3. Assessment of the Sablefish Stock in Alaska

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Executive Summary

Summary of Changes to the Assessment

Relative to last year's assessment, we have not made any major changes in the current assessment except for inclusion of new data. The changes are summarized below.

Changes to the Input Data

New data included in the assessment model were relative abundance and length data from the 2020 longline survey, relative abundance and length data from the fixed gear fishery for 2019, length data from the trawl fisheries for 2019, age data from the longline survey and fixed gear fishery for 2019, updated catch for 2019, and projected 2020 - 2022 catches. Estimates of killer and sperm whale depredation in the fishery were updated and projected for 2020 - 2022. In 2020, there was not a NMFS Gulf of Alaska trawl survey.

Changes to 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 risk table approach utilized previously and updated with new rationale.

Each of the appendices have been updated with relevant new information and analyses. In particular, the Ecosystem and Socioeconomic Profile (ESP), Appendix 3C, has been updated with new data for 2020. The catch apportionment appendix (3D) has been overhauled and updated to reflect requested changes to the operating model and apportionment strategies based on SSC and PT comments over the last year. There is one additional appendix characterizing bycatch of small sablefish in the trawl fisheries in the Bering Sea (Appendix 3E).

Summary of Results

The longline survey abundance index (relative population numbers, RPNs) increased 32% from 2019 to 2020 following a 47% increase in 2019 from 2018 (Figure 3.10c). The lowest point of the time series was in 2015. Similarly, the trawl survey biomass was at a time series low in 2013, but has more than tripled since that time (Figure 3.10c). The fishery catch-rate (CPUE) index was at the time series low in 2018, but increased 20% in 2019 (the 2020 data are not available yet; Figure 3.10c). The age and length composition data continue to indicate strong year classes in 2014, 2016, and a potentially strong, albeit highly uncertain, 2017 year class. However, 2020 assessment model estimates of the strength of the 2014 and 2016 year classes continue to be downgraded from estimates in previous assessments, including reductions from the 2019 assessment model of 27% and 25%, respectively (Figure 3.18a). Yet, these recruitment events still represent three of the top four all-time largest year classes for sablefish. Based on the strength of these recent year classes, biomass estimates have nearly quadrupled to 687,000 t in 2020 since a time series low in 2015 (Figure 3.17). Given that most of these recent year classes are still primarily immature fish, spawning biomass has not rebounded as rapidly as total biomass. Yet, from the time series low in 2018, SSB has increased by 44% to 94,000 t in 2020. Spawning biomass is projected to continue to increase rapidly in the near-term, moving the stock from below $B_{40\%}$ to well above $B_{40\%}$ in the next two years, before declining back towards $B_{40\%}$ in the long-term (Figure 3.49).

However, these projections are likely to be overly optimistic for two primary reasons: reliance on uncertain estimates of large recent year classes and their survival, as well as, increasingly large and consistent retrospective patterns that indicate an uncertain assessment model. The 2014 and 2016 year classes are projected to comprise approximately 27% and 22% of the 2021 spawning biomass, respectively (Figure 3.19). Conversely, the remnants of the two previously strong year classes in 2000 and 2008 continue to be removed from the population and represent only 4% and 5.5% of the projected 2021 spawning biomass, respectively. Thus, projections of future SSB increases rely heavily on fish from recent strong recruitment events surviving to maturity along with future data and assessments verifying year class strength. Perhaps more importantly, uncertainty in the estimates of recent year class strength has resulted in a consistent positive retrospective bias in assessment model outputs of SSB and recruitment (Figures 3.43 – 3.45). Therefore, model outputs from the 2020 stock assessment for sablefish are likely overly optimistic and models in future years may indicate that both recruitment and SSB were overestimated.

Additionally, preliminary analyses indicate that, since 2011, growth of female sablefish has slowed and maturity has been delayed (see the Growth and Maturity section). Thus, the biomass and SSB of the large recent year classes may be overestimated. Similarly, the condition of immature, age-4 fish in recent years has been below average, which could cause delayed maturation and lower survival. Furthermore, these recent, mostly immature year classes are undergoing increased removals compared to previous years, particularly in trawl fisheries (see Appendix 3E for a description of increases in Bering Sea trawl bycatch). All of these issues warrant careful monitoring in the future.

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using the mean size of the 1977 – 2016 year classes. The updated point estimate of $B_{40\%}$, is 126,389 t. Since projected female spawning biomass (combined areas) for 2021 is 134,401 t (6% higher than $B_{40\%}$, or equivalent to $B_{42\%}$), sablefish is in sub-tier "a" of Tier 3. The updated point estimates of $F_{40\%}$ and $F_{35\%}$ from this assessment are 0.100 and 0.117, respectively. Thus, the maximum permissible value of F_{ABC} under Tier 3a is 0.100, which translates into a 2021 maximum permissible ABC (combined areas) of 52,427 t. The OFL fishing mortality rate is 0.117, which translates into a 2021 OFL (combined areas) of 61,319 t. Biomass-based reference points have increased by 20% from 2019. The main factor driving these changes is the incorporation of the strong 2016 year class in the calculation of reference points for 2020, which was not incorporated in the 2019 estimate of average recruitment. It is likely that a similar pattern will occur in the next assessment, because the 2017 year class is estimated to be large, which will further increase the average recruitment used to determine reference points. Thus, relative stock status estimated in the model year 2021 stock assessment will likely decline due to further increases in the $B_{40\%}$ reference point. However, current model projections indicate that the Alaskan sablefish stock is not subject to overfishing, not overfished, and not approaching an overfished condition.

Instead of maximum permissible ABC, we are recommending that the 2021 ABC be held at the 2020 specified ABC of 22,551 t, which translates to a 57% reduction from maximum ABC. The final whale-adjusted 2021 ABC of 22,237 t is 1% higher than the 2020 whale-adjusted ABC of 22,009 t. The recommended ABC represents a 3,250 t (17%) increase from the author recommended 2020 ABC in 2019, and an 88% increase in the ABC since 2016 when the lowest ABC on record (11,795 t) was enacted. The maximum permissible ABC for 2021 is 52,427 t, which represents a 19% increase from the 2020 maximum permissible ABC of 44,065 t projected by the 2019 assessment. However, this represents a smaller increase in the maximum permissible 2021 ABC compared to the 28% increase projected by the 2019 assessment from 2020 to 2021 (i.e., the 2019 assessment projected a 2021 ABC of 56,589 t). The author recommended ABCs for 2021 and 2022 are lower than maximum permissible ABC for several important reasons that are examined in the SSC endorsed risk table approach for ABC reductions, which are summarized below.

Summary Table

Quantity/Status	As estimated or specified *last* year for: 2020	2021	As estimated or recommended *this* year for: 2021*	2022*
M (natural mortality rate)	0.105	0.105	0.098	0.098
Tier	3a	3a	3a	3a
Projected total (age 2+) biomass (t)	704,683	741,029	753,110	789,584
Projected female spawning biomass (t)	113,368	156,854	134,401	191,503
$B_{100\%}$	264,940	264,940	317,096	317,096
$B_{40\%}$	105,976	105,976	126,389	126,839
$B_{35\%}$	92,729	92,729	110,984	110,984
F_{OFL}	0.121	0.121	0.117	0.117
$maxF_{ABC}$	0.102	0.102	0.100	0.100
F_{ABC}	0.043	0.041	0.042	0.048
OFL (t)	51,726	66,361	61,319	71,756
OFL_w (t)**	**50,481**	**64,765**	**60,426**	**70,710**
max ABC (t)	44,065	56,589	52,427	61,393
ABC (t)	22,551	29,723	22,551	29,723
ABC_w (t)**	22,009	29,008	**22,237**	**29,309**
Status	As determined *last* year for: 2018	2019	As determined *this* year for: 2019	2020
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 approximate estimated catches of 21,100 t and 23,600 t (based on the ratio of estimated catch to max ABC in 2020) used in place of maximum permissible ABC for 2021 and 2022. 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.

Risk Table Summary

Below is a discussion of our rationale for suggesting an ABC below the maximum permissible value based on a summary of the 2020 risk table and the Ecosystem and Socioeconomic Profile (ESP).

While there are clearly positive signs of strong incoming recruitment, concerns exists regarding the lack of older fish contributing to spawning biomass, the uncertainty surrounding the estimates of the strength of the 2014, 2016, and 2017 year classes, and ambiguity related to how existing environmental conditions may affect the success of these year classes in the future. These concerns warrant additional caution when recommending the 2021 and 2022 ABCs. It is unlikely that the 2014 or 2016 year classes will be reduced to average or below average levels, but projecting catches under the assumption that these year classes are 3 - 10x's average introduces substantial risk given the uncertainty associated with these estimates. Recent environmental conditions, including multiple marine heat waves, appear favorable to recruitment success for sablefish. However, it is unclear whether this is a permanent productivity regime shift or a transient phase. Additionally, associated ecosystem changes may be detrimental for the condition of juvenile and adult fish. Condition factors of recent large cohorts appear to be below average, which may impede realization of the benefits of these year classes if survival and/or maturity rates have decreased. These cohorts are also beginning to recruit to the various gear types as young, small fish with associated increases in removals, especially as bycatch in the BS trawl fisheries. Increased mortality on young fish may reduce the number of fish from these year classes that survive and mature, whereas active avoidance of lower value small fish by the directed fisheries could lead to further removals of larger, mature fish and put additional strain on the severely truncated age structure and SSB.

Historically, extremely strong year classes have been sporadic and rare, yet they have become more common since 2014 despite extremely low SSB (Figure 3.18c). But, the population is becoming increasingly dependent on the 2014 and 2016 year classes (Figure 3.19). Our caution in reducing ABC in 2020 seems justified as the estimate of the 2014 year class has decreased 68% since being first estimated in the 2017 assessment. Similarly, the 2016 year class decreased 25% between the 2019 assessment and the 2020 assessment (Figure 3.18a). The large estimated year classes for 2014 and 2016 are expected to comprise about 27% and 22% of the 2021 spawning biomass in 2021 (Figure 3.19). The reliance on these young cohorts indicates a severely truncated age composition, given that the female portion of the 2014 year class will be about 60% mature and the 2016 year class will be less than 20% mature in 2021 (Table 3.12). Projected increases in future SSB rely heavily on these fish surviving to maturity along with future data and assessments verifying the strength of these year classes. However, there is a consistent positive retrospective bias in assessment model outputs of SSB and recruitment, indicating that model estimates and projections are likely overly optimistic (Figures 3.43 – 3.45). When projections were performed assuming that the 2016 and 2017 year classes were fixed at average levels, the resulting ABC decreased dramatically to 22,000 t (see Alternate Projections section). Thus, the uncertainty in recent recruitment has important implications for the determination of future catch limits. Unfortunately, tier 3 stocks have no explicit method to incorporate the uncertainty of these recent extremely large year classes into harvest recommendations or to directly account for retrospective bias.

Although survey and fishery indices of abundance show positive signs consistent with recent strong recruitment, the model fits to these indices are poor (Figures 3.3 – 3.4). The model continues to severely overestimate each of the abundance indices, suggesting an overreliance on uncertain age and length composition data from young fish as the basis for estimating large year classes. Despite all data sources suggesting an improving outlook for the sablefish population, it is apparent that the model is overstating the potential increases in stock abundance suggested by these indices.

This is the third time we have used the risk table approach to assess reductions in ABC from maximum permissible ABC. Both the assessment and the population dynamics considerations were rated 3 indicating “major concern”, which suggests that setting the ABC below the maximum permissible is warranted.

The following bullets summarize the conclusions reached in the Additional ABC/ACL Considerations section and the Ecosystem and Socioeconomic Profile in Appendix 3C:

- Retrospective bias has increased rapidly to concerning levels and demonstrates a consistent overestimation of recruitment and SSB in subsequent model years; thus, it is unlikely that the population will grow as rapidly as projected by the model.
- The estimate of the 2014 year class strength declined 68% from the 2017 to 2020 assessment models, while the 2016 year class was downgraded by 25% from the 2019 assessment; declines of this magnitude illustrate the uncertainty in these early recruitment estimates.

- Projections assuming that the large 2016 and 2017 recruitment events are equivalent to mean recruitment indicate that the 2021 ABC should be much lower (22,000 t), while results from the most plausible sensitivity models also indicated reduced ABCs compared to the Base model.
- The very large estimated year classes for 2014 and 2016 are expected to comprise about 27% and 22% of the 2021 spawning biomass, respectively; the 2014 year class will be about 60% mature while the 2016 year class will be 20% mature in 2021.
- 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.
- 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.
- Mean age of spawners has decreased dramatically since 2017 and continues a downward trend due to the continued increase in the contribution of the 2014 year class to the SSB and the decrease in the number of older fish; the 2014 year class will be a critical component of the rebuilding process.
- Age-4 body condition of the 2014 year class was below average and lower than for previous large year classes in the early 2000s; poor condition could lead to reduced survival and delayed maturity.
- Fits to abundance and biomass indices are poor for recent years, particularly fishery CPUE and the GOA trawl survey, due to the model overstating population growth compared to what is indicated in the observed indices.
- The AFSC longline survey Relative Population Weight index, though no longer used in the model, lags the Relative Population Numbers index by a few years and is only recently beginning to increase.
- Another marine heat wave formed in 2018, which may have been beneficial for sablefish juveniles in the 2014 – 2017 year classes, but it is unknown how it will affect movement, survival, growth, and maturity of late-stage juveniles and recently matured adult fish.
- Fishery performance (i.e., CPUE) has been weak in the directed fishery, with downward trends in CPUE over a long time period in much of the GOA that hit time series lows in 2018, albeit with an increase of 20% in 2019.
- Small sablefish are being caught incidentally at unusually high levels, which is shifting fishing mortality spatially and demographically; further analysis is required to fully understand the effects or whether this might reduce future contributions of the recent, large year classes to SSB.

Recommending an ABC lower than the maximum should result in more of the 2014, 2016, and 2017 year classes entering into the spawning biomass and becoming more valuable to the fishery. This precautionary ABC recommendation buffers for uncertainty until there are more observations of these potentially large year classes. Because sablefish has an annual assessment, we will be able to consider another year of age composition data in 2021 and allow this extremely young population to further mature and more fully contribute to future spawning biomass.

Spatial Catch Apportionment

In December 1999, the Council apportioned the 2000 ABC and OFL to management areas based on a 5-year exponential weighting of the survey and fishery abundance indices (termed the 'NPFMC' method). 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. Because of the high variability in apportionment schemes used prior to 2013, the authors, Plan Team, and SSC decided to fix the apportionment at the proportions from the 2013 assessment (termed the 'Fixed' method) until the apportionment scheme could be thoroughly re-evaluated and reviewed. Additionally, a recently developed three-area spatial model demonstrated different regional biomass estimates compared to the area-specific catch proportions used in the NPFMC and fixed apportionment methods. Further research on alternative apportionment methods and tradeoffs among them is underway and is summarized in Appendix 3D. The 2016 CIE review panel strongly stated that there was no immediate biological concern with the current Fixed apportionment, given the high mixing rates of the stock. However, several above average year classes of sablefish are entering the population following a long period of lower than average recruitment. The long period of low recruitment has led to increased fishing pressure on the spawning biomass due to their relative predominance in the harvestable population and increased value over smaller fish. Now, recent large recruitments have created concerns about removing too many young fish before they have had a chance to mature and contribute to the spawning population.

Because of the historically observed distribution of younger fish appearing first in western areas (BS, AI, WG) and older mature fish being more prevalent in eastern areas (CG, WY, EY), the location of catches in periods of high or low recruitment can clearly have an impact on different portions of the sablefish population-at-age. Thus, regional ABC apportionment to management areas can result in different impacts on the population depending on the assumptions utilized by the apportionment scheme. However, we currently do not have enough information on spatial processes (e.g., distribution of the population by age, movement rates by age among regions, or juvenile habitat preferences and distributions associated with large year classes) to adequately determine whether specific, reasonably distributed apportionment schemes create a conservation concern (e.g., localized depletion, age truncation, or year class reduction) for the Alaskan sablefish population. The results of simulation work (see Appendix 3D), though limited in scope of process and observation error, indicate that apportionment of ABC to the six management regions can be conducted in numerous ways with little variability in the average implications for the population. This is primarily due to the high movement rates exhibited by sablefish and the existing harvest control rule and management framework.

Although there has been considerable interest in an apportionment method that favors larger fish that are closer to maturation (i.e., 65+ cm), the simulations did not use lengths. But, we tested an age-based method that, on average, did not differ from other methods. An initial estimate of the length-based version of this method was attempted for this assessment, but some details regarding biennial length distributions in the BS and AI have not yet been resolved. Initial results of the length-based apportionment method provided regional ABCs that resembled the current fixed proportions. While this method has some appeal for avoiding smaller fish, it would need to be utilized in concert with an ABC projection that excluded smaller fish from the calculation of the total catch limit. Otherwise, it would result in a higher exploitation rate on the already beleaguered population of fully mature fish.

An apportionment method that tracks regional biomass or a best proxy thereof is likely the best defense against localized depletion or other conservation concerns (e.g., disproportionately targeting spawners in only a handful of regions or population strongholds). While there are tradeoffs among all the methods examined, the rationale for moving away from the status quo method (NPFMC) was increased uncertainty in fishery data from decreased logbook and observer samples, and increased whale depredation in the biennial BS and AI longline surveys causing less stability and less confidence in the procedure. From a biological perspective, we recommend addressing these two issues by adopting the Non-exponential Survey apportionment method. This method continues to use a five-year moving average of the longline survey proportions, but uses an unweighted average and discontinues the use of fishery data. We believe this method tracks biomass across management regions to the best of our current ability (i.e., by using estimates of regional biomass from the yearly longline survey that targets sablefish in prime adult habitat), while still buffering against variability caused by annual measurement error. Unfortunately, accounting for the distribution of biomass does not address important issues related to the age distribution of harvest or allocation of removals across fishery sectors with different distributions and removals by age or length.

Therefore, for 2021, we recommend using the Non-exponential Survey apportionment method. Given the challenges in determining what catch magnitude and distribution across management areas may result in a significant biological concern, our best scientific advice is that catch distribution should not deviate too far from survey-estimated biomass proportions across management areas. While stability in ABC is not a direct biological concern, many stakeholders find large year-to-year changes in ABC to be undesirable. The Non-exponential Survey apportionment type has some of the stabilizing benefits that come from non-exponential weighting, but without the added concern of accounting for diminishing fishery data. Since an original rationale for fixing the apportionment was to lower the variability of ABC estimates, the Plan Teams, SSC, or Council could consider a stair-step approach that would serve as a bridge between the currently utilized Fixed and the proposed Non-exponential Survey apportionment methods.

Apportionment Table (before whale depredation adjustments).

Area	**2020 ABC***	NPFMC 'Standard' Apportionment for 2021 ABC	Fixed Apportionment for 2021 ABC*	**Recommended Non-Exp. Survey Apportionment for 2021 ABC**	**% Difference from 2020 ABC**
Total	22,551	22,551	22,551	**22,551**	0%
Bering Sea	2,201	4,538	2,201	**3,714**	69%
Aleutians	2,976	5,021	2,976	**5,324**	79%
Gulf of Alaska	17,374	12,991	17,375	**13,513**	-22%
Western	2,433	2,589	2,433	**2,779**	14%
Central	7,692	5,097	7,693	**5,786**	-25%
W. Yakutat**	2,587	1,742	2,588	**1,934**	-25%
E. Yak. / Southeast**	4,662	3,563	4,662	**3,014**	-35%

* 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. 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 Whale Depredation Estimation section.

In the tables below, we begin with the author recommended and area apportioned ABC for 2021 and 2022 compared with the specified ABC in 2020. 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 (2017 - 2019) of whale depredation (t) by the amount that the ABC is increasing or decreasing from 2020 to 2021 and 2022. This amount of projected depredation is then deducted from each area ABC to produce new area ABCs for 2021 and 2022 (ABC_w). In this case, the 3-year average depredation is multiplied by 1.00, because the 2021 ABC is not recommended to increase from 2020. In 2016, the SSC decided that these calculations should also apply to OFL, so the same procedure is applied to OFLs for 2021 and 2022 below (OFL_w). Note that the decrement of depredation from OFL is expanded by the ratio of OFL to ABC, because the whale depredation estimates are based on what would occur with catches near ABC.

The recommended whale adjusted ABC is a 1% increase from the 2020 whale 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.

The following tables assume the author recommended non-exponentially weighted survey apportionment method.

Author recommended 2021 ABC (with whale depredation adjustments).

Area	AI	BS	WG	CG	WY*	EY*	Total
2020 ABC	2,976	2,201	2,433	7,692	2,587	4,662	22,551
2021 ABC	5,324	3,714	2,779	5,786	1,934	3,014	**22,551**
2017 - 2019 Avg. Depredation	17	24	94	63	43	88	329
Ratio 2021:2020 ABC	1.79	1.69	1.14	0.75	0.75	0.65	1.00
Deduct 3-Year Adjusted Avg.	-30	-40	-107	-47	-32	-57	-314
****2021 ABC_w**	**5,294**	**3,674**	**2,671**	**5,738**	**1,902**	**2,957**	**22,237**
Change from 2020 ABC_w	79%	69%	17%	-24%	-25%	-35%	1%

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

Author recommended 2022 ABC (with whale depredation adjustments).

Area	AI	BS	WG	CG	WY*	EY*	Total
2020 ABC	2,976	2,201	2,433	7,692	2,587	4,662	22,551
2022 ABC	7,017	4,896	3,662	7,626	2,550	3,973	**29,723**
2017-2019 Avg. Depredation	17	24	94	63	43	88	329
Ratio 2021:2020 ABC	2.36	2.22	1.51	0.99	0.99	0.85	1.32
Deduct 3-Year Adjusted Avg.	-39	-53	-141	-63	-42	-75	-413
****2022 ABC_w**	**6,978**	**4,843**	**3,521**	**7,563**	**2,507**	**3,898**	**29,309**
Change from 2020 ABC_w	136%	123%	55%	0%	-1%	-14%	33%

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

Author recommended 2021 – 2022 ABCs by Sector in West Yakutat and East Yakutat/Southeast adjusted for the 95:5 hook-and-line : trawl split in the EGOA.

Year	W. Yakutat	E. Yakutat/Southeast
2021	2050	2809
2022	2702	3703

Author recommended 2021 and 2022 OFLs (with whale depredation adjustments).

Year	2021	2022
2020 ABC	22,551	22,551
OFL	61,319	71,756
3-year Avg. Depredation	329	329
Ratio	2.72	3.18
Deduct 3-year Avg.	-893	-1,046
$^*OFL_w$	**60,426**	**70,710**
2019 SAFE OFL_w	**50,481**	**64,765**
Change from 2019 SAFE	20%	9%

* OFL_w is the author recommended OFL that accounts for whale depredation.

Final Summary Tables by Region for the Groundfish Plan Team

Summary Table by Region.

Area	Year	Biomass (4+)	OFL	ABC	TAC	Catch
GOA	2019	264,000	22,703	11,571	11,571	12,772
	2020	387,000	--	16,883	14,393	9,208
	2021	390,000	--	13,269	--	--
	2022	383,000	--	17,489	--	--
BS	2019	52,000	2,887	1,489	1,489	3,191
	2020	116,000	--	2,174	1,861	4,581
	2021	142,000	--	3,674	--	--
	2022	139,000	--	4,843	--	--
AI	2019	98,000	3,917	2,008	2,008	661
	2020	154,000	--	2,952	2,039	1,104
	2021	175,000	--	5,294	--	--
	2022	172,000	--	6,978	--	--

Final Whale Adjusted Catch Tables by Region.

Year	2020				2021		2022	
Region	OFL_w	ABC_w	TAC	Catch*	OFL_w	ABC_w**	OFL_w	ABC_w**
BS	--	2,174	1,861	4,581	--	3,674	--	4,843
AI	--	2,952	2,039	1,104	--	5,294	--	6,978
GOA	--	16,883	14,393	9,208	--	13,269	--	17,489
WGOA	--	2,278	1,942	1,113	--	2,671	--	3,521
CGOA	--	7,560	6,445	4,151	--	5,738	--	7,563
**WYAK	--	2,521	2,343	1,547	--	2,050	--	2,702
**EY/SEO	--	4,524	3,663	2,398	--	2,809	--	3,703
Total	50,481	22,009	18,293	14,894	60,426	22,237	70,710	29,309

* As of October 31, 2020 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

General Assessment Concerns

In this section, we list new or outstanding general assessment comments from the SSC and Plan Teams (PTs) from the 2019 assessment cycle.

"The Teams recommended that authors continue to fill out the risk tables for full assessments. The Teams recommended that adjustment of ABC in response to levels of concern should be left to the discretion of the author, the Team(s), and/or the SSC, but should not be mandated by the inclusion of a >1 level in any particular category. The Teams request clarification and guidance from the SSC regarding the previously noted issues associated with completing the risk table, along with any issues noted by the assessment authors. The Teams plan to discuss the risk table process at the September meeting." **(**Plan Team Dec 2019)

"The SSC requests the GPTs, as time allows, update the risk tables for the 2020 full assessments." (SSC Dec 2019)

"The SSC recommends dropping the overall risk scores in the tables" (SSC Dec 2019)

We provide a risk table for the third time in 2020, 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 substantial rationale for an ABC that is reduced below the maximum permissible ABC. Please see the Additional ABC/ACL Considerations section for further details for each category of the risk table.

"*The SSC supports plans for further ESP development and evaluation. These efforts should enhance the future utility indicators in stock assessments, including evaluations of uncertainty……. ESPs are a commitment to a process, not a static product. As such, consideration should be given to the regularity (and timing) of reviews and revisions. Moreover, this effort should not stop with ecosystem indicators, but continue until ecosystem information is formally incorporated into SAFEs to achieve the goal of ecosystem-based fisheries management (EBFM)."* (SSC June 2020)

We provide an updated ESP as Appendix 3C in this document. The sablefish ESP continues to evolve and improve, while indicators in the ESP are once again used in the rationale for an ABC that is below maximum permissible ABC. We continue to incorporate information from the ESP into our understanding of estimated population trajectories from the stock assessment. For instance, in the Results section we attempt to relate estimates of recent large recruitment events back to environmental conditions and ecological drivers that could be aiding recent increases in sablefish productivity. Continued collaborations among assessment and ESP authors has led to the development of a spatially explicit full life history research model that attempts to bridge adult and early life history population dynamics within an estimation framework to better include ecosystem drivers on productivity (e.g., incorporation of larval individual-based modeling, IBM, outputs into an assessment-type estimation framework). The model is still a work in progress and is meant only as a research tool. However, it is one example of how information, research, and cross-discipline ecological understanding are being bridged across SAFE and ESP development.

Concerns Specific to the Sablefish Assessment

In this section, we list new or outstanding SSC and PT comments specific to the last full Alaskan sablefish assessment in 2019.

"The Teams recommended that the authors examine poor fits and residual patterns in the abundance indices. The Teams recommended that the authors explore alternative methods to account for the 2014 and 2016 year classes, including pulse or age-specific natural mortality, time-varying selectivity, and sex-specific patterns in recruitment events." (Plan Team Nov 2019)

"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." (SSC Dec 2019)

Based on the SSC and PT recommendations, we developed a number of sensitivity runs. We explored a variety of hypotheses regarding time-variation in selectivity and natural mortality and examined whether alternative parametrizations could alleviate the poor fit to the abundance indices (see Sensitivity Run Methods and Sensitivity Run Results sections, as well as, Table 3.19 for a summary of sensitivity run categories and a summary of findings from select runs). Overall, it appeared that time-varying natural mortality along with time-varying longline survey selectivity led to the biggest overall improvements in model fit to observed data, but also led to the strongest declines in recent SSB and potential future catches (Figure 3.57). Allowing for a recent longline survey selectivity block resulted in a higher survey selectivity in recent years, particularly of young fish (e.g., age-2 and age-3), which led to greatly reduced estimates of recruitment. On the other hand, allowing natural mortality to be estimated in time blocks led to unprecedented increases in mortality in recent years and concomitant, immediate, and extreme declines in SSB. These model runs require further refinement and careful consideration before any are presented as an alternative to the Base model. Further exploration of time-varying selectivity and natural mortality will be undertaken for the 2021 assessment, likely in tandem with updated and refined data weighting procedures.

"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." (SSC Dec 2019)

"The SSC recommends that the coefficients determining the degree of whale depredation be reevaluated in the near future." (SSC Dec 2019)

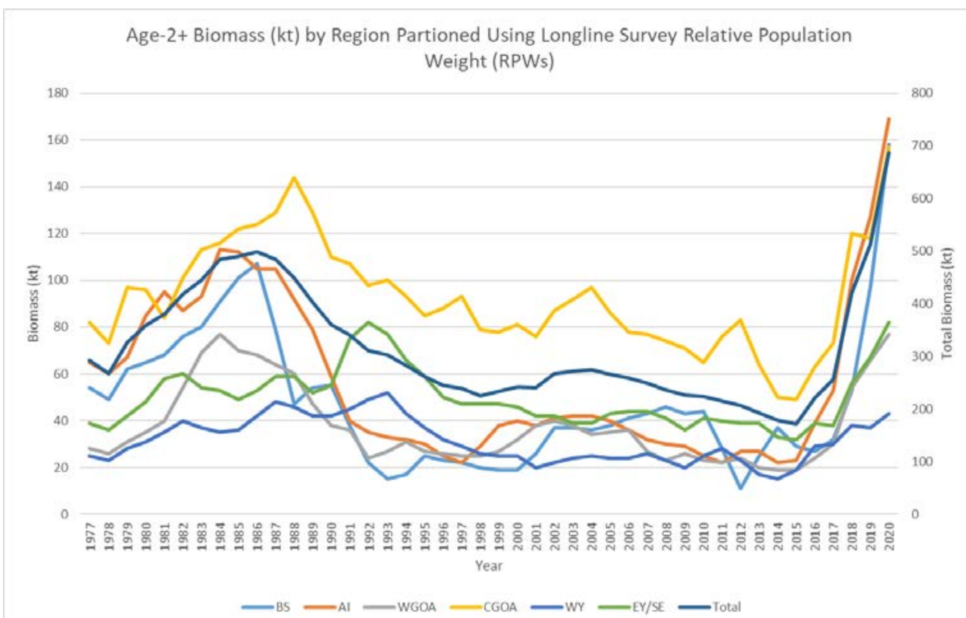
As suggested, we continue to use the estimated whale depredation to discount the recommended ABC. This process is done independently of the risk table assessment. We first develop the risk table and use this analysis to recommend an appropriate ABC. The whale depredation calculations are then developed and applied in a separate process to decrement the recommended ABC to account for whale depredation. Given the limitations in the assessment process this year, we did not attempt to incorporate the other removals into the model. Minor state fisheries catches from the northern GOA and AI are already included in the landings for the current and past assessment models, because they are reported using the Alaskan Federal Waters landing areas. Other major fisheries in the NSEI and SSEI are managed and assessed by the ADFG and not included in the current model. We will explore this option in the future. However, given the magnitude of other removals not including the NSEI and SSEI state fisheries (~300t in 2019; Table 3B.1) compared to removals from the directed and bycatch fisheries included in the model (~16,000 t in 2019; Table 3.1), it is unlikely that the addition of these removals will have any influence on the model results. Similarly, we hope to update the whale depredation coefficients in the near future. Again, though, we do not expect the estimates to vary substantially from the current estimates, which implies that re-estimation would not result in a large change to current assessment results given that current removals are on the order of ~300 t per annum. We will do our best to address these concerns in upcoming model years, but given the increasing retrospective patterns and desire to address model structure and parametrization in the near future, we believe these issues are not high priority items in comparison.

"The Teams recommended that the authors continue to include retrospective recruitment plots (aka "squid plots") to determine when estimates of large recruitment events stabilize." (Plan Team Nov 2019)

Retrospective plots have once again been included in the SAFE (Figures 3.43 – 3.45), which include the requested recruitment 'squid' plots (Figure 3.45). Unfortunately, retrospective patterns have increased drastically for the 2020 model (Mohn's rho for SSB increased from 0.061 in 2019 to 0.186 in 2020). The increase in retrospective patterns in recent years is likely due to high uncertainty in extreme year classes in 2014, 2016, and again in 2017 (as estimated in the current model). As noted in the PT comments, for a long-lived species such as sablefish, it can take multiple years before model results converge on an estimate of recruitment strength. The recruitment squid plots demonstrate that for the large 2014 and 2016 year classes, subsequent models with more data have continually downgraded initial estimates of year class strength (Figure 3.45). It would be expected that these recruitment events, along with the large 2017 year class estimated in the 2020 Base model, will likely continue to shrink in subsequent model years. Based on squid plots of less strong, but older, year classes with more informative data, it may take upwards of 5 to 6 years before estimates converge to stable solutions (e.g., see the 2010 year class estimate; Figure 3.45, bottom panel). Given the contracted age composition of sablefish along with the extreme size and uncertainty of these recent recruitment events, it is not surprising that retrospective patterns have increased in recent years. Fish from these large recruitment events are increasingly becoming a large fraction of the total SSB, and are expected to comprise upwards of 50% of the projected 2021 spawning biomass (Figure 3.19). Thus, uncertainty in the size of the initial cohort and subsequent downgrades in their strength as new data is provided to the model leads to similar direct downgrades in estimates of SSB. In fact, the estimate of Mohn's rho of 0.186 for SSB estimates is commensurate with the reduction in the 2014 and 2016 year classes between the 2019 and 2020 assessment models (~25% reduction; Table 3.17). Thus, although the increase in Mohn's rho from 0.061 in 2019 to 0.186 in 2020 is worrisome, there may be reason to believe that estimates will return to previous low values as the estimates of large recruitment events become more stable in future model years.

"The Teams recommended Option 2 for the OFL specification, combining the BS and AI OFLs. While the Teams support Option 2, they also recommended following the Council's spatial management policy, including the development of management controls to mitigate regional bycatch." (Plan Team Nov 2019)

Given the spatially aggregated nature of the current assessment model configuration, it is difficult to provide any guidance or model outputs to support spatial management options. We continue to use a spatially explicit operating model to explore the impact of regional apportionment of the total ABC (see Appendix 3D for updates, as well as, responses to SSC and PT comments regarding apportionment below). We also provide approximations of regional abundance by partitioning the total biomass to management area using the proportion of longline survey catch by area (see Table 3.15 and Figure below). These results suggest that the central GOA has consistently been the primary center of biomass throughout the time series, whereas the biomass in the eastern and western GOA have been relatively stable, but at comparatively low levels. Peaks in biomass in the early 1980s were associated with increases in the BSAI along with the central GOA, but subsequent declines were disproportionately observed in the BSAI. Conversely, the recent precipitous increases due to the influx of young fish from recent strong year classes has resulted in a surge in biomass in the BSAI and the central GOA with similar, yet less pronounced, increases in the eastern and western GOA. However, we reiterate that these are approximations and that results are primarily driven by the distribution of catches in the longline survey. But, these trends generally reflect exploratory spatial modeling results for sablefish, which indicate that the western areas (i.e., BSAI and western GOA) likely comprise a large proportion of the total Alaskan sablefish biomass (K. Fenske, pers. comm.).



In regards to bycatch mitigation, we have also developed an appendix that explores the increase of bycatch of small sablefish in the Bering Sea trawl fisheries (see Appendix 3E). Once again, we have no direct input on mitigation measures, but we believe the appendix provides an informative descriptive analysis of recent bycatch issues. In regards to the NPFMC Spatial Management Policy, we have no new scientific information indicating further stock structure separation is needed and look forward to further guidance on development of management controls.

"The SSC supports the ongoing efforts to examine sablefish dynamics including Alaska, Canada, and the US west coast. The SSC encourages continued efforts to reconcile potential differences in ageing criteria

among these regions and among laboratories with respect to asynchrony in recruitment." (SSC December 2019)

Multiple ongoing projects continue to explore sablefish dynamics and ageing criteria across the Northeast Pacific. Age reading groups across agencies have addressed sablefish ageing through the Committee of Age Reading Experts (CARE) group and have worked together to develop ageing criteria. Sablefish remain a difficult species to age, especially in the first several years of life, but an otolith exchange that includes young fish from the 2013 and 2014 year classes is planned. Additional work pertinent to sablefish population dynamics and biology on a coast-wide basis is ongoing with the Pacific Sablefish Transboundary Assessment Team (PSTAT), which had an annual meeting in April, 2020. The group is currently finalizing a manuscript analyzing tagging data from all three regions to provide estimates of connectivity within and among areas. The results will be utilized within a spatially explicit operating model that is currently in development. The operating model should be completed within 1 – 2 years and will allow exploration of the impacts of connectivity, biological structure, and regional productivity on the robustness of regional management measures.

Concerns Specific to Sablefish Apportionment

"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 Dec 2019)

"The SSC recommended that the analysis could benefit from an extended discussion regarding the conditioning of the operating model" (SSC June 2020)

"The SSC recommends that the analysts consider incorporating additional sources of variability as part of the simulation where appropriate, if possible." (SSC June 2020)

"The SSC further recommends that a 'base case' simulation should include more realistic catch vs. ABC ratios where appropriate, perhaps limited to historically observed levels of effort by area." (SSC June 2020)

"The SSC also recommends consideration of the adjustment to the coastwide ABC to reduce harvest (implementing a larger OFL-ABC buffer) when abundance of older spawners is low, such as was applied in 2019 and 2020, and whether this should be included." (SSC June 2020)

"The SSC requests a model check be performed based on one apportionment approach and an estimation model provided with very precise data from the operating model, (and perhaps extended farther into the future) to evaluate the implementation of the Council's harvest control rule; the expectation being that the stock should equilibrate at or above B40." (SSC June 2020)

*"The SSC recommended adding two additional performance metrics: the effort required to achieve the ABC in each area, and the variance in apportionment in each management area, displaying the latter metric as a mean-variance plot for each of the approache*s." (SSC June 2020)

"As supporting information for the policy decision, the SSC suggests the Council consider requesting a complementary social and economic analysis that would map area-based apportionment to the vessels, processors and communities that participate in the fishery in different areas, and calculate the mean and variance of business-level indicators." (SSC June 2020)

"The SSC requests guidance from the Council on its goals, such that the SSC may guide the analysts in developing the appropriate scope of information to support subsequent results and discussion on sablefish subarea ABC apportionment." (SSC June 2020)

A complete, point by point response to SSC comments regarding apportionment is provided in Appendix 3D. In addition, an author recommended apportionment method is presented in the Area Allocation of Harvests section of the main document. In response to SSC suggestions at the June SSC meeting, multiple OM and EM configurations have been explored to try to increase the variability in the OM. Unfortunately, implementing many recommendations was not possible due to constraints of the estimation model leading to a high proportion of models not converging. The simulation results at this time result in a wide range of potential outcomes, despite the median values for each apportionment type being very similar and having relatively little OM process or observation error. We maintain that there appears to be minimal concern with any of the apportionment options seriously considered to date – likely due to the harvest control rule and no assumed stock recruit relationship. In Appendix 3D we present a retrospective analysis applying 12 apportionment options to historic ABCs to help guide selecting of apportionment for the future.

Introduction

Distribution

Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the Gulf of Alaska (GOA), westward to the Aleutian Islands (AI), and into the Bering Sea (BS; Wolotira et al. 1993). Adult sablefish occur along the continental slope, shelf gullies, and in deep fjords, generally at depths greater than 200 m. Sablefish observed from a manned submersible were found on or within 1 m of the bottom (Krieger 1997). In contrast to the adult distribution, juvenile sablefish spend their first two to three years on the continental shelf of the GOA, and occasionally on the shelf of the southeast BS. The BS shelf is utilized widely by young sablefish in some years and seldom used during other years (Shotwell et al. 2014). However, there has been an increase in abundance of young sablefish in the Bering Sea in recent years concomitant with large recent year classes (Appendix 3E).

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). The current assessment model assumes a single, homogenous population of Alaskan sablefish across all sablefish management areas including the Bering Sea (BS), Aleutian Islands (AI), western Gulf of Alaska (WGOA), central Gulf of Alaska (CGOA), and eastern Gulf of Alaska (EGOA; including western Yakutat, WY, eastern Yakutat, EY, and the southeast GOA, SE).

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 feed 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).

Distribution, Movement, and Tagging

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.). 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. 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, and in 2020, multiple sport fishermen targeting salmon reported high bycatch of age-1 sablefish throughout all of Southeast Alaska. Additionally, trawlers targeting Pollock in the Bering Sea in 2019 and 2020 encountered young sablefish (likely the 2014, 2016, and 2017 year classes) in record numbers (see Appendix 3E).

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. The time series of sampling in SJBB continued in 2020 with one sampling trip thanks to the efforts of the Alaska Department of Fish and Game – Sitka and the crew of the R/V Kittiwake. The ADFG graciously volunteered their time and service to ensure this historical time series was not interrupted when Auke Bay Laboratory staff were unable to perform this fieldwork due to COVID restrictions. The sampling trip occurred September 1 – 2, 2020. The ADFG fished four rods for a total of 44 hours and tagged 437 juvenile sablefish. This ties 2016 for highest CPUE (9.9 fish per rod hour). The average length of fish was 315 mm, the second lowest average length in the time series. The lowest value was in 2016.

Adult Movement

Using tag-recapture data, a movement model for Alaskan sablefish was developed 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 correlated (r = -0.74) 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.

2020 Sablefish Tag Program Recap

The Auke Bay Laboratory continued the 40+ year time series of sablefish tagging in 2020. Approximately 1,230 sablefish were tagged on the annual NMFS longline survey. It should be noted that there was a change in sampling design on the 2020 survey, so this number cannot be compared directly with past surveys. Approximately 400 sablefish tags have been recovered in 2020 to date. Of those recovered tags, the longest time at liberty was approximately 40 years (14,739 days), the shortest recovered tag at liberty was for 26 days, and the greatest distance traveled was 1,504 nautical miles from a fish tagged in the southeast Aleutian Islands on 6/8/2012 and recovered off Baranof Island in Southeast Alaska on 5/13/2020.

Fishery

Early U.S. Fishery, Development until 1957

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 - 1973 in the BS (McDevitt 1986). Substantial Korean catches were reported from 1974 - 1983 scattered throughout Alaska. Other countries reporting minor sablefish catches were the Republic of Poland, Taiwan, Mexico, Bulgaria, the 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. From a year round fishery in 1983, the fishing season shrank to 10 days in 1994, warranting the “derby” fishery label.

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 2019 there were 1,966 landings recorded in the Alaska fishery (NOAA 2016).

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 would 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).

The primary gear used for directed sablefish harvest in Alaska is longline gear, which 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 is usually 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.

Pot fishing in the BSAI IFQ fishery is allowed under regulation. Pot gear use began to increase in 2000 and the average percent of sablefish caught in pots from 2000-2020 was 41% of the fixed gear catch. From 2000 to 2008 catch in pots had increased to 10-68% of the fixed gear catch and then decreased to ~30% from 2009-2016. Recently there was an increase from 2017-2020, with a time series high of 73% in 2020 (as of October 28, 2020). The percent of fixed gear catch in the BS in pot gear was continuously high from 2001-2020, with an average of 63% of the fixed gear catch in pots. The AI matched the overall BSAI trend more closely, with highs in 2003-2007 and from 2017-2020, with the series high in 2020 at 75%. Unlike the BS, there was a low period from 2009-2016, where the average catch in pots was only 9%. The recent uptick since 2017 in the AI could be related to a recent increase in pot gear for the purpose of avoiding killer whale depredation on hook and line gear. It could also be related to an increase in the catch of smaller fish, because small fish are more likely to be caught in pot gear than in hook and line gear and have been more abundant than in past years. In summary, in the BS the proportion of fish caught in pots is consistently high, whereas in the AI it is inconsistent and ranges from 3-75% from 2000-2020. See the Pot Fishery Effort and Catch Rates section for a full description of pot fishery effort and CPUE.

In response to consistent sperm whale depredation on hook and line gear, the NPFMC passed a regulation in 2015 to allow pot fishing in the GOA starting in 2017. In 2017 and 2018 pot fishing made up a small proportion of the fixed gear catch (10% and 12%, respectively). The proportion of fixed gear catch in pots in the GOA increased to 20% in 2019 and then again to 44% in 2020. The overall catch in pots in the GOA increased each year from 898 t in 2017 to 3,882 t in 2020, while hook and line catch has decreased from 8,181 t to 4,990 t (as of October 28, 2020). See the Pot Fishery Effort and Catch Rates section for a full description of pot fishery effort and CPUE.

Sablefish also are caught incidentally during directed trawl fisheries for other species groups such as rockfish and deepwater flatfish, and more recently walleye pollock. Allocation of the TAC by gear group varies by management region and influences the amount of catch in each region (see the Management

Measures/Units section; Table 3.1, Figures 3.1 - 3.2). Allocation percentages by area are: 80% to fixed gear and 20% to trawl in the Western and Central GOA; 95% to fixed gear and 5% to trawl in the Eastern GOA; 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 Islands. In recent years have there been unprecedented increases in sablefish bycatch (see the Bycatch and Discards section and Appendix 3E for a discussion of recent BS trawl fishery bycatch), resulting in rapid changes in the composition of catch by fishing gear (Table 3.1, Figure 3.1). For much of the last twenty years, trawl gear bycatch has constituted around 10% of total catch, but this proportion increased rapidly starting around 2016 and was at 31% in 2019 and 43% in 2020 (based on estimated catch; Table 3.1). A majority of these increases in proportion of total catch coming from the trawl fishery occurs in the BS and AI (Tables 3.1 – 3.2, Figures 3.1 – 3.2). In particular, the BS has seen a dramatic increase in total catch from 532 t in 2016 to around 5,000 t in 2020, much of it associated with trawl bycatch (Tables 3.1 - 3.2). The increased catch in trawl gear is primarily due to the increased prevalence of small sablefish from recent strong year classes on the primary fishing grounds in the eastern Bering Sea.

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. State catch from the northern GOA and AI minor fisheries are included in the current assessment, because they 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. Major state fisheries in the NSEI and SSEI are managed and assessed by the ADFG and catch associated with these fisheries are not included in the current model.

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 in 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 in 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 in 1990.

IFQ management

Amendment 20 to the GOA Fishery Management Plan and amendment 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 Community Development Quota (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 in April, 1997. The percentage depends on the target species: 1% for pollock, Pacific cod, Atka mackerel, “other species”, and aggregated amounts 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 in 2009 in the GOA, to 1% for sablefish.

Allowable gear

Amendment 14 to the GOA Fishery Management Plan banned the use of pots for fishing for sablefish in the GOA in response to gear interactions that inhibited the fixed-gear sector during the short, open access derby fishing seasons. The Amendment went into effective on 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 on 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.

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 10,000 t in 2016. In the last four years, catches have continually increased to around 17,000t in 2020, which matches recent time series high removals from the mid-2000s (Table 3.1). Increased catch is associated with increasing trawl bycatch, while directed fixed gear catch has remained relatively stable for the last five years (Figure 3.1). 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. In 2020, the BS TAC and ABC were exceeded by nearly 3,000 t (M. Furuness, pers. comm.). However, total TAC and ABCs for the entire Alaska stock have still not been fully utilized and the OFL has not been exceeded (Table 3.3).

Bycatch and Discards

Sablefish discards and discard rates are available for hook-and-line gear and all “other” gear types combined, because there are confidentiality concerns when there are low vessel sample sizes for trawl or pot vessels (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 1,588 t from 2010 - 2020. Despite the average being stable, discards increased in 2018 to 2,646 t and to a record high of 4,656 t in 2020. The increase was in “other” gear in 2019 and 2020 in the BSAI and from 2018 - 2020 in the GOA (Table 3.4). Discard rates also increased during the same years in “other” fisheries. For example, in the BSAI the total discard rate increased from 19% in 2018 to 49% in 2020, partly because of sablefish being put on PSC status. The increase was in hook and line and in “other” fisheries; however, most of the sablefish bycatch is in “other” fisheries. In the GOA, the rate was highest in 2018 (44%) and decreased in 2019 and 2020 (Table 3.4). The dramatic increase in the BSAI may be due to an increase in the abundance of small sablefish in the BSAI (see a full analysis of small sablefish in trawl fisheries in Appendix 3E). The largest increases in sablefish bycatch were in the BSAI pollock mid-water trawl, GOA pollock bottom trawl, GOA arrowtooth flounder, BSAI arrowtooth flounder, and the BSAI Greenland turbot fisheries (data not shown due to confidentiality rules).

Table 3.5 shows the average bycatch of Fishery Management Plans (FMP) groundfish species in the sablefish target fishery from 2013-2020. GOA thornyhead (610 t/year; 187 t discarded) and shark (637 t/year; 636 t discarded) are the highest bycatch species groups. There is also substantial bycatch of GOA shortraker and rougheye/blackspotted rockfish, GOA skate, “other” rockfish, and Pacific cod, ranging from 103-265 t/year for each group. Bycatch of several species have decreased in recent years; for example, the total catch of BSAI skate has decreased every year from 2013-2020, starting at 121 t and decreasing to 5 t. Despite having the highest average catch in the sablefish fishery, catch of thornyhead rockfish has been decreasing nearly every year, from 938 t in 2013 to 234 t in 2020. “Other” rockfish follow the same trend, decreasing from 209 t to 32 t, and Pacific cod bycatch decreased from 209 t to 32 t. Conversely, there are some higher catches in recent years: there was an anomalous high catch of 1,136 t of sharks in 2018; catches of GOA shortraker rockfish were on average 361 t from 2018-2019 but the average for the time series was only 181 t; and there were 429 t of arrowtooth flounder caught in 2018, whereas the average of the series is 230 t.

Giant grenadier, a nontarget species that is an Ecosystem Component in both the GOA and BSAI FMPs, make up nearly all of the nontarget species bycatch (Table 3.6). The highest bycatch of giant grenadier in recent years was 15,053 t in 2013, but has remained below 9,333 t since then. Starting in 2017, bycatch of grenadiers has been on the decrease and in 2019 it was 3,927 t; so far in 2020 it is only 2,379 t. Other nontarget taxa that typically have catches over one ton per year are corals (bryozoans), eelpouts, miscellaneous fishes and crabs, sea anemone, sea stars, and snails (Table 3.6).

The predominant prohibited species caught in sablefish fisheries is golden king crab (13,981 individuals/year on average in the BSAI and 88 in the GOA; 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 and the low number of crabs caught each year. There was an anomalous high catch of golden king crab of 38,905 individuals in 2018, due to catch in the BSAI pot fishery, but it decreased the next year and was 5,374 in 2020 (Table 3.7, see “other” gear). Estimates of Pacific halibut bycatch were high in past SAFE reports because all Pacific halibut caught in sablefish IFQ fisheries were included in PSC estimates, despite some being retained when there was Pacific halibut IFQ on-board. Because retained IFQ halibut cannot be separated from discarded halibut in the AKRO catch accounting system, this year the estimates of Pacific halibut in Table 3.7 are only for non-IFQ sablefish sets, defined as those sets where sablefish had the greatest weight. Pacific halibut PSC in Table 3.7 is in all gear and areas, with the majority in "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 - **2020**
Trawl fisheries	Catch	1960 - **2020**
Japanese longline fishery	Catch-per-unit-effort (CPUE)	1964 - 1981
U.S. fixed gear fishery	CPUE, length	1990 - **2019**
	Age	1999 - **2019**
U.S. trawl fisheries	Length	1990,1991,1999, 2005 - **2019**
Japan-U.S. cooperative longline survey	CPUE, length	1979 - 1994
	Age	1981, 1983, 1985, 1987, 1989, 1991, 1993
Domestic longline survey	CPUE, length	1990 - **2020**
	Age	1996 - **2019**
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) represent total catch (landings plus bycatch or discards assuming 100% mortality) and include catches from minor State-managed fisheries in the northern GOA and in the AI region. 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. 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 -

1990 (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, which is possible to conduct annually because of its cost-recovery design where catch is sold to offset survey costs. 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.

<u>Observer Data</u>

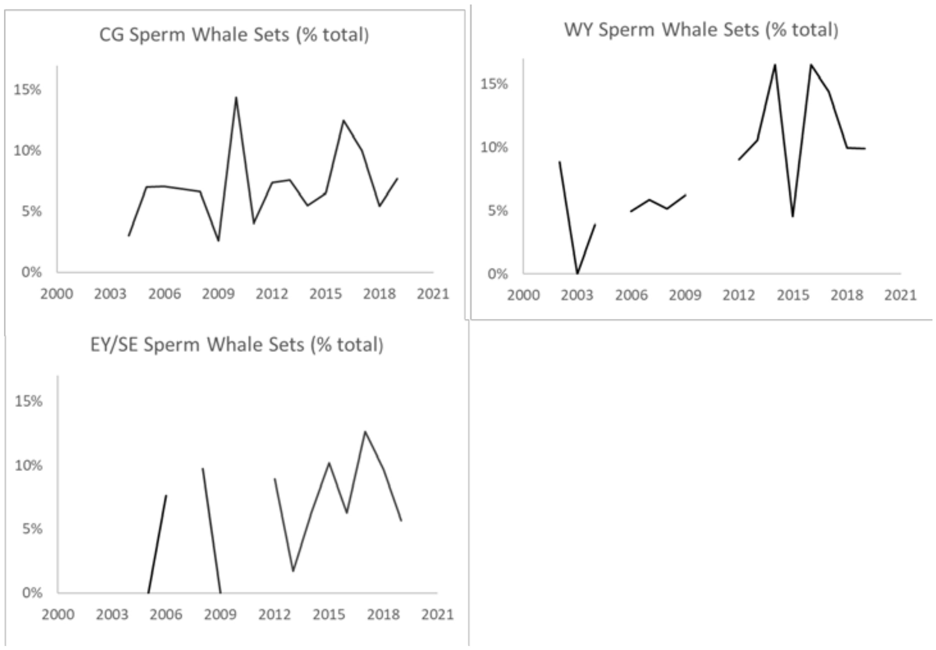
For analysis of observed sablefish catch rates in the sablefish target fishery, we first have to determine the target of the set, because the target is not declared in the observer data set. To do this, we compare the catch of sablefish to other target species that are typically caught on longline gear: 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.

Without taking into account electronic monitoring (EM) sets, which lack effort data and cannot be used for CPUE calculations, and focusing only on sablefish target sets that were used for catch rate analyses, the total weight of all sablefish in observed targeted longline sets in federal waters represented 5% (833 mt) of the total longline catch in federal waters in 2019. The percent of the IFQ catch observed was 0.4% in the BS (down from 8%), 6% in the EY/SE, 8% in the WG, 11% in WY (up from 8%), 4% in the CG, and the AI cannot be reported due to confidentiality. The number of human-observed sets and vessels has declined in the AI, CG, WG, and EY/SE since 2016 (Table 3.9). However, the number of sets remained high in EY/SE. Unlike in other areas, in WY in 2015 there was an anomalously high number of vessels, with a decrease in 2017 and 2018 (18 and 19 vessels, respectively) and back to 24 vessels in 2019. The total number of vessels observed decreased in 2015 and has remained low ever since. These changes or fluctuations in sample sizes do not coincide with observer restructuring, but may be related to the increase in EM in the GOA. For example, in EY/SE the number of vessels decreased from 46 in 2016 to 33 in 2019, which is still above average (22 vessels/year since 1995).

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 12% in the BS, 2% 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 21. Likely because of this small sample size, the annual range in the rate of depredation is 3 - 26%. In the EBS, there were high depredation rates from 2000 - 2002 (19%), a decrease from 2003 - 2014 (7%), and then an increase to an average rate of 20% from 2015 - 2019. 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 a 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 6% in the CG and EY/SE areas and 7% in WY. In EY/SE there were high rates mid-time series and then again in recent years (Figure below). In WY there have also been increases since 2012.

Figure. Percent of human observed sablefish targeted longline sets with sperm whale depredation by FMP sub-area. Years with fewer than three vessels were not included due to confidentiality. Only the Central Gulf of Alaska (CG), West Yakutat (WY), and East Yakutat/Southeast (EY/SE) consistently have sperm whale depredation rates greater than 1%.



<u>Electronic Monitoring</u>

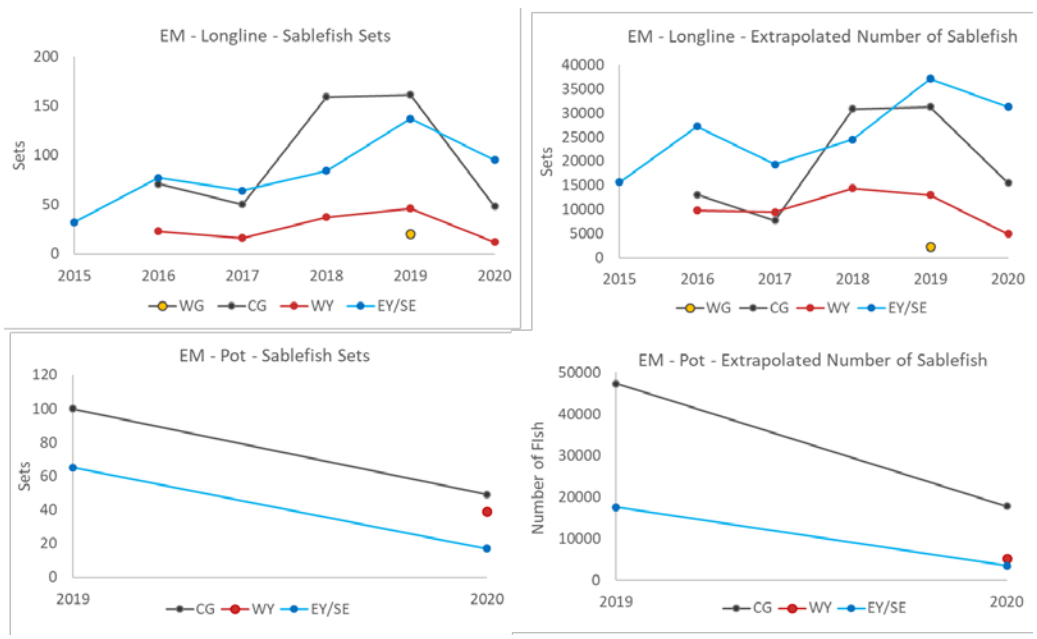
Electronic monitoring (EM) has replaced human observers on some vessels fishing pot and logline gear in the sablefish fishery, as well as, other fixed gear fisheries. A portion of video is later reviewed and a count of each species is recorded. This fish count is extrapolated to the whole set and the extrapolated set weight is calculated as the extrapolated count times the average weight for vessel strata (e.g., the area, gear, and target species). Unlike data from sets with human observers, the EM data does not include measured weights or a measure of effort, such as the number of hooks, hook spacing, or the number of pots. Therefore, we cannot use EM data to calculate CPUE. The Table below provides the number of vessels observed, while the following Figure provides the extrapolated number of sablefish caught for longline and pot gear. These sets have been defined as targeting sablefish, because sablefish comprised the highest weight by species in the set.

Table. The number of vessels observed by electronic monitoring (EM) by year, gear, and FMP sub-area (though September 19th, 2020). C indicates that the data is confidential, because there are fewer than three vessels. HAL is hook and line gear.

Gear	Year	BS	AI	WGOA	CGOA	WY	EY/SE
HAL	2015	-	-	-	C	C	5
	2016	-	-	-	3	3	12
	2017	-	-	C	4	3	12
	2018	-	C	C	19	9	26
	2019	-	-	4	21	12	30
	2020	C	-	C	4	4	24
Pot	2019	-	-	-	5	2	6
	2020	-	-	C	9	6	6

EM data is most prevalent in the Central (CGOA) and eastern GOA (see Table above). Data is available in these areas starting in 2015 and they have the highest number of vessels participating in EM. Because small vessels are prevalent in EY/SE, which can have capacity issues for the number of people, the shift to EM was initiated on longline vessels in EY/SE, and so higher participation is expected in this area. EM use has been increasing in the CGOA, but there was a large decrease in 2020 (data is only available through September 19, 2020 at this time). In EY/SE there has been an increase in vessel participation from 5 in 2015 to 30 in 2019 and is now 24 for 2020. Even though the number of vessels with EM is lower in the CGOA, the number of sets is higher in some years. This may be attributed to longer trips in the CGOA. Vessels fishing pot gear are now being observed with EM, as well. There have been more than 2 vessels in 2019 and 2020 in the Central and eastern GOA, with a high of 9 in the CGOA in 2020.

Figure. The number of sets (left column) and the extrapolated number of sablefish (right column) observed by FMP sub-area with electronic monitoring of longline (top row) or pot gear (bottom row). Data is not shown if there were fewer than 3 vessels. See table above for sample sizes.



<u>Logbook Data</u>

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 that 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 2019, after the data was screened for missing data fields, 55% of sets came from vessels under 60 ft. A higher proportion of the catch is documented in logbooks than by observers. In 2019, 27% of the fixed gear catch was documented in logbooks, while only 6% of the catch was covered by observers. In the filtered logbook data, 72% of the data was from longline gear, which is commensurate with the percentage of longline gear (76%) represented in the observer data. Some data are included in both data sets if an observer was onboard and a logbook was turned in.

Since 2017, 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. These data are not required fields and so all data is voluntary. Participation in recording whale data, which includes noting both presence and absence, increased in 2018. However, identifying actual whale depredation may be more subjective than just presence of whales during hauling, so care must be taken when utilizing data from logbooks. In 2018, more vessels were using the new logbooks that included whale information (see the Table below). From 2018 to 2019 logbooks that included whale data was stable in the CG and EY/SE areas, decreased in the WG from 77% of sets to 55%, and increased in WY to 90% of sets (2,269). Sample sizes in the CG, WY, and EY are all much higher than in other areas and the % participation ranged from 86 - 90% in 2019. The WG had the next highest samples (an average 513 sets), with lower participation (55 - 77%). The AI has fewer samples, but had high participation in 2018 and 2019 (96 and 99%).

Table. 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), and East Yakutat/Southeast (EY). No data in presented in the Bering Sea due to small sample sizes and confidentiality (C).

Area	Year	Total sets	Total sets with data	% sets with data	% sets with mammals	% killer whales	% sperm whales
AI	2017	471	237	50	8	2	6
	2018	238	235	99	8	3	5
	2019	278	268	96	15	7	7
BS	2017	C					
	2018	C					
	2019	C					
WG	2017	692	394	57	17	6	10
	2018	758	612	77	19	5	13
	2019	622	534	55	27	14	10
CG	2017	2,635	1,822	69	22	1	21
	2018	3,085	2,624	85	23	1	23
	2019	2,822	2,473	88	22	2	20
WY	2017	2,203	1,488	68	35	1	35
	2018	2,668	2,050	77	43	0	42
	2019	2,513	2,269	90	32	0	32
EY	2017	1,490	1,242	83	30	1	30
	2018	2,009	1,785	89	32	0	31
	2019	2,163	1,851	86	25	0	25

Whale data from logbooks show that killer whale depredation has increased in the AI from 2% in 2017 to 7% in 2019. This same trend was in the WG (6% to 14%). Sperm whale presence is in all areas except for the BS. Presence is lowest in the AI and increases as you go east, with a slight decline from WY to EY. In the AI presence was 6% on average and was steady. The rate was higher in the WG and also consistent, with sperm whale presence noted for 11% of sets on average. There were high samples sizes in the CG and in the more eastern areas. In the CG, sperm whale presence was also steady through time with an average of 21% of sets. In WY, there was a peak of 42% of sets with sperm whale presence in 2018, whereas it was 25% in 2017 and 32% in 2019. In EY, there was a slight downward trend, with a decrease in 2019 from 31% to 25%. In future years we will be able to evaluate trends in whale presence in the logbook data. These data are a quantitative measure of the relative presence of whales in each management area and have substantial sample sizes, which is not the case with observer data. We greatly appreciate the fleet filling out these new data fields voluntarily, particularly because whale presence is not recorded with existing EM protocols.

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).

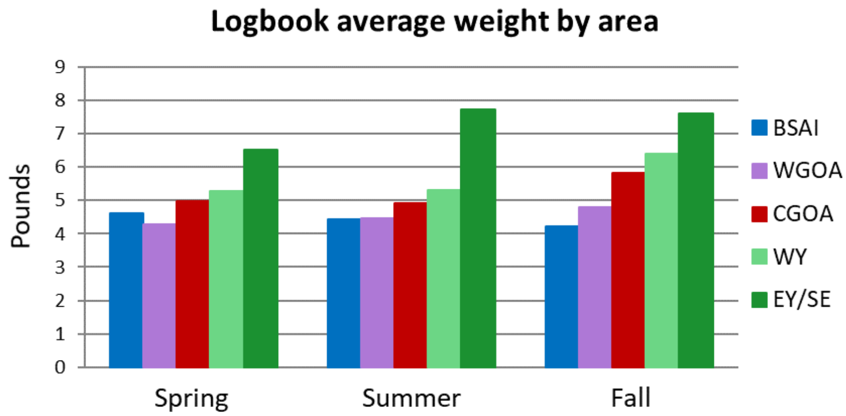
CPUE in the CGOA, WY, and EY/SE have been on long declining trends starting in the 2000's and extending through 2019, which is the end of the available time series (fishery data from 2020 will not be available until 2021; Table 3.9, Figures 3.5 - 3.6). The one exception was a small increase in the observer data in the CGOA in 2019, which has a lower sample size than logbooks. The WGOA fishery CPUE increased in 2017 and has remained stable. The AI observer data is confidential in some years due to low vessel sample sizes and so we are not able to present data from 2016 to 2019. In the AI logbook data CPUE was up in 2018 and increased further in 2019, reaching the range of CPUEs from 2009 - 2016 (Table 3.9). Prior to these increases in CPUE, AI logbook CPUE was at a time series low in 2017. Observer coverage in the BS is sporadic, but CPUE increased from low values in 2015 and 2017 to an above average level in 2019.

The two fishery data sources are combined into one fishery CPUE index by weighting each data set by the inverse of the CV. Because of larger sample sizes in the logbook data set compared to observer data, logbook confidence intervals are generally narrower and are weighted more heavily in the combined fishery index of abundance (Table 3.9 and Figure 3.6). Unlike fishery data, the AFSC longline survey data is available through 2020 and the CPUE has increased rapidly in all areas in the last two years, particularly the AI, WGOA, and CGOA in 2020 (Figure 3.5).

Seasonal Changes in Fish Size

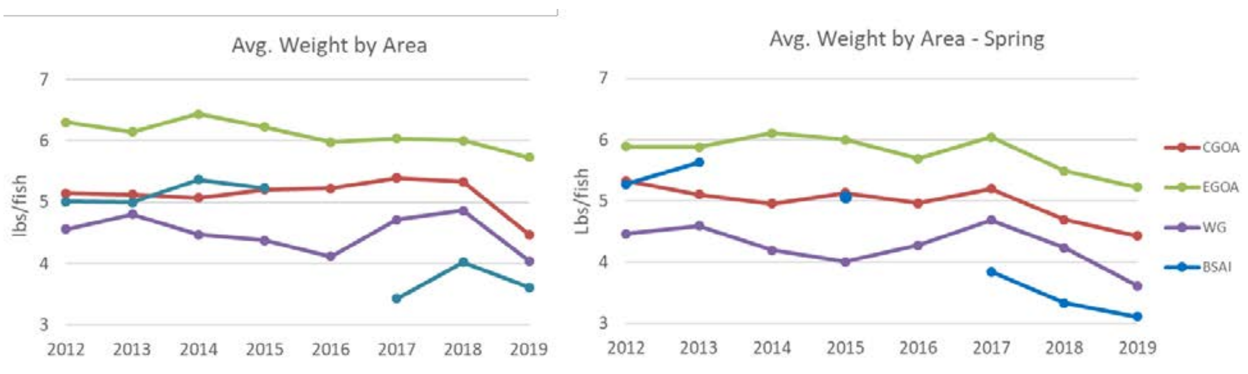
The average fish weight by set from logbooks is available from 2012 - 2019. Data from all longline sets were included if there was weight and count information, regardless of target species. When the data are aggregated for all years, there is an increasing trend in weight toward the east (see Figure below). The largest fish were from the EY/SE area with an average weight of 7.7 lbs in the summer and fall. For comparison, the average fish size in the WGOA was 4.8 lbs in the fall. In general, the average weight of harvested sablefish in longline gear is largest in the fall in the GOA.

Figure. Average sablefish weight in longline gear in spring, summer, or fall from 2012 - 2019.



We now have enough data to show trends through time by FMP areas without confidentiality concerns, with the exception of some years in the BSAI (see Figure below). Over all seasons, there is a gradual decrease in average size in the EGOA and a recent decline in other areas (left panel). Seasonally, there is more data available in the spring than in other seasons and so only that data is presented below (right panel). The decrease in weight since 2017 is more evident in the spring than for data averaged over the whole year. The 2014 year class is much larger than average and so the decrease in size in 2018 and 2019 may be related to these fish being caught as 4- or 5-year-olds. Relatively few sablefish under age-4 are caught in hook and line fisheries and surveys.

Figure. Annual average sablefish weight in longline fisheries by area for all seasons (left panel) and for spring only (right panel). When there were fewer than three vessels, data is not shown.



Pot Fishery Effort and Catch Rates

The following data summaries on pot gear are for sablefish targeted sets, which was determined in the same manner as described in the Observer Data section above.

Observer samples sizes and catch rates: For observer data in the AI there have been fewer than three vessels in 8 of the 10 years, so this data is not presented. In the BS there is more data than in the AI, but vessel sample sizes decreased substantially in 2013, possibly related to observer restructuring (see Table below). It is difficult to have confidence in the observer data CPUE estimates (lbs/pot) or to discern trends, because pot catch rates have high standard errors (SE). Overall, CPUE was higher in the GOA than in the BS.

Logbook sample size: Pot fishing was allowed in the GOA starting in 2017. Compared to observer data, there is data from more vessels and sets in all areas, with the exception of the BS. The quantity of data increased compared to 2017 in 2018 and 2019. There are now 15 vessels in the CG and 14 in WY voluntarily participating in the logbook program. There are fewer in EY, 4 vessels, and in WG, 7 vessels. In the WG, there was the least amount of data in 2019. Of the vessels fishing pot gear that turned in logbooks, there were few vessels <60 ft in the AI and BS, but 48% of vessels in the CG were <60 ft, 53% in the WG, 57% in WY, and 79% in EY, on average.

The logbook data set currently surpasses the observer data set in terms of sample sizes. We appreciate that the fleet has voluntarily given sablefish data to the International Pacific Halibut Commission to be transferred to Auke Bay Laboratories. We will continue to analyze this growing data set and evaluate ways to use it in the stock assessment.

Logbook catch rates: Along with higher sample sizes, SEs were lower in the logbook data compared to observer data in the GOA. CPUE increased in the CG and WY through time. In the WG CPUE was highest in 2017. It is difficult to evaluate any changes in EY/SE. Although the CPUE high was in 2018, this value was accompanied by a high SE making uncertainty in this estimate higher than in other years. The CPUEs in the AI were similar to those in the GOA, but the CPUEs are difficult to interpret due to low sample sizes.

Table. Information on sablefish pot fisheries from observer and logbook data by FMP sub-area and year. When there are fewer than three vessels the data is not shown due to confidentiality (C).

Source	Area	Year	Vessels	Pots	Sets	lbs./pot	SE
Observer	CG	2017	3	1,156	28	28	12
		2018	7	5,230	167	45	14
		2019	7	3,271	97	58	12
Logbook	CG	2017	9	10,398	273	25	4
		2018	12	18,892	533	34	5
		2019	15	28,944	851	40	5
Observer	WG	2017	3	466	19	74	23
		2018	3	1,800	55	53	15
		2019	C	-	-	-	-
Logbook	WG	2017	3	2,936	74	49	12
		2018	8	12,628	344	33	9
		2019	7	11,653	246	34	6
Observer	WY	2017	C	-	-	-	-
		2018	5	758	35	64	25
		2019	4	859	32	70	22
Logbook	WY	2017	10	18,106	606	26	4
		2018	11	11,655	383	33	7
		2019	14	17,728	585	39	6
Observer	EY/SE	2017	C	-	-	-	-
		2018	3	358	21	48	20
		2019	4	1,236	54	60	7
Logbook	EY/SE	2017	8	5,133	215	36	6
		2018	8	4,739	196	50	12
		2019	7	4,595	186	42	5
Logbook	AI	2017	C	-	-	-	-
		2018	6	29,683	396	34	6
		2019	4	10,279	161	30	4

Table (Cont.). Information on sablefish pot fisheries from observer and logbook data for the Bering Sea sub-area by year. When there are fewer than three vessels the data is not shown due to confidentiality (C).

Source	Area	Year	Vessels	Pots	Sets	lbs/pot	SE
Observer	BS	1996	C	-	-	-	-
		1998	C	-	-	-	-
		1999	3	3,090	28	7	5
		2000	3	798	22	15	9
		2001	C	-	-	-	-
		2002	3	3,810	75	23	2
		2003	6	13,319	264	15	1
		2004	7	15,061	251	13	4
		2005	6	10,817	212	29	4
		2006	6	12,794	222	24	4
		2007	6	11,558	193	34	4
		2008	6	16,352	279	29	4
		2009	8	27,731	338	17	3
		2010	4	18,121	271	14	4
		2011	8	25,038	361	7	2
		2012	5	17,885	248	15	4
		2013	C	-	-	-	-
		2014	C	-	-	-	-
		2015	3	3,807	76	12	3
		2016	C	-	-	-	-
		2017	3	7,872	92	28	10
		2018	5	10,035	111	35	7
		2019	4	3,029	43	39	13
Logbook	BS	2017	5	46,004	581	20	2
		2018	C	-	-	-	-
		2019	2	1,573	21	18	21

Pot fishery bycatch: The pot gear effort and catch in the GOA has increased since the fishery was opened in 2017. For more details on catch and bycatch see “*Recent U.S fishery, 1977 to present*”. In the GOA, bycatch in the sablefish pot fishery is largely comprised of Pacific halibut, Pacific cod, and arrowtooth flounder. Smaller amounts of shortraker rockfish, shortspine thornyhead, octopus, and “other rockfish” are also caught in the GOA. There is less bycatch in the BSAI. In the BS there has been 3 t of Greenland turbot bycatch on average since 2010. There was 4 t of arrowtooth flounder caught on average from 2014 - 2020, which was a decrease from 2010 - 2013 (15 t average). In the AI there is less bycatch, with 4 t of arrowtooth flounder on average, 2 t of Kamchatka flounder, and 1 t of Greenland turbot.

Surveys and Indices

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

AFSC Surveys

Longline Survey

Overview: Catch, effort, age, length, weight, and maturity data are collected during sablefish longline surveys. These longline surveys likely provide an accurate index of sablefish abundance (Sigler 2000).

Japan and the U.S. conducted a cooperative longline survey for sablefish in the GOA annually from 1978 to 1994, adding the AI region in 1980 and the eastern BS in 1982 (Sasaki 1985, Sigler and Fujioka 1988). Since 1987, the Alaska Fisheries Science Center has conducted annual longline surveys of the upper continental slope, referred to as domestic longline surveys, designed to continue the time series of the Japan-U.S. cooperative survey (Sigler and Zenger 1989). The domestic longline survey began annual sampling of the GOA in 1987, biennial sampling of the AI in 1996, and biennial sampling of the eastern BS in 1997 (Rutecki et al. 1997). The domestic survey also samples major gullies of the GOA in addition to sampling the upper continental slope. The order in which areas are surveyed was changed in 1998 to reduce interactions between survey sampling and short, intense fisheries. Before 1998, the order was AI and/or BS, Western Gulf, Central Gulf, Eastern Gulf. Starting in 1998, the Eastern Gulf area was surveyed before the Central Gulf area. Interactions between the fishery and survey are described in Appendix 3A.

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 high 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, afterwards mostly trended downward through 2015, which was the lowest estimate of RPNs in the domestic survey time series (Figure 3.3). Since 2015, longline survey RPNs have been steadily increasing with the 2020 catches representing the highest RPNs observed in the time series. Although RPNs have been trending upwards in all regions, the most significant increases were observed in the western GOA and BSAI (Figure 3.7). In the GOA, the 2020 survey demonstrated similar CPUE for most stations across each area except for a handful of stations in the CGOA area, wherein CPUE generally increased substantially (Figure 3.8a). Although not fit in the assessment model, longline survey relative population weights (RPWs) generally demonstrate a similar trend to the RPNs, but increases are often not as substantial and lag those in the RPN when large year classes represent a majority of the survey catch, which has been the case over the last five years (Figures 3.3 and 3.10b). For instance, RPW and RPN indices strongly diverged from 2015 to 2018, because the abundance of young fish increased RPNs, which had little effect on RPWs (Figure 3.10b). However, since 2018 RPWs have sharply increased, which better matches the trends in RPNs (Figure 3.10b).

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, no stations were depredated by killer whales in 2016 and 2 stations were depredated in 2018. In 2020, depredation in the AI was at the highest level observed in the time series (7 stations).

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 WGOA. In 2020, sperm whale depredation occurred at 6 stations in EY/SE and 4 stations in the WY areas (Table 3.11). In the CGOA, depredation dropped from 6 stations in 2019 to 3 stations in 2020. Although sperm whales are sometimes observed in the WGOA, there has only been depredation observed at one station in 2012, 2017, and 2020. In the AI there was also one station depredated in 2012, 2014, and 2016, but none in 2018 or 2020. 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; past studies of depredation on the longline survey showed no significant effect; and sperm whale depredation is difficult to detect (Sigler et al. 2007). However, due to recent increases in sperm whale presence and depredation at survey stations, as indicated by whale observations and results of recent studies, we evaluated a statistical adjustment to survey catch rates using a general linear modeling approach (Hanselman et al. 2010). This approach demonstrated 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 = 0.70). 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. Yet, gully stations from 2019 to 2020 demonstrated a stable abundance, whereas slope stations increased rapidly (Figure 3.8b). 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.

Trawl Surveys

Trawl surveys of the upper continental slope to 500 m and occasionally to 700 - 1000 m, which corresponds to depths inhabited by adult sablefish, have been conducted biennially or triennially since 1980 in the AI and 1984 in the GOA. 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 few sablefish. Trawl survey biomass indices were not used in the assessment model prior to 2007, because they were not considered good indicators of the relative biomass of adult sablefish. For instance, the full range of adult sablefish habitat is not always sampled since some surveys do not extend beyond 500 m, while adult sablefish are 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 may be good at tracking biomass of smaller and younger fish. For instance, the GOA trawl survey index demonstrates strong increases since 2015, which corresponds well with associated trends in the longline survey RPWs and RPNs (Figures 3.3 – 3.4).

Currently, the GOA trawl survey biomass estimates (<500 m depth, Figure 3.4) and length data (<500 m depth) are incorporated into the model and provide a pseudo recruitment index for the whole population (given that the trawl survey generally catches small sablefish). AI and BS Slope trawl survey biomass estimates are not used in the assessment model given their relatively low sablefish biomass estimates, high sampling error, and relatively short time series, especially in the BS. Estimates in these two areas have decreased slowly since 2000, but the Aleutian Islands biomass doubled from 2016 – 2018 (Figure 3.9). However, the largest proportion of sablefish biomass is in the GOA, so using only trawl survey biomass from this area should be indicative of the overall population. The GOA trawl survey index was at its lowest level of the time series in 2013, but has more than tripled in 2019 (Table 3.10, Figure 3.4).

IPHC Longline Survey

The IPHC conducts a longline survey each year to assess Pacific halibut, which is not included in the current assessment. This survey differs from the AFSC longline survey in gear configuration and sampling design, but catches substantial numbers of sablefish. However, length/age compositional data for sablefish are not taken on the IPHC survey making it difficult to utilize in an age-based assessment. 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. 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 moderately well (correlation coefficient of 0.42), 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 (correlation coefficient of 0.5) described above, which samples the same depths (Figure 3.10a).

While the two longline surveys have shown consistent patterns for some years, they strongly diverged through much of the 2000s. In 2015 the IPHC index decreased substantially and was the lowest in the time series, which agrees with the AFSC index which was near a time series low in 2015 (Figure 3.10a). As with both the longline and trawl surveys, the IPHC survey has demonstrated strong increases since about 2017, which further corroborates the existence of strong recent year classes. 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.

Overall Abundance Index Trends

Relative abundance has cycled through three valleys and two peaks, the latter around 1970 and 1985 (Table 3.10, Figures 3.3 and 3.4). The post-1970 decrease likely was due to heavy fishing. The 1985 peak was associated with exceptionally large late 1970's year classes. Since 1988, relative abundance was generally stable with a slight downward trend, but all indices demonstrated a strong decrease in the mid-2000s until about 2015 (Figures 3.3 – 3.4, 3.8b, 3.9, and 3.10a). Regionally, abundance decreased faster in the BS, AI, and WGOA and more slowly in the CGOA and EGOA (Figure 3.7). The last several survey data points have demonstrated considerable rebound, particularly in the combined Western areas (Figures 3.3 – 3.4 and 3.7).

Regions Not Incorporated in the Assessment Model

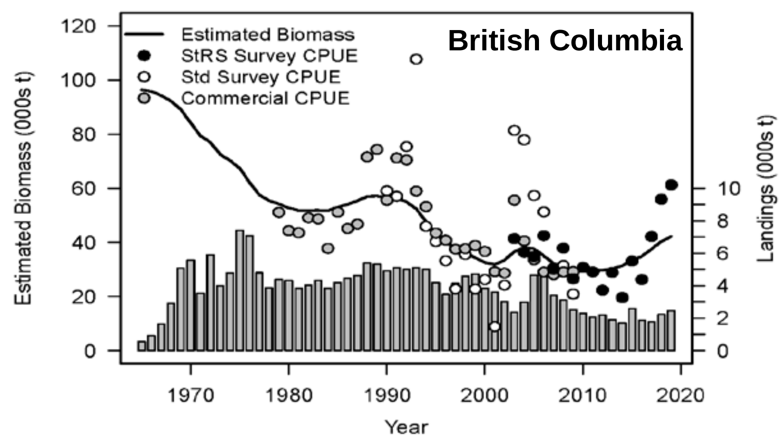
Alaska Department of Fish and Game (ADFG) Management Areas

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 – 2019 (Figure 3.11a). NSEI fishery CPUE declined in the strongly in the 1990s, but has been relatively stable with a slight upward trend since the early 2000s (Figure 3.11a). In SSEI, survey CPUE had been declining from 2011 to 2015, but has seen a general upward trend since that time (Figure 3.11b). The lowest points in the time series of CPUE for each of these areas is about 2015, which corresponds to time series lows in biomass in our assessment. However, the assessment of the NSEI stock suggests that the abundance in that area has remained at low levels since 2000 with only minor recent increases (Figure 3.11a), which differs from the strongly increasing biomass estimates for Alaskan Federal waters in our assessment (Figure 3.17).

Department of Fish and Oceans (DFO) Canada

Sablefish stocks in coastal Canada are managed and assessed by DFO using a surplus production model fit to landings and three indices of abundance, including a random stratified trap survey, along with a management procedure approach chosen through management strategy evaluation (Brandon Connors, pers. comm.). The trap survey was at a time series low in in 2014, but rapidly increased from 2016 to 2019 (approximately tripling). The overall estimated biomass trend in B.C. is similar to the trend in Alaska and recent increases are strong like in Alaskan Federal waters (see figure below).

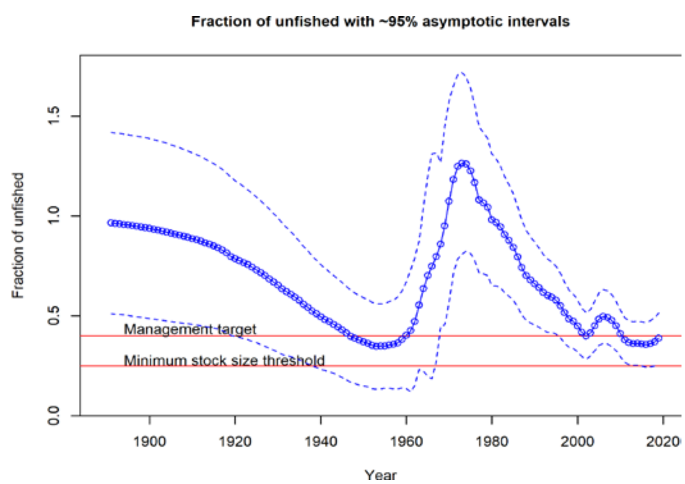
Figure. Observed landings, commercial CPUE, and survey CPUE, as well as, estimated biomass from a surplus production model of British Columbia sablefish (from Brandon Connors, pers. comm.).



Northwest Fisheries Science Center

In 2019, a full assessment was conducted for the West Coast sablefish fishery (Haltuch et al. 2019). The west coast has also had an emergence of several recent large year classes and the stock is now expected to be at or near the target reference point (see figure below).

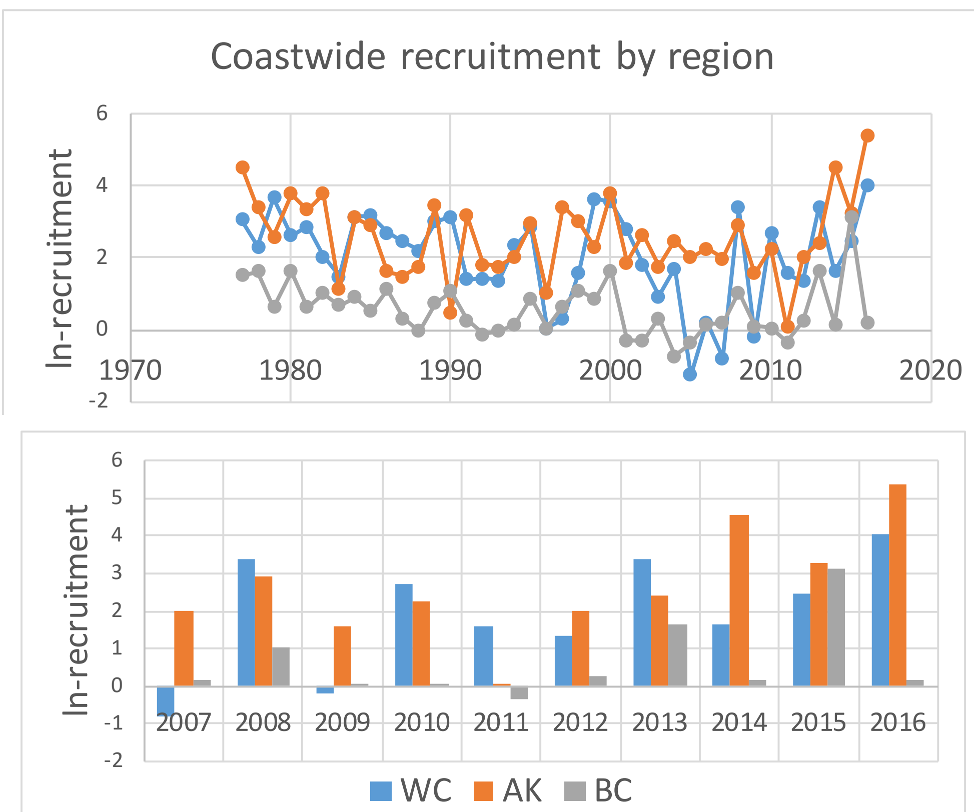
Figure. Time series of total biomass relative to the unfished biomass for west coast USA sablefish (from Haltuch et al. 2019).



Coastwide Comparison of Population Dynamics

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 other areas. A Pacific Sablefish Transboundary Assessment Team (PSTAT) consisting of scientist from the U.S. (west coast and Alaska regions), Canada, and the state of Alaska has been formed in an attempt to better understand the dynamics and population trends of sablefish across the eastern Pacific Ocean (Fenske et al. 2018). The group is developing spatially explicit tagging analyses and operating models to estimate connectivity among regions and eventually explore impacts of regional management measures on population units throughout the coast. Additionally, age reading groups across agencies have addressed sablefish ageing through the Committee of Age Reading Experts (CARE) group and have worked together to develop ageing criteria.

Figure. Recruitment estimates in log-space from across the eastern Pacific, including the west coast of the USA (WC), Alaska Federal waters (AK), and British Columbia, Canada (BC). The top panel shows recruitment by area back to 1977, while the bottom panels demonstrates the same values for the recent time period (2007 – 2016).



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 dynamics, and likelihood equations are described in Box 1. The analysis was completed using AD Model Builder software, a C++ based software for development and fitting of general nonlinear statistical models (Fournier et al. 2012).

The model assumes a single area across the entire Gulf of Alaska, Bering Sea, and Aleutian Islands. As noted, the population is tracked by sex, including both population dynamics and fishery exploitation. A forward projecting, age structured statistical catch-at-age (SCAA) approach is utilized to project the fishery forward in time by age from yearly estimated recruitments at age-2 and derived initial age structure in 1960. Primary demographic parameters are estimated outside the model and treated as fixed inputs, including maturity-, length-, and weight-at-age. The model assumes two primary fishing fleets (i.e., the directed fixed gear fishery and the combined trawl gear fisheries) with independent dynamics, each of which is assumed to operate homogenously across the entire model domain. Three fishery-independent surveys (i.e., cooperative longline, domestic longline, and domestic Gulf of Alaska trawl) are also modeled along with two fishery-dependent CPUE indices (i.e., historic Japanese longline and domestic longline). The model predicts and directly fits a variety of data sources including: fixed gear and trawl catch (including discards assuming 100% mortality), separated by fleet; historic Japanese longline CPUE in weight; domestic longline fishery CPUE in weight; cooperative longline survey relative population numbers; domestic longline survey relative population numbers; domestic trawl survey biomass; age frequency compositions for the fixed gear fishing fleet, cooperative longline survey, and domestic longline survey; and length frequency compositions for the fixed gear fishery, trawl fishery, cooperative longline survey, domestic longline survey, and trawl survey. Parameter estimation is handled through a statistical maximum likelihood estimation (MLE) framework by fitting (i.e., minimizing the differences between) the observed and predicted data sets. Stock status is determined through internal estimation of management reference points (e.g., $F_{40\%}$ and $B_{40\%}$), while projections of future catch limits (e.g., ABC and OFL) are handled externally and described in the Harvest Recommendations section.

Definitions

Spawning biomass is the biomass estimate of mature females. Total biomass is the estimate of all sablefish age-2 and greater. Recruitment is measured as the number of age-2 sablefish. Fishing mortality is fully-selected *F*, meaning the mortality at the age the fishery has fully selected the fish.

Model Alternatives

There are no model alternatives to consider for the 2020 assessment. The main features of Model 16.5 (Base model) compared to models developed before 2016 are:

1) Inclusion of annual variance calculations including uncertainty of whale observations in the domestic longline survey index.
2) Additional catch mortality in the longline fisheries from sperm and killer whales.

3) Natural mortality is estimated.

Parameters Estimated Outside the Assessment Model

The following table lists the parameters that are estimated independently of the assessment model and used as fixed inputs. None of these inputs have been updated in the 2020 model.

Table. Maturity, growth, and weight equations used to define the biological inputs for the stock assessment model. All parameters are estimated independently and fixed in the assessment model.

Parameter name	Value		Source
Time period	1960 - 1995	1996 - current	
Maturity-at-length – females	$m_a = 1/(1+e^{-0.4*(L-65)})$		Sasaki (1985)
Maturity-at-length – males	$m_a = 1/(1+e^{-0.4*(L-57)})$		Sasaki (1985)
Maturity-at-age – females	$m_a = 1/(1+e^{-0.84*(a-6.60)})$		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		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. The model assumes recruitment at age-2 when fish first become susceptible to the gear and tracks age-based dynamics from age-2 to age-31+ where the terminal age is a plus group (i.e., it accounts for the dynamics of all fish of that age and all older ages as a single unit).

Growth and Maturity

Sablefish grow rapidly in early life with an average rate of 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 achieve an average length of 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; 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 have increased slightly over time. New age-length conversion matrices were constructed using these curves by fitting to the standard deviations of the collected lengths-at-age assuming normal error (Figure 3.12a). The new matrices provided a superior fit to the data. Therefore, we use a bias-corrected and updated growth curve for data collected from 1981 - 1993 and a separate growth curve for years when samples were collected randomly (1996 - 2004; Echave et al. 2012). We have continued to use a random sampling method since 2004, and so the more recent growth curve has been used in all years since 1996.

The maturity data currently used in the Alaska sablefish stock assessment were collected over 35 years ago and maturity was classified macroscopically, using a visual assessment during the summer (1978 - 1983; Sasaki 1985). In addition, only lengths were recorded, which were later converted to ages using an age-length matrix to obtain an age-at-maturity model. For the model used in this assessment, 50% of females are mature at 65 cm and 50% of males are mature at 57 cm (Sasaki 1985), which corresponds to age-6.5 for females and age-5 for males (Table 3.12). Maturity parameters were estimated independently of the assessment, then incorporated into the model as fixed values. 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. Maturity equations are provided in the above biological inputs Table.

In 2011, the AFSC conducted a winter cruise out of Kodiak to sample sablefish when they were 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 (i.e., not contributing to the spawning population) 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 at gully stations 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 in the assessment. When skip spawners were classified as immature the age at 50% maturity was 7.9 years, which is 1.3 years older than what is used currently in the assessment. 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 the 2015 collection season (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 adequately 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 future spawning. Therefore, fish that may spawn could be classified as skip spawning or immature during earlier periods of the survey. 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. Because histological maturity has the highest accuracy at the end of the AFSC survey, which finishes in the central GOA, we were able to use these classifications as the true maturity.

Using these observations we were able to develop a model to predict maturity of individual fish using their body condition, age, and length (Rodgveller, 2019). This model was then used to predict population-level maturity in the Central GOA from 1996 - 2018, producing a time series of maturity for the first time. Because age and length are both in the predictive model, annual differences will be related to temporal changes in growth. From 2011 - 2018 (with the exception of 2017) fish matured at older ages compared to 1996 - 2010 (see Figure below).

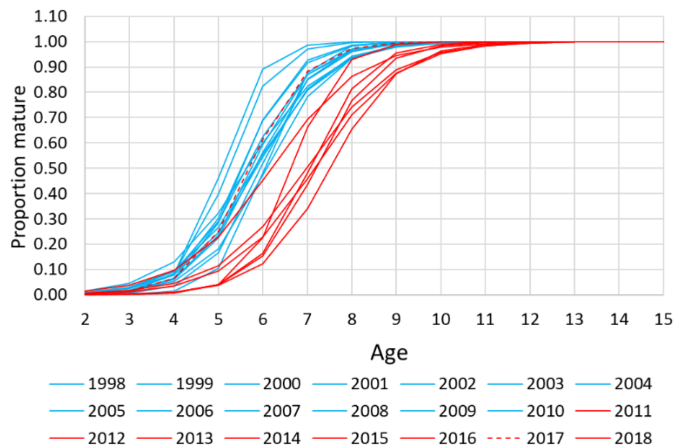


Figure. Maturity-at-age curves for female sablefish sampled in the Central Gulf of Alaska on the AFSC longline surveys from 1996 - 2010 (blue) and from 2011 - 2018 (red). The dashed, red line is the 2017 maturity prediction, which represents the only year post-2010 where maturity-at-age was higher than in years prior to 2010.

Like maturity, growth rates were reduced in the recent time period (see Figure below).

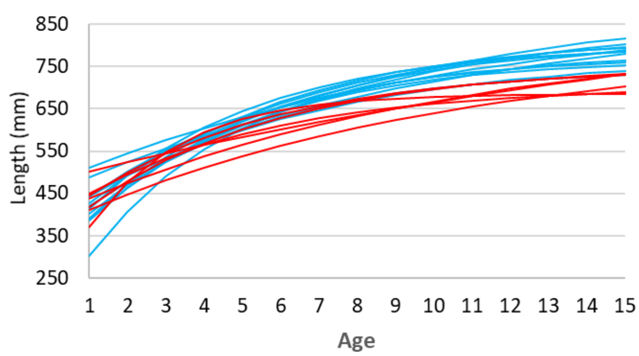


Figure. Annual length-at-age (growth) curves for female sablefish sampled in the Central Gulf of Alaska on the AFSC longline surveys from 1996 - 2010 (blue) and from 2011 - 2018 (red).

The potential impact that increased density of sablefish due to abnormally large recent recruitment events may have on growth and/or maturity warrants further exploration. Additionally, there may be differences in biological parameters spatially, particularly between gully and slope habitats. Overall, these preliminary results indicate that there may be a shift towards slower growth and later maturity in recent years. However, more in-depth analyses are required to draw firm conclusions and the AFSC continues to study potential changes in the biology of sablefish. In the future, the growth and maturity rates used in the model will be updated when available data are sufficient to support estimates that reflect the biology across the entire model domain.

Maximum Age

Sablefish are long-lived; ages over 40 years are regularly recorded (Kimura et al. 1993). Reported maximum age for Alaska is 94 years (Kimura et al. 1998). Canadian researchers report age determinations up to 113 years[1]. The current assessment accounts of age-based dynamics until age-31, at which point a plus group is assumed for all ages greater than 31.

Ageing Error and Age-Length Conversions

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). The ageing error matrix is directly incorporated into the model to account for uncertainty in the ageing process. Age-length conversions (Figure 3.12a) are used to convert length to ages to allow fitting length compositions within an age-based assessment model. The ageing error matrix is directly incorporated into the model to account for uncertainty in the ageing process through the use of age-length conversion matrices (Figure 3.12a). Differences in aging are accounted for by sex and allowed to vary before and after 1996 (Figure 3.12a).

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 one 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

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

[1]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 (McAllister and Ianelli 1997), where iterating the input sample size to equal this effective sample size is often called “McAllister-Ianelli” weighting, but is not used here.

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 (i.e., for the 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.

The 2016 CIE review panel felt strongly that the model was fitting 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. These data weights have been maintained since the 2016 assessment. However, the addition of new data may cause the weights to no longer effectively maintain the desired SDNRs at one. Although continual refinement of data weights through iterative reweighting during each assessment process would be optimal, SDNRs in recent assessments have not varied substantially from the desired levels. Given the time constraints during the condensed assessment process and limited straying from the desired SDNRs of 1.0, reassessing the data weights established in 2016 has not been a priority during recent assessments. In the future, we plan to reassess the data weights to better align with the goals of the tuning process outlined during the 2016 CIE review.

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. 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. In 2018, a paper with a comprehensive examination of different modeling techniques to account for depredation 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, or 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 minimal, but generally most important in WY and EY (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 from 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 - 2019). 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 - 2019 ranged from 90 t to 325 t by killer whales in western Alaska management areas and

40 t to 310 t by sperm whales in the GOA (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 appears to be a general decline in sperm whale depredation in most areas of the GOA since 2017, predominately in the central GOA. We have not fully investigated this, but it could be partly due to more of the catch being taken with trawls and pots. Killer whale depredation has been relatively steady at time series mean levels for the last 3 to 4 years.

Although the SSC has requested that updated whale depredation coefficients be estimated and incorporated into the models, the low total removals (i.e., compared to total catch) and generally steady rates of removal indicate that reestimation is unlikely to appreciably influence the assessment. However, reevaluation of whale depredation coefficients is a future research priority.

Model Estimated Parameters and Description

A summary of the parameters estimated within the recommended assessment model are provided in the following Table.

Parameter name	Symbol	Number of Parameters
Catchability	q	6
Mean recruitment	μ_r	1
Natural mortality	M	1
Spawner-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	122
Fishery selectivity	fs_a	10
Survey selectivity	ss_a	7
Total		240

Catchability

Catchability is separately estimated for the Japanese longline fishery, the cooperative longline survey, the domestic longline survey, the U.S. longline derby fishery, the U.S. longline IFQ fishery, and the NMFS GOA trawl survey. Information is available to inform 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. In 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). The lognormal prior distributions for each catchability coefficient developed in 2007 are provided in the following Table and were again used in the current model.

Table. Prior distributions for each catchability coefficient estimated in the model.

Index	U.S. LL Survey	Coop. LL Survey	Fisheries	GOA Trawl Survey
Mean	7.857	4.693	4.967	0.692
CV	33%	24%	33%	30%

Recruitment

Recruitment does not assume a stock-recruit relationship, but instead estimates an average recruitment parameter (μ_r; 1 parameter) with loosely constrained (standard deviation, σ_r, fixed at 1.2) yearly deviations (τ_y) for the years 1933 – 2019 (88 parameters). Recruit deviations prior to the model start year (1960) are used to determine the initial age-specific initial abundance distribution in the start year. Initial cohort strength for each age in 1960 is determined in the same way as other recruitment year classes, then each cohort is decremented for mortality prior to 1960 using the estimated natural mortality rate and assuming a fixed proportion (F_{hist}; 10%) of the average longline fishery fishing mortality occurs each year prior to 1960. The recruitment value in the terminal year is set equal to the estimated median recruitment, because limited information (e.g., age composition data) is available to adequately estimate a deviation parameter.

Fishing Mortality and Selectivity

The model treats the directed (longline and other fixed gear fisheries) and the primary bycatch (pelagic and non-pelagic trawl fisheries) as independent fleets. Each fleet (fixed gear and trawl) is modeled with its own fishing mortality and fishery selectivity parameters, where the separability assumption is utilized to separate the yearly fishing mortality from the age-specific gear selectivity. Yearly fishing mortality is estimated with an average fishing mortality parameter (μ_f) for each fleet (fixed gear and trawl; 2 parameters) and yearly deviations (φ_y; 1960 - 2020) from the average value and for each fishery (122 parameters).

Gear selectivity is represented using functional forms and is separately estimated by sex for the longline survey (domestic and cooperative), fixed-gear fishery (pot and longline combined), the trawl survey, and the trawl fishery. The historic Japanese longline fishery assumes a single selectivity function that is combined across sexes and is estimated to enable fitting the associated fishery CPUE index. Selectivity for the fixed-gear fishery is estimated separately for the “derby” fishery prior to 1995 and the IFQ fishery from 1995 thereafter. Due to crowded fishing grounds during the 1985 - 1994 “derby” fishery, fishermen often reported fishing in less productive depths due to crowding (Sigler and Lunsford 2001). Conversely, fishermen can choose where they fish in the IFQ fishery, presumably targeting bigger, older fish, and depths that produce the most abundant catches. Thus, there is reasonable information indicating that fixed gear selectivity should differ before and after 1995 and the model accommodates this expectation by allowing for a selectivity time block in 1995.

Selectivity for the longline surveys and fixed-gear fisheries is restricted to be asymptotic by using the logistic function where sex-specific age at 50% selectivity ($a_{50\%}$) is estimated (5 estimated parameters for the fishing fleets and 4 for the survey fleets). Due to model instability, the other logistic selectivity parameter (i.e., the difference in age at 50% selectivity and 95% selectivity, δ, which controls the shape of the curve) is shared among similar gears and across sexes, which results in a total of two additional estimated logistic selectivity parameters (1 for the longline fisheries and 1 for the longline surveys). Selectivity for the trawl fishery and trawl survey are dome-shaped (right descending limb) and estimated with a two-parameter gamma-function and a one-parameter 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 where older fish are less likely to be found. There are four total estimated parameters for the trawl fishery gamma functions and two estimated parameters for the trawl survey power functions. In total, there are 10 estimated fishery selectivity parameters and 7 estimated survey selectivity parameters.

Natural Mortality

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 when a precise prior was 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. In the 2016 assessment, estimating natural mortality was revisited 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. We maintain natural mortality as an age- and time-invariant estimated parameter with a prior as in previous assessments dating back to 2016, but multiple sensitivity runs were explored that estimated both age and time-varying natural mortality rates (see the Sensitivity Runs section for more information).

Spawner-per-Recruit Parameters and Stock Status

The assessment model internally calculates per-recruit reference points to allow direct estimation of the fishing mortality rates (i.e., $F_{35\%}$, $F_{40\%}$, $F_{50\%}$) that bring spawning stock biomass to various levels (i.e., 35%, 40%, and 50%) of unfished spawning biomass (i.e., B_0). The spawner-per-recruit calculations assume that total fishing mortality is partitioned between the fixed gear and trawl gear fleets based on the terminal year ratio of fishing mortality rates, while age-based selectivity from the most recent selectivity time blocks are utilized (i.e., the IFQ time block for the fixed gear selectivity). Estimation of the per-recruit fishing mortality parameters is achieved by adding a penalty to the objective function to minimize deviations from the desired fraction of $B_{100\%}$ under each per-recruit scenario. The corresponding spawning stock biomass for each per-recruit scenario is calculated by multiplying the $SPR_{X\%}$ by the mean recruitment from 1979 (1977 year class) to the terminal year – 2, which removes uncertain recent recruit events from the determination of stock status indicators.

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
F_{hist}	Historical proportion of fishing mortality
$F_{X\%}$	Per-recruit fishing mortality rate that achieves $SPR_{X\%}$
$Z_{y,a}$	Total mortality for year y and age class a ($=\sum_g F_{y,a,g} + M$)
R_y	Recruitment in year y
B_y	Spawning biomass in year y
$s^g_{a,s}$	Selectivity at age a for gear type g and sex s
$A_{50\%}, d_{50\%}$	Age at 50% selection for ascending limb, age at 50% deselection for descending limb
δ	Slope/shape parameters for different logistic curves
$\mathbf{A}$	Ageing-error matrix dimensioned $a_+ \times a_+$
$\mathbf{A}_s^{\,l}$	Age to length conversion matrix by sex s dimensioned $a_+ \times \Omega$
q_g	Abundance index catchability coefficient by gear
λ_x	Statistical weight (penalty) for component x
$I_y, \hat{I}_y$	Observed and predicted survey index in year y
$P^g_{y,l,s}, \hat{P}^g_{y,l,s}$	Observed and predicted proportion at length l for gear g in year y and sex s
$P^g_{y,a,s}, \hat{P}^g_{y,a,s}$	Observed and predicted proportion at observed age a for gear g in year y and sex s
ψ^g_y	Sample size assumed for gear g in year y (for multinomial likelihood)
n_g	Number of years that age (or length) composition is available for gear g
$q_{\mu,g}, \sigma_{q,g}$	Prior mean, standard deviation for catchability coefficient for gear g
M_μ, σ_M	Prior mean, standard deviation for natural mortality
$\sigma_{r_\mu}, \sigma_{\sigma_r}$	Prior mean, standard deviation for recruitment variability

Equations describing state dynamics	**Model Description** (continued)
$N_{1,a} = \begin{cases} R_1, & a = a_0 \\ e^{(\mu_r+\tau_{a_0-a+1})} e^{-(a-a_0)(M+F_{hist}*\mu_{LL}*s_a^{LL})}, & a_0 < a < a_+ \\ e^{(\mu_r)} e^{-(a-1)(M+F_{hist}*\mu_{LL}*s_{a-1}^{LL})} \left(1 - e^{-(M+F_{hist}*\mu_{LL}*s_{a-1}^{LL}}\right)^{-1}, & a = a_+ \end{cases}$	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
$R_y = \begin{cases} e^{(\mu_r+\tau_y)}, & y \neq T \\ e^{\mu_r}, & y = T \end{cases}$	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 , if estimated
$L_\tau = 0.1 \sum_{y=1}^{T} \frac{\tau_y^2}{2\hat{\sigma}_r^2} + n \ln \hat{\sigma}_r$	Prior on recruitment deviations
$L_f = \lambda_f \sum_{1}^{g} \sum_{y=1}^{T} \phi_{y,g}^2$	Regularity penalty on fishing mortality
$L_{SPR_{X\%}} = 100 * \left(\frac{SPR_{X\%}}{SPR_0} - X\%\right)^2$	Penalty for estimating $F_{X\%}$
$L_{Total} = \sum_{x} L_x$	Total objective function value

Uncertainty

Starting with 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 the 1977 - 2016 year classes. The fishing mortality used is the current yield ratio described in the Catch Specification section multiplied by max ABC 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.

Model 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. 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). Retrospective analysis has been applied most commonly to age-structured assessments. A retrospective bias implies that successive estimates show a consistent pattern of over- or under-estimation compared to the model using the complete set of data (i.e., the 2020 Base model in the current analysis). For instance, if estimates of terminal year SSB are continually revised lower as new data is added to the model, then the terminal estimates would be consistently overestimated and the model would be considered to have a consistent positive retrospective bias. Conversely, if the terminal estimates are continually revised upwards as new data is added, then the model is underestimating the values and a negative retrospective bias exists. Ideally, a model would show no consistent trend as more years of data are added, but random fluctuations above and below the estimates from the model with the full time series of data are expected for successive retrospective peels due to variation and minor data inconsistencies across years. 'Mohn's rho', ρ, is commonly calculated as a measure of overall retrospective bias. It is the mean of the relative 'bias' across all retrospective peels, where the estimate from the model run using the full time series of data (i.e., the 2020 Base model) is used as the reference value in the bias calculation. Non-zero, but of generally small magnitude, estimates of Mohn's rho will be calculated even if the model does not show a consistent bias. However, large positive or negative values indicate a strong retrospective bias and systematic over- or under-estimation, respectively, in the quantity of interest. As a rule of thumb, Hurtado-Ferro et al. (2015) suggest $|\rho| > 0.2$ should be considered cause for concern in long-lived species, such as sablefish, and may warrant exploring model alternatives to identify potential misspecification or exploration of potential data issues.

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 and process error, such as incorrect parametrizations of natural mortality, or temporal trends in values assumed to be invariant. Examining retrospective trends can show potential biases in the model, but does not identify their source. Retrospective trends could also merely be a matter of the model having too much inertia in the age-structure and other historic data to respond to the most recent data.

For this assessment, we show the retrospective trend in spawning biomass and recruitment for ten previous assessment years (2010 - 2019) compared to estimates from the current preferred model. This analysis simply removes 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 GOA trawl survey estimate and corresponding length composition are added.

Historical Assessment Retrospective Analysis

A similar type of retrospective analysis, which addresses consistency across successive stock assessment models used as the basis of management advice, is a historical assessment retrospective analysis. Similar to a model retrospective, a historical retrospective accounts for successive peels of data, but also accounts for changes in model specifications over time. Essentially, the final assessment model used for management advice is compared backwards in time to see how both addition of new data and any modeling changes during the assessment development process may have altered model outputs in successive years. Additionally, historical analysis allows comparison of short-term model projections to realized SSB from subsequent models. Given that the sablefish assessment model has been relatively unchanged since 2016, it would be expected that a historical assessment would generally emulate the results of the model retrospective, and that any retrospective patterns would likely be attributed to model misspecification or data issues as reflected in the model retrospective.

For the current historical assessment retrospective analysis we assume a five year peel and compare the final SAFE models used as the basis for management advice from 2015 to the current 2020 model. Mohn's rho is calculated in the same was as for the model retrospective using the 2020 Base model as the reference value. However, to provide a better idea of the performance of projections, we calculate Mohn's rho based on the difference between the projected SSB from a one year projection in each peel to the corresponding realized SSB in the 2020 Base model. The resulting value provides insight into the discrepancy between the expected SSB trajectory from projections upon which catch limits are based compared to the SSB that was realized as the data and model were updated in subsequent years.

Sensitivity Runs

A variety of model sensitivity runs were performed to better understand model performance and determine whether alternate parametrizations might better fit the observed data or account for recent changes in population and fishery dynamics (i.e., account for apparently large recent recruitment events and/or potential shifts in fishery targeting and gear usage). These sensitivity runs aimed to address a variety of SSC and PT comments concerning model performance. There were eight general categories of sensitivity runs (see Table 3.19): 1) include an additional recent selectivity block for the fixed gear fleet; 2) include an additional recent selectivity block for the domestic longline survey; 3) estimate time-varying natural mortality; 4) estimate age-varying natural mortality; 5) combine additional recent selectivity blocks with age- and/or time-varying natural mortality estimation; 6) reduce data weights for domestic longline survey compositional data; 7) fix recent recruitment events at average levels; and 8) utilize high or low maturity-at-age vectors.

The models in category 1 and 5 aimed to explore whether there may have been recent changes in fishery selectivity due to changes in targeting behavior (i.e., to avoid large recent year classes of small, low-value sablefish) or distribution of gear types (i.e., an increasing shift towards pot gear and away from longline gear). Similarly, runs in category 2 and 5 explored whether changes in availability (i.e., movement of young fish into survey areas) may have led to a change in survey selectivity in recent years, which might explain the recent increases in longline survey RPNs that are composed predominantly of ages 3 to 6. For runs in categories 1, 2, and 5, new fishery and/or survey selectivity parameters (i.e., $a_{50\%}$) were estimated for a recent time block that began either in 2016 or 2017 depending on the sensitivity run.

Those runs in categories 3 – 5 explored whether changes in mortality over time and/or accounting for age-varying natural mortality could help the model better interpret contrasting signals in the observed data (i.e., strong shifts towards younger, smaller fish in the recent survey and fishery age and length compositions indicating unprecedented recruitment year classes; large increases in longline survey RPNs, but which are not commensurate with signals of year class strength from the age composition; and relatively flat or minor increases in recent fishery CPUE that is inconsistent with survey RPNs). Time-varying natural mortality with increases in recent years could indicate that recent large year classes have higher mortality and are not surviving to maturity at the same rate as previous year classes. Similarly, allowing for age-varying natural mortality could indicate that young fish have a higher mortality and large recruitment events may not add to the harvestable biomass at the rate expected when natural mortality is age-invariant. If large recruitment events are associated with stronger density-dependent mortality (i.e., as might be assumed when using common stock-recruit functional relationships) due to lack of resources, cannibalism, or expansion to sub-optimal juvenile habitat, then accounting for age- and time-varying mortality simultaneously could allow the model to increase mortality on younger ages during recent large recruitment events. A variety of parametrizations were explored that ranged in complexity and the number of estimated parameters. These included full time-varying natural mortality estimated as yearly deviations from the estimated base *M* parameter or age-varying natural mortality estimated as age-based deviations from the estimated *M* parameter. Intermediate complexity models included using various time or age blocks to reduce the number of estimated parameters, similar to how selectivity estimation is treated. Exploratory analysis was utilized to develop parsimonious parametrizations of age and time blocking based on data fits and hypothesized mortality dynamics, which led to models that utilized two time blocks (e.g., in 2010, 2016, or 2017) and/or two age blocks (e.g., estimating mortality for juvenile and adult fish separately). Models in category 5 included various combinations of the selectivity blocking from categories 1 and 2 with time- and age-varying natural mortality models from categories 3 and 4.

The models in category 6 are meant to address the concern that the new data weights implemented during the 2016 CIE review, which were meant to address earlier models over-emphasizing the longline survey, are now over-emphasizing the age composition data at the expense of the longline survey RPNs. Since 2017, large year classes have caused a drastic increase in age-3 to age-6 fish caught by both the longline survey and fixed gear fishery, but longline survey RPNs have not increased at the rate expected by the model to address these apparent extreme recruitment events. Concurrently, the fishery CPUE has shown almost no indication of recent increases in population biomass. Due to model tension caused by attempting to fit these disparate data sources, the fit to the survey RPNs and fishery CPUE have degraded rapidly in recent years, because the data weighting scheme emphasizes fits to the age composition data. Thus, a handful of sensitivity runs were carried out to identify if down weighting survey and fishery composition data could improve fits to other data sources (i.e., survey RPN and fishery CPUE).

Due to uncertainty in the estimates of recent recruitment, runs in category 7 explored the impact of fixing the 2016 and/or 2017 recruitment events at time series average values. These results illustrate the potential impacts on SSB and future catch if estimates of these year classes are downgraded, which has occurred during subsequent assessments for a number of recent large year classes (e.g., the 2014 and 2016 year classes).

Finally, category 8 sensitivity runs demonstrated the impact on SSB if the highest or lowest yearly maturity-at-age vectors based on longline survey data from 1996 - 2018 were utilized. Given that future SSB trajectories are dependent on newly recruiting fish adding to the SSB in the short-term, changes in maturity could influence the ability to achieve projected gains. For instance, preliminary data suggest that the age at 50% maturity could have increased recently, which would have important impacts on projected rebuilding. These sensitivity runs illustrate the range of impacts on SSB that changing maturity may have on model results.

Although a wide variety of model sensitivity runs were developed and explored, none are being put forth as alternatives to the Base model. These models were meant as research tools to explore alternate hypotheses regarding states of nature and potential changes within the fishery. They are also meant to address SSC and PT concerns, while providing quantitative outputs to guide future discussions on model structure and potential changes in parametrization. Versions of these sensitivity runs may be further pursued in the future as alternatives to the Base model, but current parametrizations have not been adequately analyzed to warrant suggesting any of these models as the basis of management advice. Thus, we present a select handful of generally interesting or potentially promising parametrizations as preliminary results in the next section (see Table 3.19 for a summary of sensitivity run categories and models to be discussed further in the Sensitivity Runs Results section).

Results

Model Evaluation

For this assessment, we present last year's model (Model 16.5) updated for 2020 with no model changes. The model likelihood components and key parameter estimates from the 2019 model are compared with the 2020 updated model. The two models are the same 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, fishing mortality, catchabilities, and selectivities, as well as, plausible population abundance and biomass trajectories, (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 2020 model based on changes in results from the 2019 model and it is unlikely we would reject the model that included the most recent data. The model generally produces good visual fits to the compositional data and biologically reasonable patterns of recruitment (with the possible exception of the extreme 2014, 2016, and 2017 year classes which we discuss below), abundance, and selectivities. The 2020 update shows a slightly better fit to the longline survey RPN index compared to the 2019 model, despite another historic increase in the RPN. However, the fit to the trawl survey and fishery CPUE indices remains very poor and have worsened due to the increasing divergence between the longline survey RPN increases and the relatively flat fishery CPUE. The model is fitting the unusual recent age compositions relatively well given time-invariant selectivity and fits to the compositional data are similar to the 2019 model. Therefore, the 2020 version of Model 16.5 appears to be utilizing the new information effectively. However, strong increases in model retrospective bias indicates that continued issues estimating the strength of recent strong recruitment events may be leading to chronic overestimation of terminal SSB, and that underlying process error may exist which has increased the uncertainty in model outputs (see Retrospective Analysis section below).

Box 2: Model comparison by contribution to the objective function (negative log-likelihood values) and key parameters of the reference model (16.5) and the same model updated for 2020. "% of –lnL" is the contribution of each data component to the negative log likelihood. $a_{50\%}$ is the age at fifty percent selectivity. σ_r is the recruitment variability term (i.e., the variance controlling the estimation of recruit deviations).

Model Year	**2019**		**2020**	
Likelihood Components	Value	% of -lnL	Value	% of -lnL
Catch	5	0.3%	6	0.4%
Dom. LL survey RPN	52	2.9%	61	3.3%
Coop. LL survey RPN	15	0.8%	15	0.8%
Dom. LL fishery RPW	13	0.7%	20	1.1%
Jap. LL fishery RPW	11	0.6%	10	0.5%
NMFS trawl survey	23	1.3%	28	1.5%
Dom. LL survey ages	266	14.7%	295	16.0%
Dom. LL fishery ages	282	15.7%	305	16.6%
Dom. LL survey lengths	77	4.3%	81	4.4%
Coop LL survey ages	141	7.8%	142	7.7%
Coop LL survey lengths	44	2.4%	44	2.4%
NMFS trawl lengths	455	25.2%	392	21.4%
Dom. LL fishery lengths	46	2.5%	48	2.6%
Dom. trawl fish. lengths	375	20.8%	389	21.2%
Data likelihood	1804		1836	
Objective function value	1862		1888	
Key parameters		**2019**		**2020**
Number of parameters		237		240
SSB_{2020} (kt)		113		94
$SSB_{40\%}$ (kt)		106		127
SSB_{1960} (kt)		229		168
$SSB_{100\%}$ (kt)		265		317
SPR% 2019		29.3%		23.0%
$F_{40\%}$		0.10		0.10
$F_{40\%}$ (Tier 3b adjusted)		0.10		0.10
ABC (kt)		44.00		52.41
$q_{Domestic\ LL\ Survey}$		7.30		7.96
$q_{Coop\ LL\ survey}$		5.40		5.96
$q_{Domestic\ LL\ Fishery}$		5.50		7.95
$q_{Trawl\ Survey}$		1.30		1.33
$a_{50\%}$ (Domestic LL survey)		3.70		3.62
$a_{50\%}$ (LL IFQ Fishery)		4.00		3.95
Avg. Year Class Strength (1977 - 2016)		23.30		19.77
σ_r		1.20		1.20

Time Series Results

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 as these strong year classes were removed due to fishing and natural mortality. Despite a slight rebound in the early 2000s and consistent removals (fluctuating between 15,000t and 20,000t), the biomass continued to subtly decline to a time series low of 171,000 t in 2015 (Figures 3.1 and 3.17). The large estimated 2014, 2016, and 2017 year classes (Figure 3.18b) have caused estimates of total biomass to increase rapidly since 2015 to a time series high in 2020. Based on partitioning using survey RPWs, biomass has been historically located in the Central GOA and BSAI (Table 3.15). Recent increases appear to be occurring in all areas, but are predominantly driven by extreme spikes in the areas of historical biomass concentrations (i.e., Central GOA and BSAI; Table 3.15).

Despite historically similar trends, SSB has lagged recent increases in biomass due to these increases consisting of primarily young, immature fish (Figure 3.17). SSB continued to decline to a time series low of 65,000 t in 2018 before rapid, albeit not as drastic as for biomass, rebuilding (Table 3.14; Figure 3.17). The SSB in 2020 was estimated to be at 94,000 t, which is on par with recent time series highs in the late 2000s, though much below true time series highs in the late 1960s around 240,000 t (Figure 3.17).

Unfished spawning biomass is estimated to be 317,000 t, while $B_{40\%}$ is 126,389 t (see the Summary Table). **Terminal spawning biomass is estimated to be at 30% of unfished spawning biomass, while the projected 2021 spawning biomass is estimated to increase rapidly to around 42% of unfished spawning biomass.** If projected increases in spawning biomass come to fruition, it would represent a doubling in relative SSB from a time series low of 21% of unfished biomass in 2018. The previous two above-average year classes, 2000 and 2008, each comprise approximately 4% and 5.5% of the projected 2021 spawning biomass, respectively (Figure 3.19). These two year classes are fully mature. The large estimated year classes for 2014 and 2016 are expected to comprise about 27% and 22% of the 2021 spawning biomass, whereas the similarly large 2017 year class is estimated to contribute only 6% of the projected SSB. The 2014 year class will be about 60% mature, the 2016 year class will be less than 20% mature, and the 2017 year class is only around 8% mature in 2021.

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 - 2017. Few small fish were caught in the 2005 through 2009 trawl surveys, but the 2008 year class, which was average, 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 areas for lightly selected 2- and 3-year-old fish (Figures 3.23 - 3.26). The 2015 longline survey age composition was dominated by the 2008 - 2010 year classes, which made up more than 35% of the age composition. The 2016 longline survey age composition had an extremely high proportion of age-2 fish and a relatively high proportion of age-3 fish. The 2015 and 2017 trawl survey length compositions also show a high proportion of fish ages 1 - 3, while the 2019 size comps show mainly what appear to be age-3 fish (Figures 3.20, 3.21, and 3.54). Since 2017, the longline survey age composition data represent primarily age-2 through age-5 fish (Figure 3.24), which largely represent the 2014 and 2016 year classes, and is echoed in the fixed gear fishery age compositions in those years (Figure 3.32). 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 for the 1977 – 2017 year classes was 23.0 million 2-year-old sablefish per year, which is slightly less than average recruitment during 1960 - 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 – 2017 year classes (Figure 3.18c). 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.

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 at 50% selection is 3.7 years for females in the longline survey and 4.0 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), but with much larger proportion of older males being selected. The trawl survey selectivity curves differ between males and females, where males stay selected by the trawl survey longer similar to the trawl fisheries (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, but adjusted $F_{40\%}$ was apparently exceeded from the late 1990s until 2020. Similarly, SSB has been below the $B_{35\%}$ limit since the mid-1990s. It is important to note that the management path differs from that estimated by the 2019 assessment, due to a simultaneous increase in biomass reference points, a decrease in SSB estimates, and an increase in estimated fishing mortality. The increase in reference points was primarily driven by the inclusion of the 2016 year class in the average recruitment time series used for per-recruit calculations, which helped increase the average recruitment by 1.2 million fish despite simultaneous extensive downgrades in the size of the 2014 and 2016 year classes (Figure 3.18a). The changes in SSB and fishing mortality estimates are likely related to increased retrospective patterns in the current assessment, which indicate that models with fewer years of data appear to be overly optimistic in estimates of both recruitment and SSB in recent years (see Retrospective Analysis section). When SSB estimates and projected SSB one year out from the final sablefish assessment models from 2015 to the current 2020 model are plotted simultaneously, it demonstrates that, since 2017, models used as the basis of sablefish management have been consistently overoptimistic in projections of rebuilding (Figure 3.58). Additionally, relative stock status ($SSB_{Terminal}/SSB_{40\%}$) has declined due to progressively increasing estimates of $B_{40\%}$, despite relatively stable estimates of $SSB_{Terminal}$ in successive models. Therefore, it is likely that the current management path may be overly optimistic as was the case with the 2019 assessment. Despite projected 2021 and 2022 spawning biomass estimates being above $B_{35\%}$ and $B_{40\%}$ for the 2020 model, similarly optimistic projections from previous assessments have yet to materialize despite recommended quotas being well below the maximum permissible (Figure 3.42 and 3.58).

Goodness of fit

The component contributions to the total negative log-likelihood are provided in the Figure below. Not surprisingly, given the higher input data weights, the longline survey and fishery age compositions constitute a large portion of the total likelihood. The trawl survey and fishery length compositions also account for a significant portion of the total likelihood due to the similar assigned weights.

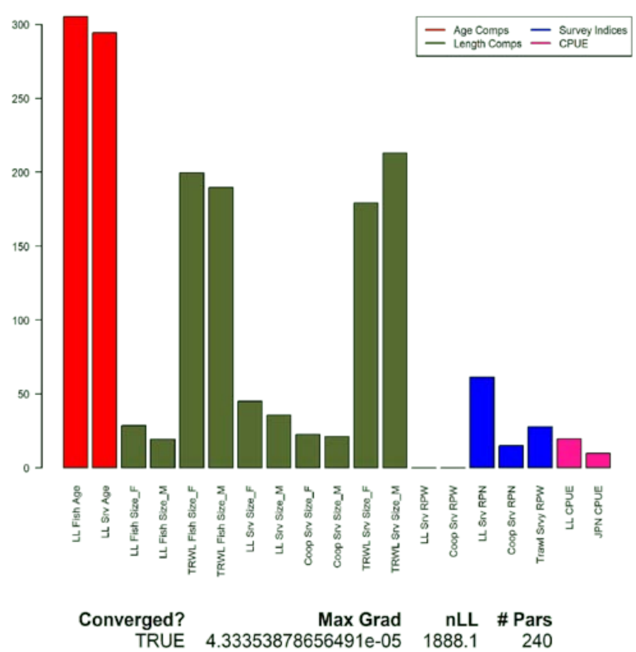


Figure. Contributions to the total negative log-likelihood by data component.

Predicted abundance indices generally track within the confidence intervals of the observations, except for the last 3 to 4 years (Figures 3.3 - 3.4). The model generally fits the trends in the historic longline survey abundance indices well, including the cooperative longline survey along with the subsequent domestic longline survey RPNs until the mid-2010s (Figure 3.3). Despite historic increases over the last three years and a time series high RPN in 2020, the model strongly overestimates the 2020 data point. This is likely due to the extreme shift in the longline survey and fishery age composition towards very young fish, which has led to historic year class estimates in recent years in the model. Although the recent longline survey RPNs corroborate the existence of strong recent year classes, increases are not as strong as the model predicts based on the length and age composition data. Although not fit in the model, the longline survey RPWs do not demonstrate as strong of increases in recent years, because the increased catch of smaller fish has led to a lag between increases in RPNs and RPWs. However, trends in RPNs and RPWs are similar and the model predicted RPW index demonstrates similar fit as to the RPN index (despite not being incorporated in the objective function).

Fit to the trawl survey was generally poor historically and has degraded again in recent years (Figure 3.4). Predictions are typically lower than observed values in the early years and higher than observed values in later years. Although the trawl survey trends in recent years generally match those of the longline survey RPNs, the model again expects a higher trawl survey index in 2017 and 2019 based on the 2014 and 2016 year classes. Like the trawl survey index, the model does not fit the fishery CPUE index in recent years. Conversely, unlike the other indices which showed minimal or moderate declines historically before increasing rapidly in recent years, the fishery CPUE demonstrates strong declines from 2005 to 2016 and has been relatively stable since 2016. Although all indices are given the same data weighting, the trawl survey and CPUE indices have higher associated variance. Thus, the model does not attempt to fit these indices as well as it does the longline survey data, which implies that trawl survey and fishery CPUE do not exert as much leverage on parameter estimates. Additionally, it should be noted that at the request of the 2016 CIE review, the abundance indices were significantly down weighted relative to the compositional data to help propagate uncertainty, which contributes to the recent poor fits to the abundance data. However, the conflicting signals between the fishery CPUE data and other indices in recent years is likely an important source of model tension, despite the limited data weighting given to the fit to the CPUE data.

Age compositions from the cooperative and domestic longline surveys were reasonably well predicted, except for not quite reaching the magnitude of the 1997, 2000, 2014, and 2016 year classes in several years (Figures 3.24 and 3.27). The 2015 and 2016 predicted survey ages expected more middle age fish and fewer fish between ages 5 - 7. The 2017 to 2019 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 and 2019. The model fits these very different data surprisingly well. The extent of the 2014 year class in the survey age compositions has been generally underestimated by the model until 2019, at which point observations and predictions generally agree. Similarly, the model is severely underestimating the size of the 2016 year class in the 2019 age compositions. Surprisingly, the 2017 year class is almost nonexistent in the survey data, but the model predicts a relatively large proportion of age-2 fish in 2019. The aggregated survey age compositions show that the cooperative survey ages are fit extremely well, while the domestic survey ages seem to imply a slight dome-shape to the selectivity (i.e., missing ages 5 - 7 sablefish, and underestimating the plus group; Figure 3.25).

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 have been caught since 2016, while overestimating the proportion of fish in size bins 57 - 65 (Figures 3.29 - 3.30). The aggregated length compositions show good predictions on average with some underestimation at middle sizes (i.e., 60 – 70 cm; 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 and 3.34 - 3.35). On average, however, the trawl lengths were fit well by the model (Figure 3.22 and 3.36). The model fit the domestic longline survey lengths poorly in the 1990s, then improved (Figures 3.37 – 3.39). 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 moderately, but is fit particularly poorly in the plus group (Figure 3.32). 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 - 2019, the fishery is clearly encountering younger fish, but not as many as the surveys (Figure 3.34). About 50% of the fish caught in 2018 were age-5 and below and this percentage increased slightly in 2019. Although the 2014 year class was strongly represented in the age composition in 2017 (as age-3 fish), the model expects that the 2014 year class should constitute a higher proportion of the age composition in 2018 and 2019. Conversely, the 2016 year class dominates the fishery age composition in 2019 (as age-3 fish), which is being severely underestimated by the model. Although the 2017 year class is starting to be picked up by the fishery in 2019 (perhaps at similar levels as the 2016 year class), the model is overestimating the strength of this year class compared to observed proportions (as was also demonstrated in the fit to the longline survey age compositions). The aggregate fit to the fixed gear fishery age compositions is generally strong, but the proportion of fish in the 31+ age group are severely underestimated.

Uncertainty

The model estimates of projected spawning biomass for 2021 (134,401 t) and 2022 (182,600 t; based on the max ABC) fall near the center of the posterior distribution of spawning biomass. Most of the probability lies between 110,000 t and 175,000 t for 2021 (Figure 3.46). The probability changes smoothly and exhibits a relatively normal distribution. The posterior distribution indicates the stock has a high probability of being above $B_{40\%}$ in 2021. However, see the following sections on retrospective analyses for discussion on caveats related to the reliability of model projections.

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 and ending spawning biomass were confounded, because it has the most influence on the model for recent abundance predictions.

We estimated the posterior probability that projected abundance will fall or stay below thresholds of 17.5% (MSST), 35% (MSY), and 40% (B_{target}) of the unfished spawning biomass based on the posterior probability estimates assuming that the max ABC is harvested each year. 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, as well as, each method’s associated level of uncertainty (Table 3.16). Mean and median catchability, natural mortality, and $F_{40\%}$ estimates were nearly identical. MCMC standard deviations were similar to Hessian approximations in most cases, which shows that there is not much more uncertainty captured through MCMC. The exception is for derived population parameters such as spawning biomass and recruitment, which are generally less precise based on MCMC posteriors compared to Hessian derived standard deviations.

Model Retrospective Analysis

Although trends are not fully consistent across all 9 peels in the retrospective analysis, the 2020 model using the full data time series consistently estimates lower SSB than models using fewer years of data (Figure 3.43). The overestimation of SSB is consistent across the time series for 1 to 3 year data peels, but with a small spike in terminal year estimates. Longer data peels are less consistent across the time series in the percent difference from the full 2020 model and generally demonstrate estimates that more closely agree with the 2020 model outputs. These results appear to hold when the retrospective analysis is performed with MCMC, as well (Figure 3.44). The increase in retrospective patterns in recent years is likely due to high uncertainty in extreme year class events in 2014, 2016, and again in 2017 (as estimated in the current model). When these year classes first enter the survey and/or fishery, the strength of the year class is extremely uncertain as there is limited size and age composition data to inform the estimate. Within SCAA models shrinkage occurs towards more precise estimates of recruitment events as more years of compositional data are added and large cohorts become more fully selected by the fishery, and are thus observed across multiple years. The rate of shrinkage likely depends on the life history and rate of increase in selectivity with age and/or size. For a long-lived species such as sablefish, it can take multiple years before model results converge on an estimate of recruitment strength. For instance, the recruitment squid plots, which illustrate successive estimates of year class strength as new data is added to the model in retrospective runs, demonstrate that for the large 2014 and 2016 year classes subsequent models with more data have continually downgraded initial estimates of year class strength (Figure 3.45). It would be expected that these recruitment events, along with the large 2017 year class estimated in the 2020 Base model, will likely continue to shrink in subsequent model years. Based on squid plots of less strong, but older year classes with more informative data, it may take upwards of 5 to 6 years before estimates converge to stable solutions (e.g., see the 2010 year class estimate; Figure 3.45, bottom panel).

Given the contracted age composition of sablefish along with the extreme size, as well as, uncertainty of these recent recruitment events, it is not surprising that retrospective patterns have increased in recent years. Fish from these large recruitment events are increasingly becoming a large fraction of the total SSB, and are expected to comprise upwards of 55% of the projected 2021 spawning biomass (Figure 3.19). Thus, uncertainty in the size of the initial cohort and subsequent downgrades in their strength as new data is provided to the model leads to similar direct downgrades in estimates of SSB. In fact, the estimate of Mohn's rho of 0.186 for SSB estimates is commensurate with the reduction in the 2014 and 2016 year classes between the 2019 and 2020 assessment models (~25% reduction; Table 3.17). Thus, although the increase in Mohn's rho from 0.061 in 2019 to 0.186 in 2020 is worrisome, there may be reason to believe that estimates will return to previous low values as the estimates of large recruitment events become more stable in future model years. However, the uncertainty in terminal year SSB and recent recruitment levels should be taken into account when developing harvest advice. Recent retrospective patterns indicate that there is a strong likelihood that the current model estimates, and particularly model projections, are overly optimistic and will be downgraded in future years as more data becomes available. Additionally, alternate sources of retrospective bias should not be ruled out. It is difficult to isolate the cause of a retrospective pattern and several alternate explanations may exist. For example, hypotheses could include environmental changes in catchability, time- or age-varying natural mortality, or changes in selectivity of the fishery or survey. In terms of data issues, fishery abundance indices, most length compositions, and all age compositions are added into the assessment with a one year lag, which increases uncertainty in terminal year parameter estimates and could lead to model instability.

Historical Assessment Retrospective Analysis

Not surprisingly, the results of the historical assessment retrospective demonstrates similar trends to that of the model retrospective, but with a stronger and more consistent positive retrospective bias. SSB has been consistently overestimated by models in preceding years (Figure 3.58). For the historical retrospective, Mohn's rho was estimated to be 0.30 compared to 0.19 for the model retrospective analysis. However, the historical assessment retrospective analysis is only using the five most recent assessment models (compared to a 10 year peel in the model retrospective analysis) in which the retrospective bias has been elevated compared to older models (e.g., those prior to 2016). Results indicate that projections upon which maximum permissible ABC estimates are made have been overly optimistic. Since 2017, projections have suggested that SSB will increase dramatically, but subsequent models have determined that the realized SSB has shown only moderate increases (Figure 3.58). Additionally, estimates of biological reference points (e.g., $B_{40\%}$) have simultaneously increased in subsequent model years at the same time that realized SSB has been downgraded (the one exception being the 2019 model for which $B_{40\%}$ declined substantially compared to the 2018 model). The large increase in reference points in 2020 was primarily driven by the inclusion of the large 2016 year class in the average recruitment time series used in reference point calculations (Figure 3.18a; Table 3.17). Even though projected 2021 and 2022 spawning biomass estimates are above $B_{35\%}$ and $B_{40\%}$ for the 2020 model, similarly optimistic projections from previous assessments have yet to materialize despite recommended quotas being well below the maximum permissible (Figure 3.42 and 3.58). The rapidly increasing model and historical retrospective patterns are cause for concern and may warrant further precautionary approaches to setting harvest levels. Given the consistent trend since the 2017 assessment, it is highly probable that the 2020 projections are extremely overoptimistic in regards to the rebuilding capacity of the sablefish population in Alaska. Further work is needed to explore the cause of retrospective patterns, including both data exploration and testing new model assumptions and parametrizations. However, there is strong evidence that the increasing retrospective patterns in recent years are likely related to uncertainty in extreme recent recruitment events (i.e., the 2014, 2016, and now 2017 year classes), which are increasingly dominating the SSB, yet have been consistently revised downwards in subsequent model years (Table 3.17; Figures 3.19 and 3.45).

Sensitivity Run Results

Results across categories for representative sensitivity runs are provided in Table 3.19 and comparison of select model runs are provided in Figure 3.57. Generally, adding a recent selectivity block to the fixed gear fishery minimally improved model fits to the compositional data, but no appreciable changes in model results occurred. Adding a time block to the longline survey led to further modest improvements in fit to both the longline survey RPN and fishery CPUE. However, the addition of a recent longline survey time block drastically decreased SSB_{2020} along with estimates of recent year class strength, while the associated 2021 ABC was estimated to decrease substantially to 31,000 t. Essentially, models in category 1 and 2 estimated increased selectivity in recent years, especially on age-2 fish, thereby leading to decreased estimates of recent recruitment events (Figure 3.57). There may be justification for allowing changes in fishery selectivity due to potential changes in fishery targeting and gear changes alone, but the impacts were minimal when only increases in fishery selectivity were allowed. Implications of changing longline survey selectivity were more drastic, because compositional data from the longline survey are the primary source of information on strong recent recruitment events. Allowing an increase in survey selectivity since 2016 allowed the model to interpret the increasing proportion of small, young fish in the survey as a mixture of a change in availability, as well as, large year classes. A number of hypotheses exist that lend credence to the potential for changes in availability (i.e., distribution) of young fish. For instance, density-dependent spillover from optimal juvenile habitat or warming water temperatures due to recent marine heatwaves, which might force juveniles into deeper, colder water, could both explain increasing availability of fish in slope waters at earlier ages. In the future, variations of these time-varying selectivity models will be explored in tandem with updated and refined data weighting protocols.

Allowing for a time block in natural mortality (category 3) greatly improved the fit to the longline survey RPN and fishery CPUE, because the model could maintain recent high recruitment events then remove these young fish (i.e., due to increased natural mortality in recent years, ~4x's greater) before they became highly selected by the fishery or survey. However, sharp declines in SSB begin in the year that the time block was implemented (e.g., 2016), despite increased estimates of recent recruitment events (Table 3.19; Figure 3.57). Although time-varying natural mortality generally led to improved fit to the data, the sudden sharp changes in mortality do not appear plausible and would have important implications for reference points and future catches. Age-varying natural mortality (category 4) tended to similarly estimate higher mortality for younger fish (~4 – 10x's greater), but did not greatly improve model fit to the data (Figure 3.57). Various combinations of time-varying selectivity and time- and/or age-varying natural mortality (category 5) tended to demonstrate similar patterns as any of the model changes applied in isolation (e.g., category 1 through 4 sensitivity models; Table 3.19; Figure 3.57). Overall, it appeared that time-varying natural mortality along with time-varying longline survey selectivity led to the biggest overall improvements in model fit to observed data, but also led to the strongest declines in recent SSB and potential future catches. Further exploration of time-varying selectivity and mortality will be undertaken for the 2021 SAFE to see if model performance can be improved through alternate parametrizations that also reflect observed and supportable hypotheses regarding population or fishery dynamics.

Results of sensitivity runs in categories 6 to 8 were relatively straightforward and did not provide any improvement in model performance or insight into population dynamics. Reducing the weight of compositional data led to minor improvements in fit to other data sources, while fixing recent recruitment events at average levels reduced terminal year SSB; both results were as expected. The model runs with alternate maturity-at-age schedules provided bounds on the potential current and future SSB that might be expected given the high proportion of young fish in the population. As would be expected, using lower higher ages at 50% maturity, which were derived from recent longline survey histological samples, led to greatly reduced estimates of terminal SSB (~30,000 t less than the Base model; Table 3.19).

Harvest Recommendations

Reference Fishing Mortality Rate

Sablefish are managed under Tier 3 of NPFMC harvest rules. Reference points are calculated using the average year class strength from 1977 - 2016. The updated point estimate of $B_{40\%}$, is 126,389 t. Since projected female spawning biomass (combined areas) for 2021 is 134,401 t (6% higher than $B_{40\%}$, or equivalent to $B_{42\%}$), sablefish is in sub-tier "a" of Tier 3. The updated point estimates of $F_{40\%}$, and $F_{35\%}$ from this assessment are 0.100 and 0.117, respectively. Thus, the maximum permissible value of F_{ABC} under Tier 3a is 0.100, which translates into a 2021 ABC (combined areas) of 52,427 t. The adjusted OFL fishing mortality rate is 0.117, which translates into a 2021 OFL (combined areas) of 61,319 t. Biomass-based reference points have increased by 20% from 2019. The main factor driving these changes is the incorporation of the strong 2016 year class in the calculation of reference points for 2020, which was not incorporated in the 2019 estimate of average recruitment. It is likely that a similar pattern will occur in the next assessment, because the 2017 year class is estimated to be large, which will further increase the average recruitment used to determine reference points. Thus, relative stock status in 2021 will likely decline due to further increases in the $B_{40\%}$ reference point. However, current model projections indicate that this stock is not subject to overfishing, not overfished, and not 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 2020 numbers-at-age as estimated in the assessment. This vector is then projected forward to the beginning of 2021 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (yearend) catch for 2020. 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 2020 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 2021, 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 2021 and 2022, F is set equal to the F associated with the author's recommended whale corrected ABC. For the remainder of the future years, maximum permissible ABC is used. (Rationale: Sablefish ABC is adjusted due to risk table considerations and the recommended ABC is routinely not fully utilized, but uncertainty about increased discards may increase total catch closer to the max ABC in 2023 and 2024).
>
> *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 – 2019 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 B_{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 B_{MSY} level in 2020, or 2) above ½ of its B_{MSY} level in 2020 and above its B_{MSY} level in 2030 under this scenario, then the stock is not overfished.]
>
> *Scenario 7*: In 2021 and 2022, 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 B_{MSY} level in 2022, or 2) above 1/2 of its B_{MSY} level in 2022

and expected to be above its B_{MSY} level in 2032 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). 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 2021 and 2022. The methodology for determining these pre-specified catches is described below in the Specified Catch Estimation section.

Specified Catch Estimation

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. For current year catch, we apply an expansion factor to the official catch on or near October 1 based on the 3-year average of catch taken between October 1 and December 31 in the last three complete catch years (e.g. 2017 - 2019 for the 2020 catch). For catch projections in the next two years, we use 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 due to the lower catch in the first year out and the amount of catch taken before spawning in the projection two years out (because sablefish are currently in Tier 3a).

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48 to both 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 2021, it does not provide the best estimate of OFL for 2022, because the mean 2021 catch under Scenario 6 is predicated on the 2021 catch being equal to the 2021 OFL, whereas the actual 2021 catch will likely be less than the 2021 OFL. A better approach is to estimate catches that are more likely to occur as described in the Specified Catch Estimation section. 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 (2019) is 16,624 t. This is less than the 2019 OFL of 32,798 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 2020:

a. If spawning biomass for 2020 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2020 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2020 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 2030 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 2022 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2022 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2022 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2032. If the mean spawning biomass for 2032 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, overfishing is not occurring, the stock is not overfished, and it is not approaching an overfished condition.

F to achieve previous year's OFL: For Tier 1 – 3 stocks, Species Information System (SIS) requirements necessitate provision of the fishing mortality rate from the current model that would have produced a catch for the previous year equivalent to the previous year's OFL as utilized for the provision of management advice.

The OFL for last year (2019) was specified as 32,798 t. The fishing mortality rate required to achieve the OFL would have been 0.124.

Alternative Projections

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 runs (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 1977 - 2016 year classes. This projection predicts that the mean and median spawning biomass will be above both $B_{35\%}$ and $B_{40\%}$ by 2021 and will 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.

The alternative projections were also run with recent recruitment year classes (i.e., 2016 and 2017) held at levels associated with previous time series highs from the recent time period (i.e., 2016 and 2017 year classes were fixed at the magnitude of the 1977 year class). As recent strong year classes continue to be downgraded in size (e.g., the 2014 year class), the extreme magnitude of these recruitment events appear to be stabilizing near the estimates of the 1977 year class (if not slightly below). Thus, this projection allows the dynamics of the population to be forecasted based on recent recruitment that may be more in line with what future models are likely to estimate the strength of these recruitment events to be. An additional projection set the 2016 and 2017 year classes at the time series mean, which helps understand what the impacts would be if recent recruitment is actually below the 1977 year class (i.e., as is now the case with the 2014 year class).

When the 2016 and 2017 year classes are set equivalent to the 1977 year class, the projected ABC for 2021 decreases to 35,000 t. Moreover, when these year classes are set equivalent to the mean recruitment level, the ABC decreases further to 22,000 t.

Ecosystem Considerations

This section has been replaced by the Ecosystem and Socioeconomic Profile (ESP) located in Appendix 3C, which provides more contemporary and informative analysis to guide ABC and TAC considerations. The last complete Ecosystem Considerations section for sablefish can be found in Hanselman et al. (2017).

Socioeconomic Considerations

As with the previous section, this section has been replaced by the Ecosystem and Socioeconomic Profile (ESP) located in Appendix 3C, which provides an economic performance report.

Additional ABC/ACL Considerations

Should the ABC be Reduced?

The risk table approach is used when assessment authors believe that there is sufficient justification and assessment uncertainty to warrant advising that the ABC be set below the maximum permissible ABC (as determined from standard projections and the NPFMC harvest control rules). The risk table provided below is then applied to qualitatively determine the perceived level of risk associated with the assessed stock.

	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

Risk level is determined by evaluating the severity of four 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; environmental and ecosystem considerations; and fishery performance 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

The results of this 4 category evaluation are discussed in the following sections and summarized in the Risk Table Summary section.

Assessment Related Considerations

Data and model uncertainty are typically considered first under this category for a stock assessment. But, 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, 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.

Historically, the Alaska sablefish assessment has typically had one of the lowest retrospective bias estimates of assessments at the AFSC. This bias had fluctuated between 0.02 and 0.09 in the last several years, but it is consistently positive, which means that each year it slightly overestimates spawning biomass. Unfortunately, the level of retrospective bias in both recruitment and SSB has increased significantly in the 2020 model. For instance, Mohn’s rho is estimated to be around 0.18 for estimation of SSB. The increase in retrospective bias is likely due to high uncertainty in extreme year class events in 2014, 2016, and again in 2017 (as estimated in the current model). When these year classes first enter the survey and/or fishery, the strength of the year class is extremely uncertain as there is limited size and age composition data to inform the estimate. Within SCAA models, shrinkage occurs towards more precise estimates of recruitment events as more years of compositional data are added and large cohorts become more fully selected by the fishery, and are thus observed across multiple years. The large 2014 year class has been summarily reduced in each subsequent assessment since first being estimated in 2017 and is now estimated to be 68% smaller than originally thought. Similarly, the large 2016 year class was reduced by 25% from the 2019 assessment.

Because historical assessment model retrospective analyses account for changes in data, model structure, and data quantity simultaneously, it may provide a better indication of the overall retrospective pattern that might be expected from one assessment cycle to the next. Not surprisingly, when the one year projected SSB estimates from the previous year's model are compared to the realized SSB in the terminal year of subsequent Base models, the historical retrospective bias increased compared to the that from the full 10 year model retrospective analysis (i.e., Mohn's rho was estimated to be 0.30 for SSB in 2020). Thus, it appears that projections upon which maximum permissible ABC estimates are made have been overly optimistic (Figure 3.58). Despite projected 2021 and 2022 spawning biomass estimates being above $B_{35\%}$ and $B_{40\%}$ for the 2020 model, similarly optimistic projections from previous assessments have yet to materialize despite recommended quotas being well below the maximum permissible (Figure 3.42 and 3.58). The rapidly increasing model and historical retrospective patterns are cause for concern. Thus, the uncertainty in terminal year SSB and recent recruitment levels should be taken into account when developing harvest advice. Recent retrospective patterns indicate that there is a strong likelihood that the current model estimates, and particularly model projections, are overly optimistic and will be downgraded in future years as more data becomes available.

The sablefish assessment is one of only a few assessments in the North Pacific that is fit to multiple abundance indices, and the only one that fits fishery CPUE data. Although all indices now generally indicate population growth, there are varying signals on the rate of population increase (Figures 3.3 – 3.4, 3.10a). The longline survey abundance index (relative population numbers) increased 32% from 2019 to 2020 following a 47% increase in 2019 from 2018 (Figure 3.10c). Similarly, the trawl survey biomass was at a time series low in 2013, but has more than tripled since that time (Figure 3.10c). The fishery CPUE index was at the time series low in 2018, but increased 20% in 2019 (the 2020 data are not available yet; Figure 3.10c). Conflicting signals in the indices is expected as indices in numbers (i.e., longline survey RPNs) respond quickly to incoming year classes, but indices in weight (e.g., longline survey RPWs, trawl survey biomass, and fishery CPUE) are delayed, taking longer to respond because those young fish have low weight. In addition, surveys like the GOA trawl survey that capture fish at earlier life stages will respond to large incoming recruitment events sooner than other indices that may better reflect the adult dynamics. Moreover, the age and length composition data continue to indicate strong year classes in 2014, 2016, and a potentially strong, albeit highly uncertain, 2017 year class. The model appears to rely heavily on uncertain age and length composition data from young, small fish leading to the estimation of large year classes, which conflicts with signals of overall population growth from the indices of abundance. Overall, the model overestimates each of the abundance indices in the terminal year (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. Specifically, in the early part of the GOA trawl survey time series, the model underestimates survey biomass for multiple consecutive years (Figure 3.4). Additionally, at the request of the 2016 CIE review, the abundance indices were significantly down weighted relative to the compositional data to help propagate uncertainty, which contributes to the recent poor fits to the abundance data. This down weighting 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 biomass and abundance indices at the same time. Although all data sources suggest an improving outlook for the sablefish population, it is apparent that the model is overstating the potential increases in stock abundance suggested by these indices

The current assessment model also does not account for spatial processes, because it assumes a single homogenous population distributed across the entire Alaskan Federal waters management zone with each fishing fleet likewise demonstrating identical characteristics across the entire domain. Despite there being a genetically panmictic population of sablefish throughout Alaskan waters, there is clear evidence of spatiotemporal heterogeneity in both the distribution of the resource and the removals (Figures 3.2 and 3.7). Although high movement rates and connectivity among regions may limit the potential for localized depletion of the resource, developing assessment models that better address spatial processes may improve estimates of productivity and better account for regional dynamics. An exploratory three-area spatial sablefish assessment model was recently 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, because the whale depredation effects used in the management model starting in 2016 have not been incorporated in the spatial model. 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. However, there were spatial differences in total and spawning biomass for the three modelled 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) comprised 25% of total biomass. Model explorations examining alternative movement rates and model spatial parameterizations suggested that the model was sensitive to both of these axes of uncertainty. Further work and refinement is needed to more comprehensively understand ongoing spatial processes and resultant impact on regional distributions. However, the lack of spatial structure in either fleet or population dynamics should also be considered a source of potential assessment uncertainty in the current model.

A number of sensitivity runs were undertaken to determine if better fits to the data, especially the abundance indices, could be obtained with alternate model parametrizations, while also exploring whether retrospective patterns could be diminished. This work continued the in-depth explorations of selectivity and natural mortality estimation undertaken during the 2018 assessment year (Hanselman et al., 2018). Of the sensitivity runs presented this year, allowing both fishery and survey selectivity to change in 2016 (i.e., implementing a recent time block for selectivity parameter estimation) appeared to be the most plausible. Results indicated a slight improvement in fit to the data, but retrospective patterns persisted. However, the rebuilding trajectory was much more tempered due to strong reductions in recent recruitment, which resulted in a 2021 maximum permissible ABC of 31,000 t (reductions in projected ABC were common across a majority of sensitivity runs explored). Lack of time-varying natural mortality or selectivity is likely an additional source of uncertainty.

We also conducted two sensitivity runs using results from the longline survey maturity estimates to bracket uncertainty in maturity estimates by using the youngest maturing ogive and the oldest maturing ogive. Clearly, the static maturity assumed in the model is an important axis of uncertainty since the estimated spawning biomass for 2020 from these sensitivity runs ranges from 61 - 136 kilotons.

In summary, despite moderate difficulty fitting differing signals in the data on recent population growth, the model demonstrates relatively good fits to the variety of data sources given the limited time-varying parameters utilized. It has also been robust to most historical population trends, including both population declines and subsequent rebuilding. However, the repeated substantial decrease of the 2014 year class and now the 2016 year class is concerning given the increased reliance on these recruitment events to support future SSB growth. Additionally, the sudden increase in the magnitude of the retrospective bias indicates that projections in recent years have been overly optimistic, while associated assessment uncertainty must be considered higher than in previous years. **Therefore, we rated the assessment related concern as level 3, major concern.**

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 2014. Although still surmised to be a very large recruitment event, the 2014 year class is now estimated to be slightly below the previous recent time series high that occurred in 1977. However, the 2016 year class now appears as large as the first estimates of the 2014 year class, representing a time series high. Similarly, the 2017 year class was estimated for the first time in 2020 and also appears to be one of the top three largest recruitment events on record. The estimates of these three recent year classes are the most pertinent uncertainties to consider when making recommendations for future harvest levels.

Ultimately, given that the magnitude of the 2014 and 2016 year classes appear to be larger than almost any other observed cohort, there is long-term promise for the recovery of the sablefish spawning stock biomass. Yet, the high uncertainty associated with their estimation along with the continual downgrading of the size of these year classes suggests that we should proceed with caution. The magnitude of the recent recruitment events is likely to continue to decline until future models converge on an estimate after seven or more years of compositional data (Figure 3.45), and the 2017 year class will probably follow a similar trajectory. Furthermore, projected rebuilding may be hampered if density-dependent mortality mechanisms exist or body condition declines during periods of high recruitment. Preliminary analyses and anecdotal evidence have suggested that body condition and growth may be declining and the age at 50% maturity may be increasing in recent years (see Maturity and Growth section). Because the assessment model employs static biological parameters since 1996, potential changes in maturity are not addressed. The 2014 year class is age-6 in 2020 and the annual longline survey data maturity curves indicate that these females may be between 18 and 62% mature. Based on sensitivity runs, this range could impact estimates of SSB by +/- 35% and would have a significant effect on our perception of stock status and ABC.

Given that recruitment since 2000 had been weak for over a decade, the stock has seen a precipitous decline in older, fully mature and fully grown fish since 2011 (Figure 3.25b). The resulting evenness of the age distribution of sablefish has dropped rapidly as has the mean age of spawners (see Appendix 3C). Similarly, the population has been below its target reference point since the mid-2000s. Thus, the sudden transition to a high recruitment regime is occurring at historically low spawning stock biomass levels (Figure 3.18c), which suggests that these recruitment events may be environmentally driven. However, as these recent year classes recruit to the fishery and begin to mature, both the fishery and population are now becoming reliant on their future success. The model projects that the 2014 and 2016 year classes will comprise almost 50% of total SSB in 2021, despite being only partially mature. Unfortunately, the NPFMC harvest control rules do not recognize the potential importance of a well-distributed age composition in the population (i.e., all fish considered mature are treated equally in the model). Given that most of the compositional data suggests that the population is effectively “fishing down” the majority of mature cohorts, any impediments to these recent year classes reaching fully mature ages could negatively impact the population and future ABCs. Similarly, if the recent improvement in productivity is associated with transient environmental or ecosystem conditions, then it is likely that the sablefish resource and fishery will be reliant on these handful of year classes for a decade or more, as has been the case with the slightly above average 2000 and 2008 cohorts.

Model estimated year class strength can potentially be verified by exploring the observed compositional data. For instance, the presence of 2-year-olds in the age composition data 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, albeit not altogether convincing, 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). Surprisingly, the presence of 3-year-olds in the survey age composition Alaska-wide was shown as an extremely strong predictor of recruitment, which was driven almost entirely by the strong relationships for the 2014 and 2016 year classes (Figure 3.52). In 2019, this relationship was no better than the current relationship with 2-year-olds in the longline survey age compositions and was highest in the EGOA. In 2020, the EGOA age-3 survey age compositions show good correlation with the 2014 year class, but the time series relationship was not strong (Figure 3.53a). Conversely, the age compositions of age-3 fish in the WGOA show strong correlation, primarily due to moderate alignment with the 2014 year class and a very strong match with the 2016 year class (Figure 3.53b). Thus, the model appears to be relying heavily on survey age composition data to estimate the unprecedented size of the 2016 year class, which is present in all three regions but primarily associated with the western areas (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. However, since we have length compositions a year earlier than the age compositions, we examined them for signals of recruitment. Examining the length compositions for a select group of trawl survey years showed that 2017 and 2019 survey catches were dominated by young fish (Figure 3.54). The 2007 survey demonstrated what the size composition looks like in the absence of any recent large recruitments. The 2001 survey showed 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 (Figure 3.54). When recruitment events were aligned with the respective surveys that would have first detected them, only the 2001 survey detected one-year-olds at a high level corresponding to the large 2000 year class (Figure 3.56a). 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). Because trawl survey lengths have not always 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).

Concurrently with increased signals of strong recruitment, there has been a strong increase of incidental catch of small fish in the trawl fisheries in both the GOA and BS (Figures 3.34 – 3.35; Appendix 3E). Additionally, full retention policies have forced directed fisheries to retain a larger proportion of smaller, less valuable fish (Figures 3.29 – 3.30, 3.32). Increased fishing mortality on young fish could prevent them from reaching maturity and adding significantly to the SSB. However, given the size of these year classes it is unlikely that moderate increases in removals of young fish will severely impact survival into mature ages. Similarly, if increased natural mortality occurs due to density-dependence or increased predation during the juvenile phases, then fishery removals of small fish may, to some degree, replace these natural mortality processes and not significantly reduce the likelihood of successfully reaching maturity.

Overall, productivity remains high and recent year class sizes are still well above average despite continual downgrades in estimates of strength. Thus, what was originally identified as an anomalous and unprecedented 2014 year class during the 2017 assessment appears to be a proven, consistent, and encouraging trend. However, because of the uncertainty in the 2014, 2016, and potentially 2017 year classes, the systematic truncation of the age structure over the last decade, and the uncertainty of how quickly the 2014 and 2016 year classes will successfully become mature spawners, there are myriad population dynamics concerns. **Hence, we also rate the population dynamics as a level 3, major concern.**

Environmental and 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, or 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 smaller scale surveys 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. We evaluate and summarize this category of the risk table below.

There are concerns about increased variability and decreased predictability of the ecosystem. Similar to the estimates for the large 2014 year class of sablefish, recent stock assessment recruitment estimates of GOA Pacific cod suggested an enormous 2012 year class. However, this estimate has also since declined severely as more recent survey indices have been included in the assessment. Although many factors, including retrospective bias or variable abundance indices, may explain these similar patterns across species, the severe declines in realized recruitment could also be related to unforeseen environmental factors. For Pacific cod, declines were linked to heat wave induced increased metabolic demands that could not be met, resulting in fish in poor condition and high mortality (Barbeaux et al., 2020). In general, higher ambient temperatures incur bioenergetic costs for ectothermic fish such that, all else being equal, consumption must increase to maintain fish condition. Thus, the persistent higher temperatures may be considered a negative indicator for sablefish. Similarly, growth and reproduction of larval, juvenile, and adult sablefish are sensitive to ocean temperature (e.g., Sogard and Olla 1998, Appendix 3C).

Unlike for Pacific cod, though, sablefish have shown higher recruitment during heat wave years. It is possible that the increased recruitment in 2014, 2016, and possibly 2017 was related to higher productivity and increased food supply for larvae, which may be linked to increased temperature or competitive release due to mortality or movement of predators. Regular occurrence of marine heat waves may bode well for future sablefish recruitment. However, if recent recruitment success is unrelated to these environmental conditions, then it is critical that recent year classes survive to contribute to the depleted spawning biomass. An additional consideration is the impact that these persistent marine heat waves may have on young sablefish as they begin to migrate into their adult habitat, especially on the availability of resources and prey items. Since sablefish are opportunistic feeders, they may have some built in resilience to the loss of any particular prey item. But, with continued declines in many other groundfish stocks, the total available prey base may not be adequate to sustain sablefish at very high growth rates or anomalous population densities (e.g., if multiple extreme year classes recruit simultaneously).

In general, 2020 temperatures at depth in the EBS and GOA appeared to be average to warm. Following two years of physical oceanographic perturbations, the EBS experienced a return to near normal climatic conditions in 2020. Rapid build-up of sea ice, exceeding median ice extent during February and March, retreated quickly. Summer sea surface temperatures through August were above average in the southern and northern Bering Sea, similar to those observed in 2019. Summer bottom temperatures and the spatial extent of the cold pool were average. In the GOA, sea surface temperatures in the WGOA returned to long-term mean levels for winter and spring following heat wave conditions throughout 2019. Temperatures were again elevated in the summer and fall, while residual heat remains at depth.

The ESP evaluates a number of relevant indicators, which are:

- Consistent slope bottom temperatures may provide a helpful buffer for sablefish egg development and subsequent larval hatch during heat wave years; however, the slope temperatures have remained high since 2018.
- Non-discriminating prey selection and rapid growth of larval and YOY sablefish provide an advantage in warm years to monopolize available planktonic prey. Warm surface temperatures have persisted in the southeast Bering Sea, but have declined to near average in the eastern GOA in 2020. A consistent spring bloom occurred during 2014 - 2016 with a peak matching the timing when larval sablefish enter the surface waters in both the southeast Bering Sea and the eastern GOA. This is concurrent with decreases in the size of the offshore copepod community and decreases in nearshore euphausiid abundance in the GOA.
- Overwinter and nearshore conditions have recently been favorable for juvenile sablefish based on high growth of YOY sablefish observed in seabird diets and high CPUE of juveniles in nearshore surveys. Growth decreased substantially in 2020 from seabird diets; however, there were large increases in CPUE in the nearshore survey.
- 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. In 2020, mean age of spawners continued to decline, but evenness increased slightly as more large year classes appear.
- Condition of large, adult female sablefish on the longline survey has been low in recent years with an increase in 2018 and a return to average condition in 2019 - 2020.
- At age-4, the condition of the 2014 year class was poor, when compared to the relatively good condition of age-4 fish in previous high recruitment years, and the condition of the 2014 condition remained low through 2019.
- 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.
- Physical, zooplankton, and YOY indicators do not appear as favorable in 2020 as in the recent past for sablefish, while juvenile and adult indicators were generally average to poor, but early juvenile indicators were generally good.

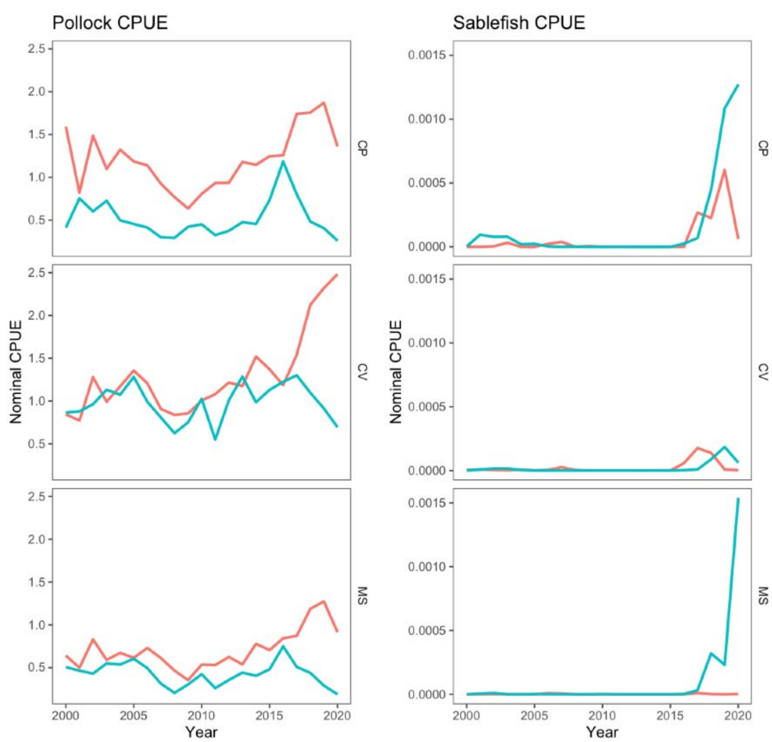
The ecosystem considerations in the ESP appear to be a mixture of positive and negative conditions in 2020. However, the effects of some of these indicators, such as marine heat waves and rapidly changing ecosystem variables, have not yet been evaluated carefully for sablefish. We are concerned that fish condition has declined since the appearance of recent, large year classes and is much worse than during the last period of large recruitments (1997 – 2000, Appendix 3C). Poor condition may impede the ability of newly recruited 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.**

Fishery Performance Considerations

There are multiple new situations occurring with fishery performance, particularly in relation to recent 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 in 2018 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.

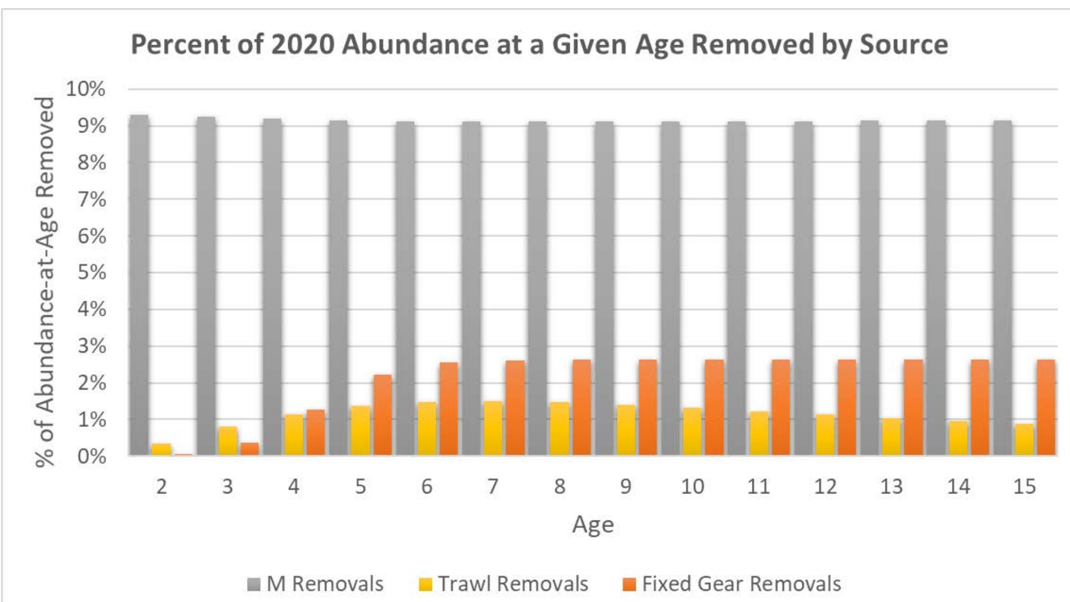
The large increase in incidental catch in the EBS trawl fisheries have shifted a higher proportion of catch into the Bering Sea and the downstream effects of this harvest of small fish in a different region are poorly understood at this time (see Appendix 3E for a discussion of these changes). Moreover, the fraction of the catch being taken by trawl fisheries has increased dramatically in recent years from typical levels of about 10% to over 40% of the total catch in 2020 (Table 3.1; Figure 3.1). It is unlikely that moderate increases in catch of young, small fish associated with portions of the trawl fleet will detrimentally influence population rebuilding in the near-term if the magnitude of recent year classes are correctly estimated in the current assessment. Similarly, given the anomalous size of recent year classes, it is inevitable that increased catches of small fish will occur across fleets as these fish recruit at different sizes to the various gears. For instance, analysis of nominal CPUE in the EBS pollock fishery, which is the primary source of trawl bycatch of sablefish in the EBS, suggests that with moderate increases in directed effort for pollock (during the B season), bycatch CPUE of sablefish has increased drastically since 2016 (J. Ianelli, pers. comm.; see Figure below). Meanwhile, incidental catch of sablefish in the GOA has decreased in the last two years, potentially signaling the 2014 and 2016 year classes are settling into deeper waters (Appendix 3C, Figure 3C.2). Large increases in incidental catch of sablefish provides further support that recent year classes are actually being realized and incrementally growing into the fishery and SSB.

Figure. Nominal CPUE for both Alaskan pollock (*Gadus chalcogrammus*) and sablefish from trawl vessels targeting pollock in the Eastern Bering Sea. Abbreviations are: CP—Catcher/Processors; CV—Catcher Vessels; and MS—Catcher Vessels delivering to Motherships. Red lines are the A season (January - May) and blues lines are the B season (June - October). From J. Ianelli, personal communication.



Furthermore, if natural mortality is higher for younger fish, which is often hypothesized for basic life history strategies, or it has increased due to density-dependent juvenile mortality associated with extremely large year classes, then there is a probable trade-off with increased mortality on young fish due to fishing. Essentially, harvest of small fish may potentially take the place of some removals due to natural deaths, thereby creating a tradeoff in the form, but not necessarily the magnitude, of mortality. Although this type of density-dependent regulation is the basis for the MSY-concept, there is no current evidence that density-dependent mortality is increasing due to these large year classes. Clearly, further examination of the magnitude and impacts of increased fishery removals of young fish is warranted. However, removals due to fishing remain a small fraction of the population abundance at each age and removals by the trawl fishery, even at young ages (~1 – 2% of total abundance at a given age), remain well below those due to natural mortality (~9% of total abundance at a given age; see Figure below). But, limited fishery-dependent data collection for sablefish in the BSAI, including reduced observer coverage in recent years for directed sablefish fishing and being a low sampling priority in pollock targeted trawl fisheries, makes elucidating the potential fishery impacts, distributional changes, or evolving age structure unlikely in the near future. Additionally, without the ability to simultaneously compare spatiotemporal estimates of resource distribution by age and fishery removals, as well as, a better understanding of the importance or location of optimal juvenile habitat, it is difficult to determine the long-term impact of removals of young fish in specific regions.

Figure. Percent of 2020 abundance at a given age removed due to different sources of fishing and natural mortality (M Removals). Percentages are based on the estimated parameters of the stock assessment model in 2020, which does not account for spatial structure. The number of ages shown is truncated at 15 to focus on the most abundant age classes.



There has also been an increasing shift to pot gear 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 and the performance risks to the fishery it poses are not presently being accounted for directly in the stock assessment model. While longline CPUE has been extremely depressed, pot fishing CPUE in the EBS has been steadily rising since about 2010 (Appendix 3C, Figure 3C.2). In addition, the rapid decline in overall market conditions, particularly due to the influx of small sablefish, may be contributing to differences in selectivity in all fisheries that are not accounted for in the assessment model (Appendix 3C, Figure 3C.2). For example, if fisheries are actively trying to avoid small fish and shifting effort onto larger, mature fish, then it may place additional pressure on the spawning stock and be hard to detect quickly, even if the model were using time-varying selectivity.

Rapid changes in the fishery due to sudden recruitment success along with limited understanding regarding the impacts these changes may have on the resource (i.e., escalating catch of recently recruited fish and increased targeting of declining mature cohorts), have increased the uncertainty related to fishery performance. Ultimately, shifting allocation of total catch among fishery sectors does not appear to be an issue for the resource at this time, but rapidly changing catch allocations is an important fishery metric that requires careful socioeconomic evaluation outside of the assessment model. **Thus, we rated the fishery performance category as level 3, a major concern.**

Risk Table Summary

This is the third time that we have used the risk table approach to assess reductions in ABC from maximum permissible ABC. Overall, the highest score for sablefish in 2020 is a Level 3—Major Concern. Since the SSC prefers not rating the risk table overall on the highest score, we also note that 3 of the 4 scores are Level 3, and none of the categories rated a Level 1. This suggests that setting the ABC below the maximum permissible is warranted. 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 directed fishery in the future. This precautionary ABC recommendation buffers for uncertainty until more observations of these potentially large year classes are made. Because sablefish is assessed annually, we will be able to consider another year of age composition data in 2021 and allow this extremely young population to further mature and more fully contribute to future spawning biomass.

Table. Risk table summary.

Assessment Related Considerations	**Population Dynamics Considerations**	**Environmental and Ecosystem Considerations**	**Fishery Performance Considerations**
Level 3: Major concern	Level 3: Major concern	Level 2: Substantially increased concern	Level 3: Major concern

In summary, while there are clearly positive signs of strong incoming recruitment, concerns exists regarding the lack of older fish contributing to spawning biomass, the uncertainty surrounding the estimates of the strength of the 2014, 2016, and 2017 year classes, and ambiguity related to how existing environmental conditions may affect the success of these year classes in the future. These concerns warrant additional caution when recommending the 2021 and 2022 ABCs. It is unlikely that the 2014 or 2016 year classes will be reduced to average or below average levels, but projecting catches under the assumption that these year classes are 3 - 10x's average introduces substantial risk given the uncertainty associated with these estimates. Recent environmental conditions, including multiple marine heat waves, appear favorable to recruitment success for sablefish. However, it is unclear whether this is a permanent productivity regime shift or a transient phase. Additionally, associated ecosystem changes may be detrimental for the condition of juvenile and adult fish. Condition factors of recent large cohorts appear to be below average, which may impede realization of the benefits of these year classes if survival and/or maturity rates have decreased. These cohorts are also beginning to recruit to the various gear types as young, small fish with associated increases in removals, especially as bycatch in the BS trawl fisheries.

Increased mortality on young fish may reduce the number of fish from these year classes that survive and mature, whereas active avoidance of lower value small fish by the directed fisheries could lead to further removals of larger, mature fish and put additional strain on the severely truncated age structure and SSB.

Acceptable Biological Catch Recommendation

Instead of maximum permissible ABC, we are recommending that the 2021 ABC be held at the 2020 specified ABC of 22,551 t, which translates to a 57% reduction from the maximum permissible ABC. The final whale-adjusted 2021 ABC of 22,237 t is 1% higher than the 2020 whale-adjusted ABC of 22,009 t. The recommended ABC represents a ~3,250 t (17%) increase from the author recommended ABC in 2019, and an 88% increase in the ABC since 2016 when the lowest ABC on record (11,795 t) was enacted. The maximum permissible ABC for 2021 is 52,427 t, which represents a 19% increase from the 2020 maximum permissible ABC of 44,065 t projected by the 2019 assessment. However, this represents a smaller increase in the maximum permissible 2021 ABC compared to the 28% increase projected by the 2019 assessment from 2020 to 2021 (i.e., the 2019 assessment projected a 2021 ABC of 56,589 t). The author recommended ABCs for 2021 and 2022 are lower than maximum permissible ABC for several important reasons that are examined in the SSC endorsed risk table approach for ABC reductions, which are summarized below.

The following bullets summarize the conclusions reached in the Additional ABC/ACL Considerations section and the Ecosystem and Socioeconomic Profile in Appendix 3C:

- Retrospective bias has increased rapidly to concerning levels and demonstrates a consistent overestimation of recruitment and SSB in subsequent model years; thus, it is unlikely that the population will grow as rapidly as projected by the model.
- The estimate of the 2014 year class strength declined 68% from the 2017 to 2020 assessment models, while the 2016 year class was downgraded by 25% from the 2019 assessment; declines of this magnitude illustrate the uncertainty in these early recruitment estimates.
- Projections assuming that the large 2016 and 2017 recruitment events are equivalent to mean recruitment indicate that the 2021 ABC should be much lower (22,000 t), while results from the most plausible sensitivity models also indicated reduced ABCs compared to the Base model.
- The very large estimated year classes for 2014 and 2016 are expected to comprise about 27% and 22% of the 2021 spawning biomass, respectively; the 2014 year class will be about 60% mature while the 2016 year class will be 20% mature in 2021.
- 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.
- 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.
- Mean age of spawners has decreased dramatically since 2017 and continues a downward trend due to the continued increase in the contribution of the 2014 year class to the SSB and the decrease in the number of older fish; the 2014 year class will be a critical component of the rebuilding process.
- Age-4 body condition of the 2014 year class was below average and lower than for previous large year classes in the early 2000s; poor condition could lead to reduced survival and delayed maturity.

- Fits to abundance and biomass indices are poor for recent years, particularly fishery CPUE and the GOA trawl survey, due to the model overstating population growth compared to what is indicated in the observed indices.
- The AFSC longline survey Relative Population Weight index, though no longer used in the model, lags the Relative Population Numbers index by a few years and is only recently beginning to increase.
- Another marine heat wave formed in 2018, which may have been beneficial for sablefish juveniles in the 2014 – 2017 year classes, but it is unknown how it will affect movement, survival, growth, and maturity of late-stage juveniles and recently matured adult fish.
- Fishery performance (i.e., CPUE) has been weak in the directed fishery, with downward trends in CPUE over a long time period in much of the GOA hitting time series lows in 2018, albeit with an increase of 20% in 2019.
- Small sablefish are being caught incidentally at unusually high levels, which is shifting fishing mortality spatially and demographically; further analysis is required to fully understand the effects or whether this might reduce future contributions of the recent, large year classes to SSB.

Recommending an ABC lower than the maximum should result in more of the 2014, 2016, and 2017 year classes entering into the spawning biomass and becoming more valuable to the fishery. This precautionary ABC recommendation buffers for uncertainty until there are more observations of these potentially large year classes. Because sablefish has an annual assessment, we will be able to consider another year of age composition data in 2021 and allow this extremely young population to further mature and more fully contribute to future spawning biomass.

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.

TAC Considerations

Outside of the ABC recommendation, there may be situations where the assessment can address “socioeconomic uncertainty” or where socioeconomic data used in conjunction with observed biological data 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 a strict maximum ABC calculation.

For instance, the economic performance report provided in the ESP (Appendix 3C) shows that sablefish ex-vessel value (per pound) increased as the ABC and total catch dropped in the mid-2010s. 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 (Appendix 3C, Figure 3C.2). Specifically, the 2014 and 2016 year classes will not approach maximum value for several more years, because somatic growth occurs more rapidly than fish dying from natural mortality at younger ages (Figures 5 and 6 in Appendix 3C of Hanselman et al. 2018). Increased ABCs that consist primarily of six-year-old or younger fish will likely result in continued poor market conditions and reduced profits (Appendix 3C, Hanselman et al. 2018).

Area Allocation of Harvests

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. Because of the high variability in apportionment schemes used prior to 2013, the SSC decided to fix the apportionment at the proportions from the 2013 assessment until the apportionment scheme could be thoroughly re-evaluated and reviewed. A three-area spatial model that was developed for research into spatial biomass and apportionment showed different regional biomass estimates than the 5-year exponential weighted method approved by the Council and the 'fixed' apportionment methods. Further research on alternative apportionment methods and tradeoffs among them is underway and is summarized in Appendix 3D. The 2016 CIE review panel strongly stated that there was no immediate biological concern with the current apportionment, given the high mixing rates of the stock. However, several above average year classes of sablefish are entering the population following a long period of lower than average recruitment. The long period of low recruitment had led to increased fishing pressure on the mature spawning biomass due to their relative predominance in the harvestable population and increased value over smaller fish. Now, recent large recruitments have created concerns about removing too many young fish before they have had a chance to mature and contribute to the spawning population.

Because of the historically observed distribution of younger fish appearing first in western areas (BS, AI, WG), and older mature fish being more prevalent in eastern areas (CG, WY, EY), the location of catches in periods of high or low recruitment can clearly have an impact on different portions of the sablefish population-at-age. High catches in western areas (BS, AI, WG) may lead to higher mortality on younger fish when year classes are above average (see Appendix 3E), but we do not have sufficient information to determine what impact that may have on population rebuilding. Given the magnitude of recent large year classes, it is unlikely that moderate increases in catch of young fish will harm the stock. Similarly, it is likely that the higher natural mortality associated with younger fish (based on basic life history strategies and potential density-dependent mortality) is being shifted to fishing mortality. Conversely, purposely avoiding mortality on younger fish may inadvertently lead to increased mortality on larger, mature fish. Given the shift in age structure of the current population from older ages to younger ones and the reliance of SSB on a few older age classes, increased harvest on older fish could result in further age truncation and reductions in the spawning stock. Impacts may be exacerbated further if recent year classes do not materialize at the strength estimated by the assessment (e.g., due to retrospective bias and/or increased natural mortality).

Regional ABC apportionment to management areas can result in different impacts on the population depending on the assumptions utilized by the apportionment scheme. However, we currently do not have enough information on spatial processes (e.g., distribution of the population by age, movement rates by age among regions, or juvenile habitat preferences and distributions associated with large year classes) to adequately determine whether specific, reasonably distributed apportionment schemes create a conservation concern (e.g., localized depletion, age truncation, or year class reduction) for the sablefish population. The results of the simulation work, though limited in scope of process and observation error, indicate that apportionment of ABC to the six management regions can be conducted in numerous ways with little variability in the average implications for the population. This is primarily due to the high movement rates exhibited by sablefish and the existing harvest control rule and management framework. Spawning fish and age-1 fish have been found in all management areas, but we do not have sufficient data to understand if the Alaska sablefish population is dependent on one or more productive spawning locations or juvenile habitats to sustain the population. Without this sort of information, we suggest that it is important to protect spawning biomass in all management areas and to keep fishing mortality on immature fish to reasonable levels.

An apportionment method that tracks regional biomass or a best proxy thereof is likely the best defense against localized depletion or other conservation concerns (e.g., disproportionately targeting spawners in only a handful of regions or population strongholds). From a biological perspective, we recommend the Non-exponential Survey apportionment method detailed below, because it tracks biomass across management regions to the best of our current ability (i.e., by using estimates of regional biomass from the yearly longline survey that targets sablefish in prime adult habitat). Additionally, the rolling 5-year weighting scheme serves as a buffer against survey uncertainty due to sampling variability and whale depredation. Unfortunately, accounting for the distribution of biomass does not address important issues related to the age distribution of harvest or allocation of removals across fishery sectors with different distributions and removals by age/length. However, as noted, limited tools exist to determine the impact of spatiotemporally and demographically varying removals.

Further research focused on identifying sablefish spawning locations and optimal juvenile habitat, drivers of recruitment success, the impact of harvesting large year classes from a single management area, and an understanding of whether spawning aggregations or natal homing exists would help explain the potential conservation concerns of any harvest apportionment plans. In addition, biological research that could inform the spatial operating model used for simulation would help refine our simulated population dynamics. Ultimately, the Alaskan sablefish resource is currently undergoing a period of extreme and unprecedented demographic change. Identifying the implications of existing fishery harvests and apportionment across regions would require conditioning the operating model on current conditions. However, two potential issues arise. First, as previously noted, there is a general lack of information on the spatiotemporal distribution of the resource by age, particularly the dynamics and movement of recently recruited fish, to enable an accurate operating model to be developed. Second, it is likely that these conditions are either spasmodic or transient, in which case, by the time an operating model can be adequately conditioned, dynamics may have returned to more ‘average’ conditions, such as those observed for much of the late 1990s, 2000s, and early-2010s. Although work continues on refining the operating model to better emulate existing sablefish dynamics, perfect mimicry of the system is not feasible and apportionment strategies will always necessarily require decisions based on imperfect knowledge and uncertain data. Continued work on developing a spatial assessment model for sablefish will help reduce the need for apportionment (as area-specific ABCs can be directly specified), while also helping to condition future operating models based on directly estimated parameters.

2021 Apportionment Recommendation

For 2021, the author’s preferred apportionment is the Non-exponential Survey apportionment because: 1) it reflects our best estimate of the biomass distribution for sablefish; 2) the non-exponential 5-year rolling weighting scheme can temper some of the uncertainty in survey estimates due to whale depredation and interannual survey variability; and 3) this method does not rely on fishery data, which is becoming increasingly sparse in some management areas. Given the challenges in determining what catch magnitude and distribution across management areas may result in a significant biological concern, our best scientific advice is that catch distribution should not deviate too far from survey-estimated biomass proportions across management areas.

Therefore, for 2021, we recommend using the Non-exponential Survey apportionment method. The area specific ABCs resulting from this approach are provided in the Table below.

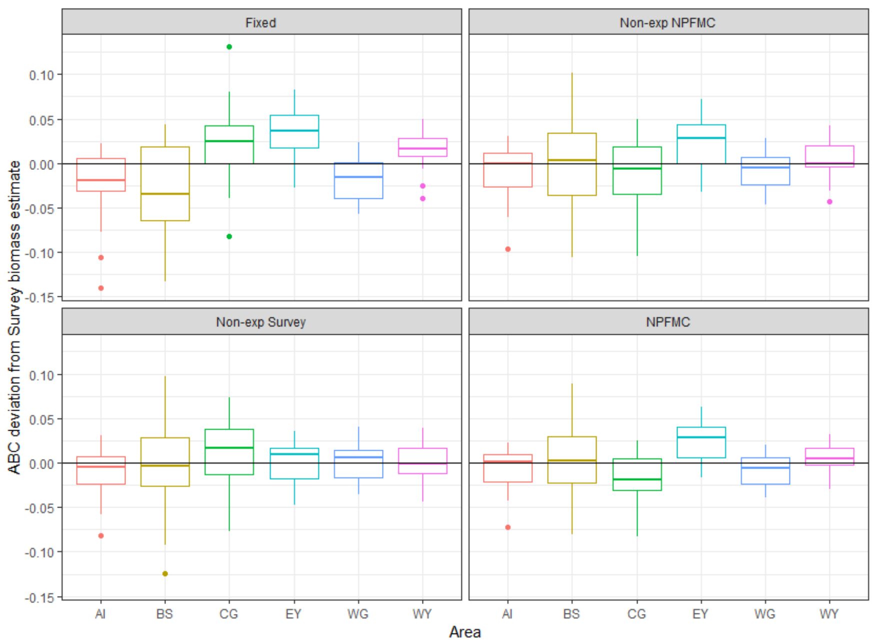
Apportionment Table (before whale depredation adjustments).

Area	2020 ABC*	NPFMC 'Standard' Apportionment for 2021 ABC	Fixed Apportionment for 2021 ABC*	Recommended Non-Exp. Survey Apportionment for 2021 ABC	% Difference from 2020 ABC
Total	22,551	22,551	22,551	**22,551**	0%
Bering Sea	2,201	4,538	2,201	**3,714**	69%
Aleutians	2,976	5,021	2,976	**5,324**	79%
Gulf of Alaska (subtotal)	17,374	12,991	17,375	**13,513**	-22%
Western	2,433	2,589	2,433	**2,779**	14%
Central	7,692	5,097	7,693	**5,786**	-25%
W. Yakutat**	2,587	1,742	2,588	**1,934**	-25%
E. Yak. / Southeast**	4,662	3,563	4,662	**3,014**	-35%

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

The previous NPFMC apportionment method was frozen in 2013 due to increased variability in apportionments, but this was during a long period of poor recruitment. Resulting catches from both the survey and fishery were composed of old, adult sablefish and the population was likely distributed in preferred adult habitat. The extremely spasmodic recruitment events that have recently occurred illustrate the potential for substantial distributional shifts in the population. These shifts, however, are largely due to the emergence of large year classes and are composed of juvenile fish. These events have been extremely rare historically and little is understood regarding the underlying biology leading to these patterns of distribution. While stability in ABC is not a direct biological concern, many stakeholders find large year-to-year changes in ABC to be undesirable. The Non-exponential Survey apportionment method has some of the stabilizing benefits that come from non-exponential weighting, but without the added concern of accounting for diminishing fishery data (see Figure below). If moving from the Fixed apportionment to Non-exponential Survey apportionment is too disruptive, the SSC or Council could consider a stair-step approach that would serve as a bridge between Fixed and Non-exponential Survey apportionment.

Figure. Difference between the proportion of the total ABC in an area and the proportion of the longline survey estimated biomass in an area aggregated across years for each apportionment method (panel). Boxplots demonstrate whether or not the ABC is being apportioned to area at the same proportion as biomass (based on the longline survey estimates of the proportion of biomass in each area). Values greater than zero indicate that the proportion of ABC in a region is larger than the proportion of biomass in that region, while the opposite is true when values are less than zero. Boxplot lines indicate the median value across years, the upper and lower portions of the box indicate the 1st and 3rd quartiles, and the whiskers represent the largest values truncated at 1.5x's the interquartile range. Fixed apportionment uses the 2014 apportionment proportions to assign total ABC to an area, NPFMC apportionment is an exponentially weighted moving average of survey and fishery indices, Non-exponential NPFMC apportionment is an non-exponentially weighted moving average of survey and fishery indices (all years get equal weight), and Non-exponential Survey apportionment is a non-exponentially weighted moving average of the longline survey abundance index.



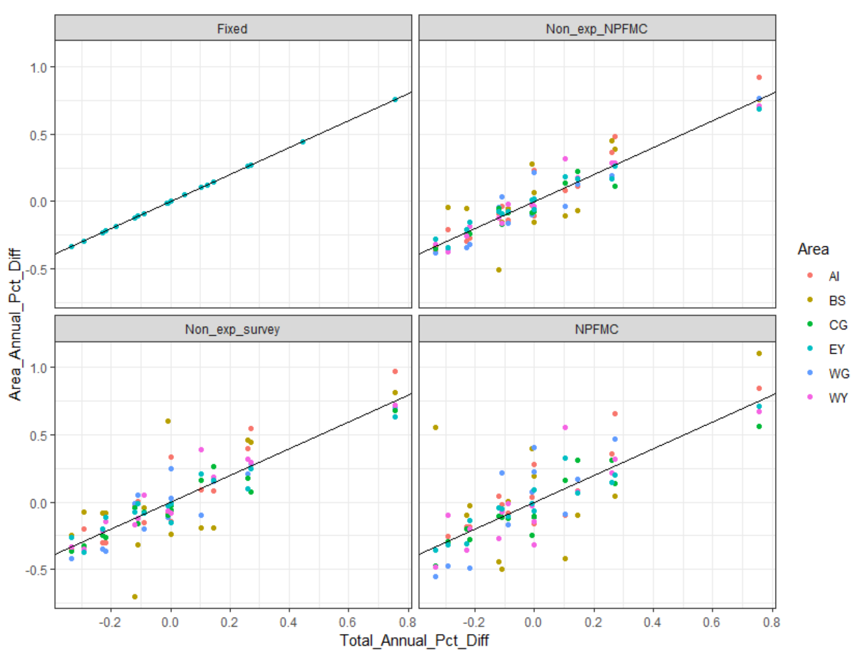
Fishery Data Quality and Quantity Concerns

There is a declining availability of fishery data from some management areas, which are needed to calculate the fishery RPW index underpinning several of the apportionment methods (i.e., any type with "NPFMC" in the name, as well as, the Blended apportionment scheme). These apportionment types rely on survey and fishery data. Observer coverage continues to be low in the Bering Sea; the realized observer coverage rate for partial coverage hook-and-line vessels targeting sablefish in the BSAI in 2019 was 0.00% (Appendix Table B-2 in Ganz et al. 2020). Additionally, voluntary logbook submissions have declined in some regions, and the introduction of electronic monitoring has changed the availability of weight and effort data for the fishery index. Low observer or logbook sample sizes generally lead to increased variability and thus increased instability in apportionment, particularly for the BS and AI. Fishery data are valuable for tracking spatial trends in abundance-at-age; however, there may be insufficient information to use apportionment methods that require fishery data in all areas in the future. In addition, the use of pot gear is increasing in several management areas, and the fishery RPW index does not incorporate pot data. This gear change further diminishes the quantity of fishery data available until methods are developed to address the shift in gear types. We still present the NPFMC and Non-exponential NPFMC apportionment types for comparison, but note that the long-term viability of these methods may be limited. In addition, the NPFMC apportionment method led to high variability in area specific ABCs because of its higher weights on the most recent abundance indices with high measurement error, particularly in the BSAI.

TAC Stability Performance Metric

The Fixed apportionment method has contributed to ACL overages in recent years due to the recent high recruitment events which are disproportionately appearing in primarily the western management areas (see Appendix 3E). As small, juvenile fish from these year classes arrive, they can cause large, abrupt shifts in the distribution of sablefish abundance. Apportionment methods that are responsive to shifts in biomass may be important to allow adaptive management and avoid unnecessarily small area-specific catch caps or prohibited species catch status due to apportionments that do not reflect resource distribution. However, an apportionment method that is too responsive to changing biomass distributions (e.g., the Terminal LL Survey apportionment scheme) may be too variable, which can cause large year-to-year changes in apportioned ABC to one or more management areas. Non-exponential Survey apportionment avoids the issue of tracking biomass changes too rapidly and is relatively stable (see Figure below and Appendix 3D, Figure 3).

Figure. Change in year-to-year area-specific ABC compared to year-to-year change in total ABC. The x-axis is the percent change in total ABC (ABC summed across areas) and the y-axis is the corresponding percent change in ABC for an area. Each panel represents an apportionment type and colored circles represent different management areas. The black line is the 1:1 line; colored circles falling above the line indicate that the area's percent change in apportioned ABC is greater than the overall percent change in ABC, while circles below the line indicate that the area ABC change is less than the overall ABC.



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 60,426 t for the combined stock. Since 2020, the OFL is no longer apportioned by region.

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 knowledge regarding 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. Similarly, developing research models that better account for both resource and fishery spatial structure would be helpful tools for understanding resource distribution and the impacts of fishing on recent strong year classes. Several directions for future sablefish research are proposed and many projects are already ongoing:

1) Refine the fishery abundance index to utilize a core fleet, identify covariates that affect catch rates, and incorporate data from pot gear.
2) Consider new strategies for incorporating annual growth and maturity data.
3) Re-examine selectivity assumptions, as well as, how these assumptions are impacted by decisions about data weighting.
4) Explore alternate model structures that account for changes in fleet structure and associated spatiotemporal changes in gear selectivity (e.g., increasing usage of pot gear, changes in targeting behavior, and differences in selectivity across management areas).
5) Develop stock assessment parametrizations that address time- and age-varying natural mortality.
6) Continue to explore the use of environmental data to aid in determining recruitment. Research along these lines is ongoing and includes development of a spatially explicit full life cycle model that incorporates larval individual-based modeling outputs to inform connectivity during early life history stages and ecosystem drivers of settlement success. Development of this model is continuing and the goal is to use it as a research tool to explore the impact of varying hypotheses regarding spatial processes and environmental drivers across life stages. Results from this modeling framework will be reported in upcoming ESPs.
7) We have developed a spatially explicit research assessment model that includes movement, which examines smaller-scale population dynamics while retaining the assumption of a single, Alaska-wide sablefish stock. Further work is planned to refine the model and incorporate mark-recapture data. Results and ongoing work will be noted in future SAFE reports.
8) Incorporation of the long time series of tag recaptures could help refine estimates of fishing mortality, as well as, allow estimation of time-varying natural mortality parameters. Developing a tag-integrated assessment model will be a research priority in coming years.
9) Evaluate differences in condition (i.e., weight-at-length and energetic storage), maturity-at-age, and stock structure among management areas for spatial and temporal variation.
10) Continue work on developing a coastwide sablefish operating model through the Pacific Sablefish Transboundary Assessment Team (PSTAT).

11) Explore the impacts of increasing removals of young, small sablefish by the various fisheries, particularly in the Bering Sea.

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Tables

Table 3.1. Alaska sablefish catch (t) including 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 GOA includes West Yakutat and East Yakutat / Southeast. 2020 catches are as of October 31, 2020 (www.akfin.org). The current year catch value is incomplete and the assessment uses the specified catch approach noted in the text to account for removals during the remaining portion of the current year. The assessment model catches includes whale depredation and are slightly increased compared to the values presented here.

		By Area								By Gear		
Year	Grand Total	Bering Sea	Aleutian Islands	Western GOA	Central GOA	Eastern GOA	West Yakutat	East Yak/SEO	Unknown	Fixed	Trawl	Proportion Trawl
1960	3,054	1,861	0	0	0	1,193			0	3,054	0	0.00
1961	16,078	15,627	0	0	0	451			0	16,078	0	0.00
1962	26,379	25,989	0	0	0	390			0	26,379	0	0.00
1963	16,901	13,706	664	266	1,324	941			0	10,557	6,344	0.38
1964	7,273	3,545	1,541	92	955	1,140			0	3,316	3,957	0.54
1965	8,733	4,838	1,249	764	1,449	433			0	925	7,808	0.89
1966	15,583	9,505	1,341	1,093	2,632	1,012			0	3,760	11,823	0.76
1967	19,196	11,698	1,652	523	1,955	3,368			0	3,852	15,344	0.80
1968	30,940	14,374	1,673	297	1,658	12,938			0	11,182	19,758	0.64
1969	36,831	16,009	1,673	836	4,214	14,099			0	15,439	21,392	0.58
1970	37,858	11,737	1,248	1,566	6,703	16,604			0	22,729	15,129	0.40
1971	43,468	15,106	2,936	2,047	6,996	16,382			0	22,905	20,563	0.47
1972	53,080	12,758	3,531	3,857	11,599	21,320			15	28,538	24,542	0.46
1973	36,926	5,957	2,902	3,962	9,629	14,439			37	23,211	13,715	0.37
1974	34,545	4,258	2,477	4,207	7,590	16,006			7	25,466	9,079	0.26
1975	29,979	2,766	1,747	4,240	6,566	14,659			1	23,333	6,646	0.22
1976	31,684	2,923	1,659	4,837	6,479	15,782			4	25,397	6,287	0.20
1977	21,404	2,718	1,897	2,968	4,270	9,543			8	18,859	2,545	0.12
1978	10,394	1,193	821	1,419	3,090	3,870			1	9,158	1,236	0.12
1979	11,814	1,376	782	999	3,189	5,391			76	10,350	1,463	0.12
1980	10,444	2,205	275	1,450	3,027	3,461			26	8,396	2,048	0.20
1981	12,604	2,605	533	1,595	3,425	4,425			22	10,994	1,610	0.13
1982	12,048	3,238	964	1,489	2,885	3,457			15	10,204	1,844	0.15
1983	11,715	2,712	684	1,496	2,970	3,818			35	10,155	1,560	0.13
1984	14,109	3,336	1,061	1,326	3,463	4,618			305	10,292	3,817	0.27
1985	14,465	2,454	1,551	2,152	4,209	4,098			0	13,007	1,457	0.10
1986	28,892	4,184	3,285	4,067	9,105	8,175			75	21,576	7,316	0.25
1987	35,163	4,904	4,112	4,141	11,505	10,500			2	27,595	7,568	0.22
1988	38,406	4,006	3,616	3,789	14,505	12,473			18	29,282	9,124	0.24
1989	34,829	1,516	3,704	4,533	13,224	11,852			0	27,509	7,320	0.21
1990	32,115	2,606	2,412	2,251	13,786	11,030			30	26,598	5,518	0.17
1991	26,536	1,209	2,190	1,931	11,178	9,938	4,069	5,869	89	23,438	3,097	0.12
1992	24,042	613	1,553	2,221	10,355	9,158	4,408	4,750	142	21,131	2,910	0.12
1993	25,417	669	2,078	740	11,955	9,976	4,620	5,356	0	22,912	2,506	0.10
1994	23,580	694	1,727	539	9,377	11,243	4,493	6,750	0	20,642	2,938	0.12
1995	20,692	930	1,119	1,747	7,673	9,223	3,872	5,352	0	18,079	2,613	0.13
1996	17,393	648	764	1,649	6,773	7,558	2,899	4,659	0	15,206	2,187	0.13
1997	14,607	552	781	1,374	6,234	5,666	1,930	3,735	0	12,976	1,632	0.11
1998	13,874	563	535	1,432	5,922	5,422	1,956	3,467	0	12,387	1,487	0.11
1999	13,587	675	683	1,488	5,874	4,867	1,709	3,159	0	11,603	1,985	0.15
2000	15,570	742	1,049	1,587	6,173	6,020	2,066	3,953	0	13,551	2,019	0.13
2001	14,065	864	1,074	1,588	5,518	5,021	1,737	3,284	0	12,281	1,783	0.13
2002	14,748	1,144	1,119	1,865	6,180	4,441	1,550	2,891	0	12,505	2,243	0.15
2003	16,411	1,012	1,118	2,118	6,994	5,170	1,822	3,347	0	14,351	2,060	0.13
2004	17,520	1,041	955	2,173	7,310	6,041	2,241	3,801	0	15,864	1,656	0.09
2005	16,585	1,070	1,481	1,930	6,706	5,399	1,824	3,575	0	15,029	1,556	0.09
2006	15,551	1,078	1,151	2,151	5,921	5,251	1,889	3,362	0	14,305	1,246	0.08
2007	15,958	1,182	1,169	2,101	6,004	5,502	2,074	3,429	0	14,723	1,235	0.08
2008	14,552	1,141	899	1,679	5,495	5,337	2,016	3,321	0	13,430	1,122	0.08
2009	13,062	916	1,100	1,423	4,967	4,656	1,831	2,825	0	12,005	1,057	0.08
2010	11,931	753	1,047	1,354	4,508	4,269	1,578	2,690	0	10,927	1,004	0.08
2011	12,978	707	1,026	1,400	4,924	4,921	1,897	3,024	0	11,799	1,179	0.09
2012	13,869	743	1,205	1,353	5,329	5,238	2,033	3,205	0	12,767	1,102	0.08
2013	13,645	634	1,063	1,384	5,211	5,352	2,105	3,247	0	12,607	1,037	0.08
2014	11,588	314	821	1,202	4,756	4,495	1,673	2,822	0	10,562	1,025	0.09
2015	10,973	211	431	1,014	4,647	4,670	1,840	2,829	0	9,888	1,085	0.10
2016	10,259	532	349	1,058	4,200	4,120	1,656	2,463	0	8,920	1,338	0.13
2017	12,270	1,159	590	1,181	4,843	4,497	1,698	2,798	0	9,990	2,280	0.19
2018	14,332	1,595	660	1,405	5,792	4,881	1,860	3,021	0	10,503	3,830	0.27
2019	16,624	3,191	661	1,545	6,296	4,931	1,808	3,124	0	11,423	5,201	0.31
2020	14,894	4,581	1,104	1,113	4,151	3,944	1,547	2,398	0	8,509	6,385	0.43

Table 3.2. Catch (t) in the Aleutian Islands and the Bering Sea by gear type from 1991 - 2020. Both CDQ and non-CDQ catches are included. Catches in 1991 - 1999 are averages. Catch as of October 31, 2020 (www.akfin.org).

Aleutian Islands				
Year	Pot	Trawl	Longline	Total
1991-1999	6	73	1,210	1,289
2000	103	33	913	1,049
2001	111	39	925	1,074
2002	105	39	975	1,119
2003	316	42	760	1,118
2004	384	32	539	955
2005	688	115	679	1,481
2006	461	60	629	1,151
2007	632	40	496	1,169
2008	177	76	646	899
2009	78	75	947	1,100
2010	59	74	914	1,047
2011	141	47	838	1,026
2012	77	148	979	1,205
2013	87	58	918	1,063
2014	160	26	635	821
2015	12	15	403	431
2016	21	30	298	349
2017	270	129	191	590
2018	281	179	199	660
2019	203	241	217	661
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	379	1,067	148	1,595
2019	410	2,553	228	3,191

Table 3.3. Summary of management measures with time series of catch, ABC, OFL, and TAC. All values are in tons.

Year	Catch	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	16,624	32,798	15,068	15,068	
2020[1]	14,894	50,481	22,009	18,293	TAC smaller than ABC based on AP recommendation OFL changed to Alaska-wide

[1] Catch is as of Oct. 31, 2020 (Source: www.akfin.org).

Table 3.4. Discarded catch of sablefish (t), percent of total catch discarded, and total catch (t) by gear type (H&L=hook & line, Other = pot, trawl, and jig, combined for confidentiality) by FMP area for 2010 - 2020. Source: NMFS Alaskan Regional Office Catch Accounting System via AKFIN (www.akfin.org), accessed on October 31, 2020020. Discards are included in the assessment model catch assuming 100% mortality.

		BSAI			GOA			Combined		
Year	Gear	Discard	%Discard	Catch	Discard	%Discard	Catch	Discard	%Discard	Catch
2010	H&L	34	3%	1,186	374	4%	9,236	408	4%	10,422
	Other	5	1%	614	47	5%	901	52	3%	1,514
	Total	39	2%	1,800	421	4%	10,136	460	4%	11,936
2011	H&L	21	2%	1,096	406	4%	10,164	427	4%	11,260
	Other	8	1%	638	179	16%	1,098	187	11%	1,736
	Total	29	2%	1,734	585	5%	11,262	614	5%	12,996
2012	H&L	14	1%	1,199	250	2%	11,063	263	2%	12,262
	Other	13	2%	752	65	8%	861	77	5%	1,613
	Total	26	1%	1,950	315	3%	11,925	341	2%	13,875
2013	H&L	27	3%	1,068	574	5%	11,100	601	5%	12,168
	Other	3	1%	630	48	6%	846	51	3%	1,476
	Total	30	2%	1,698	622	5%	11,946	652	5%	13,644
2014	H&L	31	4%	742	440	5%	9,487	471	5%	10,228
	Other	1	0%	385	78	8%	967	80	6%	1,352
	Total	32	3%	1,127	518	5%	10,453	550	5%	11,580
2015	H&L	13	3%	489	593	6%	9,312	606	6%	9,800
	Other	5	3%	153	181	17%	1,060	186	15%	1,212
	Total	19	3%	641	774	7%	10,371	793	7%	11,012
2016	H&L	77	18%	415	650	8%	8,315	726	8%	8,730
	Other	7	1%	465	186	18%	1,058	193	13%	1,524
	Total	83	9%	880	836	9%	9,373	919	9%	10,254
2017	H&L	53	18%	297	590	7%	8,181	643	8%	8,478
	Other	148	10%	1,438	498	21%	2,363	646	17%	3,801
	Total	201	12%	1,735	1,087	10%	10,544	1,289	10%	12,279
2018	H&L	73	21%	348	589	7%	8,359	662	8%	8,707
	Other	342	18%	1,857	1,642	44%	3,706	1,984	36%	5,564
	Total	415	19%	2,205	2,231	18%	12,066	2,646	19%	14,270
2019	H&L	168	38%	445	634	8%	7,857	801	10%	8,302
	Other	1,834	41%	4,448	1,915	39%	4,959	3,749	40%	9,407
	Total	2,001	41%	4,893	2,549	20%	12,816	4,551	26%	17,709
2020	H&L	123	40%	306	384	8%	4,838	507	10%	5,143
	Other	2,712	49%	5,485	1,437	25%	5,689	4,149	37%	11,174
	Total	2,835	49%	5,790	1,822	17%	10,527	4,656	29%	16,317
	H&L	58	8%	690	498	6%	8,901	556	6%	9,591
mean	Other	462	30%	1,533	571	27%	2,137	1,032	28%	3,670
	Total	519	23%	2,223	1,069	10%	11,038	1,588	12%	13,261

Table 3.5. Mean bycatch (t) of FMP groundfish species in the targeted sablefish fishery from 2013 - 2020. Other = pot and trawl combined due to confidentiality. D =Discarded, R = Retained. Source: NMFS Alaskan Regional Office Catch Accounting System via AKFIN (www.akfin.org), accessed on October 31, 2020.

	Hook and line			Other			All gears		
Species	D	R	Total	D	R	Total	D	R	Total
GOA Thornyhead	179	402	581	8	21	29	187	423	610
Shark	551	0	552	6	0	6	636	0	637
GOA Shortraker Rockfish	175	78	253	9	3	12	184	81	265
Arrowtooth Flounder	116	8	124	89	17	106	205	25	230
GOA Skate, Other	176	1	177	4	0	4	180	1	181
GOA Skate, Longnose	156	6	162	1	0	1	179	7	186
GOA Rougheye Rockfish	98	80	178	1	3	3	112	95	207
Other Rockfish	55	42	98	2	5	7	65	54	119
Pacific Cod	53	25	78	2	10	12	63	41	103
BSAI Skate	36	1	37	0	0	0	42	1	42
Greenland Turbot	13	5	18	3	4	7	18	10	28
GOA Skate, Big	16	0	16	0	0	0	19	0	19
Sculpin	12	0	12	1	0	1	14	0	14
GOA Demersal Shelf	1	10	12	0	0	0	2	12	14
BSAI Kamchatka	8	1	10	4	12	16	14	15	29
GOA Deep Water Flatfish	10	0	10	19	5	24	33	6	39
BSAI Shortraker Rockfish	5	1	6	0	1	1	5	2	8
Octopus	5	0	5	2	0	2	7	0	7
BSAI Other Flatfish	4	0	4	0	9	9	5	10	15
GOA Shallow Water	3	0	3	1	1	2	6	1	7
Pollock	2	0	2	11	12	22	14	13	27
Pacific Ocean Perch	2	0	2	1	7	8	3	9	11
Flathead Sole	1	0	1	1	6	8	3	7	10

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 31, 2020.

Group Name	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Benthic urochordata	1.3	0.0	0.0	0.5	0.0	1.0	1.0	0.1	0.0
Brittle star unidentified	4.7	0.1	0.7	2.1	0.3	0.6	0.6	0.4	0.4
Corals Bryozoans	7.7	12.8	5.2	4.6	5.9	2.2	10.2	3.6	1.4
Eelpouts	0.6	1.1	0.8	0.2	1.1	2.4	7.6	0.2	0.1
Grenadiers	9,769	15,035	7,338	7,297	9,332	6,799	5,697	3,927	2,379
Invertebrate unidentified	7.9	0.3	0.1	0.5	0.2	0.8	0.5	0.4	0.1
Misc. crabs	6.9	6.0	6.4	3.6	5.2	5.2	4.0	2.9	5.0
Misc. fish	11.5	31.3	28.4	17.2	15.6	24.1	30.2	152.6	51.6
Scypho jellies	0.0	0.0	5.5	0.2	0.2	0.0	0.6	0.7	0.2
Sea anemone unidentified	1.0	1.0	3.1	14.1	1.8	2.0	14.5	1.9	1.2
Sea pens whips	0.3	0.4	2.3	2.8	1.3	1.1	0.4	0.6	0.7
Sea star	3.2	15.7	11.6	9.6	9.3	21.6	13.7	6.3	8.3
Snails	12.1	8.8	3.7	3.4	0.2	2.9	2.9	7.9	3.6
Sponge unidentified	1.0	3.4	1.7	3.5	0.5	0.7	0.3	0.3	0.4
State-managed Rockfish	0.0	0.1	0.1	0.1	0.2	0.4	0.0	0.1	0.0
Urchins, dollars, cucumbers	0.8	0.9	0.8	2.5	0.2	0.2	1.2	1.3	0.4

Table 3.7. Prohibited Species Catch (PSC) estimates (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 is defined as pot and trawl gears combined because of confidentiality. Source: NMFS Alaska Regional Office Catch Accounting System PSCNQ via AKFIN (www.akfin.org), accessed on October 31, 2020.

				BSAI				
Hook and	Year	Bairdi	Chinook	Golden	Halibut (t)*	Other	Opilio	Red KC
	2013	-	15	600	5	-	-	-
	2014	-	-	576	6	-	-	40
	2015	-	9	177	0	-	-	206
	2016	22	0	49	0	0	27	5
	2017	3	0	0	0	0	4	1
	2018	8	0	0	0	0	17	10
	2019	3	0	3	0	0	12	0
	2020	2	0	0	2	0	11	0
	Mean	5	3	176	2	0	9	33
Other	2013	365	-	858	4	-	315	-
	2014	-	-	3,573	1	-	1,689	-
	2015	-	-	29,038	0	-	26	-
	2016	142	-	11,696	5	-	14	18
	2017	689	-	16,034	7	-	465	51
	2018	525	98	38,905	32	-	261	1,060
	2019	171	-	4,965	7	-	122	6
	2020	213	-	5,374	3	-	375	25
	Mean	263	12	13,805	7	-	408	145
Sum	**BSAI**	268	15	13,981	9	0	417	178

				GOA				
HAL	2013	78	-	93	4	-	-	24
	2014	6	-	39	0	-	-	-
	2015	166	-	38	6	-	-	12
	2016	0	-	39	3	-	0	0
	2017	20	-	72	3	-	-	-
	2018	-		71	1	-	-	-
	2019	59	-	82	1	-	-	-
	2020	-	-	49	-	-	-	-
	Mean	41	-	60	2	-	0	5
Other	2013	-	-	-	11	-	-	-
	2014	-	-	18	2	-	-	-
	2015	25	-	-	3	-	-	-
	2016	-	-	47	11	-	-	-
	2017	150	-	26	4	-	-	-
	2018	2,760	-	-	40	-	-	-
	2019	200	-	92	10	-	-	-
	2020	101	-	38	4	-	2	-
	Mean	405	-	28	11	-	0	-
Sum	**GOA**	446	-	88	13	-	0	5

*The Pacific halibut bycatch only includes sets determined to be sablefish targets that are not in the IFQ fishery.

Table 3.8. Sample sizes for age and length data for Alaska sablefish. Japanese fishery data are from Sasaki (1985), U.S. fishery data are from the observer databases, and longline survey data are from longline survey databases. Trawl survey data are from AKFIN. All fish were sexed before measurement, except for the Japanese fishery data.

	LENGTH							AGE		
Year	U.S. NMFS trawl survey (GOA)	Japanese fishery Trawl	Japanese fishery Longline	U.S. fishery Trawl	U.S. fishery Fixed	Cooperative longline survey	Domestic longline survey	Cooperative longline survey	Domestic longline survey	U.S. fixed gear fishery
1963			30.562							
1964		3,337	11,377							
1965		6,267	9,631							
1966		27,459	13,802							
1967		31,868	12,700							
1968		17,727								
1969		3,843								
1970		3,456								
1971		5,848	19,653							
1972		1,560	8,217							
1973		1,678	16,332							
1974			3,330							
1975										
1976			7,704							
1977			1,079							
1978			9,985							
1979			1,292			19,349				
1980			1,944			40,949				
1981						34,699		1,146		
1982						65,092				
1983						66,517		889		
1984	12,964					100,029				
1985						125,129		1,294		
1986						128,718				
1987	9,610					102,639		1,057		
1988						114,239				
1989						115,067		655		
1990	4,969			1,229	32,936	78,794	101,530			
1991				721	28,182	69,653	95,364	902		
1992				0	20,929	79,210	104,786			
1993	7,168			468	21,943	80,596	94,699	1,178		
1994				89	11,914	74,153	70,431			
1995				87	17,735		80,826			
1996	4,615			239	14,416		72,247		1,176	
1997				0	20,330		82,783		1,214	
1998				35	8,932		57,773		1,191	
1999	4,281			1,268	28,070		79,451		1,186	1,141
2000				472	32,208		62,513		1,236	1,152
2001				473	30,315		83,726		1,214	1,003
2002				526	33,719		75,937		1,136	1,059
2003	5,003			503	36,077		77,678		1,128	1,185
2004				694	31,199		82,767		1,185	1,145
2005	4,901			2,306	36,213		74,433		1,074	1,164
2006				721	32,497		78,625		1,178	1,154
2007	3,773			860	29,854		73,480		1,174	1,115
2008				2,018	23,414		71,661		1,184	1,164
2009	3,934			1,837	24,674		67,978		1,197	1,126
2010				1,634	24,530		75,010		1,176	1,159
2011	2,114			1,877	22,659		87,498		1,199	1,190
2012				2,533	22,203		63,116		1,186	1,165
2013	1,249			2,674	16,093		51,586		1,190	1,157
2014				2,210	19,524		52,290		1,183	1,126
2015	3,472			2,320	20,056		52,110		1,191	1,176
2016				1,630	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			2,620	13,537		98,023		1,193	1,140
2020							100,066			

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
2019	C	C	C	3	1	2019	0.33	0.01	003	18	3

Table 3.9 (cont.)

Western Gulf-Observer						Central Gulf-Observer					
Year	CPUE	SE	CV	Sets	Vessels	Year	CPUE	SE	CV	Sets	Vessels
1990	0.64	0.14	0.22	178	7	1990	0.54	0.04	0.07	653	32
1991	0.44	0.06	0.13	193	16	1991	0.62	0.06	0.09	303	24
1992	0.38	0.05	0.14	260	12	1992	0.59	0.05	0.09	335	19
1993	0.35	0.03	0.09	106	12	1993	0.60	0.04	0.07	647	32
1994	0.32	0.03	0.10	52	5	1994	0.65	0.06	0.09	238	15
1995	0.51	0.04	0.09	432	22	1995	0.90	0.07	0.08	457	41
1996	0.57	0.05	0.10	269	20	1996	1.04	0.07	0.07	441	45
1997	0.50	0.05	0.10	349	20	1997	1.07	0.08	0.08	377	41
1998	0.50	0.03	0.07	351	18	1998	0.90	0.06	0.06	345	32
1999	0.53	0.07	0.12	244	14	1999	0.87	0.08	0.10	269	28
2000	0.49	0.06	0.13	185	12	2000	0.93	0.05	0.06	319	30
2001	0.50	0.05	0.10	273	16	2001	0.70	0.04	0.06	347	31
2002	0.51	0.05	0.09	348	15	2002	0.84	0.07	0.08	374	29
2003	0.45	0.04	0.10	387	16	2003	0.99	0.07	0.07	363	34
2004	0.47	0.08	0.17	162	10	2004	1.08	0.10	0.09	327	29
2005	0.58	0.07	0.13	447	13	2005	0.89	0.06	0.07	518	32
2006	0.42	0.04	0.13	306	15	2006	0.82	0.06	0.08	361	33
2007	0.37	0.04	0.11	255	12	2007	0.93	0.06	0.07	289	30
2008	0.46	0.07	0.16	255	11	2008	0.84	0.07	0.08	207	27
2009	0.44	0.09	0.21	208	11	2009	0.77	0.06	0.07	320	33
2010	0.42	0.06	0.14	198	10	2010	0.80	0.05	0.07	286	31
2011	0.54	0.12	0.22	196	12	2011	0.85	0.08	0.10	213	28
2012	0.38	0.04	0.11	147	13	2012	0.74	0.07	0.09	298	27
2013	0.34	0.02	0.06	325	18	2013	0.51	0.05	0.10	419	34
2014	0.41	0.06	0.15	190	16	2014	0.56	0.03	0.05	585	57
2015	0.36	0.07	0.18	185	14	2015	0.52	0.04	0.08	793	54
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
2019	0.45	0.05	0.12	148	8	2019	0.44	0.05	0.12	344	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
2019	0.53	0.05	0.09	214	24	2019	0.55	0.04	0.08	217	33

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
2019	0.25	0.07	0.26	262	4	2019	No data				
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
2019	0.35	0.03	0.08	565	17	2019	0.32	0.02	0.06	2343	58

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
2019	0.42	0.03	0.07	2100	63	2019	0.52	0.02	0.05	1490	80

Table 3.10. Sablefish abundance index values (1,000's) for Alaska (200-1,000 m) including deep gully habitat, from the Japan-U.S. Cooperative Longline Survey, Domestic Longline Survey, and Japanese and U.S. longline fisheries. Relative population number equals CPUE in numbers weighted by respective strata areas. Relative population weight equals CPUE measured in weight multiplied by strata areas. 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		899			1,759	745	211
2020		1,186			2,596		

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, 2017, and 2019 or Bering Sea 1979-1981, 1995, 1996, 1998, 2000, 2002, 2004, 2006, 2008, 2009, 2010, 2012, 2014, 2016, 2018, and 2020.

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
2020			0	7	1	5	3	1	4	0	6	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. Estimates of sablefish recruits (Age-2), total biomass (2+), and spawning biomass from the Base model (MLE mean) along with lower and upper lower 95% credible intervals (2.5%, 97.5%) from MCMC. Recruits are in millions and biomass is in kt. The estimate for the 2018 year class (terminal year 2020 recruitment event) is omitted, because it is fixed to the estimated mean recruitment value (μ_r) with no deviation parameter estimated.

	Recruits (Age-2; millions)			**Total Biomass (kt)**			**Spawning Biomass (kt)**		
Year	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
1977	4.4	0.6	13.4	293.4	254.3	382.4	136.8	117.6	182.2
1978	5.1	0.7	15.0	267.3	230.4	348.2	124.0	106.5	165.4
1979	83.7	64.3	122.1	326.7	282.3	426.2	117.9	101.6	156.1
1980	25.4	3.5	48.1	359.5	311.1	462.8	112.6	96.9	148.0
1981	10.4	0.9	34.1	379.5	328.5	486.5	111.4	96.5	145.0
1982	40.9	17.5	70.7	417.9	362.1	540.0	115.5	100.4	149.2
1983	24.0	4.0	46.7	445.2	387.6	566.6	127.9	111.6	164.2
1984	41.0	30.0	60.4	485.3	425.6	614.0	144.6	127.3	183.9
1985	2.3	0.4	7.3	489.6	431.5	614.8	160.1	141.6	202.5
1986	20.4	10.2	33.3	497.7	440.2	616.3	173.4	153.7	217.4
1987	17.3	11.0	27.5	484.1	429.0	599.1	179.0	158.3	224.3
1988	3.9	0.6	9.4	448.6	396.7	555.8	177.9	156.6	223.8
1989	3.7	0.7	8.3	403.3	356.5	501.4	170.5	149.9	215.8
1990	5.7	3.2	9.5	359.5	316.0	449.1	160.0	139.9	203.6
1991	28.0	22.1	38.6	340.8	298.3	427.9	147.8	128.6	189.7
1992	1.2	0.2	3.5	311.5	272.6	391.8	135.6	117.5	174.6
1993	22.4	17.8	31.0	302.8	264.7	381.3	124.1	107.1	159.9
1994	5.0	1.2	10.5	282.6	246.4	356.3	112.9	97.4	145.8
1995	5.1	1.4	9.5	262.1	228.6	330.8	104.5	90.0	135.6
1996	7.1	4.8	11.1	244.6	213.3	309.5	99.3	85.8	128.9
1997	16.9	13.0	23.5	238.8	208.3	302.1	95.7	82.7	123.6
1998	2.2	0.4	5.3	225.5	196.8	284.3	92.4	80.1	119.0
1999	27.5	22.3	37.0	234.2	203.7	296.2	88.6	76.9	113.8
2000	18.2	12.0	27.6	241.9	210.8	305.5	85.1	74.0	108.8
2001	8.3	1.6	16.8	240.3	208.7	301.6	81.8	71.1	104.3
2002	40.4	32.7	56.5	267.8	233.0	340.2	81.0	70.5	103.2
2003	6.0	1.8	11.1	271.9	236.4	344.8	82.5	71.7	104.7
2004	12.3	8.4	18.5	274.3	238.2	348.0	85.4	74.2	108.3
2005	5.4	3.1	8.9	266.4	231.3	338.8	89.1	77.2	113.8
2006	10.1	6.7	15.1	259.2	224.5	329.0	93.7	81.1	119.7
2007	7.1	4.7	11.1	248.7	215.8	316.1	97.2	84.0	124.1
2008	8.0	4.9	12.1	237.2	205.3	300.6	97.4	84.0	124.3
2009	6.8	4.6	10.4	225.6	195.4	286.1	95.5	82.5	121.5
2010	16.0	12.4	22.4	223.7	193.9	284.0	92.6	80.1	117.7
2011	4.4	1.9	7.7	215.1	186.0	272.4	89.2	77.0	113.1
2012	8.5	6.2	12.4	207.4	179.3	262.4	85.1	73.3	107.8
2013	0.9	0.2	2.3	191.5	165.1	242.4	80.7	69.3	102.5
2014	6.1	4.0	9.3	178.1	153.0	226.6	76.7	65.6	97.9
2015	9.9	7.3	14.4	170.8	145.9	218.2	73.4	62.5	94.0
2016	67.7	55.6	91.5	220.5	188.0	285.1	69.6	58.8	89.3
2017	26.6	18.0	40.3	256.2	218.2	332.5	66.2	55.7	85.4
2018	163.7	130.2	224.8	420.7	355.0	549.9	65.4	54.8	85.0
2019	123.4	91.6	178.4	596.7	501.7	781.2	73.1	61.3	94.9
2020				686.9	576.6	893.6	94.4	79.8	122.0

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 1990-2020 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	Total Alaska
1977	54	65	28	82	25	39	293
1978	49	60	26	73	23	36	267
1979	62	67	31	97	28	42	327
1980	65	85	35	96	31	48	359
1981	68	95	40	84	35	58	380
1982	76	87	54	101	40	60	418
1983	80	93	69	113	37	54	445
1984	91	113	77	116	35	53	485
1985	101	112	70	122	36	49	490
1986	107	105	68	124	42	53	498
1987	79	105	64	129	48	59	484
1988	47	92	60	144	46	59	449
1989	54	79	47	129	42	52	403
1990	55	59	38	110	42	55	360
1991	38	40	36	107	45	75	341
1992	22	35	24	98	49	82	311
1993	15	33	27	100	52	77	303
1994	17	32	31	93	43	66	283
1995	25	30	27	85	37	59	262
1996	23	25	26	88	32	50	245
1997	22	22	25	93	29	47	239
1998	20	29	25	79	26	47	225
1999	19	38	27	78	25	47	234
2000	19	40	32	81	25	46	242
2001	26	38	38	76	20	42	240
2002	37	41	40	87	22	42	268
2003	37	42	38	92	24	39	272
2004	36	42	34	97	25	39	274
2005	38	40	35	86	24	43	266
2006	41	36	36	78	24	44	259
2007	43	32	27	77	26	44	249
2008	46	30	23	74	23	41	237
2009	43	29	26	71	20	36	226
2010	44	25	23	65	25	41	224
2011	28	22	22	76	28	40	215
2012	11	27	24	83	23	39	207
2013	25	27	20	64	17	39	192
2014	37	22	19	50	15	33	178
2015	29	23	19	49	19	32	171
2016	27	39	24	63	29	39	221
2017	32	53	30	73	30	38	256
2018	53	100	54	120	38	56	421
2019	97	127	66	118	37	67	512
2020	158	169	77	157	43	82	687

Table 3.16. Key parameter estimates along with their uncertainty including 95% Bayesian credible intervals (BCI) from MCMC analysis. Recruitment year classes are in millions of fish and SSB is in kilotons (kt).

Parameter	μ (MLE)	μ (MCMC)	Median (MCMC)	σ (MLE)	σ (MCMC)	BCI Lower	BCI Upper
$q_{Domestic\_LL\_Srvy}$	7.96	7.73	7.74	0.75	0.73	6.33	9.20
$q_{Coop\_LL\_Srvy}$	5.96	5.79	5.79	0.56	0.54	4.76	6.88
q_{Trawl_Srvy}	1.33	1.28	1.28	0.16	0.15	1.00	1.61
M	0.10	0.10	0.10	0.01	0.01	0.09	0.11
$F_{40\%}$	0.10	0.11	0.11	0.02	0.03	0.07	0.17
2020 SSB (kt)	94.44	98.34	97.36	10.29	10.85	79.74	121.77
2014 Year Class	67.73	71.20	70.22	8.60	9.20	55.56	91.53
2016 Year Class	163.65	170.66	168.44	22.72	24.14	130.33	224.79
2017 Year Class	123.44	129.24	127.55	20.96	22.00	91.47	167.08

Table 3.17. Comparison of 2019 Base model estimates and 2020 Base model estimates. Recruitment is in millions of fish, while SSB and Biomass are in kilotons.

Year	2019 SAFE Recruitment	2020 SAFE Recruitment	Difference (%)	2019 SAFE Spawning Biomass	2020 SAFE Spawning Biomass	Difference (%)	2019 SAFE Total Biomass	2020 SAFE Total Biomass	Difference (%)
1977	5.4	4.39	-19%	153	137	-11%	332	293	-12%
1978	6.8	5.12	-25%	139	124	-11%	304	267	-12%
1979	92.6	83.73	-10%	132	118	-11%	368	327	-11%
1980	29.7	25.39	-15%	126	113	-11%	405	359	-11%
1981	13.4	10.41	-22%	124	111	-10%	427	380	-11%
1982	43.8	40.94	-7%	128	116	-10%	467	418	-11%
1983	28.1	23.99	-15%	141	128	-9%	496	445	-10%
1984	43.6	40.98	-6%	159	145	-9%	537	485	-10%
1985	3.1	2.33	-25%	175	160	-9%	539	490	-9%
1986	22.5	20.41	-9%	189	173	-8%	545	498	-9%
1987	18	17.28	-4%	194	179	-8%	529	484	-8%
1988	5	3.92	-22%	192	178	-7%	490	449	-8%
1989	4.5	3.75	-17%	184	171	-7%	441	403	-9%
1990	5.9	5.70	-3%	172	160	-7%	394	360	-9%
1991	31.2	28.02	-10%	159	148	-7%	374	341	-9%
1992	1.6	1.24	-22%	146	136	-7%	342	311	-9%
1993	23.9	22.37	-6%	133	124	-7%	331	303	-9%
1994	6.2	4.99	-20%	121	113	-7%	309	283	-9%
1995	5.7	5.09	-11%	112	104	-7%	287	262	-9%
1996	7.6	7.15	-6%	106	99	-6%	267	245	-8%
1997	18.9	16.88	-11%	103	96	-7%	261	239	-9%
1998	2.8	2.17	-23%	99	92	-7%	246	225	-8%
1999	30.2	27.54	-9%	95	89	-7%	256	234	-9%
2000	20.5	18.16	-11%	91	85	-6%	264	242	-8%
2001	9.9	8.28	-16%	88	82	-7%	263	240	-9%
2002	44.8	40.41	-10%	87	81	-7%	294	268	-9%
2003	6.5	6.02	-7%	89	83	-7%	298	272	-9%
2004	14.1	12.28	-13%	92	85	-7%	301	274	-9%
2005	5.7	5.42	-5%	97	89	-8%	292	266	-9%
2006	11.9	10.14	-15%	102	94	-8%	285	259	-9%
2007	7.5	7.06	-6%	106	97	-8%	273	249	-9%
2008	9.4	7.99	-15%	106	97	-8%	261	237	-9%
2009	7.3	6.79	-7%	104	96	-8%	248	226	-9%
2010	18.6	16.04	-14%	101	93	-8%	247	224	-9%
2011	4.8	4.38	-9%	98	89	-9%	238	215	-10%
2012	9.7	8.50	-12%	93	85	-9%	229	207	-9%
2013	1.1	0.91	-17%	89	81	-9%	212	192	-10%
2014	7.5	6.13	-18%	85	77	-10%	199	178	-10%
2015	11.3	9.90	-12%	81	73	-9%	191	171	-11%
2016	93.2	67.73	-27%	78	70	-11%	264	221	-16%
2017	26	26.63	2%	74	66	-10%	307	256	-17%
2018	218.5	163.65	-25%	75	65	-13%	527	421	-20%
2019				86	73	-15%	632	597	-6%

Table 3.18. Sablefish spawning biomass (kilotons), fishing mortality, and yield (kilotons) for the seven projection harvest scenarios (columns) outlined in the Population Projections section. Abundance is projected by drawing from the 1979 - 2018 recruitments. The 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 Catches)	Half Maximum F	5-year Average F	No Fishing	Overfished	Approaching Overfished
			Spawning Stock Biomass (kt)				
2020	94.4	94.4	94.4	94.4	94.4	94.4	94.4
2021	134.4	134.4	134.4	134.4	134.4	134.4	134.4
2022	181.8	191.5	189.6	185.0	198.0	179.1	181.8
2023	227.7	253.6	247.7	235.9	271.1	220.8	227.7
2024	256.9	285.6	291.0	270.9	334.4	245.2	252.7
2025	266.0	294.9	312.1	285.4	377.1	250.1	257.6
2026	261.4	288.6	317.1	284.9	401.0	242.4	249.4
2027	250.1	274.7	311.7	276.4	412.1	229.1	235.3
2028	236.4	258.2	301.5	264.6	415.5	214.2	219.6
2029	222.7	241.7	291.2	251.9	414.3	199.9	204.5
2030	209.7	226.2	280.9	239.6	410.4	186.8	190.8
2031	198.0	212.3	268.7	228.0	405.0	175.2	178.6
2032	187.8	200.0	258.4	217.7	399.0	165.3	168.2
2033	179.0	189.5	250.0	208.6	392.9	156.9	159.3
			Fishing Mortality				
2020	0.045	0.045	0.045	0.045	0.045	0.045	0.045
2021	0.100	0.039	0.050	0.080	0.000	0.117	0.117
2022	0.100	0.037	0.050	0.080	0.000	0.117	0.117
2023	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2024	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2025	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2026	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2027	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2028	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2029	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2030	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2031	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2032	0.100	0.100	0.050	0.080	0.000	0.117	0.117
2033	0.100	0.100	0.050	0.080	0.000	0.116	0.116
			Yield (kt)				
2020	17.7	17.7	17.7	17.7	17.7	17.7	17.7
2021	52.4	21.1	26.7	42.2	0.0	61.3	52.4
2022	58.6	23.6	31.1	47.9	0.0	67.5	58.6
2023	58.0	64.1	32.1	48.2	0.0	65.9	67.8
2024	54.7	60.1	31.6	46.3	0.0	61.3	62.9
2025	50.6	55.3	30.3	43.4	0.0	56.0	57.4
2026	46.5	50.5	28.8	40.5	0.0	50.9	52.1
2027	42.8	46.1	27.3	37.6	0.0	46.4	47.4
2028	39.6	42.3	25.8	35.1	0.0	42.5	43.3
2029	36.8	39.1	24.5	32.9	0.0	39.3	40.0
2030	34.6	36.4	23.3	31.1	0.0	36.8	37.3
2031	32.8	34.3	22.4	29.6	0.0	34.8	35.2
2032	31.3	32.5	21.5	28.3	0.0	33.0	33.4
2033	30.0	31.1	20.8	27.2	0.0	31.5	31.8

* Projections are based on approximate estimated catches of 21,100 t and 23,600 t (based on the ratio of estimated catch to max ABC in 2020) used in place of maximum permissible ABC for 2021 and 2022. This was done in response to management requests for a more accurate two-year projection.

Table 3.19. Summary of select sensitivity runs by category. Model names match those used in Figure 3.57. Note that negative log-likelihood (nLL) values are not directly comparable due to changes in model structure, likelihood penalties, data weighting, and the number of estimated parameters. The summary of model results generally reflect the results across model runs within each category, but results may differ slightly.

Category	Representative Model Name	Model Description	nLL	# Parameters	SSB_{2020} (kt)	Summary of Model Results
Base Model	Base	Base model as described in text	1888	240	94	Difficulty simultaneously fitting comp data, LL survey RPNs, and fishery CPUE.
1. Add LL Fishery Selectivity Time Block	Sel Fish 2016	Implement selectivity time block for fixed gear fleet beginning in 2016	1878	242	92	Slightly improved fit to comp data, no appreciable change in dynamics.
2. Add LL Survey Selectivity Time Block	Sel Fish and Srvy 2016	Implement time block for fixed gear and longline survey selectivity beginning in 2016	1835	244	73	Slightly improved fit to comp, LL survey RPN, and fishery CPUE data; drastic reduction in strength of recent year class estimates and resulting SSB_{2020}.
3. Estimate Time-Varying *M*	M Block 2016	Implement natural mortality time block beginning in 2016 and estimate new M parameter for recent years	1809	241	56	Recent M is 4x's greater; fit to LL survey comp data remains similar, but fit to LL survey RPN and fishery CPUE improves dramatically; recent large year class strength nearly doubles, but SSB declines rapidly starting in 2016 and SSB_{2020} is nearly half of Base model estimate.
4. Estimate Age-Varying *M*	M Age Vary to Age-6	Estimate age-varying natural mortality deviations for ages 2 through 6, then hold M constant at the estimated base M parameter for remaining ages	1839	245	119	M on young fish is 4 - 10x's greater than on older fish; slightly improved fit to compositional data, but no appreciable difference in fit to LL RPN or CPUE data compared to the base model; recruitment estimates for recent strong year classes are ~4x's greater, while SSB_{2020} is significantly higher than the Base model.
5. Selectivity Time Blocks and Time- and/or Age-Varying *M*	M Block 2016, Fish+Srvy 2016	Implement a time block in 2016 for fixed gear selectivity, LL survey selectivity, and natural mortality	1802	245	50	Results are nearly identical to the M Block 2016 model, but with slightly reduced recent recruitment estimates and SSB_{2020}.
	M_2016, Sel_2016, M_Imm_Mat_Ag4	Implement a time block in 2016 for fixed gear selectivity, LL survey selectivity, and natural mortality, while estimating aged based natural mortality parameters grouped by ages (i.e., one mortality rate applies to ages 2 through 4 and the other applies to ages 5+)	1772	246	49	Similar results to M Block 2016, Fish+Srvy 2016 model, but with increased *M* for younger ages and reduced recent recruitment estimates; fit to compositional data is slightly improved.
6. Reduce LL Survey Compositional Data Weights	LL Srvy Comps Half Wt	Decrease the weight to LL survey age and length composition data by half	1620	240	103	Similar results to the Base model, but with increased SSB_{2020} estimates.
7. Fix Recent Recruitment to Average	Set 2017 YC to Ave (1979-2016)	Set the 2017 recruitment year class to the average value from 1979 to 2016	1979	239	72	Reduced recent recruitment estimates compared to the Base model and greatly reduced SSB_{2020}.
8. Alternate Maturity-at-Age Vectors	High a50, Low Mat	Implement a reduced maturity-at-age vector based on the highest a_{50}	1888	240	61	Changes in maturity-at-age act as a scalar on SSB, but with disproportionate impacts in recent years due to the prevalence of young fish from recent large year classes.
	Low a50, High Mat	Implement an increased maturity-at-age vector based on the lowest a_{50}	1888	240	136	

Figures

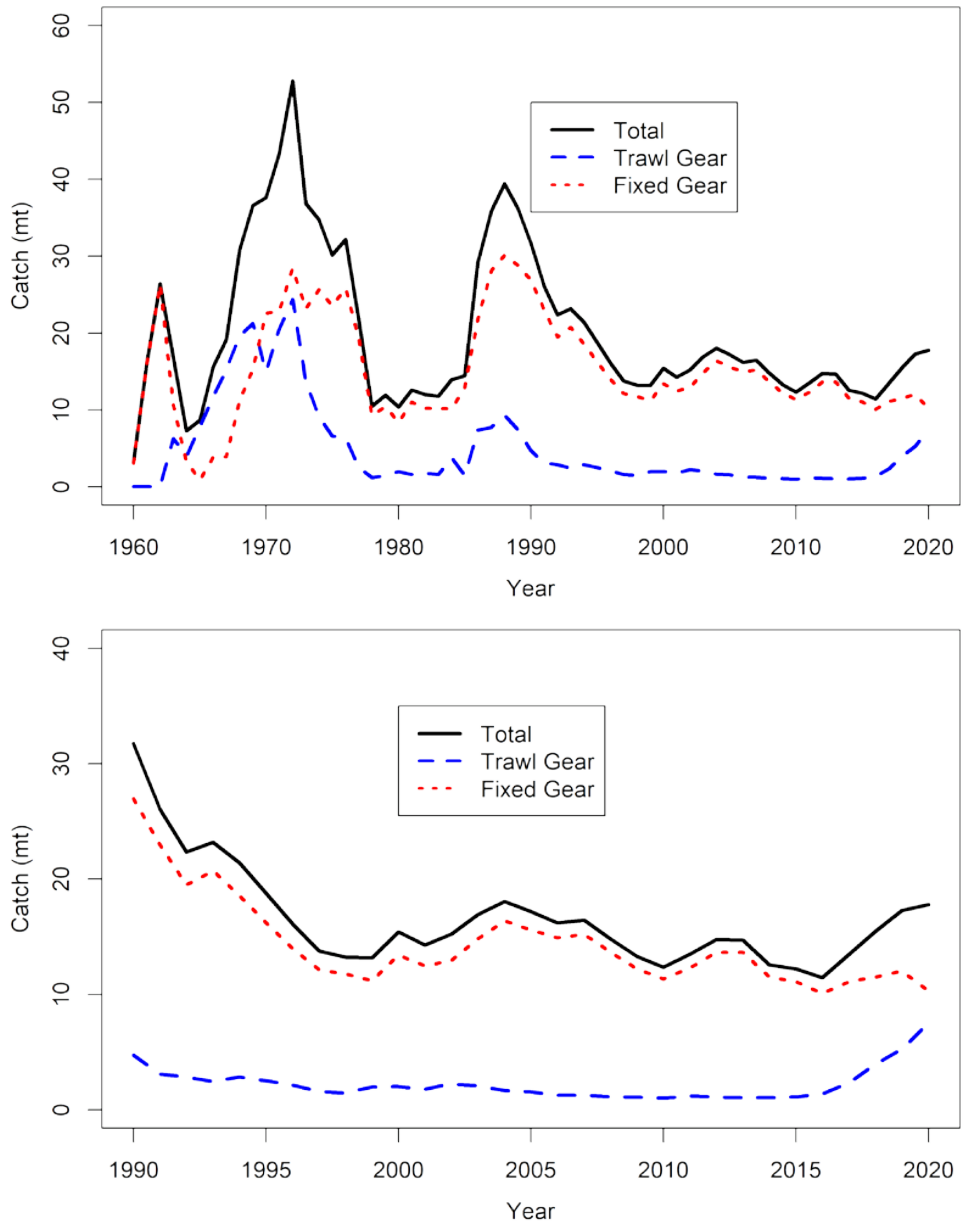


Figure 3.1. Long term and recent sablefish catch by gear type.

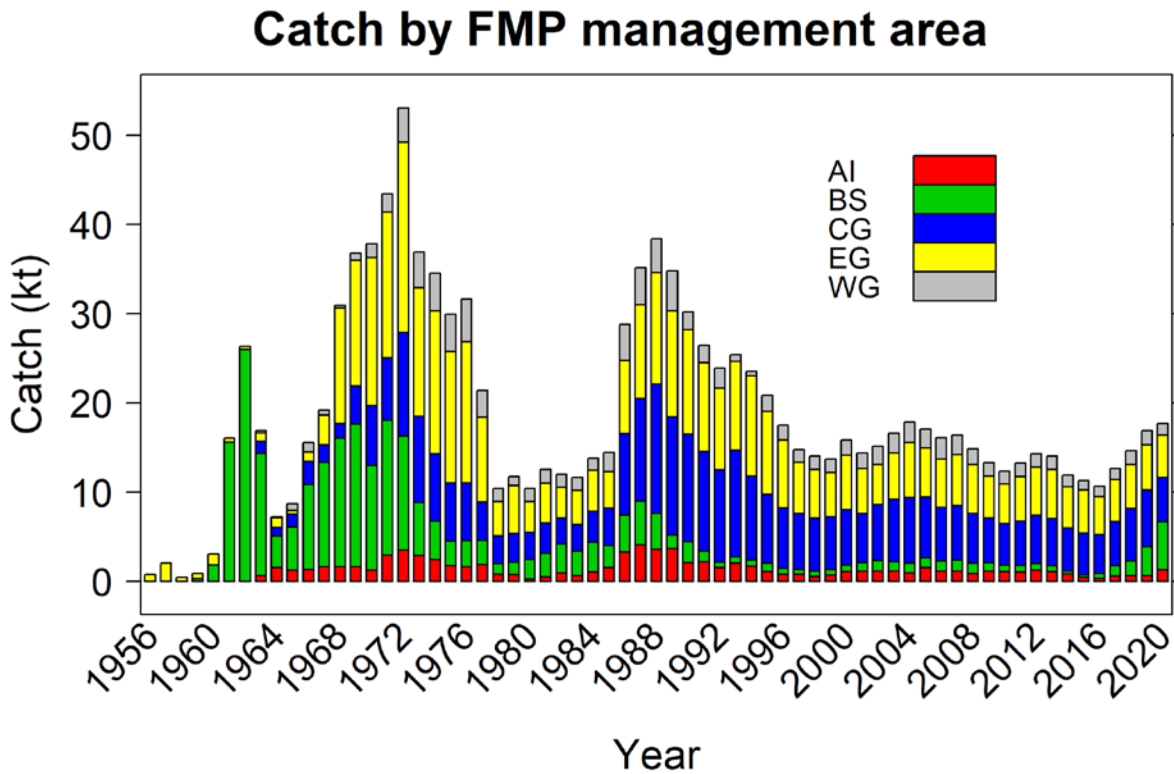


Figure 3.2. Sablefish fishery total reported catch (kt) by North Pacific Fishery Management Council area and year.

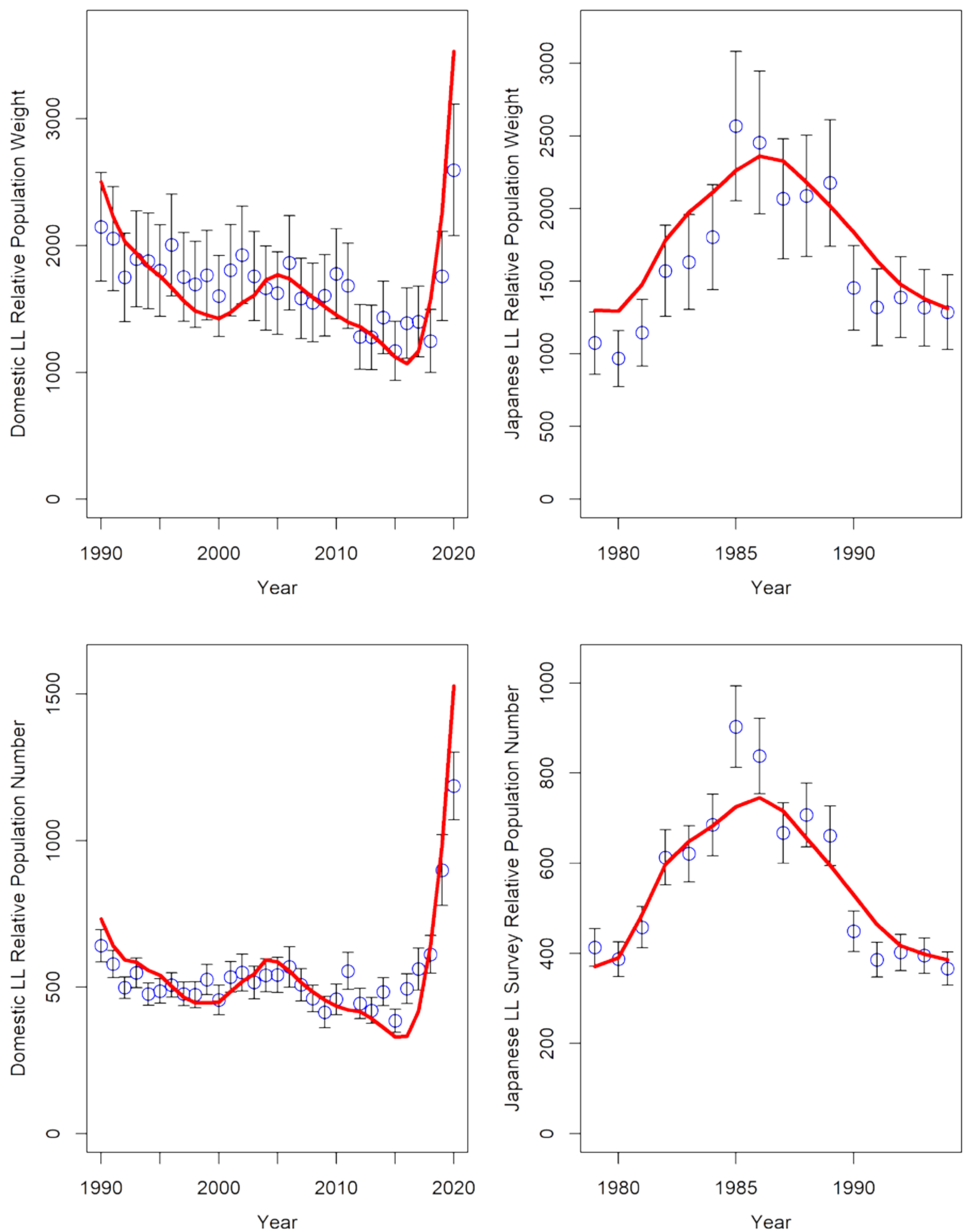


Figure 3.3. Observed and predicted sablefish relative population weight and numbers for 1990 - 2020 for U.S. longline survey and for 1979 - 1994 for U.S.-Japan cooperative survey. Points are observed estimates with approximate 95% confidence intervals. Solid red line is model predicted. The relative population weights are not fit in the models, but are presented for comparison.

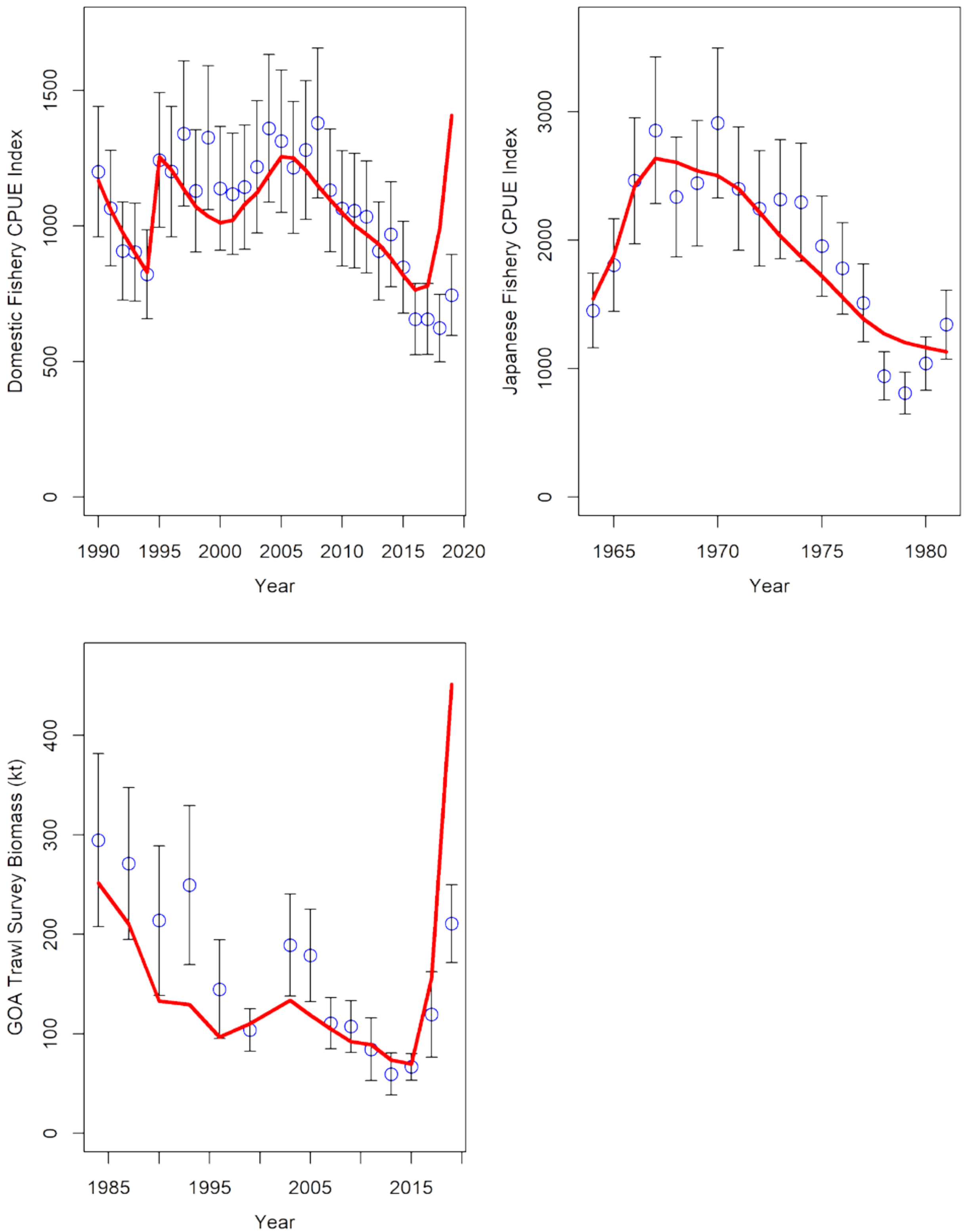


Figure 3.4. Observed and predicted sablefish abundance indices. Fishery CPUE indices are on top two panels. GOA trawl survey is on the bottom left panel. Points are observed values with approximate 95% confidence intervals, while solid red lines are model predictions.

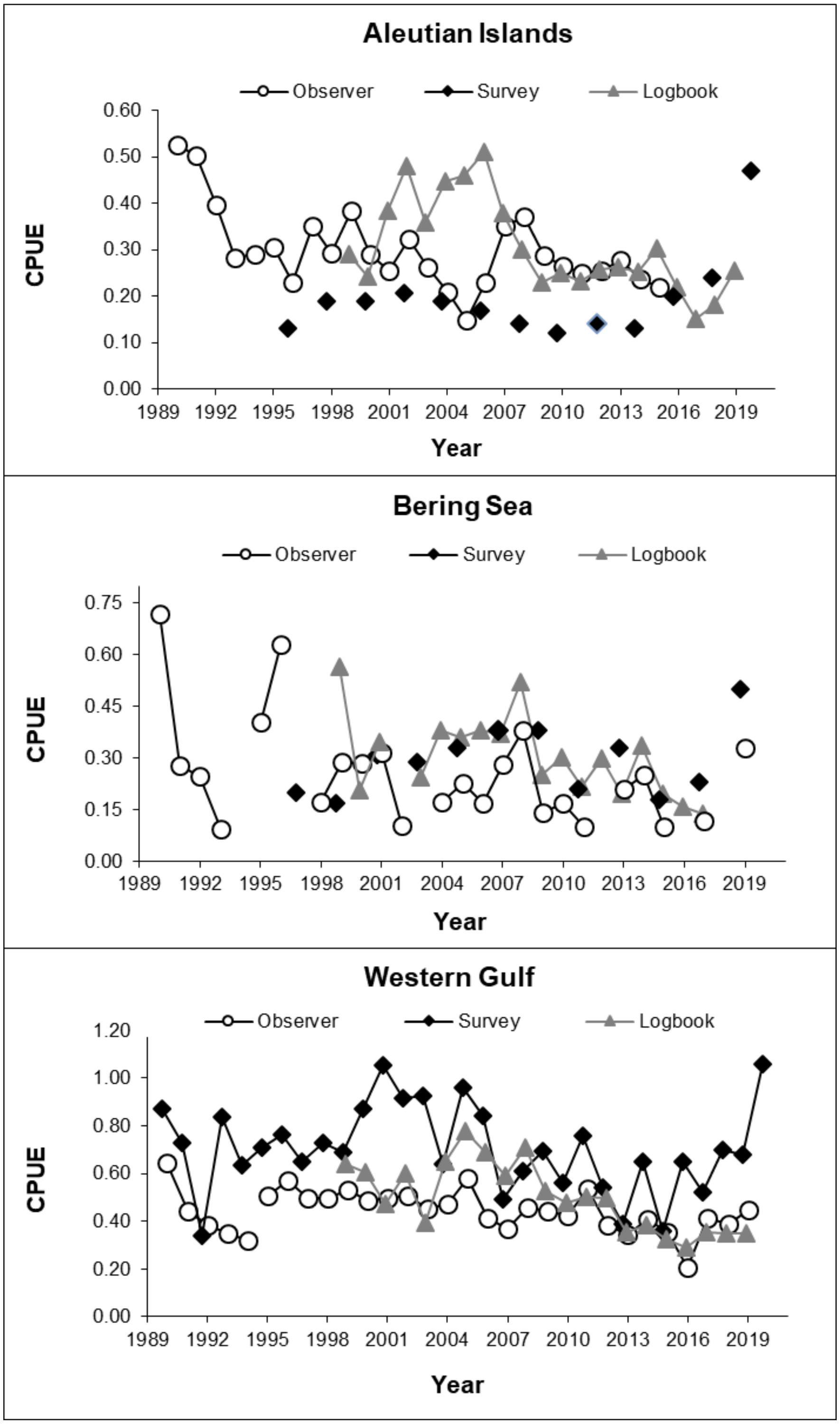


Figure 3.5. Average fishery catch rate (pounds/hook) by region and data source for longline survey and fixed gear fishery data. The fishery switched from open-access to individual quota management in 1995. Due to confidentiality concerns, data is not presented for years when there were fewer than three vessels reporting data for the fishery.

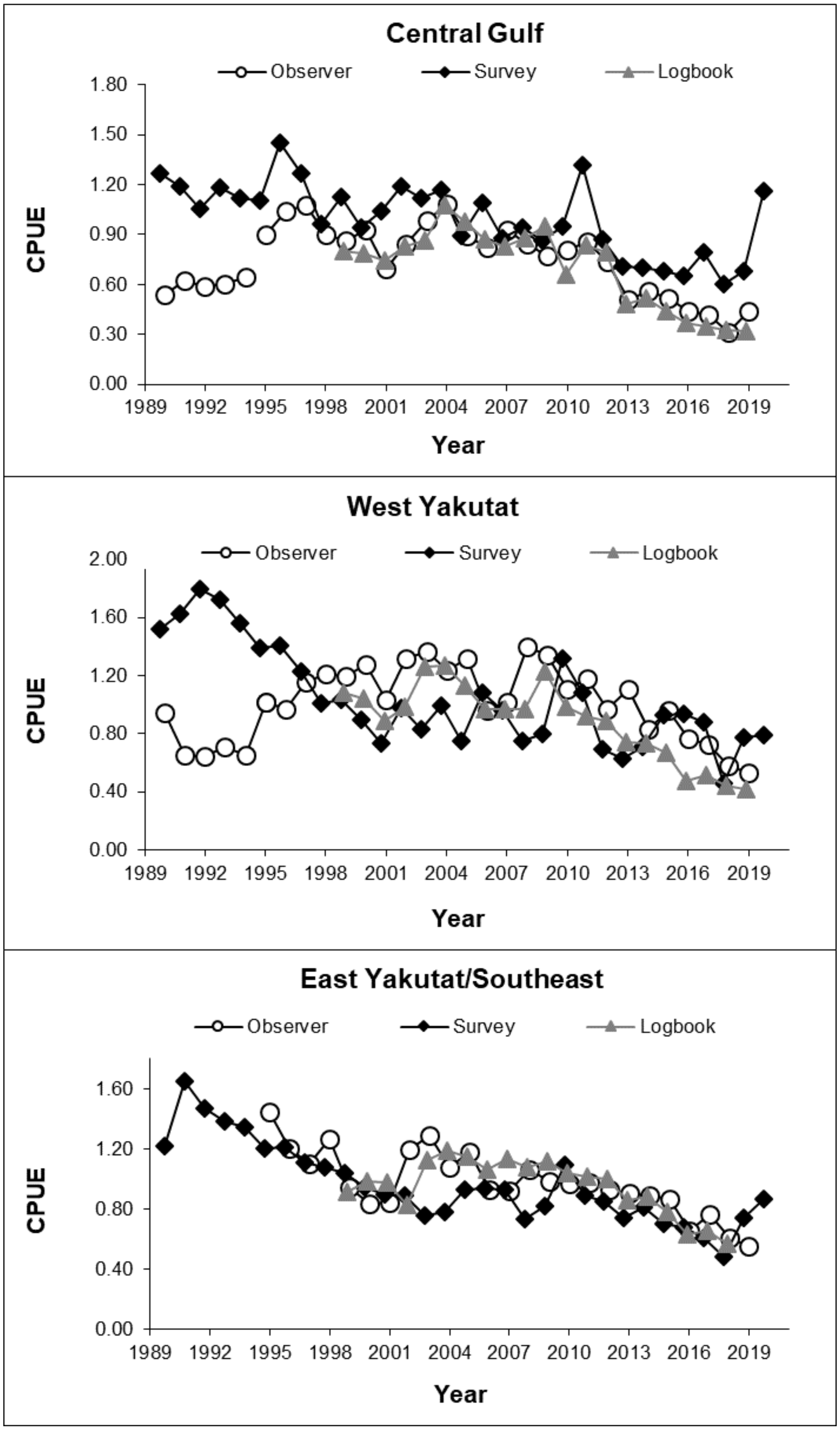


Figure 3.5. (Cont.).

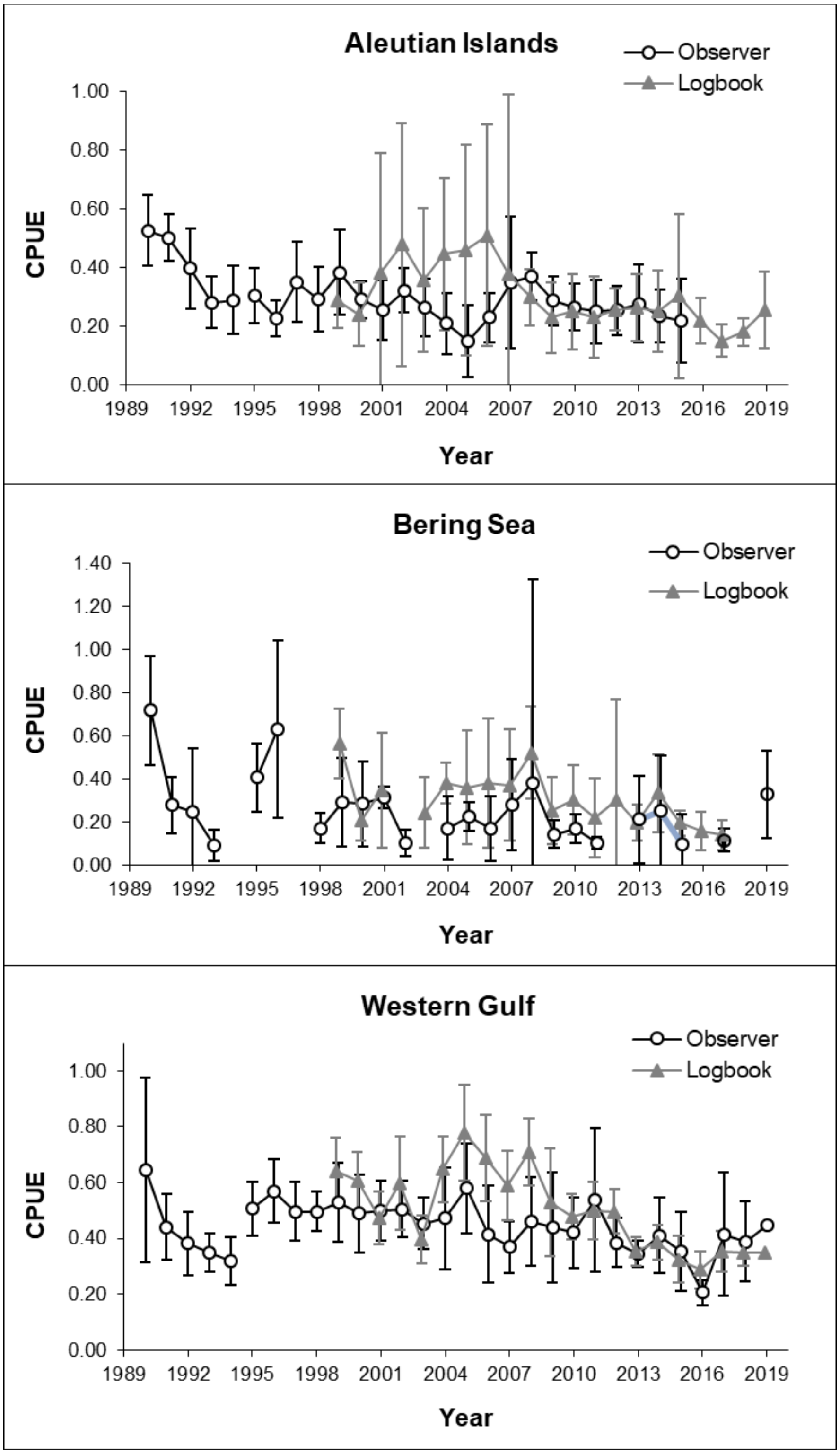


Figure 3.6. Average fixed gear fishery catch rate (pounds/hook) and associated 95% confidence intervals by region and data source. The fishery switched from open-access to individual quota management in 1995. Due to confidentiality concerns, data is not presented for years when there were fewer than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

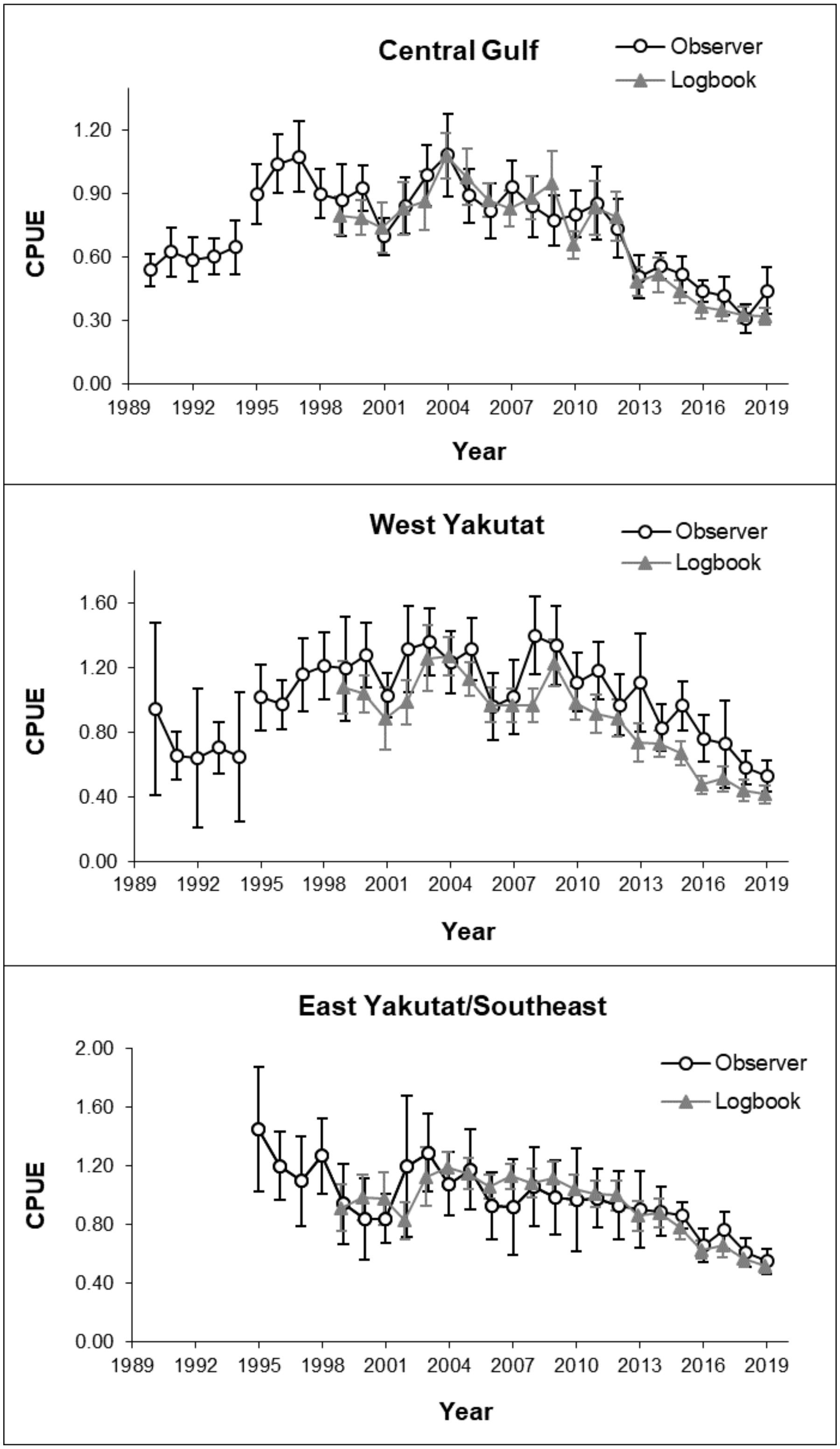


Figure 3.6. (Cont.)

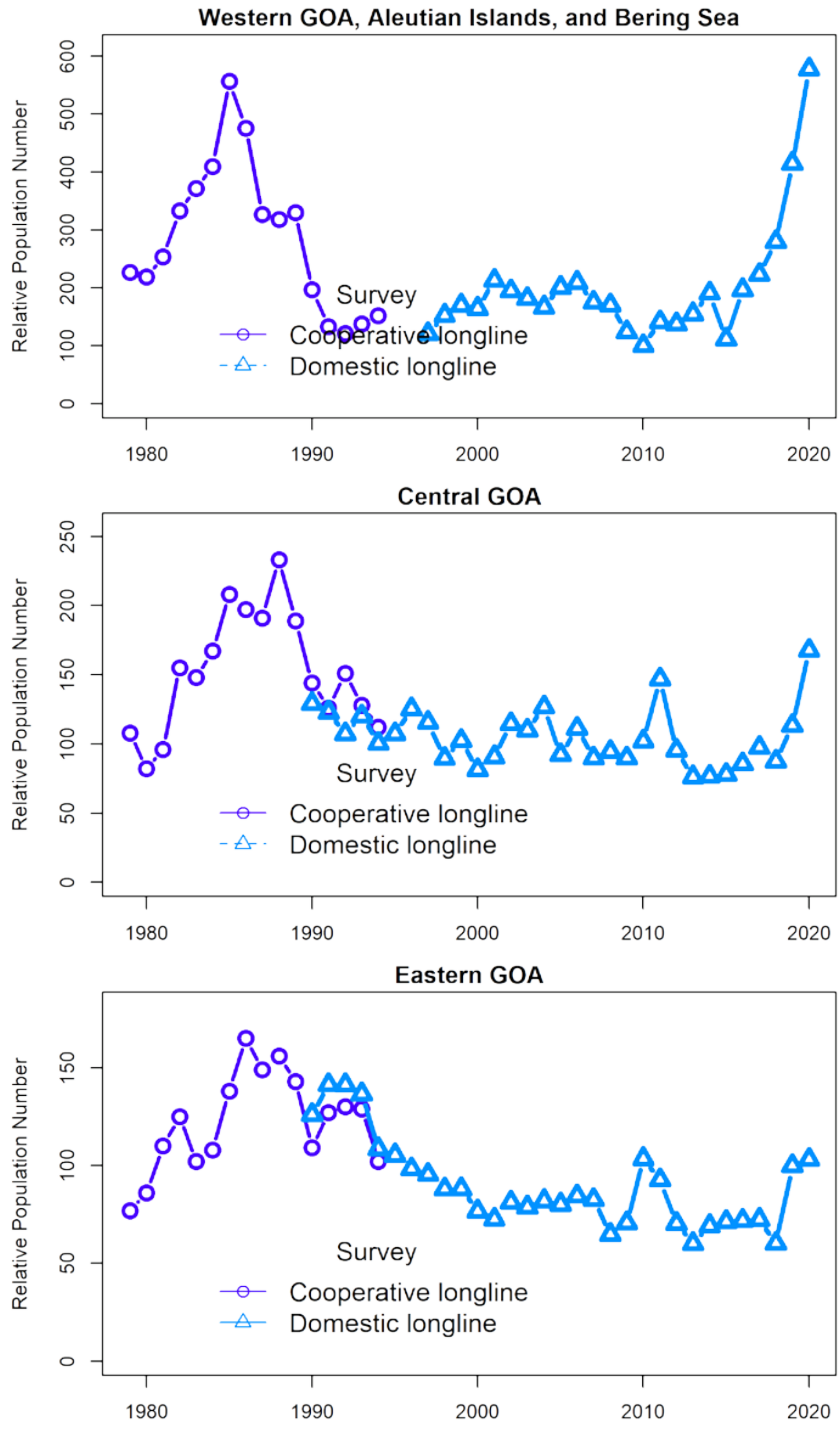


Figure 3.7. Relative abundance (numbers) by region and survey. The regions Bering Sea, Aleutians Islands, and western Gulf of Alaska are combined in the first panel. The two surveys are the Japan-U.S. cooperative longline survey and the domestic (U.S.) longline survey. The values for the U.S. survey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

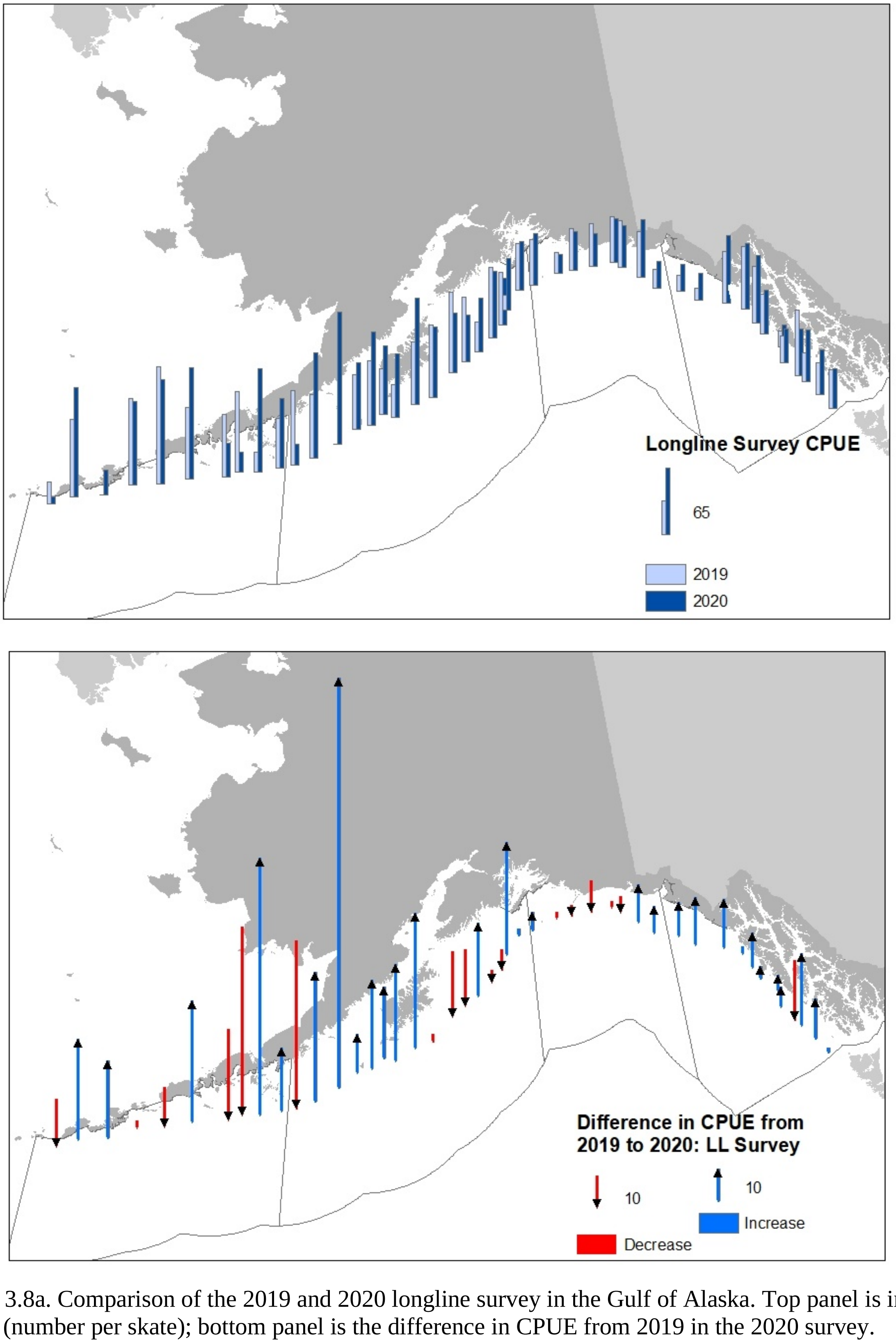


Figure 3.8a. Comparison of the 2019 and 2020 longline survey in the Gulf of Alaska. Top panel is in CPUE (number per skate); bottom panel is the difference in CPUE from 2019 in the 2020 survey. Numbers are not corrected for sperm whale depredation.

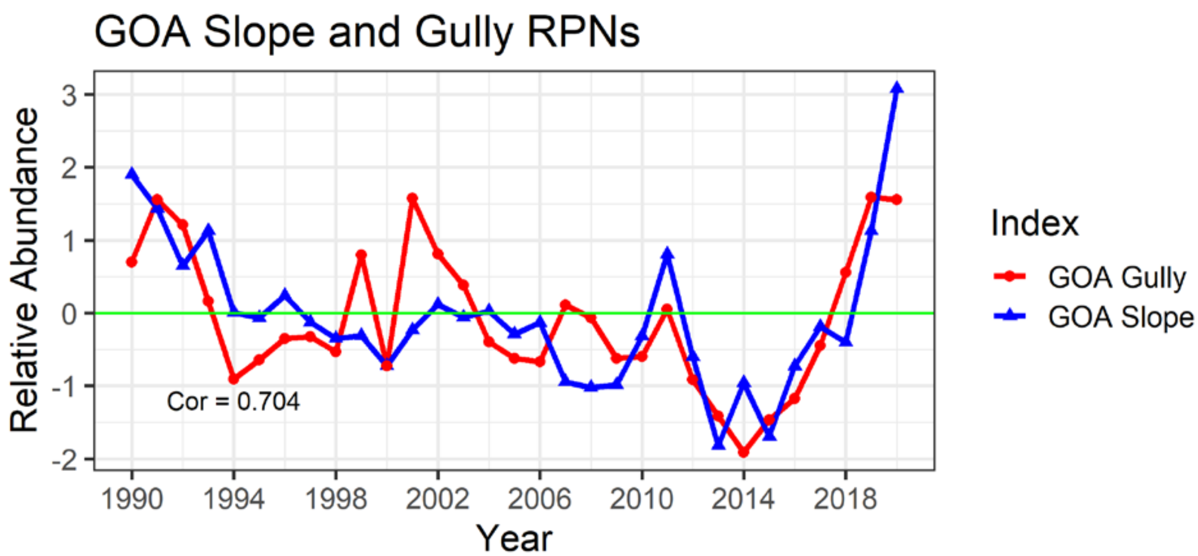


Figure 3.8b. Comparison of abundance trends in GOA gully stations versus GOA slope stations.

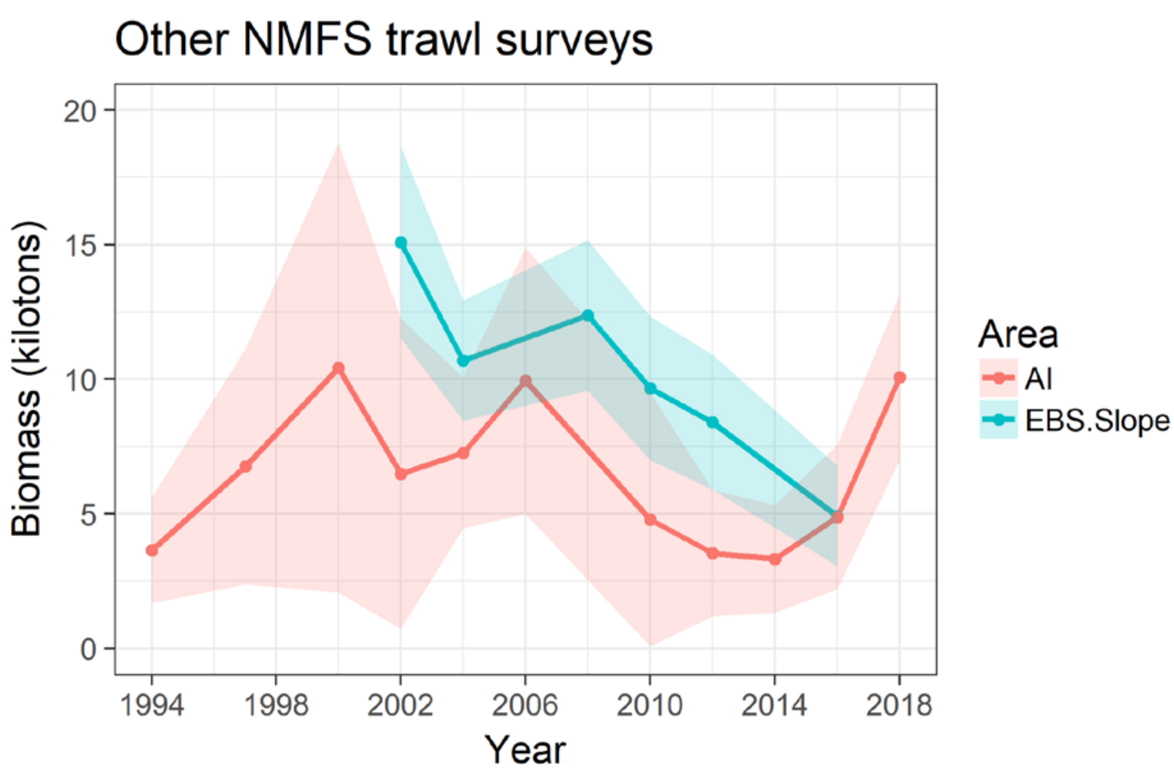


Figure 3.9. NMFS Bering Sea Slope and Aleutian Island trawl survey biomass estimates.

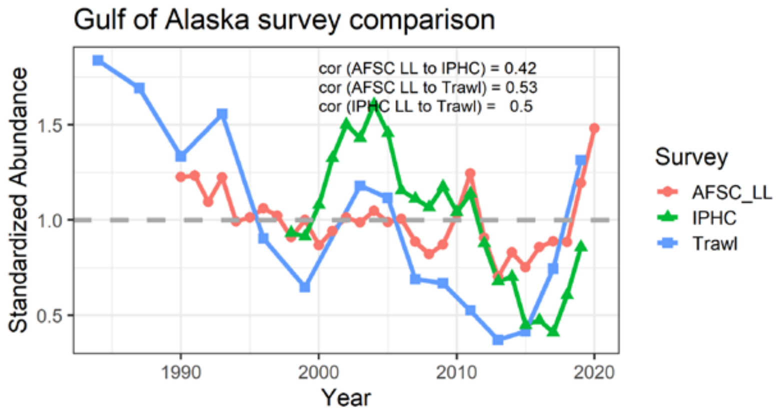


Figure 3.10a. Comparisons of IPHC and AFSC longline surveys, and the NMFS trawl survey trends in relative abundance of sablefish in the Gulf of Alaska. Correlation coefficients shown are when surveys occurred in the same years.

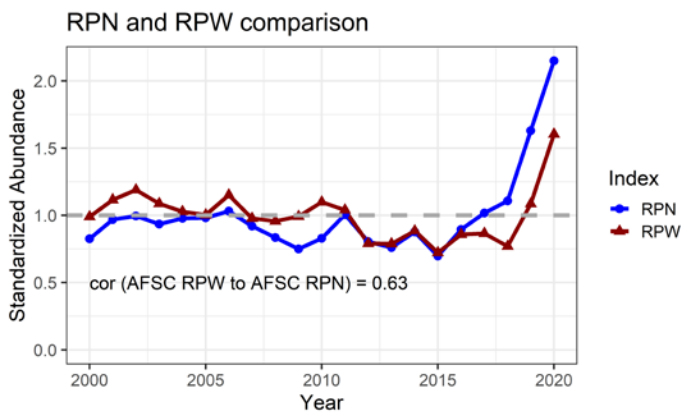


Figure 3.10b. Comparisons of AFSC longline survey indices. Relative Population Weight (RPW) is in weight and Relative Population Numbers (RPN) is in numbers. Only the RPN index is fit in the assessment model.

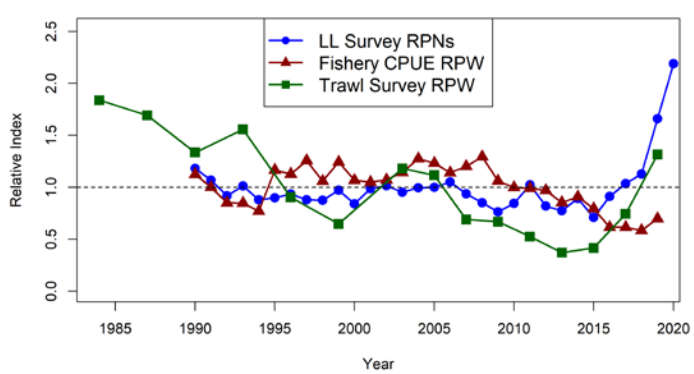


Figure 3.10c. Comparison of the three indices used in the stock assessment model including the AFSC longline survey RPNs, the fixed gear fishery CPUE, and the NMFS trawl survey RPWs. Each index is relativized to the associated mean value for the time series.

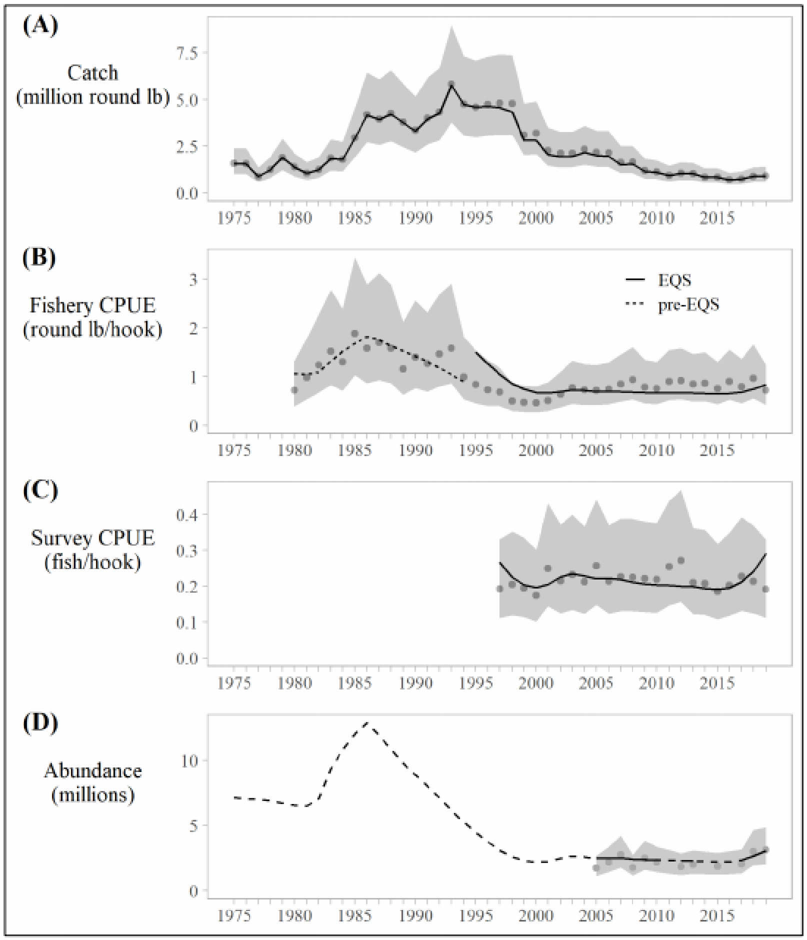


Figure 3.11a. Results of the Northern Southeast Inside (NSEI) sablefish stock assessment performed by the ADFG and reproduced here with permission (Sullivan et al., 2020). Observed data points are provided as grey dots and model predicted values as black lines. Assumed error distributions are given by the grey shaded polygons. Values include: total harvest (A); fishery CPUE pre- and post-implementation of the equal quota share (EQS) program in 1994 (B); longline survey CPUE (C); and mark-recapture abundance estimates (D).

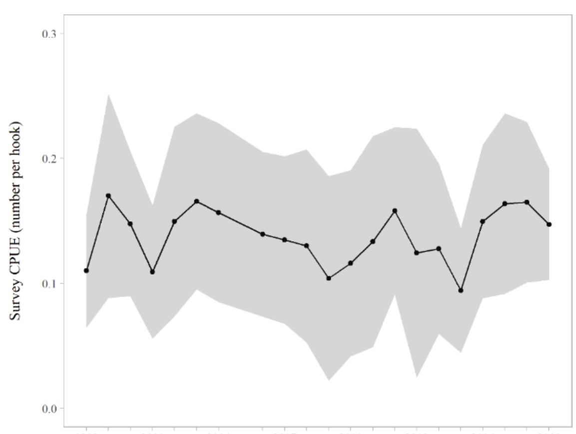


Figure 3.11b. Southern Southeast Inside (SSEI) sablefish longline survey catch-per-unit-effort (CPUE) in individuals/hook from 1998 to 2019. Reproduced here with permission (Ehresmann et al., 2020)

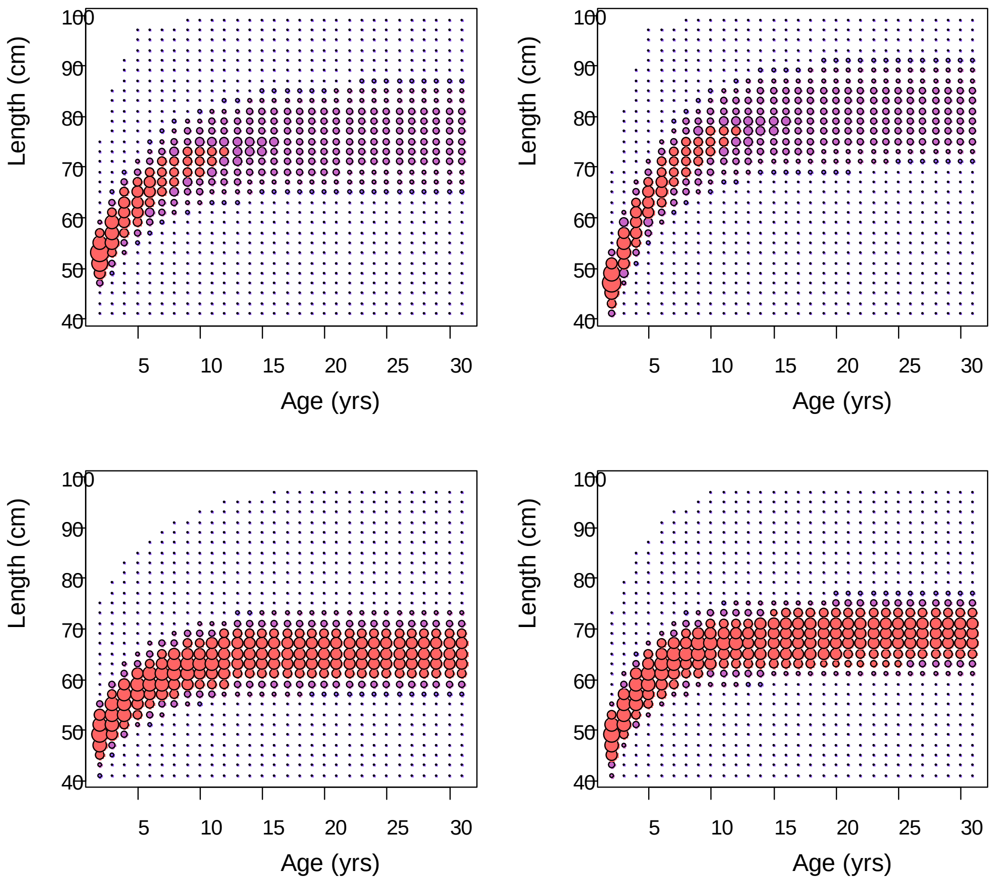


Figure 3.12a. Age-length conversion matrices for sablefish. Top panels are female, bottom panel are males, left is 1960-1995, and right is 1996 - 2020.

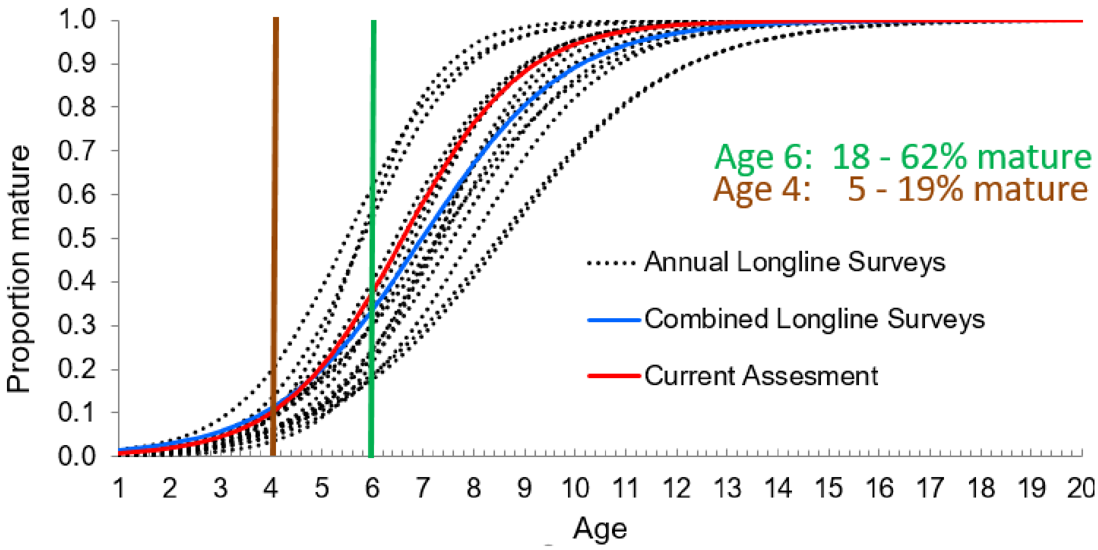


Figure 3.12b. Logistic maturity curves estimated from annual longline survey macroscopic scans. Dashed lines illustrate the annual variability, the red solid line is the estimate from the pooled data which is similar to the static value used in the assessment. Age-4 (brown vertical line) and age-6 (green vertical line) are highlighted to show the range of maturity estimates for the large 2014 and 2016 year classes.

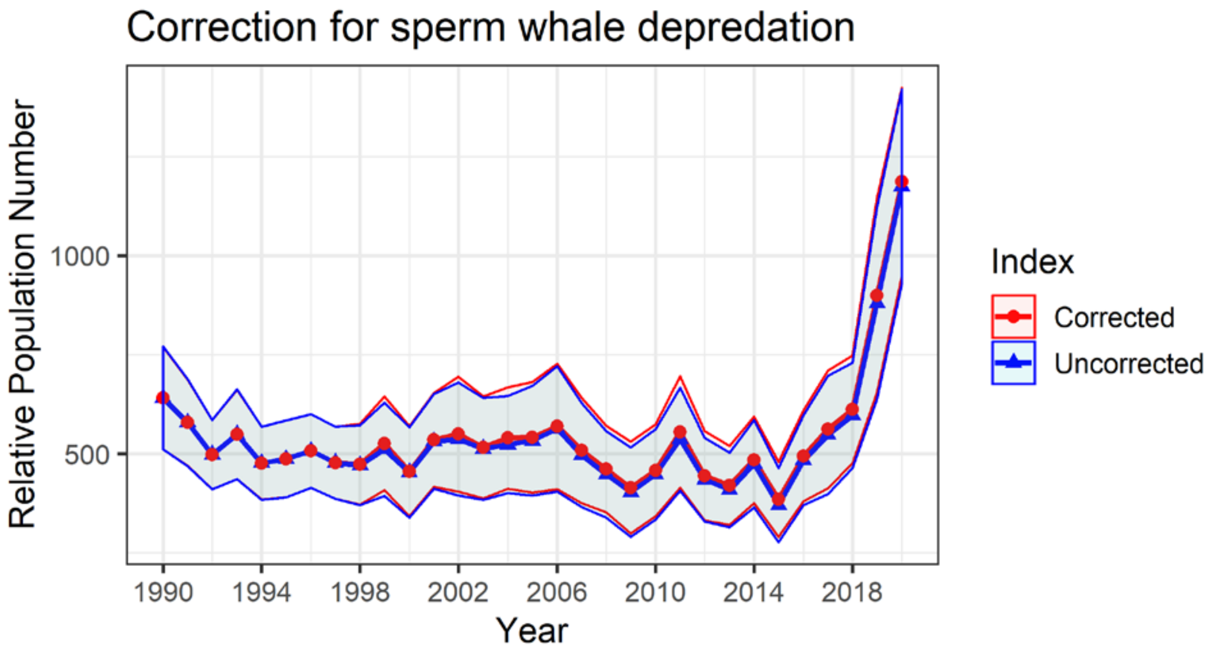


Figure 3.13. Total longline sablefish RPN index with (red circles) and without (blue triangles) sperm whale corrections 1990 - 2020. Shaded regions are approximate 95% confidence intervals.

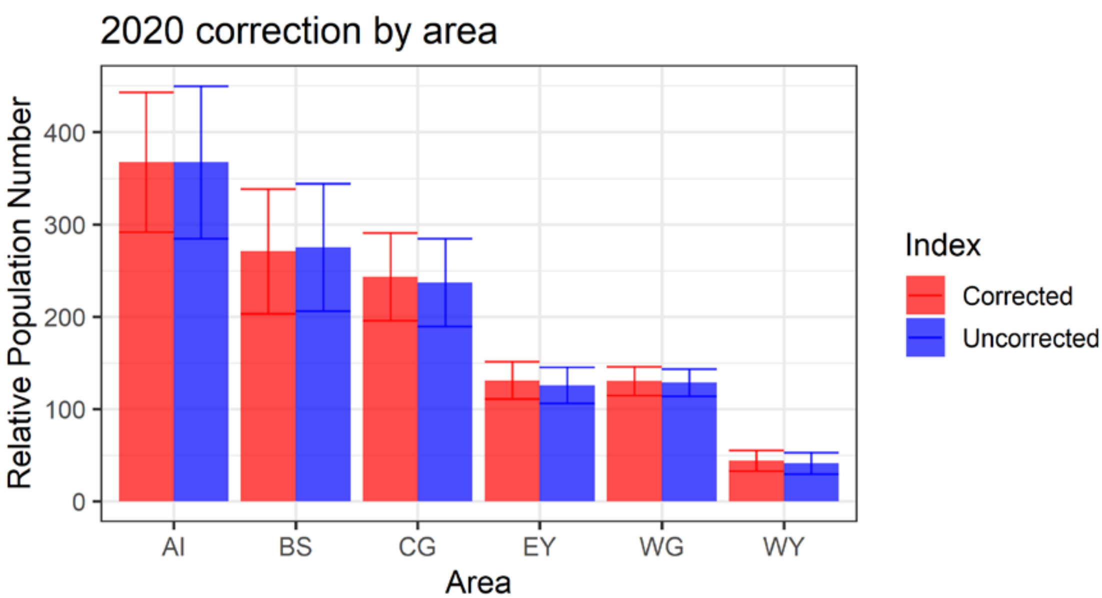


Figure 3.14. Longline sablefish RPN index by area with (red bars) and without (blue bars) sperm whale corrections 1990 - 2020. Error bars are approximate 95% confidence intervals.

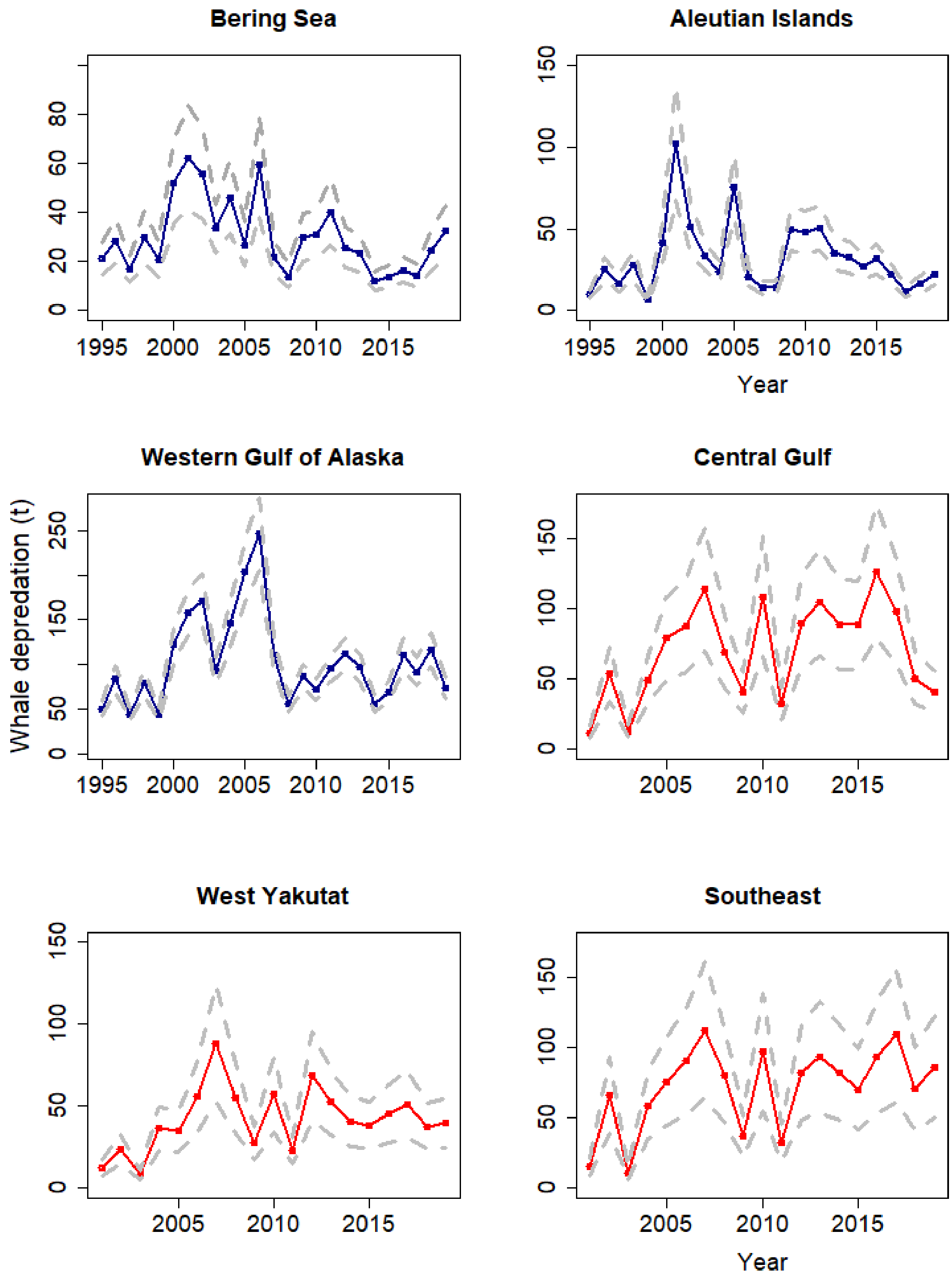


Figure 3.15. Estimated sablefish catch removals (t) with ~95% confidence bands by region due to sperm whale (red) and killer whale (blue) depredation, 1995 - 2019. 2019 is not a complete estimate.

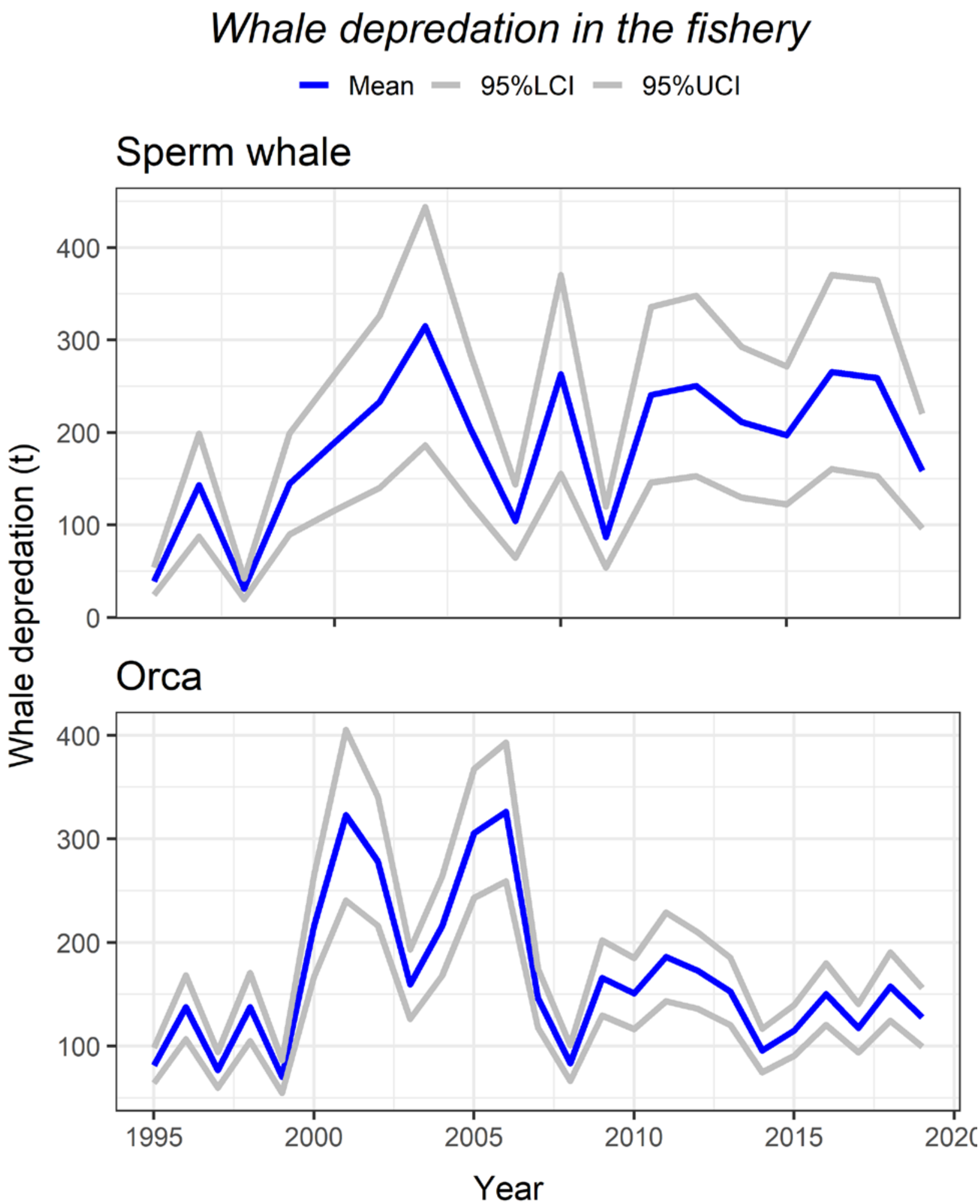


Figure 3.16. Additional estimated sablefish mortality (blue) by two whale species with 95% asymptotic normal confidence intervals (grey lines).

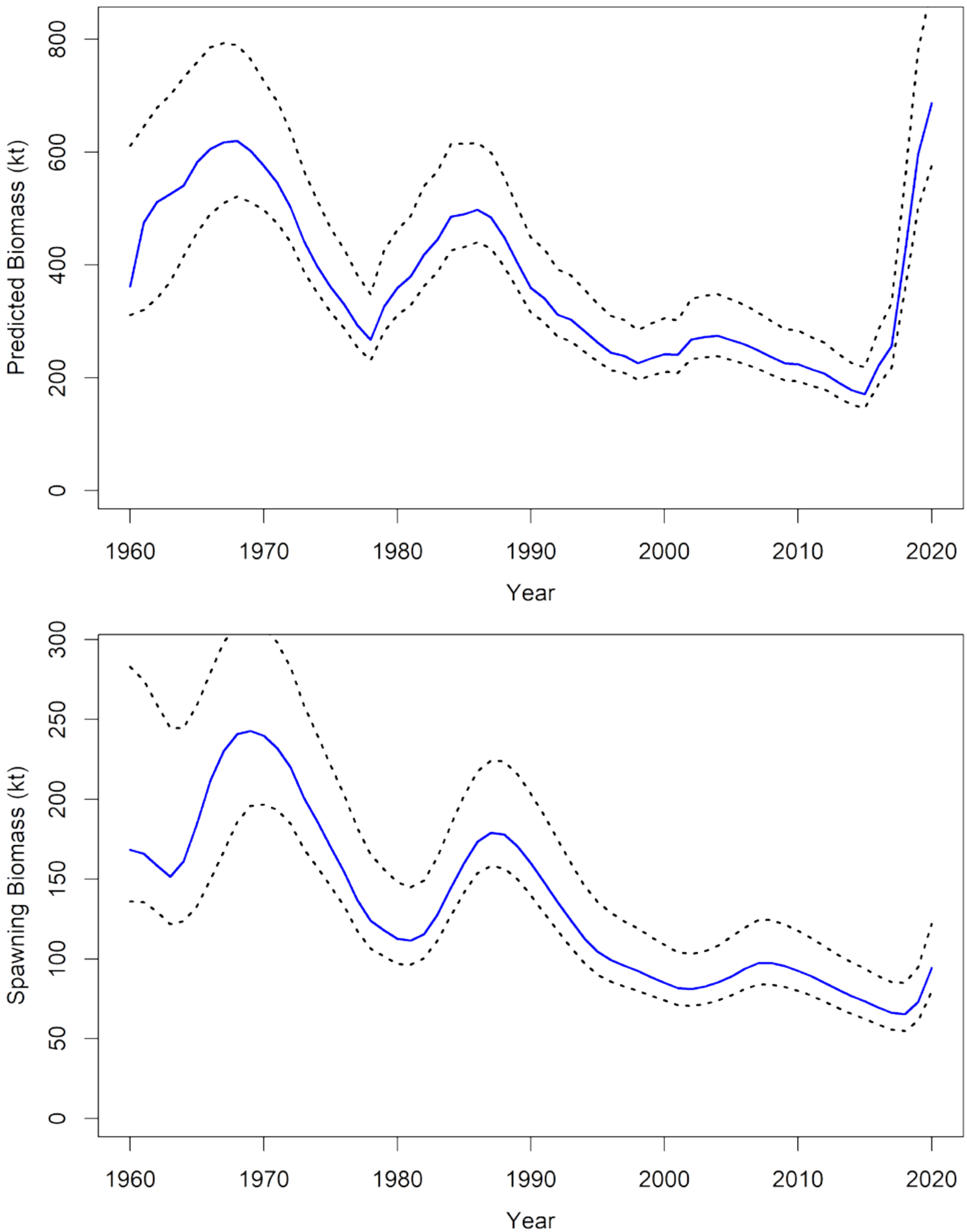


Figure 3.17. Estimated sablefish total biomass (top panel) and spawning biomass (bottom panel) with 95% MCMC credible intervals. Values are in kilotons.

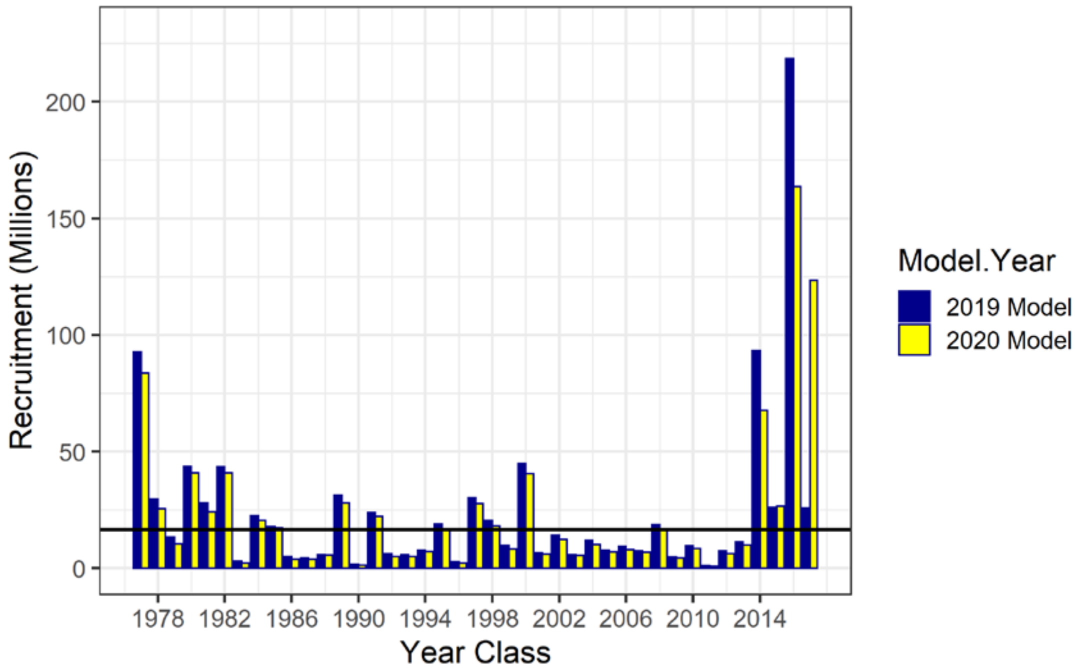


Figure 3.18a. Estimated recruitment by year class (1977-2017) in number of age-2 fish (millions of fish) for the 2019 and 2020 models. Black line is mean recruitment from the 2020 model for 1977 to 2017 yearclasses. Note that the 2017 yearclass for the 2019 model is equivalent to the estimated mean recruitment value (μ_r) given that no recruit deviation is estimated in the terminal year.

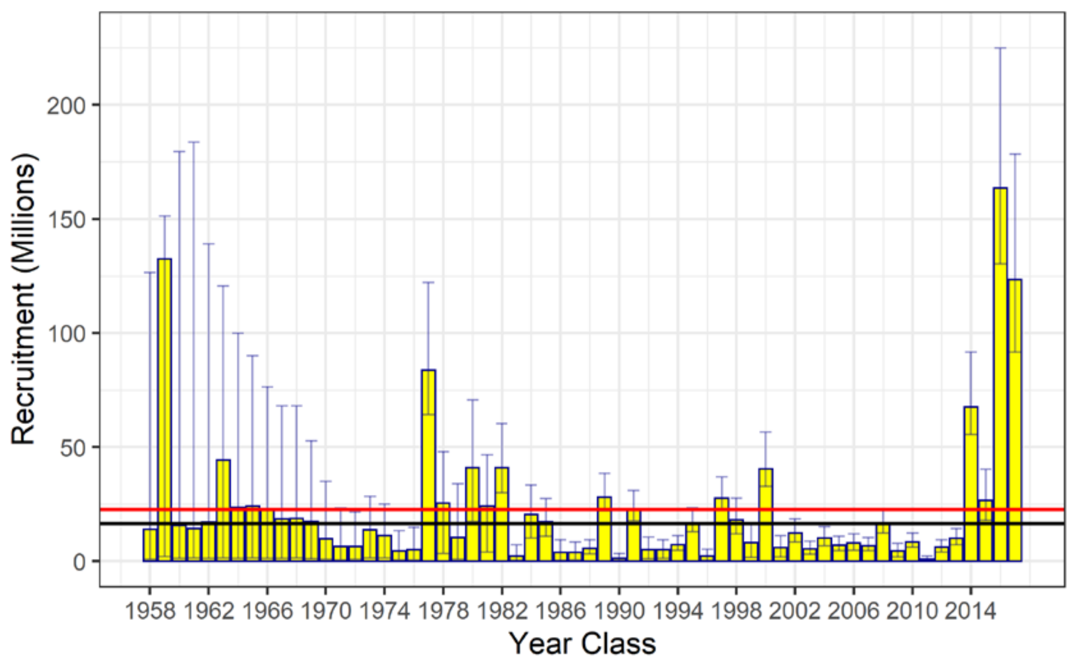


Figure 3.18b. Estimated recruitment of age-2 sablefish (millions of fish) with 95% credible intervals from MCMC by year class (recruitment year minus two). Red line is overall mean, while black line is recruitments from year classes between 1977 and 2017. Credible intervals are based on MCMC posteriors. The estimate for the 2018 year class (terminal year 2020 recruitment event) is omitted, because it is fixed to the estimated mean recruitment value (μ_r) with no deviation parameter estimated.

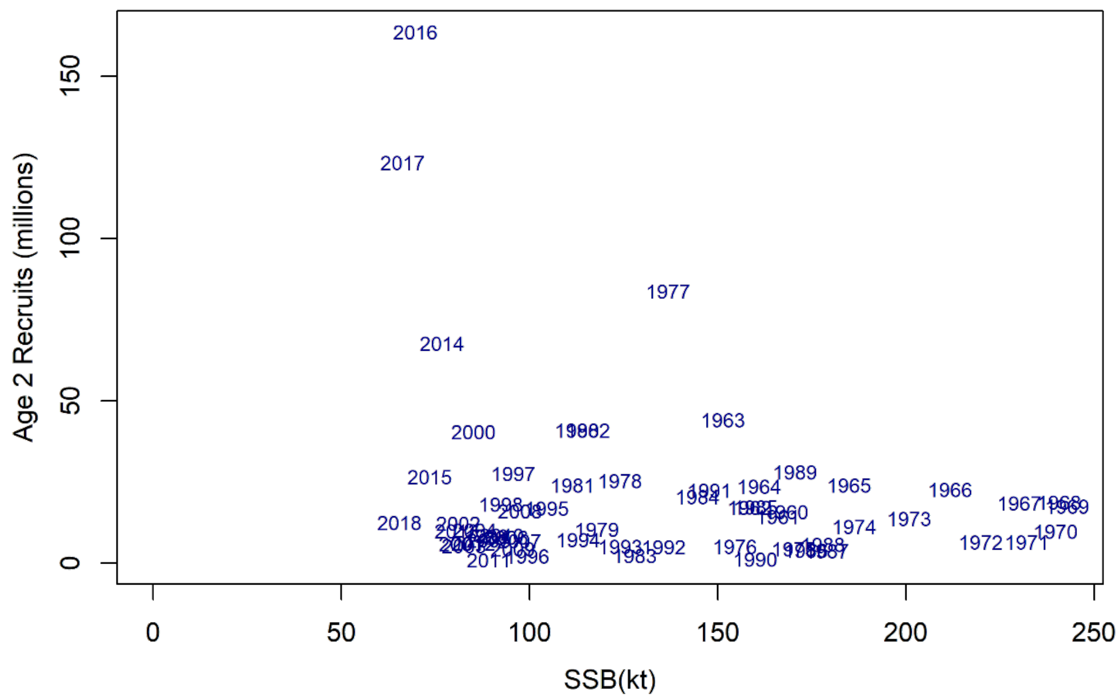


Figure 3.18c. Age-2 recruits (millions of fish) and corresponding spawning stock biomass (kt) for each year class (identified by plotted year text).

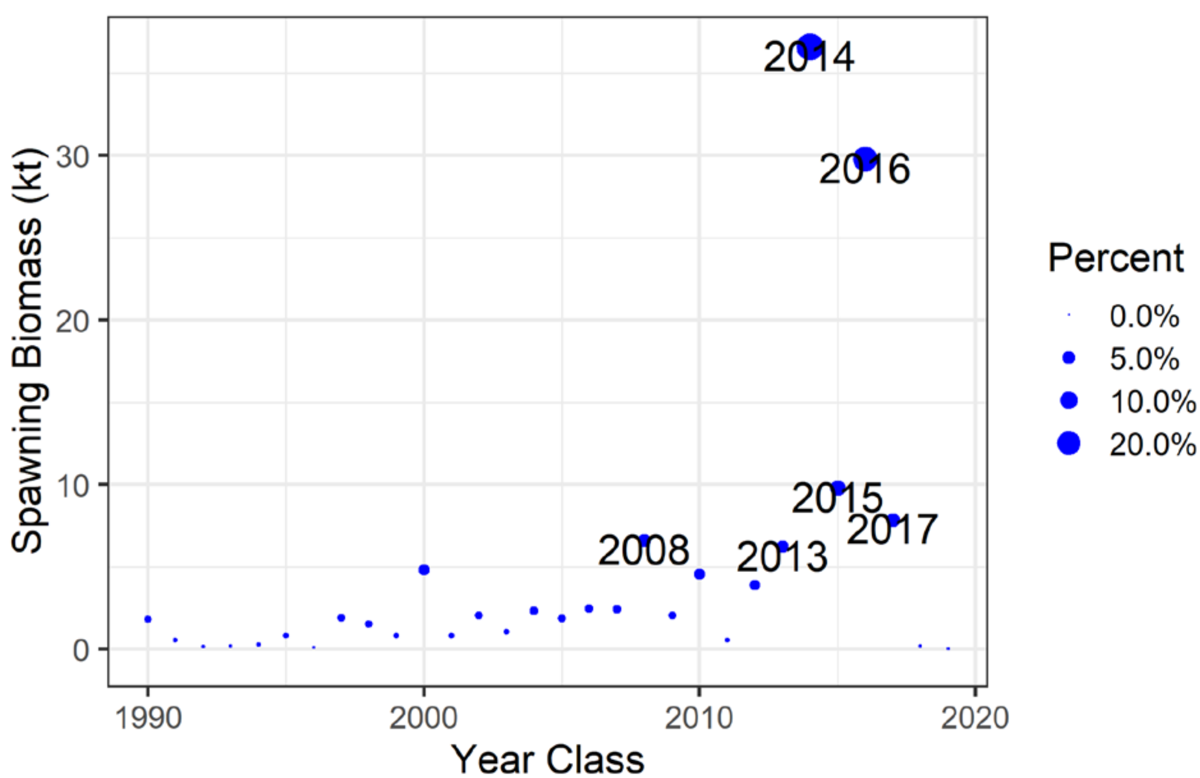


Figure 3.19. Contribution of the last 30 year classes to the projected female spawning biomass in 2021.

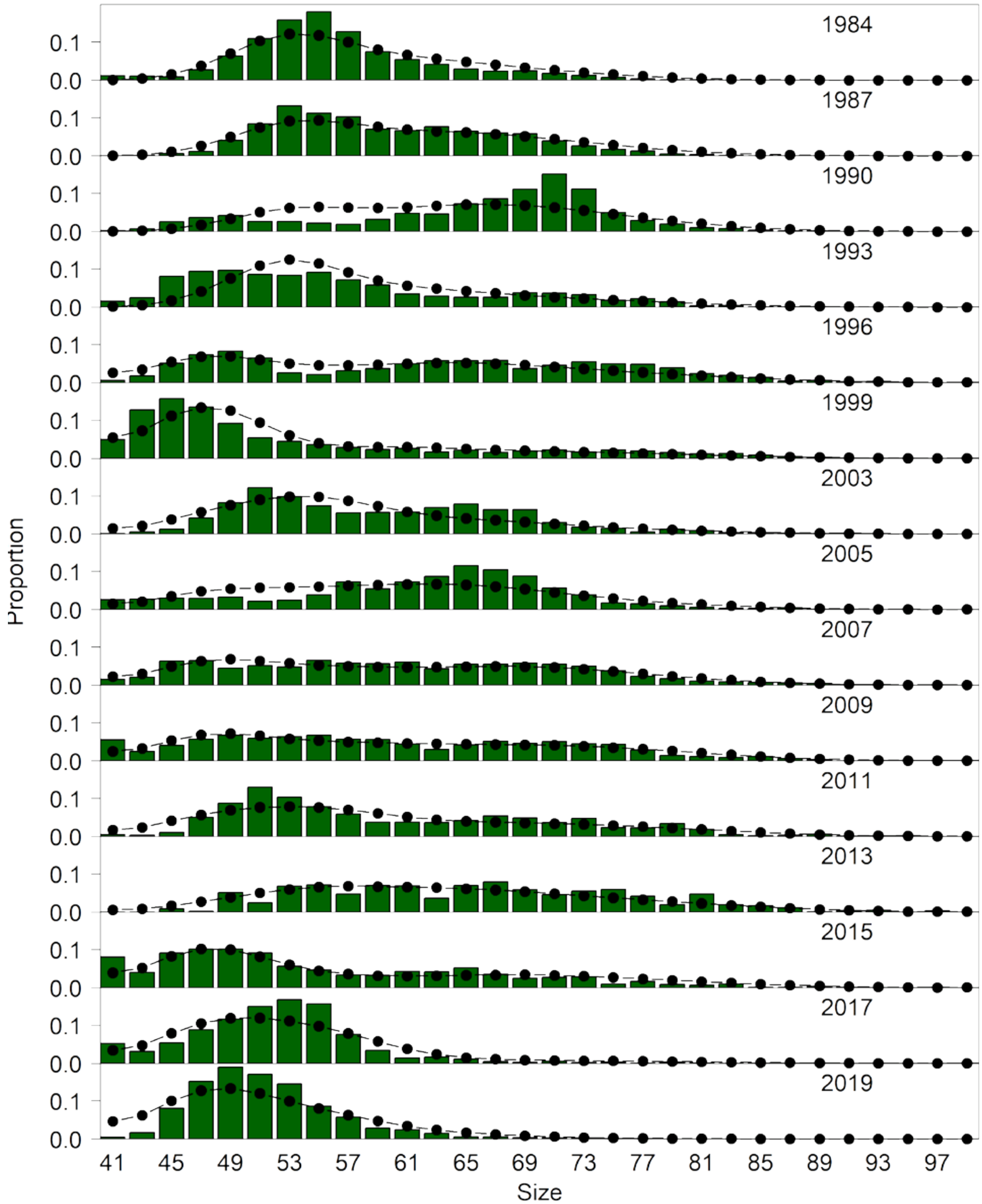


Figure 3.20. Gulf of Alaska bottom trawl survey length (cm) compositions for female sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

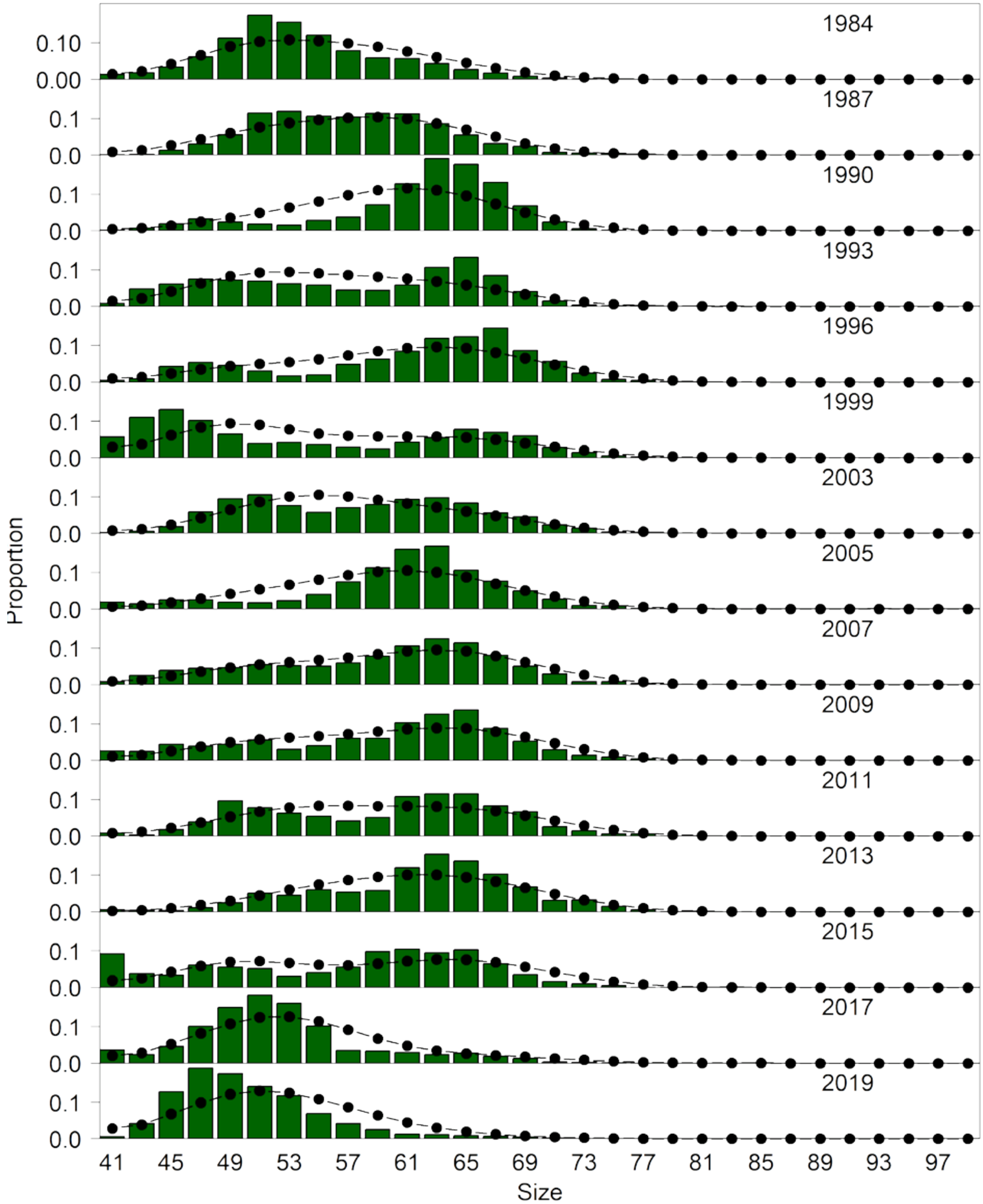


Figure 3.21. Gulf of Alaska bottom trawl survey length (cm) compositions for male sablefish at depths <500 m. Bars are observed frequencies and lines are predicted frequencies.

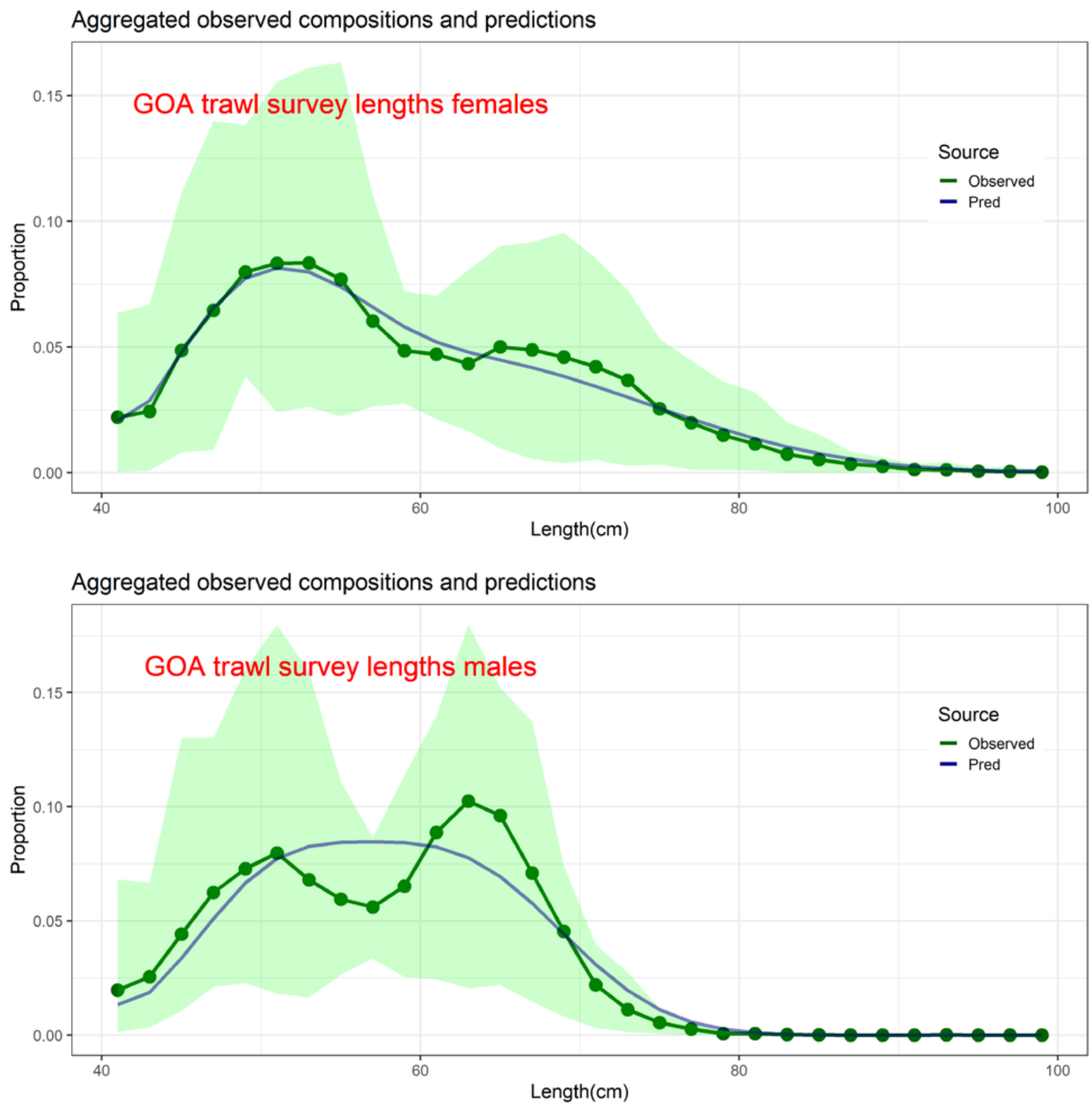


Figure 3.22. Mean observed (green line) Gulf of Alaska trawl survey length compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

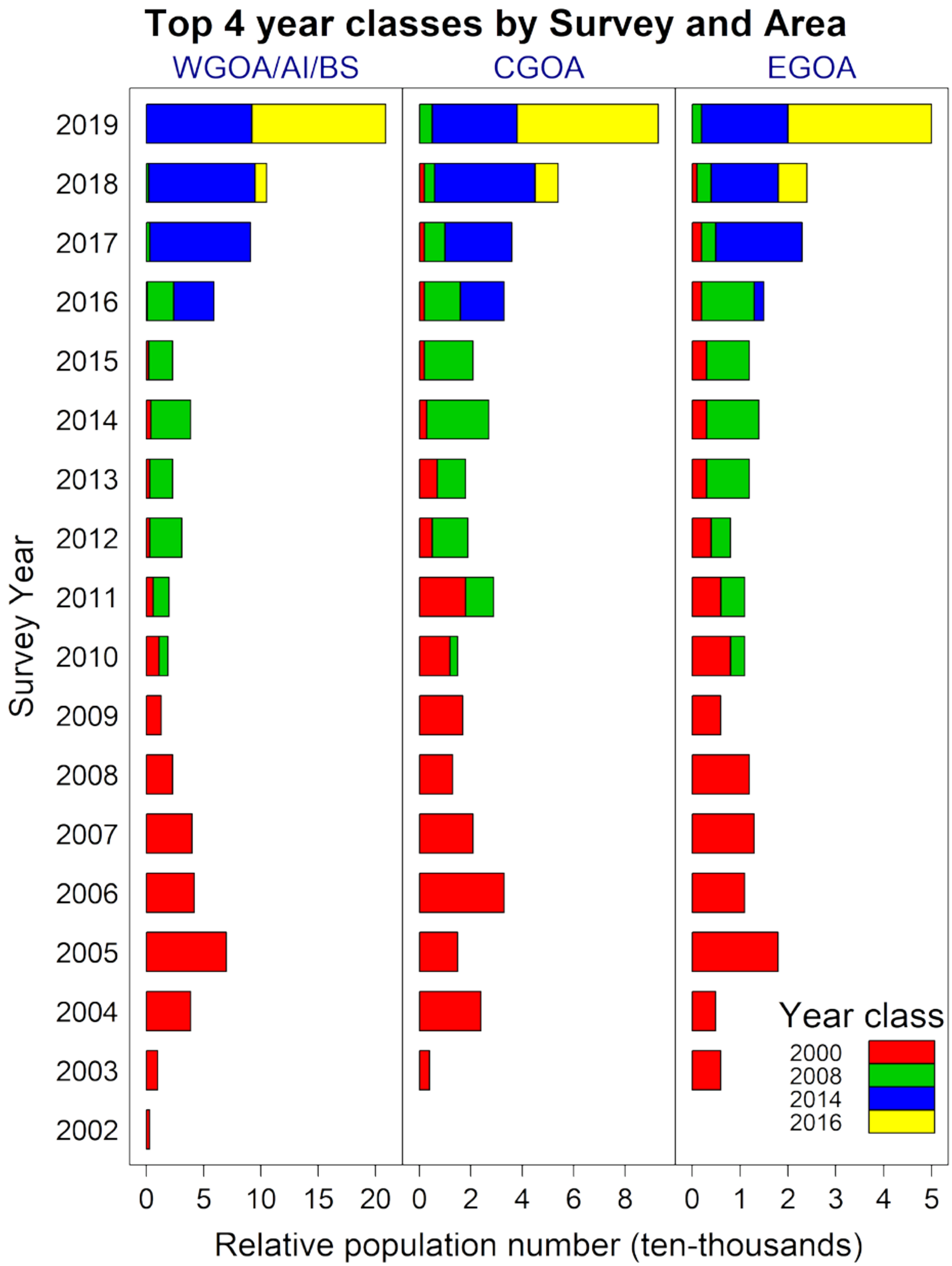


Figure 3.23. Above average 2000, 2008, 2014, and 2016 year classes' relative population abundance in the longline survey by year and area.

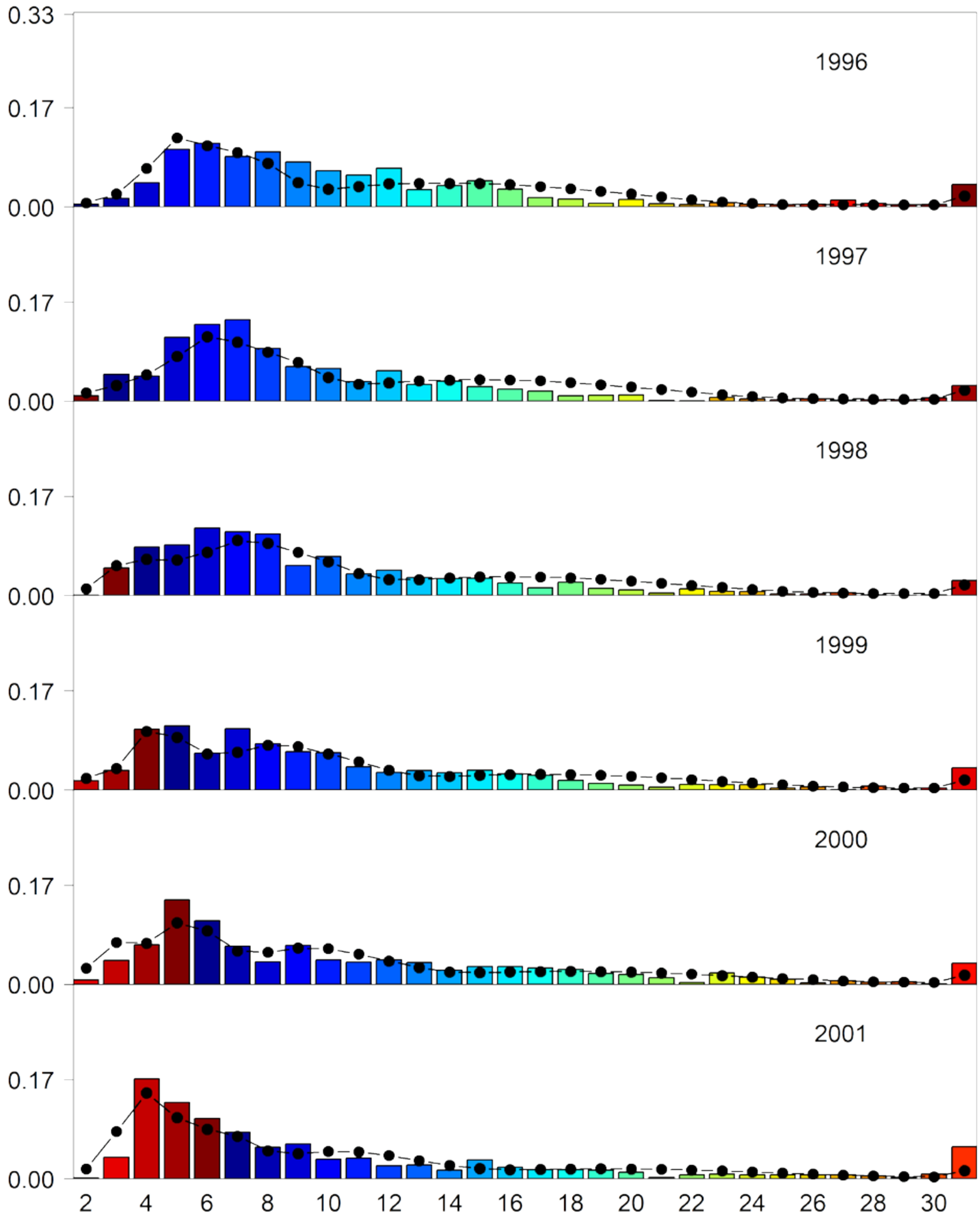


Figure 3.24. Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

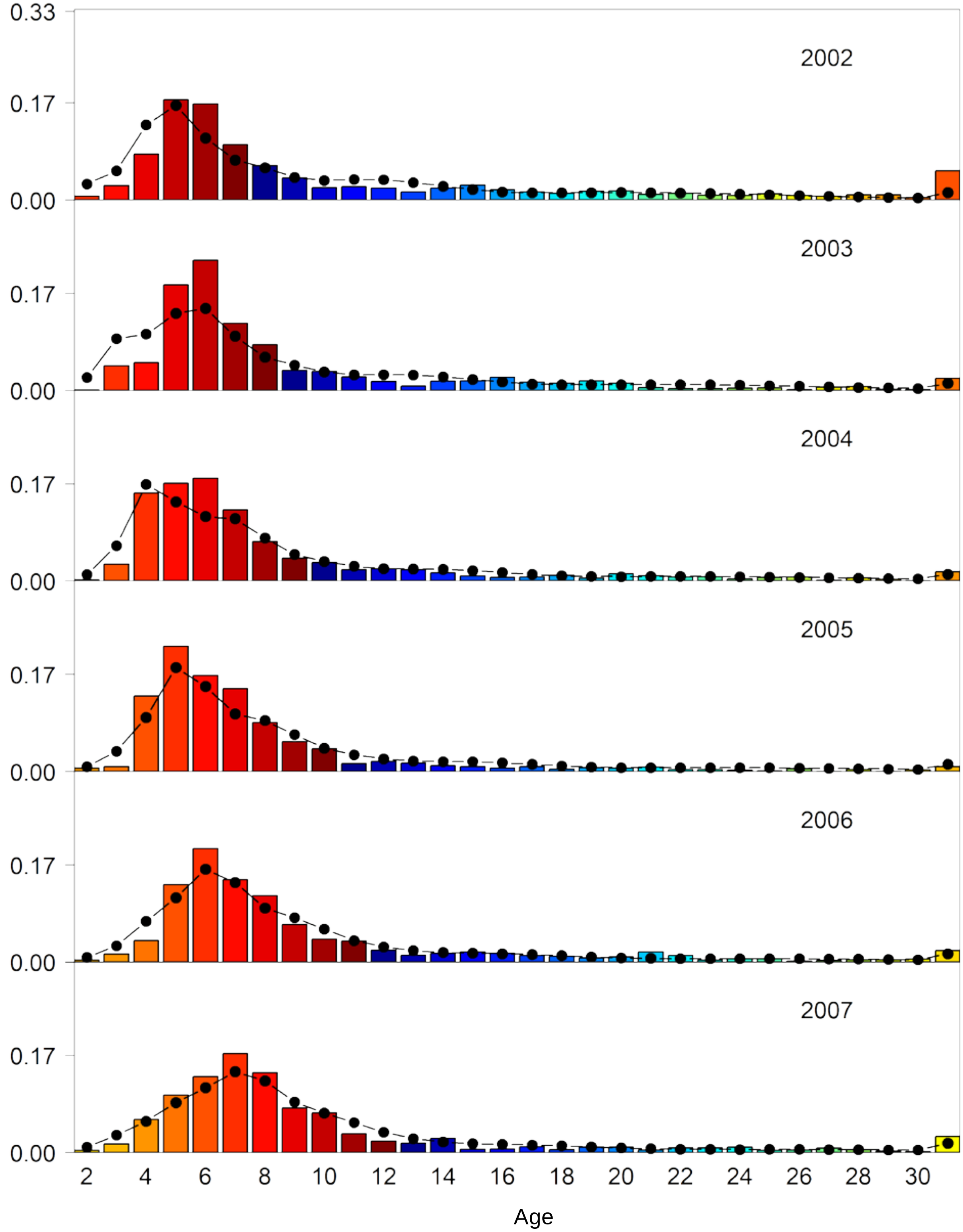


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

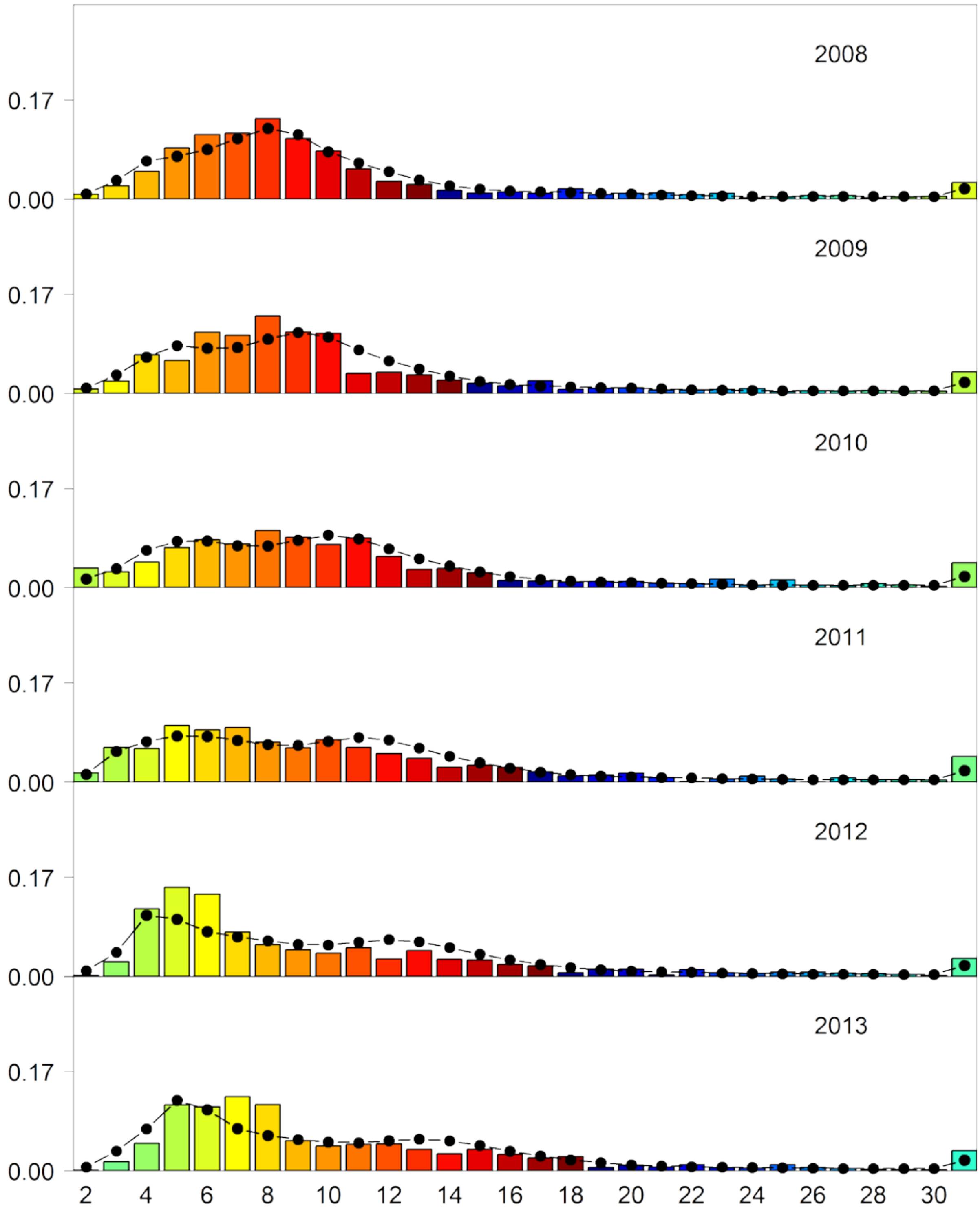


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

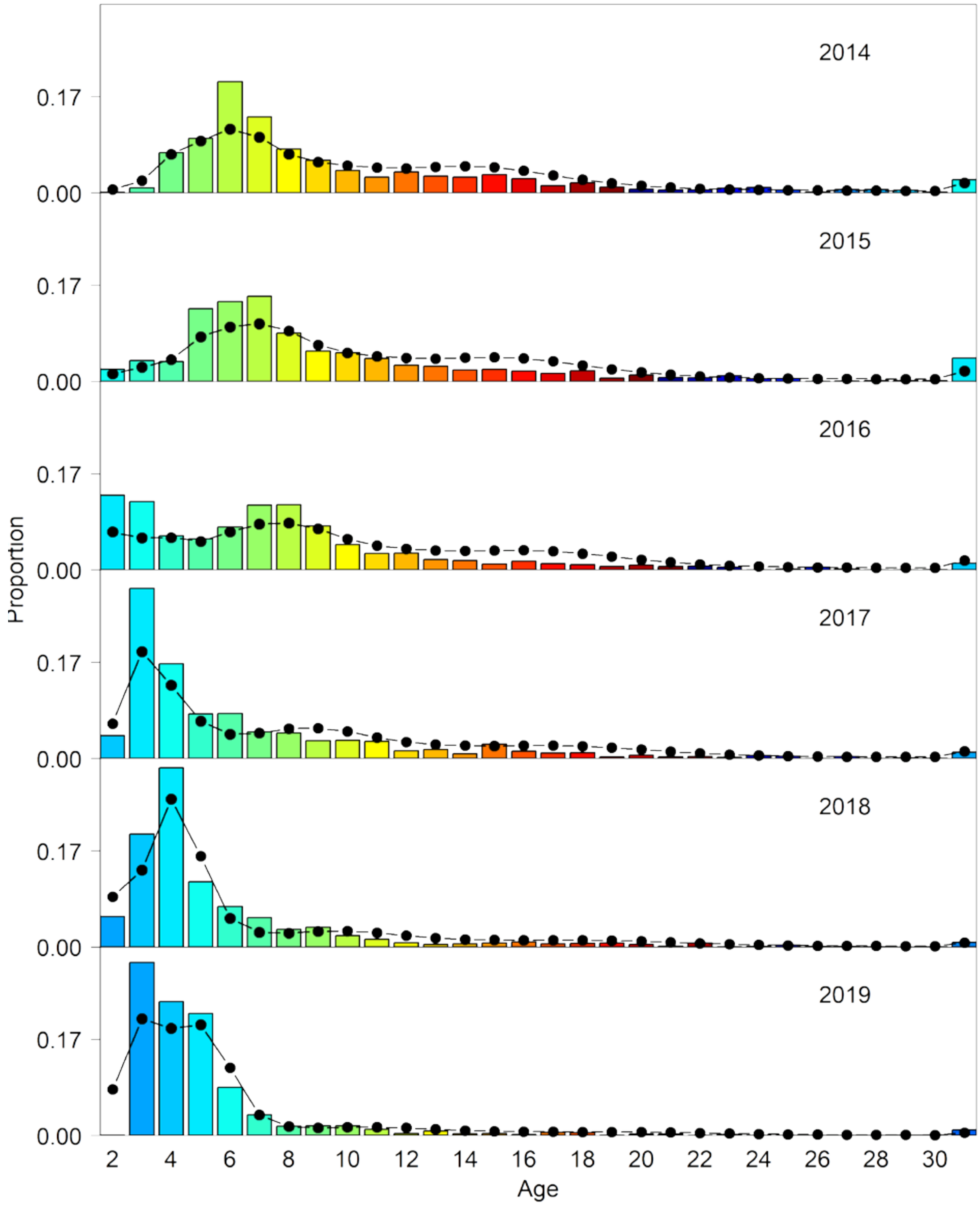


Figure 3.24 (cont.). Domestic longline survey age compositions. Bars are observed frequencies and lines are predicted frequencies.

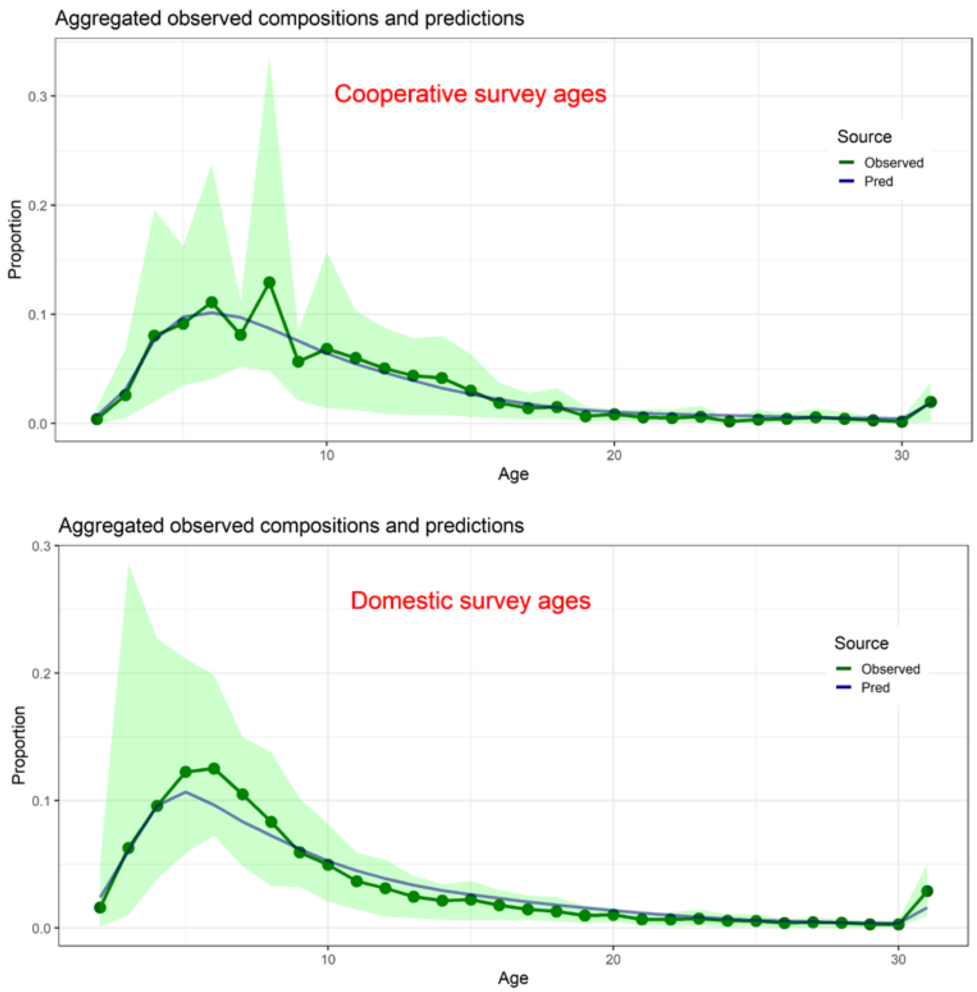


Figure 3.25a. Mean observed (green line) cooperative (top panel) and domestic (bottom panel) longline survey age compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals.

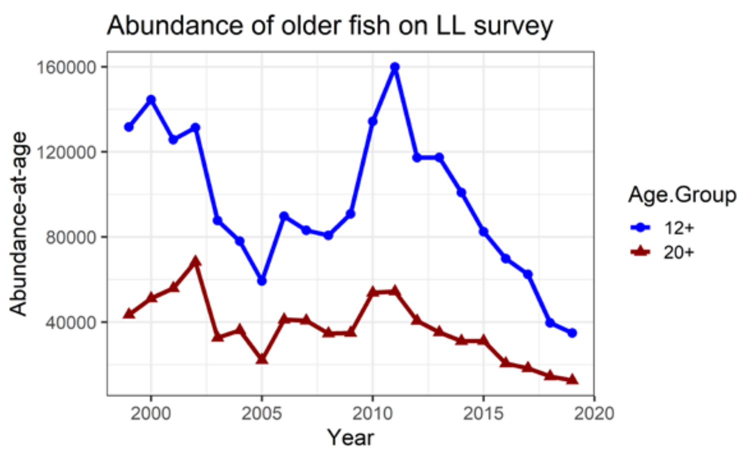


Figure 3.25b. Relative population numbers of fish age-12 and above (blue circles) and age-20 and aboce (red triangles) caught on the AFSC longline survey during 1999 – 2019.

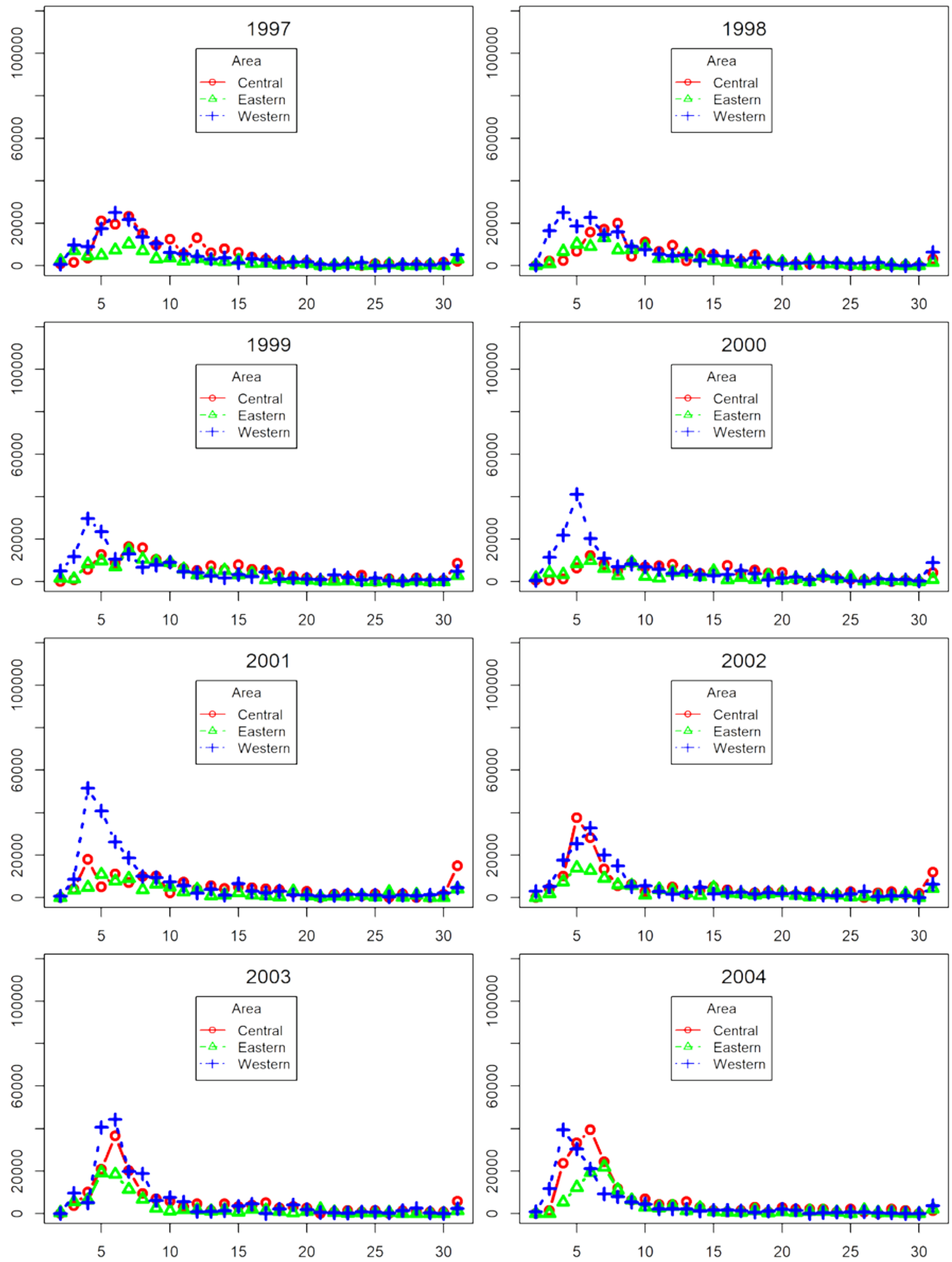


Figure 3.26. Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined into the 'western' area.

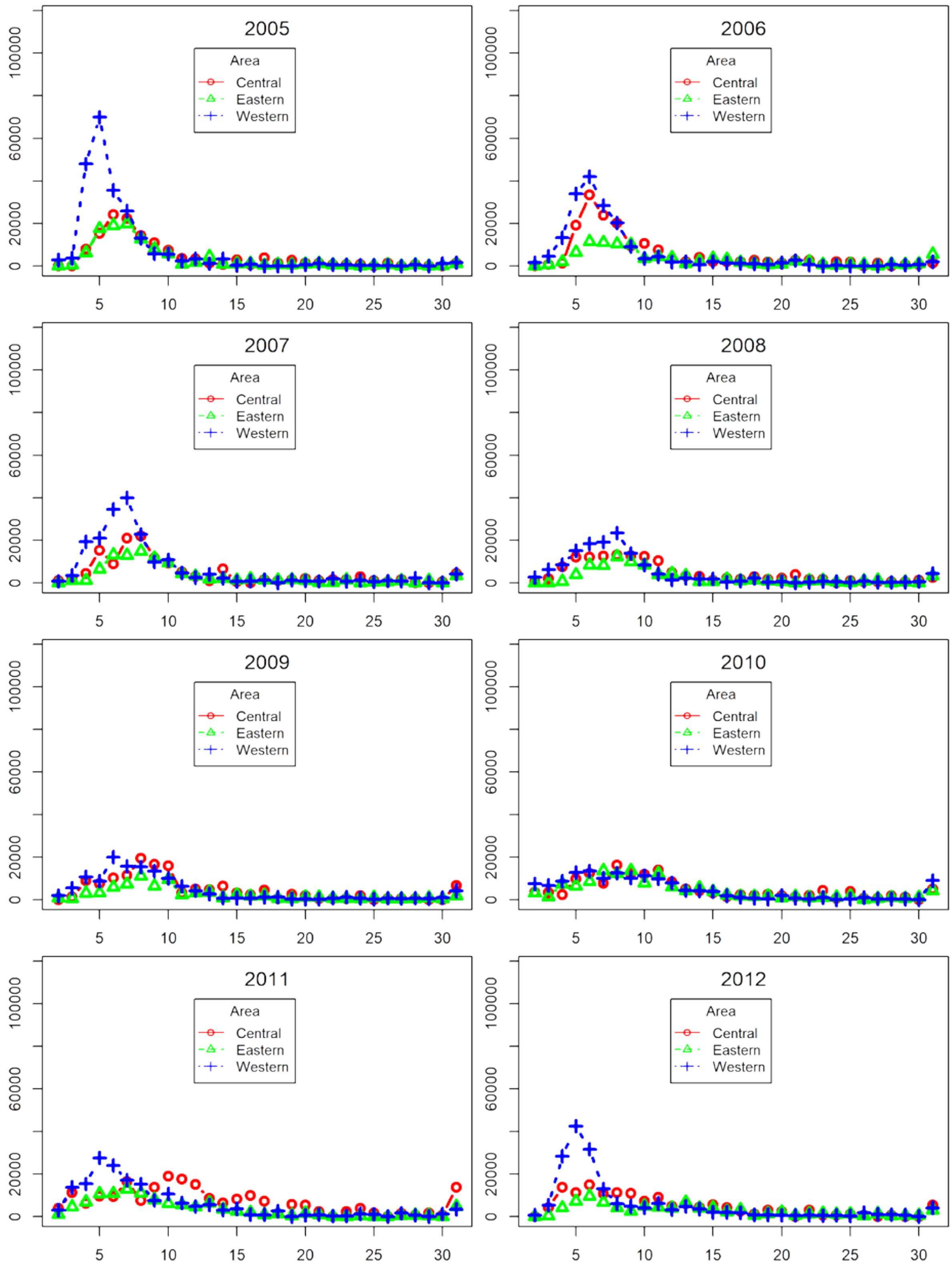


Figure 3.26 (Cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined into the 'western' area.

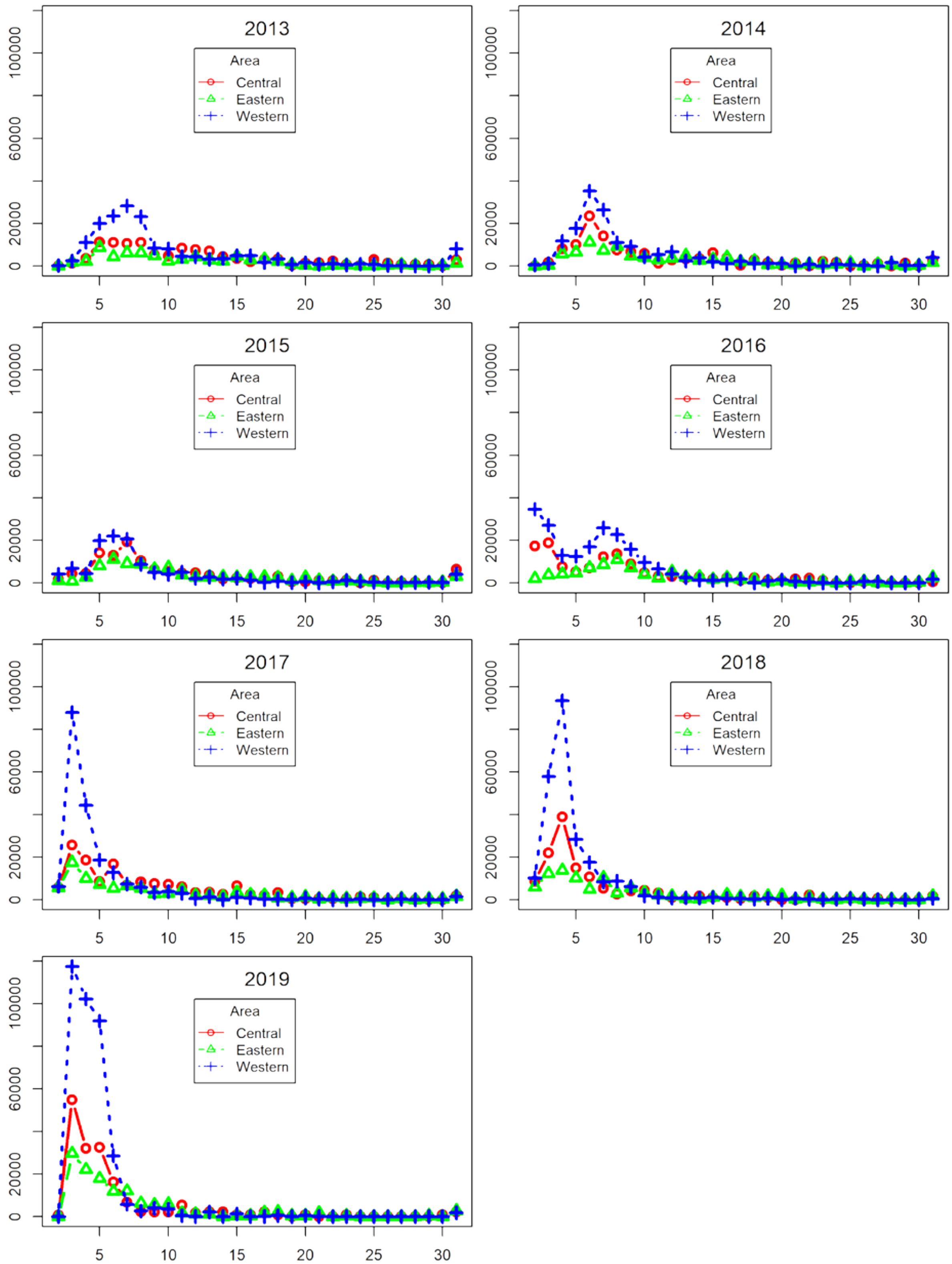


Figure 3.26 (Cont.). Relative abundance (number in thousands) by age and region from the domestic (U.S.) longline survey. The regions Bering Sea, Aleutian Islands, and Western Gulf of Alaska are combined into the 'western' area.

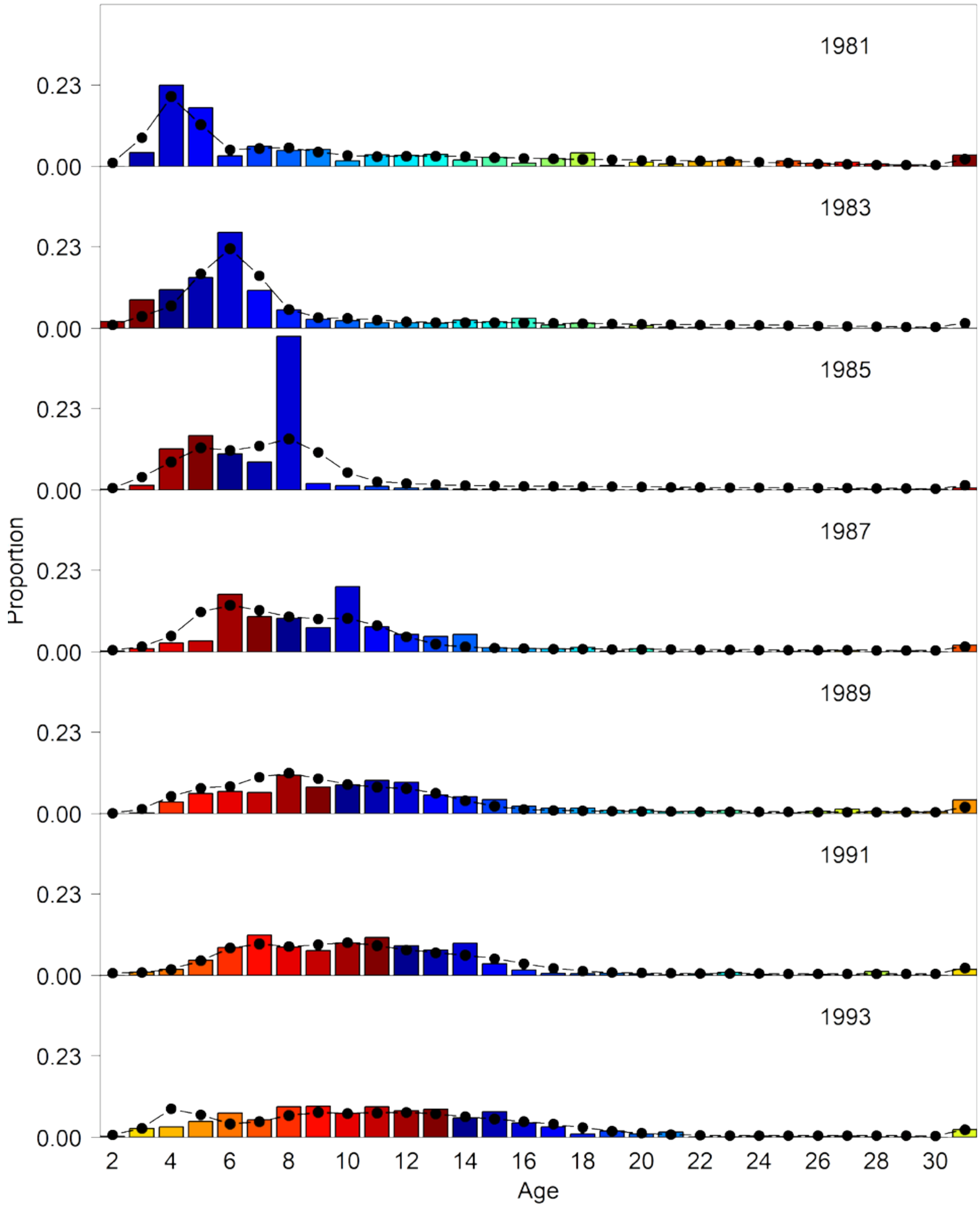


Figure 3.27. Japanese longline survey age compositions. Bars are observed frequencies and line is predicted frequencies.

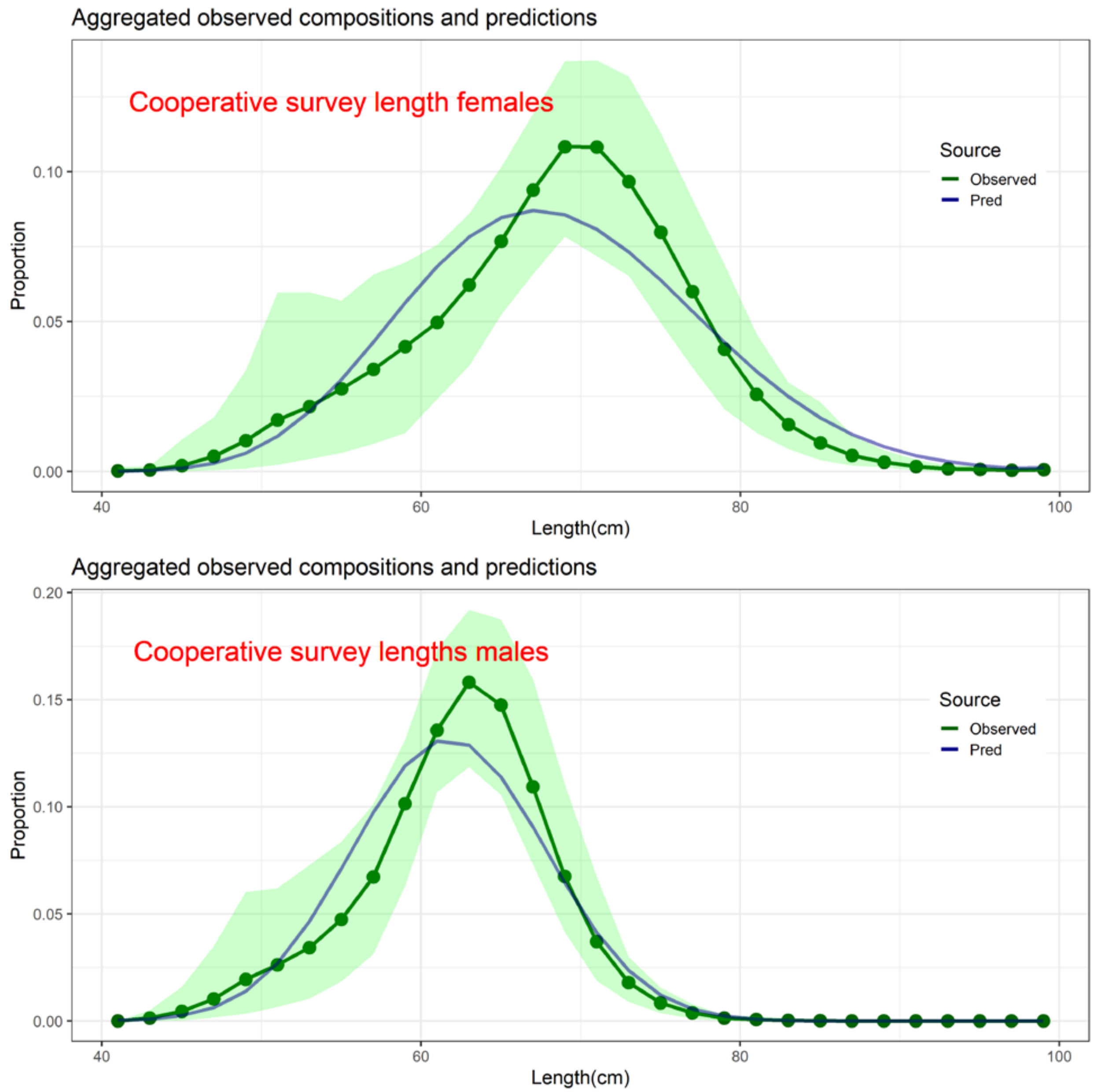


Figure 3.28. Mean observed (green line) cooperative longline survey length compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

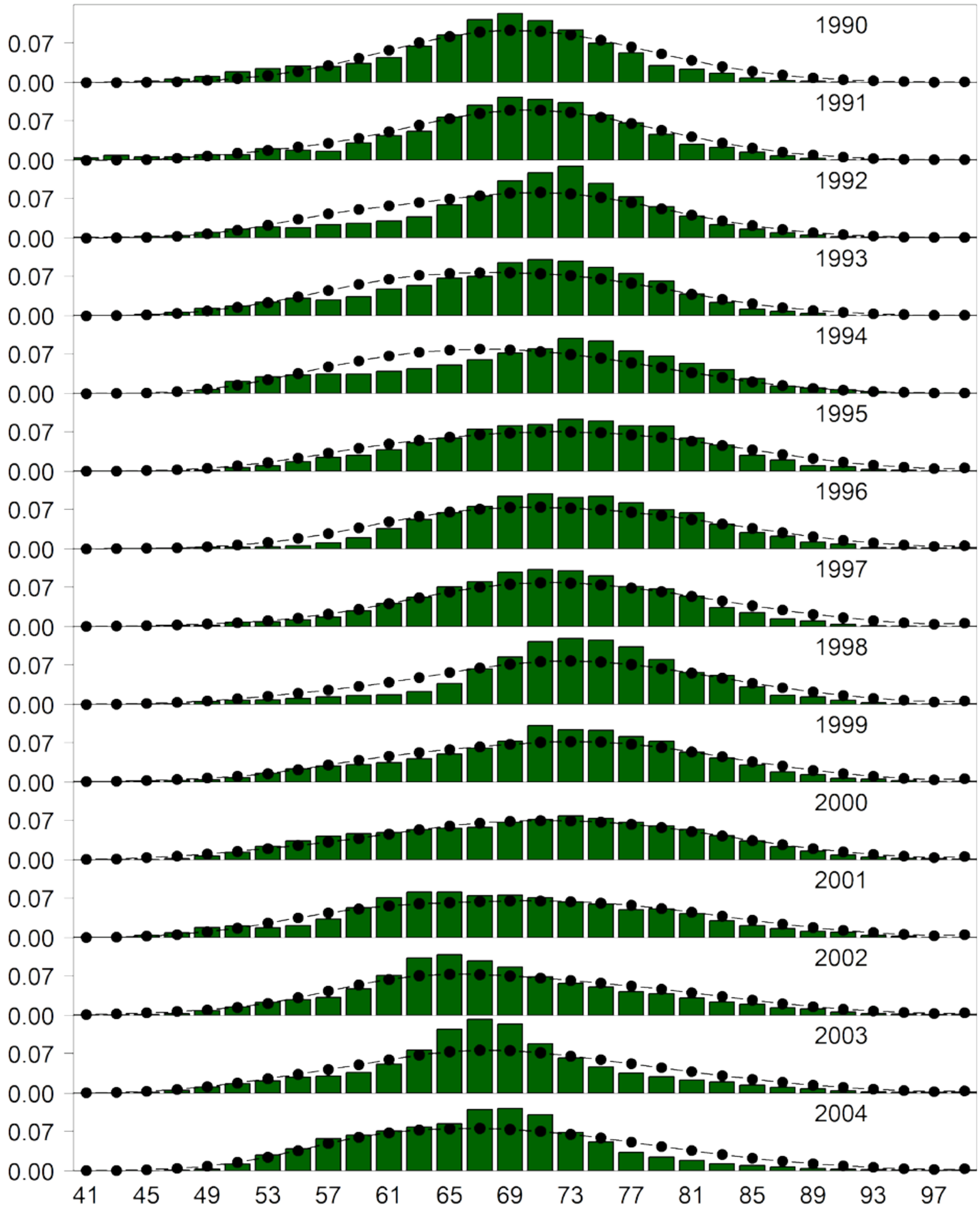


Figure 3.29. Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

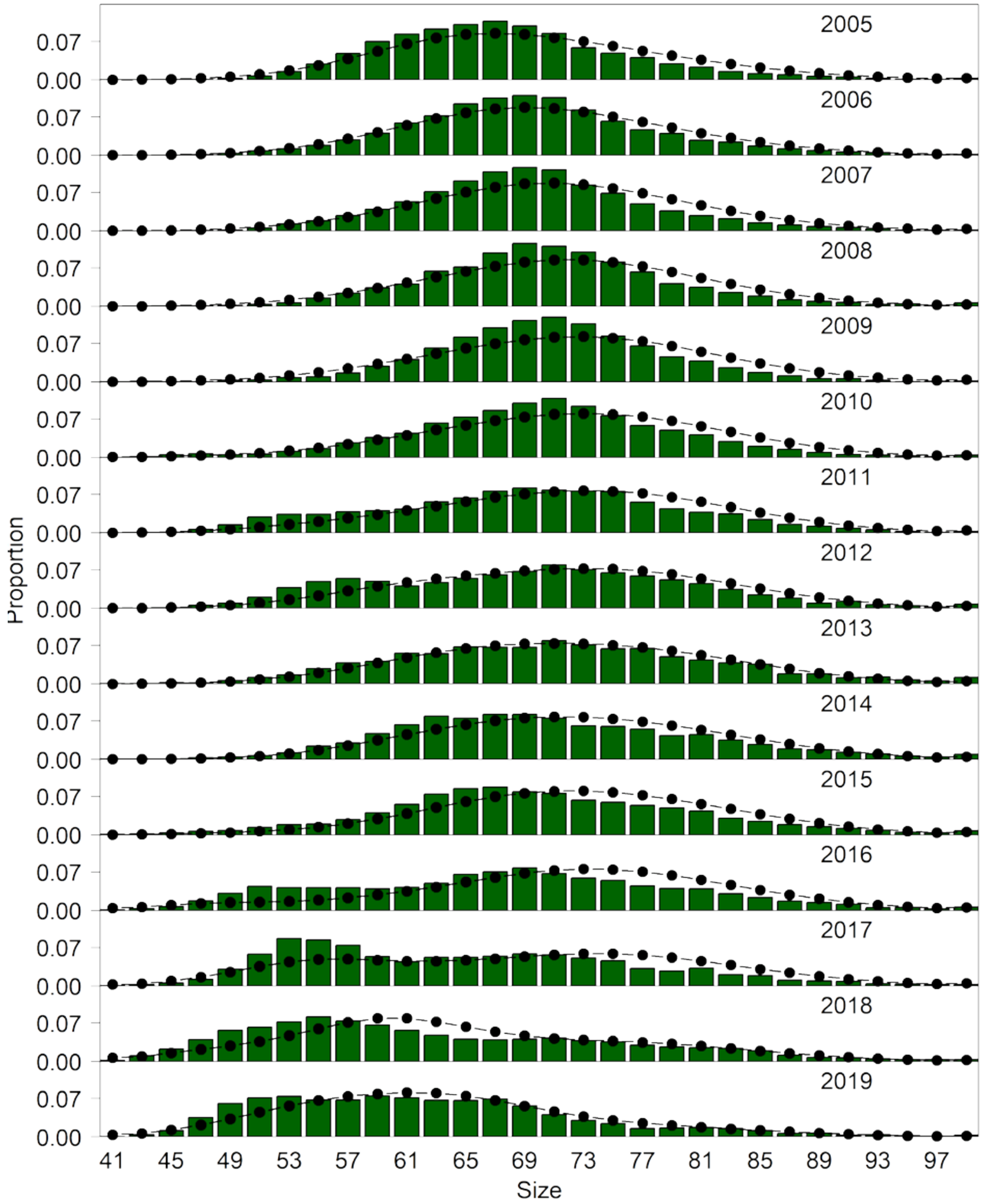


Figure 3.29 (cont.). Domestic fixed gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

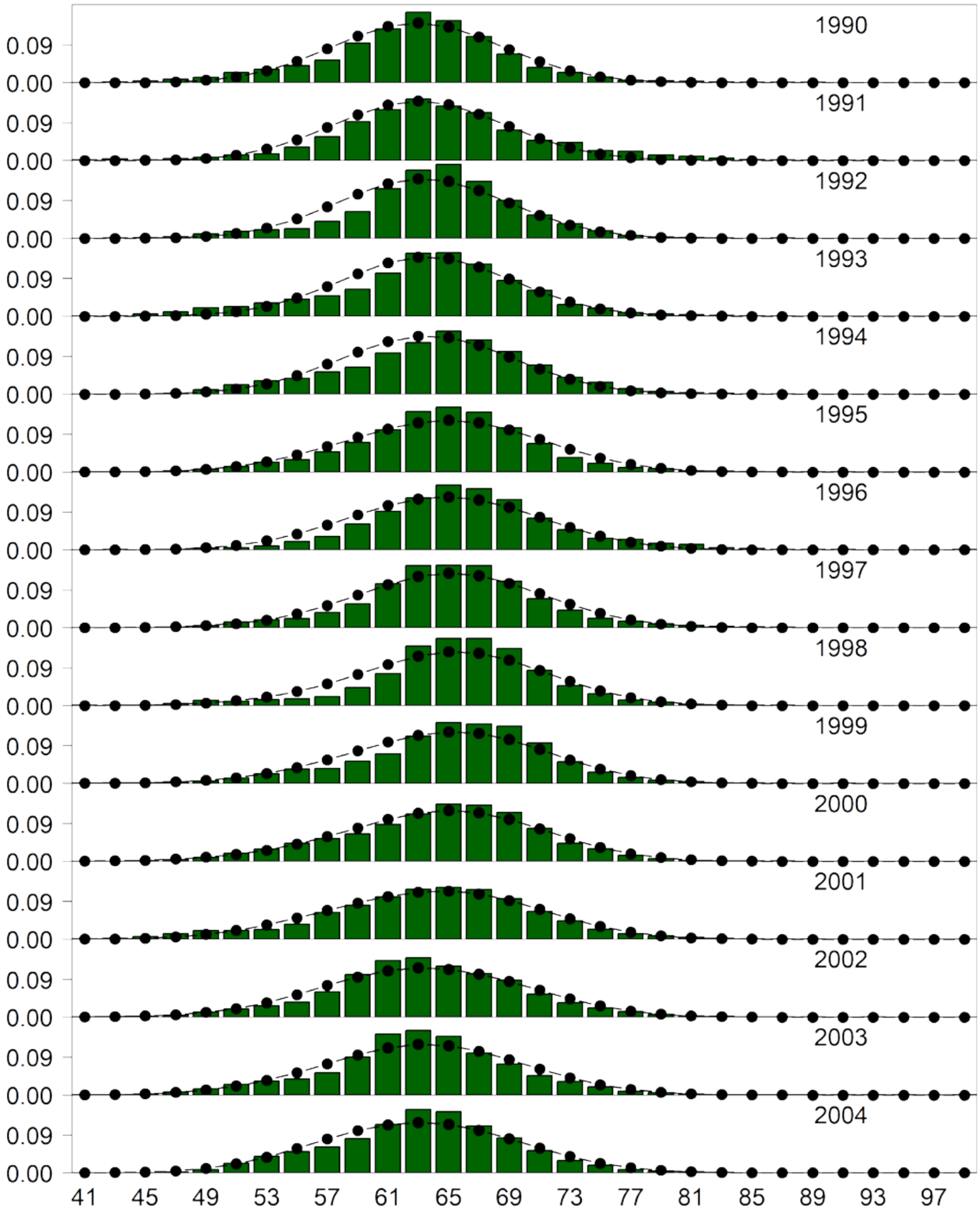


Figure 3.30. Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

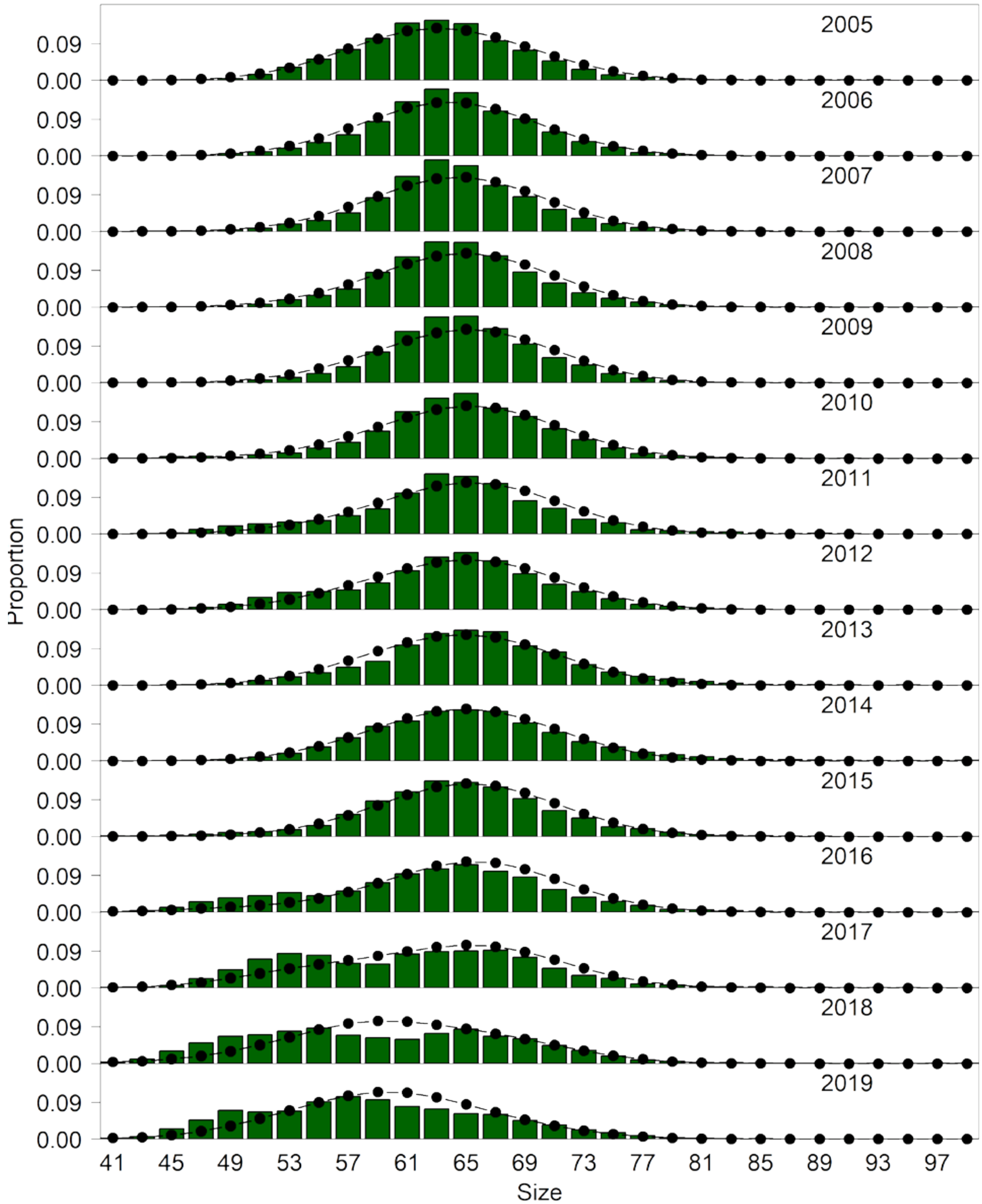


Figure 3.30 (Cont.). Domestic fixed gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

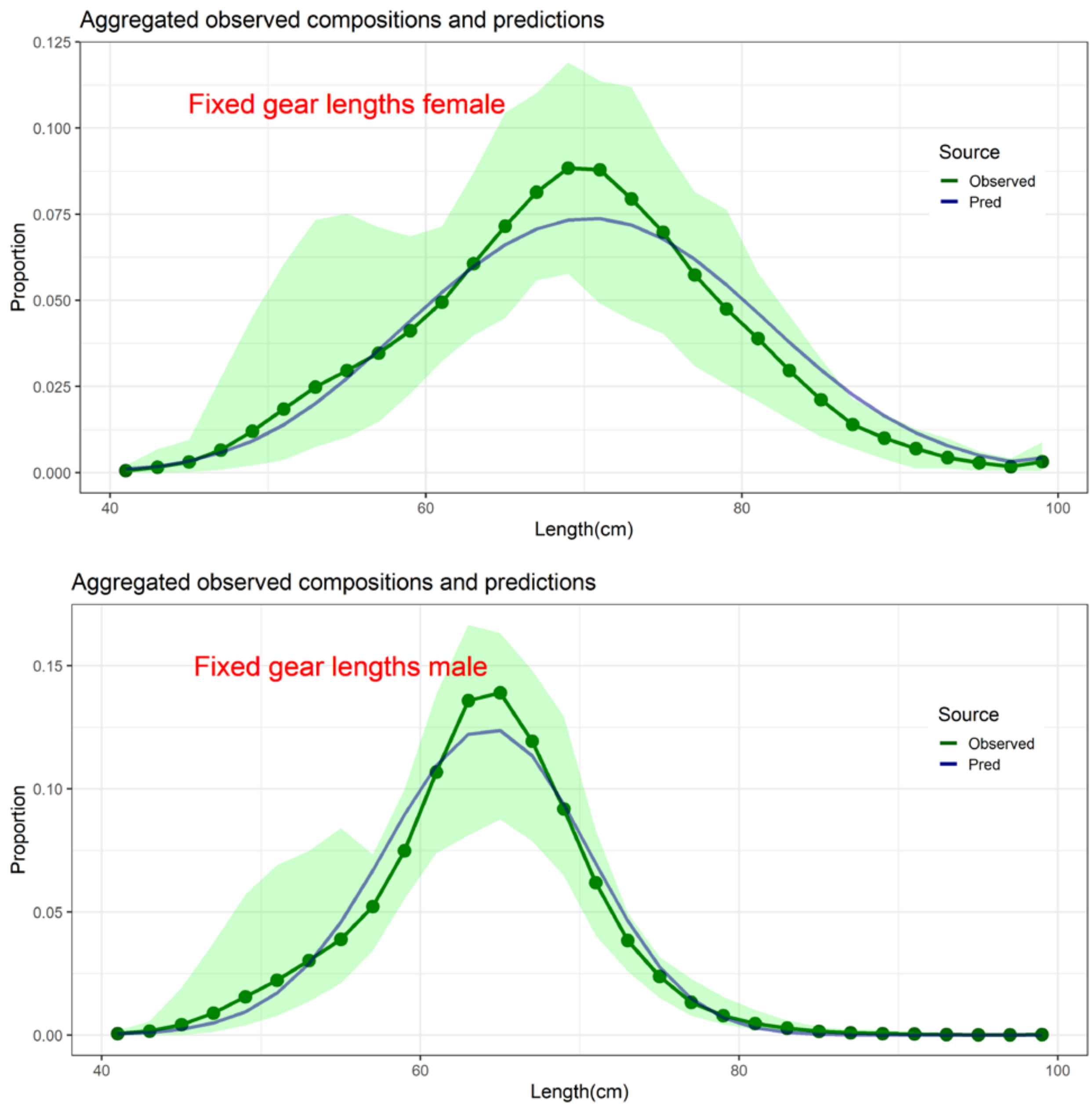


Figure 3.31. Mean observed (green line) domestic fixed gear fishery length compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

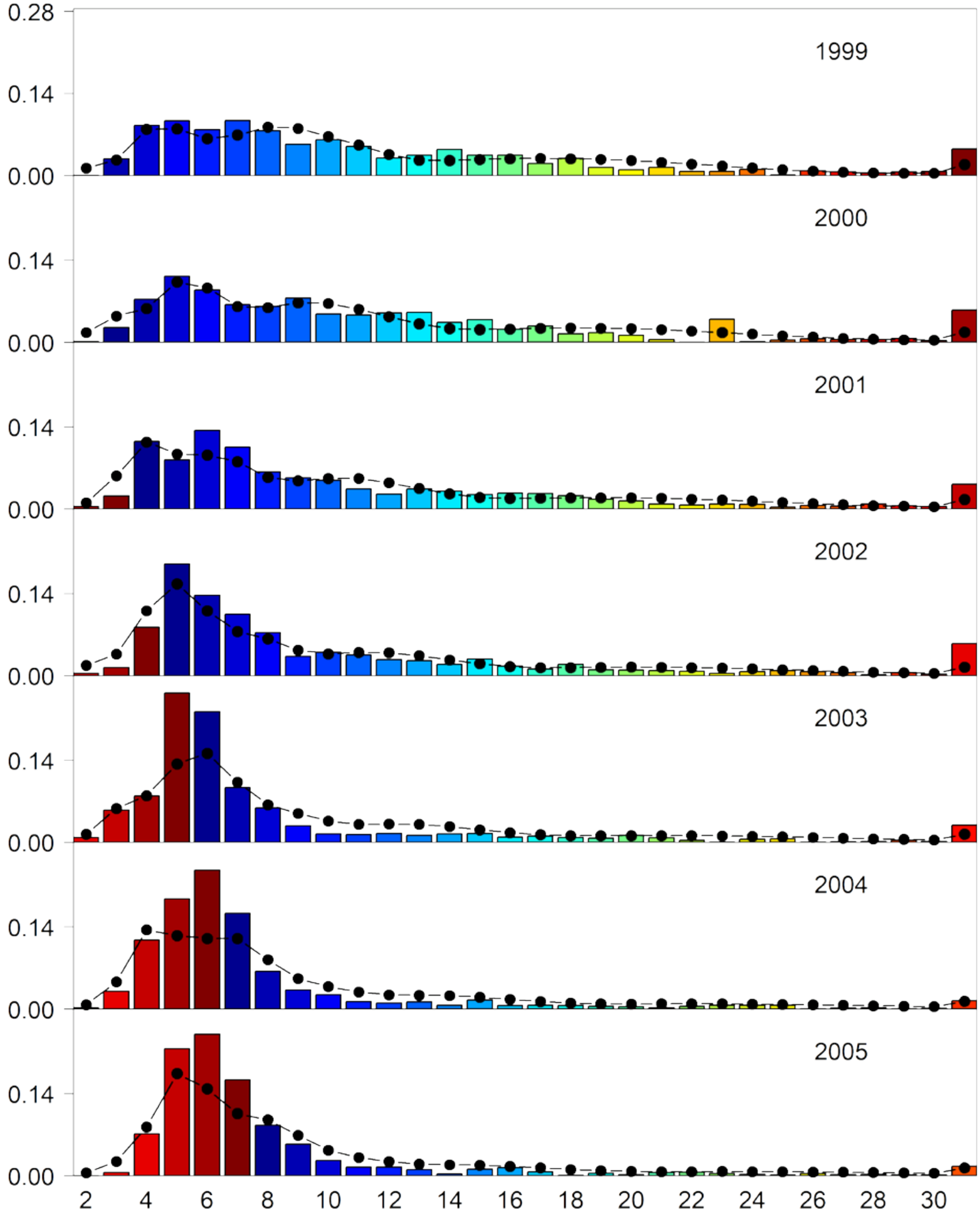


Figure 3.32. Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

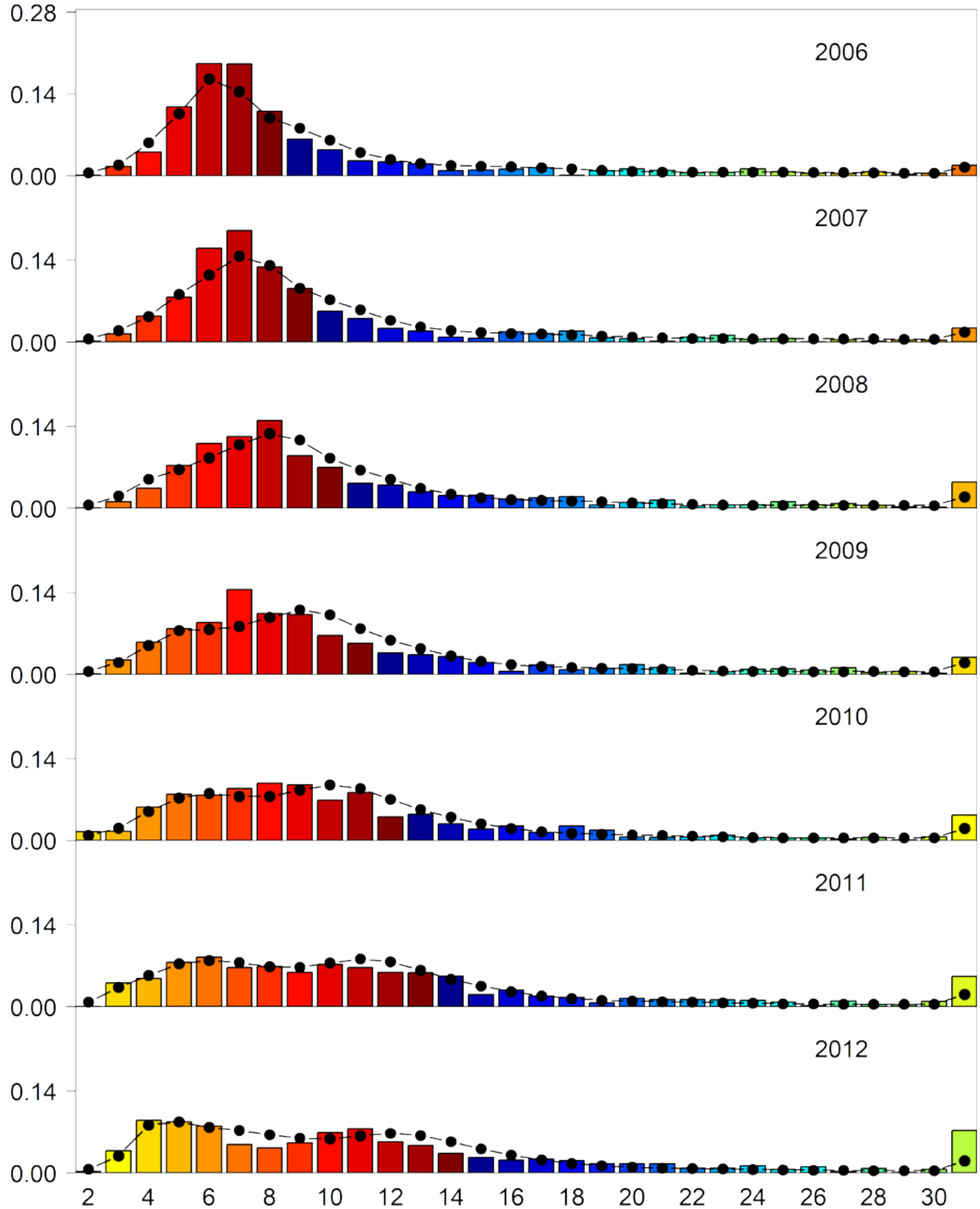


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

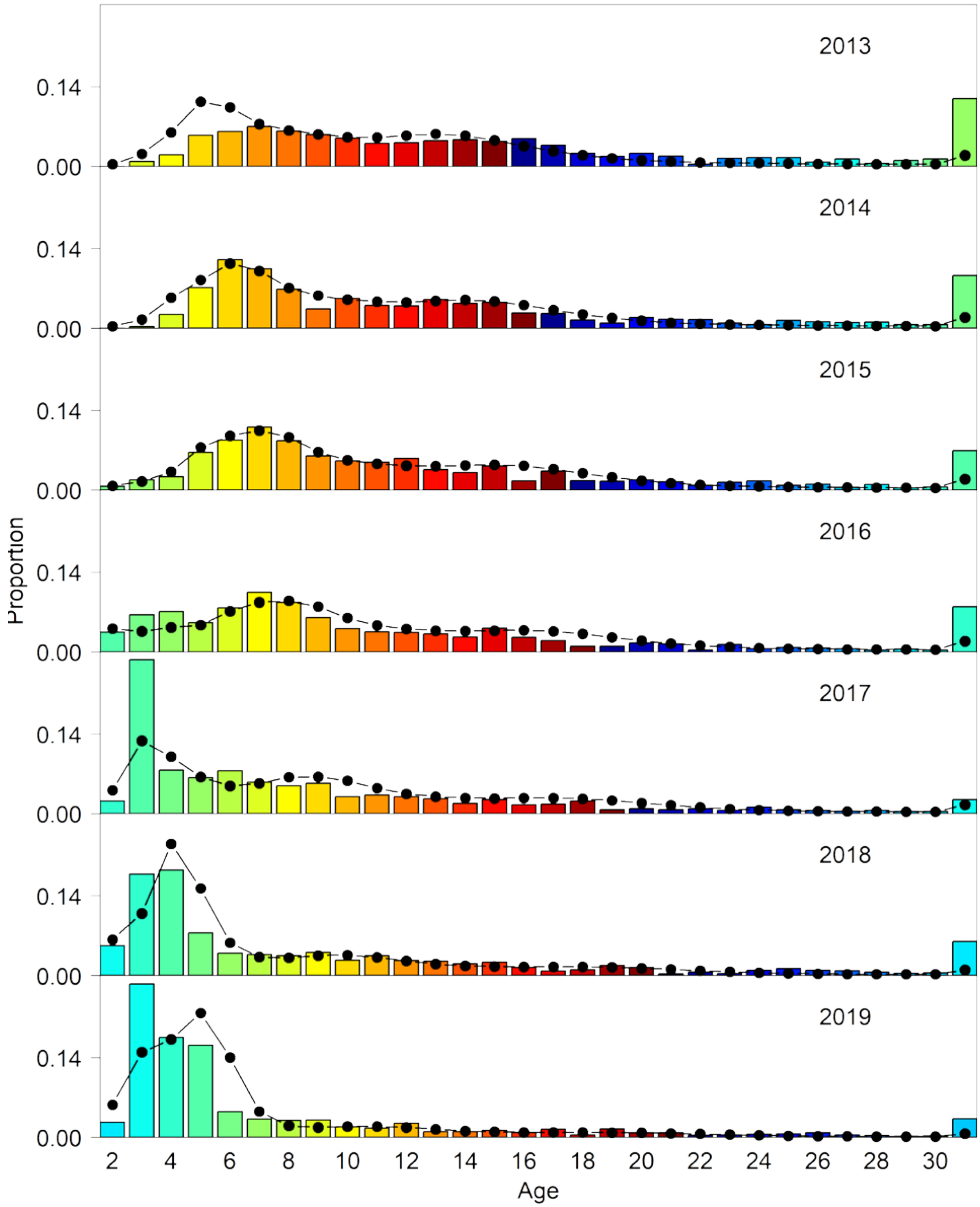


Figure 3.32 (cont.). Domestic fishery age compositions. Bars are observed frequencies and lines are predicted frequencies.

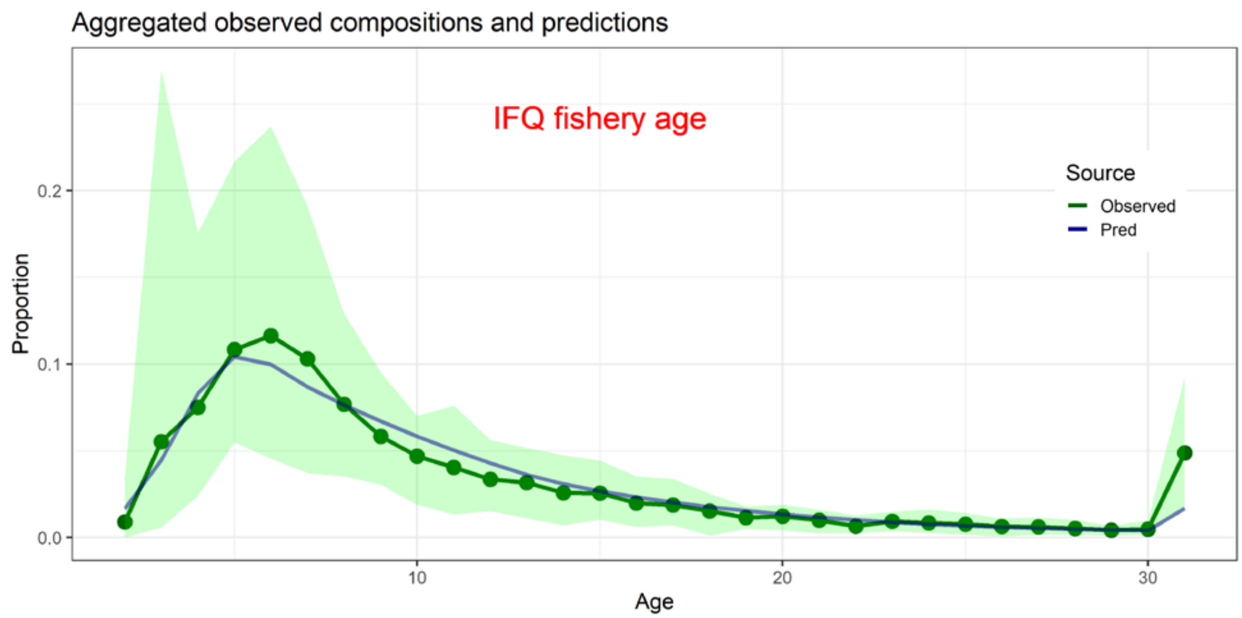


Figure 3.33. Mean observed (green line) domestic fixed gear fishery age compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals.

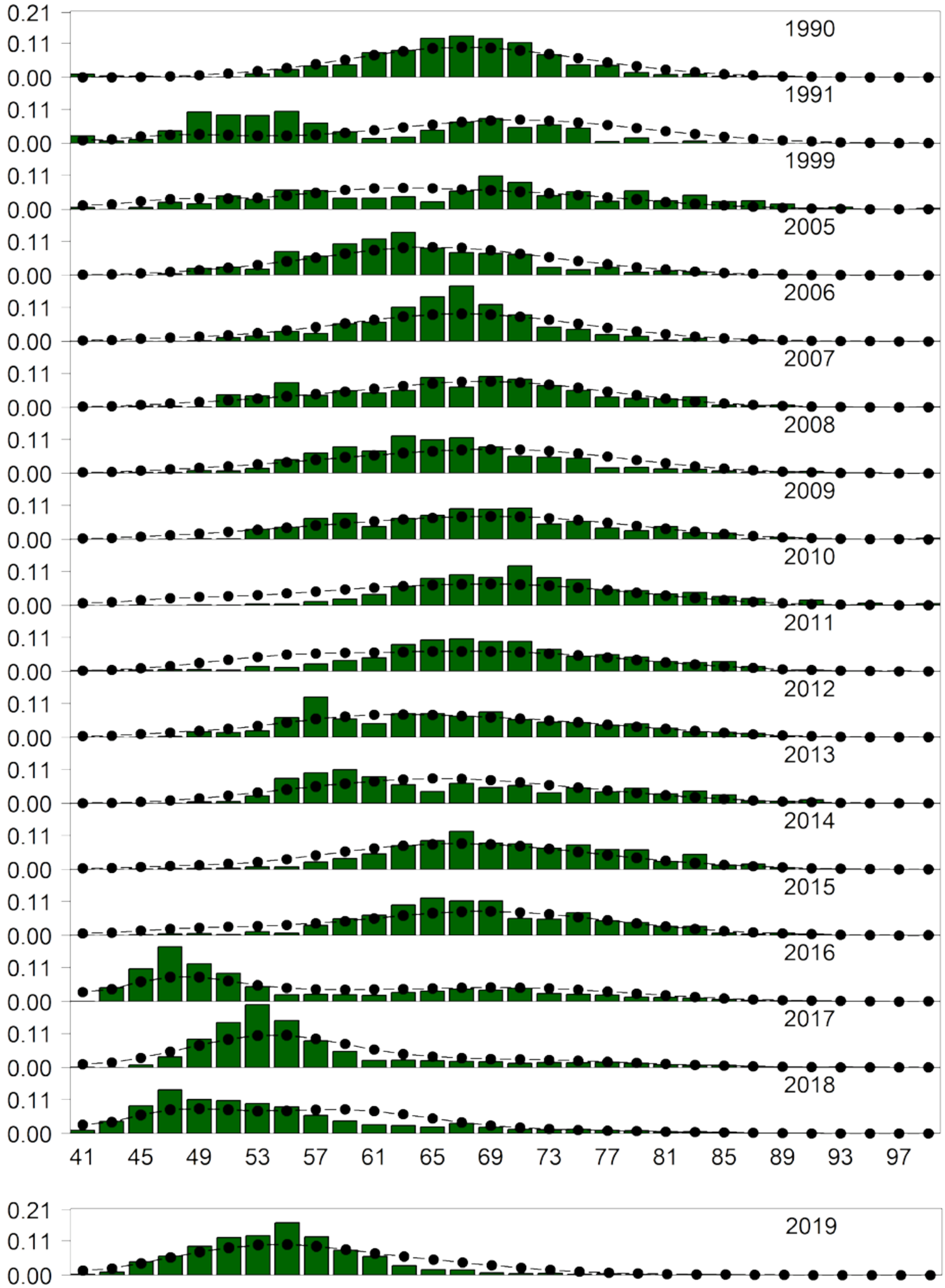


Figure 3.34. Domestic trawl gear fishery length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

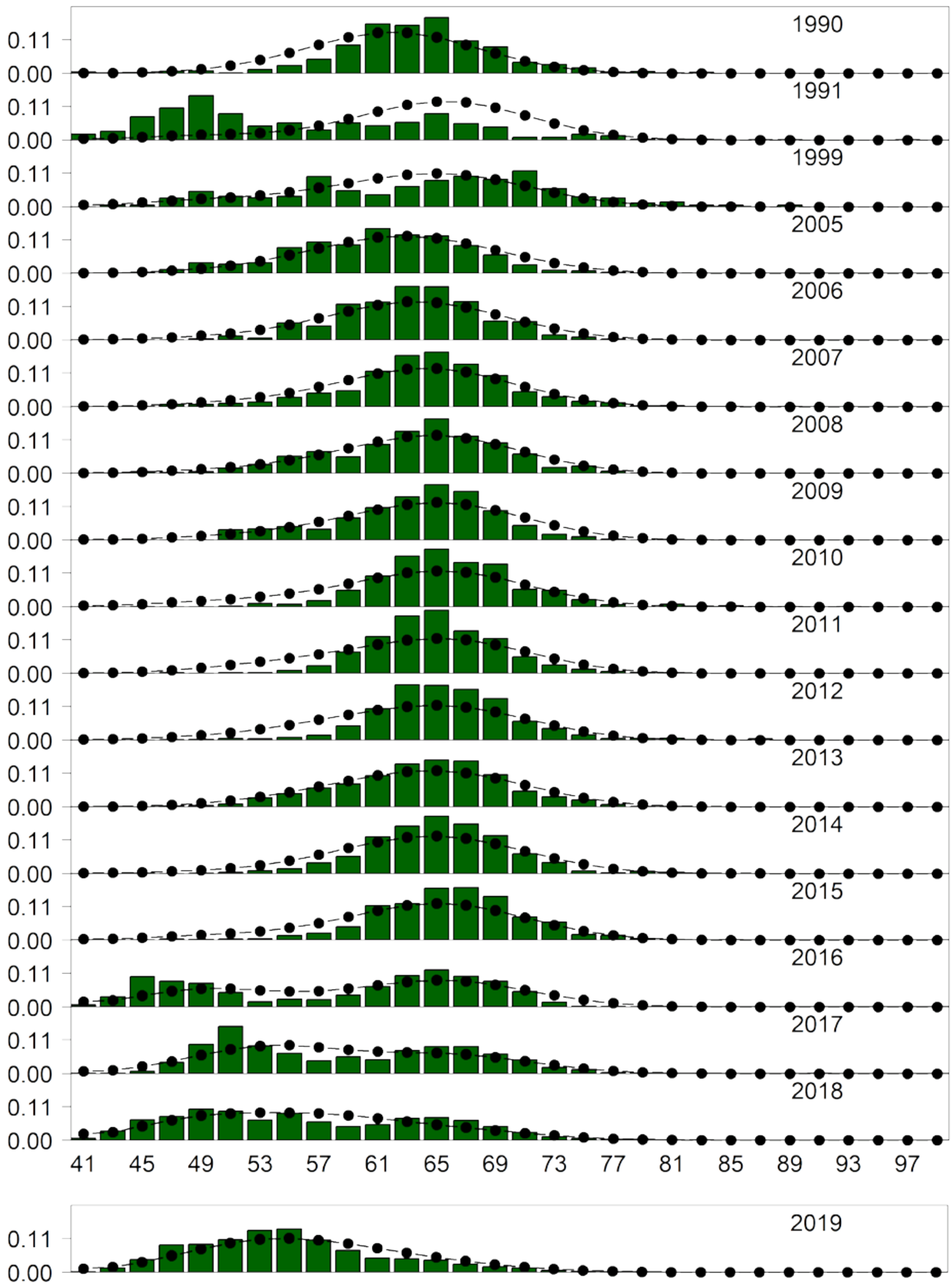


Figure 3.35. Domestic trawl gear fishery length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

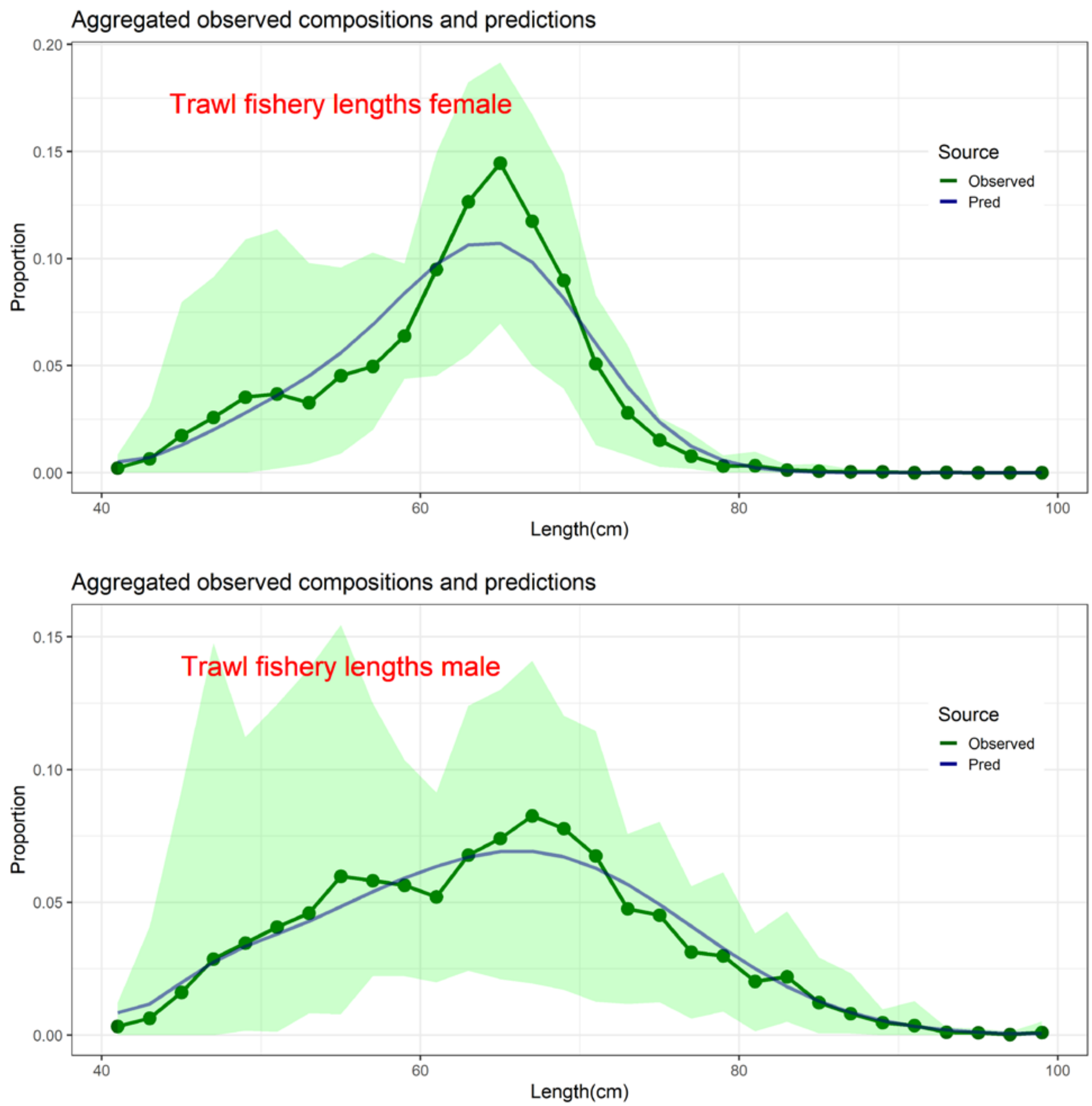


Figure 3.36. Mean observed (green line) domestic trawl fishery length compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

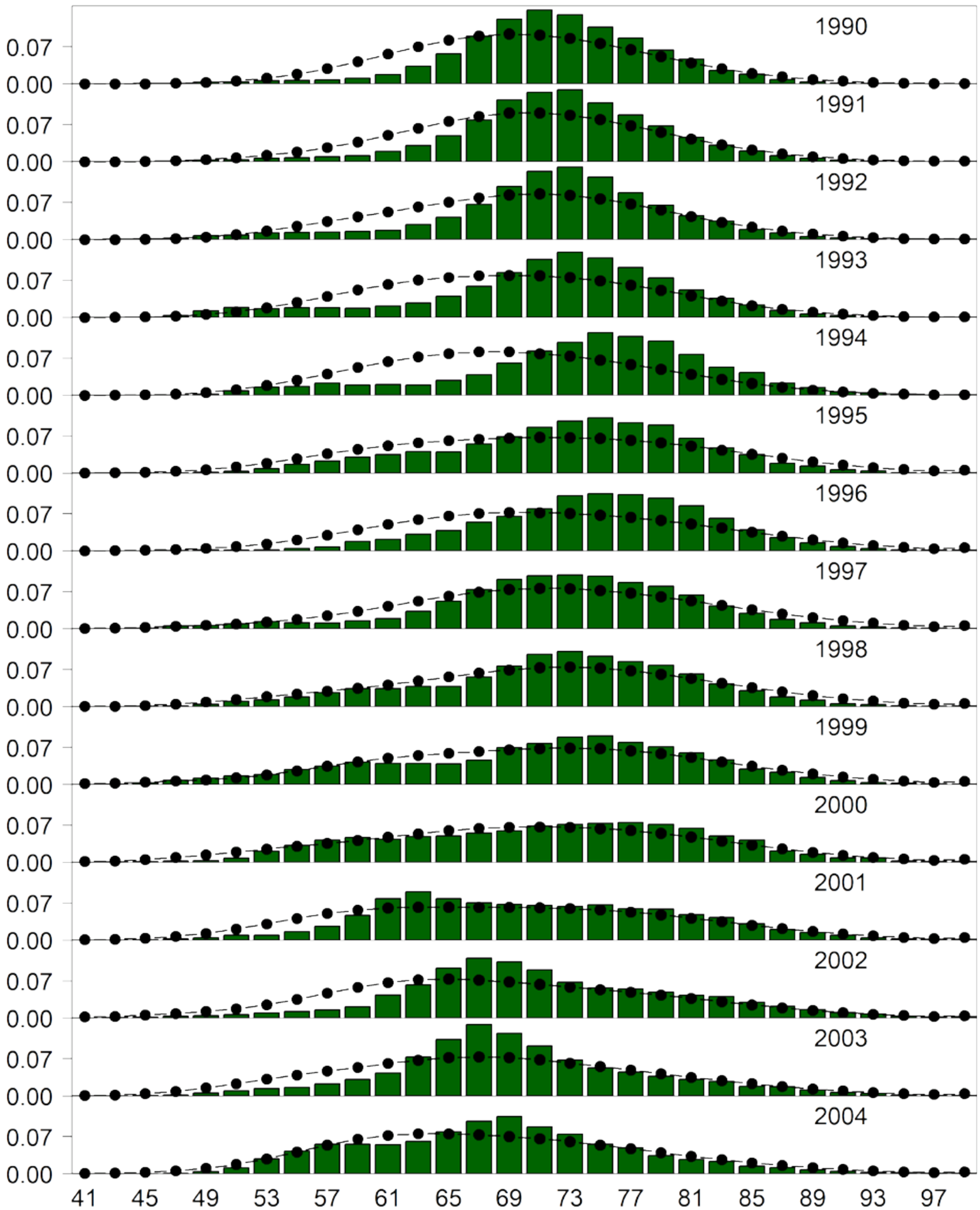


Figure 3.37. Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

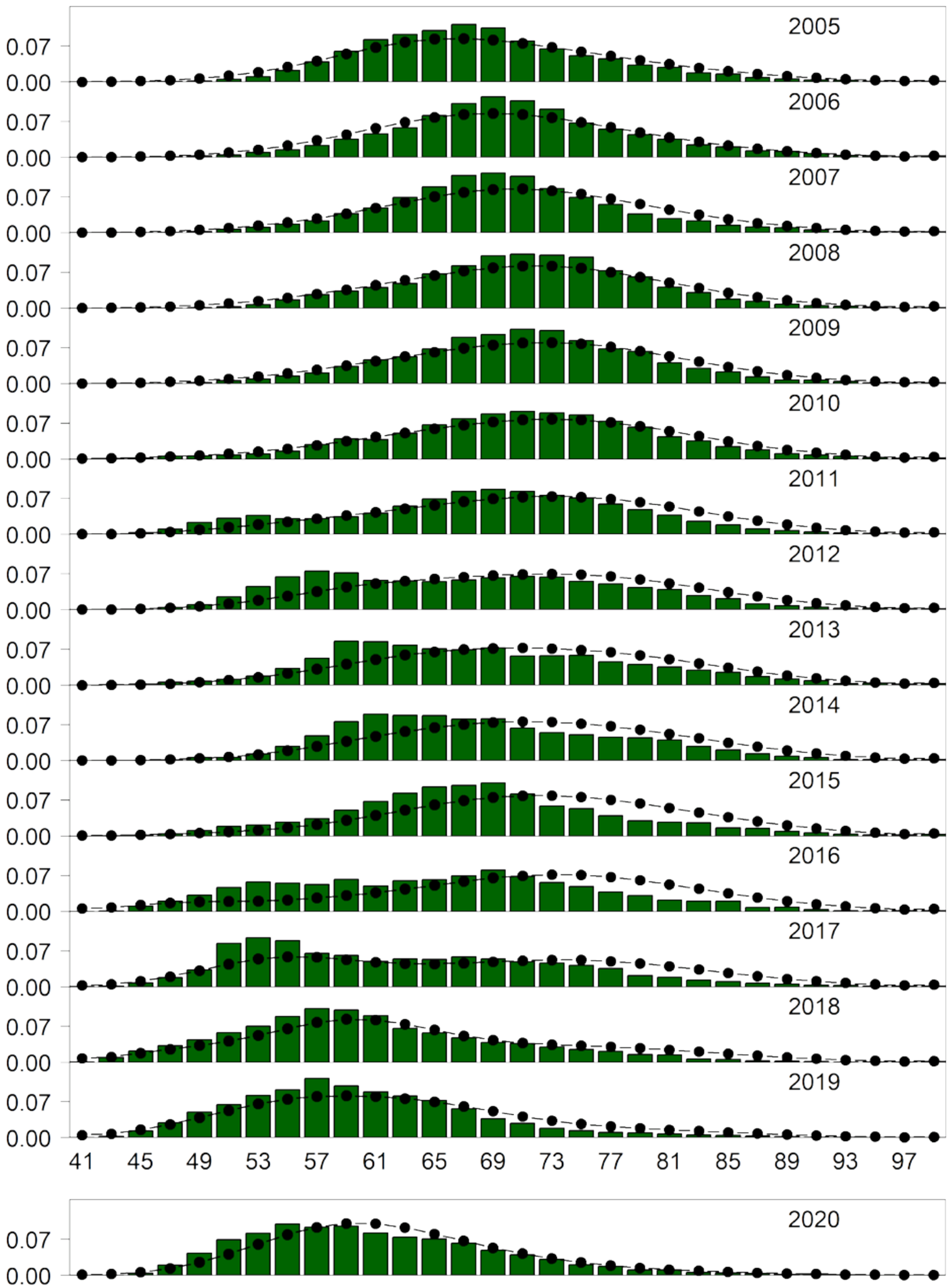


Figure 3.37 (cont.). Domestic longline survey length (cm) compositions for females. Bars are observed frequencies and lines are predicted frequencies.

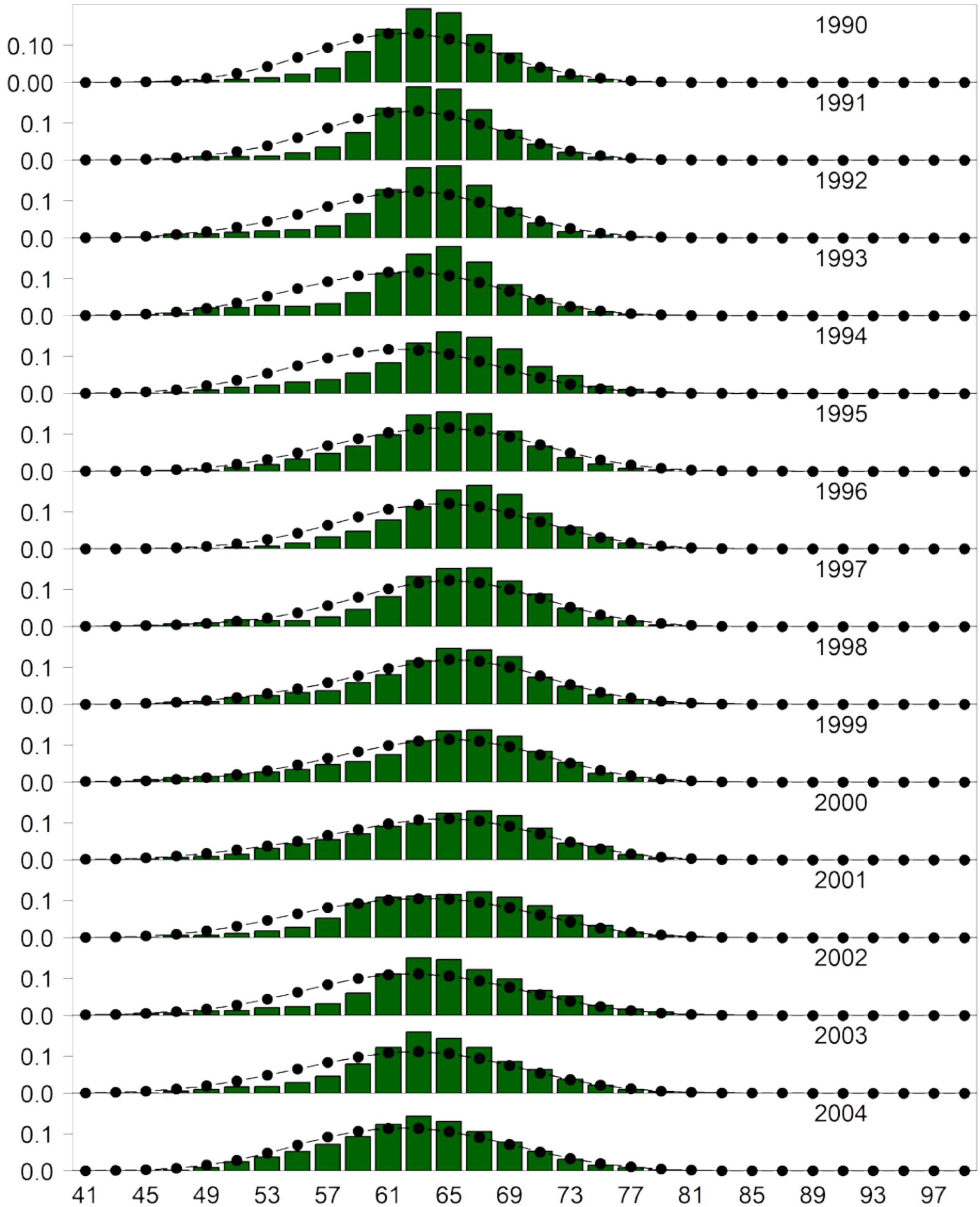


Figure 3.38. Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

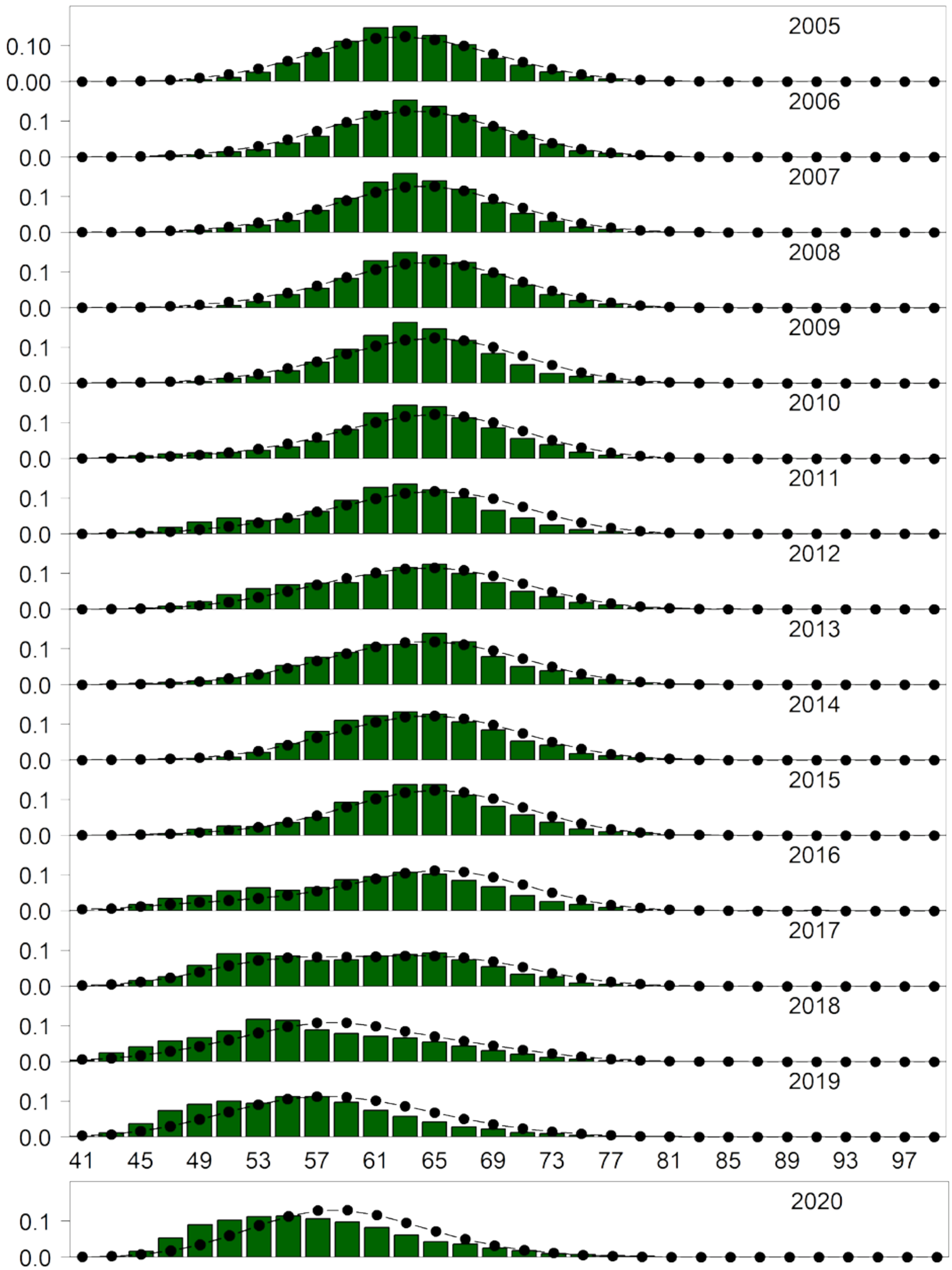


Figure 3.38. (Cont.). Domestic longline survey length (cm) compositions for males. Bars are observed frequencies and lines are predicted frequencies.

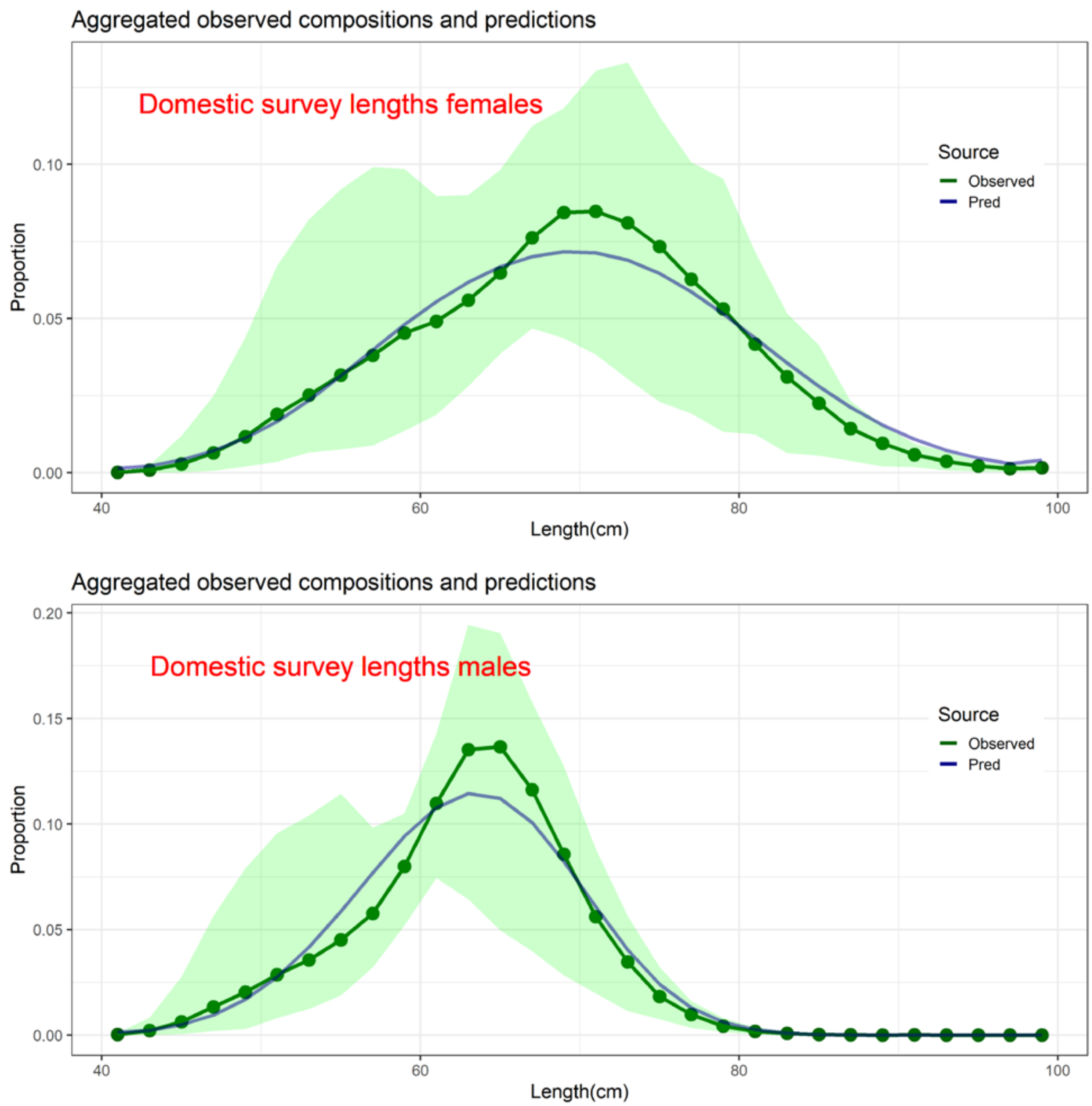


Figure 3.39. Mean observed (green line) domestic longline survey length compositions aggregated across years along with the average fit of the Base model (blue line). The green bands are the 90% empirical confidence intervals. Fit to female length compositions are provided in the top panel and fit to male length compositions are provided in the bottom panel.

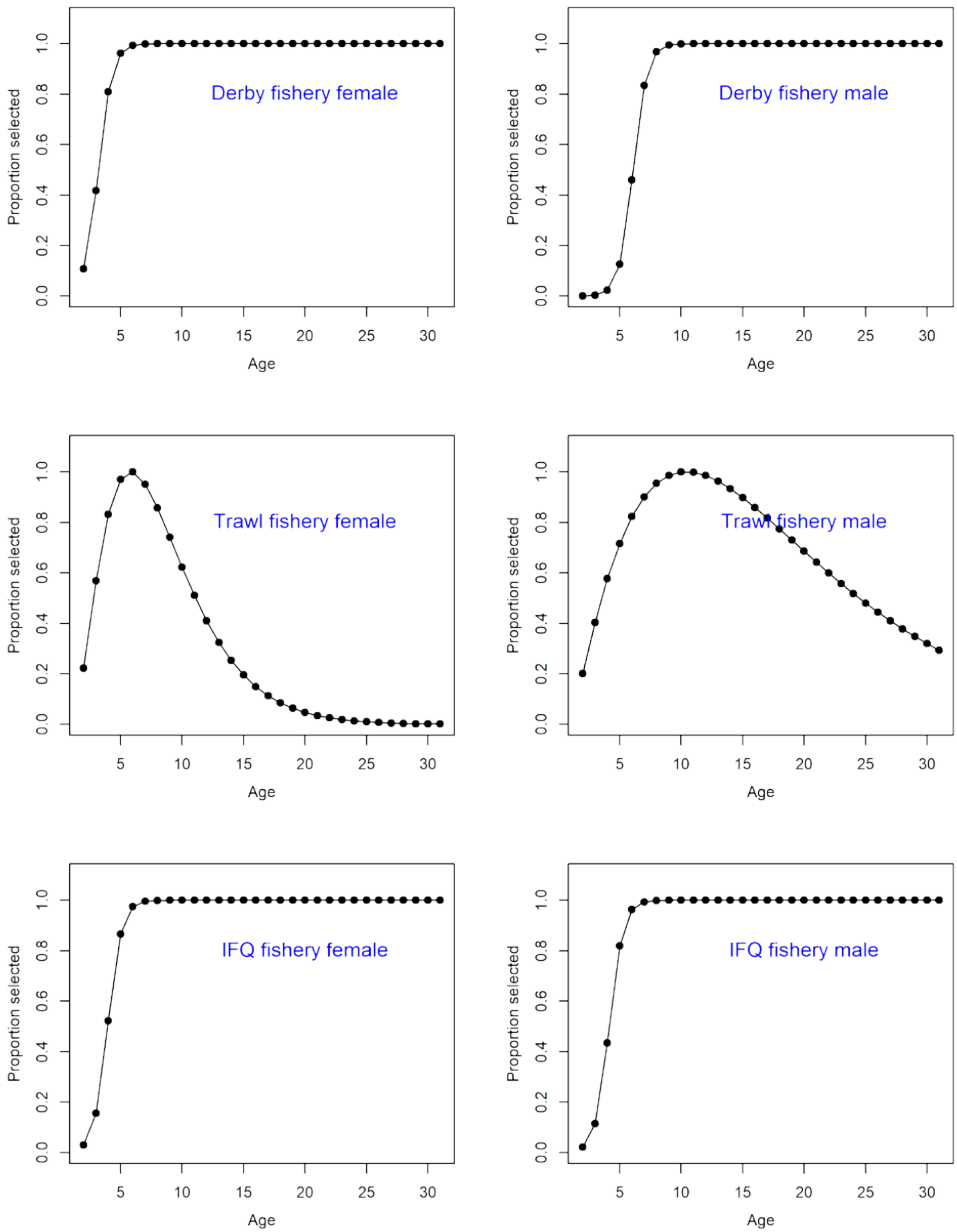


Figure 3.40. Estimated fishery and survey selectivity. The derby longline fishery occurred until 1994, then the fishery switched to an IFQ system in 1995.

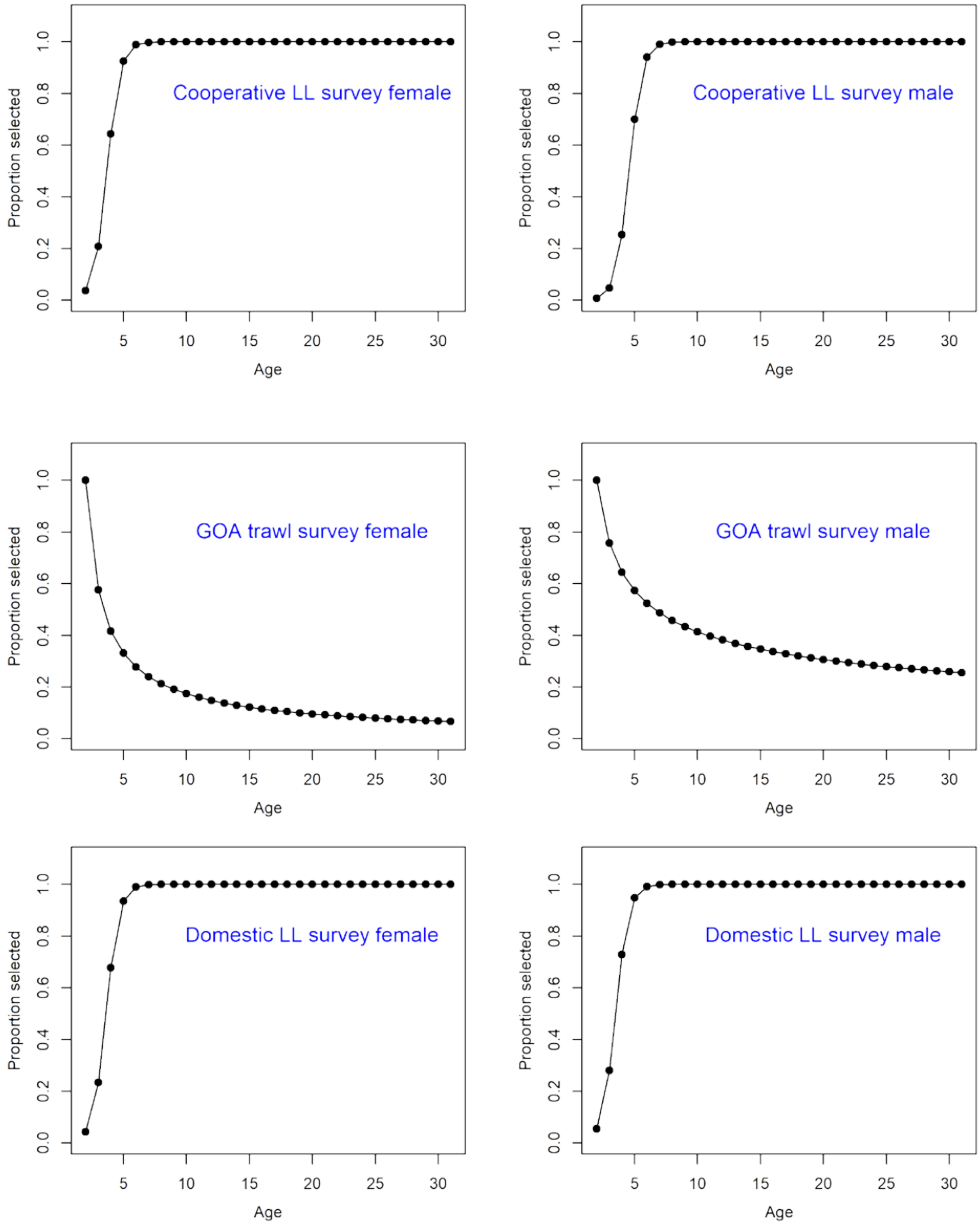


Figure 3.40 (Cont.). Estimated selectivity.

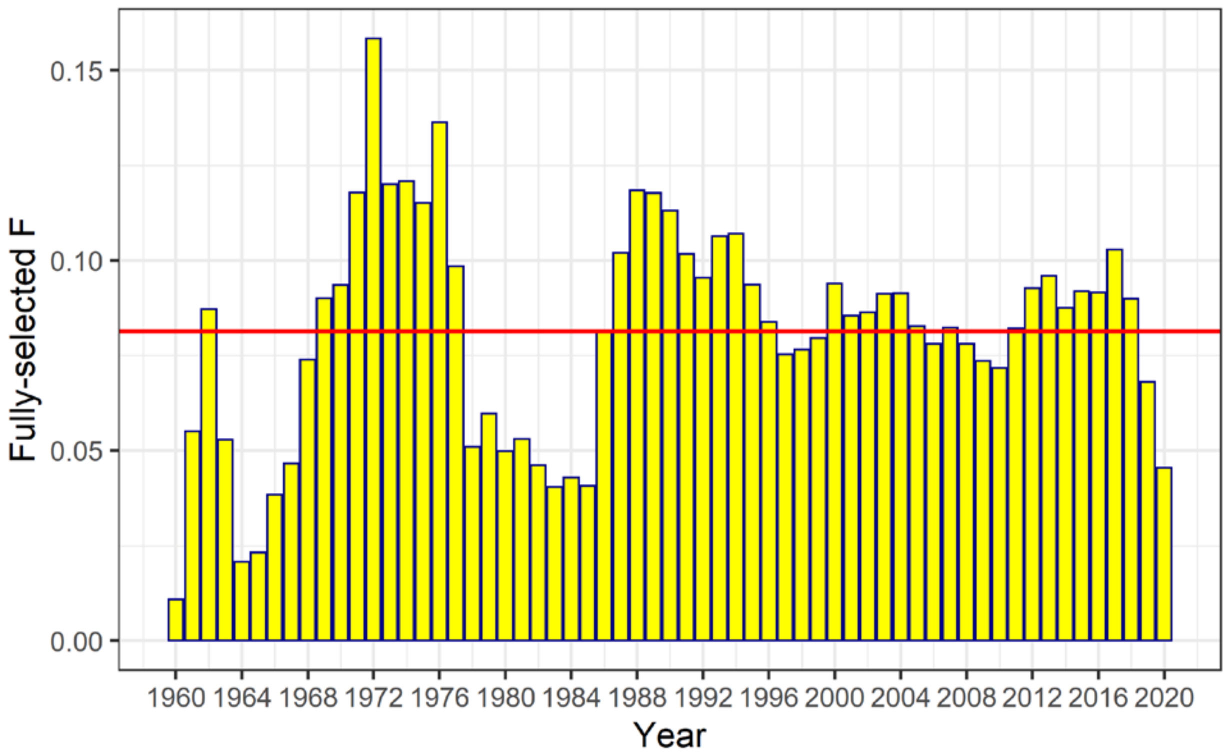


Figure 3.41. Time series of combined fully-selected fishing mortality for fixed and trawl gear for sablefish. Red line is the mean fishing mortality for the entire time series.

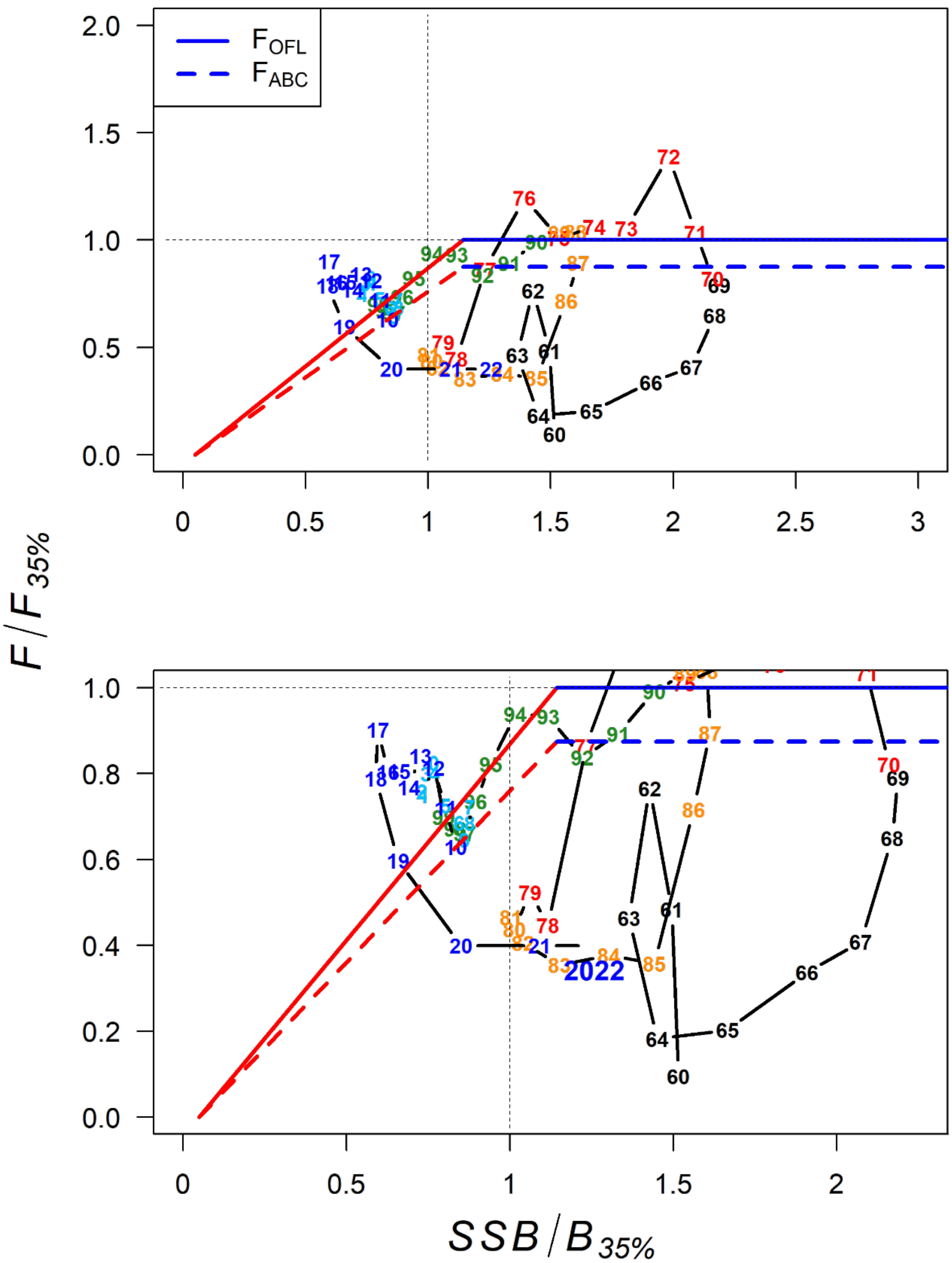


Figure 3.42. Phase-plane diagram of time series of sablefish estimated spawning biomass relative to the level at $B_{35\%}$ and fishing mortality relative to $F_{35\%}$ (equal to F_{OFL}) for the Base model. F_{ABC} for the max ABC is equivalent to $F_{40\%}$, which is demonstrated by the dashed lines. The solid line represents fishing at F_{OFL}, but with a target of $B_{40\%}$. The bottom panel is zoomed in to examine more recent years.

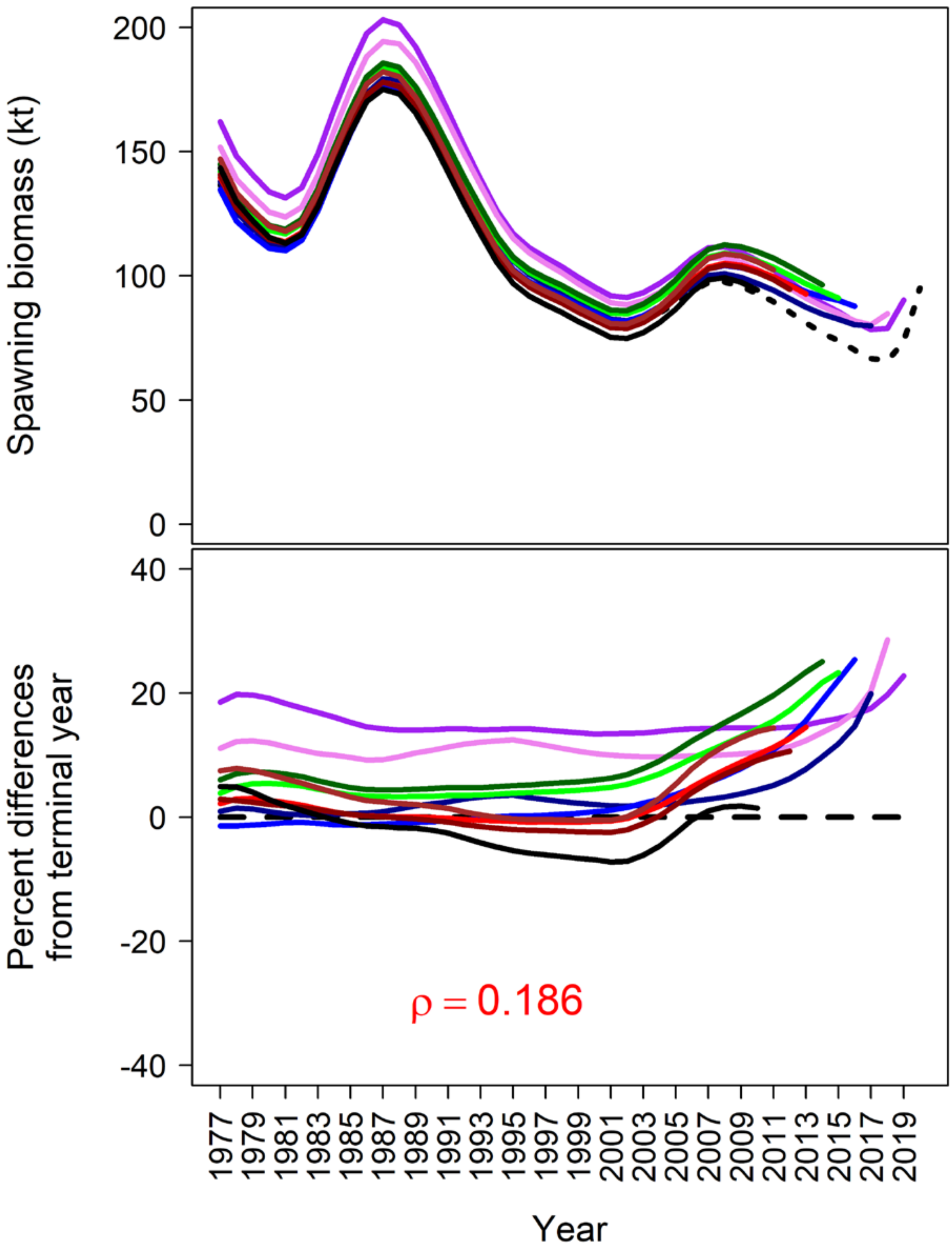


Figure 3.43. Retrospective trends for spawning biomass (top) and percent difference from terminal year (bottom) from 1977- 2020. Mohn's rho (ρ) is provided in red (bottom panel).

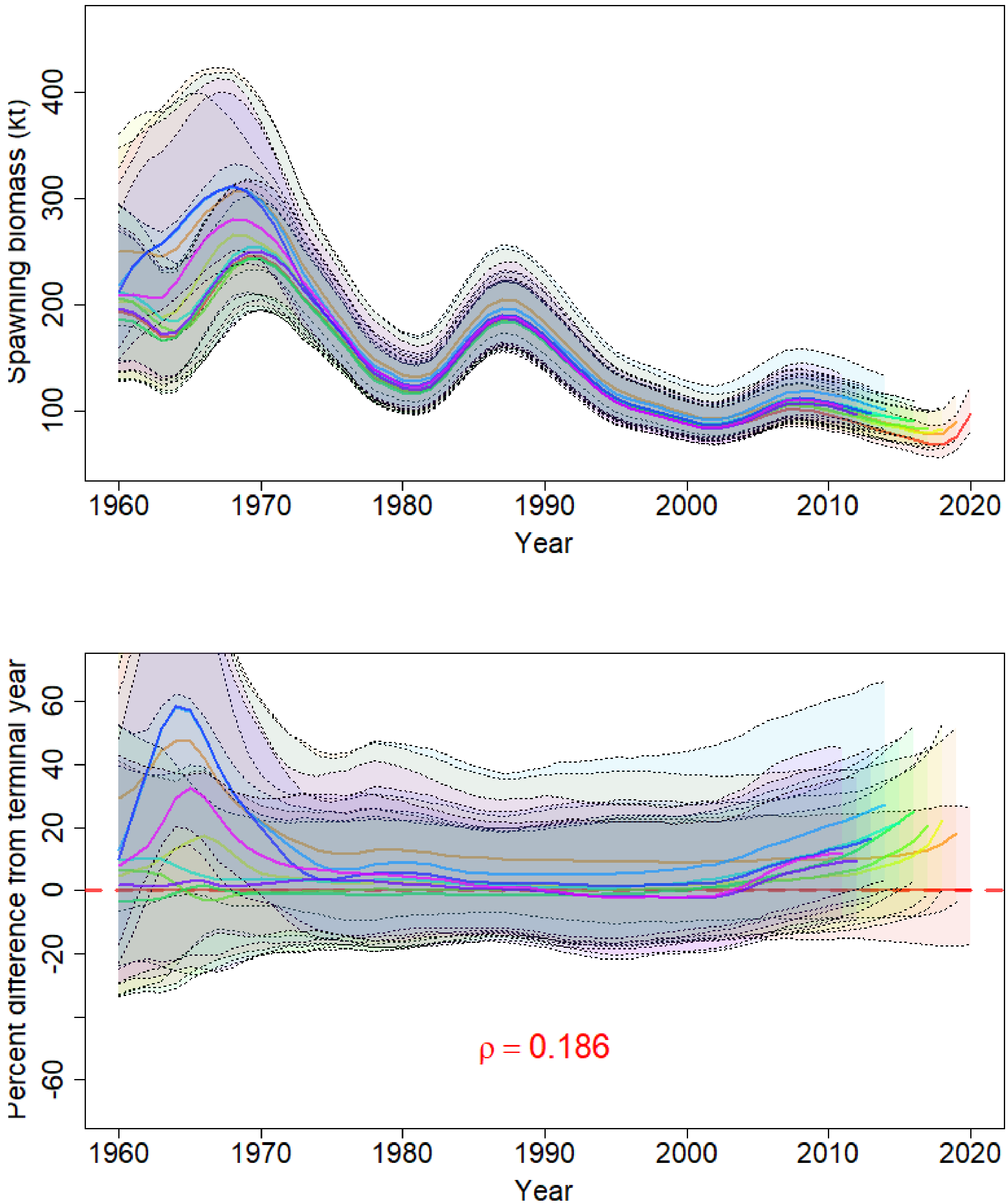


Figure 3.44. Retrospective trends for absolute spawning biomass (top) and percent difference in spawning biomass (bottom) from 2020 model results (red line). 95% MCMC credible intervals are provided in both figures and correspond to the associated color coded retrospective runs.

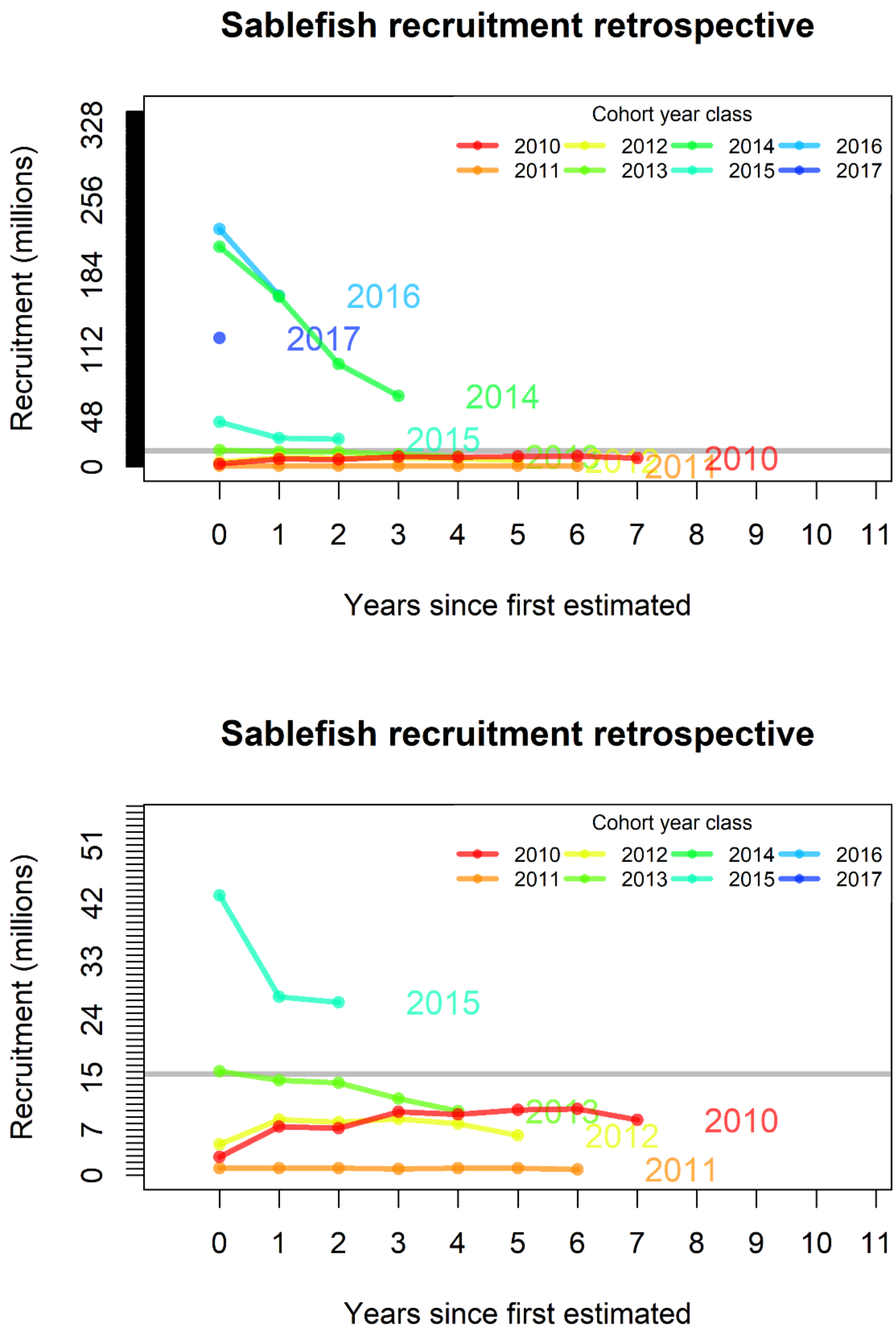


Figure 3.45. Squid plot of the development of initial estimates of age-2 recruitment since year class 2010 through year class 2017 from retrospective analysis. Top panel includes 2014 and 2016 year classes. Number to right of terminal year indicates year class. Bottom panel excludes the 2014, 2016, and 2017 year classes.

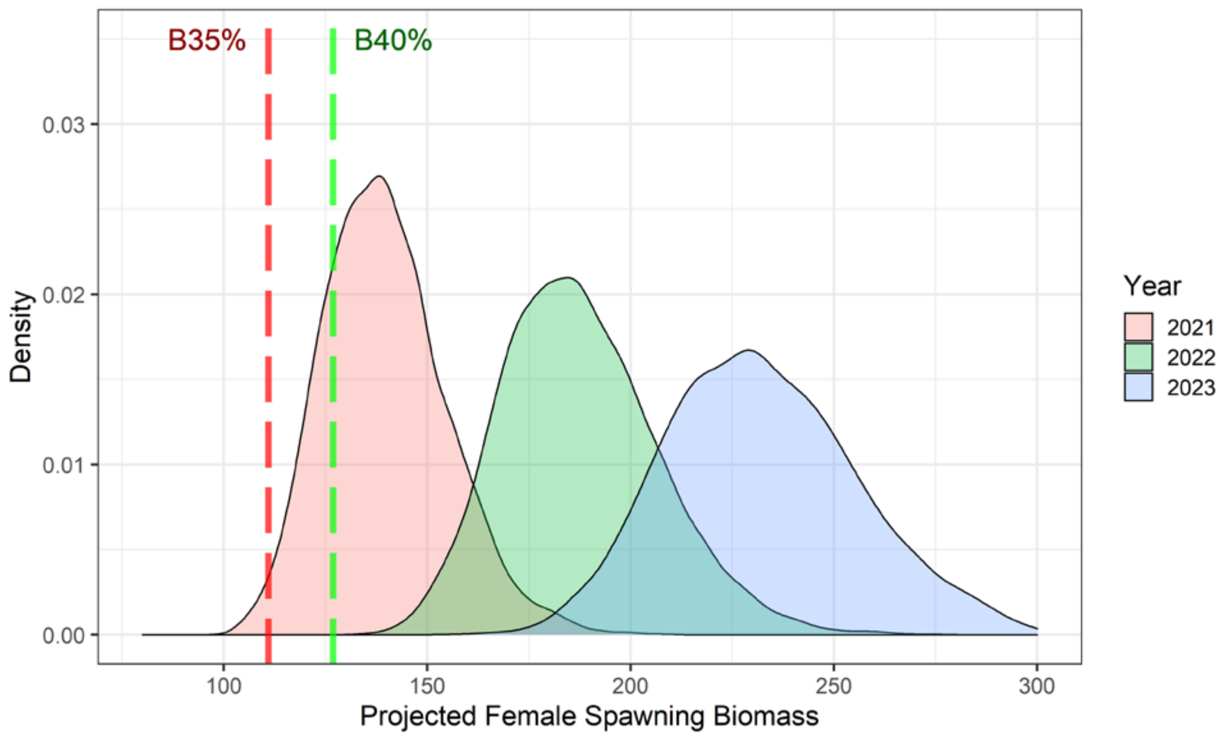


Figure 3.46. Posterior probability distribution for projected spawning biomass (kilotons) in years 2021 – 2023. The dashed lines are estimated $B_{35\%}$ and $B_{40\%}$ from the 2020 Base model.

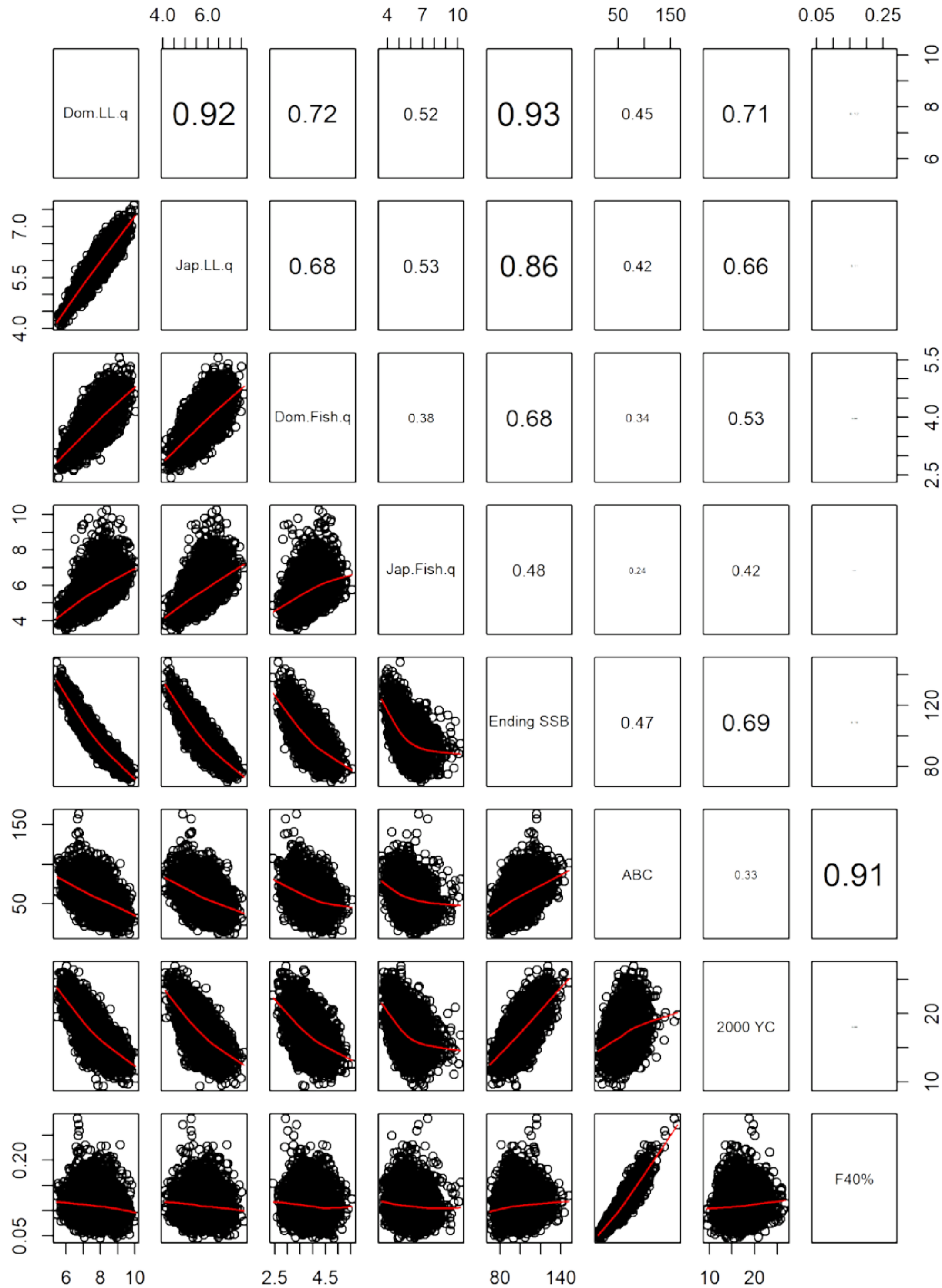


Figure 3.47. Pairwise scatterplots of key parameter MCMC runs. Red curve is loess smooth. Numbers in upper right hand panel are correlation coefficients between parameters.

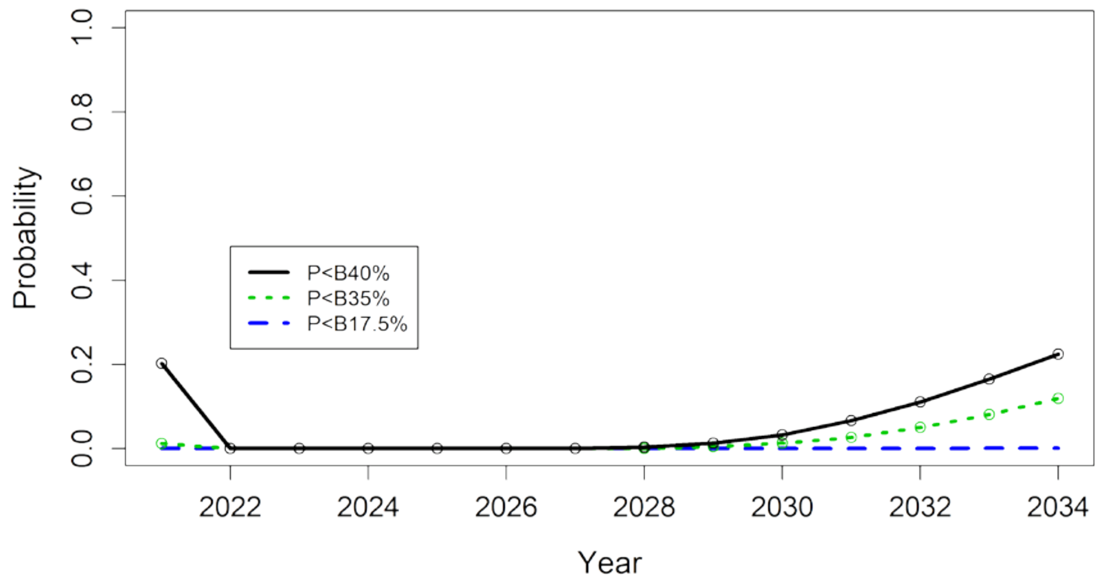


Figure 3.48. Probability that projected spawning biomass in a given projection year (from MCMC) will fall below $B_{40\%}$, $B_{35\%}$ and $B_{17.5\%}$.

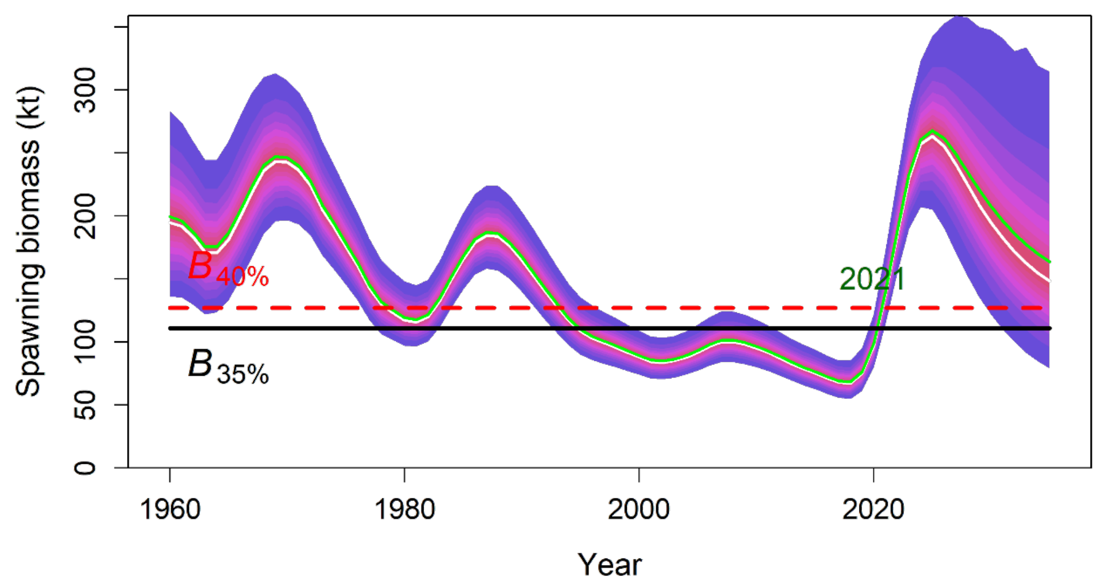


Figure 3.49. Estimates of female spawning biomass (kilotons) and their uncertainty from MCMC runs. White line is the median and green line is the mean, while shaded fills are 5% increments of the posterior probability distribution of spawning biomass based on MCMC simulations. Width of shaded area is the 95% credibility interval.

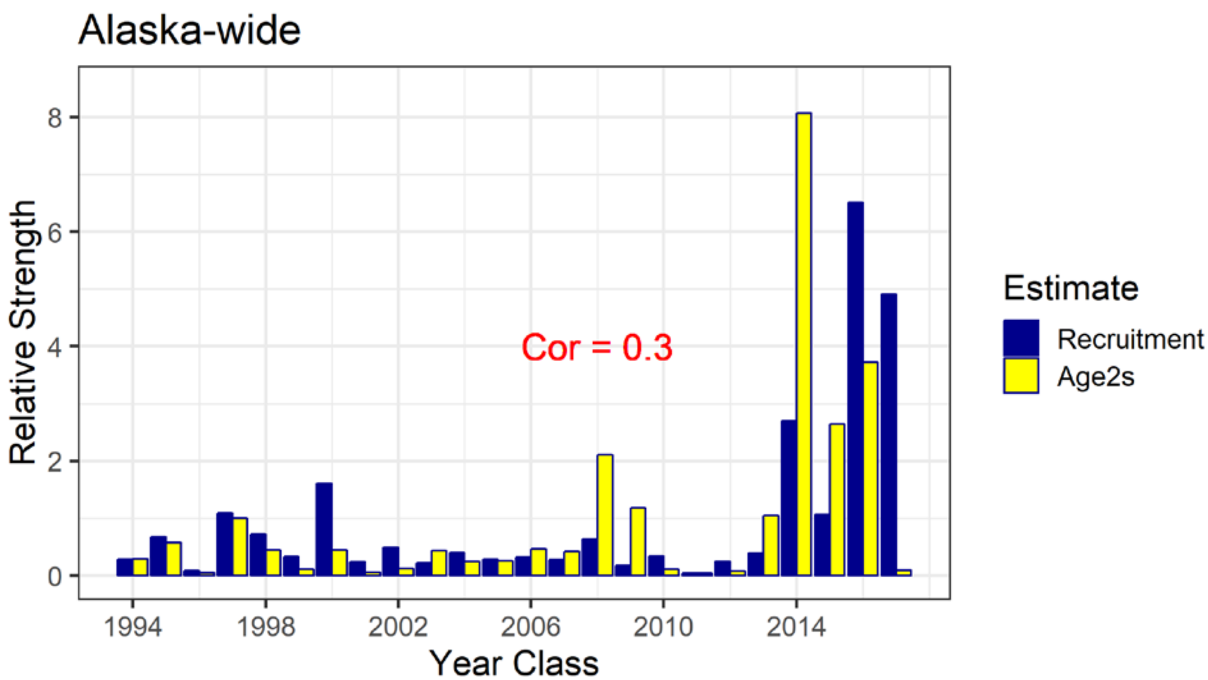


Figure 3.50. Comparison of 2-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

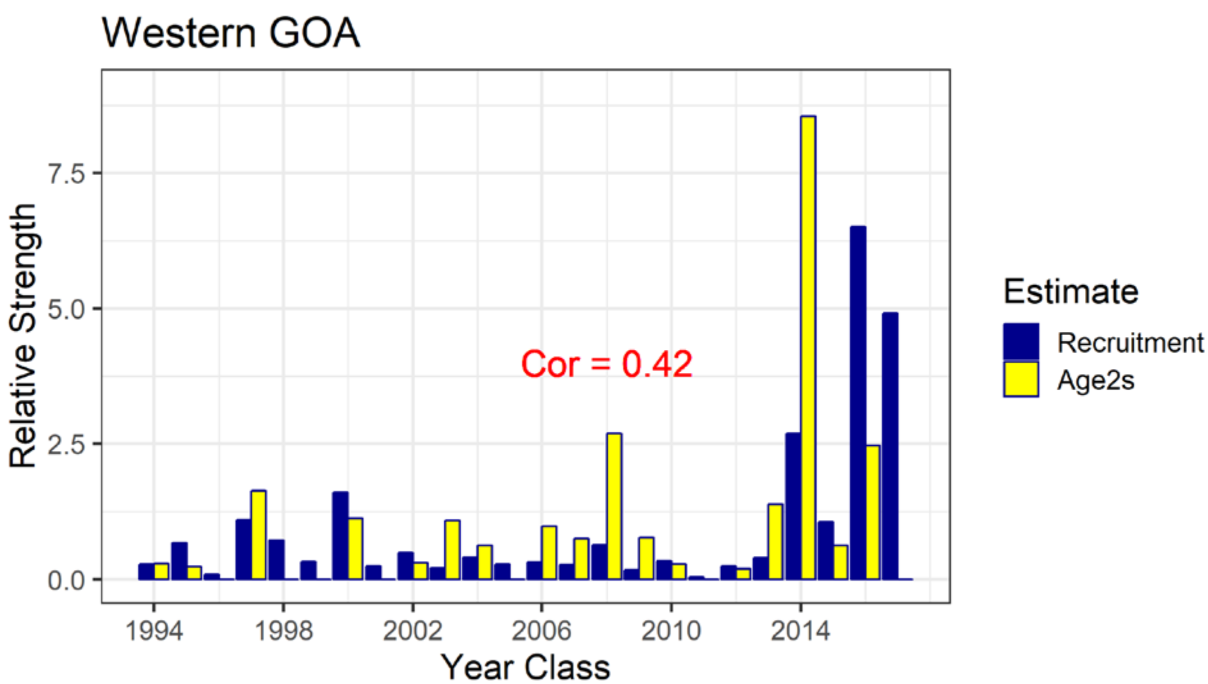


Figure 3.51. Comparison of 2-year-olds in the longline survey age composition from the Western GOA with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

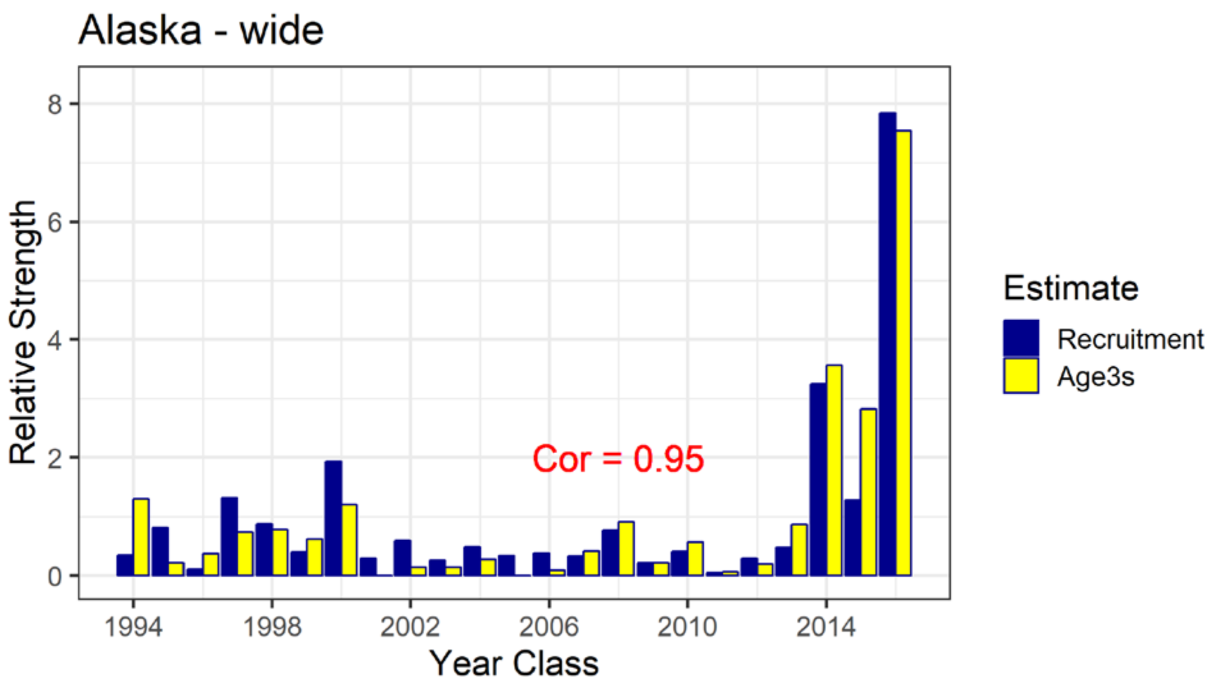


Figure 3.52. Comparison of 3-year-olds in the longline survey age composition with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

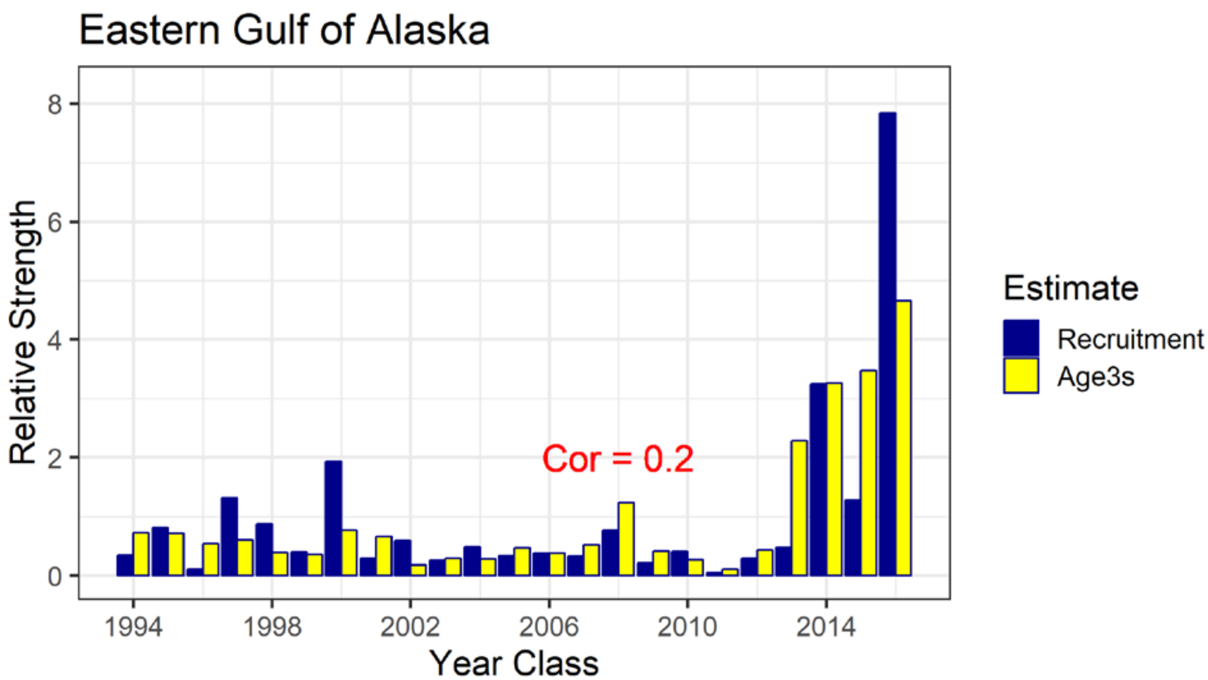


Figure 3.53a. Comparison of 3-year-olds in the longline survey age composition from the Eastern GOA with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

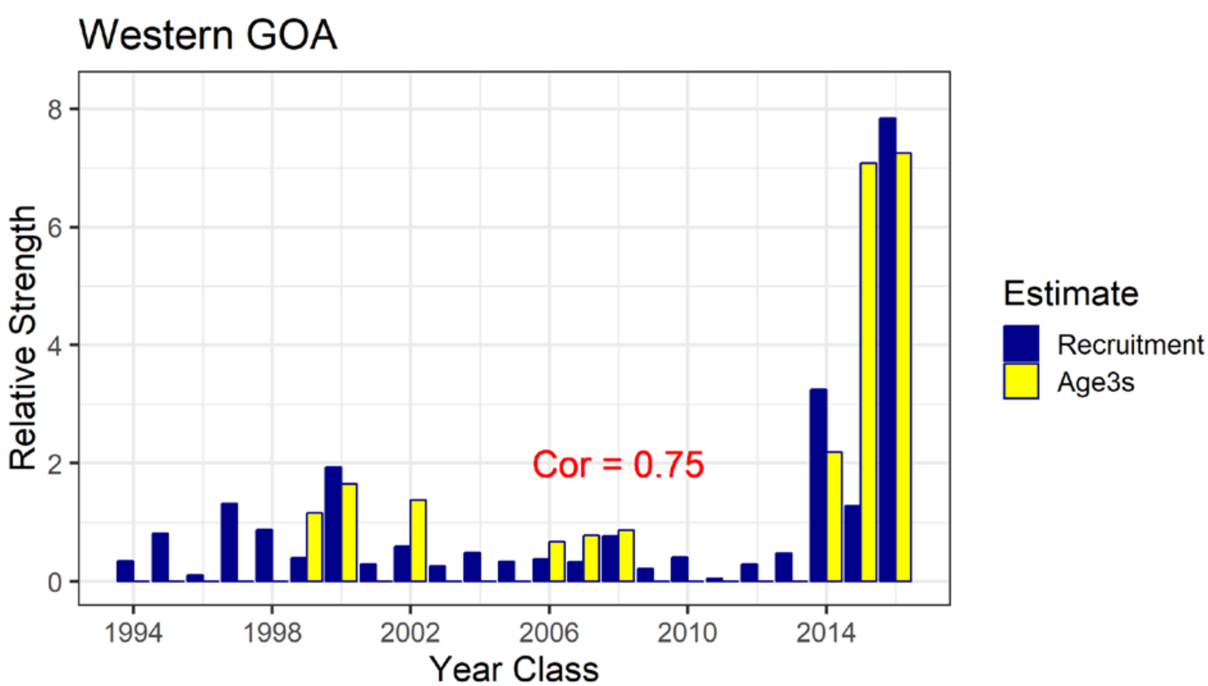


Figure 3.53b. Comparison of 3-year-olds in the longline survey age composition from the Western GOA with the corresponding year class. Strength is relative to the mean abundance (i.e., a strength of 3 is 3x average).

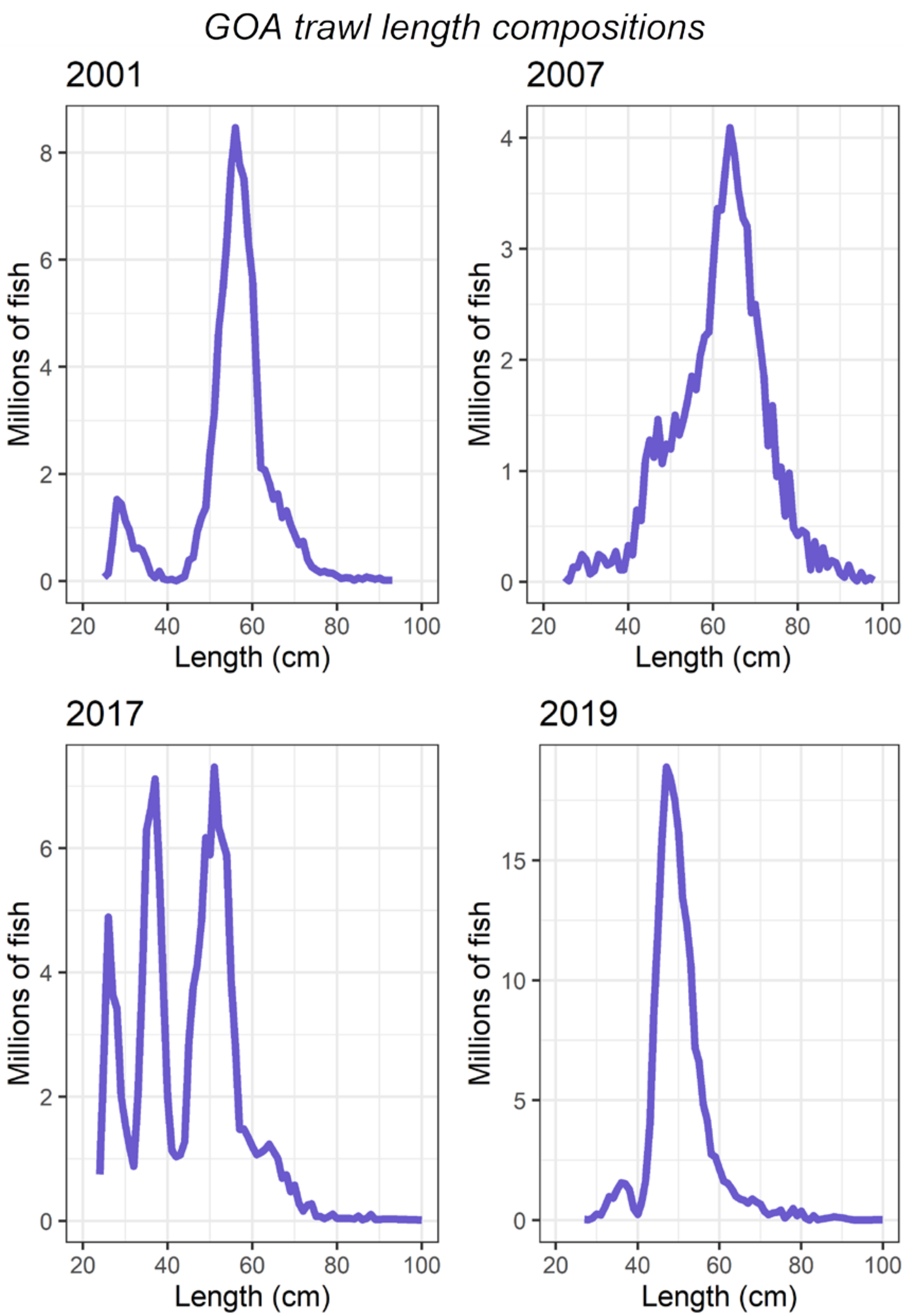


Figure 3.54. Select years of Gulf of Alaska trawl survey length compositions.

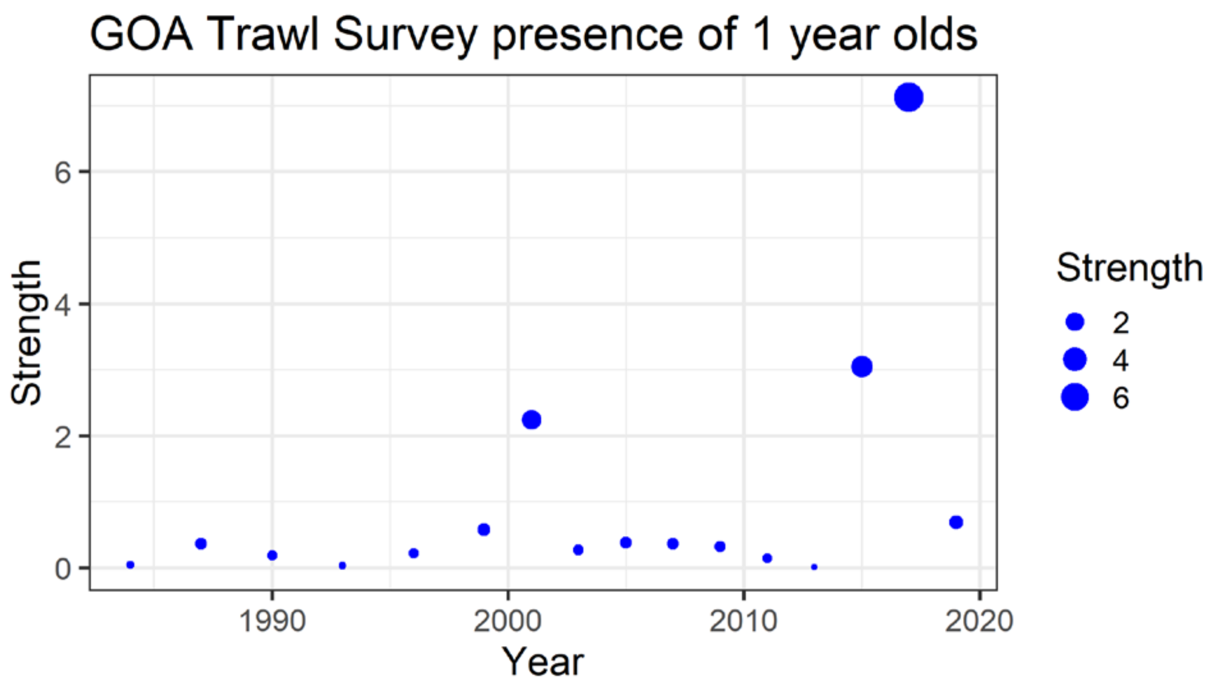


Figure 3.55. Presence of one-year-old (Length < 34 cm) sablefish in the Gulf of Alaska trawl survey. Strength is relative to the mean abundance (i.e., a strength of 7.5 is 7.5x average).

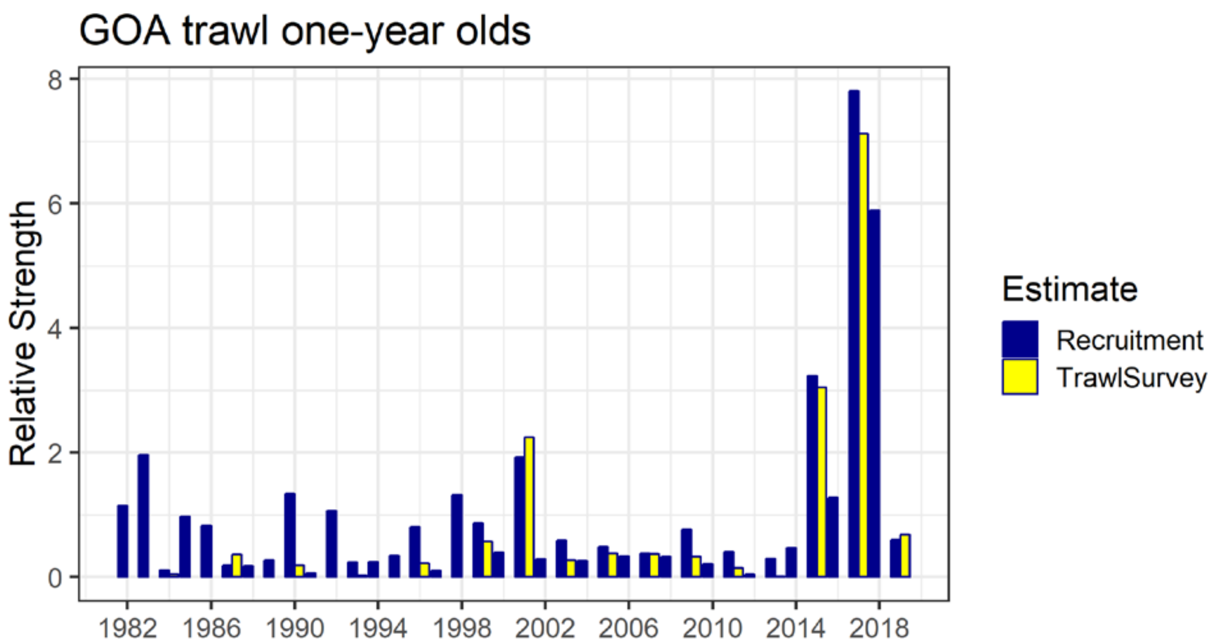


Figure 3.56a. Strength of presence of one-year-old (Length < 32 cm) sablefish in the Gulf of Alaska trawl survey compared to the respective year classes of recruitment estimated by the stock assessment. Strength is relative to the mean abundance or recruitment (i.e., a strength of 7.5 is 7.5x average). Year class is the x-axis year minus one (i.e., the recruitment value for 2019 represents the 2018 year class).

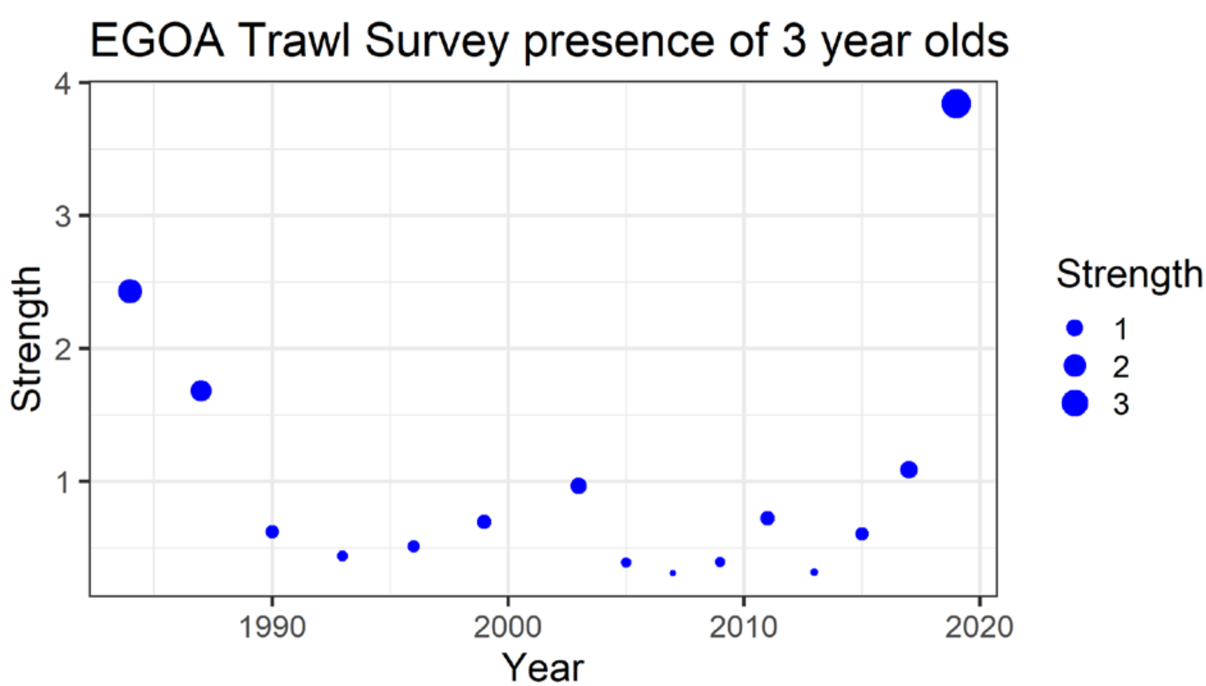


Figure 3.56b. Presence of 3-year-old (42 cm > Length <55 cm) sablefish in the Gulf of Alaska trawl survey. Strength is relative to the mean abundance (i.e., a strength of 7.5 is 7.5x average).

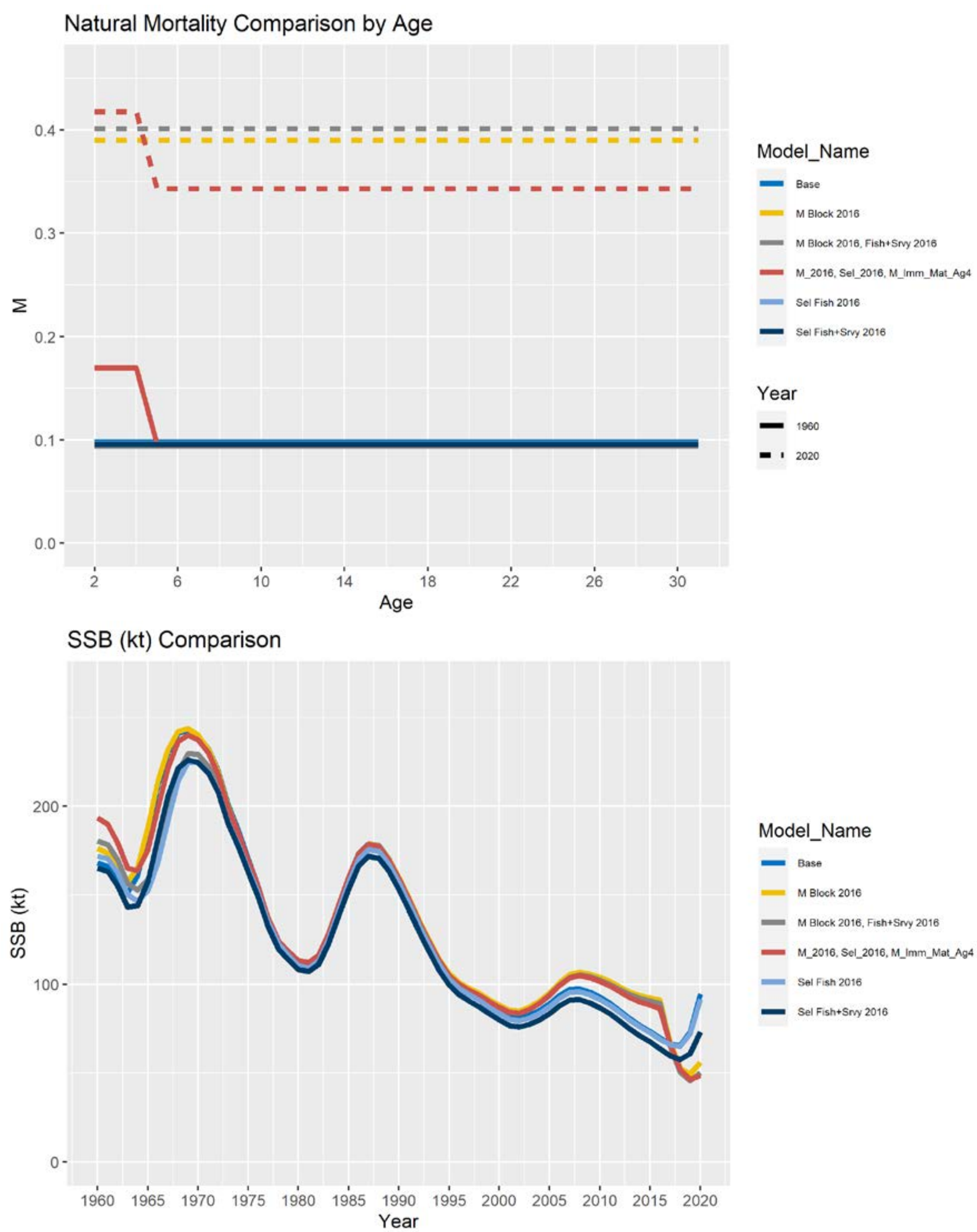


Figure 3.57. Results of select sensitivity runs (colored lines). Model descriptions and names are provided in Table 3.19. The top panel illustrated the model estimated age-specific natural mortality rates at the beginning of the time series (1960; solid lines) and the end of the time series (2020; dashed lines). The bottom panel depicts the time series of *SSB* (kt).

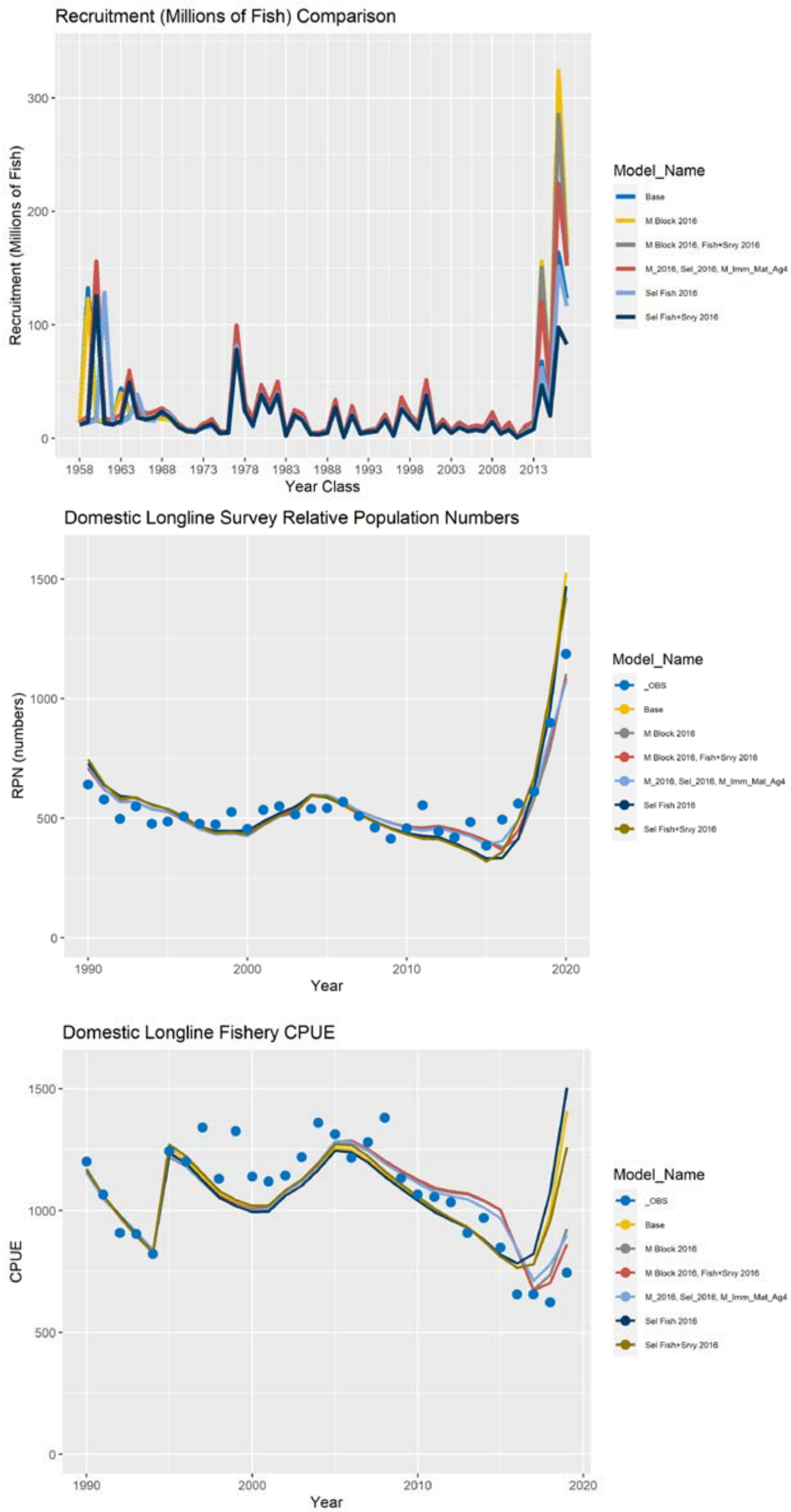
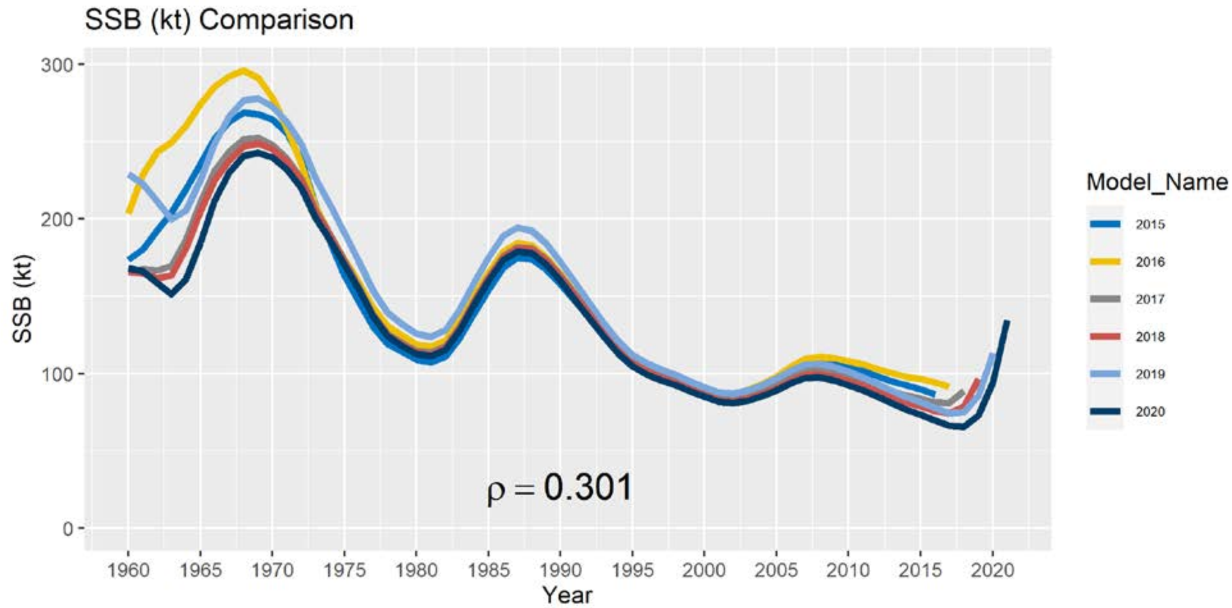


Figure 3.57 (Cont.). Results of select sensitivity runs (colored lines). Model descriptions and names are provided in Table 3.19. The top panel depicts the time series of recruitment (millions of fish). The middle panel illustrates the model fit (solid lines) to the observed domestic longline survey relative population numbers (RPNs; points). The bottom panel depicts the model fit (solid lines) to the observed domestic longline fishery CPUE (points).



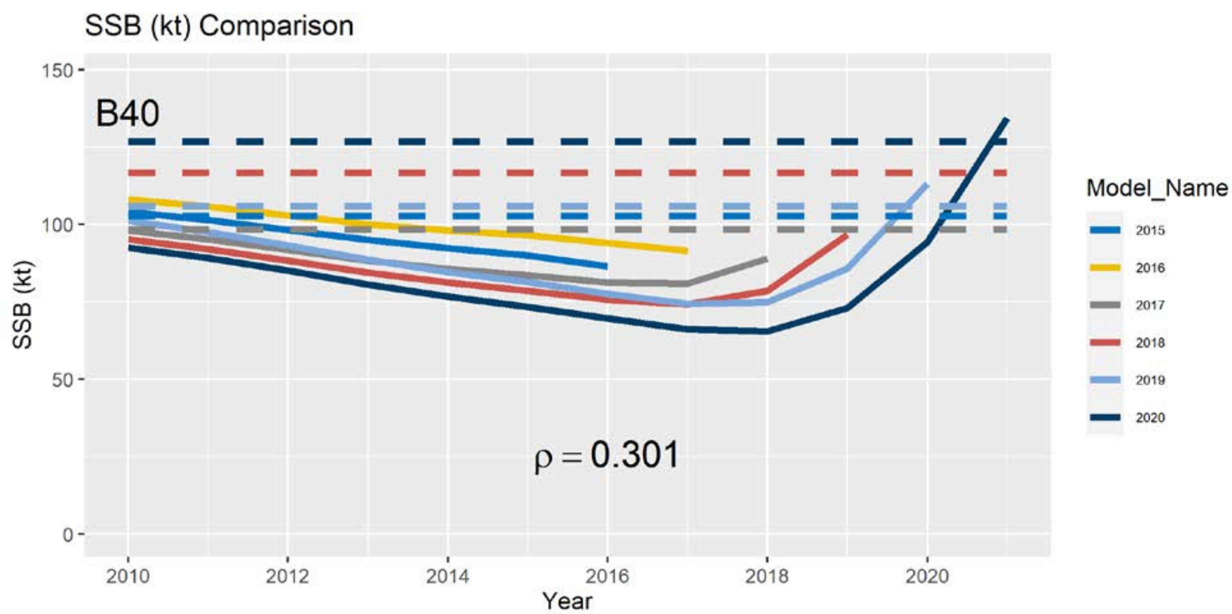


Figure 3.58. Results of an assessment model 'historic' retrospective illustrating estimated and projected (terminal year + 1 year) spawning stock biomass (in kilotons) from the last six sablefish assessments (model years 2015 to 2020). The top panel shows the entire time series of SSB from each assessment model, while the bottom panel shows the same results since 2010 overlaid with corresponding estimates of $B_{40\%}$. Mohn's rho is provided below the lines in each plot.

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. Starting 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 (Table 3A.1). However, in 2020 there were a few instance of vessel interactions. In the GOA, there was 1 interaction with a longliner in West Yakutat and 3 interactions with pot boats (2 in the Central GOA and 1 in the Western GOA). There was also one interaction in the Aleutian Islands with a trawler.

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.

Tables

Table 3A.1 Count of longline survey and fishery vessel interactions by area, fishery gear type, and year.

	Longline		Trawl		Pot		Total	
Year	Stations	Vessels	Stations	Vessels	Stations	Vessels	Stations	Vessels
1995	8	7	9	15	0	0	17	22
1996	11	18	15	17	0	0	26	35
1997	8	8	8	7	0	0	16	15
1998	10	9	0	0	0	0	10	9
1999	4	4	2	6	0	0	6	10
2000	10	10	0	0	0	0	10	10
2001	1	1	1	1	0	0	2	2
2002	3	3	0	0	0	0	3	3
2003	4	4	2	2	0	0	6	6
2004	5	5	0	0	1	1	6	6
2005	1	1	1	1	0	0	2	2
2006	6	6	1	2	0	0	7	8
2007	8	6	2	2	0	0	10	8
2008	2	2	2	2	0	0	4	4
2009	3	3	0	0	0	0	3	3
2010	2	2	1	1	0	0	3	3
2011	3	3	0	0	0	0	3	3
2012	5	5	0	0	0	0	5	5
2013	5	5	0	0	0	0	5	5
2014	2	2	0	0	0	0	2	2
2015	3	3	1	1	0	0	6	6
2016	5	5	1	1	0	0	6	6
2017	8	10	3	3	3	3	13	16
2018	9	9	3	3	0	0	12	12
2019	4	4	1	1	4	4	9	9
2020	1	1	1	1	3	3	5	5

Appendix 3B. Supplemental Catch Data

In order to address NS1 total accounting requirements, non-commercial removals are presented here. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities in federal waters, and does not include removals taken in fisheries other than those managed under the groundfish FMPs. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. The sablefish research removals are substantial relative to the other supplemental catch sources and compared to the research removals for many other species. The majority of these research removals are from a dedicated sablefish NMFS longline survey. Additional sources of significant removals are the NMFS bottom trawl surveys and the International Pacific Halibut Commissions longline survey. Total removals from non-commercial activities has ranged from 197-224 t since 2010. This represents <2% percent of the recommended ABC annually. These removals are a low risk to the sablefish stock.

Tables

Table 3B.1. Total removals of sablefish (t) from research surveys in the BSAI and GOA FMPs since 1977. Trawl survey sources are a combination of the NMFS echo-integration and GOA, AI, and BS slope bottom trawl surveys, and occasional short-term research projects. Data above horizontal lines are from the 2010 sablefish stock assessment (Hanselman et al. 2010). Other data were obtained from the Alaskan Regional Office via AKFIN (www.akfin.org) accessed on 10/25/20.

Year	Trawl Survey	Japan-US Longline Survey	Domestic Longline Survey	IPHC Longline Survey*	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			411
1985	186	390			576
1986	123	396			519
1987	117	349			466
1988	15	389	303		707
1989	4	393	367		764
1990	26	272	366		664
1991	3	255	387		645
1992	0	281	393		674
1993	39	281	362		682
1994	1	271	322		594
1995	0		388		388
1996	13		428		441
1997	1		343		344
1998	26		292	50	368
1999	43		298	49	390
2000	2		269	53	324
2001	11		311	48	370
2002	3		396	58	457
2003	16		272	98	386
2004	2		276	98	376
2005	18		256	92	366
2006	2		287	64	353
2007	17		261	48	326
2008	3		256	46	305
2009	14		241	47	302
2010	3		271	50	324
2011	8		277	39	324
2012	3		204	27	233
2013	4		178	22	204
2014	1		198	32	231
2015	9		175	17	201
2016	2		200	15	217
2017	7		218	11	236
2018	2		175	20	197
2019	15		249	36	300

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

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

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November 2020

With Contributions from:

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Executive Summary

National initiative and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Alaska sablefish (*Anoplopoma fimbria*) due to the highly variable recruitment in recent years. Scores for stock assessment prioritization, habitat prioritization, climate vulnerability assessment, and data classification analysis were moderate to high. Additionally, the Groundfish Plan Team and SSC have supported the ESP for sablefish and requested continued analysis on the recent recruitment fluctuations.

We follow the standardized template for conducting an ESP and present results of applying the ESP process through a metric and subsequent indicator assessment. We use information from a variety of data streams available for the Alaska sablefish stock. 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.

Please refer to the last full ESP document for further information regarding the ecosystem and socioeconomic linkages for this stock (Shotwell et al., 2019, available online within the sablefish stock assessment and fishery evaluation report of Hanselman et al., 2019, Appendix 3C, pp. 157-202 at: https://archive.afsc.noaa.gov/refm/docs/2019/sablefish.pdf).

Summary of Changes in Assessment Inputs

Changes in the Data

We provide the data table from the last full ESP for reference and include any new data sources used to create this report (Appendix Table 3C.1). New datasets include daily sea surface temperatures (SST) from the NOAA Coral Reef Watch Program and chlorophyll *a* concentration from MODIS satellite sensors. The data are accessed through the ERDDAP maintained by NOAA CoastWatch West Coast Regional Node and Southwest Fisheries Science Center's Environment Research Division.

Changes in the Ecosystem Processes

There were no changes to the ecosystem processes section. We include the ecosystem processes by life history stage table and associated conceptual model from the last full ESP for reference (Appendix Table 3C.2, Appendix Figure 3C.1). We also updated the conceptual model figure with arrows that provide the direction of the ecosystem processes by life stage based on the indicator suite for the current year.

Changes in the Socioeconomic Processes

Sablefish have historically been 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. Since 2017 the TACs increased as a result of a strong 2014 year-class. Total catches increased 15% to 17.6 thousand t and retained catches increased 6% to 12.3 thousand t (Appendix Table 3C.3a). The retention rate (ratio of retained catch to total catch), typically above 90% prior to 2017, has dropped to 74% in 2019. This is in part related to the higher catch of juvenile sablefish by Bering Sea trawlers targeting other species. However, retention rates in the GOA have also decreased from 90-95% prior to approximately 80% in 2018 and 2019, likely related to small fish sizes.

Revenues decreased 20% to $73.6 million in 2019 as ex-vessel prices fell 26% to $2.60/lb (Appendix Table 3C.3a). The decrease in the ex-vessel price was a reflection of a commensurate decrease in first-wholesale price to $4.80/lb (Appendix Table 3C.3b). First-wholesale value decreased to $78.3 million in 2019. The price decrease since 2017 is the result of smaller average fish size as the 2014 year-class has not fully grown to a higher marketable price, and an influx of the 2016 and 2017 year-classes. The increased abundance and supply of smaller fish puts downward pressure on the price of small fish, increases the price margin between small and large fish, and lowers the average price. Similarly, export prices, which are typically a strong indicator of first-wholesale prices, were decreasing through 2019.

The U.S. accounted for roughly 88% of global sablefish catch in 2019 and Alaska accounted for roughly 70% of the U.S. catch. Canada caught 11% 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 impacts that influence wholesale and export prices. Most sablefish caught 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 77% in 2010-2014 to 65% in 2019 (Appendix Table 3C.3c). 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 generally increasing (Appendix Table 3C.3c). The U.S.-Japanese exchange rate weakened in 2019 but has remained relatively stable since 2016. The strength of the U.S. dollar puts downward pressure on the price of exported goods as it further increases prices for foreign importers. Additionally, increased global supply, media reports of inventory buildup in Japan, and the small size of fish have put downward pressure on sablefish prices in 2019.

An analysis of commercial processing and harvesting data may be conducted to examine sustained participation for those communities substantially engaged in a commercial fishery. The Annual Community Engagement and Participation Overview (ACEPO) is a new report in preparation to evaluate engagement at the community level. The analysis focuses on providing an overview of harvesting and processing sectors of identified highly engaged communities for groundfish and crab fisheries in Alaska. Community sketches are also prepared for the highly engaged communities. This same information can be evaluated at the stock level for inclusion in the ESP. The analysis separates variables into two categories of fisheries involvement: commercial processing and commercial harvesting. Processing engagement is represented by the amount of landings and associated revenues from landings in the community, the number of vessels delivering in the community, and the number of processors in the community. Harvesting engagement is represented by: the landings, revenues associated with vessels owned by community residents, the number of vessel landings owned by residents in the community, and the number of distinct resident vessel owners whose vessels made landings in any community. By separating commercial processing from commercial harvesting, the engagement indices highlight the importance of fisheries in communities that may not have a large amount of landings or processing in their community, but have a large number of fishers and/or vessel owners that participate in commercial fisheries who are based in the community. To examine the relative harvesting and processing engagement of each community, a separate principal components factor analysis (PCFA) was conducted each year for each category to determine a community's engagement relative to all other Alaska communities.

Top communities may be selected for each sector based on the value and volume of a given stock landed (for processing engagement) and value and volume harvested (for harvesting engagement). One indication of community engagement in processing activities for a given fishery is calculating the portion of the total stock's fishery landed in each community as well as the percentage of the total revenue those communities get from that fishery. The associated value of a given stock harvested by vessels owned by community residents may be examined to explore community engagement in harvesting activities for that stock. This community engagement analysis has been conducted for several groundfish stocks in Alaska and included in those ESPs (e.g., GOA pollock, EBS Pacific cod, GOA Pacific cod). The analysis has not yet been completed for sablefish, but we plan to include results in the ESP when it is completed. To date, the most highly engaged communities with the sablefish fishery are Seward, Kodiak, Sitka, and Homer, accounting for almost 48% of the regional value landed.

Changes in the Indicator Suite

We included several updates to indicators using new data sources and methodology and new indicators that were identified as data gaps in previous ESPs. For the sea surface temperature indicators we have moved to using the NOAA Coral Reef Watch Program products as they are supported operationally by

NOAA and NESDIS and are updated daily (Watson, 2020). For proxy measures of primary production we provide a combination indicator of chlorophyll *a* concentration and the timing of the spring bloom, which utilizes ocean color data from the MODIS satellite sensor and are also available in real-time (Watson et al., 2020). When taken together, the chlorophyll *a* biomass during the sablefish larval peak (May) and the spring bloom timing for the region of interest allow for evaluating the match or mismatch of sablefish larvae with their prey. We have switched to evaluating the copepod community size data from the Continuous Plankton Recorder in the GOA east and west oceanic regions in order to capture the shifts from a large to small celled zooplankton community, which is indicative of surface warming (Ostle, 2020). Condition indicators have been recalculated to be consistent with the RACE Groundfish Assessment Program methods used on the bottom trawl survey data and suggested by the SSC (Rohan, 2020). Unlike the methods used for RACE/GAP groundfish indicators, we assumed a single stratum for each indicator, and, therefore, did not weight length-weight residuals by stratum-specific area biomass or corresponding relative population numbers or weight (RPN/RPW). Also, sample sizes for indicator groups were frequently too low to stratify, especially in the survey data. We have removed a previously used indicator that combined all juvenile females because it included multiple year classes and was difficult to interpret. We continue with the age-4 condition indicator to represent younger, immature female sablefish because they are well-represented in the survey as compared to ages 2 or 3. We also updated the price indicator to an average price over all sizes to be comparable to the exvessel value indicator.

Changes in the Indicator Monitoring Analysis

Indicators are monitored 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*). Following recommendations from the SSC in February 2020, we have added a scoring calculation to the first stage traffic light test. Similar to last year, the indicator values are evaluated if they are greater than (+), less than (-), or within (•) one standard deviation of the long-term mean for the time series. A value is then provided for the traffic-light based on whether the indicator creates conditions that are good (1) or poor (-1) for sablefish (Caddy et al., 2015) as defined by the conceptual model and associated processes tables. We then assign a simple score based on the value compared to the long term mean and traffic light code. If a high value of an indicator generates good conditions for sablefish and is also greater than one standard deviation from the mean, then that value receives a +1 score. If a high value generates poor conditions for sablefish and is greater than one standard deviation from the mean, then that value receives a -1 score. All values less than or equal to one standard deviation from the long-term mean are average and receive a 0 score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. We also calculate the overall ecosystem and socioeconomic score and provide these aggregated scores for the past twenty years as the majority of indicators were available throughout this time period. The scores over time allow for comparison of the indicator performance and the history of stock productivity.

Summary of Results

We have updated the indicator suite from the last full ESP as described above in the "Changes in the Indicator Suite" subsection (Appendix Table 3C.4, Appendix Figure 3C.2). The following list of indicators for sablefish is organized by categories, three for ecosystem indicators (physical, lower trophic, and upper trophic) and three for socioeconomic indicators (fishery performance, economic, and community) and provides information on whether the indicator was updated or new this year with references where possible. Please refer to the last full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions for this stock (Shotwell et al., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Appendix Figure 3C.2a and Appendix Figure 3C.2b, respectively.

Ecosystem Indicators

1. Physical Indicators (Appendix Figure 3C.2a.a-f)
    - Annual marine heatwave cumulative index over the central GOA, 1982 to present (contact: S. Barbeaux).
    - Summer temperature anomalies at 250 m isobath during the AFSC annual longline survey, 2005 to present (contact: K. Siwicke).
    - UPDATED: Late spring (May-June) daily sea surface temperatures (SST) for the eastern GOA and southeastern Bering Sea (Watson, 2020) from the NOAA Coral Reef Watch Program which provides the Global 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018), 1985 to present (contact: J. Watson).
    - NEW: Derived chlorophyll *a* concentration during spring seasonal peak (May) in the eastern GOA and southeastern Bering Sea were obtained from MODIS satellite sensor at a 4x4 km resolution and aggregated 8-day composite. Peak timing of the spring bloom was calculated for individual ADF&G statistical areas in the southeastern Bering Sea (SEBS) and for the eastern GOA (EGOA) region (Nielson et al., 2020, Watson et al., 2020). For the EBS the peak timing was then averaged across all statistical areas in order to weight each stat area equally. This is to avoid giving inner shelf areas more weight since the chlorophyll *a* biomass is higher in those areas during the peak. Data available from 2003 to present (contact: J. Nielsen for EBS and J. Watson for EGOA).
2. Lower Trophic Indicators (Appendix Figure 3C.2a.g-j)
    - NEW: Abundance of copepod community size from the continuous plankton recorder (CPR) for the offshore waters of the GOA split into a western and eastern section (Ostle and Batten, 2020), 2002-2019 (contact: C. Ostle).
    - Summer euphausiid abundance for the Kodiak core survey area (Ressler et al., 2019), available for variable years historically and biennially since 2013 (contact: P. Ressler).
    - Age-0 sablefish growth rate from auklet diets in Middleton Island (Arimitsu and Hatch, 2020), available from 1978 to present (contact: M. Arimitsu and S. Hatch).
3. Upper Trophic Indicators (Appendix Figure 3C.2a.k-t)
    - Sablefish catch-per-unit-effort and lengths from the ADF&G large mesh bottom trawl survey of crab and groundfish, 1988 to present (contact: K. Spalinger).
    - Catch-per-unit-of-effort of juvenile sablefish (<400 mm, likely age-1) collected on summer AFSC bottom-trawl surveys. 1984 to present (contact: K. Shotwell).
    - Mean age of sablefish female spawning stock biomass from the most recent sablefish stock assessment model, 1977 to present (contact: D. Hanselman)
    - Measure of evenness or concentration of age composition by cohort of female sablefish from the most recent sablefish stock assessment model, 1977 to present (contact: D. Hanselman).
    - UPDATED: Summer sablefish condition for age-4, immature female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly for otoliths in the annual GOA AFSC longline survey (legs 2-7 including slope and cross gully stations), 1996 to present (contact: J. Sullivan and K. Siwicke).
    - Arrowtooth flounder total biomass (metric tons) from the most recent stock assessment model, 1977 to present (contact: K. Shotwell).
    - Incidental catch of sablefish in the GOA arrowtooth flounder fishery, data available from AKFIN, 1992 to present (contact: K. Shotwell).

- UPDATED: Summer sablefish condition for large adult (>=750 mm) female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly for otoliths in the annual GOA AFSC longline survey (legs 2-7 including slope and cross gully stations), 1996 to present (contact: J. Sullivan and K. Siwicke).

Socioeconomic Indicators

1. Fishery Performance Indicators (Appendix Figure 3C.2b.a-d)
    - Catch-per-unit-of-effort of sablefish in tons from the longline fisheries in the GOA, 1996 to present (contact: C. Rodgveller and D. Hanselman).
    - Catch per unit of effort of sablefish in tons estimated from the pot fisheries in the eastern Bering Sea, 1999 to present (contact: C. Rodgveller and D. Hanselman).
    - Incidental catch estimates of sablefish in the Bering Sea fisheries excluding the sablefish fishery provided by AKFIN, 1991 to present (contact: K. Shotwell).
    - Incidental catch estimates of sablefish in the GOA fisheries excluding the sablefish fishery provided by from AKFIN, 1991 to present (contact: K. Shotwell).
2. Economic Indicators (Appendix Figure 3C.2b.e-h)
    - UPDATED: Sablefish condition for large (>= 750 mm) female sablefish. Body condition was estimated using a length-weight relationship (Laman and Rohan, 2020) from data collected randomly by observers for otoliths in the GOA and BSAI fisheries, 1999 to present (contact: J. Sullivan and K. Siwicke).
    - Annual estimated real ex-vessel value measured in millions of dollars and inflation adjusted to 2019 USD (contact: B. Fissel).
    - UPDATED: Average real ex-vessel price per pound of sablefish measured in millions of dollars and inflation adjusted to 2019 USD (contact: B. Fissel).

At this time, we report the 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, but we provide updates of new ecosystem enhanced models in development.

Stage 1, Traffic Light Test:

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.2a.a-h). There has been increased sea surface warming in the GOA and BSAI ecosystems and the presence of a series of major heatwaves from 2014-2016 and again in 2019 (Appendix Figure 3C.2a.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 AFSC longline survey, which is in prime sablefish habitat, has not deviated greatly from the 15-year mean (Appendix Figure 3C.2a.b). However, this index has remained positive for the last four years, a deviation from the historical fluctuations around the mean, suggesting these deeper waters may remain somewhat warmer than average (~0.1°C) from 2017-2020. 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, but the EGOA surface temperature has decreased to near average conditions in 2020 (Appendix Figure 3C.2a.c-d). Chlorophyll *a* concentration or biomass during the peak sablefish larval abundance period (May) has been low in the EGOA and SEBS with a peak only in 2014 in the EGOA and 2014 and 2015 in the SEBS (Appendix Figure 3C.2a.e-f). This has increased somewhat in the SEBS in 2020 but still remains below the long-term mean of the time series. Also, the spring bloom timing, which was relatively steady in the EGOA and SEBS from 2014 through 2016, appears to be fluctuating dramatically in both regions since then and now has an early timing in 2020 in the EGOA and slightly earlier timing in the SEBS (Appendix Figure 3C.2a.g-h). The copepod community size in the offshore eastern and western GOA appears to be trending to a smaller community size in the GOA but returning to average in the SEBS (Appendix Figure 3C.2a.i-j). There was no update on the euphausiid abundance index as this was an off year for the GOA surveys (Appendix Figure 3C.9a.k). 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) 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.2a.l). Peak growth occurred in 2014-2016 and again with a very high anomaly in 2019, but has returned to near average growth in 2020. Age-1 sablefish were captured in high numbers in the ADF&G large mesh survey in 2015 and 2017, and to a lesser extent in 2019 and again in high numbers in 2020 (Appendix Figure 3C.3b) and in the AFSC bottom trawl survey in 2015 and 2017 (Appendix Figure 3C.2a.n). The ADF&G survey has also shown an increasing trend for sablefish catch-per-unit-of-effort (CPUE) since 2015 with the exception of 2017 (Appendix Figure 3C.3a). 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.m). 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.

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 and 2016 year-class begins to mature (Appendix Figure 3C.2a.o). Age evenness has severely declined in recent years and is far less 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 is potentially less resilient to future shifts in environmental conditions (Appendix Figure 3C.2a.p). 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. Body condition of sablefish females captured on the longline survey can be used to measure the health of fish arriving at the adult habitat. The summer condition of age-4 female mature fish on the AFSC longline survey has fluctuated over time but appears to be on an overall decreasing trend since 2015 (Appendix Figure 3C.2a.q). Specifically, the condition of age-4 females in 2018 and 2019 (or the 2014 and 2015 year-class) is poor when compared to the relatively good condition of age-4 female fish in previous high recruitment years (2001, 2002, and 2004, for the 1997, 1998, and 2000 year-classes). This potential poor survival from early recruitment success at the YOY stage was also confirmed in the continued 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. This implies that there may be additional factors contributing to the survival of these strong year-classes following the overwinter survival and nearshore residency that may have to do with the lipid accumulation in maturing sablefish and their subsequent ability to spawn (Rodgveller et al., 2018; Shotwell et al., 2019).

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. Therefore, it may be useful to consider impacts of potential predator biomass on sablefish when 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.2a.r). 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.2a.s). This may mean that young sablefish moving to adult slope habitat have a higher level of competition and predation resulting in the measured poor body condition (Appendix Figure 3C.2a.q). Condition of large adult female sablefish from the AFSC longline survey was very low from 2015 to 2017 but has since improved to average or above average levels from 2018 to 2020 (Appendix Figure 3C.2a.t), which is a positive sign given the increasing reliance on the 2014 cohort contribution to the sablefish population. It is also clear that size at age for ages 4-6 of both male and female sablefish has declined since the late 1990s, which reflects the lack of large spawners in the population (Appendix Figure 3C.4).

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 but improved in preliminary 2020 estimates (Appendix Figure 3C.2b.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 record highs in 2018-2020 (Appendix Figure 3C.2b.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.2b.c-d), but decreased in the GOA in 2020. These catches are primarily from 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 that may increase competition and predation for sablefish. For economic trends, large adult female sablefish condition in the GOA and BSAI fisheries appear to be steady at average for the past several years (Appendix Figure 3C.2b.e-f). The relative condition by region of the large female spawners may provide some insight into habitat quality by region and the subsequent value of these fish considering observed increase in lipids with increasing body size and condition. Overall, the real ex-vessel value and average price per pound of the fishery has declined dramatically since 2017 likely due to increased catch of small fish as the 2014 year-class entered the fishery (Appendix Figure 3C.2b.g-h).

Traffic light scores by category and overall are provided in Appendix Table 3C.4. For the indicators available in the current year, the traffic light analysis shows decrease in the physical indicators, stable in the lower trophic indicators and increase in the upper trophic indicators. This is a switch from last year where physical and lower trophic indicators were increasing and upper trophic was decreasing (Appendix Table 3C.4a). Socioeconomic indicators were also mixed but with fishery performance indicators switching from decreasing last year to increasing this year and economic indicators continuing to decrease (Appendix Table 3C.4b). We also provide the direction of the current year score from the previous year score for these categories with arrows on the conceptual model graphic for quick reference (Figure 3C.1). The historical traffic light score over all ecosystem and socioeconomic indicators demonstrates a fairly strong negative relationship between the ecosystem and socioeconomic trends since 2007 and positive relationship prior to that time (Figure 3C.5). This may reflect the delayed response between the increases in sablefish following large recruitment events (e.g., 1997, 2000, 2014, 2016) and subsequent value to the fishery.

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. 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.6a). 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 1996 through the 2017 estimate of 2 year-olds or the 2015 year-class. We then provide the mean relationship between each predictor variable and log sablefish recruitment over time (Appendix Figure 3C.5b, left side), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Appendix Figure 3C.5b, 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 continue to be the summer juvenile sablefish CPUE from the ADF&G large mesh survey and the catch from the arrowtooth flounder fishery in the GOA (Appendix Figure 3C.6). The summer juvenile condition indicator was removed from this analysis.

Stage 3, Modeling Test:

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 Integrated Life Cycle (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 ADF&G index continues to have a high inclusion probability in the stage 2 test and could be used directly in the model as a survey for age-1 plus sablefish. Utilizing indicators as indices directly inside the model would have the desirable property of influencing ABC recommendations in a neutral way.

Ecosystem 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 changes in inputs and results from the last full ESP, we provide the following set of ecosystem considerations that may be used for reference in the main SAFE report.

- Surface temperatures in the EGOA have cooled relative to 2019. Meanwhile, waters in the SEBS continue to be warm, with continued (though less intense than 2019) heatwave conditions. Heat also remains in the system at depth.
- Chlorophyll *a* concentration remains low in both regions and spring bloom timing is earlier in the EGOA and slightly earlier in the SEBS
- Growth of YOY sablefish has returned to average but CPUE remains large for juveniles in the nearshore surveys suggesting overwinter and nearshore conditions are still favorable
- Mean age of spawners and age evenness continue to decrease suggesting higher reliance on the recent large 2014 and 2016 year-classes in the female spawning biomass
- Condition of the 2011, 2013-2015 year-classes is poor when compared to the relatively good condition of age-4 fish in previously high recruitment years
- Spatial overlap between sablefish migrating to adult slope habitat and the arrowtooth flounder population may have increased, based on continued recent large increases in incidental catch in the arrowtooth flounder fishery and may imply potentially higher competition and predation
- Overall, physical indicators were still positive but less so than in 2019, lower trophic indicators were stable and upper trophic indicators improved slightly.

Socioeconomic 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 changes in inputs and results from the last full ESP, we provide the following set of socioeconomic considerations that may be used for reference in the main SAFE report.

- Community indicators for highly engaged communities are being prepared for sablefish and will be included in future ESPs
- 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 continues to increase in the BSAI in 2020 but has decreased in the GOA, which may imply shifting distribution of sablefish into non-preferred habitat in the BSAI and settlement of the 2014 year class into deeper waters of the GOA
- Large adult female sablefish condition in the GOA and BSAI fisheries appear to be steady at average for the past several years, which provides some insight on the habitat quality by region and the subsequent value of these fish
- Real ex-vessel value and average price per pound have declined dramatically since 2017

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. Continued development of high-resolution remote sensing (e.g., regional surface temperature, transport estimates, mesoscale eddy activity, 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 is updated, a more detailed synthesis of gut contents could improve the evaluation of these condition indices and potentially generate time-series indicators of stomach fullness or energy content per individual sablefish. These could provide 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 Alaska 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 analysis. 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 boosted regression trees. 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.

Responses to SSC and Plan Team Comments on ESPs in General

"Regarding ESPs in general, the SSC recommends development of a method to aggregate indices into a score that could be estimated over time and compared to stock history. One potential pathway forward may be to normalize and use an unweighted sum of all the indicators where all time series overlap, or just assign +1 or -1 to each indicator so that a neutral environment would be zero." (SSC, February 2020)

"The Teams discussed concerns of over-emphasizing the 1:1 weighting on the first stage. In the absence of information to indicate an appropriate weighting strategy, it is recommended to not rely too heavily on the uninformed 1:1 weighting to select appropriate indicators. The Teams also requested that the ESP team/authors consider appropriately caveating the indicators to ensure they are interpreted species-specific and not over generalized. The Teams support continuing with the current 3-stage indicator analyses for now, and re-evaluate as the ESP process develops, recognizing that the actual value of the integrated index is yet to be clearly demonstrated although it is one high-level summary statistic that may be valuable to examine." (Joint Groundfish Plan Team, September 2020)

We provide a simple score following the SSC recommendation and compare the 1:1 weighting of indicators in this first stage score with the results of the second stage Bayesian Adaptive Sampling (BAS) method that produces inclusion probabilities for a subset of indicators with the most potential for informing a stock assessment parameter of interest (in this case recruitment of sablefish). This second stage may provide insight on how to weight the indicators in the first stage for a more informed score.

"The Teams support the current formats and timelines for now. This question may need to be revisited as the ESP process develops." (Joint Groundfish Plan Team, September 2020)

We provide this partial ESP for the sablefish stock that follows the partial SAFE template in an effort to produce an executive summary version of the ESP. This template may go through some revision as the ESPs continue to develop.

Responses to SSC and Plan Team Comments Specific to this ESP

"The SSC appreciates the excellent continued work of the authors on the ESP. This ESP provides a strong example for authors of other SAFE chapters. The SSC encourages the authors to focus on explaining the mechanisms underlying the observed declines in the estimated size of the 2014 year class." (SSC, December 2019)

We elaborate on potential mechanisms underlying the declines in the 2014 year class within the first stage indicator analysis section.

"The SSC appreciates the authors' effort to identify fishery performance indicators that provide relevant insight into stock status. The SSC encourages the authors to continue to explore community related socioeconomic indicators and suggests that they focus on substantially engaged and/or substantially dependent communities recognizing that in small communities, even a low level of engagement in absolute terms can result in a relatively high level of dependence on that fishery. Further, communities selected for inclusion in the analysis should not be based on commercial landings alone, as engagement in the relevant commercial fishery(ies) can and does occur through locally owned vessel activity, crew employment and income, locally occurring processing activity, and support service activity. Dependency can usefully be measured via vessel and processing diversity and annual round activity and spatial variations, among other factors (recognizing that data availability will vary widely across communities, especially for support service activity). Additionally, as noted in public testimony, it is important to recognize that sablefish are economically important to community fleets across a variety of gear types.

To be useful in an ESP application, community engagement in and dependency on the relevant fishery(ies) need to be tracked with indicator time series data to allow for the recognition of trends that could serve as ecosystem "yellow flags" or "red flags," consistent with other indicators. Indices such as Regional Quotient and Local Quotient are particularly useful in a report card context for a variety of reasons, including the ability to provide information where data confidentiality considerations would be otherwise be a major analytic constraint, but they need to be clearly defined." (SSC, December 2019)

We provide a short summary of new developments in community indicators and the ACEPO report in the *Changes in the Socioeconomic Processes* subsection. We plan to include relevant processing and harvesting engagement indicators when they become available for the sablefish fishery.

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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 et al., 2019; Siddon and Zador, 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
AFSC Ecosystem Survey	Shelf and slope age-0 summer ecosystem 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
AFSC 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
AFSC Longline Survey	Longline survey of groundfish on stratified stations set 37-54 km apart using standard groundline	1987-2018	GOA annual
AFSC 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
Coral Reef Watch Program	NOAA Coral Reef Watch Program, Global 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3.1, derived from CoralTemp v1.0. product (NOAA Coral Reef Watch, 2018)	1985 – present	Global
MODIS	4 km MODIS ocean color data aggregated 8-day composites.	2003 – present	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

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 et al., 2019; Siddon and Zador, 2019) and the Economic Status Report (Fissel et al., 2019) for more details.

Title	Description	Years	Extent
Climate Model Output	Daily sea surface temperatures from the NOAA High-resolution Blended Analysis Data	1977 – present	Central GOA
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.2 Key processes affecting survival by life history stage for sablefish. See Shotwell et al. 2019 for a fully referenced description of processes in the table.

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 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, abundant prey 3. Currents that facilitate nearshore transport	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 3. Currents that transport onto shelf 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 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 juvenile sablefish are 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, 2010-2014 average and 2015-2019.

	2010-2014 Average	2015	2016	2017	2018	2019
Total Catch K mt	13.6	11.7	10.9	13.0	15.3	17.6
Retained Catch K mt	13.0	10.8	9.9	11.5	12.3	13.1
Value M US$	$113.3	$94.4	$92.9	$119.1	$92.4	$73.6
Price/lb US$	$4.09	$3.97	$4.38	$4.99	$3.50	$2.60
% value GOA	91%	95%	96%	97%	95%	92%
Vessels #	330	292	288	281	294	263
Proportion CV	88%	90%	88%	85%	84%	87%

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, 2010-2014 average and 2015-2019.

	2010-2014 Average	2015	2016	2017	2018	2019
Quantity K mt	7.51	6.06	5.86	6.59	7.22	7.40
Value M US$	$113.8	$91.0	$102.1	$123.8	$99.9	$78.3
Price/lb US$	$6.87	$6.81	$7.90	$8.52	$6.28	$4.80
H&G share	96%	98%	97%	97%	97%	93%

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, 2010-2014 average and 2015-2019.

	2010-2014 Average	2015	2016	2017	2018	2019
Global catch K mt	20.0	18.7	17.2	19.1	19.9	-
U.S.Share of global	89%	86%	89%	90%	88%	-
AK share of global	65%	58%	57%	60%	62%	-
Export Volume K mt	9.54	6.66	5.58	5.73	6.57	6.21
Export value M $	$ 92.74	$ 82.26	$ 80.82	$ 86.48	$ 84.73	$ 68.01
Export Price/lb US$	$ 4.41	$ 5.60	$ 6.57	$ 6.84	$ 5.85	$ 4.97
Japan value share	77%	63%	59%	66%	63%	65%
China value share	10%	17%	21%	18%	20%	18%
Exchange rate, Yen/Dollar	90.2	121.0	108.8	112.2	110.4	109.0

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

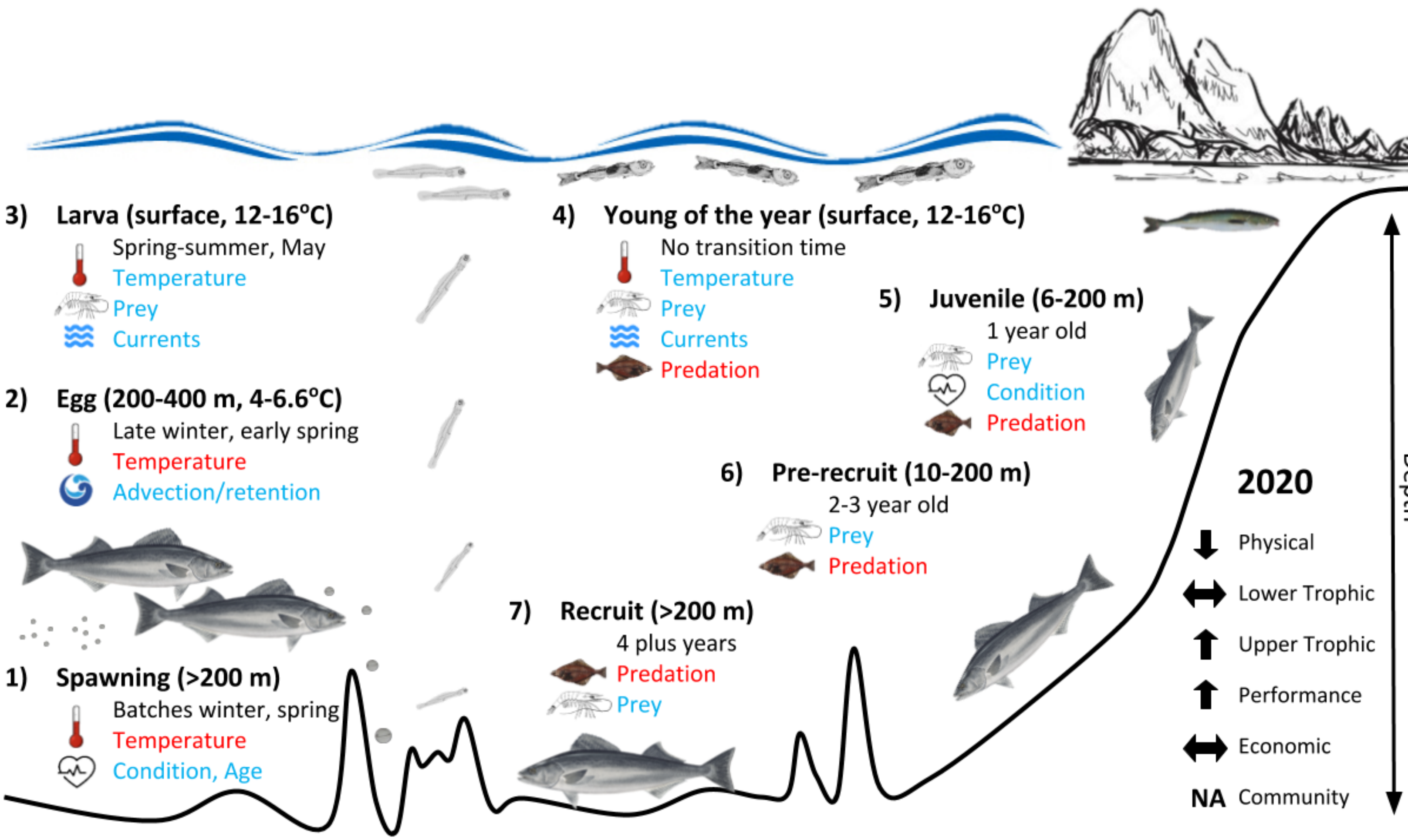
Appendix Table 3C.4a. First stage ecosystem indicator score analysis for sablefish by four main categories (physical, lower trophic, upper trophic, and overall ecosystem). Each indicator is scored based on the traffic light evaluation for that indicator (1 if a positive value increase creates good conditions for sablefish, -1 if positive increase create poor conditions for sablefish, 0 otherwise), multiplied by the value relative to the long-term mean of the time series (greater than, less than, or within 1 standard deviation). Those scores are summed by category and then divided by the total number of indicators for that category. Number of indicators for each category are also provided. NA = no indicators available. Color coding based on column, blue = 1 shading through white = 0 shading through red = -1.

	Physical		Lower Trophic		Upper Trophic		Total Ecosystem	
Year	Score	# Indicators	Score	# Indicators	Score	# Indicators	Score	# Indicators
2000	0.00	3	1.00	1	0.14	7	0.25	12
2001	0.00	3	0.00	1	0.13	8	0.08	13
2002	0.00	3	0.00	3	0.00	7	0.00	14
2003	0.43	7	-0.50	4	-0.13	8	0.00	20
2004	0.14	7	0.33	3	0.00	7	0.17	18
2005	0.38	8	0.00	4	-0.13	8	0.10	21
2006	-0.25	8	0.00	3	-0.29	7	-0.21	19
2007	-0.25	8	0.67	3	-0.50	8	-0.20	20
2008	-0.38	8	0.00	3	-0.29	7	-0.26	19
2009	0.00	8	0.33	3	-0.13	8	0.00	20
2010	0.13	8	-0.33	3	-0.14	7	-0.05	19
2011	0.00	8	0.50	4	0.00	8	0.10	21
2012	-0.50	8	-0.33	3	-0.14	7	-0.32	19
2013	0.00	8	0.00	4	-0.38	8	-0.19	21
2014	0.25	8	0.00	3	-0.14	7	0.05	19
2015	0.25	8	0.00	4	0.00	8	0.10	21
2016	0.38	8	0.00	3	-0.14	7	0.05	19
2017	0.00	8	-0.25	4	-0.13	8	-0.14	21
2018	0.00	8	-0.33	3	0.14	7	-0.05	19
2019	0.50	8	0.00	4	-0.13	8	0.10	21
2020	0.13	8	0.00	1	0.00	6	0.06	16

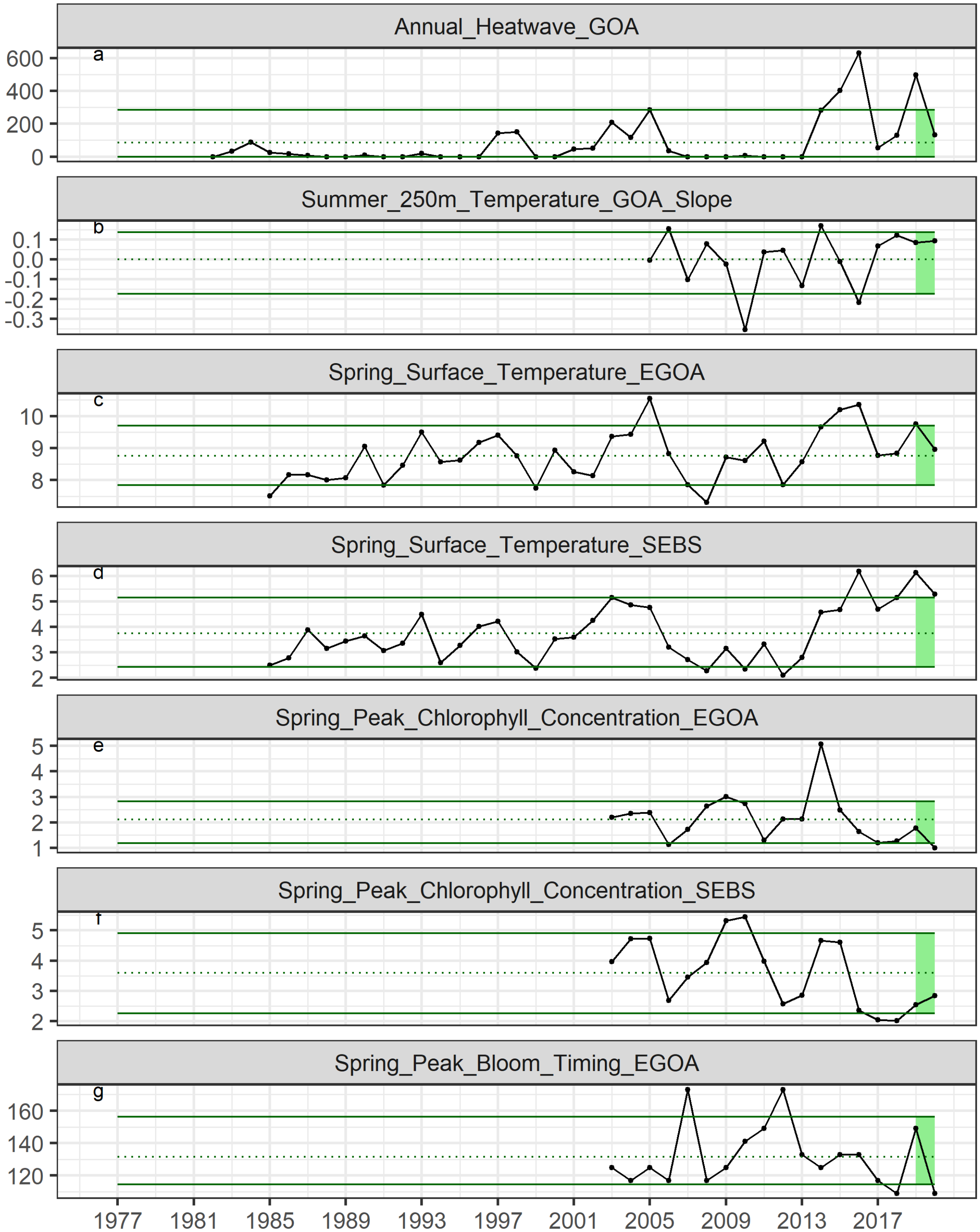
Appendix Table 3C.4b. First stage socioeconomic indicator score analysis for sablefish by four main categories (performance, economic, community, and overall socioeconomic). Each indicator is scored based on the traffic light evaluation for that indicator (1 if a positive value increase creates good socioeconomic environment for sablefish, -1 if positive increase create poor conditions for sablefish, 0 otherwise), multiplied by the value relative to the long-term mean of the time series (greater than, less than, or within 1 standard deviation). Those scores are summed by category and then divided by the total number of indicators for that category. Number of indicators for each category are also provided. NA = no indicators available. Color coding based on column, blue = 1 shading through white = 0 shading through red = -1.

	Fishery Performance		Economic		Community		Total Ecosystem	
Year	Score	# Indicators	Score	# Indicators	Score	# Indicators	Score	# Indicators
2000	0.33	6	0.00	0	NA	NA	0.20	5
2001	0.33	6	0.00	0	NA	NA	0.40	5
2002	0.17	6	0.00	0	NA	NA	0.20	5
2003	0.00	6	0.00	2	NA	NA	0.00	7
2004	0.33	6	-0.50	2	NA	NA	0.00	7
2005	0.00	6	-0.50	2	NA	NA	-0.14	7
2006	-0.17	6	0.00	2	NA	NA	-0.14	7
2007	0.17	6	0.00	2	NA	NA	0.14	7
2008	0.00	6	0.00	2	NA	NA	0.00	7
2009	0.00	6	0.00	2	NA	NA	0.00	7
2010	0.00	6	0.00	2	NA	NA	0.00	7
2011	-0.17	6	1.00	2	NA	NA	0.14	7
2012	0.17	6	0.50	2	NA	NA	0.29	7
2013	-0.17	6	0.00	2	NA	NA	0.00	7
2014	0.17	6	0.00	2	NA	NA	0.14	7
2015	0.00	6	0.00	2	NA	NA	0.00	7
2016	-0.17	6	0.00	2	NA	NA	0.00	7
2017	-0.20	5	0.50	2	NA	NA	0.17	6
2018	-0.20	5	0.00	2	NA	NA	0.00	6
2019	-0.40	5	-1.00	2	NA	NA	-0.50	6
2020	0.00	5	-1.00	2	NA	NA	-0.33	6

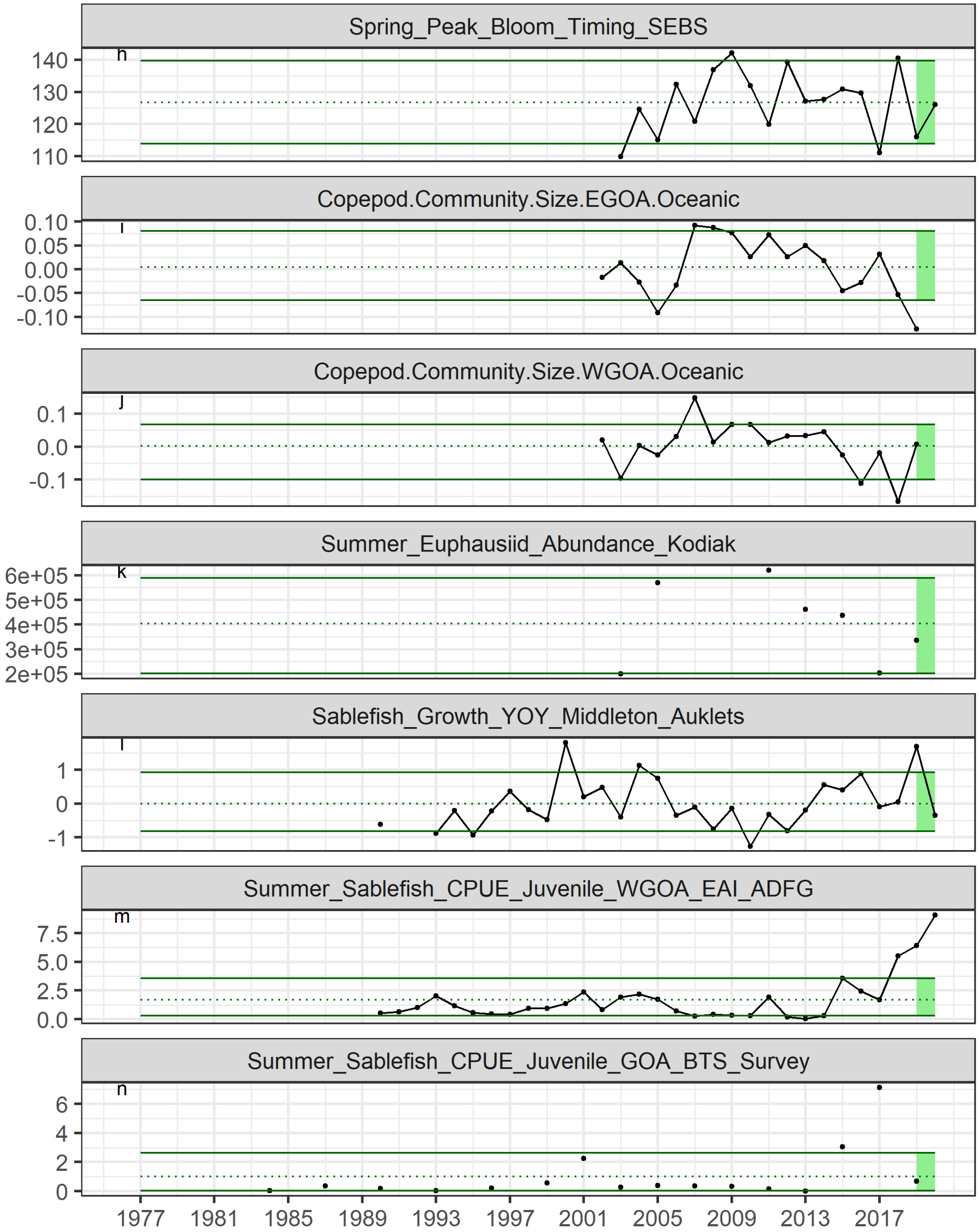
Figures



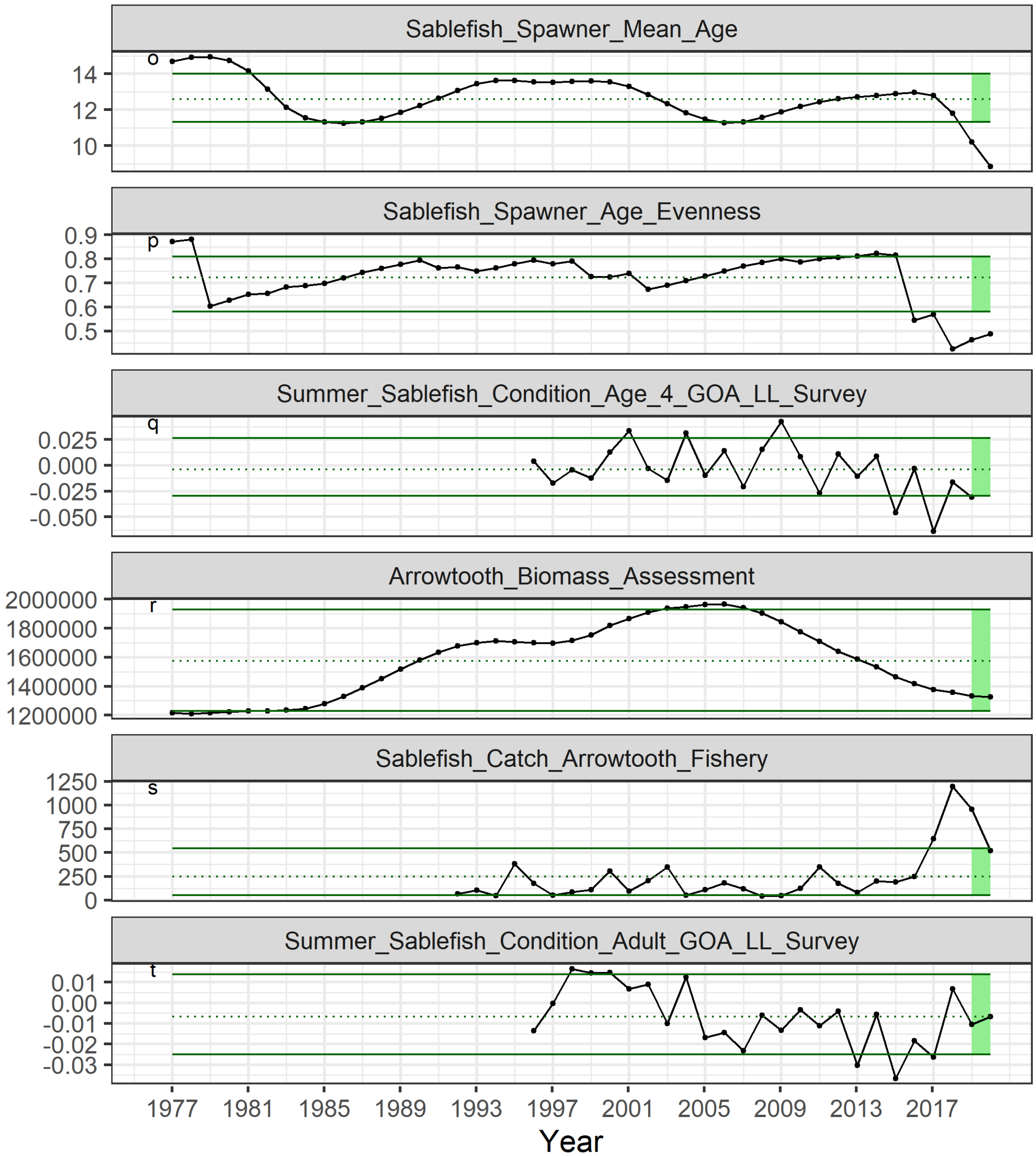
Appendix Figure 3C.1: Life history conceptual model for sablefish summarizing ecological information and key ecosystem processes affecting survival by life history stage. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival. Trend of current year value compared to last year's value depicted with arrows on the left. NA means no indicators for that category.



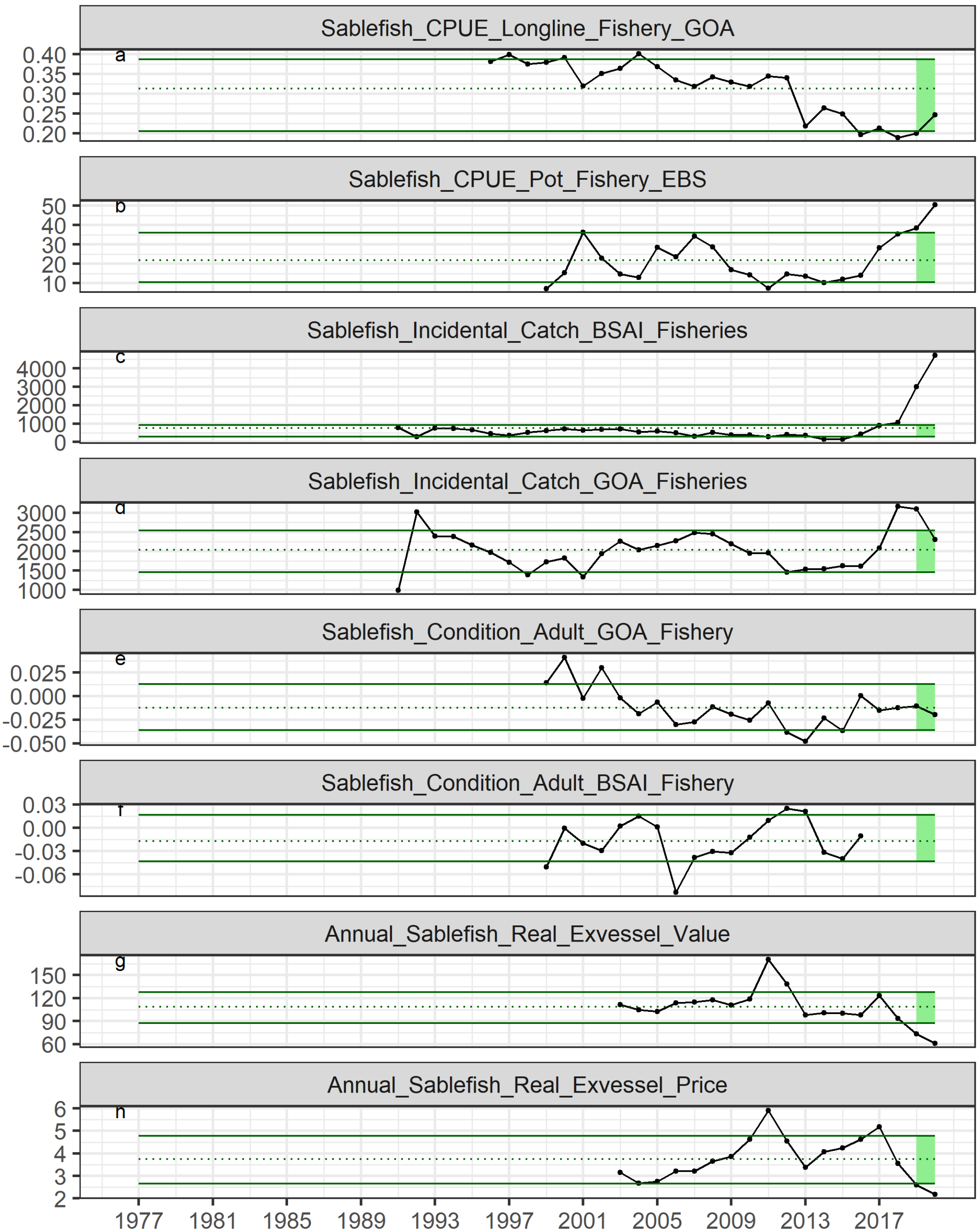
Appendix Figure 3C.2a. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results.



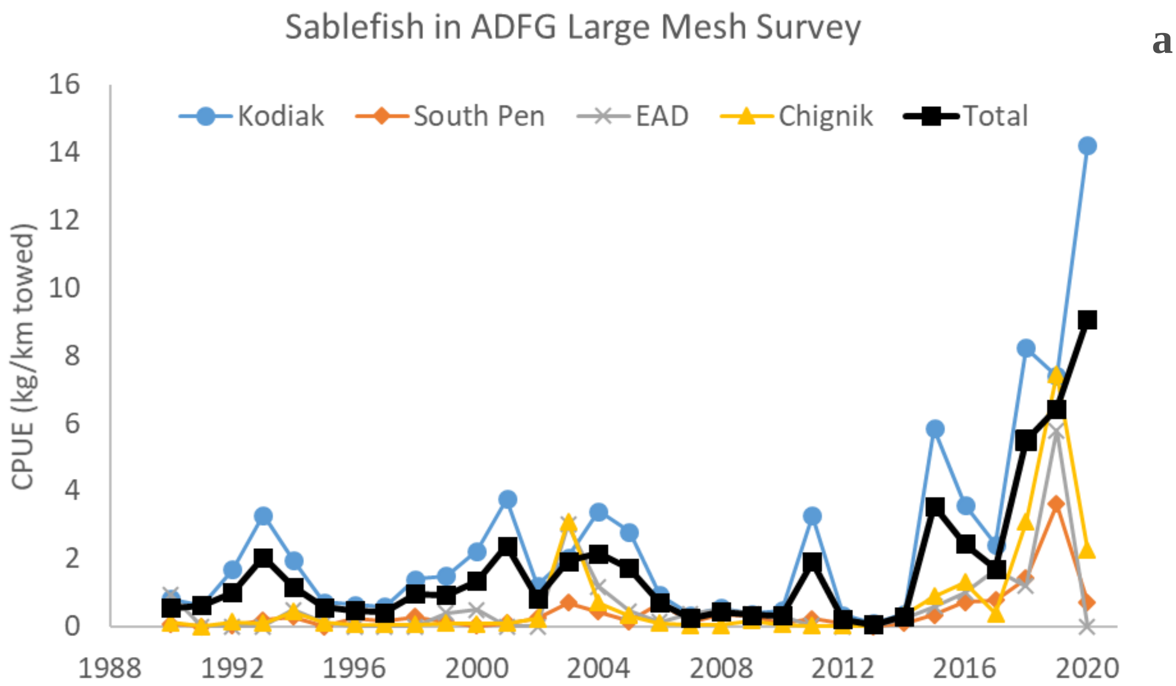
Appendix Figure 3C.2a (cont.). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results.

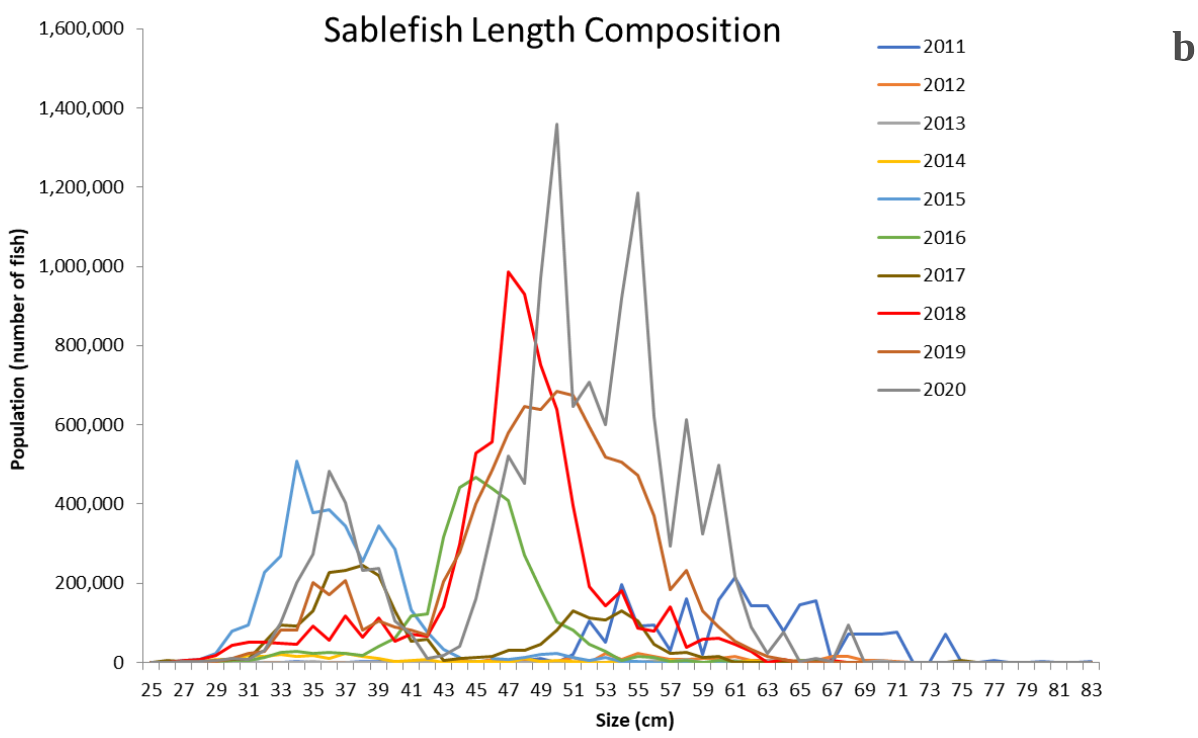


Appendix Figure 3C.2a (cont). Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results.



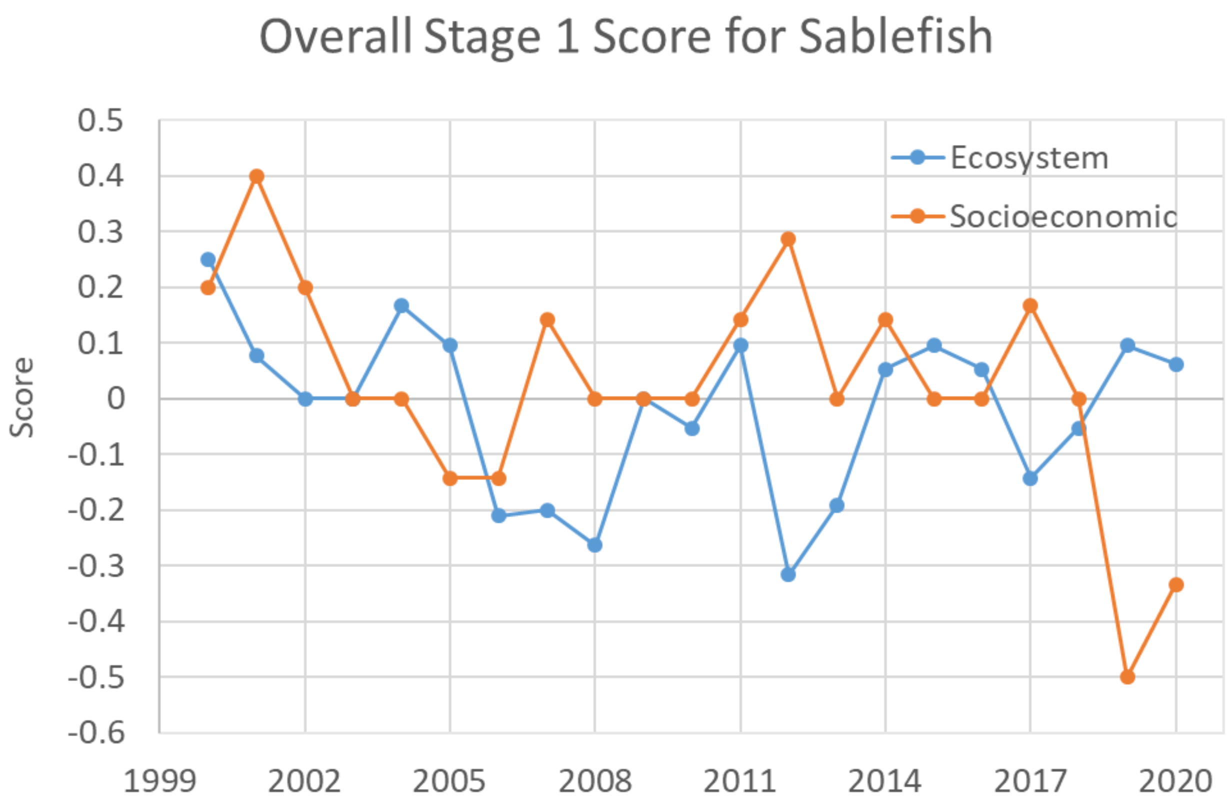
Appendix Figure 3C.2b. Selected ecosystem indicators for sablefish with time series ranging from 1977 – present. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of the time series. Light green shaded areas represent the most recent year of the traffic light analysis results.



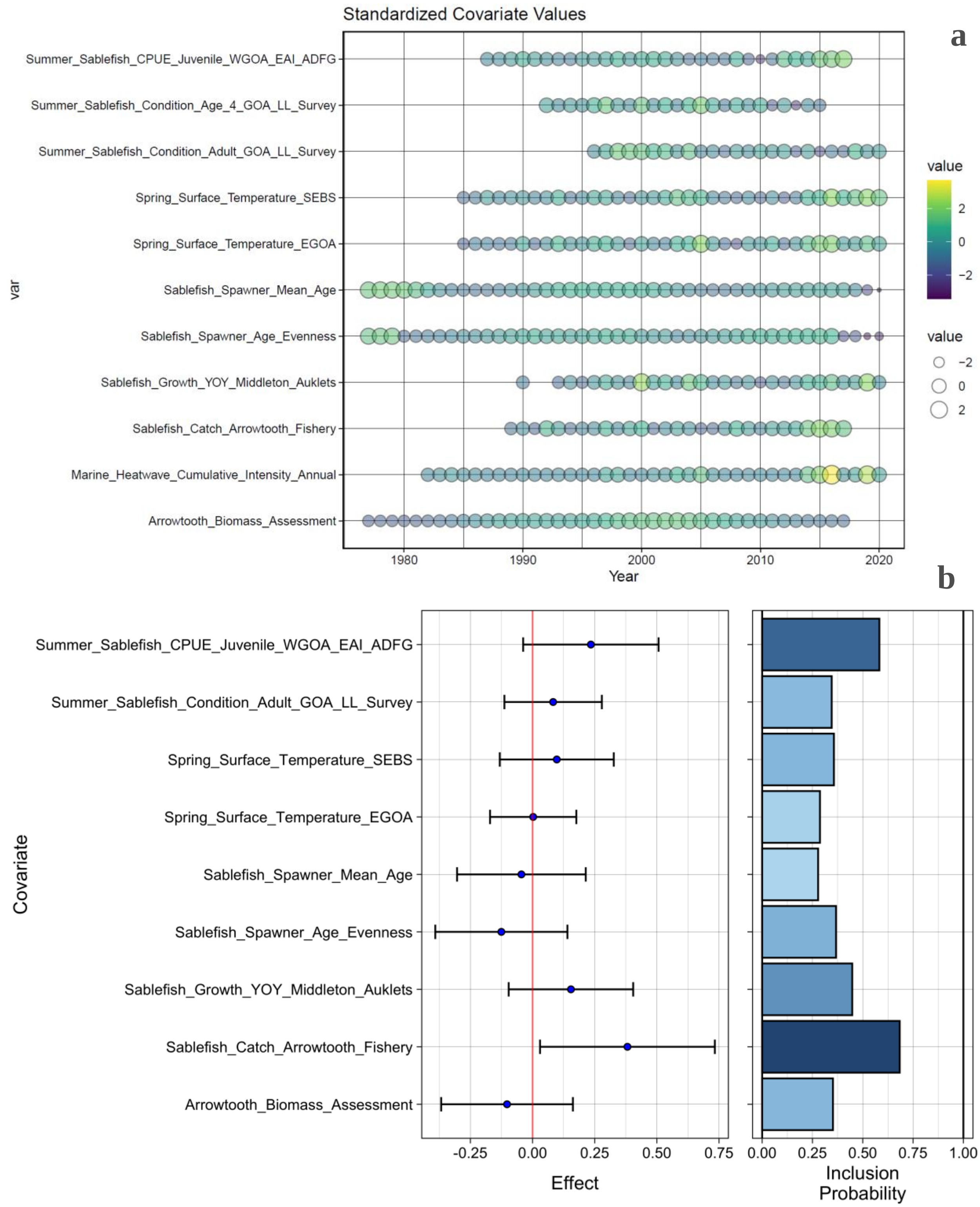


Appendix Figure 3C.3: Catch-per-unit-effort (top graph) from 1990 to present and length (cm) composition (bottom graph) from 2011 to present of sablefish in the ADF&G large-mesh survey (EAD = Eastern Aleutians District).

Appendix Figure 3C.4: Average length-at-age for ages 4, 5, 6 of males and female sablefish in the AFSC longline survey from 1995 to present in the GOA. Length is measured in centimeters.



Appendix Figure 3C.5: Simple traffic light score for overall ecosystem and socioeconomic categories from 2000 to present.



Appendix Figure 3C.6: Bayesian adaptive sampling output showing (a) standardized covariates prior to subsetting and (b) the mean relationship and uncertainty (95% confidence intervales) 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. An Examination of Sablefish ABC Apportionment

Introduction

Each year the sablefish stock assessment estimates ABC and OFL values that are subsequently apportioned among six management areas (Aleutian Islands, AI, Bering Sea, BS, Western Gulf of Alaska, WG, Central GOA, CG, West Yakutat, WY, and East Yakutat/Southeast Outside, EY). Beginning in December 1999, the North Pacific Fisheries Management Council apportioned the 2000 ABC and OFL based on a 5-year exponential weighting of the survey abundance index, and, later, using both the survey and fishery abundance indices. This apportionment method was used from 2000 - 2013. In 2014 a Fixed apportionment method was adopted. Under Fixed apportionment, the ABC apportioned to management areas was fixed at the 2013 proportions, because the objective of reducing variability in apportionment was not being achieved using the 5-year exponential weighting method (identified as ‘NPFMC’ apportionment in the tables and figures of this appendix).

Table 3D.1 shows the ABC values used for management of sablefish for 2000 - 2020. Total ABC has ranged between 11,794 – 23,000 metrics tons over the past two decades. Beginning in 2014, apportionment to management areas was fixed at the 2013 apportionment proportions. No corrections for whale depredation were made until 2017, when the ‘Fixed’ apportionment was continued, but apportionment values to areas were adjusted for whale depredation.

Two types of analyses have been developed to examine apportionment: 1) a simulation-based analysis that projects the sablefish population forward assuming a range of potential future scenarios, and 2) a new retrospective-based analysis that applies historic ABCs to past fishery and survey data to show what apportionment would have been in the past. This appendix summarizes both of these analyses conducted on apportionment and presents a subset of apportionment methods for consideration in 2020 for application to 2021 and beyond.

Simulation-Based Analysis

For the simulation analysis we developed a 6-area (matching the six sablefish management areas) operating model (OM) and a 1-area estimation model (EM) that latter of which is similar in structure to the current age-structured stock assessment model. The OM can account for potential area-specific dynamics in fleet or fish behavior (e.g. catchability, selectivity, and biological rates), while fish movement among regions can 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 - 2041. We have attempted to closely condition the OM to match our best estimates of sablefish population dynamics as we currently understand them.

Recruitment in the forward projection period is drawn from a normal distribution with a specified mean and standard deviation, and no autocorrelation. Recruits are distributed to the six management areas for each model year and iteration using a multinomial distribution, which generates alternative proportions to areas using a sample size of 100 and the mean proportions of age-2 sablefish distribution from the longline survey (1981 - 2017). No stock recruitment relationship is assumed because some of the largest observed recruitments have come from low spawning biomass. Additionally, little is known regarding spawning behavior, spawning aggregations, or juvenile distributions other than the movement rates of tagged fish among management regions, which are incorporated in the EM. Thus, all management areas are treated equally in regards to spawning and juvenile habitat importance.

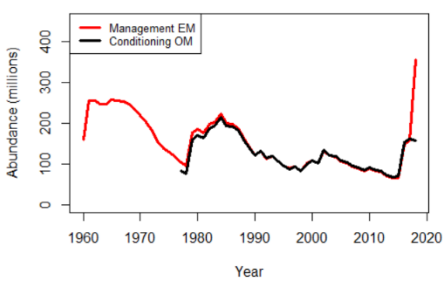
The EM is similar to the stock assessment model currently used for sablefish management, but begins in 1977 instead of 1960, does not include length compositions, and does not include a trawl survey index of abundance. After the conditioning period, data are generated in the OM. Fishery and survey indices and age compositions are generated from the OM population with observation error, and these simulated data are aggregated across areas into a single area dataset that is then passed to the single-area EM.

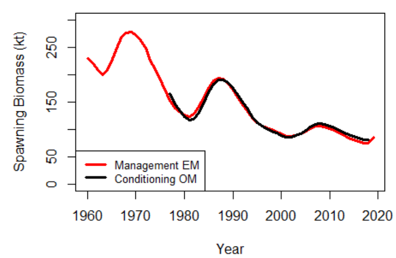
In the forward projecting period, the OM-EM is iterative, looping through years. For each of the apportionment methods explored, 200 or more replicate simulations covering years 2019 - 2041 are run with different process and observation error deviates in reach realization. The intention was to keep the EM as close as possible to the assessment model used for management and to condition the OM so that the forward projection period began with an OM population that was as similar to the current estimates of the size and age-distribution of the real-world sablefish population as possible.

In February 2020 a public meeting was held to show preliminary simulation results. Based on this feedback, several simulation apportionment options were changed. In June, the simulation methods were presented to the SSC for feedback, and several suggestions for changes to the OM were made, with responses to the comments provided below.

Response to SSC Comments

1) *The SSC recommended that the analysis could benefit from an extended discussion regarding the conditioning of the operating model, specifically addressing whether the model is able to recreate the historical biomass trends by area.*





The OM during the conditioning period was designed to produce a simulated population that was a close match to the historical estimates from the stock assessment used for management (Management EM) by specifying the catch, recruitment, and other parameters during this period. The resulting OM population does closely match the Management EM values for biomass, abundance, catch, and recruitment (subset shown in the Figure above). Note that the terminal year abundance in the OM conditioning period is less than the management EM values, because the OM recruitment in 2018 was set at the long term mean (16.5 million instead of 200+ million estimated by the Management EM). This was done to improve simulation EM convergence, as the high 2018 recruitment seemed to cause a substantial proportion of the simulation EMs to not converge in the first forward projection year (2019).

2) *[Do] the age-independent movement rates applied adequately reflect the most recent analysis of historical sablefish tagging?*

During the presentation to the SSC in June, it was mistakenly reported that movement rates were age-invariant. For use in the simulation work to date, age-specific movement rates were estimated from tagging data for ages 1 - 15. Ages 16+ all move the same for the rest of the ages in the OM. These estimates are derived using the model described in the Hanselman et al. (2015) sablefish movement paper. Movement rates in the simulation work are time-invariant. This is the best estimate for movement rates among Alaska management regions that we are able to produce at this time.

3) *The SSC noted that the sources of variability included in the simulation framework were limited to future recruitment magnitude and distribution, and the estimation error associated with determining the following year's ABC and the ABC distribution (for those options where the distribution was based on estimates or simulated data). The SSC suggests that a large number of additional sources of variability could be important contributors to variability in realized apportionment, including: parameter uncertainty and process error in the operating model (such as time-varying movement rates, mortality, catchability, and selectivity), mismatch between the specified ABC and actual catches, particularly in western areas where this has been historically common, and precautionary adjustments to the coastwide ABC. These additional sources of variability could interact to create additional variability in realized apportionment results relative to those observed from simulations. The SSC recommends that the analysts consider incorporating additional sources of variability as part of the simulation where appropriate, if possible.*

Variability is included via the recruitment magnitude and distribution, and via age composition and abundance index 'sampling' of the simulated OM population. We do contend that there is quite a large amount of variability in realizations from the simulations within each apportionment alternative, but central tendency of them yield fairly similar results. In the process of setting up the simulations, as well as in response to the SSC comments, a large variety of process error, observation error, and OM and EM configurations have been attempted (singularly and in combination). Many of these attempts resulted in substantial rates (>90%) of EM non-convergence (using a maximum gradient threshold of <0.01 for 'convergence'). These models explorations are, in part, how we settled on the 'base' model configuration presented at the June SSC meeting. It does appear that the EM, as currently configured, cannot handle increased variability and/or that the OM is not properly configured to generate suitable realism when multiple components have increased variability. Given the SSC recommendations and the limitations of the simulation framework to fully evaluate some of these concerns, such as sources of variability, we were unable to fully evaluate these concerns. As a result, we conducted these analyses based on retrospective ABC apportionment for NPMFC use to determine a suitable apportionment strategy, which is presented in this appendix.

For reference, these are a subset of the many simulation explorations that have been explored in the OM (* denotes current base model assumption):

- Movement
    - Age-based using Hanselman et al. (2015) methods*
    - Age-invariant using Hanselman et al. (2015) methods
    - Age-invariant 'no movement'
    - Age-invariant 'high movement' (hypothetical values)

- Recruitment

- o Recruitment variance explorations with values ranging from 0.4 - 1.6 (0.8 is base model)
- o Recruitment autocorrelation ranging from 0.0* - 0.8
- o Mean recruitment ranging from 8.0 - 16.5 (16.5 is base model; in millions of fish)
- o Recruitment capped at various values or not capped. The current base model specifies 2018 (2016 year class) recruitment at the historic mean with no other years or caps in place. This was done because the transition year from conditioning period to forward projecting was very unstable with the early estimates of extremely high 2018 recruitment.

- Catchability
  - o Fixed*, time invariant
  - o Time varying, randomly drawn from spatial model MCMC values

- Natural mortality
  - o Time- and age-invariant*
  - o Age-based, time invariant
  - o Time-based, age invariant

- Observation error in abundance indices
  - o High, low error

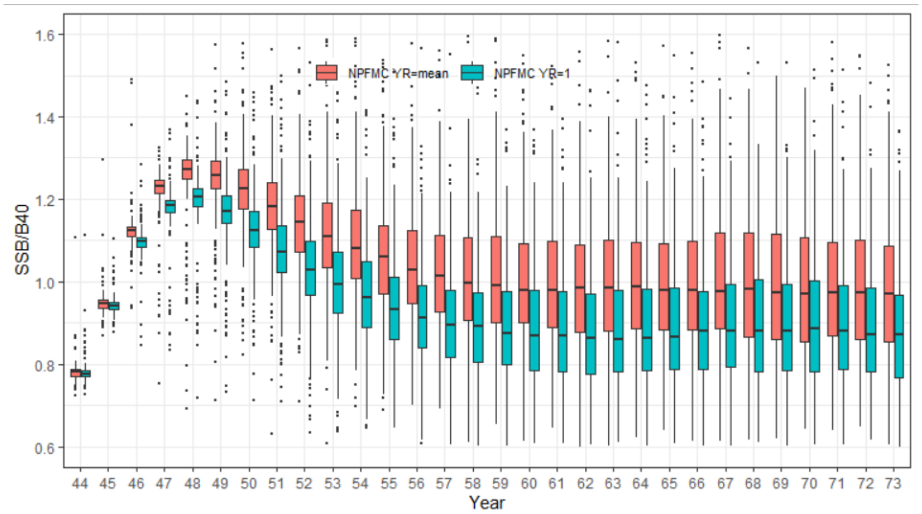
- Observation error in age compositions
  - o High, low sample sizes for multinomial

- ABC carryover – ABC from previous year is used in place of ABC from subsequent year's EM when EM does not converge

- Explorations of changes to the EM and harvest specifications include:
  - Estimate M (various bounds on M values)
  - 'Retry' function that jitters parameter initial values when the EM does not have a maximum gradient component <0.01 (up to 5 attempts are made when triggered)
  - Alternate bounds for mean fishing mortality, fishing mortality deviations, mean recruitment, recruitment deviations
  - With and without* a 1-year lag in age composition data for EM
  - Fishery index turned on* and off
  - Yield ratio of catch/ABC as recent mean or as 1 (full ABC utilization)

4) *The SSC further recommends that a 'base case' simulation should include more realistic catch vs. ABC ratios where appropriate, perhaps limited to historically observed levels of effort by area.*

This scenario has been examined and results for NPFMC apportionment are shown below (for all simulated iterations; see Table 3E.2 for apportionment method descriptions). The salmon colored boxes represent the median SSB/$B_{40\%}$ when ABC is reduced in each area to the proportion of ABC caught on average for 2009 - 2018 (10 year mean) for each management area. The teal boxes represent the median SSB/ $B_{40\%}$ when apportioned ABC is assumed to be fully caught in each region in each year. Years 44 - 73 correspond to 2019 - 2048.



As expected, the simulations which do not fully catch ABC in all areas generally result in a higher mean and median SSB/$B_{40\%}$ across simulation iterations.

Yield ratio (ABC utilization)	**NPFMC Apportionment** Mean of 2009 - 2018 Value for Each Gear and Area	**NPFMC Apportionment** ABC = catch (yield ratio = 1)
Mean SSB/$B_{40\%}$ (all runs), all years	1.21	1.13
Median SSB/$B_{40\%}$ (all runs), all years	1.06	0.94
Mean SSB/$B_{40\%}$ (all runs), last 8 years	1.18	1.14
Median SSB/$B_{40\%}$ (all runs), last 8 years	0.98	0.87

5) *The SSC also recommends consideration of the adjustment to the coastwide ABC to reduce harvest (implementing a larger OFL-ABC buffer) when abundance of older spawners is low, such as was applied in 2019 and 2020, and whether this should be included.*

This has not been examined for these simulation analyses, though the idea has merit. At present, the simulation conditioning period ends at 2018, thus it doesn't include recent years with high recruitment. To date, none of the simulations have altered the standard harvest control rule or OFL-ABC buffers. We have focused on gaining better understanding of the utility and limitations of the current model set up. It is worth noting that both the high uncertainty in recent recruitment events coupled with the sheer magnitude of recent high recruitment has confounded our ability to develop the simulations. These large, unprecedented year classes will likely alter the course of sablefish population dynamics for years to come, and in ways we do not yet fully understand.

6) *The SSC requests a model check be performed based on one apportionment approach and an estimation model provided with very precise data from the operating model (and perhaps extended farther into the future) to evaluate the implementation of the Council's harvest control rule; the expectation being that the stock should equilibrate at or above B40.*

Also see results from #4 above. A model check was conducted using the NPFMC and non-exponential NPFMC apportionment types and three separate movement scenarios in the OM (base movement, no movement, and 'well mixed' movement where 1/6 of fish stay in region x, and 1/6 depart for each of the other five regions). Simulations were projected forward for 40 years. As expected the stock equilibrated around $B_{40\%}$; mean SSB/$B_{40\%}$ for the last 20 years for the forward projecting period ranged from 0.98 - 1.30.

7) *The SSC recommended adding two additional performance metrics: the effort required to achieve the ABC in each area, and the variance in apportionment in each management area, displaying the latter metric as a mean-variance plot for each of the approaches.*

The effort required to achieve ABC in each area is a great question, but it seems it would be challenging to get sufficiently accurate inputs to provide valuable results and we're not sure how to approach this metric in the current simulation framework given the complex fishery for sablefish (i.e., due to the IFQ sector, multiple gears, and recent PSC issues). We are hesitant to propose sweeping generalizations without the influence of an economist and social scientist to evaluate the social and economic factors that affect effort and ABC realization. The mean-variance plot has not yet been developed.

8) *As time permits, it may be preferable to include more than the 200 simulation iterations completed in the preliminary analysis. The SSC suggests that evaluation of Monte-Carlo error over increasing sample sizes for several performance metrics could guide selection of the appropriate number of iterations for the final results.*

The results shown for #4 above include 300 simulation iterations. Until such a time when the OM and EM become more stable, more iterations only increase the time needed to test models.

Simulation Summary

Our conclusion from the attempts at adding additional error is that the EM is not sufficiently flexible to handle more uncertainty. The OM is also likely not sufficiently realistic in correlating process error across multiple parameters, as there's no biological or mechanistic underpinning to the process and observation error. The result is that between the EM inflexibility and OM error, there are substantial model convergence issues. Attempts to incorporate most of the suggestions from the SSC, whether singularly or in combination, resulted in only 0 - 10% of models converging for many of the suggestions.

There are areas of research that could be undertaken to improve the realism of the simulation OM. At present, we do not have sufficient research to guide better understanding of sablefish recruitment processes in Alaska. We do not know where spawning occurs, whether there's spawning site fidelity, whether specific spawning locations produce more sablefish surviving to recruitment, or which environmental/ecosystems factors may contribute to recruitment success. As such, incorporating mechanism-based recruitment in the OM or EM becomes a theoretical exercise that would be valuable for future research consideration, but it is outside the scope of these analyses as designed and currently implemented. Further simulation work is unlikely to answer the questions we have when using existing knowledge of biological parameters and inputs and the existing EM.

In addition, one result from the early simulation analyses is that the NPFMC tier-based harvest control rule appears to function well, given the assumptions of the assessment model used for management. There are many assumptions inherent in the EM model (i.e., an implicit assumption of a panmictic population for AK Federal waters, no stock-recruitment relationship, and an assumed value for the mean recruitment used for projections and OFL/ABC calculations) and it's important to recognize that these assumptions exist and impact the evaluation of the functionality of the harvest control rule.

With the above hurdles and caveats regarding the simulation analyses in mind, we have compiled the following set of retrospective analyses to complement the simulation work.

Retrospective Apportionment of ABC

In this set of analyses, we apply 12 methods for apportioning ABC based on the historical total ABC values used for management during 2000 - 2020 to augment the other work that has been presented on apportionment simulation (see Table 3D.2 for a list of apportionment methods tested). In the results, the number of years for which retrospective apportioned ABCs are available differ due to the data needs for each apportionment type.

The set of apportionment methods utilized is different from the set used in the simulation-based analyses and has evolved over time as we receive feedback from stakeholders. One apportionment method examined in the simulations, but not included here is the 'Age-based' apportionment type that was of interest to some stakeholders. For the simulations, this method used the proportion of fish at the age at 50% maturity and older to apportion ABC to areas; i.e. areas with a higher proportion of mature fish would receive more ABC. While this apportionment method hasn't been applied retrospectively in this appendix, our initial examinations using length composition data from the survey for fish 65 cm or larger in length showed that the resulting apportionment would be very similar to the Fixed apportionment proportions to areas from 2020 (see the Complete Retrospective Tables section at the end of this appendix for Fixed apportionment values). This result isn't surprising given that the Fixed apportionment was put in place during a period of lower than average recruitment when the population had a high proportion of mature, 65 cm+ fish. The data available for applying this method retrospectively (or for the future) differ from the data available via simulation; we are still vetting the data that are necessary for an Age- or Length-based apportionment type to be applied.

For the results below, we calculated survey RPW (years 1990 - 2020) and fishery RPW (1999 - 2019) values to input into the apportionment calculations. All calculations for survey and apportionment exclude whale depredation effects as the impact of whales has changed over time in individual management areas. The exact methodology for each apportionment type is provided in the Apportionment Equations section.

Retrospective Analysis Results

As total ABC changes from year to year, the amount apportioned to each management area also fluctuates. The actual ABC apportioned to each area under the 12 apportionment methods is shown in tables at the end of this summary (see Complete Apportionment Tables section). Figure 3D.1 shows the time series of apportioned ABC to management areas for each apportionment method. Note that the time series of data available differs depending on the apportionment type and the data needed for that method.

Many of the apportionment methods result in similar outcomes: the CG receives the largest amount (and thus proportion) of ABC for most years in all apportionment methods (Figures 3D.1 – 3D.2). Two apportionment types retain the same ranked order of ABC to areas every year, by design – Equilibrium and Fixed. The apportionment types that used non-exponential weighting or used 5 'on year' surveys (denoted by '_2' in the apportionment name) were visually very similar, with some year-to-year changes in rank order for BS, AI, WG, and WY, but with fewer extreme changes than observed under the Terminal_LL_survey, Exp Survey, and Exp Survey_2 apportionment methods.

ABC Stability

Each year, the total ABC changes based on the estimated abundance from the stock assessment. In addition, area-specific changes in ABC occur, and the magnitude of the change depends on the apportionment method used (Table 3D.3). While stability in year-to-year apportionment is not a biological concern, it has been repeatedly identified as a metric of importance to stakeholders.

The apportionment method used can result in area specific fluctuations that may be the same as, or more extreme than, the overall change in ABC. Figure 3D.3 is a visual representation of both of these changes, using the historic time series of total ABCs apportioned using 12 apportionment methods. For each application of an apportionment method, we calculated the annual change in ABC for year *y+1* from the previous year, *y*, for each area and for the total ABC. The x-axis is the percent change in total ABC (ABC summed across areas) and the y-axis is the corresponding percent change in ABC for an area. Each panel represents an apportionment type and colored circles represent different management areas. The black line is the 1:1 line. Colored circles falling above the line indicate that that area's percent change in apportioned ABC was greater than the overall percent change in ABC, while circles below the line indicate that the area ABC change less than the overall ABC. For the two apportionment methods that use time-invariant proportions to apportion ABC (Equilibrium and Fixed), as total ABC changes, the area ABC changes by the same amount, thus the colored circles all fall on the 1:1 line. Apportionment types with colored circles farther from the 1:1 line mean there's more change in ABC for individual areas and that apportionment type is inherently more variable (i.e., less stable). By examining which colored circles more frequently fall farther from the 1:1 line, it is possible to identify which areas may be more variable. For example, the BS (mustard yellow circles) stand out in the Terminal_LL Survey (Term_survey) and Exp_Survey methods as frequently having a much larger change in ABC than the overall change in ABC. More generally, the Terminal_LL method tends to cause ABCs for all areas to change more than the overall ABC.

Apportioned ABC Compared to Survey Biomass

Figure 3D.4 shows a comparison of how much apportioned ABC in year *y* deviated from the spatial distribution of survey-estimated biomass in the previous year. We set up the comparison this way due to the structure of the current annual management cycle, where we specify a total ABC and area-apportioned ABCs for a given year *y* during the previous year's (*y-1*) assessment process.

The Terminal_LL_survey apportionment method most closely matches the survey-estimated biomass in each management area over time by design (i.e., the medians are closest to 0 and the variance is lowest), but has strong interannual variability in those proportions, as noted previously. The Exponential_Survey method also does well for this metric, because there is no fishery index data providing conflicting data, but, again, this method can lead to strong year-to-year changes in area specific ABCs. Conversely, the apportionment methods that are based on unchanging proportions over time (Equilibrium and Fixed) result in apportionment proportions to areas that do not generally track sablefish biomass (as estimated from the longline survey). Overall, the Non-exponential survey apportionment method appeared to provide the best balance of the primary conservation (i.e., area ABC proportions reflect biological distribution) and economic (i.e., limited interannual variability) performance metrics examined. ABCs generally reflected the shifting biomass across regions without allowing large swings in the proportion of the ABC assigned to a region from one year to the next.

Conclusions and Recommendations

During the February 2020 public meeting, a variety of concerns were voiced with each apportionment method, though not every concern or preferred outcome was shared by all participants. The primary issues that were raised during the public meeting included:

1) Interannual stability in ABC is desired.

2) An apportionment method where area specific ABC proportions generally match observed sablefish biomass by area over time should be developed.

3) Concerns remain about the potential to harvest too many immature fish and too many large spawning females, as well as, the current relative scarcity of large fish.

4) Replacing the current ‘Fixed' apportionment with a new method may result in a large swing in the area specific ABCs in the transition year, thus requiring a multi-year plan to make the change more gradual.

There is no single apportionment method that will address all of these concerns, as some desired outcomes are in conflict with each other. The suite of apportionment methods presented attempts to address as many of these stakeholder concerns as possible, though, it must also be recognized that there are tradeoffs to each apportionment type.

Apportionment methods that closely track survey estimated biomass each year (such as Terminal LL Survey) can result in large year-to-year changes in ABC for a given area. However, instability is an undesirable trait for some stakeholders. Options such as the Non-exponential NPFMC, Non-exponential Survey, or Blended apportionment types fall in the middle, with some year-to-year instability, while still being influenced by the longline survey biomass estimates in spatial areas.

Non-exponential weighting, whether for fishery or survey data, provides more stable ABCs than exponential weighting. But, stability generally comes at the cost of greater mean deviation from the observed distribution of biomass (as determined by the longline survey), because all five years of data are given equal weight. Similarly, the ‘_2’ apportionment types that draw from five ‘on years’ of BS and AI survey data are more stable, but have greater deviations from observed longline survey biomass. These greater deviations from observed biomass may be due to the BS and AI regions drawing input from their ‘on year’ surveys from up to 10 years past, whereas GOA surveys occur every year.

The most stable apportionment types (Equilibrium and Fixed) can lead to ABC proportions by area that deviate substantially from the spatial biomass estimated by the longline survey. As observed over the past two years, this deviation from observed biomass can result in area specific ABCs that are lower under Fixed apportionment than under temporally variable methods such as the NFPMC apportionment. The lack of a dynamic connection to shifting resource distribution is a contributing factor to recent ABC overages in some areas. The recent large recruitment events have led to changes in sablefish distribution, population length structure (as younger, immature fish move through management areas and into different depths), and have had socio-economic impacts (due to both size and total abundance of marketable sablefish, as well as, increased bycatch).

For 2021, we recommend that apportionment options NPFMC, Non-exponential NPFMC, and Non-exponential Survey be given consideration for 2021 and beyond. It is clear that Fixed apportionment has become unsuitable due to the high recruitments, which show up in some management areas before others and cause large shifts in distribution and sablefish abundance. Apportionment methods that are responsive to shifts in biomass are important from a conservation perspective, but an apportionment method that is too responsive to changing biomass distributions (such as Terminal LL Survey) may be undesirable, because it is too unstable.

Additionally, we are concerned about the declining availability of fishery data from some management areas, which is needed to calculate the fishery RPW index underpinning several of the apportionment methods (any type with “NPFMC” in the name, as well as, the Blended apportionment type). These apportionment types rely on survey and fishery data. Observer coverage continues to be low in the Bering Sea with the realized observer coverage rate for partial coverage hook-and-line vessels targeting sablefish in the BSAI in 2019 at 0.00% (Appendix Table B-2 in Ganz et al., 2020). Additionally, voluntary logbook submissions have declined in some regions, and the introduction of electronic monitoring has changed the availability of weight and effort data for the fishery index. Low observer or logbook sample sizes generally lead to increased variability, and thus increased instability in apportionment, particularly for the BS and AI. Fishery data are valuable for tracking spatial trends in abundance-at-age; however, if current trends continue, there may be insufficient fishery data to use apportionment methods that require fishery data in all areas. In addition, the use of pot gear is increasing in several management areas, and the fishery RPW index does not use pot data. This gear change further diminishes the quantity of fishery data available until methods are developed to address the shift in gear types. We still present the NPFMC and Non-exponential NPFMC apportionment types for comparison, but note our concern about the long-term viability of these methods given decreases in available fishery data. In addition, our past experience with the NPFMC apportionment method led to high variability in area-specific ABCs when spawning biomass was in decline due to many years of below average recruitment. The Non-exponential Survey apportionment type has some of the stabilizing benefits of the NPFMC and non-exponential NPFMC, but without added concern from diminishing fishery data.

The previous NPFMC apportionment method was frozen in 2013 due to increased variability in apportionment, but this was during a long period of poor recruitment resulting in catches from both the survey and fishery that were composed of old, adult sablefish, and the population was likely distributing into preferred adult habitat. The extremely spasmodic recruitment events that have recently occurred illustrate the potential for substantial distributional shifts in the population. These events have been rare historically and little is understood regarding the underlying biology leading to these patterns of distribution. The results of the simulation work indicate that apportionment of ABC to the six management regions can be conducted using a variety of alternative methods, none of which result in severe negative implications to the population biologically. The reason for the limited impact on the population is twofold: high movement rates of sablefish essentially spread localized mortality across the entire population, while a strong and responsive harvest control rule and management framework prevent the population as a whole from being over exploited. However, the OM is not currently able to emulate the extreme demographic and spatial shifts in the population that have occurred with these recent large year classes. Although rare, it is important to consider the effect that large year classes have on population distribution and apportionment so that the chosen apportionment method will be effective at conserving the population. Similarly, while stability in ABC is not a biological concern, many stakeholders find large year-to-year changes in ABC to be undesirable, and implementing an apportionment strategy that is too responsive to these types of strong distributional changes may unnecessarily detriment the various fisheries.

Further research is needed to understand if the Alaska sablefish population is truly panmictic or if spawning aggregations or preferred juvenile habitat exist. Collection of information on area specific distribution of young fish, the location of spawners, and genetic stock structure may help inform managers on how to best apportion sablefish in Alaska, especially when there are large recruitment events or if specific portions of the population are critical to recruitment success. In the interim, the proposed Non-exponential Survey apportionment method appears to be the best existing strategy to assign total ABC to regions, because it has the benefit of generally matching the proportion of the biomass in each area without extreme interannual variation in those proportions. Thus, it balances to the primary conservation and economic performance metrics raised during recent stakeholder and SSC meetings.

Tables

Table 3D.1. Summary of ABCs and the apportionment method used since 2000. ABC values are in tons and have been adjusted for whale depredation since 2017, as noted in the Apportionment Method column.

Year	BS	AI	WG	CG	WY	EY/SEO	Total ABC	Apportionment Method
2000	1384	2446	1928	5921	1890	3431	17,000	NPFMC
2001	1560	2500	2010	5410	1880	3540	16,900	NPFMC
2002	1930	2550	2240	5430	1770	3380	17,300	NPFMC
2003	2550	2740	2260	5670	1880	3300	18,400	NPFMC
2004	3006	3449	2927	7300	2348	3970	23,000	NPFMC
2005	2440	2620	2540	7250	2390	3760	21,000	NPFMC
2006	3060	3100	2670	6370	2090	3710	21,000	NPFMC
2007	2980	2810	2470	6190	2100	3550	20,100	NPFMC
2008	2860	2440	1890	5500	1950	3390	18,030	NPFMC
2009	2720	2200	1640	4990	1640	2890	16,080	NPFMC
2010	2790	2070	1660	4510	1480	2720	15,230	NPFMC
2011	2850	1900	1620	4740	1830	3100	16,040	NPFMC
2012	2230	2050	1780	5760	2080	3350	17,250	NPFMC
2013	1580	2140	1750	5540	1860	3360	16,230	NPFMC
2014	1339	1811	1480	4681	1574	2837	13,722	Fixed, No whale corrections
2015	1333	1802	1473	4658	1567	2823	13,656	Fixed, No whale corrections
2016	1151	1557	1272	4023	1353	2438	11,794	Fixed, No whale corrections
2017	1274	1758	1349	4514	1468	2743	13,083	Fixed, Whale corr. applied
2018	1464	1988	1544	5158	1672	3131	14,957	Fixed, Whale corr. applied
2019	1489	2008	1581	5178	1671	3141	15,068	Fixed, Whale corr. applied
2020	2174	2952	2278	7560	2521	4524	22,009	Fixed, Whale corr. applied

Table 3D.2. Apportionment types and years available for retrospective comparison. 'Non-exp' indicates non-exponential weighting of five years of fishery/survey data, 'Exp' indicates exponential weighting where the most recent year has the greatest influence on results due to higher weighting. Apportionment types ending in '_2' indicate that the survey data component draws from five 'on year' surveys for the BS and AI. For example, for the 2020 apportioned ABC using the NPFMC_2 method, survey relative population weights (RPW) from the WG, CG, WY, and EY/SEO for years 2015 – 2019 are used. For the BS, RPWs from years 2011, 2013, 2015, 2017, 2019 are included. From the AI, RPWs from years 2010, 2012, 2014, 2016, 2018 are used. The number of years available to perform the retrospective analysis changes due to differences in the years of data required to run each apportionment method.

Apportionment Method	Years	Description	Comments
Fixed	2000- 2020	Uses the 2014 apportionment proportions to divide total ABC	Status quo. Becoming less defensible because of the observed deviations from biomass distribution.
Equilibrium	2000 - 2020	Uses the average (2000 - 2019) NPFMC apportionment proportions to divide total ABC	Not a preferred option going forward because of the substantial deviations from biomass distribution.
NPFMC	2005 - 2020	Exponentially weighted moving average of survey and fishery indices using the last 5 years of data	Recommended for consideration. Concern exists about the fishery data for BS and AI as some years there is very little data; this method had undesired variability during a period of prolonged below average recruitment.
NPFMC_2	2011 - 2020	Exponentially weighted moving average of survey and fishery indices using the five 'on year' survey data points for all areas	Similar to NPFMC, but may not track recent biomass distributions well.
Non-exp NPFMC	2005 - 2020	Non-exponentially weighted moving average of survey and fishery indices using the last 5 years of data	Recommended for consideration. Non-exponential weighting is stabilizing because past five years are weighted equally instead of last year getting heavily weighted; concern exists over reduced quantity of fishery data.
Non-exp NPFMC_2	2005 - 2020	Non-exponentially weighted moving average of survey and fishery indices using the five 'on year' survey data points for all areas	Similar to Non-exp NPMC, but may not track recent biomass distributions well.
Non-exp Survey	2000 - 2020	Non-Exponentially weighted moving average of survey index using the last 5 years of data	Recommended for consideration. Non-exponential weighting is stabilizing and survey data tracks biomass.
Non-exp Survey_2	2000 - 2020	Non-Exponentially weighted moving average of survey index using the five 'on year' survey data points for all areas	Similar to Non-exp Survey, but may not track recent biomass distributions well.
Exp Survey	2000 - 2020	Exponentially weighted moving average of survey index using the last 5 years of data	Shows fairly substantial year-to-year variability in apportioned ABCs.
Exp Survey_2	2000 - 2020	Exponentially weighted moving average of survey index using the five 'on year' survey data points for all areas	Similar to Exp Survey, but may not track recent biomass distributions well.
Terminal LL Survey	2000 - 2020	Proportions based on terminal year of the survey index	Not a preferred option going forward; shows substantial year-to-year variability in apportioned ABCs
Blended	2005 - 2020	Apportionment proportions are an equally weighted combination of NPFMC and Equilibrium proportions	Not a preferred option going forward as this is a relatively complicated method, especially given the low gains in both stability and ability to track regional biomass over time.

Table 3D.3. The percent change in apportioned ABC to each management area from year *y*-1 to year *y*, and the percent change in total ABC for the past 20 years, after any whale corrections have been applied. The percent change is calculated as $(ABC_y - ABC_{y-1})/(ABC_y)*100$.

Year	BS	AI	WG	CG	WY	EY/SEO	Total ABC	Method
2000	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	NPFMC
2001	12.7%	2.2%	4.3%	-8.6%	-0.5%	3.2%	-0.6%	NPFMC
2002	23.7%	2.0%	11.4%	0.4%	-5.9%	-4.5%	2.4%	NPFMC
2003	32.1%	7.5%	0.9%	4.4%	6.2%	-2.4%	6.4%	NPFMC
2004	17.9%	25.9%	29.5%	28.7%	24.9%	20.3%	25.0%	NPFMC
2005	-18.8%	-24.0%	-13.2%	-0.7%	1.8%	-5.3%	-8.7%	NPFMC
2006	25.4%	18.3%	5.1%	-12.1%	-12.6%	-1.3%	0.0%	NPFMC
2007	-2.6%	-9.4%	-7.5%	-2.8%	0.5%	-4.3%	-4.3%	NPFMC
2008	-4.0%	-13.2%	-23.5%	-11.1%	-7.1%	-4.5%	-10.3%	NPFMC
2009	-4.9%	-9.8%	-13.2%	-9.3%	-15.9%	-14.7%	-10.8%	NPFMC
2010	2.6%	-5.9%	1.2%	-9.6%	-9.8%	-5.9%	-5.3%	NPFMC
2011	2.2%	-8.2%	-2.4%	5.1%	23.6%	14.0%	5.3%	NPFMC
2012	-21.8%	7.9%	9.9%	21.5%	13.7%	8.1%	7.5%	NPFMC
2013	-29.1%	4.4%	-1.7%	-3.8%	-10.6%	0.3%	-5.9%	NPFMC
2014	-15.3%	-15.4%	-15.4%	-15.5%	-15.4%	-15.6%	-15.5%	Fixed, No whale corrections
2015	-0.4%	-0.5%	-0.5%	-0.5%	-0.4%	-0.5%	-0.5%	Fixed, No whale corrections
2016	-13.7%	-13.6%	-13.6%	-13.6%	-13.7%	-13.6%	-13.6%	Fixed, No whale corrections
2017	10.7%	12.9%	6.1%	12.2%	8.5%	12.5%	10.9%	Fixed, Whale corrections applied
2018	-15.6%	56.0%	14.5%	14.3%	13.9%	14.1%	14.3%	Fixed, Whale corrections applied
2019	1.7%	1.0%	2.4%	0.4%	-0.1%	0.3%	0.7%	Fixed, Whale corrections applied
2020	44.3%	44.6%	50.2%	45.0%	51.1%	44.9%	46.1%	Fixed, Whale corrections applied

Figures

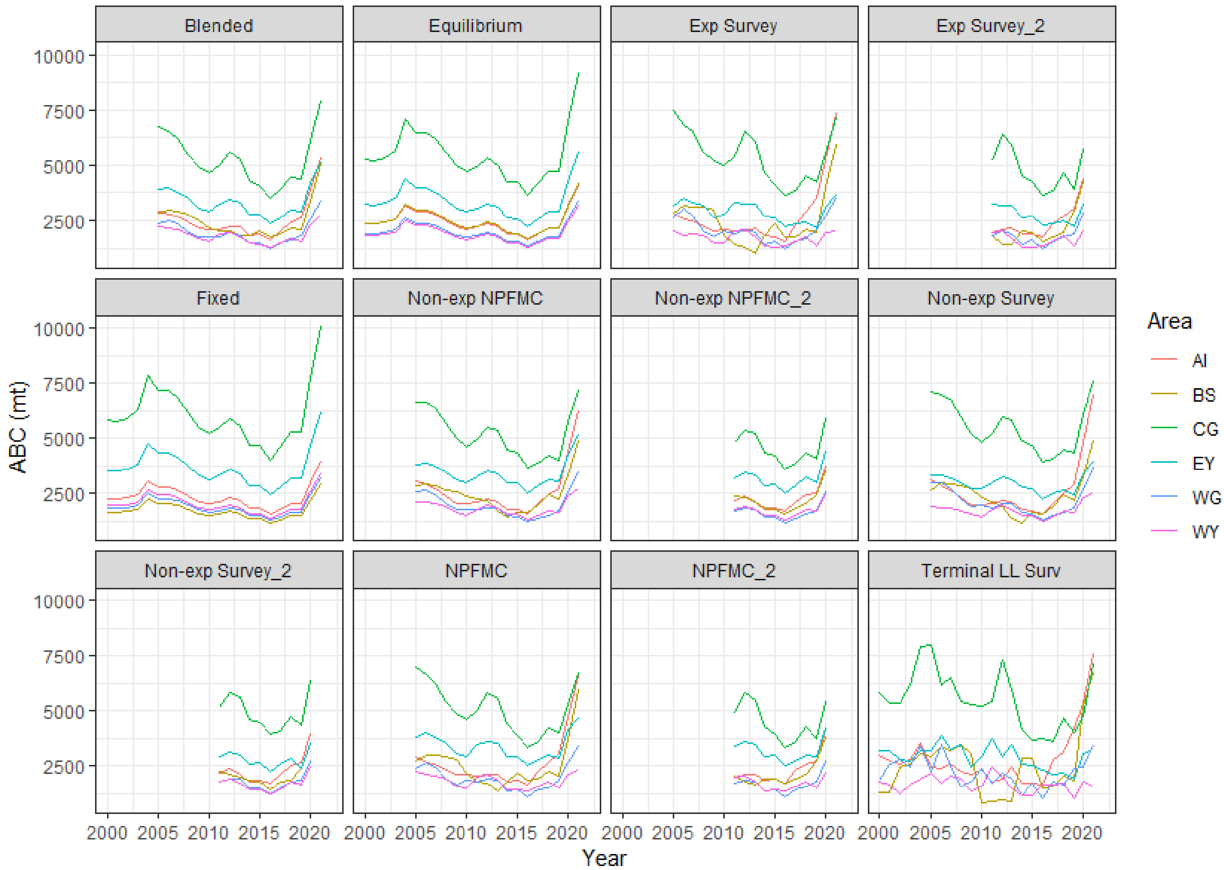


Figure 3D.1. Sablefish ABC by area over time for each apportionment method. ABC values do not include whale depredations corrections. Note that methods that start later use data going further back in the averages for that method.

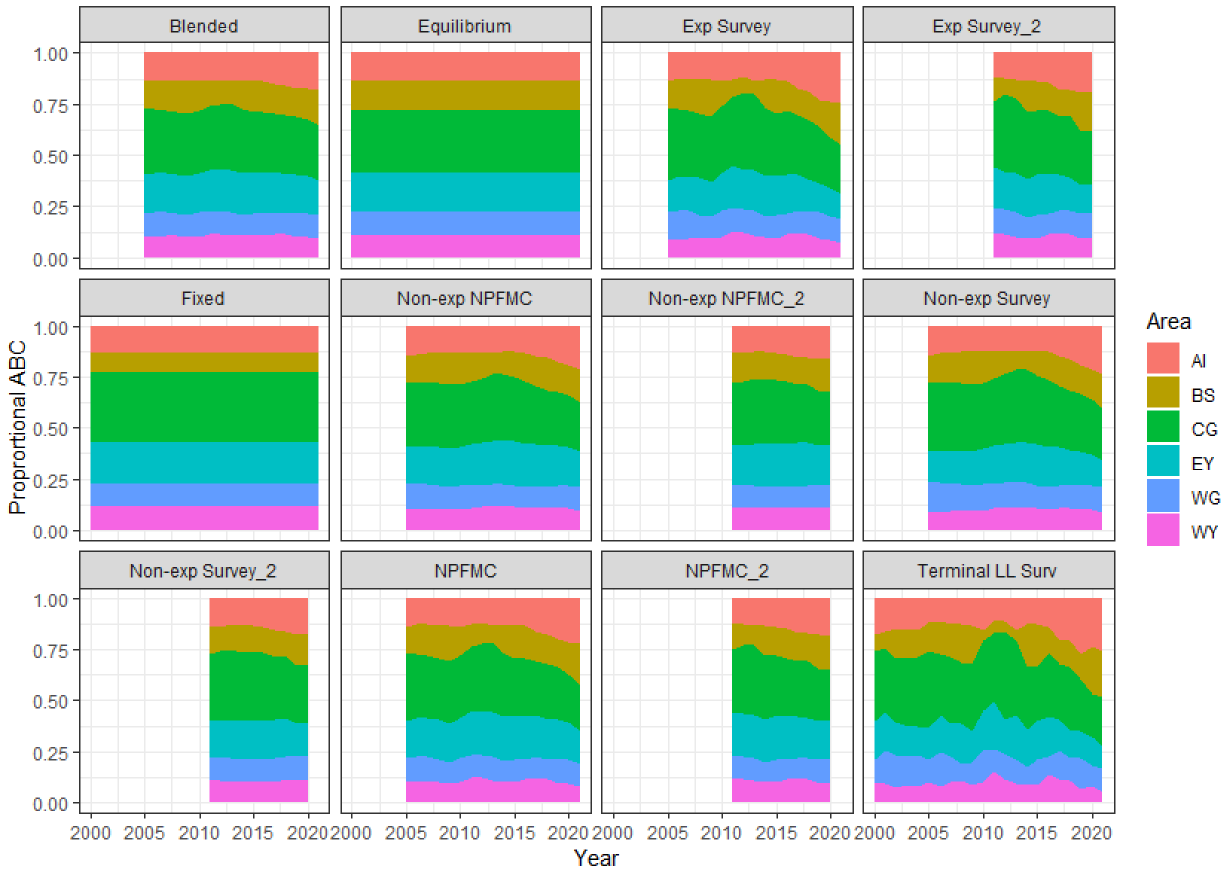


Figure 3D.2. Proportion of ABC apportioned to each region by year for each apportionment type. ABC values do not include whale depredation corrections. Note that methods that start later use data going further back in the averages for that method.

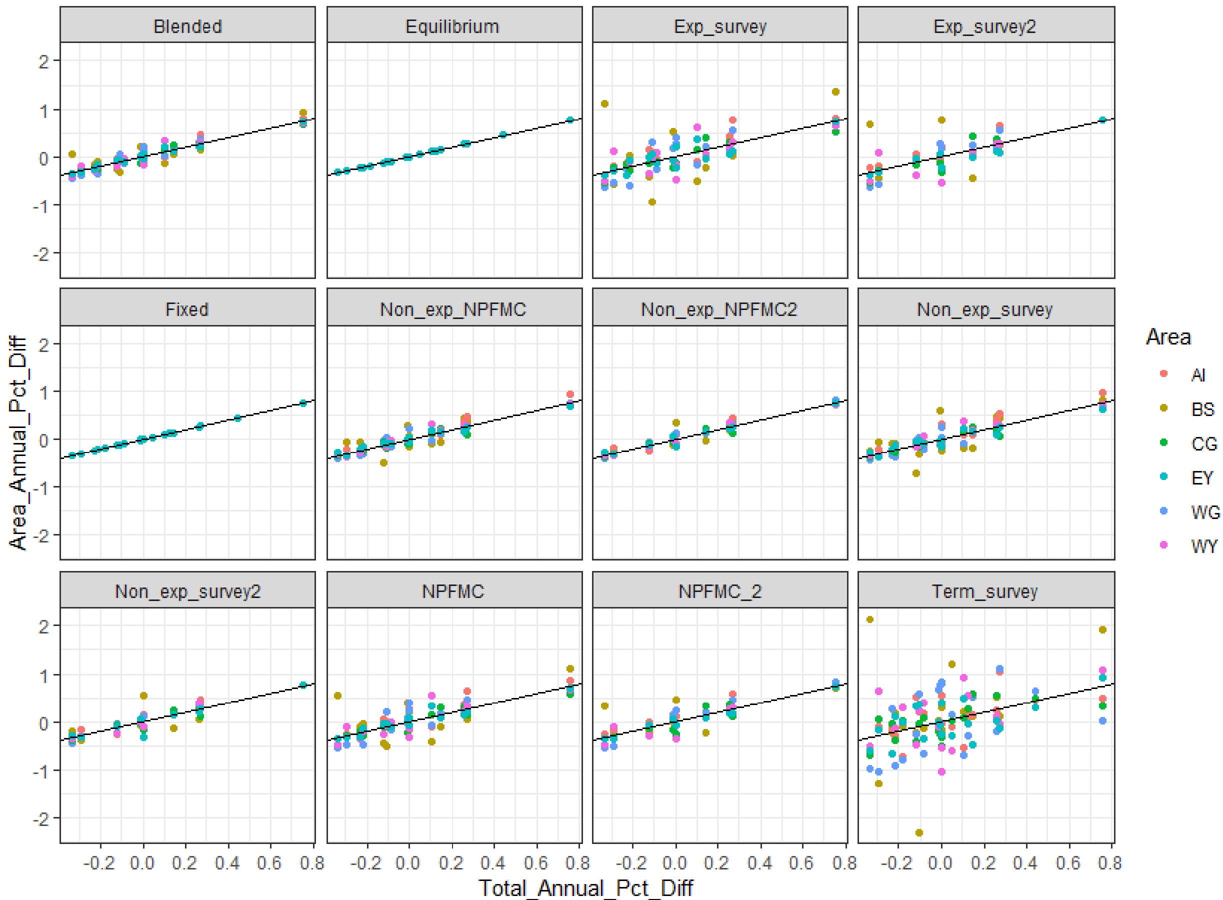


Figure 3D.3. Change in year-to-year area specific ABC compared to year-to-year change in total ABC.

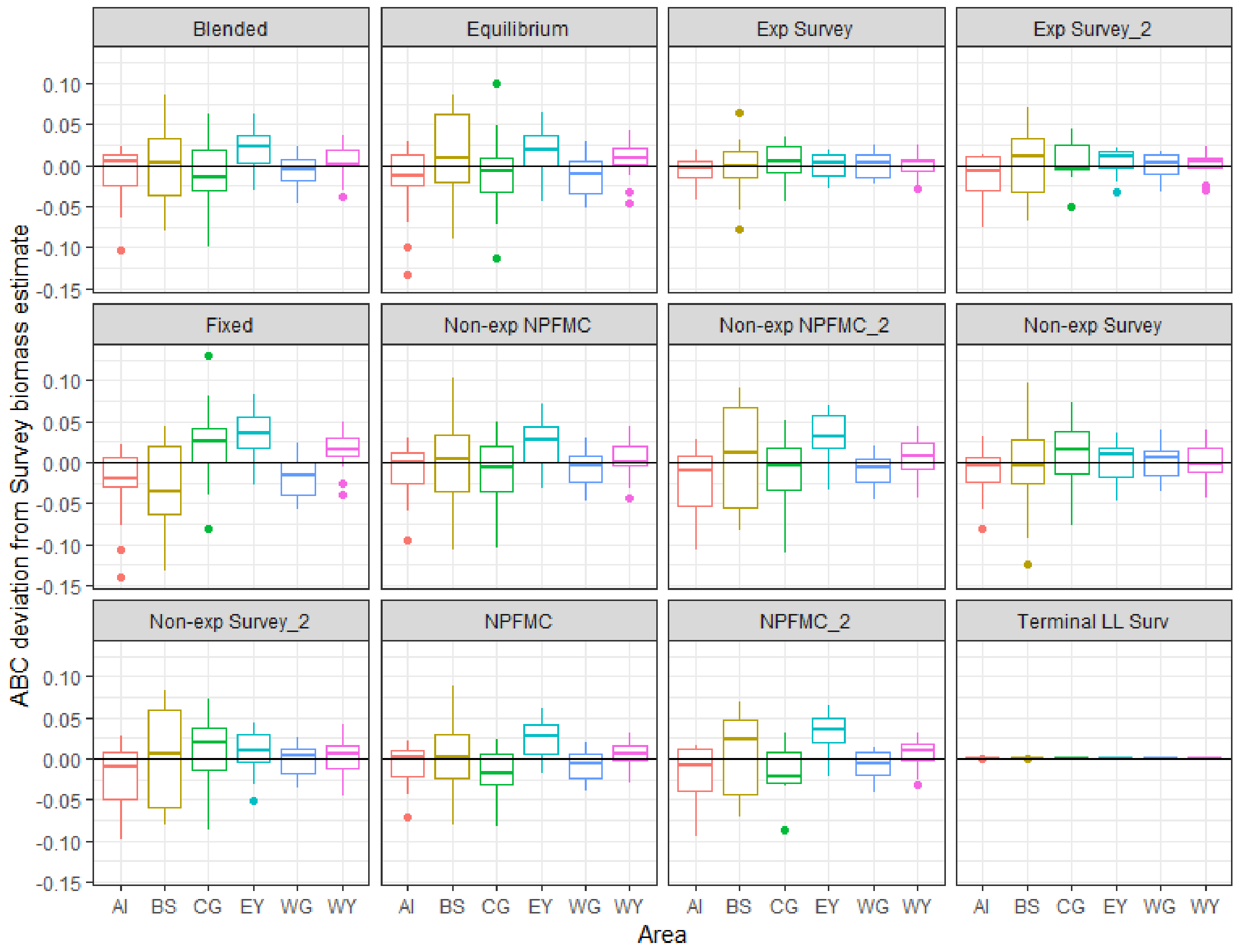


Figure 3D.4. Difference between the proportion of the total ABC in an area and the proportion of the longline survey estimated biomass in an area aggregated across years for each apportionment method (panel). Boxplots demonstrate whether or not the ABC is being apportioned to area at the same proportion as biomass (based on the longline survey estimates of the proportion of biomass in each area). Values greater than zero indicate that the proportion of ABC in a region is larger than the proportion of biomass in that region, while the opposite is true when values are less than zero. Boxplot lines indicate the median value across years, the upper and lower portions of the box indicate the 1st and 3rd quartiles, and the whiskers represent the largest values truncated at 1.5x's the interquartile range.

Apportionment Equations

Acceptable Biological Catch (ABC), ψ, was apportioned to each management area, *m*, for each year, *y*, using the 10 apportionment methods outlined below. Proportions for retrospective analyses are calculated before accounting for whale depredation.

Fixed: Utilized the proportions from the 2013 assessment, which have been applied as fixed proportions for the apportionment of ABC in 2014 - 2020.

$$\psi_{y,m} = ABC_y * \rho_m,$$

where ρ_m for this apportionment type was a vector equal to 0.10, 0.13, 0.11, 0.34, 0.11, 0.21 for areas Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, and East Yakutat/SE Outside.

Equilibrium: Proportions in each area are based on the mean proportions, ρ_m, implemented from 2005 - 2013.

$$\psi_{y,m} = ABC_y * \rho_m,$$

where ρ_m for this apportionment type was a vector equal to 0.14, 14, 0.11, 0.31, 0.11, 0.19 for areas Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, and East Yakutat/SE Outside.

NPFMC: A 5-year exponentially weighted moving average of fishery and survey abundance indices ($I_{fish,y,m}$ and $I_{surv,y,m}$, respectively) was utilized. The survey index is given double the weight (w_{surv} = 2) of the fishery index (w_{fish} = 1). For this apportionment method, data is only included from the last five years, which implies that survey data from the BS and AI include fewer than five data points (i.e., due to surveys in these areas being conducted every other year). This was the method accepted by the NPFMC for apportioning sablefish ABC for 2000 - 2013.

$$\psi_{y,m} = ABC_y * 1/(w_{surv} + w_{fish}) * \left[\left(w_{surv} * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{surv,y=y-k+1,m}}\Big/{\sum_m I_{surv,y=y-k+1,m}}\right)\right) + \left(w_{fish} \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{fish,y=y-k,m}}\Big/{\sum_m I_{fish,y=y-k,m}}\right)\right)\right],$$

where the exponential weighting factor ($\overrightarrow{\rho_k}$) for this apportionment type was a vector equal to 0.5, 0.25, 0.125, 0.0625, 0.0625 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4 for the survey index and years *y*-1, *y*-2, *y*-3, *y*-4, *y*-5 for the fishery CPUE index.

NPFMC_2: Same as the NPFMC method, but using five ‘on’ years for BS and AI surveys in the calculations (i.e., five data points are included for both BS and AI survey data).

Non-Exp NPFMC: A 5-yr moving average of fishery and survey indices was utilized with all years equally weighted.). For this apportionment method, data is only included from the last five years, which implies that survey data from the BS and AI include fewer than five data points (i.e., due to surveys in these areas being conducted every other year).

$$\psi_{y,m} = ABC_y * 1/(w_{surv} + w_{fish}) * \left[\left(w_{surv} * \sum_{k=1}^{5} \vec{\rho}_k * \left(I_{surv,y=y-k+1,m} \big/ \sum_m I_{surv,y=y-k+1,m} \right)\right) + \left(w_{fish} * \sum_{k=1}^{5} \vec{\rho}_k * \left(I_{fish,y=y-k,m} \big/ \sum_m I_{fish,y=y-k,m} \right)\right)\right],$$

where ρ_k for this apportionment type was a vector equal to 0.2, 0.2, 0.2, 0.2, 0.2 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

Non-Exp NPFMC_2: Same as the Non-Exp NPFMC, but using five ‘on’ years for BS and AI surveys in the calculations (i.e., five data points are included for both BS and AI survey data).

Non-Exp Survey: Similar to the NPFMC apportionment method, but using survey index data only. $\vec{\rho}_k$ for this apportionment type was a vector equal to 0.2, 0.2, 0.2, 0.2, 0.2 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

$$\psi_{y,m} = ABC_y * \sum_{k=1}^{5} \vec{\rho}_k * \left(I_{surv,y=y-k+1,m} \big/ \sum_m I_{surv,y=y-k+1,m} \right)$$

Non-Exp Survey_2: Same as the Non-Exp Survey method, but using five ‘on’ years for BS and AI surveys in the calculations (i.e., five data points are included for both BS and AI survey data).

Exp Survey: Similar to the NPFMC apportionment method, but using survey index data only. $\vec{\rho}_k$ for this apportionment type was a vector equal to 0.5, 0.25, 0.125, 0.0625, 0.0625 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

$$\psi_{y,m} = ABC_y * \sum_{k=1}^{5} \vec{\rho}_k * \left(I_{surv,y=y-k+1,m} \big/ \sum_m I_{surv,y=y-k+1,m} \right)$$

Exp Survey_2: Same as the Exp Survey method, but using five 'on' years for BS and AI surveys in the calculations (i.e., five data points are included for both BS and AI survey data).

Terminal LL Survey: The relative proportions of biomass in each area from the terminal year of the longline survey is utilized.

$$\psi_{y,m} = ABC_y * {I_{surv,y,m}} / {\sum_m I_{surv,y,m}}$$

Blended: Half of the ABC is apportioned using the Equilibrium method and half is apportioned using the NPFMC method.

$$\psi_{y,m} = \left({1}/{2}\, ABC_y * \rho_m\right) + {1}/{2}\; ABC_y * 1/(w_{surv} + w_{fish}) * \left[\left(w_{surv} * \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{surv,y=y-k+1,m}}/{\sum_m I_{surv,y=y-k+1,m}}\right)\right) + \left(w_{fish} \sum_{k=1}^{5} \vec{\rho}_k * \left({I_{fish,y=y-k,m}}/{\sum_m I_{fish,y=y-k,m}}\right)\right)\right],$$

where ρ_m for this apportionment type was a vector equal to 0.14, 14, 0.11, 0.31, 0.11, 0.19 for areas Bering Sea, Aleutian Islands, Western GOA, Central GOA, West Yakutat, and East Yakutat/SE Outside. ρ_k for this apportionment type was a vector equal to 0.5, 0.25, 0.125, 0.0625, 0.0625 for years *y*, *y*-1, *y*-2, *y*-3, *y*-4.

Complete Retrospective Apportionment Tables

Each Table below provides the apportionment of ABC (in metric tons) to management areas. For a given year, the ABC summed across management areas (total ABC) is the same for all apportionment methods. These values do not include adjustments for whale depredation or the 95:5 hook and line : trawl split.

Fixed Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	1659	2243	1834	5799	1951	3514	17000
2001	1649	2230	1823	5765	1939	3493	16900
2002	1688	2283	1866	5901	1985	3576	17300
2003	1795	2428	1985	6277	2111	3803	18400
2004	2244	3035	2481	7846	2639	4754	23000
2005	2049	2771	2265	7163	2410	4341	21000
2006	2049	2771	2265	7163	2410	4341	21000
2007	1961	2652	2168	6856	2306	4155	20100
2008	1759	2379	1945	6150	2069	3727	18030
2009	1569	2122	1735	5485	1845	3324	16080
2010	1486	2010	1643	5195	1748	3148	15230
2011	1565	2117	1730	5472	1841	3316	16040
2012	1683	2276	1861	5884	1979	3566	17250
2013	1584	2142	1751	5536	1862	3355	16230
2014	1339	1811	1480	4681	1575	2836	13722
2015	1333	1802	1473	4659	1567	2823	13657
2016	1151	1557	1272	4023	1353	2438	11795
2017	1318	1783	1457	4608	1550	2792	13509
2018	1501	2030	1659	5246	1765	3179	15380
2019	1501	2030	1659	5246	1765	3179	15380
2020	2201	2976	2433	7692	2588	4661	22551
mean	*1671*	*2259*	*1847*	*5840*	*1965*	*3539*	
median	*1649*	*2230*	*1823*	*5765*	*1939*	*3493*	

Equilibrium Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	2396	2363	1925	5259	1834	3224	17000
2001	2382	2349	1914	5228	1823	3205	16900
2002	2438	2404	1959	5352	1866	3281	17300
2003	2593	2557	2084	5692	1985	3489	18400
2004	3241	3196	2605	7115	2481	4362	23000
2005	2959	2918	2378	6496	2265	3982	21000
2006	2959	2918	2378	6496	2265	3982	21000
2007	2833	2793	2276	6218	2168	3812	20100
2008	2541	2506	2042	5578	1945	3419	18030
2009	2266	2235	1821	4974	1735	3049	16080
2010	2146	2117	1725	4711	1643	2888	15230
2011	2260	2229	1816	4962	1730	3042	16040
2012	2431	2397	1953	5336	1861	3271	17250
2013	2287	2256	1838	5021	1751	3078	16230
2014	1934	1907	1554	4245	1480	2602	13722
2015	1925	1898	1547	4225	1473	2590	13657
2016	1662	1639	1336	3649	1272	2237	11795
2017	1904	1877	1530	4179	1457	2562	13509
2018	2167	2137	1742	4758	1659	2917	15380
2019	2167	2137	1742	4758	1659	2917	15380
2020	3178	3134	2554	6976	2433	4276	22551
mean	*2413*	*2379*	*1939*	*5297*	*1847*	*3247*	
median	*2382*	*2349*	*1914*	*5228*	*1823*	*3205*	

NPFMC Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	2697	2899	2364	6971	2243	3827	21000
2006	2969	2677	2651	6609	2089	4005	21000
2007	2976	2570	2442	6233	2082	3797	20100
2008	2936	2343	1910	5414	1886	3541	18030
2009	2792	2138	1638	4898	1579	3035	16080
2010	2170	2121	1826	4631	1522	2959	15230
2011	1762	2017	1749	5015	2013	3484	16040
2012	1680	2103	1908	5859	2088	3611	17250
2013	1348	2148	1813	5560	1825	3536	16230
2014	1782	1797	1374	4382	1434	2952	13722
2015	2172	1830	1428	3880	1414	2931	13657
2016	1860	1611	1125	3349	1349	2501	11795
2017	1902	2243	1423	3594	1585	2763	13509
2018	2224	2686	1533	4201	1765	2970	15380
2019	2064	3085	1877	3978	1506	2870	15380
2020	3638	4751	2636	5291	2115	4120	22551
mean	*2311*	*2439*	*1856*	*4992*	*1781*	*3306*	
median	*2171*	*2196*	*1820*	*4957*	*1795*	*3259*	

NPFMC_2 Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	NA	NA	NA	NA	NA	NA	21000
2006	NA	NA	NA	NA	NA	NA	21000
2007	NA	NA	NA	NA	NA	NA	20100
2008	NA	NA	NA	NA	NA	NA	18030
2009	NA	NA	NA	NA	NA	NA	16080
2010	NA	NA	NA	NA	NA	NA	15230
2011	2019	2005	1697	4909	1984	3426	16040
2012	1803	2138	1878	5797	2066	3568	17250
2013	1630	2112	1777	5460	1785	3465	16230
2014	1922	1856	1346	4297	1404	2898	13722
2015	1917	1935	1451	3946	1430	2978	13657
2016	1742	1714	1127	3353	1349	2510	11795
2017	1893	2287	1429	3574	1572	2754	13509
2018	2147	2574	1574	4276	1791	3018	15380
2019	2698	2733	1777	3765	1499	2908	15380
2020	3835	4170	2706	5454	2175	4211	22551
mean	*2161*	*2353*	*1676*	*4483*	*1705*	*3174*	
median	*1919*	*2125*	*1636*	*4286*	*1679*	*2998*	

Non-exp NPFMC Apportionment

Year	BS	AI	WG	CG	WY	EY	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	2814	3063	2608	6607	2116	3792	21000
2006	2909	2909	2633	6635	2078	3836	21000
2007	2837	2719	2425	6364	2057	3698	20100
2008	2628	2375	2070	5652	1877	3428	18030
2009	2564	2047	1744	4984	1648	3093	16080
2010	2379	2013	1774	4586	1522	2956	15230
2011	2260	2102	1741	4906	1786	3245	16040
2012	2188	2225	1857	5492	1954	3534	17250
2013	1696	2130	1821	5346	1836	3402	16230
2014	1427	1775	1502	4489	1566	2963	13722
2015	1641	1749	1429	4307	1549	2983	13657
2016	1603	1574	1201	3626	1284	2508	11795
2017	1948	2008	1379	3834	1482	2858	13509
2018	2442	2415	1519	4177	1712	3115	15380
2019	2263	2713	1693	4026	1666	3019	15380
2020	3320	4345	2492	5725	2390	4279	22551
mean	*2307*	*2385*	*1868*	*5047*	*1783*	*3294*	
median	*2321*	*2178*	*1759*	*4945*	*1749*	*3180*	

Non-exp NPFMC_2 Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	NA	NA	NA	NA	NA	NA	21000
2006	NA	NA	NA	NA	NA	NA	21000
2007	NA	NA	NA	NA	NA	NA	20100
2008	NA	NA	NA	NA	NA	NA	18030
2009	NA	NA	NA	NA	NA	NA	16080
2010	NA	NA	NA	NA	NA	NA	15230
2011	2359	2167	1702	4836	1768	3209	16040
2012	2323	2368	1804	5377	1915	3463	17250
2013	2130	2110	1755	5180	1768	3288	16230
2014	1850	1785	1436	4308	1496	2847	13722
2015	1743	1839	1403	4219	1511	2942	13657
2016	1537	1675	1193	3600	1278	2512	11795
2017	1843	2076	1393	3842	1482	2872	13509
2018	2035	2429	1596	4339	1759	3222	15380
2019	2429	2541	1699	4034	1693	2985	15380
2020	3501	3756	2557	5905	2458	4374	22551
mean	*2175*	*2275*	*1654*	*4564*	*1713*	*3171*	
median	*2082*	*2138*	*1648*	*4324*	*1726*	*3097*	

Non-exp Survey Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	2660	3089	2961	7081	1885	3324	21000
2006	3009	2879	3006	6991	1810	3305	21000
2007	2947	2663	2721	6741	1858	3170	20100
2008	2828	2286	2270	5921	1731	2994	18030
2009	2713	1963	1907	5232	1553	2712	16080
2010	2314	1969	1955	4835	1461	2695	15230
2011	2101	2065	1866	5236	1776	2996	16040
2012	1906	2156	2017	5975	1946	3249	17250
2013	1340	2121	2004	5841	1791	3134	16230
2014	1183	1784	1624	4865	1516	2749	13722
2015	1604	1704	1537	4637	1467	2709	13657
2016	1548	1541	1282	3945	1233	2246	11795
2017	1934	2032	1481	4092	1431	2540	13509
2018	2440	2478	1643	4472	1681	2665	15380
2019	2163	2927	1864	4343	1616	2467	15380
2020	3265	4797	2648	6114	2326	3401	22551
mean	*2247*	*2403*	*2049*	*5395*	*1693*	*2897*	
median	*2238*	*2138*	*1931*	*5234*	*1706*	*2872*	

Non-exp Survey_2 Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	NA	NA	NA	NA	NA	NA	21000
2006	NA	NA	NA	NA	NA	NA	21000
2007	NA	NA	NA	NA	NA	NA	20100
2008	NA	NA	NA	NA	NA	NA	18030
2009	NA	NA	NA	NA	NA	NA	16080
2010	NA	NA	NA	NA	NA	NA	15230
2011	2249	2163	1809	5129	1748	2941	16040
2012	2109	2370	1937	5803	1888	3142	17250
2013	1991	2091	1906	5592	1689	2962	16230
2014	1818	1798	1526	4594	1411	2575	13722
2015	1758	1839	1497	4505	1410	2648	13657
2016	1448	1693	1270	3906	1224	2253	11795
2017	1777	2134	1502	4105	1430	2561	13509
2018	1830	2498	1759	4716	1752	2825	15380
2019	2412	2669	1873	4354	1656	2416	15380
2020	3536	3914	2746	6385	2428	3542	22551
mean	*2093*	*2317*	*1782*	*4909*	*1664*	*2787*	
median	*1910*	*2149*	*1784*	*4655*	*1673*	*2737*	

Exp Survey Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	2810	2833	2666	7505	2004	3181	21000
2006	3143	2592	3071	6844	1835	3516	21000
2007	3098	2533	2696	6537	1925	3310	20100
2008	3126	2249	1994	5634	1827	3200	18030
2009	2939	2028	1758	5177	1519	2659	16080
2010	1817	2116	2050	5010	1487	2750	15230
2011	1412	2003	1899	5375	2035	3316	16040
2012	1262	2023	2096	6526	2075	3268	17250
2013	1027	2185	1963	6058	1737	3260	16230
2014	1817	1801	1433	4643	1338	2690	13722
2015	2342	1738	1558	4127	1282	2610	13657
2016	1753	1572	1187	3664	1366	2252	11795
2017	1785	2328	1564	3867	1588	2378	13509
2018	2100	2891	1682	4523	1759	2425	15380
2019	1973	3539	2066	4248	1386	2167	15380
2020	3992	5287	2704	5515	1928	3125	22551
mean	*2275*	*2482*	*2024*	*5328*	*1693*	*2882*	
median	*2036*	*2217*	*1978*	*5276*	*1748*	*2938*	

Exp Survey_2 Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	NA	NA	NA	NA	NA	NA	21000
2006	NA	NA	NA	NA	NA	NA	21000
2007	NA	NA	NA	NA	NA	NA	20100
2008	NA	NA	NA	NA	NA	NA	18030
2009	NA	NA	NA	NA	NA	NA	16080
2010	NA	NA	NA	NA	NA	NA	15230
2011	1797	1985	1821	5216	1991	3229	16040
2012	1446	2075	2050	6433	2042	3204	17250
2013	1450	2131	1909	5910	1677	3154	16230
2014	2027	1889	1390	4515	1292	2608	13722
2015	1959	1895	1593	4225	1306	2680	13657
2016	1576	1727	1190	3671	1365	2267	11795
2017	1772	2395	1572	3837	1568	2365	13509
2018	1983	2724	1744	4635	1798	2497	15380
2019	2924	3012	1916	3928	1375	2224	15380
2020	4287	4416	2810	5760	2017	3261	22551
mean	*2122*	*2425*	*1799*	*4813*	*1643*	*2749*	
median	*1878*	*2103*	*1783*	*4575*	*1623*	*2644*	

Terminal LL Survey Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	1312	2999	1850	5855	1763	3220	17000
2001	1326	2750	2604	5343	1671	3205	16900
2002	2458	2621	2819	5375	1242	2785	17300
2003	2613	2795	2455	6149	1644	2744	18400
2004	3046	3532	3382	7915	1917	3208	23000
2005	2905	2431	2255	7997	2216	3195	21000
2006	3392	2366	3464	6189	1701	3888	21000
2007	3188	2585	2490	6495	2071	3270	20100
2008	3484	2224	1554	5392	1933	3442	18030
2009	3084	2088	1778	5292	1386	2451	16080
2010	827	2315	2381	5199	1558	2950	15230
2011	914	1762	1680	5444	2481	3758	16040
2012	968	1897	2190	7297	1958	2940	17250
2013	868	2460	1929	5947	1542	3484	16230
2014	2885	1736	1167	4153	1193	2588	13722
2015	2873	1719	1734	3635	1188	2508	13657
2016	1485	1643	1012	3703	1655	2297	11795
2017	1563	2821	1775	3585	1627	2138	13509
2018	2017	3156	1616	4704	1718	2169	15380
2019	1847	4188	2410	4009	1013	1914	15380
2020	5211	5366	2435	4734	1749	3056	22551
mean	*2298*	*2641*	*2142*	*5448*	*1677*	*2915*	
median	*2458*	*2460*	*2190*	*5375*	*1671*	*2950*	

Blended Apportionment

Year	BS	AI	WG	CG	WY	EY/SEO	Sum
2000	NA	NA	NA	NA	NA	NA	17000
2001	NA	NA	NA	NA	NA	NA	16900
2002	NA	NA	NA	NA	NA	NA	17300
2003	NA	NA	NA	NA	NA	NA	18400
2004	NA	NA	NA	NA	NA	NA	23000
2005	2828	2909	2371	6733	2254	3905	21000
2006	2964	2798	2514	6553	2177	3994	21000
2007	2904	2682	2359	6226	2125	3805	20100
2008	2739	2424	1976	5496	1916	3480	18030
2009	2529	2186	1729	4936	1657	3042	16080
2010	2158	2119	1775	4671	1582	2924	15230
2011	2011	2123	1783	4988	1872	3263	16040
2012	2056	2250	1931	5598	1975	3441	17250
2013	1818	2202	1825	5290	1788	3307	16230
2014	1858	1852	1464	4314	1457	2777	13722
2015	2049	1864	1487	4053	1444	2761	13657
2016	1761	1625	1230	3499	1311	2369	11795
2017	1903	2060	1477	3886	1521	2662	13509
2018	2196	2412	1637	4479	1712	2943	15380
2019	2116	2611	1809	4368	1583	2893	15380
2020	3408	3942	2595	6133	2274	4199	22551
mean	*2331*	*2379*	*1873*	*5076*	*1790*	*3235*	
median	*2137*	*2226*	*1796*	*4962*	*1750*	*3152*	

Appendix 3E. Sablefish Bycatch in the Eastern Bering Sea

Recently sablefish bycatch has increased dramatically in the pelagic and non-pelagic trawl fisheries occurring in the eastern Bering Sea (EBS; Figure 3E.1). Prior to 2019, there was minimal sablefish bycatch; for example, from 2016 to 2018, the recorded bycatch of sablefish in the EBS in pelagic and non-pelagic trawl gear ranged from 257 - 1,018 t (Table 3E.1), increasing 2.5 times higher from 2018 to 2019 and increasing another 1.5 times from 2019 to 2020, as of Oct. 15, 2020 (Table 3E.1). In the EBS pelagic trawl fishery, which is made up completely of the walleye pollock fishery, bycatch is increasing at a much higher rate than in the non-pelagic trawl fisheries; in 2020 the sablefish bycatch is more than 7 times what it was in 2018. Sablefish bycatch in non-pelagic trawls has increased in a number of fisheries (e.g., walleye pollock, arrowtooth flounder, flathead sole in 2019, Kamchatka flounder, Greenland turbot, and rockfish), yet remained stable in hook and line and pot fisheries, which catch larger, older fish that are more commonly found in deeper, benthic habitat. Therefore, it is likely that increasing sablefish bycatch in pelagic and non-pelagic trawl fisheries is related to the presence of smaller, younger fish before they have fully recruited to the directed fishery.

Observer data on lengths can be used to assess what sized fish are being encountered and if there have been any changes through time that may indicate the presence of different year classes. Sablefish length data are extremely limited in the pelagic trawl fishery; there were six fish with lengths taken in 2019, zero from 2015 through 2018, and 865 in 2020. In the 2020 pelagic trawl fishery there was a bimodal distribution in lengths with peaks at 29 cm, corresponding to age-1 sablefish and the 2019 year class, and 52 cm, which likely corresponds to age-3 through age-5 fish and would predominantly be comprised of the 2015 - 2017 year classes (Figure 3E.2).

There is more data available from the non-pelagic trawl fisheries than the pelagic trawl fishery from 2016 - 2020. The length distribution of sablefish bycatch in non-pelagic trawl gear predominately encompasses what are likely age-2 to age-6 fish. The relatively narrow length ranges in 2016 and 2017 may be due to high catches of the large 2014 year class, with the peak length shifting from 47 cm in 2016 to 51 cm in 2017 (Figure 3E.3). In 2018 there was a wider range of lengths, reflecting that there was more than one age class present. The first mode, with a peak at 46 cm are likely age-2 fish from the 2016 year class and the second is likely predominantly age-3 and age-4 fish from the 2015 and 2016 year classes. In 2019 and 2020 there were fewer small, age-2 fish, and there were more large fish. The 2020 non-pelagic trawl lengths did not include the small, age-1 fish that were abundant in the pelagic trawl observed lengths (Figures 3E.2 and 3E.3). For 2019 and 2020, the larger lengths makes it more difficult to assign ages, but they likely range from 3 to 6 years old, corresponding to the 2013 to 2016 year classes in 2019 and the 2014 to 2017 year classes in 2020. The length at 50% maturity and the age at 50% maturity currently used in the assessment for females is 65 cm and 6.6 years, respectively, and for males it is 57 cm and 5 years; therefore, the great majority of these fish are likely immature (Figure 3E.3).

The average weight of sablefish bycatch in each observed haul can also demonstrate which year classes are being caught (where the average weight is the extrapolated sablefish weight in a haul divided by the extrapolated number of sablefish). Hereafter, we focus on EBS data from 2015 to 2020 for non-pelagic trawl fisheries and 2016 - 2020 in the pelagic trawl fishery, due to a lack of data in 2015 in pelagic gear (sample sizes in Table 3E.2). When the average weight for the haul was less than 0.5 kg we assumed that age-1 sablefish were the dominant age group. The non-pelagic fishery frequently encountered age-1 sablefish in 2015, 2017, and 2020, indicating that the 2014, 2016, and 2019 year classes were more prevalent in bycatch than normal (Figures 3E.4 and Table 3E.2). This is particularly visible in the 0 - 100 m depth strata (Figure 3E.4). Following the appearance of large 2014 and 2016 year classes as age-1 in 2015 and 2017, the average weight of sablefish bycatch increased each subsequent year for all depths combined, suggesting that these fish continued to be intercepted as bycatch as age-2, age-3, and age-4 in each subsequent year (Figure 3E.4).

In 2015, 2017, and 2020, age-1 sablefish bycatch was high in one or more fisheries (Figure 3E.4), and lengths showed an abundance of age-1 fish in 2020 (Figure 3E.2), as well as age-2 fish in 2016 and 2018, which would have been age-1 in 2015 and 2017 (Figure 3E.3). In the years with high age-1 bycatch, sablefish were caught within a relatively small, concentrated area off of Unimak Island and the slime bank along the southern Alaska Peninsula (Figure 3E.5), which was unlike the broad spatial distribution of all observed sablefish bycatch within the EBS trawl fisheries (Figure 3E.1). This matches with observations of juvenile sablefish in prior years, where age-1 sablefish were found only in some years. In the 2008 sablefish SAFE, it was noted that "...the Bering Sea shelf is utilized significantly [by juvenile sablefish] in some years and virtually not used during other years."

Age-1 bycatch is not currently a reliable index of year class strength, but if there are indications of a larger than average 2019 year class over the next several years (e.g., model estimated age-2 biomass estimate is high in 2021 and continues in future years), it is possible that sablefish will continue to be caught as bycatch in the EBS due to the 2019 year class being selected at subsequent ages in the pelagic and non-pelagic trawl fisheries.

Tables

Table 3E1. Sablefish bycatch (t) in the non-pelagic and pelagic trawl fisheries occurring in the eastern Bering Sea.

Year	Non-pelagic	Pelagic	Total
2015	17	0	17
2016	239	18	257
2017	588	91	679
2018	623	395	1,018
2019	1,275	1,223	2,498
2020	1,008	2,853	3,862

Table 3E.2. Number of observed hauls for the pelagic and non-pelagic EBS fisheries and the percent of hauls with average weights <0.5 kg by year, which are assumed to be age-1 fish.

	Pelagic		Non-pelagic	
Year	Total hauls	% <0.5	Total hauls	% <0.5
2015	0	N/A	190	77%
2016	135	0%	204	2%
2017	439	43%	240	9%
2018	492	<1%	151	1%
2019	890	<1%	183	7%
2020	122	38%	123	37%

Figures

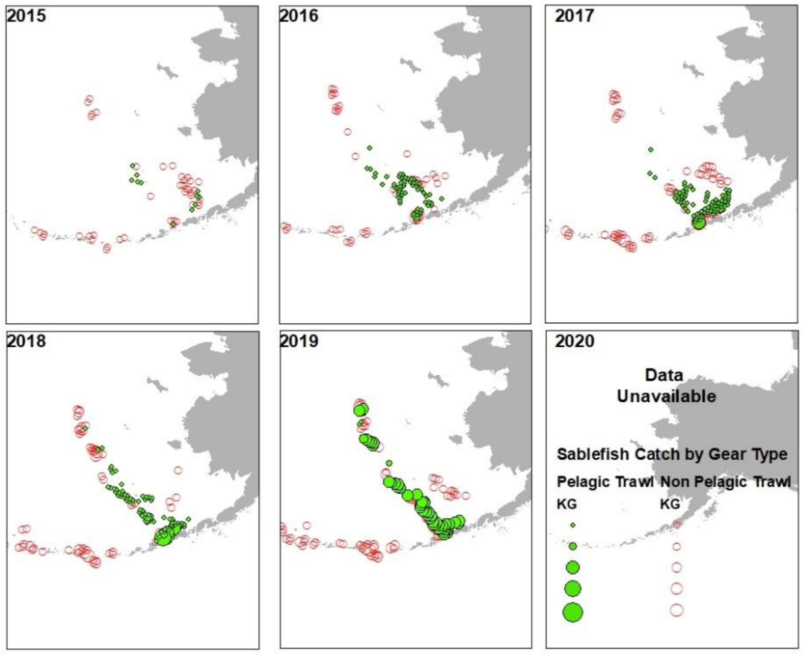


Figure 3E.1. Spatial distribution of observed sablefish bycatch (kg) in pelagic (filled green circles) and non-pelagic (open red circles) trawl gear within the eastern Bering Sea from 2015 - 2019. Catch data that has been gridded to meet confidentiality is not yet available for 2020. Data provided by the Fisheries Monitoring and Analysis division website, queried October 15, 2020 (https://www.fisheries.noaa.gov/resource/map/alaska-groundfish-fishery-observer-data-map).

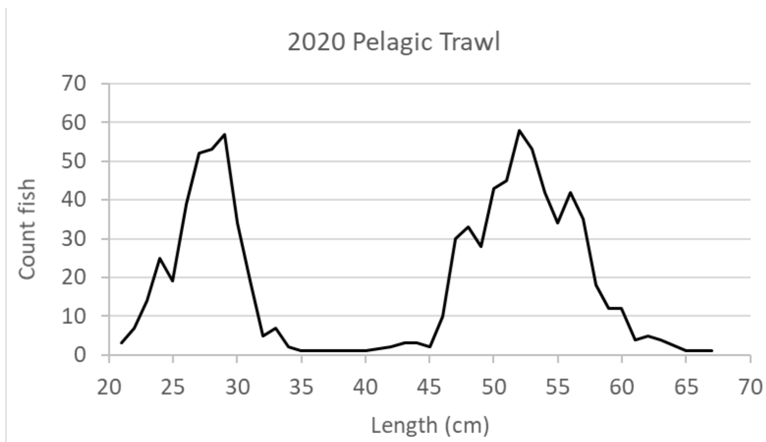


Figure 3E.2. Count of sablefish of each length from observed hauls in the non-pelagic or pelagic trawl fisheries occurring in the EBS in 2020.

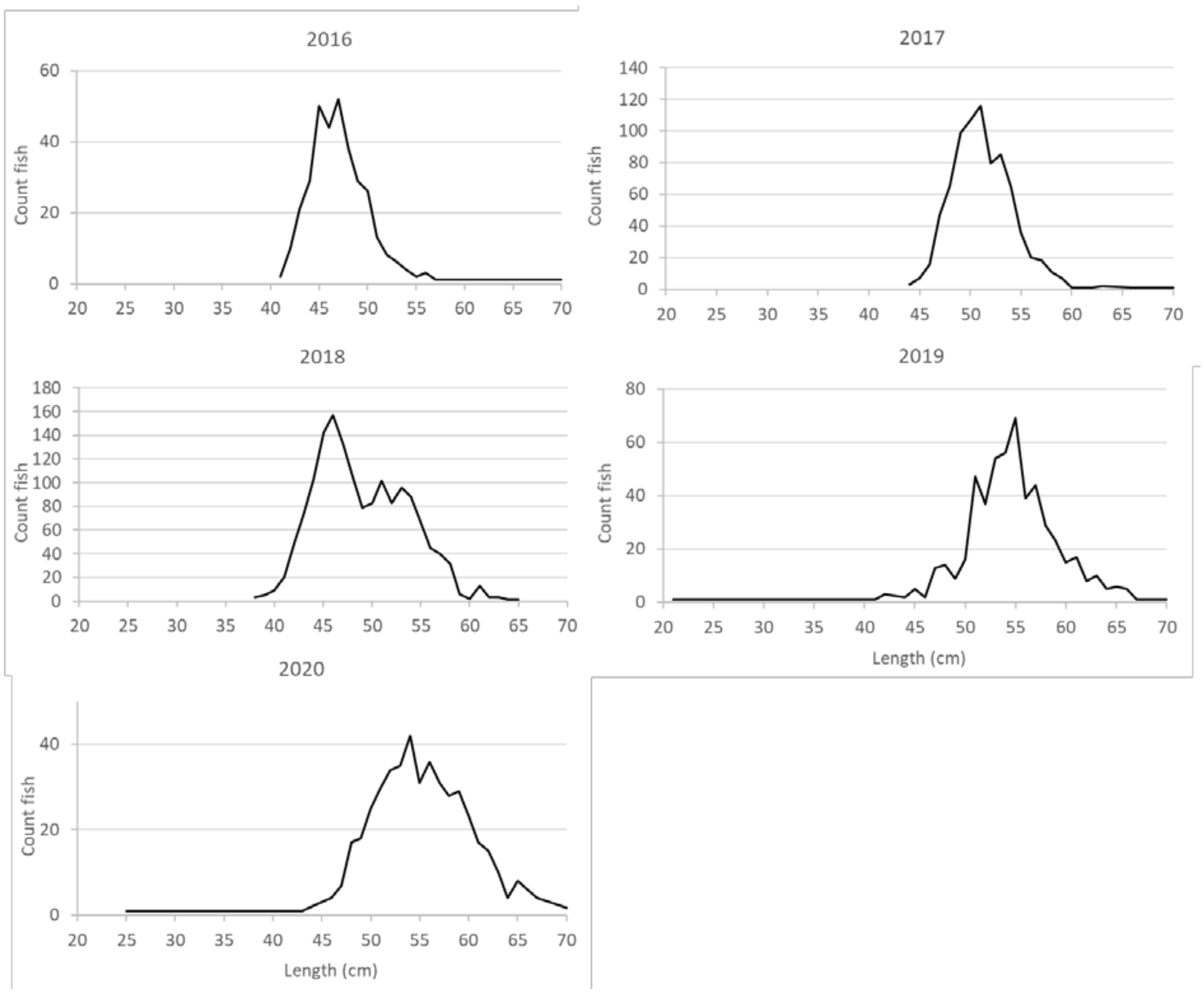


Figure 3E.3. Lengths from sablefish caught in the non-pelagic trawl fishery. Note that the y-axis scales vary by year.

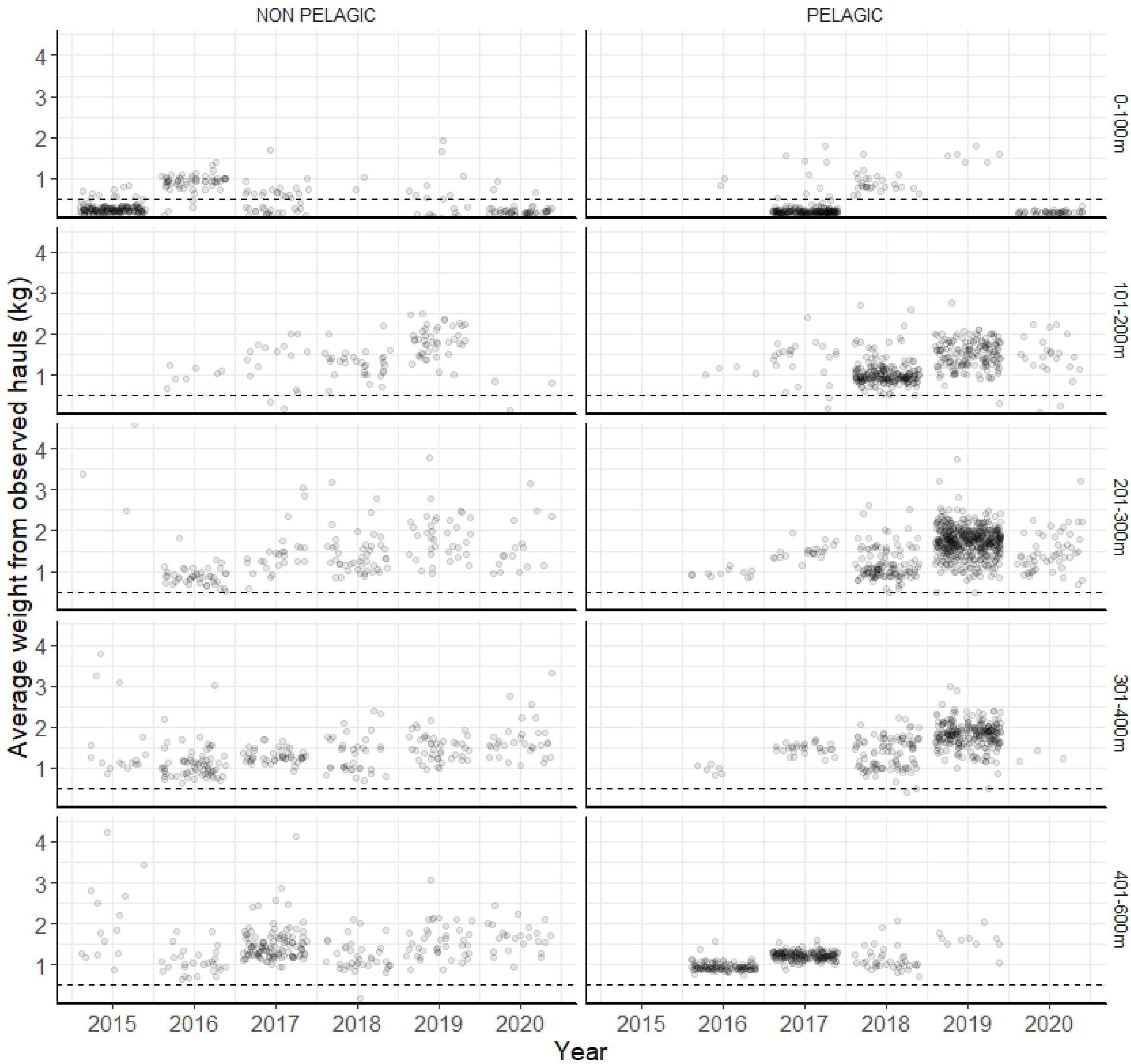


Figure 3E.4. Average weight of sablefish from observed hauls in the Eastern Bering Sea non-pelagic (left) and pelagic (right) trawl fisheries. Catches are separated by 100 or 200 m depth bins (horizontal solid lines and labeled on the right). The horizontal dashed lines at 0.5 kg delineate likely age-1 fish below the line from older fish above the line. There was no data available in the pelagic trawl fishery in 2015.

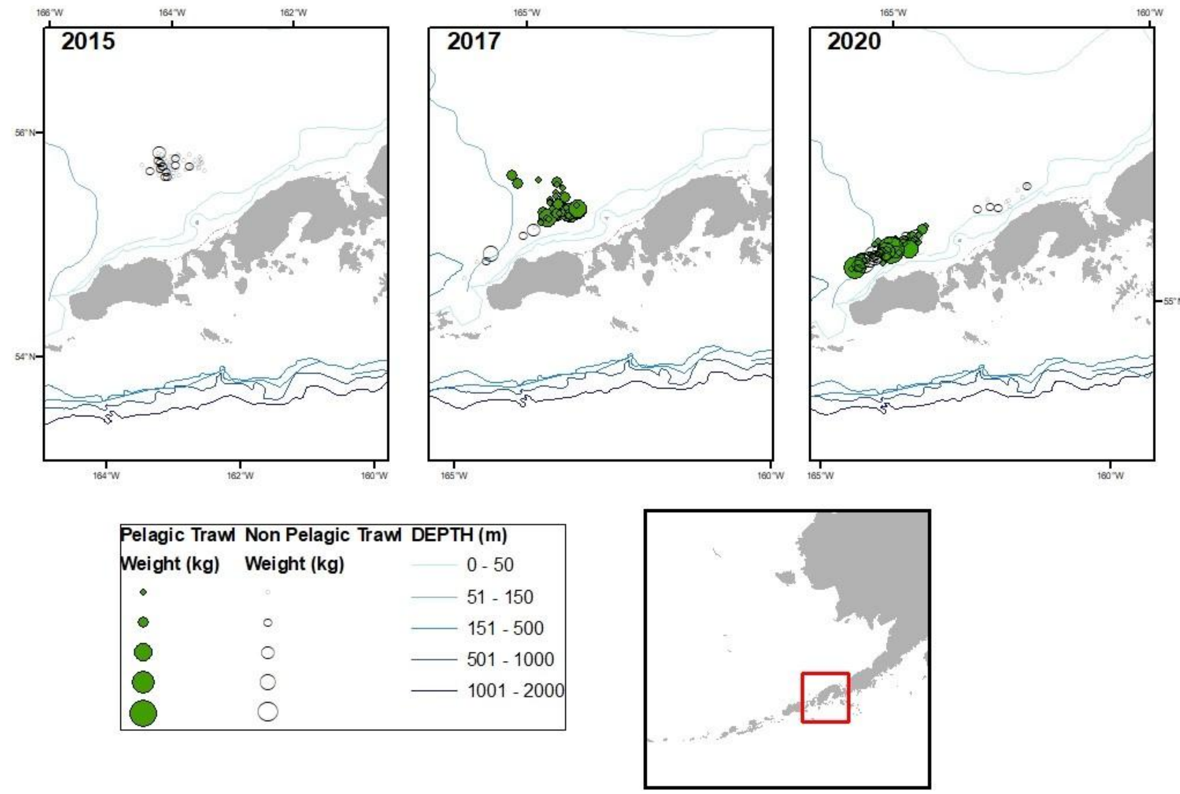


Figure 3E.5. Spatial distribution of observed sablefish bycatch (kg) in pelagic (filled green circles) and non-pelagic (open red circles) gear in which the average weight for the haul was less than 0.5 kg (age-1 sablefish). Data provided by NORPAC catch database accessed via the Alaska Fishery Information Network (AKFIN). Locations shown have been generalized to generic center locations of a 20 x 20 sq. km grid if there were 3 or more unique vessels, as per NOAA/NMFS regulations.