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 2020 and 2021 ABC recommendations, we consider all four of these types of risk considerations to recommend that the 2020 ABC should be set equal to 25% greater than the 2019 ABC, which translates to a reduction of about 57% from the maximum ABC allowed by the reference model. **The increase of 25% represents the largest increase in ABC from 1996 to present, when both the Alaska-wide assessment and IFQs existed. The last recommendation to substantially increase the ABC occurred in 2003, when the stock had appeared to have rebuilt above target levels because of the appearance of several above-average year classes. The stock steadily declined after that large increase in ABC resulting in ABC reductions for much of the next decade (Figure 3.57).** We expect that the 2014 - 2016 year classes are larger than those high recruitments events during 1997 – 2000 that were used to justify the large increase in 2003. However, it is important to use this example as a cautionary lesson. Recommending an ABC lower than the maximum should result in more of the 2014 and 2016 year classes entering into the spawning biomass and becoming more valuable to the fishery. This precautionary ABC recommendation buffers for uncertainty until more observations of these potentially large year classes are made. Because sablefish is an annual assessment, we will be able to consider another year of age composition data in 2020 and allow this extremely young population to further mature and more 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 56% from 2017 to 2019. A decline of this magnitude illustrates the uncertainty in these early recruitment estimates.
2. Fits to abundance indices are poor for recent years, particularly fishery CPUE and the GOA trawl survey.
3. The AFSC longline survey Relative Population Weight index, though no longer used in the model is still only just above average.
4. The retrospective bias is positive (i.e., historical estimates of spawning biomass increase as data is removed).
5. Mean age of spawners has decreased dramatically since 2017 and continues a downward trend, suggesting higher importance of the contribution of the 2014 year class to adult spawning biomass; however, age-4 body condition of this year class was poor, and much lower than during the last period of strong recruitments
6. The very large estimated year classes for 2014 and 2016 are expected to comprise about 33% and 14% of the 2020 spawning biomass, respectively. The 2014 year class is about 50% mature while the 2016 year class should be less than 15% mature in 2020.
7. 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.
8. Evenness in the age composition has dramatically declined, which means future recruitment and fishing success will be highly dependent on only a few cohorts of fish.
9. Spatial overlap between sablefish returning to adult slope habitat and the arrowtooth flounder population may have increased resulting in potentially higher competition and predation
10. Another marine heat wave formed in 2018, which may have been beneficial for sablefish recruitment in 2014 - 2016, but it is unknown how it will affect fish in the population or future recruitments.
11. Fishery performance has been very weak in the directed fishery with CPUE at time-series lows in 2018.
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.

In addition to the reductions from max ABC detailed above, it is now standard practice to recommend a lower ABC than maximum permissible based on estimates of whale depredation occurring in the fishery. This reduction was first 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 in both the survey and the fishery. The methods and calculations are described in the ***Accounting for whale depredation*** section.

Survey trends do support raising ABC from last year. Although there was a large increase in the domestic longline survey index time series in the last two years, and a large increase (> 3x) in the GOA bottom trawl survey since 2015, these increases are offset by the very low status of the fishery abundance index seen in 2017 and 2018. The fishery abundance index has been trending down since 2007. The IPHC GOA sablefish index was not used in the model, but was at a time series low in 2017. However, the IPHC index was up 41% in 2018. 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 appeared extremely strong initially, but year classes have sometimes failed to materialize later and the estimate of this year class has declined by more than half since the 2017 assessment. The initial estimate of the 2016 year class is as large as the 2014 estimate was when it was first estimated, but it may decline similarly to the 2014 initial estimate.

Because of the estimated size of the 2014 and 2016 year classes, 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 using the author's specified catches to 56,589 t in 2021 and 60,812 t in 2022 (see Table 3.18).

Projected 2020 spawning biomass is 43% of unfished spawning biomass. Spawning biomass had increased from a low of 32% of unfished biomass in 2002 to 40% in 2008 and had declined again to about 32% of unfished biomass in 2018, but is projected to increase rapidly in 2020. The previous two above-average year classes, 2000 and 2008, each comprise 6% and 8% of the projected 2020 spawning biomass, respectively. These two year classes are fully mature in 2020. The very large estimated year classes for 2014 and 2016 are expected to comprise about 33% and 14% of the 2020 spawning biomass. The 2014 year class is about 50% mature while the 2016 year class should be less than 15% mature in 2020.

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, beginning in 2011, we observed that the objective to reduce variability in apportionment was not being achieved using the 5-year exponential weighting method for apportionment. Since 2007, the mean change in apportionment by area has increased annually (Figure 3.58A). 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 3.58B). These large annual changes in apportionment result in increased annual variability of ABCs by area, including areas other than the Bering Sea (Figure 3.58C). 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. 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 2020, we recommend continuing with the apportionment fixed at the proportions used for 2013-2019.**

Apportionment Table (before whale depredation adjustments)

Area	**2019 ABC**	Standard apportionment for 2020 ABC	**Recommended fixed apportionment for 2020 ABC***	**Difference from 2019**
Total	15,380	19,225	19,225	25%
Bering Sea	1,501	4,050	1,876	25%
Aleutians	2,030	3,102	2,537	25%
Gulf of Alaska (subtotal)	11,849	12,073	14,812	25%
Western	1,659	2,247	2,074	25%
Central	5,246	4,510	6,558	25%
W. Yakutat**	1,765	1,803	2,206	25%
E. Yak. / Southeast**	3,179	3,513	3,974	25%

* 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 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 2020 and 2021 compared with the specified ABC in 2019. 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 (2016-2018) of whale depredation (t) by the amount that the ABC is increasing or decreasing from 2019 to 2020 and 2021. This amount of projected depredation is then deducted from each area ABC to produce new area ABCs for 2020 and 2021 (ABC_w). In this case the 3 year-average depredation is multiplied by 1.00 because the 2020 ABC is not recommended to increase from 2019. In 2016 the SSC decided that these calculations should also apply to OFL, so the same procedure is applied to OFLs for 2020 and 2021 below (OFL_w). Note that the decrement of depredation from OFL is expanded by the ratio of OFL to ABC as the whale depredation estimates are based on what would occur with catches near ABC.

The total change in recommended adjusted ABC is a 25% increase from the 2019 adjusted ABC. This varied slightly by area as projected whale depredation differed a little from last year. We continue to recommend this method of accounting for whale depredation in the fishery because it occurs at the stock assessment level and does not create additional regulations or burden on in-season management.

Author recommended 2020 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2019 ABC	2,030	1,501	1,659	5,246	1,765	3,179	15,380
2020 ABC	2,537	1,876	2,074	6,558	2,206	3,974	19,225
2016-2018 avg. depredation	16	19	105	91	45	94	370
Ratio 2020:2019 ABC	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Deduct 3 year adjusted average	-20	-23	-132	-113	-56	-118	-462
****2020 ABC_w**	**2,517**	**1,853**	**1,942**	**6,445**	**2,150**	**3,856**	**18,763**
Change from 2019 ABC_w	25%	24%	23%	24%	29%	23%	25%

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

Author recommended 2021 ABC (with whale depredation adjustments)

Area	AI	BS	WG	CG	WY*	EY*	Total
2019 ABC	2,030	1,501	1,659	5,246	1,765	3,179	15,380
2021 ABC	3,171	2,346	2,592	8,197	2,757	4,968	24,031
2016-2018 avg. depredation	16	19	105	91	45	94	370
Ratio 2021:2019 ABC	1.56	1.56	1.56	1.56	1.56	1.56	1.56
Deduct 3 year adjusted average	-25	-29	-165	-141	-70	-147	-578
****2021 ABC_w**	**3,146**	**2,317**	**2,427**	**8,055**	**2,687**	**4,821**	**23,453**
Change from 2019 ABC_w	57%	56%	54%	56%	61%	53%	56%

* 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	Year	W. Yakutat	E. Yakutat/Southeast
nd-line: trawl split in	2020	2,343	3,663
	2021	2,928	4,580

Author recommended 2020/2021 OFLs (with whale depredation adjustments)

Year	**2020**				**2021**			
Area	**AI**	**BS**	**GOA**	**Total**	**AI**	**BS**	**GOA**	**Total**
2019 ABC	2,030	1,501	11,849	15,380	2,030	1,501	11,849	15,380
OFL	6,826	5,049	39,850	51,725	8,757	6,477	51,127	66,361
3 year average depredation	16	19	335	370	16	19	335	370
Ratio OFL:2019ABC	3.36	3.36	3.36	3.36	4.31	4.31	4.31	4.31
Deduct 3 year average	-55	-62	-1,127	-1,244	-70	-80	-1,446	-1,596
2019 OFL_w	**4,350**	**3,221**	**25,227**	**32,798**	**4,350**	**3,221**	**25,227**	**32,798**
2020 OFL_w*	**6,771**	**4,987**	**38,723**	**50,481**	**8,687**	**6,397**	**49,681**	**64,765**
Change from 2019	56%	55%	53%	54%	100%	99%	97%	97%

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

Summary table

	As estimated or specified *last* year for:		As estimated or recommended *this* year for:	
Quantity/Status	2019	2020	2020*	2021*
M (natural mortality rate)	0.100	0.100	0.105	0.105
Tier	3b	3a	3a	3a
Projected total (age 2+) biomass (t)	488,273	513,502	704,683	741,029
Projected female spawning biomass (t)	96,687	129,204	113,368	156,854
$B_{100\%}$	291,845	291,845	264,940	264,940
$B_{40\%}$	116,738	116,738	105,976	105,976
$B_{35\%}$	102,146	102,146	92,729	92,729
F_{OFL}	0.096	0.117	0.121	0.121
$maxF_{ABC}$	0.081	0.099	0.102	0.102
F_{ABC}	0.044	0.051	0.043	0.041
OFL (t)	33,141	45,692	51,726	66,361
OFL_w (t)**	32,798	**45,220**	**50,481**	**64,765**
max ABC (t)	28,171	38,916	44,065	56,589
ABC (t)	15,380	20,620	19,225	24,031
ABC_w (t)**	15,068	20,144	**18,763**	**23,453**
Status	As determined *last* year for:		As determined *this* year for:	
	2017	2018	2018	2019
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 19,225 t and 24,031 t (Author's ABC) used in place of maximum permissible ABC for 2020 and 2021. 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	2018	356,000	22,703	11,505	11,505	12,083
	2019	264,000	25,227	11,571	11,571	9,528
	2020	387,000	38,723	14,393		
	2021	390,000	49,681	17,990		
BS	2018	94,000	2,887	1,464	1,464	1,598
	2019	52,000	3,221	1,489	1,489	2,994
	2020	116,000	4,987	1,853		
	2021	117,000	6,397	2,317		
AI	2018	65,000	3,917	1,988	1,988	660
	2019	98,000	4,350	2,008	2,008	490
	2020	154,000	6,771	2,517		
	2021	155,000	8,687	3,146		

Year	2019				2020		2021	
Region	OFL	ABC	TAC	Catch*	OFL	ABC**	OFL	ABC**
BS	3,221	1,489	1,489	2,994	4,987	1,853	6,397	2,317
AI	4,350	2,008	2,008	490	6,771	2,517	8,687	3,146
GOA	25,227	11,571	11,571	9,528	38,723	14,393	49,681	17,990
WGOA	--	1,581	1,581	1,139	--	1,942	--	2,427
CGOA	--	5,178	5,178	4,374	--	6,445	--	8,055
**WYAK	--	1,828	1,828	1,614	--	2,343	--	2,687
**EY/SEO	--	2,984	2,984	2,401	--	3,663	--	4,821
Total	32,798	15,068	15,068	13,012	50,481	18,763	64,675	23,453

* As of October 1, 2019 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 2018.

"The SSC considers the risk table approach an efficient method to organize and report this information and worthy of further investigation…The SSC recommends that one additional column be added to include concerns related to fishery/resource-use performance and behavior, considering commercial as well as local/traditional knowledge for a broader set of observations. This additional column should not include socio-economic considerations, but rather indications of concern such as inability to catch the TAC, or dramatic changes in spatial or temporal distribution that could indicate anomalous biological conditions. The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4)." (SSC, December 2018)

"Given that the risk table and ESP are clearly in development and are likely to evolve in important ways, the SSC suspends its requests for "OK-ness" and "inference of impending decline" for individual stock authors of all assessments…The SSC would like to see how these new processes and products develop to determine if they are able to provide the type of information needed to provide an early detection of ecosystem change. In addition, risk tables only need to be produced for groundfish assessments that are in a "full" year in the cycle." (SSC, June 2019)

"The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table." (SSC, October 2019)

The comments that pertain to the risk table have been grouped together. We we provide a risk table for the second time in 2019, as recommended by the SSC. Following the completion of this exercise, the highest score for this stock is a Level 3 and the authors provide susbtantial rationale for an ABC be reduced below maximum permissible ABC. Please see the **Additional ABC/ACL Considerations** section for further details for each category of this risk table.

Responses to SSC and Plan Team Comments Specific to this Assessment

In this section, we list new or outstanding comments on assessments in general from the last full assessment in 2018.

"The SSC noted that the adjustment to the maximum ABC to account for predicted whale depredation is now an established method that does not rely on the risk table, and should be considered a separate exercise and a standard practice moving forward. There was some discussion that the state fisheries, recreational catch and research removals have recently been of similar magnitude to the predicted whale depredation and could be considered for inclusion into the mortality used in the assessment and ABC considerations, as is the case for several other assessments, in the future. The SSC highlighted the importance of how selectivity and natural mortality are treated in this assessment to both the scale of the estimates as well as the stability of the model. The SSC requests that the authors continue to address lack-of-fit to compositional data in this assessment through exploration of alternative selectivity approaches including time-varying methods. In addition, the uncertainty described by the prior developed for natural mortality, but not included in the assessment, remains an important avenue for development. The SSC looks forward to seeing models in 2019 that continue to explore both of these issues. If individual models that include the uncertainty in these processes simultaneously remain unstable, then ensemble approaches including models representing alternative hypotheses may be an alternative solution. The SSC continues to request that a new apportionment approach be presented next year, noting that the percentages have now been static for many years. The potential for changes in distribution in the fishery and/or the population may become more pronounced with the increasing contribution of the 2014 year class." (SSC December 2019)

We attempted a number of exploratory models this year that explored whether selectivity alternatives could alleviate the poor fit to the abundance indices in last year's assessment model. Most of the outstanding fit issues can be attributed to 2016 when we followed CIE advice to substantially downweight the abundance indices to provide better fits to the compositional data and propagate additional uncertainty to biomass results. We chose to bring no new models forward in 2019 because any minor model specification changes are overwhelmed by the extraordinary recent increases in young fish in the population.

"In light of the most recent genetic research suggesting no population structure throughout the species range in the NE Pacific, the SSC strongly encourages the collaborative work with Canadian and West coast scientists on a combined stock assessment. Comparisons of recruitment among regions could also add information on the distribution and coherence of the 2014 year class." (SSC December 2019)

A new comparison of recruitment in the three major regions has been added in the section ***Other areas summary***. The coastwide working group continues to make progress, producing several seminar presentations and a publication in 2019 (Kapur et al. 2019) demonstrating geographic structure in sablefish growth. The intent of the collaboration is not to produce a combined stock assessment, but to develop a combined operating model that can be used for simulation exercises.

The Team recommends that the authors bring forward two alternatives to OFL in November: (1) combine "the BS and AI and (2) combine OFL Alaska-wide." (JPT September 2019)

"The SSC recommends that the authors bring forward three OFL options for the November PT and December SSC meeting: 1) Status quo; 2) combine the BS and AI; 3) an Alaska-wide specification. The SSC requests that the authors describe the history of the area-OFLs and assessment, a description of the conservation concerns as they relate to the need for sub-area OFLs versus those addressed with ABC apportionment, and whether some concerns could be addressed through management or policy measures outside of the specification process (this may need to be a separate request to NMFS management). The ongoing work on spatial management and stock structure could be informative as to whether the current spatial scales of the OFLs are appropriate." (SSC October 2019).

The historical record has very little written information on the switch between a BSAI OFL and separate BS and AI OFLs. The Federal Register does not have any information on it, and past stock assessments have little either. Prior to 1996, stock assessments were done separately for the BSAI and the GOA. When the BSAI assessment was done separately, it had separate ABCs for the BS and the AI and a single OFL. Because of high movement rates estimated from tagging studies, the August 1996 sablefish assessment was the first time an Alaska-wide age-structured model was presented. This model was accepted in 1996 November/December Plan Team and SSC deliberations and the stock has been assessed Alaska-wide since. When this model was accepted the authors used the apportionment strategy that the Council had used previously to specify TACs for establishing ABCs for the BS, AI, and GOA. The authors then assigned OFLs to each of these ABCs which to them seemed like a natural step. It should be noted that at the time, the GOA apportionment was for dividing ABC to subarea TACs, not ABCs and the GOA ABC was Gulf-wide, as was the GOA OFL. This changed in the 1997 assessment, when these TAC apportionments began to be called sub-area ABCs. Additionally, it should be noted that in sablefish status determination scenarios (Table 3.18), overfishing and overfished determinations are only reported at the full stock assessment level, and if an OFL is exceeded in a subarea, the assessment would not report that the Alaska-wide stock was experiencing "overfishing."

Recent discussion with the previous assessment authors (pers. comm. J. Fujioka, M. Sigler, and S. Lowe) revealed that there were informal verbal discussions of ABC and OFL spatial scale issues when they were making the transition to an Alaska-wide assessment. There was general agreement from former authors that when there is an ABC the OFL should be specified at the same spatial scale. For example, during the same period (1995-1997) when sablefish ABC and OFL changes were occurring, GOA Pacific ocean perch (POP) were recovering from rebuilding and ABCs and OFLs were implemented by subarea for that stock because there was a conservation concern. There was a concurrent concern raised at the time that the sablefish OFL could be exceeded due to the trawl fishery overages before all IFQs were taken. If this happened, fishermen would be motivated to quickly catch their IFQs early in the season, thus restarting the derby aspect of the sablefish longline fishery. At the time of these changes in ABC and OFL, there were significant overages occurring in both fixed and trawl fisheries in different areas. This appears to be the potential situation the sablefish fishery finds itself in presently.

The most recent recommendation by the Plan Teams germaine to this discussion was when they were discussing the rationale of the subarea OFLs for Gulf of Alaska POP after OFL was exceeded in the Western GOA in 2012. The Team in September requested the authors bring forward the rationale for the previous specification of subarea OFLs and options for future OFLs, similar to the PT and SSC requests being addressed here. The authors cite the overfished status and the rebuilding plan in the early 1990s as the rationale for the area-specific OFLs that were implemented at that time. An excerpt from the 2012 November GOA Groundfish Plan Team minutes:

"*The Team discussed options for apportioning future OFLs which included apportioning by 1) management area (status quo); 2) GOA-wide; or 3) areas fished/not fished. Team members questioned whether apportioning OFLs to the management area level is relevant given the stock is well above target* *levels and multiple levels of precaution are built into the current management regime to prevent regular overharvest. Exceeding the Western GOA OFL is of some concern but the Team believes the overall population is less vulnerable to such occasional overages. Therefore, the Plan Team recommends maintaining area specific ABCs but apportioning OFLs across the area currently open to bottom trawling (Western, Central, WYAK) and the area closed to bottom trawling (EYAK/SEO). This recommendation is supported by material presented in Appendix 9A: "Evaluation of stock structure for Gulf of Alaska Pacific ocean perch*." This would suggest that at that time, absent specific rationale for area-specific OFLs, that the Plan Team's preference was for OFLs over broader areas when there was not an obvious stock status issue.

In 2019, we find ourselves wondering whether OFL spatial scale is really an assessment concern or an allocative or legal decision. Based on previous analyses of sablefish movement, our current assumption about stock-recruitment relationships, and on our current work on spatial models, we would not expect that occasional small overages of ABC or OFL in a subarea to have a substantial effect on future productivity or yield. In general previous analyses and the 2016 CIE noted that the extremely high movement rates suggested a low risk for localized depletion at a range of reasonable fishing mortalities. There is an argument that could be made that an ABC and OFL should be set at the level of what we consider a stock, and that the implication of sub FMP-area ABCs or even FMP area ABCs and OFLs implies that sablefish are different stocks in those areas or have distinct stock structure, which we believe is a dubious conclusion. That being said, the existence of subarea ABCs and OFLs provides a buffer for the many uncertainties that remain about the stock including whether some areas are more important for spawning than others, the potential for future fish movement patterns to be disrupted by rapid environmental changes, or the unknown importance of sablefish as forage for a variety of species in years of high abundance (Appendix 3C). Given these different perspectives, we choose to remain agnostic as to what the right approach might be and only lay out the options requested. Some options may provide management benefits or efficiencies, but we do not have the appropriate information or data to recommend a scientific basis for one option over another.

1) Status quo (sub-area ABCs and OFLs, for the BS, AI, and GOA)
    a. Sablefish is not unique in that there is one assessment conducted for both BS and AI, even though it is unique that the GOA is also included. Many BSAI stocks have separate assessments with ABCs and OFLs specified for AI and BS individually. These likely evolved due to biological differences or conservation concerns, and are similar to how GOA POP had been done during rebuilding.
2) FMP area OFLs with FMP sub-area ABCs (i.e., OFL for BSAI, OFL for GOA)
    a. Several stocks have one stock assessment for BSAI combined such as Greenland turbot and Other rockfish with separate ABCs but one OFL.
3) Alaska-wide OFL with FMP sub-area ABCs
    a. This option would be unique to sablefish and unlike any other Alaska stock assessment.

Option	**Description**	**Area**	**AI**	**BS**	**WG**	**CG**	**WY**	**EY**
		ABC	2,517	1,853	1,942	6,445	2,150	3,856
1	Status Quo	OFL	6,771	4,987	38,723			
2	FMP - OFL	OFL	11,758		38,723			
3	Alaska - OFL	OFL	50,481					

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 gillnets set at night during 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

2019 Sablefish Tag Program Recap

The Auke Bay Laboratory continued the 40+ year time series of sablefish tagging in 2019. Approximately 5,400 sablefish were tagged on the annual NMFS longline survey, the highest number of sablefish tagged on the longline survey in one year. Approximately 400 sablefish tags have been recovered in 2019 to date. Of those recovered tags, the longest time at liberty was approximately 40 years (14,586 days), the shortest recovered tag at liberty was for 4 days, and the greatest distance traveled was 1,900 nautical miles from a fish tagged off of southern California on 11/3/1980 and recovered off Kodiak Island, Alaska on 5/2/2018.

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.). More recently, gulfwide reports of abundant young of the year and subsequent age-1 fish began in 2014 and have been received in varying levels since. In 2014, numerous reports of young of the year being caught were received from several sources gulfwide; large catches in the NOAA surface trawl surveys in the EGOA in the summer (W. Fournier, August, 2014, NOAA, pers. comm.), the Alaska Department of Fish and Game surveys in Prince William Sound (M. Byerly, 2014, ADFG, pers. comm.), and salmon fishermen in the EGOA reported large quantities of YOY sablefish in the stomachs of troll caught coho salmon in 2014 and 2015. In 2015 and 2016, additional reports of age-1 fish (2014 year class) and YOY (2016 year class) were received: the Gulf of Alaska NMFS bottom trawl survey caught a substantial number of one-year-old sablefish, particularly in the Western GOA. There were also YOY sablefish in Pacific pomfret stomachs caught in summer surface trawl surveys in the Gulf of Alaska (C. Debenham, September, 2016, NOAA, pers. comm.), and charter fishermen in the CGOA reported frequent catches of one year old sablefish while targeting coho salmon (K. Echave, September, 2015, NOAA, pers. comm.). Numerous fisheries reported high numbers of YOY sablefish again in 2018 and 2019. Several reports were received in August and September 2018 from commercial seiners in Southeast Alaska catching lots of “6 inchers,” everywhere from Deep Inlet near Sitka to Cross Sound. Additionally, trawlers targeting Pollock in the Bering Sea in 2019 encountered young sablefish (likely the 2014 and 2016 year classes) in record numbers, finding them “unavoidable.” In 2019, total sablefish catch in the Bering Sea approached OFL due to the unexpected difficulty in avoiding incidental catch of sablefish by the trawl fisheries.

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 useful when forecasting upcoming recruitment trends.

The time series of sampling in SJBB continued in 2019 with two sampling trips for tagging and diet analysis. These corresponded with a diet and energetics study by a graduate student with the University of Alaska. The first sampling trip occurred March 16 - 19, 2019. Four rods were fished approximately 10hrs/day and 11 sablefish were caught. The second sampling trip occurred July 15 – 19, 2019. Four rods were fished approximately 10 hrs/day and a total of 708 fish were caught, which was a relatively high catch-per-unit effort compared to past years. Average size of fish in July was 31 cm. In their first two years, the age of a sablefish can easily be inferred by their length and the time of year. In July, most sablefish near 31 cm are age-1.

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 estimated from time at liberty were similar to the stock assessment.

Using these data, a three-area spatial sablefish assessment model was developed to examine regional sablefish biomass. 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 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, trawl catch increased from 30 t in 2016 to 129 t in 2017 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 Magnuson-Stevens Fishery Conservation and Management Act (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 2018 but have begun to increase in 2019, mainly from a higher amount of trawl catch (Table 3.3, Figure 3.2). TACs in the GOA are nearly fully utilized, while TACs in the BS and AI had been rarely fully utilized. Starting in 2018, and accelerating in 2019, the BS TACs and ABCs have been 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 similar, averaging 1,118 t during 2010 - 2019. However, from 2017-2019 discards increased in the EBS in both hook-and-line and "other" gear and was also higher than normal in the hook-and-line fisheries in 2016. In the GOA, discards were higher in "other" fisheries in 2018-2019 (Table 3.4). Many of these discard rates increased from 1%-15% to 20-40%. This dramatic increase is likely due to the prevalence of young, small fish. There were many fisheries in the BSAI and the GOA with higher discard rates. The largest increases were in the BSAI pollock mid-water trawl, GOA arrowtooth flounder, BSAI Kamchatka flounder, GOA pollock bottom trawl, and the BSAI flathead sole fisheries.

Table 3.5 shows the average bycatch of Fishery Management Plans' (FMP) groundfish species in the sablefish target fishery during 2012 – 2018. The largest bycatch group is GOA thornyhead rockfish (679 t/year, 217 t discarded). Sharks and skates and arrowtooth flounder are also taken in substantial numbers and are mostly discarded. In 2018, there was an increase in flatfish, Pacific cod, other rockfish, shortraker rockfish, rougheye rockfish, skate, thornyhead, Pacific ocean perch, pollock, sablefish, and shark bycatch.

Giant grenadier, 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. The highest bycatch of giant grenadier in recent years was 11,554 t in 2013, but has remained below 7,500 mt since then (Table 3.6). Other nontarget taxa that have catches over one ton per year are corals (bryozoans), snails, sponges, sea stars, and miscellaneous fishes and crabs. In 2018, catch of these corals was higher than average at 9 mt (average = 6.6 mt). The highest catch was in 2013 at 12.7 mt.

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 (14,827 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. Golden king crab bycatch was at a high of 38,905 individuals in 2018, due to catch in the BSAI pot fishery (Table 3.7, see “other” gear).

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-**2019**
Trawl fisheries	Catch	1960-**2019**
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964-1981
U.S. fixed gear fishery	CPUE, length	1990-**2018**
	Age	1999-**2018**
U.S. trawl fisheries	Length	1990,1991,1999, 2005-**2018**
Japan-U.S. cooperative longline survey	CPUE, length	1979-1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990-**2019**
	Age	1996-**2018**
NMFS GOA trawl survey	Abundance index	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, **2019**
	Lengths	1984, 1987, 1990, 1993, 1996, 1999, 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, **2019**

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 since 2009. Estimates of all removals not associated with a directed fishery, including research catches, 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 are high because of the annual AFSC 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, which occurs primarily in State waters. Total removals from activities other than the 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 weight 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 7% (1,027 mt) of the total longline catch in federal waters in 2018. The percent of the IFQ catch observed was 8% in the BS (up from 2%), 5% in the EY/SE (down from 10%), 9% in the WG, 8% in WY, 5% in the CG (down from 10%), and the AI cannot be reported due to confidentiality. The number of observed sets in the WG was down in 2017 and 2018 (81 sets and 108 sets, respectively) (Table 3.9). The number of vessels declined in the EYSE, CG, WG, and BS areas (Table 3.9). In the WG there are now just 7 vessels and there are often fewer than 3 in the AI and BS.

Killer whale depredation has been recorded by observers since 1995. Killer whales typically depredate on longline gear 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 and 2018 there were very few sets observed in the AI and BS and there were fewer than 3 vessels in 2018. In the CG, 1% of sets were depredated by killer whales, which is 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 2018 the rates were below this more recent average; 4% of sets were depredated in the CG, 9% in WY, and 10% in EY/SE.

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) started collecting logbooks dockside in all areas. This increasing trend is likely due to the strong working relationship the IPHC has with fishermen, their diligence in collecting logbooks dockside, and because many vessels <60 feet are now participating in the program voluntarily. In 2018, after the data was screened for missing data fields, 63% of sets came from vessels under 60 ft. A higher proportion of the catch is documented in logbooks than by observers; in 2018 36% of the fixed gear catch was documented in logbooks and 7% 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 and 2018, whale presence and gear depredation were included in logbooks. The data fields were designed cooperatively by NMFS and IPHC because both species are affected by depredation. In 2018 some vessels were not yet using these new logbooks. These data are not required fields and so all data is voluntary. Participation in recording whale observations was high in 2017 and higher in 2018, see below. In 2018, the majority of sets had mammal data recorded, which includes observations indicating no mammals were present. Sets with sperm whale presence recorded increased in EY, WY, and WG in 2018, but decreased in the CG and AI. These rates are higher than those recorded in the observer data set. In future years we will be able to see trends in whale presence in logbook data and we hope to continue to see an increase in the quantity of whale observations as the fleet continues to adopt the new logbooks and increases their voluntary participation. We greatly appreciate the fleet filling out these new data fields voluntarily.

Table below: The percentage of logbook sets with data, i.e., those where mammal presence or absence of mammals was recorded (% sets with data); the percentage of sets with data with marine mammals present (% of sets with mammals); and the % of sets with data that had killer whales (% killer whales) or sperm whale present (% sperm whales). Management areas include the Aleutian Islands (AI), Bering Sea (BS), Western Gulf of Alaska (WG), Central Gulf of Alaska (CG), West Yakutat (WY), ad East Yakutat/Southeast (EY).

	Area	% sets with data	% sets with mammals	% killer whales	% sperm whales
2017					
	AI	55	7	0	7
	BS	27	19	19	0
	WG	61	21	4	15
	CG	68	28	0	28
	WY	71	28	2	26
	EY	83	30	1	29
2018					
	AI	88	27	24	2
	BS	100	0	0	0
	WG	88	14	4	10
	CG	88	20	0	19
	WY	77	37	0	36
	EY	86	32	0	31

Longline catch rates

Sets where there was killer whale depredation are excluded from catch rate calculations in observer data, but whale depredation has only recently been documented in logbooks (starting in 2017). 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).

Overall the fishery catch rate indices were down with a couple of slight upticks. There was a declining trend in the AI from 2015 to 2017; however, there was an increase in logbook data in 2018. There were so few vessels observed in the AI and BS that in 2018 data cannot be presented due to confidentiality. In 2016 and 2017 BS CPUE was the lowest in the time series in the logbook dataset; for non-confidential years, CPUE was very low in the observer data in 2015 and 2017.

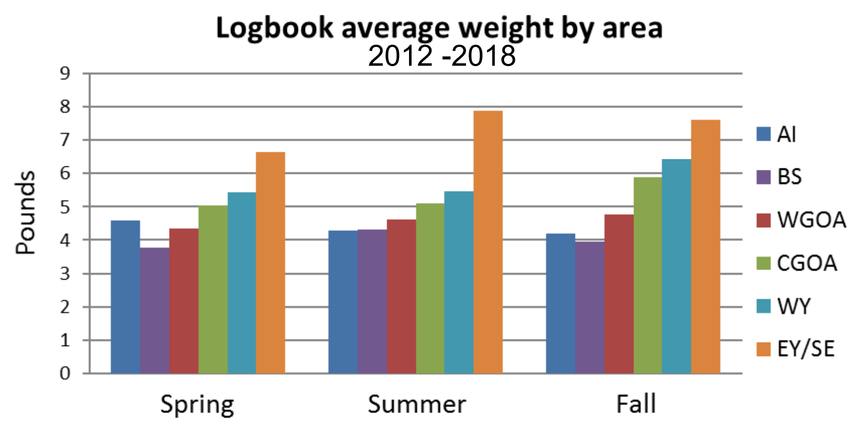
In the GOA, the overall longline CPUE trend was downward. The overall trend in the CG has been declining since 2012 and in 2018 the CPUE was the lowest in the time series. There has also been a downward trend in WY in both data sets since 2009 and the CPUE in 2018 was at its lowest point in the time series (starting in 1990). CPUE declined in EY/SE in 2018 and was at its lowest point since 1994. There was an increase in CPUE in the WG in 2017 and it was stable in 2018, which is the first area where strong year classes usually appear, as young, small fish.

Because of larger sample sizes in the logbook data set compared to observer data, logbook confidence intervals are generally narrower thus these 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 logbooks from 2012-2018. Data were included if there was weight and count information and if the average weight for the set was reasonable. When the data are aggregated for all years, there is an increasing trend in weight toward the east, with the largest fish in the EY/SE area. Fish are largest in the fall in the GOA. Fish size stays consistent throughout the year in the BS, and the largest fish in the AI are caught in the spring.

In some areas, annual mean fish weight was the highest in 2018. Although not shown, annual average fish weight was largest in the EY/SE area in 2014, 2015, and was a close third in 2018. The weights in WG were highest in 2013 and 2018. The average weights in the CGOA were generally stable, but highest in 2018. Note in the table below that there are lower sample sizes in the WY and EY/SE areas in summer and fall than in other areas in all seasons. This could lead to larger fluctuations than in other areas and seasons. In the summer in EY/SE, the highest average was in 2012 and 2018 (8.1 lbs). There were too few vessels in each year in the AI and BS; thus the maximum weight by year cannot be reported.



Count of hook and line logbook sets used for calculations of average weight by area and season for 2012 - 2018.

Area	Spring	Summer	Fall	Total
BS	977	544	350	1,811
AI	1,232	871	479	2,582
WGOA	1,221	1,855	766	3,742
CGOA	4,261	2,597	1,458	8,316
WY	1,811	407	158	2,376
EY/SE	1,064	339	422	1,825

Pot fishery catch rate analysis

Pot fishery sample sizes and catch rates: Pot sets in these data summaries are for sablefish targeted sets, as described under "Observer Data" above. 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 and many of these vessels fish in multiple management areas within the GOA. In the 2017 logbook dataset, there were 17 vessels fishing pots in the GOA; 10 of these vessels were <60 ft. In 2018 there were 19 vessels fishing pots in the GOA; 12 of these vessels were <60 ft and three of the 19 vessels also fished in the AI.

In the observer data set, there were 9 and 12 vessels fishing pots in the GOA in 2017 and 2018, respectively.

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

<u>Longline survey</u>

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 strongly diverged in 2017 and 2018 because the abundance of young fish increased RPNs, while had little effect on RPWs (Figure 3.10b). However, in 2019 RPWs sharply increased relative to 2018.

The 2013 and 2015 survey estimates of RPNs were the lowest points in the domestic time series, but the 2016 and 2017 increases put the index near average; 2018 was well above average and 2019 was higher still. In the GOA, 2019 survey catches were consistently higher by station than in 2018 in all areas (Figure 3.8a).

Whale Depredation: Killer whale depredation on the survey 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. The AI is sampled in even years and the BS in odd. Since 2009, depredation rates in the BS have been high, including 11 affected stations in 2017 and 10 in 2019 (Table 3.11). 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 whales are most common in the EGOA (WY and EY/SE) and the CGOA and occasionally depredate in the WG. In the EY/SE areas the number of stations with depredation was high, at 9 of 17 stations. In 2019 it dropped to only 4. (Table 3.11). In the CGOA depredation doubled from 3 stations to 6 out of 16 in 2019. Although sperm whales are sometimes observed in the WGOA, there has only been depredation observed at one station in 2012, 2017, and 2019. In the AI there was also one station depredated in 2012, 2014, and 2016, but none in 2018. Sperm whale depredation has not been recorded during the survey in the Bering Sea.

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 1990-2019 are well correlated with slope catches ($r = 0.69$). 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 2018 and 2019 both indices were seeing an influx of fish simultaneously. 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.

<u>Trawl surveys</u>

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 1984-2019 are shown in Table 3.10. The GOA trawl survey index was at its lowest level of the time series in 2013, but has more than tripled by 2019.

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

<u>IPHC Longline Surveys</u>

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).

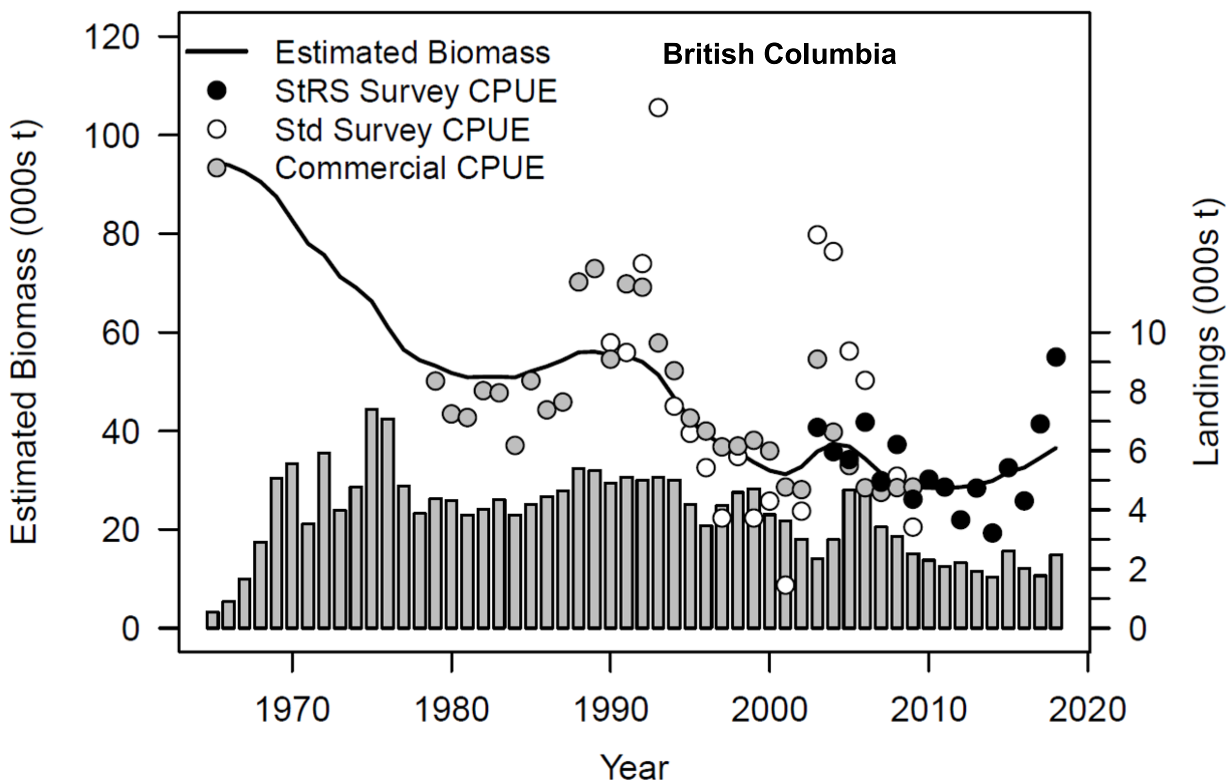
While the two longline surveys have shown consistent patterns for most years, they diverged in 2010 and 2011 and again recently. In 2014 the AFSC survey index increased, while the IPHC index was stable. In 2015 the IPHC index decreased substantially and was the lowest in the time series which agrees 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 but there is substantial increase in 2018, but still below average. 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.

<u>Alaska Department of Fish and Game</u>

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 survey CPUE seems to be stabilizing after a steep decline from 2011 to 2013, with an uptick in younger fish seen during 2016 – 2018 (Figure 3.11a). NSEI fishery CPUE continues to rise in 2018 (Figure 3.11b). In SSEI, survey CPUE has been declining since 2011 but also saw an uptick during 2016 – 2018 (Figure 3.11c). The lowest points in the time series of CPUE for each of these areas is about 2000, which corresponds to 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 – 2018 represent a considerable increase in biomass in the trap survey (approximately tripling) 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].

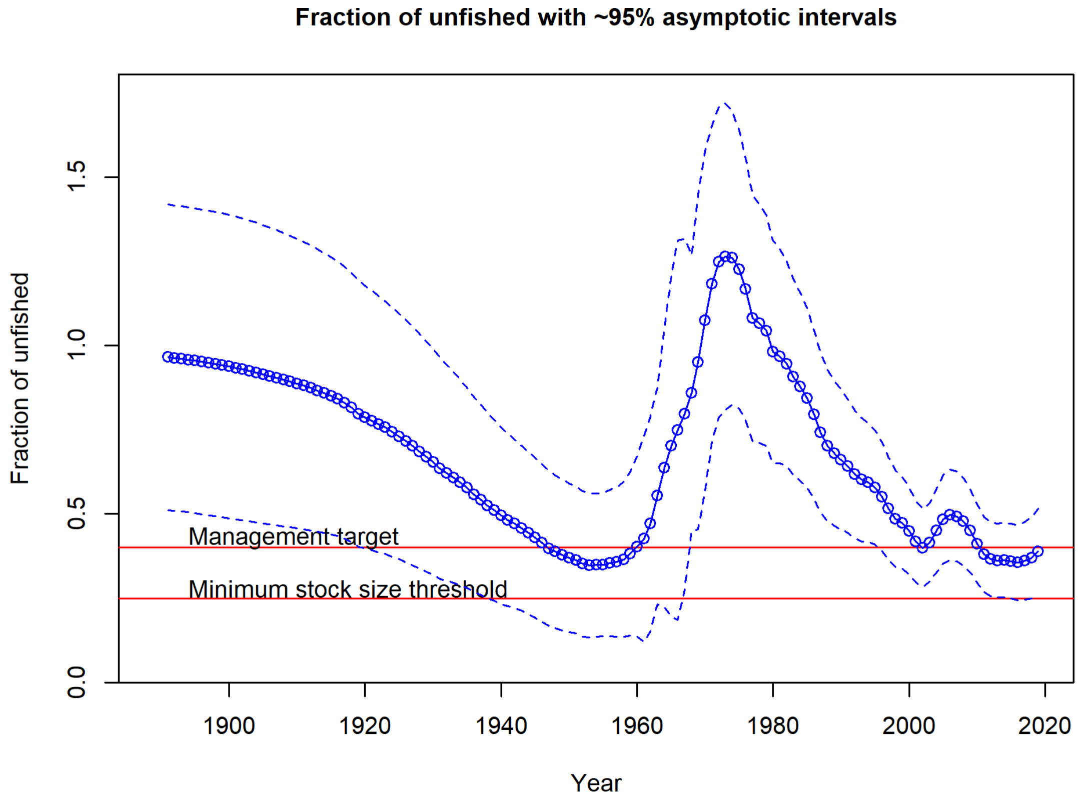


Northwest Fisheries Science Center

In 2019, a full assessment was conducted for the West Coast sablefish fishery (Haltuch et al. 2019[2]). They are also seeing an emergence of several large year classes and the stock is now expected to be at or near the target reference point (see figure below).

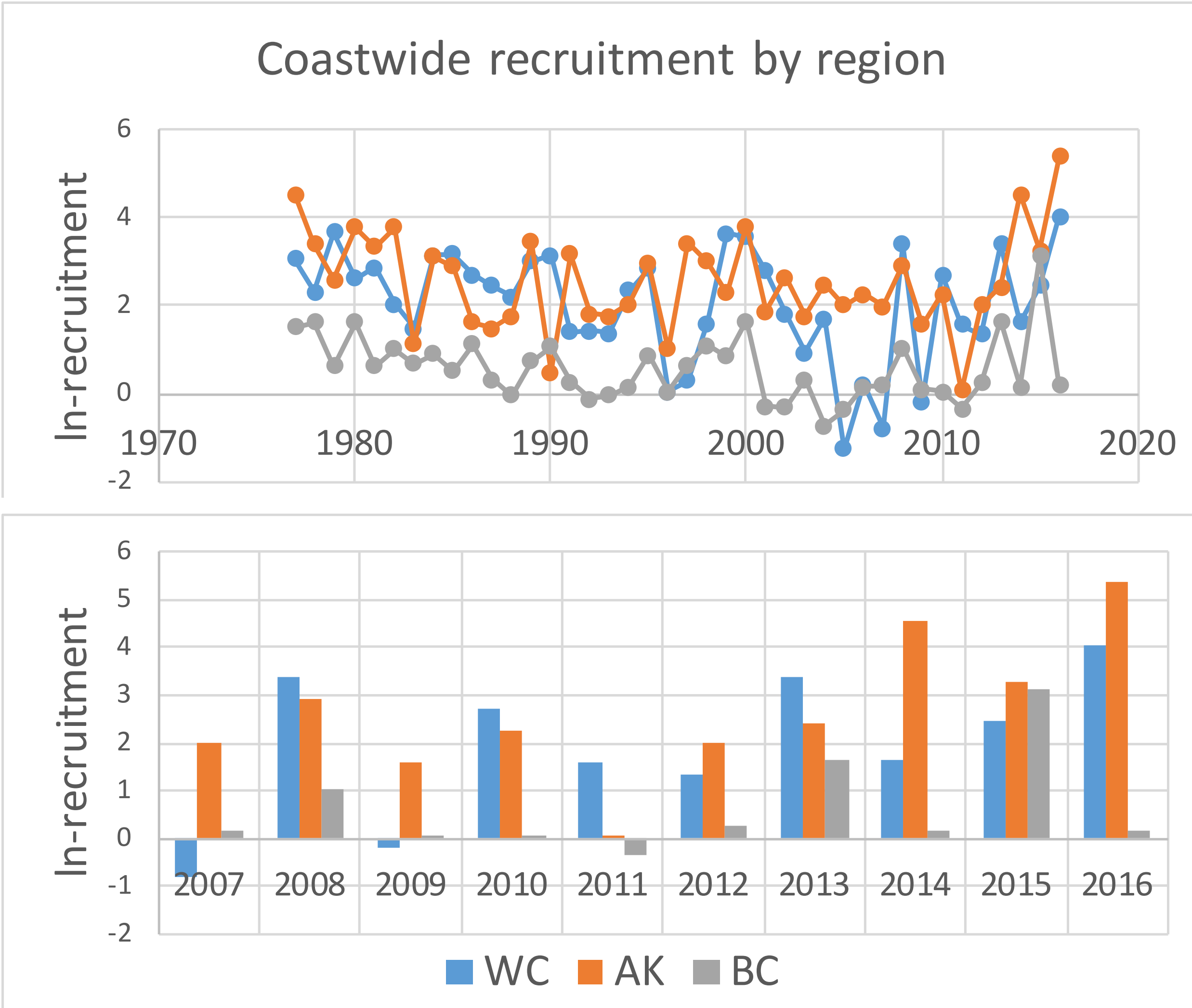
[1] Brendan Conners, pers. commun. Nov. 1, 2019. Department of Fisheries and Oceans, Canada.

[2] https://www.pcouncil.org/wp-content/uploads/2019/08/H5_Att7_Sablefish_Full_E-Only_SEPT2019BB.pdf



<u>Other areas summary</u>

The figure below shows the recruitment estimates across the greater Pacific sablefish stock. Historically, the recruitment estimates from the West Coast and Alaska have been strongly correlated, but recently that correlation has decreased. The main reason for this is an interesting pattern where the WC is estimating strong 2013 and 2016 year classes, BC is estimating strong 2013 and 2015 year classes, and AK estimates show strong 2014 and 2016 year classes. These estimates raise the question of whether favorable environmental conditions triggering reproductive success are slightly offset between these areas or whether these differing years are artefacts of ageing error, or how ageing error is utilized in the respective assessment models. However, the overall concurrent trends seen in Canada and the West Coast 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 (Fenske et al. 2018).



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 several surveys have shown considerable 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 2019 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 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 using 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 using Pearson residuals as

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

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

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

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

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

For the 2010 recommended assessment model, we used average SDNR as a criterion to help reweight the age and length compositions. SDNR is a common metric used for goodness of fit in other fisheries, particularly in New Zealand (e.g. Langley and Maunder 2009) and has been recommended for use in fisheries models in Alaska during multiple CIE reviews, such as Atka mackerel and rockfish. We iteratively reweighted the model by setting an objective function penalty to reduce the deviations of average SDNR of a data component from one. Initially, we tried to fit all multinomial components this way, but due to tradeoffs in fit, it was found that the input sample sizes became too large and masked the influence of important data such as abundance indices. Given that we have age and length samples from nearly all years of the longline surveys, we chose to eliminate the attempt to fit the length data well enough to achieve an average SDNR of one, and reweighted all age components and only length components where no age data exist (e.g. domestic trawl fishery). The abundance index SDNRs were calculated, but no attempt was made to adjust their input variance because we have *a priori* knowledge about their sampling variances. This process was completed before the 2010 data were added into the assessment and endorsed by the Plan Teams and SSC in 2010. We used these weightings until this year. The 2016 CIE review panel felt strongly that the model was using the longline survey too precisely in the model which resulted in overly precise model outputs. For the 2016 assessment we tuned the domestic longline survey to have an SDNR of one, while maintaining the other previously tuned size and age compositions at an SDNR of one. The rest of the abundance indices were given the same weight as the domestic longline survey to maintain the relative weighting.

Whale depredation estimation

Sperm whales on the longline survey

Sets on the AFSC longline survey impacted by killer whale depredation have always been removed from calculations because of the significant and variable impacts killer whales can have on catch rates. Sperm whale depredation is more difficult to detect and has not previously been considered when calculating catch rates. Presence and evidence of depredation by sperm whales on the AFSC longline survey have increased significantly over time ($p < 0.05$, Hanselman et al. 2018). 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 2001-2018 (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 decline in sperm whale depredation in some areas in 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	88
Average fishing mortality	μ_f	2
Fishing mortality deviations	ϕ_y	120
Fishery selectivity	fs_a	9
Survey selectivity	ss_a	8
Total		237

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 1933-2018. 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 1960-2019 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 1979-2017 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
$s^g_{a,s}$	Selectivity at age a for gear type g and sex s
$A_{50\%}, d_{50\%}$	Age at 50% selection for ascending limb, age at 50% deselection for descending limb
δ	Slope/shape parameters for different logistic curves
$\mathbf{A}$	Ageing-error matrix dimensioned $a_+ \times a_+$
$\mathbf{A}_s^{\ l}$	Age to length conversion matrix by sex s dimensioned $a_+ \times \Omega$
q_g	Abundance index catchability coefficient by gear
λ_x	Statistical weight (penalty) for component x
$I_y, \hat{I}_y$	Observed and predicted survey index in year y
$P^g_{y,l,s}, \hat{P}^g_{y,l,s}$	Observed and predicted proportion at length l for gear g in year y and sex s
$P^g_{y,a,s}, \hat{P}^g_{y,a,s}$	Observed and predicted proportion at observed age a for gear g in year y and sex s
ψ^g_y	Sample size assumed for gear g in year y (for multinomial likelihood)
n_g	Number of years that age (or length) composition is available for gear g
$q_{\mu,g}, \sigma_{q,g}$	Prior mean, standard deviation for catchability coefficient for gear g
M_μ, σ_M	Prior mean, standard deviation for natural mortality
$\sigma_{r_\mu}, \sigma_{\sigma_r}$	Prior mean, standard deviation for recruitment variability

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

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

Logistic selectivity

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

Inverse power family

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

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

Reparameterized gamma distribution

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

Exponential-logistic selectivity

Observation equations

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

Catch biomass in year *y*

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

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

For this assessment, we present last year's model (Model 16.5) updated for 2019 with no model changes. A comparison of the model likelihood components and key parameter estimates from 2018 are compared with the 2019 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 appropriate to compare their negative log likelihoods so we cannot compare them by the first criterion above. In general we can only evaluate the 2019 model based on changes in results from 2018 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 and 2016 which we discuss below), abundance, and selectivities. The 2019 update shows a slightly better fit to the longline survey index compared to 2018, but the fit to the trawl and fishery indices are still very poor. The model is fitting the unusual recent age compositions relatively well given time-invariant selectivity. Therefore, the 2019 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 2018 reference model (16.5) and the same model updated for 2019."% of –lnL" is the contribution of each data component to the negative log likelihood.

Year Model Name	**2018** 16.5		**2019** 16.5	
Likelihood Components	Value	% of -lnL	Value	% of -lnL
Catch	5	0.3%	5	0.3%
Dom. LL survey RPN	48	3.0%	52	2.9%
Coop. LL survey RPN	15	1.0%	15	0.8%
Dom. LL fishery RPW	8	0.5%	13	0.7%
Jap. LL fishery RPW	9	0.6%	11	0.6%
NMFS trawl survey	16	1.0%	23	1.3%
Dom. LL survey ages	237	14.8%	266	14.7%
Dom. LL fishery ages	253	15.8%	282	15.7%
Dom. LL survey lengths	72	4.5%	77	4.3%
Coop LL survey ages	142	8.9%	141	7.8%
Coop LL survey lengths	43	2.7%	44	2.4%
NMFS trawl lengths	351	22.0%	455	25.2%
Dom. LL fishery lengths	42	2.6%	46	2.5%
Dom. trawl fish. lengths	356	22.3%	375	20.8%
Data likelihood	1596		1804	
Objective function value	1646		1862	
Key parameters				
Number of parameters	234		237	
$B_{this\ year}$ (Female SSB (kt)for current year)	76		78	
$B_{40\%}$ (Female spawning biomass (kt))	117		106	
B_{1960} (Female spawning biomass (kt))	166		229	
$B_{0\%}$ (Female spawning biomass (kt))	292		265	
SPR% current	26.0%		29.3%	
$F_{40\%}$	0.099		0.102	
$F_{40\%}$ (Tier 3b adjusted)	0.081		0.102	
ABC(kt)	28.2		44.0	
$q_{Domestic\ LL\ survey}$	7.9		7.3	
$q_{Japanese\ LL\ survey}$	6.0		5.4	
$q_{Domestic\ LL\ fishery}$	6.0		5.5	
$q_{Trawl\ Survey}$	1.3		1.3	
$a_{50\%}$ (domestic LL survey selectivity)	3.8		3.7	
$a_{50\%}$ (LL fishery selectivity)	3.9		4.0	
μ_r (average recruitment)	18.1		22.5	
σ_r (recruitment variability)	1.2		1.2	

Time Series Results

Definitions

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

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 estimates of the 2014 and 2016 year classes are causing estimates of total biomass to increase rapidly in 2019.

Projected 2020 spawning biomass is 43% of unfished spawning biomass. Spawning biomass had increased from a low of 32% of unfished biomass in 2002 to 40% in 2008 and had declined again to about 32% of unfished biomass in 2018, but is projected to increase rapidly in 2020. The previous two above-average year classes, 2000 and 2008, each comprise 6% and 8% of the projected 2020 spawning biomass, respectively. These two year classes are fully mature in 2020. The very large estimated year classes for 2014 and 2016 are expected to comprise about 33% and 14% of the 2020 spawning biomass. The 2014 year class is about 50% mature while the 2016 year class should be less than 15% mature in 2020 (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 - 2016. 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. Age-2 or 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-2 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 2- and 3-year-old fish (Figures 3.23 -3.27). The 2015 longline survey age composition is dominated by the 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- fish. The 2015 and 2017 trawl survey length compositions also show a high proportion of fish ages 1-3, while the 2019 size comps show mainly what ppear to be age-3 fish (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 also appeared early in all areas and strongly in the CGOA and Western areas (Figure 3.23).

Average recruitment during 1979-2019 was 19.2 million 2-year-old sablefish per year, which is slightly less than average recruitment during 1958-2019 (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 exert as much leverage on parameter estimates and consequently the model does not fit it 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 and 2016 year classes. The 2019 RPN prediction is much closer to the observed value than the notable departure in 2018 in last year's assessment. 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, 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 and 2018 longline survey age compositions look dramatically different with the age 3 and 4s having the highest proportions. About 70% of the fish in the longline survey age composition were age 5 and below in 2018. 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 - 2018, the fishery is clearly encountering younger fish, but not as many as the surveys. About 50% of the fish caught in 2018 were age-5 and below.

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 the assessment model in 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 2020 and 2021 spawning biomass estimates are above $B_{35\%}$ and $B_{40\%}$.

Uncertainty

The model estimates of projected spawning biomass for 2020 (113,368 t) and 2021 (156,854 t) fall near the center of the posterior distribution of spawning biomass. Most of the probability lies between 90,000 and 150,000 t for 2020 (Figure 3.46). The probability changes smoothly and exhibits a relatively normal distribution. The posterior distribution clearly indicates the stock is above $B_{40\%}$.

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 negligible and about a 20% chance it is below $B_{40\%}$. During the next three years, the probability of being below $B_{17.5\%}$ is near zero, the probability of being below $B_{35\%}$ is low, and the probability of staying below $B_{40\%}$ is also low (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 (2009-2018) 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 0.061, a decrease from 0.094 in 2018, is relatively low (a small positive retrospective bias) compared to most assessments at the AFSC (Hanselman et al. 2013). This small positive bias is a mild 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). "Normal" sized recruitment estimates appear to have little trend over time (Figure 3.45). Only the 2013 year classes started near average indicating low presence of age 2 sablefish in most of the recent data until 2014. However, the 2014 year class significantly decreased from 2017 to 2019.

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 1977-2015. The updated point estimate of $B_{40\%}$, is 105,976 t. Since projected female spawning biomass (combined areas) for 2020 is 113,368 t (7% higher than $B_{40\%}$, or $B_{43\%}$), sablefish is in sub-tier “a” of Tier 3. The updated point estimates of $F_{40\%}$, and $F_{35\%}$ from this assessment are 0.102 and 0.121, respectively. Thus, the maximum permissible value of F_{ABC} under Tier 3a is 0.102, which translates into a 2020 ABC (combined areas) of 44,065 t. The adjusted OFL fishing mortality rate is 0.121, which translates into a 2020 OFL (combined areas) of 51,726 t. An important consideration is that these reference points do no yet include the 2016 year class and next year. When the 2016 year class enters the recruitment time series, relative stock status will decline because the $B_{40\%}$ reference point will increase substantially. Model projections indicate that this stock is not subject to overfishing, not 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 MSFCMA.

For each scenario, the projections begin with the vector of 2019 numbers at age as estimated in the assessment. This vector is then projected forward to the beginning of 2020 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2019. 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 2019 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 2020, 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 2020 and 2021, 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 2020 and 2021).
>
> *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 2014-2018 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 2019, or 2) above ½ of its MSY level in 2019 and above its MSY level in 2029 under this scenario, then the stock is not overfished.)

Scenario 7: In 2020 and 2021, *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 2021, or 2) above 1/2 of its MSY level in 2021 and expected to be above its MSY level in 2031 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 2020 and 2021. 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 2020, it does not provide the best estimate of OFL for 2021, because the mean 2020 catch under Scenario 6 is predicated on the 2020 catch being equal to the 2020 OFL, whereas the actual 2020 catch will likely be less than the 2020 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 (2018) is 14,341 t. This is less than the 2018 OFL of 29,507 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 2019:

a. If spawning biomass for 2019 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2019 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2019 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 2029 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 2021 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2021 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2021 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2031. If the mean spawning biomass for 2031 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. 2016-2018 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 3a).

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 1979-2017 age-2 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).

Socioeconomic Considerations

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 $94 million in 2018. In addition these are the summary bullets:

- Fishery CPUE indicators are showing contrasting trends by gear type and differ from trends in exploitable biomass suggesting potential temporal or spatial fluctuations in gear selectivity
- Catch of sablefish in non-sablefish targeted fisheries has recently been increasing in both the GOA and BSAI, which may imply shifting distribution of sablefish into non-preferred habitat
- Ex-vessel value of the fishery has remained relatively stable since 2013, but prices of small fish have declined dramatically in recent years

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. This table has been updated in 2019 to include "Fishery Performance."

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
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	No apparent fishery/resource-use performance and/or behavior 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 relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing 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 as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
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	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

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
4. Fishery performance considerations
    a. Rapid change in fishing mortality by a gear type
    b. Change in fishery effort or catch-per-unit-effort (CPUE)
    c. Change in value of size categories resulting altered selectivity or spatial distribution
    d. Change in regulations that affect fishery behavior

<u>Assessment-related considerations</u>

Data and model uncertainty is what is typically considered first in a 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 of assessments at the AFSC. This bias has fluctuated between 0.02 and 0.09 in the last several years, but it is always positive, which means that each year it slightly overestimates spawning biomass. 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 population, these two indices greatly diverged in 2018 (Figure 3.10b) but have started to track again in 2019. 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 in 2017 and 2018. Conversely, the biomass index from the GOA trawl survey has shown a strong increase from its low in 2015, tripling by the 2019 survey. Some of this conflict in indices is expected as indices in numbers respond quickly to incoming year classes, but indices in weight are delayed, taking longer to respond because those young fish have low weight. In addition, surveys like the GOA trawl survey capture fish at earlier life stages so this index may potentially conflict with other indices that encounter more adult fish (the longline survey RPW and fishery RPW) and will respond to a large incoming recruitment sooner than these other indices. 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. This downweighting appeared to have a minimal effect when the incoming age compositions were more typical, but now appears to have a large effect as the model struggles to fit the extremely high abundance of young fish in the age compositions and the observed survey biomass index at the same time.

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 (<34 cm) in the Gulf of Alaska trawl survey from 1984-2019 (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, but not the 2019 survey (Figure 3.56a). 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. However, the 1-year-olds that first appeared in 2017 appear to line up well with the newly estimated 2016 year class, and are showing up as 3-year-olds in the trawl survey lengths in the EGOA (Figure 3.56b).

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 decreased 30% between the 2017 and 2018 assessment model estimates, and declined by a total of 56% in 2019. In 2017, we showed 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, an unmodeled age-dependent mortality process, and ageing error.

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 repeated substantial decrease in this year's estimate of the 2014 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 (10x average). The 2018 assessment still estimated the 2014 year class as the strongest ever to recruit (7x average) and is currently estimated to be more than 4x average. Thus, the 2014 year class is now estimated to be less than half the size of when it was first estimated. . The 2016 year class is now appearing as large as the 2014 year class appeared in 2017. We consider the estimates of the 2014 and 2016 year classes to be the most pertinent uncertainty to consider for the immediate recommendations of harvest levels. With only three observations of the 2014 year class and one observation of the 2016 year class, the sum of these two estimates are estimated to be equal to the sum of all the other year classes since 1993. 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 is now classified as 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 and a very low proportion of large fish.

The 2014 year class? was estimated to be 10x average in 2017, but the estimate has decreased considerably since then. 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 had 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 evenness of the age distribution of sablefish has dropped rapidly as has the mean age of spawners (see Appendix 3C), and both the fishery and population are now becoming dominated by these incoming year classes. The NPFMC harvest control rules do not recognize the potential importance of a well-distributed age composition (all fish considered mature are treated equally in the model) to the population but all data suggests we are effectively "fishing down" the majority of age classes in the sablefish population and increasingly relying on one or two large year classes to support the population.

These signs of high recruitment hold long-term promise for the recovery of the spawning stock biomass. Because the magnitude of the 2014 and 2016 year classes are so much higher than anything seen historically and the there were large declines in the 2014 recruitment estimate from 2017 to 2019, we should proceed with caution; the estimate may continue to decline and the 2016 year class may follow a similar trajectory. For example, there may be density dependence or other concerns that affect survival differently than previous year classes. Currently, much of the projected recovery of the spawning biomass is dependent on the maturation of the 2014 and 2016 year classes. 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 6 years old in 2020 and the annual longline survey data maturity curves indicate that these females could be between 18 and 62% mature. This range has a significant effect on our perception of stock status and ABC.

Spawning biomass estimated in 2019 is lower than spawning biomass projected in 2018 despite the expectation of a rapid increase. Almost 50% of the projected 2020 spawning biomass is made up of just two young year classes. Because of the uncertainty in the unprecedented size of the 2014 and 2016 recruitments, the hollowing out of the older ages, and the uncertainty of how quickly the 2014 and 2016 year classes will successfully become spawners, there are myriad population dynamics concerns. Last year, we rated the population-dynamic concern as level 4, an extreme concern. Since this is the second time we have seen a massive recruitment estimate, it becomes less of an unprecedented event, so we rate population dynamics as a level 3 major concern.

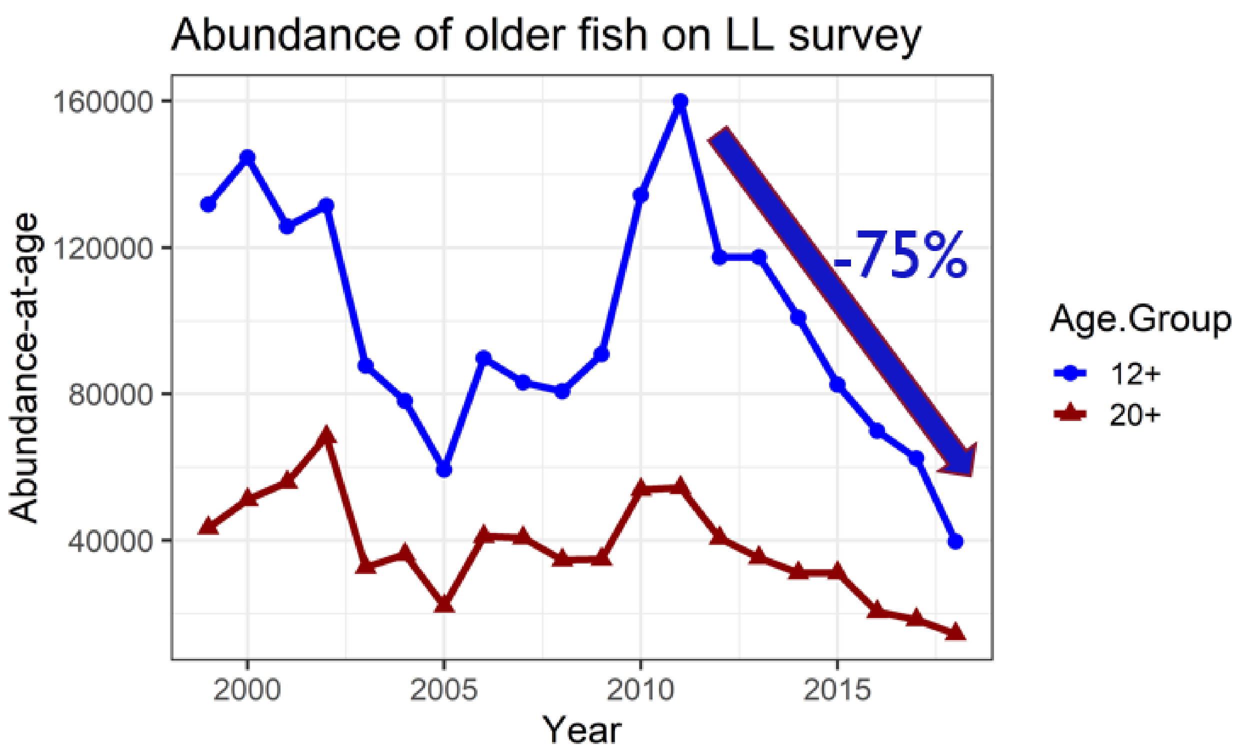


Figure. Relative population numbers of pooled fish 12 and greater (blue circles) and 20 and greater (red triangles) caught on the AFSC longline survey during 1999 – 2018.

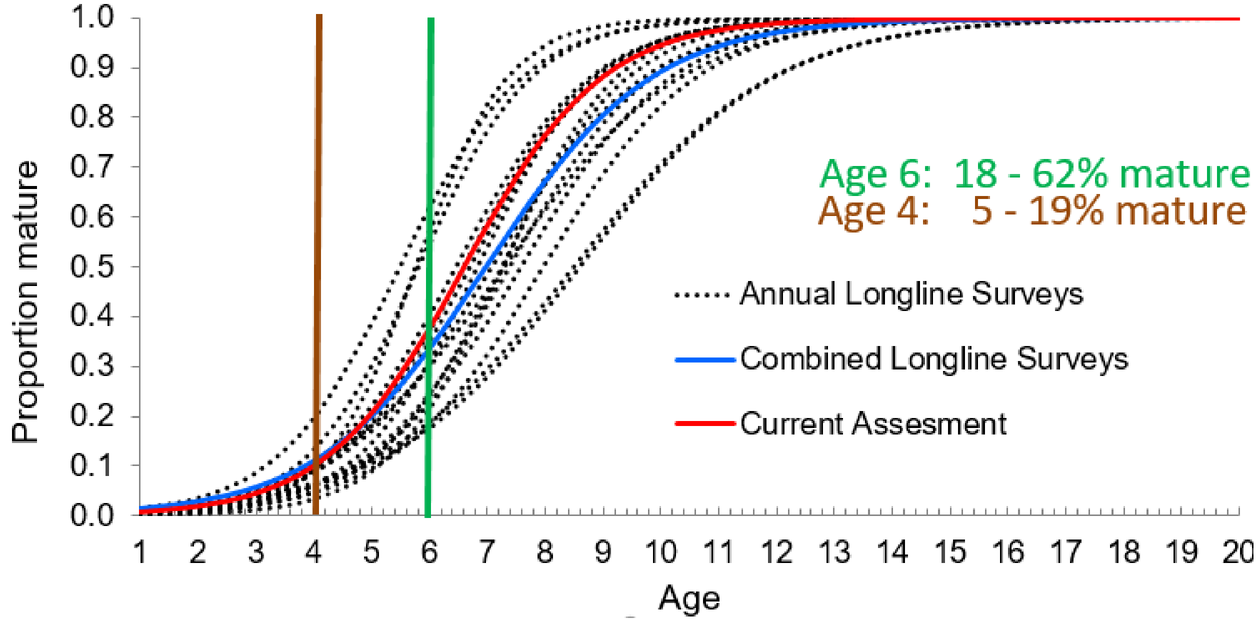


Figure. Logistic maturity curves estimated from annual longline survey macroscopic scans. Dashed lines illustrate the annual variability, the red solid line is the estimate from the pooled data which is similar to the static value used in the assessment. Age-4 (brown vertical line) and age-6 (green vertical line) are highlighted to show the range of maturity estimates for the large 2014 and 2016 year classes.

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.

In the sablefish SAFE, the standard ***Ecosystem Considerations*** section is not included. Instead an Ecosystem and Socioeconomic Profile (ESP) has been developed 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 related 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.

The ESP evaluates a number of relevant indicators, and they are summarized with the following bullet points:

- Consistent slope bottom temperatures may provide a helpful buffer for sablefish egg development and subsequent larval hatch during heatwave years
- Non-discriminating prey selection and rapid growth of larval and YOY sablefish provide an advantage in warm years to monopolize on available plankton prey
- Overwinter and nearshore conditions have recently been favorable for juvenile sablefish based on high growth of YOY sablefish observed in seabird diets and large CPUE of juveniles in nearshore surveys
- Body condition of juveniles that are caught in offshore adult habitat has been below average since 2014 and poor for the 2014 and 2016 year-classes
- Mean age of spawners and age evenness have decreased recently, suggesting higher contribution of the recent large 2014 year-class to the adult spawning biomass
- Condition of the 2014 year-class is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years and this is accompanied by a decrease in the size of the 2014 year class recruitment strength in the most recent model recruitment estimates
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population may have increased, based on recent large increases in incidental catch in the arrowtooth flounder fishery and could lead to higher competition and predation
- Condition of the overall population in slope habitat has been decreasing since 2015 and may impact young sablefish arriving in already poor condition
- Overall, physical, YOY, and early juvenile indicators were generally good for sablefish while juvenile and adult indicators were generally average to poor.

Overall, the ecosystem considerations in the ESP appear to be a mixture of positive and negative conditions in 2019. However, the effects of some of these indicators, such as marine heat waves and rapidly changing ecosystem variables, have not yet been evaluated carefully for sablefish. We are concerned that 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.**

<u>Fishery performance considerations</u>

Fishery performance risk is a new category added in 2019. There are multiple new situations occurring with fishery performance, particularly with regard to these large recruitment events. Some factors are already accounted for in the stock assessment, which should not contribute to the rating here. These include the historic low in longline fishery CPUE and effects of whale depredation. However, there have been large changes to the mixture of gears contributing to fishing mortality, and the spatial extent of the fishery that are not necessarily fully accounted for in the Alaska-wide assessment. Directed IFQ CPUE is at historic lows yet OFLs are being approached in the Bering Sea due to incidental trawl catches. The large increase in incidental catch in the EBS trawl fisheries have shifted much more catch into the Bering Sea and the downstream effects of this harvest of small fish in a different region are poorly understood at this time. There has also been a shift to pot gear that has been increasing in the Gulf of Alaska since its legalization in 2017, primarily to avoid whale depredation. While we are accounting for whale depredation, this shift in gear type to avoid depredation and the performance risks to the fishery it poses are not presently being accounted for directly in the stock assessment model.

In addition, these shifts in gear and presence of a very different age structure in the population may be leading to changes in selectivity in the fishery that we are not explicitly examining in the model at this time. For example, if fisheries are actively trying to avoid these year classes and putting more pressure on the spawning stock, this might be hard to detect quickly, even if the model were using time-varying selectivity. **Given the rapid changes in the fishery because of the sudden recruitment success, we rated the fishery performance category as a level 3, a major concern.**

The results of this 4 category template are summarized in the table below:

Assessment-related considerations	Population dynamics considerations	Environmental/ecosystem considerations	Fishery performance considerations	Overall score (highest of the individual scores)
Level 2: Substantially increased concern	Level 3: Major concern	Level 2: Substantially increased concern	Level 3: Major concern	Highest—Level 3: Major concern

In summary, while there are clearly positive signs of strong incoming recruitment, there are concerns regarding the lack of older fish contributing to spawning biomass, the uncertainty surrounding the estimates of the strength of the 2014 and 2016 year classes, and the uncertainty about the environmental conditions that may affect the success of these year classes in the future. These concerns warrant additional caution when recommending the 2020 and 2021 ABCs. It is unlikely that the 2014 or 2016 year classes will be average or below average, but projecting catches under the assumption that these year classes are 4x and 10x average introduces substantial risk given the uncertainty associated with these estimates. Prior to these two year classes, only one other large year class since 1999 has been observed and the population is becoming dependent on these two recent year classes. There is only one observation of the 2016 year class in the age compositions to support the magnitude of this estimate. Our caution in reducing ABC in 2019 seems justified as the estimate of the 2014 year class has decreased 56% since first estimated. The cause of this decrease could be imprecision in the age composition measurement for the first year it was seen, or a biological factor, such as an increase in natural mortality. Future surveys will help determine the magnitude of the 2014 and 2016 year classes; there are indications that subsequent year classes may also be above average.

This is the second time we have used the risk-matrix approach to assess reductions in ABC from maximum permissible ABC. The overall score of level 3 indicates at least one "major 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 2020 and 2021 ABC recommendations, we consider all four of these types of risk considerations to recommend that the 2020 ABC should be set equal to 25% greater than the 2019 ABC, which translates to a reduction of about 57% from the maximum ABC allowed by the reference model. **The increase of 25% represents the largest increase in ABC from 1996 to present, when both the Alaska-wide assessment and IFQs existed. The last recommendation to substantially increase the ABC occurred in 2003, when the stock had appeared to have rebuilt above target levels because of the appearance of several above-average year classes. The stock steadily declined after that large increase in ABC resulting in ABC reductions for much of the next decade (Figure 3.57).** We expect that the 2014 - 2016 year classes are larger than those high recruitments events during 1997 – 2000 that were used to justify the large increase in 2003. However, it is important to use this example as a cautionary lesson. Recommending an ABC lower than the maximum should result in more of the 2014 and 2016 year classes entering into the spawning biomass and becoming more valuable to the fishery. This precautionary ABC recommendation buffers for uncertainty until more observations of these potentially large year classes are made. Because sablefish is an annual assessment, we will be able to consider another year of age composition data in 2020 and allow this extremely young population to further mature and more fully contribute to future spawning biomass.

Acceptable biological catch recommendation

Instead of maximum permissible ABC, we are recommending the 2020 ABC to be 25% higher than the 2019 ABC, which translates to a 57% adjustment from max ABC. The final whale adjusted 2020 ABC of 18,763 t is 25% higher than the 2019 whale-adjusted ABC. The maximum permissible ABC for 2020 is 57% higher than the 2019 maximum permissible ABC of 28,171 t. The 2018 assessment projected a 38% increase in ABC for 2020 from 2019. The author recommended ABCs for 2020 and 2021 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 "major 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 56% from 2017 to 2019. A decline of this magnitude illustrates the uncertainty in these early recruitment estimates.
2. Fits to abundance indices are poor for recent years, particularly fishery CPUE and the GOA trawl survey.
3. The AFSC longline survey Relative Population Weight index, though no longer used in the model is still only just above average.
4. The retrospective bias is positive (i.e., historical estimates of spawning biomass increase as data is removed).
5. Mean age of spawners has decreased dramatically since 2017 and continues a downward trend, suggesting higher importance of the contribution of the 2014 year class to adult spawning biomass; however, age-4 body condition of this year class was poor, and much lower than during the last period of strong recruitments
6. The very large estimated year classes for 2014 and 2016 are expected to comprise about 33% and 14% of the 2020 spawning biomass, respectively. The 2014 year class is about 50% mature while the 2016 year class should be less than 15% mature in 2020.
7. 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.
8. Evenness in the age composition has dramatically declined, which means future recruitment and fishing success will be highly dependent on only a few cohorts of fish.
9. Spatial overlap between sablefish returning to adult slope habitat and the arrowtooth flounder population may have increased resulting in potentially higher competition and predation
10. Another marine heat wave formed in 2018, which may have been beneficial for sablefish recruitment in 2014 - 2016, but it is unknown how it will affect fish in the population or future recruitments.
11. Fishery performance has been very weak in the directed fishery with CPUE at time-series lows in 2018.
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.

In addition to the reductions from max ABC detailed above, it is now standard practice to recommend a lower ABC than maximum permissible based on estimates of whale depredation occurring in the fishery. This reduction was first 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 in both the survey and the fishery. The methods and calculations are described in the ***Accounting for whale depredation*** section.

Survey trends do support raising ABC from last year. Although there was a large increase in the domestic longline survey index time series in the last two years, and a large increase (> 3x) in the GOA bottom trawl survey since 2015, these increases are offset by the very low status of the fishery abundance index seen in 2017 and 2018. The fishery abundance index has been trending down since 2007. The IPHC GOA sablefish index was not used in the model, but was at a time series low in 2017. However, the IPHC index was up 41% in 2018. 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 appeared extremely strong initially, but year classes have sometimes failed to materialize later and the estimate of this year class has declined by more than half since the 2017 assessment. The initial estimate of the 2016 year class is as large as the 2014 estimate was when it was first estimated, but it may decline similarly to the 2014 initial estimate.

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. Under all scenarios attempted, the ABC was higher than the 2019 ABC, and usually much higher. The only models that were able to better fit the trawl and longline survey abundance indices were those that severely downweighted survey and fishery ages.

We conducted two sensitivity runs using results from the longline survey maturity estimates. Since the 2014 year class would be 6 in 2020, 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 2020 ranges from 102 -163 kilotons.

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 and 2016 year classes 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 in Hanselman et al. 2018). A combination of a much larger catch because of a large increase in ABC that consisted of a high proportion of six-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, beginning in 2011, we observed that the objective to reduce vaiability in apportionment was not being achieved using the 5 year exponential weighting method for apportionment. Since 2007, the mean change in apportionment by area has increased annually (Figure 3.58A). 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 Aleution 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 3.58B) These large annual changes in apportionment result in increased annual variability of ABCs by area, including areas other that the Bering Sea (Figure 3.58C). 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 apatial 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 tradeoff is underway and is summarized in ***Appendix 3D***. Meanwhilem it see imprudent to move to an interim apportionment or return to the former apportionment method until the proposed tange of methods have been identified and evaluated. The 2016 CIE review panel strongly stated that there was no immediate biological concern with the current apportionment, given the high mixing rates of the stock. **Therefore, for 2020, we recommend continuing with apportionment fixed at the proportions used for 2013-2019.**

Apportionment Table (before whale depredation adjustments)

Area	2019 ABC	Standard apportionment for 2020 ABC	**Recommended fixed apportionment for 2020 ABC***	**Difference from 2019**
Total	15,380	19,225	**19,225**	25%
Bering Sea	1,501	4,050	**1,876**	25%
Aleutians	2,030	3,102	**2,537**	25%
Gulf of Alaska (subtotal)	11,849	12,073	**14,812**	25%
Western	1,659	2,247	**2,074**	25%
Central	5,246	4,510	**6,558**	25%
W. Yakutat**	1,765	1,803	**2,206**	25%
E. Yak. / Southeast**	3,179	3,513	**3,974**	25%

* 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 a full $F_{35\%}$ harvest rate as prescribed for OFL in Tier 3a and adjusting for projected whale depredation results in a value of 50,481 t for the combined stock. The OFL is apportioned by region, Bering Sea (4,987 t), AI (6,771 t), and GOA (38,723 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 have developed a spatially explicit research assessment model that includes movement, which examines smaller-scale population dynamics while retaining a single stock hypothesis Alaska-wide sablefish model.
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.

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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. 2019 catches are as of October 1, 2019 (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	14,342	1,598	660	1404	5,800	4,880	1,860	3,020	0	10,504	3,838
2019	13,012	2,995	490	1,139	4,373	4,015	1,615	2,400	0	8,745	4,268

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991-2019. Both CDQ and non-CDQ catches are included. Catches in 1991-1999 are averages. Catch as of October 1, 2019 (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	14,341	29,507	14,957	14,957	
2019[1]	13,012	32,798	15,068	15,068	

[1] Catch is as of Oct. 1, 2019 (Source: www.akfin.org).

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 2010-2019. Source: NMFS Alaska Regional Office via AKFIN, October 1, 2019.

		BSAI			GOA			Combined		
Year	Gear	Discard	%Discard	Catch	Discard	%Discard	Catch	Discard	%Discard	Catch
2010	H&L	37	3.1%	1,187	371	4.0%	9,231	408	3.9%	10,418
	Other	5	0.9%	613	47	5.3%	900	53	3.5%	1,514
	Total	42	2.3%	1,800	419	4.1%	10,131	461	3.9%	11,931
2011	H&L	21	1.9%	1,096	396	3.9%	10,148	417	3.7%	11,243
	Other	8	1.3%	638	179	16.3%	1,097	187	10.8%	1,735
	Total	29	1.7%	1,733	575	5.1%	11,245	604	4.7%	12,978
2012	H&L	13	1.1%	1,197	253	2.3%	11,060	266	2.2%	12,257
	Other	13	1.7%	751	65	7.5%	861	77	4.8%	1,612
	Total	26	1.3%	1,948	318	2.7%	11,921	344	2.5%	13,869
2013	H&L	28	2.6%	1,067	598	5.4%	11,101	626	5.1%	12,168
	Other	4	0.6%	630	48	5.6%	846	51	3.5%	1,476
	Total	32	1.9%	1,697	646	5.4%	11,947	678	5.0%	13,645
2014	H&L	40	5.3%	750	441	4.6%	9,486	480	4.7%	10,236
	Other	1	0.3%	385	78	8.1%	967	80	5.9%	1,351
	Total	41	3.6%	1,135	519	5.0%	10,453	560	4.8%	11,588
2015	H&L	14	2.9%	489	593	6.4%	9,277	608	6.2%	9,766
	Other	5	3.5%	153	184	17.4%	1,054	189	15.7%	1,207
	Total	20	3.1%	642	777	7.5%	10,331	797	7.3%	10,972
2016	H&L	77	18.5%	415	653	7.8%	8,316	730	8.4%	8,731
	Other	9	1.9%	466	191	18.0%	1,060	199	13.1%	1,526
	Total	86	9.7%	881	843	9.0%	9,376	929	9.1%	10,257
2017	H&L	47	17.2%	273	431	6.0%	7,215	478	6.4%	7,488
	Other	173	13.2%	1,307	335	17.9%	1,875	508	16.0%	3,183
	Total	220	13.9%	1,580	766	8.4%	9,090	986	9.2%	10,670
2018	H&L	73	21.1%	348	600	7.2%	8,371	673	7.7%	8,718
	Other	396	20.7%	1,911	1,648	44.4%	3,713	2,044	36.3%	5,624
	Total	469	20.8%	2,258	2,249	18.6%	12,083	2,718	18.9%	14,342
2019	H&L	110	34.7%	318	528	8.4%	6,277	638	9.7%	6,594
	Other	1,479	46.7%	3,167	987	30.3%	3,251	2,465	38.4%	6,418
	Total	1,589	45.6%	3,485	1,514	15.9%	9,528	3,103	23.8%	13,012
2010-2018	H&L	39	5.1%	758	482	5.2%	9,356	521	5.1%	10,114
mean	Other	68	9.0%	762	308	22.4%	1,375	377	17.6%	2,136
	Total	107	7.0%	1,520	790	7.4%	10,731	897	7.3%	12,250

Table 3.5. Bycatch (t) of FMP Groundfish species in the targeted sablefish fishery averaged from 2012-2018. Other = Pot and trawl combined because of confidentiality. D =Discarded, R = Retained Source: AKFIN, October 1, 2019

	Hook and Line			**Other Gear**			**All Gear**		
Species	D	R	Total	D	R	Total	D	R	Total
GOA Thornyhead Rockfish	205	437	642	11	25	37	217	462	679
Shark	542	0	542	5	0	5	547	0	547
GOA Shortraker Rockfish	174	84	258	15	2	16	189	85	274
Arrowtooth Flounder	136	13	148	104	19	123	240	31	271
GOA Skate, Other	166	2	168	5	0	5	170	2	172
GOA Skate, Longnose	162	7	169	1	0	1	163	8	170
GOA Rougheye Rockfish	96	79	175	1	2	3	97	81	178
Other Rockfish	58	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	46	1	47
GOA Deep Water Flatfish	12	0	12	22	7	29	34	7	41
Greenland Turbot	16	11	27	4	2	5	20	12	32
BSAI Kamchatka Flounder	13	1	15	4	11	15	18	12	30
Pollock	2	0	2	13	13	26	15	13	28
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	10	0	10	1	0	1	11	0	11
Pacific Ocean Perch	2	0	2	1	7	8	3	8	10
GOA Rex Sole	0	0	0	8	2	10	8	2	10
Octopus	4	0	4	1	0	1	5	0	5
GOA Shallow Water Flatfish	4	0	4	1	1	2	5	1	6

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, 2019.

Group Name	2011	2012	2013	2014	2015	2016	2017	2018	2019
Benthic urochordata	0.13	1.25	0.00	0.00	0.49	0.00	1.06	0.92	0.00
Brittle star unidentified	0.48	4.66	0.11	0.67	2.09	0.34	0.59	0.70	0.15
Corals Bryozoans	5.75	7.66	12.70	5.17	4.55	5.96	1.61	8.98	3.06
Eelpouts	0.64	0.63	1.14	0.79	0.24	1.08	2.35	10.95	1.83
Grenadiers	8,640	8,586	11,554	5,916	5,789	7,346	5,623	4,328	2,813
Invertebrate unidentified	2.29	7.78	0.18	0.12	0.53	0.21	0.19	0.51	0.49
Misc crabs	8.51	6.77	5.83	6.40	3.50	4.87	5.13	4.06	2.46
Misc fish	15.92	10.98	31.21	28.31	17.58	15.99	17.38	31.47	25.00
Scypho jellies	0.68	0.00	0.00	5.51	0.24	0.18	0.02	0.52	0.34
Sea anemone unidentified	3.48	1.03	0.95	3.07	14.11	1.79	2.11	15.09	2.06
Sea pens whips	1.59	0.28	0.38	2.33	2.84	1.29	1.14	0.43	0.80
Sea star	3.95	3.13	15.73	11.58	9.68	8.99	21.83	12.98	4.22
Snails	20.02	12.25	8.83	3.66	3.37	0.18	2.88	3.09	1.45
Sponge unidentified	2.16	0.98	3.39	1.67	3.52	0.50	0.72	0.30	0.18
State-managed Rockfish	0.00	0.03	0.12	0.12	0.09	0.22	0.43	0.01	0.00
Urchins, dollars, cucumbers	0.26	0.79	0.87	0.79	2.49	0.22	0.22	1.19	0.79

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, 2019.

				BSAI				
Hook and Line	Year	Bairdi	Chinook	Golden KC	Halibut	Other salmon	Opilio	Red KC
	2013	-	15	540	63	-	-	-
	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	8	0	0	5	0	16	10
	2019	1	0	2	1	0	2	0
	Mean	5	4	192	19	0	7	37
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	525	98	38,905	12	-	261	1,060
	2019	68	-	3,680	2	-	160	21
	Mean	259	1	16,727	7	-	424	164
	BSAI	**263**	**17**	**16,951**	**27**	**0**	**431**	**202**
				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	473	-	-	-
	2019	116	-	38	371	-	-	-
	Mean	56	-	56	324	-	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	2,760	29	-	55	28	-	-
	2019	157	-	108	8	-	-	-
	Mean	442	4	29	14	6	0	-
	GOA	**498**	**4**	**84**	**338**	**6**	**0**	**5**

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		
	U.S. NMFS trawl survey (GOA)	Japanese fishery		U.S. fishery		Cooperative longline survey	Domestic longline survey	Cooperative longline survey	Domestic longline survey	U.S. fixed gear fishery
Year		Trawl	Longline	Trawl	Fixed					
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				1,630	12,857		63,434		1,197	1,169
2017	4,157			2,625	12,345		67,721		1,190	1,190
2018				3,306	13,269		69,218		1,188	1,174
2019	7,867						102,725			

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
2018	C	C	C	7	1	2018	C	C	C	4	1

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
2018	0.39	0.06	0.16	108	7	2018	0.31	0.03	0.11	339	25

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
2018	0.58	0.05	0.09	138	19	2018	0.61	0.05	0.07	188	28

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
2018	0.18	0.02	0.13	207	7	2018	C	C	C	1	1

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
2018	0.35	0.02	0.07	565	21	2018	0.33	0.02	0.06	2256	62

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
2018	0.45	0.03	0.08	2219	72	2018	0.57	0.03	0.05	1429	85

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	623	
2019		881			1,759		211

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
2019	0	10			1	4	6	3	6	0	4	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	5.4	1	16	332	279	428	153	129	203
1978	6.8	1	19	304	253	393	139	117	185
1979	92.6	70	131	368	310	476	132	112	174
1980	29.7	10	57	405	342	519	126	106	164
1981	13.4	2	33	427	360	541	124	105	161
1982	43.8	23	72	467	398	592	128	110	165
1983	28.1	7	51	496	425	623	141	122	181
1984	43.6	33	62	537	463	671	159	138	203
1985	3.1	1	9	539	467	669	175	153	221
1986	22.5	10	37	545	475	675	189	165	237
1987	18.0	12	28	529	462	655	194	170	244
1988	5.0	1	11	490	428	608	192	169	242
1989	4.5	1	9	441	384	549	184	161	234
1990	5.9	3	10	394	341	492	172	149	222
1991	31.2	24	42	374	323	470	159	137	206
1992	1.6	0	4	342	295	430	146	125	190
1993	23.9	19	33	331	285	419	133	114	173
1994	6.2	1	12	309	266	392	121	103	159
1995	5.7	2	11	287	247	363	112	96	147
1996	7.6	5	12	267	230	338	106	91	140
1997	18.9	14	26	261	224	329	103	88	134
1998	2.8	1	6	246	211	310	99	85	129
1999	30.2	24	41	256	220	322	95	82	123
2000	20.5	13	31	264	227	333	91	79	118
2001	9.9	3	20	263	226	332	88	76	113
2002	44.8	35	61	294	252	372	87	75	112
2003	6.5	2	12	298	256	378	89	77	114
2004	14.1	9	21	301	258	382	92	79	118
2005	5.7	3	10	292	250	371	97	83	124
2006	11.9	8	17	285	243	361	102	87	130
2007	7.5	5	12	273	234	346	106	91	135
2008	9.4	6	14	261	223	331	106	91	136
2009	7.3	5	11	248	212	315	104	89	133
2010	18.6	14	26	247	211	313	101	86	129
2011	4.8	2	8	238	203	300	98	83	124
2012	9.7	7	14	229	197	290	93	79	118
2013	1.1	0	2	212	181	269	89	75	113
2014	7.5	5	11	199	169	253	85	72	108
2015	11.3	8	17	191	162	244	81	69	104
2016	93.2	76	125	264	222	341	78	65	100
2017	26.0	16	40	307	258	395	74	62	96
2018	218.5	177	326	527	447	707	75	62	97
2019	25.9	17	35	632	531	842	86	72	111

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 1990-2019 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	61	74	32	92	29	44	332
1978	56	68	29	82	27	41	304
1979	69	76	35	109	32	48	368
1980	73	96	39	108	35	54	405
1981	76	106	45	95	40	65	427
1982	85	97	60	113	45	67	467
1983	89	104	77	126	41	60	496
1984	101	125	85	129	38	59	537
1985	111	123	78	134	40	54	539
1986	117	115	74	136	46	58	545
1987	86	115	70	141	52	64	529
1988	51	100	66	158	50	65	490
1989	59	86	51	141	46	57	441
1990	60	65	42	121	46	60	394
1991	41	44	40	118	49	82	374
1992	25	39	27	108	54	90	342
1993	16	36	30	110	56	84	331
1994	19	35	34	102	48	72	309
1995	27	33	29	93	41	64	287
1996	25	27	29	97	35	55	267
1997	24	24	27	101	32	52	261
1998	22	31	28	86	28	51	246
1999	21	42	30	85	27	51	256
2000	21	43	34	88	27	51	264
2001	29	41	42	83	22	46	263
2002	41	45	44	95	24	46	294
2003	40	46	42	101	26	43	298
2004	40	46	38	107	28	43	301
2005	42	44	38	95	26	47	292
2006	45	40	40	86	26	49	285
2007	48	35	29	85	29	48	273
2008	50	33	26	82	25	45	261
2009	48	32	29	78	22	40	248
2010	48	27	26	72	28	46	247
2011	31	24	24	84	31	44	238
2012	13	29	27	91	26	43	229
2013	28	30	22	71	19	43	212
2014	42	25	21	56	17	37	199
2015	33	25	21	55	21	36	191
2016	32	47	29	76	34	46	264
2017	38	64	36	88	36	46	307
2018	66	125	68	150	48	70	527
2019	119	157	81	146	46	83	632

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
$q_{domesticLL}$	7.30	7.19	7.18	0.70	0.70	5.82	8.57
q_{coopLL}	5.39	5.33	5.32	0.51	0.50	4.38	6.32
q_{trawl}	1.27	1.23	1.22	0.15	0.15	0.97	1.53
M	0.105	0.107	0.107	0.007	0.007	0.094	0.120
$F_{40\%}$	0.102	0.113	0.109	0.247	0.032	0.065	0.188
2020 SSB (kt)	113.3	117.6	239.0	35.0	38.9	176.9	324.0
2014 Year Class	93.2	97.1	96.0	12.1	12.7	75.3	124.6
2018 Year Class	218.5	242.3	239.0	35.0	38.9	176.9	324.0

Table 3.17. Comparison of 2018 results versus 2019 results. Biomass is in kilotons.

Year	2018 SAFE Spawning Biomass	2019 SAFE Spawning Biomass	Difference (%)	2018 SAFE Total Biomass	2019 SAFE Total Biomass	Difference (%)
1977	137	153	12%	295	332	13%
1978	125	139	11%	269	304	13%
1979	119	132	11%	330	368	12%
1980	114	126	10%	363	405	11%
1981	112	124	11%	383	427	11%
1982	117	128	10%	422	467	11%
1983	129	141	10%	449	496	11%
1984	146	159	9%	491	537	9%
1985	162	175	8%	496	539	9%
1986	175	189	8%	503	545	8%
1987	181	194	7%	490	529	8%
1988	180	192	7%	453	490	8%
1989	173	184	6%	408	441	8%
1990	163	172	6%	365	394	8%
1991	150	159	6%	345	374	8%
1992	138	146	5%	316	342	8%
1993	127	133	5%	308	331	8%
1994	115	121	5%	287	309	8%
1995	107	112	5%	266	287	8%
1996	101	106	5%	248	267	8%
1997	97	103	6%	242	261	8%
1998	94	99	5%	228	246	8%
1999	90	95	6%	239	256	7%
2000	86	91	6%	246	264	7%
2001	83	88	6%	246	263	7%
2002	82	87	6%	274	294	7%
2003	84	89	6%	279	298	7%
2004	87	92	6%	281	301	7%
2005	91	97	6%	274	292	7%
2006	96	102	6%	267	285	7%
2007	99	106	7%	257	273	6%
2008	100	106	6%	245	261	7%
2009	98	104	7%	234	248	6%
2010	95	101	7%	234	247	6%
2011	92	98	6%	227	238	5%
2012	88	93	6%	220	229	4%
2013	84	89	6%	204	212	4%
2014	81	85	5%	193	199	3%
2015	79	81	3%	189	191	1%
2016	76	78	2%	318	264	-17%
2017	79	74	-6%	399	307	-23%
2018	79	75	-5%	449	527	17%
2019		86			632	

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 2020 and 2021 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)				
2019	85.8	85.8	85.8	85.8	85.8	85.8	85.8
2020	113.4	113.4	113.3	113.4	113.4	113.4	113.4
2021	150.9	156.9	157.2	154.3	164.1	148.6	150.9
2022	194.0	210.3	210.8	203.1	230.2	188.1	194.0
2023	227.5	246.0	257.8	244.0	295.3	217.0	223.6
2024	241.9	260.8	285.4	265.7	343.1	227.0	233.7
2025	240.1	258.0	293.7	269.7	370.5	222.0	228.2
2026	229.5	245.6	290.3	263.1	382.7	209.4	214.8
2027	215.5	229.6	279.6	251.7	385.6	194.2	199.0
2028	201.0	213.2	267.5	238.5	383.1	179.3	183.3
2029	187.3	197.7	256.2	225.4	377.5	165.6	168.9
2030	175.0	183.8	244.8	213.0	370.3	153.6	156.4
2031	164.2	171.7	233.7	201.9	362.5	143.3	145.7
2032	155.1	161.4	225.3	192.1	354.6	134.8	136.7
			Fishing mortality				
2019	0.050	0.050	0.050	0.050	0.050	0.050	0.050
2020	0.102	0.055	0.051	0.075	-	0.121	0.121
2021	0.102	0.053	0.051	0.075	-	0.121	0.121
2022	0.102	0.102	0.051	0.075	-	0.121	0.121
2023	0.102	0.102	0.051	0.075	-	0.121	0.121
2024	0.102	0.102	0.051	0.075	-	0.121	0.121
2025	0.102	0.102	0.051	0.075	-	0.121	0.121
2026	0.102	0.102	0.051	0.075	-	0.121	0.121
2027	0.102	0.102	0.051	0.075	-	0.121	0.121
2028	0.102	0.102	0.051	0.075	-	0.121	0.121
2029	0.102	0.102	0.051	0.075	-	0.121	0.121
2030	0.102	0.102	0.051	0.075	-	0.121	0.121
2031	0.102	0.102	0.051	0.075	-	0.121	0.121
2032	0.102	0.102	0.051	0.075	-	0.120	0.120
			Yield (kt)				
2019	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2020	44.1	44.1	22.5	32.5	-	51.7	44.1
2021	54.8	56.6	29.0	41.3	-	63.4	54.8
2022	56.6	60.8	31.2	43.6	-	64.5	66.3
2023	53.9	57.7	31.1	42.5	-	60.6	62.2
2024	50.0	53.2	29.9	40.2	-	55.3	56.7
2025	45.8	48.6	28.4	37.5	-	50.1	51.2
2026	41.9	44.2	26.8	34.9	-	45.4	46.3
2027	38.4	40.3	25.3	32.5	-	41.3	42.0
2028	35.5	37.0	23.8	30.3	-	37.8	38.4
2029	33.0	34.3	22.6	28.5	-	35.0	35.5
2030	31.0	32.1	21.5	26.9	-	32.8	33.2
2031	29.4	30.3	20.6	25.6	-	31.0	31.4
2032	28.1	28.8	19.8	24.6	-	29.5	29.8

* Projections in Author's F (Alternative 2) are based on estimated catches of 19,225 t and 24,031 t (Author's ABC) used in place of maximum permissible ABC for 2020 and 2021. This was done in response to management requests for a more accurate two-year projection.

Figures

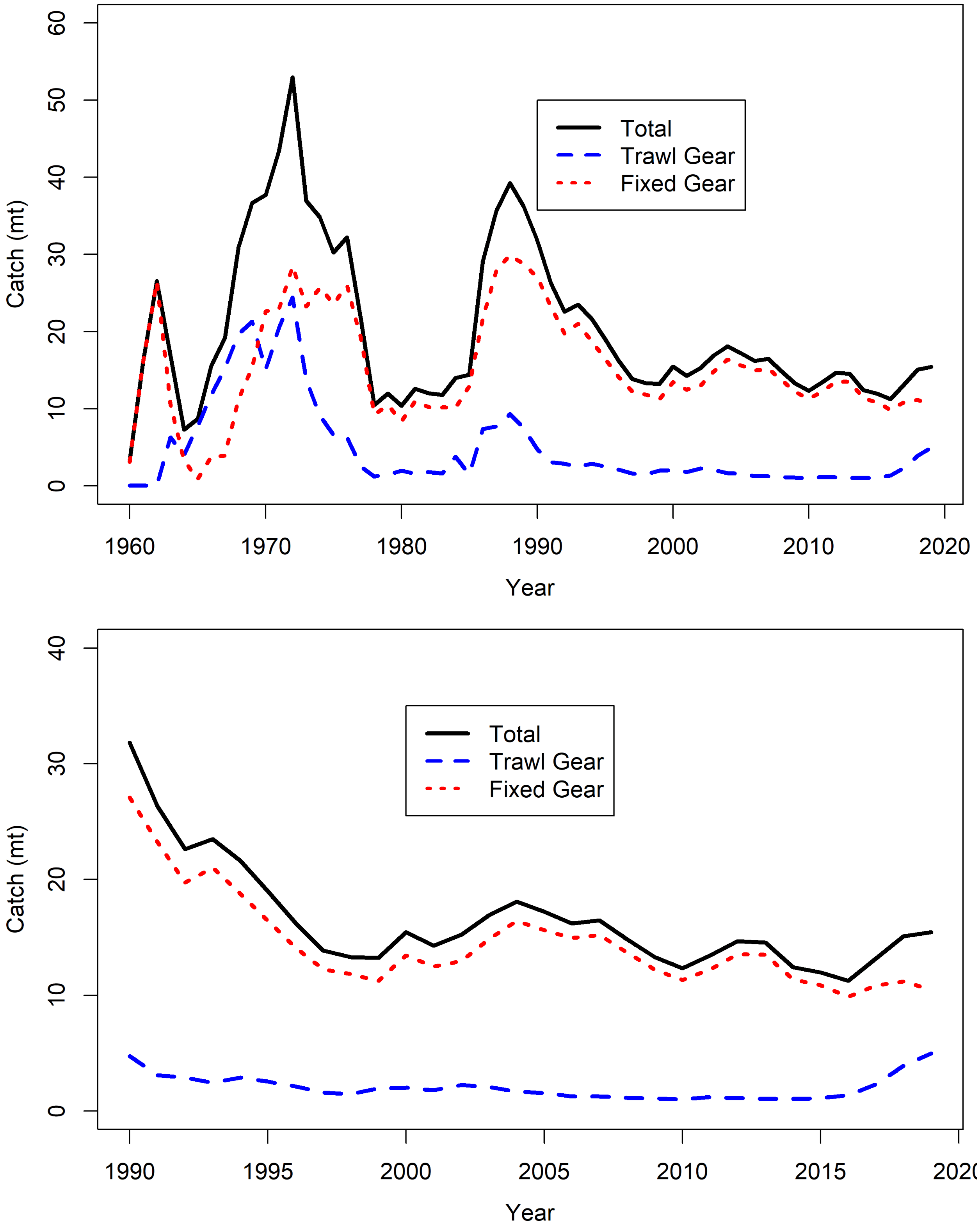


Figure 3.1. Long term and short term sablefish catch by gear type.

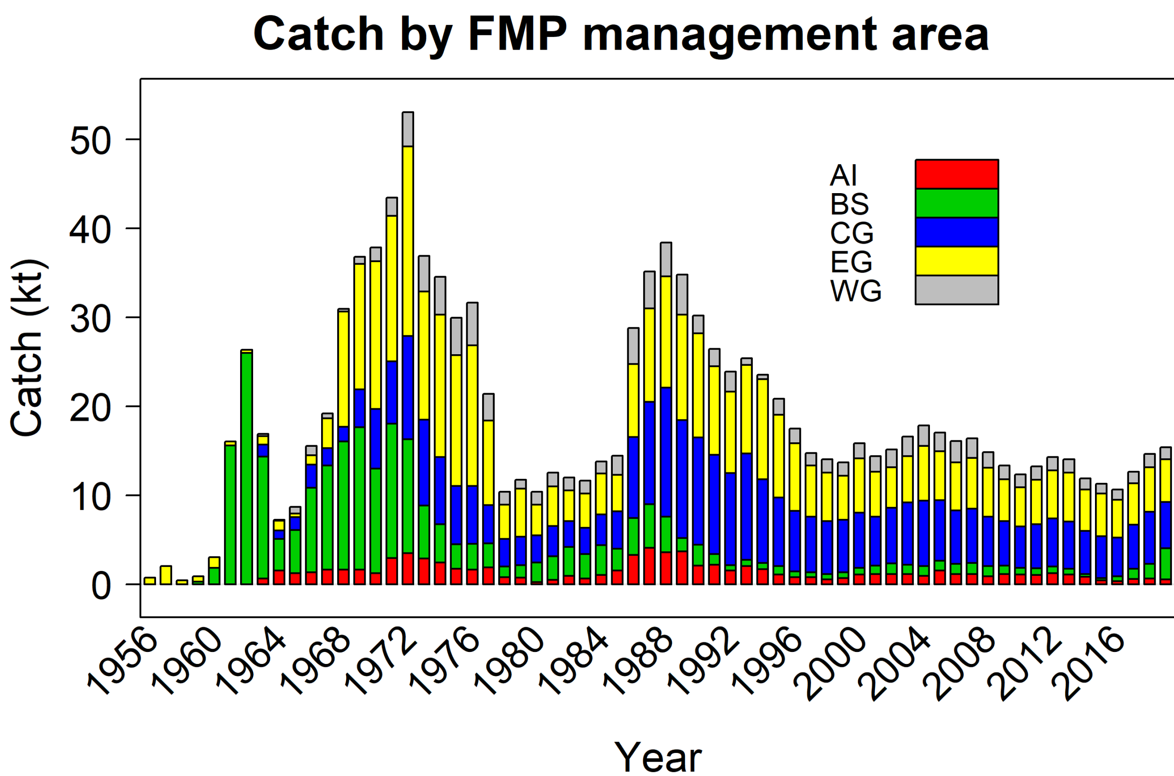


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

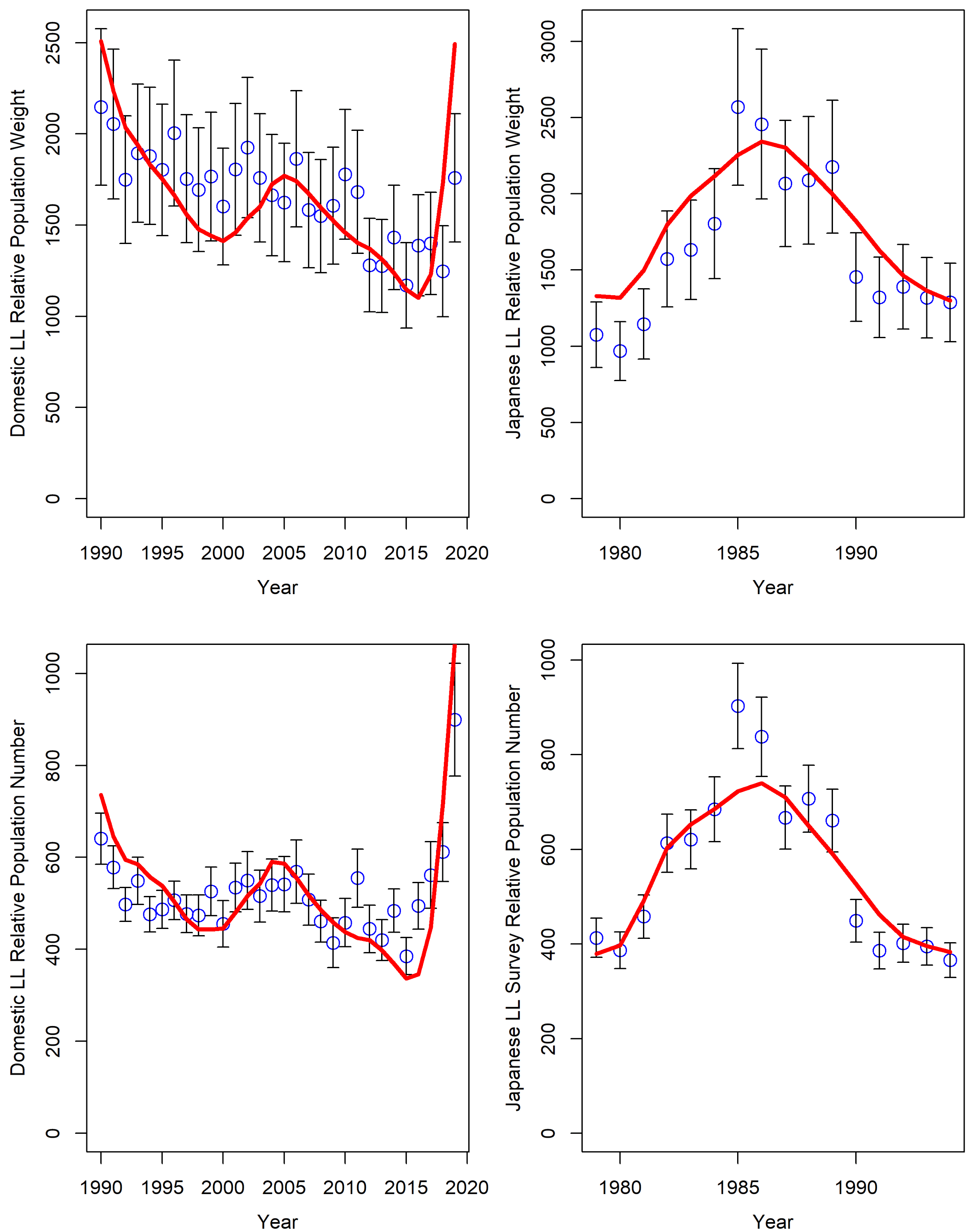


Figure 3.3. Observed and predicted sablefish relative population weight and numbers for 1990-2019 for U.S. longline survey and for 1979-1994 for U.S.-Japan cooperative survey. Points are observed estimates with approximate 95% confidence intervals. Solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

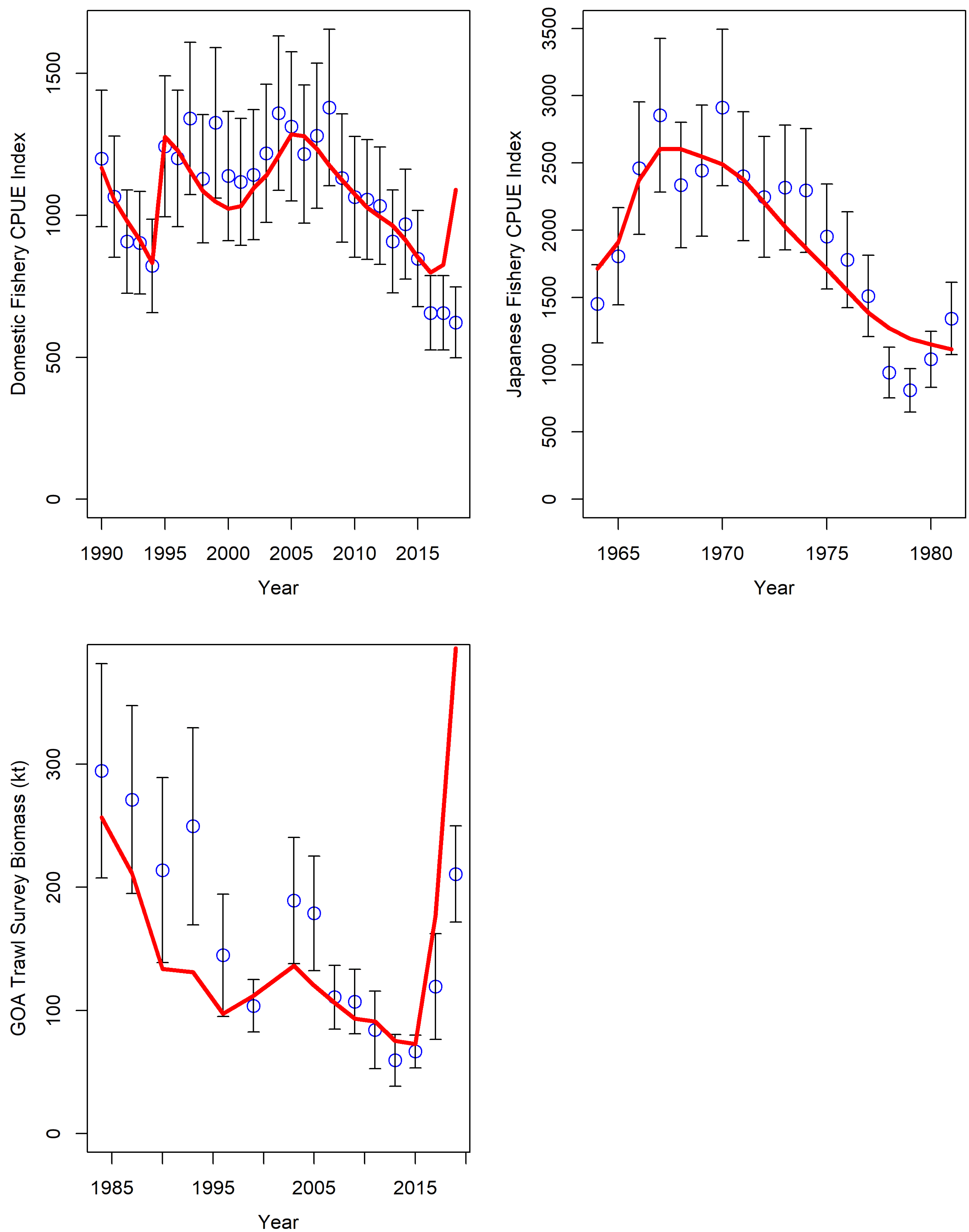


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed estimates with approximate 95% confidence intervals while solid red lines are model predictions.

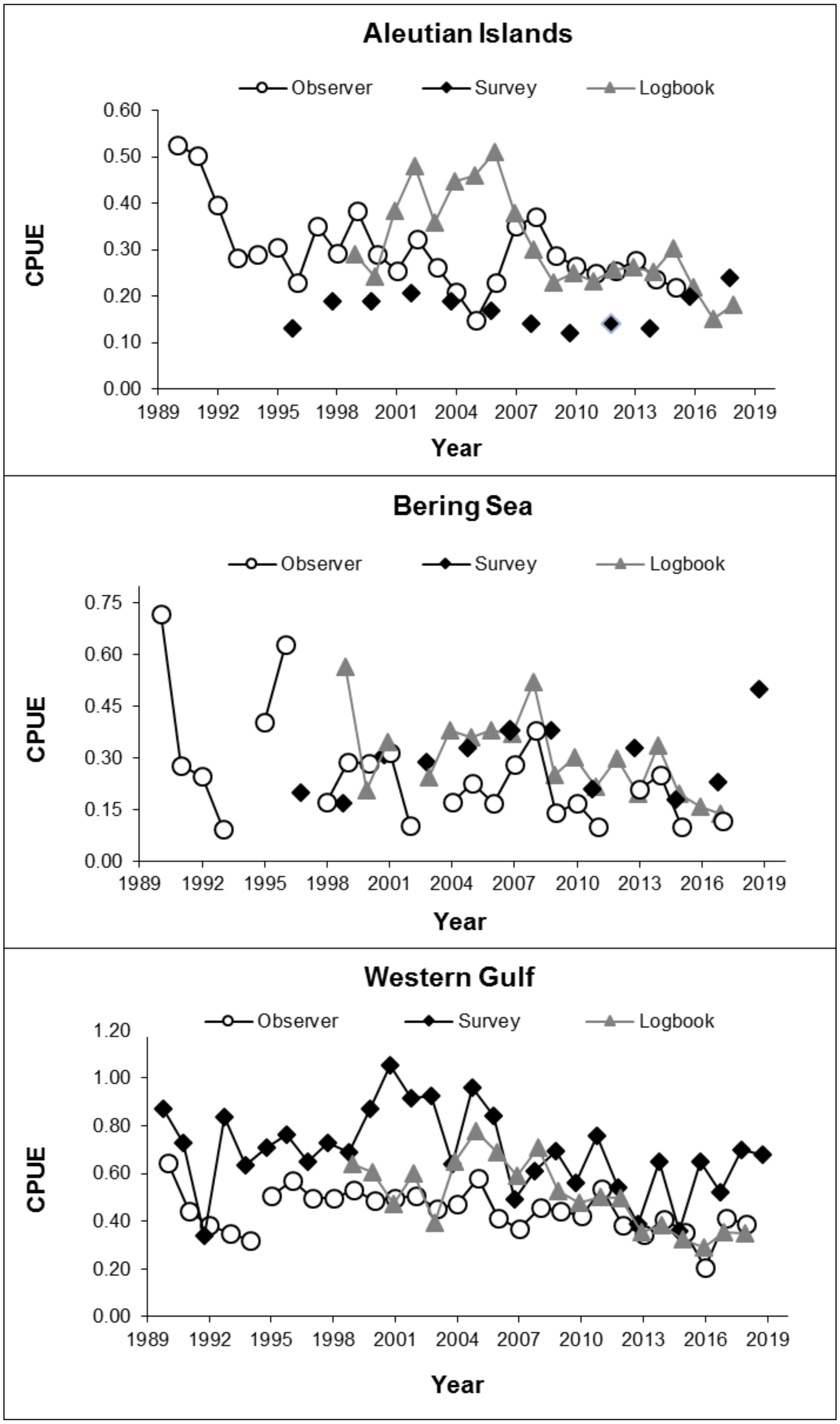


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fishery data. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data in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

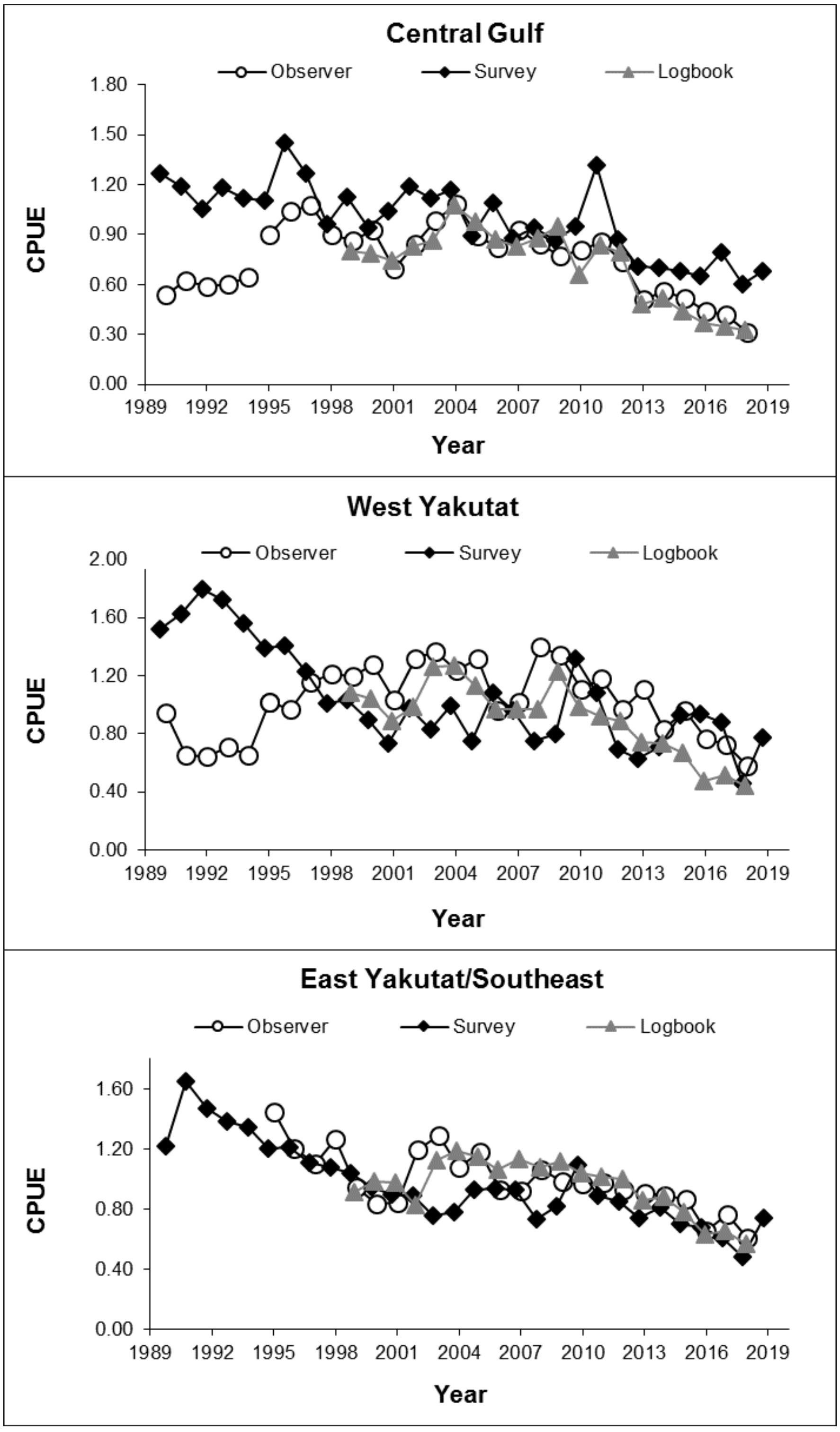


Figure 3.5. (continued).

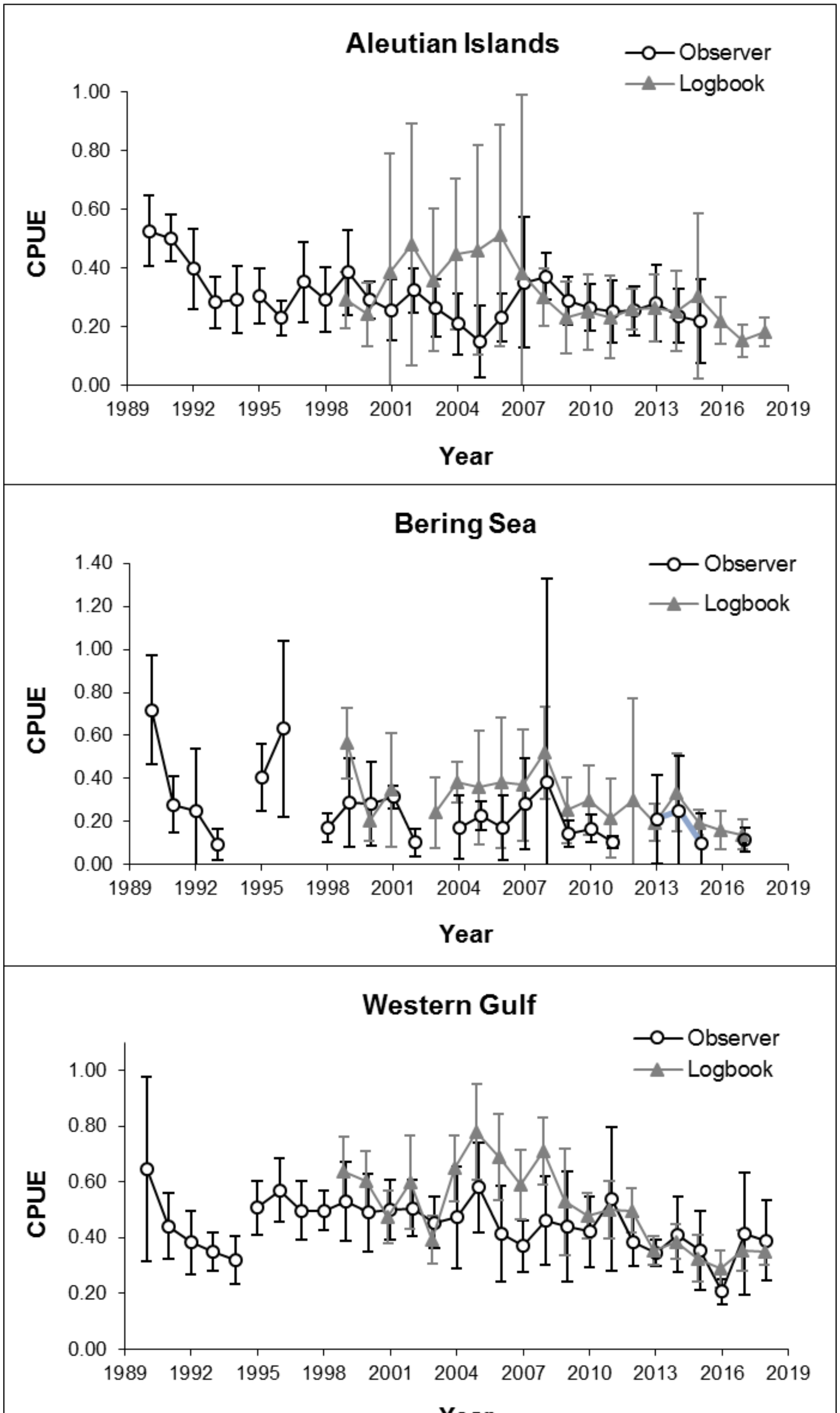


Figure 3.6. Average fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Data is not presented for years when there were fewer than three vessels. This occurred in observer data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

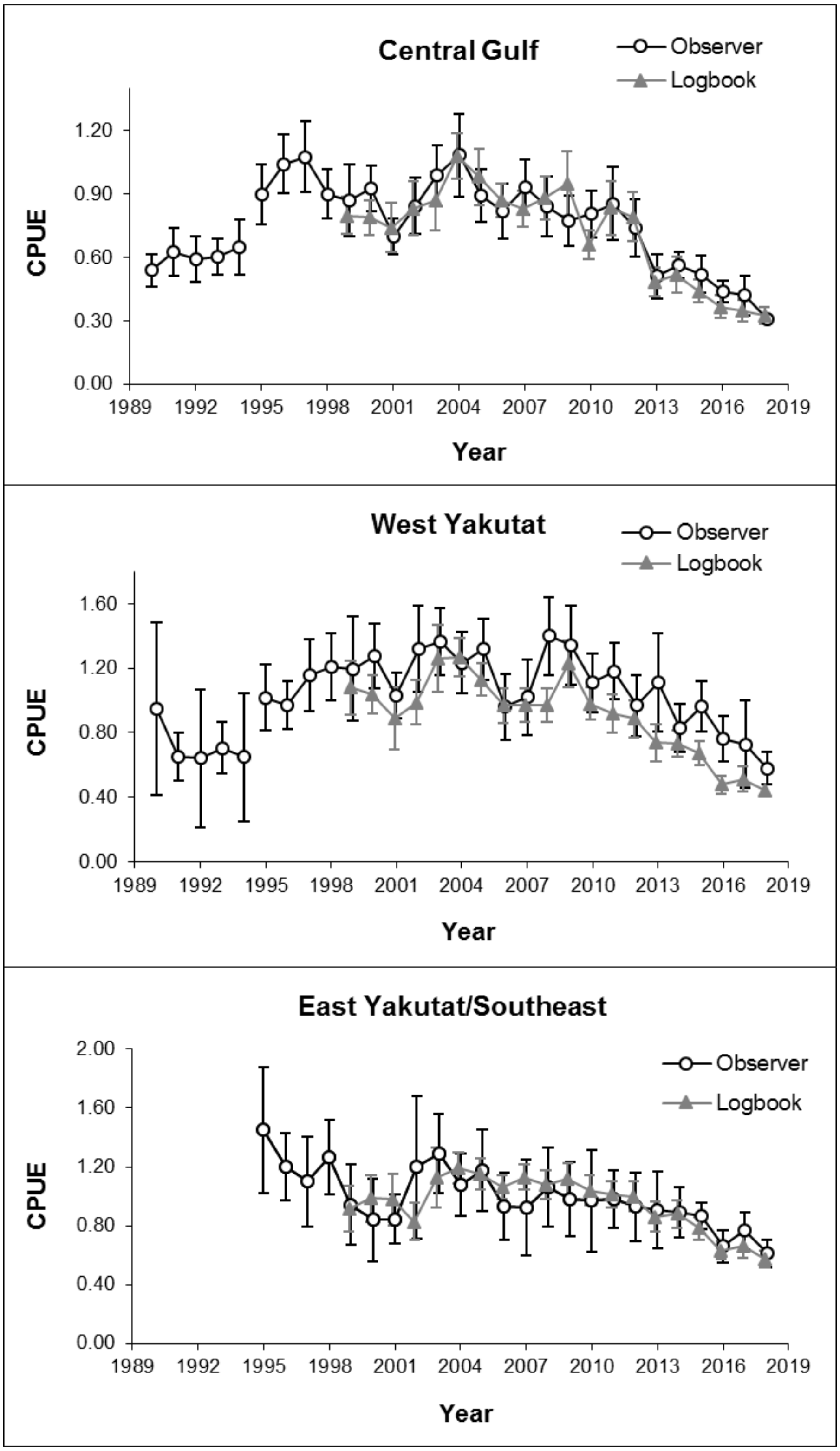


Figure 3.6. (continued)

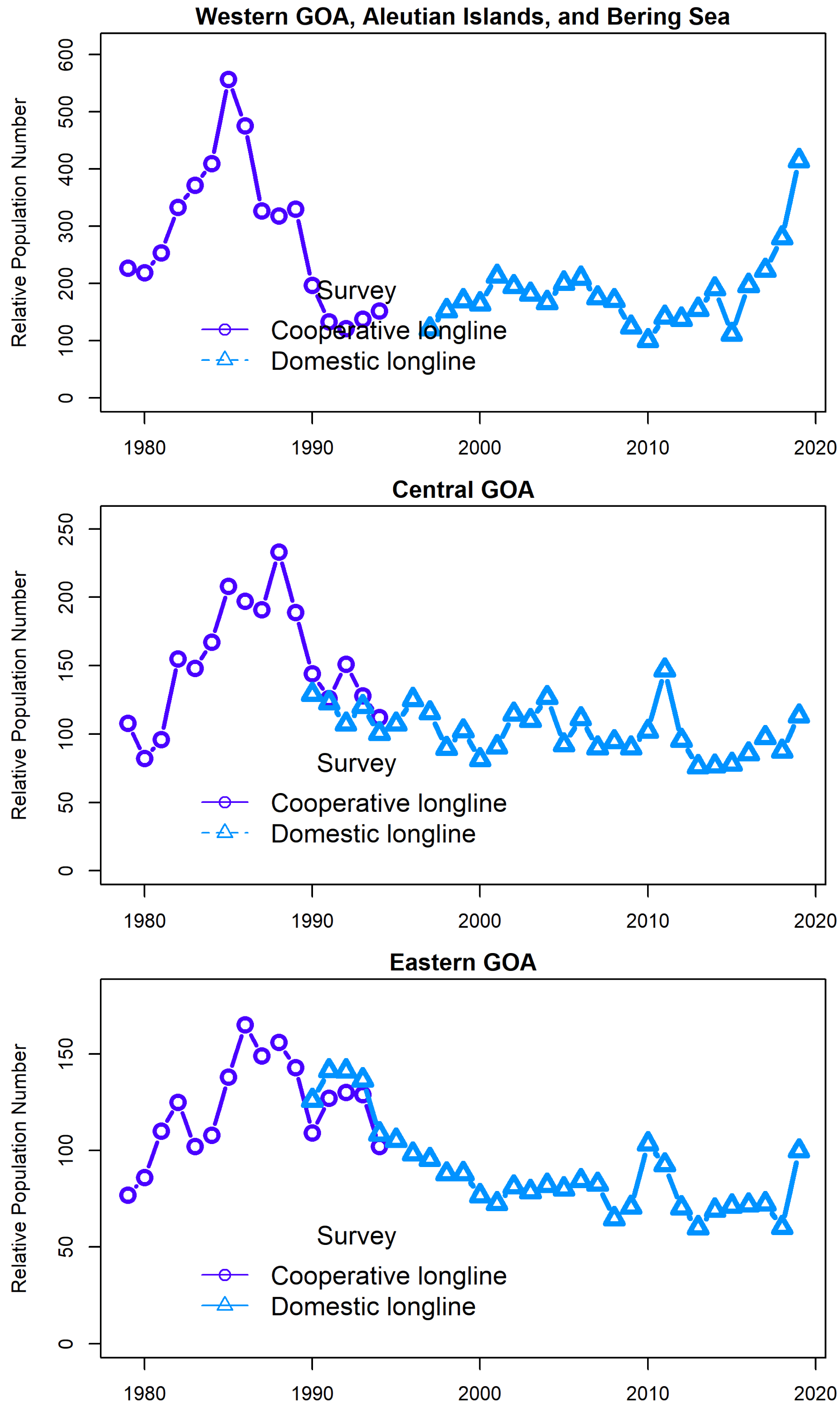


Figure 3.7. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first plot. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. In this plot, the values for the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

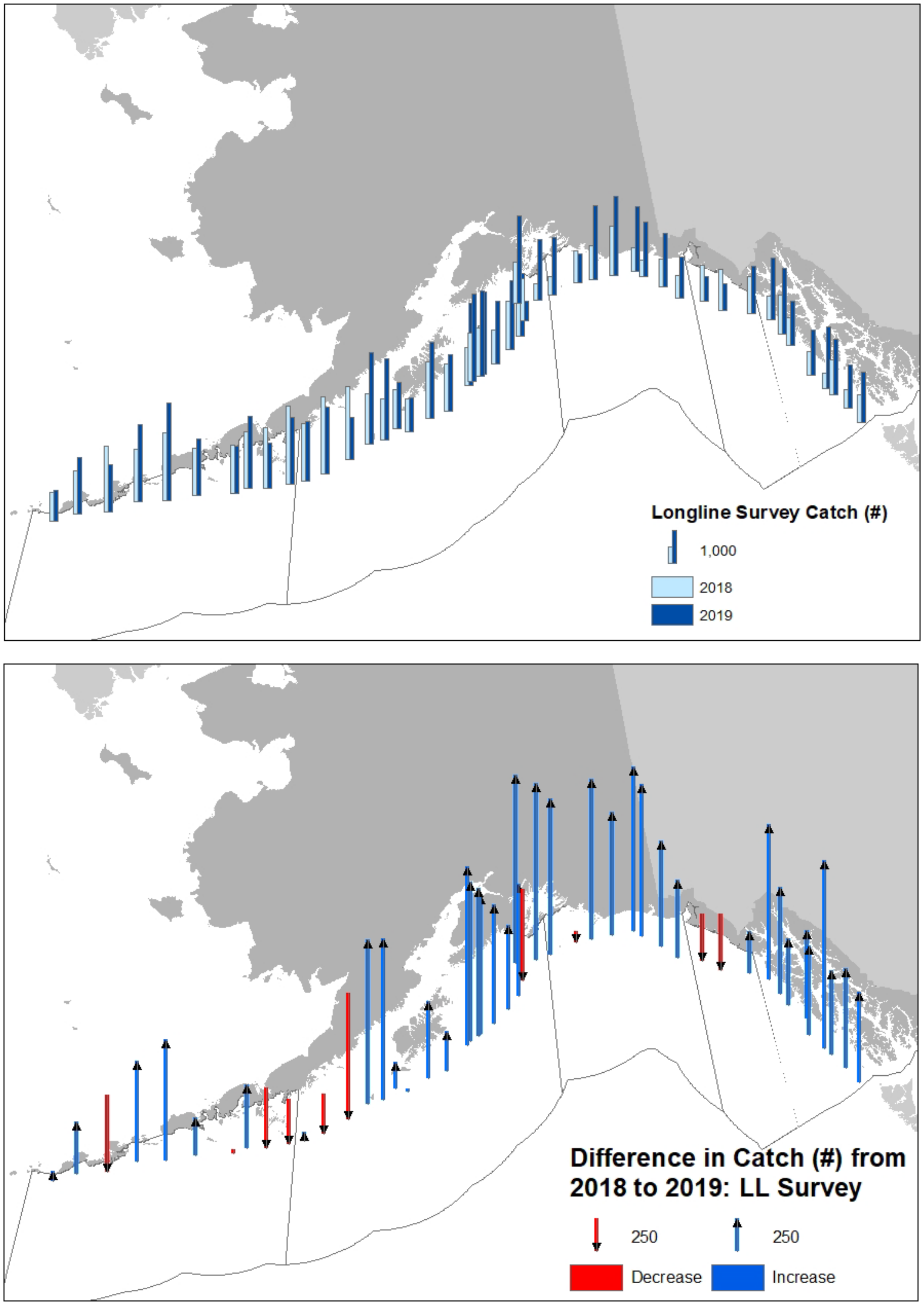


Figure 3.8a. Comparison of the 2018 and 2019 longline survey in the Gulf of Alaska. Top panel is in absolute numbers of fish caught; bottom panel is the difference from 2018 in 2019. Numbers are not corrected for sperm whale depredation.

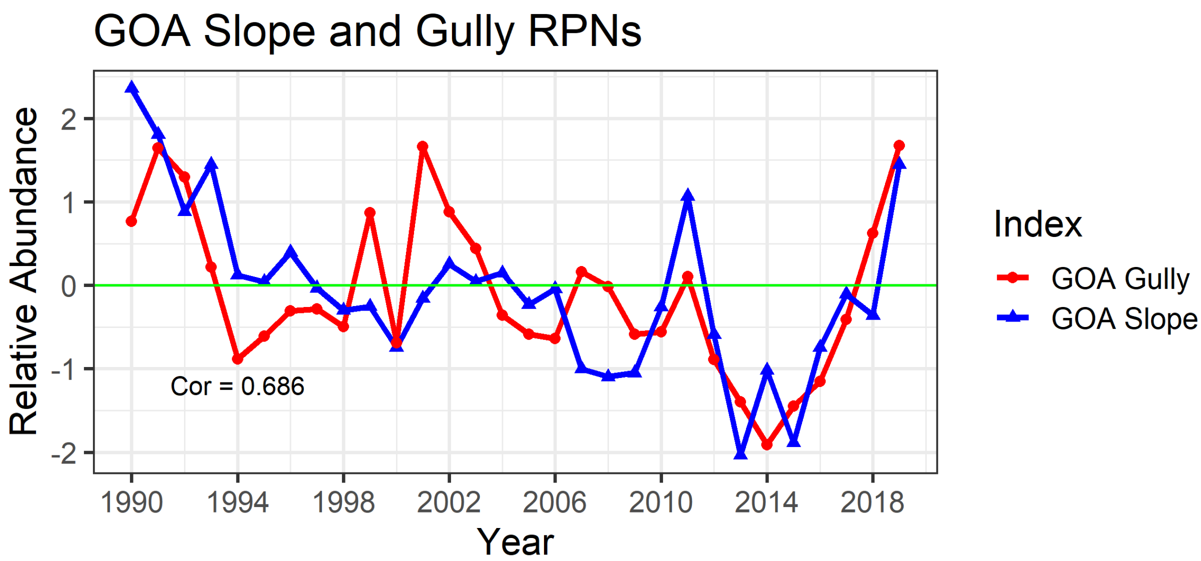


Figure 3.8b. Comparison of abundance trends in GOA gully stations versus GOA slope stations.

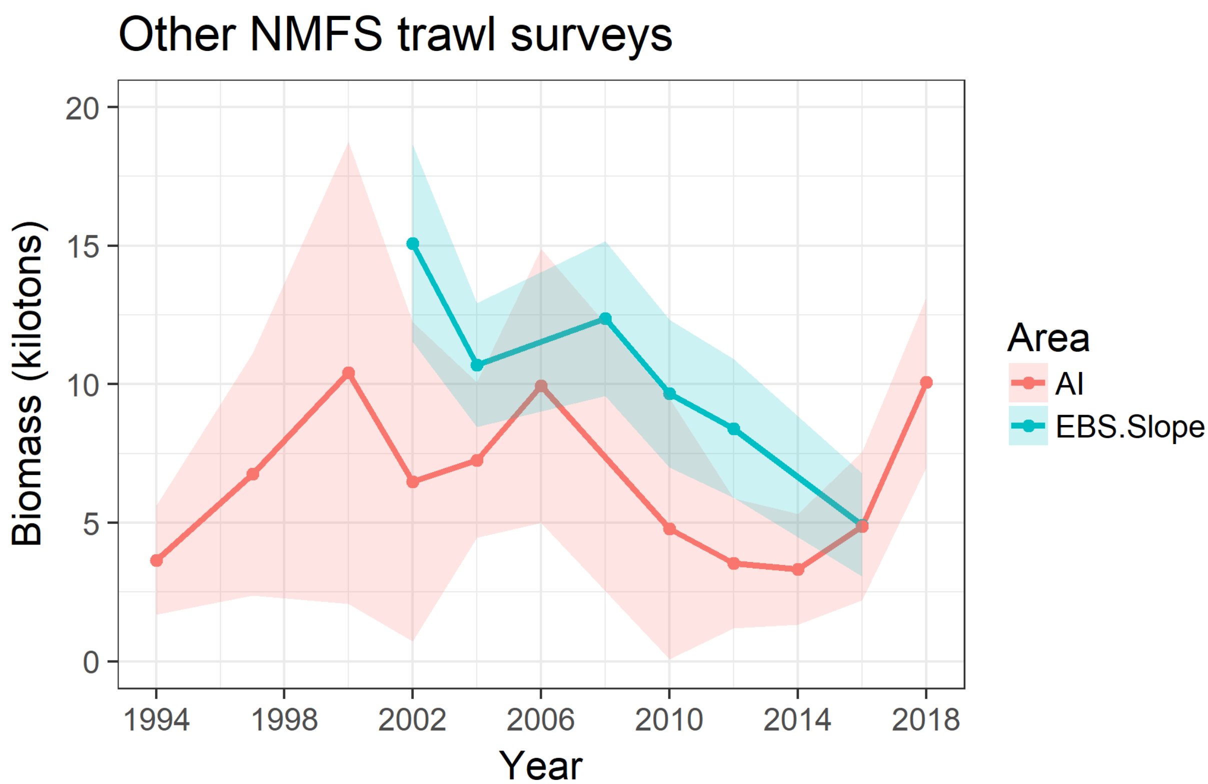


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates.

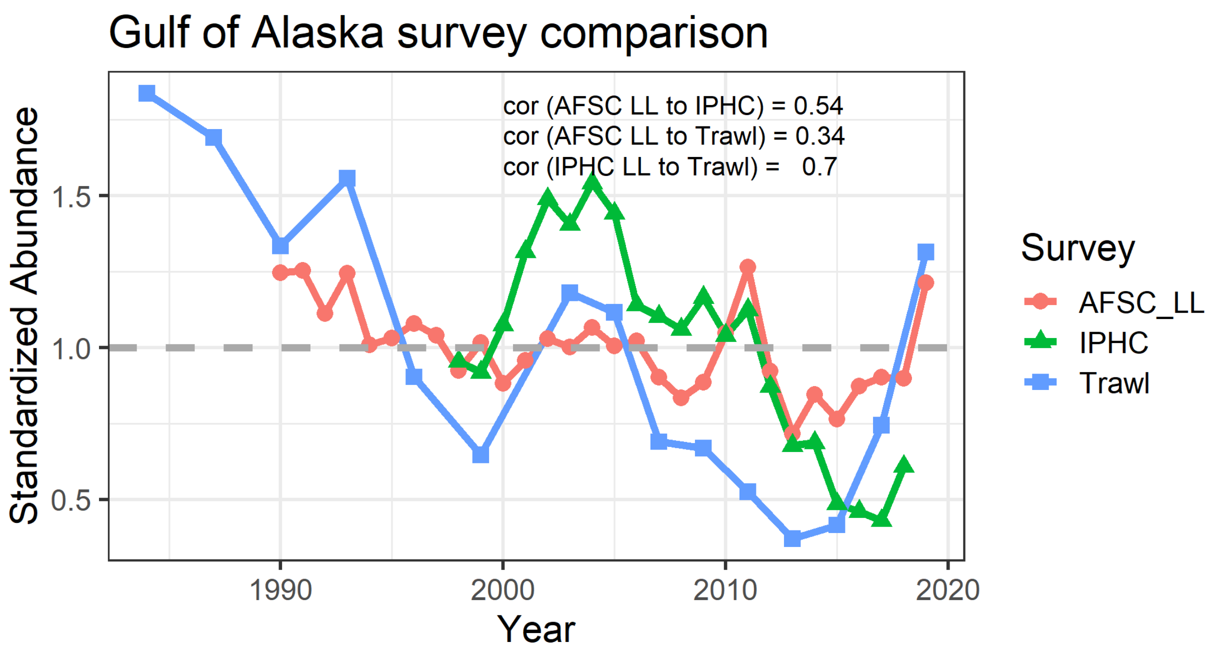


Figure 3.10a. Comparisons of IPHC and AFSC longline surveys, and the NMFS trawl survey trends in relative abundance of sablefish in the Gulf of Alaska. Correlation coefficients shown are when surveys occurred in the same years.

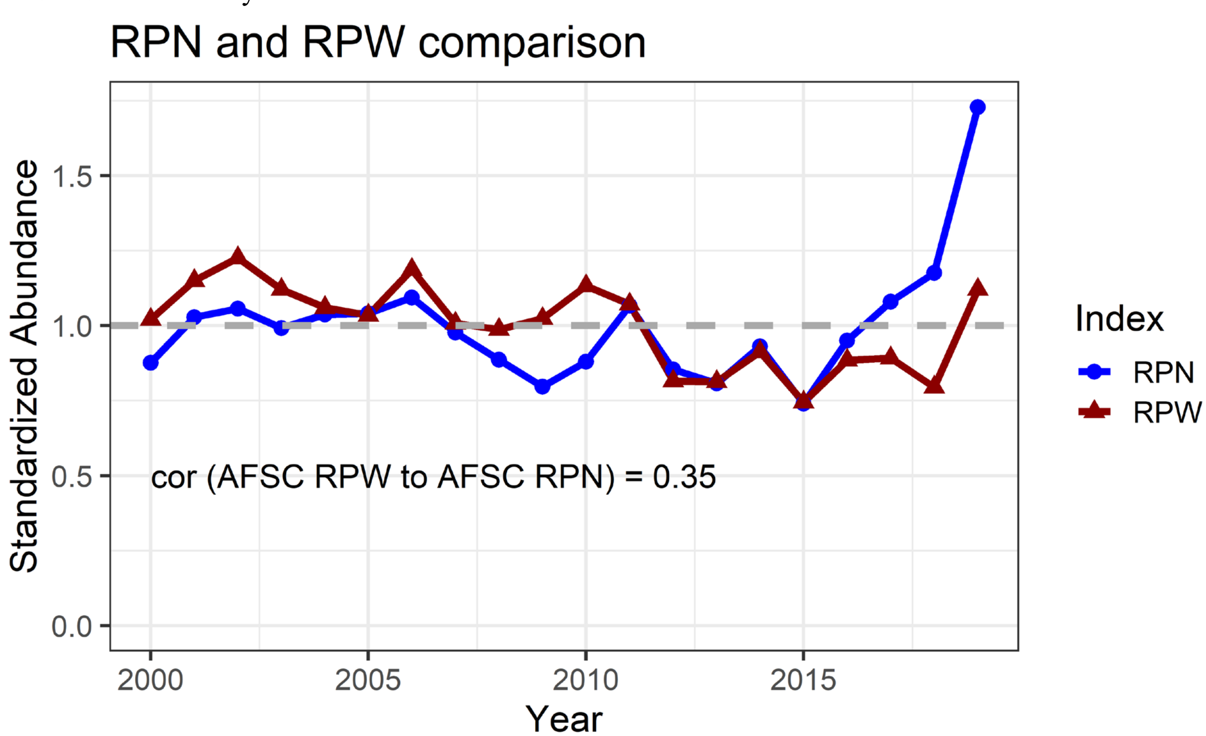


Figure 3.10b. Comparisons of AFSC longline survey indices. Relative Population Weight (RPW) is in weight and Relative Population Numbers (RPN) is in numbers. Only the RPN index is fit in the assessment model.

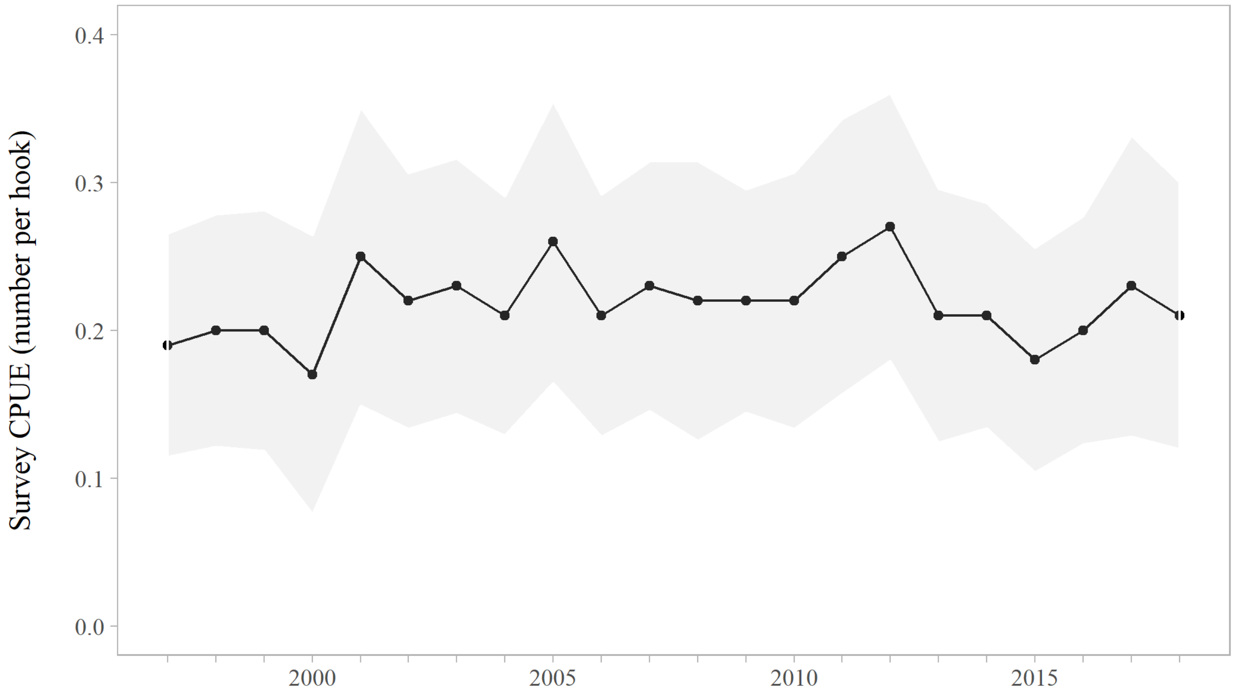


Figure 3.11a. Northern Southeast Inside (NSEI) sablefish longline survey catch-per-unit-effort (CPUE) in individuals/hook from 1997 to 2018. A three-hour minimum soak time was used on the NSEI sablefish longline survey (from A. Olson, November, 2019 ADFG, pers. comm.)

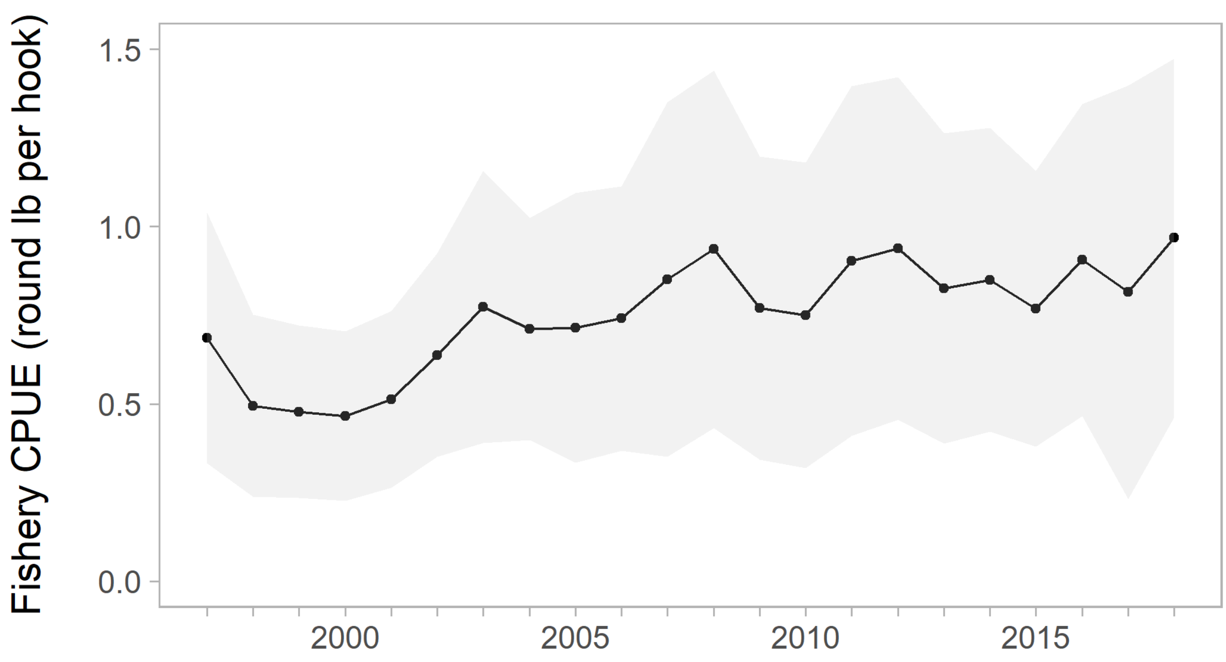


Figure 3.11b. Northern Southeast Inside (NSEI) commercial sablefish fishery catch-per-unit-effort (CPUE) in pounds/hook from 1997 to 2018 (from A. Olson, November, 2019 ADFG, pers. comm.)

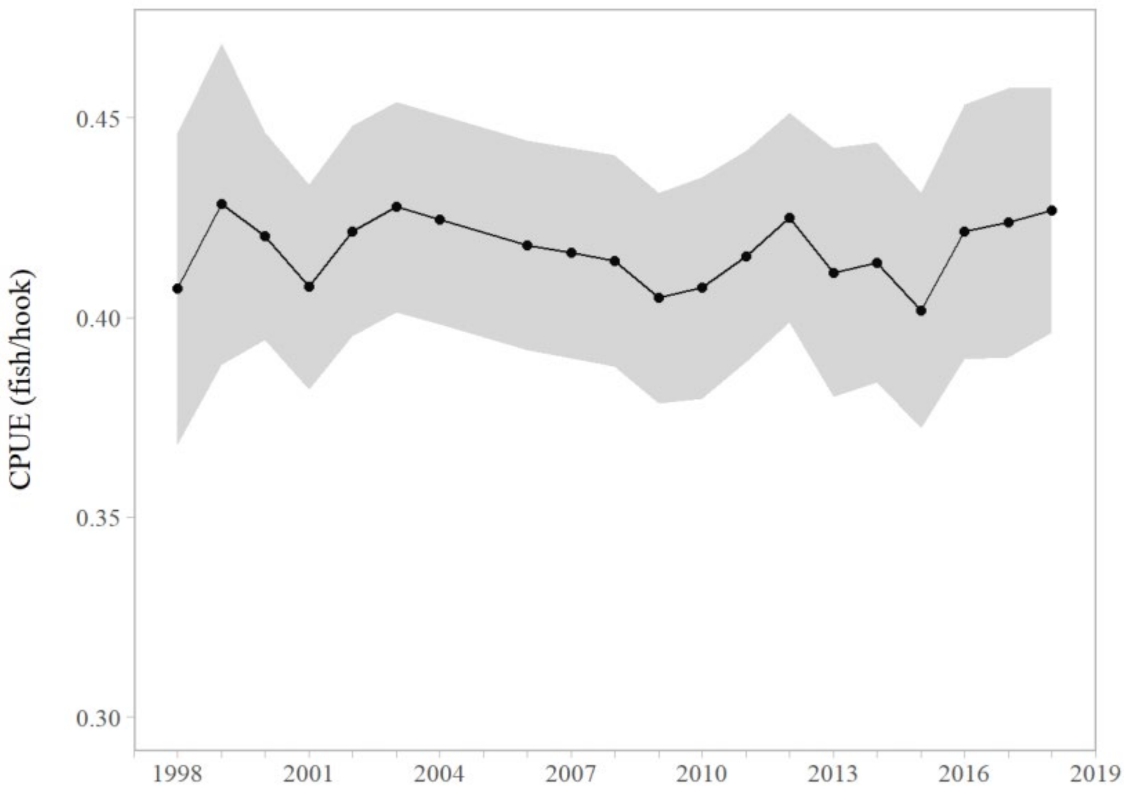


Figure 3.11c. Southern Southeast Inside (SSEI) sablefish longline survey catch-per-unit-effort (CPUE) in individuals/hook from 1997 to 2018. (from A. Olson, November, 2019 ADFG, pers. comm.)

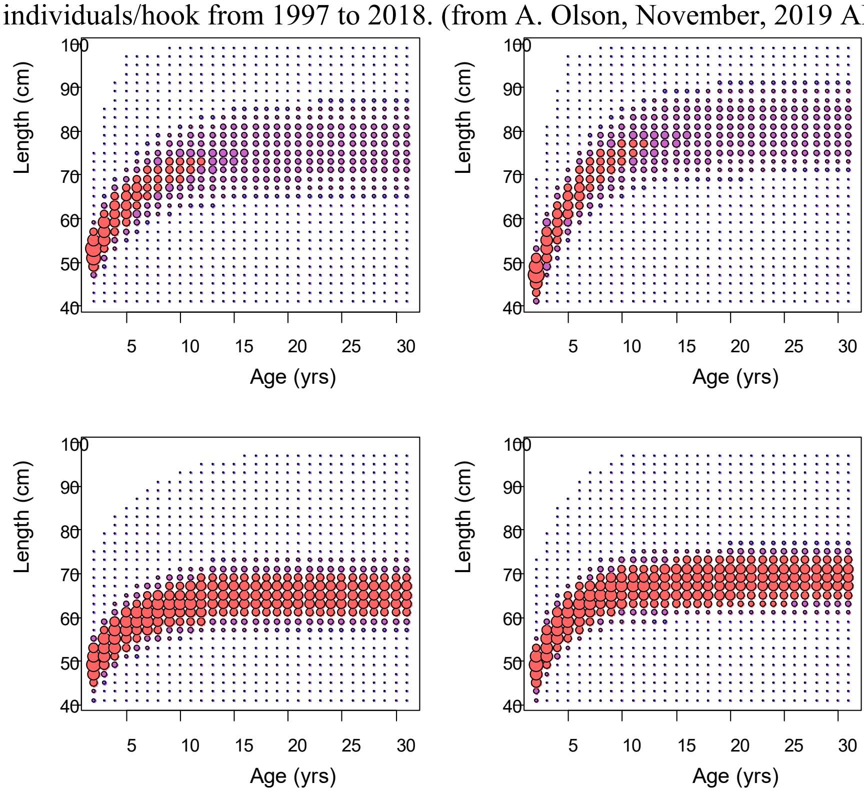


Figure 3.12. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996-2019.

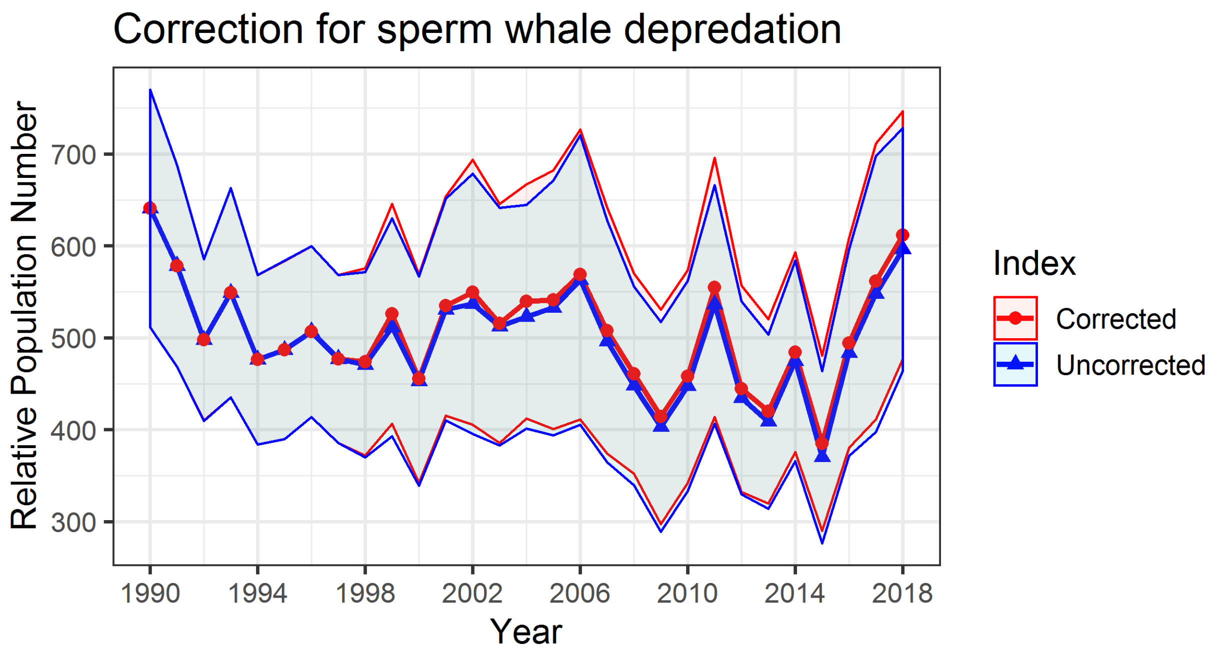


Figure 3.13. Total longline sablefish RPN index with (red circles) and without (blue triangles) sperm whale corrections 1990-2019. Shaded regions are approximate 95% confidence intervals.

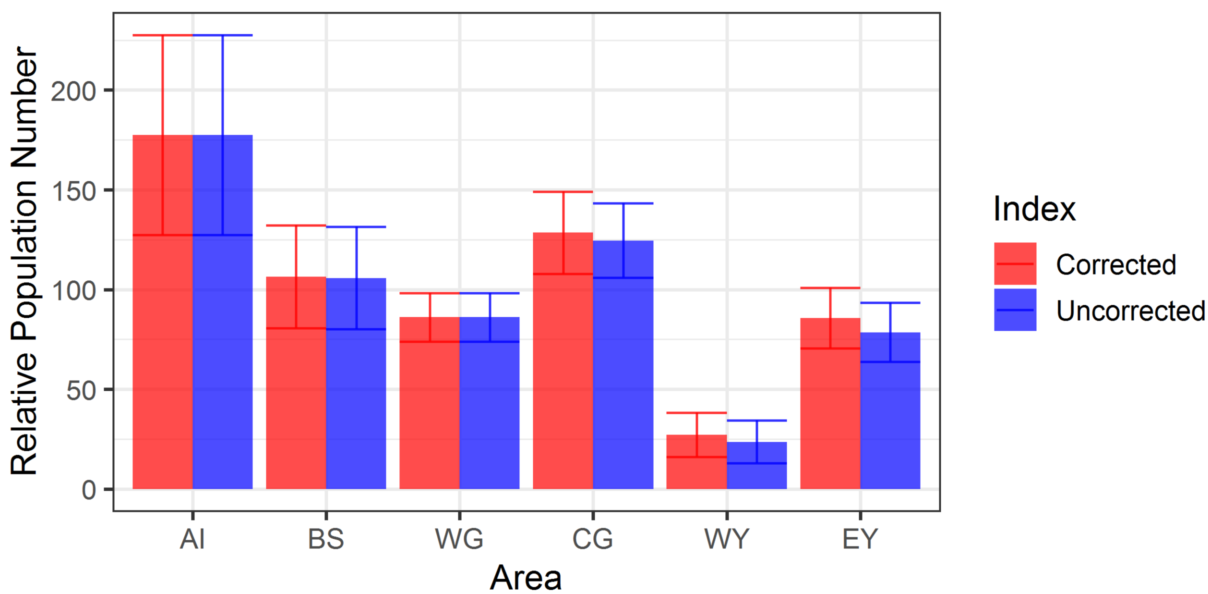


Figure 3.14. Longline sablefish RPN index by area with (red bars) and without (blue bars) sperm whale corrections 1990-2019. Error bars are approximate 95% confidence intervals.

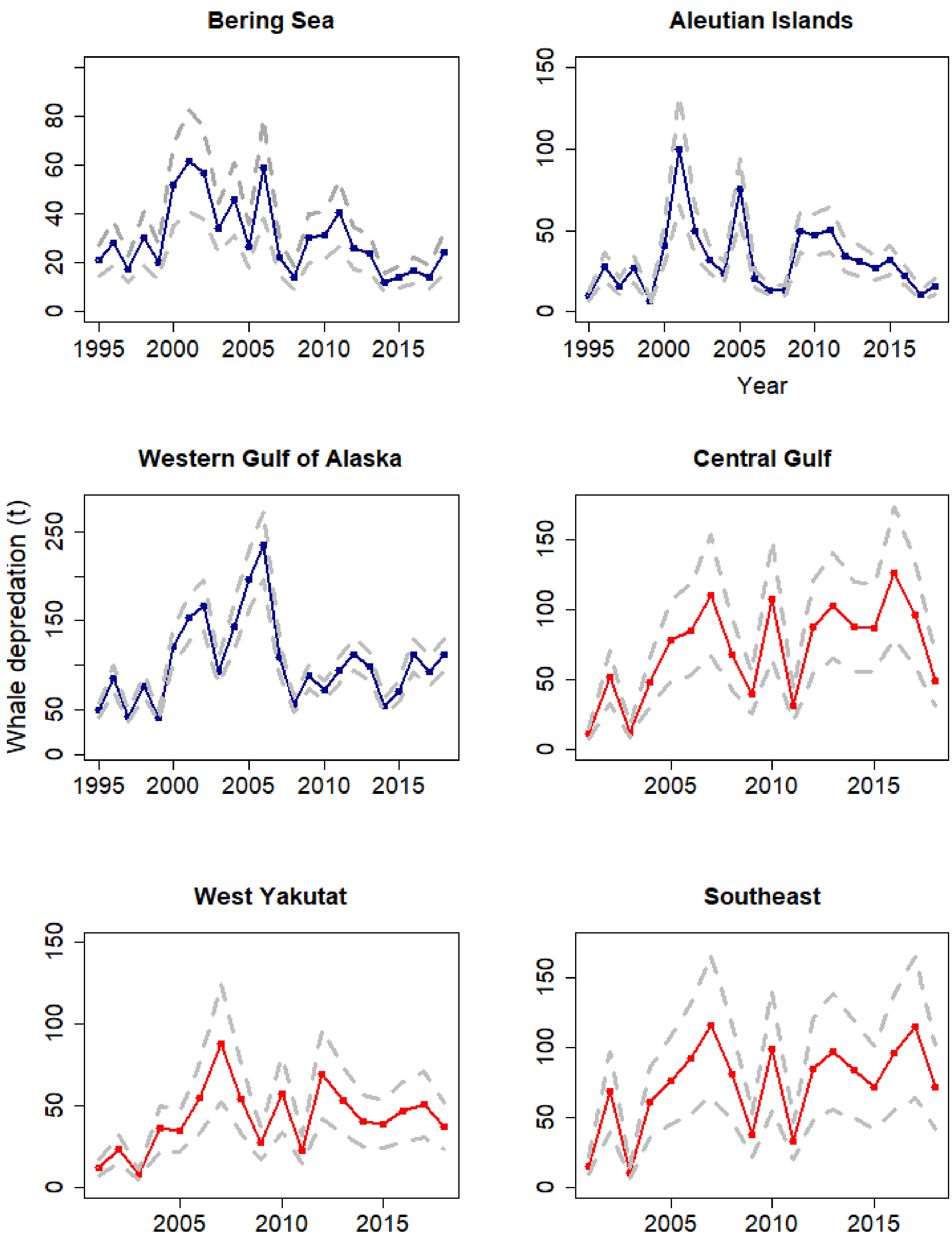


Figure 3.15. Estimated sablefish mortality (t) by year due to killer whales (blue) in the Bering Sea, Aleutian Islands, and Western Gulf of Alaska and sperm whales (red) in the Central Gulf of Alaska, West Yakutat, and Southeast Alaska with ~95% confidence bands. Estimated sablefish catch removals (t)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

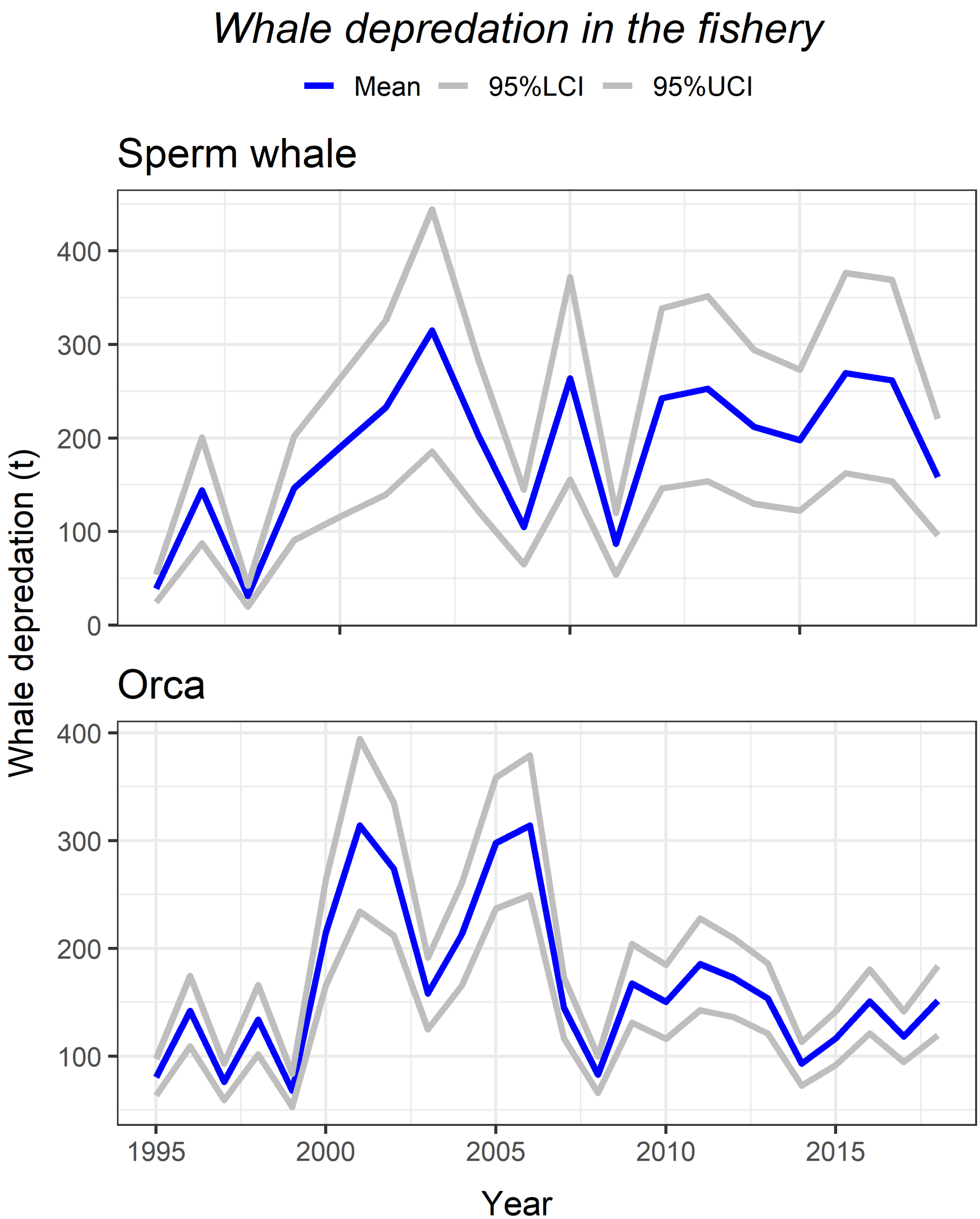
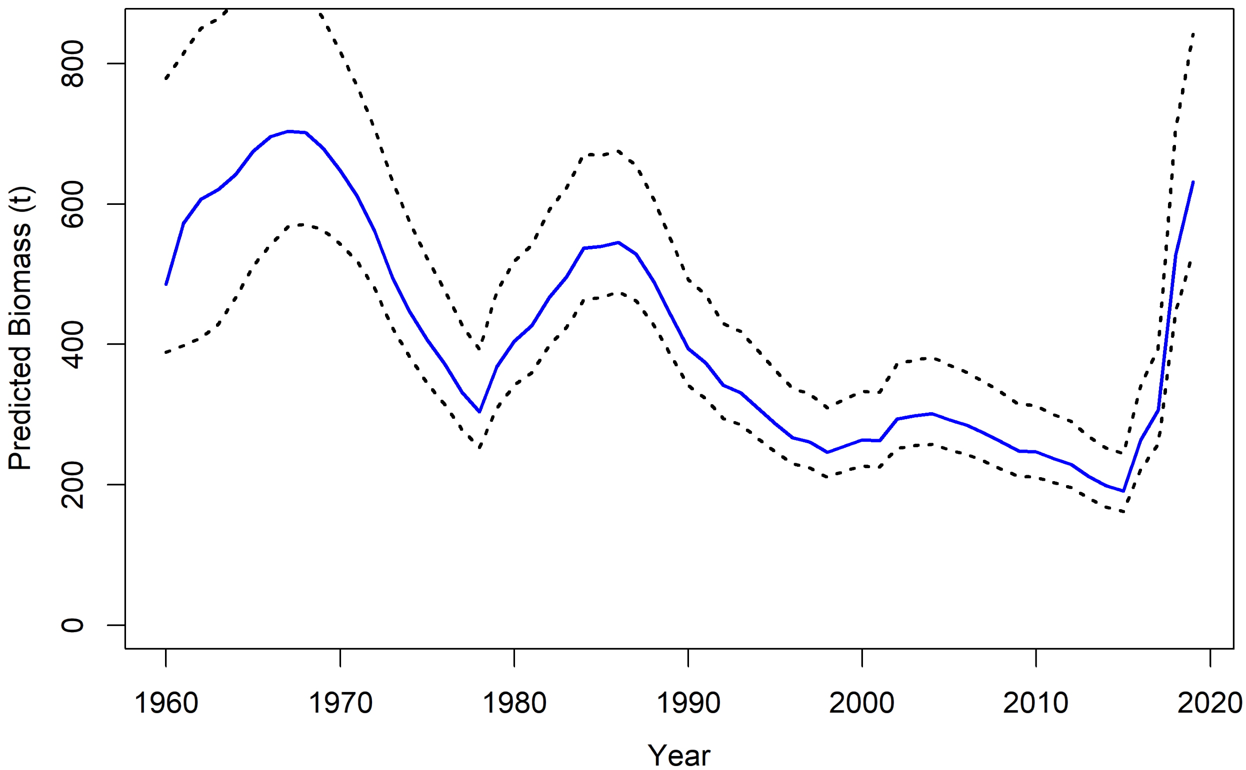


Figure 3.16. Additional estimated sablefish mortality (blue) by two whale species with 95% asymptotic normal confidence intervals (grey lines).



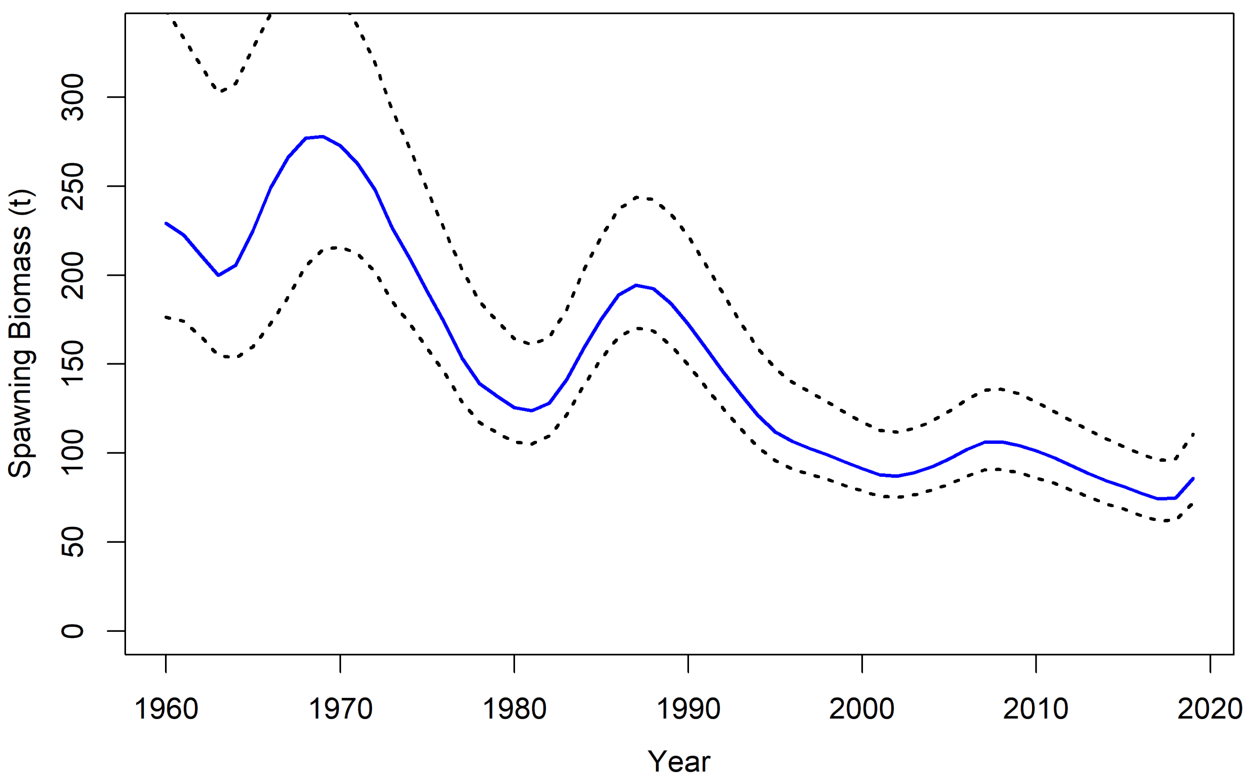


Figure 3.17. Estimated sablefish total biomass (thousands t) and spawning biomass (bottom) with 95% MCMC credible intervals.

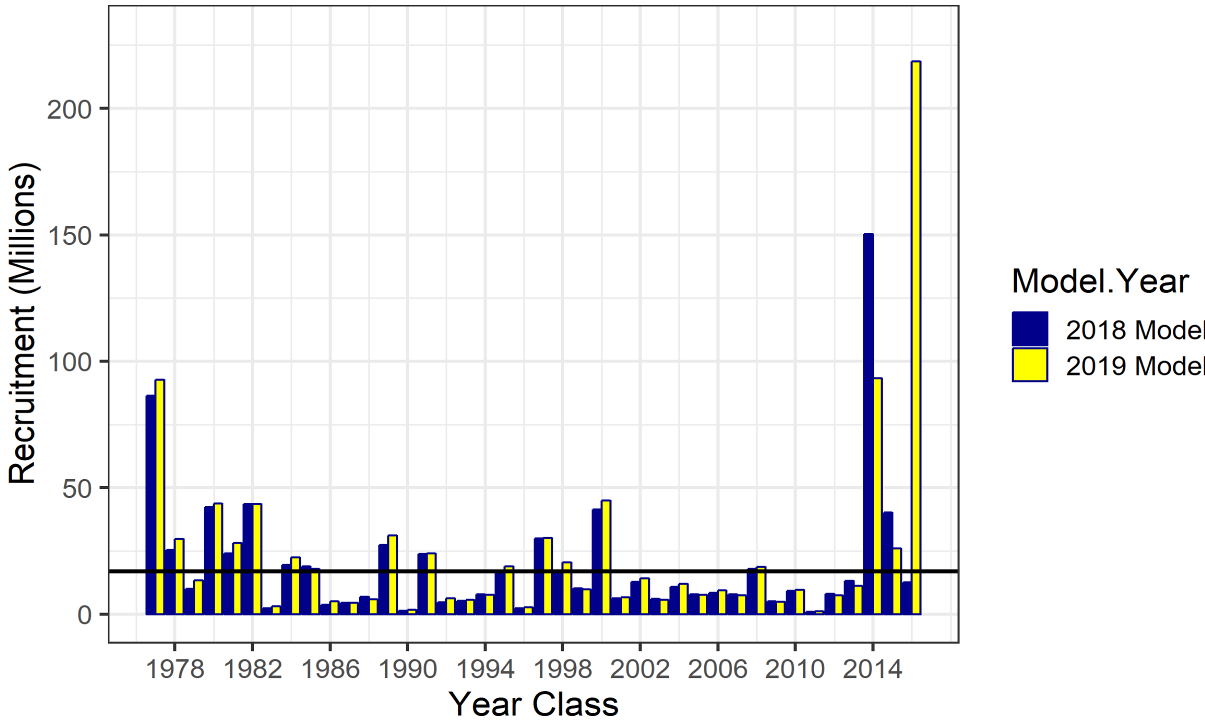


Figure 3.18a. Estimated recruitment by year class 1977-2014 (number at age 2, millions) for 2018 and 2019 models.

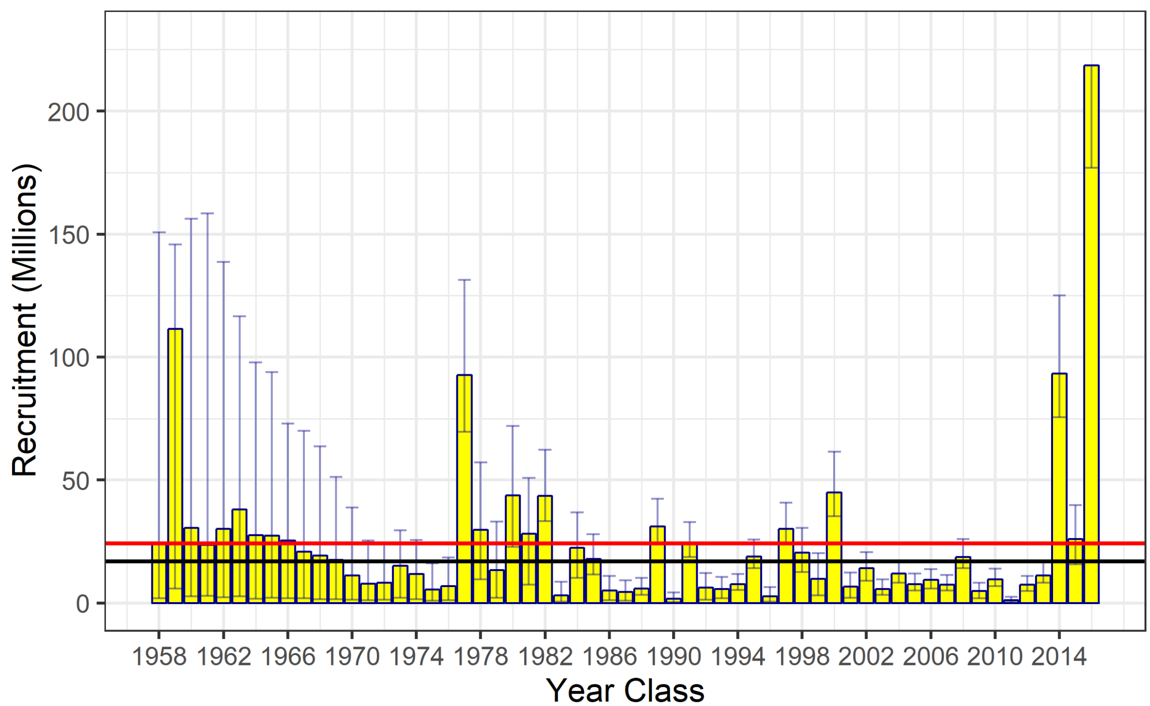


Figure 3.18b. Estimates of the number of age-2 sablefish (millions) with 95% credible intervals by year class. Red line is overall mean, blue line is recruitments from year classes between 1977 and 2016. Credible intervals are based on MCMC posterior. Upper confidence interval is omitted for the 2014 year class.

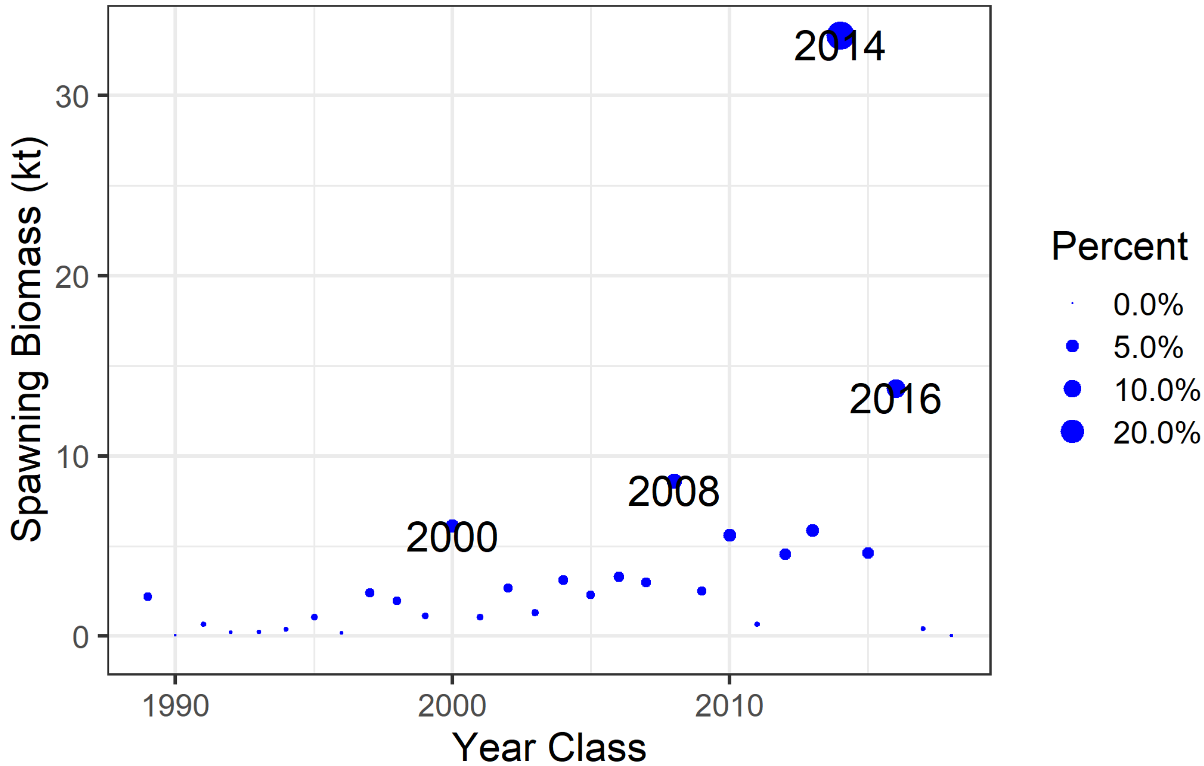


Figure 3.19. Relative contribution of the last 30 year classes to next year's female spawning biomass.

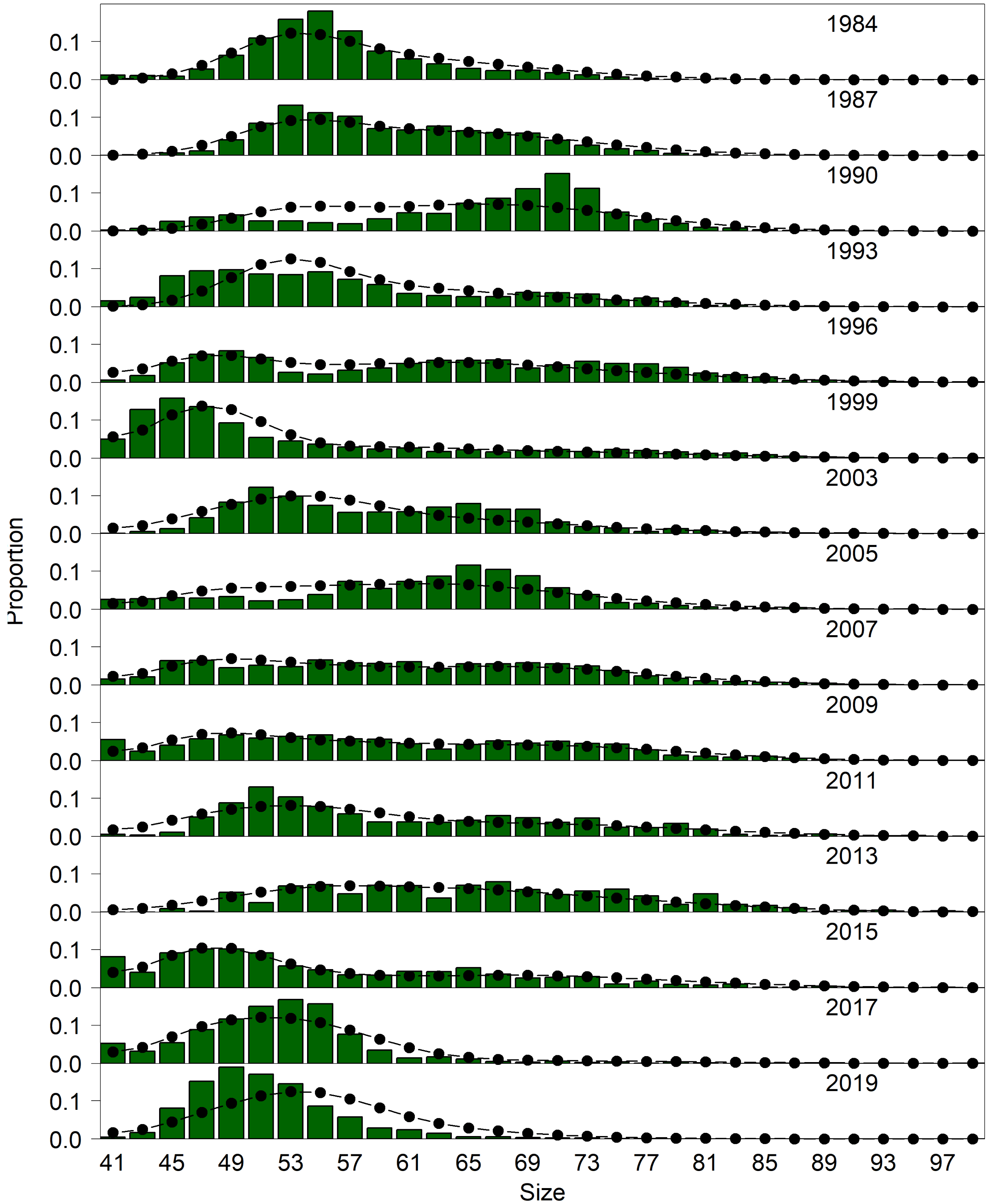


Figure 3.20. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

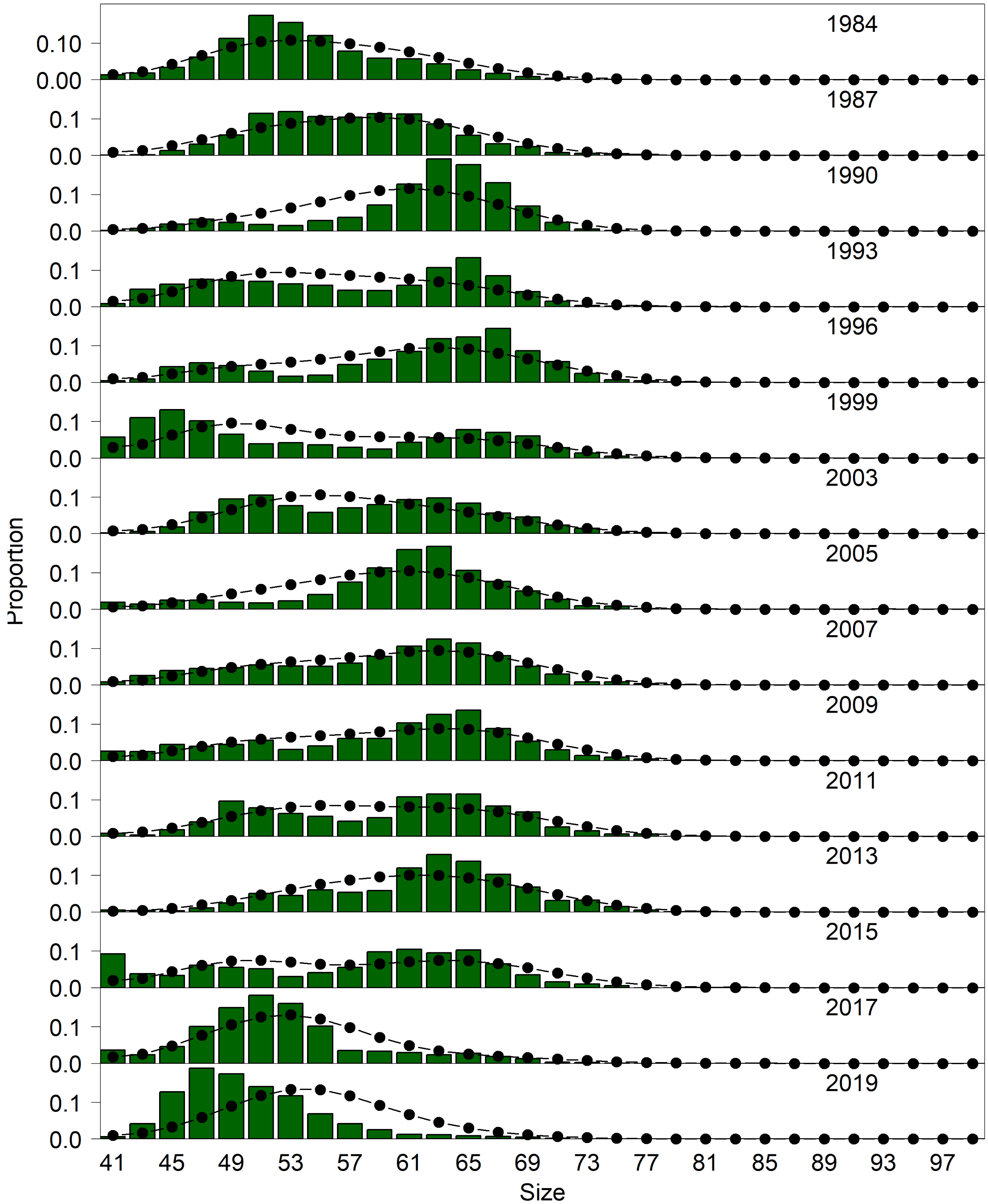


Figure 3.21. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

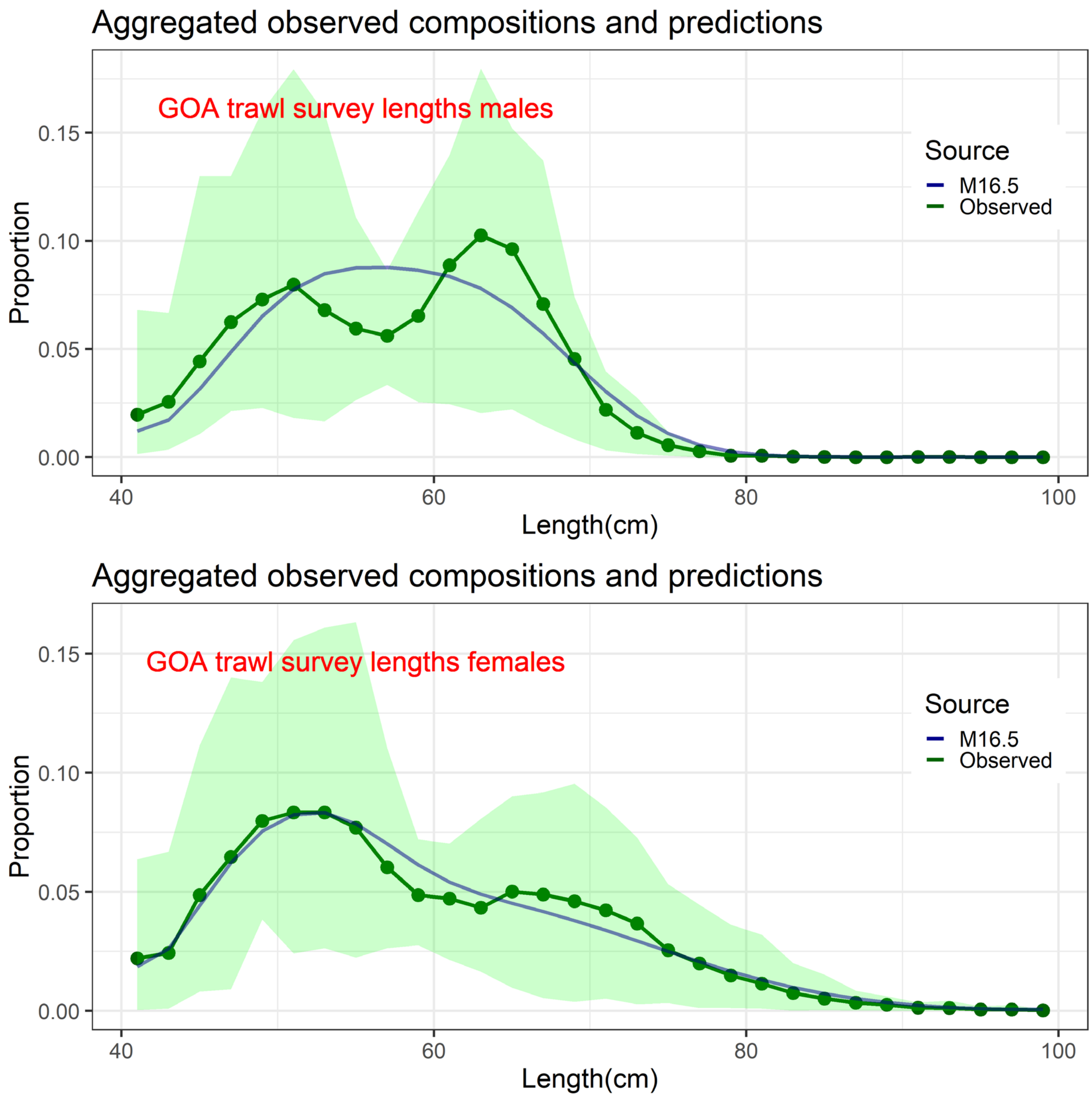


Figure 3.22. Gulf of Alaska trawl survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

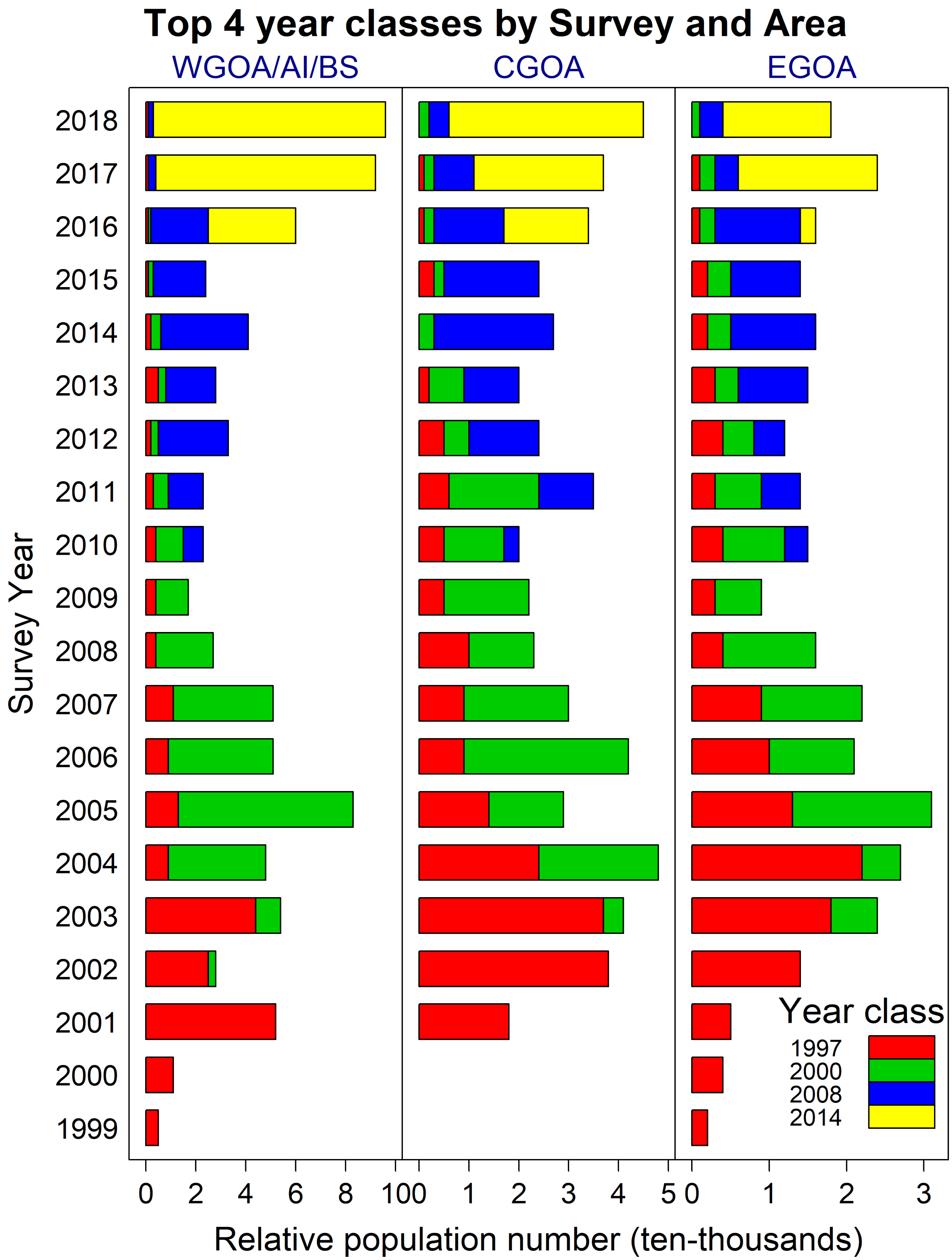


Figure 3.23. Above average 1997, 2000, 2008, and 2014 year classes' relative population abundance in each survey year and area.

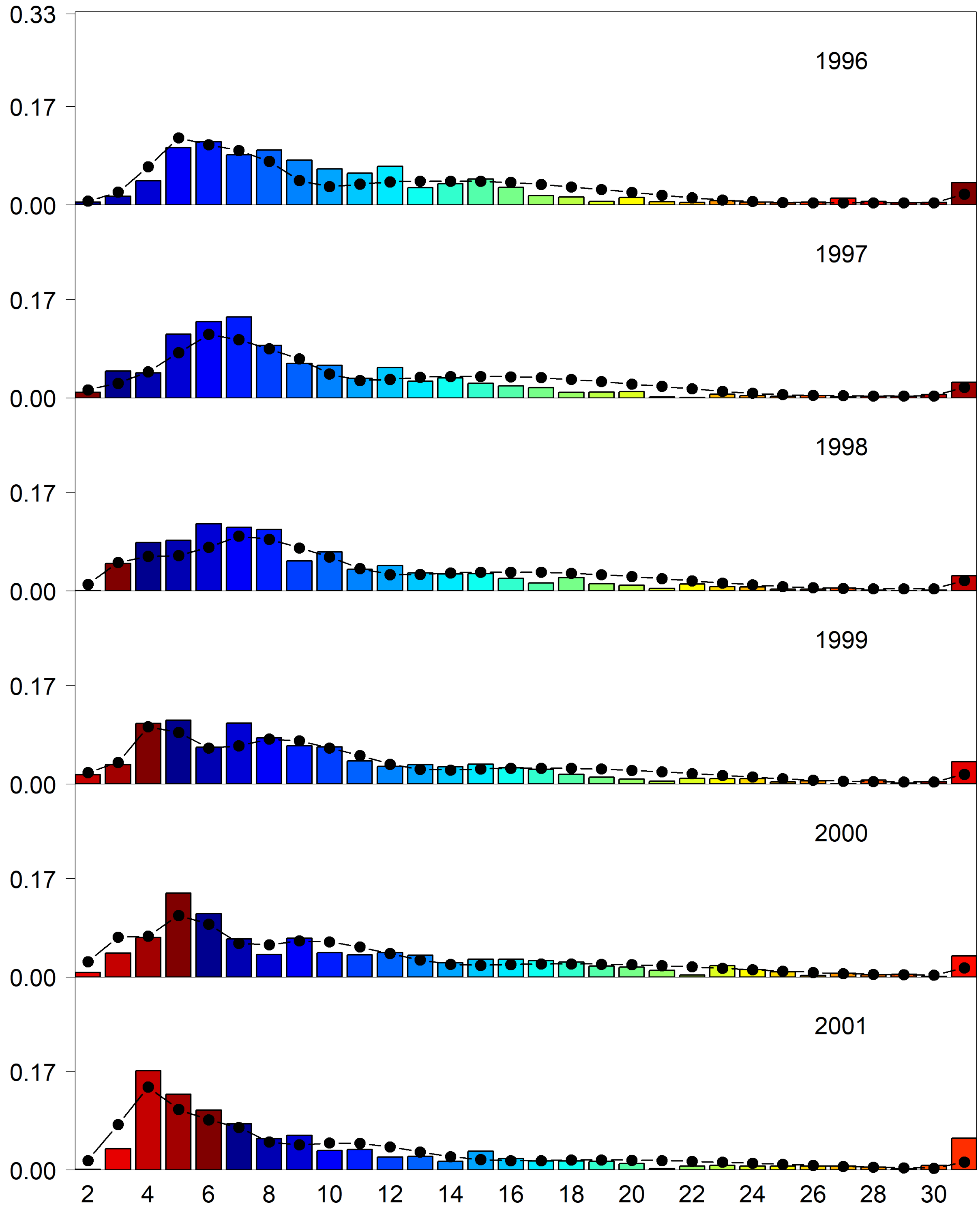


Figure 3.24. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

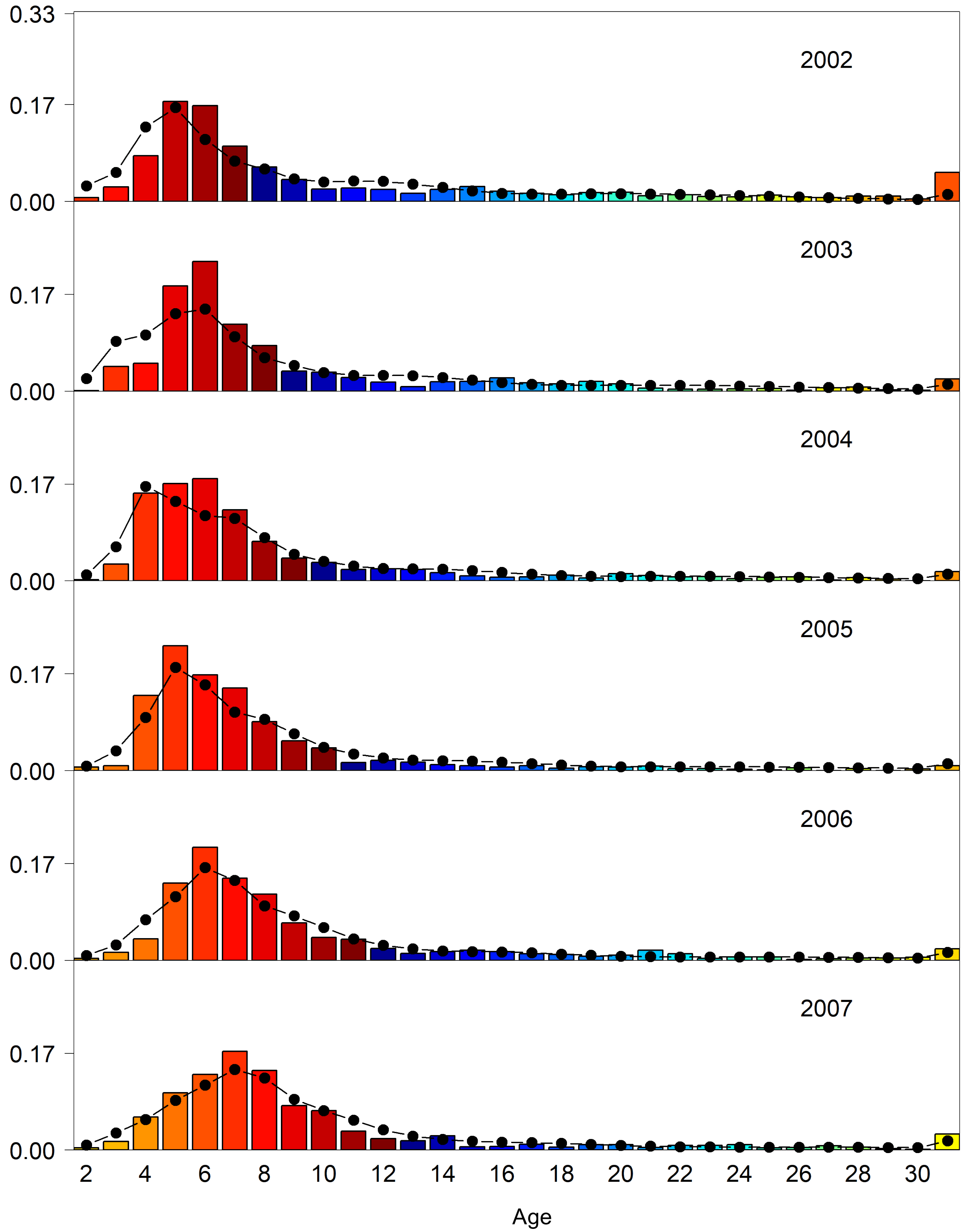


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

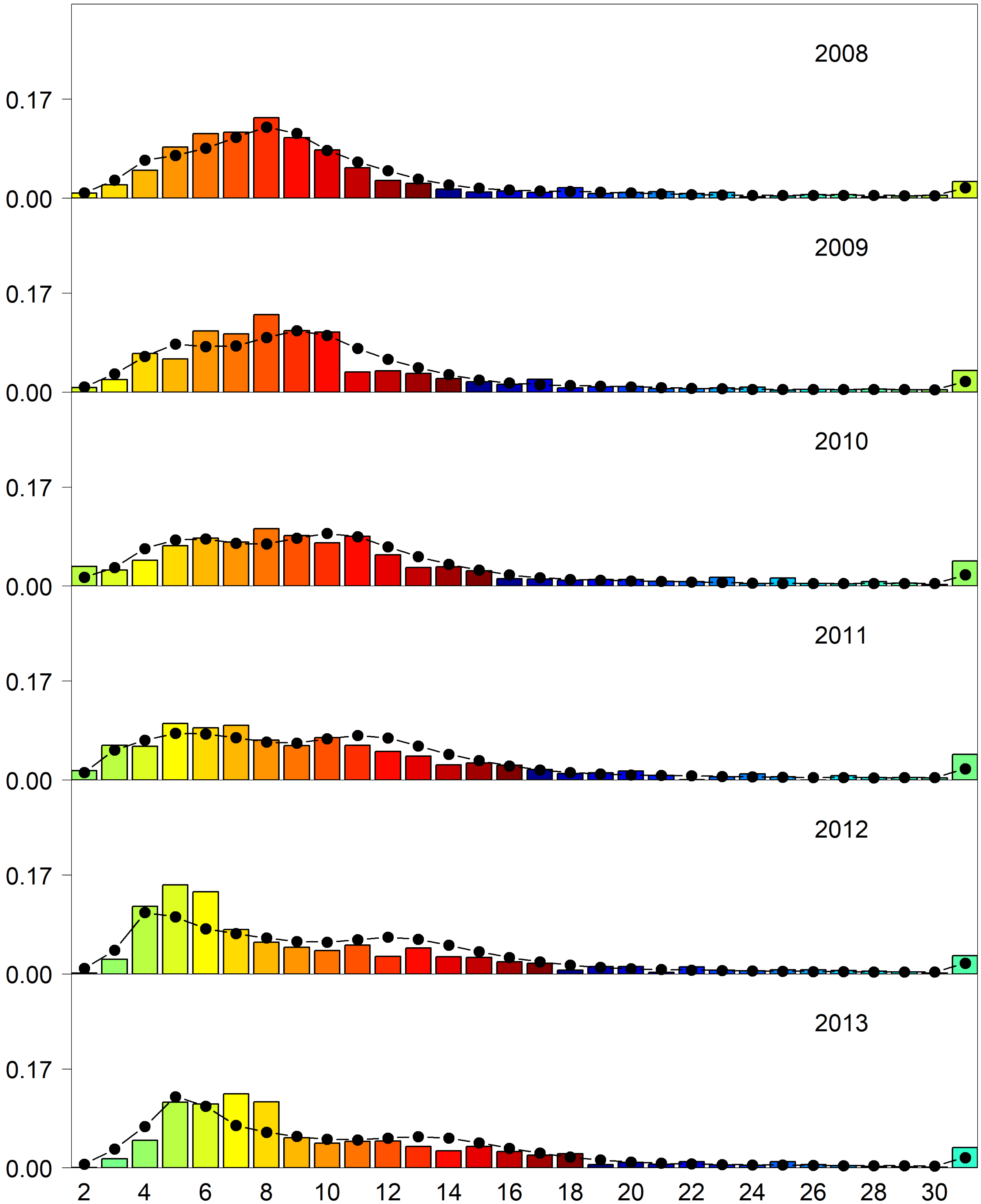


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

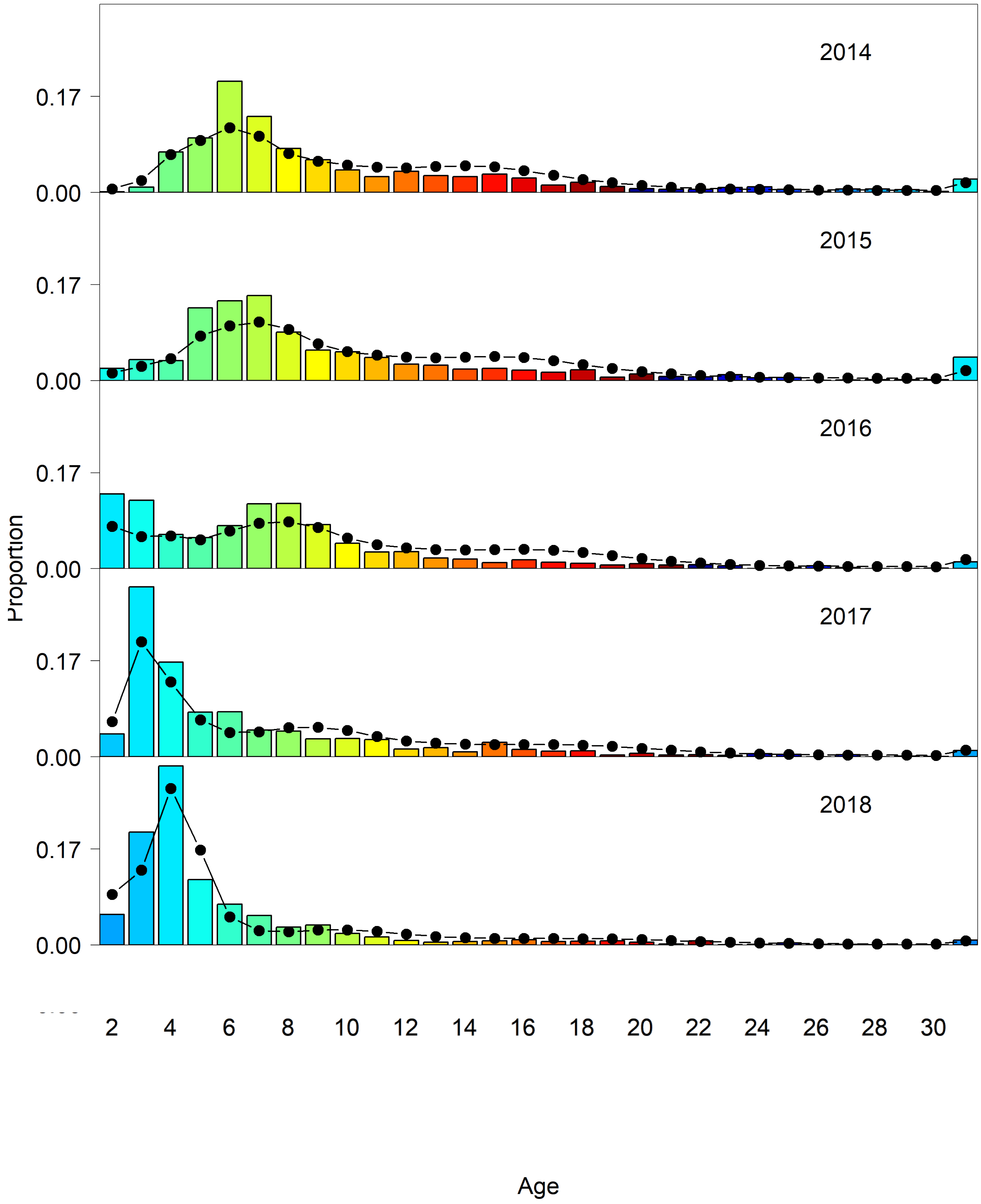


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

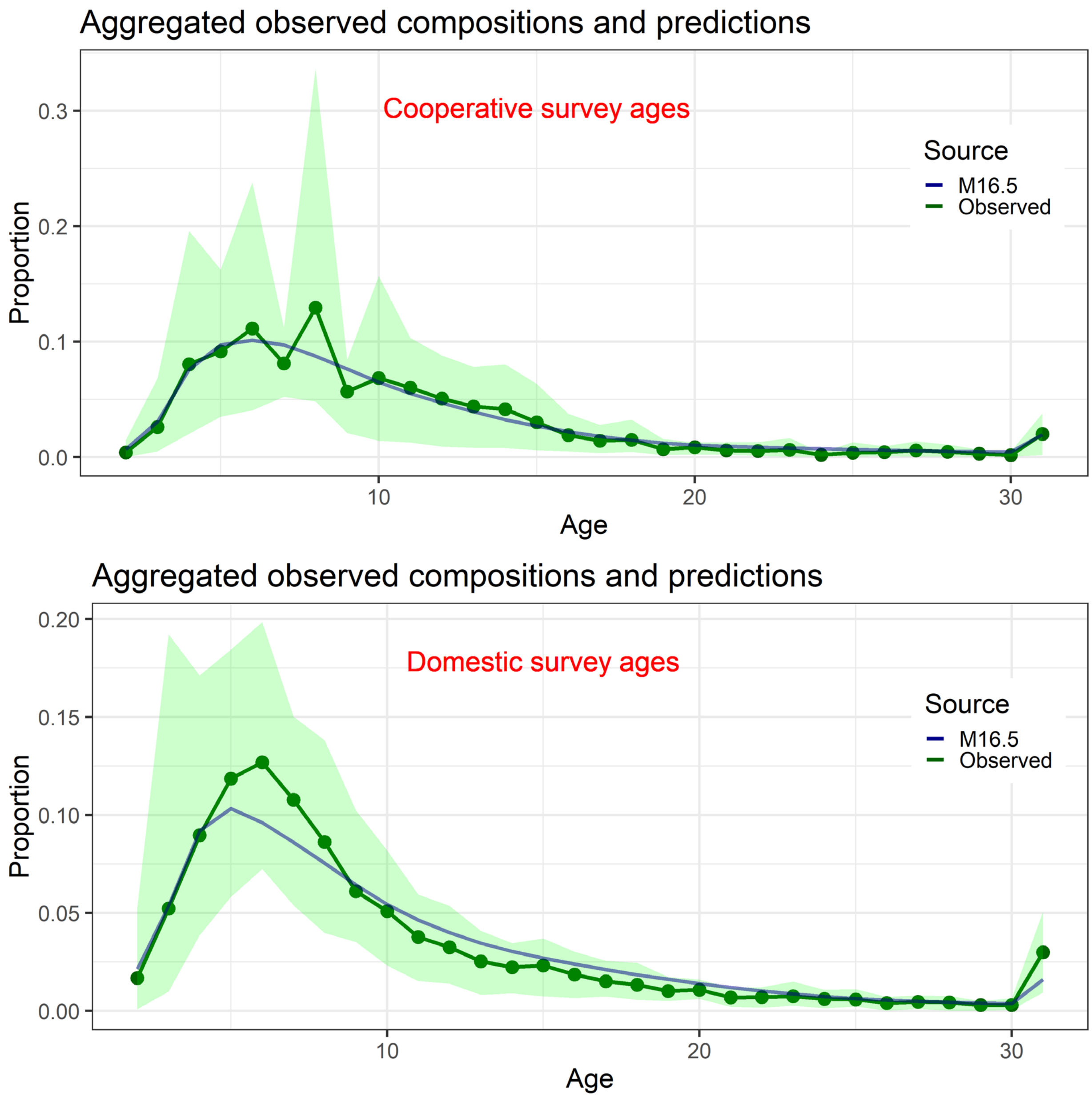


Figure 3.25. Cooperative and domestic survey age compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

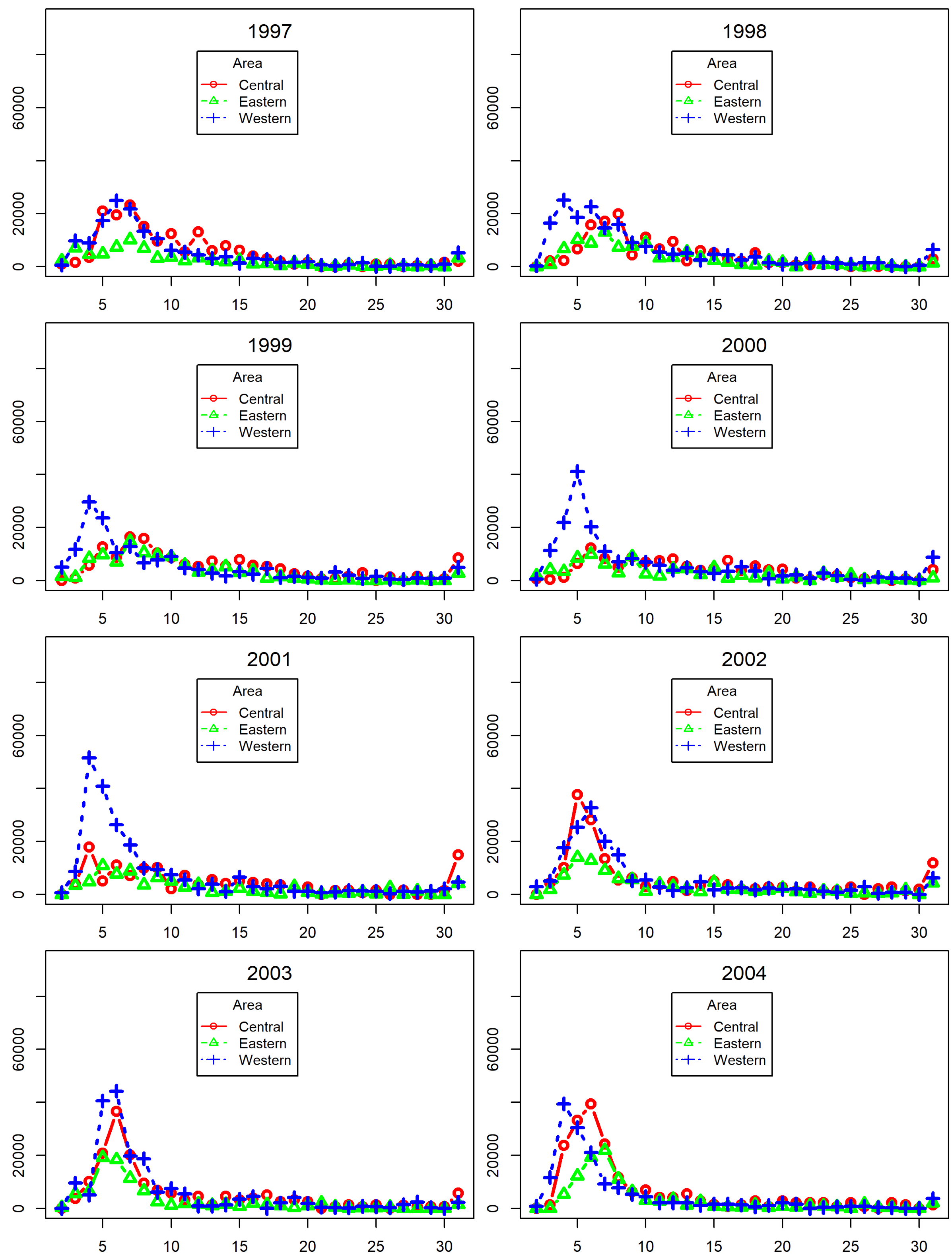


Figure 3.26. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

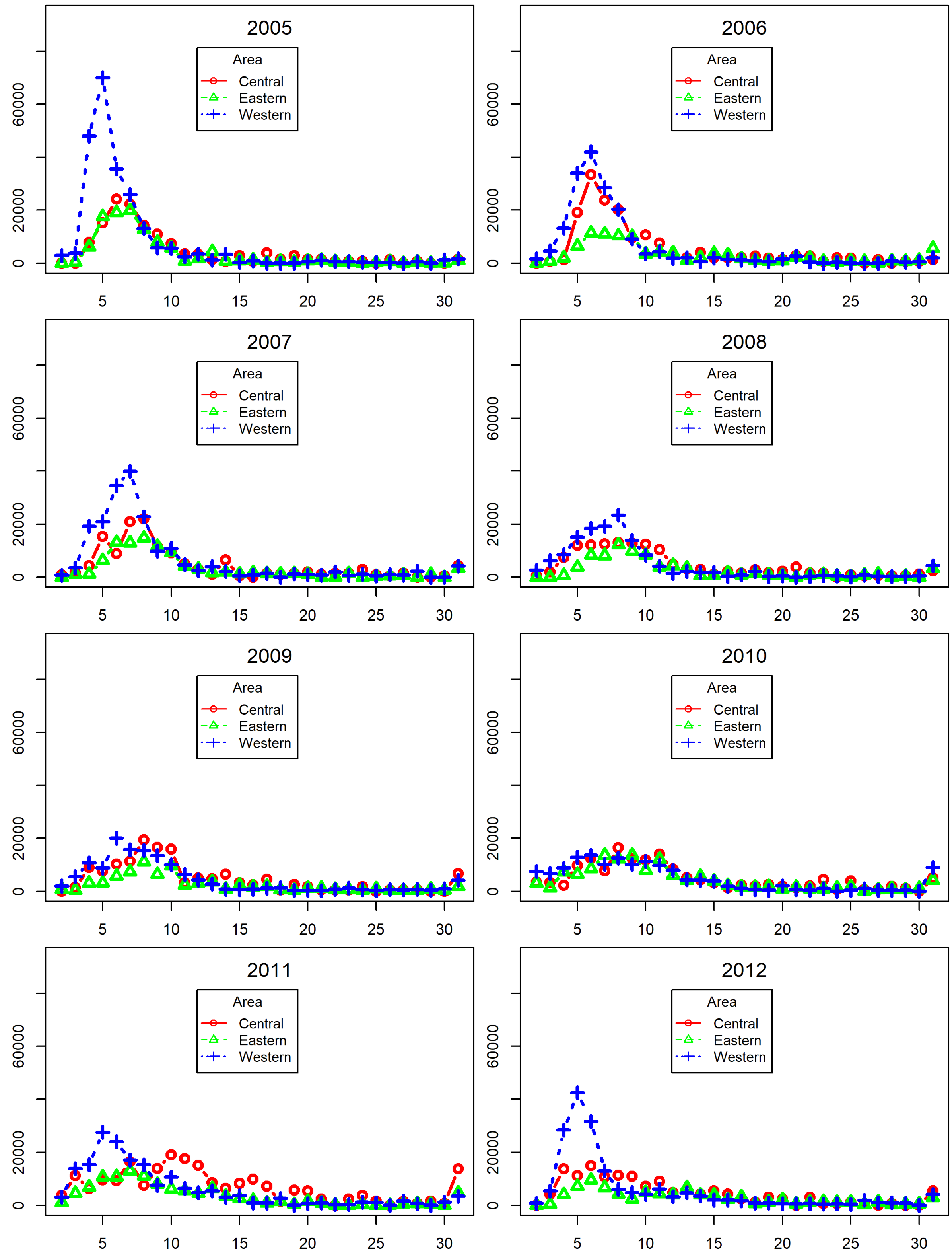


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

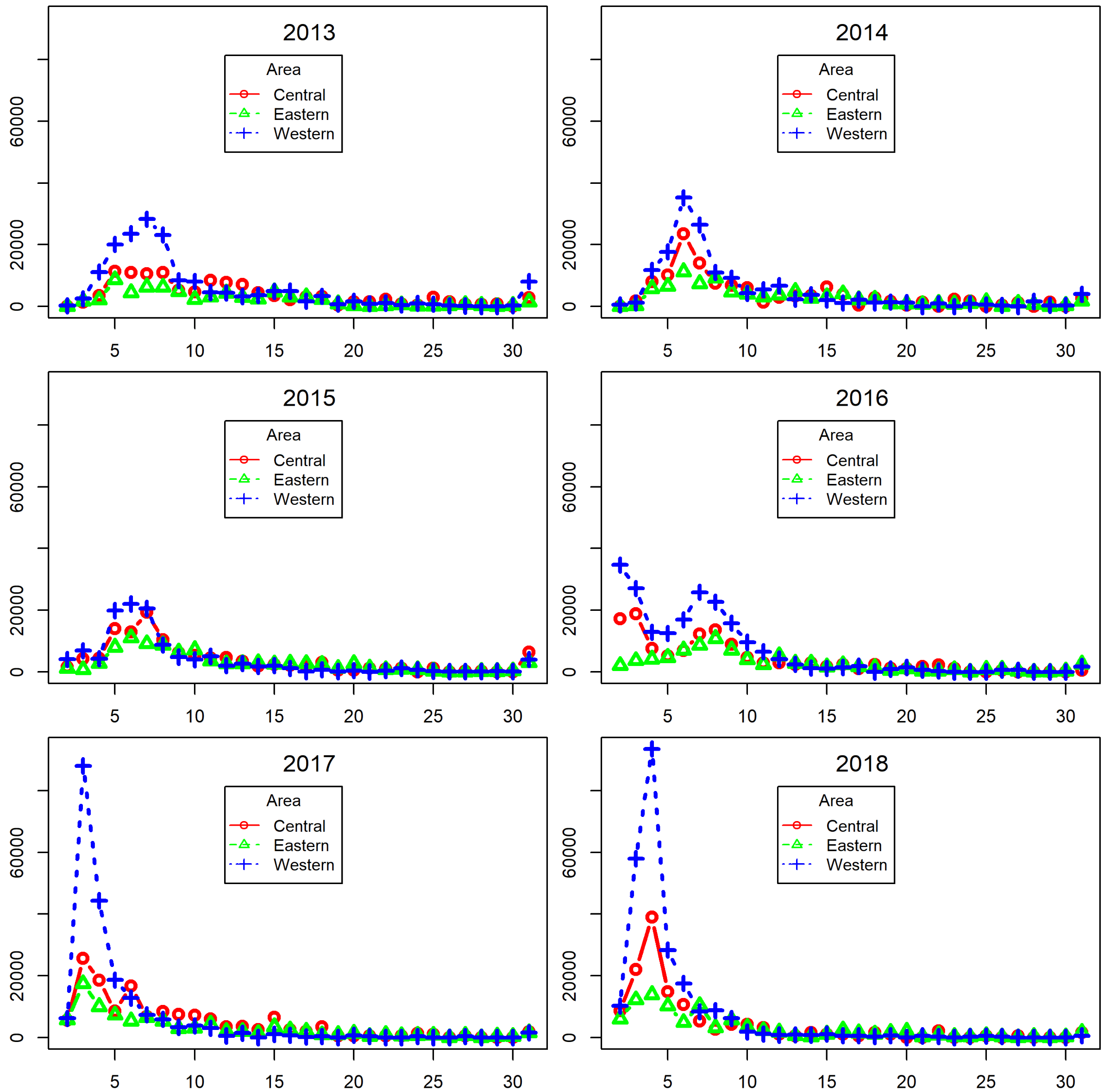


Figure 3.26 (cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined.

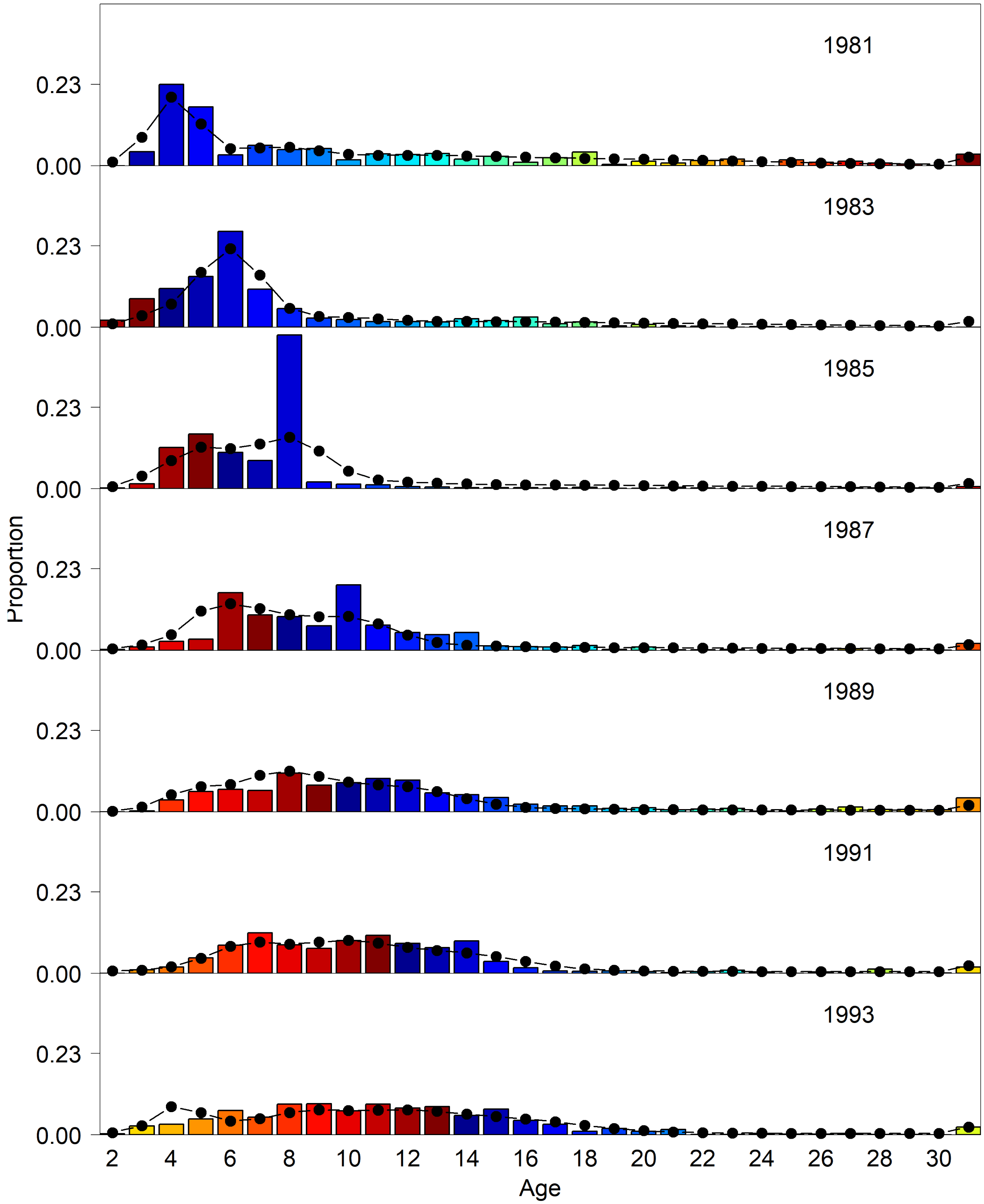


Figure 3.27. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

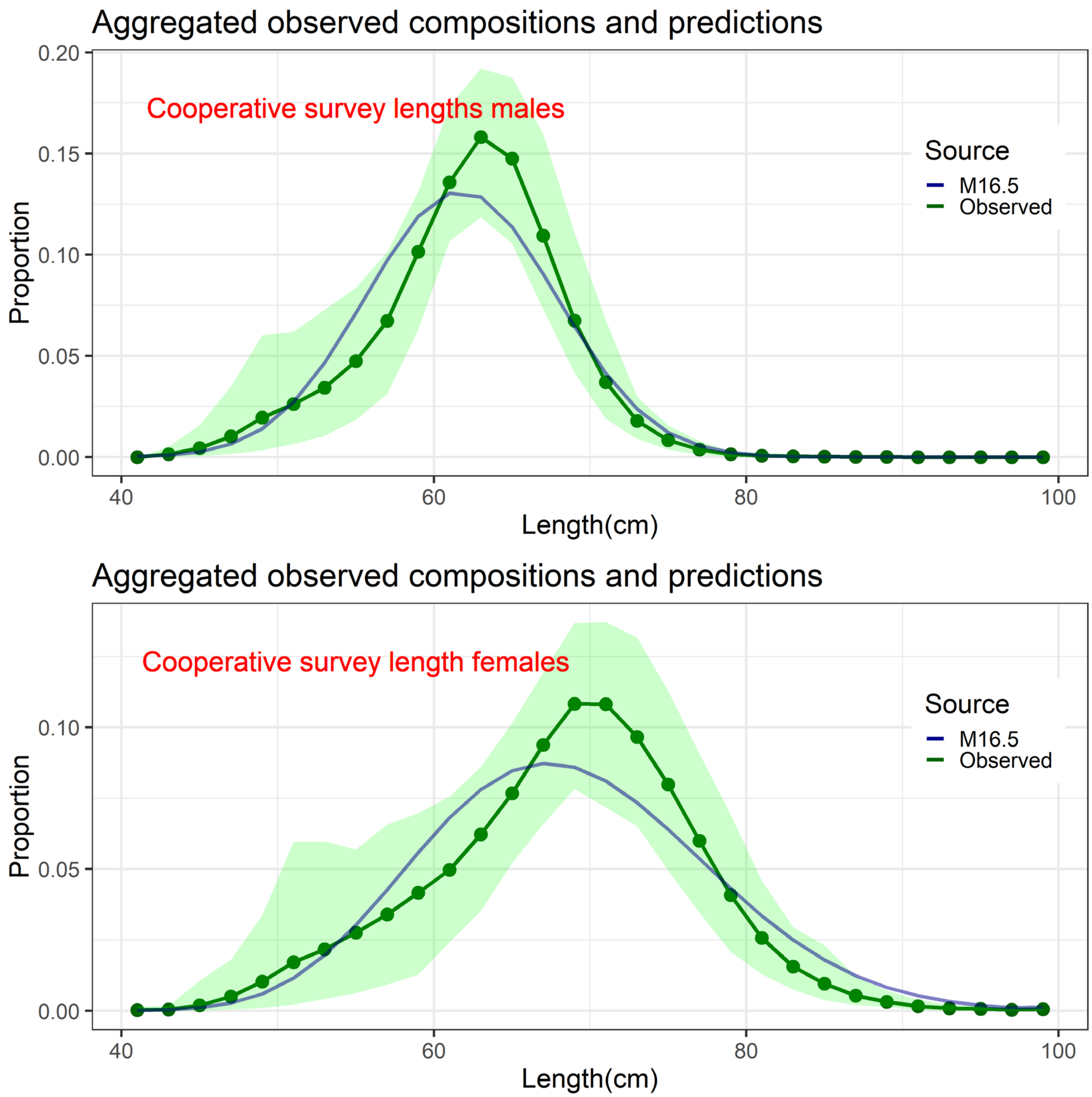


Figure 3.28. Cooperative longline survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

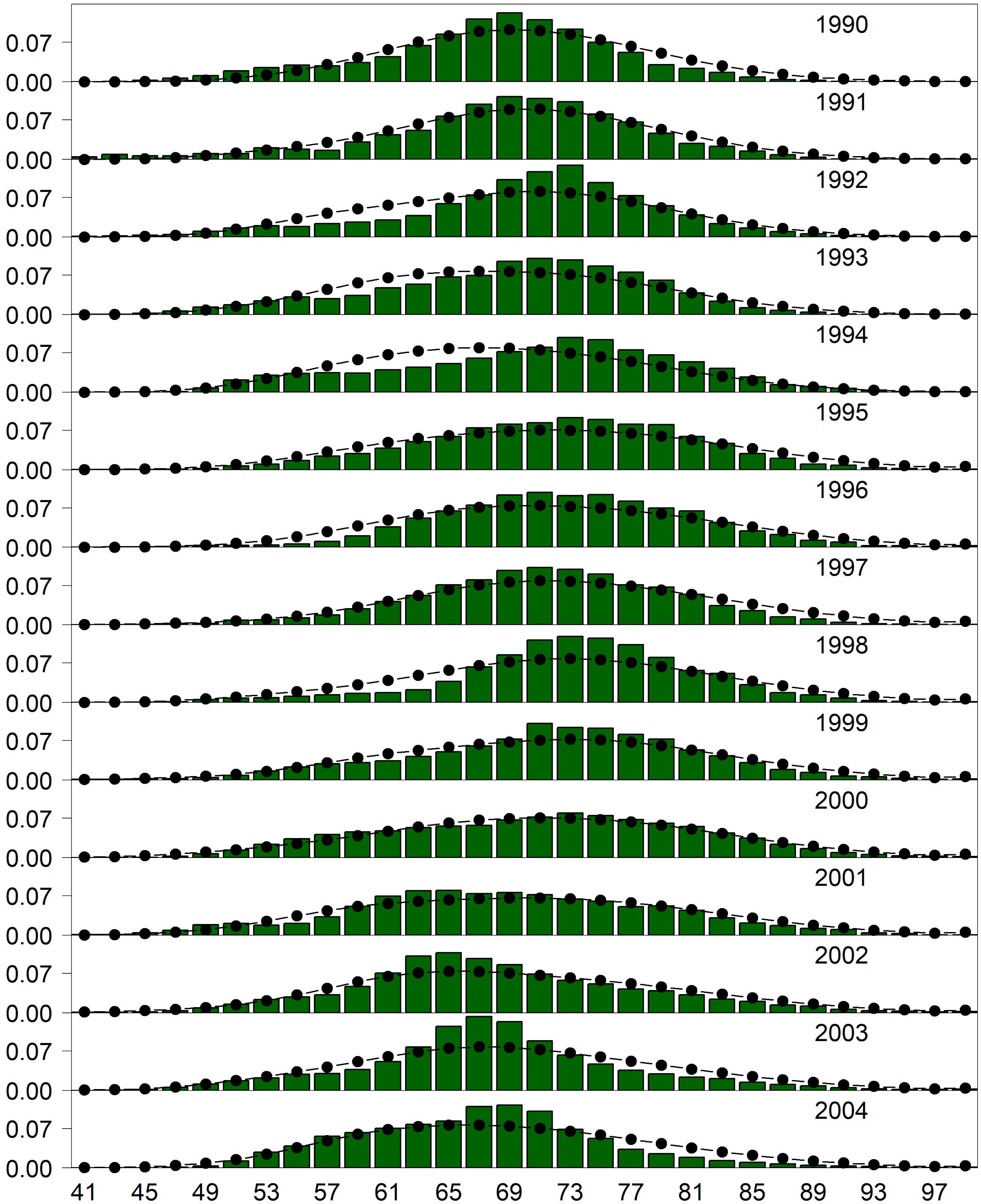


Figure 3.29. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

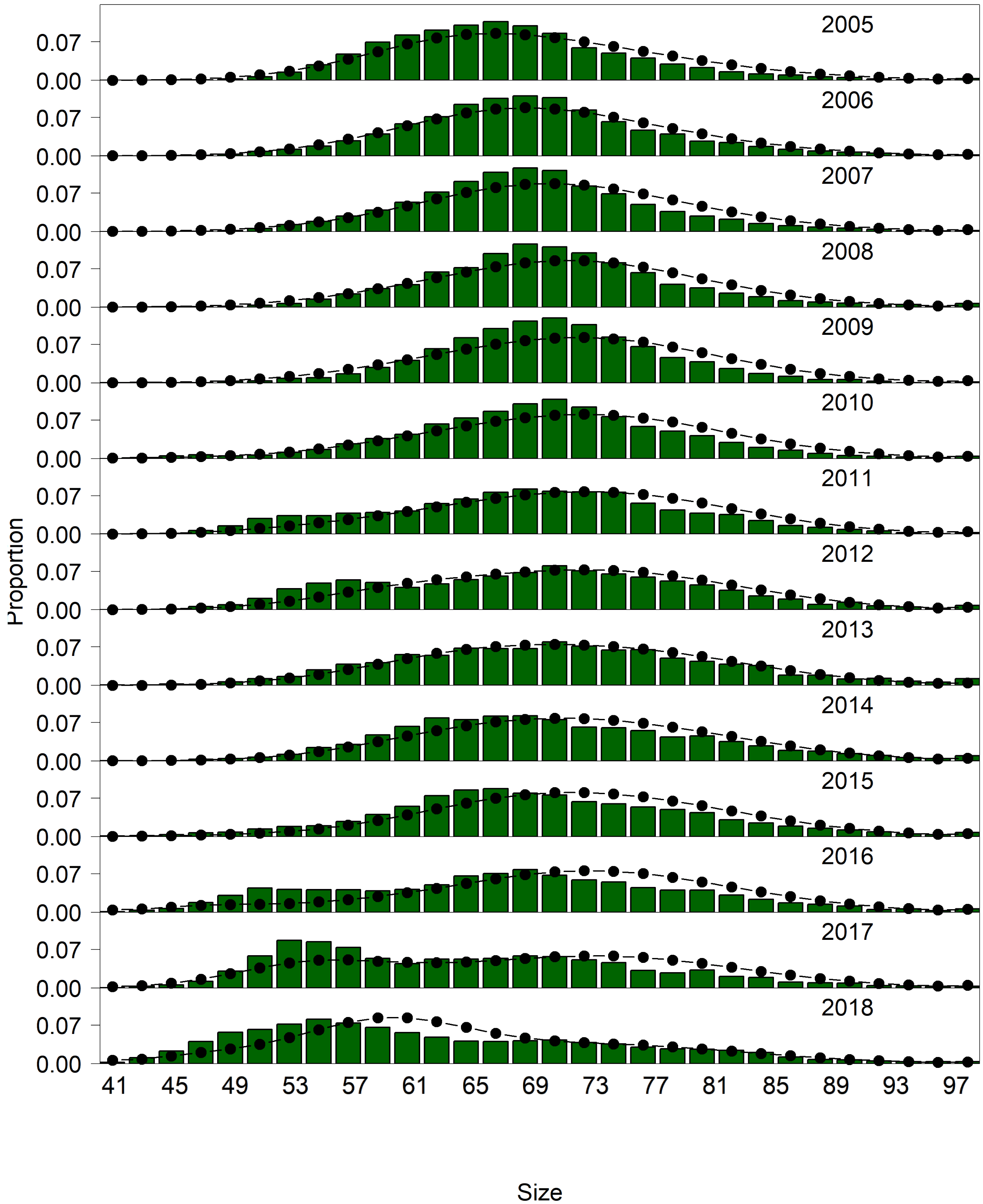


Figure 3.29 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

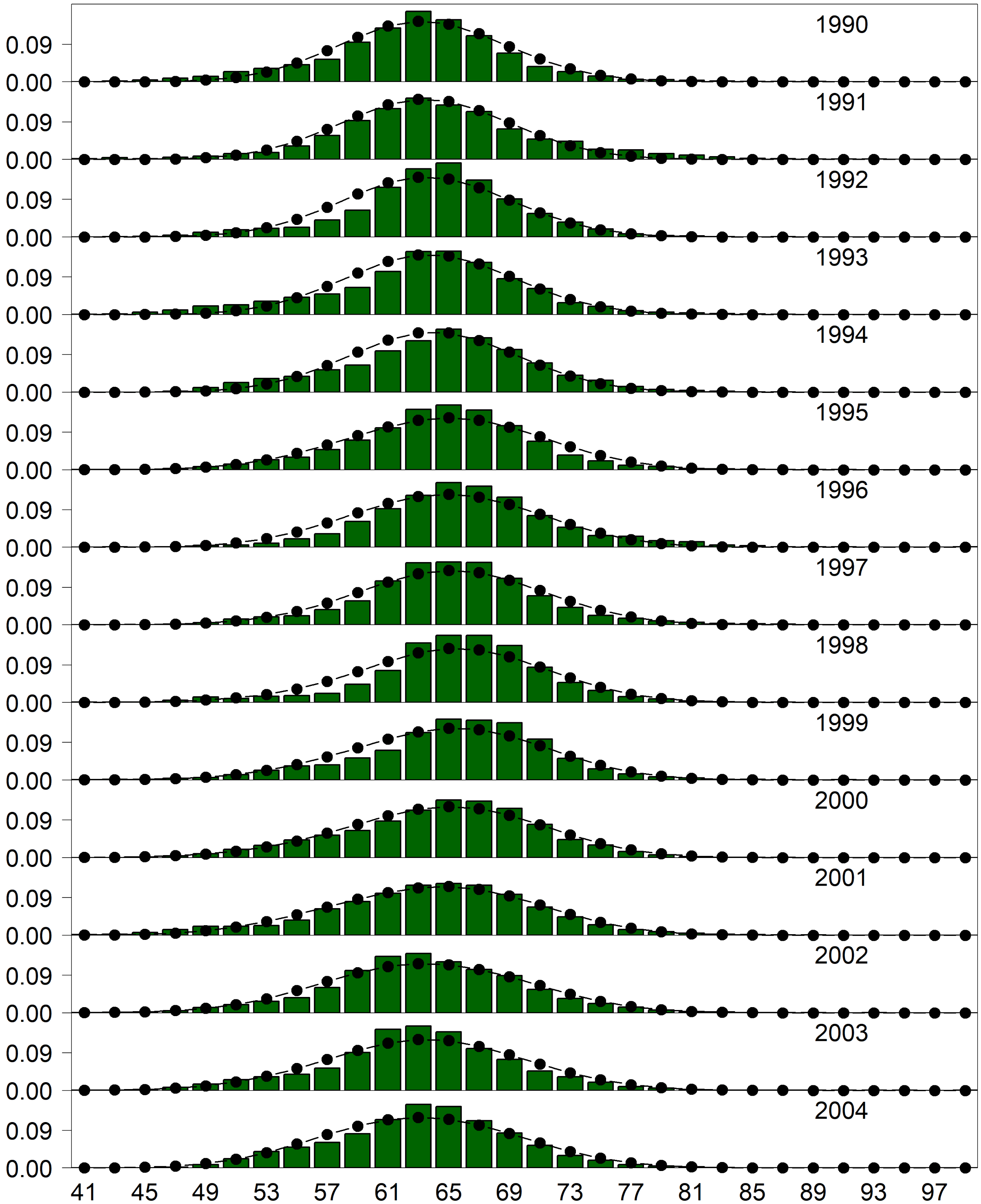


Figure 3.30. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

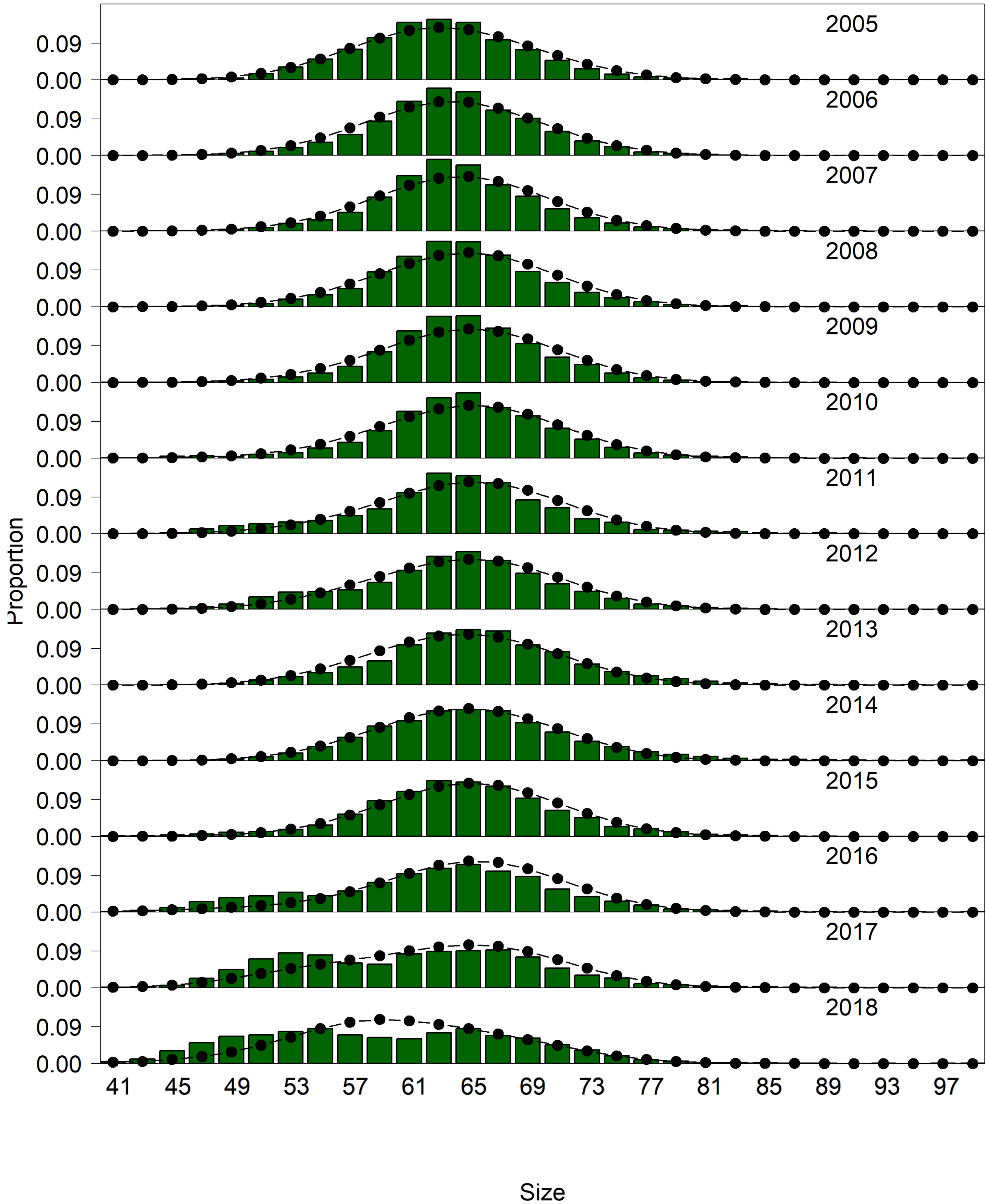


Figure 3.30 (cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

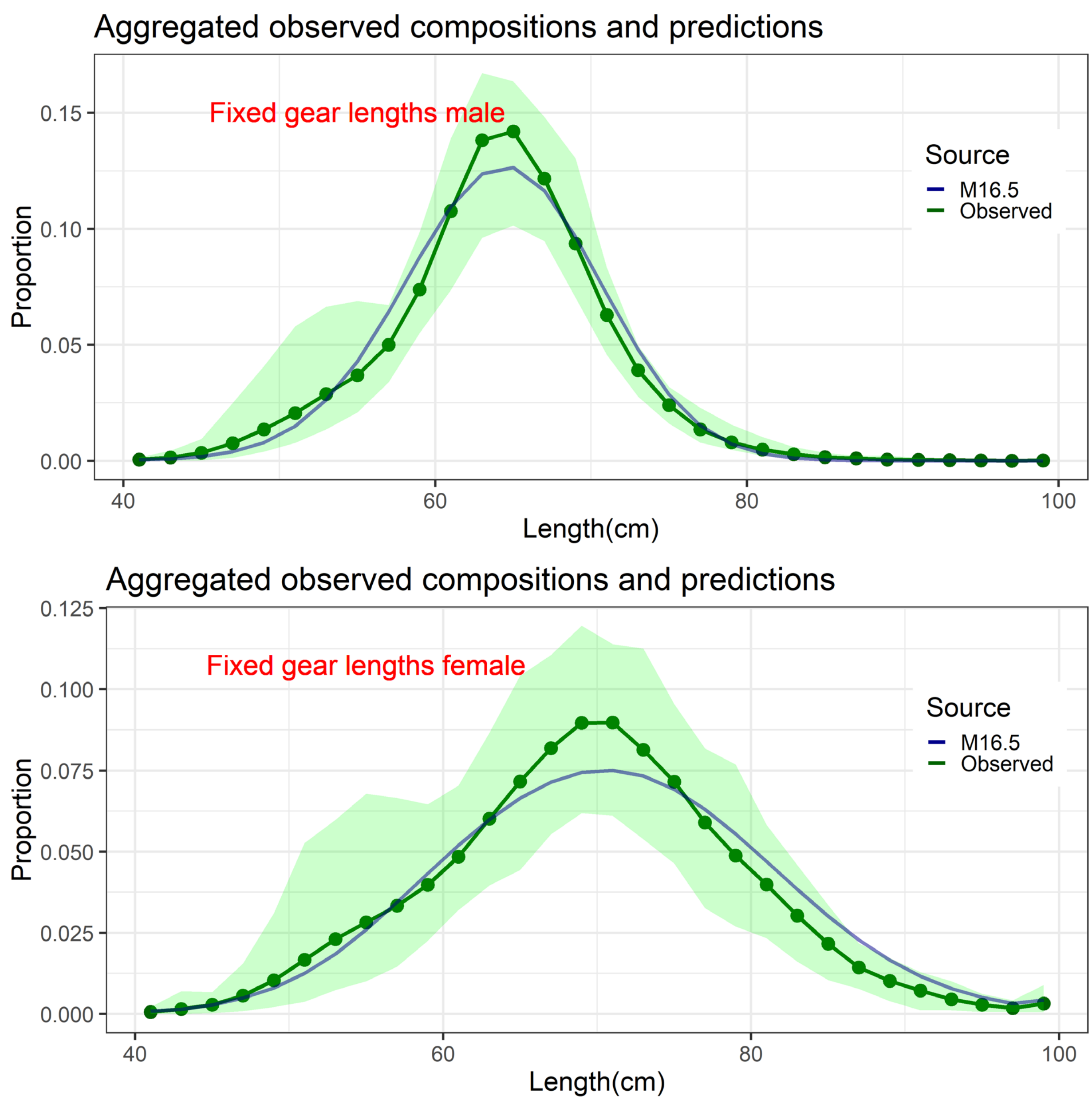


Figure 3.31. Domestic fixed gear fishery length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

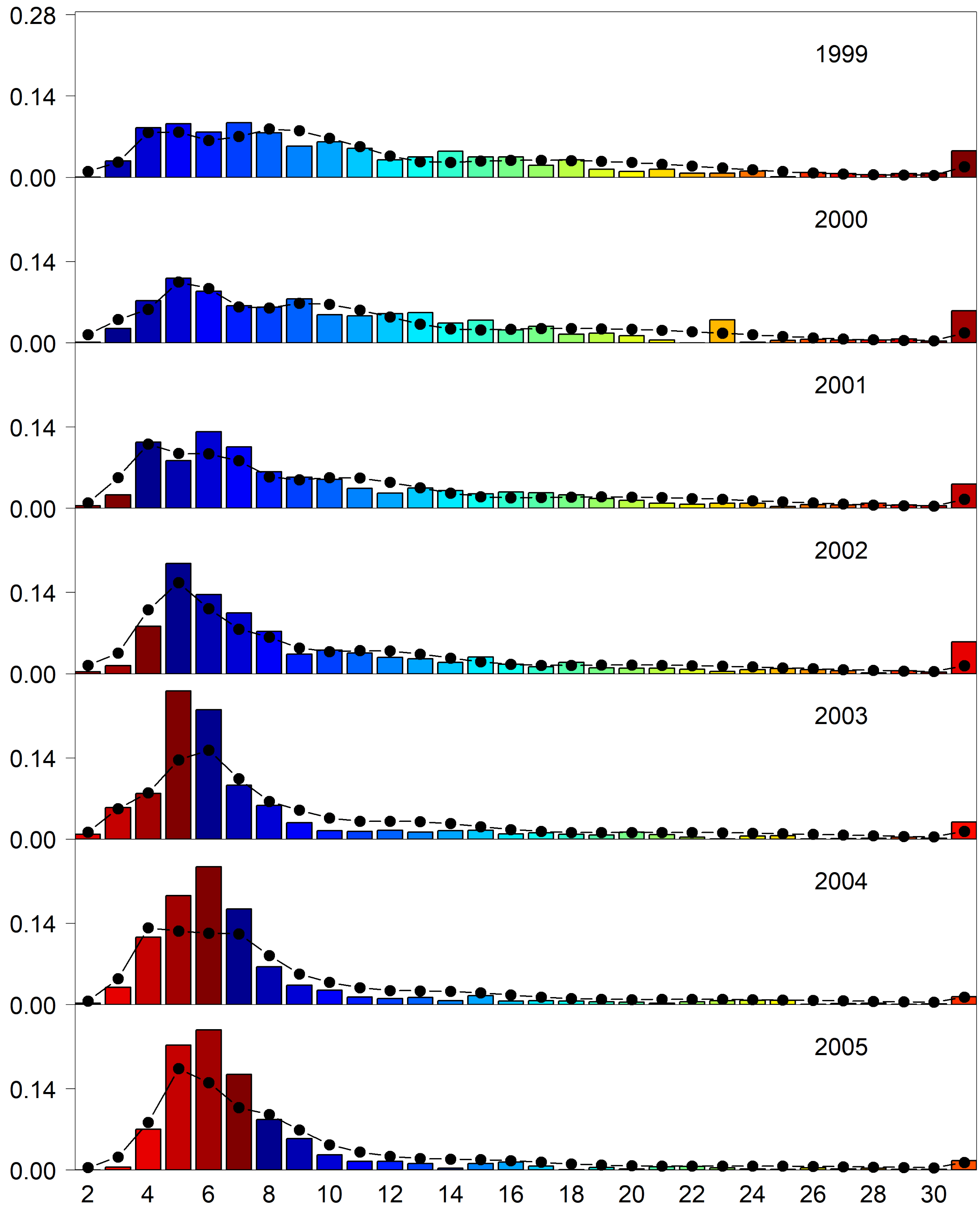


Figure 3.32. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

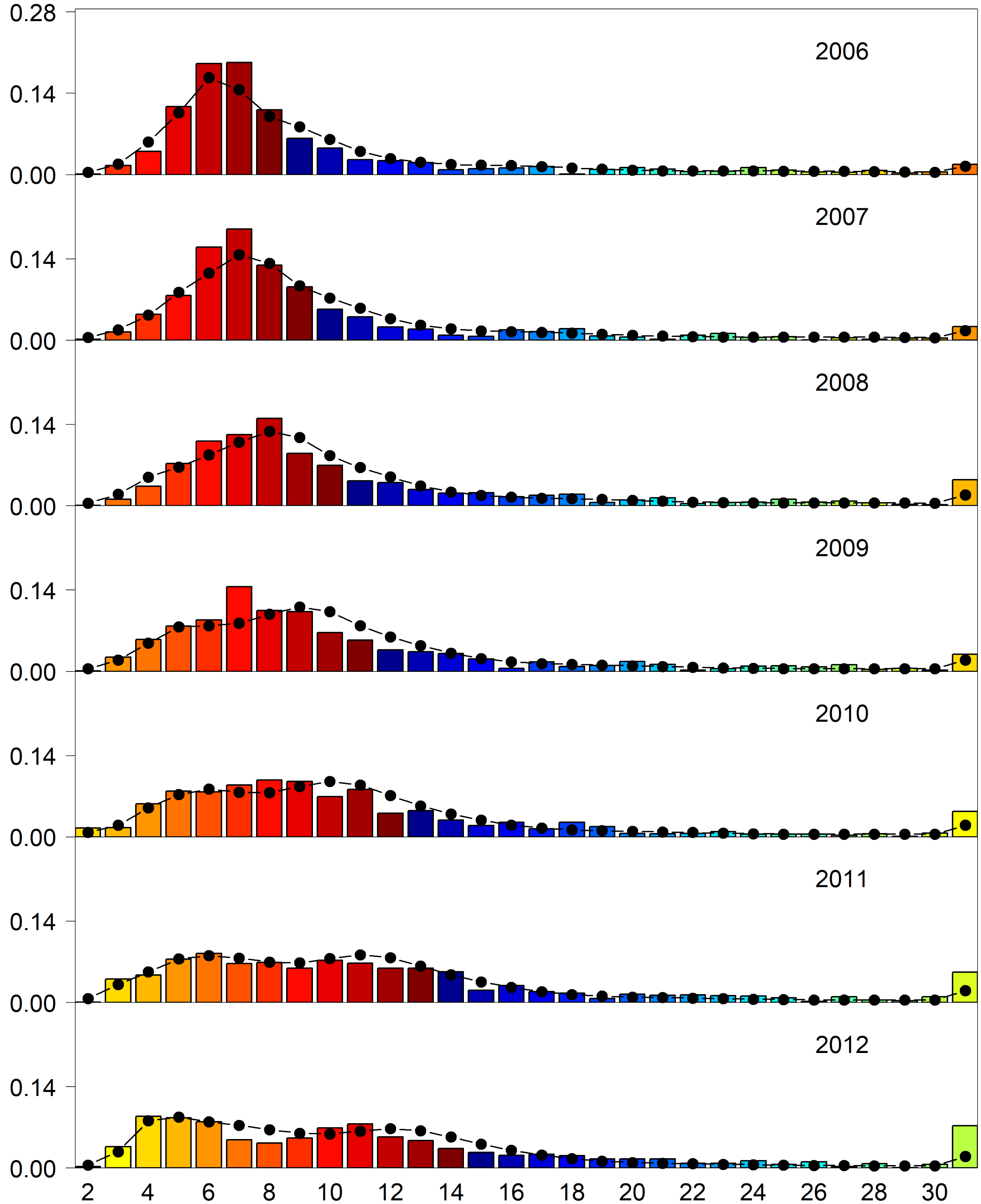


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

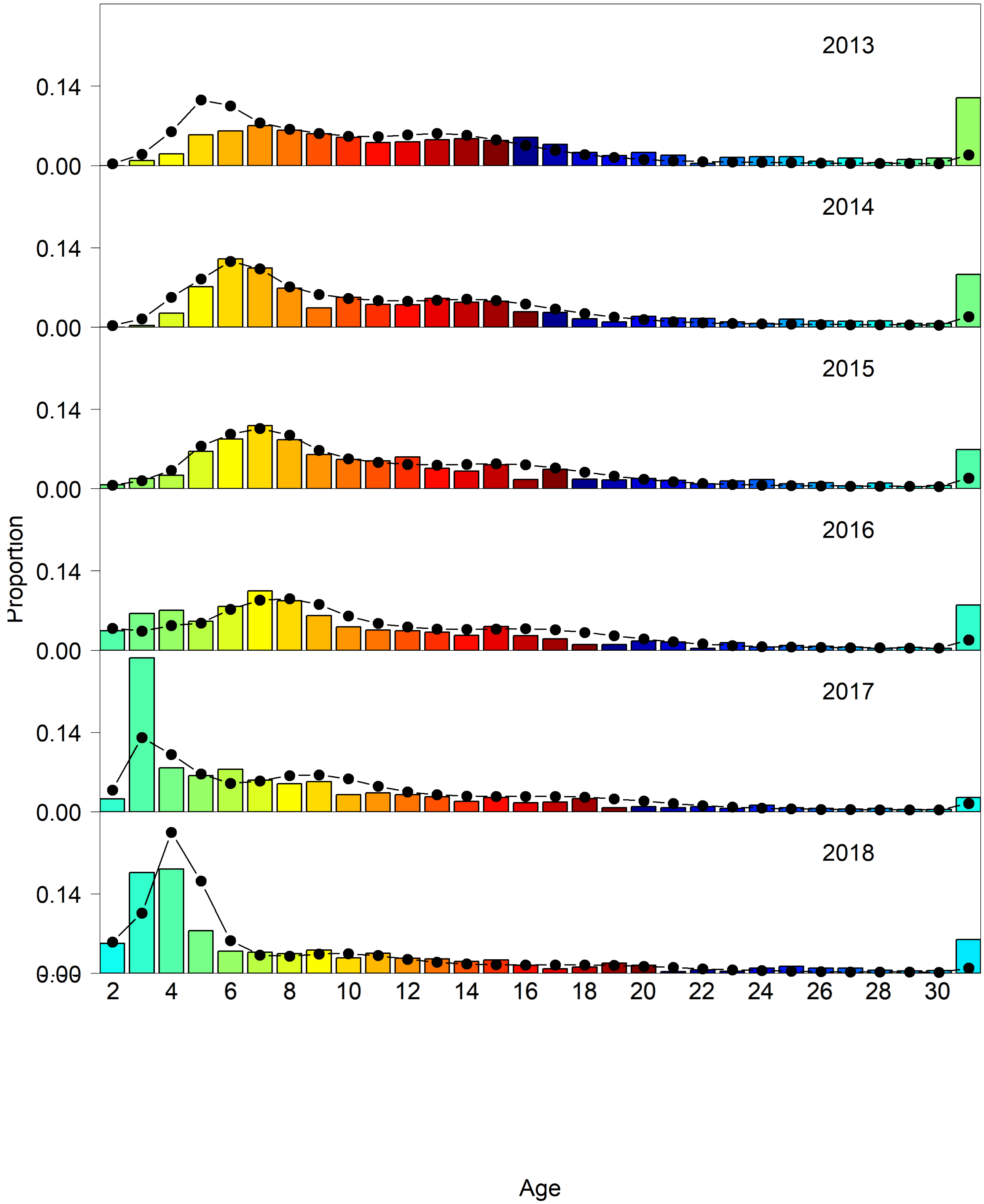


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

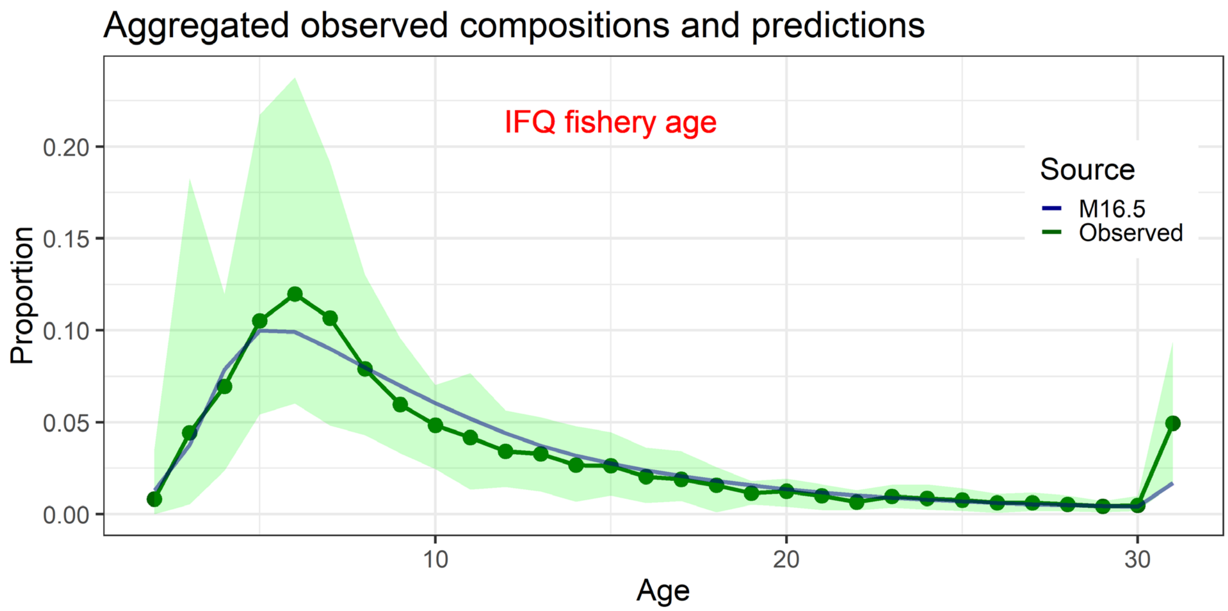


Figure 3.33. Domestic fishery age compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

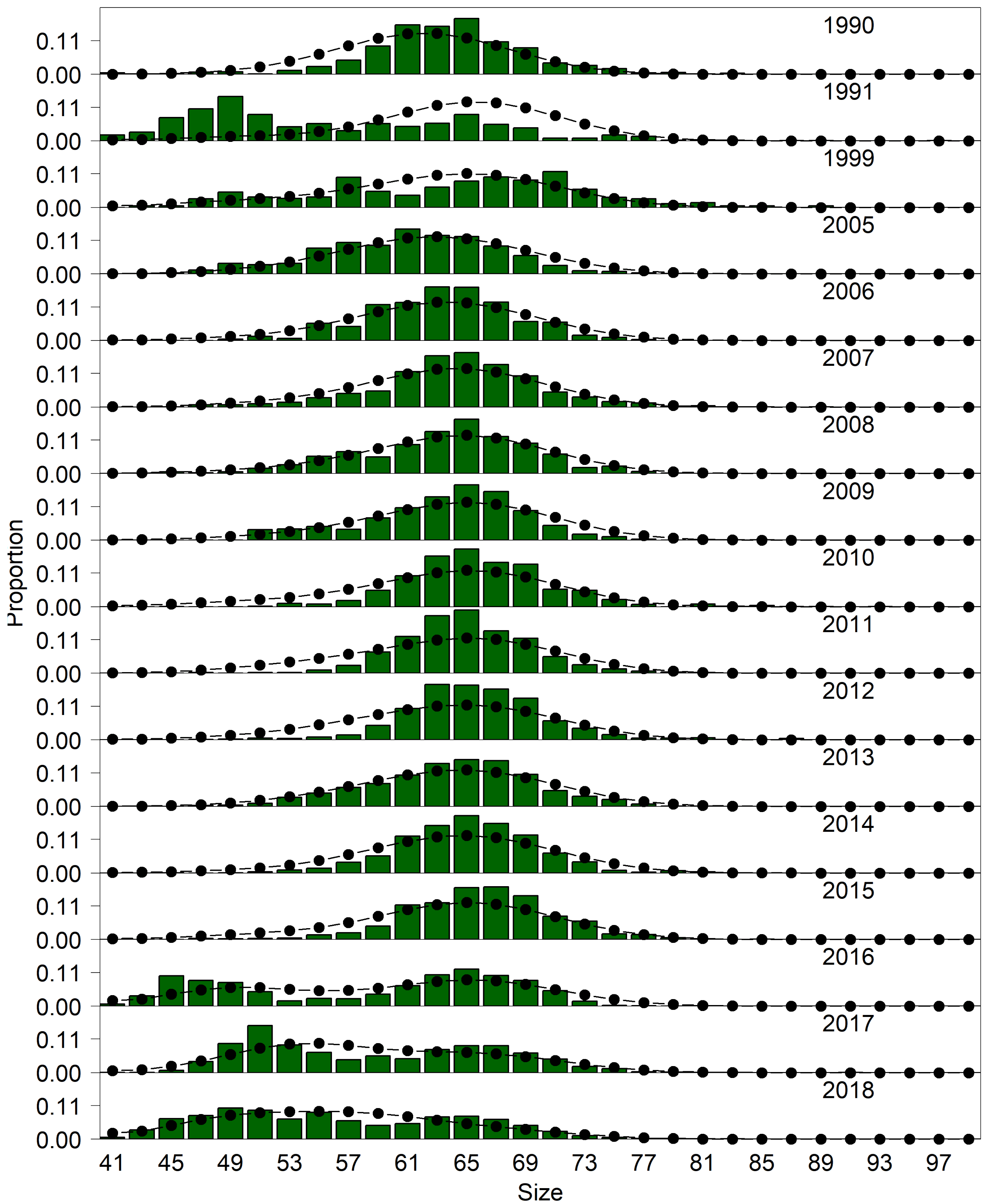


Figure 3.34. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

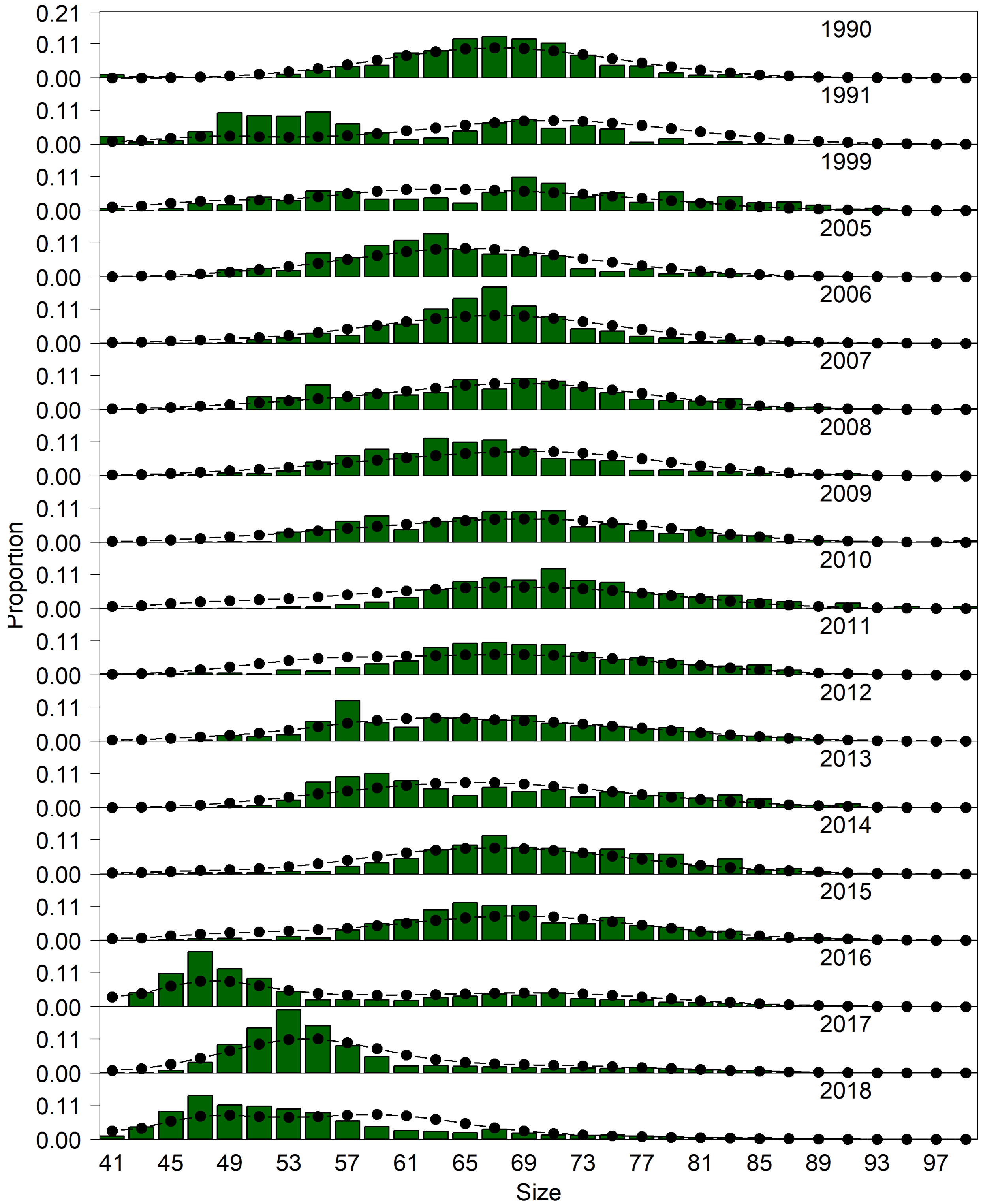
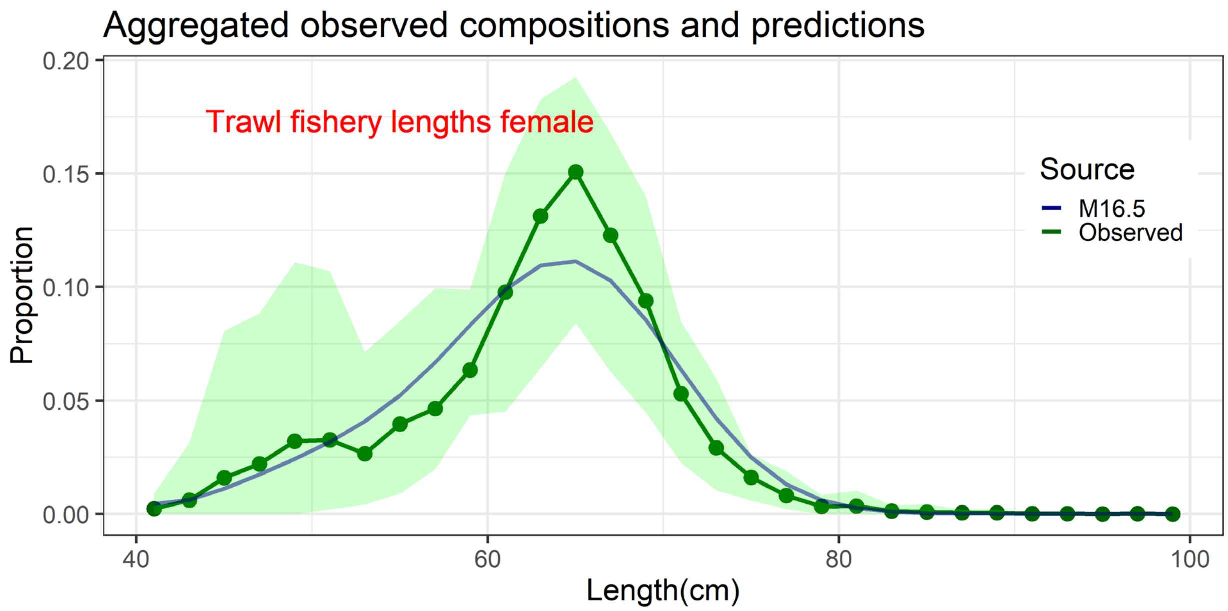


Figure 3.35. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.



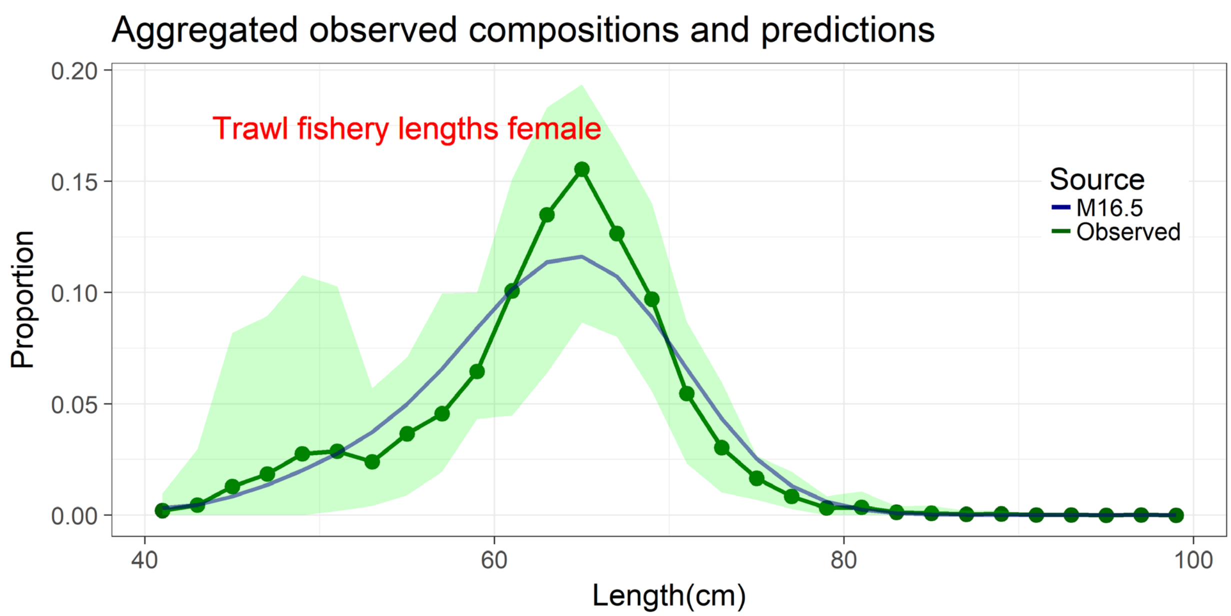


Figure 3.36. Domestic trawl fishery length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

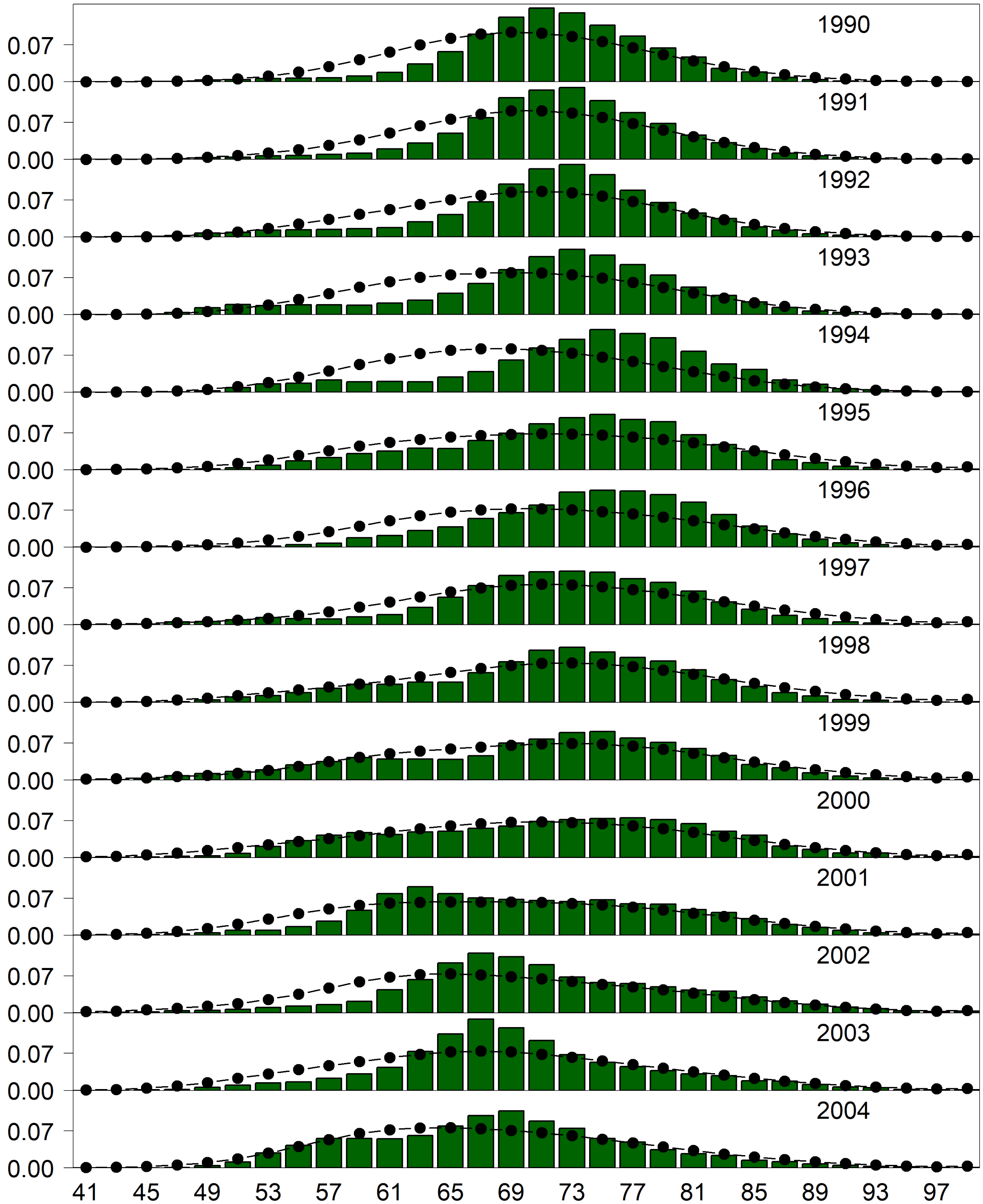


Figure 3.37. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

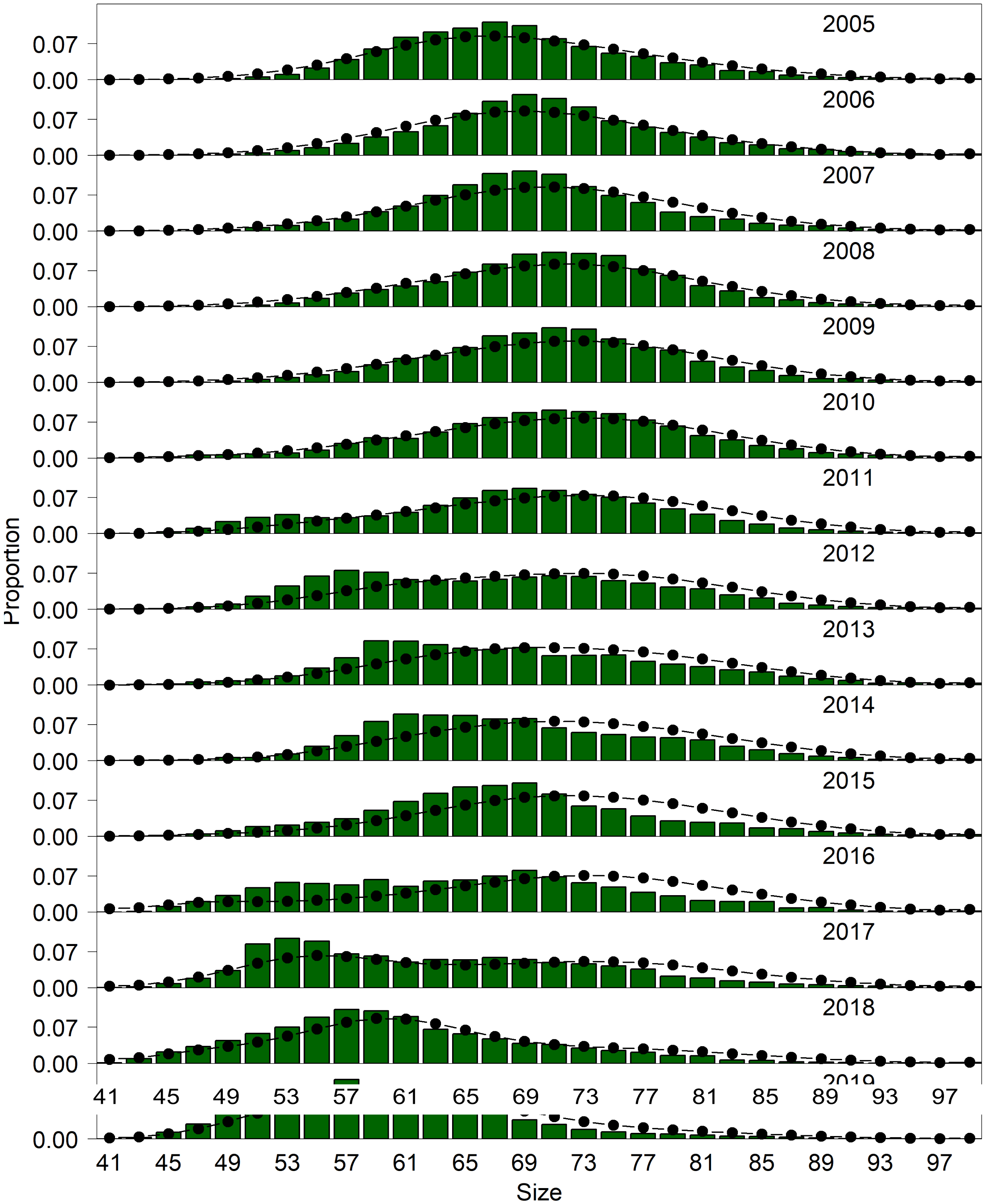


Figure 3.37 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

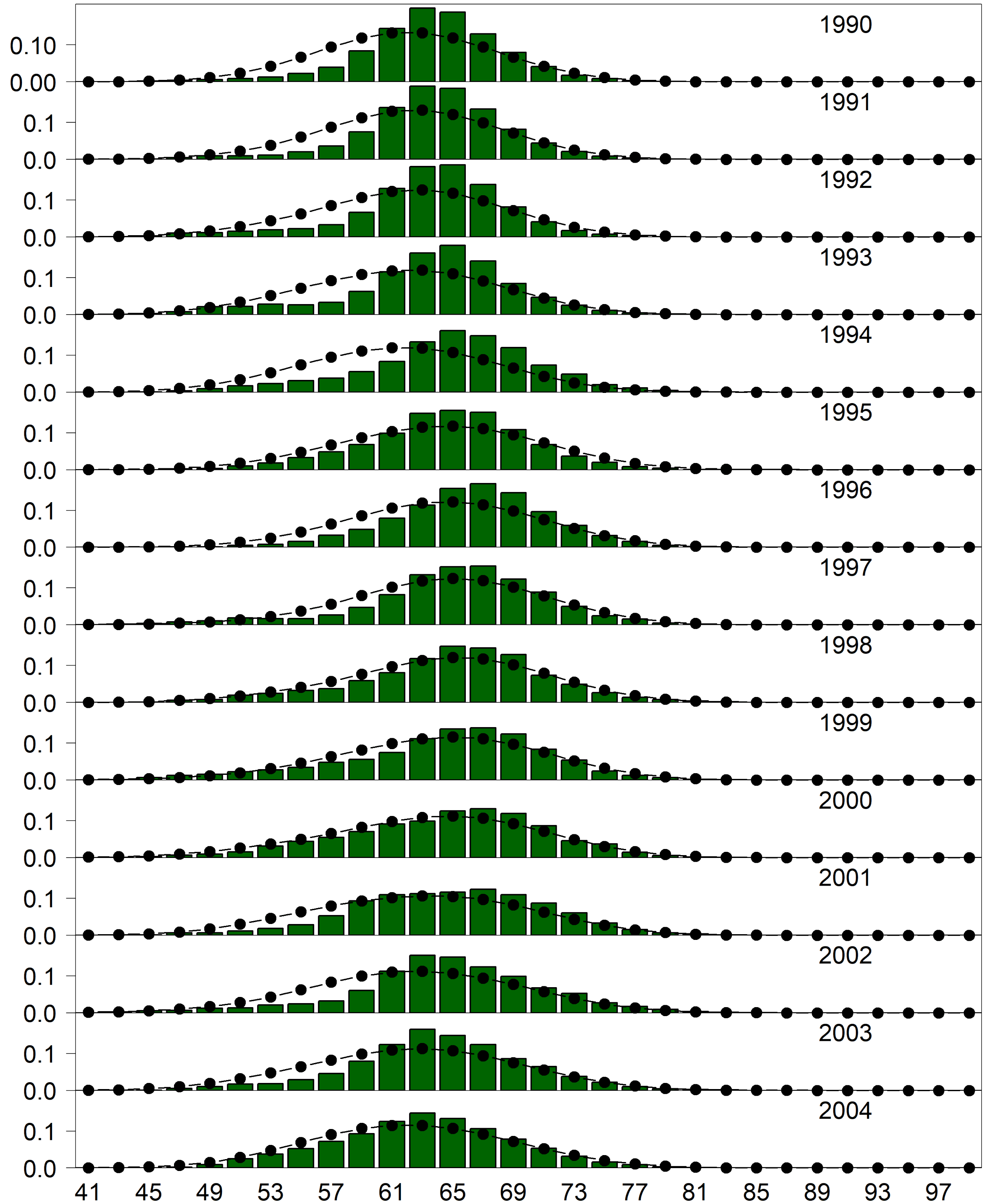


Figure 3.38. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

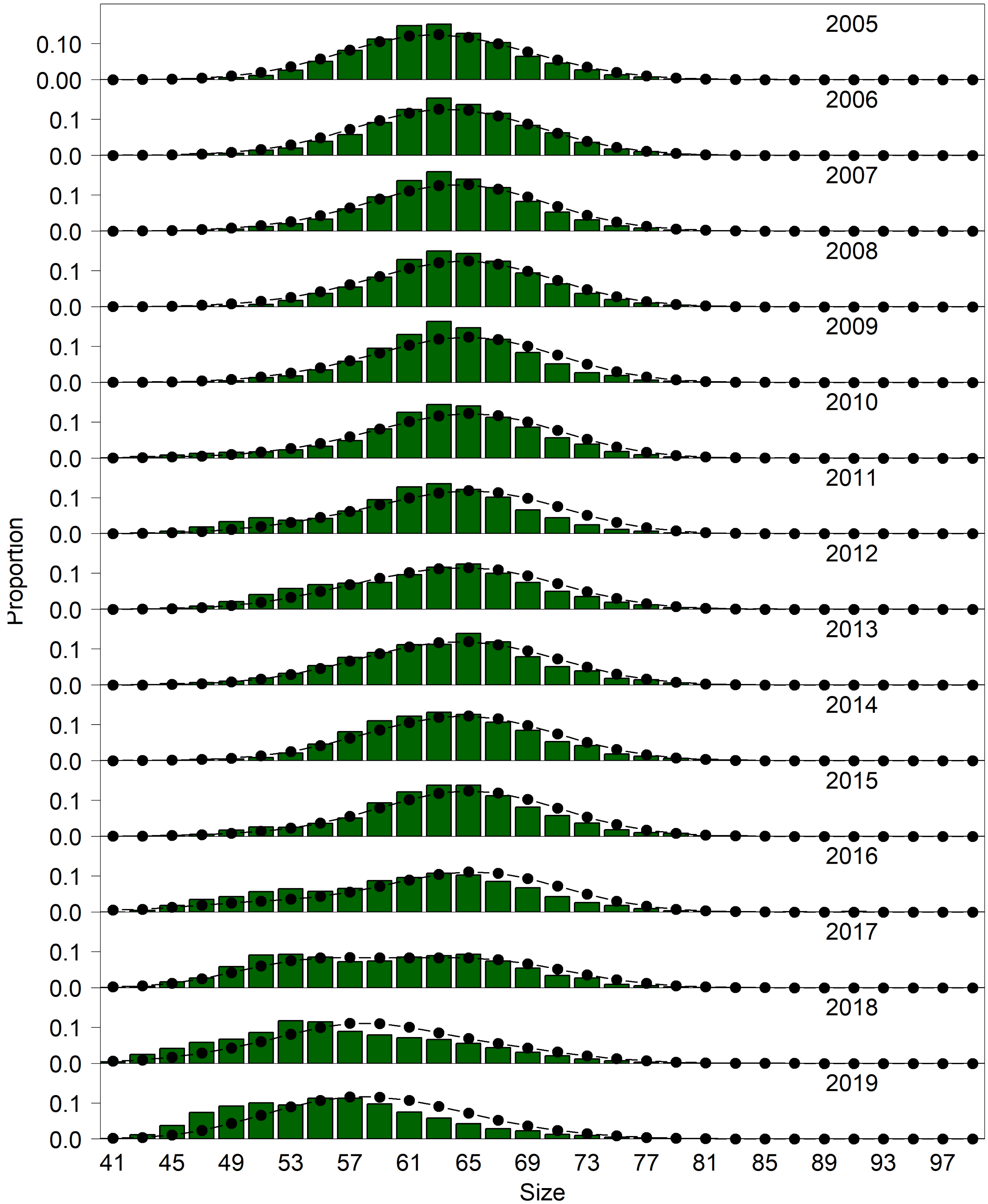


Figure 3.38. (cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

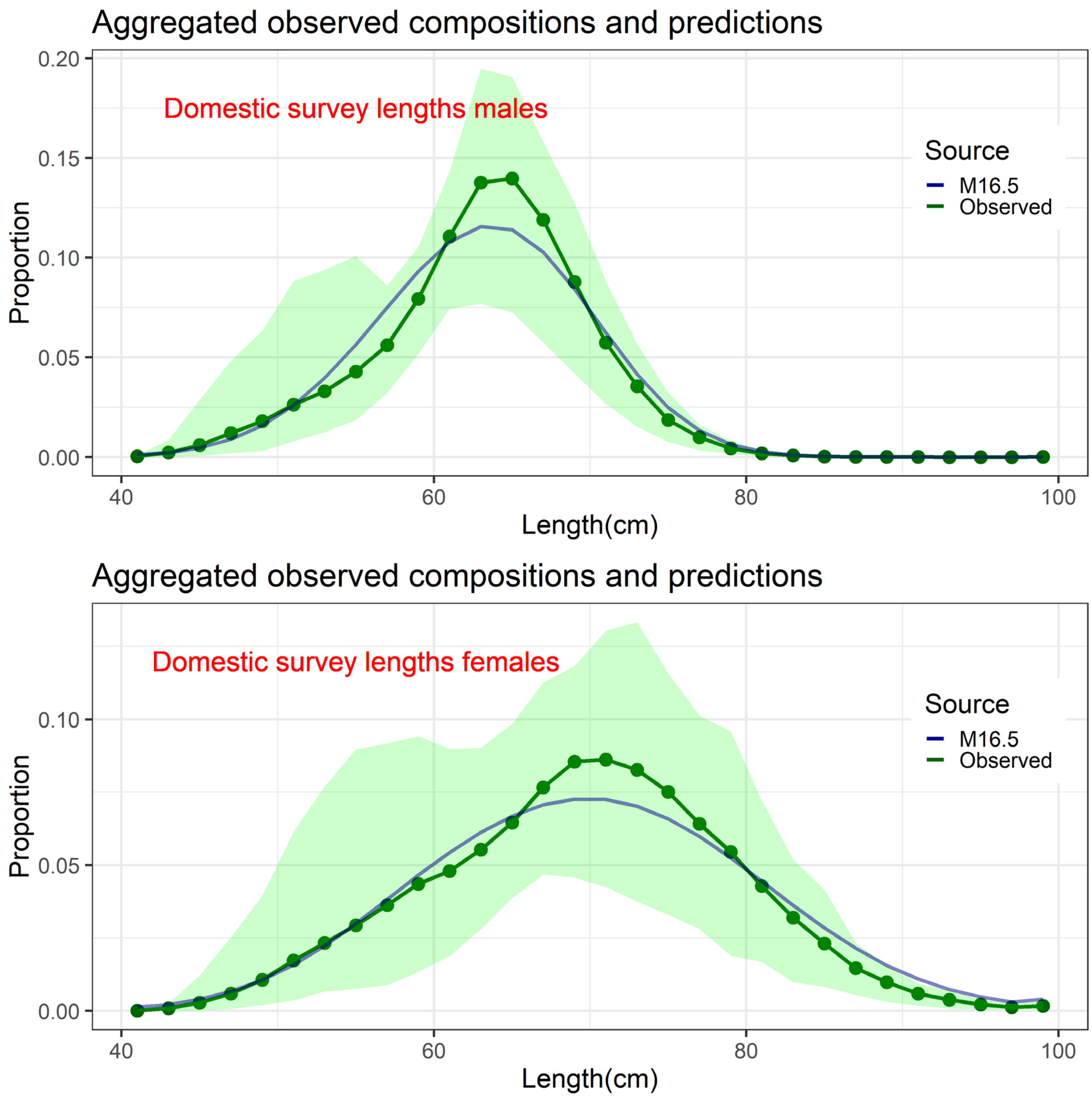


Figure 3.39. Domestic longline survey length compositions aggregated across years and with the average fit of Model 16.5. Mean observed are the blue dots, the green bands are the 90% empirical confidence intervals.

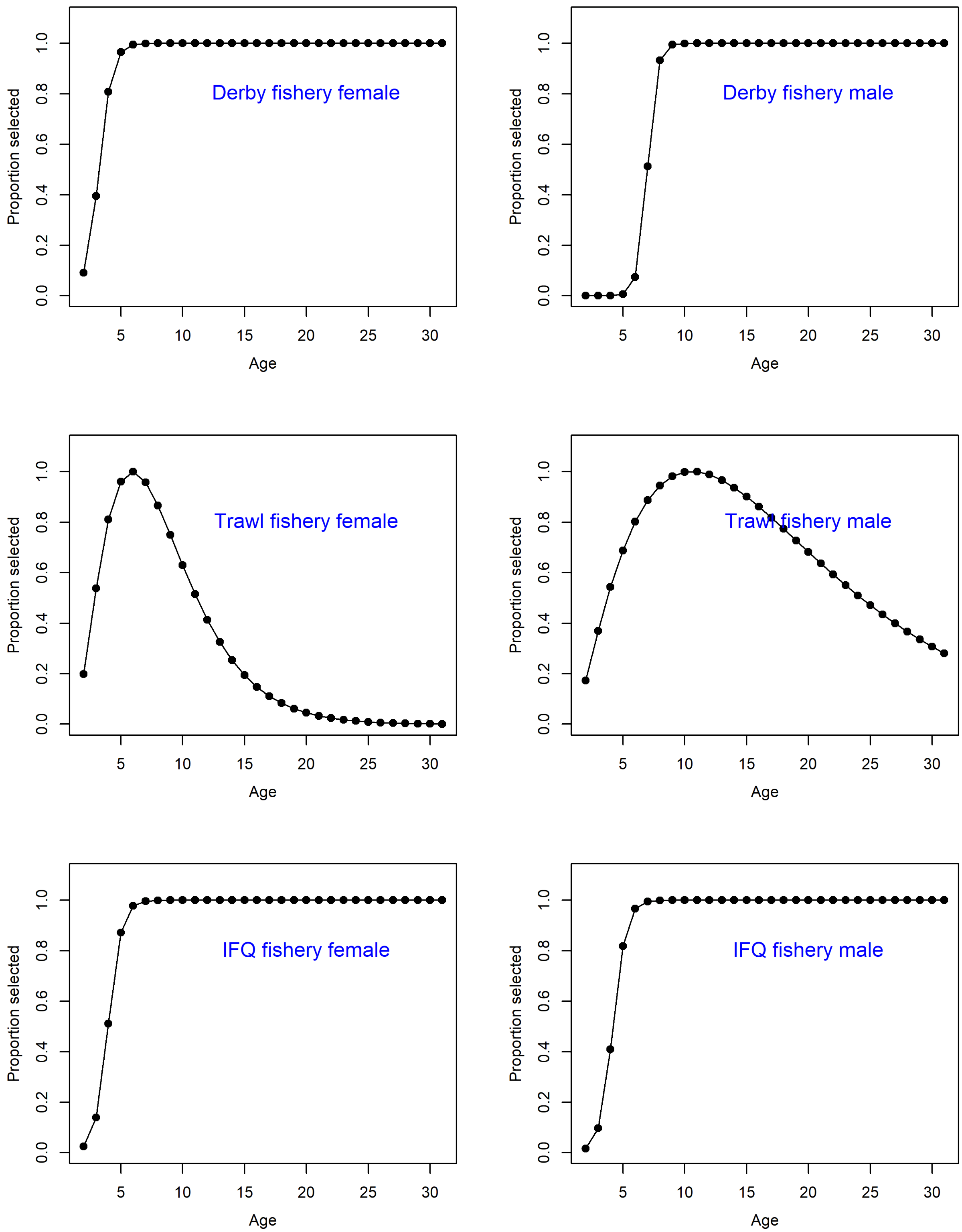


Figure 3.40. Sablefish selectivities for fisheries. The derby longline occurred until 1994 when the fishery switched to IFQ in 1995.

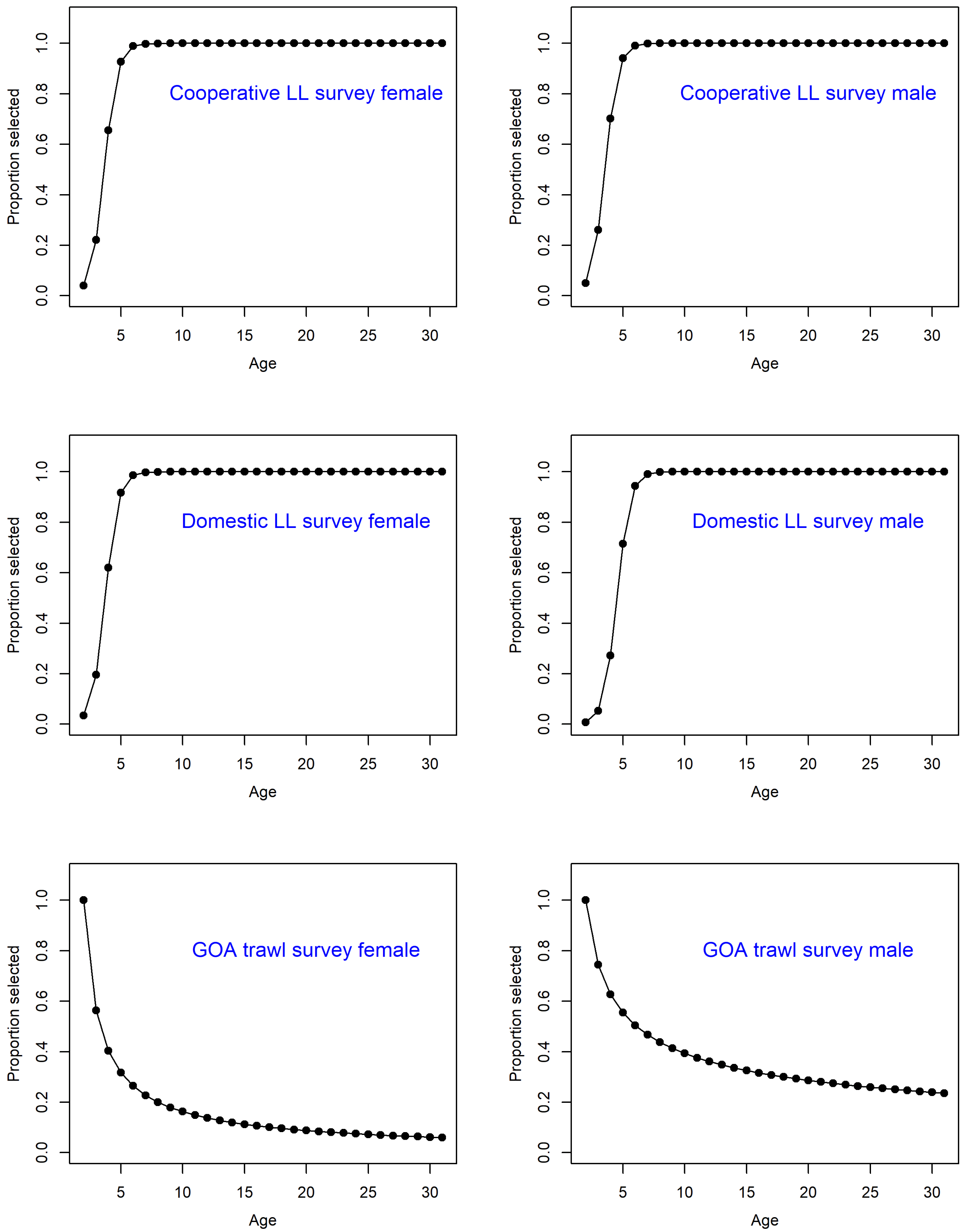


Figure 3.40 (cont.). Sablefish selectivities for surveys.

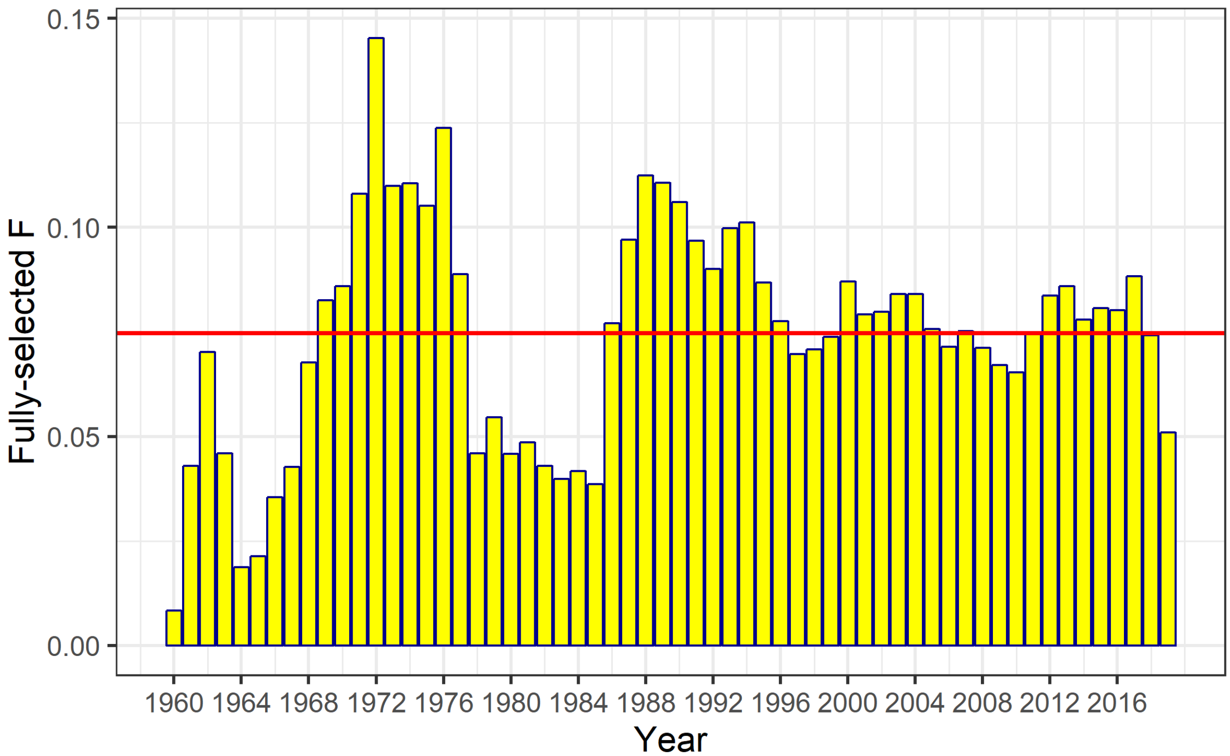


Figure 3.41. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish.

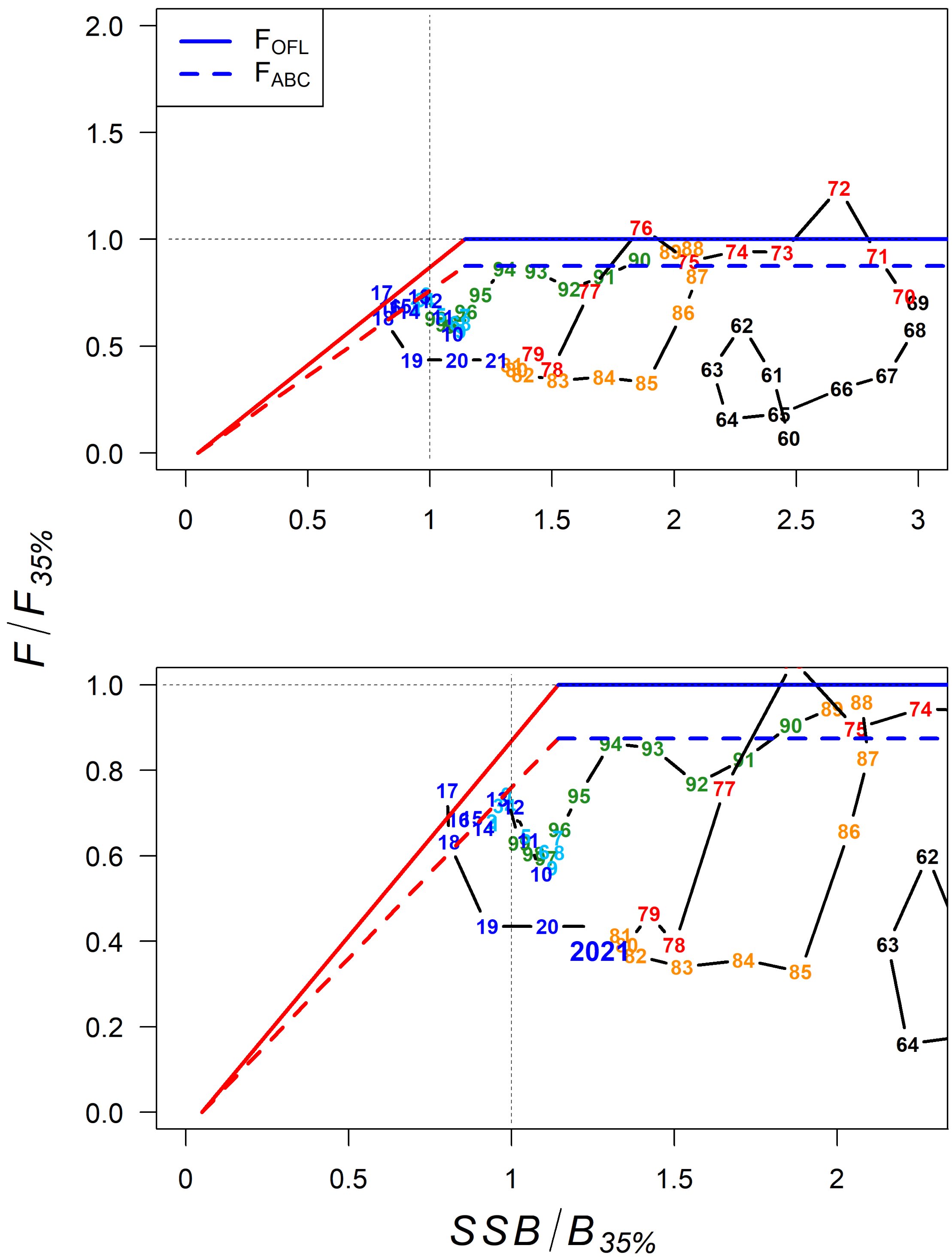


Figure 3.42. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the unfished level and fishing mortality relative to F_{OFL} for author recommended model. Bottom is zoomed in to examine more recent years.

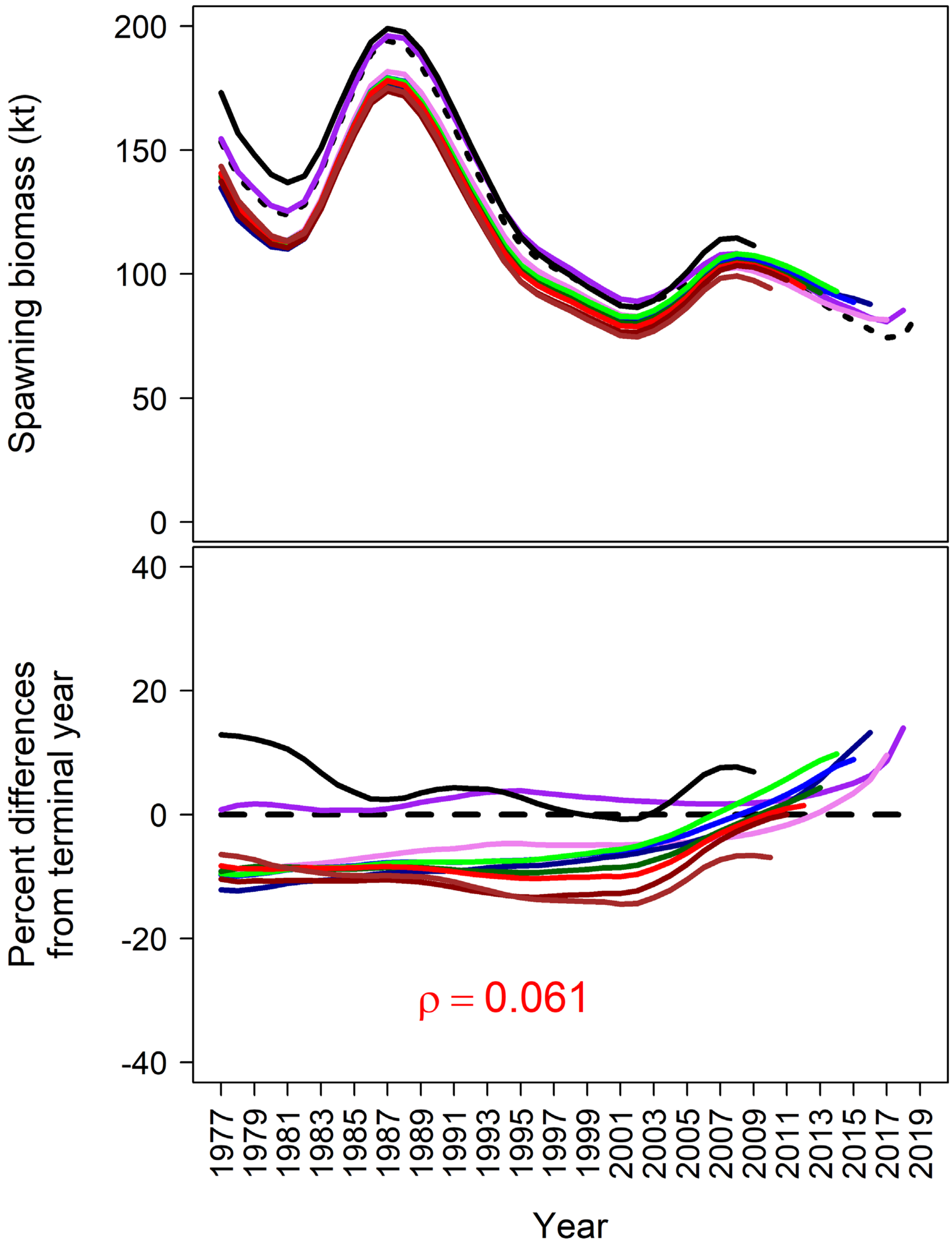


Figure 3.43. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 1977- 2019.

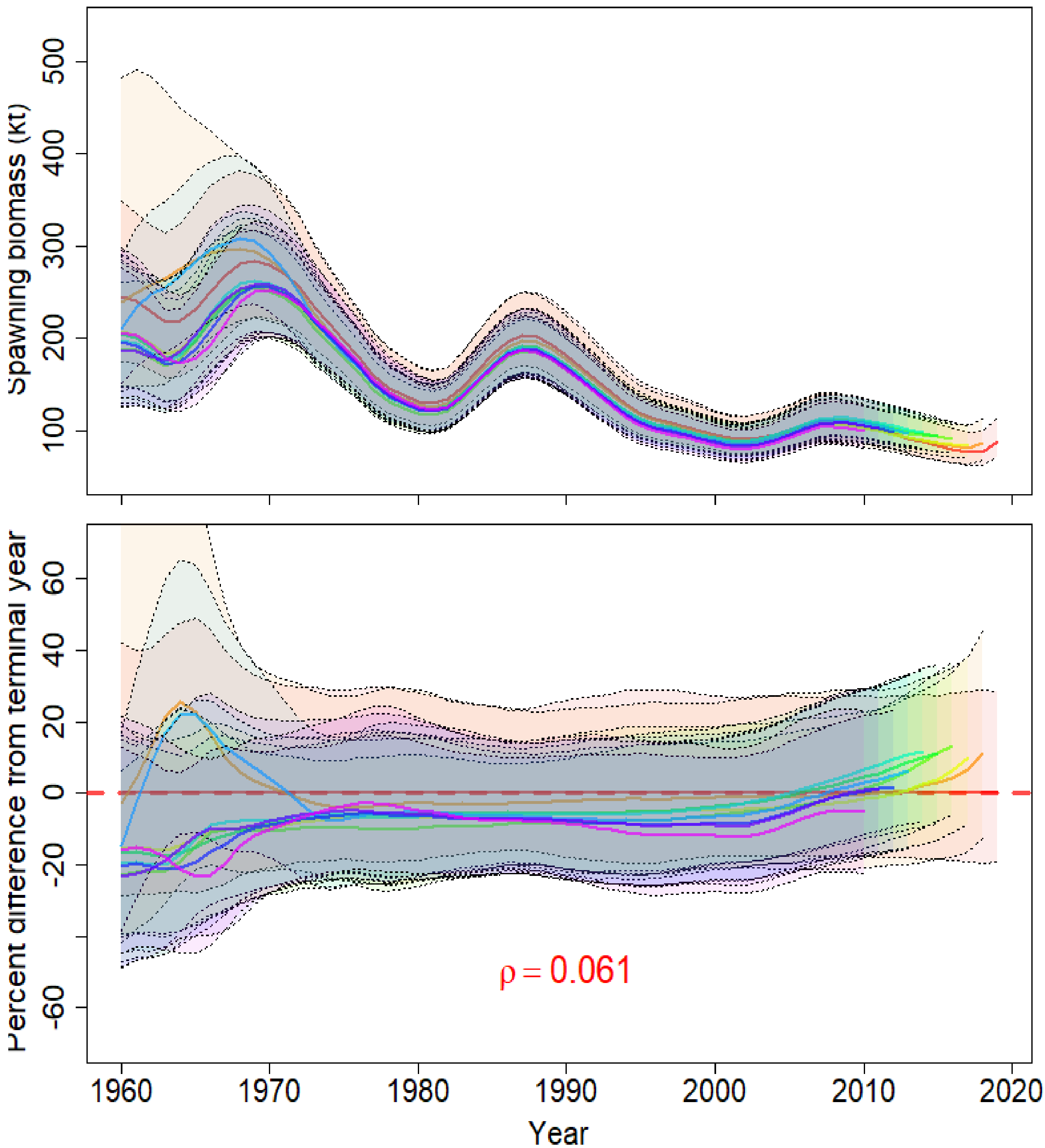


Figure 3.44. Retrospective trends for spawning biomass (top) and percent difference (bottom) from terminal year (2019) from 1960-2018 with 95% MCMC credible intervals.

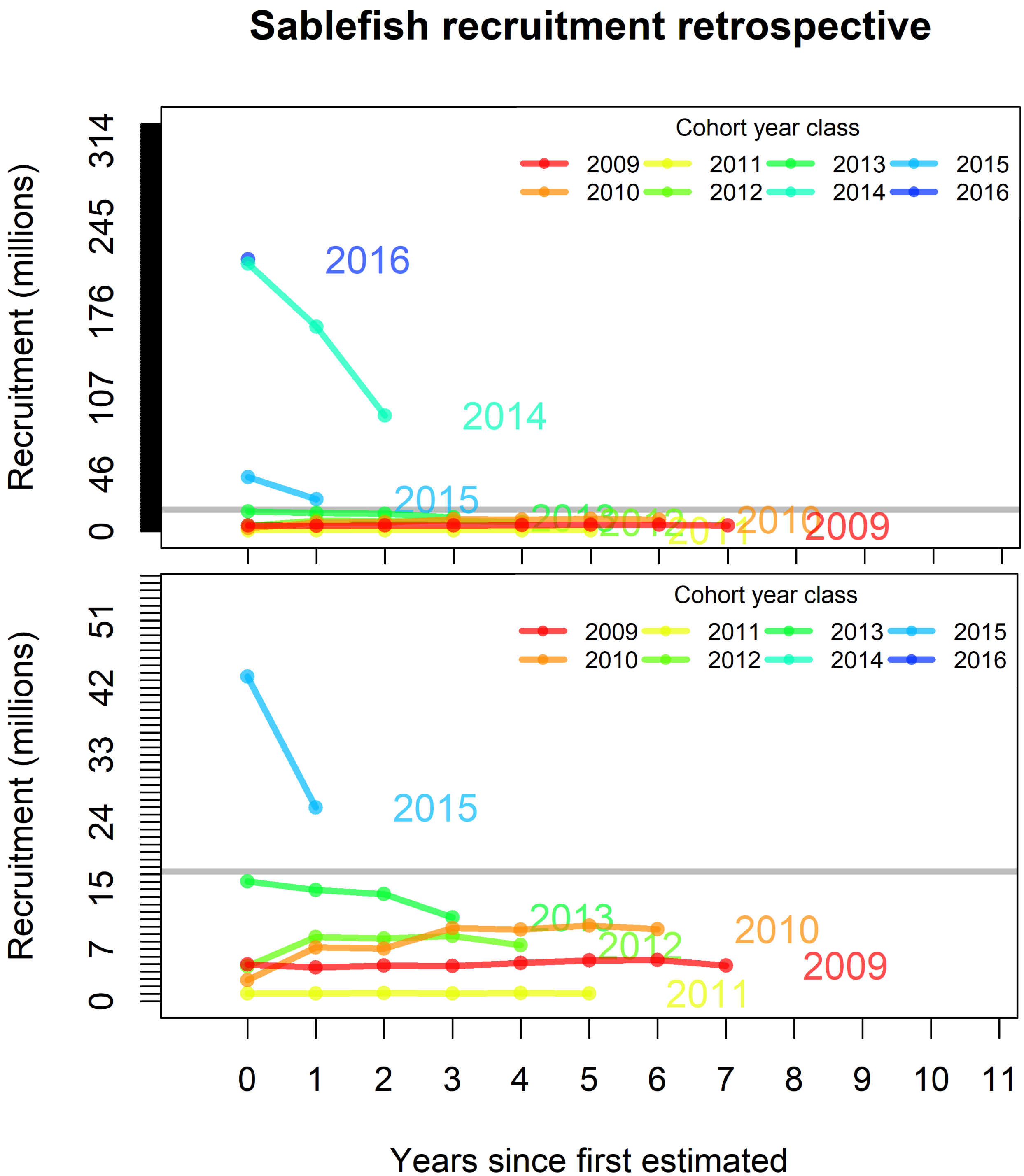


Figure 3.45. Squid plot of the development of initial estimates of age-2 recruitment since year class 2009 through year class 2016 from retrospective analysis. Top panel includes 2014 and 2016 year classes. Number to right of terminal year indicates year class. Bottom panel excludes the 2014 and 2016 year classes.

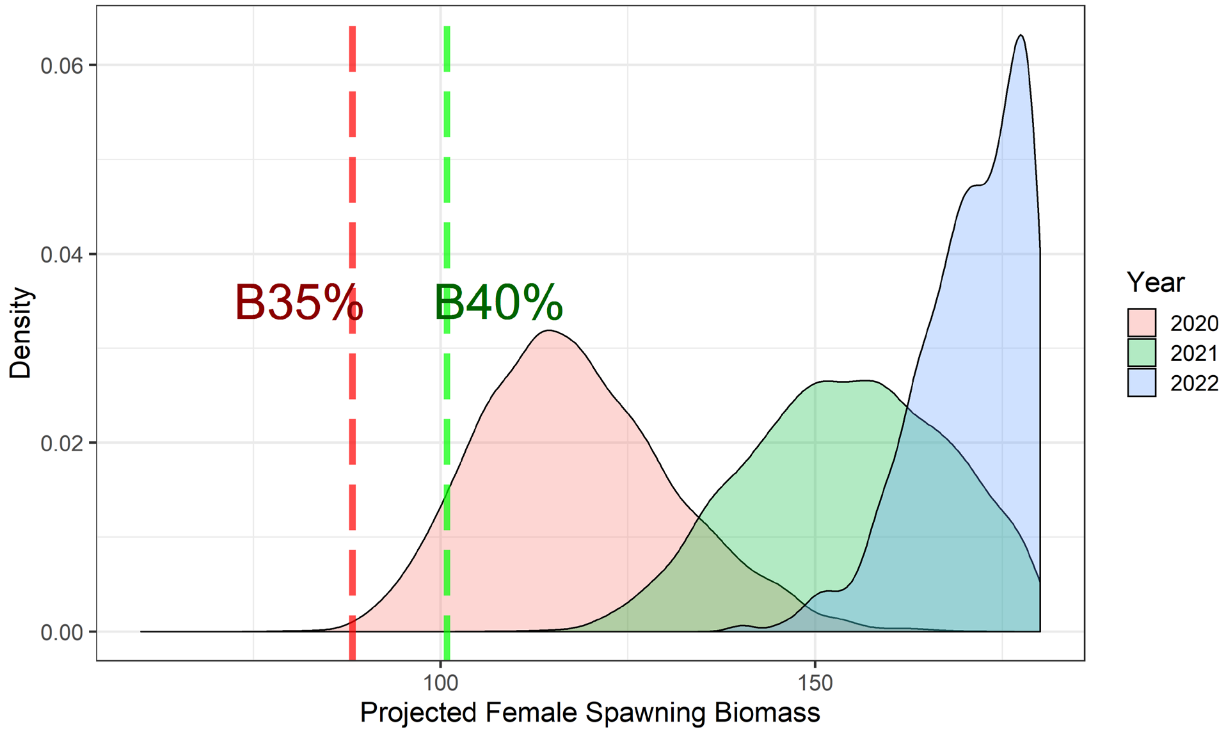


Figure 3.46. Posterior probability distribution for projected spawning biomass (thousands t) in years 2019 – 2021. The dashed lines are estimated B35% and B40% for 2019.

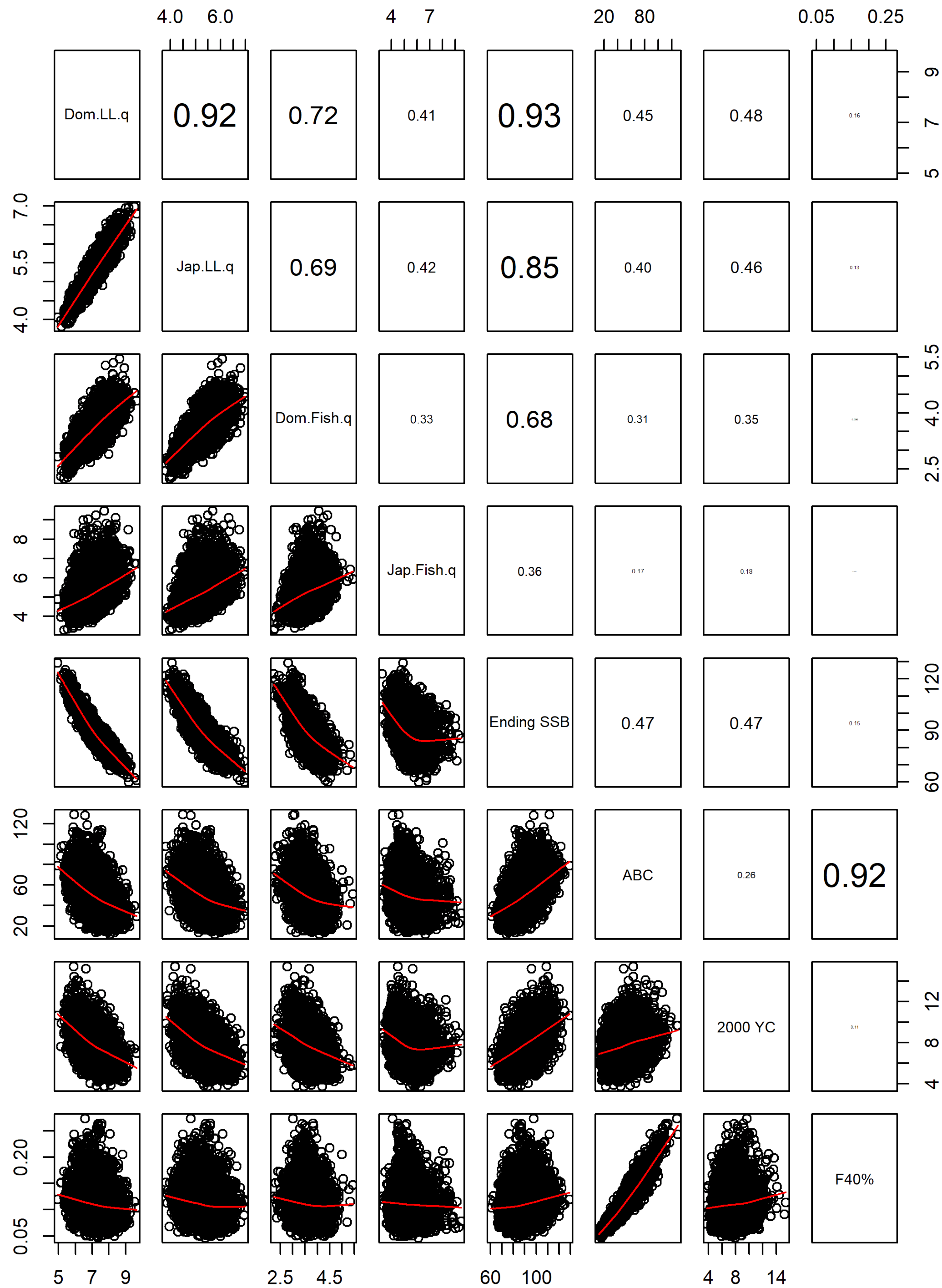


Figure 3.47. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

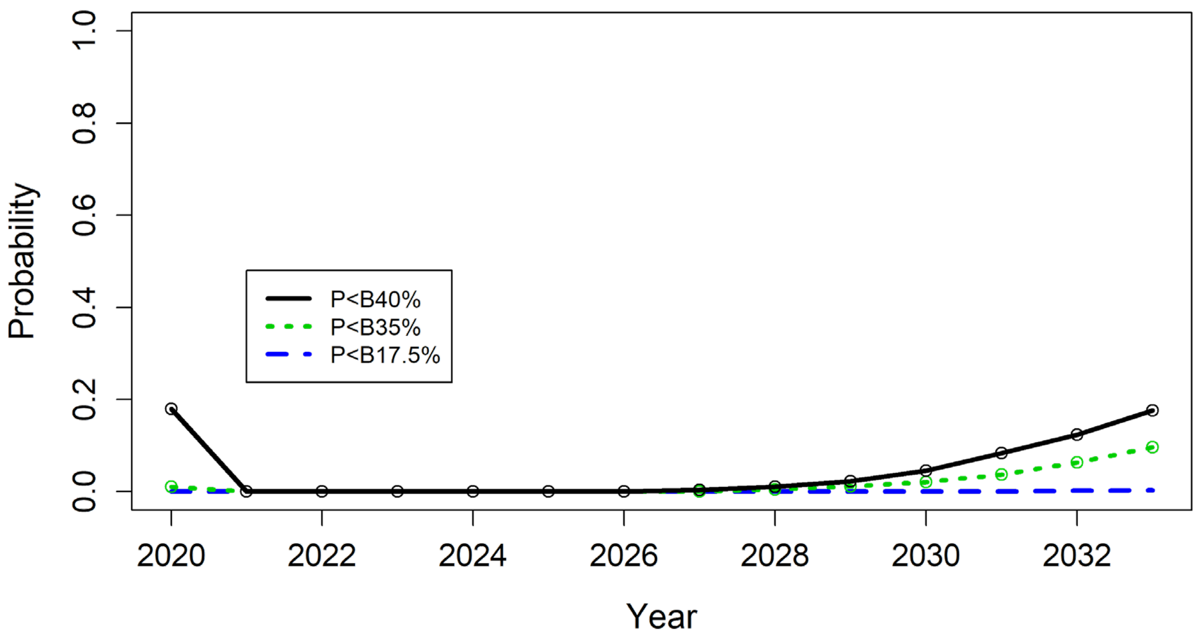


Figure 3.48. Probability that projected spawning biomass (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

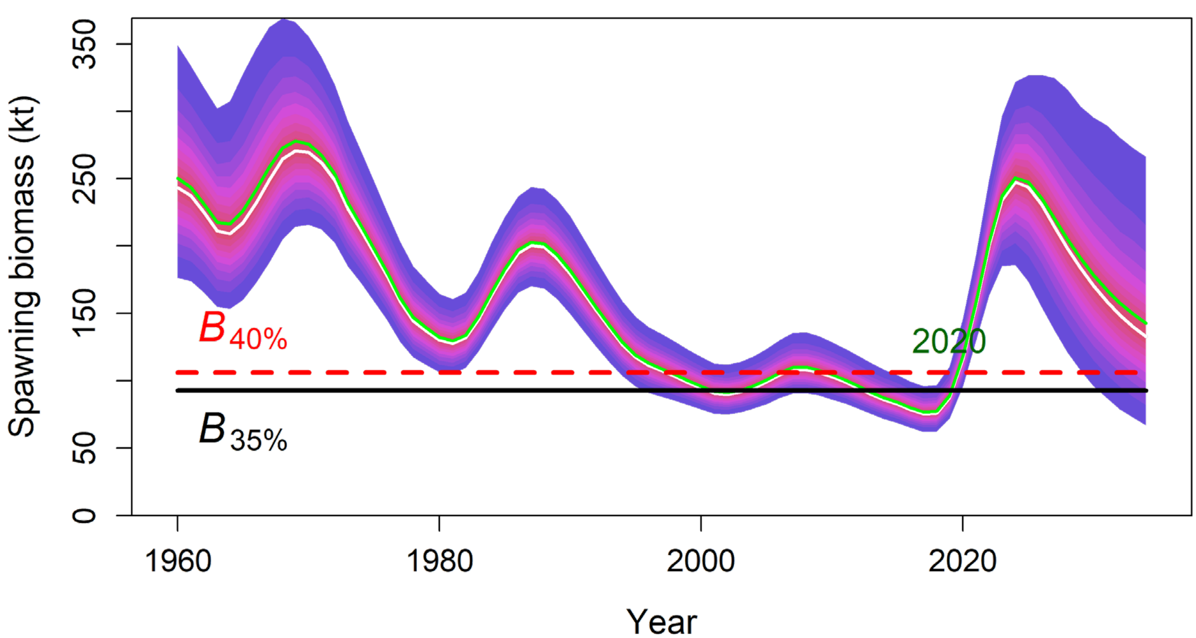


Figure 3.49. Estimates of female spawning biomass (thousands t) and their uncertainty. White line is the median and green line is the mean, shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval. Harvest policy is the same as the projections in Scenario 1 but with a yield multiplier of 0.95.

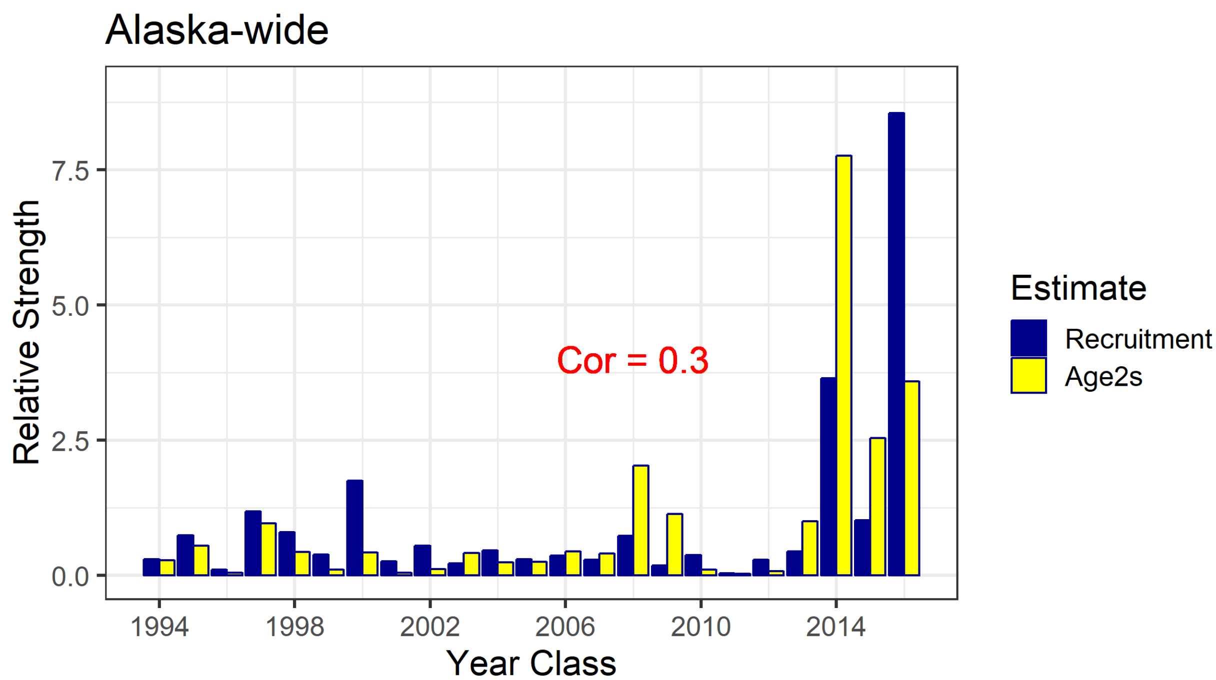


Figure 3.50. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

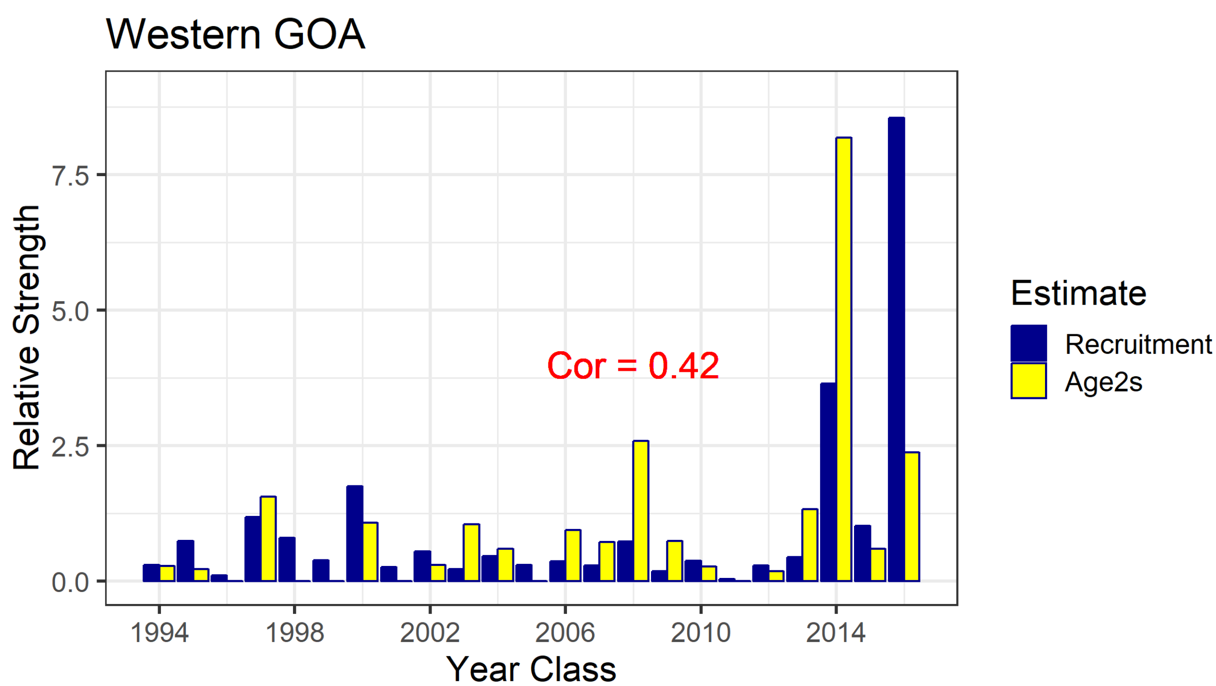


Figure 3.51. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

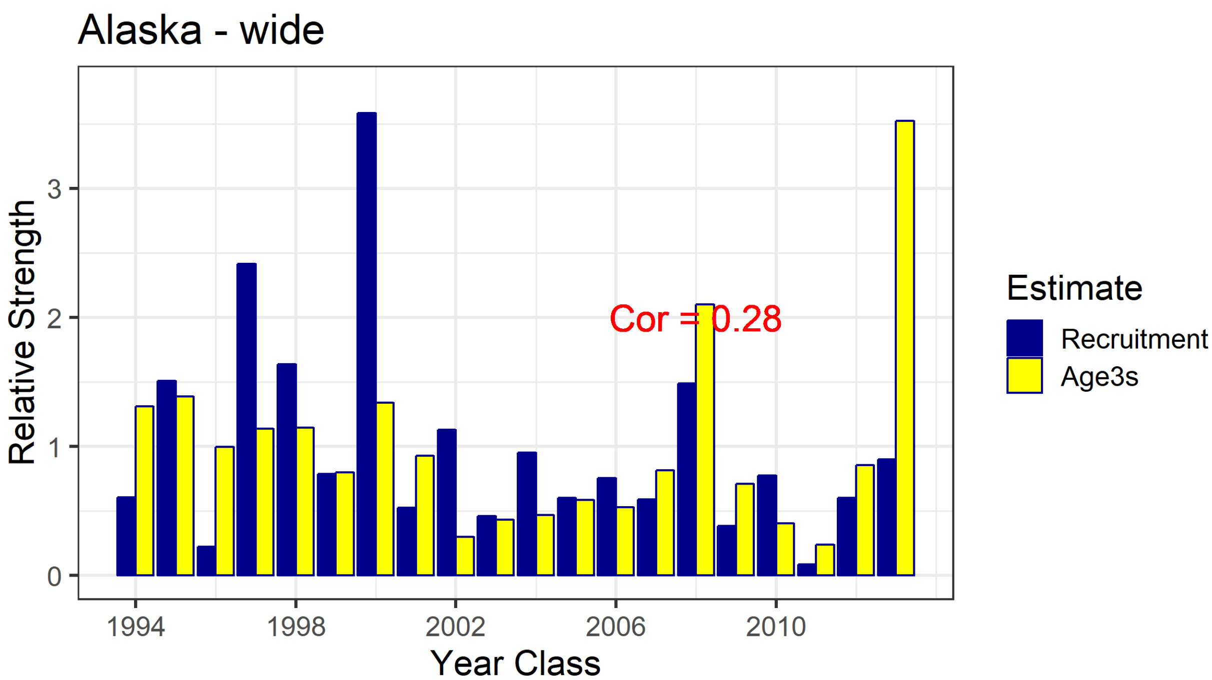


Figure 3.52. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

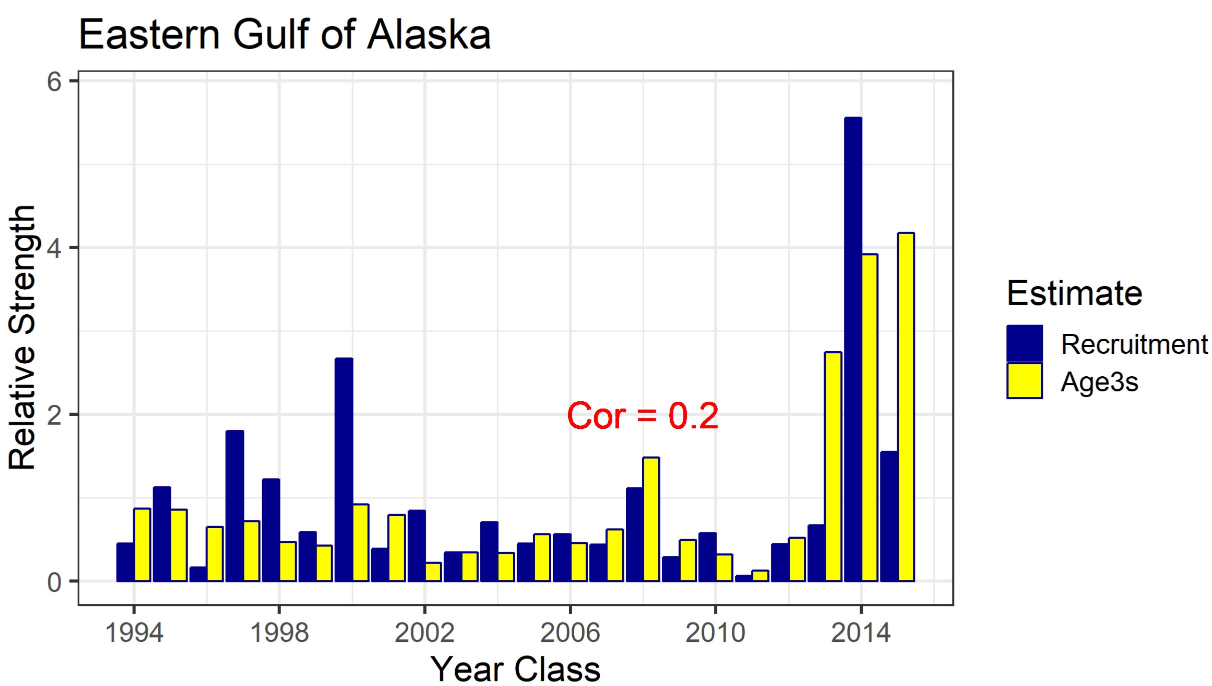


Figure 3.53. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

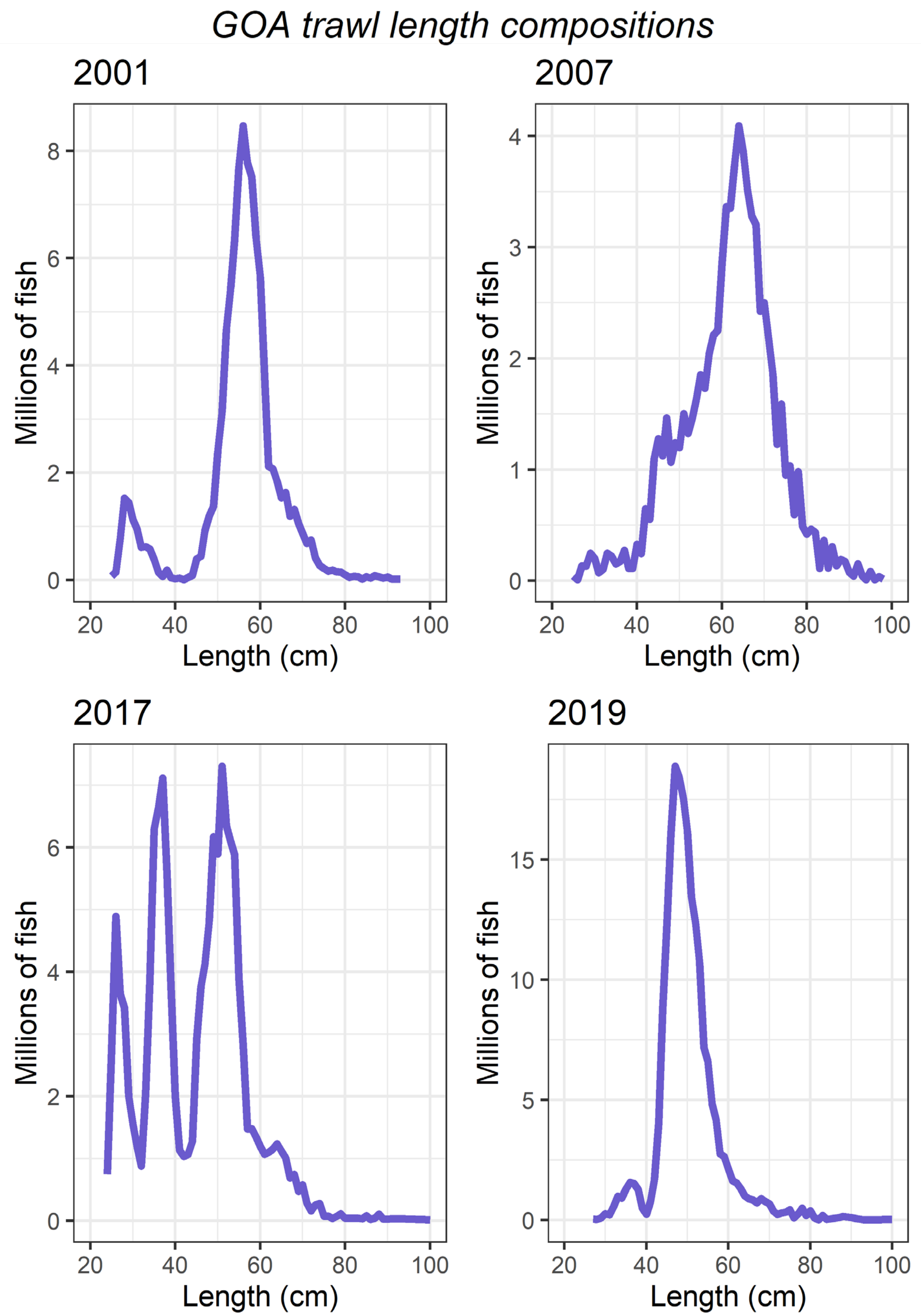


Figure 3.54. Select years of Gulf of Alaska trawl survey length compositions.

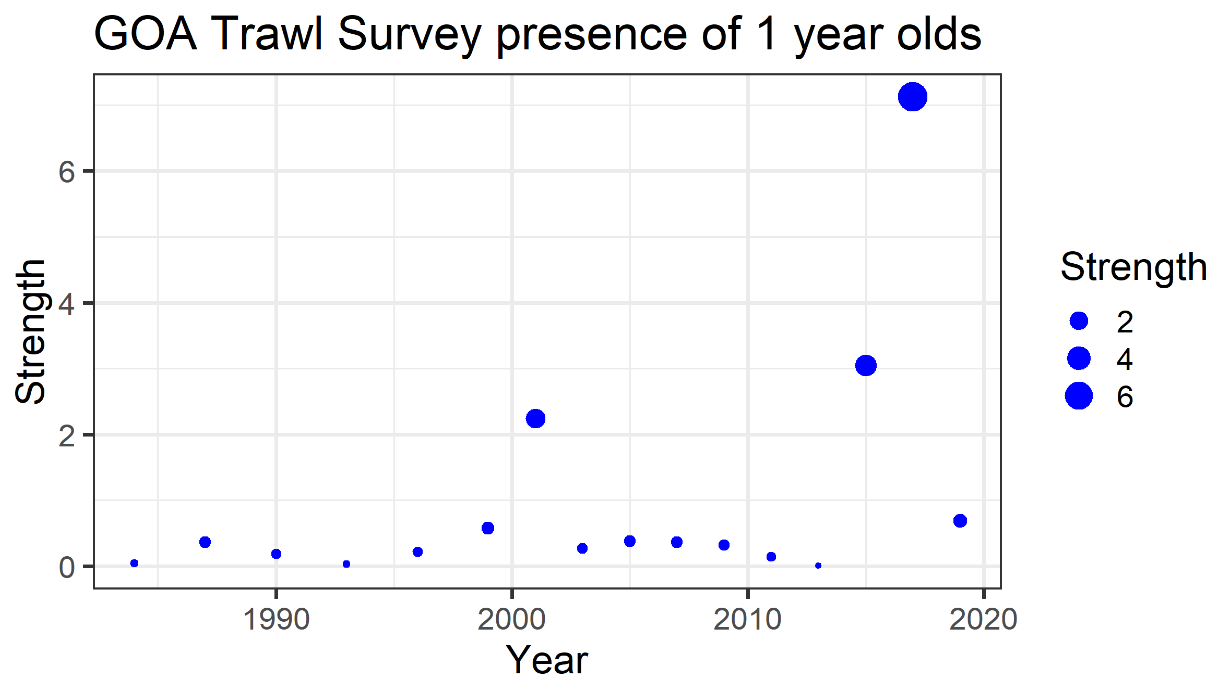


Figure 3.55. Presence of one-year-old (Length < 34 cm) sablefish in the Gulf of Alaska trawl survey. Strength is relative to the mean abundance (i.e., a strength of 7.5 is 7.5x average).

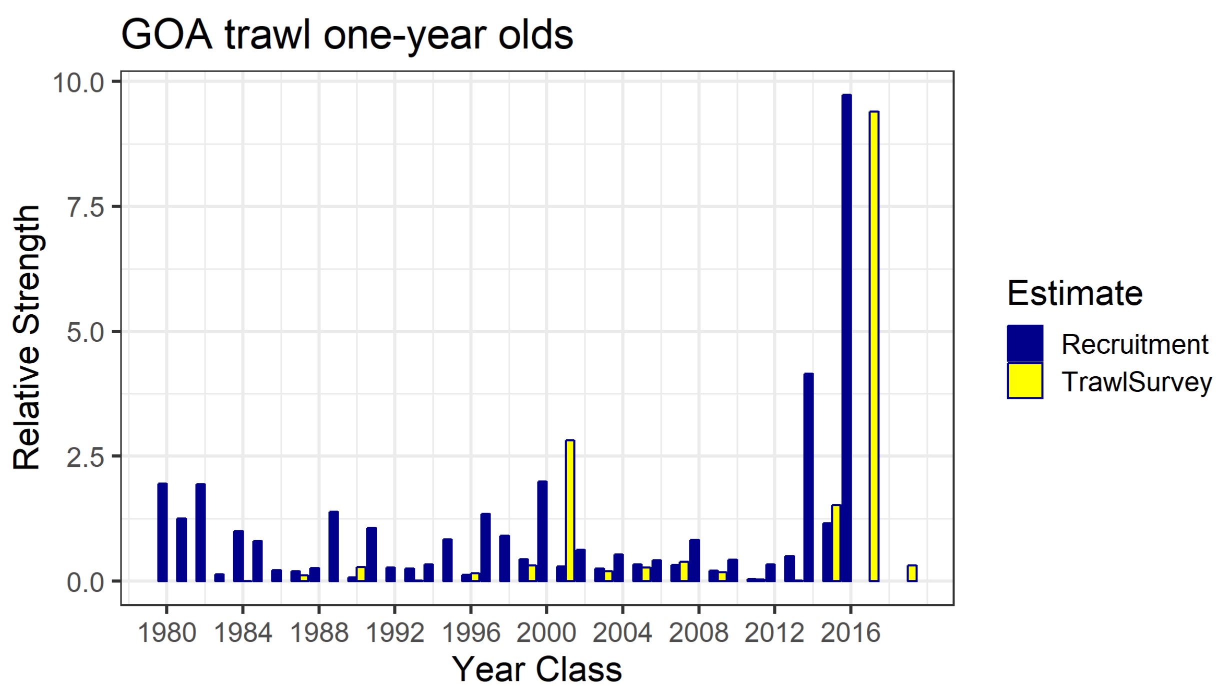


Figure 3.56a. Strength of presence of one-year-old (Length < 32 cm) sablefish in the Gulf of Alaska trawl survey compared to the respective year classes of recruitment estimated by the stock assessment. Strength is relative to the mean abundance or recruitment (i.e., a strength of 7.5 is 7.5x average).

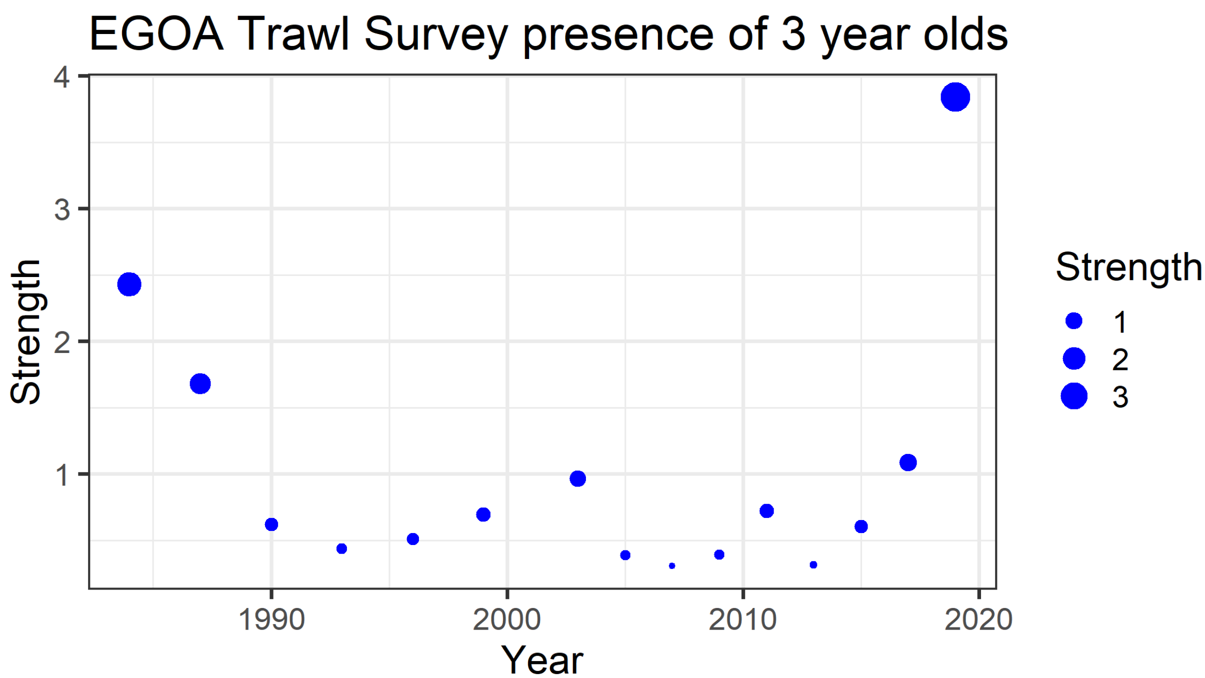


Figure 3.56b. Presence of 3-year-old (42 cm > Length <55 cm) sablefish in the Gulf of Alaska trawl survey. Strength is relative to the mean abundance (i.e., a strength of 7.5 is 7.5x average).

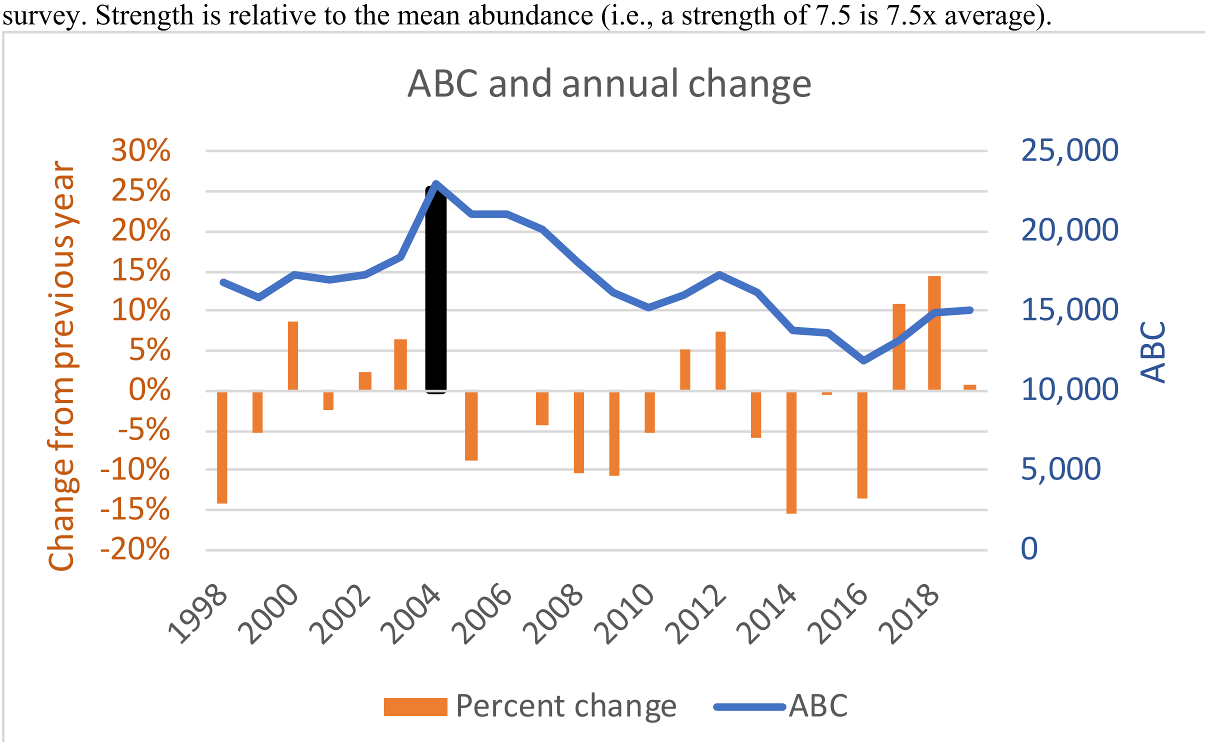


Figure 3.57. Time series of ABC, and percent change in ABC since the Alaska-wide assessment began in 1997. The black bar was a 25% increase in 2003 for the 2004 fishery based on recent recruitment.

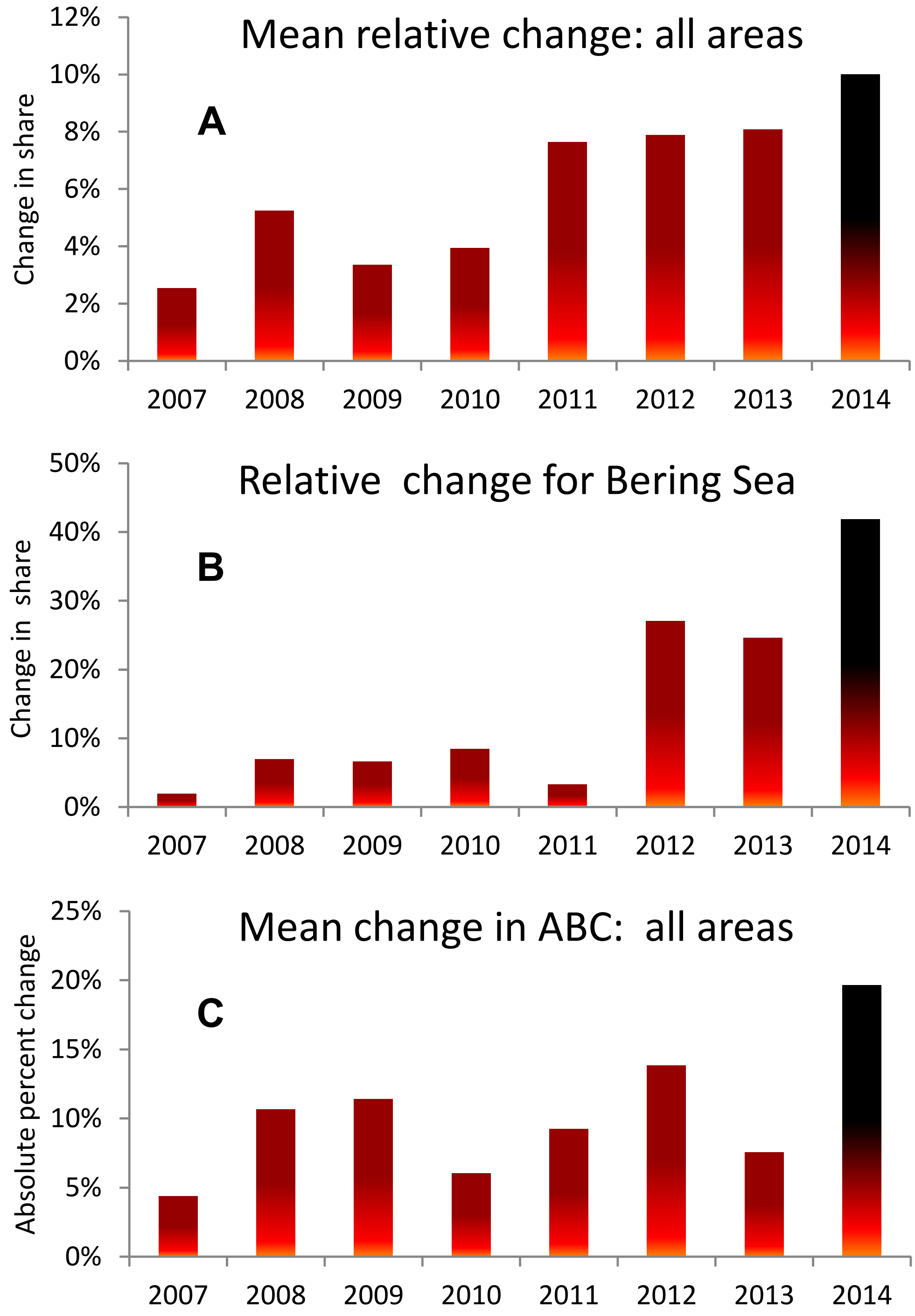


Figure 3.58. (A) The mean relative change in apportionment percentages across areas from 2007-2014. (B) The relative change in the apportionment share for the Bering Sea from 2007-2014. (C) The mean change in ABC for each area from 2007-2014.

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. In 2019, a letter was included with the calendar that included details of the request for the fleet to avoid survey stations and rationale. Additionally, throughout the survey, the skipper of the survey vessel makes announcements on the radio detailing the planned set locations for the upcoming days. Vessels encountered near survey stations are contacted by the survey vessel captain and interviewed to determine potential effects on survey catches. 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 2019 there were several interactions. In the GOA, there were 4 interactions with longliners (1 in Central GOA, 1 in East Yakutat and 2 in Southeast) and 3 interactions with pot boats (2 in Central GOA and 1 in Southeast). There were also two interactions in the Bering Sea; 1 with a trawler and 1 with a pot boat.

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
2019	4	4	1	1	4	4	9	9

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		18	-	263	49	15	345
2011		26	-	274	39	16	355
2012		41	-	195	27	39	301
2013		40	-	178	21	35	275
2014		29	-	188	30	29	276
2015		57	-	175	16	46	295
2016		33	-	183	15	31	262
2017	**AKRO**	57	-	216	9	48	331
2018		54	-	160	20	50	284

* 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.

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

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Executive Summary

National initiative scoring and AFSC research priorities suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish. Annual guidelines for the AFSC support research that improves our understanding of environmental and climate forcing of ecosystem processes with a focus on variables that can provide direct input into or improve stock assessment and management. 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 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 through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic processes for sablefish by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment.

Ecosystem Considerations

- Consistent slope bottom temperatures may provide a helpful buffer for sablefish egg development and subsequent larval hatch during heatwave years
- Non-discriminating prey selection and rapid growth of larval and YOY sablefish provide an advantage in warm years to monopolize on available plankton prey
- Overwinter and nearshore conditions have recently been favorable for juvenile sablefish based on high growth of YOY sablefish observed in seabird diets and large CPUE of juveniles in nearshore surveys
- Body condition of juveniles that are caught in offshore adult habitat has been below average since 2014 and poor for the 2014 and 2016 year-classes
- Mean age of spawners and age evenness have decreased recently suggesting higher contribution of the recent large 2014 year-class to the adult spawning biomass
- Condition of the 2014 year-class is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years and this is accompanied by a drop of 2014 year class recruitment strength in the most recent model recruitment estimates
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population may have increased, based on recent large increases in incidental catch in the arrowtooth flounder fishery and may imply potentially higher competition and predation
- Condition of the overall population on slope habitat has been decreasing since 2015 and may impact young sablefish arriving in already poor condition
- Overall, physical, YOY, and early juvenile indicators were generally good for sablefish while juvenile and adult indicators were generally average to poor.

Socioeconomic Considerations

- Fishery CPUE indicators are showing contrasting trends by gear type and differ from trends in exploitable biomass suggesting potential temporal or spatial fluctuations in gear selectivity
- Catch of sablefish in non-sablefish targeted fisheries has recently been increasing in both the GOA and BSAI, which may imply shifting distribution of sablefish into non-preferred habitat
- Large, adult female sablefish condition in the GOA and BSAI fisheries appear to be in somewhat opposing trends during the year prior to large year-class events.
- Ex-vessel value of the fishery has remained relatively stable since 2013, but prices of small fish have declined dramatically in recent years

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 it with the stock assessment. A consistent approach has been 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 Review*). The ESP uses data collected from a 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).

This ESP for Alaska sablefish (*Anoplopoma fimbria*) follows the template for ESPs (Shotwell et al., *In Review*) and replaces the previous ecosystem considerations section in the main sablefish stock assessment and fishery evaluation (SAFE) report. Information from the original ecosystem considerations section may be found in Hanselman et al. (2017).

The ESP process consists of the following four steps:

1.) Evaluate national initiative and stock assessment classification scores (Lynch et al., 2018) along with regional research priorities to assess the priority and goals for conducting an ESP.
2.) Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.
3.) Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.
4.) Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

Justification

The national initiative prioritization scores for Alaska sablefish are overall 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 to high range of all groundfish scores based on productivity, susceptibility (Ormseth and Spencer, 2011), and sensitivity to future climate exposure (Spencer et al., 2019). The new data classification scores for Alaska sablefish suggest a data-rich stock with high quality data for catch, size/age composition, abundance, life history and ecosystem linkage categories (Lynch et al., 2018). These initiative scores and data classification levels suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish particularly given the high level of life history information and current application of ecosystem linkages in the operational assessment. Additionally, AFSC research priorities support ecosystem research on understanding recent recruitment fluctuations of Alaska sablefish.

Data

Initial information on sablefish was gathered through a variety of national initiatives that were conducted by AFSC personnel in 2015 and 2016. These include (but were not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment classification. Data from an earlier productivity susceptibility analysis conducted for all groundfish stocks in Alaska were also included (Ormseth and Spencer, 2011). Data derived from this effort served as the initial starting point for developing the ESP metrics for stocks in the BSAI and GOA groundfish fishery management plans (FMP). Please see Shotwell et al., *In Review*, for more details.

Supplementary data were also collected from the literature and a variety of process studies, surveys, laboratory analyses, accounting systems, and regional reports (Appendix Table 3C.1). Information for the first year of life was derived from ecosystem surveys and laboratory analyses run by multiple programs and divisions at the AFSC (e.g., Ecosystems and Fisheries Oceanography Coordinated Investigations (EcoFOCI), Recruitment Processes Alliance (RPA), Resource Assessment and Conservation Engineering (RACE) Division, Resource Ecology and Fisheries Management (REFM) Division, Auke Bay Laboratory (ABL) Division, Marine Mammal Laboratory (MML) Division), Pacific Continuous Plankton Recorder (CPR, Batten 2019), and the GulfWatch Alaska (GWA) Program. Data for early stage juveniles (less than 400 mm) through adult (greater than 550 mm) were consistently available from the AFSC bottom trawl and longline surveys, the Alaska Department of Fish and Game's (ADF&G) large mesh survey, and the North Pacific Observer Program administered by the Fisheries Monitoring and Analysis (FMA) division.

Data from Ecosystem Status Report (ESR) contributions were provided through personal communication with the contact author of the contribution (e.g., Ressler et al., 2019). 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). Remote sensing data were collected through coordination with CoastWatch personnel at the Southwest Fisheries Science Center and initial development of an AFSC-specific ERDDAP (Simons, 2019). High resolution regional ocean modeling system (ROMS) and nutrient-phytoplankton-zooplankton (NPZ) data were provided through personal communication with authors of various publications (e.g., Laman et al., 2017, Gibson et al., *In Press*) that use these data.

The majority of sablefish economic value data were compiled and provided by the Alaska Fisheries Information Network (AKFIN). Sablefish ex-vessel pricing 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 Assessment

We first provide the analysis of the national initiative data used to generate the baseline metrics for this second step of the ESP process and then provide more specific analyses on relevant ecosystem and/or socioeconomic processes. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and improve mechanistic understanding of ecosystem or socioeconomic pressures on the stock.

National Metrics

The national initiative data were summarized into a metric panel (Appendix Figure 3C.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 (see Shotwell et al., *In Review* for more details). 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 inverted 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 indicating a high level of vulnerability for sablefish (Appendix Figure 3C.1, yellow and red shaded area, respectively). For ecosystem metrics, recruitment variability for sablefish fell within the 90th percentile rank of vulnerability. Length at 50% maturity, maximum length 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, range in latitude, range in depth, fecundity, breeding strategy, adult mobility, habitat dependence, and prey specificity.

Recruitment variability (standard deviation of log recruitment) for the sablefish stock is above the value of 0.9 which is considered very high recruitment variability (Lynch et al., 2018) and one of the highest among the Alaska groundfish stocks. Additionally, the relatively lower natural mortality, the larger size at 50% maturity, and the larger maximum length are characteristics of lower 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 additional evaluation of ecosystem and socioeconomic processes would be valuable for sablefish with particular attention to understanding the extreme recruitment variability and economic performance to assist with subsequent indicator development.

Ecosystem Processes

Data evaluated over ontogenetic shifts (e.g., egg, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. We evaluate the life history stages of sablefish along four organizational categories of 1) distribution, 2) timing, 3) condition, and 4) trophic interactions to gain mechanistic understanding of influential ecosystem processes. We include a detailed life history synthesis (Appendix Table 3C.2a), an associated summary of relevant ecosystem processes (Appendix Table 3C.2b), a conceptual model summarizing the life history and ecosystem processes tables (Appendix Figure 3C.2), four life history graphics along the organizational categories (Appendix Figure 3C.3-6, updated from Shotwell et al., *In Review*), and provide supportive information from the literature, surveys, process studies, laboratory analyses, and modeling applications.

A suite of habitat variables can be used to predict the distribution of the stock by life history stage and determine the preferred properties of suitable habitat. The recent EFH update for Alaska groundfish included models and maps of habitat suitability distributions by stage and 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 (Appendix Figure 3C.3). 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 (Appendix Figure 3C.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 timing or phenology of the pre-adult life stages (Appendix Figure 3C.2a) can be examined seasonally to understand match or mismatch with both physical and biological properties of the ecosystem (Appendix Figure 3C.4). We synthesized data on the egg, larval, early juvenile and late juvenile life stages (Appendix Table 3C.2a) and restricted to the core sampling area (western GOA only) for consistency across years for the egg and larval data. Data from the early and late juvenile stages were derived from bottom trawl and longline surveys. Physical and biological seasonal climatologies 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 600 mm 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 (June through August), 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. Juveniles are ubiquitous in the epipelagic zone of shelf, slope, and basin waters in the eastern and western GOA in summer and fall, which corresponds to the onset of the fall bloom but prior to the peak of bottom temperature which has a delayed onset from surface warming (Appendix Figure 3C.4).

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 (Appendix Figure 3C.5). 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 (Appendix Figure 3C.5, 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.

Young-of-the-year (YOY) sablefish prey mostly on euphausiids (Sigler et al. 2001) and copepods (Grover and Olla 1990), while juvenile and adult sablefish are opportunistic feeders (Appendix Figure 3C.6c,d). Since juvenile and adult sablefish feed opportunistically, diets differ throughout their range. In general, sablefish < 600 mm consume more euphausiids, shrimp, and cephalopods, while sablefish > 600 mm consume more fish (Yang and Nelson 2000). In the GOA, fish constituted 3/4 of the stomach content weight of adult sablefish with the remainder being invertebrates (Yang and Nelson 2000). Of the fish found in the diets of adult sablefish, pollock were the most abundant item while eulachon, capelin, Pacific herring, Pacific cod, Pacific sand lance, and flatfish also were found. Squid were the most important invertebrate and euphausiids and jellyfish were also present. In southeast Alaska, juvenile sablefish also consume juvenile salmon at least during the summer months (Sturdevant et al. 2009, Coutre, 2014). Off the coast of Oregon and California, fish made up 76 percent of the diet (Laidig et al. 1997), while euphausiids dominated the diet off the southwest coast of Vancouver Island (Tanasichuk 1997). Off Vancouver Island, herring and other fish were increasingly important as sablefish size increased; however, the most important prey item was euphausiids. Given that YOY and early juveniles sablefish predominantly feed on euphausiids (Appendix Figure 3C.6c,d), the availability and abundance of euphausiids may have an impact on YOY and early juveniles survival. Juvenile sablefish (< 600 mm FL) prey items overlap with the diet of small arrowtooth flounder. On the continental shelf of the GOA, both species consumed euphausiids and shrimp predominantly; these prey items are prominent in the diet of many other groundfish species as well. The diet overlap may cause competition for resources between small sablefish and other groundfish species. It is unlikely that juvenile and adult sablefish are affected by availability and abundance of individual prey species because they are opportunistic feeders. However, potential shifts in prey quality (e.g., for vital proteins or energy density) and system level changes in ecosystem productivity could impact the growth or survival of juvenile and adult sablefish.

The main predators of YOY sablefish during their pelagic stage are adult coho and chinook salmon and a variety of seabirds, although other predators such as pomfret have been increasing in recently years likely due to their increase in the GOA during warmer years (Strasburger, *pers. commun.*). Sablefish were the fourth most commonly reported prey species in the salmon troll logbook program from 1977 to 1984 (Wing 1985), however the effect of salmon predation on sablefish survival is unknown. YOY sablefish make up a variable percentage of the diet for piscivorous seabirds such as rhinoceros auklets and black-legged kittiwakes (Hatch et al., 2019). The only other fish species reported to prey on YOY sablefish in the GOA is Pacific halibut; however, sablefish comprised less than 1% of their stomach contents (M. Yang, October 14, 1999, NOAA, pers. comm.). Analyses of diet data taken from early surveys on the bottom trawl survey (pre-2001) suggest late juvenile and adult sablefish may not have been a prominent prey item (Appendix Figure 3C.6b). This is possibly due to either their historically low and sporadic abundance or their early development of swimming structures that allow them to evade predators. However, during their return trip from nearshore to adult habitat, young sablefish share residence on the continental shelf with potential predators such as arrowtooth flounder, halibut, Pacific cod, bigmouth sculpin, big skate, and Bering skate, which are the main piscivorous groundfishes in the GOA (Yang et al. 2006). It seems possible that during high recruitment years such as we are presently observing, predation on sablefish by other fish may increase due to shifts in spatial overlap on the continental shelf from an expanding population. Recent increases in incidental catch of small sablefish in multiple fisheries in both the GOA and BSAI suggest potential for increases in predation and competition. Sperm whales are likely a major predator of adult sablefish. Fish are an important part of sperm whale diet in some parts of the world, including the northeastern Pacific Ocean (Kawakami 1980). Fish have appeared in the diets of sperm whales in the eastern AI and GOA. Although fish species were not identified in sperm whale diets in Alaska, sablefish were found in 8.3% of sperm whale stomachs off of California (Kawakami 1980).

Socioeconomic Processes

Sablefish are primarily harvested by catcher vessels in the GOA, which typically account for upwards of 90% 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. Since the mid-2000s, decreasing biomass has ratcheted down the TAC and catch, a trend that continued up to 2016. In 2017 and 2018 the TACs increased as a result of a strong 2014 year-class. Alaska-wide total catches increased 18% to 15.3 thousand t and retained catches increased 7% to 12.3 thousand t (Appendix Table 3C.3a). The retention rate (ratio of total catch to retained catch), typically above 90%, dropped to 80% in 2018. This is in part related to the higher prohibited species catch of juvenile sablefish by Bering Sea trawlers targeting other species.

Revenues decreased 22.5% to $92.4 million in 2018 as ex-vessel prices fell 30% to $3.50/lb (Appendix Table 3C.3a). The decrease in the ex-vessel price was a reflection of a commensurate decrease in first-wholesale price to $6.28/lb (Appendix Table 3C.3b). First-wholesale value decreased to $100 million in 2018. 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 value in the fishery as catches declined. The 2017 price was the highest seen since prices peaked in 2011 at $8.71/lb. The 2018 price decrease is the result of smaller average fish size as the 2014 year-class has not fully grown to a higher marketable price. The increased abundance and supply of smaller fish puts downward pressure on price of small fish, increases the price margin between small and large fish, and lowers the average price. Export prices through June 2019 (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% of the U.S. catch. Canada catches roughly 10% of the global supply and a small amount is also caught by Russia. As the primary global producer of sablefish the significant supply changes in Alaska have market impact that influence wholesale and export prices. Most sablefish caught and produced are 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 79% in 2009-2013 to 63% in 2018 (Appendix Table 3C.3c). In recent years industry reports and U.S. import-export figures indicate that the strong demand for sablefish in the U.S. and foreign demand outside of Japan, including Europe, China and Southeast Asia. U.S. exports as a share of U.S. production has declined over time indicating increased domestic consumption. China's share of export value has also been increasing (Appendix Table 3C.3c). The US-Japanese exchange rate has remained relatively stable since 2016. The strength of the US dollar puts downward pressure on the price of exported goods as it further increases prices for foreign importers.

Twenty percent of the BSAI sablefish total allowable catch (TAC) allocated to vessels using hook-and-line or pot gear and 7.5% of the sablefish TAC allocated to trawl gear are reserved for use in the Community Development Quota (CDQ) program, which was implemented in 1995. The Sablefish IFQ program includes a cost recovery provision. Cost recovery has ranged from $0.75 million to $2.30 million and 1.0% to 3% of the ex-vessel value of the fishery, with 2015 being the first year the fishery reached the 3% limit. The majority of revenue from landings of sablefish as part of the CDQ program (Appendix

Figure 3C.7a) are from catcher vessels (CV) but there is a smaller percentage from catch processors (CP). Overall revenue for the program has declined slightly by 4% in 2017 relative to the baseline, but contribution from CV landings have increased by 5% while contribution from CP landings has declined by 60%. CPs land on average 12% of the total landings, but the CP share has ranged from 19.9% in 1995 to 5.0% in 2016 and the CP share of the total landings has generally been declining since 2012.

In order to identify the dominant communities engaged in commercial sablefish fisheries, the Regional Quotient was calculated from baseline (1992-1994) until the most recent available data (2013). The regional quotient is a measure of the importance of the community relative to all Alaska fisheries in terms of pounds landed or revenue generated from Alaska FMP groundfish fisheries. It is calculated as the landings or revenue attributable to a community divided by the total landings or revenue from all communities and community groupings (Fissel et al., 2018). The four communities most highly engaged with the sablefish fishery: Seward, Kodiak, Sitka, and Homer account for almost 48% of the regional value landed (Appendix Figure 3C.7b). In comparison, the community Local Quotient metric shows a decline in both pounds and regional value landed in all four of the highly engaged communities. The community Local Quotient, which measures the percentage of sablefish IFQ landed within a community out of the total amount of all species landed within that community, illustrates substantial declines in all highly engaged communities (S. Wise, *pers. commun.*).

Indicators Assessment

We first provide information on how we selected the indicators for the third step of the ESP process and then provide results on the indicators analysis. In this indicator assessment a time-series suite is first created that represent the critical processes identified by the metric assessment. These indicators must be useful for stock assessment in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of stages that are statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al., *In Review*).

Indicator Suite

Studies into the survival of early life stages of sablefish have identified important processes and subsequent indicators representing temperature, transport, and stratification 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). Larval sablefish abundance has been linked to copepod abundance and YOY abundance may be similarly affected by euphausiid abundance because of their apparent dependence on a single species (McFarlane and Beamish 1992). The dependence of larval and YOY sablefish on a single prey species may be the cause of the observed wide variation in annual sablefish recruitment. 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, 2019). 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 (Appendix Figure 3C.8) has recently observed larger catches of smaller sablefish (age-1 through age-4) in the 2015 through 2019 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 and nearshore residency success for the early to late juvenile stage. Estimates of pelagic and benthic foragers as well as apex predator biomass provide information on the relative fluctuations of these guilds (BSAI

ESR, 2017). When evaluated together, the fluctuations of these guilds may represent the health of the shelf habitat for groundfish. Abundance fluctuations for the slope habitat could be evaluated in a similar fashion to investigate the quality of the primary habitat for sablefish.

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 and the FMA observer database since 1996. These data can be used as an indicator of health and productivity in a time-series of the relative condition of fish for both juvenile and adult females. Annual condition differences should be evaluated for each life stage separately because energy storage strategies differ (Appendix Figure 3C.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*).

Longevity of marine fishes is often considered to be a life history strategy to be able to weather long periods of poor conditions and capitalize when conditions are good for reproductive success (Longhusrt 1998). Sablefish clearly fit this strategy with extended periods of low recruitment and episodic large recruitment events. Different measures of female spawning age composition over time from the current stock assessment model may assist with understanding how well the population is prepared to buffer against poor environmental conditions or take advantage of good conditions when they arise. The mean age of the population and how much the population may be concentrated into different cohorts (described here as evenness) may be two options for developing indicators to assess population stability associated with a long-lived strategy for sablefish.

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). 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.

We generated a suite of ecosystem and socioeconomic indicators using the mechanisms and tested relationships listed above from previous studies and the relevant ecosystem processes identified in the metric assessment (Appendix Table 3C.2b, Appendix Figure 3C.2). The following list of indicators is organized by trophic level similarly to the ecosystem status reports (Zador and Yasumiishi, 2018) and by sablefish life history stage. Indicator title and a brief description are provided in Appendix Table 3C.4a for ecosystem indicators and Appendix Table 3C.4b for socioeconomic indicators with references, where possible, for more information.

<u>Ecosystem Indicators:</u>

1. Physical Indicators (Appendix Figure 3C.9a.a-f)
    - Annual marine heatwave index is calculated from daily sea surface temperatures for 1981 through August 2019 from the NOAA High-resolution Blended Analysis Data for the central GOA (< 300 m). Daily mean sea surface temperature data were processed to obtain the marine heatwave cumulative intensity (MHWCI) (Hobday et al., 2016) value where we defined a heat wave as 5 days or more with daily mean sea surface temperatures greater than the 90th percentile of the January 1983 through December 2012 time series (Zador and Yasumiishi, 2018).

- Summer temperature profiles were recorded during the annual longline survey along the continental slope using an SBE39 (Seabird Electronics) attached to the groundline approximately one-third of the way in from the shallow portion of a station (Malecha et al., 2019). In the GOA, 13 stations had complete temperature profiles for the entire time-series (2005–2019). Annual anomalies from the 15-year mean can be calculated by station at discrete depths, and an index for each year can be represented by the mean of these anomalies at a chosen depth. Interpolation between actual depth recordings in a profile was conducted using weighted parabolic interpolation (Reiniger and Ross, 1968). The 250 m isobath was selected to represent deeper water at the shelf-slope break where adult sablefish are typically sampled.
- Late spring (May-June) sea surface temperatures (SST) for the eastern GOA and southeastern Bering Sea were obtained from the monthly gridded 4 km Advanced Very High Resolution Radiometer (AVHRR) Pathfinder v5.3 dataset (Casey et al., 2010). These data were provided by Group for High Resolution SST (GHRSST) and the NOAA National Centers for Environmental Information (NCEI). This project was supported in part by a grant from the NOAA Climate Data Record (CDR) Program for satellites. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.
- Derived chlorophyll *a* concentration data during spring seasonal peak (May) in the eastern GOA and southeastern Bering Sea were obtained from the 4km Ocean Colour Climate Change Initiative (OC-CCI) version 4.0 monthly gridded dataset, European Space Agency available online at http://www.esa-oceancolour-cci.org. The data were downloaded from NOAA CoastWatch-West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.

2. Zooplankton Indicators (Appendix Figure 3C.9a.g-i)
    - Abundance of large copepods from the continuous plankton recorder (CPR) for the shelf and offshore waters of the central and eastern GOA (Batten, 2019).
    - Summer euphausiid abundance is represented as the acoustic backscatter per unit area (sA at 120 kHz, m2 nmi-2) classified as euphausiids and integrated over the water column and then across the surveyed area to produce an annual estimate of acoustic abundance (sA * area, proportional to the total abundance of euphausiids). The index is for the Kodiak core survey area available for variable years historically and biennially since 2013 (Ressler et al., 2019).
3. Larvae and Young-of-the-Year Indicators (Appendix Figure 3C.9a.j)
    - An age-0 sablefish growth is calculated as the coefficient for the regression of length (mm) by Julian day for each year and effectively tracks the nearshore age-0 growth rate of sablefish. Data have been collected since 1978 by the Institute for Seabird Research and Conservation and analyzed by the U.S. Geological Service. (Arimitsu and Hatch, 2019).
4. Juvenile Indicators (Appendix Figure 3C.9a.k-m)
    - The ADF&G large mesh bottom trawl survey of crab and groundfish has been conducted annually from 1988 to present and samples on a fixed grid in the Kodiak to eastern Aleutian area. Sablefish catch-per-unit-effort and lengths were summarized for the survey region. Sablefish lengths generally consist of fish between ages 2-4 and can be considered an index of sablefish juveniles in the nearshore prior to returning to adult habitat (Spalinger, 2015).
    - Catch-per-unit-of-effort of juvenile sablefish (<400 mm, likely age-1) collected on summer bottom-trawl surveys.
    - Summer sablefish condition for juvenile (designated as immature) female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data

collected randomly for otoliths in the annual GOA longline survey (legs 3-7) from 1996 to present.

5. Adult Indicators (Appendix Figure 3C.9a.n-t)
    - Mean age of sablefish female spawning stock biomass from the most recent sablefish stock assessment model.
    - Measure of evenness or concentration of age composition by cohort of female sablefish from the most recent sablefish stock assessment model.
    - Summer sablefish condition for age-4, mature female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data collected randomly for otoliths in the annual GOA longline survey (legs 3-7) from 1996 to present (Shotwell and Rodgveller, *pers. commun.*).
    - Arrowtooth flounder total biomass (metric tons) from the most recent stock assessment model (Spies et al., 2017).
    - Incidental catch of sablefish in the GOA arrowtooth flounder fishery (Shotwell, *pers. commun.*)
    - Averaged anomalies of the relative population weights for primary sampled species (giant grenadier, arrowtooth flounder, rougheye rockfish, shortraker rockfish, and shortspine thornyhead) on the GOA longline survey (Shotwell, *pers. commun.*).
    - Summer sablefish condition for large adult (>=750 mm) female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data collected randomly for otoliths in the annual GOA longline survey (legs 3-7) from 1996 to present.

<u>Socioeconomic Indicators:</u>

1. Fishery Performance Indicators (Appendix Figure 3C.9b.a-d)
    - Catch-per-unit-of-effort of sablefish in tons estimated from fishery observer data from the longline fisheries in the GOA (Hanselman, *pers. commun.*).
    - Catch per unit of effort of sablefish in tons estimated from fishery observer data from the pot fisheries in the eastern Bering Sea (Hanselman, *pers. commun.*).
    - Incidental catch estimates of sablefish in the Bering Sea fisheries excluding the sablefish fishery. Data available from Alaska Fisheries Information Network (AKFIN) (Shotwell, *pers. commun.*).
    - Incidental catch of sablefish in the GOA fisheries excluding the sablefish fishery. Data available from Alaska Fisheries Information Network (AKFIN) (Shotwell, *pers. commun.*).
2. Economic Indicators (Appendix Figure 3C.9a.e-h)
    - Sablefish condition for large (>= 750 mm) female sablefish. Body condition was estimated using a length-weight regression (Boldt et al., 2017) from data collected randomly by observers for otoliths in the GOA and BSAI fisheries from 1999 to present (Shotwell and Rodgveller, *pers. commun.*).
    - Annual estimated real ex-vessel value measured in millions of dollars and inflation adjusted to 2018 USD (Fissel et al., 2019).
    - Average price per pound of small sablefish in BSAI fixed gear fisheries (Armstrong et al., 2018).

Indicator Monitoring Analysis

We provide the list and time-series of indicators (Appendix Table 3C.4, Appendix Figure 3C.9) and then monitor the indicators using three stages of statistical tests that gradually increase in complexity depending on the stability of the indicator for monitoring the ecosystem or socioeconomic process and the data availability for the stock (Shotwell et al., *In Review*). At this time, we report the initial results of the first and second stage statistical tests of the indicator monitoring analysis for sablefish. The third stage will require more indicator development and review of the ESP modeling applications.

Stage 1, Traffic Light Test:

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the current year where available (Appendix Table 3C.4). Both measures are based on one standard deviation from the long-term mean (log-transformed) of the time series. A symbol is provided if the most recent year of the time series is greater than (+), less than (-), or within (•) one standard deviation of the long-term mean for the time series. If the most recent year is also the current year then a color fill is provided for the traffic-light ranking based on whether the relative value creates conditions that are good (blue), average (white), or poor (red) for sablefish (Caddy et al., 2015). The blue or red coloring does not always correspond to a greater than (+) or less than (-) relative value. In some cases the current year data were not available. This identifies data gaps for evaluating ecosystem and socioeconomic data for sablefish and highlights potential future research priorities.

The sablefish population is currently experiencing a series of unusually large year-classes which are concurrent with large shifts in the physical environment (Appendix Figure 3C.9a.a-f). There have been increased sea surface warming in the GOA and BSAI ecosystems and the presence of a series of major heatwaves from 2014-2016 and potentially again in 2019 (Appendix Figure 3C.9a.a,c-d). This warming is also evident in bottom temperatures taken on the AFSC bottom trawl surveys and the International Pacific Halibut Commission (IPHC) surveys in hotspots throughout the continental shelf region. However, the warming was not particularly present over much of the slope environment, which may provide a buffer during spawning and egg deposition. Specifically, the 250-m slope temperature index from the longline survey which is in prime sablefish habitat, has not deviated greatly from the 15-year mean (Appendix Figure 3C.9a.b). However, this index has remained positive for the last three years, a deviation from the historical fluctuations around the mean, suggesting these deeper waters may remain somewhat warmer than average (~0.1°C) from 2017-2019. Late spring sea surface temperatures near the edges of the Alaska sablefish population in the eastern GOA (EGOA) and southeast Bering Sea (SEBS) were very high in 2015-2016 and again in 2019 during the peak sablefish larval time period (Appendix Figure 3C.9a.c-d). Primary production during the peak spring bloom time period in Alaska (May) has steadily been decreasing in these two areas with a peak only in 2014 in the EGOA (Appendix Figure 3C.9a.e-f). In contrast, the mesozooplankton biomass in the central and eastern GOA has been fairly high since 2014 on the shelf and high to average offshore except for 2018 (Appendix Figure 3C.9a.g-h). This most recent decline was largely due to a drop in large copepods which may have to do with the recent declines in the phytoplankton community (Batten, 2019). The euphausiid abundance index in the central GOA region has been steadily decreasing since 2011 but has returned to near average conditions in 2019 (Appendix Figure 3C.9a.i). The mixed physical and lower trophic level indices suggest that the warming has diverse regional impacts on the plankton community but that a variety of prey options are available for larval and YOY sablefish. During exceptionally warm years these conditions may provide an advantage for larval and YOY sablefish due to their non-discriminating prey selection and potential for rapid growth.

The high growth during warm years is reflected in the samples of young-of-the-year (YOY) and juvenile sablefish. Growth of YOY sablefish from rhinoceros auklet diet samples on Middleton Island show an increasing trend in growth since a low in 2012 (Appendix Figure 3C.9a.j). Peak growth occurred in 2014-2016 and again with a very high anomaly in 2019. Age-1 sablefish were also captured in high numbers in the ADF&G large mesh in 2015, 2017, and somewhat in 2019 (Appendix Figure 3C.8b) and in the bottom trawl survey in 2015 and 2017 (Appendix Figure 3C.9a.l). The ADF&G survey has also shown an increasing trend for sablefish catch-per-unit-of-effort (CPUE) overall since 2015 with the exception of 2017 (Appendix Figure 3C.8a). Overall, this survey likely contains a mix of different aged sablefish from age-1 through age-3 or age-4 and so the CPUE index is an index of cohort strength across the previous 3-4 years (Appendix Figure 3C.9a.k). However, when combined with the length frequencies this survey is useful for identifying continued survival of sablefish throughout their residency on the shelf before transiting to the slope adult environment. Body condition of sablefish female juveniles captured on the longline survey (generally around age 3) can be used to measure the health of fish arriving at the adult habitat. This index has been at or below average since 2014 and the condition of age-3 juveniles in 2017 and 2019 (which would be the 2014 and 2016 year-class) was fairly poor (Appendix Figure 3C.9a.m). This implies that there may be additional factors contributing to the strength of the year-class following the overwinter survival and nearshore residency.

Mean age of spawners as estimated by the current stock assessment model has declined rapidly since 2017 implying a larger contribution of younger fish to the spawning stock biomass as the 2014 year-class begin to mature (Appendix Figure 3C.9a.n). Age evenness has severely declined in recent years and is far less even than the low point in the 1980s after the large 1977 year-class suggesting that the age composition of the population is made up of very few cohorts and potentially less resilient to future shifts in environmental conditions (Appendix Figure 3C.9a.o). Additionally, skip spawning was found to be more prevalent at younger ages (Rodgveller et al. 2018), therefore, the contribution of the 2014 year-class (and subsequent large year-classes) to future recruitment may be more variable than older year classes. The summer condition of age-4 female mature fish on the longline survey has been poor since 2015 (Appendix Figure 3C.9a.p). Specifically, the condition of age-4 in 2018 (or the 2014 year-class) is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years (2001, 2002, and 2004, for the 1997, 1998, and 2000 year-classes). This age-4 bottleneck was also confirmed in the drop of the 2014 year-class recruitment estimate in the most recent sablefish stock assessment model to around the strength of the 1977 year-class.

Given non-specific dietary requirements at the maturing-to-adult stages, it is likely less useful to explore prey requirements than it is to interpret changes in predation. It, therefore, may be useful to consider impacts of potential predator biomass on sablefish transitioning to the offshore slope environment. Arrowtooth flounder has been considered a primary predator of young sablefish; however, the most recent biomass estimates from the stock assessment indicate a recent decline in total biomass (Appendix Figure 3C.9a.q). Conversely, the incidental catch estimates of sablefish in the GOA arrowtooth flounder fishery have increased dramatically since 2016 suggesting potentially higher levels of spatial overlap between the arrowtooth and sablefish populations (Appendix Figure 3C.9a.r). This may mean that young sablefish returning to adult slope habitat have a higher level of competition and predation resulting in the measured poor body condition (Appendix Figure 3C.9a.p). The relative health of the slope habitat has also been on a decreasing trend since 2015 as measured by the relative population weights (RPW) of major non-sablefish species on the longline survey (Appendix Figure 3C.9a.s). The cause of this decreasing trend is unknown but may also impact sablefish arriving in poor condition to their adult slope habitat and cause them to incur higher stress levels. Condition of large adult female sablefish from the longline survey is moderately positively correlated to the slope habitat relative health indicator and the recent declining trend in condition up until 2017 may also be reflective of this decreasing trend in slope habitat relative health. The condition indicator of large adult females is also highly variable over time (Appendix Figure 3C.9a.t) and is somewhat concerning given the increasing reliance on the 2014 cohort contribution to the sablefish population.

With regard to fishery performance, the CPUE of sablefish in the GOA longline fishery has been below average since 2011 and on a steadily decreasing trend to the lowest of the time series in 2019 (Appendix Figure 3C.9b.a). This is contrasted by the CPUE of the pot fishery in the eastern Bering Sea which was below average from 2009-2016 and recently increased to near record high in 2018 (Appendix Figure 3C.9b.b). These contrasting trends are concerning as they do not track the estimated exploitable biomass from the current stock assessment model and there may be temporal fluctuations in gear selectivity that are not accounted for in the current model configuration. Sablefish catch has been increasing recently in the non-sablefish target fisheries for both the GOA and BSAI fisheries (Appendix Figure 3C.9b.c-d). This is primarily due to increases of catch in the rockfish and arrowtooth flounder fisheries in the GOA and the

Greenland turbot and midwater pollock fisheries in the BSAI. Rapid changes of catch may imply shifting distribution of the sablefish population into non-preferred habitat and may increase competition and predation for sablefish. For economic trends, large adult female sablefish condition in the GOA and BSAI fisheries appear to be in somewhat opposing trends during the year prior to large year-class events (Appendix Figure 3C.9b.e-f). This may reflect pre-spawning condition, which appeared low in the BSAI and high in the GOA prior to the 2000 year-class, but very high in the BSAI and very low in the GOA prior to the 2014 year-class. The relative condition by region of the large female spawners may provide some insight on the habitat quality by region and the subsequent value of these fish considering the clear increase in lipids as these fish increase in size (Appendix Figure 3C.4). Overall, the ex-vessel value of the fishery has remained relatively stable since 2013; however, prices for small sablefish decreased dramatically in 2018 likely due to increases in catch of small fish as the 2014 year-class entered the fishery (Appendix Figure 3C.9b.g-h).

For the indicators available in the current year, the traffic light analysis shows an approximately even mix of good, stable, and poor conditions across all indicators. Physical, YOY, and early juvenile indicators were generally good, while juvenile and adult indicators were generally average to poor (Appendix Table 3C.4a). Socioeconomic indicators were also a mix but the majority of the indicators were not available for the most recent year (Appendix Table 3C.4b). In the future, a more quantitative summary measure across all indicators could be produced to generate an overall traffic light score for the ecosystem and socioeconomic indicators, respectively.

Stage 2, Regression Test:

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and sablefish recruitment and to assess 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 test, the full set of indicators is first winnowed to the predictors that could directly relate to recruitment and highly correlated covariates are removed (Appendix Figure 3C.10a). We further restrict potential covariates to those that can provide the longest model run and through the most recent estimate of recruitment that is well estimated in the current operational stock assessment model. This results in a model run from 1990 through the 2016 estimate of 2 year-olds or the 2014 year-class. We then provide the mean relationship between each predictor variable and log sablefish recruitment over time (Appendix Figure 3C.10b, left side), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Appendix Figure 3C.10b, right side). A higher probability indicates that the variable is a better candidate predictor of sablefish recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process were the summer juvenile sablefish CPUE from the ADF&G survey, the summer juvenile sablefish condition from the longline survey, and the catch from the arrowtooth flounder fishery in the GOA (Appendix Figure 3C.10).

The BAS method requires observations of all predictor variables in order to fit a given data point. This method estimates the inclusion probability for each predictor, generally by looking at the relative likelihood of all model combinations (subsets of predictors). If the value of one predictor is missing in a given year, all likelihood comparisons cannot be computed. When the model is run, only the subset of observations with complete predictor and response time series are fit. It is possible to effectively “trick” the model into fitting all years by specifying a 0 (the long-term average in z-score space) for missing predictor values. However, this may bias inclusion probabilities for time series that have more zeros and result in those time series exhibiting low inclusion probability, independent of the strength of the true relationship. Due to this consideration of bias, we only fit years with complete observations for each covariate at the longest possible time frame. This resulted in a smaller final subset of covariates. We plan to explore alternate model runs (e.g., biennial) to potentially include more covariates in the future.

<u>Stage 3, Modeling Test:</u>

In the future, highly ranked predictor variables could be evaluated in the third stage statistical test, which is a modeling application that analyzes predictor performance and estimates risk probabilities within the operational stock assessment model. A new spatially-explicit life cycle model (SILC) is in development for sablefish that pairs output from an individual based model (IBM) with the spatial statistical catch-at-age assessment model. The overall objective is to parse the movement and survival of sablefish in their first year using influences of environmental and predation processes from the subsequent traditional spatial and biological processes estimated for juveniles and adults. Increasing the resolution of our assessment of these processes will benefit the ability for the ESP to link with regional environmental and socioeconomic processes.

Once the SILC model is more developed and published, regional estimates of recruitment could be generated and linked with appropriate indicators to explain spatial shifts in the sablefish population and tested as an alternative environmentally linked assessment. The juvenile condition indicator and heatwave index could help explain the variability in recruitment deviations and predict pending recruitment events (e.g., Shotwell et al., 2014). The juvenile ADF&G index could be used directly in the model as a survey for age-1 plus sablefish and be updated on an annual basis. Utilizing indicators as indices directly inside the model would have the desirable property of influencing ABC recommendations in a neutral way.

Recommendations

The sablefish ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the metric and indicator assessment we provide the following set of considerations:

Ecosystem Considerations

- Consistent slope bottom temperatures may provide a buffer for sablefish egg development and subsequent larval hatch during heatwave years
- Non discriminating prey selection and rapid growth of larval and YOY sablefish provide an advantage in warm years to monopolize on available plankton prey
- Overwinter and nearshore conditions have recently been favorable for juvenile sablefish based on high growth of YOY sablefish observed in seabird diets and large CPUE of juveniles in nearshore surveys
- Body condition of juveniles that are caught in offshore adult habitat has been below average since 2014 and poor for the 2014 and 2016 year-classes
- Mean age of spawners and age evenness have decreased recently suggesting higher contribution of the recent large 2014 year-class to the adult spawning biomass
- Condition of the 2014 year-class is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years and this is accompanied by a drop of 2014 year class recruitment strength in the most recent model recruitment estimates
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population may have increased based on recent large increases in incidental catch in the arrowtooth flounder fishery and may imply potentially higher competition and predation
- Body condition of the overall population on slope habitat has been decreasing since 2015 and may impact young sablefish arriving in already poor condition
- Overall, physical, YOY, and early juvenile indicators were generally good for sablefish while juvenile and adult indicators were generally average to poor.

Socioeconomic Considerations

- Fishery CPUE indicators are showing contrasting trends by gear type and differ from trends in exploitable biomass suggesting potential temporal or spatial fluctuations in gear selectivity
- Catch of sablefish in non-sablefish targeted fisheries has recently been increasing in both the GOA and BSAI which may imply shifting distribution of sablefish into non-preferred habitat

- Large adult female sablefish condition in the GOA and BSAI fisheries appear to be in somewhat opposing trends during the year prior to large year-class events.
- Ex-vessel value of the fishery has remained relatively stable since 2013, but prices of small fish have declined dramatically in recent years

Data Gaps and Future Research Priorities

While the metric and indicator assessments provide a relevant set of proxy indicators for evaluation at this time, there are certainly areas for improvement. Several indicators do not have a current year update and this may cause issues with generating a summary score for the ecosystem or socioeconomic considerations. Development of high-resolution remote sensing (e.g., regional surface temperature, transport estimates, primary production estimates) or climate model indicators (e.g., bottom temperature, NPZ variables) may assist with the current year data gap for several indicators if they sufficiently capture the main trends of the survey data and are consistently and reliably available. Some of the indicators collected for sablefish do not cover the full spatial distribution of the sablefish stock, particularly the zooplankton surveys. Potentially a large-scale zooplankton indicator that combines multiple data sources to determine a relative trend by region could be developed to more adequately capture the habitat that sablefish encounter during their first year of life.

It is important to consider the causal mechanisms for shifting condition of pre-spawning sablefish in both the survey and the fishery and the potential impact on spawning potential. There are many years of diet data collected for sablefish and many other groundfish that have not yet been incorporated into the ecopath model that initially estimated predation and consumption rates for sablefish. Once this model was updated, a more detailed synthesis on gut content could be developed to better evaluate the condition indices (which is a weight-at-length regression), potentially to generate time-series indicators of stomach fullness or energy content per individual sablefish biomass. These would help illuminate inference about competition and predation if other species were also updated in the ecopath model. It may also be useful to consider morphometric or physiological impacts on condition in pre- versus post-spawning individuals and individuals that skip spawn to measure energetic costs of spawning.

Evaluating condition and energy density of juvenile and adult sablefish samples throughout the whole population may be useful for understanding the impacts of shifting spatial distribution. Spatiotemporal comparison of condition may be useful to evaluate whether there are any regional impacts on sablefish condition during spawning. This would be highly dependent on sample size from observers for otolith fish. An evaluation of the spatial and temporal overlap between different fisheries may also provide insight on the potential new predation or competition pressures on the sablefish population. Since sablefish recruitment clearly has a weak relationship with spawning stock biomass, some of these factors may help explain and predict recruitment by determining the quality instead of the quantity of the annual spawning stock.

The monitoring analyses could also use refinement. An agreed upon target or range of the total number of indicators by category to be included in the indicator suite would help standardize any future potential scores or metrics resulting from the traffic light test. Exploration of alternatives for dealing with missing data would be very useful for updating the BAS model. One option may be to explore different types of models such as biennial or shorter time series ranges. Another may be to include a random-number as a covariate and test the inclusion probability (or perhaps many replicates) and use that inclusion probability (or its average across replicates) as a significance threshold for inclusion probability of other variables (J. Thorson, *pers. commun*.). Additional refinement on the SILC model might also allow for regional estimates of recruitment and an evaluation of a stock-recruitment relationship by region may provide insight into a selection of relevant indicators by region for future analyses.

As indicators are improved or updated, they may replace those in the current set of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. This could be accomplished in the next full ESP assessment and the timing of that will depend on how the ESP process matures. 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. We plan to create a simplified template for evaluating the ESP considerations during a partial update year.

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Tables

Appendix Table 3C.1: List of data sources used in the ESP evaluation. Please see the main sablefish SAFE document, the Ecosystem Considerations Report (Zador and Yasumiishi, 2019) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
EcoFOCI Spring Survey	Shelf larval survey in May-early June in Kodiak to Unimak Pass using oblique 60 cm bongo tows, fixed-station grid, catch per unit effort in numbers per 10 m^2	1978 – present	Western GOA annual, biennial
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 in June through August, Gulf of Alaska using Poly Nor'Eastern trawl on stratified random sample grid, catch per unit of effort in metric tons	1984 – present	GOA tri-, biennial
ABL Longline Survey	Longline survey of groundfish on stratified stations set 20-30 km apart using standard groundline	1987-2018	GOA annual
MACE Acoustic Survey	Mid-water acoustic survey in March in Shelikof Strait for pre-spawning pollock and again in summer for age 1 pollock	1981 – present	GOA annual, biennial
Seabird Surveys	Ecological monitoring for status and trend of suite of seabird species conducted by Institute for Seabird Research and Conservation and GulfWatch Alaska	1978 – present	Middleton Island, GOA
RECA Energetics Database	Compositional data and associated analyses by the Recruitment Energetics and Coastal Assessment (RECA) Program, AFSC on multiple platforms	1997 – present	Alaska variable
REEM Diet Database	Food habits data and associated analyses collected by the Resource Ecology and Ecosystem Modeling (REEM) Program, AFSC on multiple platforms	1990 – present	GOA biennial
AVHRR Pathfinder	4 km Advanced Very High Resolution Radiometer (AVHRR) version 5.3 monthly gridded sea surface temperature (SST) dataset (Group for High Resolution SST, GHRSST)	1981 – present	Global

Appendix Table 3C.1 (cont.): List of data sources used in the ESP evaluation. Please see the main sablefish SAFE document, the Ecosystem Considerations Report (Zador and Yasumiishi, 2018) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
Ocean Colour CCI	4km Ocean Colour Climate Change Initiative (OC-CCI) version 4.0 monthly gridded derived chlorophyll dataset, European Space Agency, (http://www.esa-oceancolour-cci.org)	1998 – 2018	Global
Pacific CPR	Continuous Plankton Recorder (CPR) near surface plankton net (7m) towed behind vessels of opportunity, identify and count zooplankton and hard shelled phytoplankton	2000-present	North Pacific
Climate Model Output	Daily sea surface temperatures from the NOAA High-resolution Blended Analysis Data	1977 – present	Central GOA
ROMS/NPZ Model Output	Coupled hydrographic Regional Ocean Modeling System and lower tropic Nutrient-Phytoplankton-Zooplankton dynamics model	1996 – 2013	Alaska variable
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
FMA Observer Database	Observer sample database maintained by Fisheries Monitoring and Analysis Division	1988 – present	Alaska annual
NMFS Alaska Regional Office	Catch, economics, and social values for fishing industry, data processed and provided by Alaska Fisheries Information Network	1992 – 2018	Alaska annual
Reports & Online	ADFG Commercial Operators Annual Reports, AKRO At-sea Production Reports, Shoreside Production Reports, FAO Fisheries & Aquaculture Department of Statistics	2011 – 2018	Alaska, U.S., Global annual

Appendix Table 3C.2a: Ecological information by life history stage for sablefish.

Stage		Habitat & Distribution	Phenology	Age, Length, Growth	Energetics	Diet	Predators/Competitors
Adult	**Recruit**	Shelf edge, slope, gullies (>200 m), GOA to Bering, benthic(18)	First recruit to survey and fishery age 2, high movement (10-88%)(18)	Max: 73yrs(18,19,28), 134♀/138♂ cm Average: 12 yrs L_inf=80♀/68♂ cm, K= 0.22♀/0.29♂	Low conversion efficiency, low metabolic rate(21)	Opportunistic, euphausiids, pol/cod, capelin, herring, squid, jelly(12,18,REEM)	P: Sperm whales, orca, fisheries, C: slope groundfish(18)
Adult	**Spawning**	Shelf break(1), deep water pelagic	Winter-spring, batch spawner, peak March, 25 wks, high production(1,26,17)	1st mature: 5.5 yr, 50%: 6.6 yr/65cm ♀, 5 yr/57 cm ♂(17,18), females > males	Oviparous, high fecundity (120-$1000 \cdot 10^3$) eggs, Skip-spawning(1,17,18)	Opportunistic, euphausiids, pol/cod, capelin, herring, squid, jelly(12,18,REEM)	P: Sperm whales, orca, fisheries, C: slope groundfish(18)
Offshore to Nearshore Pelagic	**Egg**	Slope (>200-400 m), sink to deeper depths, negatively buoyant(1)	Late winter to early spring, 10 wks peak egg to peak larvae (17)	Egg size: 1.8-2.2 mm, large egg size(17,RACE)	Max survival to hatch, 34-35ppt, 4-6.6°C (lab)(22)	Yolk (RACE)	
Offshore to Nearshore Pelagic	**Larvae**	Slope (>200-600 m) (hatch to yolk-sac), epipelagic over shelf and slope, 160 km offshore(1,2,7,17)	Late spring and summer, peak end May, 12 wks, epipelagic(7,16,17,19)	10-80 mm SL (1,7,16), 1.2 mm/day, develop as obligate neuston(7,10,16)	Growth threshold 22°C, optimum 12-16°C (lab)(9)	copepod nauplii, nauplii, small copepods, small and large copepods(1,29)	C: larval cottids, hexagrammids, wrymouths, non-obligate neustonic taxa(7)
Offshore to Nearshore Pelagic	**YOY**	Shelf(1), neuston and near surface (upper 10-20 cm of water column)(1,10,17)	No marked transition time to stage, move to nearshore(1,19)	60-230 mm FL (120 mm avg, neustonic), rapid growth, 1.2 mm/day(10)	Upper thermal limit near upper limit survival(9), absence lipid regulation(23)	Euphausiids, pelagic tunicates, other crustaceans, larval fish(1,10)	P: Coho and chinook salmon(31), seabirds, C: active inshore migration(1)
Nearshore Settlement	**Juvenile**	Nearshore (6-214 m), inlet, bay, fjord, strait, mixed mud, soft, proximity to rock(3,4,6)	Late summer-fall, diel pelagic feeding excursions(4,30)	300-400 mm after second summer, age 2+ yrs(25)		Herring, smelts, salmon remains, jellies(30)	P: Salmon, halibut (12,31), seabirds, C: macroalgae, sponge, anemone, whip, basket star, eelgrass, shelf groundfish(3, 12,15)
Nearshore Settlement	**Pre-Recruit**	Nearshore, shelf (10-207 m), inlet, bay, fjord, strait, mixed mud, soft, proximity to rock(3,4,6,8)	Offshore movement begins after 2nd summer(25)	<600 mm FL(5), age 2+ yrs(10)		Euphausiids, shrimp, pollock, other fish, other crustaceans, cephalopods, jellies, salmon (12,13,14)	P: Salmon, halibut (12,31), seabirds, C: sponge, whip, sea pen, coral, basket star, anemone, shelf groundfish(3,12)

Appendix Table 3C.2b. Key processes affecting survival by life history stage for sablefish.

Stage		Processes Affecting Survival	Relationship to Sablefish
Adult	**Recruit**	1. Abundance of predators/competitors in preferred slope habitat 2. Bottom temperature	Increases in main predators of sablefish would be negative but minor predators or competitors may indicate sablefish biomass increase. Increases in bottom temperature may impact spawning habitat.
	Spawning	1. Large-scale offshore thermal environment winter before spawning(20) 2. Condition, age of female spawners	Stability of offshore thermal environment may be necessary for spawning and provide buffer. Poor body condition or earlier age of female spawners may result in lowered productivity, more variable spawn timing or skip spawning, and mismatch with spring bloom.
Offshore to Nearshore Pelagic	**Egg**	1. Bottom temperatures 2. Advection/retention 3. Oxygen minimum zone	Increases in bottom temperature and advection would be negative for egg stage resulting in early hatching or dispersal from preferred habitat. Shoaling of the oxygen minimum zone may also adversely impact survival to hatch.
	Larvae	1. Surface temperature in neuston 2. Match with spring bloom(17), abundant prey 3. Currents that facilitate nearshore transport(1)	Increases in temperature and zooplankton prey may be positive for sablefish that can utilize multiple prey types and have a high growth potential at warmer temperatures. Increases in nearshore transport to preferred habitat would be positive for sablefish during settlement transition.
	YOY	1. Surface temperature in neuston 2. Spring/summer abundance of zooplankton prey(11) 3. Currents that transport onto shelf(1) 4. Predation	Increases in temperature and zooplankton prey may be positive for sablefish similar to the larval stage. Increases in nearshore transport would assist with settlement to preferred habitat and increases in predation would be negative for sablefish although this is not an abundant species and not a common prey item.
Nearshore Settlement	**Juvenile**	1. Summer/fall abundance of zooplankton prey (11) 2. Bottom temperature in nearshore 3. Predation	Increases in preferred zooplankton prey would be positive for sablefish condition as they prepare to overwinter in the nearshore and higher bottom temperatures may assist with energetic costs of settlement. Predation would be negative for sablefish, although sablefish is not a primary prey item for most stocks.
	Pre-Recruit	1. Abundance of predators/competitors during transition from nearshore to offshore habitat 2. Top-down predation increase on age 2+	Increases in encounter of main competitors and predators of juvenile sablefish would be negative but minor predators or competitors may indicate sablefish biomass increase. Increases in main predator of sablefish would be negative but minor predators such as seabirds may indicate sablefish biomass increase.

Appendix Table 3C.3a. Sablefish ex-vessel data from Alaska Fisheries. Total catch (federal and state) (thousand metric tons), catch in federal fisheries (thousand metric tons), ex-vessel value (million US$), price (US$ per pound), number of vessels, and the proportion of vessels that are catcher vessels, 2009-2013 average and 2014-2018.

	2009-2013 Average	2014	2015	2016	2017	2018
Total Catch K mt	14.0	12.3	11.7	10.9	13.0	15.3
Retained Catch K mt	13.3	11.6	10.8	9.9	11.5	12.3
Value M US$	$113.5	$94.6	$94.1	$92.9	$119.1	$92.4
Price/lb US$	$3.98	$3.82	$3.97	$4.38	$4.99	$3.50
% value GOA	90%	93%	95%	96%	97%	95%
Vessels #	337	298	290	288	281	290
Proportion CV	87%	89%	90%	88%	85%	84%

Appendix Table 3C.3b. Sablefish first-wholesale data from Alaska Fisheries. Production (thousand metric tons), value (million US$), price (US$ per pound), and head and gut share of production, 2009-2013 average and 2014-2018.

	2009-2013 Average	2014	2015	2016	2017	2018
Quantity K mt	7.66	6.70	6.06	5.86	6.59	7.22
Value M US$	$112.8	$99.1	$91.0	$102.1	$123.8	$99.9
Price/lb US$	$6.68	$6.71	$6.81	$7.90	$8.52	$6.28
H&G share	95%	97%	98%	97%	97%	97%

Appendix Table 3C.3c. Sablefish global catch (thousand metric tons), U.S. and AK shares of global catch; WA & AK export volume (thousand metric tons), value (million US$), price (US$ per pound) and the share of export value from trade with Japan and China, 2009-2013 average and 2014-2019.

	2009-2013 Average	2014	2015	2016	2017	2018	2019 (thru June)
Global catch K mt	20.9	17.8	18.7	17.2	19.1	-	-
U.S.Share of global	89%	90%	86%	89%	90%	-	-
AK share of global	64%	65%	58%	57%	60%	-	-
Export Volume K mt	10.16	6.67	6.66	5.58	5.73	6.57	2.48
Export value M $	$ 94.91	$ 81.58	$ 82.26	$ 80.82	$ 86.48	$ 84.73	$ 28.80
Export Price/lb US$	$ 4.24	$ 5.55	$ 5.60	$ 6.57	$ 6.84	$ 5.85	$ 5.27
Japan value share	79%	73%	63%	59%	66%	63%	63%
China value share	10%	10%	17%	21%	18%	20%	20%
Exchange rate, Yen/Dollar	87.7	105.9	121.0	108.8	112.2	110.4	110.5

Note: Exports include production from outside Alaska fisheries.

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; 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). FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NMFS Alaska Region Blend and Catch-accounting System estimates. 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.

Appendix Table 3C.4a. First stage ecosystem indicator analysis for sablefish including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for sablefish of the current year conditions relative to 1 standard deviation of the long-term mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Heatwave GOA	Regional daily mean sea surface temperatures from NOAA climate model processed following Hobday et al., 2016 to obtain marine heatwave cumulative intensity (Barbeaux, 2019)	+
Summer 250 Temperature GOA Slope	Anomalies of summer slope temperature (ºC) at 250 m over all hauls of the ABL Longline survey (Siwicke, *pers. commun.*).	●
Spring Sea Surface Temperature EGOA	Eastern GOA late spring (May-June) sea surface temperature from Pathfinder v5.3 gridded monthly dataset (Casey et al., 2010, GHRSST, CoastWatch)	+
Spring Sea Surface Temperature SEBS	Southeast Bering Sea late spring (May-June) sea surface temperature from Pathfinder v5.3 gridded monthly dataset (Casey et al., 2010, GHRSST, CoastWatch)	+
Spring Peak Phytoplankton Production EGOA	Eastern GOA peak (May) derived chlorophyll *a* from Ocean Colour CCI v4.0 gridded monthly dataset (Jackson et at., 2017, European Space Agency, CoastWatch)	-
Spring Peak Phytoplankton Production SEBS	Southeast Bering Sea peak (May) derived chlorophyll *a* from Ocean Colour CCI v4.0 gridded monthly dataset (Jackson et at., 2017, European Space Agency, CoastWatch)	-
Large Copepod Abundance GOA Shelf CPR	Abundance of large copepods from the continuous plankton recorder over GOA shelf waters (Batten, 2019)	●
Large Copepod Abundance GOA Offshore CPR	Abundance of large copepods from the continuous plankton recorder over GOA offshore waters (Batten, 2019)	-
Summer Euphausiid Abundance Kodiak	Acoustic backscatter per unit area classified as euphausiids and integrated over the water column and across Kodiak core survey area from MACE summer survey (Ressler et al., 2019)	●
Sablefish Growth YOY Middleton Auklets	Anomalies from growth index of sablefish sampled in rhinoceros auklet diet (Arimitsu and Hatch, 2019)	+

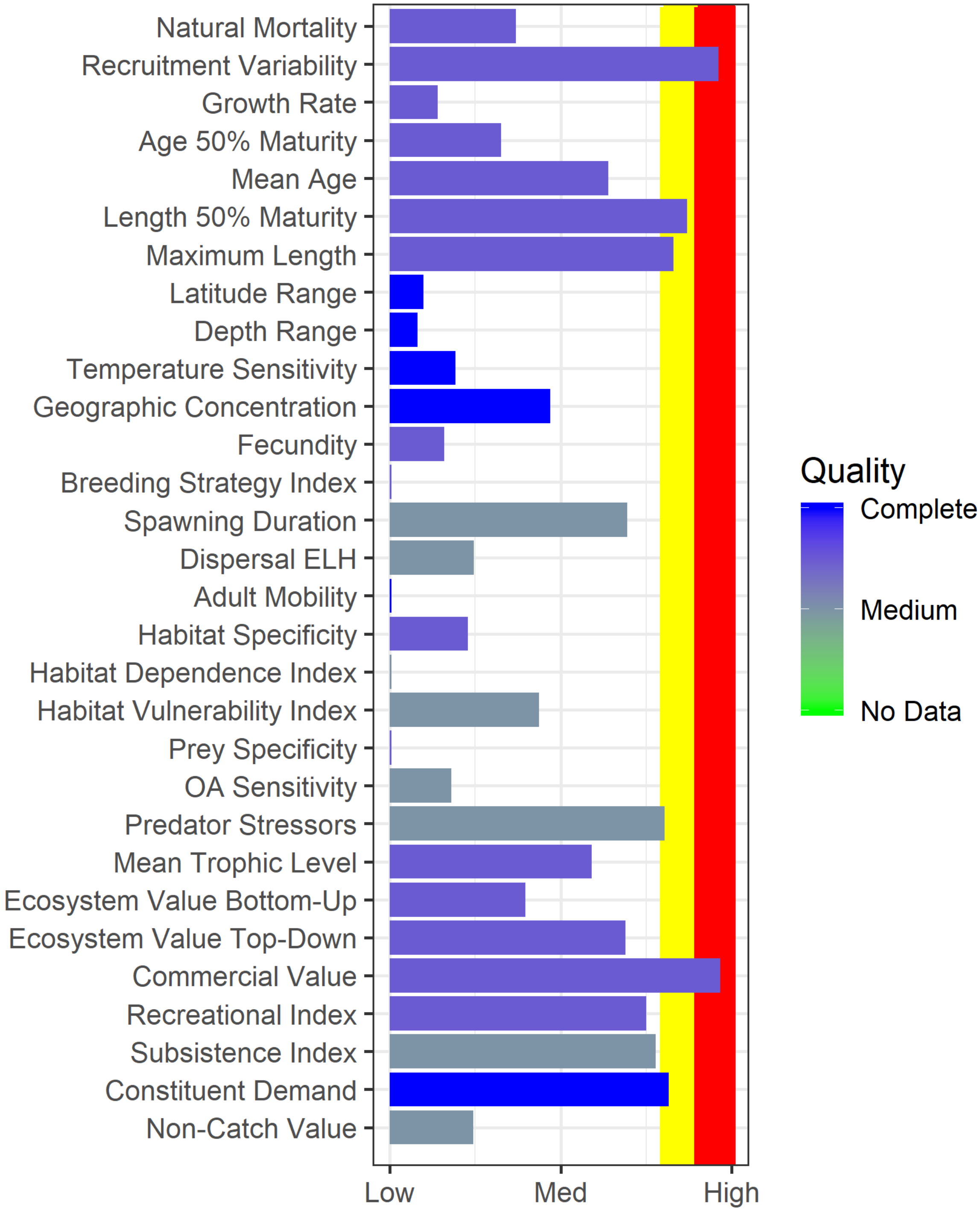
Appendix Table 3C.4a (cont.). First stage ecosystem indicator analysis for sablefish including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for sablefish of the current year conditions relative to 1 standard deviation of the long-term mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Summer Sablefish CPUE Juvenile ADF&G Survey	Catch-per-unit-of-effort for juvenile sablefish in the ADF&G large-mesh survey (Spalinger, *pers. commun.*, 2019)	+
Summer Sablefish CPUE Juvenile GOA BTS Survey	Catch-per-unit-of-effort for age-1 sablefish in the GOA bottom trawl survey (Hanselman, *pers. commun.*)	●
Summer Sablefish Condition Juvenile GOA LL Survey	Length-weight regression of immature juvenile female sablefish sampled randomly for otoliths in the GOA Longline survey, legs 3-7 (Rodgveller, Shotwell, *pers. commun.*)	-
Sablefish Spawner Mean Age	Mean age of spawning sablefish from the most recent sablefish stock assessment model (Hanselman, *pers. commun,*)	-
Sablefish Spawner Age Evenness	Concentration of age composition by cohort (evenness) of female sablefish from the most recent sablefish stock assessment model (Hanselman, *pers. commun.*)	-
Summer Sablefish Condition Age 4 GOA LL Survey	Length-weight regression of age 4 female sablefish sampled randomly for otoliths in the GOA Longline survey, legs 3-7 (Shotwell, Rodgveller, *pers. commun.*)	●
Arrowtooth Biomass Assessment	Total biomass estimates from arrowtooth flounder stock assessment model output (Spies et al., 2017)	●
Sablefish Incidental Catch Arrowtooth Fishery	Incidental catch of sablefish in the GOA arrowtooth flounder fishery (Shotwell, *pers. commun.*)	+
Summer Benthic Abundance GOA LL Survey	Averaged anomalies of the relative population weights for primary sampled species on the GOA longline survey (Shotwell, *pers. commun.*)	-
Summer Sablefish Condition Adult GOA LL Survey	Length-weight regression of large (>=75 cm) female sablefish sampled randomly for otoliths in the GOA Longline survey, legs 3-7 (Shotwell, Rodgveller, *pers. commun.*)	●

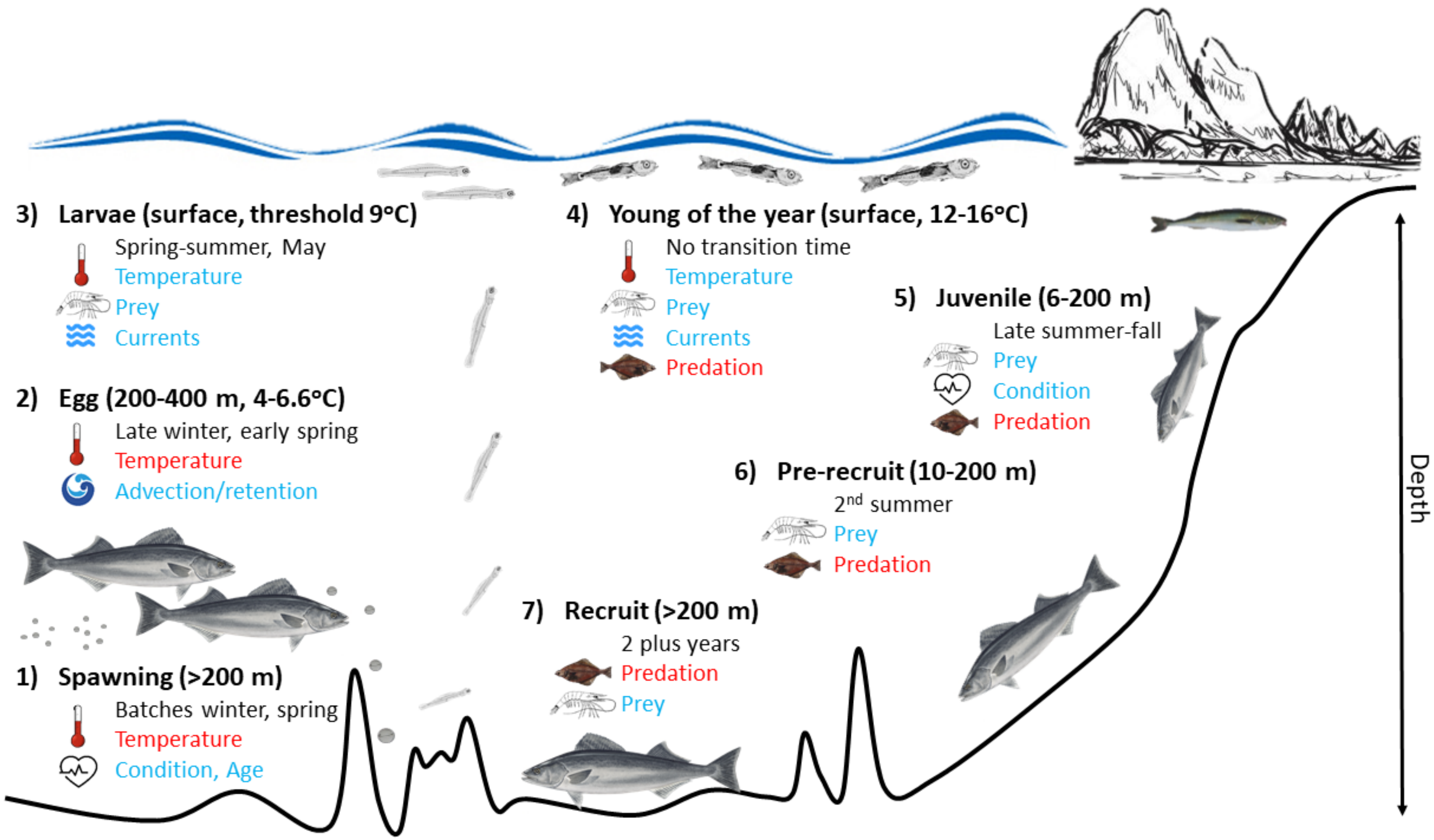
Appendix Table 3C.4b. First stage socioeconomic indicator analysis for sablefish including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for sablefish of the current year conditions relative to 1 standard deviation of the long-term mean (yellow = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Sablefish CPUE Longline Fishery GOA	Catch per unit of effort of sablefish from the longline fisheries in the GOA (Hanselman, *pers. commun.*)	-
Sablefish CPUE Pot Fishery EBS	Catch per unit of effort of sablefish from the pot fisheries in the eastern Bering Sea (Hanselman, *pers. commun.*)	+
Sablefish Incidental Catch BSAI Fisheries	Incidental catch of sablefish in the Bering Sea fisheries excluding the sablefish fishery (Shotwell, *pers. commun.*)	+
Sablefish Incidental Catch GOA Fisheries	Incidental catch of sablefish in the GOA fisheries excluding the sablefish fishery (Shotwell, *pers. commun.*)	●
Sablefish Condition Adult GOA Fishery	Length-weight regression of large (>=75 cm) female sablefish sampled by observers during in the GOA fisheries (Shotwell, Rodgveller, *pers. commun*.)	●
Sablefish Condition Adult BSAI Fishery	Length-weight regression of large (>=75 cm) female sablefish sampled by observers during in the BSAI fisheries (Shotwell, Rodgveller, *pers. commun*.)	+
Annual Sablefish Real Ex-vessel Value	Estimate of real ex-vessel value in millions inflation adjusted to 2018 USD (Fissel et al., 2019)	●
Small Sablefish Price	Average price per pound of small sablefish in BSAI fixed gear fisheries (Armstrong et al., 2018)	-

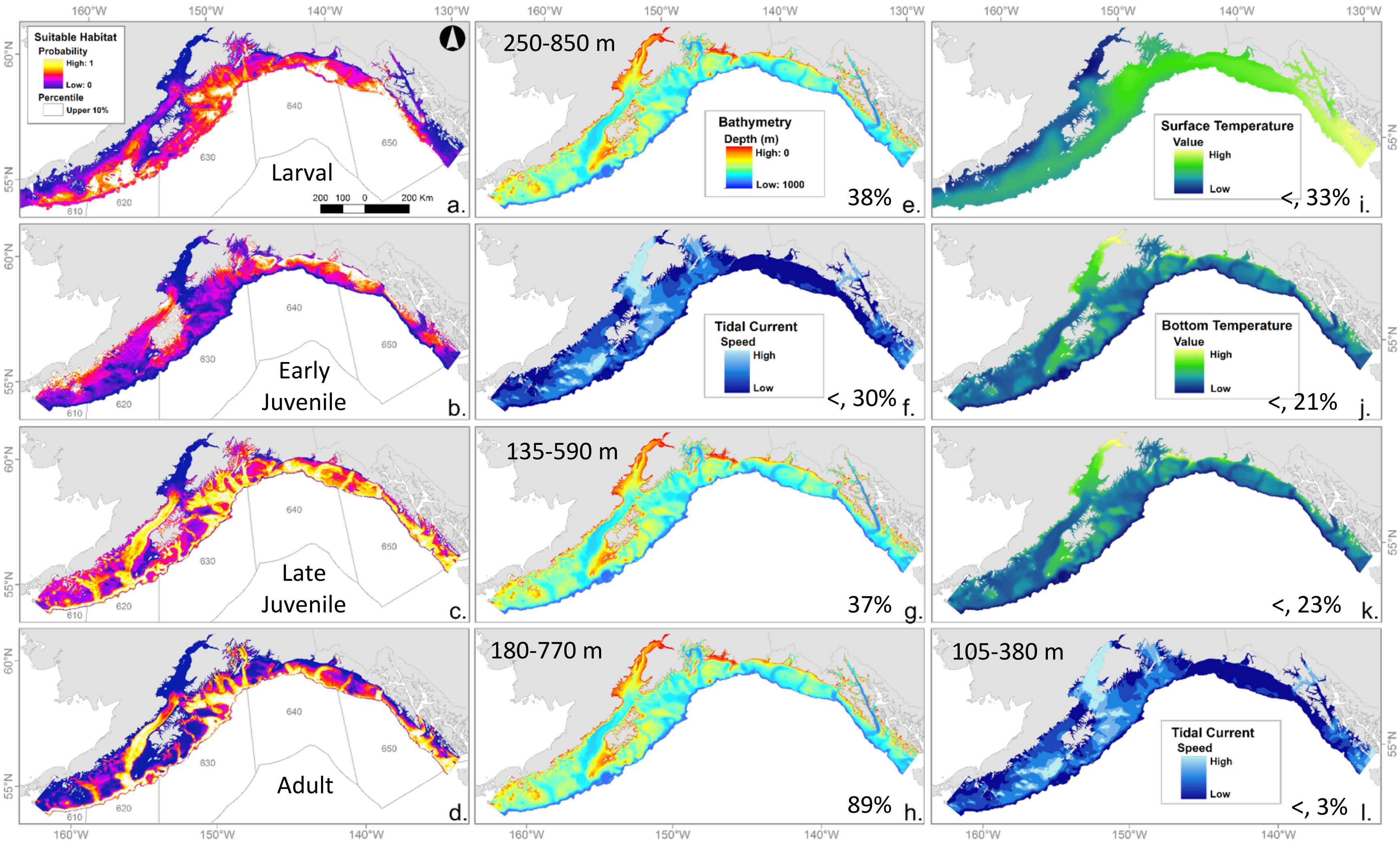
Figures



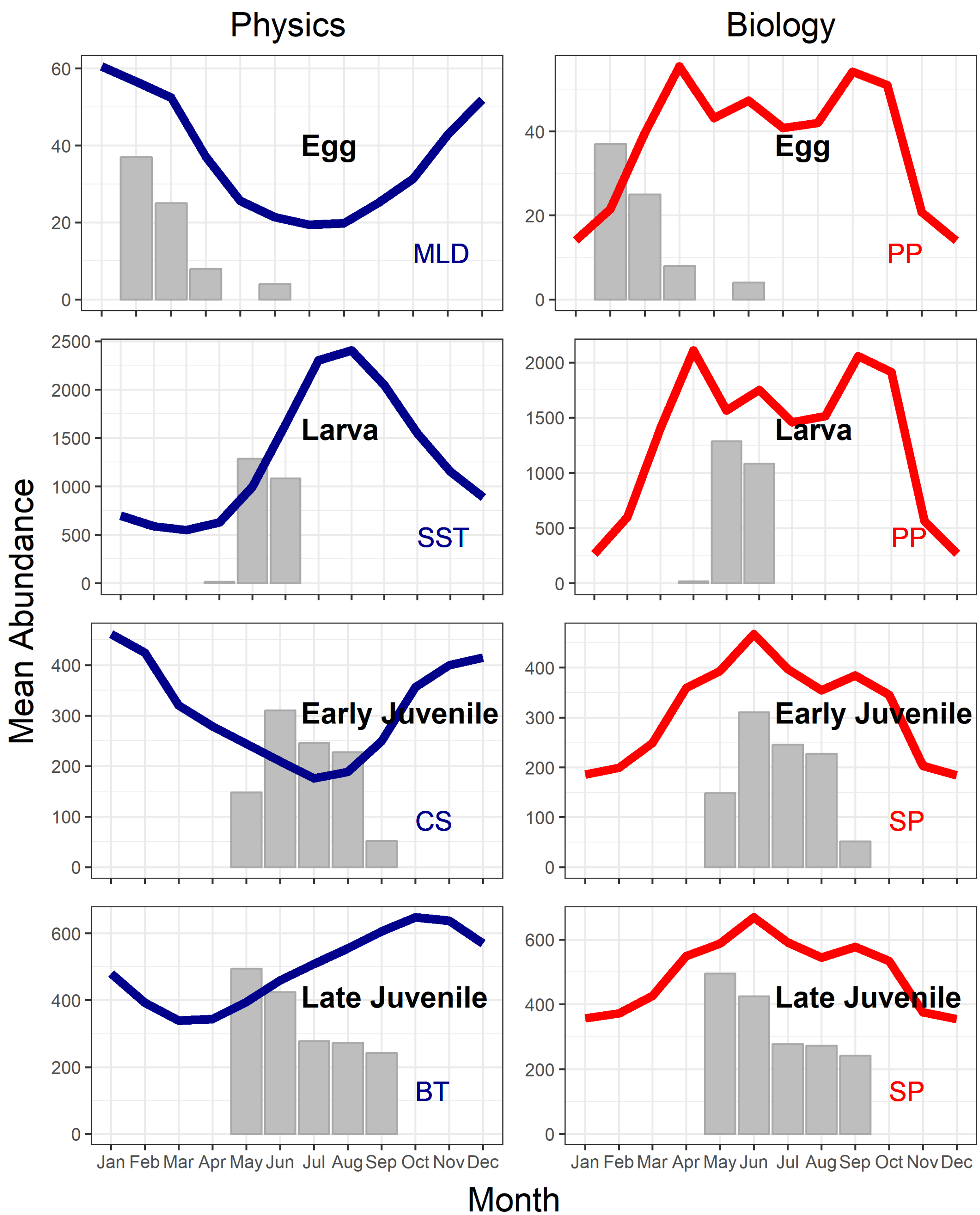
Appendix Figure 3C.1. Baseline metrics for sablefish graded as percentile rank over all groundfish in the FMP. Red bar indicates 90th percentile, yellow bar indicates 80th percentile. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions).



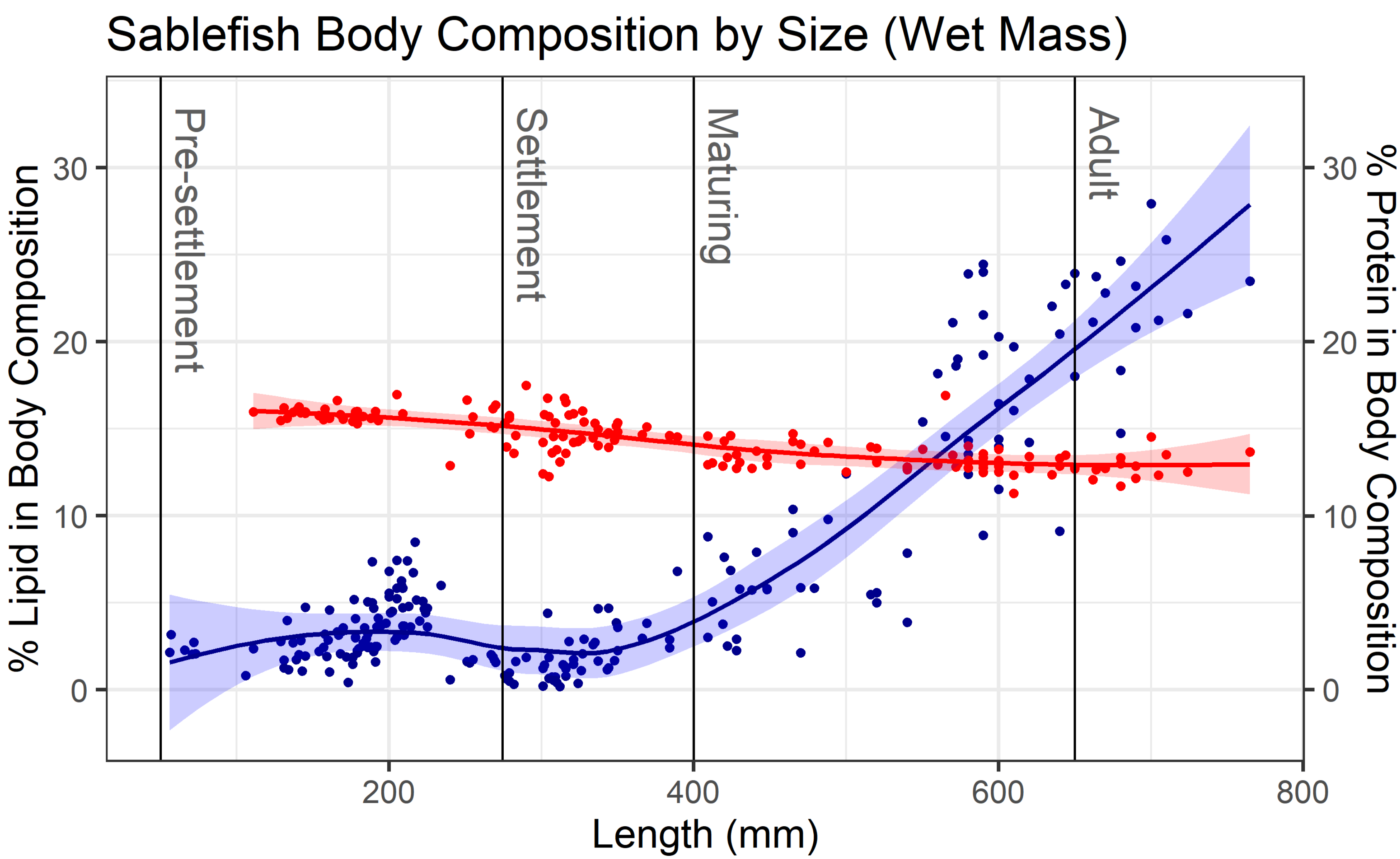
Appendix Figure 3C.2: Life history conceptual model for sablefish summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.



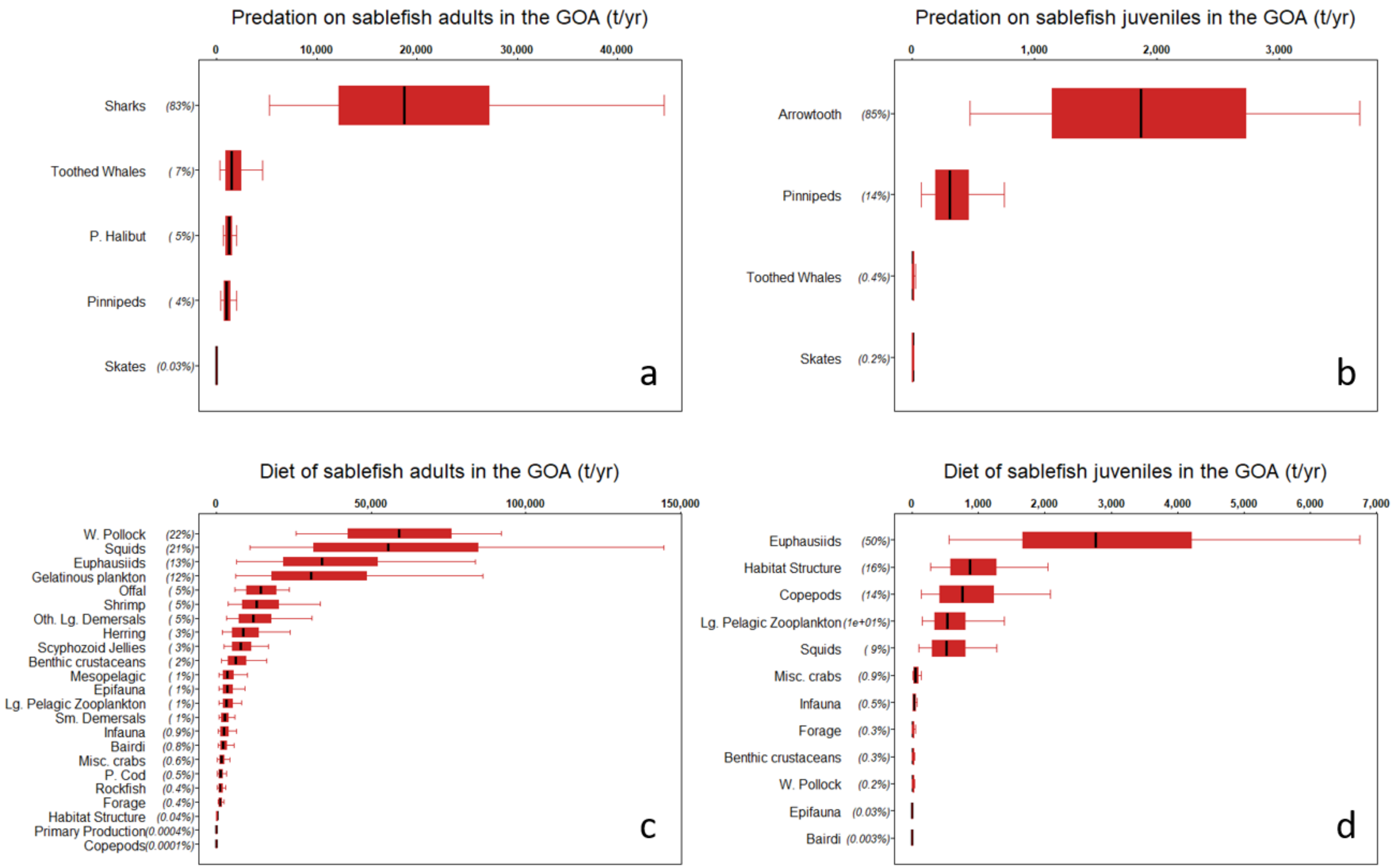
Appendix Figure 3C.3. Sablefish probability of suitable habitat by life stage (a=larval, b=early juvenile, c=late juvenile, and d=adult) with predictor habitat variables representing the highest (e=depth, f=tidal current speed, g=depth, h=depth) and second highest contribution (i=surface temperature, j=bottom temperature, k=bottom temperature, and l=tidal current speed). Upper 10 %-ile 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.



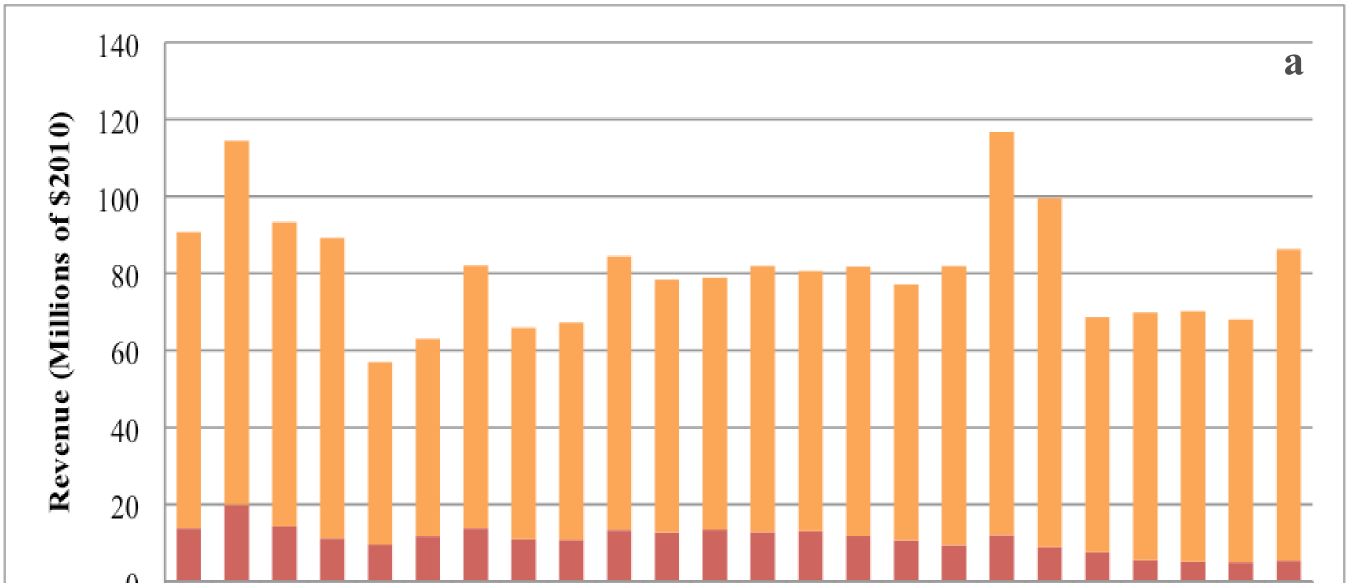
Appendix Figure 3C.4. Sablefish average abundance by month over all years available for the egg, larval, nearshore juvenile, and offshore juvenile stages available from EcoFOCI for egg and larvae stages, and AFSC bottom trawl and longline surveys for juvenile stage. Relevant climatologies from the hydrographic and plankton models provide physical and biological indices (MLD = mixed layer depth, SST = surface temperature, CS = current speed, BT = bottom temperature, PP = primary productivity, and SP = secondary productivity, see Laman et al., 2017, Gibson et al., *In Press*, for more details).



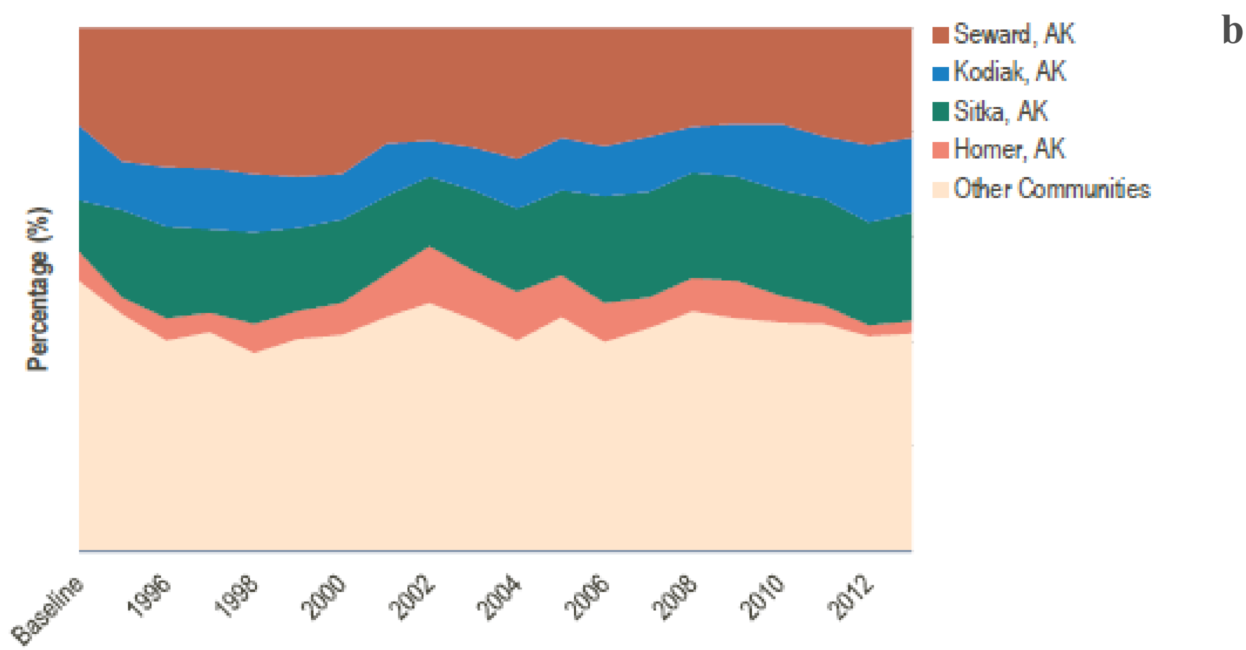
Appendix Figure 3C.5. Sablefish percent body composition by length (mm), blue dots are % lipid by size, red dots are % protein by size and lines represent smoother (loess) for trend visualization. Horizontal lines depict the average size at different life stage transitions and the adult transition is based on size at 50% female maturity.



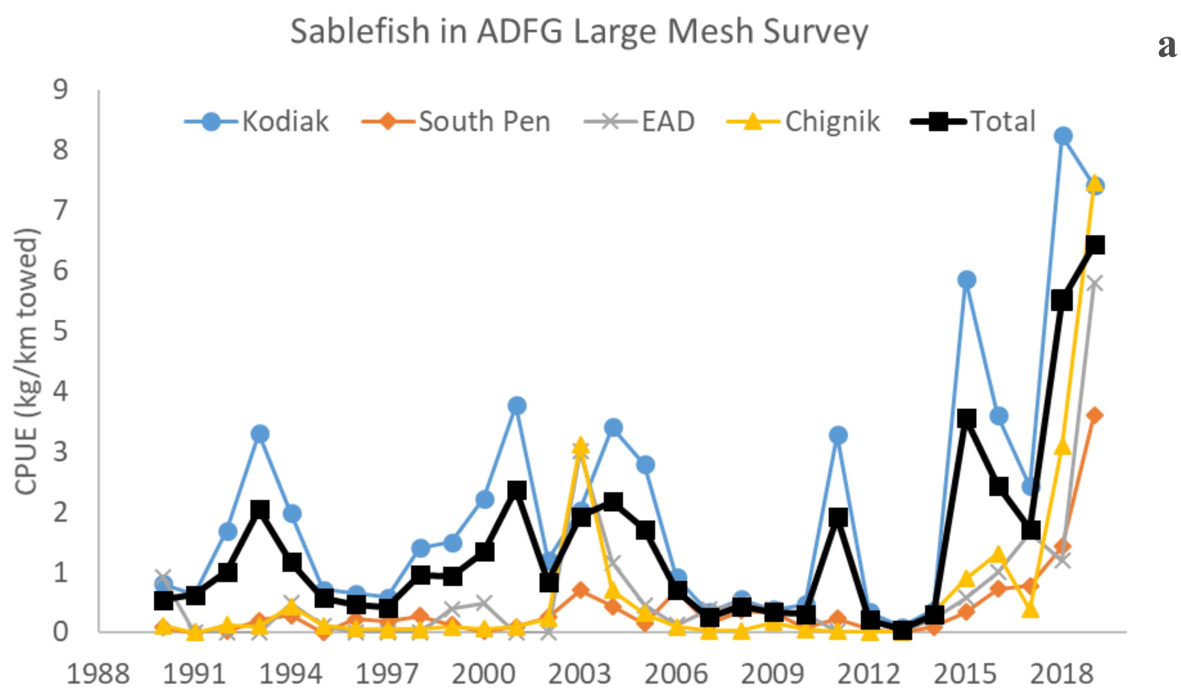
Appendix Figure 3C.6. Sources of predation mortality for (a) adult (>200 mm) and (b) juvenile sablefish (<=200 mm) in the GOA, and diet composition for (c) adult and (d) juvenile sablefish in the GOA (Aydin et al., 2007).

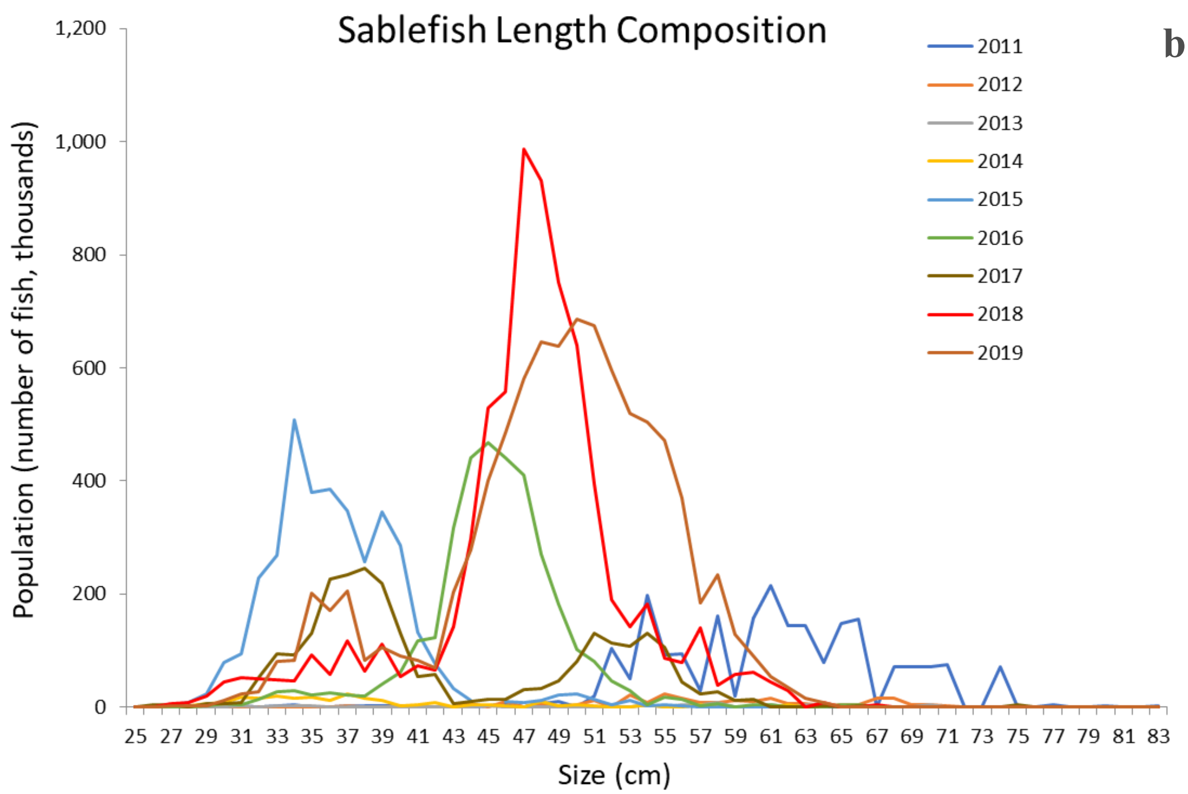


	Baseline	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CV	76.9	94.5	79.0	78.0	47.4	51.3	68.3	54.9	56.5	71.1	65.6	65.5	69.1	67.6	70.0	66.5	72.4	104.8	90.7	61.0	64.3	65.1	63.0	80.9
CP	13.8	19.9	14.3	11.2	9.6	11.7	13.8	11.0	10.8	13.4	12.8	13.4	12.9	13.1	11.8	10.7	9.5	12.0	8.9	7.6	5.6	5.1	5.0	5.4

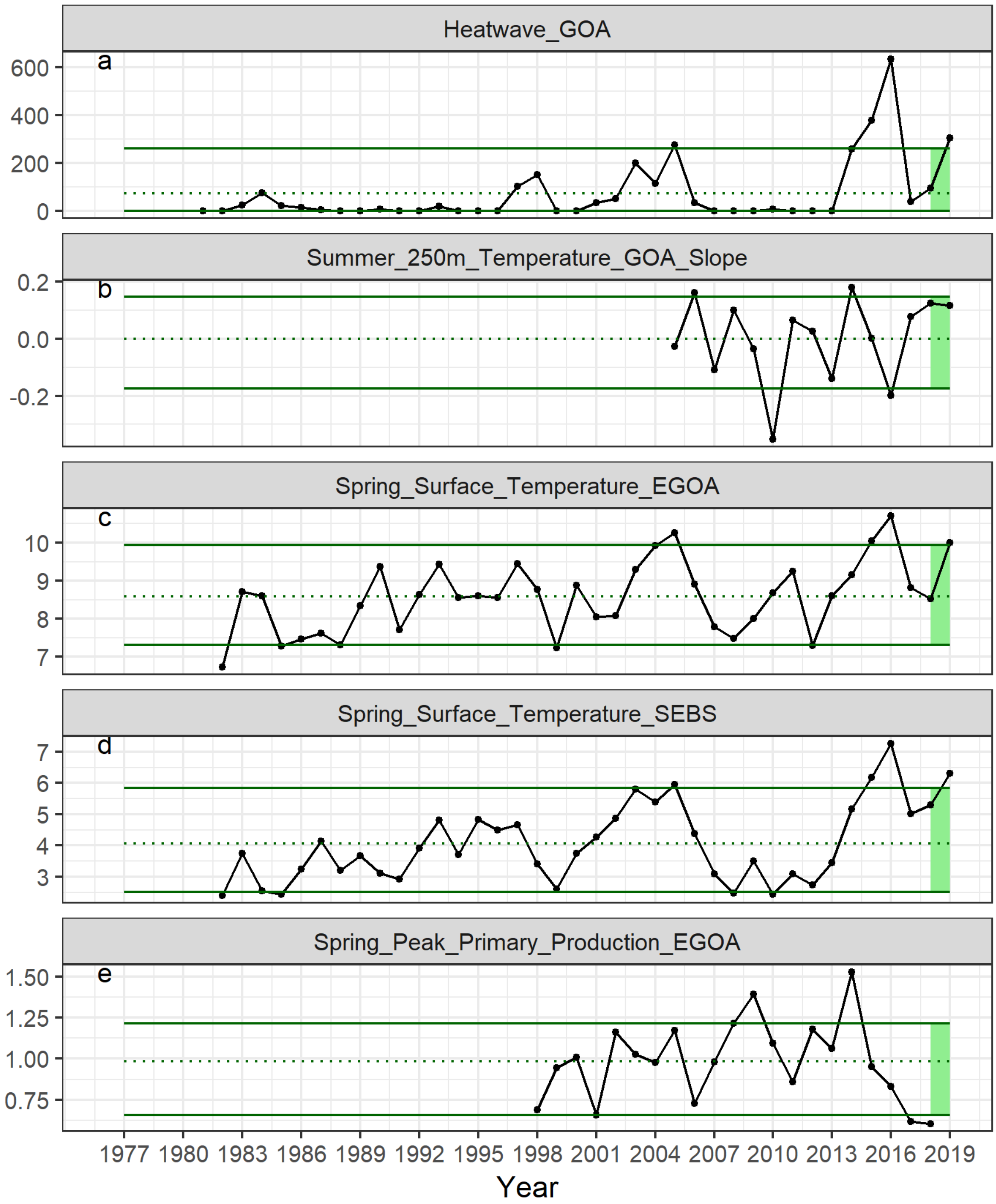


Appendix Figure 3C.7. Revenue in millions from landings of sablefish as part of the Community Development Quota (CDQ) program separated by catcher vessels (CV) and catcher processors (CP) (a) and Regional Quotient (expressed in percent) for communities highly engaged in the sablefish IFQ portion of the Alaska Halibut and Sablefish Individual Fishing Quota Program (b).

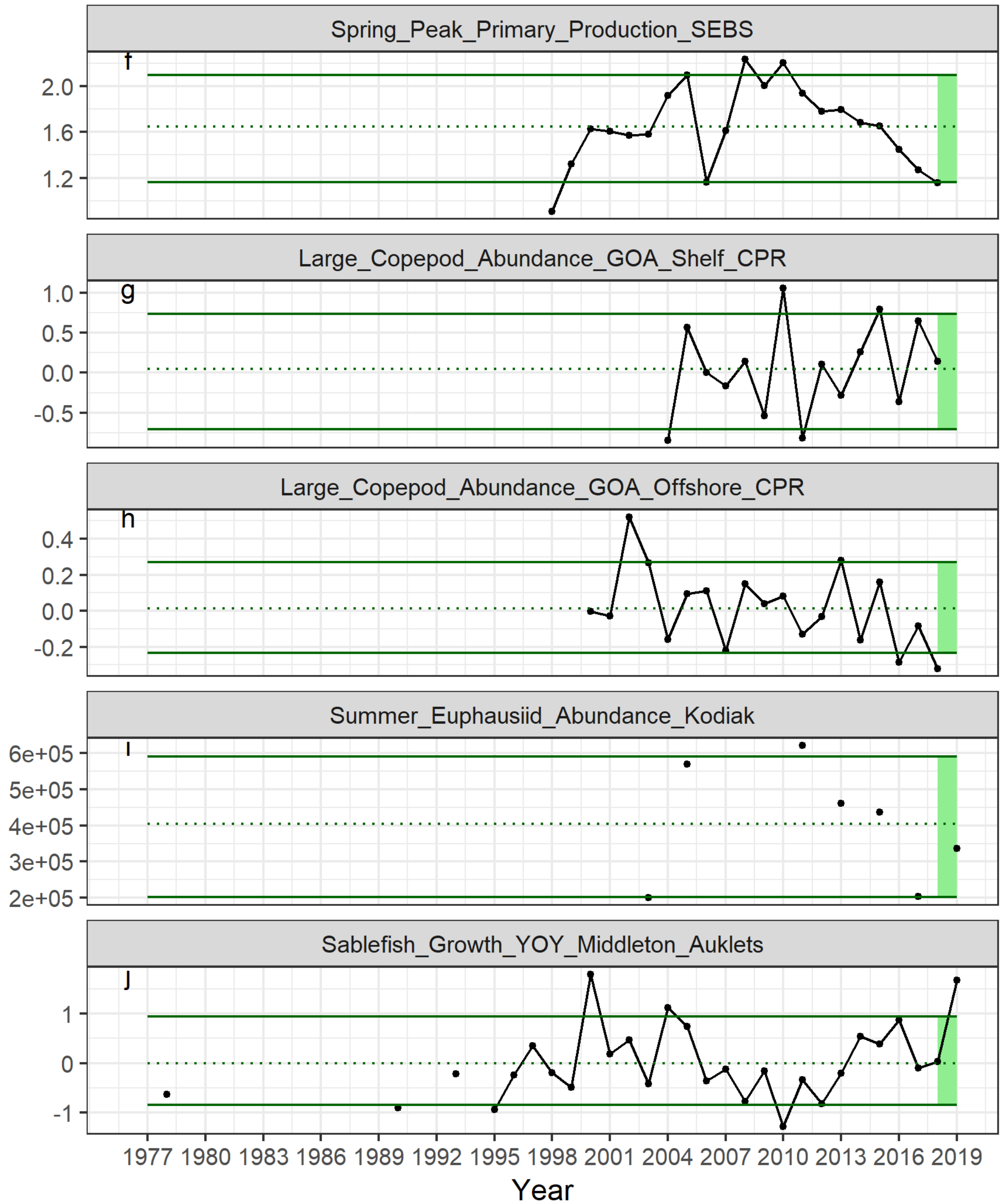




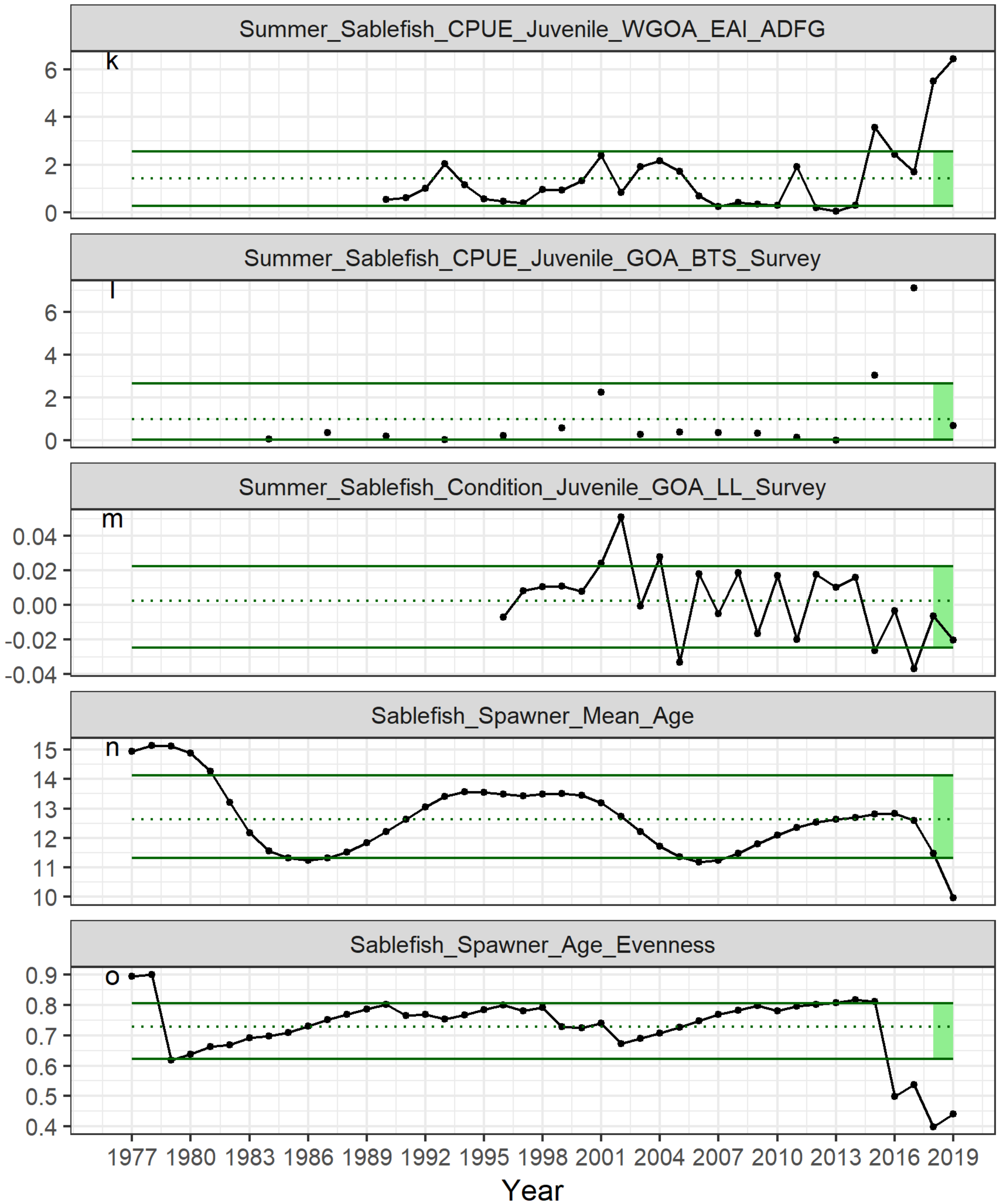
Appendix Figure 3C.8: Catch-per-unit-effort (top graph) from 1990 to present and length (cm) composition (bottom graph) from 2011 to present of sablefish in the ADF&G large-mesh survey.



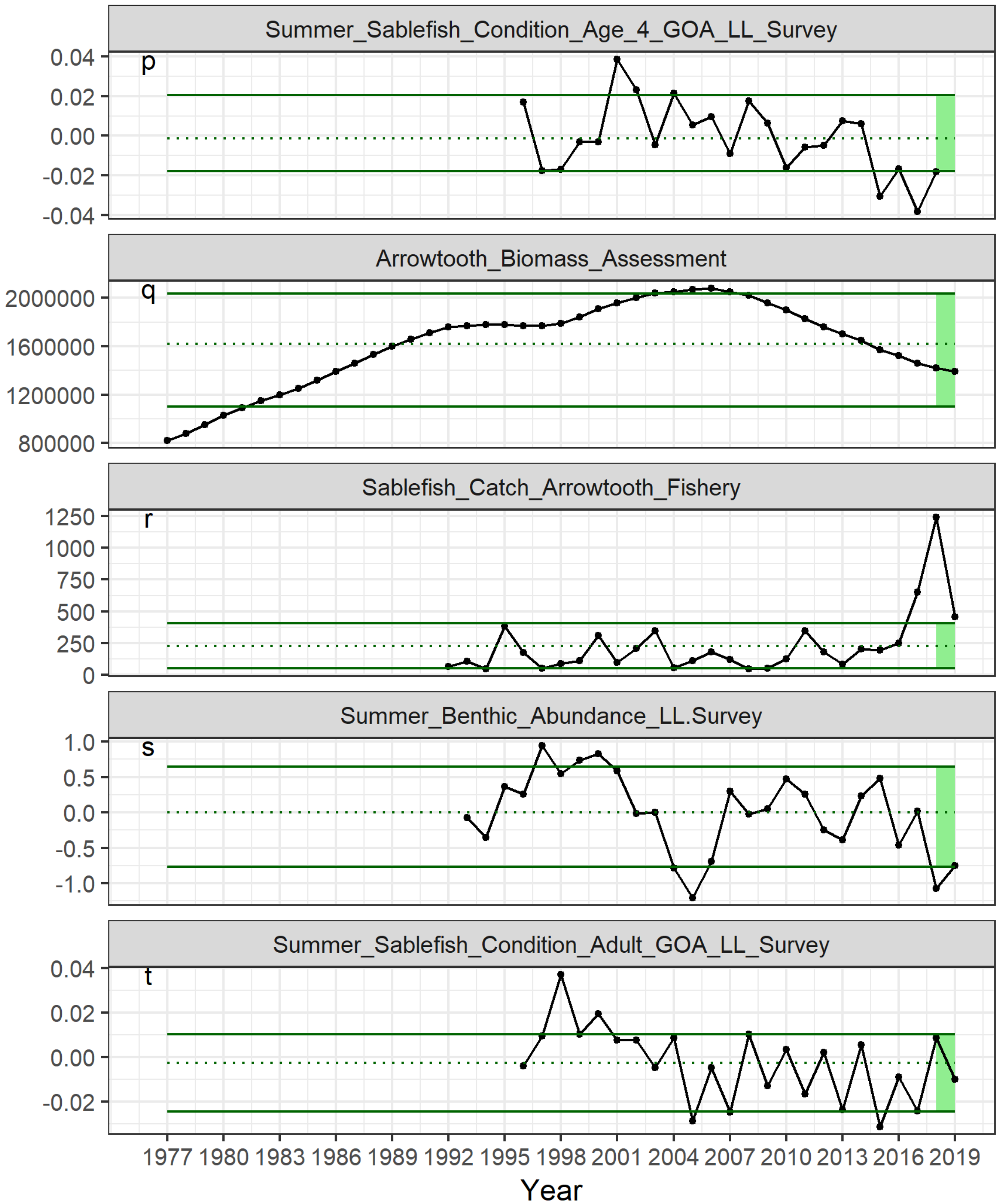
Appendix Figure 3C.9a. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



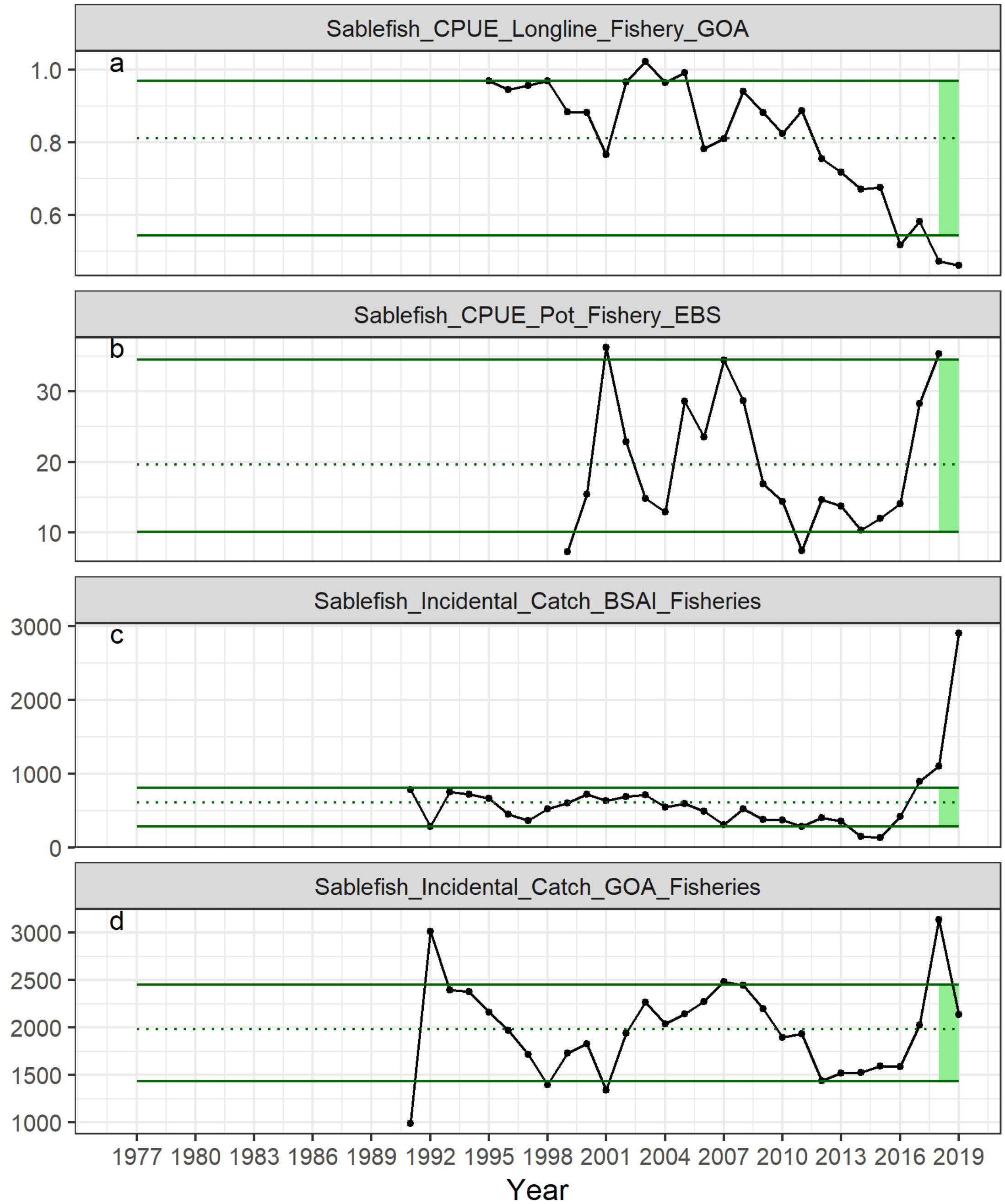
Appendix Figure 3C.9a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



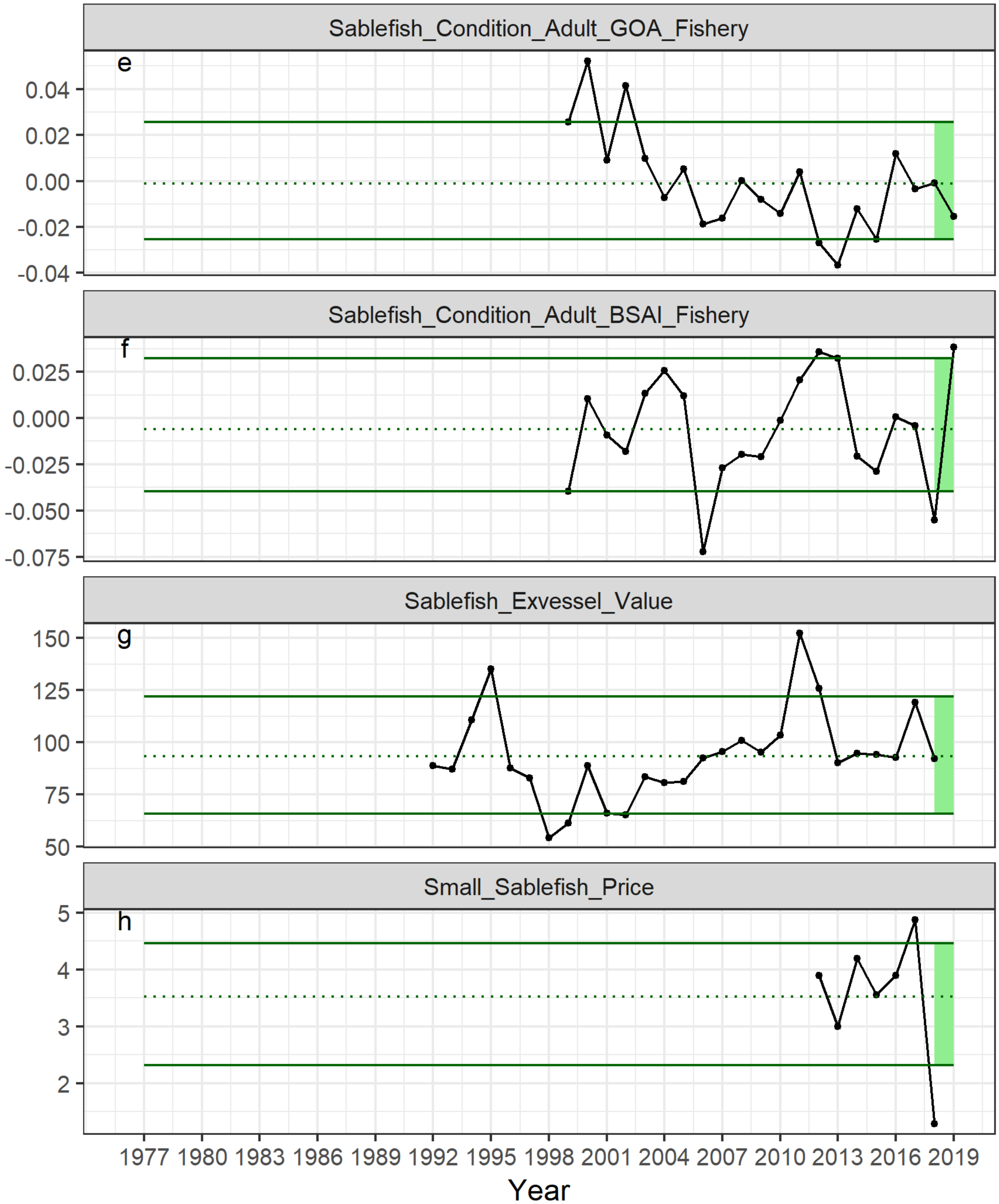
Appendix Figure 3C.9a (cont). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



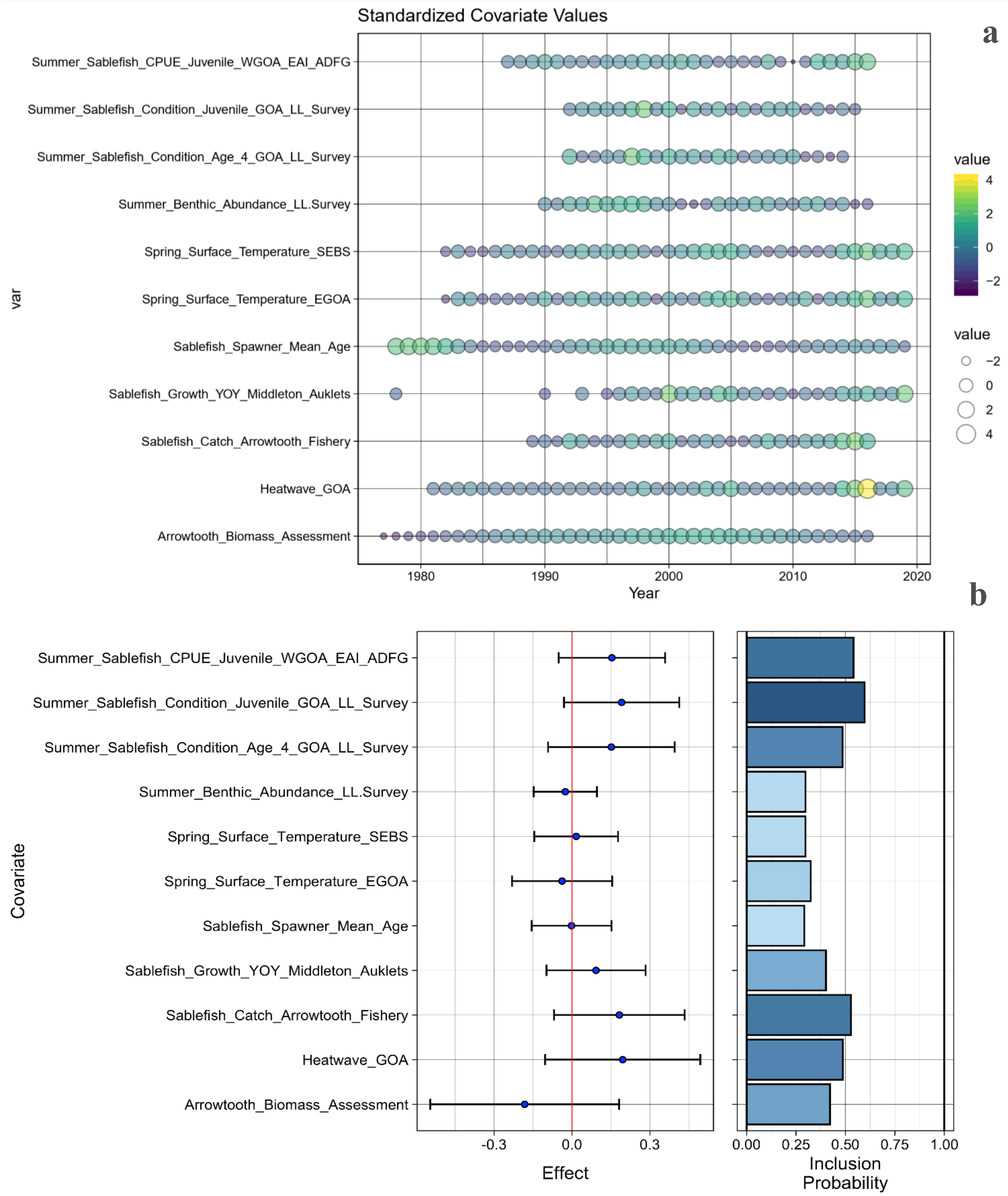
Appendix Figure 3C.9a (cont). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



Appendix Figure 3C.9b. Selected socioeconomic 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 year for traffic light analysis.



Appendix Figure 3C.9b. Selected socioeconomic indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10$_{th}$ percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent year for traffic light analysis.



Appendix Figure 3C.10: Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (1 standard deviation) with log sablefish recruitment, in each estimated effect (left bottom graph), and marginal inclusion probabilities (right bottom graph) for each predictor variable of the subsetted covariate set.

Appendix 3D. Preliminary evaluation of alternative sablefish apportionment strategies

Kari Fenske, Curry Cunningham, Dana Hanselman

October 28, 2019

Introduction and methods overview

Sablefish (*Anoplopoma fimbria*) in Alaska are managed on an Alaska-wide scale because movement rates among management regions are high and exploitation rates are sufficiently low. Each year the sablefish stock assessment model estimates ABC and OFL values that are subsequently apportioned among six management regions. The combined ABC has been apportioned to regions using weighted moving 5-year average methods since 1993; this method was intended to reduce the magnitude of inter-annual changes in apportionment, providing stability between years for harvesters. However, since 2014, apportionment of sablefish ABC among management regions has been fixed at the 2013 recommended proportions because the objective of reducing variability in apportionment was not being achieved. To evaluate alternative apportionment strategies, we developed a simulation-estimation framework that includes a spatial operating model combined with a modified stock assessment estimation model. Through simulation analysis, we examine sablefish biomass responses to varying fishing mortality rates among management regions and the influence of alternative apportionment strategies.

The primary objective of the analyses presented in this document is to examine the performance of a suite of sablefish ABC apportionment methods. This is a work in progress and we are seeking feedback on operating model (OM) and estimation model (EM) designs, alternative performance metrics that would be useful in comparing outcomes of apportionment methods, developing recommendations, and any other suggestions for simulation and model performance.

These apportionment simulation analyses contain two primary components, a 6-area OM and a 1-area EM that is similar to the design of the current age-structured stock assessment model. The six OM areas correspond to the six sablefish management areas: Aleutian Islands (AI), Bering Sea (BS), Western Gulf of Alaska (WGOA), Central GOA (CGOA), West Yakutat (WY), and East Yakutat/Southeast Outside (EY/SEO). The OM is spatially explicit so potential area-specific dynamics in fleet or fish behavior (e.g. catchability, selectivity, or fish movement) may be simulated. The OM simulates data in two periods - a deterministic conditioning period for years 1977-2018 that is the same across simulations, and a stochastic forward projection period which runs for years 2019-2028. The EM is similar to the EM currently used for sablefish management, but begins in 1977 instead of 1960, does not include length compositions, and does not include a trawl survey index of abundance. After the conditioning period, data are generated by the OM, samples are generated from the OM population with observation error, and these simulated data are combined into a single area dataset that is passed to the single-area EM.

In the forward projecting period, the OM-EM is iterative, looping through years. **The order of operations for year *y* are:**

OM - Read in previous year's apportioned ABC by area

Estimate the F required to catch ABC for each area

Apply F and M to OM population

Move fish among areas

Sample the population for fishery and longline survey abundance indices and for longline survey and fixed gear fishery age compositions

Build the data file and pass it to the EM in AD Model Builder

Run the EM (fit the simplified assessment model to simulated data) and get an estimate of the next year's ABC (then repeat for the next year).

For each of the 11 apportionment methods explored, 100 replicate simulations covering years 1977-2028 are run with different process and observation error deviates in reach realization.

The following are assumptions in these simulations:

We assume ABC=TAC and 100% of apportioned ABC is caught in each region.

We do not correct for whale depredation in the ABC or survey index.

Recruitment occurs at age 2 and recruitment is split equally between males and females. Recruitment draws for the incoming recruitment classes during the forward projections are capped at 50 million. The large 2014 year class in the conditioning period has also been reduced from 150 million fish to 50 million. These changes were made to improve EM convergence.

The NPFMC Tier 3 harvest control rules are still in place and used for determining ABC in the EM; we are only simulating different methods for apportioning ABC to management areas.

Alternative apportionment scenarios examined

In the analyses presented in this document we examine 11 apportionment methods: Equal, Fixed, Equilib, NPFMC, Exp_survey_wt, Exp_fish_wt, Non-Exp_NPFMC, Part_fixed, Age_based, Term_LLsurv, All_to_one. A summary of each apportionment method is below.

Equal: Each region receives 1/6 of the ABC.

Fixed: The apportionment proportions from the 2013 assessment that have been applied as fixed proportions for 2014-2018.

Equilibrium: Proportions in each area are based on the stationary distribution of the movement rates.

NPFMC: A 5-yr exponentially weighted moving average of fishery and survey indices; survey weight is 2x fishery weight (NPFMC accepted method, used 2000-2013).

Exp_survey_wt: Similar to 'NPFMC' option but using survey index only.

Exp_fishery_wt: Similar to 'NPFMC' option but using fishery index only.

Non-Exp_NPFMC: A 5-yr moving average of fishery and survey indices.

Partial_fixed: BS and AI receive 10% of the ABC each, WG, CG, WY, and EY are apportioned based on NPFMC method.

Age_based: Based on the proportions of fish at age of 50% maturity in each area - i.e. areas with greater proportion of fish at age of 50% maturity or greater will be apportioned a greater proportion of ABC. Results shown in this document are for an age at 50% = 6.

Term_LLsurv: Terminal year of longline survey (no exponential weighting).

All_to_one: 95% of ABC is apportioned to one area and 1% to the other five management areas. This is an extreme example to show model behavior, not a scenario intended for management. For this document, the Bering Sea area was chosen to receive 95% of the ABC.

Performance metrics and summary of simulation results

There are several key concerns regarding apportionment that we examine and they can be loosely grouped into broader, but related, categories of 1) sustainability, 2) stability, and 3) value/other. The table below summarizes a few examples from each of these categories to illustrate the tradeoffs among apportionment types, and further details and results are included in the report text.

Table 1. Comparison of performance metrics for each apportionment method for the forward projecting period. In the table, '**Mean SSB/B40**' is the mean across simulations and areas of the ratio of terminal year (2028) SSB to B40 estimated by the terminal year estimation model for each apportionment method. The performance metric described as '**Apportionment match to SSB**' (and also for total biomass) gives the mean absolute percent difference between SSB proportions by area (using OM data) and the proportions of ABC each area would receive under the respective apportionment methods. A value near zero indicates the apportionment method closely matches the true population biomass in each area. '**Mean depletion SSB2028/SSB1977**' is the mean across simulations and areas of the ratio of estimated SSB in 2028 to SSB in 1977. The '**Mean Interannual Variability**' performance metric is the mean (across simulations and areas or just simulations) interannual variability in ABC. '**Mean ABC**' is the mean ABC across simulations and areas (for 'all areas') or the proportion of ABC apportioned to each management area. The '**Mean age**' performance metric is the mean age in the OM population in a given management area across simulations. Finally, the '**Relative Mean Value of catch**' presents the expected value of sablefish catches using an assumption of market value of sablefish at age from recent (2018) market value data, as relative proportions across apportionment methods and areas.

Table 1.

Performance metric	Equal	Fixed	Equilib.	NPFMC	Exp- survey	Exp-fish	Non-Exp_ NPFMC	Partial fixed	Age based	Terminal LLsurv	All to one
	Apportionment Method										
Sustainability											
Mean SSB/B_{40}	0.96	0.97	0.96	0.97	0.97	0.96	0.97	0.97	0.96	0.97	1.01
Apportionment match to SSB (%)	53.4	27.8	25.5	17.0	11.4	30.5	16.6	21.3	45.3	11.3	162.0
Apportionment match to total biomass (%)	70.2	53.7	49.9	43.5	40.1	50.4	42.6	46.5	63.4	39.9	162.2
Mean Depletion SSB_{2028}/SSB_{1977}	0.66	0.66	0.65	0.65	0.66	0.65	0.66	0.65	0.65	0.65	0.69
Variability											
Mean interannual varibility - all areas (%)	14.0	13.7	14.1	13.7	14.0	14.0	14.1	14.2	14.0	14.1	17.1
Mean interannual varibility - BS (%)	14.0	13.7	14.1	16.0	15.4	18.1	17.0	14.2	19.7	15.3	17.1
Mean interannual varibility - AI (%)	14.0	13.7	14.1	14.7	14.5	16.9	15.4	14.2	14.6	14.4	17.1
Mean interannual varibility - WGOA (%)	14.0	13.7	14.1	15.3	14.8	17.0	16.3	16.3	16.7	14.7	17.1
Mean interannual varibility - CGOA (%)	14.0	13.7	14.1	13.8	14.1	14.4	14.2	14.7	13.9	14.3	17.1
Mean interannual varibility - WYAK (%)	14.0	13.7	14.1	12.8	13.7	12.1	13.3	13.5	12.9	14.0	17.1
Mean interannual varibility - EY/SEO (%)	14.0	13.7	14.1	12.4	13.3	11.8	13.2	13.0	12.3	13.8	17.1
ABC and age structure											
Mean ABC - all areas	20.6	20.3	20.3	20.4	20.5	20.3	20.6	20.4	20.3	20.3	22.3
Mean ABC (prop. by area) - BS (%)	0.17	0.10	0.09	0.08	0.07	0.11	0.08	0.10	0.13	0.07	0.95
Mean ABC (prop. by area) - AI (%)	0.17	0.13	0.14	0.10	0.10	0.08	0.10	0.10	0.17	0.10	0.01
Mean ABC (prop. by area) - WGOA (%)	0.17	0.11	0.13	0.14	0.12	0.19	0.14	0.14	0.14	0.12	0.01
Mean ABC (prop. by area) - CGOA (%)	0.17	0.34	0.27	0.29	0.31	0.26	0.29	0.29	0.17	0.31	0.01
Mean ABC (prop. by area) - WYAK (%)	0.17	0.11	0.14	0.14	0.14	0.13	0.14	0.14	0.18	0.14	0.01
Mean ABC (prop. by area) - EY/SEO (%)	0.17	0.21	0.23	0.24	0.25	0.23	0.25	0.24	0.21	0.25	0.01
Mean Age of population BS	5.6	5.7	5.7	5.7	5.8	5.7	5.7	5.7	5.7	5.8	5.5
Mean Age of population AI	6.8	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.8	6.9	7.1
Mean Age of population WGOA	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.5
Mean Age of population CGOA	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.3
Mean Age of population WY	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	8.0
Mean Age of population EY/SEO	8.5	8.5	8.5	8.4	8.4	8.5	8.4	8.5	8.5	8.5	8.9
Value											
Relative mean value of catch BS	0.87%	0.80%	0.79%	0.79%	0.77%	0.82%	0.79%	0.81%	0.85%	0.78%	1.28%
Relative mean value of catch AI	0.80%	0.76%	0.78%	0.74%	0.74%	0.73%	0.74%	0.75%	0.83%	0.76%	0.65%
Relative mean value of catch WGOA	1.04%	0.97%	1.00%	1.03%	0.99%	1.09%	1.03%	1.03%	1.04%	1.01%	0.88%
Relative mean value of catch CGOA	3.02%	3.21%	3.12%	3.20%	3.18%	3.15%	3.20%	3.19%	3.02%	3.22%	2.84%
Relative mean value of catch WY	1.19%	1.12%	1.16%	1.17%	1.16%	1.16%	1.18%	1.17%	1.23%	1.19%	1.03%
Relative mean value of catch EY/SEO	2.14%	2.18%	2.21%	2.24%	2.23%	2.23%	2.26%	2.24%	2.20%	2.26%	1.96%

Performance Metrics Results

Sustainability

The sustainability of the sablefish population is a primary scientific objective and we evaluate how different methods of ABC apportionment perform with respect to:

1) maintaining spawning stock biomass (SSB), for all areas combined, at or above the B40 biological reference point;

2) the degree to which the ABC proportions by area for each apportionment method match the longline survey proportions of spawning and total biomass observed ('known' from OM) in each area;

3) terminal year SSB depletion relative to 1977 SSB.

In the following figures, the boxplots show the median (thick line inside the box) and the 25th and 75th percentile interquartile range (box lower and upper border) across the replicate 100 simulations of each time series. The vertical bars represent the largest and smallest values within 1.5 times the interquartile range, and any values outside these ranges are shown as points.

Sustainability metric 1: Maintaining SSB, for all areas combined, at or above the B40 biological reference point.

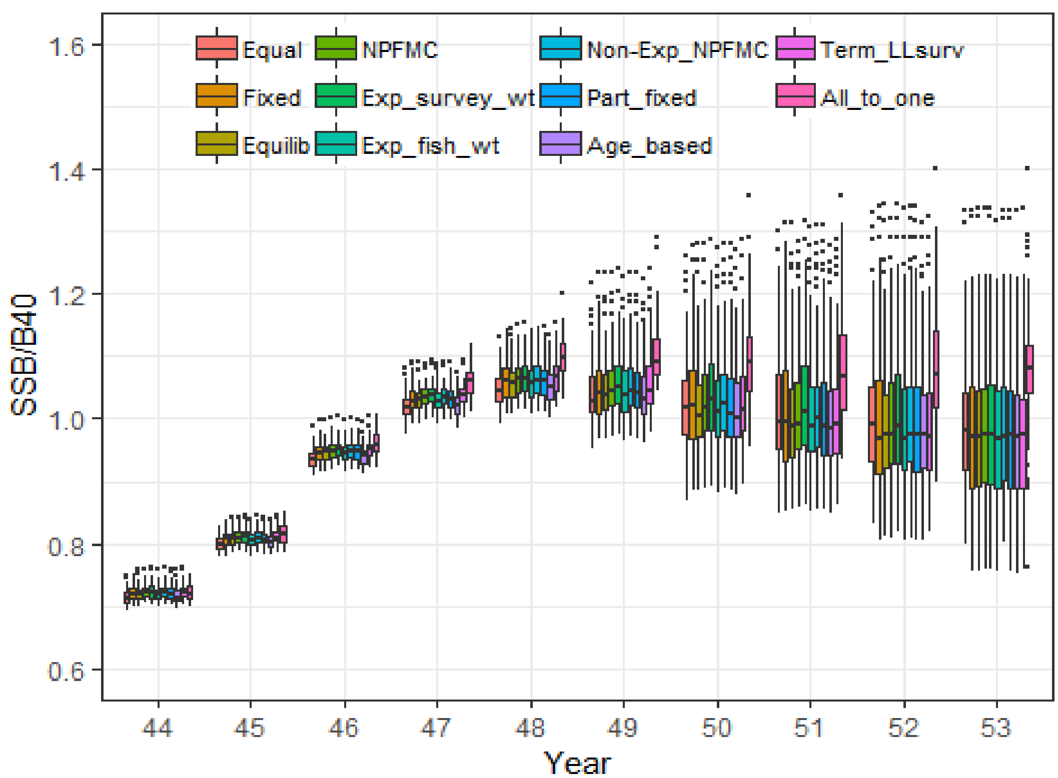


Figure 1. Spawning biomass/B40 for each year of forward projecting simulations (year 44 = 2019) and each apportionment method.

For each year, simulation, and apportionment method we calculate the SSB/B40 ratio from the EM output. The NPFMC harvest control rule is designed to limit fishing mortality when SSB/B40 falls below

1. The apportionment methods all perform similarly with respect to SSB/B40, which suggests the harvest control rule is functioning as intended, independent of the apportionment strategy.

Sustainability metric 2: The percent difference between ABC proportions by area and the spawning and total biomass observed ('known' from OM).

Because we use a single-area stock assessment for management, we do not currently have estimates of sablefish total biomass or spawning stock biomass in each management area, though the longline survey should produce a reasonable estimate. However, since this is a simulation, we can examine how well each apportionment method tracks the 'true' (simulated) population's spawning and total biomass in each management area.

Table 2. The mean absolute percent difference between 'true' spawning biomass proportions and proportion of ABC by area for each apportionment method. Values close to zero indicate that the apportionment method more closely matches the underlying population spawning biomass by area.

	Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt	Non-Exp_NPFMC
BS	100.2	55.9	48.3	39.5	24.3	63.5	37.9
AI	60.2	34.4	39.2	4.8	10.4	16.5	7.6
WGOA	41.9	4.3	19.0	26.0	11.3	49.1	23.9
CGOA	55.6	9.6	14.6	5.7	1.5	16.3	6.2
WY	9.8	32.2	12.7	11.1	8.0	17.7	10.3
EY-SEO	52.2	30.1	19.3	15.1	12.9	19.9	13.6

	Part_fixed	Age_based	Term_LLsurv	All_to_one
BS	55.7	77.6	23.7	172.9
AI	8.2	60.5	10.1	148.6
WGOA	24.4	28.3	11.3	147.9
CGOA	8.0	55.1	1.7	170.0
WY	13.6	18.3	7.9	161.2
EY-SEO	17.7	31.8	13.0	171.7

Table 3. The mean absolute percent difference between 'true' total biomass proportions and proportion of ABC by area for each apportionment method. Low values indicate that the apportionment method more closely matches the underlying population total biomass by area.

	Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt	Non-Exp_NPFMC
BS	135.8	107.3	101.9	95.3	84.1	111.8	94.4
AI	80.6	60.8	64.8	34.7	40.7	22.9	34.0
WGOA	74.8	40.8	55.2	61.8	48.4	81.9	60.0
CGOA	50.8	16.0	9.3	5.6	8.3	11.4	5.6
WY	6.5	43.2	23.6	22.5	19.5	29.0	21.4
EY-SEO	72.9	54.1	44.7	41.4	39.6	45.3	40.1

	Part_fixed	Age_based	Term_LLsurv	All_to_one
BS	107.2	121.3	83.4	180.3
AI	38.4	81.3	40.3	141.5
WGOA	60.1	63.0	48.2	140.7
CGOA	5.1	50.0	8.4	170.0
WY	24.9	9.9	19.3	164.0
EY-SEO	43.5	55.0	39.5	176.5

Table 4. Mean absolute percent difference between 'true' spawning biomass proportions and proportion of ABC for each apportionment method.

Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt	Non-Exp_NPFMC	Part_fixed	Age_based	Term_LLsurv	All_to_one
53.4	27.8	25.5	17.0	11.4	30.5	16.6	21.3	45.3	11.3	162.0

Table 5. Mean absolute percent difference between 'true' total biomass proportions and proportion of ABC for each apportionment method.

Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt	Non-Exp_NPFMC	Part_fixed	Age_based	Term_LLsurv	All_to_one
70.2	53.7	49.9	43.5	40.1	50.4	42.6	46.5	63.4	39.9	162.2

Sustainability metric 3: Terminal year SSB depletion relative to 1977 SSB.

Depletion is defined here as the spawning biomass in the terminal year of each EM simulation relative to the spawning biomass in the EM starting year. For these simulations, the EM starting year is 1977 and end years range from 2019-2028. Note that 1977 is not virgin biomass so 'depletion' in this context provides relative information between methods, but should not be confused as a reduction from an unfished state.

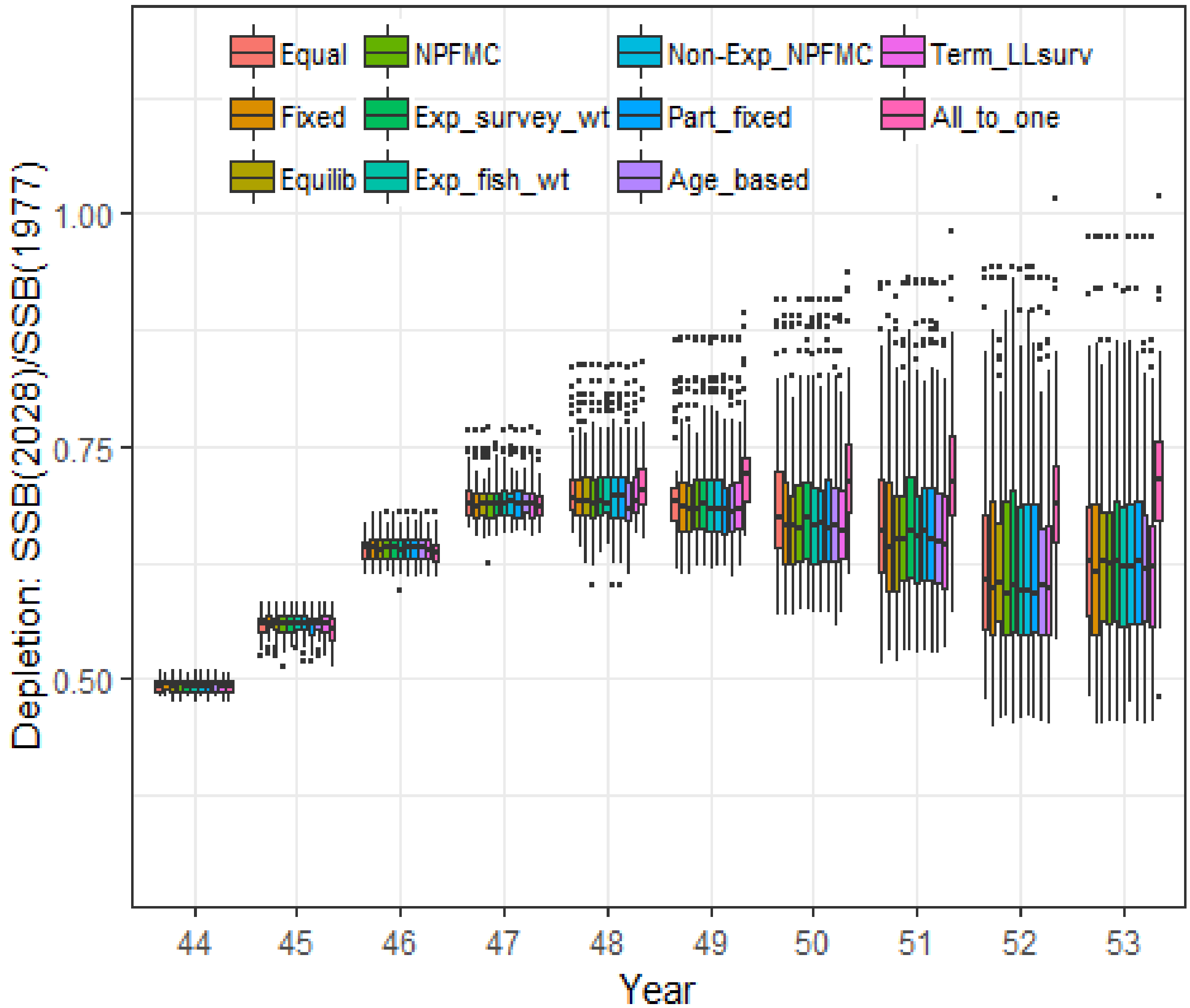


Figure 2. SSB depletion for each forward projecting year and apportionment method.

<u>Summary of sustainability metrics</u>
Most of the apportionment methods perform similarly with respect to maintaining the sablefish spawning biomass at or near B40. A notable exception is the 'All_to_one' apportionment method, which has higher B40 estimates. The NPFMC harvest control rule, which is being used in these analyses, is designed to adjust fishing mortality to maintain the sablefish population at or near B40.

As expected, the apportionment methods that are static (fixed proportions) over time result in ABC apportionment proportions by area that generally do not track the underlying population spawning biomass very well. Apportionment methods that vary apportionment to management areas using the survey index of abundance tend to have a closer match between ABC apportioned to areas and the proportion of spawning biomass in each area. If there are benefits to maintaining spawning biomass in all spatial areas (e.g. if there were spatial differences in fecundity about which we are unaware), an apportionment method with a low value for this metric would be better.

Similar to the SSB/B40 performance metric, the apportionment methods perform similarly to each other with respect to depletion. The 'All_to_one' apportionment method is an outlier and is less depleted than the others.

Variability in ABC from year to year

Total ABC and the proportion of ABC apportioned to management areas can change each year, and individual management area ABCs may not move in the same direction or proportion as the overall ABC. In 2013, the year-to-year change in ABC apportioned to each management area was higher than desired and prompted the recommendation to freeze ABC proportions to management regions for the next several years.

Table 6. The mean absolute percent change in ABC (kt) summed over areas.

Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt	Non-Exp_NPFMC	Part_fixed	Age_based	Term_LLsurv	All_to_one
13.96	13.74	14.13	13.69	14.01	14.03	14.15	14.17	13.96	14.15	17.13

Table 7. The mean absolute percent change in ABC (kt) for each area and apportionment method.

	Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt	Non-Exp_NPFMC	Part_fixed	Age_based	Term_LLsurv	All_to_one
BS	13.96	13.74	14.13	15.96	15.37	18.08	16.97	14.17	19.66	15.30	17.13
AI	13.96	13.74	14.13	14.73	14.48	16.88	15.37	14.17	14.59	14.40	17.13
WGOA	13.96	13.74	14.13	15.29	14.81	17.05	16.29	16.34	16.70	14.73	17.13
CGOA	13.96	13.74	14.13	13.83	14.10	14.37	14.16	14.66	13.91	14.28	17.13
WY	13.96	13.74	14.13	12.82	13.71	12.06	13.33	13.48	12.86	14.01	17.13
EY-SEO	13.96	13.74	14.13	12.42	13.31	11.78	13.20	13.01	12.28	13.76	17.13

<u>Summary of variability performance metric</u>

Higher values mean greater fluctuations in ABC from year to year. Apportionment methods that are 'fixed' over areas (proportions apportioned to areas do not change over time) still have some interannual variability because the total ABC is increasing or decreasing as the sablefish population abundance changes. The amount of total ABC interannual change can vary among apportionment methods because we remove non-converged runs from these summary analyses and the specific runs for each method may vary. While all apportionment methods except the 'All to one' apportionment performed similarly with respect to variability in ABC summed over areas, the variability for individual management areas differed. The 'Age-based', 'Exp_fish_wt' and 'Non_exp_NPFMC' apportionment methods had the most interannual variability for individual areas, on average.

Sablefish value and other considerations

This category groups performance metrics that are social or economic in nature and evaluates each apportionment method with respect to:

1) Mean ABC across management areas and years for the forward projecting simulation period;

2) Mean ABC by management area, across years for the forward projecting simulation period;

3) The proportion of forward projecting years where ABC in each region is greater than a specified threshold;

4) Median age of fish in each management area (from the OM);

5) Median age of catch in each management area (from the OM);

6) Median value of catch in each management area.

<u>*Social/economic metric 1:* The mean ABC for each apportionment method combines data across years, fleets (a.k.a. gears), areas, and simulations for 2019-2028.</u>

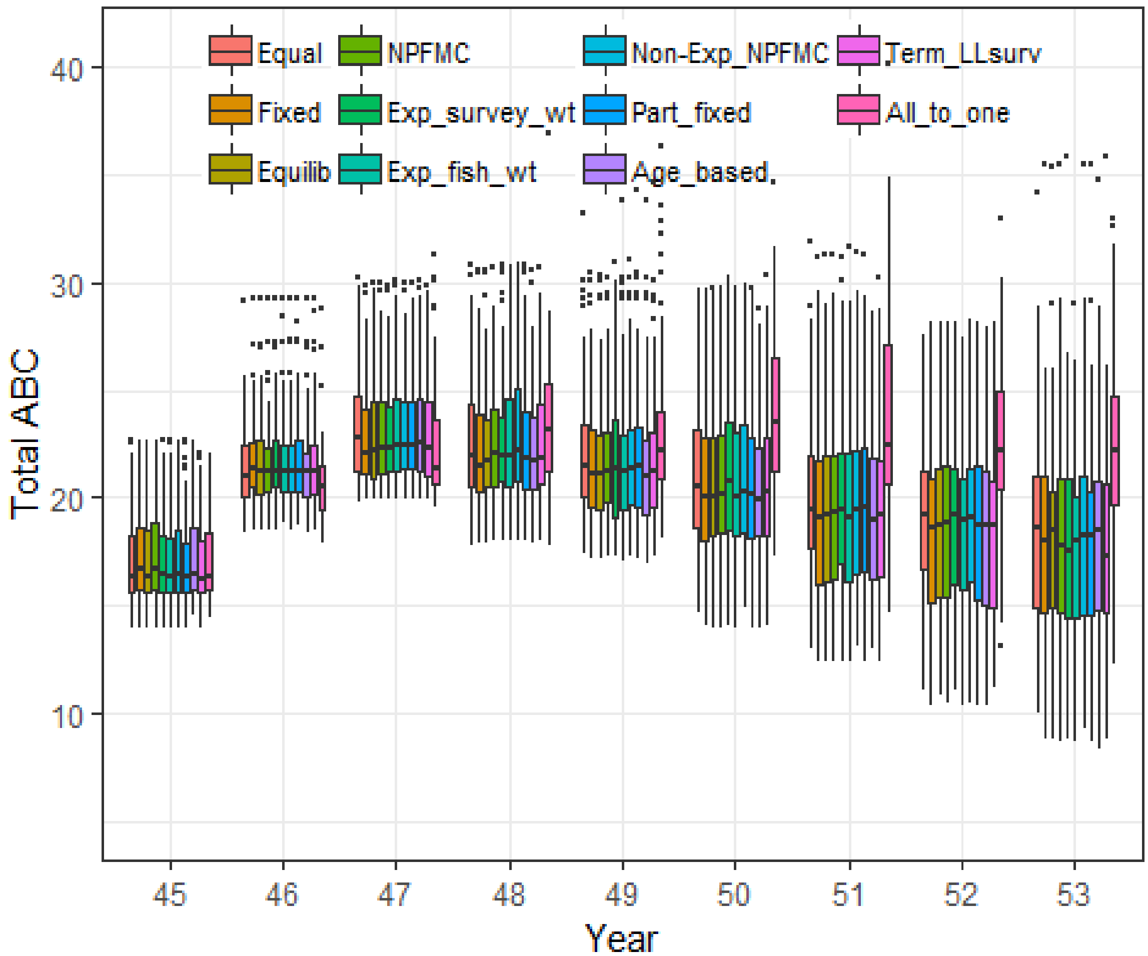


Figure 3. Total ABC (kt) by year for each apportionment method.

<u>*Social/economic metric 2:* Mean ABC apportioned to each management area (mean of all years and simulations) under the different apportionment methods is a key output of interest.</u>

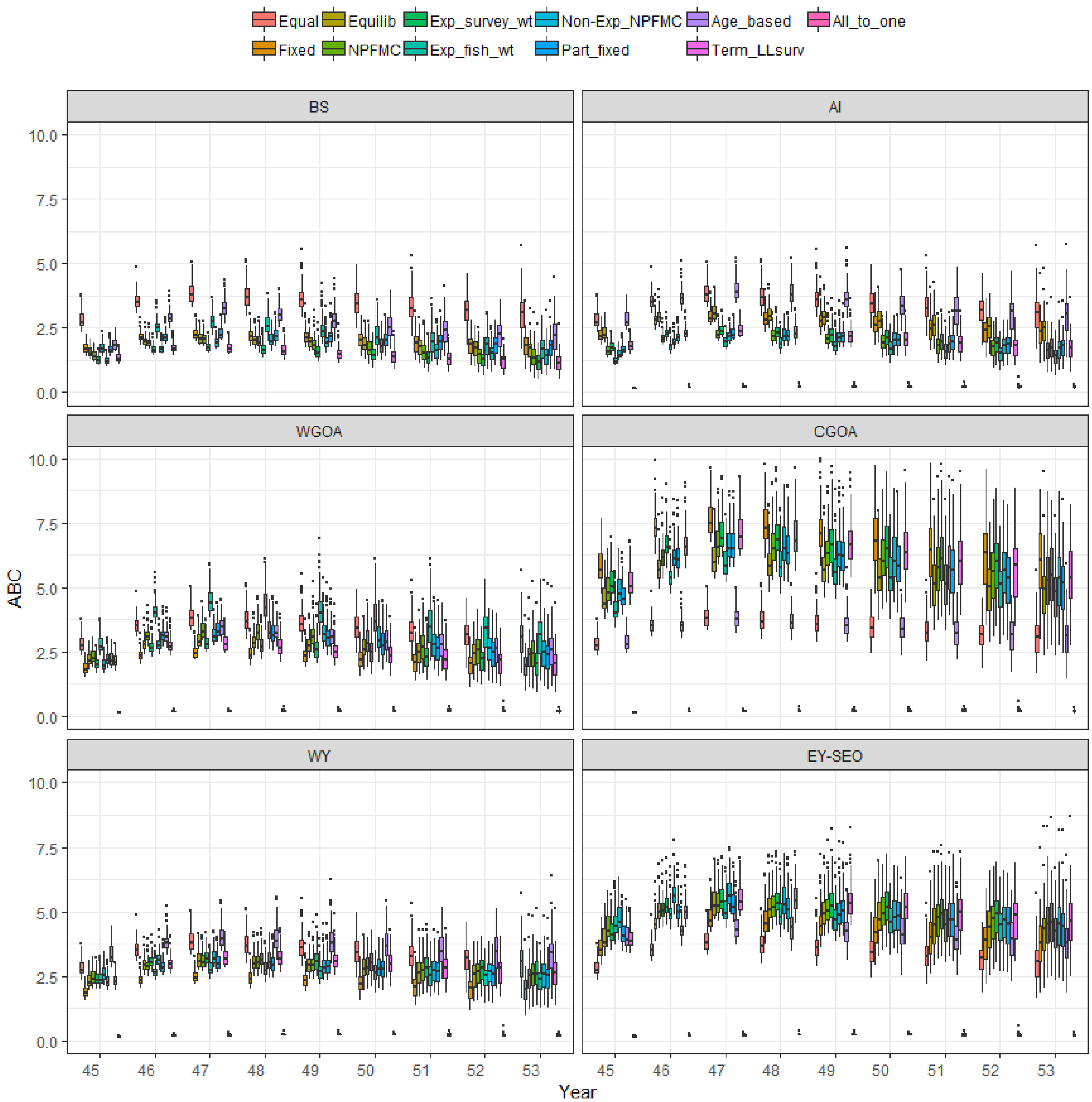


Figure 4. ABC (kt) by area for each apportionment method.

<u>*Social/economic metric 3:* ABC relative to minimum thresholds.</u>

Next we examine the proportion of years and simulations where apportioned ABC summed over areas is above a specified threshold value. It is simple to change the threshold value being evaluated; the present value of the ABC threshold for management areas combined is 10.26 kt. This value was chosen because it's the lowest catch for all gears combined from years 1996-2018.

Table 8. The proportion of years and simulations where total ABC is above the all-area threshold (10.26 kt).

Apportionment	Proportion
Equal	0.997
Fixed	0.996
Equilib	0.997
NPFMC	0.996
Exp_survey_wt	0.999
Exp_fish_wt	0.996
Non-Exp_NPFMC	0.999
Part_fixed	0.995
Age_based	0.996
Term_LLsurv	0.999
All_to_one	1.000

It may also be of value to set a threshold for individual management areas. We are presenting results for a threshold of 0.84 kilotons for each management area. This value represents the average catch in the Bering Sea for 1996-2018, which has the lowest average catch of all regions.

Table 9. The proportion of years and simulations where total ABC is above the all-area threshold (0.84 kt).

	Equal	Fixed	Equilib	NPFMC	Exp_survey_wt	Exp_fish_wt
BS	1.000	1.000	0.999	0.986	0.972	0.996
AI	1.000	1.000	1.000	0.998	0.999	0.993
WG	1.000	1.000	1.000	1.000	1.000	1.000
CGOA	1.000	1.000	1.000	1.000	1.000	1.000
WY	1.000	1.000	1.000	1.000	1.000	1.000
EY-SEO	1.000	1.000	1.000	1.000	1.000	1.000

	Non-Exp_NPFMC	Part_fixed	Age_based	Term_LLsurv	All_to_one
BS	0.991	1.000	1.000	0.969	1.000
AI	0.999	1.000	1.000	0.999	0.100
WG	1.000	1.000	1.000	1.000	0.100
CGOA	1.000	1.000	1.000	1.000	0.100
WY	1.000	1.000	1.000	1.000	0.100
EY-SEO	1.000	1.000	1.000	1.000	0.100

Social/economic metric 4: Age of fish in each management area using OM simulated abundance.

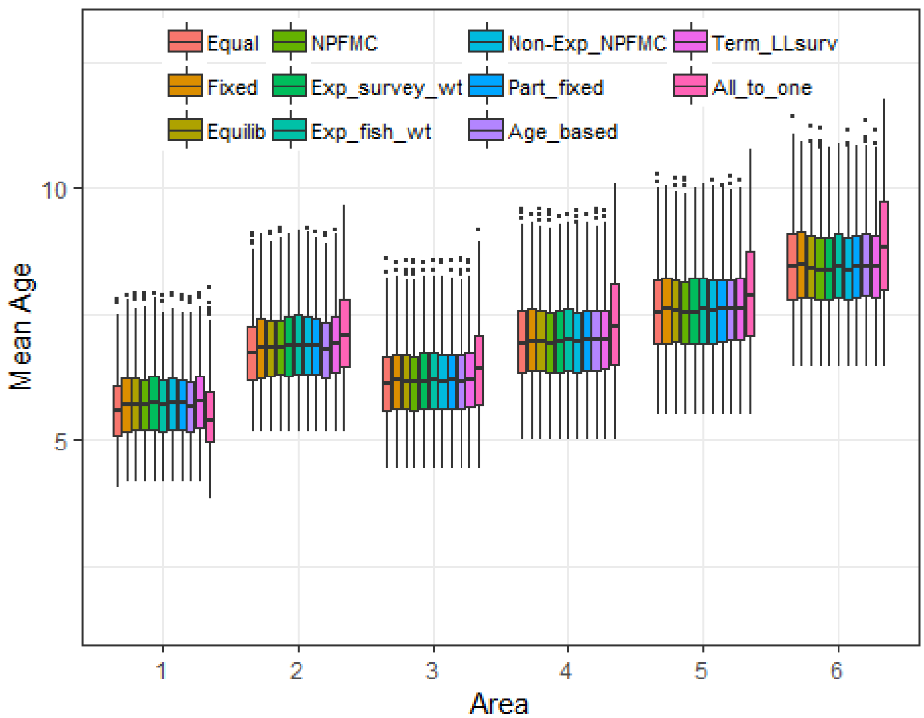


Figure 5. Age of sablefish in each management area.

Social/economic metric 5: Age of catch in each management area using the OM data.

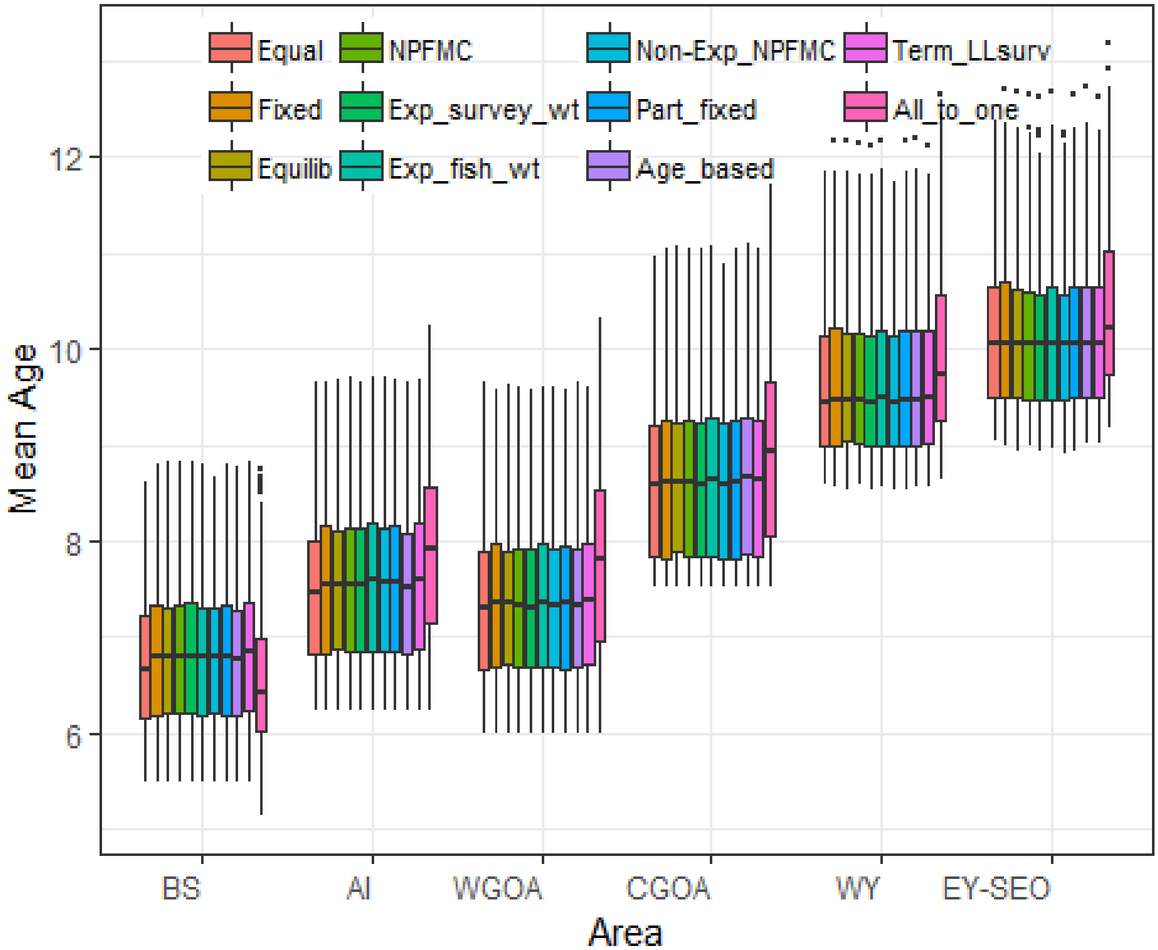


Figure 6. Age of sablefish catch in each management area.

<u>*Social/economic metric 6:* An estimate of the value of catch in each management area, using the sablefish catch (in numbers) at age from the EM (for all areas) and mean price at age per market category.</u>

Market value for sablefish may be influenced by many factors, but size and grade of fish are two key components. We used recent market value data (2012-2018) to generate a range of potential scenarios for fish price at age. We analyzed four price/kg scenarios, ‘high’, ‘medium’, ‘low’, and ‘recent’, accounting for recovery rates. The ‘high’, ‘medium’, and ‘low’ scenarios use the maximum, mean, and minimum price/kg for 2012-2018 for each market category, respectively. The ‘recent’ value is the 2018 market price/kg for each market category.

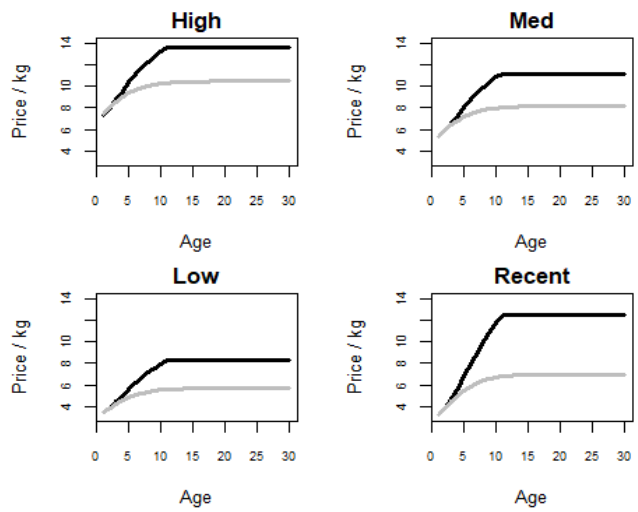


Figure 7. The four scenarios of market price ($/kg) used for this performance metric. We apply price per kg at age to the catch at age estimated under the apportionment methods for an approximate estimate of mean value of catch under the apportionment methods. Black lines represent females, gray represents males.

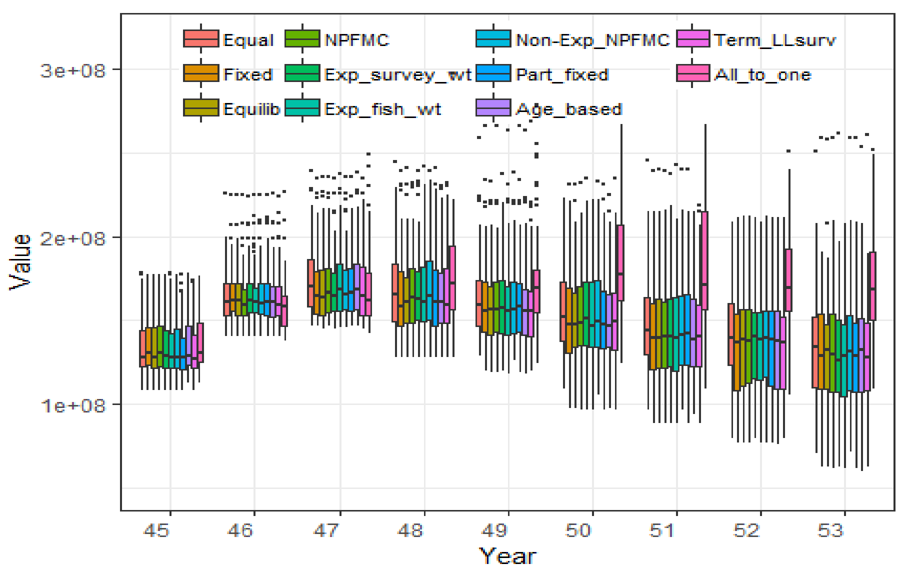


Figure 8. Value (US $) of catch from each apportionment method, using 'High' market value scenario and assuming 100% of apportioned ABC is caught.

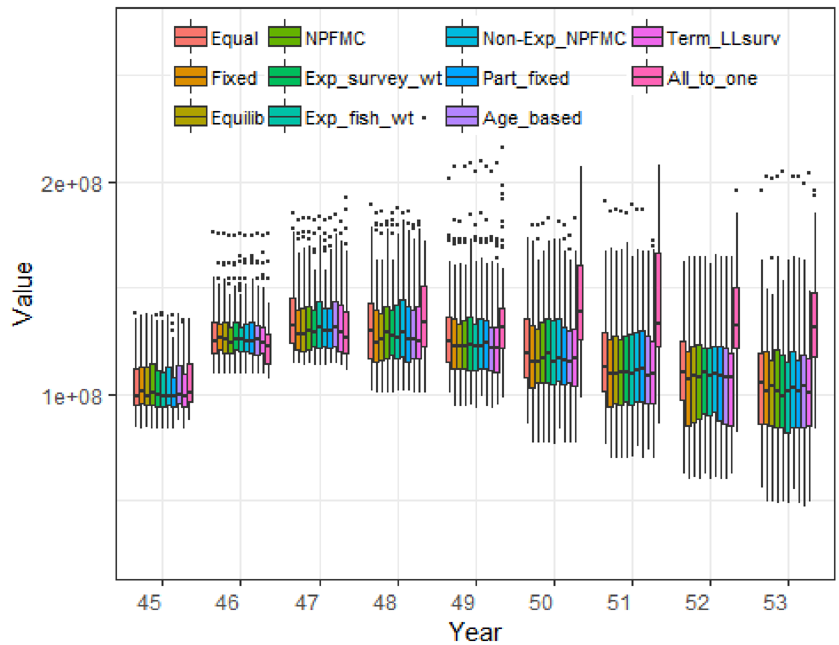


Figure 9. Value (US $) of catch from apportionment methods, using 'Medium' market value scenario and assuming 100% of apportioned ABC is caught.

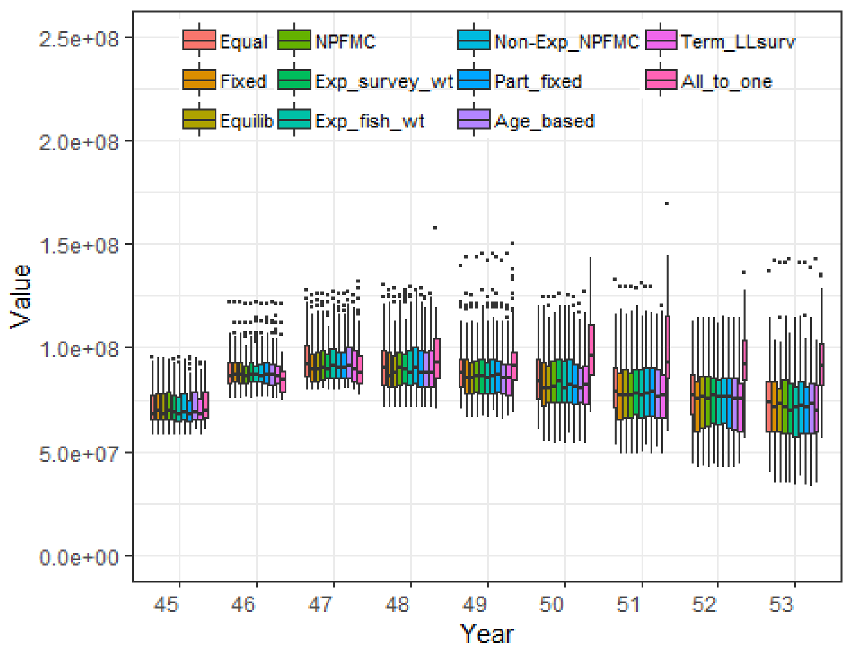


Figure 10. Value (US $) of catch from apportionment methods, using 'Low' market value scenario and assuming 100% of apportioned ABC is caught.

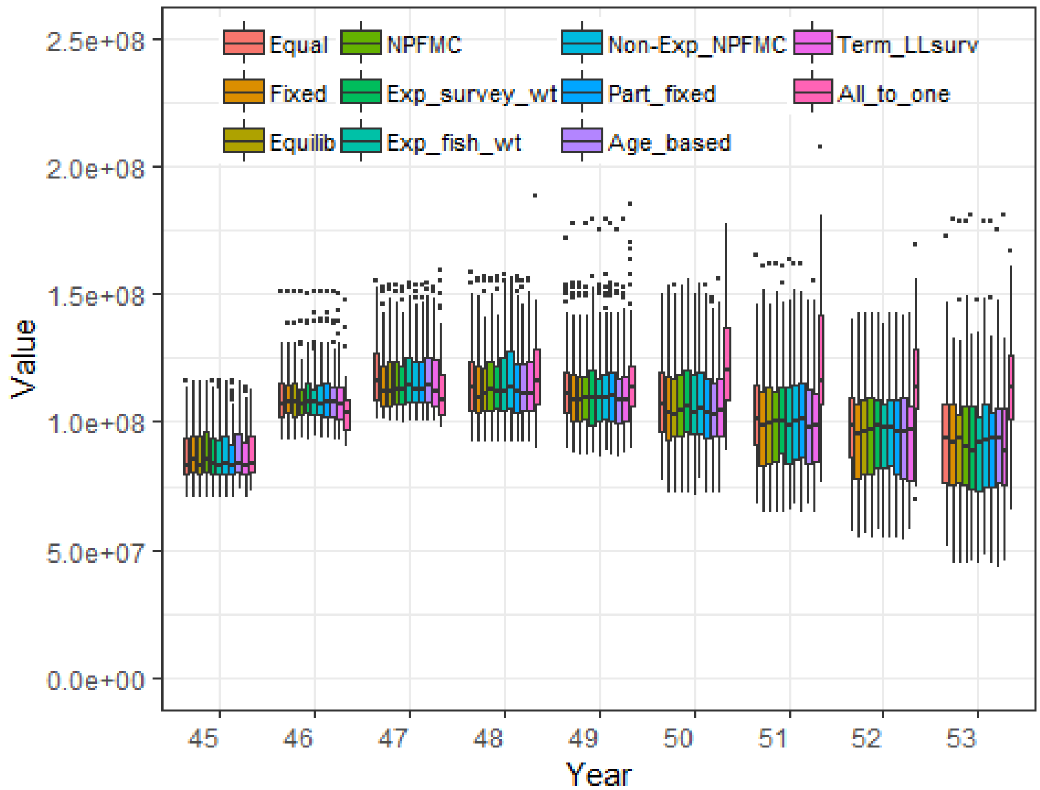


Figure 11. Value (US $) of catch from apportionment methods, using 'Recent' market value scenario and assuming 100% of apportioned ABC is caught.

Summary of results from 'Value' performance metrics:

Mean ABC for management areas and years combined varies relatively little between most apportionment methods (Figure 3, Table 1). The 'All_to_one' apportionment method resulted in a higher mean ABC (mean over years and management areas).

There are large differences in mean apportionment of ABC to spatial areas for all but the 'Equal' apportionment method (Figure 4). The Central GOA region has the greatest proportion of apportionment in all but the 'All_to_one' method, which apportions 95% of ABC to the Bering Sea (for this example), and the 'Age-based' method, which apportions a greater proportion of ABC to the EY/SEO region than the CGOA region.

All apportionment methods have a similarly high proportion of years, simulations, and/or areas above the specified thresholds. The summary analyses can be conducted with alternative threshold values that may be of interest to stakeholders and managers.

The mean age of fish in the population and in catches are similar for a given spatial area, across apportionment methods (Figure 5), though the mean age varies between management areas. The oldest fish in both the OM population and catches are in the EY/SEO area in this OM configuration, likely due to the (specified) movement rates.

The apportionment methods also perform similarly with respect to the value of catch each year in the forward projections.

Further details on OM and EM, model validation figures, and more output

OM Conditioning period

The OM model begins by establishing initial numbers at age for each area in 1976. Initial N for 1976 is input as the 2018 management EM total abundance estimated for 1977. This is split into 6 spatial areas using the proportion of abundance by area from longline survey abundance estimates and split into initial age and sex proportions using proportion by sex and age from 2018 management EM for 1976 numbers at age. Numbers at age are converted to biomass at age using the age-weight relationship as described in the sablefish 2018 SAFE report.

The OM conditioning period is deterministic and thus recruitment deviations and catches are the same for all simulations. Movement rates are specified for all 6 areas and the OM is set up to accommodate age-based movement, however, at present movement is age-invariant. During the OM conditioning period, recruitment estimates from the management EM are input values, as are realized catch levels. The F that is estimated to produce that catch level is used for harvest removals. Please see appendix 1 for OM population dynamics equations.

Movement rates used in the OM are externally estimated using the methods described in Hanselman et al. (2015), based upon 30+ years of tag release and recapture data. The model described in the paper was re-run for 6 areas and those movement values are input to the OM.

Table 10: Movement rates assumed by the OM are based on 30+ years of tag release and recapture data, as detailed in Hanselman et al. (2015).

	To EY	To WY	To CG	To WG	To BS	To AI
From EY	0.74	0.08	0.15	0.03	0.00	0.00
From WY	0.14	0.19	0.48	0.15	0.02	0.02
From CG	0.11	0.19	0.49	0.16	0.03	0.02
From WG	0.04	0.12	0.32	0.29	0.12	0.11
From BS	0.01	0.03	0.09	0.22	0.63	0.03
From AI	0.00	0.01	0.05	0.11	0.05	0.78

Conditioning period validation

The figures and tables below are presented to show the ability of the spatial OM within the conditioning period to match the current management EM (the 2018 sablefish assessment), and to further describe the methods for setting up the OM. In general, the OM results for the conditioning period provide a good match to estimates from the most recent stock assessment ("Management EM", Hanselman et al. 2018). Some differences exist due to movement, the initial conditions specification, and spatial OM parameters which differ from the management EM.

Abundance in numbers, biomass, and spawning biomass generated from the OM generally matches the Management EM quite closely (Figures 1-3). However, the current runs being shown reduce the 2014

OM recruitment from 150 million recruits to 50 million recruits. This reduction is evident in the comparison figures below.

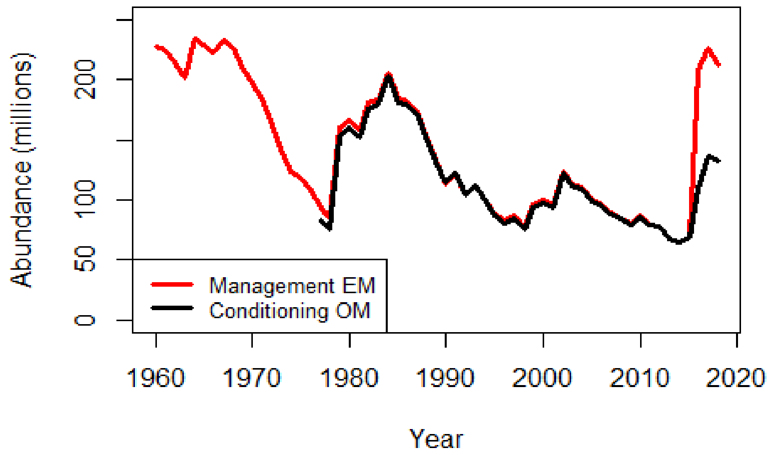


Figure 12: Abundance in numbers (millions of fish, summed over areas) generated from the OM compared to the Management EM.

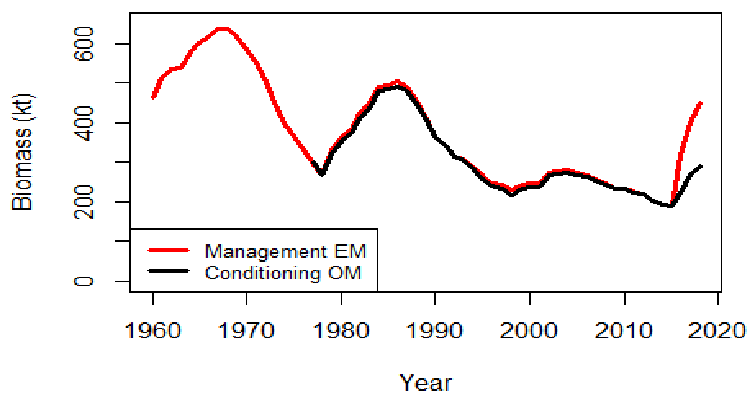


Figure 13: Biomass (kt) summed over areas, generated from the OM compared to the Management EM.

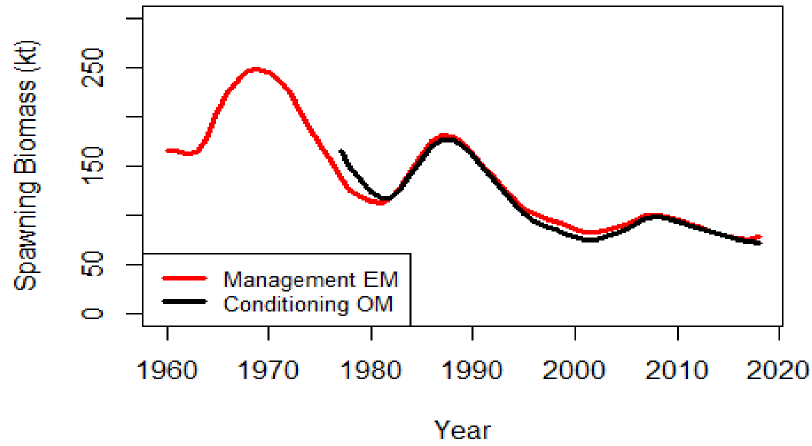


Figure 14: Spawning biomass (kt), summed over areas, generated from the OM compared to the Management EM.

The OM catch was designed to match the Management EM observed catch. An F-solving function in the OM takes input catch by gear/fleet, area, and year, and estimates the fishing mortality required to realize that level of catch, using OM numbers at age and selectivity. The estimated F rate is then used to simulate abundance in the next year of an OM iteration.

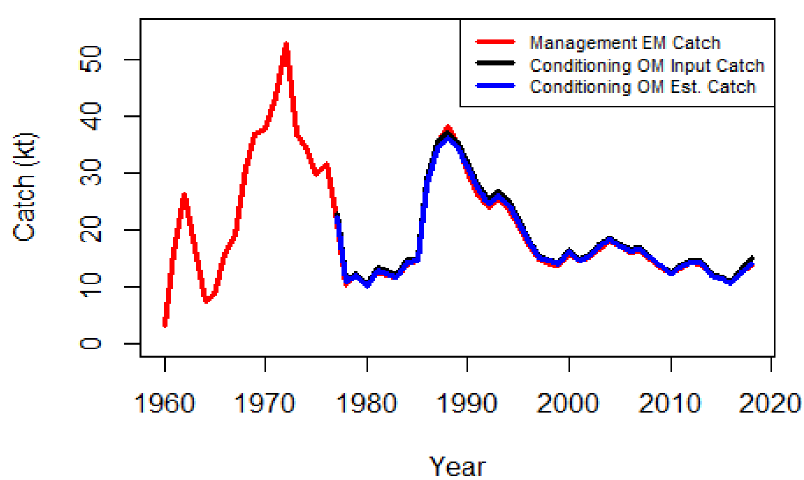


Figure 15: Catch (kt) for the Management EM, the input catch values for the OM, and the estimated OM catch values.

The OM recruitment for the conditioning period was designed to match the EM recruitment. Management EM recruitment values (in numbers) for 1977-2018 are input and split into 6 areas based on the average proportion of age-2 sablefish in each area of the longline survey, and also split equally between males and females (see equations in Appendix 2).

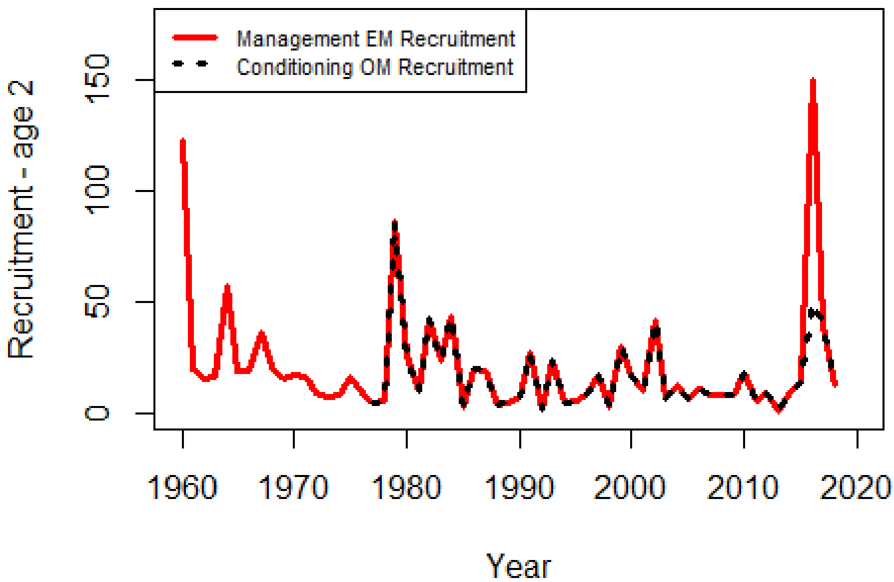


Figure 16: OM and EM recruitment for the conditioning period (in millions of fish) for all management areas summed are identical by design, except for the 2014 year class which we reduced in the OM to improve convergence in the forward simulation period.

Table 11. Values for age-2 proportions by area from the longline survey that are used to split recruitment into spatial areas.

BS	AI	WGOA	CGOA	WY	EY-SEO
0.14	0.07	0.14	0.43	0.14	0.09

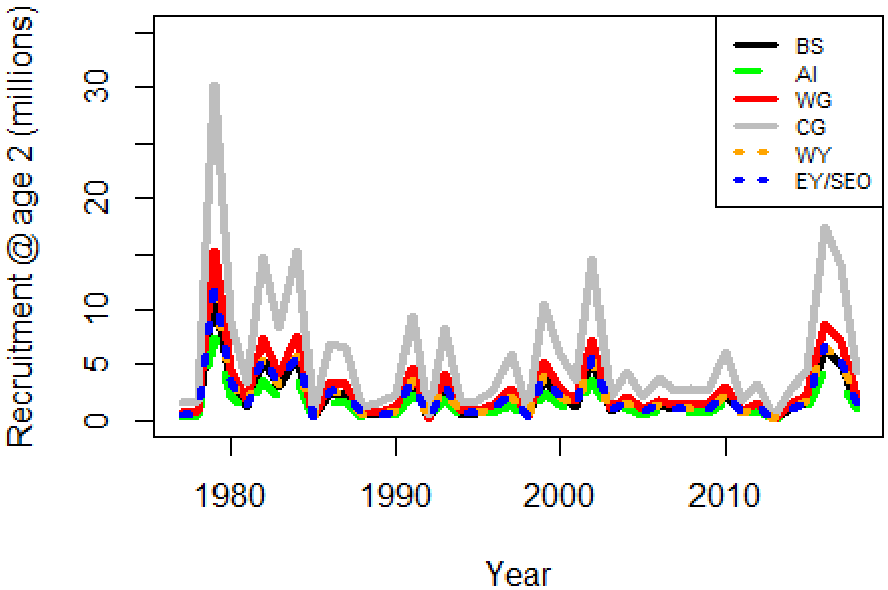


Figure 17: The resulting recruitment of age-2 fish to each management area for the conditioning period, after splitting into spatial areas using the proportions in Table 2.

Recruitment for the forward projecting period is the same across apportionment simulations and does not assume a stock recruitment relationship. Using the same suite of recruitment draws across each apportionment method allows for a more similar comparison of results. Recruitment for n.years x n.sims is drawn once (from a multinomial distribution with mu=16.5 and sigma=0.8 and with autocorrelation parameter = 0.2) and isused for all apportionment methods. Recruitment is also capped at 100 million recruits; any simulated values greater than that value are reduced to 100 million. Mean recruitment (mu; average log-recruitment) and recruitment standard deviation (sigma) for the multinomial are input from the management EM. Recruitment in each year is divided into OM spatial areas based on the mean proportion of age-2 (recruitment age) sablefish in each area from the longline survey for 1977-2018, as described above.

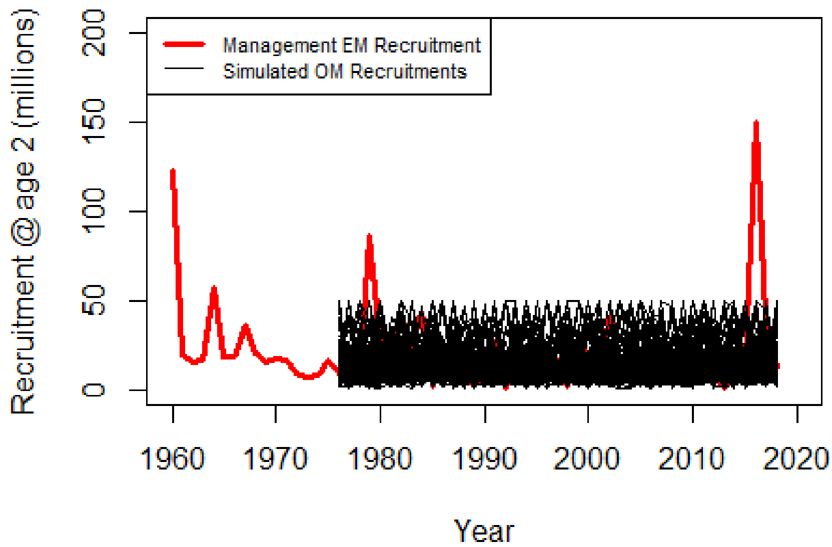


Figure 18: For comparison, the conditioning period recruitment draws for 100 simulations compared to The Management EM estimated recruitment is shown here. Note that these values ARE NOT USED in the conditioning period.

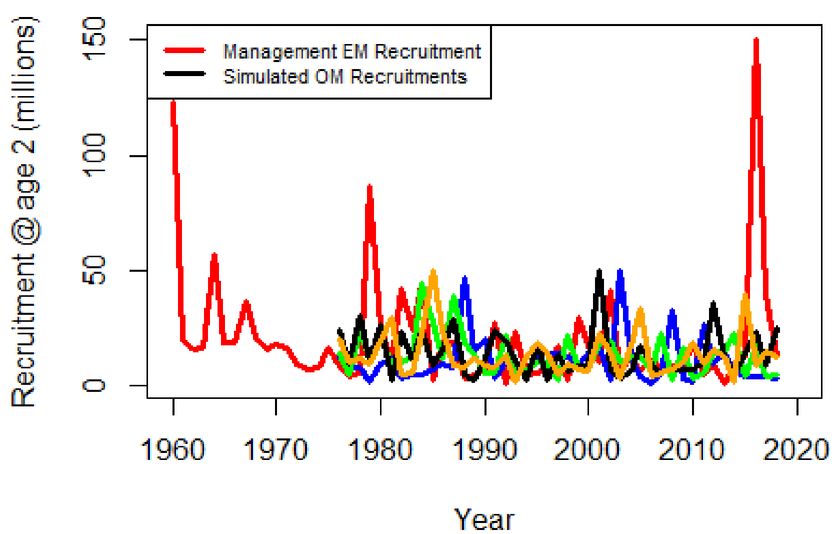


Figure 19: Recruitment estimates for a few individual simulations to illustrate the individual variability and scale of simulated recruitment.

Sampling OM population for abundance indices, age comps

The EM requires a longline survey abundance index, a fishery CPUE index, and survey and fishery age compositions. For both the conditioning period and the forward projecting period, the OM population is 'sampled' with logistic observation error for the indices of abundance. For each spatial area in the OM, we sample abundance for the survey and biomass for the fishery index, both with 15% sigma for observation error. Spatial areas are summed for each index, resulting in a single fishery and a single survey index. Fits to indices of abundance are shown in the next section (Forward looping model output).

Age compositions are sampled from each spatial OM regional abundance using multinomial error and a sample size of 200. Age compositions are combined across spatial errors (weighted by catch/survey abundance in each area) to a single set of survey and a single set of fishery age comps that are not sex specific.

EM specifications

For 2019 onward in each annual time step, the EM is fit to data 'sampled' from the OM population, or to simulated population attributes with added observation error. As a reminder, the order of operations for year *y* are: OM - Read in previous year's apportioned ABC by area (from the EM), estimate the F required to catch ABC for each area, apply F and M to OM population, move fish between areas, sample the population for fishery and longline survey abundance indices and for longline survey and fixed gear fishery age compositions, add observation error to these data types, update the .dat file with new data for the simulation year, fit the EM in ADMB to the updated data (.dat file), and return the EM and get an estimate of the next year's ABC (then repeat for the next year).

Forward looping EM output

EM Convergence

Maximum Gradient values for EM

First, we look at the proportion of years within a simulation and apportionment scenario that converged. Non-converged models/years/sims ARE NOT removed from the following analyses. For these simulations, a model was considered 'converged' for a given year if the maximum gradient component was < 0.01. It is important to note that in the real world, a stock assessment scientist would have several options for improving convergence, first and foremost by iteratively adjusting both starting values and estimation phase for key model parameters. Non-convergence in this simulation exercise may be resulting from specific iterations (alternative states of nature) wherein the sablefish population is outside the range of what has been observed historically and where manual tuning of the EM would be required, a process that has not been replicated here.

Table 12. The proportion of simulations that converged (using maximum gradient component < 0.01 as a criteria for determining convergence) for each year for each apportionment method.

```
      Equal         Fixed       Equilib         NPFMC Exp_survey_wt
       0.67          0.68          0.78          0.80          0.74
Exp_fish_wt Non-Exp_NPFMC    Part_fixed     Age_based   Term_LLsurv
       0.81          0.82          0.78          0.76          0.83
```

```
  All_to_one
        0.52
```

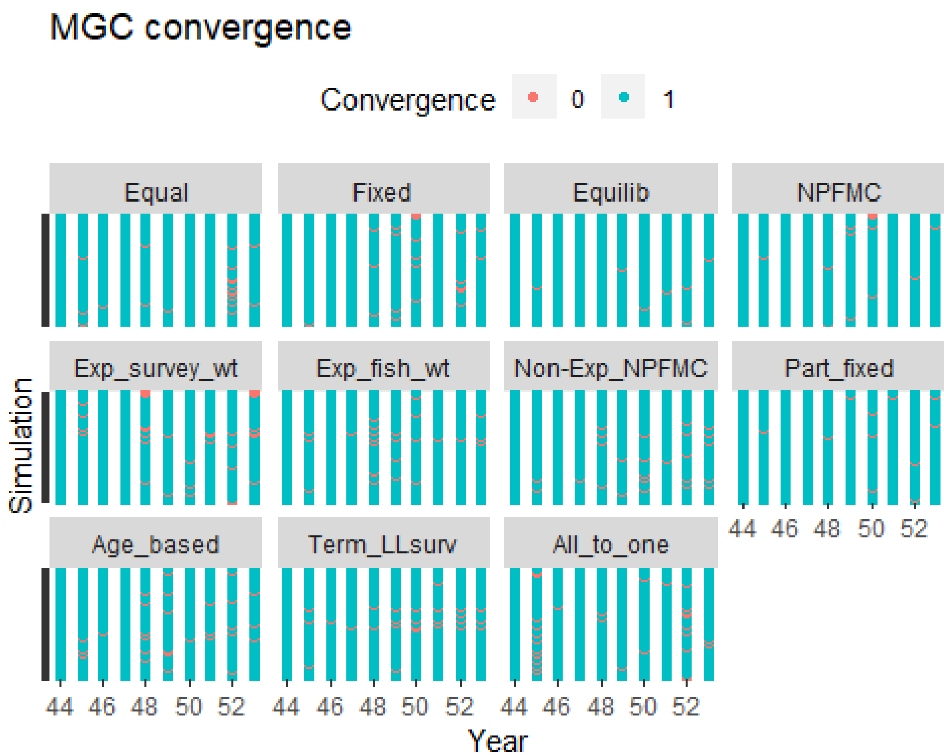


Figure 20. Converged (blue) and non-converged (orange) models using a maximum gradient criteria of 0.01 to determine convergence.

<u>Objective function values for EM</u>

Model convergence is not the only metric worth examining for model performance. It is useful to know which years and simulations (across apportionment methods) had models crash completely (where the objective function value is 'nan', indicating model failed to find a solution). A crashed model tends to have a domino effect on performance of models (in both convergence and crashing) in subsequent years. The following table shows the percentage of all years and simulations for which the EM produced an objective function value (the model ran to completion, though it may still have not adequately converged based on our defined convergence criteria).

Table 13. The percentage of years and simulations that resulted in a crashed model ('nan' for the objective function value) for each apportionment method.

```
        Equal         Fixed       Equilib         NPFMC Exp_survey_wt
         0.85          0.92          0.93          0.89          0.92
  Exp_fish_wt Non-Exp_NPFMC    Part_fixed     Age_based    Term_LLsurv
         0.92          0.93          0.93          0.94          0.92
   All_to_one
         0.75
```

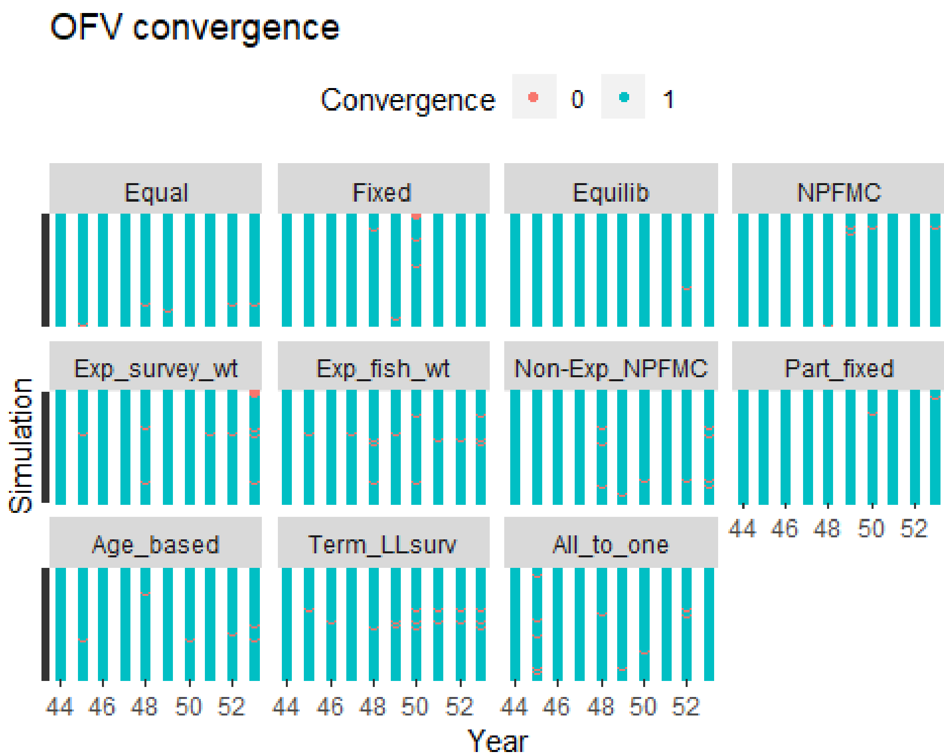
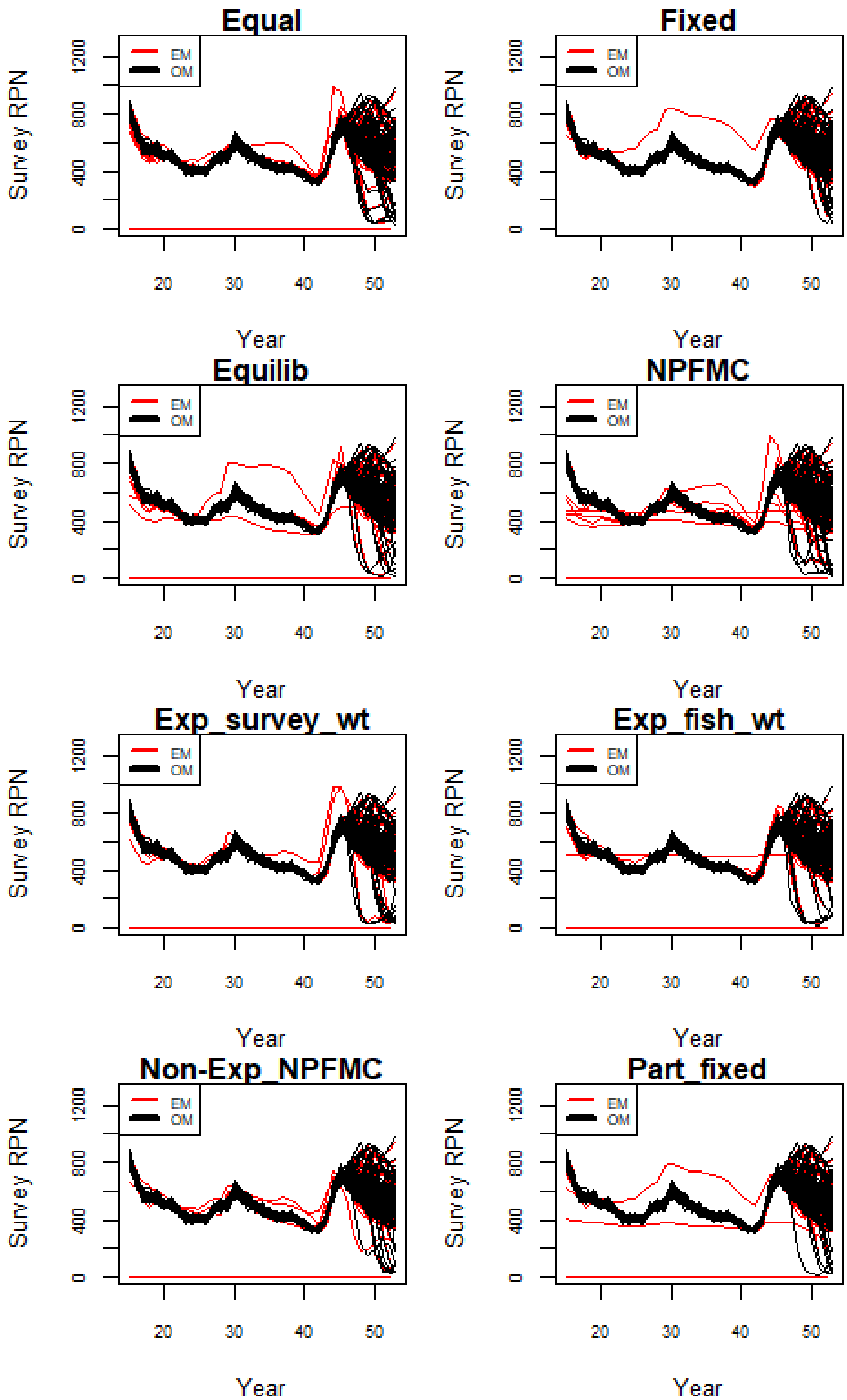


Figure 21. Converged (blue) and non-converged (orange) models using the presence or absence of an objective function value to determine model performance.

Indices

US longline survey index (RPN)

The OM ('true') and EM estimates for the longline survey abundance index are shown below for each apportionment method.


Equal
Fixed
Equilib
NPFMC
Exp_survey_wt
Exp_fish_wt
Non-Exp_NPFMC
Part_fixed
EM
OM
Survey RPN
0
400
800
1200
20
30
40
50
Year

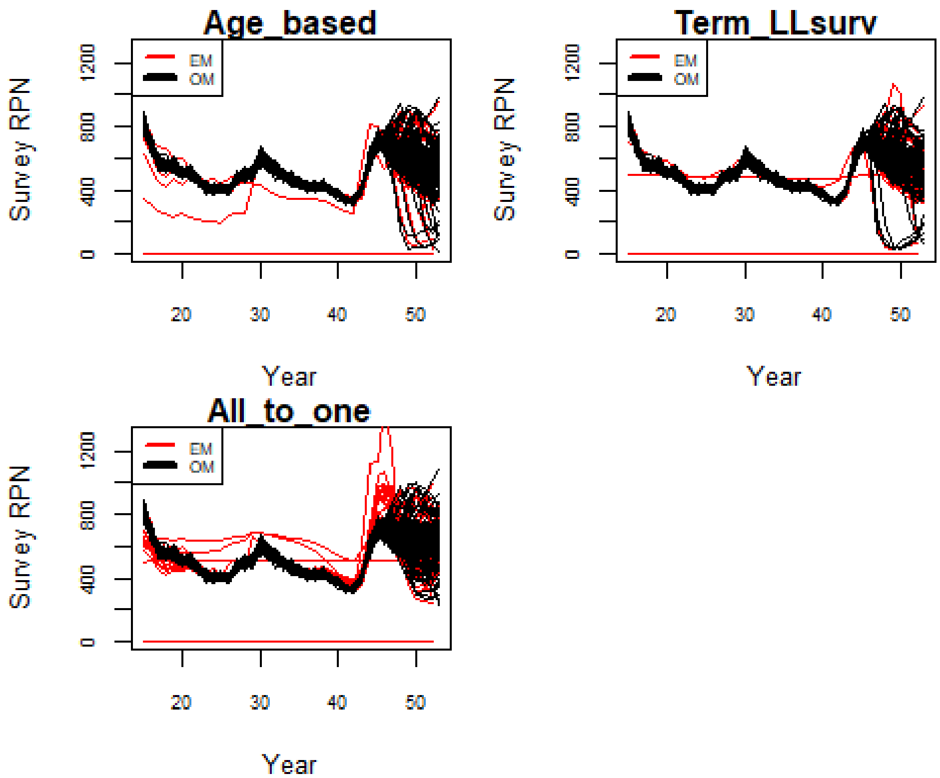


Figure 22. US longline survey indices for all years and simulations. Note that the forward projecting period begins in year 44 (2019); prior to that, the conditioning period is deterministic.

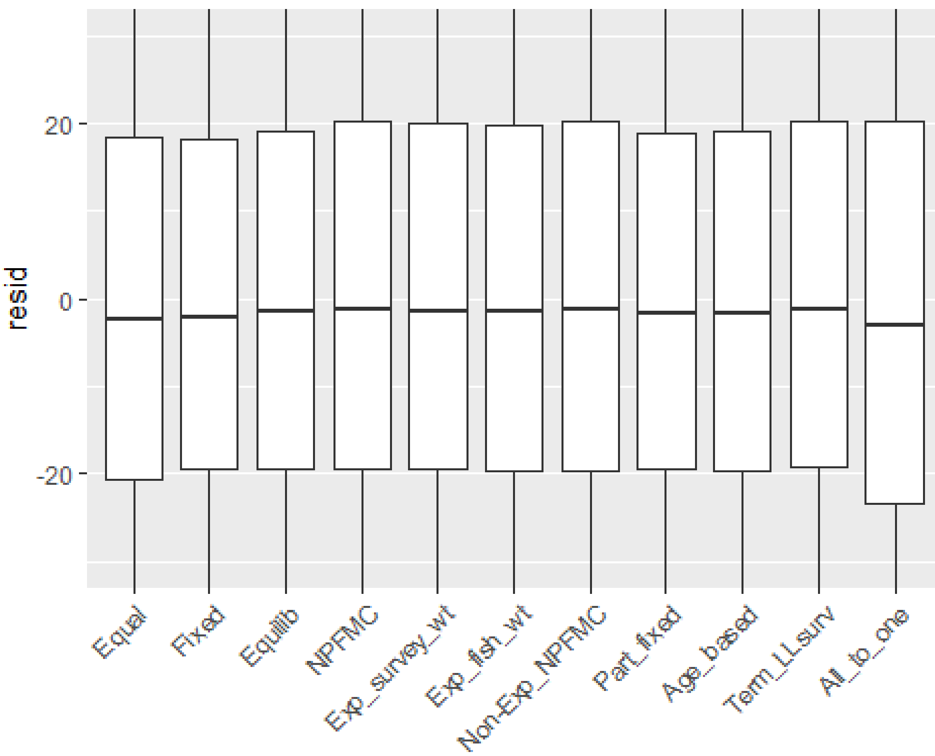
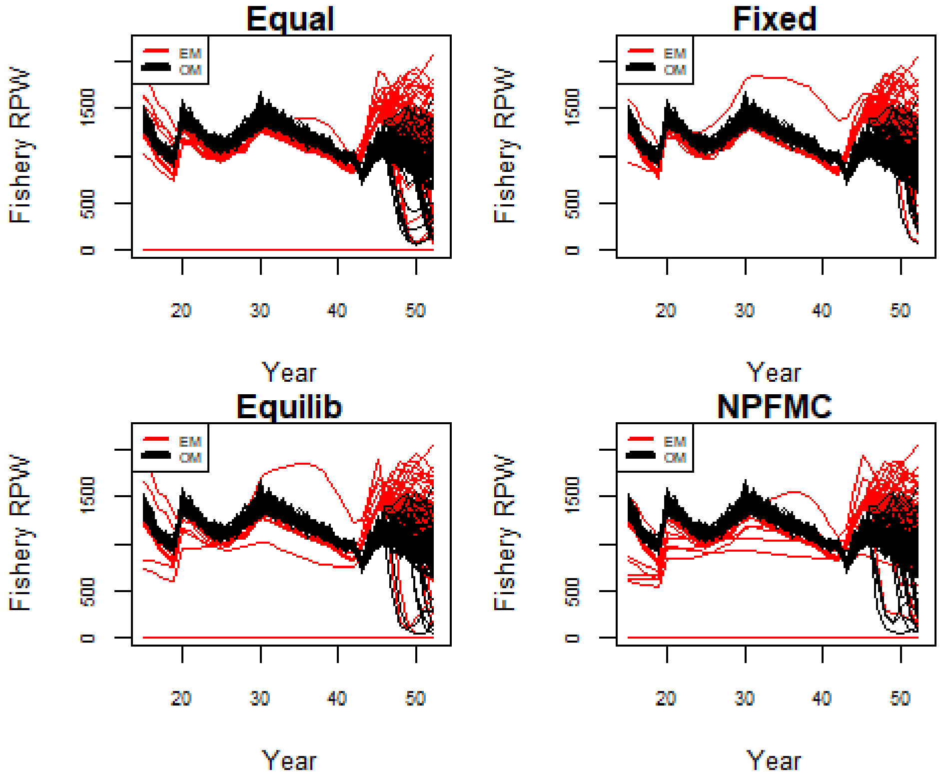


Figure 23. Boxplots of the residuals between the EM and OM for the EM terminal year (2028) for all simulations and each apportionment method.

US longline fishery index (RPW)

The OM ('true') and EM estimates for the longline fishery abundance index are shown below for each apportionment method.



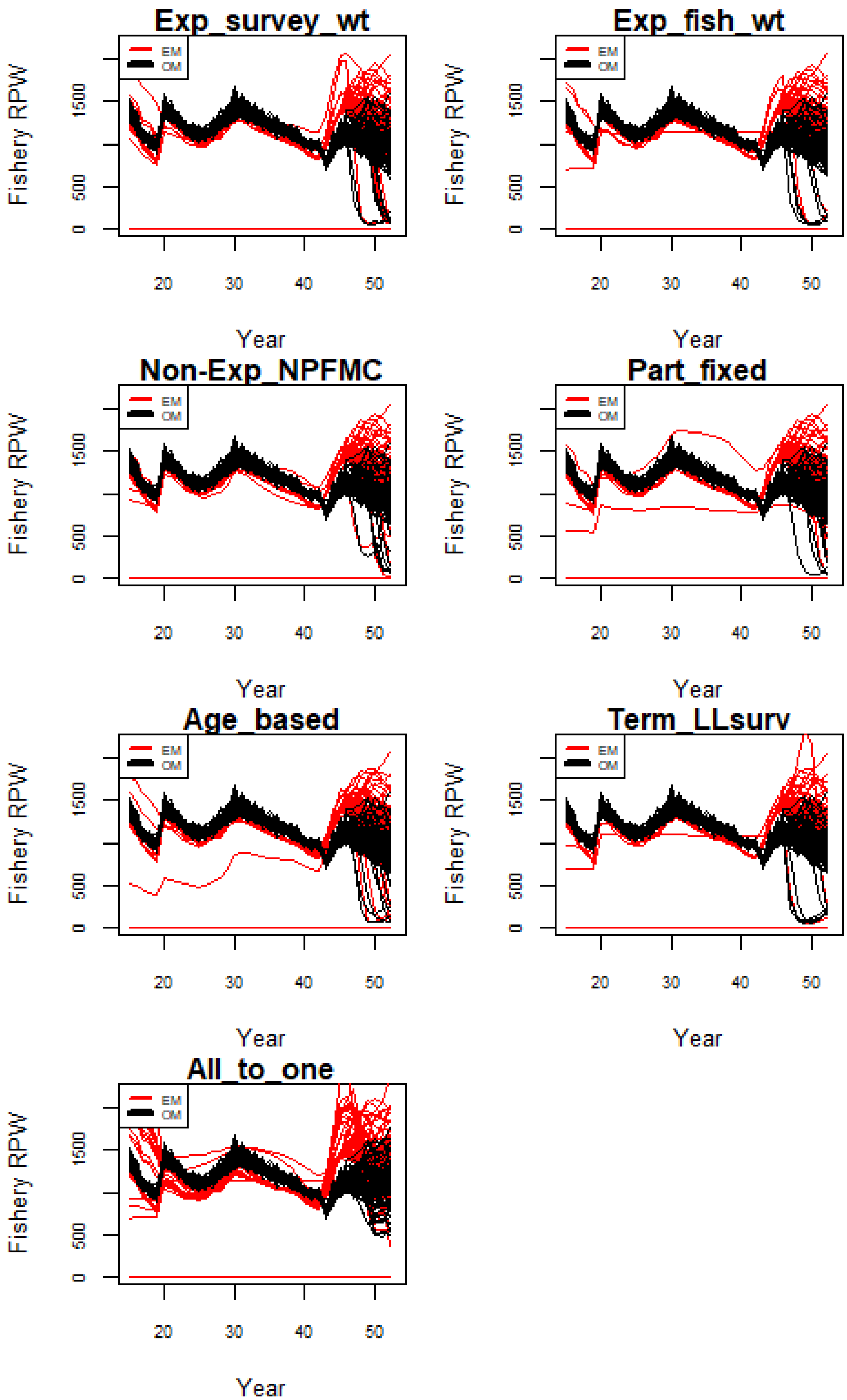


Figure 24. US fixed gear fishery index for all years and simulations. Note that the forward projecting period begins in year 44 (2019); prior to that, the conditioning period is deterministic.

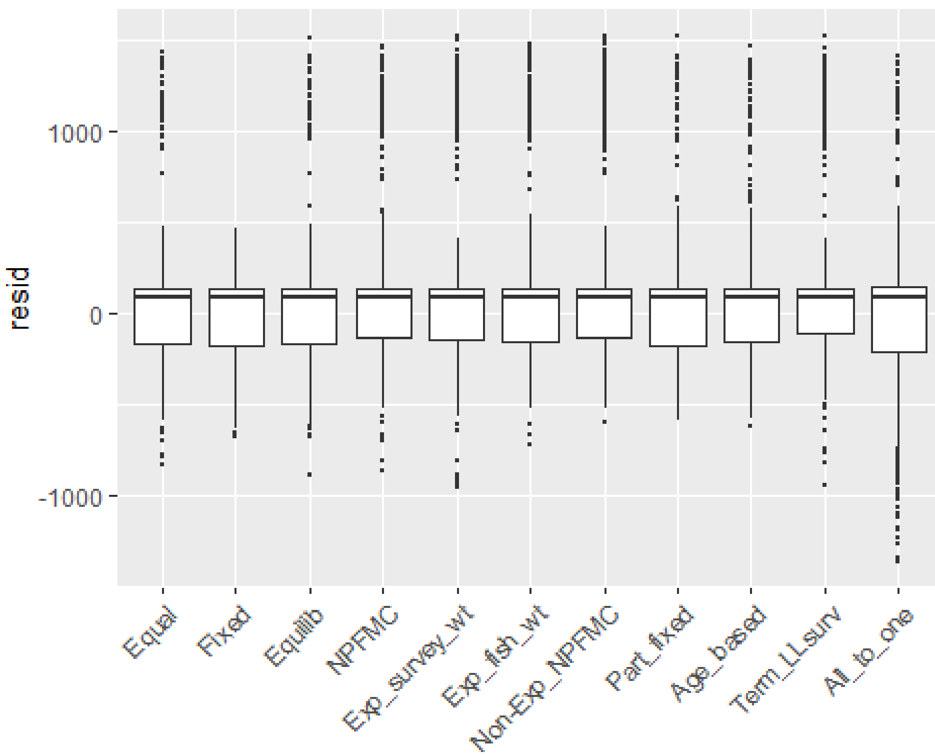


Figure 25. Boxplots of residuals between the EM and OM for the EM terminal year of the fishery index (2028) for all simulations and each apportionment method.

Recruitment

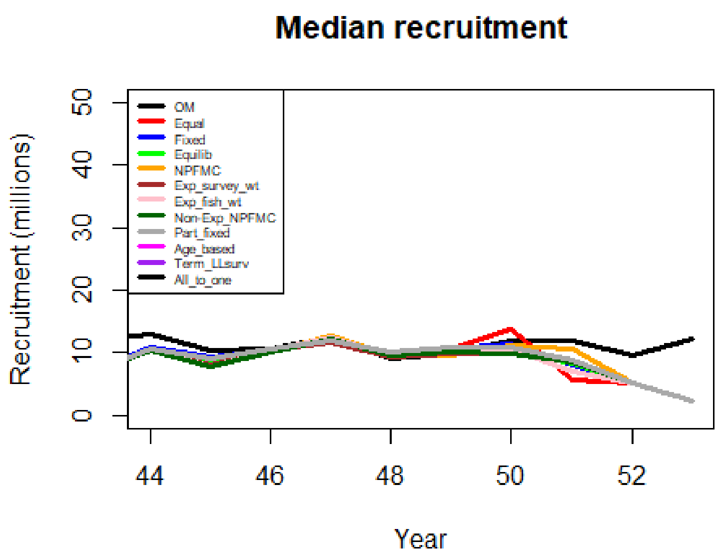


Figure 26. Median EM estimated recruitment and the OM recruitment, across all simulations. Recall that OM recruitment (black line) is the same across apportionment methods and it is only the estimated recruitment from the EM for each apportionment method that will vary.

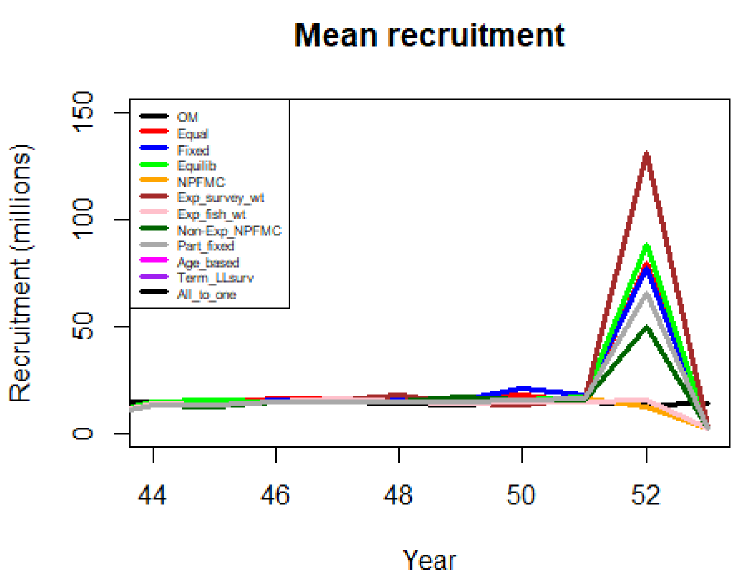
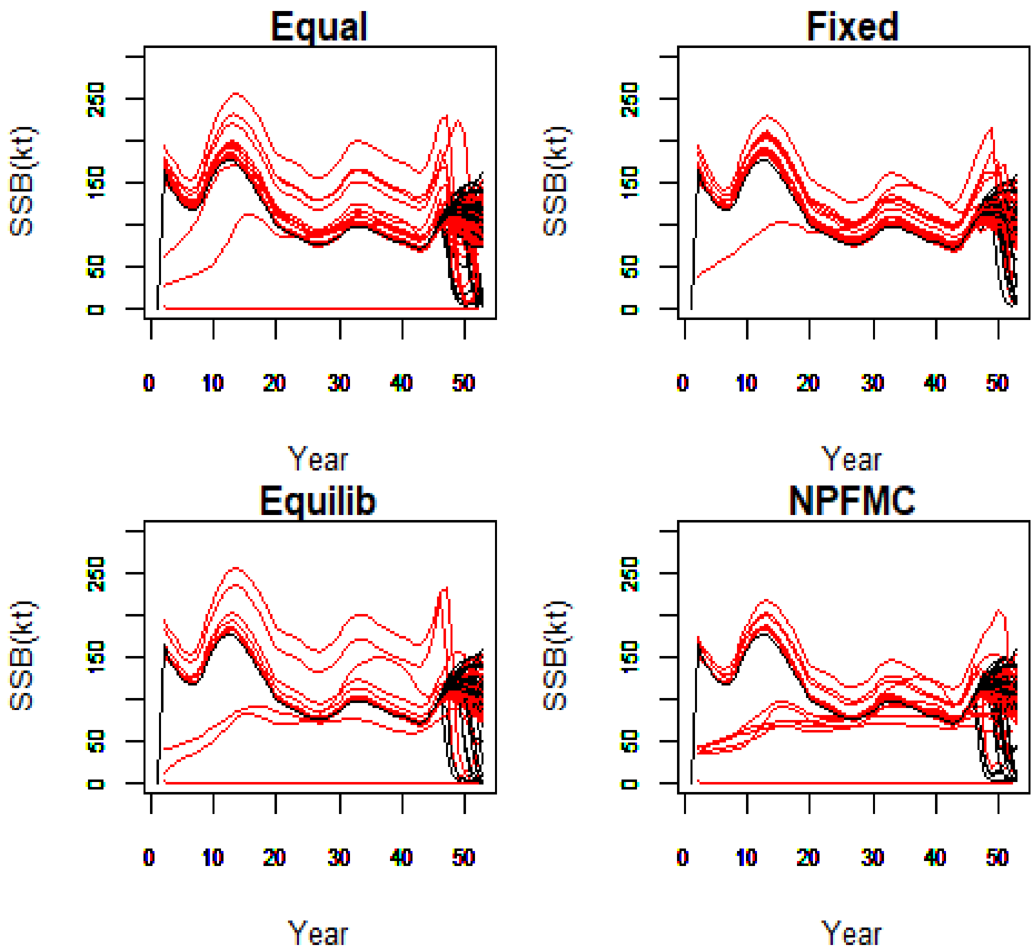
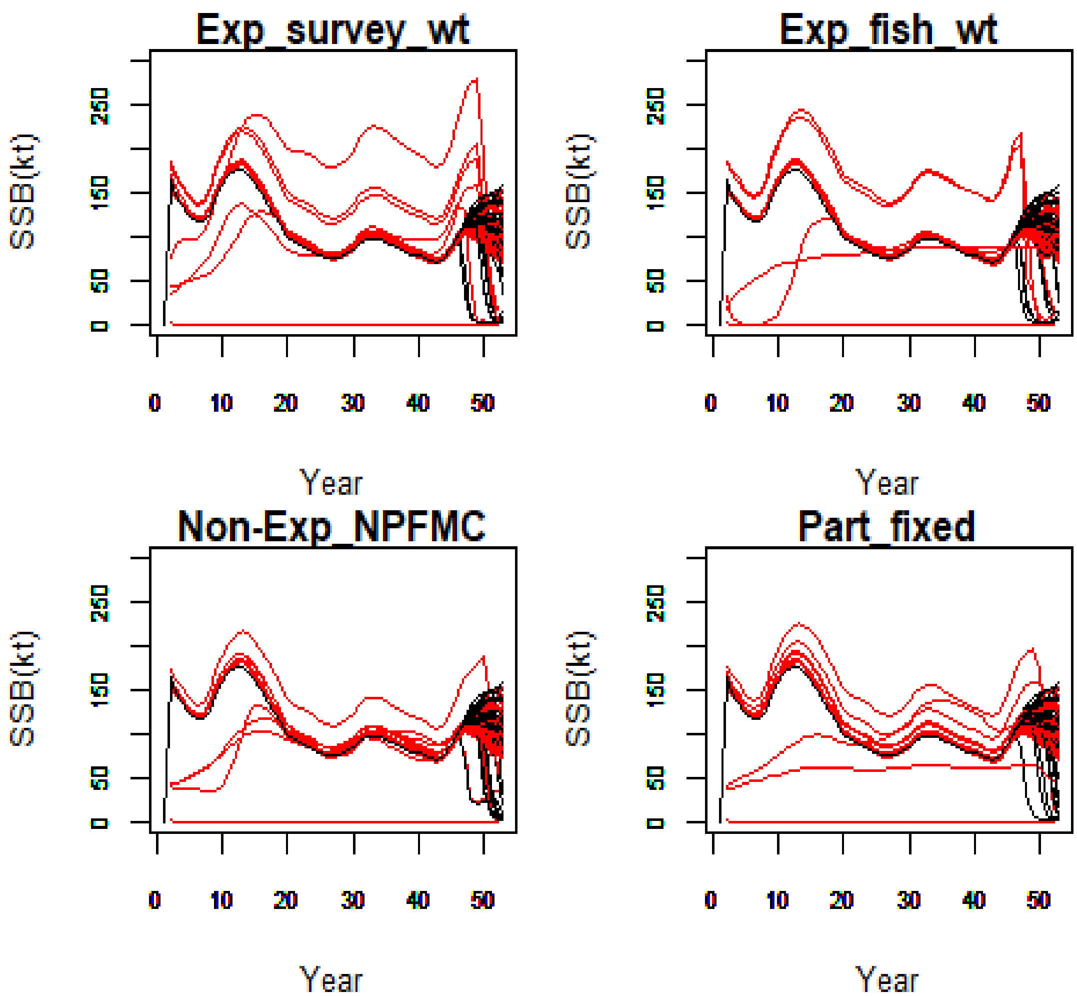


Figure 27. Mean EM estimated recruitment and the OM recruitment, across all simulations. Recall that OM recruitment (black line) is the same across apportionment methods and only the estimated recruitment from the EM for each apportionment method will vary.

SSB time series




Exp_survey_wt
Exp_fish_wt
Non-Exp_NPFMC
Part_fixed
SSB(kt)
Year
0
50
150
250
0
10
20
30
40
50

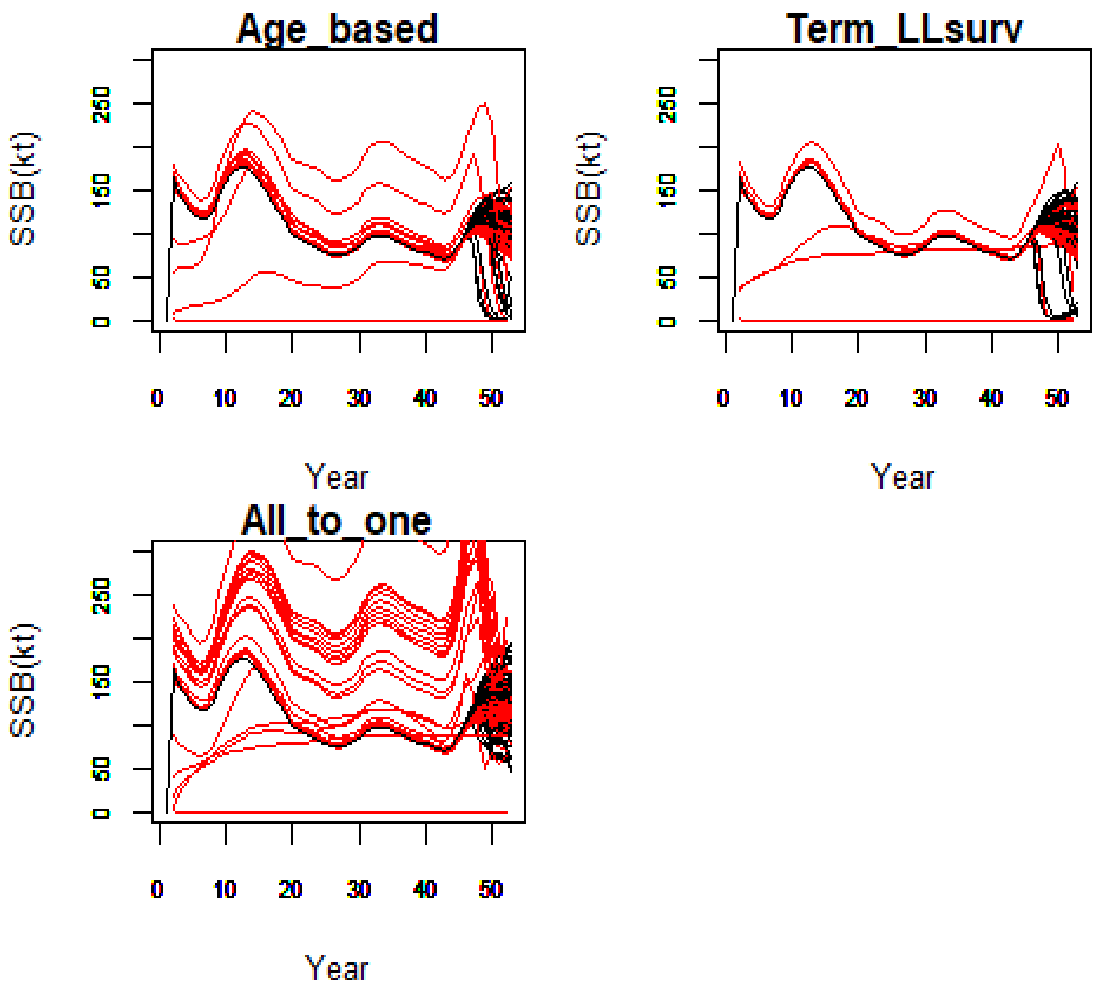


Figure 28. SSB for the OM (black) and EM (red); each line is a separate simulation. Recall that the conditioning period (years 0-43 are equivalent to 1977-2018) is deterministic for the OM and is the same for all simulations.

SSB residuals

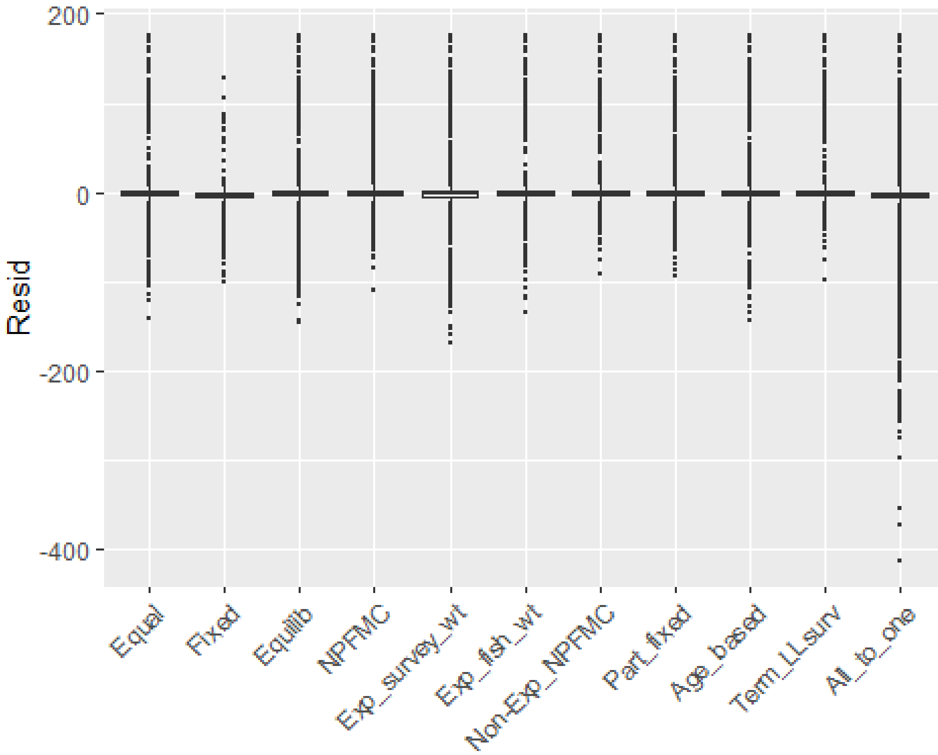


Figure 29. OM-EM SSB residual distribution for each apportionment method.

Appendix 3D.1 - additional information and figures

Apportionment specifics

Several apportionment methods have fixed or input specifications.

For 'Fixed' apportionment, the proportions of ABC by area (in order Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, East Yakutat/SEO) are: 10%, 13%, 11%, 34%, 11%, 21%.

For 'Equilibrium' apportionment, the proportions of ABC under the stationary distribution of the movement rates (areas in same order as above): 9%, 14%, 13%, 27%, 14%, 23%.

For 'Fixed' apportionment, Bering Sea and Aleutian Islands each receive 10% of the ABC. This value can be easily changed if desired.

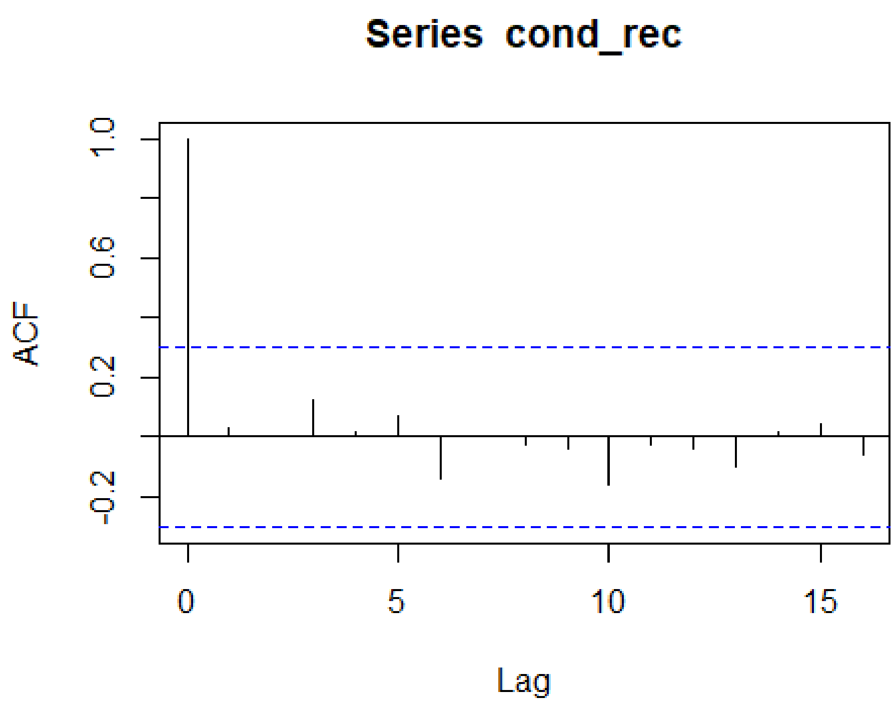
For 'A_L.mat' apportionment, the age at 50% maturity is assumed to be age-5 (it is really closer to age 5.5 but we cannot use half ages).

Recruitment from the Management EM is used during the conditioning period for the OM, and it has a small amount of autocorrelation (in its 'uncorrected' form, before we reduce 2014 from 150 million recruits to 50 million recruits). For the simulations shown here, we have used an autocorrelation parameter of 0.2 when generating OM recruitment. With the 2014 high recruitment removed, there does not appear to be any appreciable autocorrelation in recruitment:

Selectivity

OM Selectivity

These figures compare the apportionment OM selectivity values to values from the Management EM.



OM Longline fishery pre-IFQ selectivity

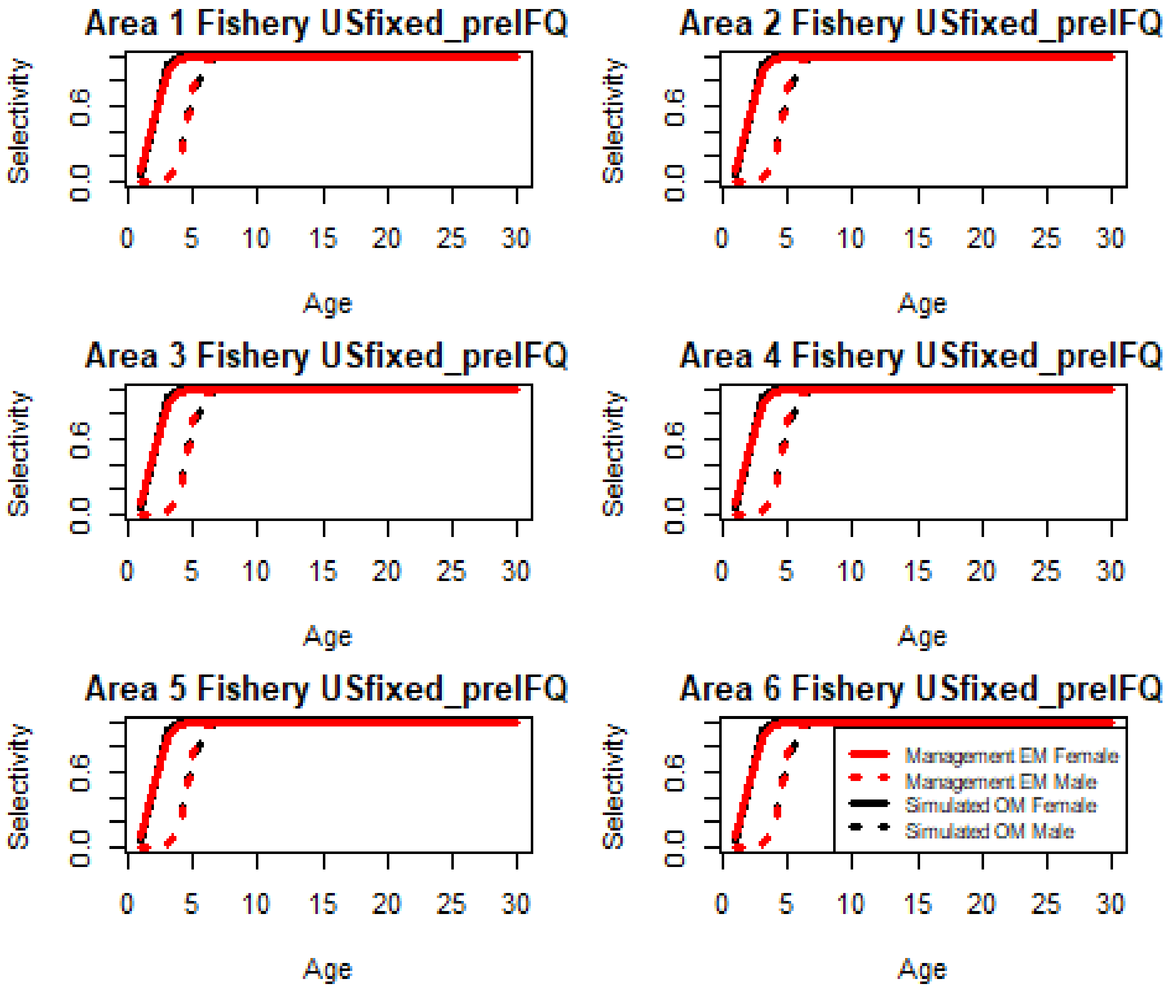


Figure 30: US fixed gear pre-IFQ (pre-1995) selectivity for each area has a logistic form. US fixed gear pre-IFQ selectivity is sex-specific but does not differ between spatial areas; OM values are the same as the values estimated from the spatial 'research' EM which is under development and has been reported on in the past.

OM Longline fishery Post-IFQ selectivity

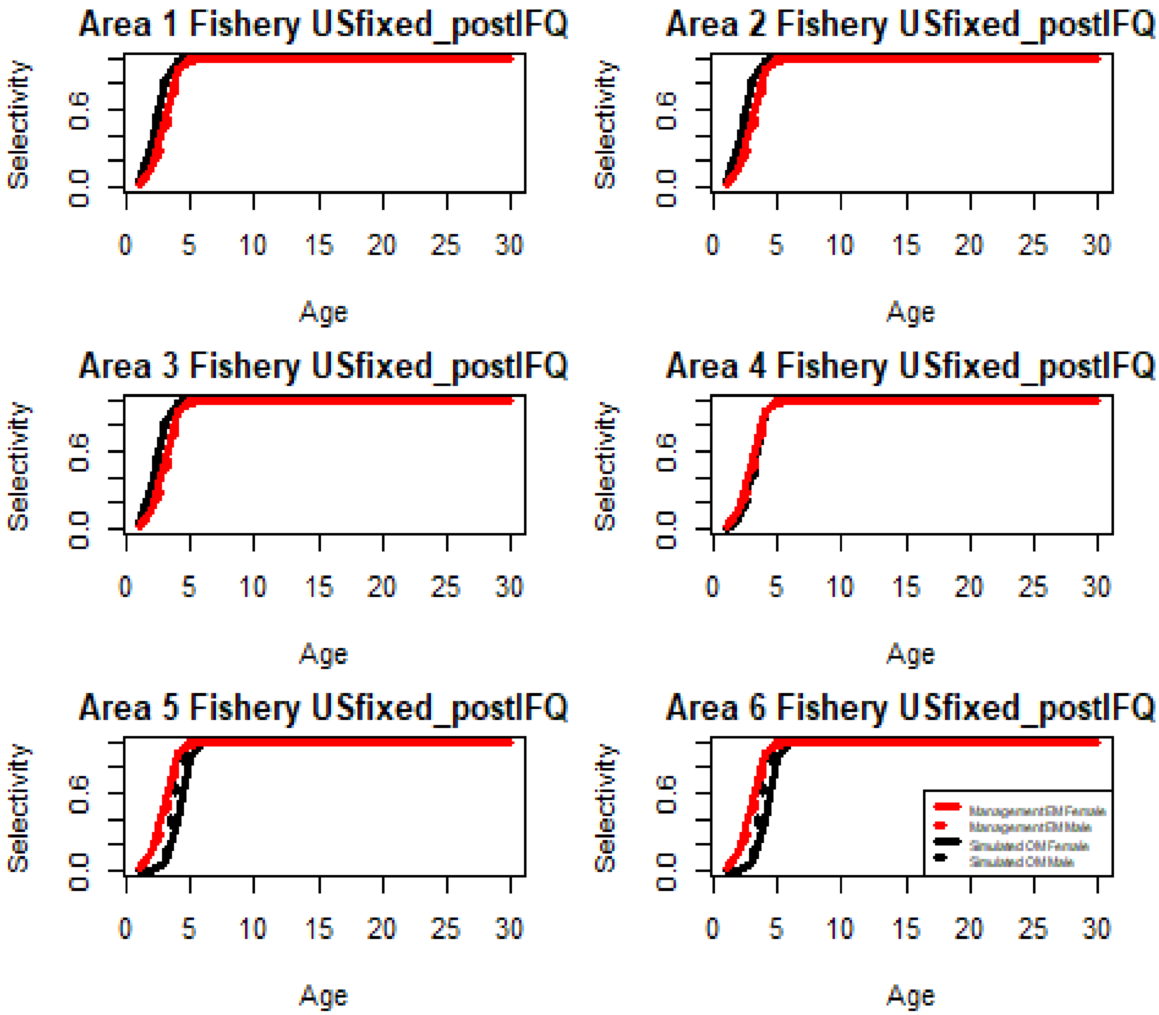


Figure 31: US fixed gear post-IFQ selectivity for each area has a logistic form. The values are sex-specific and there are some spatial differences for some areas. OM values for each area are based on the estimated selectivity values from the spatial 'research' EM.

<u>OM Trawl fishery selectivity</u>

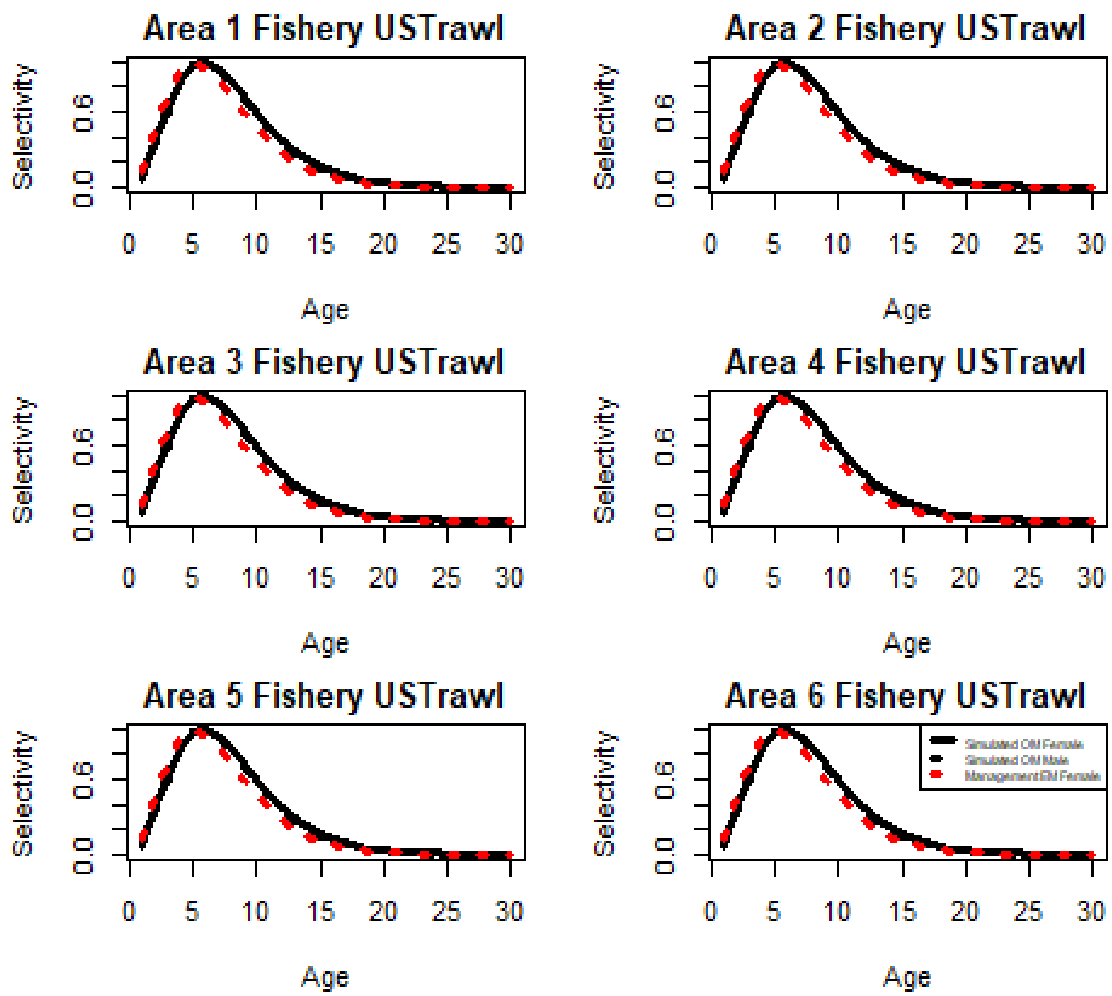


Figure 32: US trawl fishery selectivity for the OM is dome shaped. The values are sex specific and do not vary spatially. Values are from the ‘research’ spatial EM.

<u>OM Longline survey selectivity</u>

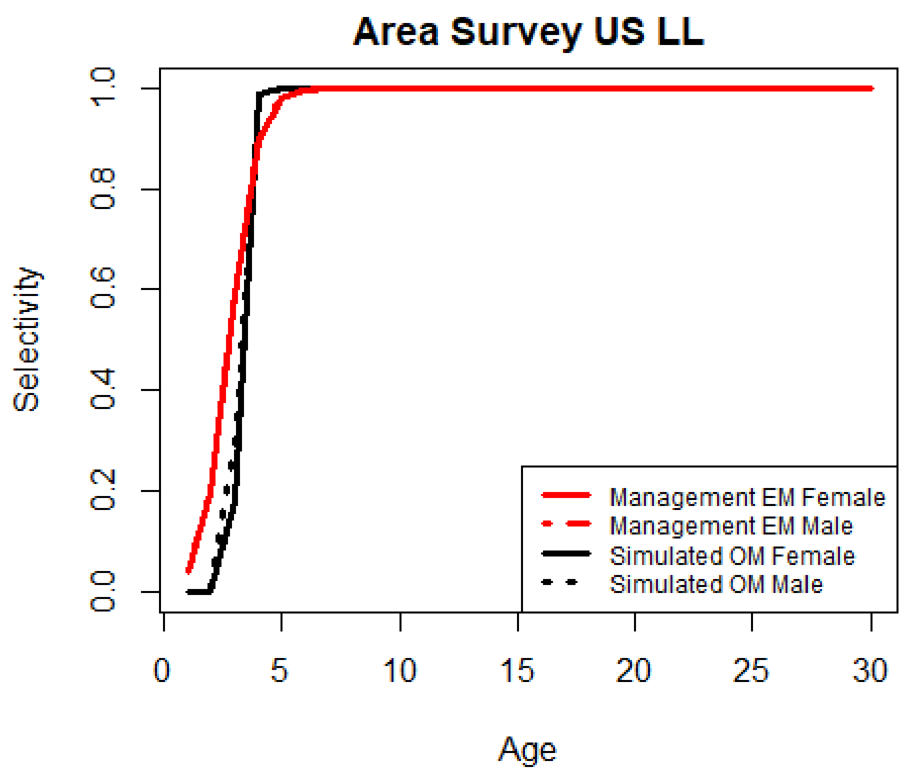


Figure 33: US longline survey selectivity parameters are not spatial but are sex specific and are based on the spatial ‘research’ EM values.

<u>OM Longline (USJP cooperative) survey selectivity</u>

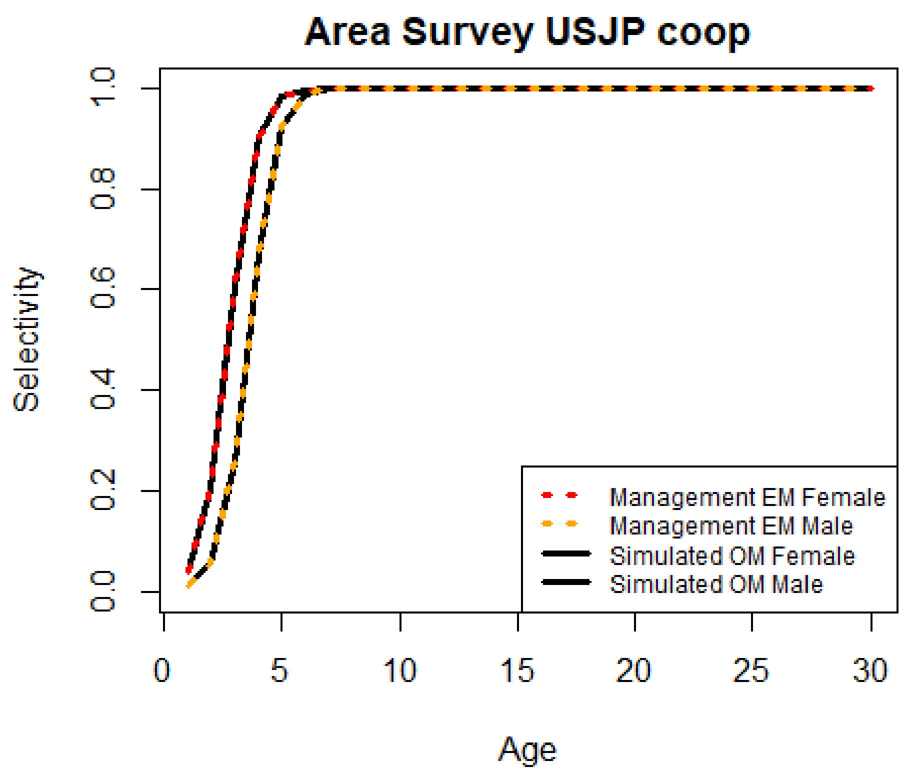
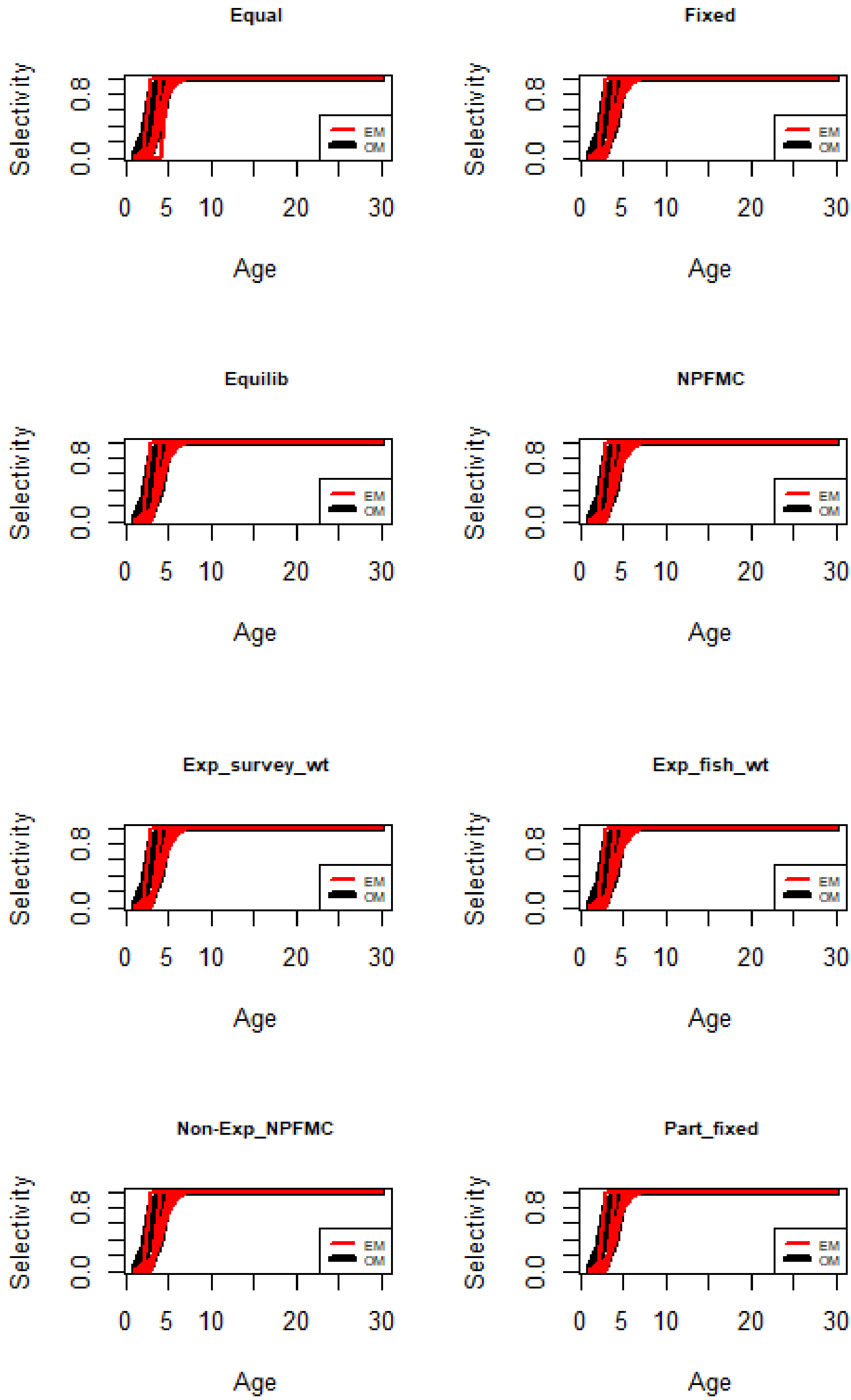


Figure 34: The USJP cooperative longline survey selectivity parameters. These are not spatial but are sex specific and values are based on the management EM values.

EM Selectivity

The next series of figures shows the EM estimated selectivity alongside the OM selectivity for the post-IFQ fixed gear fishery and the longline survey, these are the only two that are estimated in the EM.

<u>EM Longline fishery Post-IFQ</u>



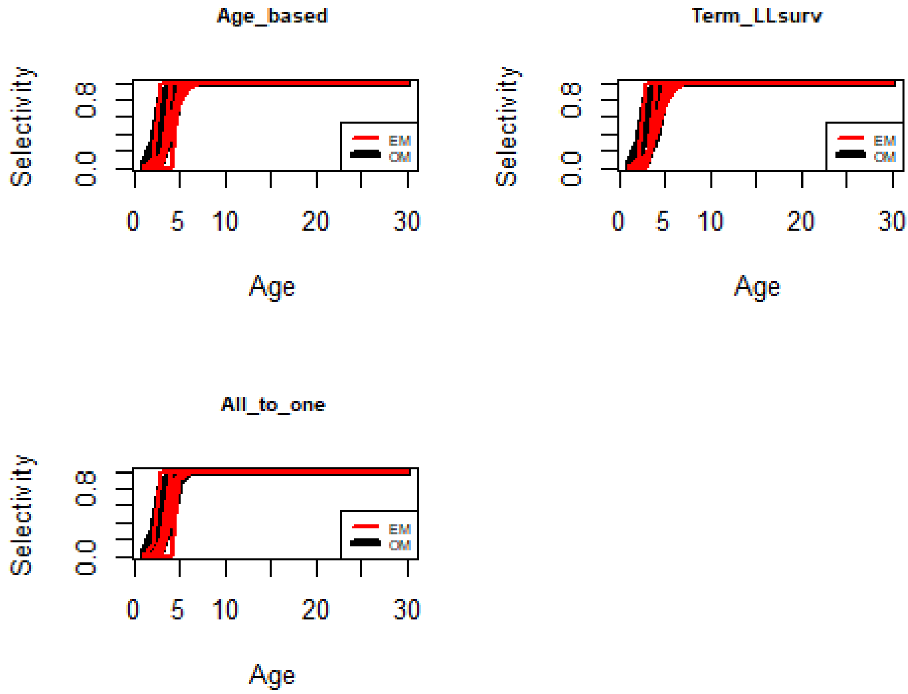


Figure 35. EM estimated female sablefish selectivity for the longline fishery, post-IFQ years for each apportionment method. Each red line in a single figure panel represents a different simulation and year. Selectivity does differ over some spatial areas in the OM, but cannot be estimated spatially in the single-area EM.

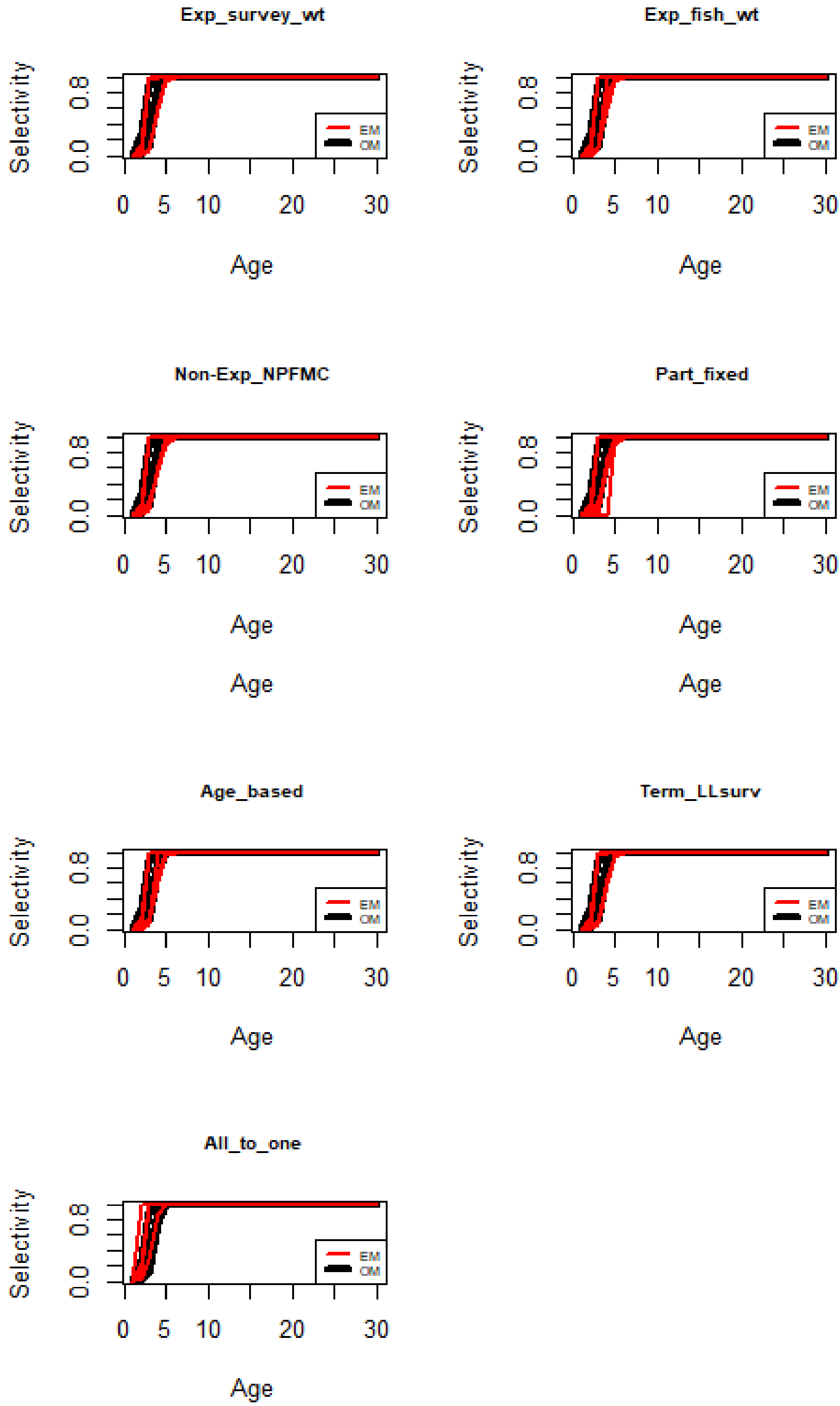

Exp_survey_wt
Exp_fish_wt
Non-Exp_NPFMC
Part_fixed
Age_based
Term_LLsurv
All_to_one
Selectivity
0.0
0.8
0 5 10 20 30
Age
EM
OM

Figure 36. EM estimated male sablefish selectivity for the longline fishery, post-IFQ years for each apportionment method. Each red line in a single figure panel represents a different simulation and year. Selectivity does differ over some spatial areas in the OM, but cannot be estimated spatially in the single-area EM.

EM Longline survey selectivity

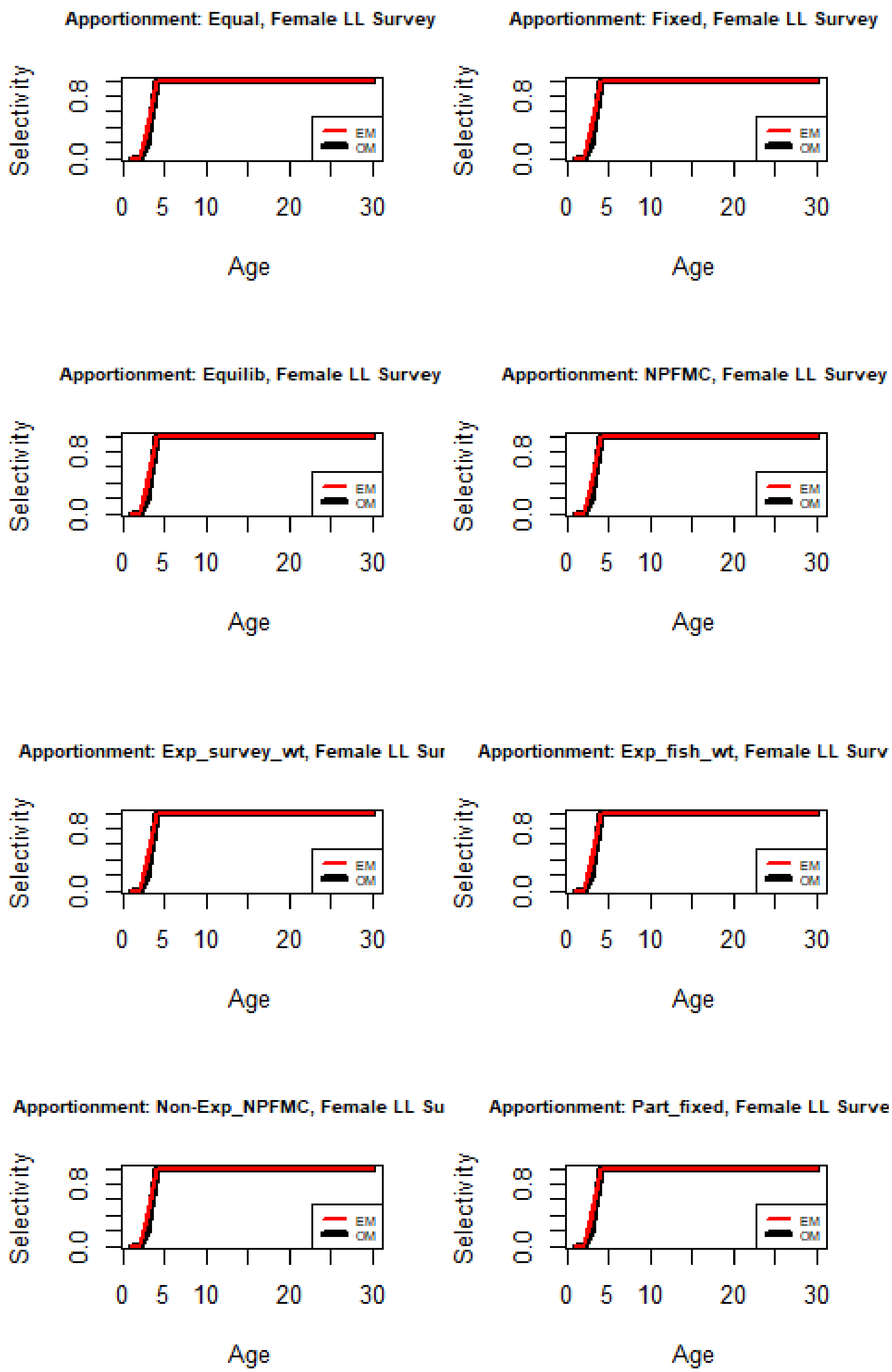
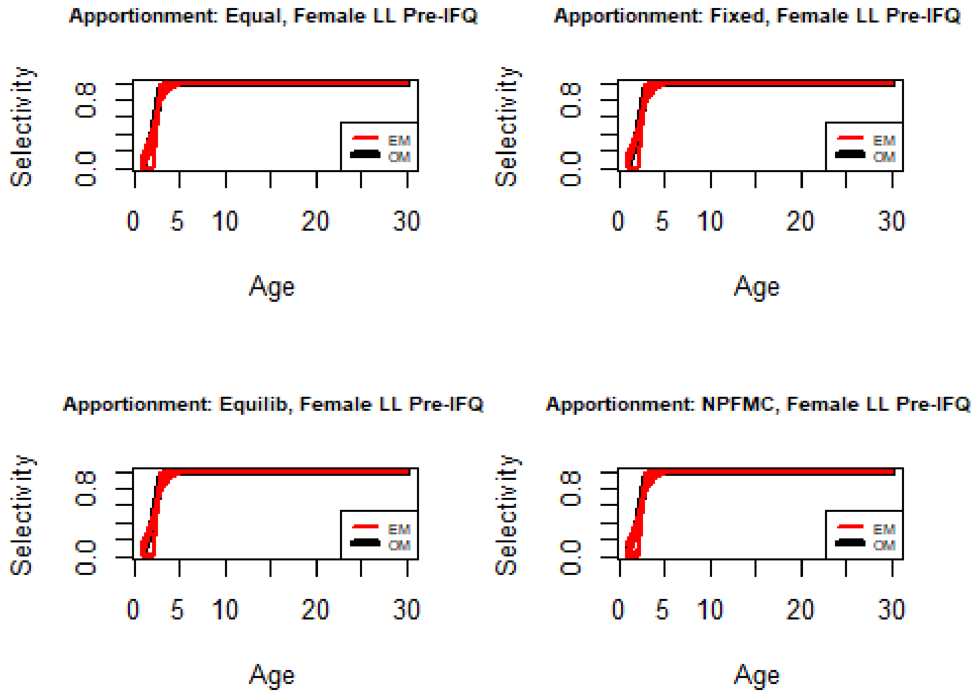
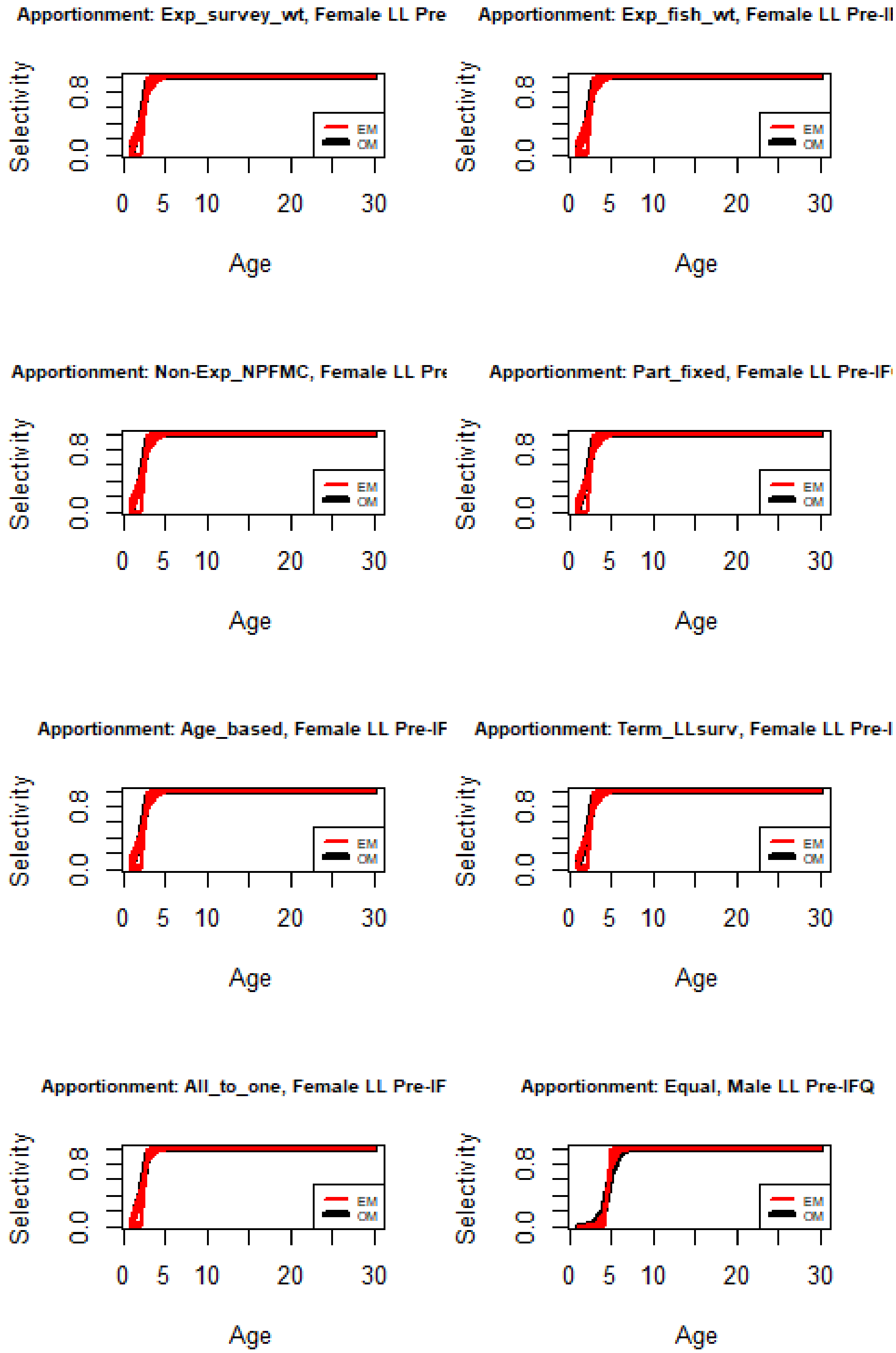


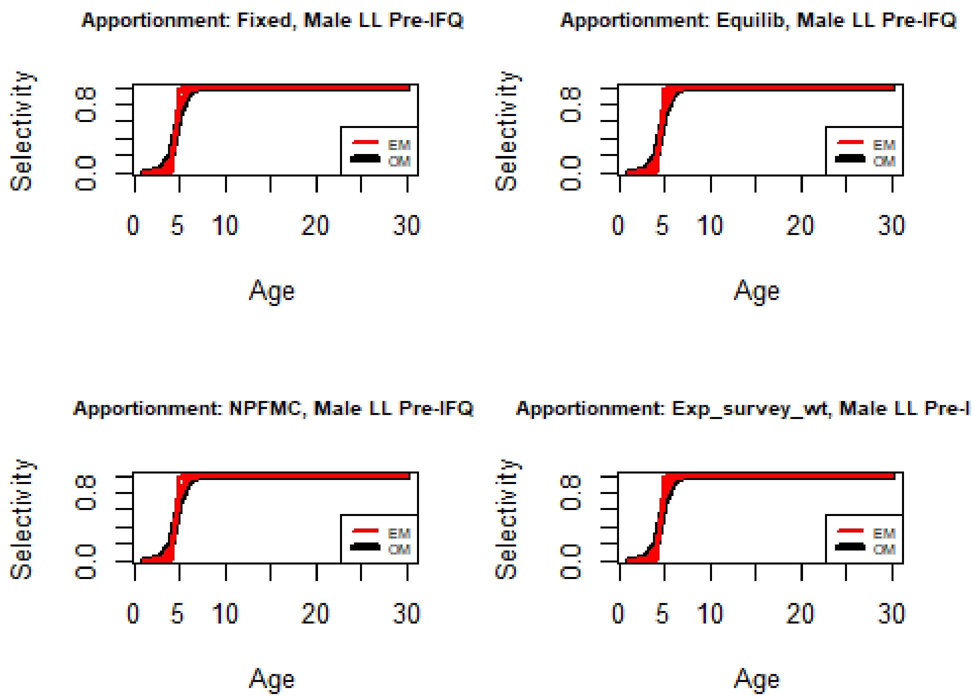
Figure 37. EM estimated female selectivity for the longline survey for each apportionment method. Each red line in a single figure panel represents a different simulation and year. Selectivity does not differ over spatial areas in the OM.

There are no length comps in the EM and only age comps for 1999 forward for the longline survey and the fixed gear fishery. As such, there's no data informing selectivity for the pre-IFQ fishery or trawl fishery in the EM. However, figures below show EM estimates and OM values for selectivity for these fisheries.

<u>Longline fishery Pre-IFQ selectivity (fixed, not estimated parameters)</u>


Apportionment: Equal, Female LL Pre-IFQ
Apportionment: Fixed, Female LL Pre-IFQ
Apportionment: Equilib, Female LL Pre-IFQ
Apportionment: NPFMC, Female LL Pre-IFQ
Selectivity
0.0
0.8
Age
0
5
10
20
30
EM
OM


Apportionment: Exp_survey_wt, Female LL Pre
Apportionment: Exp_fish_wt, Female LL Pre-II
Apportionment: Non-Exp_NPFMC, Female LL Pre
Apportionment: Part_fixed, Female LL Pre-IF
Apportionment: Age_based, Female LL Pre-IF
Apportionment: Term_LLsurv, Female LL Pre-I
Apportionment: All_to_one, Female LL Pre-IF
Apportionment: Equal, Male LL Pre-IFQ
Selectivity
0.0
0.8
0
5
10
20
30
Age
EM
OM


Apportionment: Fixed, Male LL Pre-IFQ
Apportionment: Equilib, Male LL Pre-IFQ
Apportionment: NPFMC, Male LL Pre-IFQ
Apportionment: Exp_survey_wt, Male LL Pre-I
Selectivity
0.0
0.8
0
5
10
20
30
Age
EM
OM

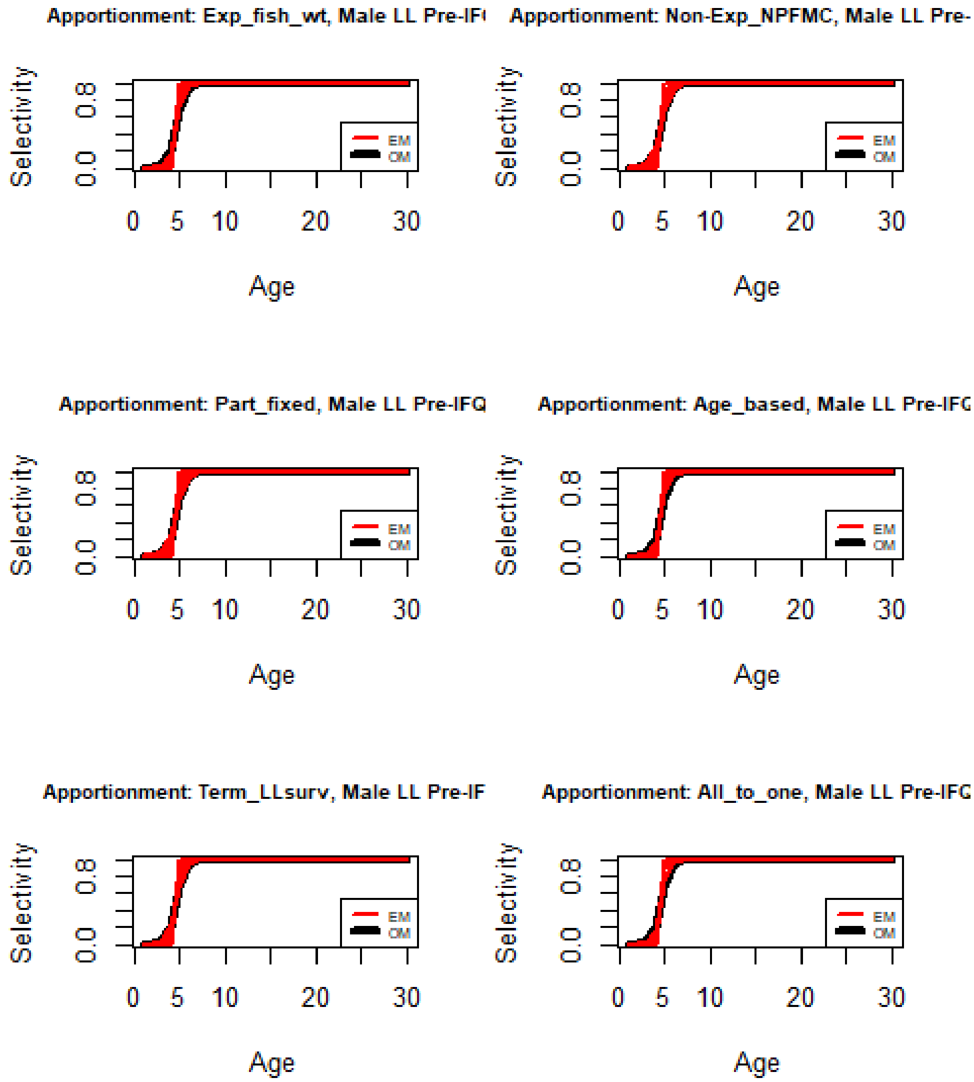
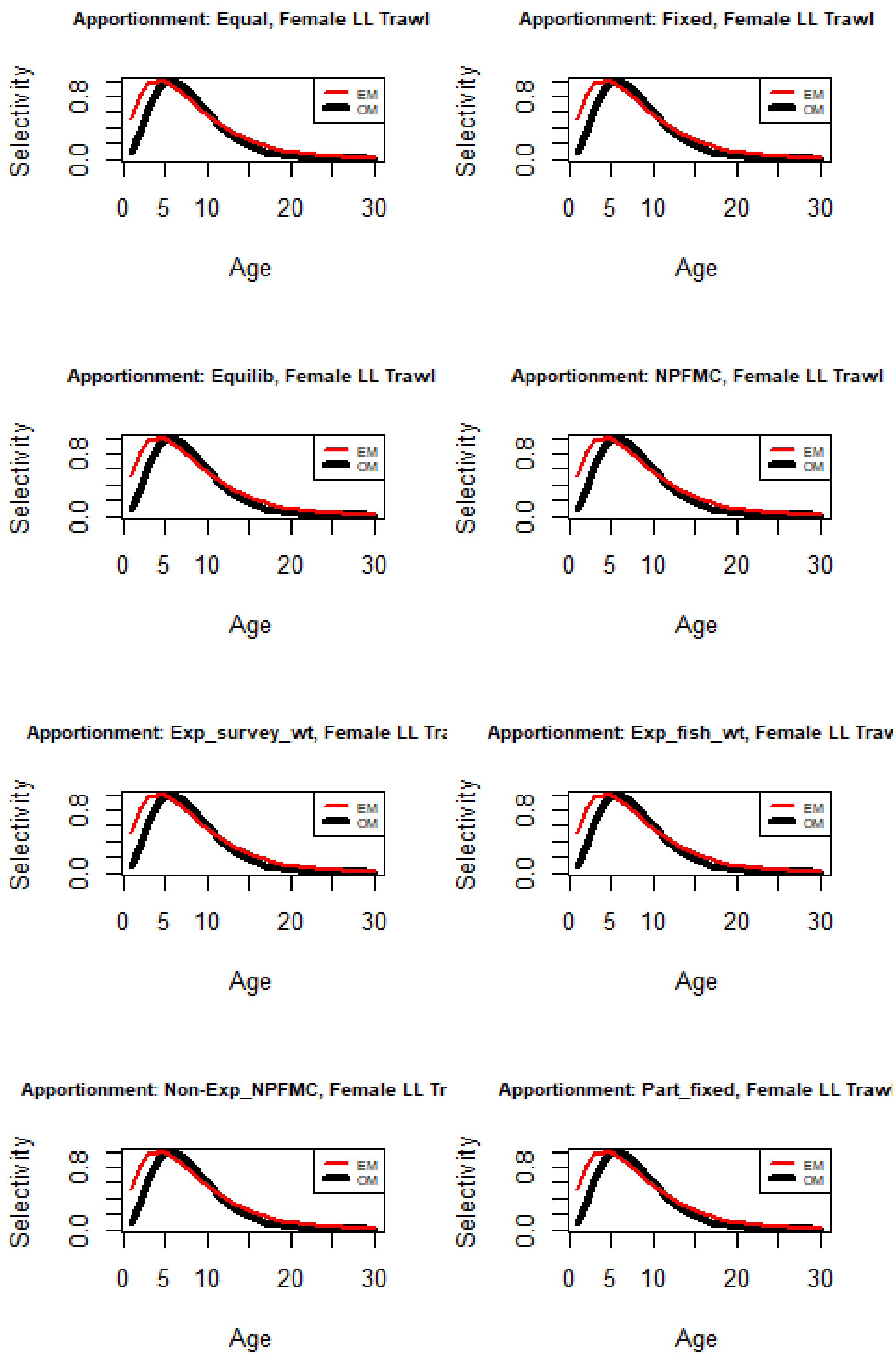
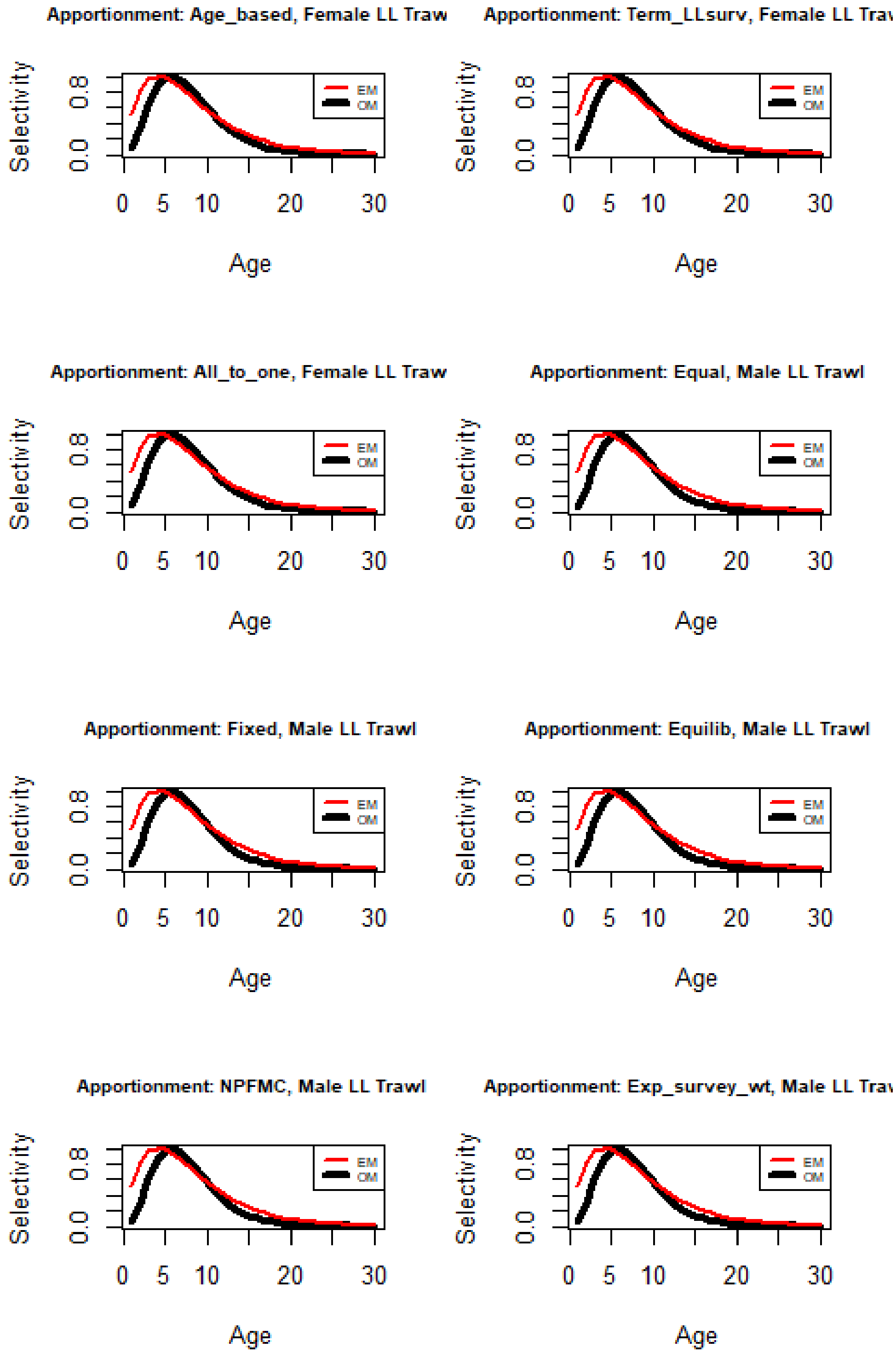


Figure 39. EM estimated selectivity for the longline fishery pre-IFQ years for each sex and apportionment method. Each red line in a single figure panel represents a different simulation and year. Pre-IFQ selectivity does not differ over spatial areas in the OM.

Trawl fishery (fixed, not estimated parameters)




Apportionment: Age_based, Female LL Traw
Apportionment: Term_LLsurv, Female LL Tra
Apportionment: All_to_one, Female LL Traw
Apportionment: Equal, Male LL Trawl
Apportionment: Fixed, Male LL Trawl
Apportionment: Equilib, Male LL Trawl
Apportionment: NPFMC, Male LL Trawl
Apportionment: Exp_survey_wt, Male LL Tra
Selectivity
0.0
0.8
Age
0
5
10
20
30
EM
OM

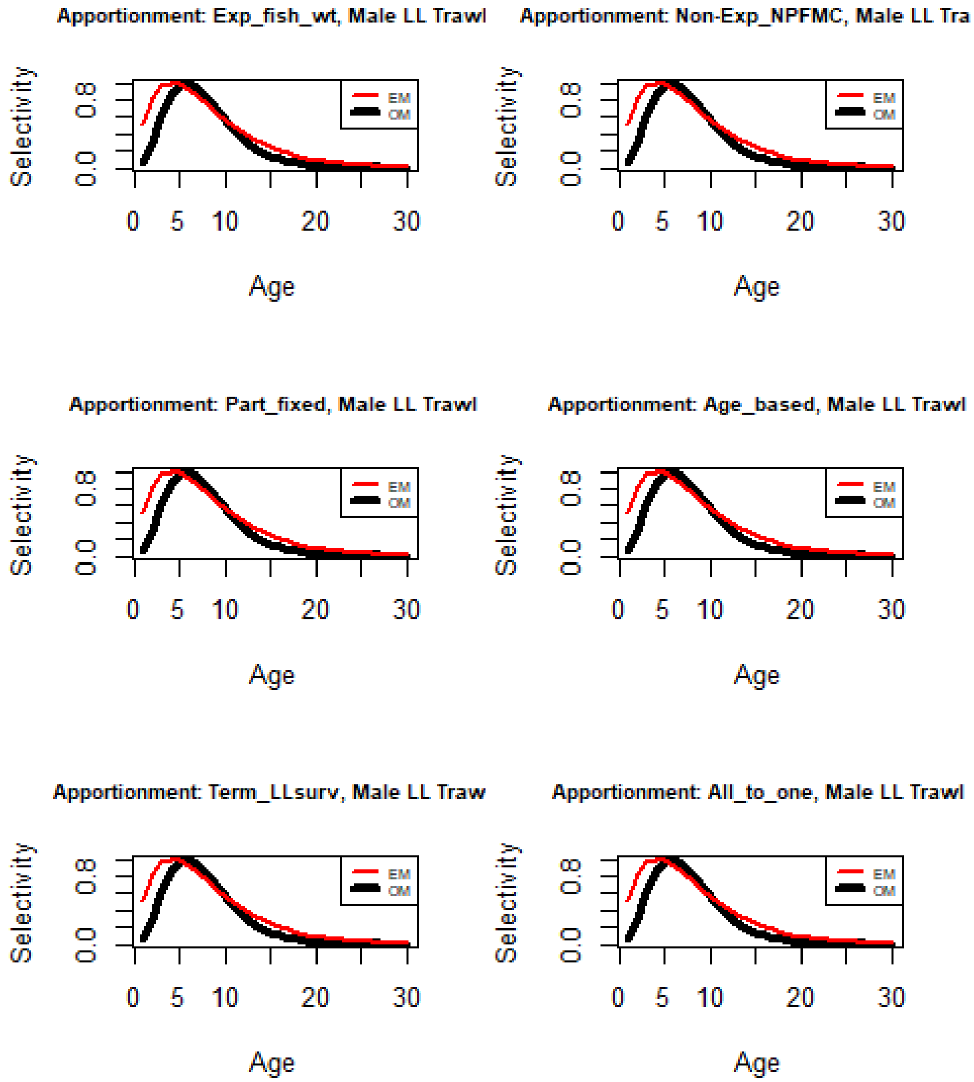


Figure 40. EM estimated selectivity for the trawl fishery for each sex and apportionment method. Each red line in a single figure panel represents a different simulation and year. Selectivity does not differ over spatial areas in the OM.

Catchability

The distribution of catchability (q) parameter estimates from the EM is shown below as boxplots. For each apportionment option (x axis) the box shows the median (thick line inside the box) and the 25th and 75th percentile interquartile range (box lower and upper border) of EM q estimates across all years and simulations. The vertical bars represent the largest and smallest values within 1.5 times the interquartile range, and any values outside these ranges are shown as points. The red line is the OM value of catchability.

Fixed gear fishery, foreign years

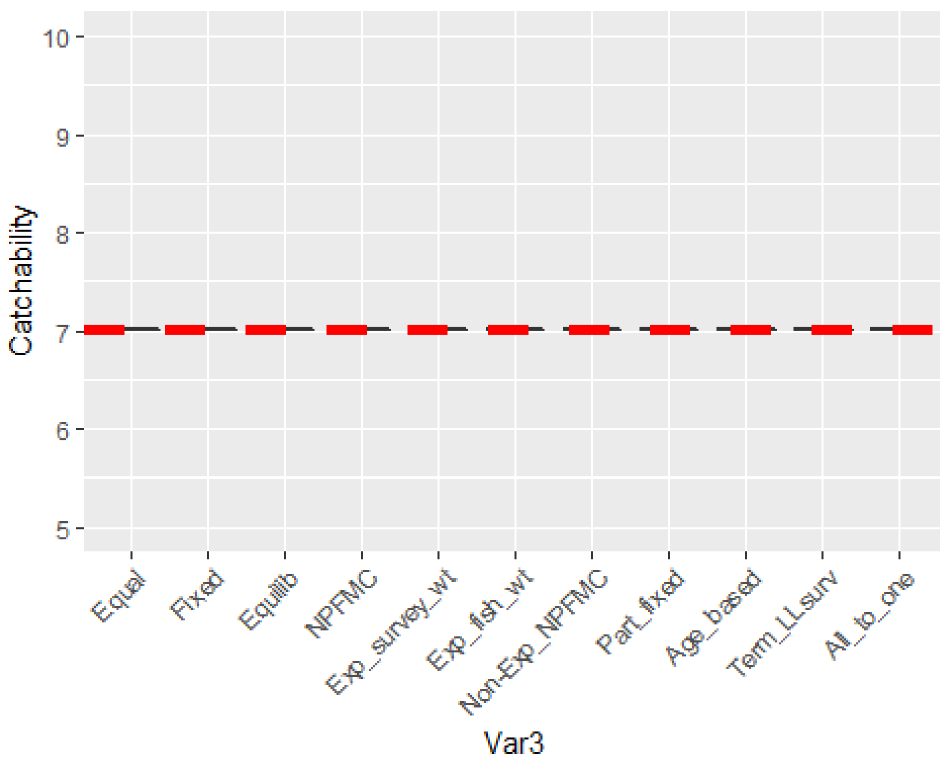


Figure 41. Catchability (q) parameter estimates from the EM (black) for each apportionment method. The red line is the OM value of q.

Longline fishery Pre-IFQ

For the boxplots below, the dashed red line is OM q for BS, AI, and WG. The solid red line is OM q for CG, and the dotted line is OM q for WY and EY/SEO.

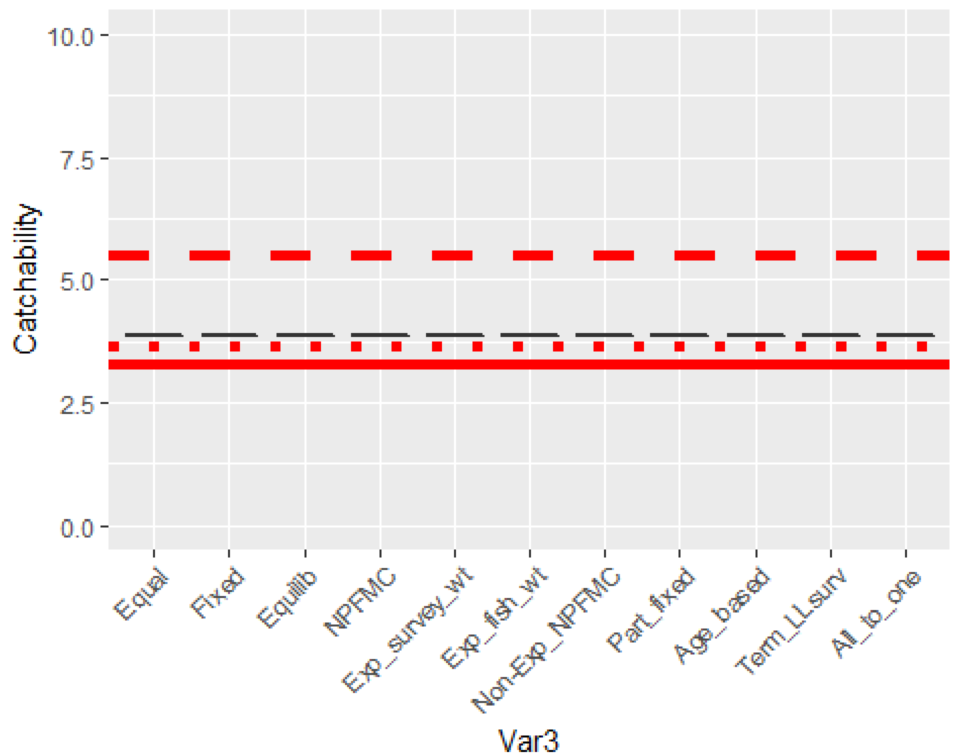


Figure 42. Catchability (q) parameter estimates from the EM (black) for each apportionment method. The red line is the OM value of q.

<u>Longline fishery Post-IFQ</u>

For the boxplots below, the dashed red line is OM q for BS, AI, and WG. The solid red line is OM q for CG, and the dotted line is OM q for WY and EY/SEO.

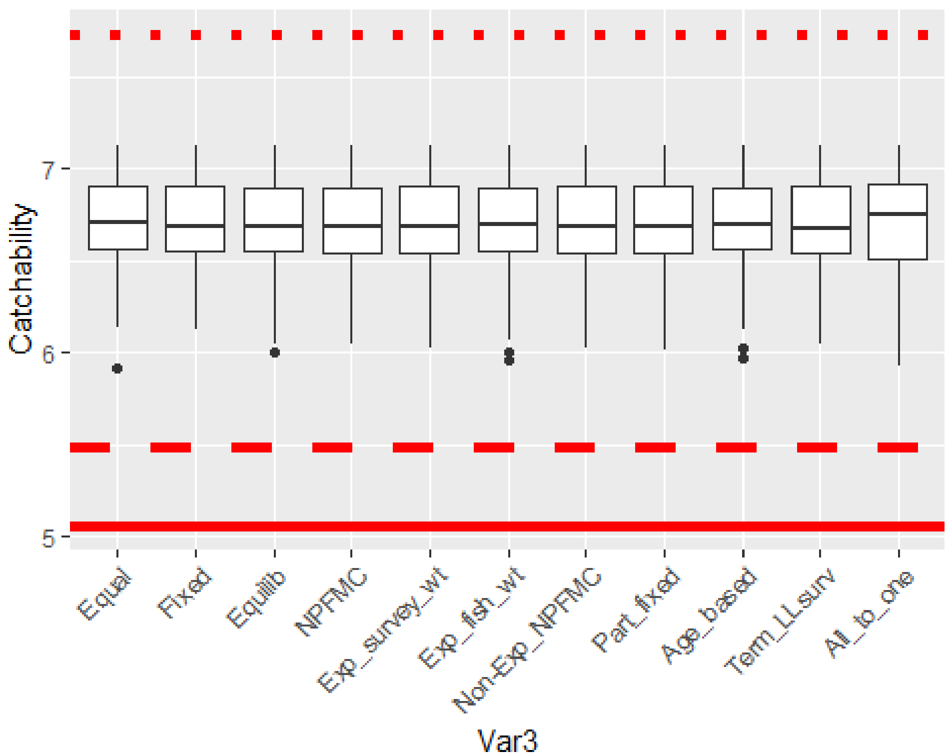


Figure 43. Catchability (q) parameter estimates from the EM (black) for each apportionment method. The red line is the OM value of q.

<u>Longline survey (US years)</u>

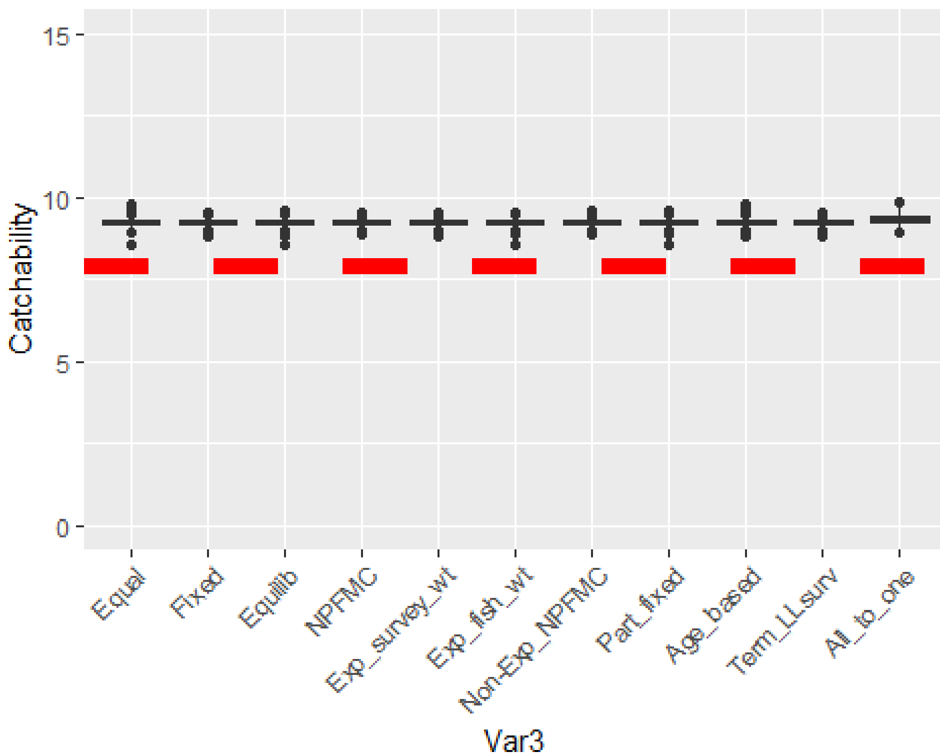


Figure 44. Catchability (q) parameter estimates from the EM (black) for each apportionment method. The red line is the OM value of q.

<u>Longline survey (USJP years)</u>

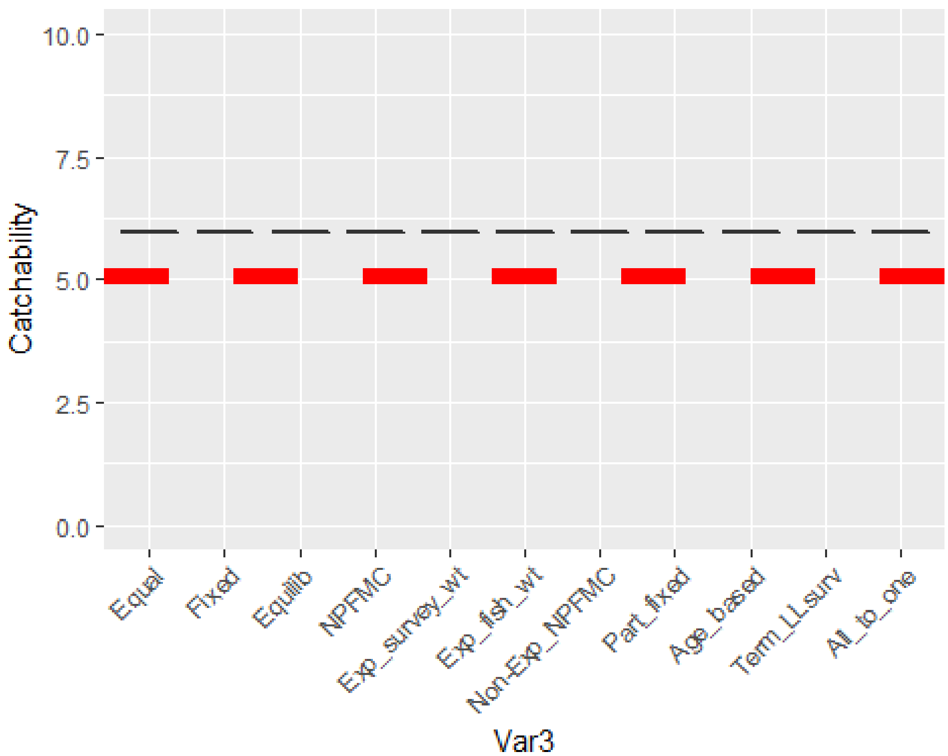


Figure 45. Catchability (q) parameter estimates from the EM (black) for each apportionment method. The red line is the OM value of q.